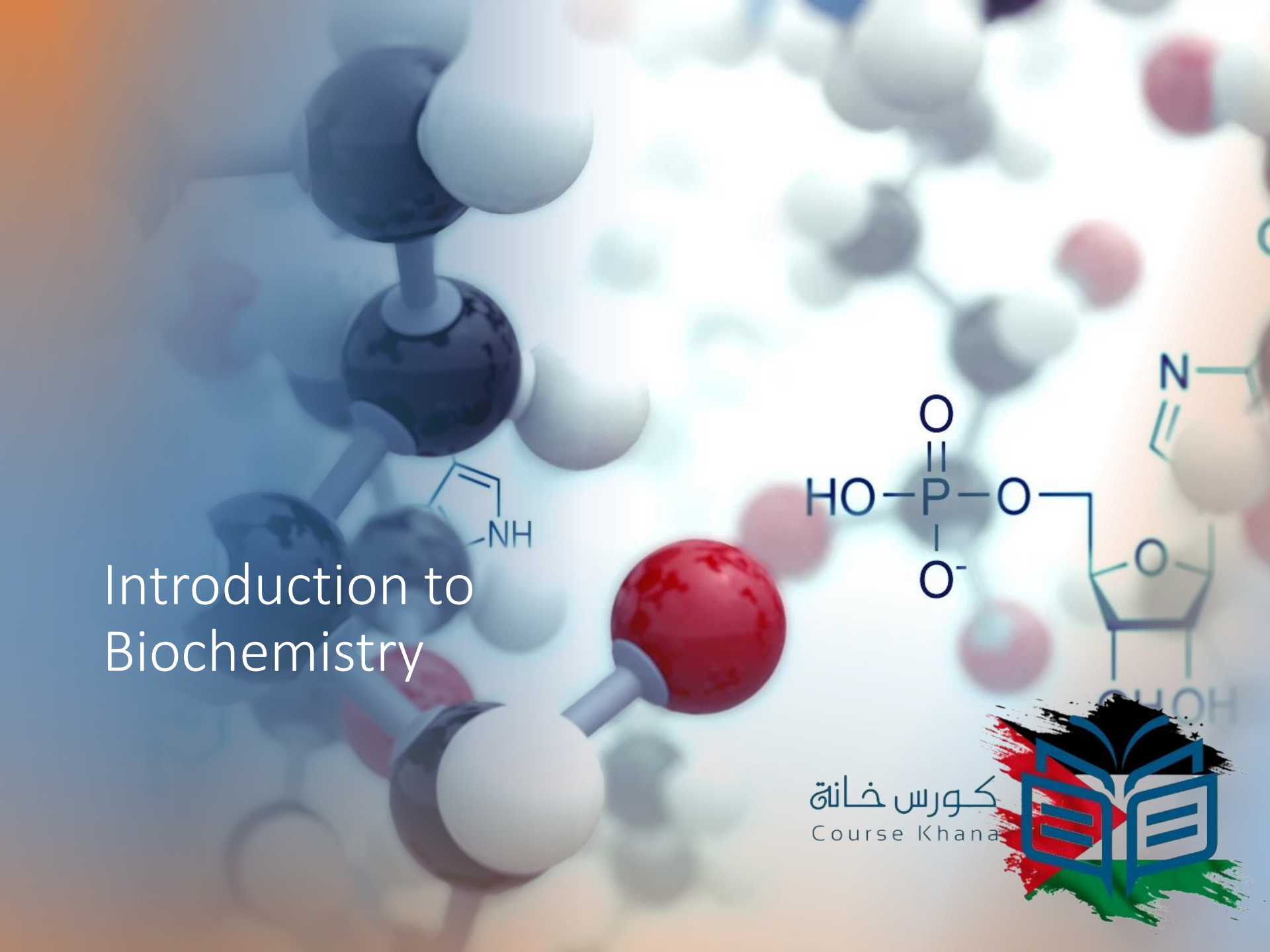
Introduction to Biochemistry



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.

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

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

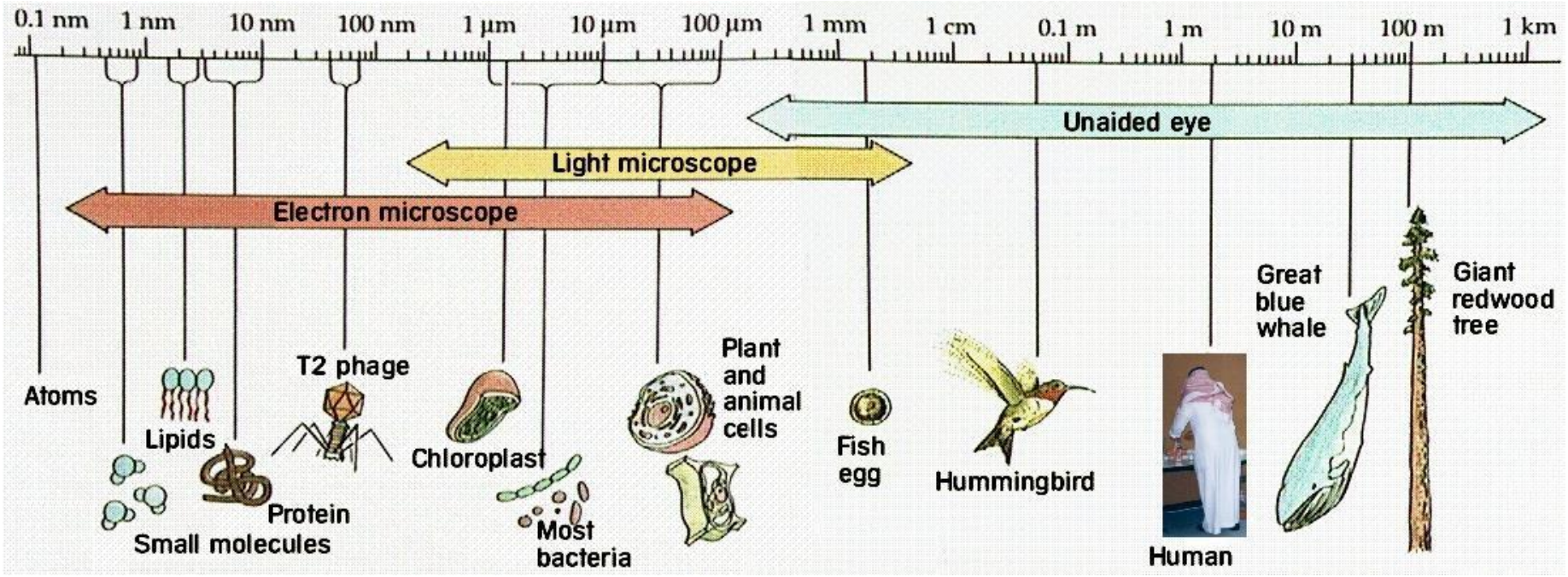
- Living matter consists of some chemical elements.
- Those elements bind together to form molecules.
- Most of compounds in Biological systems are organic compounds (have Carbon)
- Chemical compounds have reactive functional groups that participate in biological structure and biochemical reactions.
- 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°



Typical Cells

- Cells from different organisms have different shapes, structures, and sizes.
- All cells have protoplasm.

