Chapter 4

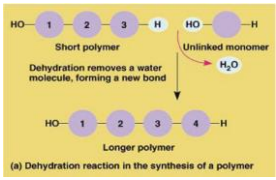
Macromolecules

Macromolecules

- Smaller organic molecules join together to form larger molecules
  - Macromolecules
- 4 major classes of macromolecules
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

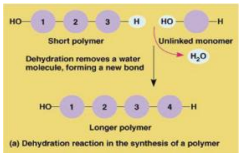
Polymers

- Long molecules built by linking chain of repeating smaller units
  - Polymers
  - Monomers = repeated small units
  - Covalent bonds



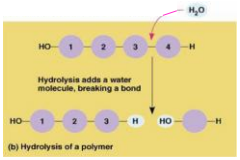
How to build a polymer

- Condensation reaction
  - Dehydration synthesis
  - Joins monomer by "taking" H_2O out
    - 1 monomer provides OH
    - The other monomer provides H
    - Together these form H_2O
  - Requires energy and enzymes

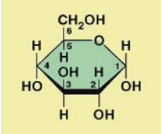


How to break down a polymer

- Hydrolysis
  - Use H_2O to break apart monomers
    - Reverse of condensation reaction
    - H_2O is split into H & OH
    - H & OH group attach where the covalent bond used to be
  - Ex. Digestion is hydrolysis



Carbohydrates



So what's all this talk about carb's?

- Atkin's Diet
- South Beach Diet

Carbohydrates

- Carbohydrates are composed of C, H, O
- Function:
  - Energy
  - Raw materials
  - Energy storage
  - Structural materials
- Monomer: sugars
- Ex. Sugars & starches

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

Sugars

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

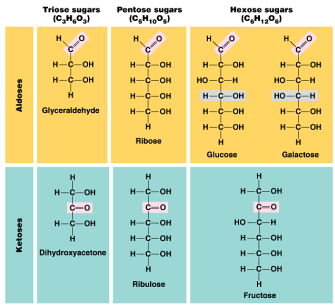
What functional groups?

Carbonyl

Aldehyde

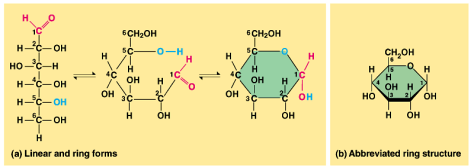
Ketone

Hydroxyl



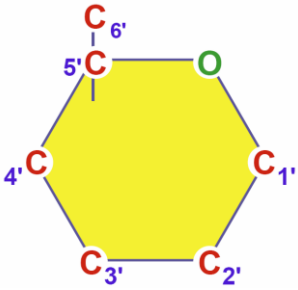
Sugar structure

- 5C & 6C sugars form rings in aqueous solutions
  - In cells!



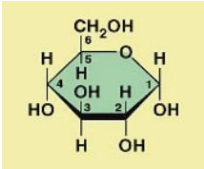
Carbons are numbered

Numbered carbons



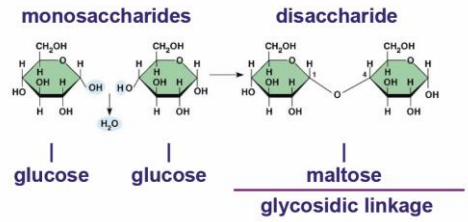
Simple & complex sugars

- Monosaccharides
  - Simple 1 monomer sugars
  - Glucose
- Disaccharide
  - 2 monomers
  - Sucrose
- Polysaccharide
  - Large polymer
  - starch



