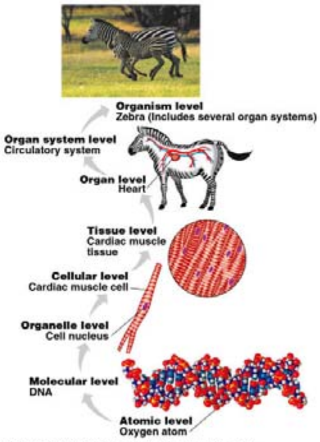
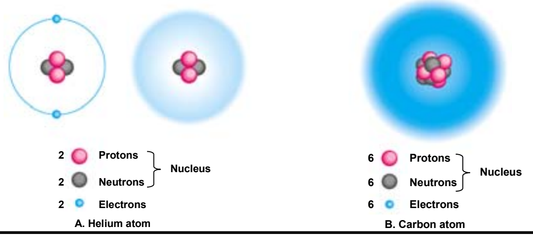


The Chemical Basis of Life

Atoms

- **Atoms** consist of a nucleus of positively charged protons and neutrally charged neutrons.
- Negatively charged electrons are arranged outside the nucleus.



Atoms, Molecules, Ions, and Bonds

Electronegativity

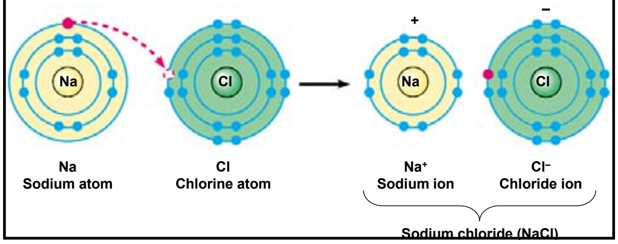
- The **electronegativity** of an atom, or the ability of an atom to attract electrons, plays a large part in determining the kind of bond that forms.

Molecules

- **Molecules** are groups of two or more atoms held together by **chemical bonds**.
- Chemical bonds between atoms form because of the interaction of their electrons.

1. Ionic bonds

- Because of their positive or negative charges, these atoms are **ions**.
- The attraction of the positive ion to the negative ion constitutes the ionic bond.



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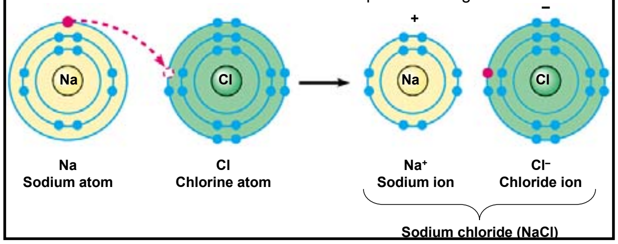
1. Ionic bonds

- **Ionic** bonds form between two atoms when one or more electrons are *transferred* from one atom to the other. This bond occurs when the electronegativities of the atoms are very different and one atom has a much stronger pull on the electrons (high electronegativity) than the other atom in the bond.
- The atom that gains electrons has an overall negative charge, and the atom that loses electrons has an overall positive charge.



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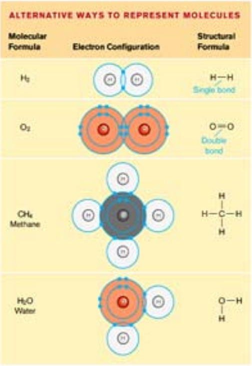
2. Covalent bonds

- **Covalent** bonds form when electrons between atoms are *shared*, which means that neither atom completely retains possession of the electrons (as happens with atoms that form strong ionic bonds).
- Covalent bonds occur when the electronegativities of the atoms are similar.



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1. Ionic bonds

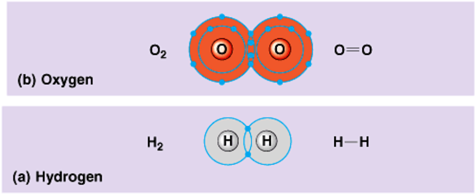
- Sodium and chlorine form ions (Na^+ and Cl^-), and the bond formed in a molecule of sodium chloride (NaCl) is an ionic bond.

Polar covalent

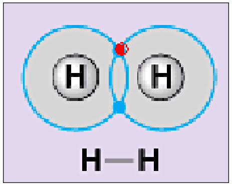
- **Polar covalent** bonds form when electrons are *shared unequally*.
- Atoms in this kind of bond have electronegativities that are different and an unequal distribution of the electrons results.
- The electrons forming the bond are closer to the atom with the greater electronegativity and produce a negative charge, or **pole**, near that atom.
- The area around the atom with the weaker pull on the electrons produces a positive pole.

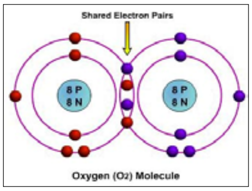
Nonpolar covalent

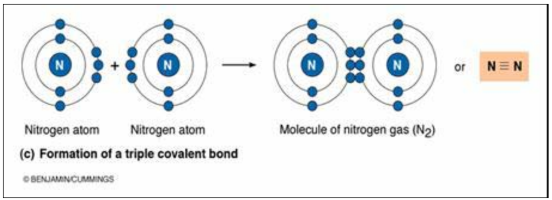
- **Nonpolar covalent** bonds form when electrons are *shared equally*.
- When the two atoms sharing electrons are identical, such as in oxygen gas (O_2), the electronegativities are identical and both atoms pull equally on the electrons.



- **Single covalent, double covalent, and triple covalent bonds form when two, four, and six electrons are shared, respectively.**





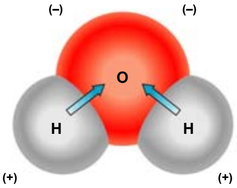


(c) Formation of a triple covalent bond

© BENJAMIN/CUMMINGS

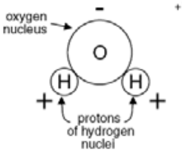
Polar covalent

- In a molecule of water (H_2O), for example, electrons are shared between the oxygen atom and each hydrogen atom.
- Oxygen, with a greater electronegativity, exerts a stronger pull on the shared electrons than does each hydrogen atom. This unequal distribution of electrons creates a negative pole near the oxygen and positive poles near each hydrogen atom.

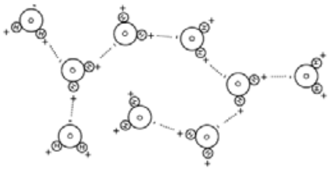


3. Hydrogen bonds

- In water, the positive pole around a hydrogen atom forms a hydrogen bond to the negative pole around the oxygen atom of *another* water molecule



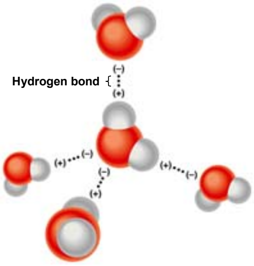
A water molecule showing polarity created by covalent bonds.



Hydrogen bonding between water molecules.

