

Session 2

BUILDING BLOCKS

Fundamental Units of Organisms

◆ All life is from 68 molecular building blocks

Nucleic Acids
8 nucleosides

Nucleic Acids (DNA and RNA)

Deoxyadenosine, Deoxycytidine, Deoxyguanosine, Deoxythymidine, Adenosine, Cytidine, Guanosine, Uridine

Glycans
32+ sugars

Glycans

Fucose, Galactose, Glucose, Glucuronic Acid, Mannose, N-Acetylgalactosamine, N-Acetylglucosamine, Neuraminic Acid, Xylose, Nononic Acid, Octulosonic Acid, Arabinose, Anabenzofuranose, Cellobiose, Fructose, Galactofuranose, Galacturonic Acid, Glucosyllic Acid, Heptose, Legonaminic Acid, Mannuronic Acid, N-Acetylglucosamine, N-Acetylgalacturonic Acid, N-Acetylmannosamine, N-Acetylmannosaminuronic Acid, N-Acetylmuramic Acid, N-Acetylserosamine, N-Acetylglucosamine, Perosamine, Pseudaminic Acid, Rhamnose, Talose

Proteins
20 amino acids

Proteins

Alanine, Arginine, Aspartic Acid, Asparagine, Cysteine, Glutamic Acid, Glutamine, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, Serine, Threonine, Tryptophan, Tyrosine, Valine

Lipids
8 types

Lipids

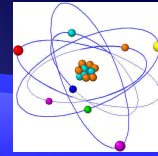
Fatty Acids, Glycerolipids, Glycerophospholipids, Polyketides, Prenol Lipids, Saccharolipids, Sphingolipids, Sterol Lipids

dA, dC, dG, dT, rA, rC, rG, rU
A, R, D, N, C, E, Q, G, H, L, L, K, M, F, P, S, T, W, Y, V
Fuc, Gal, Glc, GlcA, Man, GalNAc, GlcNAc, NeuAc, Xyl, Kdn, Kdo, Ara, Aral, Col, Frc, Gall, GalUA, GlcLA, Hep, Leg, ManUA, FucNAc, GalNAcUA, ManNAc, ManNAcUA, MurNAc, PerNAc, QuiNAc, Per, Pae, Rha, Tal
Fa, Gl, Glpi, Pk, Pi, Sel, Sphi, Stt

"From the construction, modification, and interaction of these components, the cell develops and functions." –James Marth

J. Marth "A Unified Vision of the Building Blocks of Life" *Nature Cell Biology*, 2008,10(9):1015-16

Atoms

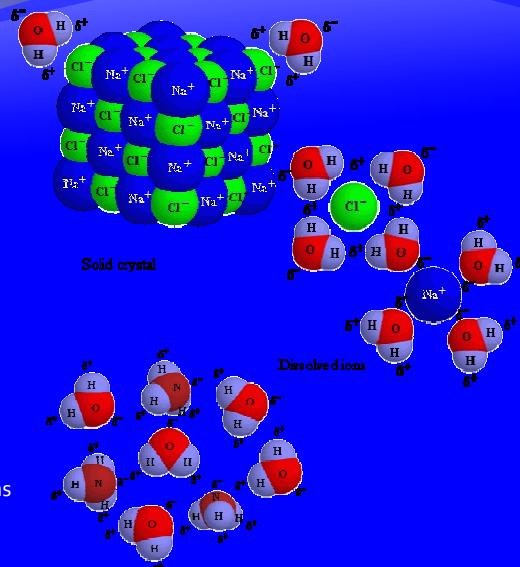


- ◆ Six basic elements
 - Hydrogen (H), Carbon (C), Nitrogen (N), Oxygen (O), Phosphorous (P), Sulfur (S)
- ◆ Valence electrons determine the bonding
- ◆ Electronegativity determines the polarity
- ◆ Composition is similar between living organisms

Atoms	H	C	N	O	P	S
Valency	1	4	5	6	5	6
Electronegativity	2.1	2.5	3.0	3.5	2.1	2.5
H. Sapien (%)	9.3	19.4	0.8	62.8	0.6	0.6
Bacteria (%)	9.9	12.14	3.0	73.7	0.6	0.3
Earth (%)	0.9	0.2	0.9	50	0.12	0.12

Molecules

- ◆ Covalent bonds
 - Shared electrons
 - Single (C-C), Double (C=C), and rarely Triple (C≡C)
 - Bond angles determined by unshared electron pairs
- ◆ Ionic bonds
 - Electrostatics
- ◆ Hydrogen bonds
 - Electrons sharing is stronger around electronegative atoms
 - e.g., O = 3.5 vs H = 2.1
 - Water is polar because of its slightly negative oxygen and slightly positive hydrogen atoms
 - Ethanol, acetone, and long chains of hydrocarbons are nonpolar
 - e.g., C = 2.5 vs H = 2.1



