

Lecture 2: Chemistry of Cells

Aims:

Part A

- What is an atom, element, molecule?
 - the Periodic Table
- What chemical bonds hold atoms together?
- What is an acid, a base?

Part B

- What molecules make up a cell?
- What are the energy sources of a cell?
 - sugars, fatty acids
- What are the subunits of proteins?
- What are the subunits of DNA and RNA?
- What is a macromolecule?

Alberts et al, Chapter 2, 3 & 4

Some Definitions

Matter is a combination of elements.

Elements - substances that can not be broken down or converted into any other chemical form; composed of a single type of atom. E.g. hydrogen, carbon

Atom - the smallest particle of an element that still retains its distinctive chemical properties.

Other than pure elements, the characteristics of substances depend on the way their atoms are linked together in groups to form molecules.

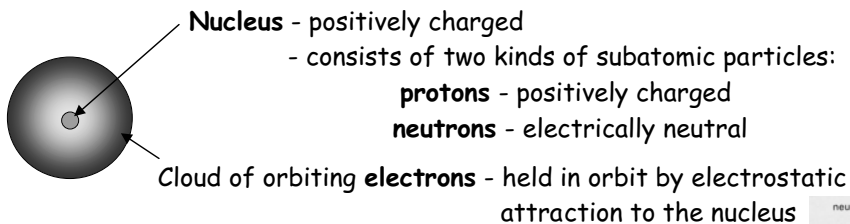
Molecule - group of atoms held together by covalent bonds.

Living cells are made up of substances.

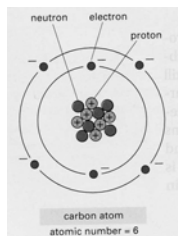
In order to understand how living organisms are built from inanimate matter, it's important to know how the chemical bonds that hold atoms together in molecules are formed.

Organic - compound made of carbon, includes all molecules from which living cells are made, apart from water

The Atom



Atomic number = number of protons in the atomic nucleus
E.g. Hydrogen (H) - nucleus composed of a single proton,
so atomic no. = 1; H is the lightest element
Carbon (C) has 6 protons in nucleus so atomic no. = 6



- Electric charge carried by each proton is equal & opposite to that of an electron.
An atom as a whole is electrically neutral (no. of electrons = no. of protons).
- The atomic number is the same for all atoms of a given element.
This determines the chemical behavior of the element.

Thus, atomic number is the number of protons in the nucleus of an atom of an element.

The Atom

Neutrons - uncharged subatomic particles; essentially same mass as protons
- contribute to the structural stability of the nucleus
..... if too many/few, nucleus may disintegrate by radioactive decay
- do not alter the chemical properties of the atom

Thus an element can exist in several physically distinguishable but chemically identical forms called **isotopes**.

Each **isotope** has a **different number of neutrons** but **same number of protons**.....
..... multiple isotopes (stable & unstable) occur naturally.

e.g. C exists as carbon 12 (^{12}C) (6 protons & 6 neutrons)
unstable radioactive isotope ^{14}C has 6 protons + 8 neutrons
- basis of technique of ^{14}C dating of organic material in archaeology

Radioactivity - the spontaneous transformation of an unstable atom, resulting in emission of radiation; decay or disintegration of an atom.

Parts of an atom

- **Protons** give an element its identity
 - Every time you add a proton, you create a new element
- **Electrons** give an element its personality
 - What it will interact with
- **Neutrons** determine an element's stability
 - Radioactive isotopes
 - H = hydrogen
 - H + 1 neutron = deuterium
 - H + 2 neutrons = tritium (radioactive)

The Atom: Weight

Atomic weight of an atom is the mass of an atom of an isotope expressed in daltons

Molecular weight is the mass of a molecule expressed in daltons

This mass is relative to that of a H atom.

It's essentially equal to no. of protons + neutrons that the atom or molecule contains

Electrons are lighter and contribute nil to the total mass.

Dalton is the unit of molecular mass

- It's approximately equal to the mass of a hydrogen atom
- It's one-twelfth (1/12) the mass of an atom of ^{12}C (1.66×10^{-24} g)

Atom size < 1 nm e.g. C atom is ~ 0.2 nm in diameter

One proton or neutron weighs ~ $1/(6 \times 10^{23})$ gram

-> 1 g of H contains 6×10^{23} atoms

Why "dalton"?after the Chemist John Dalton of course!

Atomic Number vs Atomic Weight

Atomic number = The number of protons in an atom.

Atomic weight = the mass of the protons, neutrons and electrons in an atom.

Protons and neutrons weigh about the same
Electrons weigh almost nothing

Thus, atomic weight $\approx$
number of protons + number of neutrons

Atomic Number vs Atomic Weight

Element	Atomic Number (protons)	Atomic Weight (protons + neutrons)
H	1	1
He	2	4
C	6	12
N	7	14
O	8	16
Na	11	23 (12 neutrons)

The Periodic Table

Mendeleev - 1861, Noticed elements occur in a periodic fashion

Atomic number

Symbol

Atomic weight

Metal

Semimetal

Nonmetal

(c)1998
Kremer Paul

115 discovered, some predicted but not yet discovered

Molecular Weight

Molecular weight is the sum total of all the atoms in a molecule.
The units are "grams/mole" or "daltons"

Molecule	Calculation using atomic weight	Molecular Weight
H ₂	2 * 1 =	2
H ₂ O	2*1 + 1*16 =	18
C ₂ H ₅ OH	2*12+6*1+16=	46
NaCl	1*23 + 1*35=	58

Avogadro's Number - counting by numbers of molecules

Avogadro's number

- A factor describing the relationship between quantities in grams measured in terms of individual atoms or molecules
- Value of 6.02×10^{23} atoms/mole
- It's the **number of daltons (molecular mass units) in 1 gram**

It's equal to the number of molecules in M grams of a substance whose molecular weight is M daltons.

If a substance has a **molecular weight** of M,
then 6×10^{23} molecules of it will have a mass of M grams
-> this quantity is called one **mole** of the substance

A **mole** is M grams of a substance, where M is its relative molecular mass (MW)

One Mole will contain 6.02×10^{23} molecules of the substance.

e.g. 1 mole of Carbon weighs 12 g

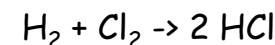
Molar (M) solutions have a concentration of 1 mole of the substance in 1 liter of solution
e.g. 1 M of carbon has 12 g/l units! mM -> mg/l of carbon

Why Use Moles ?