3. Hydrogen bonds

- **Hydrogen** bonds are weak bonds between *molecules*.
- They form when a positively charged *hydrogen* atom in one covalently bonded molecule is attracted to a negatively charged area of another covalently bonded molecule.

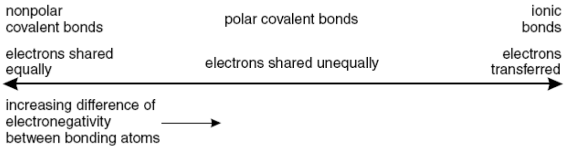


Properties of Water

- The hydrogen bonds among water molecules contribute to some very special properties for water.

1. *Water is an excellent* **solvent**.

- Ionic substances are soluble (they dissolve) in water because the poles of the polar water molecules interact with the ionic substances and separate them into ions.
- Substances with polar covalent bonds are similarly soluble because of the interaction of their poles with those of water.
- Substances that dissolve in water are called **hydrophilic** (“water loving”).
- Because they lack charged poles, nonpolar covalent substances do not dissolve in water and are called **hydrophobic** (“water fearing”).



nonpolar covalent bonds | polar covalent bonds | ionic bonds

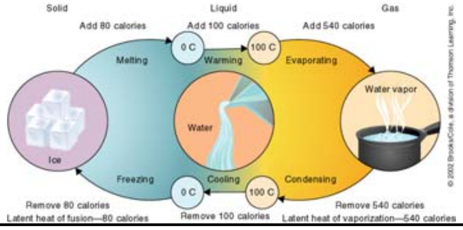
electrons shared equally | electrons shared unequally | electrons transferred

increasing difference of electronegativity between bonding atoms →

- **2. *Water has a high* heat capacity.**

You must add a relatively large amount of energy to warm (and boil) water or remove a relatively large amount of energy to cool (and freeze) water.

When sweat evaporates from your skin, a large amount of heat is taken with it and you are cooled.



- **2. *Water has a high* heat capacity.**

Heat capacity is the degree to which a substance changes temperature in response to a gain or loss of heat.

Water has a high heat capacity, changing temperature very slowly with changes in its heat content.

Thus, the temperatures of large bodies of water are very stable in response to the temperature changes of the surrounding air.

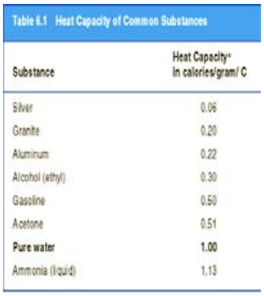
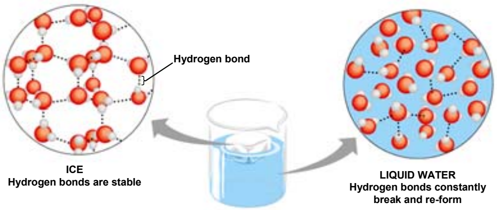


Table 6.1 Heat Capacity of Common Substances

Substance	Heat Capacity* in calories/gram/ C
Silver	0.06
Granite	0.20
Aluminum	0.22
Alcohol (ethyl)	0.30
Gasoline	0.50
Acetone	0.51
Pure water	**1.00**
Ammonia (liquid)	1.13

3. *Ice floats.*

- Hydrogen bonds are typically weak, constantly breaking and reforming, allowing molecules to periodically approach one another.
- In the solid state of water, the weak hydrogen bonds between water molecules become rigid and form a crystal that keeps the molecules separated and less dense that its liquid form.
- If ice did not float, it would sink and remain frozen due to the insulating protection of the overlaying water.

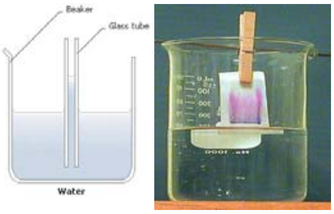


3. *Ice floats.*

- Unlike most substances that contract and become more dense when they freeze, water *expands* as it freezes, becomes less dense than its liquid form, and, as a result, floats in liquid water.

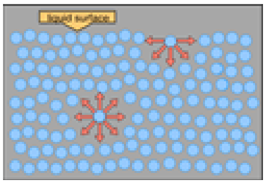
5. *Water adheres to other molecules*.

- **Adhesion** is the attraction of *unlike* substances. When water adheres to the walls of narrow tubing or to absorbent solids like paper, it demonstrates **capillary action** by rising up the tubing or creeping through the paper.



4. *Water has strong* cohesion *and high* surface tension.

- Cohesion, or the attraction between *like* substances, occurs in water because of the hydrogen bonding between water molecules.
- The strong cohesion between water molecules produces a high surface tension, creating a water surface that is firm enough to allow many insects to walk upon without sinking.



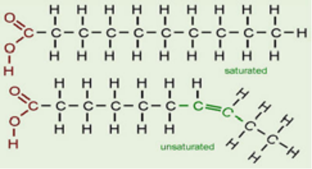

Basilisk Lizard

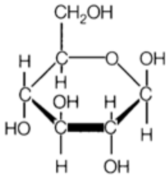
Organic Molecules

- **Organic molecules** are those that have carbon atoms.
- In living systems, large organic molecules, called **macromolecules**, may consist of hundreds or thousands of atoms.
- Most macromolecules are **polymers**, molecules that consist of a single unit (**monomer**) repeated many times.

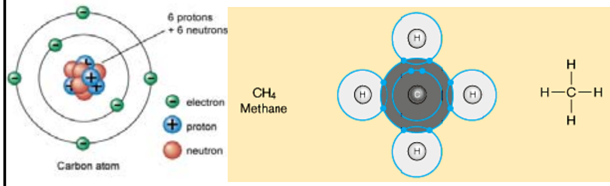
Organic Molecules

- Complex molecules can be formed by stringing carbon atoms together in a straight line or by connecting carbons together to form rings.
- The presence of nitrogen, oxygen, and other atoms adds additional variety to these carbon molecules.

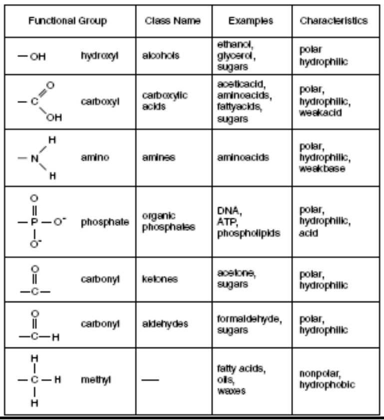




- Four of carbon’s six electrons are available to form bonds with other atoms.
- Thus, you will always see four lines connecting a carbon atom to other atoms, each line representing a pair of shared electrons (one electron from carbon and one from another atom).