Chemical Reactions

- ◆ Products and Reactants
 - $C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O + \text{Energy}$
- ◆ Catalysts (Enzymes)
 - Energetically favorable if Gibbs free energy $\Delta G \leq 0$
 - Catalysts are intermediaries to help lower activation energy
 - ◆ Without enzyme

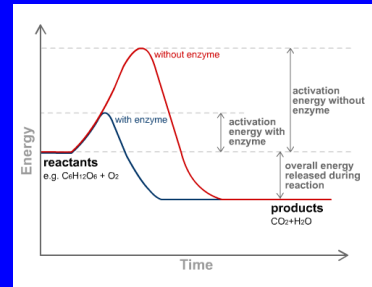
$$A-B + C \rightarrow A + B-C$$
 - ◆ With enzyme

$$A-B + C + E \rightarrow A-B-E + C$$

$$\rightarrow A + B-E + C$$

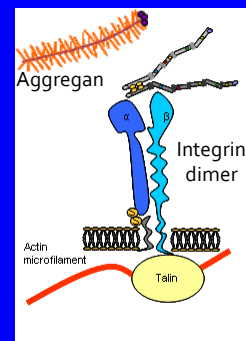
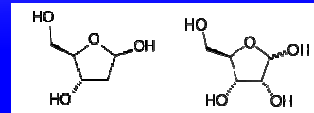
$$\rightarrow A + B-E-C$$

$$\rightarrow A + B-C + E$$



Glycans

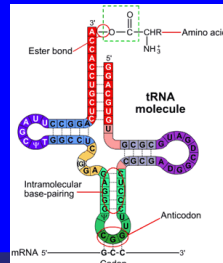
- ◆ "Carbohydrates" – hydrated carbons, (C, H, O)
- ◆ Integral Building Blocks
 - Nucleic Acids
 - Deoxyribose - DNA
 - Ribose - RNA
 - Protein
 - Glycoproteins – transmembrane proteins, e.g. integrins
 - Proteoglycans – protein core with polysaccharide chains, e.g. ECM's aggrecan
 - Lipids
 - Glycolipids – located in extracellular layer of the cell membrane



Nucleic Acids

[covered in hw 1]

- ◆ DNA – genetic code
 - Adenine, Guanine, Cytosine, Thymine
- ◆ RNA – translation into proteins
 - Adenine, Guanine, Cytosine, Uracil
 - Messenger RNA (mRNA)
 - Transfer RNA (tRNA)



TRANSCRIPTION AND TRANSLATION

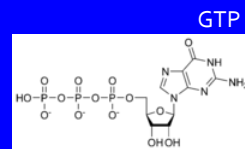
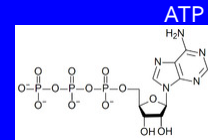
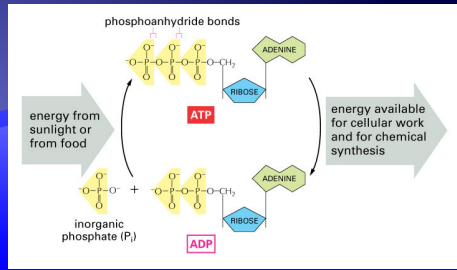
TRANSCRIPTION: In the nucleus, the cell's machinery copies the gene sequence into messenger RNA (mRNA), a molecule that is similar to DNA. Like DNA, mRNA has four nucleotide bases - but in mRNA, the base uracil (U) replaces thymine (T).

TRANSLATION: The protein-making machinery, called the ribosome, reads the mRNA sequence and translates it into the amino acid sequence of the protein. The ribosome starts at the sequence AUG, then reads three nucleotides at a time. Each three-nucleotide codon specifies a particular amino acid. The "stop" codons (UAA, UAG and UGA) tell the ribosome that the protein is complete.

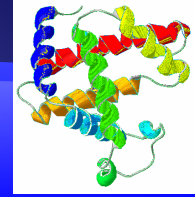
ATP & GTP

[not covered in hw 1]

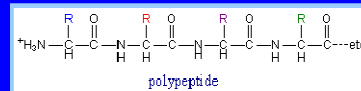
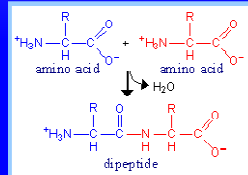
- ◆ ATP – energy currency
 - Adenosine triphosphate
 - $ATP + H_2O \rightarrow ADP + PO_4^{3-} + 7.3 \text{ kcal/mol}$
 - Actin & Myosin
- ◆ GTP - regulatory
 - Guanosine triphosphate
 - G-protein Signal Transduction
 - Microtubules



