Chapter 2
The Chemical Level of Organization

- Matter
  - elements
  - atoms and molecules
- Chemical bonds
- Chemical energy
- Chemical reactions
- Inorganic compounds
- Organic compounds

2-1

How Matter is Organized

- Chemistry is the science of the structure and interactions of matter.
  - all living things consist of matter.
- Matter is anything that occupies space.
  - mass is the amount of matter in any object.
  - weight is the force of gravity acting on matter.
- In outer space, weight is close to zero, but mass remains the same as on Earth.

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Chemical Elements

- Elements are substances that can not be split into simpler substances by ordinary means.
  - 112 elements (92 occur naturally)
  - 26 of naturally occurring elements are in the body
  - represented by chemical symbols (first 1-2 letters of name)
- 4 elements form 96 % of the body's mass
  - hydrogen, oxygen, carbon and nitrogen
- Trace elements are present in tiny amounts
  - such as copper, tin, selenium & zinc

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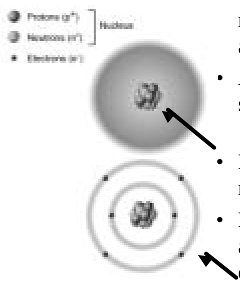
Structure of Atoms



- Atoms are the smallest units of matter that retain the properties of an element
- Atoms consist of 3 types of subatomic particles
  - protons, neutrons and electrons
- Nucleus contains protons (p+) & neutrons (neutral charge)
- Electrons (e-) surround the nucleus as a cloud (electron shells are designated regions of the cloud)

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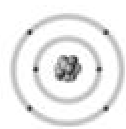
Electron Shells



- Most likely region of the electron cloud in which to find electrons
- Each electron shell can hold only a limited number of electrons
  - first shell can hold only 2 electrons
  - 2nd shell can hold 8 electrons
  - 3rd shell can hold 18 electrons
  - higher shells (up to 7) hold many more electrons
- Number of electrons = number of protons
- Each atom is electrically neutral; charge = 0

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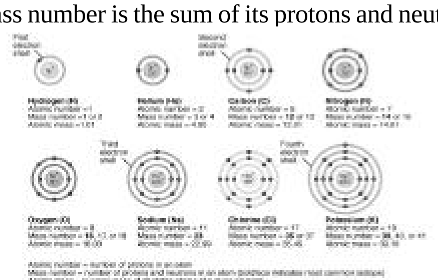
Atomic Number & Mass Number

- Atomic number is number of protons in the nucleus.
- Mass number is the sum of its protons and neutrons.



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Isotopes

- Atoms of an element with different numbers of neutrons & different mass numbers
- All isotopes of an element have same properties
  - have same number of electrons (which determine its chemical properties)
- Only radioactive isotopes are unstable
  - decay over time to a more stable configuration
  - half-life is time required for half of the radioactive atoms in a sample to decay

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Effects of Radiation

- Radioactive isotopes can pose a serious health threat
  - break apart molecules & cause tissue damage
- Decay of naturally occurring radioactive isotopes releases small amounts of radiation
  - radon-222 gas may seep out of soil in basement
  - increases the risk of lung cancer
- Radioactive isotopes used beneficially in medical imaging procedures & treat cancer

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Atomic Mass

- Mass is measured as dalton (atomic mass unit)
  - neutron has mass of 1.008 daltons
  - proton has mass of 1.007 daltons
  - electron has mass of 0.0005 dalton
- Atomic mass (atomic weight) is close to the mass number of its most abundant isotope.