- They are usually divided into two broad groups: Eukaryotes and Prokaryotes.
  - Eukaryotic cells (Eu = true; kary = nucleus): have a membrane-bound nucleus and a variety of organelles and internal membranes.

  - Prokaryotic cells (Pro = before) are smaller (a general rule) and lack much of the internal compartmentalization and complexity of eukaryotic cells; No membrane-bound nucleus or other organelles.

  - Viruses do not always conform to cell theory:
    - one or more of the basic cell components is missing.
    - Inside the host cell, viruses are living matters.

Sizes and Shapes of Cells

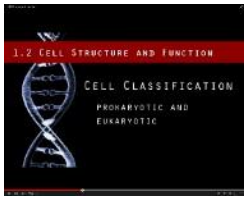
Notice: Cells in the figure is represented according to the proportion of its size using the suitable scale.

Prokaryotes

- Prokaryotes; all in one!!
  - It shows a limited range of morphologies but very diverse metabolic capabilities.
- Prokaryotes are often single-celled organisms.
  - Do NOT have true nucleus or organelles.
  - Most have circular or "looped" DNA
  - lack much of the internal membranous compartmentalization
  - Mainly unicellular organisms
- Prokaryotes are divided into two major lineage:
  - Eubacteria (true bacteria): inhabit soils, surface waters, and the tissues of other living or decaying organisms. Most of the well studied bacteria, including *Escherichia coli*, are eubacteria.
  - Archeabacteria (Greek *arche*-, "origin"): most inhabit extreme environments—salt lakes, hot springs, highly acidic bogs, and the ocean depths. It includes:
    - Methanogens (oxygen-free milieus)
    - Halophiles (require high concentrations of salt)
    - Thermophiles (live in hot regions, 80^{o}C, in a pH< 2)

video

Cell, tissue, organ
https://www.youtube.com/watch?v=HBvfBB_oSTc



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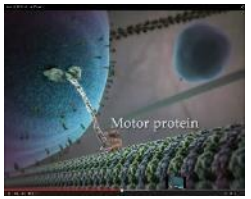

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Organisms, Organs, & Organelle

- Organism is a complete living entity
  - Unicellular organisms such as Bacteria, Protists, etc (mostly prokaryotic).
  - Multicellular organisms such as all animals and most plants. These organisms have different Levels of Cellular Organization, (mostly eukaryotic).

  - The Level of Cellular Organization is arranged from lower to higher level as follows:
    1. Cells
    2. Tissues (Epithelia, Connective, Muscle, Nerve Tissue)
    3. Organs (Heart, skin, kidney, etc.)
    4. Organ systems (circulatory, respiratory, digestive, etc)
    5. Organisms (Human, bovine, etc)

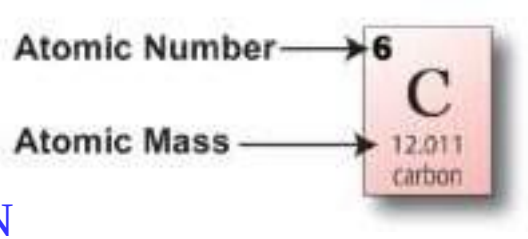
Characteristics of Living Organisms

There are 6 main Characteristics:

1- The highly organized Cells
2- Relation with energy
3- Grow and Reproduce with high fidelity
4- Interact with environment
5 Movement
6 Homeostasis

The matter versus element and molecule?

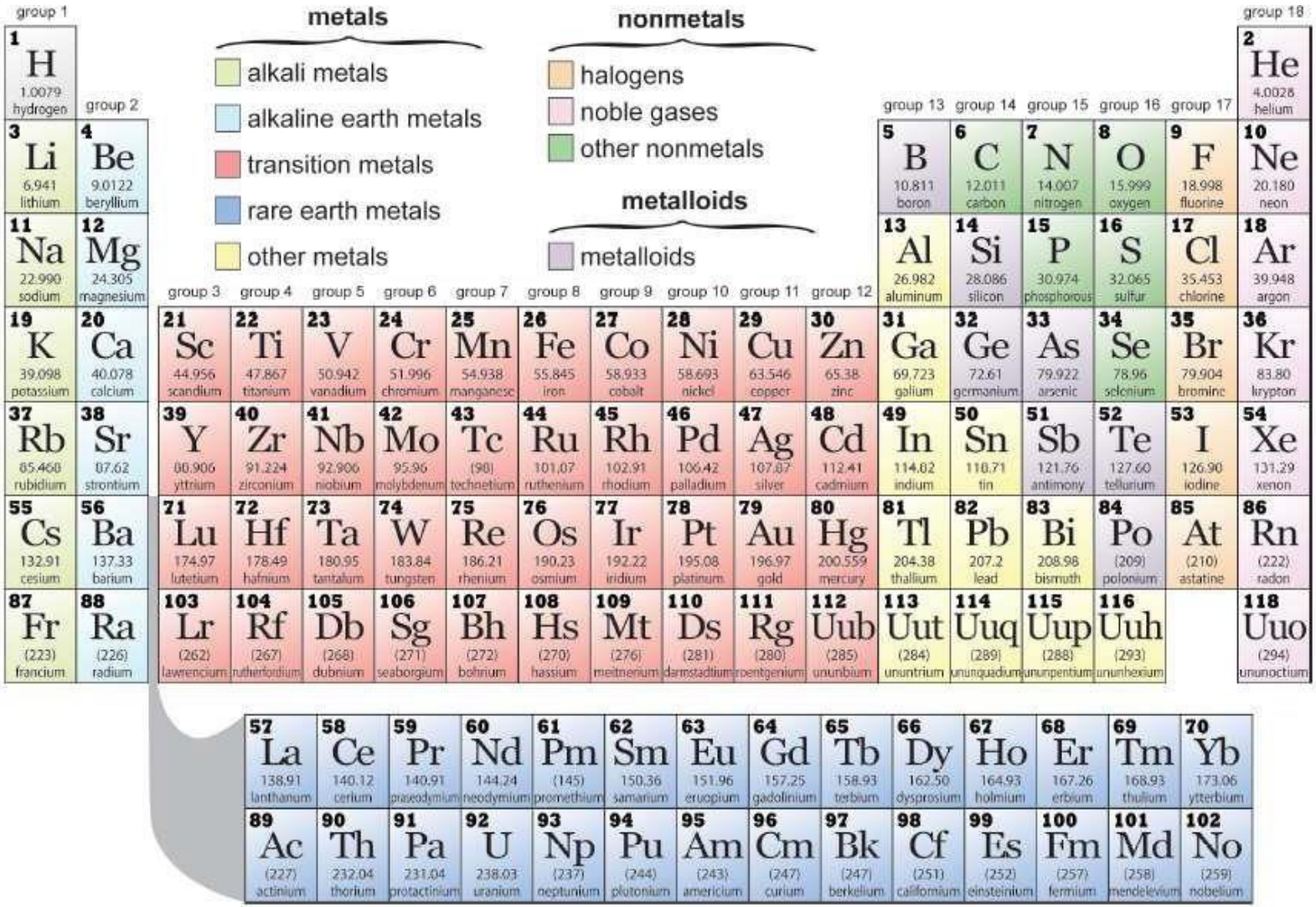
- **The matter** is anything that has mass and volume (occupies space).
  - There are 118 elements on the periodic table 92 of them are natural.
  - An element consists of atoms of the same kind.
  - Any element consist of atoms. The atom is formed from nucleus (having protons and neutrons) and circulating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



