

## Chemistry and Biochemistry

MED 164

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## Objectives

- What is an atom?
- What are components of atoms?
- How do atoms form molecules/compounds?
- What type of reactions are needed for life?

## Chemistry is important to life

- Chemistry is the study of matter!
- Biochemistry is the study of the matter that makes up life!
- All living things are constantly undergoing millions of chemical reactions
- Chemical reactions make every thing possible!
- Living organisms are a huge chem lab

## Matter

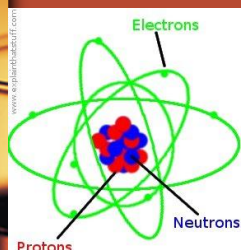
- Matter is anything that has mass and takes up space.
- Matter is made of atoms
- There are three states of matter
  - Liquid
  - Gas
  - Solid

## Atoms that make up living organisms

- Carbon
- Hydrogen
- Nitrogen
- Oxygen
- Phosphorous
- Sulfur
- There are other trace elements present

## Atoms are basic level of matter

### Components of Atoms



- Protons
  - Positively charged particles in nucleus
- Neutrons
  - Particles in the nucleus that have no charge
- Electrons
  - Negatively charged particles that orbit the nucleus of the atom
  - Smallest of the three particles

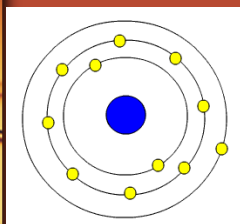
## Electron Orbits Determine Reactivity

- Electrons orbit around nucleus in orbital shells
- Shells can contain 2 or 8 electrons
  - 1<sup>st</sup> shell holds 2 electrons
  - Other shells hold 8 electrons
  - Simpler model than reality but generally holds true for physiology
- Atoms are stable when outer shell is full of electrons
- Think how happy you are when your belly is full!

## Electron Orbits Determine Reactivity

- Atoms seek to form partnerships that allow them to fill their outer shell
- Partnerships occur by a few mechanisms
- Atoms can give up electrons completely
- Atoms can share electrons
  - Sharing can be an equal or an unequal partnership
  - Water is an example of an unequal partnership

## Sodium



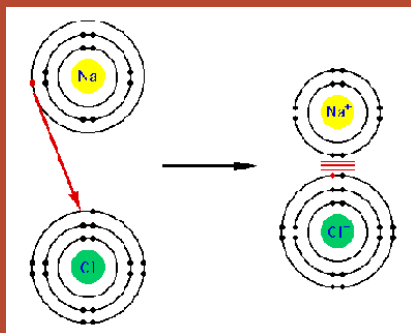
<http://www.cartage.org.lb/en/themes/Sciences/Chemistry/GeneralChemistry/Matter/Atoms/TheAtom/atom3.gif>

- Look at the outer shell
- How many electrons are there?
- If the atom loses that electron, how many electrons are in outer shell?
- What is the charge of an atom, that loses a single electron?

## Ions

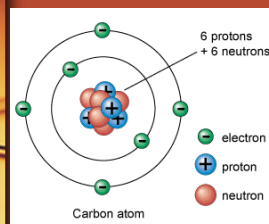
- Atoms that lose or gain electrons are called ions
- Cations are ions that have lost at least one electron
- Anions are ions that have gained at least one electron
- Cations and anions are attracted to each other because of the charge on the atoms
  - Think of what happens if a positive magnet comes near a negative magnet