The more common functional groups with their properties are listed



Functional Group		Class Name	Examples	Characteristics
$-OH$	hydroxyl	alcohols	ethanol, glycerol, sugars	polar hydrophilic
$-C(=O)OH$	carboxyl	carboxylic acids	aceticacid, aminoacids, fattyacids, sugars	polar, hydrophilic, weakacid
$-NH_2$	amino	amines	aminoacids	polar, hydrophilic, weakbase
$-P(=O)(O^-)-O^-$	phosphate	organic phosphates	DNA, ATP, phospholipids	polar, hydrophilic, acid
$-C(=O)-$	carbonyl	ketones	acetone, sugars	polar, hydrophilic
$-C(=O)-H$	carbonyl	aldehydes	formaldehyde, sugars	polar, hydrophilic
$-CH_3$	methyl	—	fatty acids, oils, waxes	nonpolar, hydrophobic

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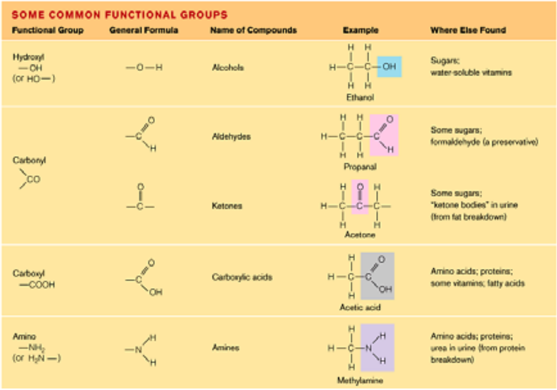
Functional groups

- Many organic molecules share similar properties because they have similar clusters of atoms, called **functional groups**.
- Each functional group gives the molecule a particular property, such as acidity or polarity.

Functional groups are the groups of atoms that participate in chemical reactions

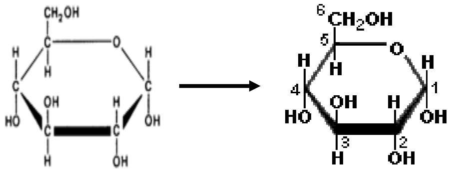
Carbohydrates



SOME COMMON FUNCTIONAL GROUPS

Functional Group	General Formula	Name of Compounds	Example	Where Else Found
Hydroxyl —OH (or HO—)	—O—H	Alcohols	Ethanol	Sugars; water-soluble vitamins
Carbonyl >CO	$-C(=O)H$	Aldehydes	Propanal	Some sugars; formaldehyde (a preservative)
	$-C(=O)-$	Ketones	Acetone	Some sugars; "ketone bodies" in urine (from fat breakdown)
Carboxyl —COOH	$-C(=O)OH$	Carboxylic acids	Acetic acid	Amino acids; proteins; some vitamins; fatty acids
Amino $-NH_2$ (or H_2N-)	$-NH_2$	Amines	Methylamine	Amino acids; proteins; urea in urine (from protein breakdown)

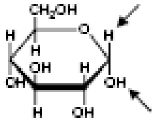
- (Note that the symbol C for carbon may be omitted in ring structures; a carbon exists wherever four bond lines meet.)



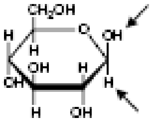
Carbohydrates

Carbohydrates are classified into three groups according to the number of sugar (or saccharide) molecules present.

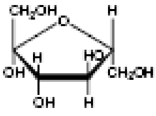
- **1. A monosaccharide** is the simplest kind of carbohydrate. It consists of a single sugar molecule, such as fructose or glucose.



Alpha Glucose

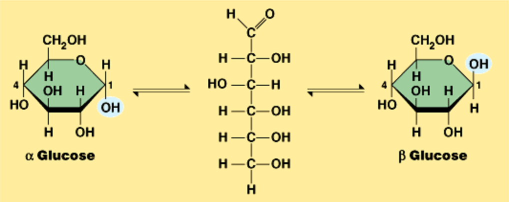


Beta Glucose



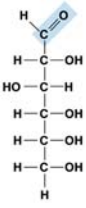
Fructose

- Two forms of glucose, **α-glucose** and **β-glucose**, differ simply by a reversal of the H and OH on the first carbon.
- Even very small changes in the position of certain atoms may dramatically change the chemistry of a molecule.

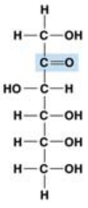


(a) α and β glucose ring structures

- Sugar molecules have the formula $(CH_2O)n$, where *n* is any number from 3 to 8.
- For **glucose**, *n* is 6, and its formula is $C_6H_{12}O_6$.
- The formula for **fructose** is also $C_6H_{12}O_6$, but as you can see in Figure, the placement of the carbon atoms is different.



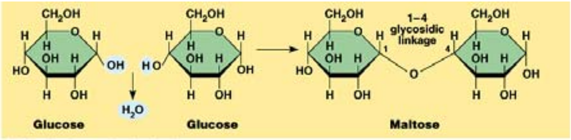
Glucose



Fructose

2. A disaccharide

- This type of chemical reaction, where a simple molecule is lost, is generally called a **condensation** reaction (or specifically, a **dehydration** reaction, if the lost molecule is water).



(a) Dehydration synthesis of maltose

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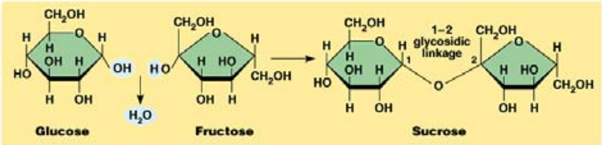
2. A disaccharide

- **A disaccharide** consists of two sugar molecules joined by a **glycosidic linkage**.
- During the process of joining, a water molecule is lost. Thus, when glucose and fructose link to form sucrose, the formula is $C_{12}H_{22}O_{11}$ (not $C_{12}H_{24}O_{12}$).



(b) Dehydration synthesis of sucrose

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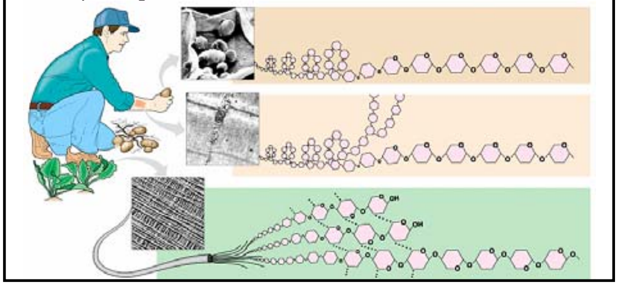
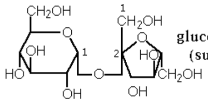
3. A polysaccharide

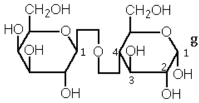
- A **polysaccharide** consists of a series of connected monosaccharides.
- Thus, a polysaccharide is a polymer because it consists of repeating units of a monosaccharide.



