بسم الله الرحمن الرحيم

King Saud University
College of Science
Department of Biochemistry

Biochemical fundamentals of Life
(BCH 103)

Introductory Biochemistry
Elements and Chemical Bonds

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BCH 103
Biochemical fundamentals of Life

- Course Symbol & No. : BCH 103
- Credit Hours : 2 (2+0)
- Prerequisite :
- Class schedule : Monday
  8:00 pm to 10:00 pm.
- Class location : 2B2 building No. 5
- Examinations : Continuous Assessment Tests (CAT)
  - First (30 Marks) Sun, 00/00/1440h – 00/00/2018
  - Second (30Marks) Tues, 00/00/1440h – 00/00/2018
  - Final (40 Marks)

BCH 103 course description

Course title: Biochemical fundamentals of Life	**Course number and code: BCH 103**
Previous course requirement: None	**Language of the course: English**
Course level: Third Level	**Effective hours: 2 (2+0+0)**

This course covers general introduction to biochemistry. It describes the living cell, its organelles and the general foundations determining cell structure and functions. It also covers relevant chemical concepts, properties of water as main constituent of life, chemicals elements and their distribution in earth and cell, different chemical bonds, functional groups chemical equilibrium and homeostasis, acids, bases and buffer solution, the formation of macro-molecules from small building blocks.

هذا المقرر هو مقدمة عامة للكيمياء الحيوية، يشمل وصف للخلية الحية وعضياتها والاسس العامة المحددة لتركيب الخلية ووظائفها، يغطي المقرر أيضاً مفاهيم كيميائية ذات علاقة بالكيمياء الحيوية، خواص الماء كمكون رئيس للحياة، العناصر الكيميائية ونسبها في الأرض والخلية الحية، الروابط الكيميائية المختلفة، المجموعات الوظيفية، التوزيع الكيميائي وحالة الاستدامة في الخلايا الحية، الأحماض والقلويات والمحاليل المنظمة، التفاعلات العامة في الكيمياء الحيوية، طريقة تكوين الجزيئات الكبيرة من وحدات بنائية أصغر.

Course objectives

- **Distinguish the chemical concepts of biochemistry (chemical bonds, functional groups, equilibrium, and energy).**	- **معرفة المبادئ الكيميائية للكيمياء الحيوية (الروابط، المجموعات الوظيفية، الاتزان والطاقة).**
- **Structure, characteristics and properties of water.**	- **معرفة تركيب وخصائص الماء.**
- **Buffer composition and their role in the biological system.**	- **فهم تركيب المحاليل المنظمة ودورها في الأنظمة الحيوية.**
- **Understand the cell structure, classification, and the function of organelles.**	- **فهم تركيب الخلية، تصنيفها ووظائف العضيات.**
- **Gain knowledge about the biomolecules and their assembly to macromolecules.**	- **اكتساب المعرفة الخاصة بالجزيئات الحيوية وارتباطها لتكوين الجزيئات الكبيرة.**

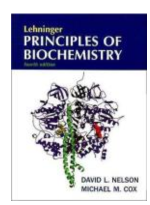
Course Description (1_cont.)

Topics	Weeks	Lectures
Definition and Introduction: General introduction to Biochemistry Elements: Atoms (C, O, H, etc) and essential elements (Mg, Ca, etc), versus earth composition. Biomolecules: H_2O, amino acids, saccharides, nucleic acids, lipids, vitamins, and heme) Assembly of molecules (proteins, DNA, RNA, carbohydrates, membranes	3	1-6
Chemical Concepts- importance to biochemistry: Chemical bonds: Covalent, ionic, hydrogen bond, hydrophobic interactions, Van der Waals interactions. Functional groups. Chemical Equilibrium Free Energy	3	7-12
Structure and Properties of water: Structure of water. Hydrogen bonding and solubility of molecules. Surface tension. Expansion upon freezing. High boiling point. Ionization of H_2O Weak acids and bases (pH and pK and Handerson Hasselbalch equation Buffer systems	3	13-18
Biochemistry pathways: information (molecular biology) versus Structural (chemistry); Living versus nonliving Cell theory Cells, organelles and organisms	5	19-28

Books

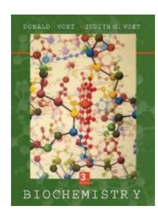
- **Lehninger: Principles of Biochemistry**

by DL. Nelson and MI. Cox (latest edition)



- **Biochemistry.**

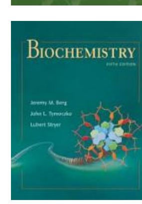
by D. Voet and J. Voet (latest edition)



- **Biochemistry**

by J.M. Berg, J.L. Tymoczko, G.J. Gatto, L. Stryer

(latest edition)



What is Biochemistry?

- Biochemistry is the chemistry of the living cell.
  - It describes in molecular terms the structures, mechanisms, function and chemical processes shared by all living organisms.
  - It provides fundamental understanding of the molecular basis for the function of living things.
  - It provides a broad understanding of the molecular basis of life.
  - It explains what goes wrong to produce a disease.
- Examples:
  - The chemical structures of biomolecules.
  - Interactions leading to formation of supermacro-molecules , cells, multi-cellular tissues, and organisms.
  - Bioenergetics of the reactions in the cell.
  - Storage and transmission of information.
  - Chemical changes during reproduction, aging, and death of cells.
  - Regulation of chemical reactions inside living cells.

