Biological Chemistry

Introduction to Biological Chemistry

It is the study of the chemistry of living things.

Metabolism

- **Metabolism is the total collection of all chemical processes. It involves inter-conversions of matter and energy.**
- **Enzymes catalyze these conversions which follow distinct reactions & discrete pathways.**
- **Substrates (reactants) react to form products.**

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Metabolism

- **Metabolism consists of catabolism and anabolism.**
- **Anabolism:** ***constructive (biosynthetic)***
  - **Processes that build molecules up.**
  - **Usually reductive & endothermic (energonic).**
- **Catabolism:** ***degradative***
  - **Processes that break molecules down.**
  - **Usually oxidative & exothermic (exergonic).**

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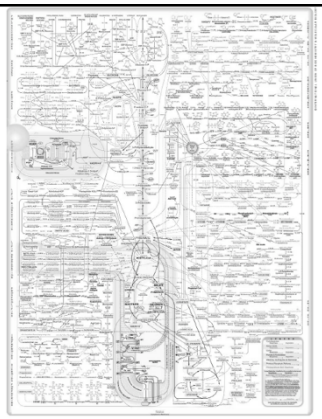

Important Biochemicals

- **Many of the biologically important molecules are polymers (biopolymers).**
- **Three classes of biopolymers:**
  - ***proteins,***
  - ***polysaccharides (carbohydrates),***
  - ***nucleic acids.***

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What do biopolymers provide for us heterotrophs?

Nutritionally:

- ***Proteins*** **are a rich source of nitrogen and also provide essential amino acids.**
- ***Carbohydrates*** **provide needed energy and essential components for nucleotides and nucleic acids.**

Genetically:

- ***Nucleic Acids*** **store and transmit genetic information, and are responsible for endogenous protein synthesis.**

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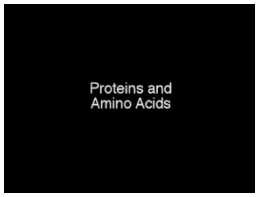
Proteins



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Protein Types -

- **Enzymes: *Glutamine synthetase* - 12 subunits of 468 residues each; total mol. wt. = 600,000 daltons**
- **Regulatory proteins: *Insulin* - α -alpha chain of 21 residues, β - beta chain of 30 residues; total mol. wt. of 5,733 amu**
- **Structural proteins: *Collagen***

  ***Connectin proteins*, β - MW of 2.1 million g/mol; length = 1000 nm; can stretch to 3000 nm.**
- **Transport proteins: *Hemoglobin***
- **Contractile proteins: *Actin, Myosin***
- **Specialized proteins: *Antifreeze in fish***

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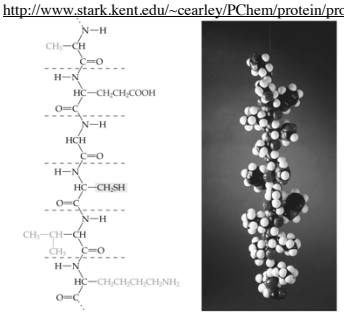
Proteins: Size, Shape & Self Assembly

http://www.stark.kent.edu/~cearley/PChem/protein/protein.htm



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Some Examples of Structural Proteins

Collagen: connective tissue

myosin-actin: muscle

Michael Ferenczi

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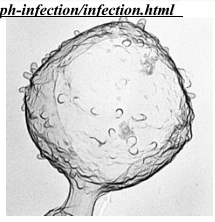
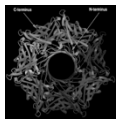
Mechanical proteins

Pathogens & Cell Invasion

http://chemconnections.org/organic/chem226/Announcements-info/Staph-infection/infection.html





Streptococcus pyogenes
96,000 x
Vincent A. Fischetti Ph.D., Rockefeller University
http://www.chm.bris.ac.uk/motm/motm.htm

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Antibodies

Prolific Immunoproteins

Human's total ~ 100 x 10 ^{6} immunoproteins

Combinatorial syntheses from libraries of 250, 10, and 6 possible contributors

Human Genome ~20,000 proteins

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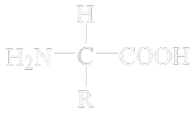
α-Amino Acids: protein building blocks

