The Structure and Function of Macromolecules

Chapter 5

- Objectives
  - List the four major classes of macromolecules.
  - Distinguish between monomers and polymers.
  - Draw diagrams to illustrate condensation and hydrolysis reactions.
  - Distinguish between monosaccharides, disaccharides, and polysaccharides.
  - Describe the formation of a glycosidic linkage and distinguish between the glycosidic linkages found in starch and cellulose.
  - Distinguish between saturated and unsaturated fats.
  - Distinguish between a protein and a polypeptide.

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- Explain how a peptide bond forms between two amino acids.
- Describe the four levels of protein structure
- Explain what determines protein conformation and why it is important.
- List four conditions under which proteins may be denatured.
- List the major components of a nucleotide, and describe how these monomers are linked to form a nucleic acid.
- Briefly describe the three-dimensional structure of DNA.

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The Molecules of Life

- Another level in the hierarchy of biological organization is reached when small organic molecules are joined together
- A polymer is a long molecule consisting of many similar building blocks called monomers
  - Three of the classes of life's organic molecules are polymers
    - Carbohydrates
    - Proteins
    - Nucleic acids

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The Synthesis and Breakdown of Polymers

- Small molecules are combined together by enzymes
- Condensation reactions remove H^+ from one molecule and OH^- from other molecule; fragments join to form a new compound and water
- Hydrolysis is reverse of condensation
  - The molecule is split by addition of H^+ to one component and OH^- to the other

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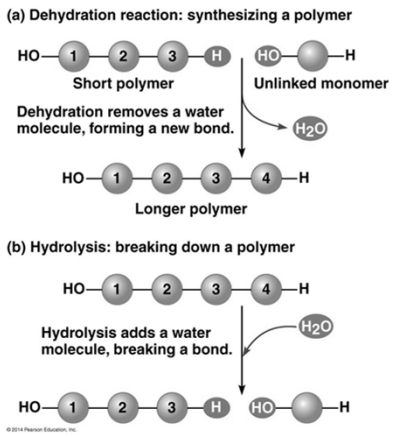

The Diversity of Polymers

- Each class of polymer is formed from a specific set of monomers
- Although organisms share the same limited number of monomer types, each organism is unique based on the arrangement of monomers into polymers
- An immense variety of polymers can be built from a small set of monomers

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Carbohydrates

- Can be simple sugar or large molecule made of sugar units
  - monosaccharide-one sugar unit
    - ribose and deoxyribose (5C) found in nucleic acids
    - glucose (6C) primary energy source

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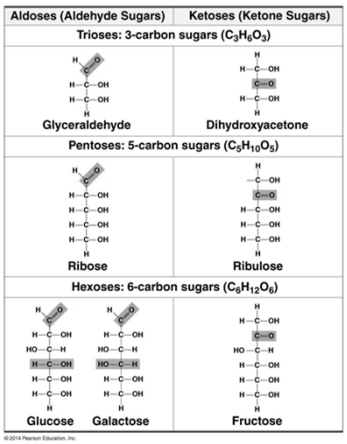

- Monosaccharides exist in two forms
  - linear molecules
  - circular molecules
- The two forms are interchangeable
  - circular form is linked together to form sugar polymers

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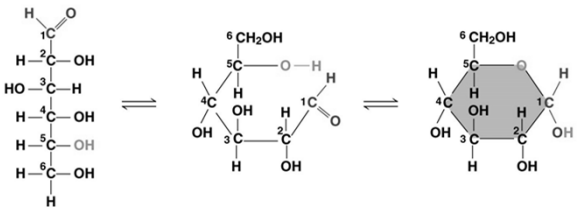
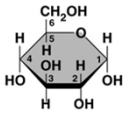


(a) Linear and ring forms



(b) Abbreviated ring structure

- Oligosaccharide-two covalently-bound monosacharides
  - sucrose-glucose+fructose
  - lactose-glucose+galactose
  - maltose-glucose+glucose