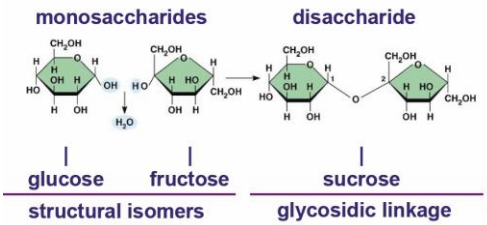
Building sugars

- Dehydration synthesis



Building sugars

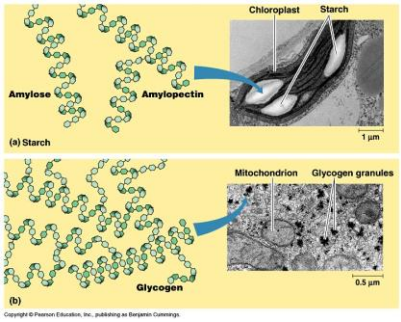
- Dehydration synthesis



Polysaccharide

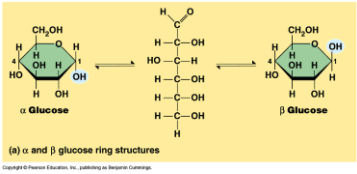
- Polymer of sugars
  - Costs little energy yo build
  - Easily reversible – release energy
- Function:
  - Energy storage
    - Starch (plants)
    - Glycogen (animals)
  - Building materials = structure
    - Cellulose (plants)
    - Chitin (arthropods & fungi)

Branched vs. linear polysaccharides



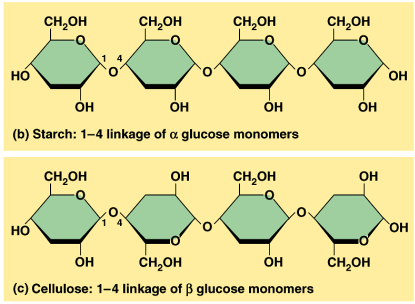
Polysaccharide diversity

- Molecular structure determine function



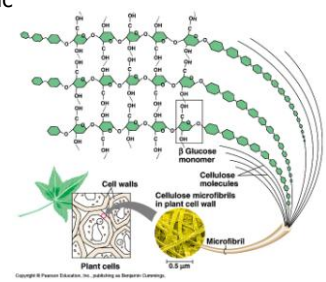
- Isomers of glucose
- How does structure influence function…

Digesting starch vs. cellulose



Cellulose

- Most abundant organic compound on earth



Glycemic Index

- Which food will get into your blood more quickly?
  - Apple
  - Rice cakes
  - Corn flakes
  - Bagel
  - Peanut M&M

Glycemic Index

- Ranking of carbohydrates based on their immediate affect on blood glucose (blood sugar) levels
- Carbohydrate food that breakdown quickly during digestion have the highest glycemic indices. Their blood sugar response is fast and high.

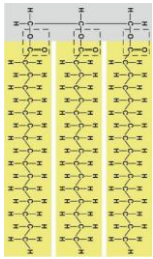
Glycemic Index

- Which food will get into your blood more quickly?
  - Apple - 36
  - Rice cakes - 82
  - Corn flakes - 84
  - Bagel - 72
  - Peanut M&M - 33

Lipids

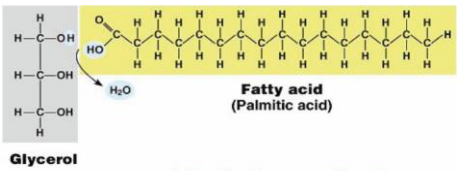
Lipids

- Lipids are composed of C, H, O
  - Long hydrocarbon chains
- Diverse group
  - Fats
  - Phospholipids
  - Steroids
- Do NOT form polymers
  - Big macromolecule made of subunit smaller molecules
  - Not a continuing chain



Fats

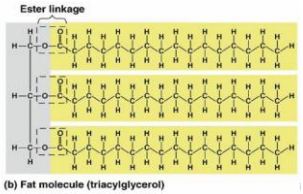
- Structure:
  - Glycerol (3C alcohol) +fatty acid
    - Fatty acid = long HC "tail" with COOH group at head