Learning goals:

- Distinguishing features of living organisms
- Structure and function of the parts of the cell
- Roles of small and large biomolecules
- Energy transformation in living organisms
- Regulation of metabolism and catalysis
- Coding of genetic information in DNA
- Role of mutations and selection in evolution

Principal Areas of Biochemistry

- **Structure-function relationship:**
  - Structural Chemistry for proteins, carbohydrates, DNA/RNA, lipids, and every other component in the cell.
  - Functions of these components
  - Relationship between structure and function.
- **Metabolism**:
  - Catabolism: Pathways of chemical reactions leading to the breakdown of molecules
  - Anabolism: pathways of chemical reactions leading to synthesis of molecules.
  - Bioenergetics of reaction as well as management of cellular Energy.
- **Cellular communication**
  - Storage, transmission, and expression of genetic information
    - DNA replication and protein synthesis.
  - Cell-cell communication & interaction
  - Signal transduction

History of Biochemistry

Biochemistry is only about 100 year-old science:
Some major events in its history.

1990 Gene Therapy

1970 PCR & Recombinant DNA

1966 Genetic codes unveiled.

1959 3-D structure of hemoglobin

1953 Watson and Crick proposed the double helix for DNA

1944 Avery, MacLeod, and McCarty showed DNA to be the agent of genetic transformation.

1937 Krebs elucidated the citric acid cycle.

1926 Sumner crystallized urease.

1925 The glyclolytic pathway revealed

1897 Buchner : *in-vitro* experiment with cell extracts.

1869 Miescher isolated nucleic acids.

1828 Wohler synthesized urea from ammonium cyanate

Inorganic → organic
$NH_4CNO \rightarrow CO(NH_2)_2$

What is the matter?

- **The matter** is anything that has mass and volume (occupies space).
  - -In chemical point of view matter is made up of atoms.
  - -Atoms are formed from nucleus (having protons and neutrons) and circulating negatively charges electrons.
  - -Atoms having specific numbers of protons form elements
  - -There are 118 elements on the periodic table 92 of them are natural.
  - -All living and non-living matter are made of elements.
  - -Group of elements can form molecules of compounds.

In biochemistry, we are interested in the chemical structure and reactions in living cells.

So, the introduction for biochemistry is the study of the living cell.

The origin of Life

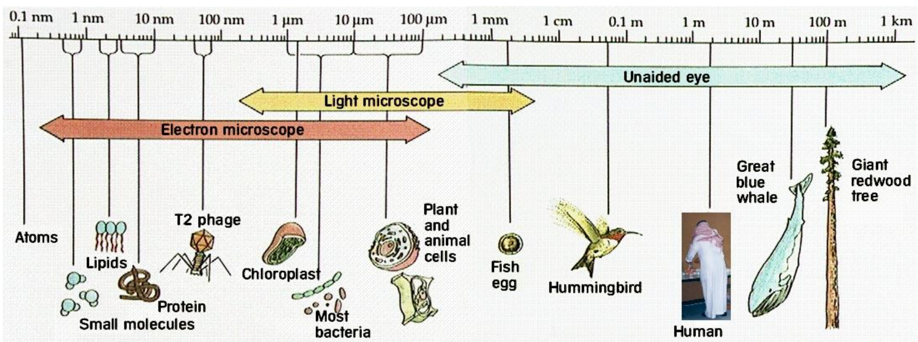
- Living matter consists of some chemical elements.
- Those elements bind together to form molecules.
- Most of compounds in Biological systems are organic compounds (have Carbon)
- Chemical compounds have reactive functional groups that participate in biological structure and biochemical reactions.
- Polymerization of organic molecules form more complex structure by the mean of condensation reaction with the removal of water.
- The key of origin of living matter is the formation of membranes that separate the critical molecules required for replication and energy capture.
- Larger polymers of molecules form macromolecules that all together provide biological specificity of the living matter. E.g. carbohydrates, proteins, lipids, genetic material (DNA and RNA) etc.

Biological Hierarchies

- Biological Hierarchy: Simple Molecules are used to Build Complex Structures

Elements → Molecule → Cell → Tissue → Organ → Organism → Population → Species → Biosphere

- Relative sizes (or ranges) for some biological things, and the resolving power of available tools!
- Note that the scale is logarithmic.
- Remember: 1 m = 10 dm = 100 cm = 1000mm = 10^6 µm = 10^9 nm = 10^{10} A°



Dimensions

- Dimensions in Biochemistry are often expressed as angstrom (Å), nanometer (nm), or micrometer (µm).

You must know this and be comfortable using them.

1 Å = 10^{-10} m,   1 nm=10 Å   1 µm=10,000 Å

Length is very important!!

C - C bond is	1.54 Å	1 mm= 10^{-3} m
Hemoglobin	65Å	1 µm = 10^{-6} m
Ribosome	300Å	1 nm = 10^{-9} m
Viruses	100 - 1000Å	1 Å = 10^{-10} m
Cells	1-10 µm or 10,000- 100,000 Å	

Information about structure come from:
light microscope: range of 2000 Å or 0.2µm
X-ray crystallography, electron microscope or NMR: 1 Å ⇒ 10^4 Å range

Time scale

Life is in Constant Flux

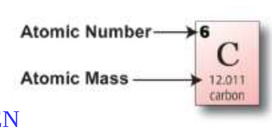
- Substrates to products in 10^{-3} sec (ms)
- Unwinding of DNA in 10^{-6} sec (μs)

10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}	1	10^{3}	10^{6}	10^{9}	10^{12}
femto	pico	nano	micro	milli	Base Unit	kilo	mega	giga	tera
f	p	n	μ	m		K	M	G	T

- femto fs — excitation of chlorophyll
- pico ps — charge separation in photosynthesis
- nano ns — hinge protein action
- micro μs — DNA unwind
- milli ms — enzymatic reactions
- 10^{3} — generation of bacteria
- 2.3×10^{9} sec — average human life span

