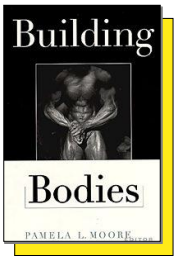
Macromolecules

Building Blocks of Life

Macromolecules

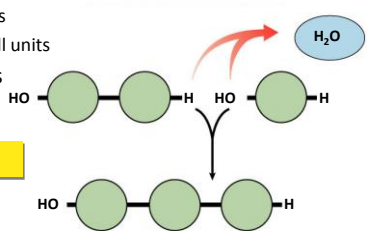
- Smaller organic molecules join together to form larger molecules
  - macromolecules
- 4 major classes of macromolecules:
  - carbohydrates
  - lipids
  - proteins
  - nucleic acids



Polymers

- Long molecules built by linking repeating building blocks in a chain
  - monomers
    - building blocks
    - repeated small units
  - covalent bonds

Dehydration synthesis

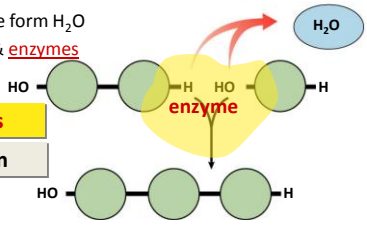


How to build a polymer

- Synthesis
  - joins monomers by "taking" H_2O out
    - one monomer donates OH^-
    - other monomer donates H^+
    - together these form H_2O
  - requires energy & enzymes

Dehydration synthesis

Condensation reaction

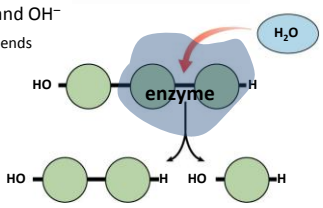


How to break down a polymer

- Digestion
  - use H_2O to breakdown polymers
    - reverse of dehydration synthesis
    - cleave off one monomer at a time
    - H_2O is split into H^+ and OH^-
      - H^+ & OH^- attach to ends
  - requires enzymes
  - releases energy

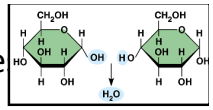
Hydrolysis

Digestion



Macromolecule Overview

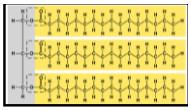
Carbohydrate



- Monomer
  - Monosaccharide
    - Carbon ring
- Polymer
  - Polysaccharide
- Bond
  - Glycosidic linkage

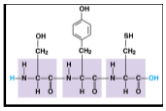
- Function
  - energy
  - raw materials
  - energy storage
  - structural compounds
- Examples
  - glucose, starch, cellulose, glycogen

Lipids



- Structure / building block
  - Glycerol, 3 fatty acids (neutral fat)
  - Phosphate, 2 fatty acids (phospholipid)
- Bond
  - Ester linkage (fat)
- Function
  - Energy storage (neutral fat)
  - Membranes (phospholipid)
  - Hormones (steroid)
- Examples
  - fat, phospholipids, steroids

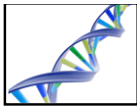
Proteins



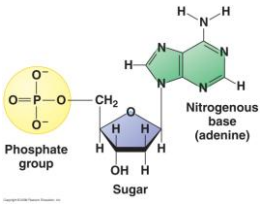
- Monomer
  - amino acids
    - N-C-C backbone
- Polymer
  - Polypeptide
  - Protein (functional unit)
- Bond
  - Peptide bond

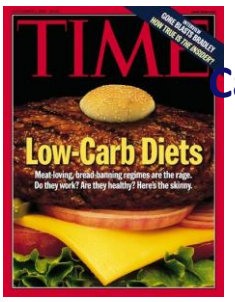
- Function
  - Enzymes, defense, receptors, transport, structure, signals
- Examples
  - digestive enzymes, membrane channels, insulin hormone, actin

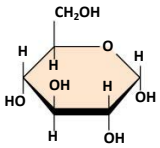
Nucleic acids



- Monomer
  - Nucleotide
    - Phosphate group, nitrogenous base, sugar
- Bond
  - Phosphodiester bond
- Function
  - information storage & transfer
- Examples
  - DNA, RNA







Carbohydrates

energy molecules

Carbohydrates

- Carbohydrates are composed of C, H, O

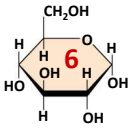
carbo - hydr - ate

$$(CH_2O)_x \xrightarrow{CH_2O} C_6H_{12}O_6$$

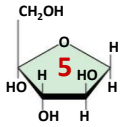
- Function:
  - energy ◆ energy storage
  - raw materials ◆ structural materials
- Monomer: sugars
- ex: sugars, starches, cellulose

