Introduction to Organic Chemistry and Biochemistry

Part I - Organic Chemistry

Hydrocarbons are molecules that contain only hydrogen and carbon atoms
Each Carbon atom forms 4 bonds and each hydrogen forms 1 bond

Hydrocarbons include (among other things)
alkanes - all single bonds between carbons
alkenes - one or more double bonds between carbons
alkynes - one or more triple bonds between carbons
aromatics - contain benzene ring or similar structures

- benzene is hexagonal structure with resonance hybrid between alternating single and double bonds between carbons around ring C_6H_6 and 1 H attached to each C

Alkane C_nH_{2n+2}

CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
C_5H_{12}	pentane
C_6H_{14}	hexane
C_7H_{16}	heptane
C_8H_{18}	octane
C_9H_{20}	nonane
$C_{10}H_{22}$	decane

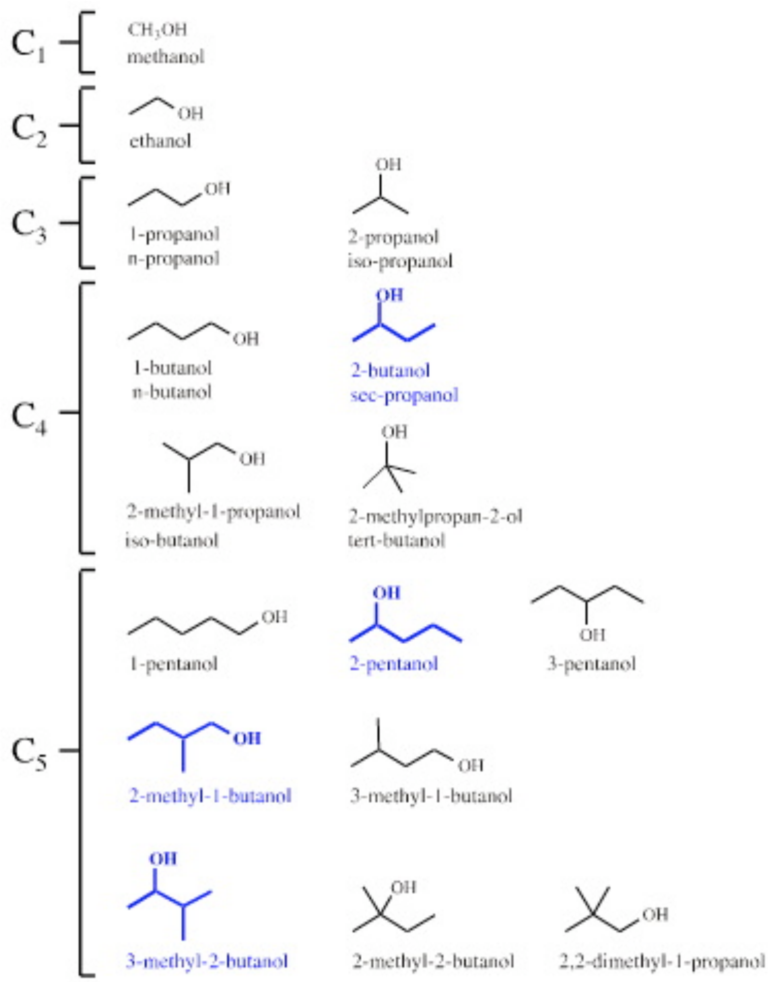
Complexity

Organic molecules can form long or branched chains and rings and have other attached atoms. There is essentially an unlimited number of possible organic molecules. About 20+ million organic molecules have been identified and studied to date.

Part of the complexity of organic molecules comes from the great diversity of structures possible even with the same molecular formula. Some of this diversity is illustrated below with various isomers of alcohols (OH group).

Compounds that have the same molecular formula but different structural formulas are defined as isomers.

Each isomer will have different physical properties of boiling point, melting point, solubility, density, and unique chemical properties.



http://www.meta-synthesis.com/webbook/09_organic/organic.html

Sources of Hydrocarbons

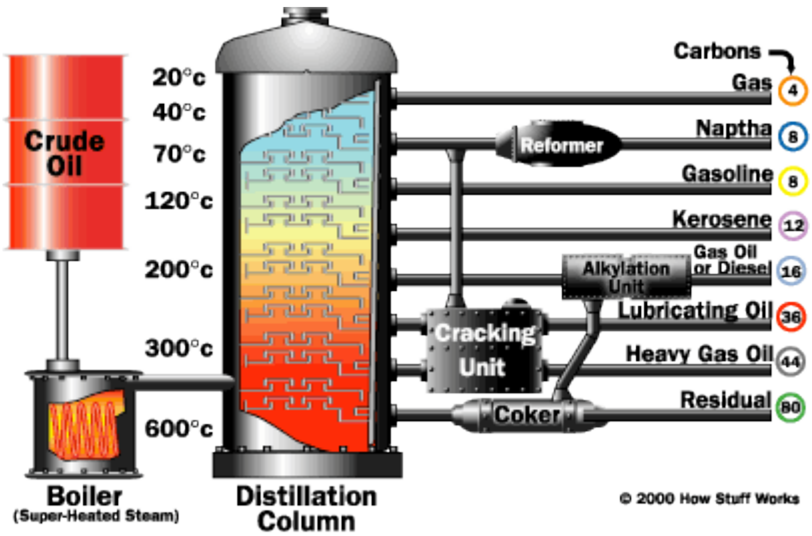
Oil, coal, natural gas- from decomposition of animal/ vegetable matter
Plants build up larger molecules $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$

Refining Petroleum

Boiling Range	Carbon Atoms	Fraction	Use
-164 – 20	1 – 4	gas	fuel, heating
20 – 90	5 – 7	petroleum ether	solvent

35 – 220	5 – 12	gasoline	fuel
200 – 315	12 – 16	kerosene	heating jet fuel
250 – 375	15 – 18	fuel oil	Diesel Fuel, heating
350	16 – 20	oil, grease	lubrication

Separation- Fractionating Tower
Conversion – Cracking oil to gasoline



http://www.enewsbuilder.net/aopl/e_article000374007.cfm?x=b11,0,w

Functional Groups

When other atoms such as oxygen or nitrogen are included in an organic molecule the added atoms can change the physical and chemical properties dramatically and these groups of atoms are called functional groups.

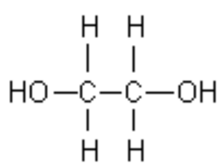
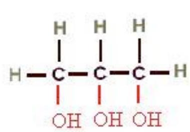
Name	Functional Group	General Formula
Alcohol	-OH	R-OH
Ether	-O-	R-O-R’
Aldehyde	-CH=O	R-CH=O
Ketone	-C=O	R-C=O R’
Carboxylic acid	HO-C=O	OH-C-O

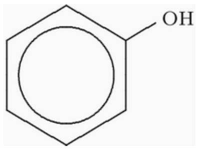
R

Ester	O=C-O-	O=C-O-R’ R
Amine	-N-	R-N-R , H-N-R, H-N-R’ R H R
Amide	O=C-N-	O=C-NH_2 R

R and R’ represent any hydrocarbon group that completes the molecular structure

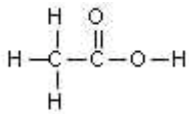
<u>Examples of Organic Molecules and Functional Groups</u>

<u>Type</u>	<u>Structure</u>	<u>Name</u>	<u>Use/ Effect</u>
Alcohol			
	CH_3-OH	Methanol (wood alcohol)	Poison, blindness,death
	CH_2-CH_2-OH	Ehtanol (grian alcohol)	Ingredient in beer, wine Cirrhous (scarring) of liver Byproduct of fermentation
		Ethylene glycol (dihydroxy alc.)	Antifreeze in radiator
	 Glycerol (Glycerine - propane 1,2,3, triol - 3 hydroxyl (OH) functional group)	Glycerol (Glycerine) (Trihydroxy alc.)	Lubricant