You work with number of molecules

H₂ instead of
H² or 2H

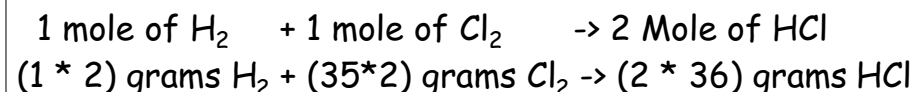
How much would you combine?



Not the same number of molecules



This has one molecule of H for each molecule of Cl



Calculating Moles

n = number of moles (mol)

$n = cv$ c =concentration, v =volume

$n = m/Mw$ M = Mass (g) MW = molecular weight

Example

.25 liter of a .5 M solution contains ? Moles
 $(.25 \text{ L} * .5 \text{ M/L}) = 0.125 \text{ Moles}$

9 grams of water is how many moles?

$9 \text{ g} / 18 \text{ g/M} = .5 \text{ Moles}$

Calculating with Moles

I need 5×10^6 molecules of salt

How many grams is that?

$n = m/Mw$

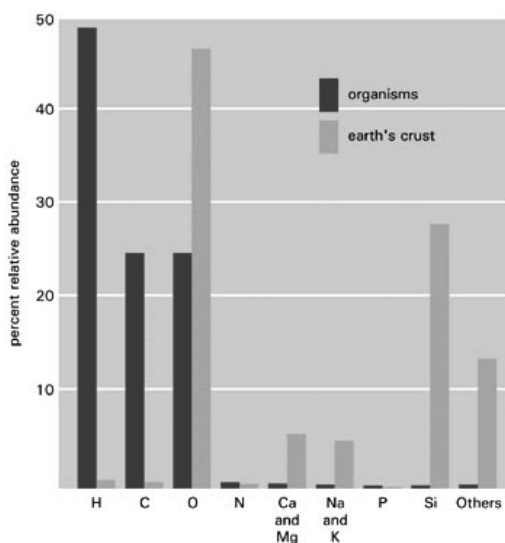
1 mole = 6×10^{23} , how many moles is 5×10^6 ?

$1/6 \times 10^{23} = X/5 \times 10^6$, solve for X. $X = 8.3 \times 10^{-18}$

$8.3 \times 10^{-18} = m/58$, solve for m. $\text{Mass} = 4.8 \times 10^{-16} \text{ g}$

How would you weigh that out?

The Elements



The abundance of some chemical elements in the nonliving world (earth's crust) compared to their abundance in the tissues of an animal.

Abundance is expressed as a % of the total number of atoms present in the sample e.g. ~50% of the atoms in a living organism are H atoms.

Survey excludes mineralized tissues e.g. bone & teeth because they contain large amounts of inorganic salts of calcium & phosphorus.

The relative abundance of elements is similar in all living organisms.

Electron arrangement

The outermost electrons determine how atoms interact

Electron shell: the number of electrons that can be in an orbit (state of movement)

Electron Shell (energy level)		Maximum no. of electrons
innermost shell (closest to nucleus) tightly bound		2
2nd shell	electrons less tightly bound	8
3rd	even less bound	8
4th		18
5th		18

- Atom most stable: electrons fill the shells in order; thus chemically unreactive e.g. He with 2 electrons; H only 1 electron thus highly reactive
- Atoms with incomplete outer electron shells are able to react with one another to form molecules e.g. C : 2 + 4, N : 2 + 5, Na : 2 + 8 + 1

They interact with other atoms to gain or lose enough electrons to achieve a **completed** outermost shell. Thus generating chemical bonds.

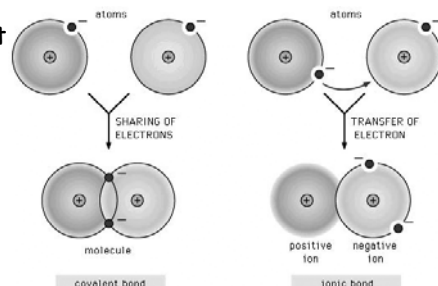
Chemical Bonds

Ionic Bond: formed between two atoms when electrons are donated by one atom to another

Covalent Bond: formed when two atoms share a pair of electrons

Polar covalent Bond: when the pair of electrons is shared unequally resulting in partial transfer between the atoms e.g. at times with H

Valence: the number of electrons an atom must acquire or lose (by sharing or transfer) to attain a filled outer shell



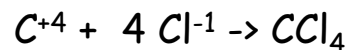
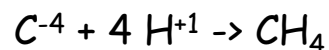
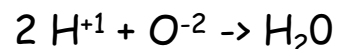
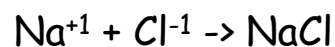
- Crucial role of outer electron shell in determining the chemical properties of an element is evident in their ordering (taking account their atomic number) in the periodic table
e.g. metals have incomplete outer shells but inert gases have full outer shells

A happy atom has a filled outer shell

valence electrons - the outermost and most reactive electrons

Element	Outer Shell	Max outer electrons	Takes electrons	Gives electrons
H	1	2	1	1
He	2	2	0	0
C	4	8	4	4
N	5	8	3	0
O	6	8	2	0
Cl	7	8	1	0
Na	1	8	0	1
Mg	2	8	0	2

Atoms that have e^- , give to those who don't



Ions

	sodium (Na)	+	chlorine (Cl)	=	sodium chloride (NaCl)
	solid		gas		salt crystals
atomic no.	11	(2+8+1)	17	(2+8+7)	

Ion: atom or molecule carrying an electrical charge, either positive or negative

E.g. electron jumps from Na to Cl $\rightarrow$ both atoms become electrically charged ions

Na $\rightarrow$ one less electron than protons in nucleus $\rightarrow$ single +ve charge: Na^+

Cl gained electron thus Cl^-

Cations: positive ions

Anions: negative ions

Opposite charges $\rightarrow$ ions are attracted to each other e.g. Na^+ & Cl^-

thus held together by ionic bond (attractive force holding together ions of opposite charge)

E.g Salts: substances held together solely by ionic bonds

Favorable interaction between water molecules & ions $\rightarrow$ many salts are soluble

i.e. dissociating into individual ions each surrounded by a group of water molecules

Chemical Bonds

Bond Type	Length (nm)
Covalent	0.15
Noncovalent: Ionic	0.25
Hydrogen	0.30
van der Waals	0.35

- **Bond length:** the distance between atoms linked in a specific chemical bond
- **Bond strength:** the energy required to break a bond between two atoms expressed in kilocalories per mole (kcal/mol)

[Bond energy the strength of the chemical linkage between two atoms, measured by the energy in kilocalories needed to break it]

Kcal = the amount of energy to raise temp of 1 liter of water by 1°C
Kjoule = 0.239 kcal

Exact values of bond strength and length depends on the atoms involved.