Sugars

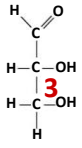
- Most names for sugars end in *-ose*
- Classified by number of carbons
  - 6C = hexose (glucose)
  - 5C = pentose (ribose)
  - 3C = triose (glyceraldehyde)



Glucose



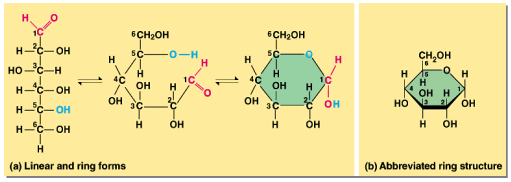
Ribose



Glyceraldehyde

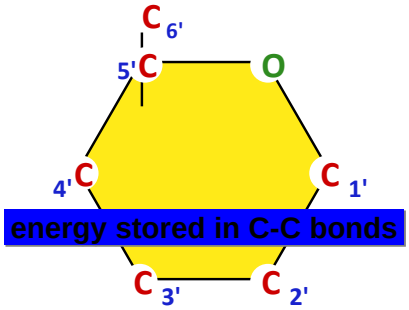
Sugar structure

5C & 6C sugars form rings in solution



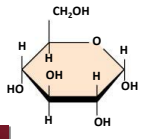
Carbons are numbered

Numbered carbons



Simple & complex su

- Monosaccharides
  - simple 1 monomer sugars
  - glucose
- Disaccharides
  - 2 monomers
  - sucrose
- Polysaccharides
  - large polymers
  - starch

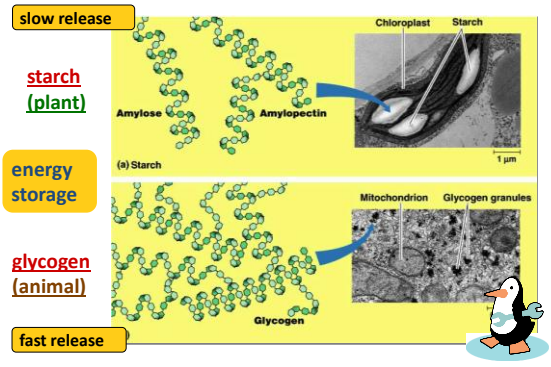


Glucose

Polysaccharides

- Polymers of sugars
  - costs little energy to build
  - easily reversible = release energy
- Function:
  - energy storage
    - starch (plants)
    - glycogen (animals)
      - in liver & muscles
  - structure
    - cellulose (plants)
    - chitin (arthropods & fungi)

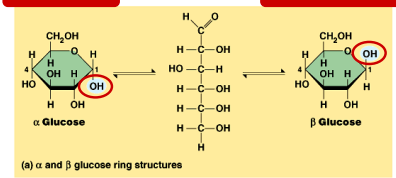
linear vs. branched polysaccharides



Polysaccharide diversity

- Molecular structure determines function

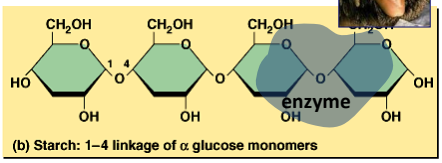
in starch | in cellulose



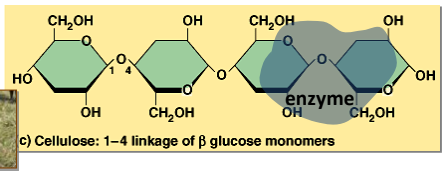
- isomers of glucose
- structure determines function…

Digesting starch vs. cellulos

starch easy to digest

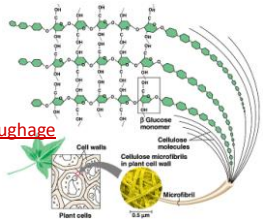


cellulose hard to digest



Cellulose

- Most abundant organic compound on Earth
  - herbivores have evolved a mechanism to digest cellulose
  - most carnivores have not
    - that's why they eat meat to get their energy & nutrients
    - cellulose = undigestible roughage



Cow

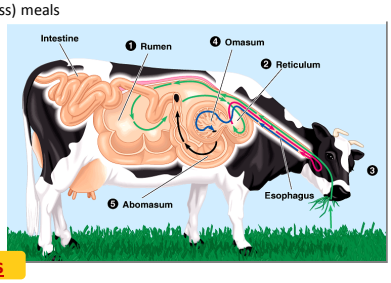
can digest cellulose well; no need to eat other sugars

Gorilla

can't digest cellulose well; must add another sugar source, like fruit to diet

Helpful bacteria

- How can herbivores digest cellulose so well?
  - BACTERIA live in their digestive systems & help digest cellulose-rich (grass) meals