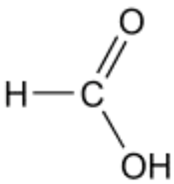


Phenol — Destructive to animal tissue

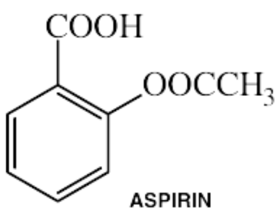
Carboxylic Acid



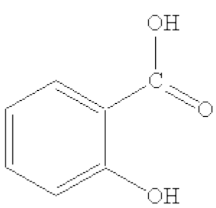
Pure glacial — Destroy animal tissue, vinegar is a dilute solution of acetic acid



Formic acid — Causes pain from ant bite

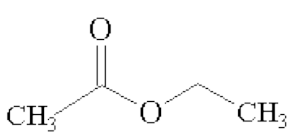


Acetylsalicylic acid (ASA) — aspirin

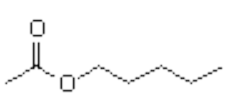


Salicylic acid

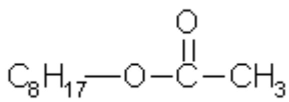
Ester



Ethyl acetate — Remover for fingernail polish

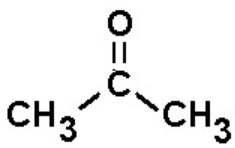


N-pentyl acetate — Aroma of bananas

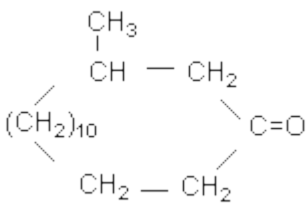


N-octyl acetate Aroma of oranges

Ketone



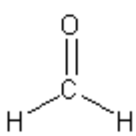
Acetone Solvent for plastics



Muscone

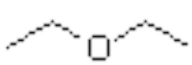
Muscone musk oil, cologne, perfurme

Aldehyde



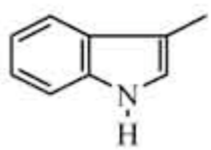
Formaldehyde Embalming fluid, preservative

Ether



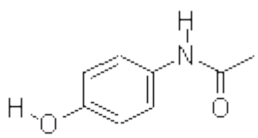
Ethyl ether general anesthetic

Amine



Scatol Smell of fecal matter
(3-methylindole)

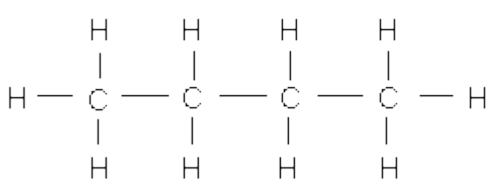
Amide



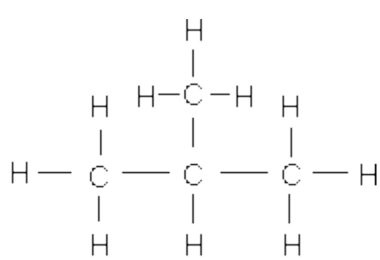
4- Acetamido phenol (Acetominophen) Active ingredient in tylenol

<u>Isomers</u> - same formula different structure

Structural Isomers – Differ in sequence of atoms
C_4H_{10}



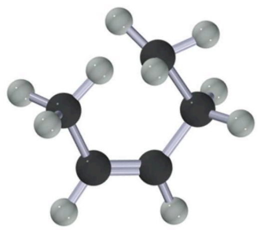
butane



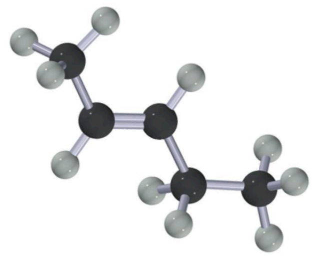
methylpropane

http://www.avogadro.co.uk/organic/isomer.htm

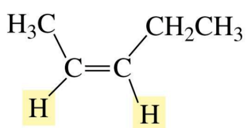
Stereoisomers – same sequence but different in spatial arrangement
Geometric isomers – double bond



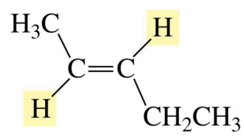
cis-2-pentene



trans-2-pentene



cis-2-pentene

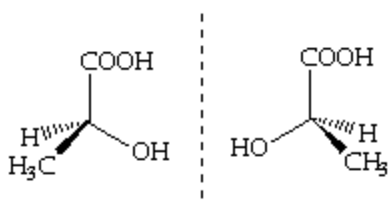


trans-2-pentene

http://wps.prenhall.com/wps/media/objects/724/741576/chapter_05.html

Optical isomers – due to chirality of carbon , chiral carbon has 4 different groups on carbon

Lactic acid builds up in muscle tissue and causes soreness



(+) Lactic acid Levorotatory

(-) Lactic acid Dextrorotatory

http://www.ch.ic.ac.uk/vchemlib/mol/glossary/

Part II – Biochemistry

Introduction

Biochemistry is the chemistry of living things.

To understand and control or modify (for disease prevention or other purposes) chemical reactions of living organisms, we must understand life on the molecular level.

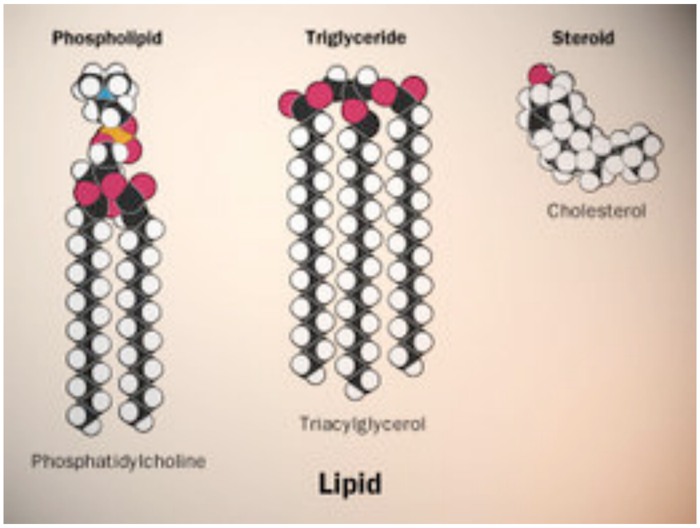
Since living things are extremely complicated then the chemical reactions and molecules must be very complex, however we can get an overview by understanding 4 types of biomolecules. We will greatly simpifly all these details by giving some general structural features of biomolecules and their primary role in living systems.

Biomolecules (basic types and their role in cells)
1) Lipids – cell membranes and energy storage in fats
2) Carbohydrates- energy source and cell surfaces
3) Proteins – molecules that do work of cell (carry out many reactions)
4) Nucleic Acids – molecules that contains instructions on how to make proteins (genetic information)