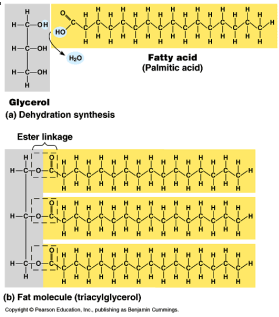
dehydration synthesis

Fat

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

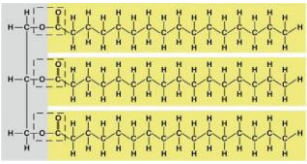


Dehydration Synthesis



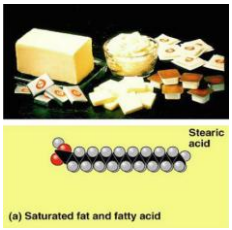
Fats

- Long HC chain
  - Polar or nonpolar
  - Hydrophilic or hydrophobic
- Function
  - Energy storage
    - Very rich
    - 2x carbohydrates
  - Cushion organs
  - Insulates body
    - Think whale blubber!



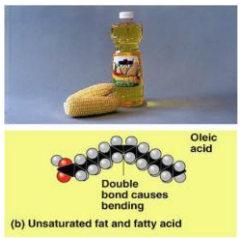
Saturated fats

- All C bonded to H
- No C=C double bonds
  - Long, straight chain
  - Most animal fat
  - Solid at room temperature
    - Contribute to cardiovascular disease (atherosclerosis) = plaque deposits



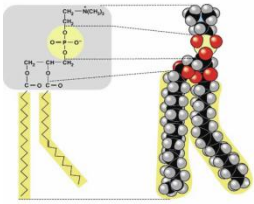
Unsaturated fats

- 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



Phospholipid

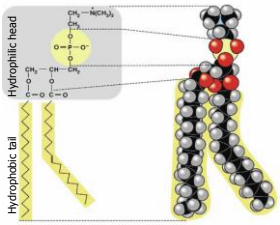
- Structure:
  - Glycerol + 2 fatty acids + PO4
    - PO4 negatively charged
    - Other small molecules may also be attached
      - Adenine (ATP)



Phospholipids

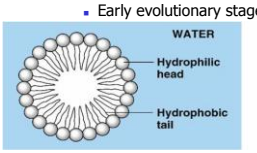
- Hydrophobic or hydrophilic?
  - Fatty acid tails = hydrophobic
  - PO4 = hydrophilic head
  - Duel "personality"

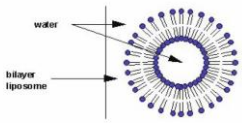
Interaction with H2O is complex and **very important!**



Phospholipids in water

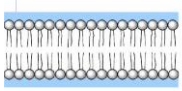
- Hydrophilic heads attracted to H2O
- Hydrophobic tails "hide" from H2O
  - Self-assemble into aggregates
    - Micelle
    - Liposome
    - Early evolutionary stage of cell

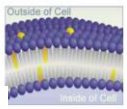


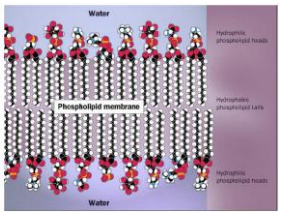


Why is this important?

- Phospholipids define outside vs. inside
- Where do we find phospholipids in cells?
  - Cell membrane

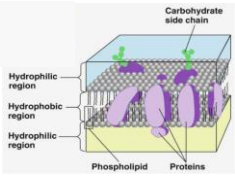






Phospholipids & cells

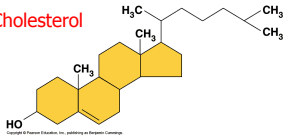
- Phospholipids of cell membrane
  - Double layer = bilayer
  - Hydrophilic heads on outside
    - In contact with aqueous solution
  - Hydrophobic tails on inside
    - Form core
  - Forms barrier between cell & external environment