Ruminants

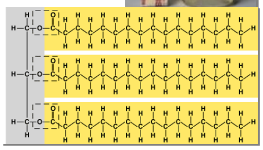
Lipids

long term energy storage
concentrated energy

2006-2007

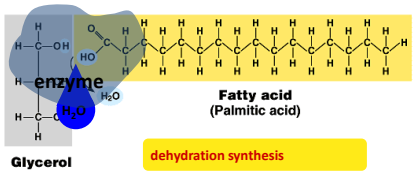
Lipids

- Lipids are composed of C, H, O
  - long hydrocarbon chains (H-C)
- "Family groups"
  - fats
  - phospholipids
  - steroids
- Do not form polymers
  - big molecules made of smaller subunits
  - not a continuing chain



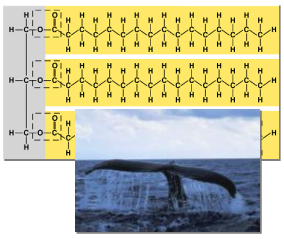
Fats

- Structure:
  - glycerol (3C alcohol) + fatty acid
    - fatty acid = long HC "tail" with carboxyl (COOH) group "head"



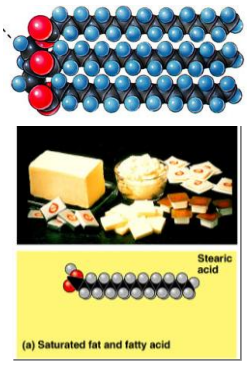
Fats store energy

- Long HC chain
  - polar or non-polar?
  - hydrophilic or hydrophobic?
- Function:
  - energy storage
    - concentrated
      - all H-C!
    - 2x carbohydrates
  - cushion organs
  - insulates body
    - think whale blubber!



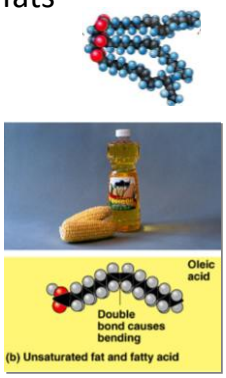
Saturated fats

- All C bonded to H
- No C=C double bonds
  - long, straight chain
  - most animal fats
  - solid at room temp.
    - contributes to cardiovascular disease (atherosclerosis) = plaque deposits

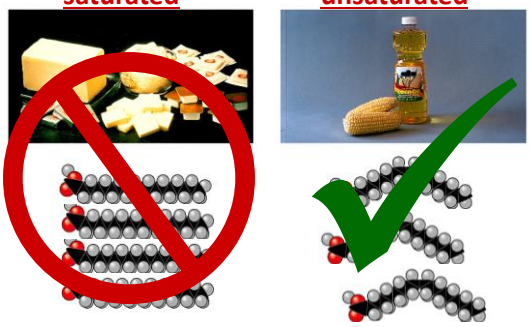


Unsaturated fats

- C=C double bonds in the fatty acids
  - plant & fish fats
  - vegetable oils
  - liquid at room temperature
    - the kinks made by double bonded C prevent the molecules from packing tightly together

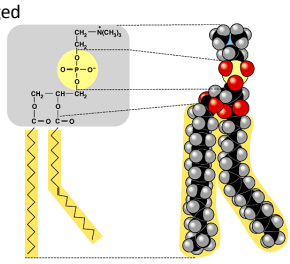


Saturated vs. unsaturated



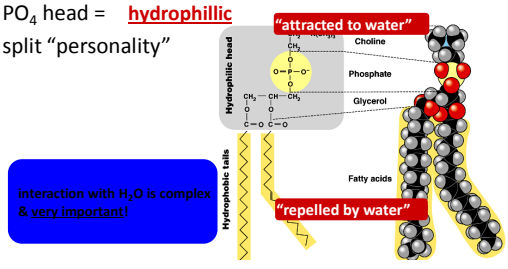
Phospholipids

- Structure:
  - glycerol + 2 fatty acids + PO_4
    - PO_4 = negatively charged



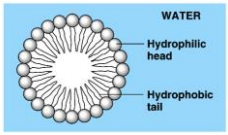
Phospholipids

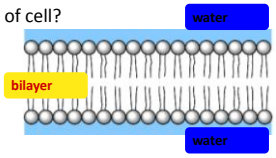
- Hydrophobic or hydrophilic?
  - fatty acid tails = **hydrophobic**
  - PO_4 head = **hydrophillic**
  - split "personality"



Phospholipids in water

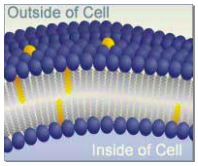
- Hydrophilic heads "attracted" to H_2O
- Hydrophobic tails "hide" from H_2O
  - can self-assemble into "bubbles"
    - bubble = "micelle"
    - can also form a phospholipid bilayer
    - early evolutionary stage of cell?