For example,

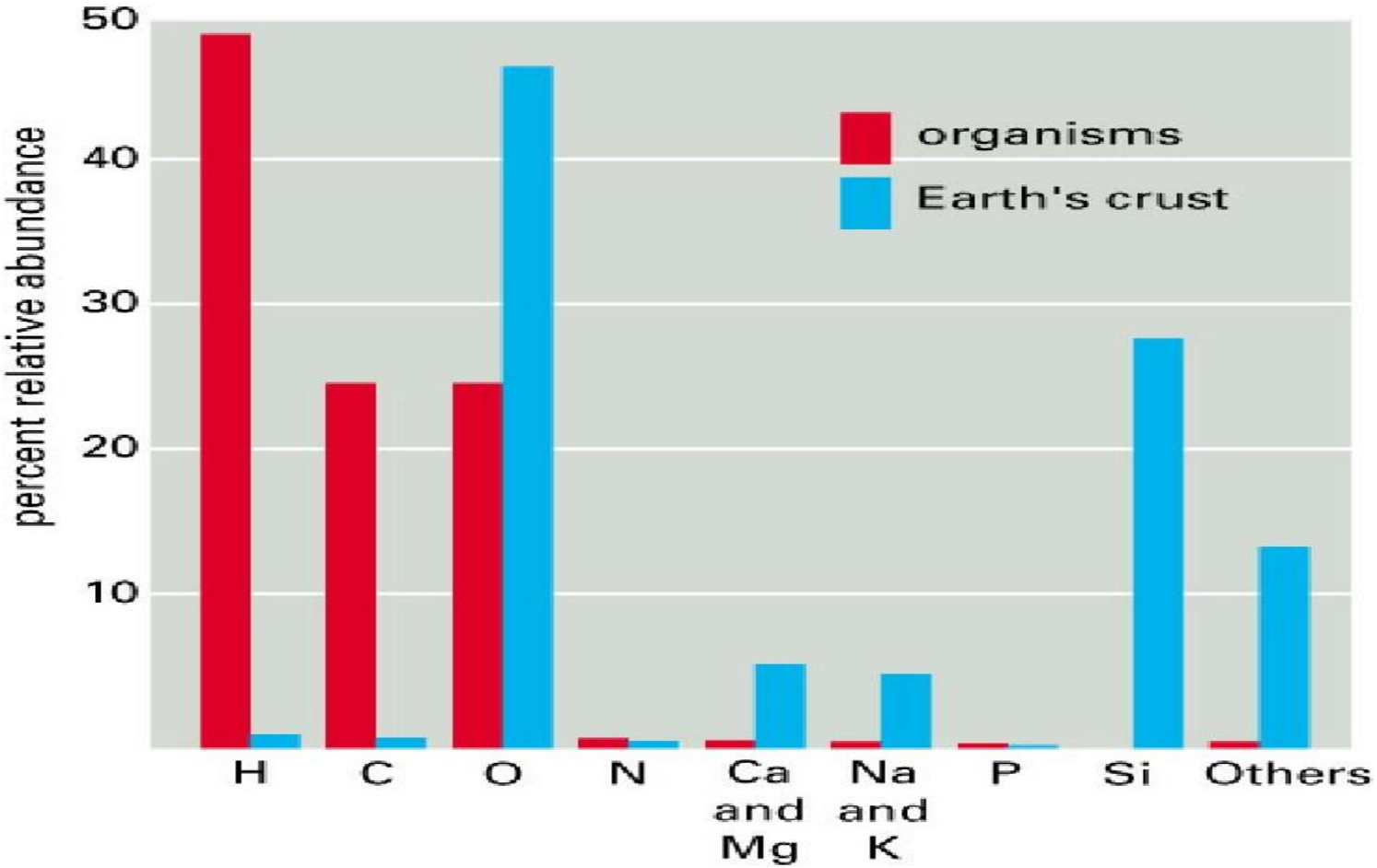
- the element that has 6 protons in its atom is CARBON
- The atom that has 7 protons is NITROGEN
- The atom that has 8 protons is OXYGEN
- Molecule is a group of two or more elements.