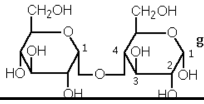
- **Some common disaccharides follow:**
- glucose + fructose = **sucrose** (common table sugar)
- glucose + galactose = **lactose** (the sugar in milk)
- glucose + glucose = **maltose**



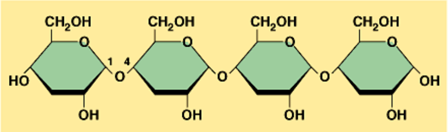
glucose α 1-2 fructose (sucrose)



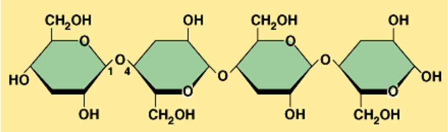
galactose β 1-4 glucose (lactose)



glucose α 1-4 glucose (maltose)



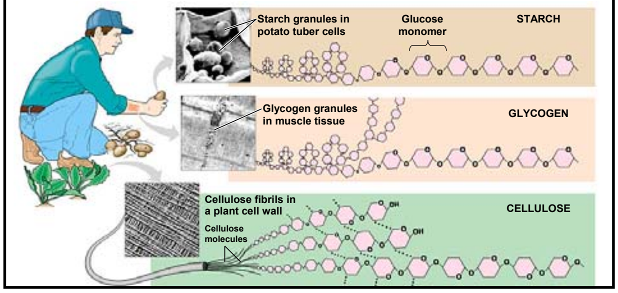
(b) Starch: 1–4 linkage of α glucose monomers



(c) Cellulose: 1–4 linkage of β glucose monomers

- **The following examples of polysaccharides may contain thousands of glucose monomers:**

- **Starch** is a polymer of α-glucose molecules. It is the principal *energy storage* molecule in plant cells.
- **Glycogen** is a polymer of α-glucose. It differs from starch by its pattern of polymer branching. It is a major *energy storage* molecule in animal cells.
- **Cellulose** is a polymer of β-glucose molecules. It serves as a *structural* molecule in the walls of plant cells and is the major component of wood.



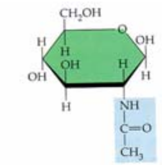
- The α-glucose in starch and the β-glucose in cellulose illustrate the dramatic chemical changes that can arise from subtle molecular changes:

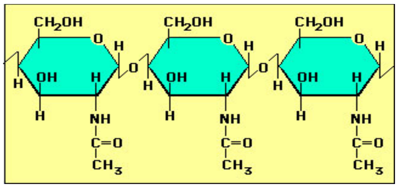
  the bond in starch can easily be broken down (digested) by humans and other animals, but only specialized organisms, like the bacteria and protozoa in the guts of termites, can break down cellulose (specifically, the β-glycosidic linkage).

Termites, sometimes called White Ants

- **Chitin** is a polymer similar to cellulose, but each β-glucose molecule has a nitrogen containing group attached to the ring.

  Chitin serves as a *structural* molecule in the walls of fungus cells and in the exoskeletons of insects, other arthropods, and mollusks.



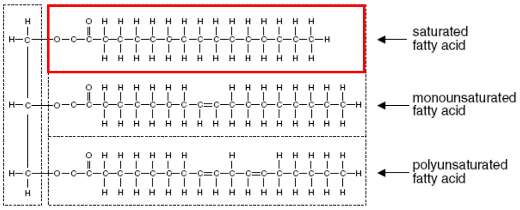


- Lipids are a class of substances that are insoluble in water (and other polar solvents) but are soluble in nonpolar substances (like ether or chloroform). There are three major groups of lipids:

1. **Triglycerides**
2. **A phospholipid**
3. **Steroids**

Lipids

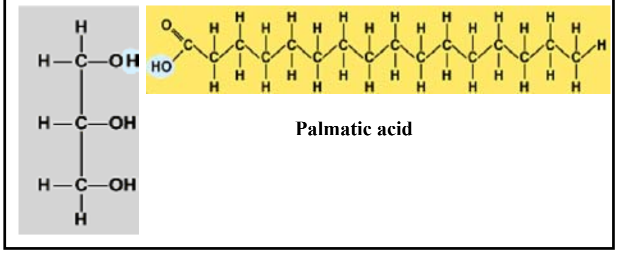
- Fatty acids vary in structure by the number of carbons and by the placement of single and double covalent bonds between the carbons, as follows:
- A **saturated** fatty acid has a single covalent bond between each pair of carbon atoms, and each carbon has two hydrogens bonded to it (three hydrogens bonded to the last carbon). You can remember this by thinking that each carbon is "saturated" with hydrogen.



Glycerol + **3 Fatty Acids** = **Triglyceride**

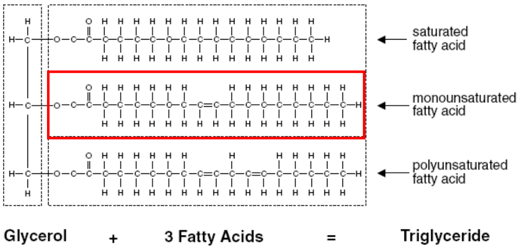
1. Triglycerides include fats, oils, and waxes.

- They consist of three **fatty acids** attached to a **glycerol** molecule.
- Fatty acids are hydrocarbons (chains of covalently bonded carbons and hydrogens) with a carboxyl group (–COOH) at one end of the chain.

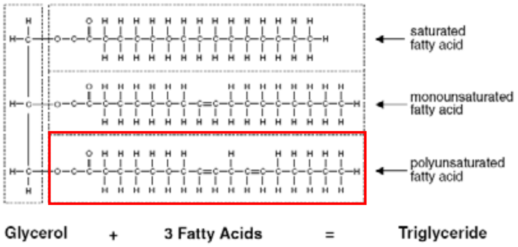


Palmatic acid

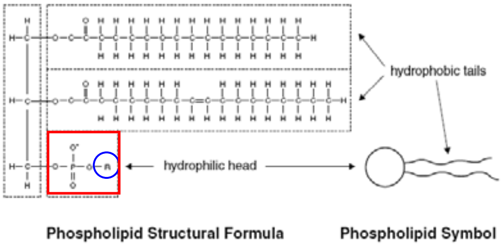
- A **monounsaturated** fatty acid has *one double* covalent bond and each of the two carbons in this bond has only one hydrogen atom bonded to it.



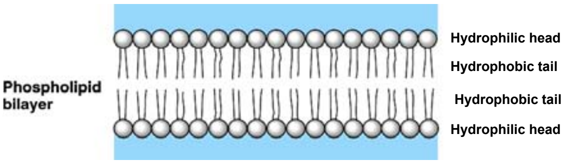
- A **polyunsaturated** fatty acid is like a monounsaturated fatty acid except that there are *two or more double* covalent bonds.



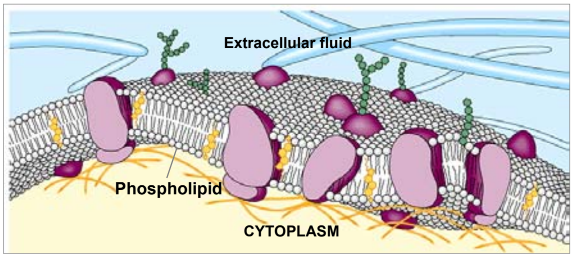
- **2. A phospholipid** looks just like a lipid except that one of the fatty acid chains is replaced by a phosphate group ($–PO_3^{2-}$). An additional chemical group (indicated by R in the Figure) is usually attached to the phosphate group.
- The two fatty acid “tails” of the phospholipid are nonpolar and hydrophobic and the phosphate “head” is polar and hydrophilic.