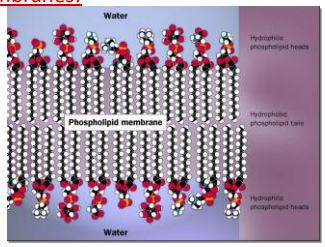




Why is this important?

- Phospholipids create a barrier in water
  - define outside vs. inside
  - they make cell membranes!

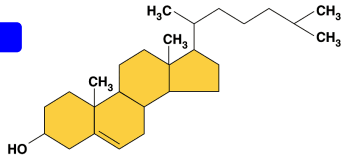




Steroids

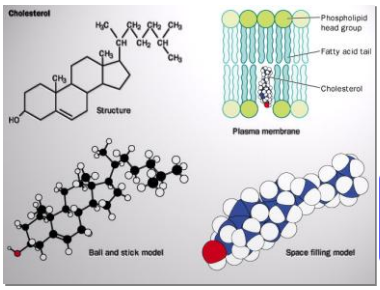
- Structure:
  - 4 fused C rings + ??
    - different steroids created by attaching different functional groups to rings
    - different structure creates different function
  - examples: cholesterol, sex hormones

cholesterol

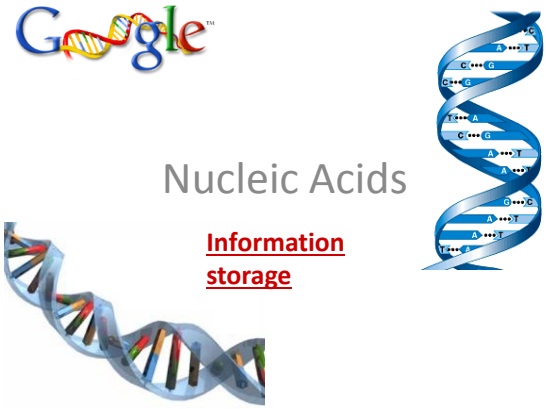


Cholesterol

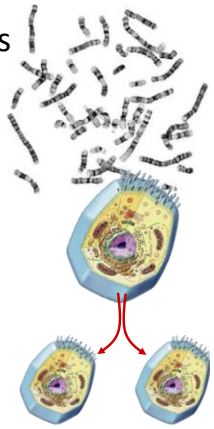
Important component of cell membrane



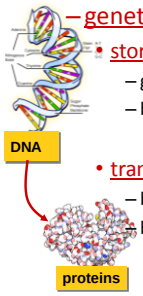
helps keep cell membranes fluid & flexible



Nucleic Acids

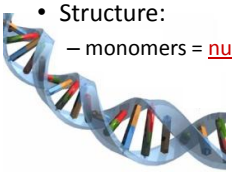


- Function:
  - genetic material
  - stores information
    - genes
    - blueprint for building proteins
      - » DNA → RNA → proteins
  - transfers information
    - blueprint for new cells
    - blueprint for next generation

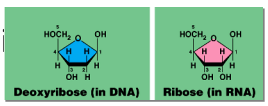


Nucleic Acids

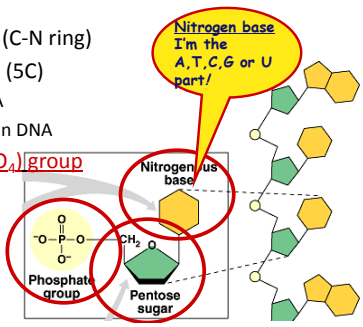
- Examples:
  - RNA (ribonucleic acid)
    - single helix
  - DNA (deoxyribonucleic acid)
    - double helix
- Structure:
  - monomers = nucleotides



Nucleoti

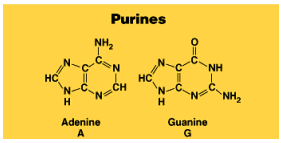


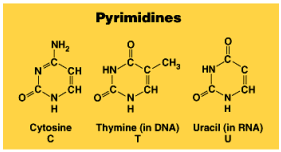
- 3 parts
  - nitrogen base (C-N ring)
  - pentose sugar (5C)
    - ribose in RNA
    - deoxyribose in DNA
  - phosphate (PO_4) group



Types of nucleotides

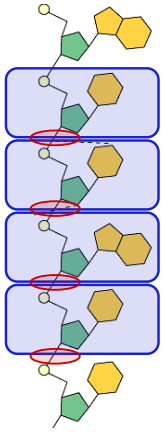
- 2 types of nucleotides
  - different nitrogen bases
  - purines
    - double ring N base
    - adenine (A)
    - guanine (G)
  - pyrimidines
    - single ring N base
    - cytosine (C)
    - thymine (T)
    - uracil (U)