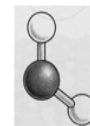
- **Covalent bonds are stronger than noncovalent bonds**

Covalent Bonds

- **Covalent bonds** form by sharing of electrons as required to fill the outermost electron shell
- The making and breaking of covalent bonds in living cells require highly specific catalysts called enzymes
- Formation of covalent bonds is dependent on the number of electrons in the outermost shell (up to 8) of the atoms (stability)
-> can form covalent bonds with as many other atoms as necessary to reach this no.
e.g. oxygen has 6 outer electrons can form 2 covalent bonds



-O-
oxygen



H₂O
water



|
-C-
|
carbon

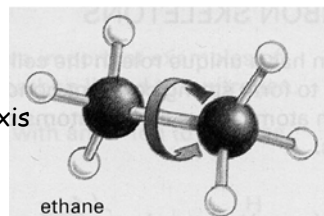
- The spatial arrangement of the covalent bonds that can be formed by oxygen.
- Molecules formed from these atoms have a precise 3-D structure.

Covalent Bonds

Single bonds: sharing of two electrons, one from each atom

Double bond: sharing of > 1 pair of electrons

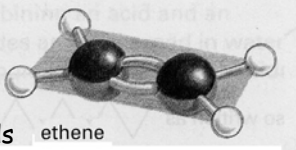
Single bond - allows rotation of one part of molecule relative to the other around the bond axis



ethane

Double bonds (between two atoms)

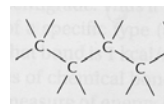
- are shorter and stronger than single bonds
- have effect on 3-D geometry of molecule (more rigid; no rotation)



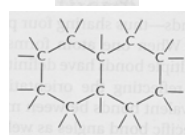
ethene

Chemical Bonds

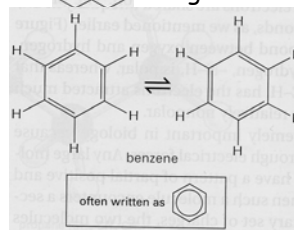
Carbon skeleton



chains



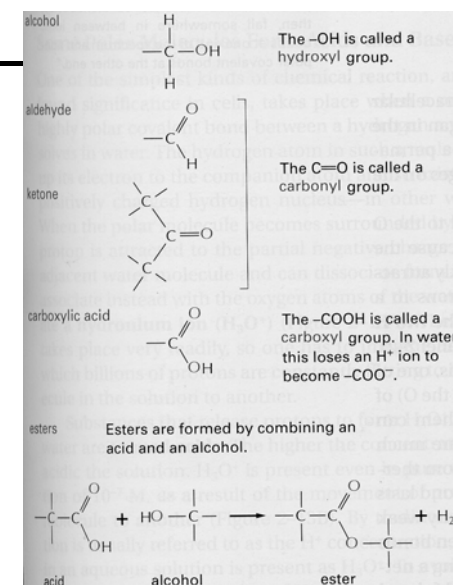
rings



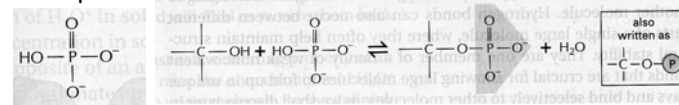
benzene

often written as

Alternating double bonds



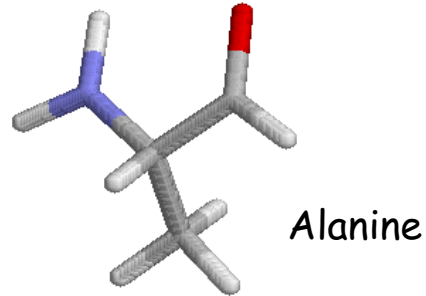
Phosphate



Molecules are not flat!

Rasmol Demo.....

Rasmol - 3D molecular visualization program
Runs on Mac, PC, UNIX
Free



Available from

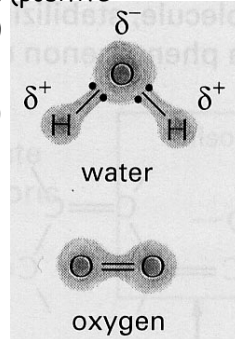
<http://www.umass.edu/microbio/rasmol/>

Covalent Bonds - Polarity

Polar structure: positive charge concentrated toward one end (positive pole) and the negative charge toward the other (negative pole)

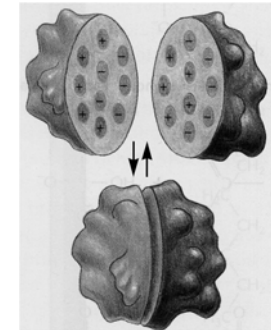
(δ^+ partial positive charge)

Electrons are not shared evenly between atoms.
The electrons are attracted more to the atom that has more protons (more positive)



Polar covalent bonds: important in cells

- two surfaces with complimentary charges will specifically be attracted to each other and bind

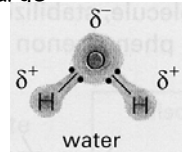


The Properties of Water

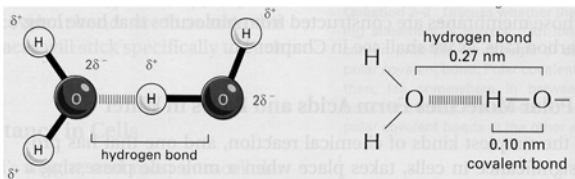
Water molecule - 2 H atoms linked via covalent bonds to O atom.