- $-NH_2$ amino group is attached to the α-carbon as is the carboxylic acid group (−COOH)

•C = α-carbon



- 20 α-amino acids are commonly found in proteins.
  - *•Our bodies can synthesize about 10 amino acids.*
  - *•Essential amino acids are the other 10 amino acids, which have to come from diet.*

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The 20 (22) Key Amino Acids

- More than 700 amino acids occur naturally, but 20 (22?)of them are especially important.
- These 22 amino acids are the building blocks of proteins. All are α-amino acids.
- They differ in respect to the group attached to the α carbon.

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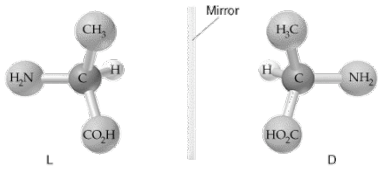
Proteins
Amino Acids



•Most of the amino acids in proteins are the L-isomer.

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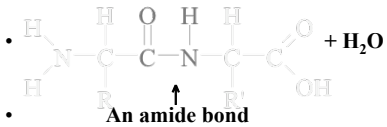
Linking α-Amino Acids

Amino acids combine by forming amide bonds.



• $+ H_2O$

• An amide bond (peptide linkage)

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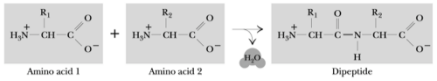
Proteins are Linear Polymers of Amino Acids



- Peptides have various numbers of amino acids.
- Peptides are always written with the $-NH_2$ terminus on the left, $-CO_2H$ on the right.
- Each amino acid unit is called a residue.
- 2 residues = dipeptide,
- 3 residues = tripeptide,
- 12-20 residues = oligopeptide,
- Many residues = polypeptide.

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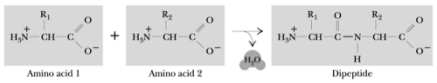
QUESTION

Proteins are made when amino acids form peptide bonds to link together. Which of the following contains the correct number and type of atoms that are necessary to define a peptide bond?

A. One carbon, two oxygen, one nitrogen
B. Two carbons, one oxygen, one nitrogen, one hydrogen
C. One carbon, two oxygen, one nitrogen, two hydrogen
D. One carbon, one oxygen, one nitrogen, one hydrogen



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Proteins
Protein Structure

- **Primary structure is the sequence of the amino acids in the protein chain.**
- **Secondary structure is the arrangement of various segments of the protein.** *(Determined by hydrogen bonding.)*
  - **Alpha helix**
    - **Other helices**
  - **Beta sheet (composed of "beta strands")**
    - **Tight turns (beta turns or beta bends)**
    - **Beta bulge**
- **Tertiary structure is the overall 3-D shape of the protein.** *(Determined by hydrogen-bonding, dipole-dipole interactions, ionic bonds, covalent bonds and London forces).*

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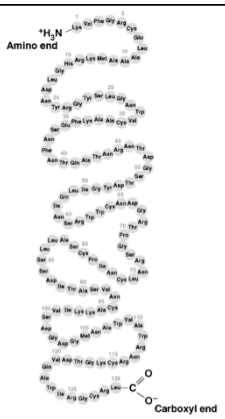
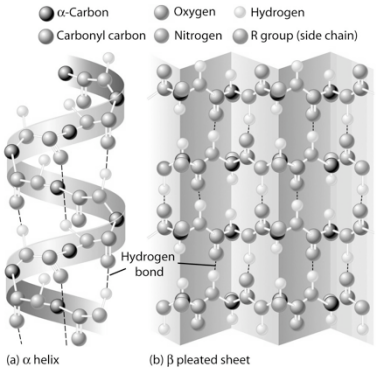
- **The** primary structure **of a protein is its unique sequence of amino acids.**
  - **Lysozyme, an enzyme that attacks bacteria, consists on a polypeptide chain of 129 amino acids.**
  - **The precise primary structure of a protein is determined by inherited genetic information.**