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Ions, Molecules, & Compounds

- Ions are formed by ionization
  - an atom that gave up or gained an electron
  - written with its chemical symbol and (+) or (-)
- Molecule
  - when atoms share electrons
  - if atoms are different elements = compound
  - written as molecular formula showing the number of atoms of each element (H_2O)

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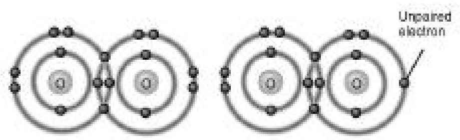
Free Radicals

- Atom with an unpaired electron in its outmost shell
- Unstable and highly reactive
- Can become stable
  - by giving up electron
  - taking one off another molecule (breaking apart



(a) Oxygen molecule (b) Superoxide free radical

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Free Radicals & Your Health

- Produced in your body by absorption of energy in ultraviolet light in sunlight, x-rays, by breakdown of harmful substances, & during normal metabolic reactions
- Linked to many diseases -- cancer, diabetes, Alzheimer, atherosclerosis and arthritis
- Damage may be slowed with antioxidants such as vitamins C and E, selenium & beta-carotene (precursor to vitamin A)

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Chemical Bonds

- Bonds hold together the atoms in molecules and compounds
- An atom with a full outer electron shell is stable and unlikely to form a bond with another atom
- Octet rule states that biologically important elements interact to produce chemically stable arrangements of 8 electrons in the valence shell.
- Whether electrons are shared, donated or acquired determines the types of bonds formed

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Ionic Bonds

- Positively and negatively charged ions attract each other to form an ionic bond
- In the body, ionic bonds are found mainly in teeth and bones
- An ionic compound that dissociates in water into + and - ions is called an electrolyte
  - the solution can conduct an electric current

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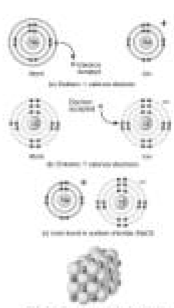
The Ionic Bond in Sodium Chloride



- Sodium loses an electron to become Na+ (cation)
- Chlorine gains an electron to become Cl- (anion)
- Na+ and Cl- are attracted to each other to form the compound sodium chloride (NaCl) – table salt
- Ionic compounds generally exist as solids

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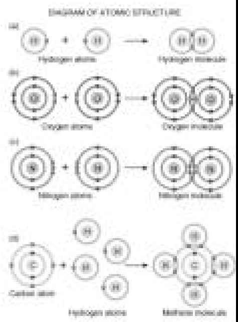
Covalent Bonds

- Atoms share electrons to form covalent bonds
- Electrons spend most of the time between the 2 atomic nuclei
  - single bond = share 1pair
  - double bone = share 2 pair
  - triple bond = share 3 pair
- Polar covalent bonds share electrons unequally between the atoms involved



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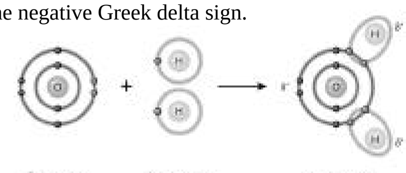
Polar Covalent Bonds

- Unequal sharing of electrons between atoms.
- In a water molecule, oxygen attracts the hydrogen electrons more strongly
  - Oxygen has greater electronegativity as indicated by the negative Greek delta sign.



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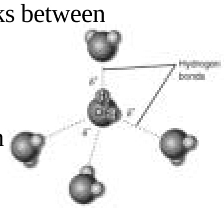
Hydrogen Bonds

- Polar covalent bonds between hydrogen and other atoms
- Only about 5% as strong as covalent bonds
- Useful in establishing links between molecules
- Large 3-D molecules are often held together by a large number of hydrogen bonds.



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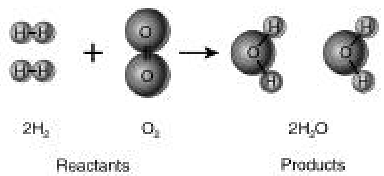
Chemical Reactions

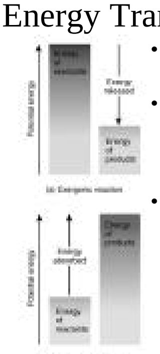
- When new bonds form or old bonds are broken
- Metabolism is all the chemical reactions in the body
- Law of conservation of mass = total mass of reactants equals the total mass of the products



Energy and Chemical Reactions

- Chemical reactions involve energy changes
- Two principal forms of energy
  - potential energy = stored energy
  - kinetic energy = energy of motion
- Chemical energy is potential energy stored in the bond of molecules
  - digestion of food releases that chemical energy so that it can be converted to heat or mechanical energy
- Law of conservation of energy
  - energy can neither be created nor destroyed--just converted from one form to another