The 2 bonds are highly polar because O is strongly attractive for electrons but H is only weakly attractive -> H positive and O negative charge

Positive region (H atoms) of one water molecule close to negative region (O) of another molecule
-> the electrical attraction between them results in a weak bond: a hydrogen bond



Hydrogen bonds: weak; can be broken by random thermal motions
BUT network of H bonds between many water molecules
- H₂O liquid at room temp with a high boiling point & high surface tension & not a gas

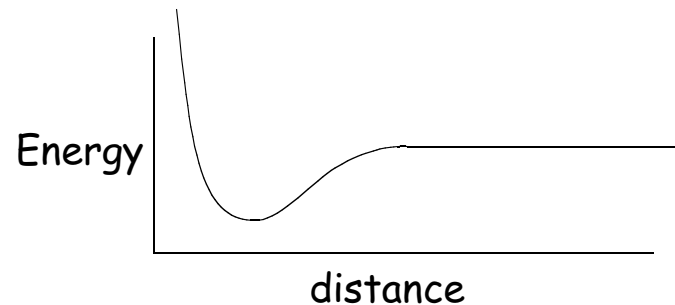


H bond 1/20th
strength of covalent

H bonds: crucial for large molecules to fold & binding to other molecules (later lect)

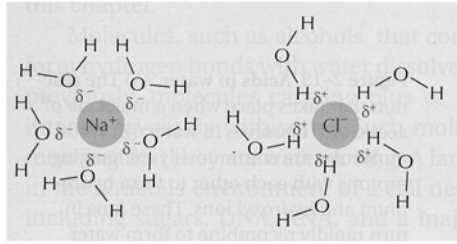
Weak Chemical Bonds

van der Waals force - weak attractive force due to fluctuating electrical charges when atoms are 0.3-0.4nm apart; at a shorter distance strong repulsive forces operate

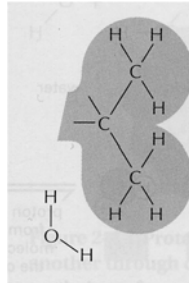


Hydrophilic/Hydrophobic

Hydrophilic molecules: charged (polar) molecules that can form H bonds with water and dissolve easily in water ; water-loving



- many components in aqueous environment of cell e.g. DNA, RNA, sugars, proteins



Hydrophobic molecules: uncharged molecules forming few or no H-bonds with water; water-hating

Hydrocarbons: H + C make stable compounds

H atoms are covalently linked to C atom by a nonpolar bond; H atoms have no net positive charge thus can't form H-bonds with other molecules

Cell membranes - have molecules which have large hydrocarbon tails

Hydrogen bonds are weak but they add up to a powerful force

Molecule	Molecular Weight	H-Bonds	Boiling Point
Water H_2O	18	Yes	$100^{\circ}C$
Methane CH_4	16	No	$-161^{\circ}C$
Benzene C_6H_6	78	No	$80^{\circ}C$

Water is small, but with H-bonds, it's stable at high temps

Acids and Bases

Chemical reaction - molecule with highly polar covalent bond between a H & a second atom dissolves in water

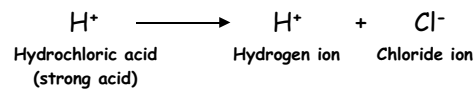
H gives up its electron and exits as a proton (H^+)

H^+ becomes surrounded by H_2O molecules, H is attracted to O atom $\rightarrow H_3O^+$
hydronium ions

Acid: substance that dissociates in water to release H^+ , which associates with H_2O to form H_3O^+

Higher concentration of H_3O^+ the more acidic the solution

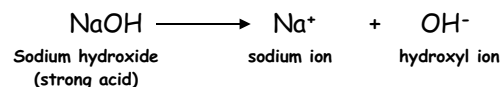
Concentration of H_3O^+ is referred to as the H^+ concentration



Base: the opposite of an acid; it **accepts** a proton in solution

It raises the concentration of hydroxyl ions (OH^-)

alternative name: alkaline



Acids and Bases

The concentration H^+ is expressed as a logarithmic scale called the **pH scale**

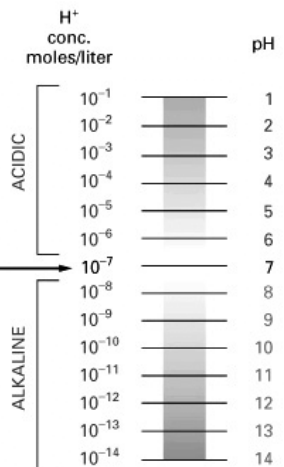
$pH (\log \text{ of } [H^+])$

$$pH = -\log_{10}[H^+]$$

Pure solution of water contains equal concentrations of both ions
Thus it's neither acid nor basic but said to be neutral, pH 7.0

For pure water

$[H^+] = 10^{-7}$ moles/liter



The acidity of a cell must be closely regulated

- molecules that can give up protons will do so more readily if concentration of H_3O^+ in solution is low

Acids and Bases

Current methods of measuring pH:



Chemical

Chemical Change
due to acid/base.
Litmus Paper
pH Paper



Electronic

Current flow in
comparison to a
reference electrode.

Chem of Cell: Part B

Recap from Chem IA:

- **Organic** - compound made of carbon,
includes all molecules from which living cells are made, apart from water
Atom, element, molecules, macromolecules -----> cells -> tissues -> organs.....
- **Atomic number** is the number of protons in the atomic nucleus
- **Atomic weight** of an atom is
the mass of an atom of an isotope expressed in **daltons**
protons + neutrons that the atom or molecule contains.
- Electrons are lighter and contribute nil to the total mass.
- Electron shells
- **Bonds:** types, length and strength
- **Hydrocarbons:** H + C make stable compounds
- Polarity
- **Acids & Bases** -> pH (log of [H⁺])

Molecules in Cells

- Organic molecules contain carbon

- Most common chemical groups
- each with distinct chemical &
physical properties

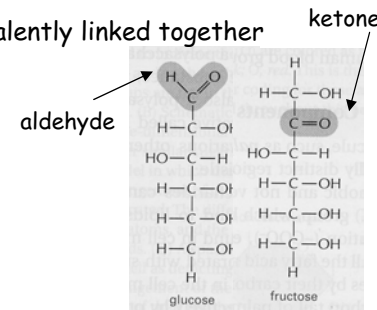
methyl	- CH ₃
hydroxyl	- OH
carboxyl	- COOH
carbonyl	- C=O
phosphate	- PO ₃ ²⁻
amino	- NH ₂