1) Lipids

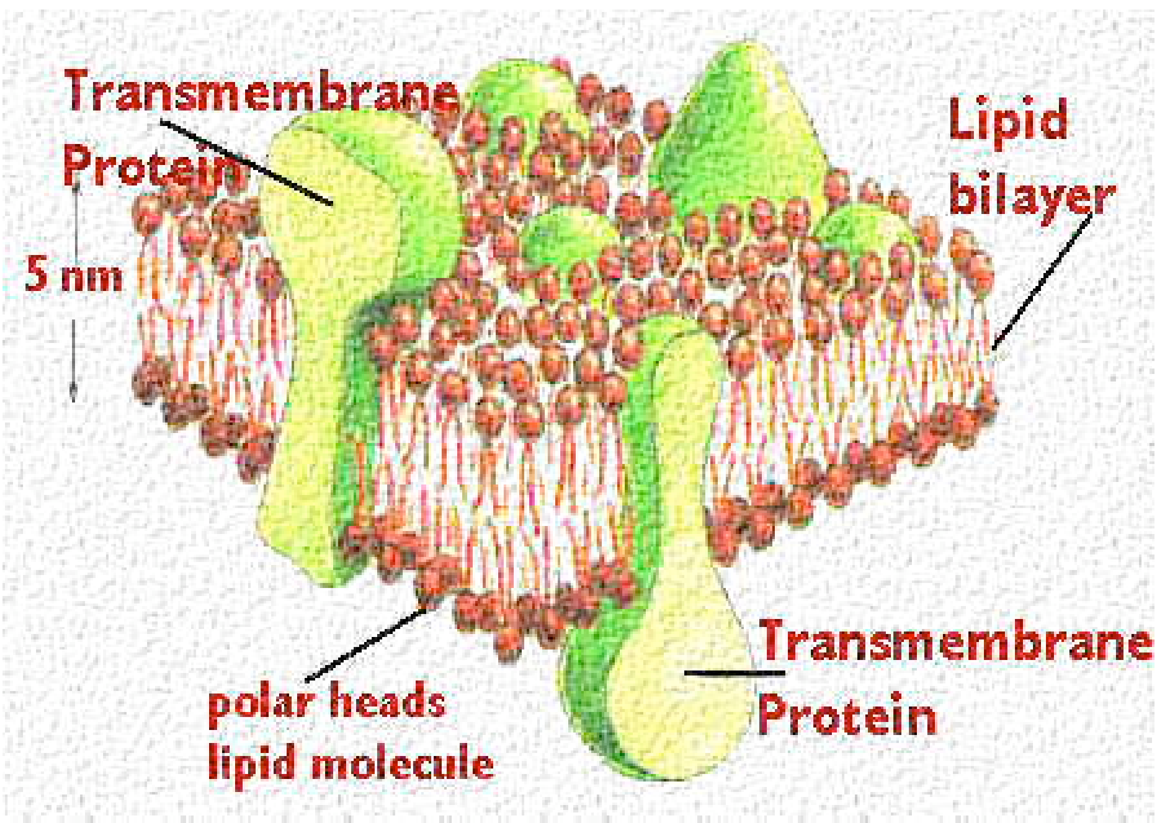
Lipids are water insoluble substances.
(a) Lipids provide structure of cell membranes
(b) Lipids provide for storage of energy for metabolism in fats
(c) Lipids or derivatives of lipids are found in hormones and some vitamins.

Some examples of a few different types of lipids are shown below.



http://upload.wikimedia.org/wikipedia/lt/thumb/5/5b/Lipids.jpg/260px-Lipids.jpg

The picture below shows that lipid molecules found in cell membranes contain a short polar end and a longer nonpolar portion. The polar end is sometimes called the "head" and the longer nonpolar portion the "tail." In the membrane shown below there is a double layer of lipids with the nonpolar tails toward the middle and the polar heads on the inner and outer surface of the membrane.



http://cellbio.utmb.edu/cellbio/membr2.jpg

For much more detail about lipids you can see the website below:

http://web.indstate.edu/thcme/mwking/lipids.html#role

2) Carbohydrates

Carbohydrates are sugars and substances that hydrolyze to yield sugars.
(Hydrolysis is the breaking of a bond by adding a water molecule (H^+ to one side and OH^- to the other)
They have formulas like $C_x(H_2O)_y$ where x, y may be from 3 up to thousands.
They are also referred to as saccharides.

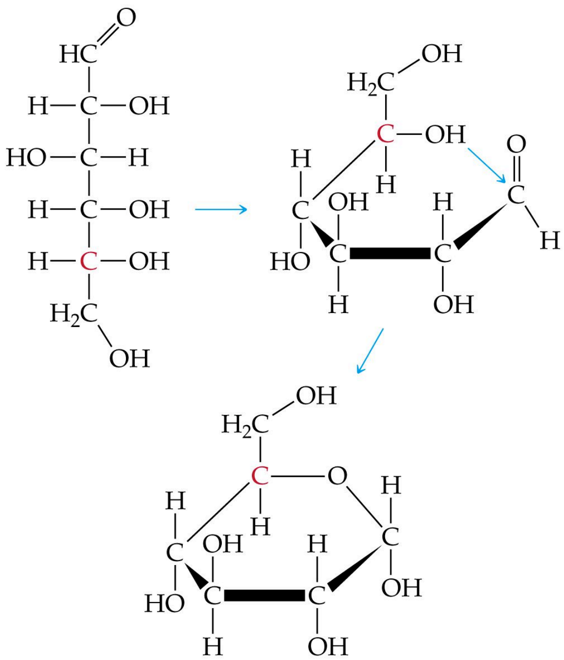
monosaccharides – do not undergo hydrolysis (examples: glucose, fructose)
disaccharides – hydrolyze to two monosaccharides (examples: sucrose, lactose)
polysaccharides – hydrolyze to many monosaccharides (examples: starch, cellulose)

Monosaccharide

example Glucose
Glucose is a sugar found widely in nature. Starch and cellulose are both made of hundreds of linked glucose molecules. Glucose is the most common organic molecule in the world because it is found in all plants.

Other carbohydrates such as starch are converted in your body to glucose prior to breakdown in your body for energy. Ultimately glucose undergoes oxidation to CO_2 and H_2O.

The formula of glucose is $C_6H_{12}O_6$ and it can exist as chain or ring form as shown below. Cyclic form is dominate (preferred).

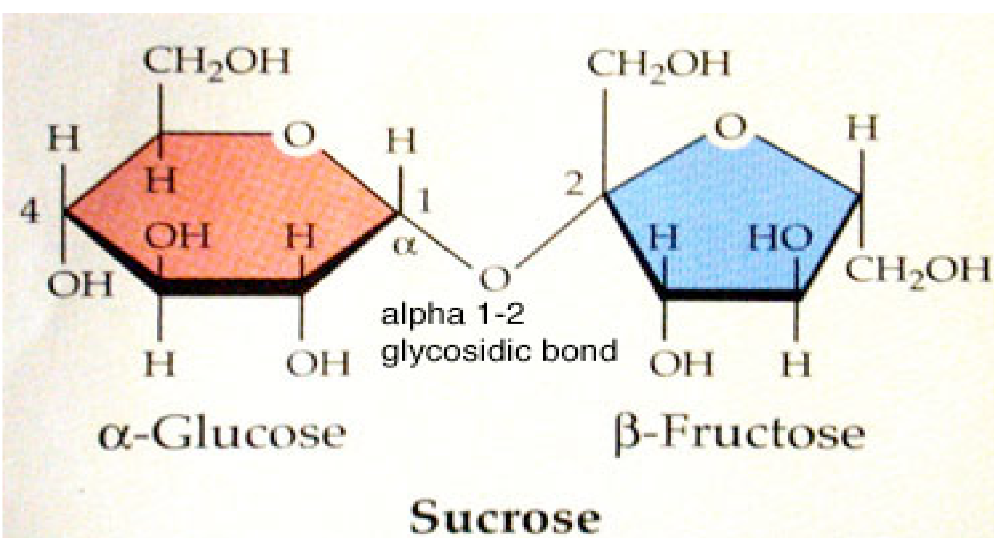


http://wps.prenhall.com/wps/media/objects/476/488316/ch19.html

Glucose contains 4 chiral carbons so the open chain form can have 16 possible structures depending on the orientation of each of the OH functional groups $2^4 = 16$. Glucose is just one of these possibilities but it is the most common one in nature.

IV fluids contain glucose and some salts.