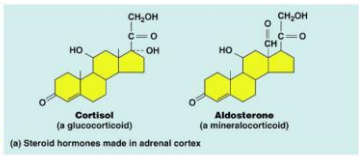
Steroids

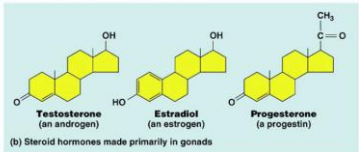
- Ex. Cholesterol, sex hormones
- 4 fused C rings
  - Different steroids created by attaching different functional groups to rings

Cholesterol



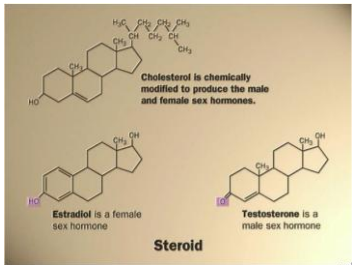
Diversity in steroids





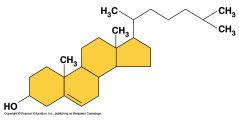
From cholesterol → Sex Hormone

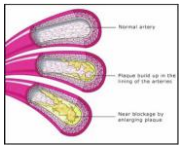
- What a big difference a little atom can make!



Cholesterol

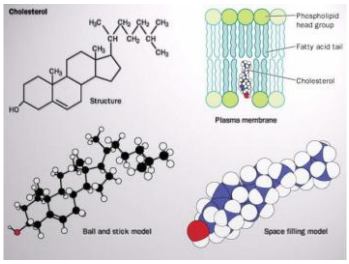
- Important cell component
  - Animal cell membranes
  - Precursor of all other steroids
    - Including vertebrate sex hormones
  - High levels in blood may contribute to cardiovascular disease





Cholesterol

Helps keep cell membranes fluid and flexible



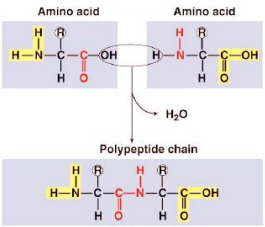
Proteins

Proteins

- Most structurally & functionally diverse group of biomolecules
- Function:
  - Involved in almost everything
    - Enzymes
    - Structure (keratin, collagen)
    - Carries & transport (membrane channels)
    - Receptors & binding (defense)
    - Contraction (actin & myosin)
    - Signaling (hormones)
    - Storage (bean seed proteins)

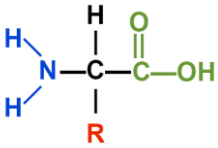
Proteins

- Structure:
  - Monomer = amino acid
    - 20 different amino acids
  - Polymer = polypeptide
    - Protein can be 1 or more polypeptide chains folded & bonded together
    - Large & complex molecule
    - Complex 3-D shape



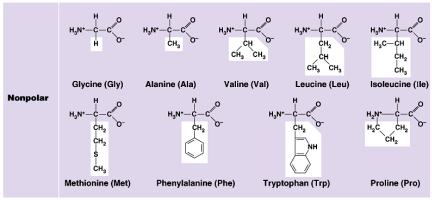
Amino acids

- Central carbon
- Amino group
- Carboxyl group
- R group (side chain)
  - Variable group
  - Confers unique chemical properties of the acid



Nonpolar amino acids

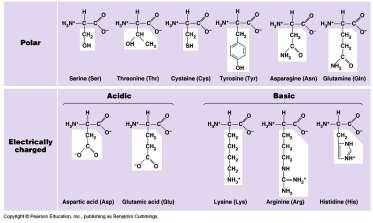
- Nonpolar & hydrophobic



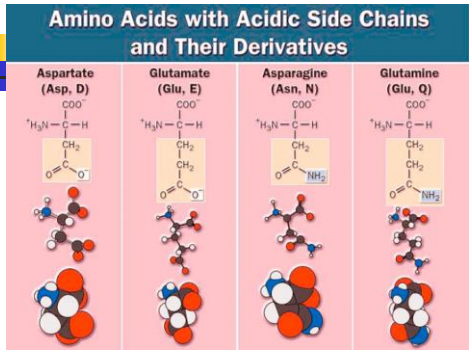
Why are these nonpolar & hydrophobic?