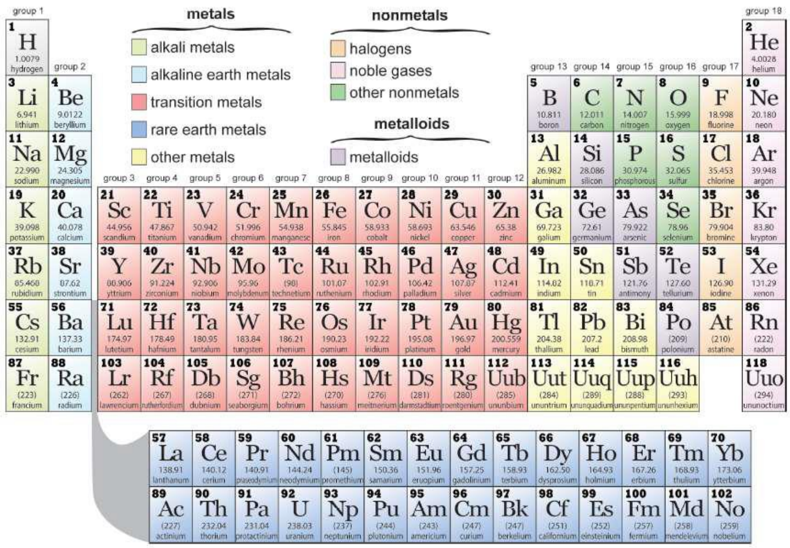
The matter versus element and molecule?

- **The matter** is anything that has mass and volume (occupies space).
  - There are 118 elements on the periodic table 92 of them are natural.
  - An element consists of atoms of the same kind.
  - Any element consist of atoms. The atom is formed from nucleus (having protons and neutrons) and circulating negatively charges electrons.
  - The atomic number of each element represent the number of protons in its nucleus.



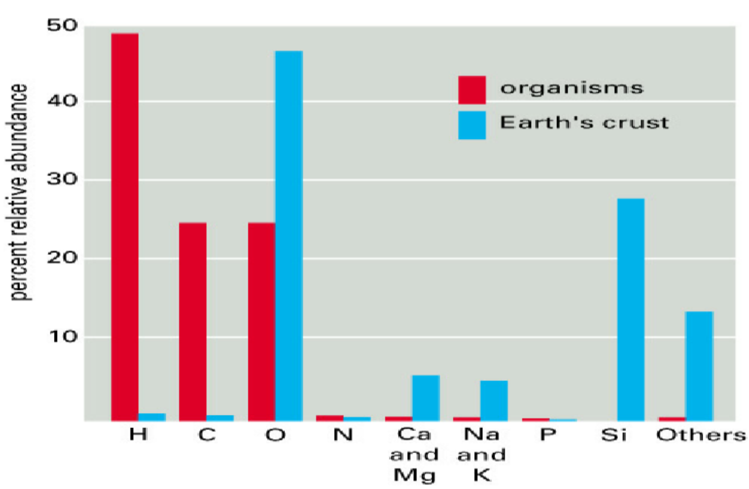
For example,
- the element that has 6 protons in its atom is CARBON
- The atom that has 7 protons is NITROGEN
- The atom that has 8 protons is OXYGEN
- Molecule is a group of two or more elements.

Periodic table of elements



Chemical elements of cell

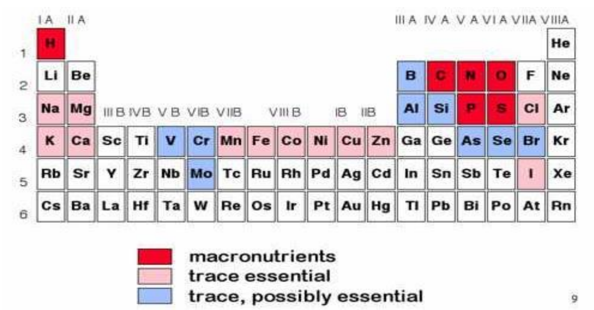
Chemical elements of a living cell are the same as in the Earth's crust, but in different proportions.



Elements in living cells

There are many classifications of elements regarding its distribution in living cells. The most used one is as follow:

- **Macronutrients** are elements that are most abundant in the cell, **(C, H, N, O, P, S)**
- **Essential elements** are found in small amounts, but essential (Na, Mg, K, Ca, Mn, Fe, Co, Ni, Zn, Cu, Cl, I).
- **Trace Possibly Essential elements**: some are common, others are less common (V, Cr, Mo, B, Al, Si, As, Se, Br).

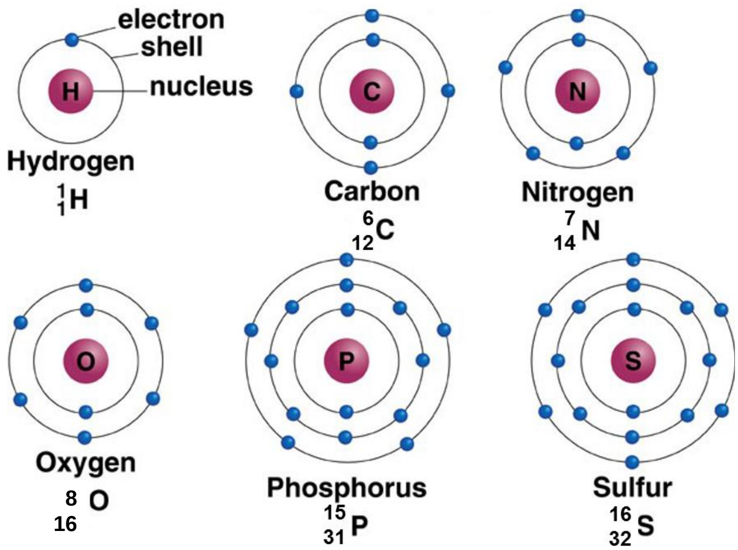


Which of the following belongs to trace elements? Mo, Co, P?