Periodic table of elements



Chemical elements of cell

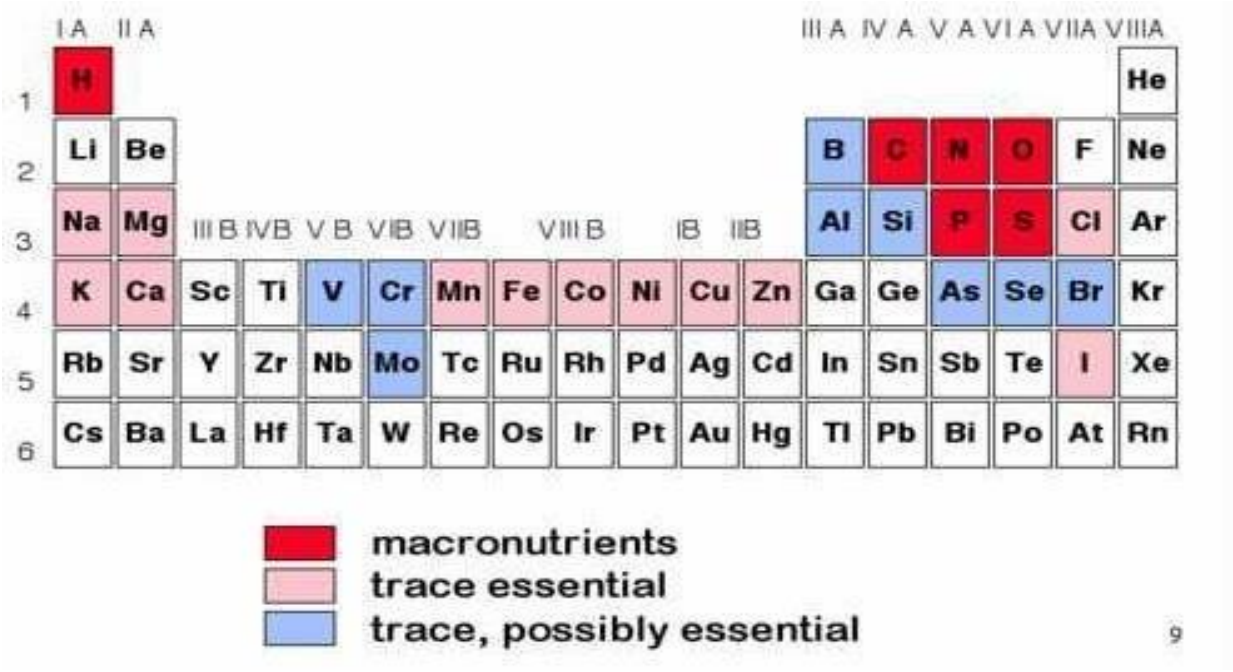
Chemical elements of a living cell are the same as in the Earth's crust, but in diferent proportions.



Elements in living cells

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

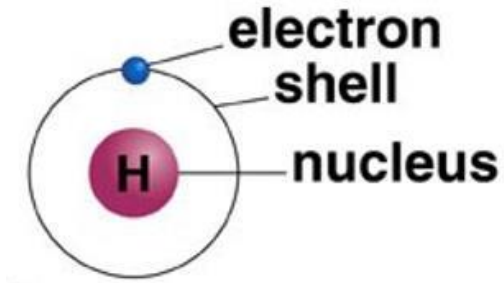
- **Macronutrients** are elements that are most abundant in the cell, **(C, H, N, O, P, S)**
- **Essential elements** are found in small amounts, but essential (Na, Mg, K, Ca, Mn, Fe, Co, Ni, Zn, Cu, Cl, I).
- **Trace Possibly Essential elements**: some are common, others are less common (V, Cr, Mo,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



Chemical Elements of Life

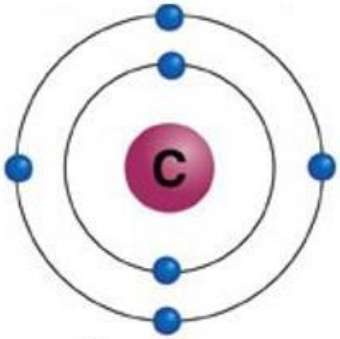
- C H N O P S: are the most abundant elements in cell.
  - They account for more than 99% of atoms in the human body
- H, O, N and C have common properties that are important to the chemistry of life.
  - They all:
    - have relatively low atomic numbers
    - capable of forming one, two, three and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



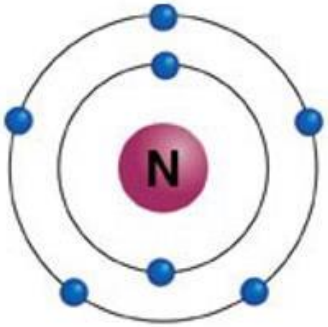
Hydrogen

$^{1}_{1}H$



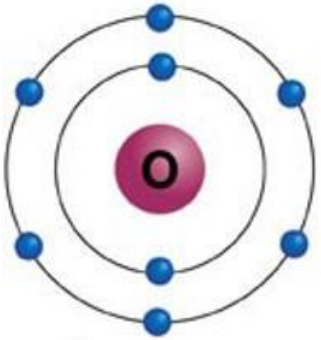
Carbon

$^{6}_{12}C$



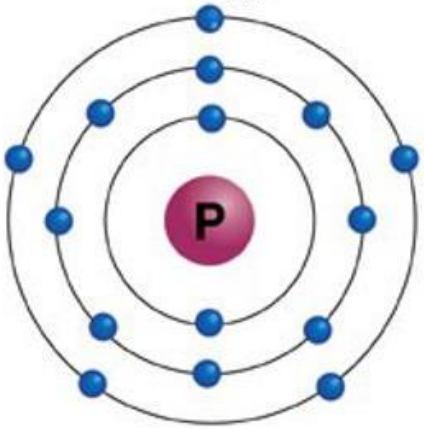
Nitrogen

$^{7}_{14}N$



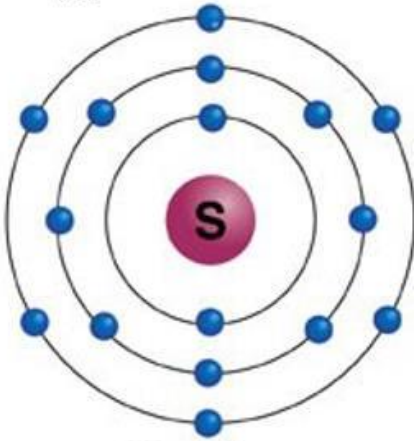
Oxygen

$^{8}_{16}O$



Phosphorus

$^{15}_{31}P$



Sulfur

$^{16}_{32}S$

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)

Ionic bond (Cont.)