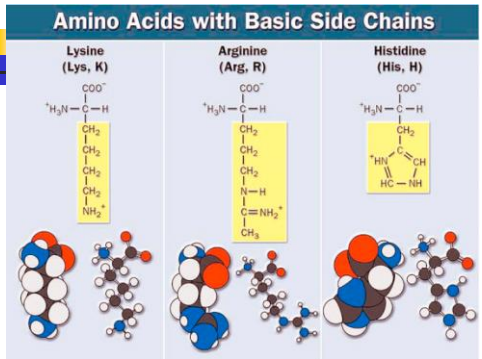
Polar amino acids

- Polar or charged & hydrophilic



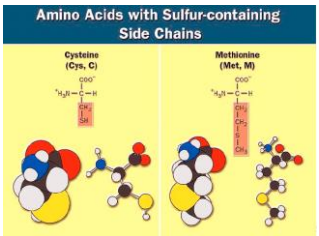
Why are these polar & hydrophilic?





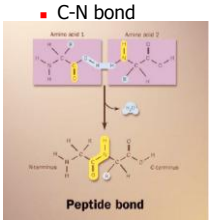
Sulfur containing amino acids

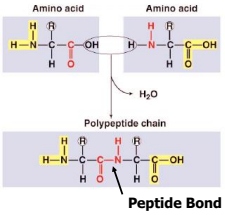
- Disulfide bridges
  - Cysteines form cross links



Building proteins

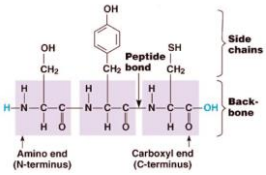
- Peptide bonds: dehydration synthesis
  - Linking NH_2 of one amino acid COOH of another
  - C-N bond





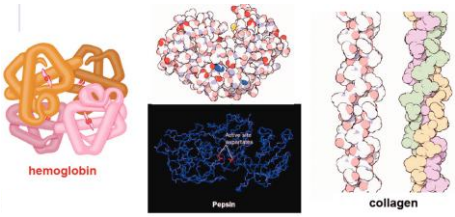
Building proteins

- Polypeptide chains
  - N-terminal = NH_2 end
  - C-terminal = COOH end
  - Repeated sequence (N-C-C) is the polypeptide backbone
    - Grow in one direction



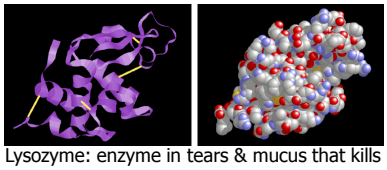
Protein structure & function

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

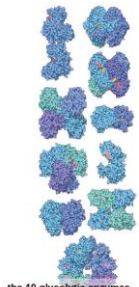


Protein structure & function

- Function depends on structure
  - All starts with the **order of amino acids**
    - What determines the order of amino acids?



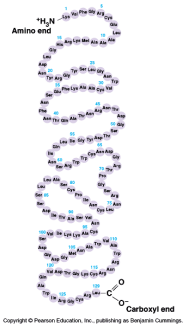
Lysozyme: enzyme in tears & mucus that kills bacteria



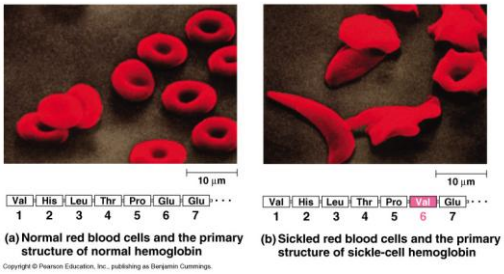
the 10 glycolytic enzymes used to breakdown glucose to make ATP

Primary (1°) structure

- Order of amino acids in chain
  - Amino acid sequence determined by DNA
  - Slight change in amino acid sequence can affect protein's structure & it's function
    - Even just one amino acid can make all the difference!