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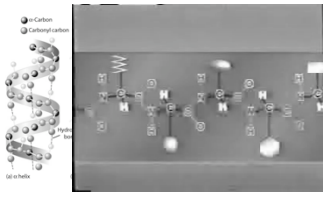

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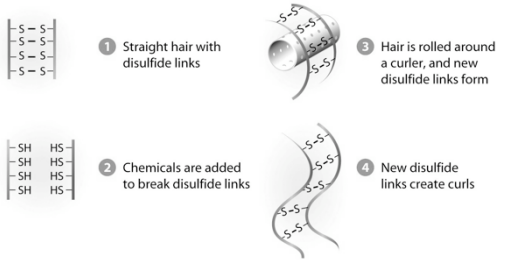

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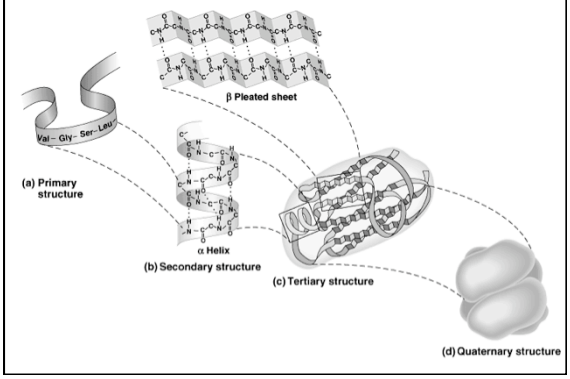
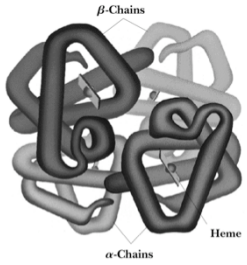
Complete Protein Structure



The quaternary structure of hemoglobin

(A tetramer)



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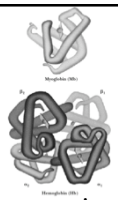
Hemoglobin (Hb) / Myoglobin (Mb)



Allosteric Effects

- **Hemoglobin transports and myoglobin stores oxygen in mammalian cells.**
- **Myoglobin is monomeric; hemoglobin is tetrameric**
- **Mb: 153 amino acids, 17, 200 da**
- **Hb: two alpha units of 141 residues, 2 beta units of 146**
- **Oxygen binding curves show the relationship of hemoglobin and myoglobin. The two proteins are in a complex equilibrium.**

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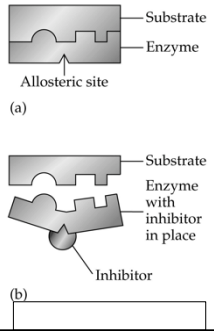
Enzyme Inhibition

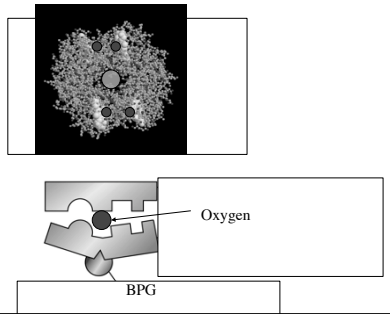
The Importance of Shape

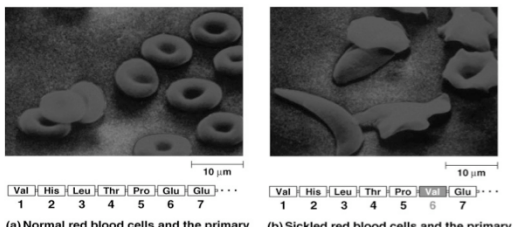


Example: Statins inhibit cholesterol biosynthesis

Hemoglobin and Oxygen Transport

An allosteric effect & sickle cell anemia





(a) Normal red blood cells and the primary structure of normal hemoglobin

(b) Sickled red blood cells and the primary structure of sickle-cell hemoglobin

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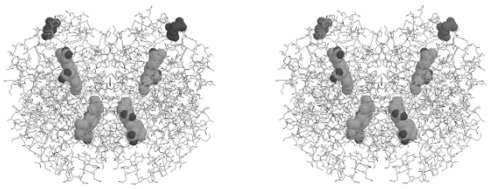
Normal hemoglobin vs sickle cell hemoglobin



Valine replaces Glutamate

http://chemconnections.org/Presentations/Columbia/slide8-3.html

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Protein Structure Summary

•1º : The linear sequence of amino acids and disulfide bonds eg. ARDV:Ala·Arg·Asp·Val.