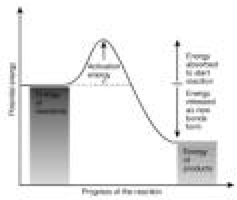
Energy Transfer in Chemical Reactions



- Forming new bonds requires energy & breaking old bonds releases energy
- Chemical reactions usually involve both
  - exergonic reactions release more energy
  - endergonic reactions absorb more energy than they release
- Human metabolism couples exergonic and endergonic reactions, so that the energy released from one reaction will drive the other.
  - Glucose breakdown releases energy used to build ATP molecules that store that energy for later use in other reactions

Activation Energy

- Atoms, ions & molecules are continuously moving & colliding
- Activation energy is the collision energy needed to break bonds & begin a reaction



- Increases in concentration & temperature, increase the probability of 2 particles colliding
  – more particles in a given space as concentration is raised
  – particles move more rapidly when temperature is raised

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Catalysts or Enzymes

- Normal body temperatures and concentrations are too low to cause chemical reactions to occur
- Catalysts speed up chemical reactions by lowering the activation energy needed to get it started
- Catalysts orient the colliding particles properly so that they touch at the spots that make the reaction happen
- Catalyst molecules are unchanged and can be used repeatedly to speed up similar reactions.

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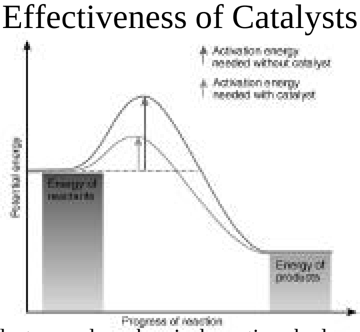
Effectiveness of Catalysts



- Catalysts speed up chemical reactions by lowering the activation energy.

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Synthesis Reactions--Anabolism

- Two or more atoms, ions or molecules combine to form new & larger molecules
- All the synthesis reactions in the body together are called anabolism
- Usually are endergonic because they absorb more energy than they release
- Example
  - combining amino acids to form a protein molecule

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Decomposition Reactions--Catabolism

- Large molecules are split into smaller atoms, ions or molecules
- All decomposition reactions occurring together in the body are known as catabolism
- Usually are exergonic since they release more energy than they absorb

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Exchange Reactions

- Substances exchange atoms
  - consist of both synthesis and decomposition reactions
- Example
  - $HCl + NaHCO3$ gives rise to $H2CO3 + NaCl$
  - ions have been exchanged between substances

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Reversible Reactions

- Chemical reactions can be reversible.
  - Reactants can become products or products can revert to the original reactants
- Indicated by the 2 arrows pointing in opposite directions between the reactants and the products
- $AB \rightleftharpoons A + B$

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Oxidation-Reduction Reactions

- Oxidation is the loss of electrons from a molecule (decreases its potential energy)
  - acceptor of the electron is often oxygen
  - commonly oxidation reactions involve removing a hydrogen ion (H+) and a hydride ion (H-) from a molecule
  - equivalent to removing 2 hydrogen atoms = 2H
- Reduction is the gain of electrons by a molecule
  - increases its potential energy
- In the body, oxidation-reduction reactions are coupled & occur simultaneously

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Inorganic Compounds & Solvents

- Most of the chemicals in the body are compounds
- Inorganic compounds
  - usually lack carbon & are structurally simple
  - water, salts, acids and bases
- Organic compounds
  - contain carbon & usually hydrogen
  - always have covalent bonds

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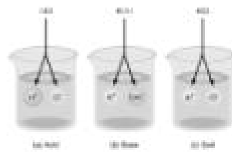
Inorganic Acids, Bases & Salts

- Acids, bases and salts always dissociate into ions if they are dissolved in water
  - acids dissociate into H+ and one or more anions
  - bases dissociate into OH- and one or more cations
  - salts dissociate into anions and cations, none of which are either H+ or OH-