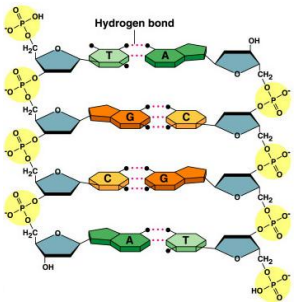
Nucleic polymer

- Backbone
  - sugar to PO_4 bond
  - phosphodiester bond
    - new base added to sugar of previous base
    - polymer grows in one direction
  - N bases hang off the sugar-phosphate backbone



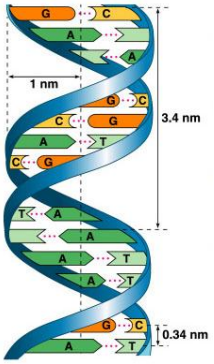
Pairing of nucleotides

- Nucleotides bond between DNA strands
  - H bonds
  - purine :: pyrimidine
  - A :: T
    - 2 H bonds
  - G :: C
    - 3 H bonds



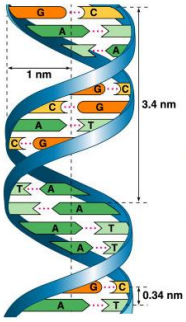
DNA molecule

- Double helix
  - H bonds between bases join the 2 strands
    - A :: T
    - C :: G



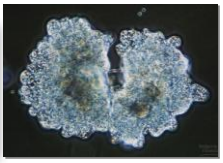
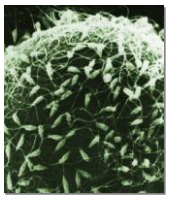
Copying DNA

- Replication
  - 2 strands of DNA helix are complementary
    - have one, can build other
    - have one, can rebuild the whole



When does a cell copy DNA?

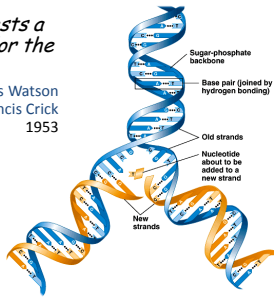
- When in the life of a cell does DNA have to be copied?
  - cell reproduction
    - mitosis
  - gamete production
    - meiosis

DNA replication

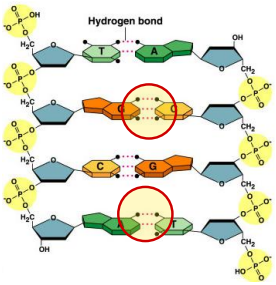
"It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material."

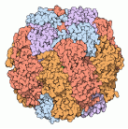
James Watson
Francis Crick
1953



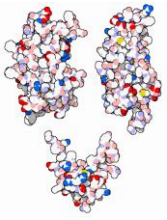
Interesting note…

- Ratio of A-T::G-C affects stability of DNA molecule
  - 2 H bonds vs. 3 H bonds
  - biotech procedures
    - more G-C = need higher T° to separate strands
  - high T° organisms
    - many G-C

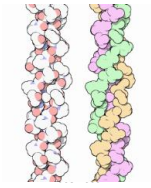




Proteins



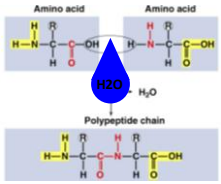
Multipurpose molecules



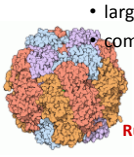
Proteins

- Most structurally & functionally diverse group
- Function: involved in almost everything
  - enzymes (pepsin, DNA polymerase)
  - structure (keratin, collagen)
  - carriers & transport (hemoglobin, aquaporin)
  - cell communication
    - signals (insulin & other hormones)
    - receptors
  - defense (antibodies)
  - movement (actin & myosin)
  - storage (bean seed proteins)

Proteins

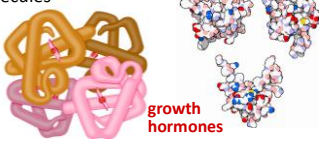


- Structure
  - monomer = amino acids
    - 20 different amino acids
  - polymer = polypeptide
    - protein can be one or more polypeptide chains folded & bonded together
    - large & complex molecules
    - complex 3-D shape



hemoglobin

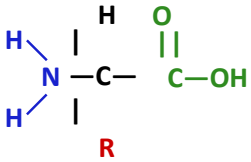
Rubisco



growth hormones

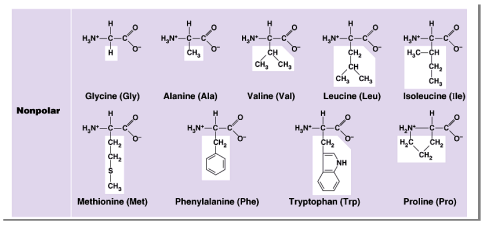
Amino acids

- Structure
  - central carbon
  - amino group
  - carboxyl group (acid)
  - R group (side chain)
    - variable group
    - different for each amino acid
    - confers unique chemical properties to each amino acid
      - like 20 different letters of an alphabet
      - can make many words (proteins)