•2º : Local structures which include, folds, turns, ∝-helices and β -sheets held in place by hydrogen bonds.

•3º : *3-D* arrangement of all atoms in a single polypeptide chain.

•4º : Arrangement of polypeptide chains into a functional protein, eg. hemoglobin.

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Protein Biosynthesis

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Carbohydrates

•High energy source for most organisms and structural material for plants.

•Empirical formula = CH_2O

•Monosaccharides (simple sugars)

- **pentoses - ribose, arabinose**
- **hexoses - fructose, glucose**

•Disaccharides (formed from 2 monosaccharides joined by a glycoside linkage)

- **sucrose (glucose + fructose)**

. Polysaccharides (many monosaccharide units)

- **starch, cellulose**

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Carbohydrates

- **Carbohydrates have empirical formula $C_x(H_2O)_x$.**
- **Carbohydrate means hydrate of carbon.**
- **Most abundant carbohydrate is glucose, $C_6H_{12}O_6$.**
- **Carbohydrates are polyhydroxy aldehydes and ketones.**
- **Glucose is a 6 carbon aldehyde sugar and fructose 6 carbon ketone sugar.**
- **The alcohol side of glucose can react with the aldehyde side to form a six-membered ring.**
- **Most glucose molecules are in the ring form.**
- **Note the six-membered rings are not planar.**

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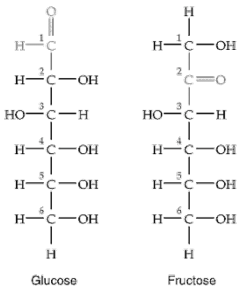
Carbohydrates



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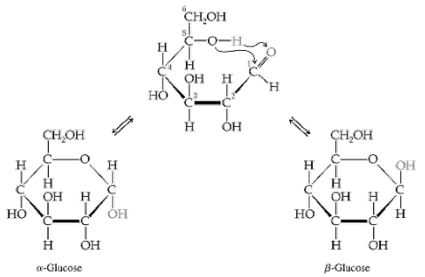
Carbohydrates



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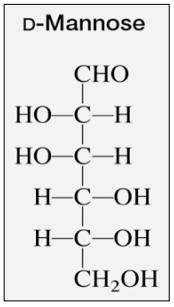
QUESTION



The monosaccharide mannose has how many chiral carbon centers?

A. None
B. Two
C. Four
D. Six

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Carbohydrates

Polysaccharides

- **Starch is poly α-glucose whereas cellulose is poly β-glucose.**
- **Enzymes that hydrolyze starch do not hydrolyze cellulose because of the different shapes of the polymers.**
- **Ingested cellulose is recovered unmetabolized.**
- **Bacteria in the stomach of animals contain cellulases, which are enzymes that enable animals to use cellulose for food.**

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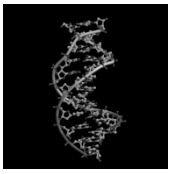
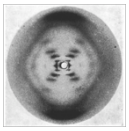
DNA: Picture 51

http://info.bio.cmu.edu/courses/03231/ProtStruc/ProtStruc.htm

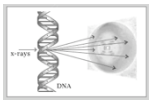
B-DNA: The advent of modeling





12 base sequence

(1953-2003)



http://molvis.sdsc.edu/pdb/dna_b_form.pdb

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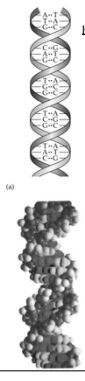
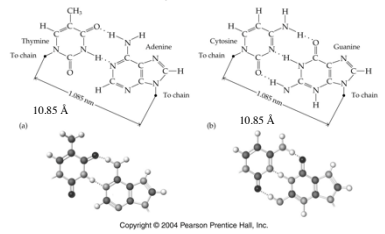
DNA: Size, Shape & Self Assembly

http://www.umass.edu/microbio/chime/beta/pe_alpha/atlas/atlas.htm

Views & Algorithms





Several formats are commonly used but all rely on plotting atoms in 3 dimensional space; .pdb is one of the most popular.