## Ionic Bonding



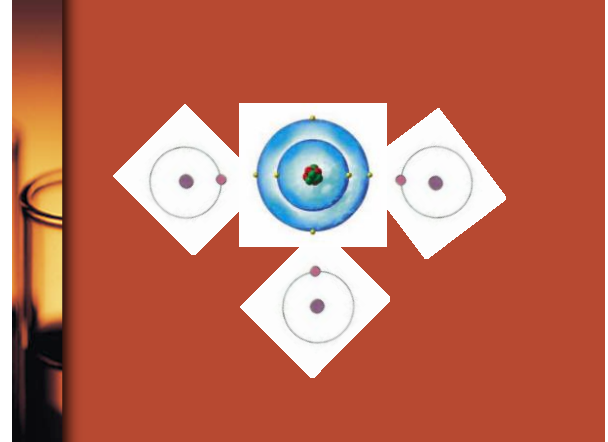
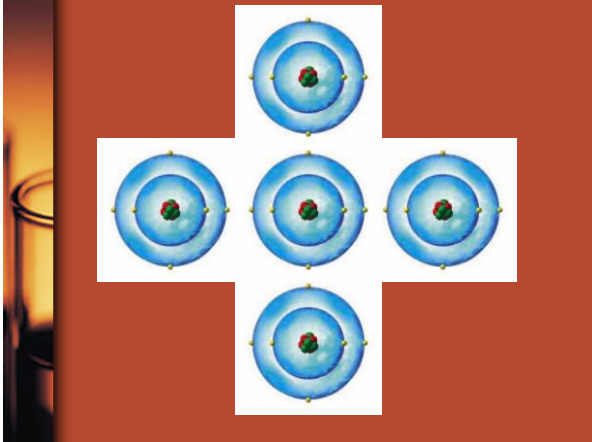
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## Carbon



[http://www.hk-phy.org/articles/laser/c-atom\\_e.gif](http://www.hk-phy.org/articles/laser/c-atom_e.gif)

- How many electrons are in outer shell?
- How many does it need to fill outer orbital?
- It is harder to steal or give away that many electrons!
- It is easier to share!



## Covalent Bonding

- Results from sharing electrons
  - Sometimes atoms can share more than one electron pair forming double bonds or even triple bonds

## Atoms form molecules

- Atoms that come together by ionic or covalent interactions create molecules
- Molecules are also called compounds
- Compounds are molecules and molecules are compounds

## Compounds in living organisms

- Living organisms take the common elements and assemble them into compounds
- Two classes of compounds
  - Inorganic
    - Made of many different elements
  - Organic
    - Primarily made of carbon, hydrogen, and oxygen
    - Make up majority of compounds in living organisms

## Inorganic Molecules

- Compounds that do not contain carbon and hydrogen in their structure
  - Water
  - Salts

## Salts

- Salts are made of ionic compounds
- Ionic compounds that contain cations or anions other than  $H^+$  or  $OH^-$
- Ions that are dissolved in solution are called electrolytes
  - Substances that conduct electricity in solution
  - $NaCl$ ,  $Ca_2CO_3$ ,  $KCl$ ,  $MgSO_4$
  - Electrolytes are very important in physiological processes

## Important Electrolytes

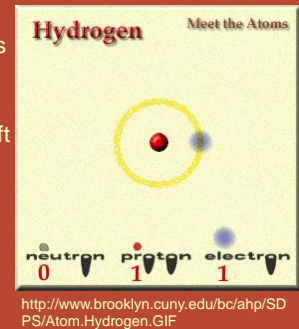
- Primary extracellular cation
  - Sodium is primary cation outside of cell
- Primary intracellular cation
  - Potassium is primary cation inside of cell

## Important Inorganic Molecules

- Water – comprises 55 -65 % of human body weight
  - Most important inorganic molecule in living systems
- Carbon Dioxide
  - Waste product of aerobic metabolism

## Acid

- Solute that dissolves in water and releases hydrogen ions
- If hydrogen loses an electron, all that is left is a proton
  - Proton Donor
- Causes a sour taste
  - Bad practice to taste fluids



## Acid

- Strength of acid depends upon how readily it dissolves in water
- Strong acids dissociate completely in water
  - Hydrochloric acid
- Weaker acids only partially dissociate in water
  - Carbonic acid