Proteins



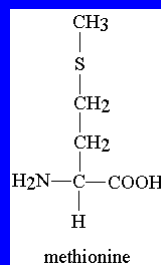
- Individual amino acids are translated into long chains called polypeptides
- Peptide bond: carboxyl + amino \rightarrow CO-NH + H₂O



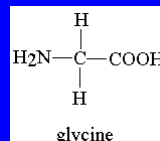
- Each amino acid in a polypeptide is called a residue (R)
- Residue sequence read from N-terminal to C-terminal
- Final sequence will "fold up" into a 3-dimensional structure
- Substitution of just one residue can change a protein's structure-function relationship

Amino Acids

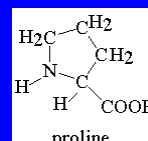
- Central carbon plus amino group (-NH₂), carboxyl group (-COOH), hydrogen atom (-H), and distinct side chain (20 in total)
- Side chains determine shape and function



methionine
Met, M
Start of all proteins



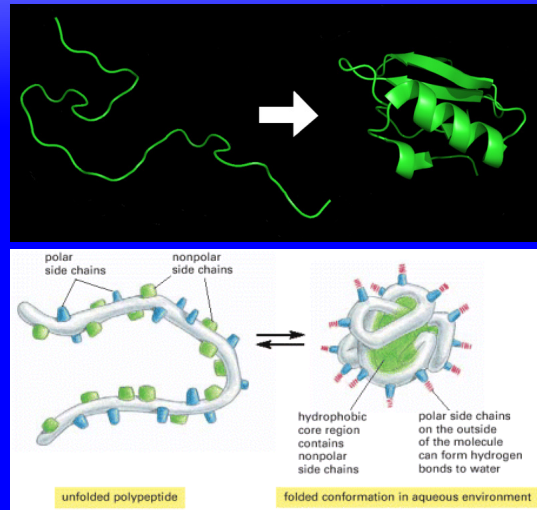
glycine
Gly, G
Simplest
Hydrophobic



proline
Pro, P
Forms a rigid kink

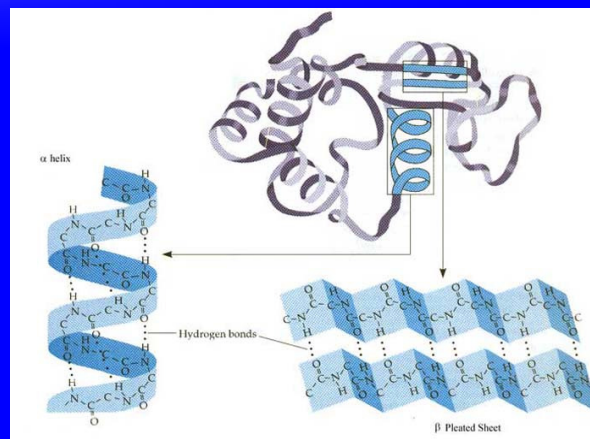
Protein Folding

- ◆ In aqueous cytoplasm, hydrophobic residues form the inner core of the protein
- ◆ Denaturing is a loss of protein structure through solvents, salts, pH, or heat



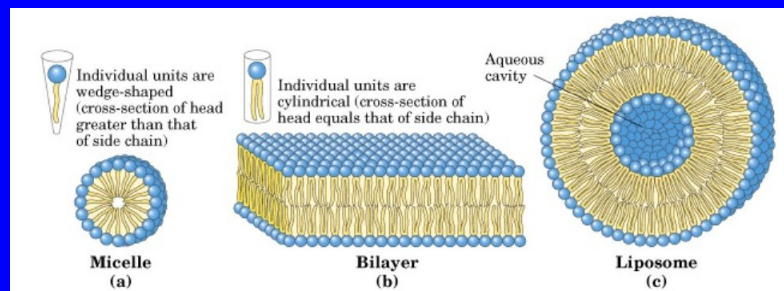
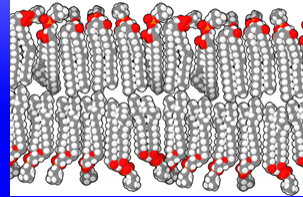
Protein Structure

- ◆ Primary – amino acid sequence
- ◆ Secondary – sub-structures through hydrogen bonds
 - Alpha helix
 - Beta sheet
- ◆ Tertiary – overall shape of a single protein unit
- ◆ Quaternary – union of more than one protein units



Lipids

- Phospholipids have nonpolar hydrocarbon chains ("tails") and polar, negatively charged phosphate groups ("head")
- In water, phospholipids cluster together to form bi-layer surfaces that shield the nonpolar tails.
- In air-water, tails point out and you have soap bubbles
- Layers held together by van der Waals forces



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Questions?