Table sugar is a disaccharide that is a combination of two sugar molecules (glucose and fructose).



http://academic.brooklyn.cuny.edu/biology/bio4fv/page/disaccharide.html

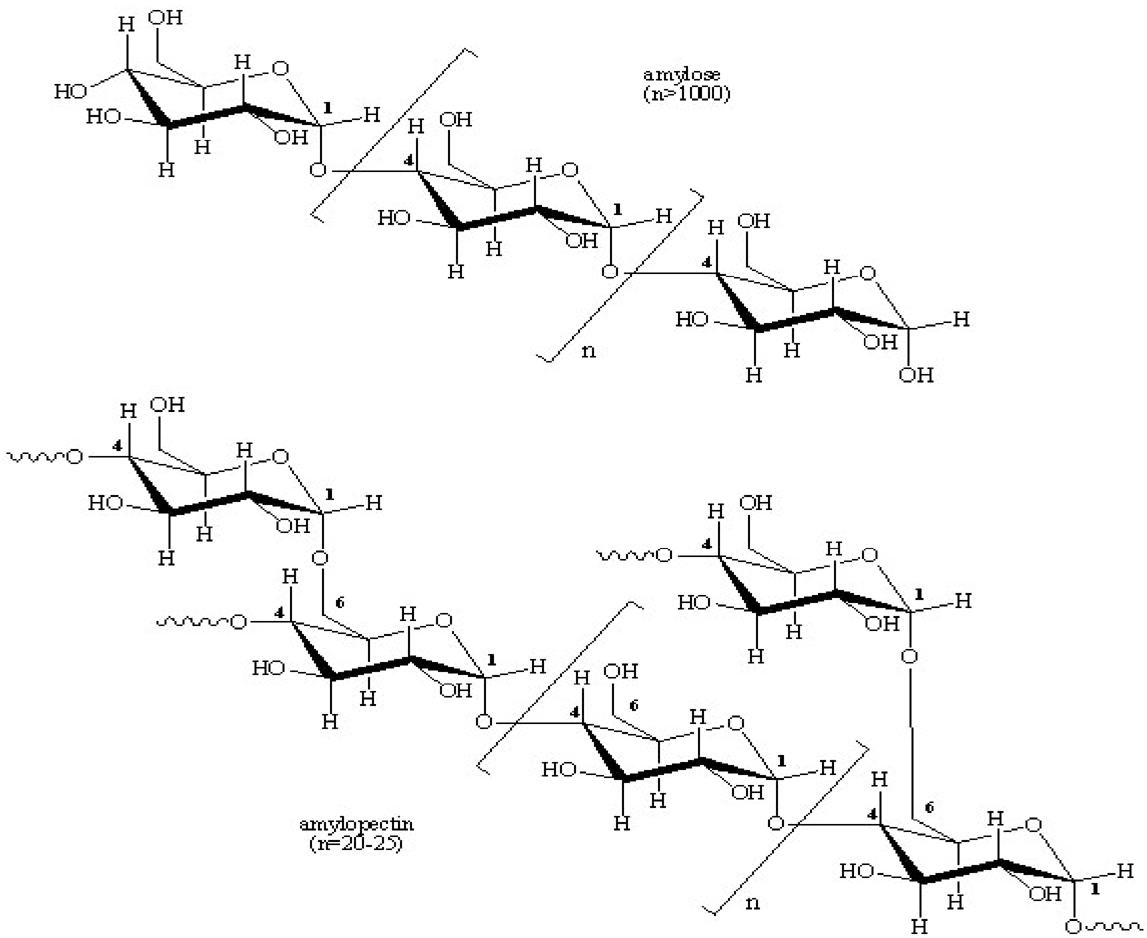
Polysaccharides are composed of many sugar molecules (monosaccharide units) linked together.

Starch is made of 200 to 3000 glucose units. Glucose is joined with all molecules in branched chain pattern with all the glucose rings with the same orientation.

Cellulose is made of 2000 to 4000 glucose units. Glucose is attached end to end to form long filament molecules. Each glucose ring has the opposite orientation of the one before it.

Unlike cows, horses, sheep, etc., humans cannot digest cellulose because we lack the enzymes necessary for this chemical reaction. The enzyme (a protein molecule) must have a certain shape that fits the molecule to undergo reaction and because of the different orientation of the glucoses starch and celluose require different enzymes. If we did not lack these enzymes, we could go into our front yards or into parks and eat grass whenever we got hungry.

Sample starch molecules are shown below that contain many glucoses linked together.



Starch
10-20% amylose (1-4-α-D-glucopyranoside) polymer
and
80-90% amylopectin (1-4, 1-6'-α-D-glucopyranoside)
>100 branched, interconnecting chains of 20-25 glucose units

http://science.pc.athabascau.ca/reagentstud.nsf/0/e008ec926d35d5d98725709200674598/$FILE/Starch%20Structure.jpg

3) Proteins

Introduction

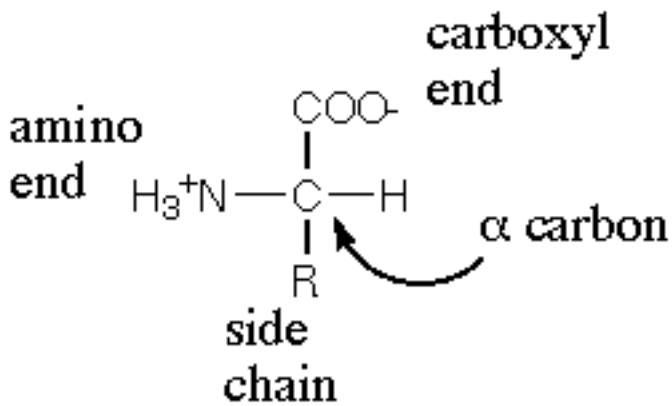
Protein molecules are in all living tissues of plant and animals
Proteins contain C, H, N, O, and S atoms
May contain other atoms as well

Proteins have many roles in our bodies and in all living things:
Covering – in hair, skin, and nails

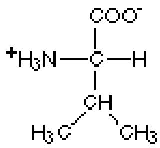
Chemical reactions – enzymes that catalyze chemical reactions
Transport - Hemoglobin carries O_2 in blood
Motion – muscles are made of proteins
Coordinate chemical activities – insulin is used in glucose metabolism

Proteins are built up from repeated units of amino acids and may have molecular weights of 6,000 to 3,000,000 amu (or g/mol)

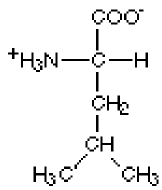
<u>Amino acids</u>
20 different amino acids are found in nature - all amino acids have amino group, carboxyl group, H atom and one other group (side chain) attached to carbon atom. Only the side group various among different amino acids. So an amino acid is defined by its side group. Ends may be charged or neutral depending on pH of solution.



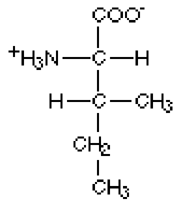
Amino acids with hydrophobic side groups



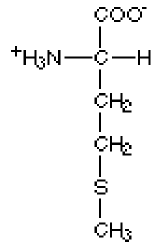
Valine
(val)



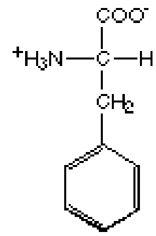
Leucine
(leu)



Isoleucine
(ile)

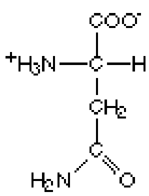


Methionine
(met)

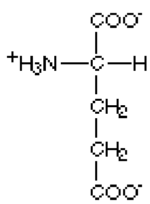


Phenylalanine
(phe)

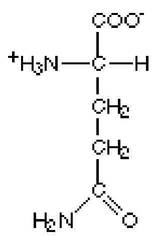
Amino acids with hydrophilic side groups



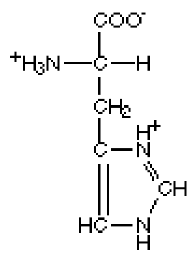
Asparagine
(asn)



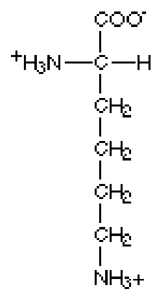
Glutamic acid
(glu)



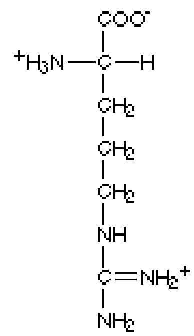
Glutamine
(gln)



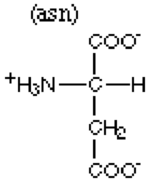
Histidine
(his)