## Base

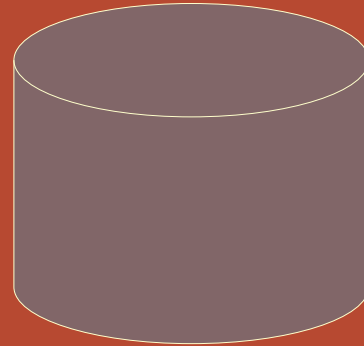
- Any substance that increases concentration of  $OH^-$  ions (Hydroxide) when dissolved in water
- Bases are proton acceptors
  - Accepts the proton that was donated by an acid
- Usually contain the hydroxide ion
  - $NaOH$  (Sodium Hydroxide)

## Neutralization Reactions

- When acid mixes with base, they react together and a molecule of water and salt is formed
- Example reaction:
  - $\text{HCl} + \text{NaOH} \rightarrow \text{HOH} + \text{NaCl}$
  - water    salt

Na OH

H Cl



## Measurement of acid and base PH

- A unit of measurement that indicates how many Hydrogen ions are in a solution
- The scale ranges from 0 -14, midpoint being 7
- If  $\text{H}^+ = \text{OH}^-$  pH is 7.0 and solution is neutral

## Measurement of acid PH

- If solution contains more  $\text{H}^+$  than  $\text{OH}^-$ , pH is less than 7.0
  - Solution is acidic
  - Further from 7.0 you go, the stronger the acid is
- Hydrochloric acid is one of the strongest acids
  - Made in our stomachs

## Measurement of base PH

- If solution contains less  $\text{H}^+$  than  $\text{OH}^-$ , pH is greater than 7.0
  - Solution is basic or alkaline
  - The higher you go away from 7.0, the more basic the solution is
  - Strong bases are as dangerous as strong acids

## pH of body fluids

- Most body fluids are near neutral
  - Urine = 5 – 8
  - Blood = 7.35 – 7.45
- One exception is fluid in the stomach
  - Stomach acid = 1 – 4
  - Low pH helps to chemically digest nutrients into small components that can be absorbed

## Buffers

- A chemical substance that prevents large changes in pH by removing excess  $H^+$  or releasing  $H^+$
- If pH is low (too many  $H^+$ ) a buffer removes  $H^+$  and tries to restore the pH to neutral
- If pH is high (too few  $H^+$ ) a buffer releases  $H^+$  and tries to restore the pH to neutral

## Buffers

- Important in maintenance of homeostasis
- Common buffers in humans
  - Bicarbonate
    - Raises pH
  - Phosphoric acid
    - Lowers pH
  - Proteins
    - Able to increase or decrease pH

## Organic Compounds

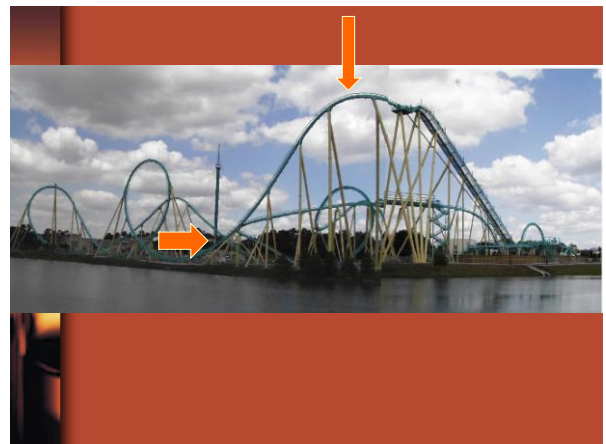
- All living things are made of mostly organic compounds
- Contain mostly carbon, hydrogen and oxygen
- Important groups of organic compounds
  - Carbohydrates
  - Proteins
  - Lipids
  - Nucleic Acids
  - Adenosine phosphate derivatives

## Carbon

- Carbon's ability to form bonds with four different elements give it unique potential in chemical realm
- Over a million unique organic compounds

## Energy

- Ability to do work or put matter in motion
- Two types of energy
  - Kinetic (mechanical) energy
    - Energy that results in production of motion or heat
    - Released energy
  - Potential (stored) energy
    - Energy that is stored in some form; waiting to be turned into kinetic energy