Chemical Elements of Life

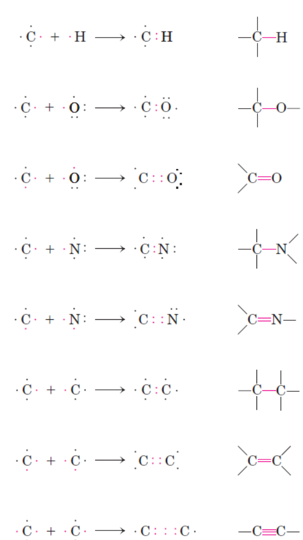
- C H N O P S: are the most abundant elements in cell.
  - They account for more than 99% of atoms in the human body
- H, O, N and C have common properties that are important to the chemistry of life.
  - They all:
    - have relatively low atomic numbers
    - capable of forming one, two, three and four bonds (for H, O, N and C , in order).
    - form the strongest covalent bonds in general.

Write the atomic number and the atomic mass of each element (CHNOPS)



Biomolecules are Compounds of Carbon with a Variety of Functional Groups

- Carbon accounts for more than half the dry weight of cells.
- It can form single bonds with hydrogen atoms, and both single and double bonds with oxygen and nitrogen atoms.
- Of greatest significance in biology is the ability of carbon atoms to form very stable carbon–carbon single bonds. Each carbon atom can form single bonds with up to four other carbon atoms.
- Two carbon atoms also can share two (or three) electron pairs, thus forming double (or triple) bonds.



The unique characteristics of Carbon

- Covalently linked carbon atoms in biomolecules can form linear chains, branched chains, and cyclic structures.
- To these carbon skeletons **functional groups** are added**,** which confer specific chemical properties on the molecule.
- The bonding versatility of carbon is a major factor that give carbon these unique characteristics in the biological system.
- No other chemical element can form molecules of such widely different sizes and shapes or with such a variety of functional groups.

- Most biomolecules can be regarded as derivatives of hydrocarbons, with hydrogen atoms replaced by a variety of functional groups to yield different families of organic compounds.
- **Examples**
  - alcohols, which have one or more hydroxyl groups;
  - amines, with amino groups;
  - aldehydes and ketones, with carbonyl groups;
  - carboxylic acids, with carboxyl groups
- The chemical "personality" of a compound is determined by the chemistry of its functional groups and their disposition in three-dimensional space.

Common Functional Groups of Biomolecules

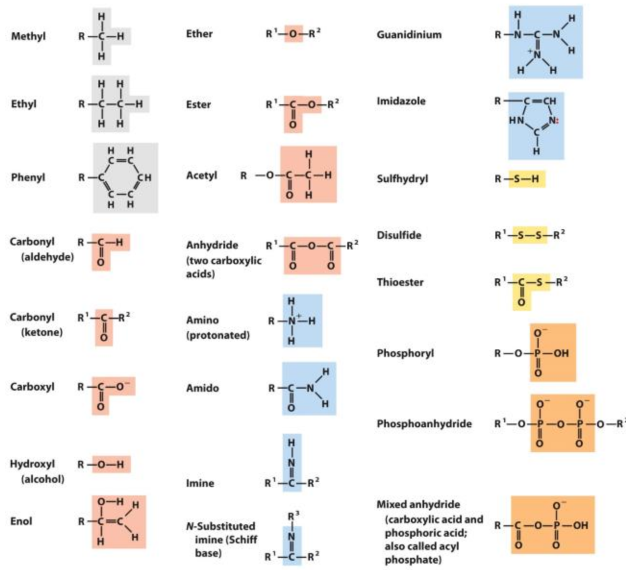


Figure 1-17
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Biological Molecules Typically Have Several Functional Groups

Many biomolecules are polyfunctional, containing two or more different kinds of functional groups, each with its own chemical characteristics and reactions.

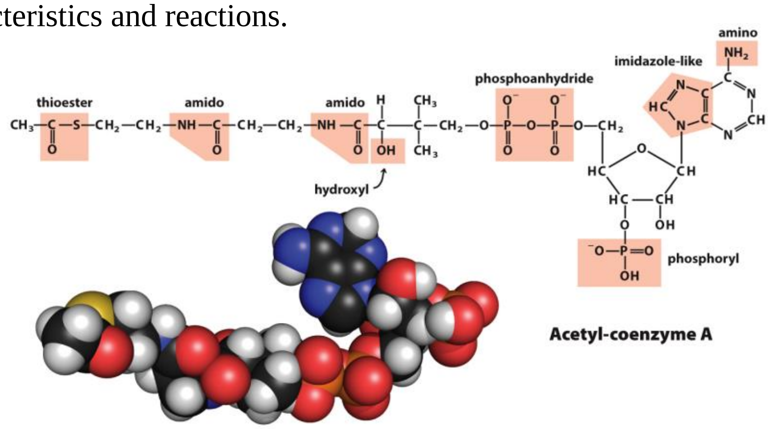

Figure 1-18
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Chemistry and Life

Living organisms operate within the same laws that apply to physics and chemistry:

- Conservation of mass, energy
- Laws of thermodynamics
- Laws of chemical kinetics
- Principles of chemical reactions