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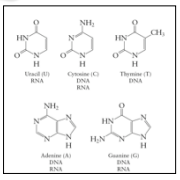
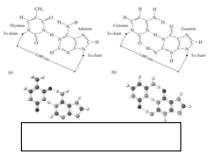
QUESTION





In the DNA structure, two strands of nucleotides become connected through hydrogen bonding. How many hydrogen bonds form between one molecule of cytosine and one molecule of guanine? In RNA uracil replaces thymine. How many hydrogen bonds form between uracil and cytosine?

A. 3; 3
B. 3; 2
C. 2; 3
D. 2; 2

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Nucleic Acids

•DNA (deoxyribonucleic acids): stores and transmits genetic information, responsible (with RNA) for protein synthesis. (Molar mass = several billion)

•RNA (ribonucleic acid): helps in protein synthesis. (Molecular weight = 20,000 to 40,000 da)

- messenger RNA
- transfer RNA

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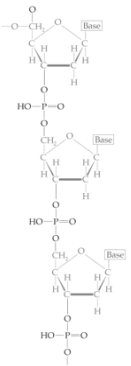
Nucleic Acids



- DNA consists of two deoxyribonucleic acid strands wound together in a double helix.
- The phosphate chains are wrapped around the outside of the DNA molecule.
- Complementary base pairs are formed from bases which optimize H-bonding: T and A or C and G.
- The complementary base pairs are held together by hydrogen bonding.
- During cell division, the DNA double helix unwinds.

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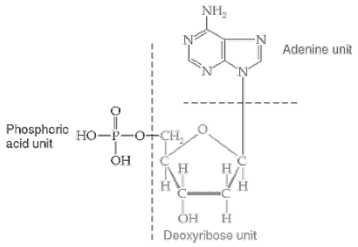
Nucleic Acids



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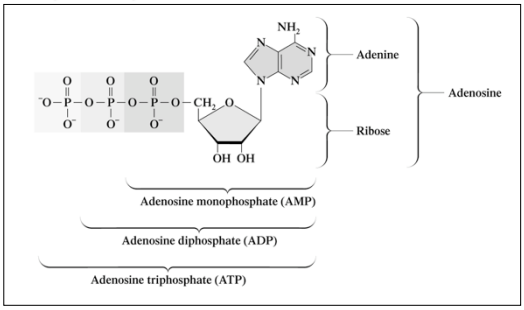
AMP, ADP, and ATP



Nucleic Acids

- DNA and RNA have different sugars (dexoyribose vs. ribose).
- There are only five bases found in DNA and RNA:
  - adenine (A),
  - guanine (G),
  - cytosine (C),
  - thymine (T found in DNA only), and
  - uracil (U found in RNA only).
- Nucleic acids are formed by condensing two nucleotides (the phosphoric acid condenses with the O-H group of the sugar).

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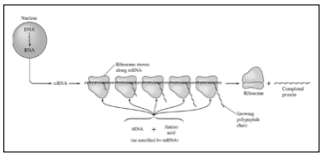
QUESTION



The "message" about which amino acids to bring together is encoded from the DNA of a cell nucleus. Once the message is released via the t-RNA, anticodons attract amino acids. How many nitrogen bases (C, G, U, A,) are used to make an anticodon?

A. two
B. three
C. four
D. U is not involved, T is.

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Important Biological Processes
Summary

http://chemconnections.org/general/chem121/biochem/bio-metabolism-2011.htm