Sickle cell anemia

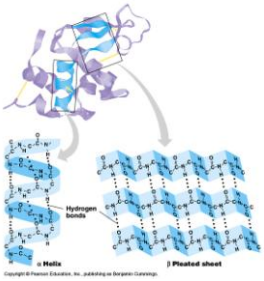


(a) Normal red blood cells and the primary structure of normal hemoglobin

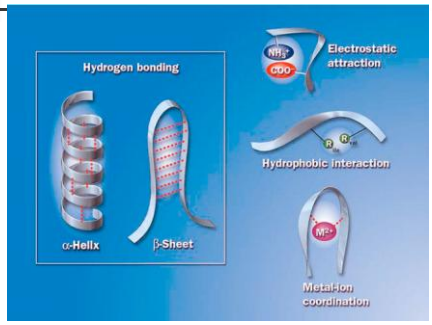
(b) Sickled red blood cells and the primary structure of sickle-cell hemoglobin

Secondary (2°) structure

- "Local shape"
  - Folding along short sections of polypeptide
    - Interaction between adjacent amino acids
    - **H-bonds** between R groups
    - Alpha-helix
    - Beta-pleated sheet

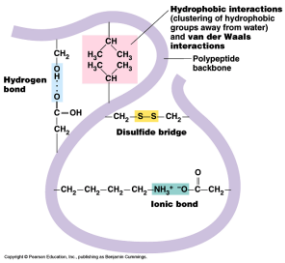


Secondary (2°) structure



Tertiary (3°) Structure

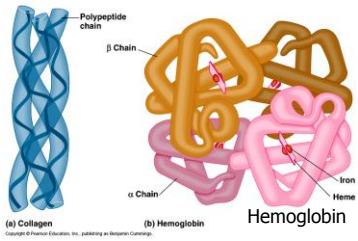
- "Whole molecule shape"
  - Determined by interactions between R groups
    - Hydrophobic & hydrophilic interactions
      - Effect of water in cell
    - H bonds
    - Ionic bonds
    - Disulfide bonds



Quaternary (4°) Structure

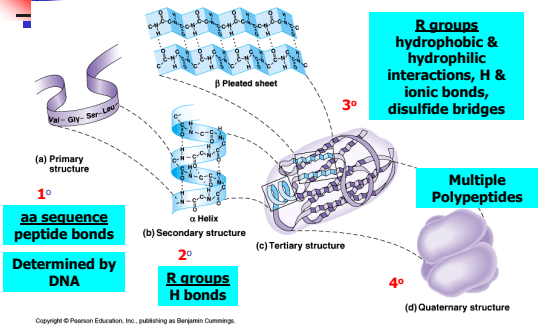
- Joins together more than 1 polypeptide chain
  - Only then is it a functional protein

Collagen = skin & tendons



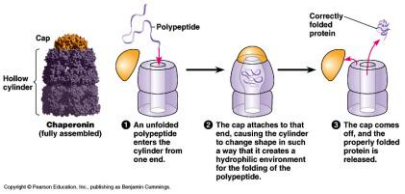
Hemoglobin

Protein Structure Review



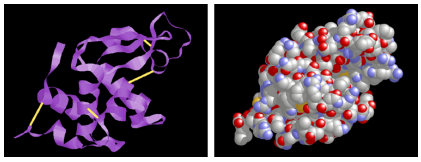
Chaperonin proteins

- Guide protein folding
  - Provide shelter for folding polypeptides
  - Keep the new protein segregated from cytoplasmic influences