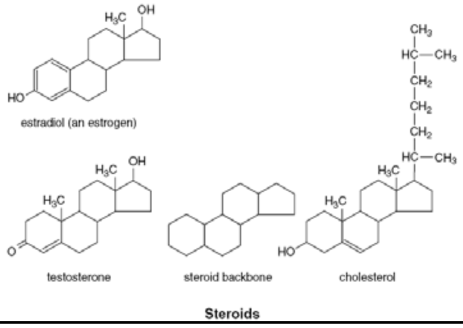
- A phospholipid is termed an **amphipathic** molecule because it has both polar (hydrophilic) and nonpolar (hydrophobic) regions.
- Phospholipids are often found oriented in sandwichlike formations with the hydrophobic tails grouped together on the inside of the sandwich and the hydrophilic heads oriented toward the outside and facing an aqueous environment.



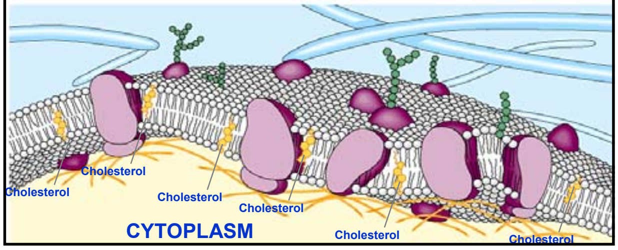
- Such formations of phospholipids provide the structural foundation of cell membranes.



- **3. Steroids** are characterized by a backbone of four linked carbon rings.
- Examples of steroids include cholesterol (a component of cell membranes) and certain hormones, including testosterone and estrogen.



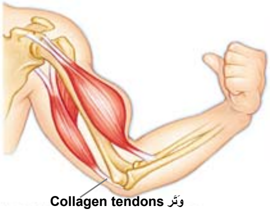
- Examples of steroids include cholesterol (a component of cell membranes)



Proteins

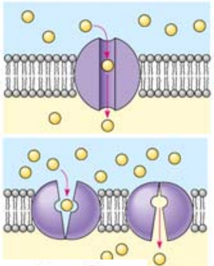
Proteins can be grouped according to their functions. Some major categories follow:

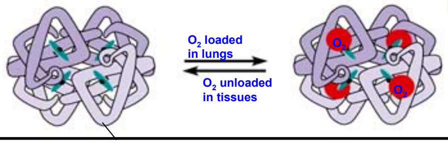
- **1. Structural proteins** such as keratin in the hair and horns of animals, collagen in connective tissues, and silk in spider webs.



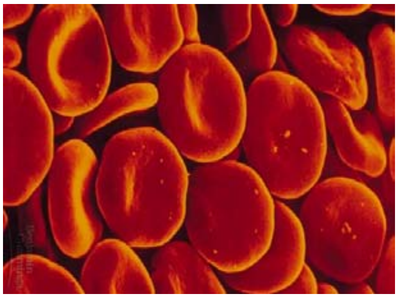
- **2. Storage proteins** such as casein in milk, ovalbumin in egg whites, and zein in corn seeds.

- **3. Transport proteins** such as those in the membranes of cells that transport materials into and out of cells and as oxygen-carrying hemoglobin in red blood cells.

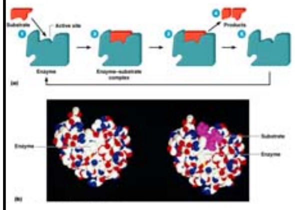


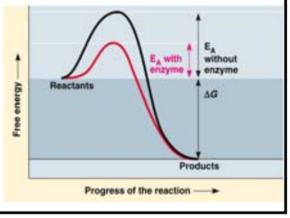


Red Blood Cells

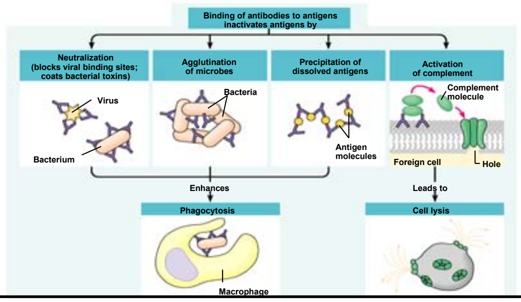


- **5. Enzymes** that regulate the rate of chemical reactions.

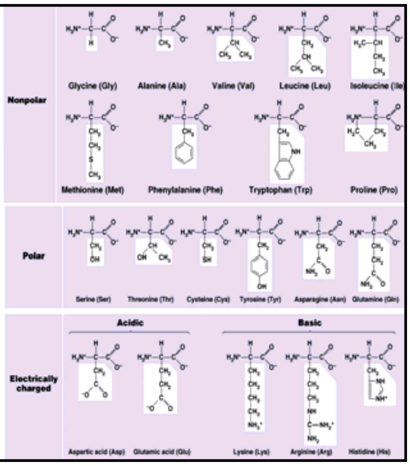


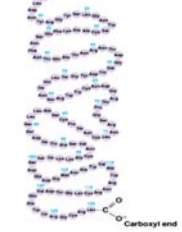


- **4. Defensive proteins** such as the antibodies that provide protection against foreign substances that enter the bodies of animals.

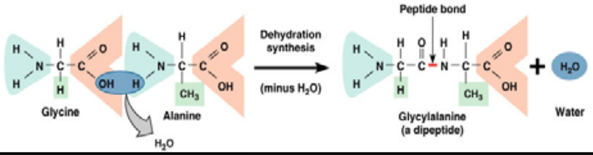


- One protein differs from another by the number and arrangement of the twenty different amino acids.

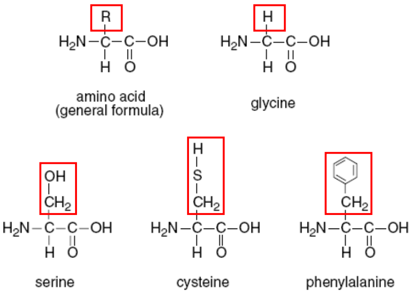




- Although the functions of proteins are diverse, their structures are similar.
- All proteins are polymers of **amino acids**, that is, they consist of a chain of amino acids covalently bonded.
- The bonds between the amino acids are called **peptide bonds**, and the chain is a **polypeptide**, or **peptide**.

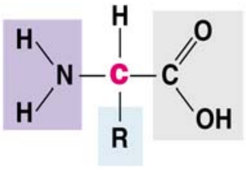


- For the simplest amino acid, glycine, the R is a hydrogen atom. For serine, R is CH_2OH.
- For other amino acids, R may contain sulfur (as in cysteine) or a carbon ring (as in phenylalanine).