## Cellular Energy

- Energy in body comes from food we eat
  - Energy is neither created nor destroyed, it is changed from one form to another
  - Dead animals and plants still have stored energy
- If we used the energy stored in food directly, we would melt
  - All organic compounds yield large amounts of heat when combusted

## Cellular Energy

- Living organisms have evolved a mechanism to transfer the energy from one molecule to another
- Energy can be released in small amounts when needed
- Adenosine triphosphate (ATP) is used to temporarily store energy in living systems

## Cellular Energy

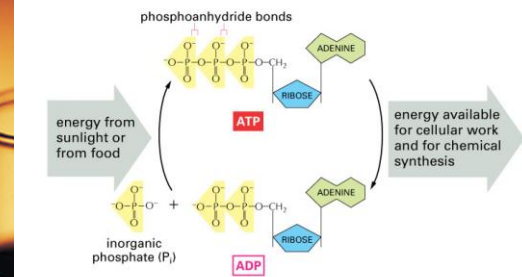
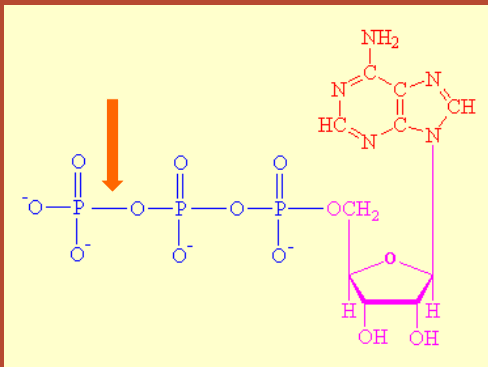


Figure 3-32 Essential Cell Biology, 2/e. (© 2004 Garland Science)

## Carbohydrates

- Groups of molecules that include sugars and starches
- Have the general formula C<sub>n</sub> H<sub>2n</sub> O<sub>n</sub>
  - Contain twice as much hydrogen as carbon and oxygen
- Equal approx. 2-3 % of body mass
- Three groups of carbs
  - Monosaccharides (monomer)
  - Disaccharides (dimer)
  - Polysaccharides (polymer)

## Monosaccharides

- Simple sugars
  - Cannot be broken down any further
- Hexose sugars (6 carbons)
  - Glucose
    - Most important simple sugar in humans
    - Can be used as an immediate energy source
    - Sometimes called blood sugar
  - Fructose
    - Sweetest simple sugar
    - Can be converted by the body into glucose

## Monosaccharides

- Galactose
  - Component of lactose (milk sugar)

## Monosaccharides

- Pentose sugars (5 carbon)
  - Sugars found in nucleic acids
  - Deoxyribose
    - Sugar in DNA
  - Ribose
    - Sugar in RNA

## Disaccharides

- Formed from a synthesis reaction of 2 monosaccharides
  - Requires removing a molecule of water from the two simple sugars and they link together
  - Can be reduced back to simple sugars by rehydration
- Sucrose (Table sugar)
  - Glucose + fructose
- Maltose
  - Glucose + Glucose

## Disaccharides

- Lactose (Milk sugar)
  - Glucose + Galactose
- Disaccharides cannot be digested by the small intestine they must be rehydrated
  - Rehydration is called hydrolysis (cut with water)

## Polysaccharides

- Polymer of sugars (Many sugars put together)
- Can be made from hundreds or thousands of monosaccharides assembled by dehydration synthesis
- Three important polysaccharides found in living organisms
  - Glycogen
  - Starch
  - Cellulose

## Glycogen

- Animal glucose storage
- Made of many glucose molecules put together in a long branched chain
- Stored in liver and skeletal muscle
- Can be accessed when demand is high for glucose
  - Broken down into individual glucose molecules when body needs sugar
- Built up for storage when too much sugar is present

## Starch

- Plant glucose storage
- Found in plants
  - Common foods that contain high starch levels
    - Potatoes
    - Pasta
    - Grains

## Cellulose

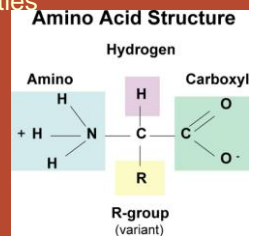
- Structural component of plant
- Made of a different form of glucose that cannot be digested by humans
- Provides no nutritive benefit
- It is needed for colon health
- Keeps you regular!