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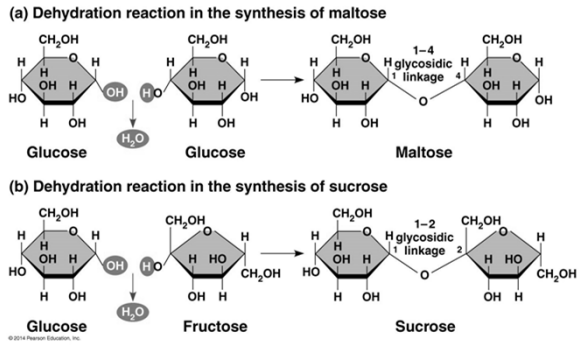

- Polysaccharide-many covalently-linked sugar units
  - Glycogen-storage form of glucose in animals
  - Starch and cellulose in plants made of glucose

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- Starch is a polymer consisting entirely of glucose monomers
  - is the major storage form of glucose in plants
  - starch (α configuration) is largely helical
- Glycogen consists of glucose monomers
  - is the major storage form of glucose in animals

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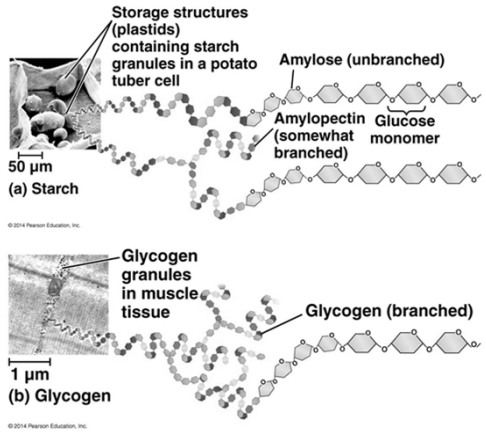

- Cellulose is a polymer of glucose
  - it has different glycosidic linkages than starch
  - is a major component of the tough walls that enclose plant cells
- Cellulose molecules (β configuration) are straight and unbranched
  - Some hydroxyl groups on the monomers of cellulose can hydrogen bond with hydroxyls of parallel cellulose molecules

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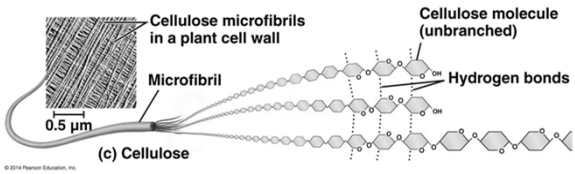

- Enzymes that digest starch by hydrolyzing α linkages can't hydrolyze β linkages in cellulose
  - the cellulose in human food passes through the digestive tract as "insoluble fiber"

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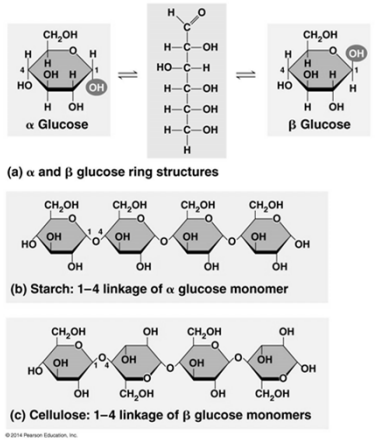

- Cellulose is difficult to digest
  - Some microbes use enzymes to digest cellulose
    - many herbivores, from cows to termites, have symbiotic relationships with these microbes

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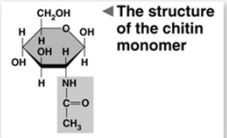
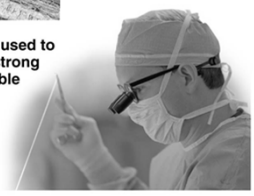
- Chitin, another important structural polysaccharide is found in the exoskeleton of arthropods
  - can be used as surgical thread



◀ The structure of the chitin monomer

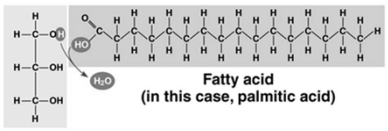
◀ Chitin, embedded in proteins, forms the exoskeleton of arthropods.

▶ Chitin is used to make a strong and flexible surgical thread.