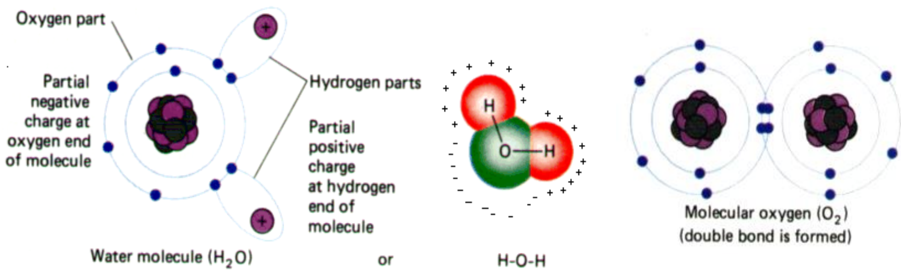
Chemistry Review

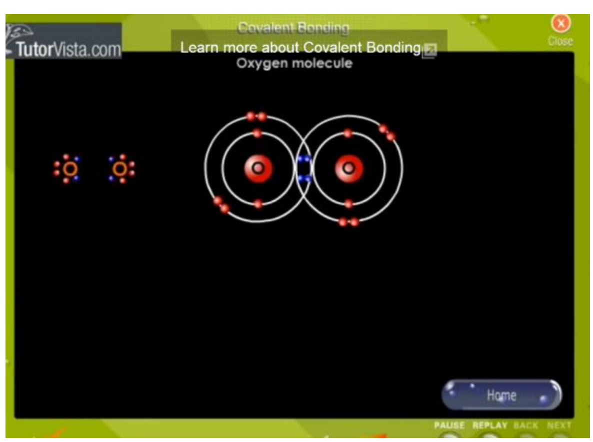
There are 5 major forces that maintain the structure of biomolecules:

- Only one is a strong force: The covalent bond
- The others are considered weak forces:
  1. The ionic bond
  2. The hydrogen bond
  3. Hydrophobic interaction (not chemical bond)
  4. Van Der Waals attraction (not chemical bond)

The Covalent Bond (Cont.)

- The strongest bond in biochemistry
- Does not dissociate or break in H_2O
- Formed by sharing of valence electrons
  - If partners are unequal, asymmetrical distribution of electrons creates partial electrical charges and therefore polar molecules





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https://www.youtube.com/watch?v=MlgKp4FUV6I
https://www.youtube.com/watch?v=X9FbSsO_beg

Noncovalent Interactions

Noncovalent interactions do not involve sharing a pair of electrons.
Based on their physical origin, we can divide them into:

- **Ionic interactions**
  - electrostatic interactions between permanently charged species, or between the ion and a permanent dipole
- **Dipole interactions**
  - electrostatic interactions between uncharged but polar molecules
- **van der Waals interactions**
  - weak interactions between all atoms, regardless of polarity
  - attractive (dispersion) and repulsive (steric) component
- **Hydrophobic Effect**
  - complex phenomenon associated with the ordering of water molecules around nonpolar substances

Examples of Noncovalent Interactions

There are 4 types of non-covalent (weak) interactions among Biomolecules in aqueous solvent.

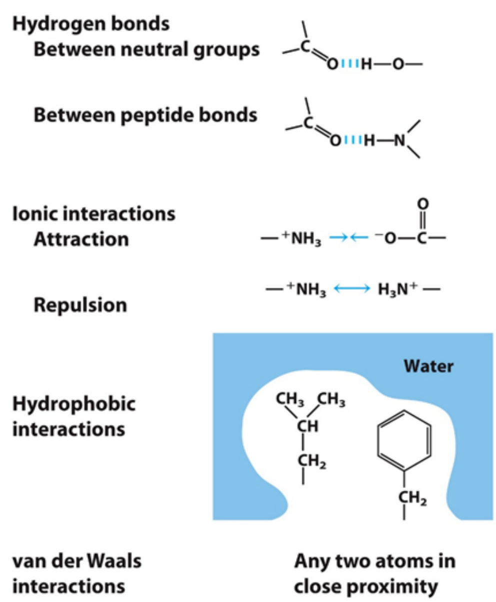

Table 2-5
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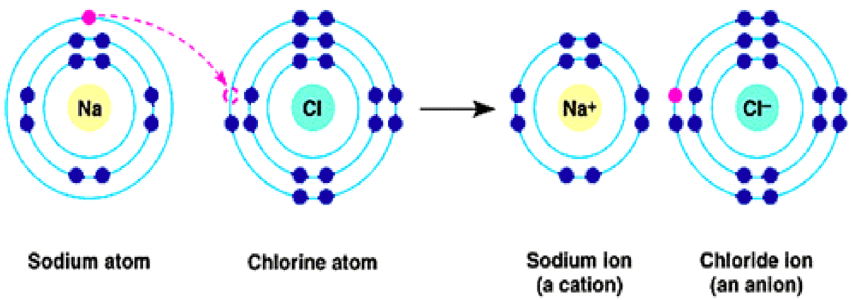
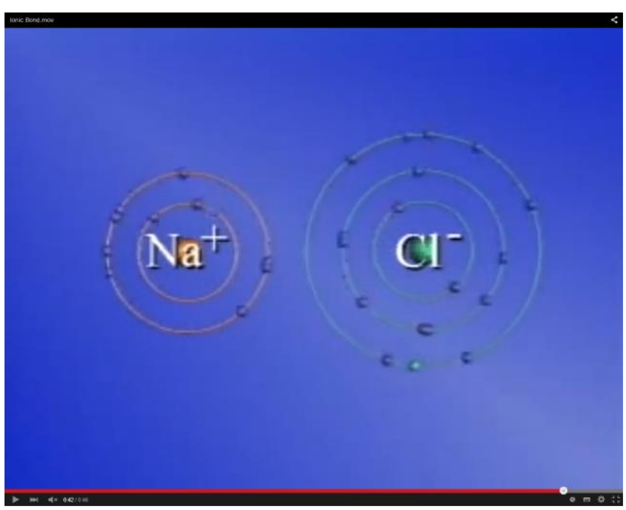
Ionic bond