## Proteins

- Give structure to cells
- Transport materials
- Bind foreign substances
- Function as catalysts of chemical reactions
- Cell signaling
- Regulate acids and bases
- Regulate fluid compartments

## Proteins

- Made of amino acids
- 20 different amino acids that contain a unique R group
- R- groups have various functions and impart different properties



## Exponential Possibilities



## Exponential Possibilities



## Possible Sequences

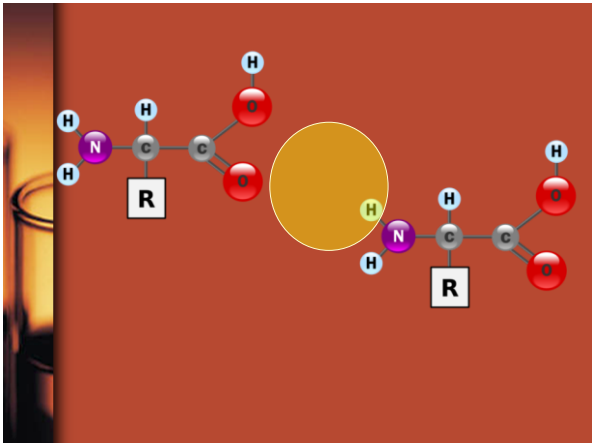
- If 2 possible coins
- Length 2 = 4 distinct possible combinations
- Length 3 = 8 distinct possible combinations
- Rule
  - Number of choices raised to the power of length
    - $2^2 = 4$
    - $2^3 = 8$
    - $2^4 = 16$

## Proteins

- Near infinite number of possibilities

Length of Protein (n)	Number of possibilities ( $20^n$ )
1	20
2	400
3	8000
4	160000
300	$2.03 \times 10^{390}$

- Humans produce approx. 100,000 diff proteins
- Animals do not have the ability to synthesize all 20 amino acids
- Must take in the amino acids that unable to synthesize



## Proteins

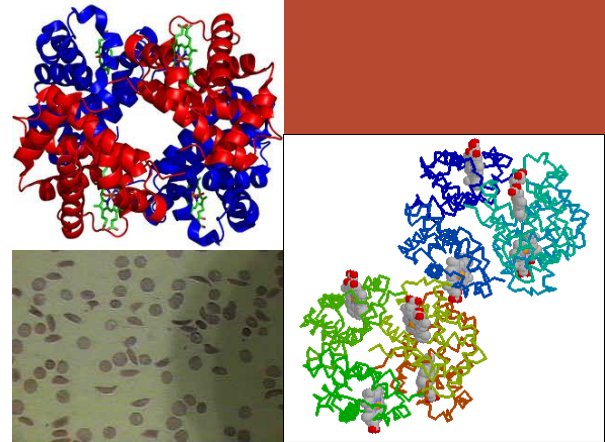
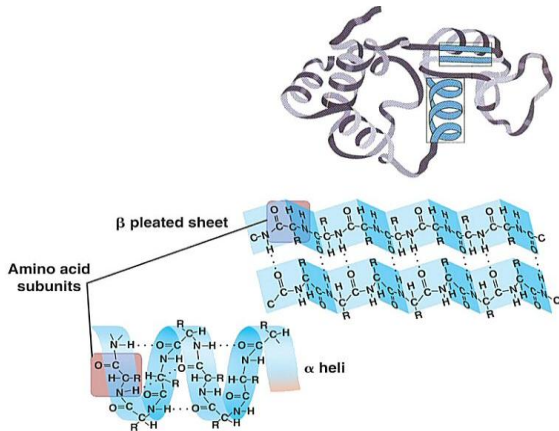
- Amino acids assemble together by dehydration synthesis
- Covalent bond forms between two amino acids
  - Peptide bond