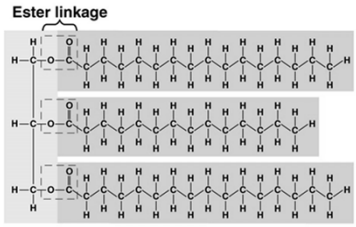


Lipids

- Hydrophobic, form membranes and act as energy stores
  - are the one class of large biological molecules that do not consist of polymers
- Lipids with fatty acids (glycerides or acylglycerols)
  - can have one (mono-), two (di-) or three (tri-) fatty acid tails attached to glycerol backbone

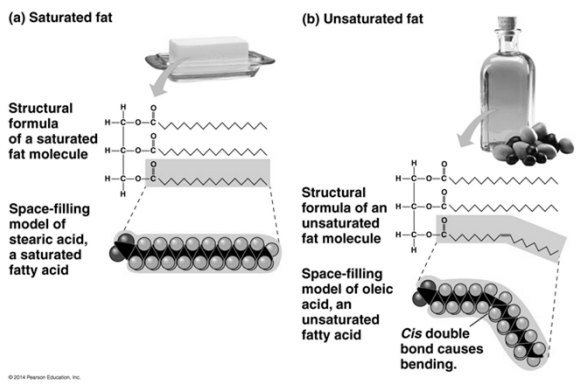


(a) One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

- Fatty acids vary in the length and number and locations of double bonds they contain
  - saturated fats have only C-C bonds in fatty acid tails; solid at room temperature
  - unsaturated fats have one or more double bond in fatty acid tails; liquid at room temperature



- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits
- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
  - hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds
  - these *trans* fats may contribute more than saturated fats to cardiovascular disease

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- Certain unsaturated fatty acids are not synthesized in the human body
  - these must be supplied in the diet
  - these essential fatty acids include the omega-3 fatty acids, which are required for normal growth and are thought to provide protection against cardiovascular disease
- The major function of fats is energy storage
  - humans and other mammals store their long-term food reserves in adipose cells
  - adipose tissue also cushions vital organs and insulates the body

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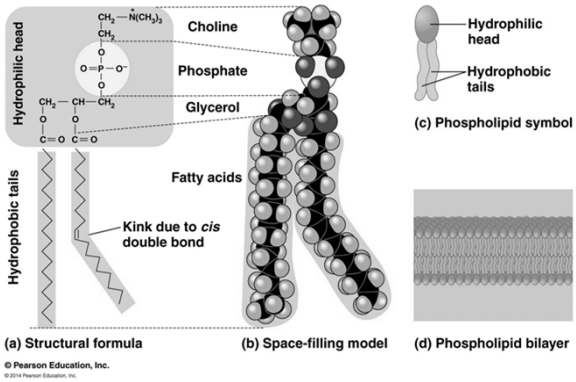
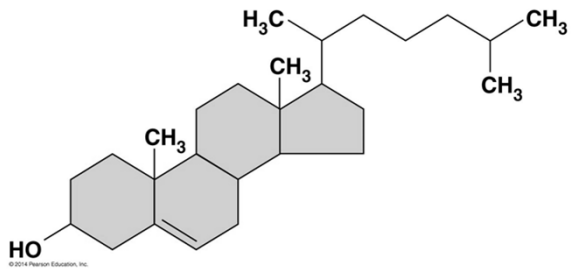
Phospholipids

- Phospholipids are diglycerides with a phosphate group attached to glycerol backbone
  - phosphate group is negatively charged
    - polar and hydrophilic
  - fatty acid tails are non-polar and hydrophobic
  - in aqueous environments, phospholipids spontaneously form aggregates
    - hydrophobic tails are shielded from water
  - in membranes phospholipids form bilayer
    - hydrophilic heads are on the outside of the bilayer
    - hydrophobic tails point inwards



Steroids

- Lipids without fatty acids
  - Steroids have a backbone of four carbon rings
  - Cholesterol is a component of animal cell membranes and can be modified to form sex hormones.