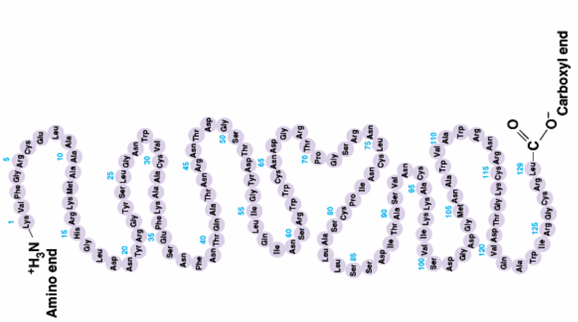


Amino Acids

- Each **amino acid** consists of a central carbon bonded to an amino group ($–NH_2$), a carboxyl group ($–COOH$), and a hydrogen atom.
- The fourth bond of the central carbon is shown with the letter R (for radical), which indicates an atom or group of atoms that varies from one kind of amino acid to another.



- **1.** The **primary structure** of a protein describes the order of amino acids.
- Using three letters to represent each amino acid, the primary structure for the protein antidiuretic hormone (ADH) can be written as Cys-Tyr-Phe-Gln-Asn-Cys-Pro-Arg-Gly.



Lysozyme, an enzyme that attacks bacteria, consists on a polypeptide chain of 129 amino acids

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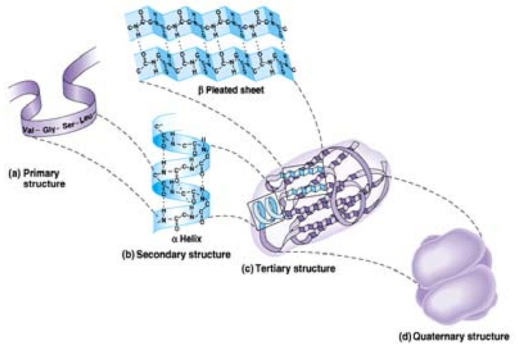
There are four levels that describe the structure of a protein:



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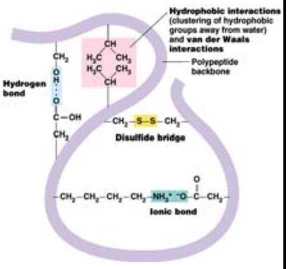
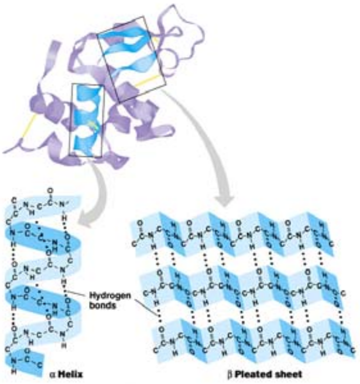
3. The **tertiary structure** of a protein includes additional three-dimensional shaping and often dominates the structure of **globular proteins**.

The following factors contribute to the tertiary structure:

- **Hydrogen bonding** between R groups of amino acids.
- **Ionic bonding** between R groups of amino acids.
- The **hydrophobic effect** that occurs when hydrophobic R groups move toward the center of the protein (away from the water in which the protein is usually immersed).
- The formation of **disulfide bonds** when the sulfur atom in the amino acid cysteine bonds to the sulfur atom in another cysteine (forming cystine, a kind of "double" amino acid). This disulfide bridge helps maintain turns of the amino acid chain



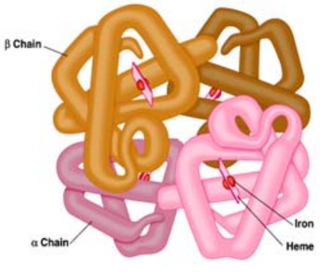
- **2.** The **secondary structure** of a protein is a three-dimensional shape that results from hydrogen bonding between the amino and carboxyl groups of adjacent amino acids.
- The bonding produces a spiral (**alpha helix**) or a folded plane that looks much like the pleats on a skirt (**beta pleated sheet**).
- Proteins whose shape is dominated by these two patterns often form **fibrous proteins**.



pleated = طيّة

Nucleic Acids

- **4.** The **quaternary structure** describes a protein that is assembled from two or more separate peptide chains.
- The globular protein hemoglobin, for example, consists of four peptide chains that are held together by hydrogen bonding, interactions among R groups, and disulfide bonds.



(b) Hemoglobin

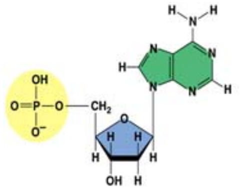
DNA

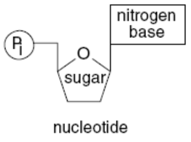
- **DNA** is a polymer of **nucleotides**.
- A DNA nucleotide consists of three parts

a **nitrogen base,**

a five-carbon sugar called **deoxyribose,**

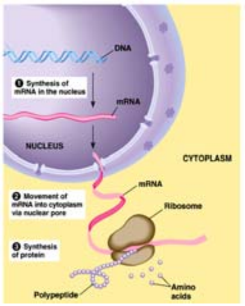
and a **phosphate group**.



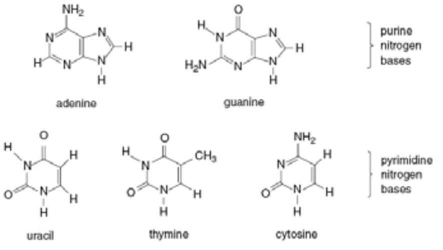


nucleotide

- The genetic information of a cell is stored in molecules of deoxyribonucleic acid (DNA).
- The DNA, in turn, passes its genetic instructions to ribonucleic acid (RNA) for directing various metabolic activities of the cell.



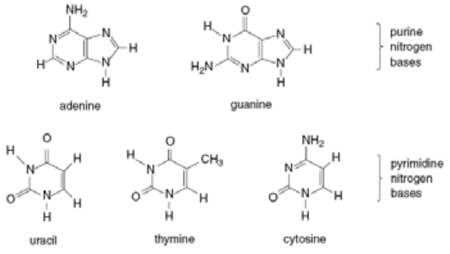
- Pyrimidines are single-ring nitrogen bases, and purines are double-ring bases.
- You can remember which bases are purines because only the two purines end with *nine*.
- The first letter of each of these four bases is often used to symbolize the respective nucleotide (A for the adenine nucleotide, for example).



Nitrogen Bases

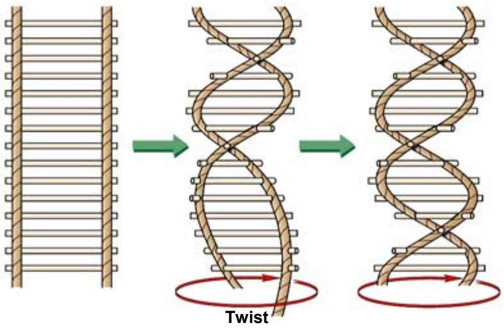
There are four DNA nucleotides, each with one of the four nitrogen bases, as follows

1. Adenine—a double-ring base (purine).
2. Guanine— a double-ring base (purine).
3. Thymine—a single-ring base (pyrimidine).
4. Cytosine— a single-ring base (pyrimidine).