- Acid & bases react in the body to form salts
- Electrolytes are important salts in the body that carry electric current (in nerve or muscle)

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Mixtures, Solutions, Colloids, & Suspensions

- Mixture is a combination of elements or compounds that are physically blended by not joined by bonds ---- air
- Common liquid mixtures
  - solutions are solutes mixed in a solute
    - usually looks clear (sweat is water and dissolved salts)
  - colloid are solutes mixed in a solute
    - particles are larger so does not look clear (milk)
    - particles do not settle out of solution
  - suspension are solutes mixed in a solute
    - particles settle out of solution because of size (blood)

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Concentration

- Concentration of a solution can be expressed as percentage or moles per liter
- Percentage
  - relative mass of a solute in a given volume of solution
- Moles per liter
  - measures total number of molecules in a given volume of solution
  - a mole is Avogadro's number or the atomic mass in grams of all of its atoms

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Water

- Most important inorganic compound in living systems
- Medium of nearly all chemical reactions
- Polarity
  - uneven sharing of valence electrons
  - partial negative charge near oxygen atom and partial positive charge near hydrogen atoms
    - makes it an excellent solvent for ionic or polar substances
    - gives water molecules cohesion
    - allows water to moderate temperature changes

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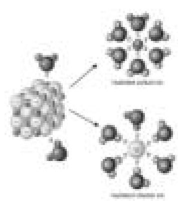
Water as a Solvent

- Most versatile solvent known
  - polar covalent bonds (hydrophilic versus hydrophobic)
  - its shape allows each water molecule to interact with 4 or more neighboring ions/molecules
    - oxygen attracts sodium
    - hydrogen attracts chloride
    - sodium & chloride separate as ionic bonds are broken
    - hydration spheres surround each ion and decrease possibility of bonds being reformed



- Water dissolves or suspends many substances

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Water in Chemical Reactions

- Participates as a product or reactant in certain reactions in the body
  - hydrolysis reactions
    - water is added to a large molecule to separate it into two smaller molecules
    - digestion of food
  - dehydration synthesis reaction
    - two small molecules are joined to form a larger molecule releasing a water molecule

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Heat Capacity of Water

- Heat capacity is high
  - can absorb a large amount of heat with only a small increase in its own temperature
    - large number of hydrogen bonds in water
      - bonds are broken as heat is absorbed instead of increasing temperature of water
  - large amount of water in body helps lessen the impact of environmental changes in temperature
- Heat of vaporization is also high
  - amount of heat needed to change from liquid to gas
  - evaporation of water from the skin removes large amount of heat

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Cohesion of Water Molecules

- Hydrogen bonds link neighboring water molecules giving water cohesion
- Creates high surface tension
  - difficult to break the surface of liquid if molecules are more attracted to each other than to surrounding air molecules
  - respiratory problem causes by water's cohesive property
    - air sacs of lungs are more difficult to inflate

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Water as a Lubricant

- Major component of lubricating fluids within the body
  - mucus in respiratory and digestive systems
  - synovial fluid in joints
  - serous fluids in chest and abdominal cavities
    - organs slide past one another

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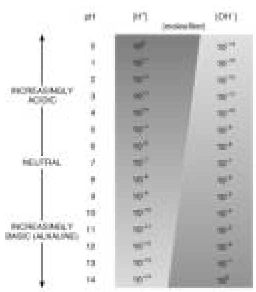
Concept of pH



- pH scale runs from 0 to 14 (concentration of H+ in moles/liter)
- pH of 7 is neutral (distilled water – concentration of OH- and H+ are equal)
- pH below 7 is acidic and above 7 is alkaline
- pH of 1 (10 times more H+ than pH of 2)

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Buffer Systems of the Body

- Body fluids vary in pH but the range of each is limited and is maintained by a variety of buffering systems.
  - gastric juice 1.2 to 3.0; saliva 6.35 to 6.85; bile 7.6 to 8.6 and blood 7.35 to 7.45
- Buffers convert strong acids to weak ones which contribute fewer H+ ions & have less effect on pH
  - carbonic acid - bicarbonate buffer system
  - together they contribute H+ or OH- ions as needed to keep the pH of the blood stable