Proteins

- Proteins account for more than 50% of the dry mass of most cells
  - Protein functions in cells include all the following:
    - Structural
    - Contractile
    - Storage
    - Defense
    - Transport
    - Signaling
    - Catalyst

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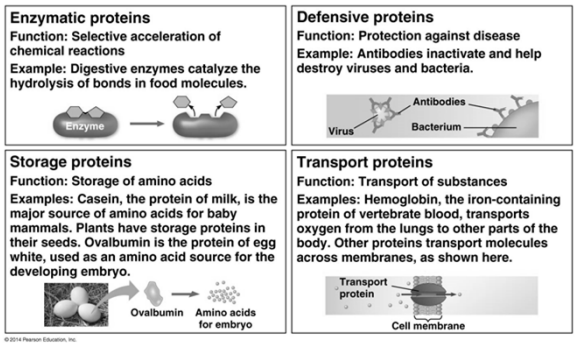

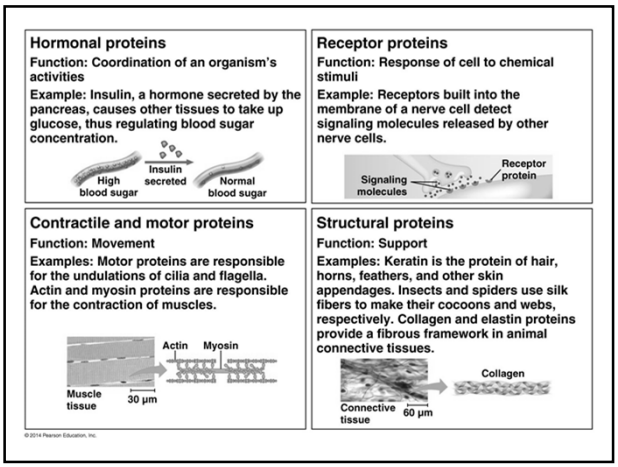

- A protein consists of one or more polypeptides
  - polypeptides are polymers of amino acids
  - amino acid has amino group, acid group, hydrogen atom and one of 20 "R" groups

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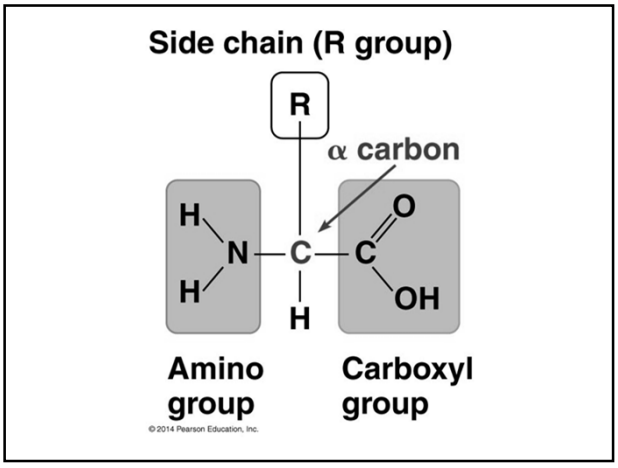
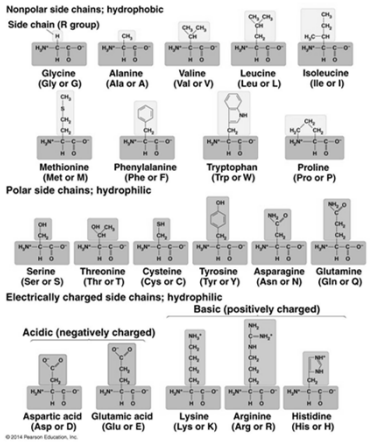
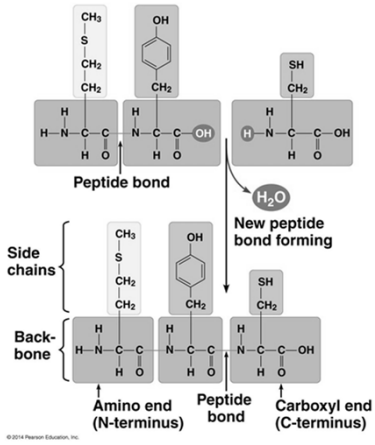


- The chemical properties of the “R” groups determine the chemical properties of the amino acids



- Peptides are polymers of the twenty amino acids linked by peptide bonds
  - formation of the peptide bond is by a condensation reaction



Protein Structure and Function

- The specific activities of proteins result from their intricate three-dimensional architecture
  - a functional protein consists of one or more polypeptides precisely twisted, folded, and coiled into a unique shape