Effect of different R groups: Nonpolar amino acids

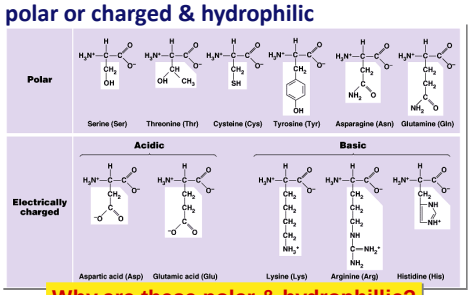
- **nonpolar & hydrophobic**



Why are these nonpolar & hydrophobic?

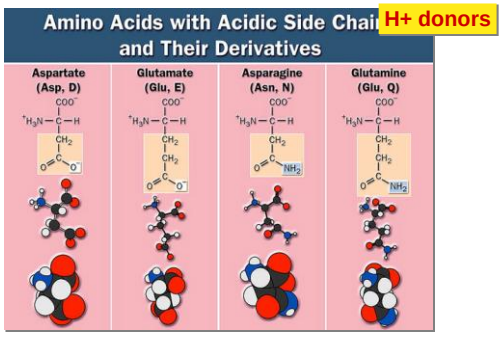
Effect of different R groups: Polar amino acids

- **polar or charged & hydrophilic**

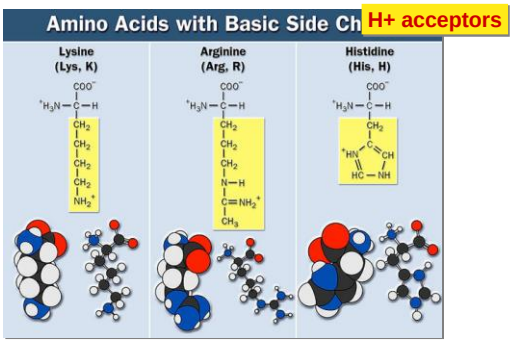


Why are these polar & hydrophillic?

Ionizing in cellular waters



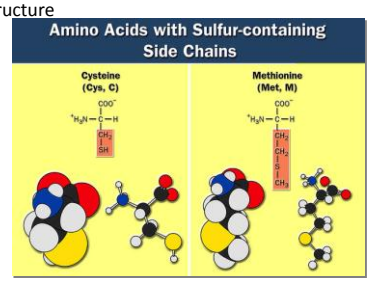
Ionizing in cellular waters



Sulfur containing amino acids

- Form disulfide bridges
  - covalent cross links betweens sulfhydryls
  - stabilizes 3-D structure

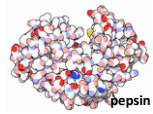
H-S – S-H

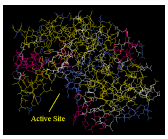


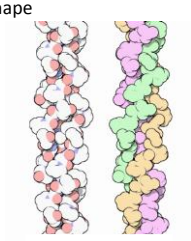
Protein structure & function

- Function depends on structure
  - 3-D structure
    - twisted, folded, coiled into unique shape


hemoglobin

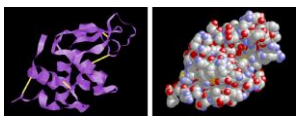

pepsin




collagen

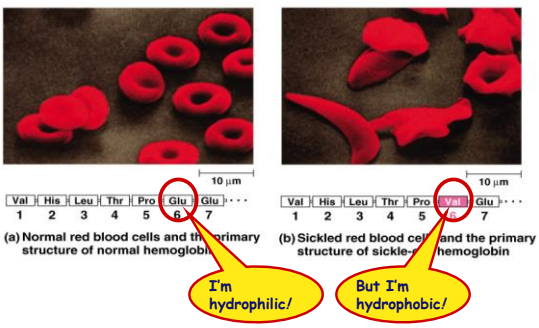
Primary (1°) structure

- Order of amino acids in chain
  - amino acid sequence determined by gene (DNA)
  - slight change in amino acid sequence can affect protein's structure & its function
    - even just one amino acid change can make all the difference!


lysozyme: enzyme in tears & mucus that kills bacteria

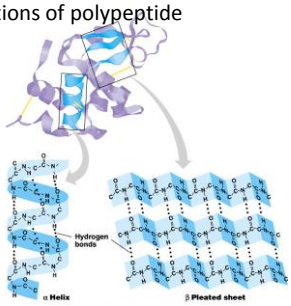
Sickle cell an

Just 1 out of 146 amino acids!