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Organic Compounds

- Always contain carbon and hydrogen
- Usually contain covalent bonds
- Usually large, unique molecules with complex functions
- Make up 40% of body mass

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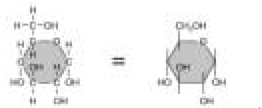
Carbon & Its Functional Groups

- Properties of carbon atoms
  - forms bonds with other carbon atoms produce large molecules
    - with many different shapes (rings, straight or branched chains)
    - do not dissolve in water
- Many functional groups can attach to carbon skeleton
  - esters, amino, carboxyl, phosphate groups (Table 2.5)
- Very large molecules called macromolecules (polymers if all monomer subunits are similar)
- Isomers have same molecular formulas but different structures (glucose & fructose are both C6H12O6
- STRUCTURAL FORMULA OF GLUCOSE



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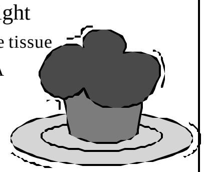
Carbohydrates

- Diverse group of substances formed from C, H, and O
  - ratio of one carbon atom for each water molecule (carbohydrates means "watered carbon")
  - glucose is 6 carbon atoms and 6 water molecules (H20)
- Main function is source of energy for ATP formation
- Forms only 2-3 % of total body weight
  - glycogen is storage in liver and muscle tissue
  - sugar building blocks of DNA & RNA (deoxyribose & ribose sugars)
- Only plants produce starches or cellulose for energy storage



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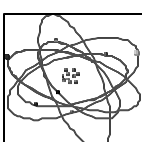

Diversity of Carbohydrates

- 3 sizes of carbohydrate molecules
  - monosaccharides
  - disaccharides
  - polysaccharides

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Monosaccharides

- Called simple sugars
- Contain 3 to 7 carbon atoms
- We can absorb only 3 simple sugars without further digestion in our small intestine
  - glucose found syrup or honey
  - fructose found in fruit
  - galactose found in dairy products

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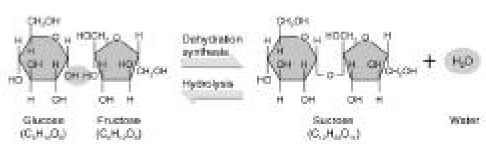
Disaccharides

- Formed by combining 2 monosaccharides by dehydration synthesis (releases a water molecule)
  - sucrose = glucose & fructose
  - maltose = glucose & glucose
  - lactose = glucose & galactose (lactose intolerance)



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Polysaccharides

- Contain 10 or 100's of monosaccharides joined by dehydration synthesis
- In animals
  - glycogen is a chain of hundreds of glucose molecules
  - found in liver & skeletal muscle
  - when blood sugar level drops, liver hydrolyzes glycogen to create and release glucose into the blood
- In plants
  - starch and cellulose are large carbohydrate molecules used for energy storage (rice, potatoes, grains)

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Lipids = fats

- Formed from C, H and O
  - includes fats, phospholipids, steroids, eicosanoids, lipoproteins and some vitamins
- 18-25% of body weight
- Hydrophobic
  - fewer polar bonds because of fewer oxygen atoms
  - insoluble in polar solvents like water
- Combines with proteins for transport in blood
  - lipoproteins

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Triglycerides

- Neutral fats composed of a single glycerol molecule and 3 fatty acid molecules
  - three-carbon glycerol molecule is the backbone
- Very concentrated form of energy
  - 9 calories/gram compared to 4 for proteins & carbohydrates
  - our bodies store triglycerides in fat cells if we eat extra food

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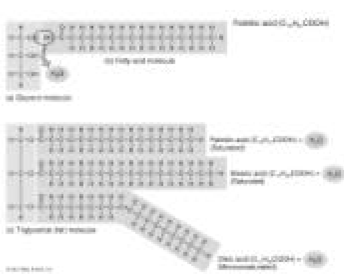
Triglycerides