- Cells contain 4 major families of small organic molecules:

sugars -> building blocks for polysaccharides
fatty acids -> fats and lipids
amino acids -> proteins
nucleotides -> nucleic acid

Sugars

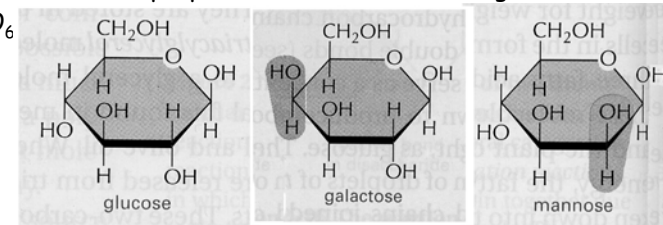
- Energy source for cells
- Subunits of polysaccharides: monosaccharides covalently linked together
- Monosaccharides: simplest sugars
-> general formula (CH₂O)_n, n = 3 to 8
-> therefore called carbohydrates



But formula doesn't fully define the molecule

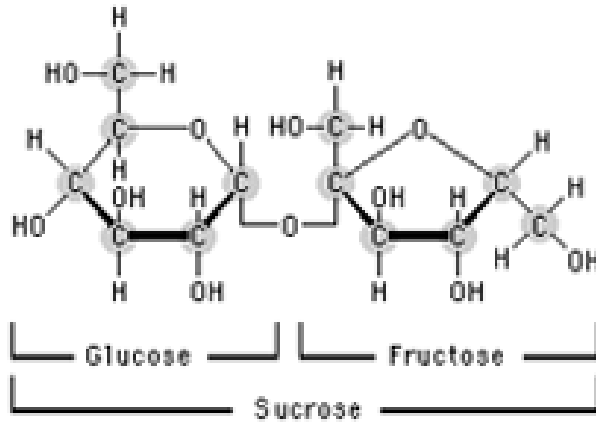
- > same formula but different in arrangement of the groups around C
- > isomers: same chemical formula but different structures
- > minor chemical properties but differ in biological effects

E.g. glucose: C₆H₁₂O₆



Sucrose

Glucose + Fructose



... Sugars

- Bond formation by condensation/hydrolysis between -OH group
- Energy source: glucose (monosac.) broken down to smaller molecules, releasing energy that cells use to do work
- Long term storage of energy by cells:
 - glycogen (polysac. of glucose units) in animals
 - starch in plants
- Used to make mechanical supports
 - e.g. cellulose of plant cell walls is a glucose polysac.
 - chitin: insect exoskeleton & fungal cell wall; polysac. of glucose derivative
- Smaller oligosac.s covalently linked to proteins -> glycoproteins
to lipids -> glycolipids
e.g. found in cell membrane

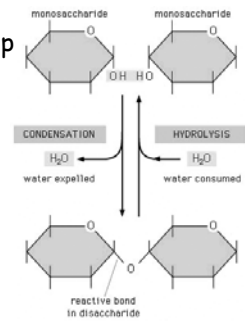
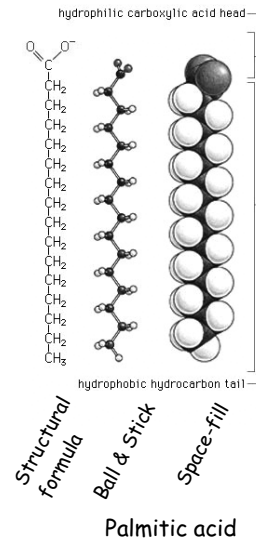


Fig 2.16

Fatty Acids

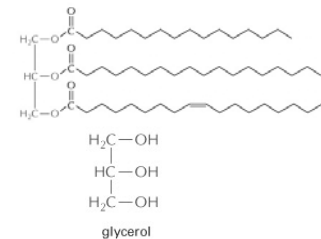
- Building blocks for fats and lipids
- Two distinct regions:
 - hydrocarbon tail + carboxyl group
 - hydrophobic hydrophilic
 - chemically reactive
- Saturated: no double bonds in HC tail (between C-C)
- Unsaturated: double bonds in HC tail e.g. oleic acid
- DBs -> kinks in tail -> interfering with molecule packing
 - saturated (hard) & polyunsat. (soft) margarine
- Fatty acids in cells: differ in length of hydrocarbon tail and number & position of DBs



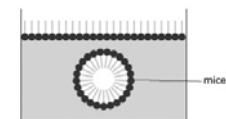
... Fatty Acids

- Stored as energy reserve: triacylglycerol (a lipid)
- broken down to 6x more usable energy than glucose
- > fatty acid chains broken into 2-C units which enter energy yielding reaction pathways (see later)

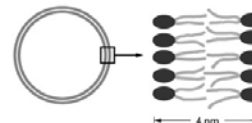
Triacylglycerol: fats found in meat, butter, cream, corn oil, olive oil



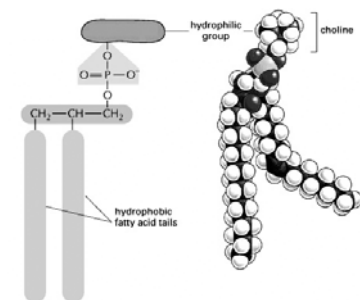
- Lipids: insoluble in water; soluble in fat and organic solvents (benzene)



- Phospholipids: hydrophilic head includes a phosphate prominent hydrophobic and hydrophilic regions
-> amphipathic