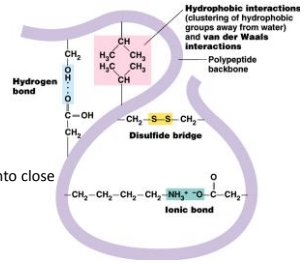
Secondary (2°) structure

- "Local folding"
  - folding along short sections of polypeptide
  - interactions between the backbones of adjacent amino acids
    - H bonds
  - forms sections of 3-D structure
    - α-helix
    - β-pleated sheet



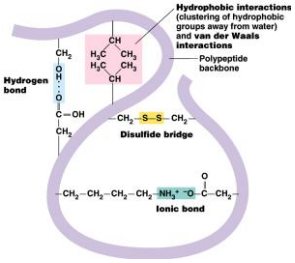
Tertiary (3°) structure

- "Whole molecule folding"
  - interactions between distant amino acid side chains
    - hydrophobic interactions
      - cytoplasm is water-based
      - nonpolar amino acids cluster away from water
    - van der Waals Interactions
      - Nonpolar molecules forced into close proximity can interact due to transient charge distribution (electron movement)



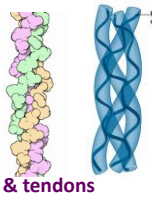
Tertiary (3°) structure

- H bonds
- Ionic bonds
- Disulfide bridges
  - covalent bonds between sulfurs in sulfhydryls (S–H) anchors 3-D shape

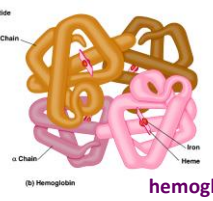


Quaternary (4°) structure

- More than one polypeptide chain bonded together
  - only then does polypeptide become functional protein
    - hydrophobic interactions



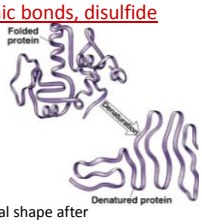
collagen = skin & tendons



hemoglobin

Protein denaturation

- Unfolding a protein
  - conditions that disrupt H bonds, ionic bonds, disulfide bridges
    - temperature
    - pH
    - salinity
  - alter 2° & 3° structure
    - alter 3-D shape
  - destroys functionality
    - some proteins can return to their functional shape after denaturation, many cannot

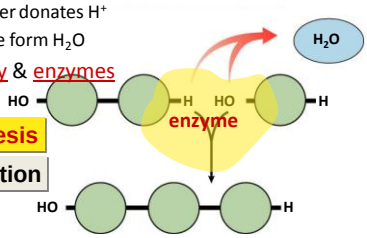


How to build a polymer

- Synthesis
  - joins monomers by "taking" H_2O out
    - one monomer donates OH^-
    - other monomer donates H^+
    - together these form H_2O
  - requires energy & enzymes

Dehydration synthesis

Condensation reaction

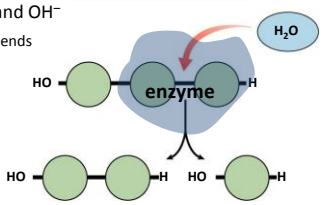


How to break down a polymer

- Digestion
  - use H_2O to breakdown polymers
    - reverse of dehydration synthesis
    - cleave off one monomer at a time
    - H_2O is split into H^+ and OH^-
      - H^+ & OH^- attach to ends
  - requires enzymes
  - releases energy

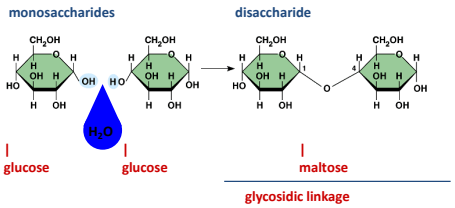
Hydrolysis

Digestion



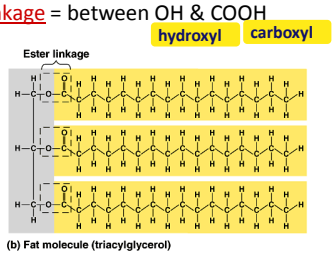
Building sugars

- Dehydration synthesis

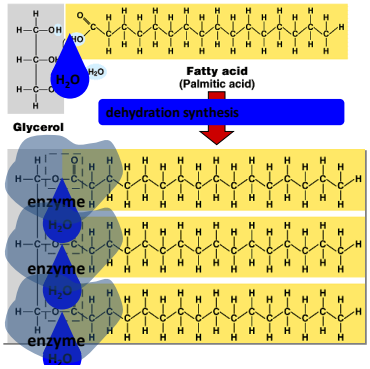


Building Fats

- Triacylglycerol
  - 3 fatty acids linked to glycerol
  - ester linkage = between OH & COOH