## Proteins

- Humans need 8 – 10 essential amino acids
  - Infants need 10
  - Adults only need 8
- Acquire essential amino acids from diet
- Need food that is rich in proteins
  - Meat from other animals
  - Beans
  - Soybeans

## Proteins

- Have four levels of structure
  - Primary structure is sequence of amino acids determined by the gene sequence
  - Secondary structure is caused by reactions between neighboring R groups
    - Alpha helices
    - Beta sheets
  - Tertiary structure results from interactions of non-neighboring amino acids
  - Quaternary structure comes from more than one peptide bonding together

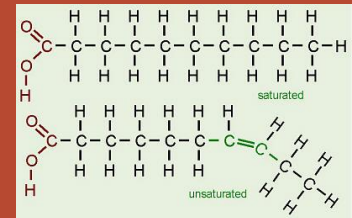
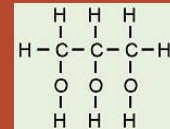


## Lipids

- Lipids are hydrophobic (water hating) molecules made mostly of carbon and hydrogen
- Include fats, waxes, steroids, cholesterol, lipoproteins, and phospholipids
- Lipids can be solid or liquid at room temperature
- Store a greater amount of energy than any other organic compound

## Lipids

- Made from two types of molecules
  - Glycerol
  - Fatty acids



## Fatty Acids

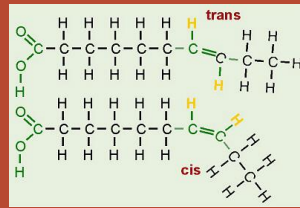
- Saturated Fatty Acids are made of single bonds between all carbon atoms
  - All bonding sites are saturated with an atom
- Unsaturated Fatty Acids contain at least one double bond between 2 carbon atoms
  - At least one site does not contain an atom
  - Monounsaturated – one double bond
  - Polyunsaturated - more than one double bond

## Fatty Acids

- Saturated fatty acids are solid at room temp
- Unsaturated fatty acids are liquid at room temp
- Saturated fatty acids are “unhealthy”

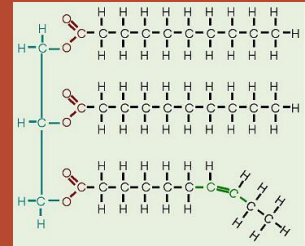
## Fatty Acids

- Two types of unsaturated fatty acids
- Cis and trans refer to the direction of the double bond
- Trans fatty acids are carcinogenic



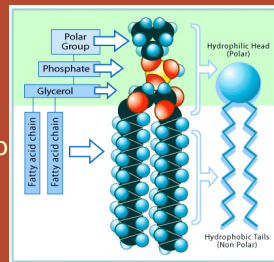
## Triglycerides

- Glycerol plus three fatty acid tails
- Rich source of energy
- Some animals get everything from triglycerides

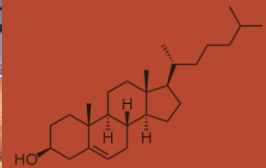


## Phospholipids

- One of the most important molecules in living organisms
- Contain a water soluble head and two insoluble fatty acid tails
- Creates membranes



## Steroids



## Steroids

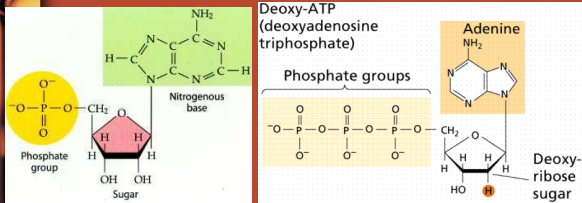
- Play a role in chemical signaling (hormones)
- Provides fluidity to cell membranes (cholesterol)

## Lipoproteins

- Combination of protein and lipid
- Allows for the transportation of lipid molecules
- HDL
  - Sometimes called good cholesterol
- LDL
  - Called bad cholesterol