- 3 fatty acids & one glycerol molecule
- Fatty acids attached by dehydration systhesis

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Saturation of Triglycerides

- Determined by the number of single or double covalent bonds
- Saturated fats contain single covalent bonds and are covered with hydrogen atoms ----lard
- Monounsaturated are not completely covered with hydrogen----olive and peanut oil
- Polyunsaturated fats contain even less hydrogen atoms ----safflower and corn oil

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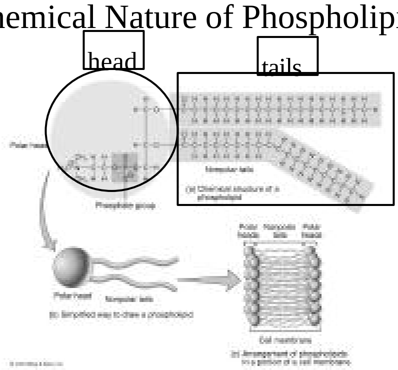
Chemical Nature of Phospholipids



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Phospholipids

- Composition of phospholipid molecule
  - a polar head
    - a phosphate group (PO4 -3) & glycerol molecule
    - can form hydrogen bonds with water
  - 2 nonpolar fatty acid tails
    - interact only with lipids
  - amphipathic(molecules with polar & nonpolar parts)
- Composition of cell membrane
  - double layer of phospholipids with tails in center

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Steroids

- Formed from 4 rings of carbon atoms joined together
- Common steroids
  - sex hormones, bile salts, vitamins & cholesterol
  - classified as sterols because have alcohol group attached to one or more of the rings
- Cholesterol found in animal cell membranes
  - starting material for synthesis of other steroids

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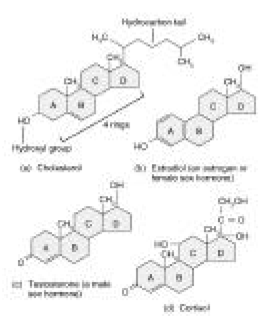
Four Ring Structure of Steroids



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Eicosanoids

- Lipid type derived from a fatty acid called arachidonic acid
  - prostaglandins = wide variety of functions
    - modify responses to hormones
    - contribute to inflammatory response
    - prevent stomach ulcers
    - dilate airways
    - regulate body temperature
    - influence formation of blood clots
  - leukotrienes = allergy & inflammatory responses

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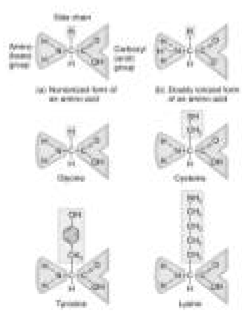
Proteins

- 12-18% of body weight
- Contain carbon, hydrogen, oxygen, and nitrogen
- Constructed from combinations of 20 amino acids.
  - dipeptides formed from 2 amino acids joined by a covalent bond called a peptide bond
  - polypeptides chains formed from 10 to 2000 amino acids.
- Levels of structural organization
  - primary, secondary and tertiary
  - shape of the protein influences its ability to form bonds

Amino Acid Structure

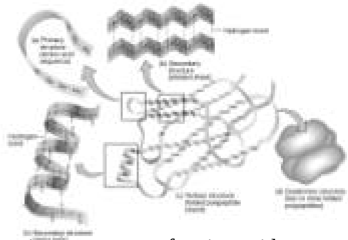
- Central carbon atom
- Amino group (NH_2)
- Carboxyl group (COOH)
- Side chains (R groups) vary between amino acids



Formation of a Dipeptide Bond

- Dipeptides formed from 2 amino acids joined by a covalent bond called a peptide bond
  - dehydration synthesis
- Polypeptides chains formed from 10 to 2000 amino acids.