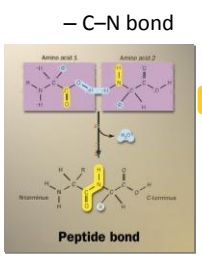


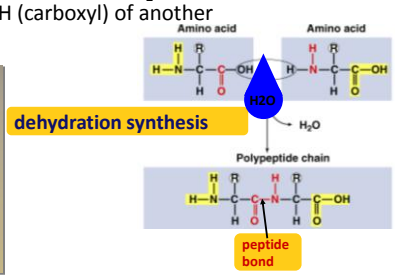
Dehydration synthesis



Building proteins

- Peptide bonds
  - covalent bond between NH_2 (amine) of one amino acid & COOH (carboxyl) of another
  - C–N bond





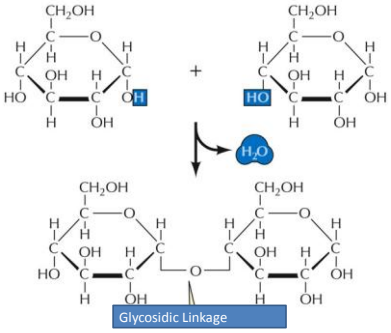
Do NOW! (on your own, no notes!)

1. Identify the **monomer** and **bond type** for *carbohydrates*, *proteins*, and *nucleic acids*.
2. Identify the three parts of a *nucleotide*
3. Name & give a function for the three classes of *lipids*.

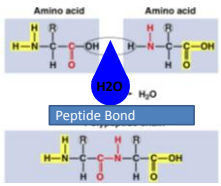
Carbohydrates

- Monomer: Monosaccharide or simple sugar

Carbohydrates



Proteins



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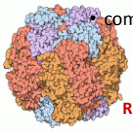
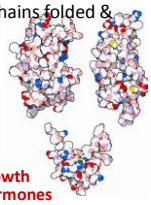
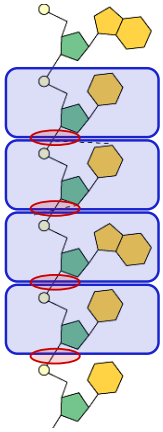

Rubisco


hemoglobin


growth hormones

Nucleic acid

- Nucleotide monomers
  - sugar to PO_4 bond
  - phosphodiester bond
    - new base added to sugar of previous base
    - polymer grows in one direction
  - N bases hang off the sugar-phosphate backbone



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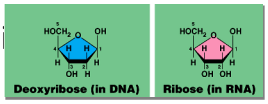
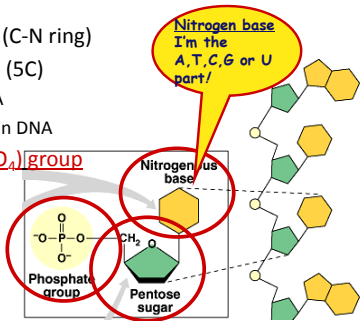
Nucleot



- 3 parts
  - nitrogen base (C-N ring)
  - pentose sugar (5C)
    - ribose in RNA
    - deoxyribose in DNA
  - phosphate (PO_4) group



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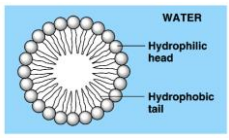
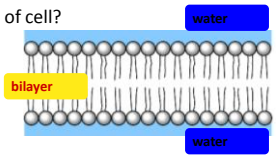
Phospholipids in water

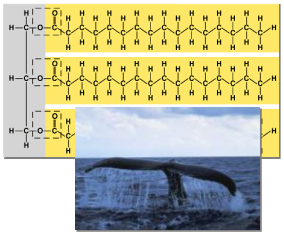
- Hydrophilic heads "attracted" to H_2O
- Hydrophobic tails "hide" from H_2O
  - can self-assemble into "bubbles"
    - bubble = "micelle"
    - can also form a phospholipid bilayer
    - early evolutionary stage of cell?





Fats store energy

- Long HC chain
  - polar or non-polar?
  - hydrophilic or hydrophobic?
- Function:
  - energy storage
    - concentrated
      - all H-C!
    - 2x carbohydrates
  - cushion organs
  - insulates body
    - think whale blubber!



Steroids

- Structure:
  - 4 fused C rings + ??
    - different steroids created by attaching different functional groups to rings
    - different structure creates different function
  - examples: cholesterol, sex hormones

cholesterol