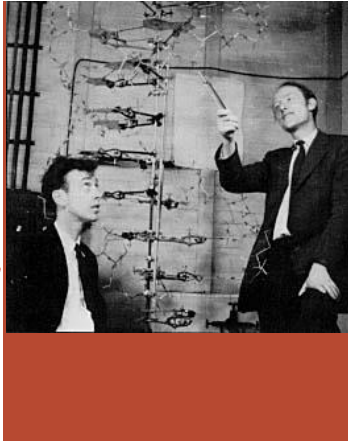
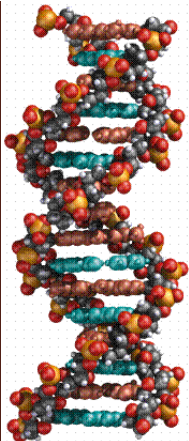
## Nucleic Acids

- Polymer of nucleotides
- Nucleotides are compounds that contain hexose sugar, phosphate group, and a nitrogen containing basic group



## DNA

- Sugar is deoxyribose
- Nitrogenous bases are
  - Adenine, Thymine, Cytosine, and Guanine
- Sequence of bases creates the genetic code and provides instructions to assemble the primary sequence of a protein
- Material passed from generation to generation



## RNA

- Sugar is ribose
- Nitrogenous bases are
  - Adenine, Uracil, Cytosine, and Thymine
- RNA is a versatile molecule
  - Used to carry amino acids
  - Regulate protein translation
  - Create structure in ribosomes
  - Fine tune protein levels
  - Many other critical functions!!!!!!

## Metabolism

- All of the biochemical reactions that occur within a living organism
  - Occur in cells of living organisms
- Two categories of metabolic reactions
- Catabolism
  - Breakdown of complex molecules into smaller components
  - Used to release energy in cells
  - Used to recycle chemical components for reuse in other biochemical compounds
  - Can be used to breakdown substances for excretion

## Metabolism

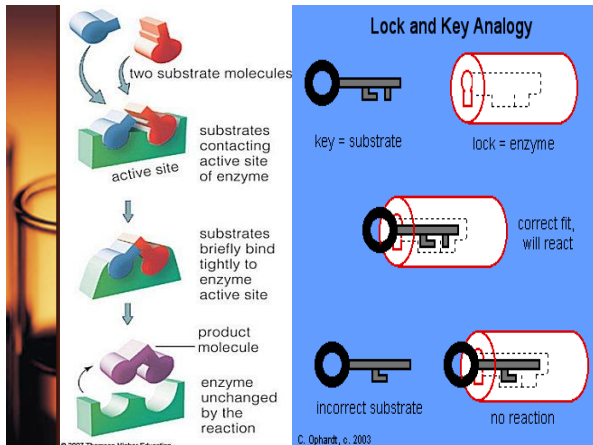
- Anabolism
  - Build up of complex compounds from simple substrates
  - Sometimes requires an input of energy
- Reactions are governed by limiting parameters
- Many medications nurses administer interact with enzymes and affect metabolic reactions

## Chemical Reactions

- Most reactions needed for life occur slowly
  - In some cases it can take millions of years for two molecules to come together
- Reactions often need energy to begin
  - Can be accelerated by changing pH or increasing temperature
  - Both processes can be deadly to cells
- Living organisms speed up process by using enzymes

## Enzymes

- Enzymes do not cause reactions that would not naturally occur to begin, it only speeds up the reaction
  - Catalyst
  - It cannot force an interaction between two substrates that would not normally come together
- Enzymes are large, globular proteins with a shape designed to specifically bind its substrates



## Enzymes Mechanism of Action

- Substrates bind to the active site of enzyme
- Substrate molecules are transformed into the product
  - Atoms can be rearranged into a different shape
  - Substrate molecules can be broken down
  - Substrate molecules can bind together to form product
- Some enzymes require a co-factor to provide necessary materials

## Conclusion

- Matter
- Atoms
- Energy
- Chemical Bonding
- Molecules/ Compounds
- Acid Base
- pH
- Organic compounds

## Conclusion

- Carbohydrates
- Lipids
- Proteins
- Nucleic Acids
- Energetic molecules
- Done!