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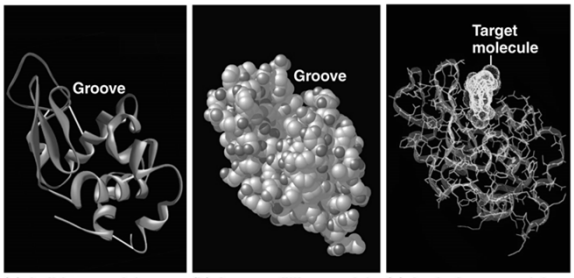

(a) A ribbon model (b) A space-filling model (c) A wireframe model

- The sequence of amino acids determines a protein's three-dimensional structure
  - a protein's structure determines how it works
  - the function of a protein usually depends on its ability to recognize and bind to some other molecule

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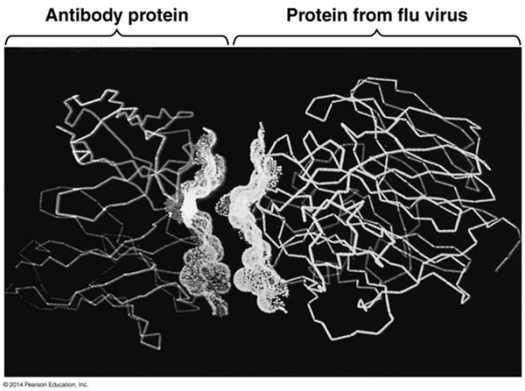

- Four levels of organization:
  - primary-amino acid sequence
  - secondary-polypeptide folding or coiling
  - tertiary-3D shape of polypeptide
  - quaternary-complexing of two or more polypeptides to form mature protein
- Primary structure is the unique sequence of amino acids in a polypeptide

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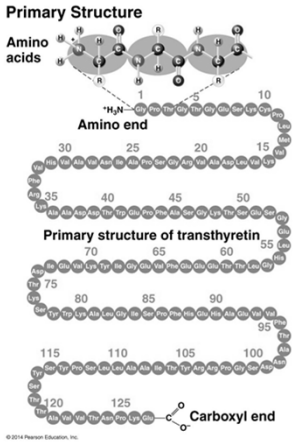

- Secondary structure is the folding or coiling of the polypeptide into a repeating configuration
  - includes the α helix and the β pleated sheet

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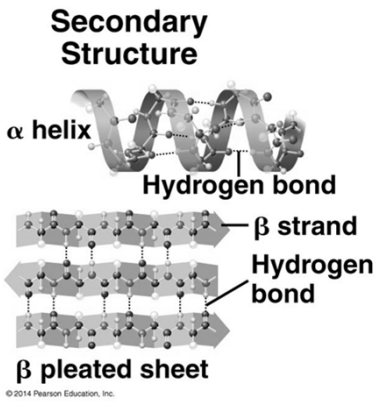

- Tertiary structure is the overall three-dimensional shape of a polypeptide
  - results from interactions between amino acids and R groups

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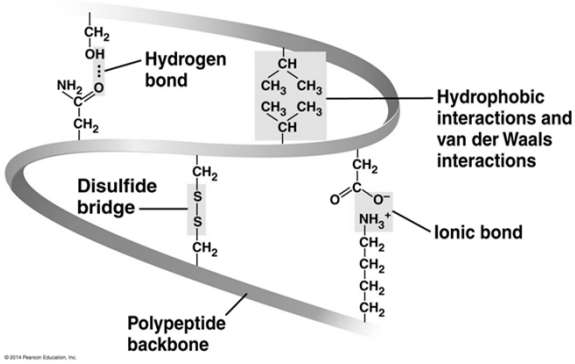
Tertiary Structure

Transthyretin polypeptide



- Quaternary structure is the overall protein structure that results from the aggregation of two or more polypeptide subunits

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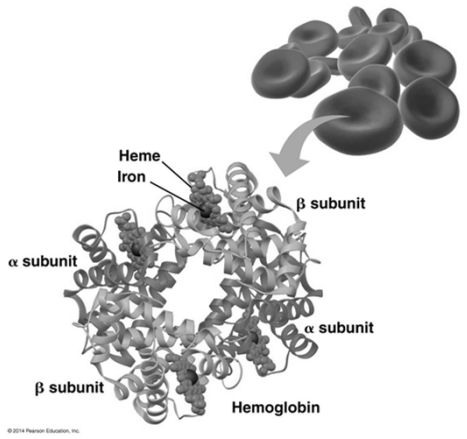