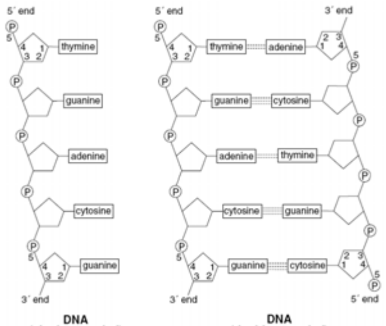


Nitrogen Bases

- When bonded in this way, DNA forms a two-stranded spiral, or double helix.



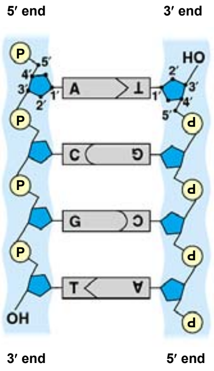
- The two strands of nucleotides, paired by weak hydrogen bonds between the bases, form a double-stranded DNA.



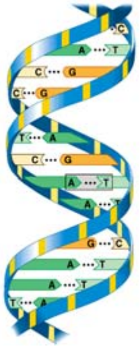
DNA (single-stranded)

DNA (double-stranded)

- The two strands of a DNA helix are antiparallel, that is, oriented in opposite directions.
- One strand is arranged in the 5‘ 3'direction; that is, it begins with a phosphate group attached to the *fifth* carbon of the deoxyribose (5' end) and ends where the phosphate of the next nucleotide would attach, at the *third* deoxyribose carbon (3').
- The adjacent strand is oriented in the opposite, or 3‘ 5'direction.



•Note that adenine always bonds with thymine and guanine always bonds with cytosine.



Chemical Reactions in Metabolic Processes

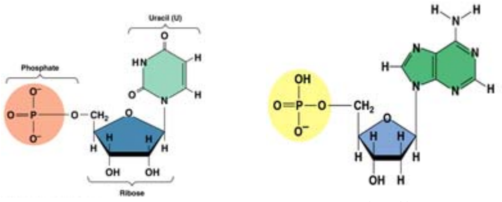
RNA

- **RNA** differs from DNA in the following ways:

1. The sugar in the nucleotides that make an RNA molecule is **ribose,** not deoxyribose as it is in DNA.

2. The thymine nucleotide does not occur in RNA. It is replaced by **uracil.** When pairing of bases occurs in RNA, uracil (instead of thymine) pairs with adenine.

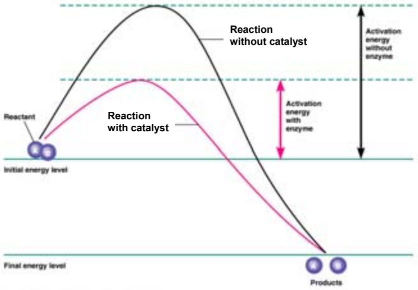
3. RNA is usually single-stranded and does not form a double helix as it does in DNA.



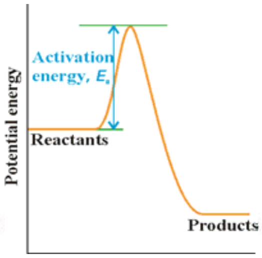
(RNA)

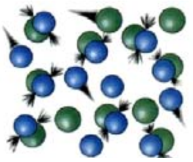
(DNA)

- Although many reactions can occur spontaneously, the presence of a **catalyst** accelerates the rate of the reaction because it lowers the activation energy required for the reaction to take place.
- A catalyst is any substance that accelerates a reaction but does not undergo a chemical change itself.
- Since the catalyst is not changed by the reaction, it can be used over and over again.



- In order for a chemical reaction to take place, the reacting molecules (or atoms) must
- first collide
- and then have sufficient energy (**activation energy**) to trigger the formation of new bonds.





Metabolic processes have the following characteristics in common:

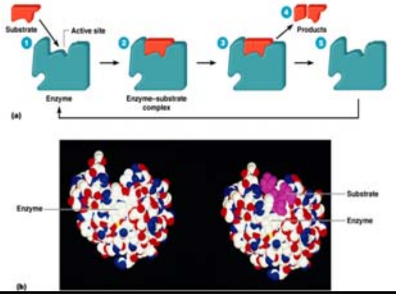
1. The net direction of metabolic reactions, that is, whether the overall reaction proceeds in the forward direction or in the reverse direction, is determined by the concentration of the reactants and the end products.

- Chemical **equilibrium** describes the condition where the rate of reaction in the forward direction equals the rate in the reverse direction and, as a result, there is no net production of reactants or products.

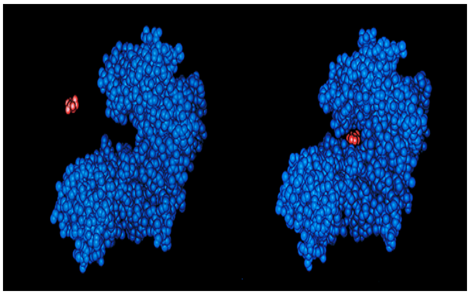
- Chemical reactions that occur in biological systems are referred to as **metabolism**.
- Metabolism includes
  - the breakdown of substances (**catabolism**),
  - the formation of new products (**synthesis** or **anabolism**),
  - or the transferring of energy from one substance to another.

Note the following characteristics of enzymes:

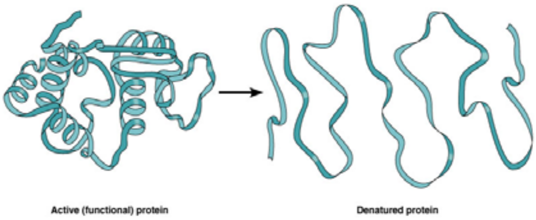
- *The* **substrate** *is the substance or substances upon which the enzyme acts*. For example, amylase catalyzes the breakdown of the substrate amylose (starch).
- *Enzymes are substrate specific*. The enzyme amylase, for example, catalyzes the reaction that breaks the α-glycosidic linkage in starch but cannot break the β-glycosidic linkage in cellulose.



- **2. Enzymes** are globular proteins that act as catalysts (activators or accelerators) for metabolic reactions.

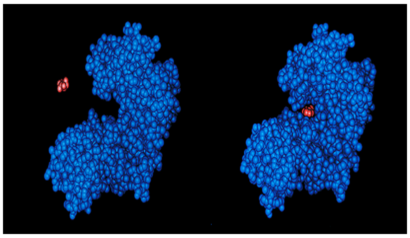


- *The efficiency of an enzyme is affected by temperature and pH.*
- The human body, for example, is maintained at a temperature of 98.6° (37 C), near the optimal temperature for most human enzymes. Above 104°(40 C), these enzymes begin to lose their ability to catalyze reactions as they become **denatured**, that is, they lose their three-dimensional shape as hydrogen bonds and peptide bonds begin to break down.



- *The* **induced-fit model** *describes how enzymes work*.

Within the protein (the enzyme), there is an **active site** with which the reactants readily interact because of the shape, polarity, or other characteristics of the active site. The interaction of the reactants (substrate) and the enzyme causes the enzyme to change shape. The new position places the substrate molecules into a position favorable to their reaction. Once the reaction takes place, the product is released.