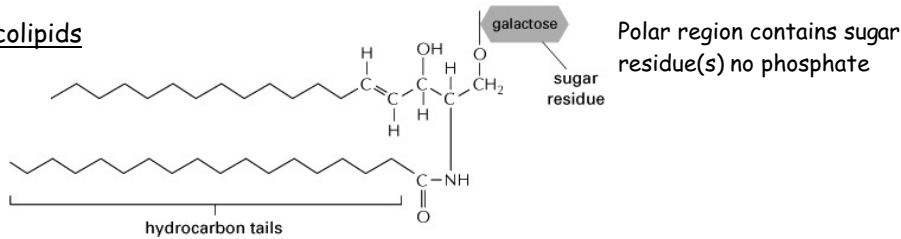


<- membranes - lipid bilayer

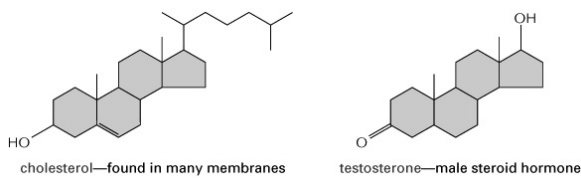


... Fatty Acids

Glycolipids

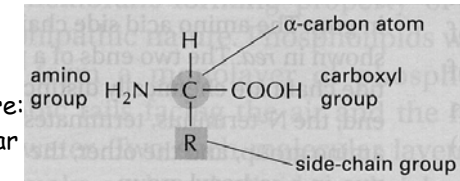


Steroids

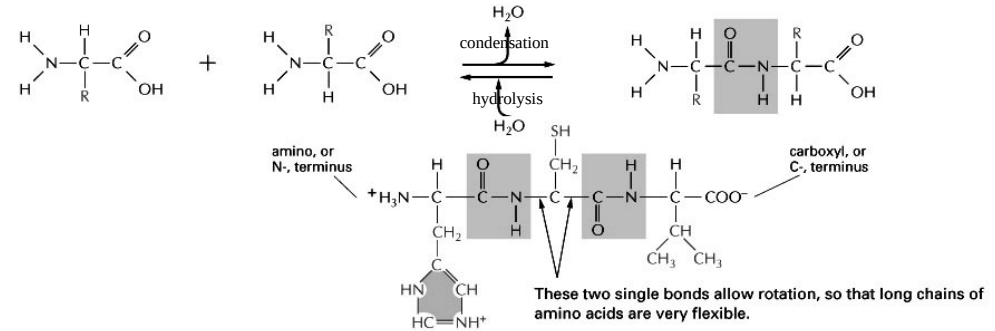


Amino Acids

- Building blocks of proteins
- Contain carboxylic acid group, amino group
- Grouped according to whether side chains are:
acidic, basic, uncharged polar, nonpolar

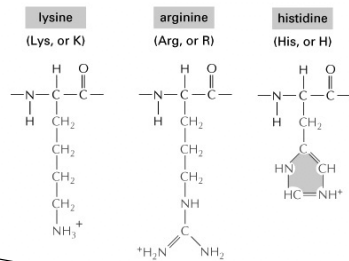


Peptide bond: The four atoms in each *gray box* form a rigid planar unit. There is no rotation around the C-N bond.

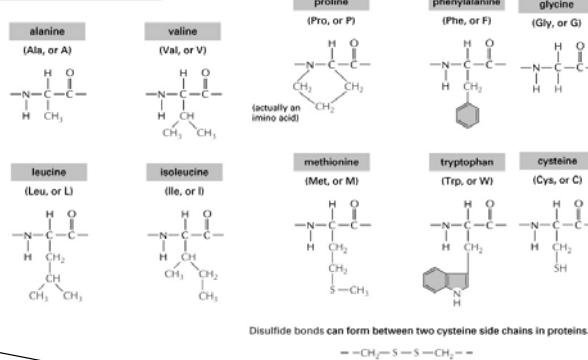


Amino Acids

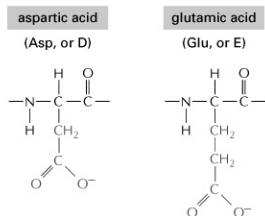
BASIC SIDE CHAINS



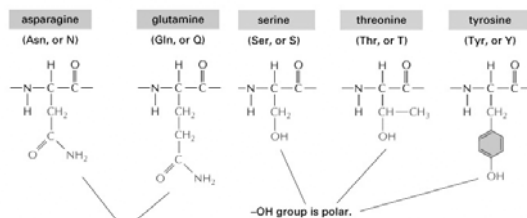
NONPOLAR SIDE CHAINS



ACIDIC SIDE CHAINS



UNCHARGED POLAR SIDE CHAINS



Although the amide N is not charged at neutral pH, it is polar.

Nucleotides

Building blocks for nucleic acid

Made up of nitrogen-containing ring compound linked to a five-carbon sugar which is either ribose or deoxyribose, and it carries one or more phosphate groups

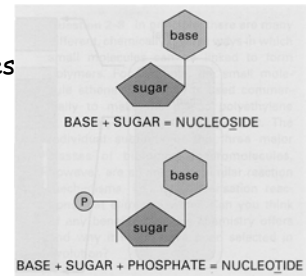
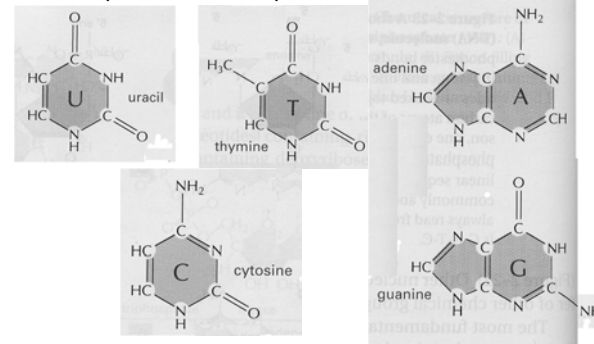
Ribonucleotides: ribose containing nucleotides