Levels of Structural Organization



- Primary is unique sequence of amino acids
- Secondary is alpha helix or pleated sheet folding
- Tertiary is 3-dimensional shape of polypeptide chain
- Quaternary is relationship of multiple polypeptide chains

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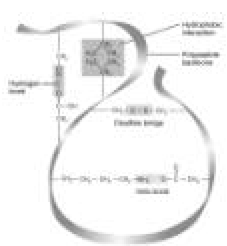
Bonds of Tertiary & Quaternary Structure



- Disulfide bridges stabilize the tertiary structure of protein molecules
- Covalent bonds between sulfhydryl groups of 2 cysteine amino acids

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Protein Denaturation

- Function of a protein depends on its ability to recognize and bind to some other molecule
- Hostile environments such as heat, acid or salts will change a proteins 3-D shape and destroy its ability to function
  - raw egg white when cooked is vastly different

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Enzymes

- Enzymes are protein molecules that act as catalysts
- Enzyme = apoenzyme + cofactor
  - Apoenzymes are the protein portion
  - Cofactors are nonprotein portion
    - may be metal ion (iron, zinc, magnesium or calcium)
    - may be organic molecule derived from a vitamin
- Enzymes usually end in suffix -ase and are named for the types of chemical reactions they catalyze

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Enzyme Functions

- Bonds made or broken when atoms, ions or molecules collide
- Enzymes speed up reactions by properly orienting colliding molecules
- 1000 known enzymes speed up metabolic reactions to 10 billion times that in beaker
- Composed of protein portion (apoenzyme) & nonprotein portion (cofactor)
  - cofactors can be metal ions or vitamins

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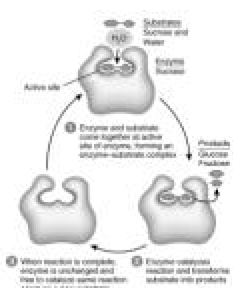
Enzyme Functionality

- Highly specific
  - acts on only one substrate
    - active site versus induced fit
  - speed up only one reaction
- Very efficient
  - speed up reaction up to 10 billion times faster
- Under nuclear control
  - rate of synthesis of enzyme
  - inhibitory substances
  - inactive forms of enzyme



2-66

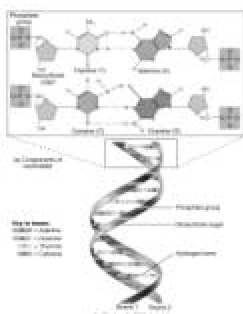
Galactosemia

- Inherited disorder in which baby lacks a digestive enzyme
- Galactose accumulates in the blood causing anorexia
- Treatment is elimination of milk from the diet

2-67

DNA Structure

- Huge molecules containing C, H, O, N and phosphorus
- Each gene of our genetic material is a piece of DNA that controls the synthesis of a specific protein
- A molecule of DNA is a chain of nucleotides
- Nucleotide = nitrogenous base (A-G-T-C) + pentose sugar + phosphate group



2-68

DNA Fingerprinting

- Used to identify criminal, victim or a child's parents
  - need only strand of hair, drop of semen or spot of blood
- Certain DNA segments are repeated several times
  - unique from person to person

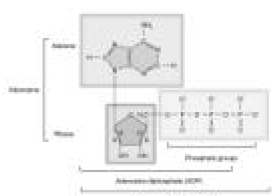
2-69

RNA Structure

- Differs from DNA
  - single stranded
  - ribose sugar not deoxyribose sugar
  - uracil nitrogenous base replaces thymine
- Types of RNA within the cell, each with a specific function
  - messenger RNA
  - ribosomal RNA
  - transfer RNA

Adenosine Triphosphate (ATP)

- Temporary molecular storage of energy as it is being transferred from exergonic catabolic reactions to cellular activities
  - muscle contraction, transport of substances across cell membranes, movement of structures within cells and movement of organelles
- Consists of 3 phosphate groups attached to adenine & 5-carbon sugar (ribose)



Formation & Usage of ATP

- Hydrolysis of ATP (removal of terminal phosphate group by enzyme -- ATPase)
  - releases energy
  - leaves ADP (adenosine diphosphate)
- Synthesis of ATP
  - enzyme ATP synthase catalyzes the addition of the terminal phosphate group to ADP
  - energy from 1 glucose molecule is used during both anaerobic and aerobic respiration to create 36 to 38 molecules of ATP