Formed by complete transfer of valence electrons between two atoms

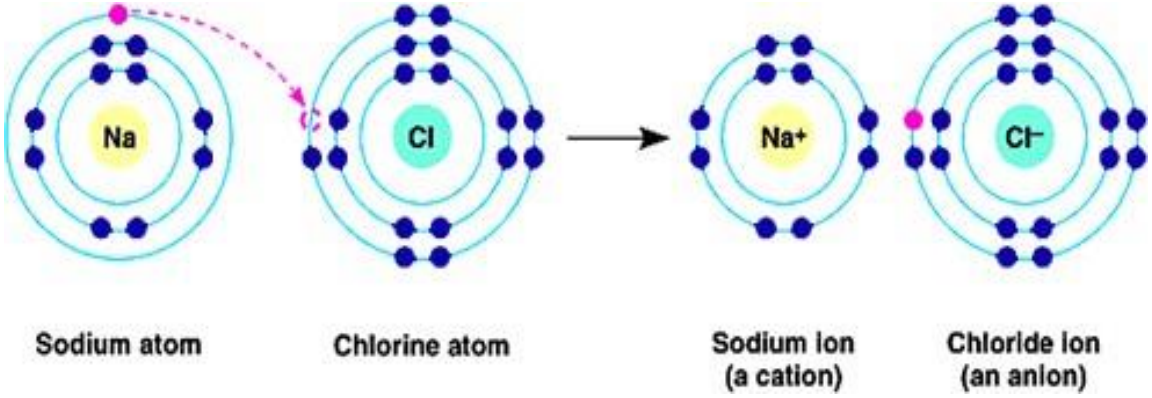
Strength is governed by a general law:

$$F = K * \frac{Q_1 * Q_2}{R^n * D}$$

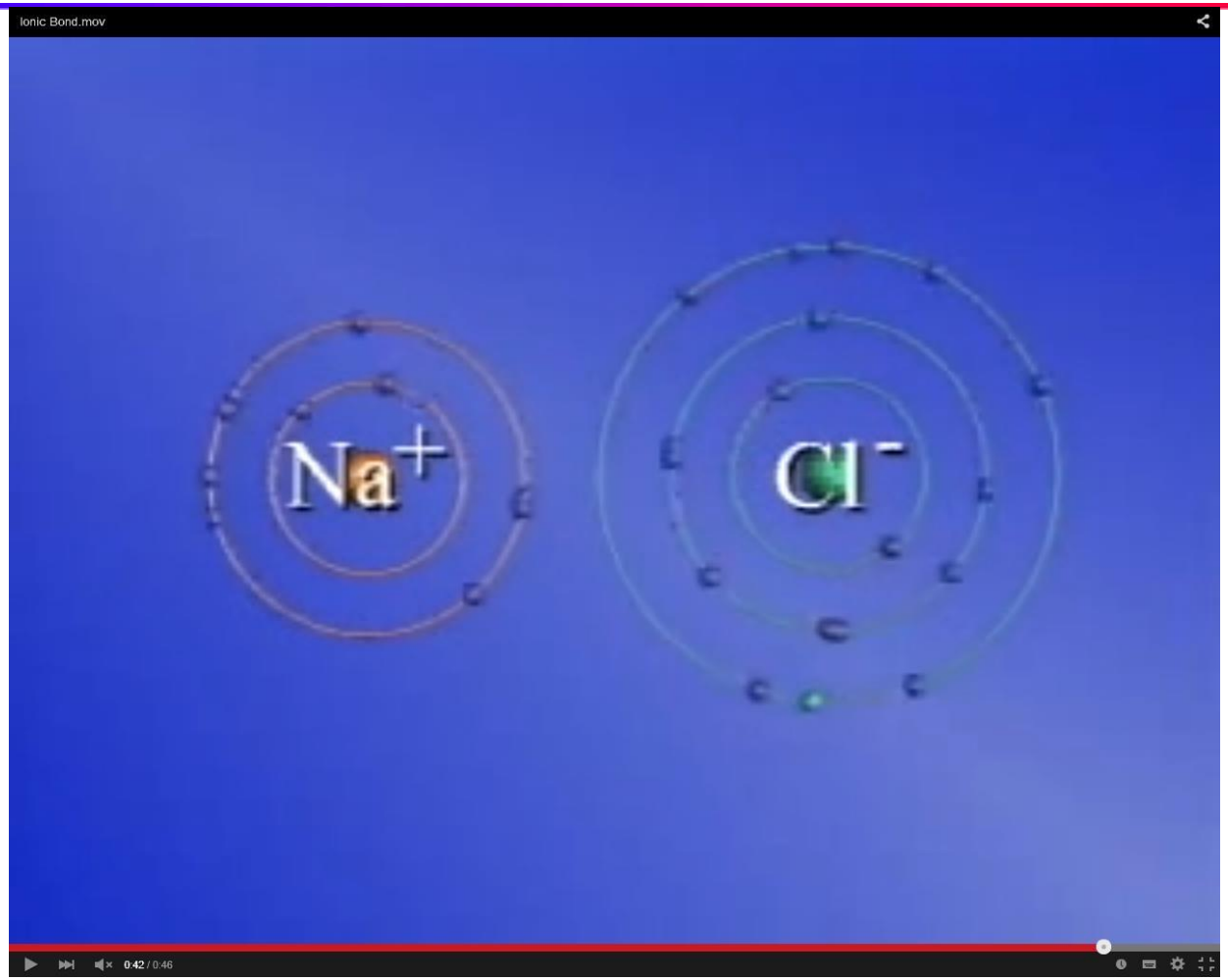
Qs are charges, R is distance between them, D = dielectric of the medium, k =constant, and n=1 or 2, depending on the nature of interaction.

D = 1 in vacuum, 2- 3 in grease, and 80 in water

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



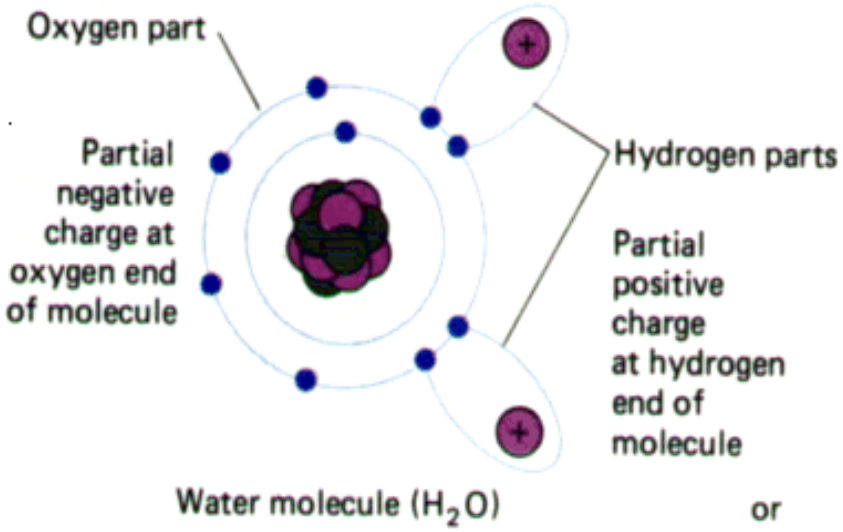
Ionic bond



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

The 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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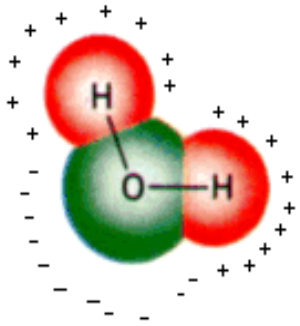