Deoxyribonucleotides: deoxyribose containing nucleotides

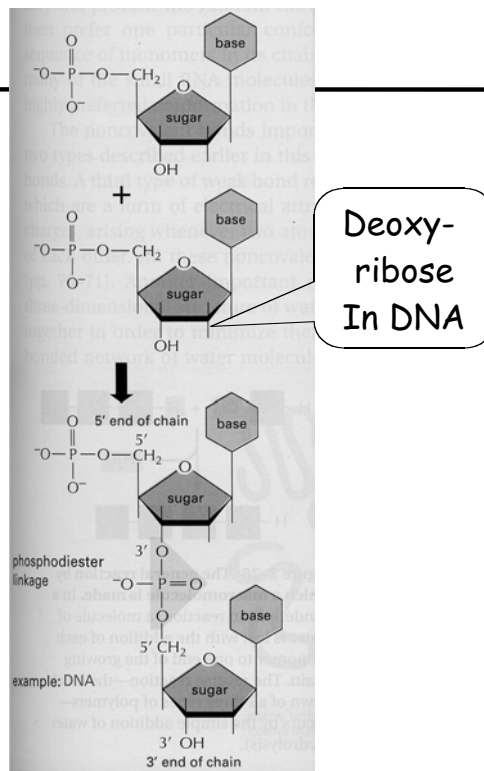
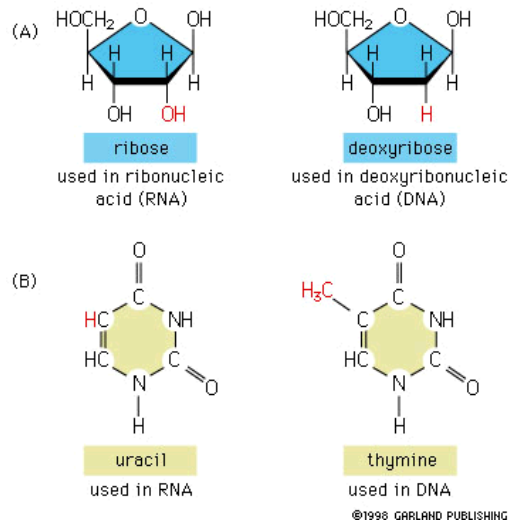
"Bases" :-

Purines: guanine (G), adenine (A)

Pyrimidines: cytosine (C), thymine (T), uracil (U)



Nucleic acid



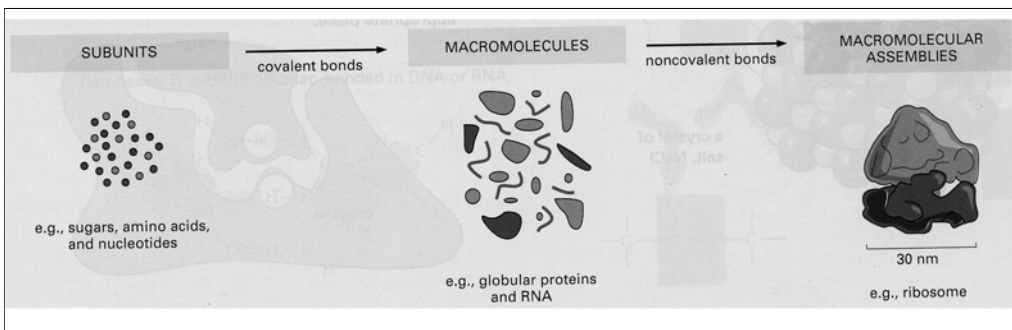
How much DNA do we have?

6×10^9 base pairs (bp)/human cell
Bp are $.34 \times 10^{-9}$ meters(m) apart
So the length of DNA /cell is
 $6 \times 10^9 \times .34 \times 10^{-9} \text{ m} = 2 \text{ meters}$

DNA has a diameter of $2 \times 10^{-9} \text{ m}$
The volume of DNA in a cell = $6.3 \times 10^{-18} \text{ m}^3$
The nucleus of a cell has a diameter of $5 \times 10^{-6} \text{ m}$
The volume of a nucleus is $65.3 \times 10^{-18} \text{ m}^3$
Or 10 times the volume of the DNA

Each cell has 2 m of DNA
Average person has 75 trillion cells 75×10^{12}
Length of DNA in a person = $150 \times 10^{12} \text{ m}$
Distance from earth to sun $150 \times 10^9 \text{ m}$
Each person has enough DNA to go to the sun and back 500 times

Layers of biological complexity



Energy

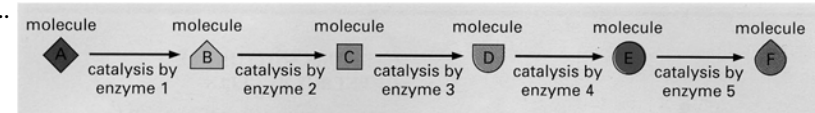
- The general principles by which cells obtain energy from environment and use it to create order
- Cells require a constant input of energy to sustain life

Chemical reactions

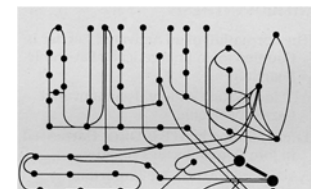
Enzymes: proteins that catalyze reactions; specific substrate
Activated carrier molecules

Linear reaction pathways linked to one another

Simple enzyme catalyzed reaction leading to a metabolic pathway...



Metabolic pathways are interconnected



Biosynthesis

Two streams of chemical reactions in cells:-

Catabolic pathway: breakdown of larger molecules to smaller molecules with the production of useful energy

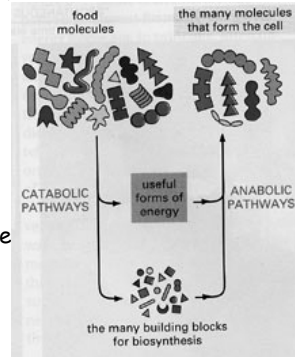
E.g. breakdown of foodstuffs generating energy and some small molecules needed for building blocks

Anabolic (biosynthetic) pathway: biochemical reaction/pathway to make larger molecules from smaller molecules

-> it uses the energy from catabolism to drive synthesis

Catabolic + Anabolic pathways
-> **metabolism** (all chemical reactions)

Major portion of energy stored in chemical bonds of food molecules is dissipated as heat -> more food is needed to derive the energy needed to produce molecules by anabolism



Energy

Living cells grow, multiply, survive, form complex organisms

-> it is not an isolated system: it takes in energy from environment (food, photons from the sun) and uses this energy to generate order via chemical reactions.