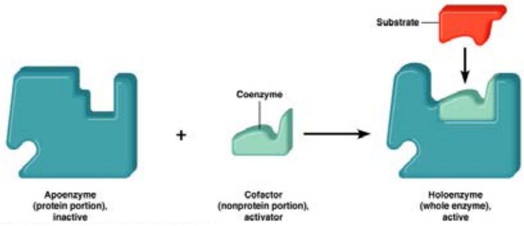


- *An enzyme is unchanged as a result of a reaction*. It can perform its enzymatic function repeatedly.

Activators

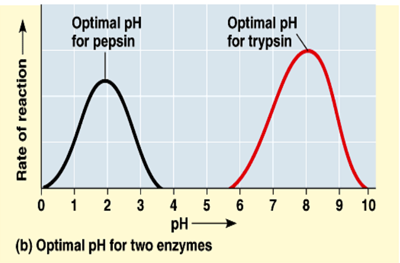
Help enzymes to keep them in active configurations

- **3. Cofactors** are nonprotein molecules that assist enzymes.
- A **holoenzyme** is the union of the cofactor and the enzyme (called an **apoenzyme** when part of a holoenzyme).
- **Coenzymes** are *organic* cofactors that usually function to donate or accept some component of a reaction, often electrons.
- Some vitamins are coenzymes or components of coenzymes.
- **Inorganic cofactors** are often metal ions, like Fe^{2+}.



pH

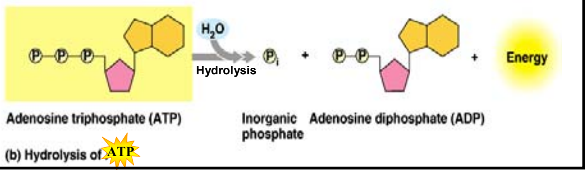
- The enzyme pepsinogen, which digests proteins in the stomach, becomes active only at a low pH (very acidic).



(b) Optimal pH for two enzymes

- *The standard suffix for enzymes is “ase,”* so it is easy to identify enzymes that use this ending (some do not).

- When ATP supplies energy to a reaction, it is usually the energy in the last bond that is delivered to the reaction.
- In the process of giving up this energy, the last phosphate bond is broken and the ATP molecule is converted to ADP (adenosine diphosphate) and a phosphate group (indicated by P*i*).

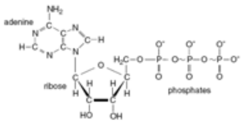


(b) Hydrolysis of ATP

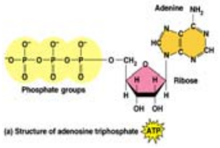
ATP

Source of activation energy for most metabolic reactions

- **4. ATP** (adenosine triphosphate) is a common source of activation energy for metabolic reactions
- ATP is essentially an RNA adenine nucleotide with two additional phosphate groups.
- The wavy lines between these two phosphate groups indicate high energy bonds.



Adenosine Triphosphate (ATP)



(a) Structure of adenosine triphosphate

How do living systems regulate chemical reactions?

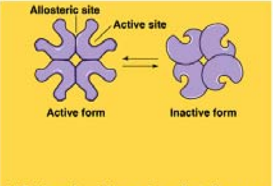
How do they know when to start a reaction and when to shut it off?

One way of regulating a reaction is by regulating its enzyme. Here are four common ways in which this is done:

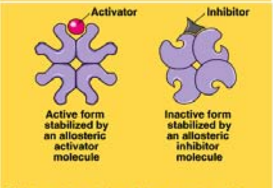
1. **Allosteric enzymes** have two kinds of binding sites—one an active site for the substrate and one an allosteric site for an **allosteric effector**.

There are two kinds of allosteric effectors:

- An **allosteric activator** binds to the enzyme and induces the enzyme’s *active* form.
- An **allosteric inhibitor** binds to the enzyme and induces the enzyme’s *inactive* form.



(a) Conformational changes in an allosteric enzyme



(b) Allosteric regulation of the enzyme’s activity

Allosteric means “anther site”, most enzymes have allosteric sites are proteins constructed from two or more polypeptide chains

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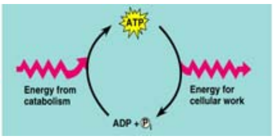
- In contrast, new ATP molecules are assembled by **phosphorylation** when ADP combines with a phosphate group using energy obtained from some energy-rich molecule (like glucose).

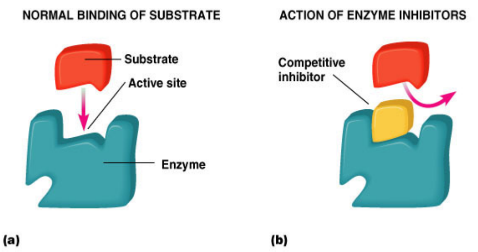


Adenosine—Ⓟ—Ⓟ—Ⓟ + H_2O ⇌ Adenosone—Ⓟ—Ⓟ + $Ⓟ_i$ + Energy

Adenosine triphosphate; Water; Adenosine diphosphate; Inorganic phosphate

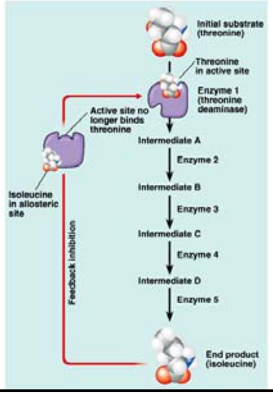
Competitive inhibition

- **2.** In **competitive inhibition**, a substance that mimics the substrate inhibits an enzyme by occupying the active site.
- The mimic displaces the substrate and prevents the enzyme from catalyzing the substrate.



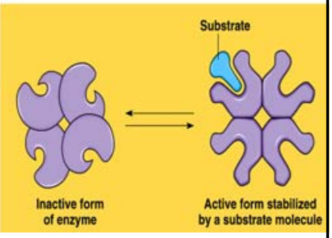
In feedback inhibition, an end product of a series of reactions acts as an allosteric inhibitor, shutting down one of the enzymes catalyzing the reaction series when products are not needed.

- ***A simple example of feedback inhibition is a thermostat connected to a heater. A sensor detects the temperature in the room, and when the temperature reaches a predetermined set point, the thermostat signals the furnace to shut off. When the temperature drops below the set point, the inhibition is released, and the furnace is turned back on.***



Cooperativity

- **4.** In **cooperativity**, an enzyme becomes more receptive to additional substrate molecules after one substrate molecule attaches to an active site.
- This occurs, for example, in enzymes that consist of two or more subunits (quaternary structure), each with its own active site.
- A common example of this process (though not an enzyme) is hemoglobin, whose binding capacity to additional oxygen molecules increases after the first oxygen binds to an active site.



Noncompetitor inhibitor

- **3.** A **noncompetitor inhibitor** binds to an enzyme at locations other than an active or allosteric site.
- The inhibitor changes the shape of the enzyme which disables its enzymatic activity.