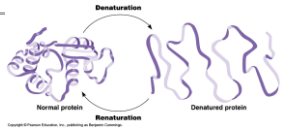
Protein models

- Protein structure visualized by
  - X-ray crystallography
  - Extrapolating from amino acid sequence
  - Computer modeling



Lysozyme

Denature a protein



- Disrupt 3° structure
  - pH
  - Salt
  - Temperature
  - Unravel or <u>denature</u> protein
  - Disrupts H bonds, ionic bonds & disulfide binds
- Some proteins can return to their functional shape after denaturation, many cannot

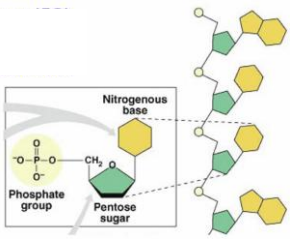
Nucleic Acids

Nucleic Acids

- Function:
  - Store & transmit hereditary information
- Examples:
  - RNA (ribonucleic acid)
  - DNA (deoxyribonucleic acid)
- Structure:
  - Monomers = **nucleotides**

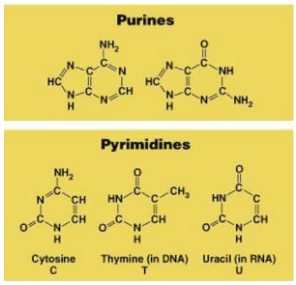
Nucleotides

- 3 parts
  - Nitrogen base (C-N ring)
  - Pentose sugar (5C)
    - Ribose in RNA
    - Deoxyribose in DNA
  - PO_4 group

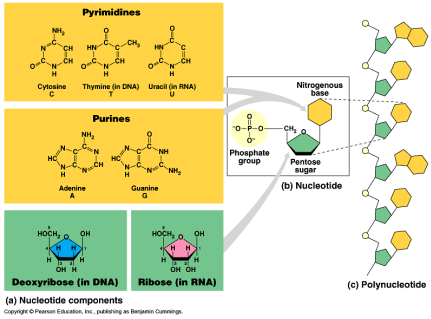


Types of nucleotides

- 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)

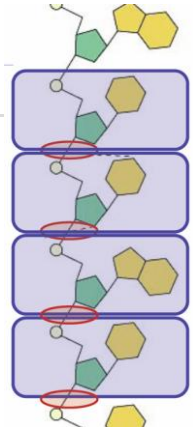


Building A Polymer



Nucleic polymer

- Backbone
  - Sugar to PO4 bond
  - Phosphodiester bond
    - New base added to sugar of previous base
    - Polymer grows in one direction
  - N bases hang off the sugar-phosphate backbone
    - *Why is this important?*



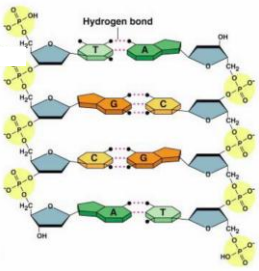
RNA & DNA

- RNA
  - Single nucleotide chain
- DNA
  - Double nucleotide chain
    - N bases bond in pairs across chains
  - Spiraled in a **double helix**
    - Double helix 1st proposed as structure of DNA in 1953 by James Watson & Francis Crick

Pairing of nucleotides

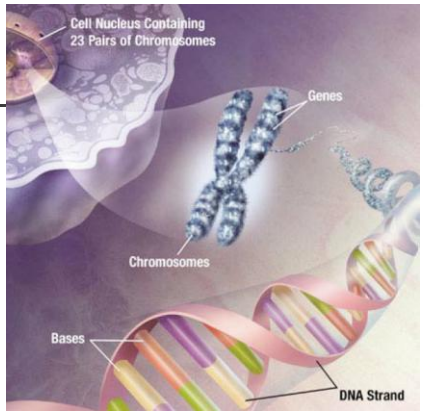
- Nucleotides bond between DNA stands
  - H bonds
  - Purine::pyrimidine
  - A::T
    - 2 H bonds
  - G::C
    - 3 H bonds

Why is this important?