Formed by complete transfer of valence electrons between two atoms

Electrostatic interaction is responsible for ionic bonds, salt linkages or ion-pairs, and hydrogen bonding



Ionic bond



https://www.youtube.com/watch?v=lODqdhxDtHM

The Hydrogen Bond

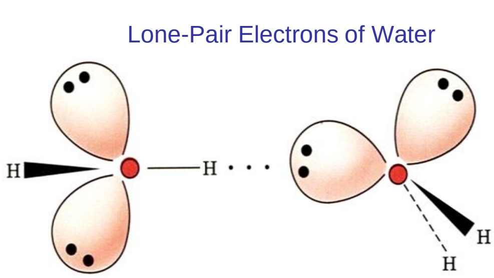
- The hydrogen bond is weak, but very important in biochemistry
- The general formula for H-bond is

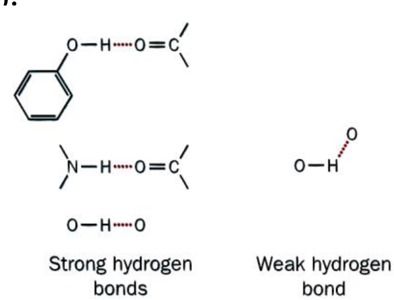
$$\overset{\delta^-}{-D}-\overset{\delta^+}{H}\cdots\cdots\overset{\delta^-}{A}-$$

- (D) is the donor atom
- (A) is the acceptor atom which must have at least one-pair of free electrons
  - Important atoms in Biochemistry are O and N
  - Carbon can neither donate nor accept H-bonding

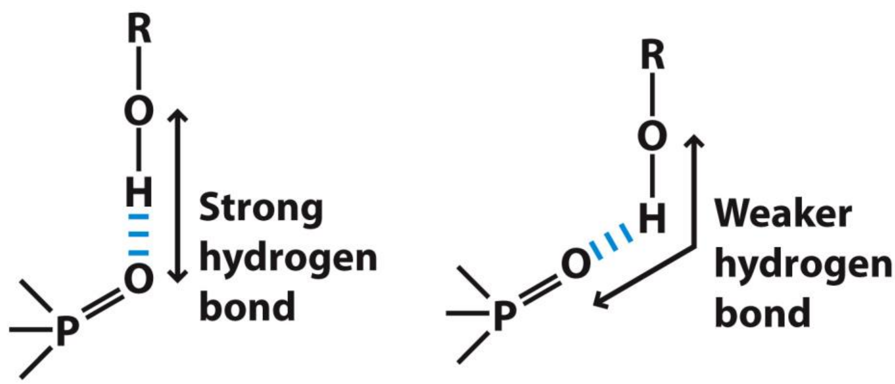
Hydrogen Bonds

- Hydrogen bonds are strong dipole-dipole or charge-dipole interactions that arise between a covalently bound hydrogen and lone pair of electrons. It can be considered as a weak ionic bond
- They typically involve two electronegative atoms (frequently nitrogen and oxygen).





- Hydrogen bonds are strongest when the bonded molecules allow for linear bonding patterns.
- Ideally, the three atoms involved are in a line.



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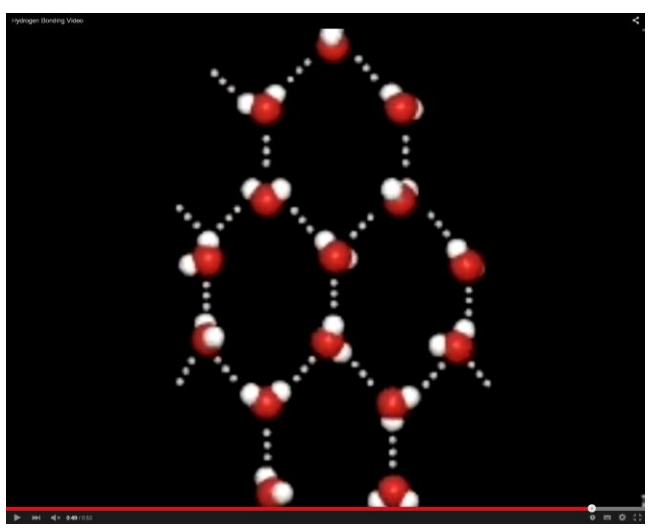
The Hydrogen Bond



https://www.youtube.com/watch?v=lkl5cbfqFRM

Importance of Hydrogen Bonds

- Source of unique properties of water
- Structure and function of proteins
- Structure and function of DNA
- Structure and function of polysaccharides
- Binding of substrates to enzymes
- Binding of hormones to receptors
- Matching of mRNA and tRNA