Lysine
(lys)

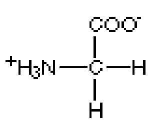


Arginine
(arg)

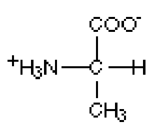


Aspartic acid
(asp)

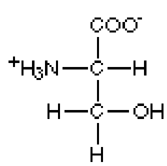
Amino acids that are in between



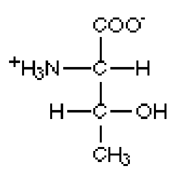
Glycine
(gly)



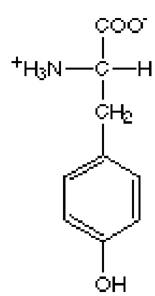
Alanine
(ala)



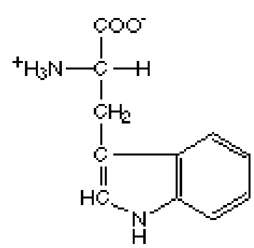
Serine
(ser)



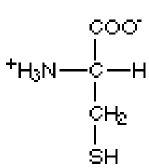
Threonine
(thr)



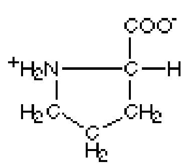
Tyrosine
(tyr)



Tryptophan
(trp)



Cysteine
(cys)

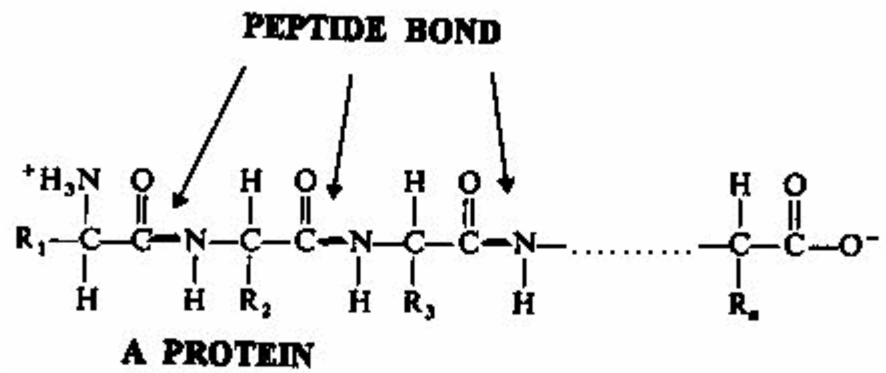


Proline
(pro)

http://images.google.com/imgres?imgurl=http://web.mit.edu/esgbio/www/lm/proteins/aa/aminoacids.gif&imgrefurl=http://web.mit.edu/esgbio/www/lm/proteins/aa/aminoacids.html&h=705&w=535&sz=9&tbnid=zTnpwxCB1b_ixM:&tbnh=140&tbnw=106&hl=en&start=1&prev=/images%3Fq%3Damino%2Bacids%26svnum%3D10%26hl%3Den%26lr%3D%26ie%3DUTF-8%26oe%3DISO-8859-1%26sa%3DG

Polypeptides

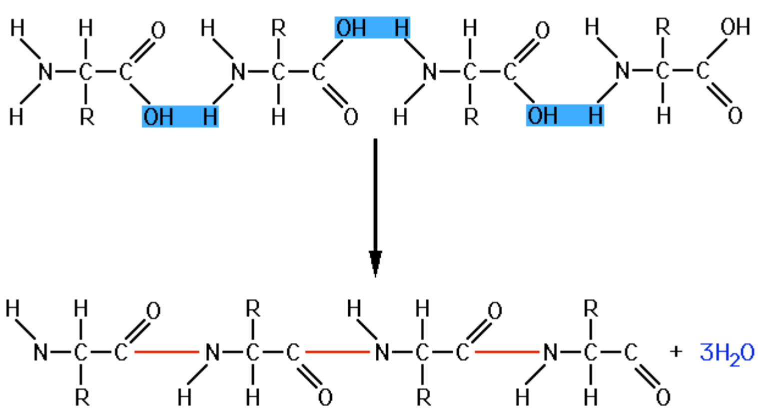
Several to many amino acids are joined together in a chain is called a polypeptide. Amino acids are held together by a peptide linkage.



http://www.benbest.com/lifeext/aging.html

R may be –H, $-CH_3$, - CH_2-benzene etc.

A peptide linkage is formed when carboxylic group and amine come together lose a water molecule and form an amide group –C(=O)–N(–H)– as shown below.



http://www.agen.ufl.edu/~chyn/age2062/lect/lect_02/lect_02.htm

3-Dimensional Structure

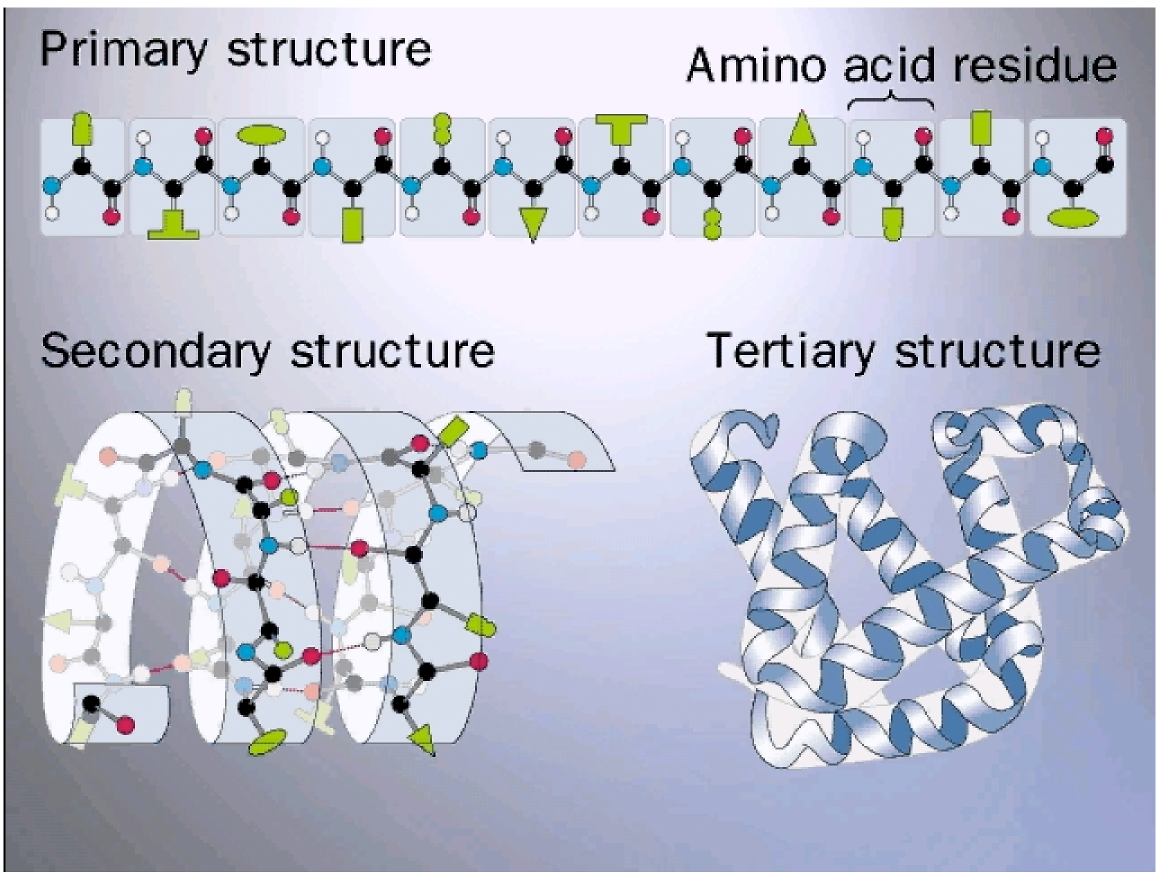
Proteins have complex three-dimensional structure.