Information polymer

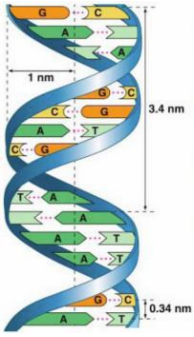
- Function
  - Series of bases encodes information
    - Like the letter of a book
    - Like binary code
  - Stored information is passed from parent to offspring
    - Need to copy accurately
  - Stored information = genes
    - Genetic information



DNA Molecule

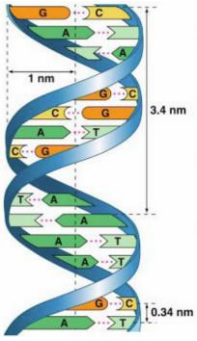
- Double Helix
  - H bonds between bases join the 2 strands
    - A::T
    - G::C

Why is it important that the strands are bonded by H bonds?



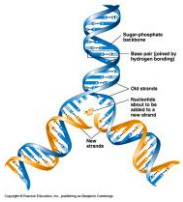
Copying DNA

- Replication
  - 2 strands of DNA helix are complementary
    - Have one, can build one
    - Have one, can rebuild the whole
  - Why is this a good system?
  - When in the life of a cell does replication occur?
    - Mitosis
    - Meiosis

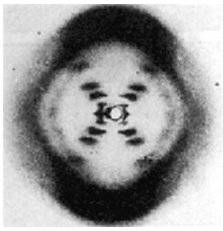


DNA replication

"It has not escapes our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material" – James Watson & Francis Crick (1953)

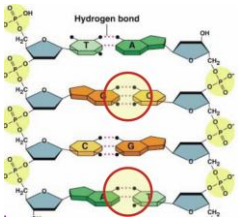


Rosalind Franklin (1920-1958)



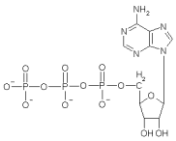
Interesting note…

- Ratio of A-T::C-G affects the stability of the DNA molecule
  - 2 H bonds vs. 3 H bonds
  - Biotech procedures
    - More G-C = need higher temp to separate strands
  - High temp organisms
    - Many G-C
  - Parasites
    - Many A-T (don't know why)



Another interesting note..

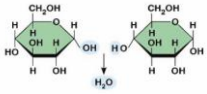
- ATP
  - Adenosine triphosphate
    - Modified nucleotide
      - Adenine ribose + P_i + P_i + P_i



Macromolecule Review

Carbohydrates

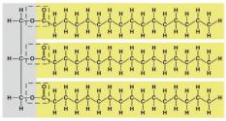
- Structure/monomer
  - Monosaccharide
- Function:
  - Energy
  - Raw materials
  - Energy storage
  - Structural compounds
- Examples
  - Glucose, starch, cellulose, glycogen



glycosidic bond

Lipids

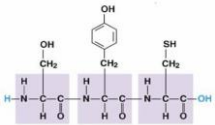
- Structure/ building blocks
  - Glycerol, fatty acids, cholesterol, H-C chains
- Function
  - Energy storage
  - Membranes
  - Hormones
- Examples
  - Fat, phospholipids, steroids



ester bond (in a fat)

Proteins

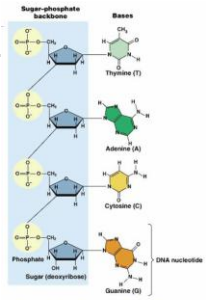
- Structure/monomer
  - Amino acids
  - Levels of structure
- Function
  - Enzyme, transport, signals, defense, structure, receptors
- Examples
  - Digestion enzymes, membrane channels, actin



peptide bond

Nucleic Acids

- Structure/monomer
  - Nucleotide
- Function
  - Information storage & transfer
- Examples
  - DNA, RNA



phosphodiester bond