Biological Relevance of Hydrogen Bonds

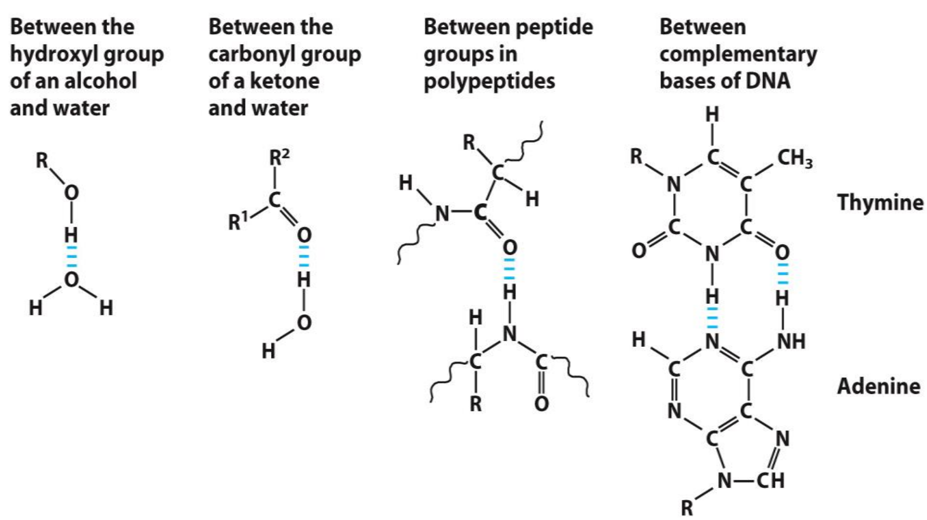


Figure 2-4
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van der Waals Interactions

- van der Waals interactions have two components:
  - attractive force (London dispersion), which depends on the polarizability. Attraction dominates at longer distances (typically 0.4–0.7 nm).
  - repulsive force (Steric repulsion), which depends on the size of atoms. Repulsion dominates at very short distances.
- There is a minimum energy distance (van der Waals contact distance).

Van Der Waals Attraction

Non-specific attractions (induced dipole-induced dipole) most effective near the contact distances.

Atom	contact Distance	Atom	contact Distance
H	1.2 Å	C	2.0 Å
N	1.5 Å	O	1.4 Å
S	1.85 Å	P	1.9 Å

Weak interaction; About 1.0 kcal/mol

- Becomes important when many atoms come in contact as in steric complementarities as in:

  a) antibodies

  b) enzyme substrate

Biochemical Significance of van der Waals Interactions

- **Weak individually**
  - easily broken, reversible
- **Universal**
  - occur between any two atoms that are near each other
- **Importance**
  - determines steric complementarity
  - stabilizes biological macromolecules
  - facilitates binding of polarizable ligands

The Hydrophobic interaction

- Non- polar groups cluster together
- Refers to the association or interaction of nonpolar components of molecules in the aqueous solution.
- The most important parameter for determining the stability of proteins, membrane, nucleic acids
- It is one of the main factors behind:
  - protein folding
  - protein-protein association
  - formation of lipid micelles
  - binding of steroid hormones to their receptors

Hydrophobic Effect Favors Ligand Binding

- Binding sites in enzymes and receptors are often hydrophobic.
- Such sites can bind hydrophobic substrates and ligands, such as steroid hormones, which displace water and increase entropy of the system.
- Many drugs are designed to take advantage of the hydrophobic effect.

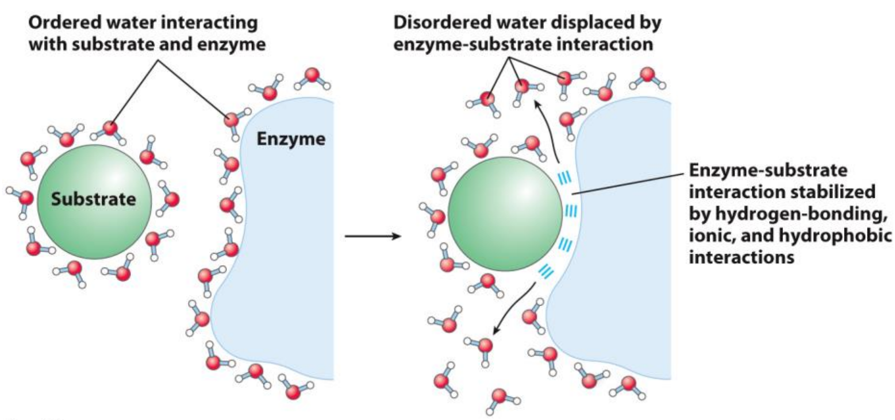

Figure 2-8
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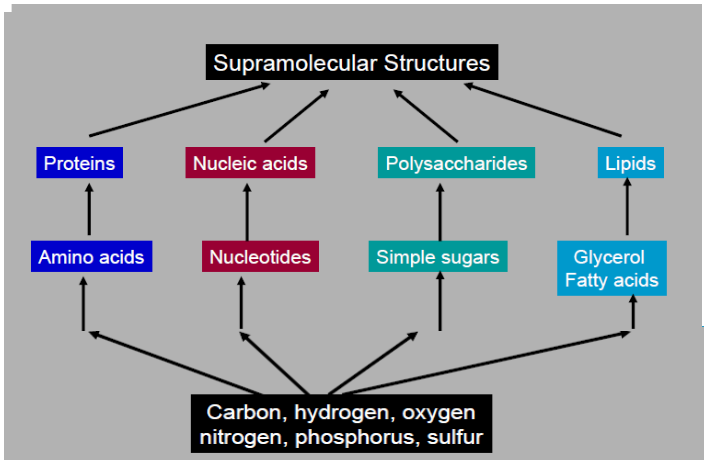
CHNOPS vs monomer vs macromolecules