Primary structure – order of amino acids in a long chain

Secondary structure – (coiled or flat) spatial arrangement due to hydrogen bonding can give rise to alpha helix or beta sheets)

For more information see:
http://academic.brooklyn.cuny.edu/biology/bio4fv/page/alpha_h.htm

Tertiary structure – arrangement of R groups gives rise to a still more complicated three dimensional structure. The different R groups are attracted by hydrogen bonding, van der Waals forces, ionic attaction, dipole interactions, disulfide S-S bonds that form, etc.)



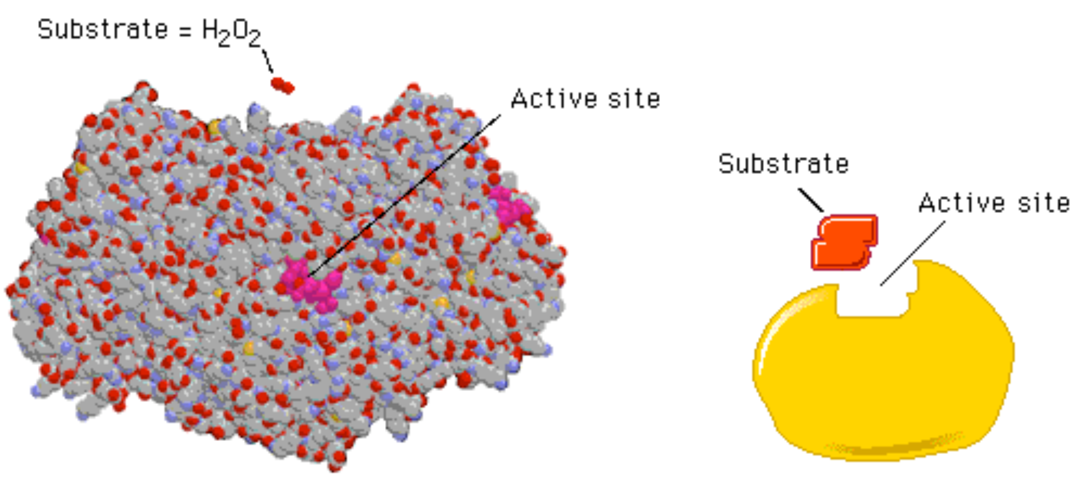
http://www.columbia.edu/cu/biology/courses/c2005/images/3levelpro.4.p.jpg

Enzymes

Reactions that take place in cells often involve enzymes which speed up chemical reactions (often by factors of a million or more) by lowering the energy barrier that must be overcome to go from reactants to products.

For example many cells contain an enzyme called catalase (or hydrogen peroxidase) that speeds up a reaction that converts hydrogen peroxide to water and oxygen. If you cut a potato and drop a slice in a dilute solution of hydrogen peroxide, you will immediately see bubbles begin to form on the surface of the potato. These bubbles are O_2 being formed from H_2O_2 in the reaction $2H_2O_2 \rightarrow 2H_2O + O_2(g)$

Proteins fold into complex three-dimensional shapes to form an opening (active site) where the reactant molecule or molecules fit and the protein (called an enzyme) helps weaken some bonds to break more easily and form new bonds leading to the product(s) which then diffuse out of active site. The reactant molecule(s) is called the substrate. The enzyme binds to the substrate.



Molecular model of catalase

Schematic model of an enzyme

http://www.phschool.com/science/biology_place/labbench/lab2/images/enzyme.gif

Coenzymes help enzymes function. many vitamins are used by the body to make coenzymes.

Since cells require many many different chemical reactions to occur the proteins, that form enzymes can be thought of as the “biological machinery” of the cell. Sometime metal atoms are incorporated into enzyme structures.

For much more detail about the catalase enzyme (if interested) see:
http://www.callutheran.edu/Academic_Programs/Departments/BioDev/omm/catalase/cat1.htm

4) Nucleic Acids

Introduction

If proteins are required for the reactions of life to occur and the protein three-dimensional structure is determined by a linear sequence of amino acids, then there has to be a means to make proteins and have information about the order of amino acids for every protein in our cells.

These instructions are coded by the molecule DNA found in the cell nucleus. This hereditary information has to

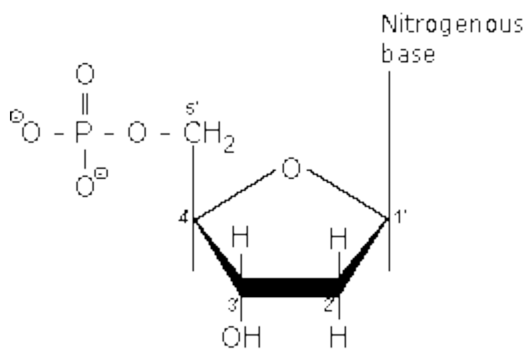
a) copy itself and be passed on to later generations of cells
b) have a means to tell how to make proteins

In humans 23 pairs (46 total) of chromosomes are made of DNA molecules that code for about 30,000 different protein amino acid sequences. This full human genetic information is found in the nucleus of almost every cell in your body.

At time of conception 23 male chromosomes in sperm and 23 female chromosomes in egg cell are combined to make "genetic directions" in 46 chromosomes for a new human. These directions determine if you hair will be curly or straight or what color and if you are born with any genetically inherited diseases such as sickle-cell anemia.

Code system that dictates the order in which amno acids are linked together is provided by molecules of Deoxyribonucleic acid (DNA)

Nucleotide



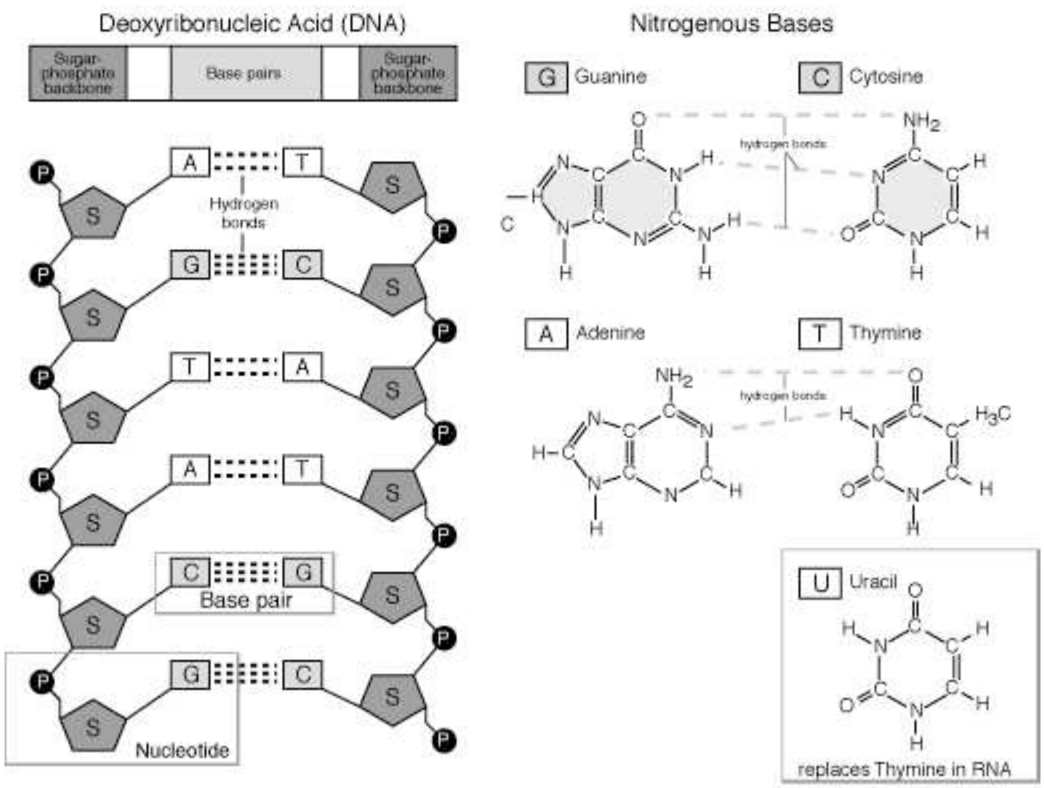
http://www.uq.edu.au/vdu/DNAStructure.htm