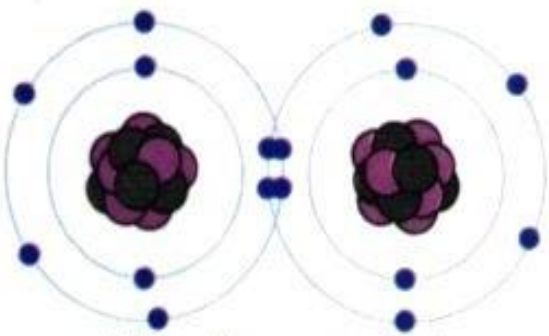

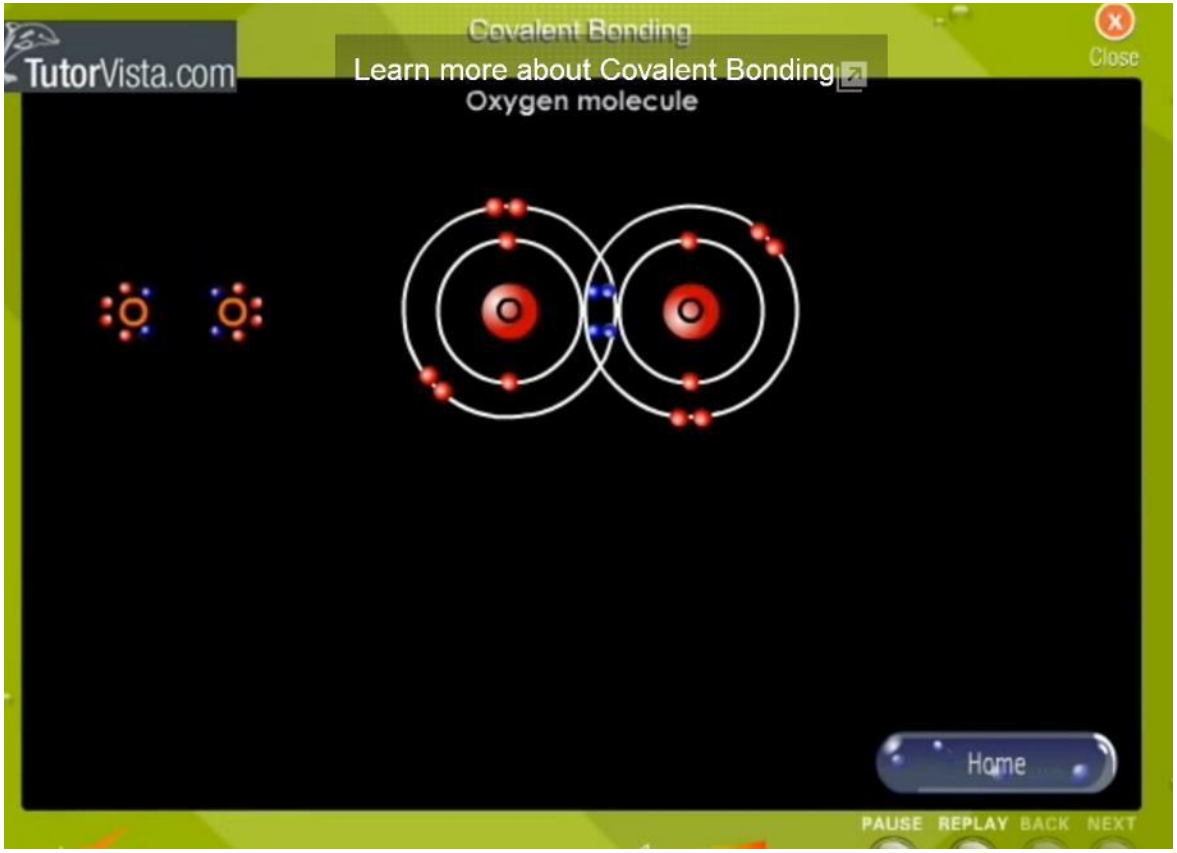

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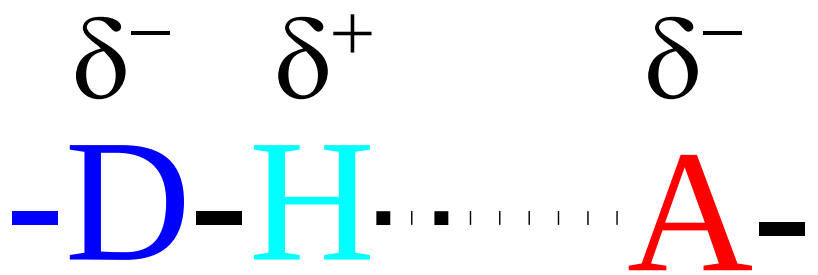
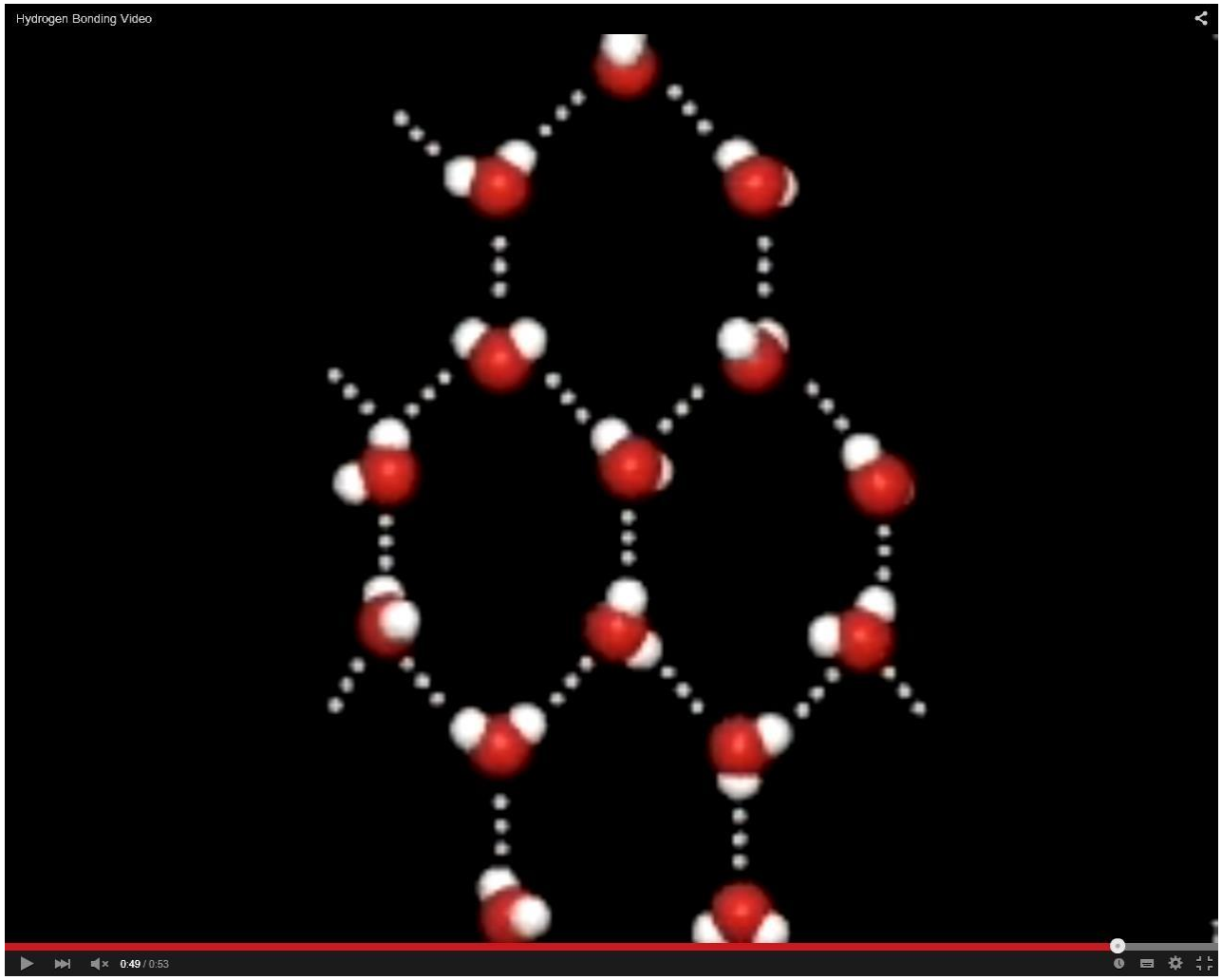
The Hydrogen Bond (Cont.)

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



- (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

The Hydrogen Bond



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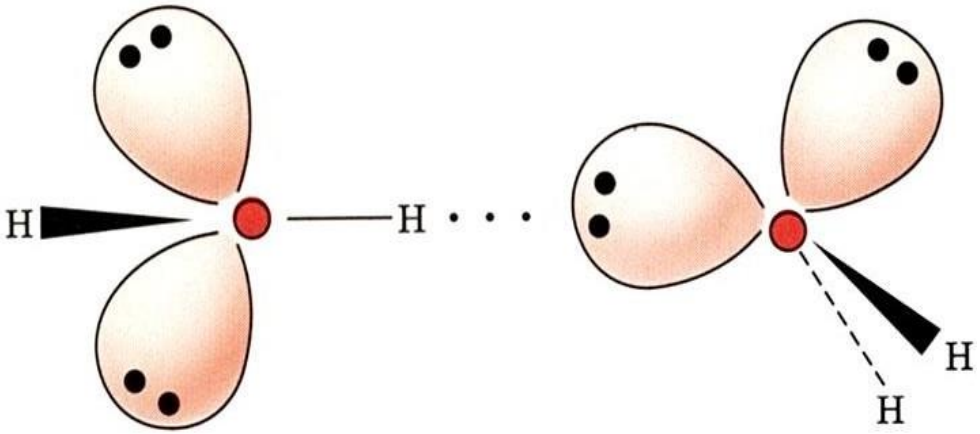
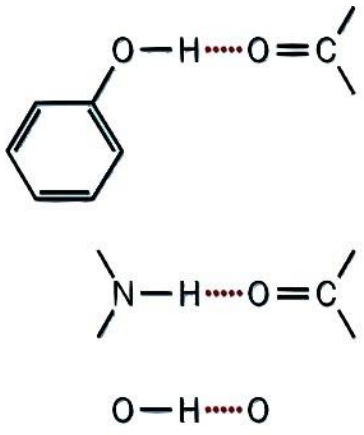
Strength of H-bond

- H-Bond is a type of dipole-dipole interaction, but can be considered as a weak ionic bond:
  - Distance (R3) is a major factor
  - D is also a major contributor in biological systems
  - Very strong angle dependence

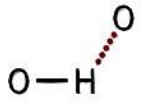
$$F = K^* \frac{Q_1 * Q_2}{R^3 * D}$$

Lone-Pair Electrons of Water





Strong hydrogen bonds



Weak hydrogen bond

Hydrophobic Interactions

Non- polar groups cluster together

$$\Delta G = \Delta H - T\,\Delta S$$

- The most important parameter for determining the stability of proteins, membrane, nucleic acids
- Very important consideration for many biochemical methods and interactions
- Entropy order- disorder. Nature prefers to maximize entropy "maximum disorder"
- Structure formations are driven by water interactions

Van Der Waals Attraction

Non-specific attractions (induced dipole-induced dipole) most effective near the contact distances. $F \sim 1/R^6$