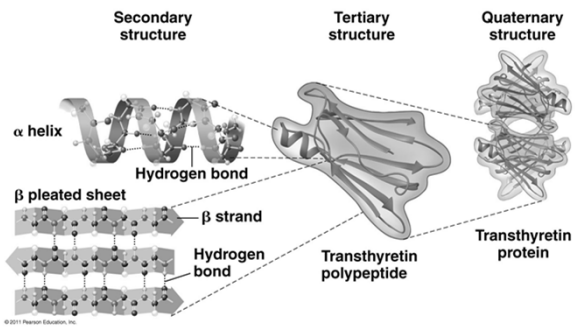

Sickle-Cell Disease: A Simple Change in Primary Structure

- Sickle-cell disease results from a single amino acid substitution in the protein hemoglobin

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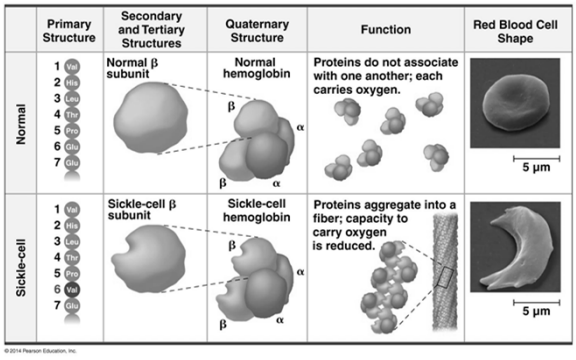

- Protein conformation depends on the physical and chemical conditions of the protein's environment
  - denaturation is the loss of 3d protein structure
    - caused by:
      - heat >60ºC
      - pH
      - salt concentration
      - chemicals
    - some proteins can regain 3d structure if denaturing conditions reversed

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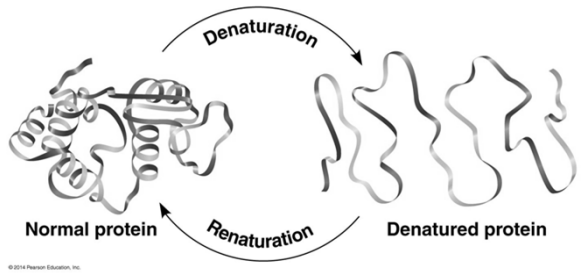

- Most proteins probably go through several intermediate states on their way to a stable conformation
  - chaperonins function to assist the proper folding of proteins
    - do not specify correct final structure of proteins
      - provide suitable environment for proteins to spontaneously fold into final form
  - diseases such as Alzheimer's, Parkinson's, and mad cow disease are associated with misfolded proteins

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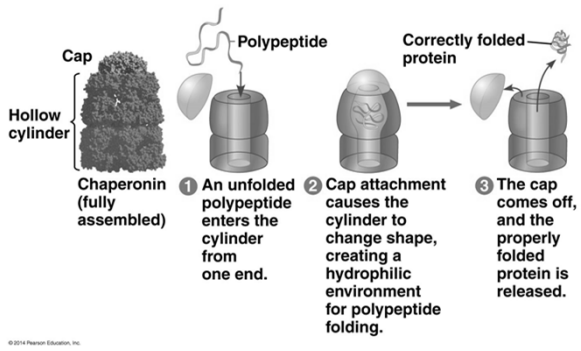

Nucleic Acids

- Store and transmit hereditary information
  - two types of molecules involved
    - deoxyribonucleic acid (DNA)
    - ribonucleic acid (RNA)
  - DNA is the genetic material of organisms
    - inherited from parents
  - information encoded in DNA directs the synthesis of RNA
    - each gene (coding region) in DNA directs the synthesis of messenger RNA (mRNA)
      - mRNA directs the synthesis of polypeptides

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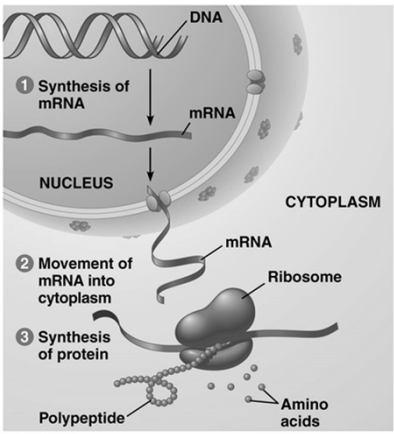