Part of the energy that the cell uses is converted into heat -> disorder in cell

Entropy: is the thermodynamic quantity that measures the degree of disorder in a system - higher entropy = more disorder

- Energy is not "consumed", "used-up", it's "converted" into another form of energy
Potential, kinetic, heat
chemical bond, electrical energy, electromagnetic energy

Plants- Photosynthesis: light energy + CO_2 + H_2O -> sugars + O_2 + heat energy

Oxidation/Reduction

Respiration: sugars + O_2 -> H_2O + CO_2

So all plants and animals are powered by chemical energy stored in the chemical bonds of organic molecules (plants: sugars; animal: food)

But organism must extract the energyoxidation

Cells obtain energy by the oxidation of organic molecules

Oxidation: the transfer of electrons from one atom to another (removal)

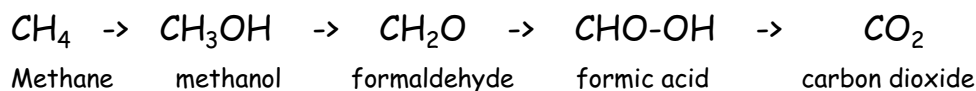
e.g. $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ loss of an electron (Iron gets oxidized)

Reduction: the addition of electrons

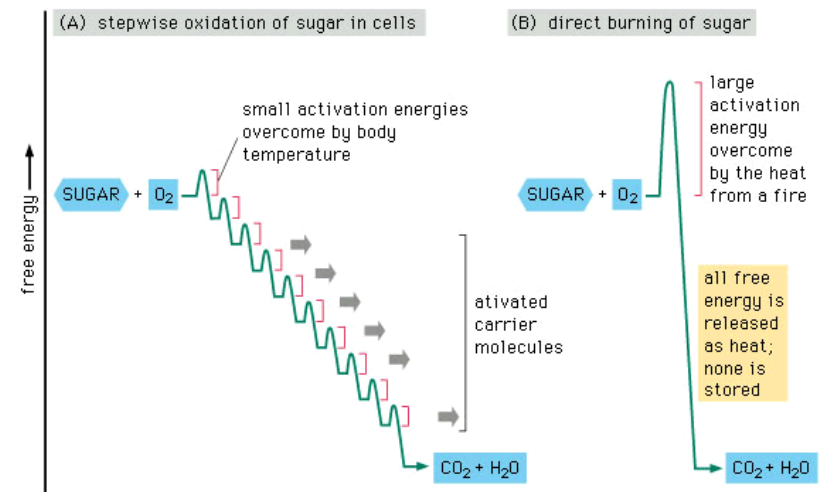
e.g. $\text{Cl} \rightarrow \text{Cl}^-$ gain of an electron (chlorine gets reduced)

e.g. respiration - sugar oxidized to CO_2 -> the O_2 gains electrons to form H_2O

Oxidation of carbon



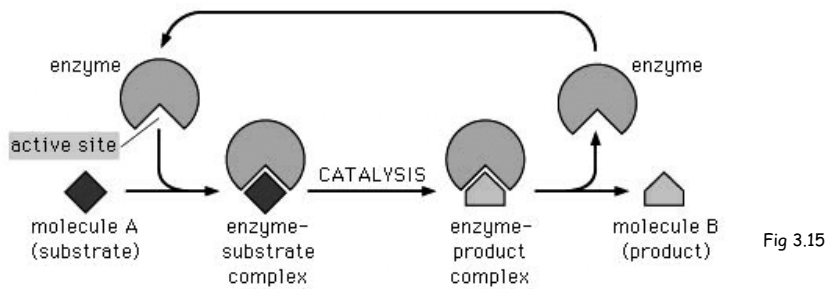
Activation barriers keep everything from happening all at once



Reaction rates.....

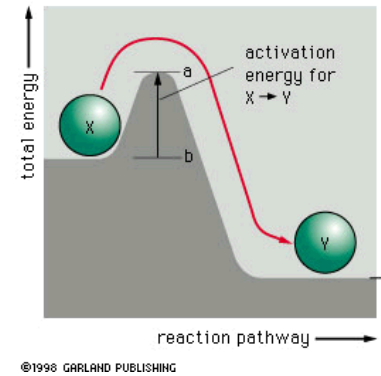
Enzymes: proteins that decrease the amount of energy required to activate a reaction thus increasing the probability of a reaction.
It's a catalyst

Each enzyme binds tightly to its substrate



Enzymes can speed up reactions but can't force energetically unfavorable reactions to occurreaction rates (discussed later lecture)

Lowering Activation Energies

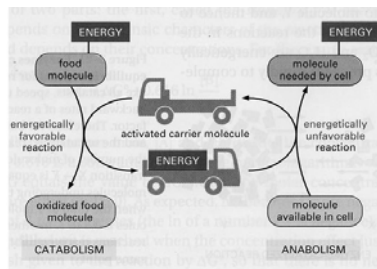


Enzymes work in part by positioning molecules in just the correct orientation and "tugging" on the atoms to get them to react.

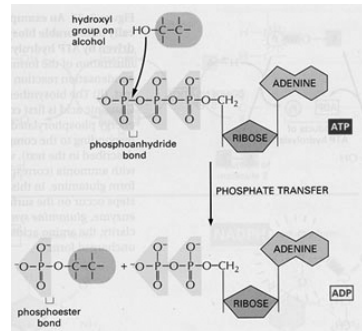
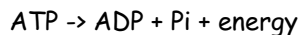
Activated Carriers

Activated carrier molecules: store energy temporarily before used to make complex molecules; stored as chemical bond energy

Involved in coupled reactions



Adenosine 5'-triphosphate (ATP):

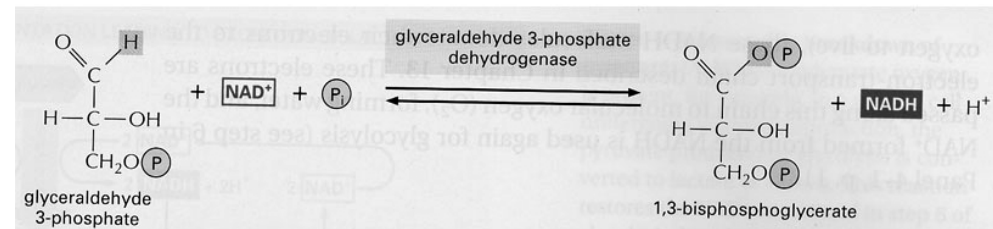


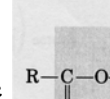
Activated Carriers

Carriers of hydride ions (H^+ plus two electrons $\rightarrow \text{H}^-$)

NADH : reduced nicotinamide adenine dinucleotide
(Catabolism)

NADPH : reduced nicotinamide adenine dinucleotide phosphate
(Anabolism, biosynthesis)





Next Class

Proteins

Alberts, Chapter 5