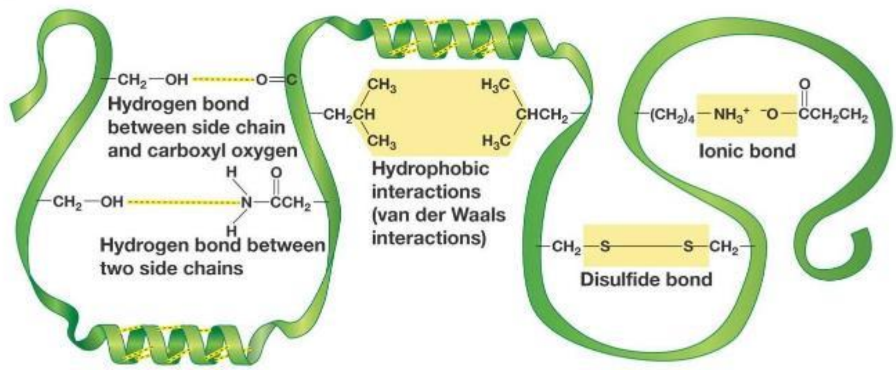


The 4 Major macromolecules

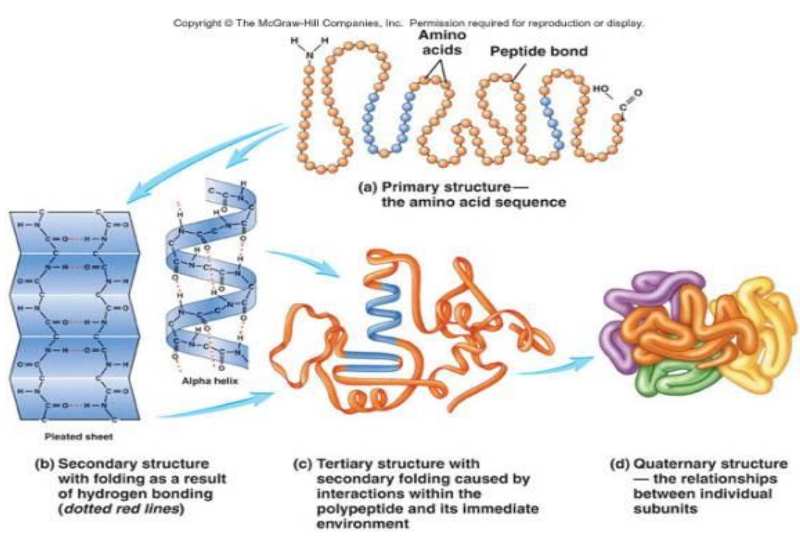
There are 4 major macromolecules (polymers) in the cell formed by condensation of smaller building blocks (monomers) by the removal of H_2O (dehydration):

Macromolecule (polymers)	Building blocks (monomers)	Name of bond
Carbohydrate	Monosaccharides	Glycosidic bond
Proteins	Amino acids	Peptide bond
Nucleic acids	Nucleotides	Phospho diester bond
Lipids	Fatty acids + alcohol	Ester bond

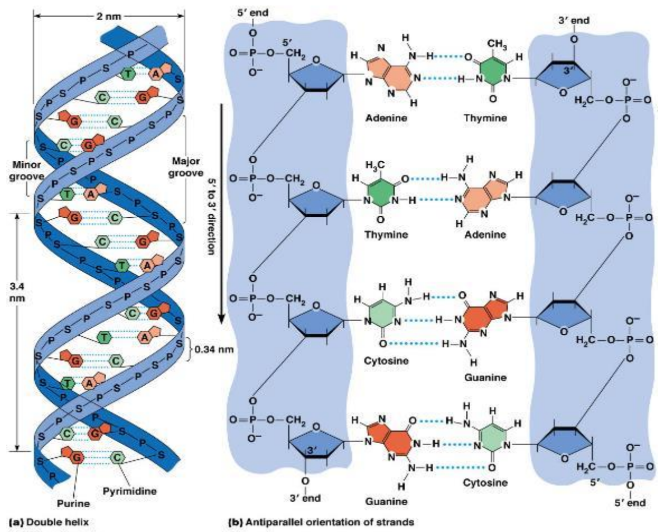
Example of macromolecule having different types of bonds (ex. Protein structure)



Example of macromolecule having different types of bonds (ex. Protein structure)

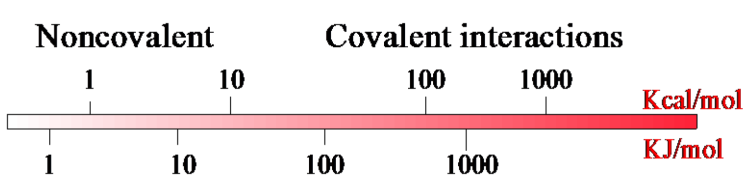


Example of macromolecule having different types of bonds (ex. DNA structure)



Energy

- Ultimate source of energy is the sun: E = hν
- where E is the energy of a bit of light called a quantum or photon of light.
- h is a very small constant called “Planck’s constant” (6.626068×10^{-34} J s) and
- “ν” is the frequency of the radiation.
  - photons of green light have E of 57 Kcal/mol
- 1 cal = 4.184 joules or 1 J= 0.239 cal; You must know this.
- Covalent interactions are stronger than noncovalent ones
  - The carbon skeleton of a molecules is thermally stable
    - e.g. C - C bond = 83 Kcal/mol or 346 KJ/mol
- The shape and interactions of molecules are governed by noncovalent interactions
  - Biomolecules shape can be modified by thermal energy.
    - Boil an egg, fry a steak or get a sunburn.



Summary of the Chemical Foundations of Biochemistry

- Because of its bonding versatility, carbon can produce a broad array of carbon–carbon skeletons with a variety of functional groups; these groups give biomolecules their biological and chemical personalities.
- A nearly universal set of several hundred small molecules is found in living cells; the interconversions of these molecules in the central metabolic pathways have been conserved in evolution.
- Proteins and nucleic acids are linear polymers of simple monomeric subunits; their sequences contain the information that gives each molecule its three-dimensional structure and its biological functions.
- Interactions between biological molecules are almost invariably stereospecific: they require a complementary match between the interacting molecules.