- Nucleotides composed of three functional parts:
  - phosphate group
  - 5C sugar-ribose in RNA, deoxyribose in DNA
  - nitrogenous base-A, T, G and C in DNA; A, U, G, and C in RNA
- Nucleotide polymers are made up of nucleotides linked by the -OH group on the 3´ carbon of one nucleotide and the phosphate on the 5´ carbon on the next

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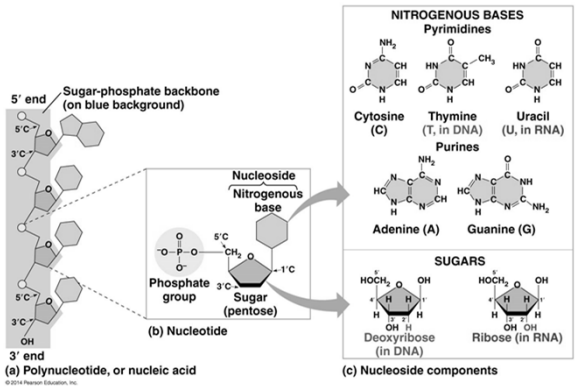

- Information is encoded in a gene by the linear order of the nucleotides
  - the sequence of bases along a nucleotide polymer is unique for each gene
    - specifies the amino acid sequence of a polypeptide

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Structure of DNA and RNA

- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a double helix
  - the backbones run in opposite 5′ → 3′ directions from each other-referred to as antiparallel
- Information is encoded in a gene by the linear order of the nucleotides
  - the sequence of bases along a nucleotide polymer is unique for each gene
    - specifies the amino acid sequence of a polypeptide
  - one DNA molecule includes many genes

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- Inheritance is based on the replication of the DNA molecule
  - Watson-Crick model first predicted how this is accomplished
    - molecule consists of two polynucleotides forming a double helix
    - the polynucleotide strands are complementary to each other
      - in DNA, A hydrogen bonds with T and G hydrogen bonds with C to hold two strands of DNA molecule together
    - each polynucleotide acts as a template for the synthesis of the complementary strand
      - results in two copies of the DNA molecule

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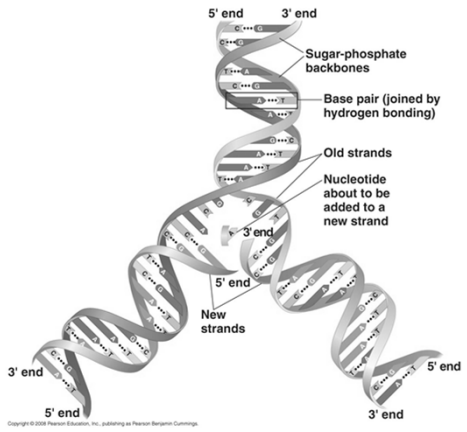

- RNA, in contrast to DNA, is single stranded
  - complementary pairing can also occur between two RNA molecules or between parts of the same molecule
  - in RNA, thymine is replaced by uracil (U) so A and U pair
  - while DNA always exists as a double helix, RNA molecules are more variable in form

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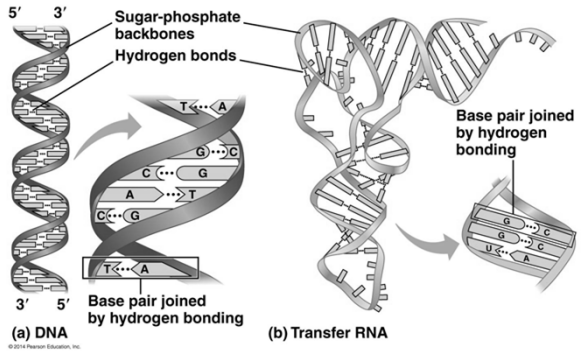

- Two other types of nucleotide-based molecules:
  - adenosine phosphates-chemical messengers and energy carriers
    - includes ATP, ADP and AMP
  - nucleotide coenzymes-transport H^+ and e^-
    - Includes NAD^+/NADH in mitochondria and $NADP^+$/NADPH in chloroplasts

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