As shown above nucleotides consist of

1. phosphate group
2. sugar molecule deoxyribose in DNA and ribose in RNA
3. nitrogen containing base

DNA and RNA

Two polynucleotide chains wound around each other in a double helix form DNA



http://www.accessexcellence.org/RC/VL/GG/basePair2.html

Nitrogen bases pair up based on number of hydrogen bonds

Adenine A	2 H bonds
Thymine T	2 H bonds
Guanine G	3 H bonds
Cytosine C	3 H bonds

A and T G and C always pair up on opposite strains of DNA

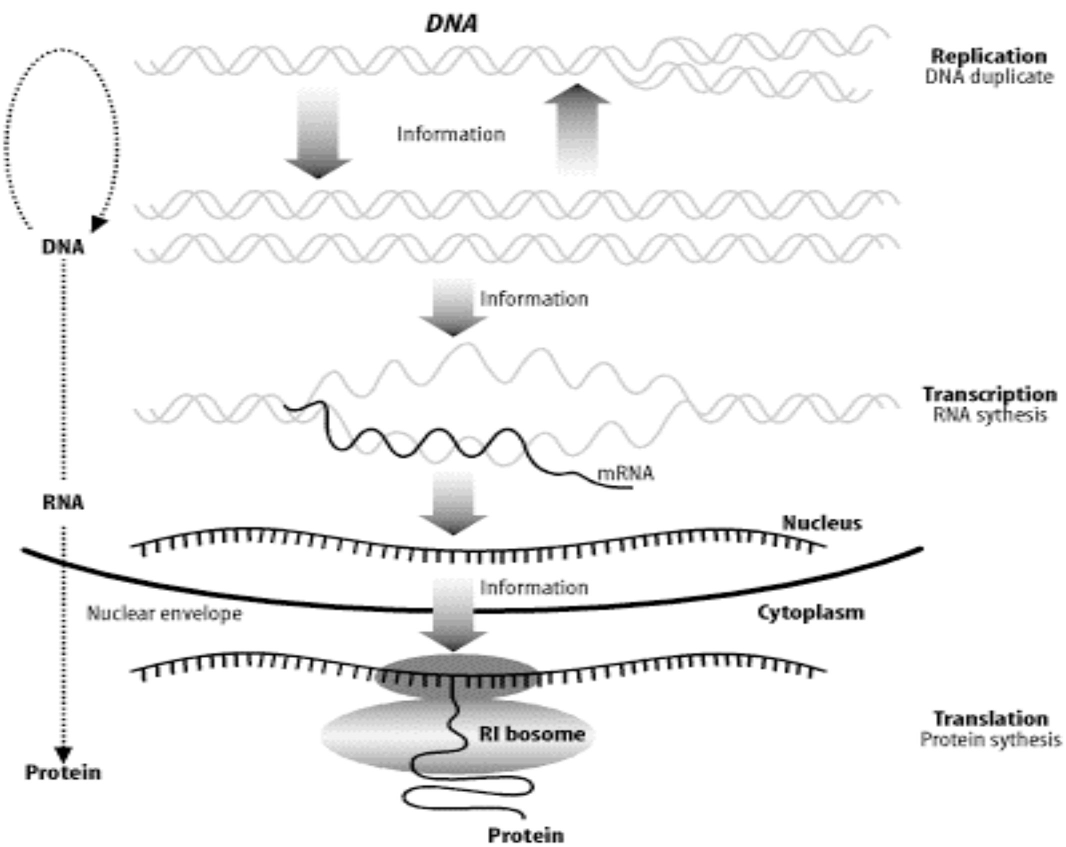
Actual synthesis of proteins also involves ribonucleic acid (RNA)
RNA (ribonucleic acid) uracil replaces thymine in RNA
Uracil U 2 H bonds

It takes 3 nitrogen bases to code for 1 specific amino acid
There are 64 possibilities (4 *4 *4 = 64) so there are sometimes more than one possible code for a specific amino acid. Code is enough to code for 20 different amino acids

<u>How to go from DNA to RNA to protein</u>

Information has to

a) copy itself and be passed on to later generations of cells
   Replication (duplicate DNA molecules made)
b) have a means to tell how to make proteins
   Transcription (copy genetic info from DNA to mRNA, mRNA leaves nucleus)
   Translation (Ribsome attaches to and moves along mRNA to facilitate linking of exact sequence of amino acids to make a unique protein – tRNA brings amino acids to lengthening protein chain)



http://safari.oreilly.com/images/0596002998/figs/blst_0201.gif

Summary

(below from website http://www.biologycorner.com/bio1/DNA.html)

DNA - DEOXYRIBONUCLEIC ACID

* blueprint of life (has the instructions for making an organism)
* established by James Watson and Francis Crick
* codes for your genes
* shape of a double helix
* made of repeating subunits called nucleotides

Gene - a segment of DNA that codes for a protein, which in turn codes for a trait (skin tone, eye color..etc), a gene is a stretch of DNA.

Nucleotide - consists of a sugar, phosphate and a base

Nucleotides (also called Bases)

Adenine, Thymine, , Guanine, Cytosine or A, T, G, C

Nucleotides pair in a specific way - called the Base-Pair Rule

Adenine pairs to Thymine

Guainine pairs to Cytosine

Memory helper - think "**A** **T**rainer **G**reat **C**ats"

How the code works

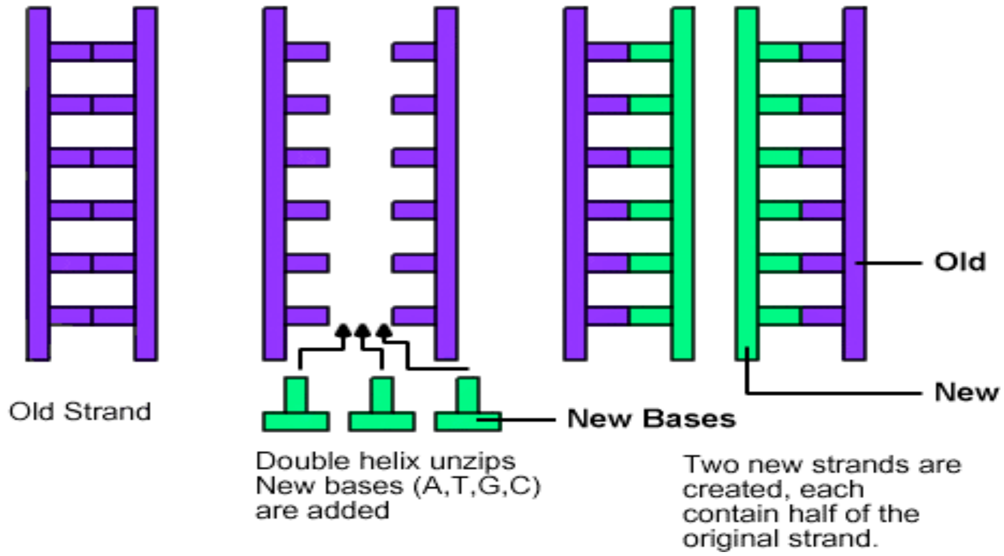
For instance, a stretch of DNA could be AATGACCAT - which would code for a different gene than a stretch that read: GGGCCATAG.

Those 4 bases have endless combinations just like the letters of the alphabet can combine to make different words.

DNA REPLICATION

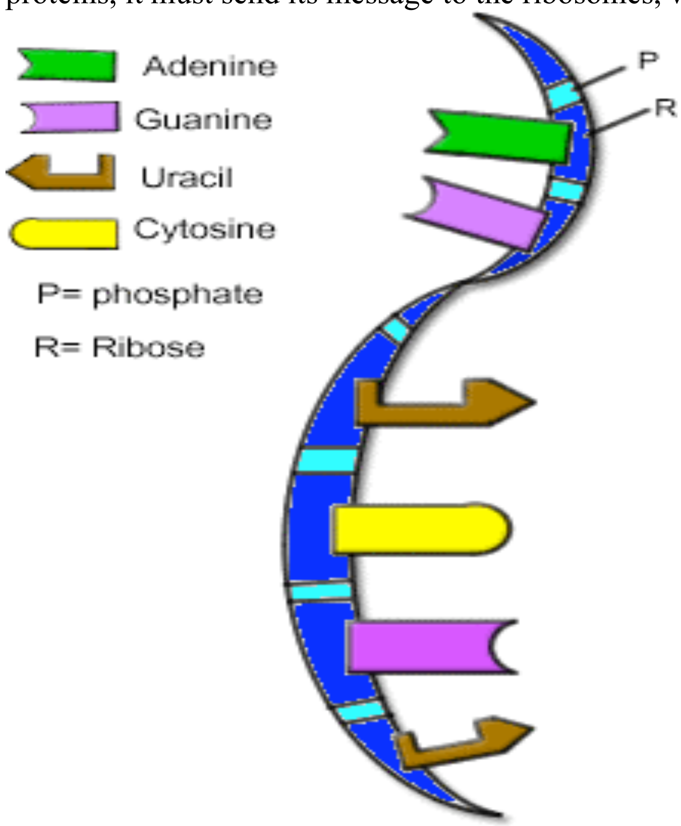
Replication is the process where DNA makes a copy of itself. Cells divide for an organism to grow or reproduce, every new cell needs a copy of the DNA or instructions to know how to be a cell. DNA replicates right before a cell divides.

DNA replication is **semi-conservative**. That means that when it makes a copy, one half of the old strand is always kept in the new strand. This helps reduce the number of copy errors.



RNA

DNA remains in the nucleus, but in order for it to get its instructions translated into proteins, it must send its message to the ribosomes, where proteins are made.



The chemical used to carry this message is **Messenger RNA (mRNA)**

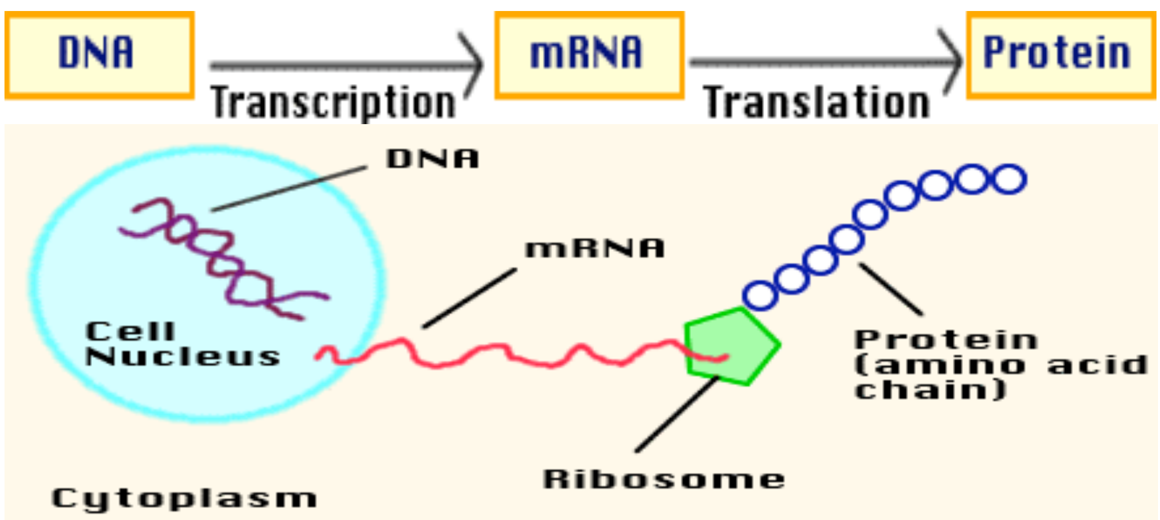
RNA = ribonucleic acid. RNA is similar to DNA except:

1. has one strand instead of two strands.
2. has uracil instead of thymine
3. has ribose instead of deoxyribose sugar

mRNA has the job of taking the message from the DNA to the nucleus to the ribosomes.

Transcription - RNA is made from DNA

Translation - Proteins are made from the message on the RNA



http://www.biologycorner.com/bio1/DNA.html

Cellular processes and definitions

Cell membrane:
Semipermeable fatty membrane that functions to regulate substances going in and out of the cell. Involved in recognition of structure through chemical reactions

Cytoplasm:
Fluid that the cell membrane encases

Organelles:
Structures within the cytoplasm with each having a specialized function such as ribosome or mitochondria

Nucleus:
Center of the cell
Houses hereditary information (genetic material)
Determines cell type and structure
Regulates cell's activities

Chromosomes: genetic material is packaged into different collections of DNA within nucleus. For example, humans have 46 different chromosomes.

Deoxyribonucleic acid (DNA):
Chemical form of genetic material
Nucleic acid that forms a long, double helix
Made up of sugar, phosphate, and nitrogen base along a long chain

Nucleotide:
One sugar joined to a nitrogen base and phosphate
Basic unit that makes up DNA

Nitrogenous Bases:
Adenine (A), Thymine (T), Guanine (G), Cytosine (C)
and Uracil (U) in place of Thymine in RNA

Base Pairing:
in DNA
A-T, G-C complementary pairs
in RNA
A-U, G-C complementary pairs

DNA in one human cell contains billions of base pairs
DNA folds to form a chromosome
The sequence of nucleotides that specifies a particular function is a gene

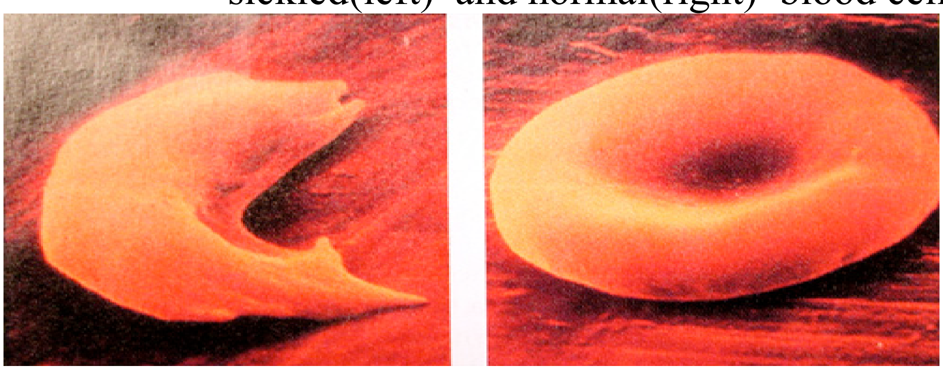
A DNA molecule can unzip down the double helix
Each unzipped DNA will produce a complementary copy (called Duplication)

Proteins:
A sequence of amino acids composes proteins
Three nucleotides form a codon to specify an amino acid
Protein can contain hundred to thousands of amino acids

Genetic Disease
If one base pair out of billions is wrong in human DNA could cause the wrong amino acid to be inserted in protein and could be enough to cause to malfunction. In sickle cell anemia disease just one incorrect amino acid in each hemoglobin molecule made causes it to have a tendency to become misshaped (sickled instead of round) and will not pass easily through capillaries and cause painful condition due to lack of oxygen in come cells.

For more info see: www.nhlbi.nih.gov/.../ Sca/SCA_WhatIs.html

sickled(left) and normal(right) blood cell



http://carnegieinstitution.org/first_light_case/horn/lessons/images/red%20blood%20cells.JPG

A small portion of a DNA molecule is shown below. A beautiful molecule in wondrous universe in which **EVERYTHING IS MADE OF ATOMS** even you.

http://sbchem.sunysb.edu/msl/dna.gif