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

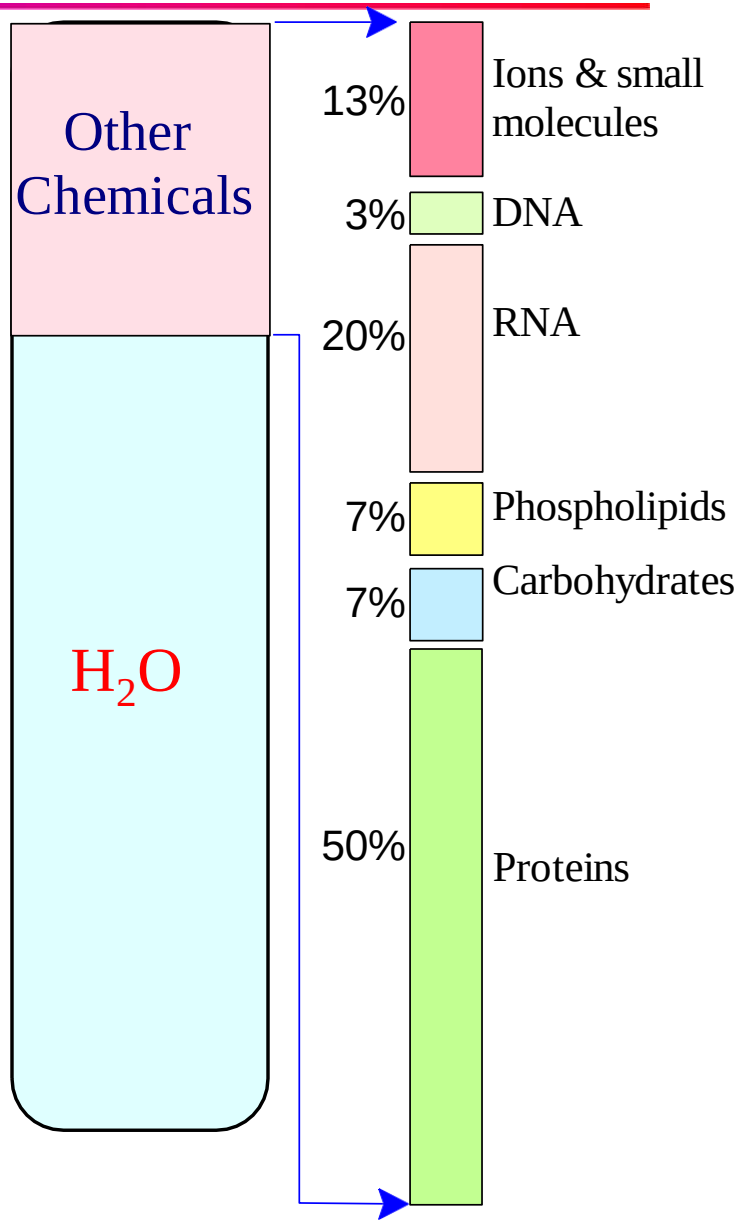
- Becomes important when many atoms come in contact as in steric complementarities as in:
  - a) antibodies
  - b) enzyme substrate

Basic Materials in Cell

All cells have these basic common materials:

- H_2O: The solvent of life. All cellular reactions are carried out in aqueous environment.
  - All chemical reactions in a cell make up its METABOLISM.
- And 4 Major macromolecules:
  1. Proteins (the cell work horses)
  2. Nucleic Acids (genetic materials)
  3. Carbohydrates (many functions)
  4. Lipids (membrane and energy source and depot)

  Notice that all macromolecules are organic compounds (i.e. contain carbon).
- Plus ions & metabolites (small amounts)

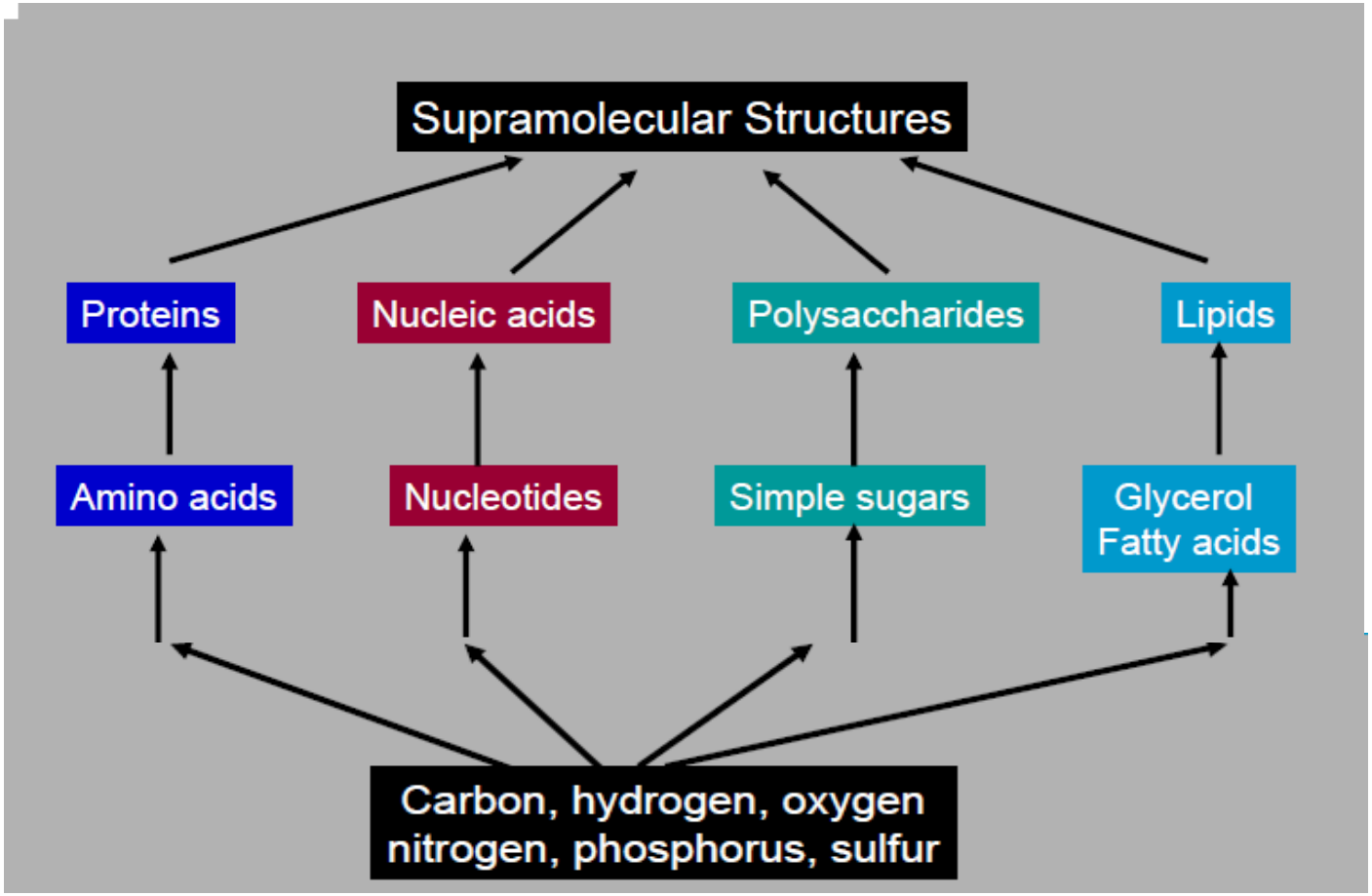


The 4 Major macromolecules

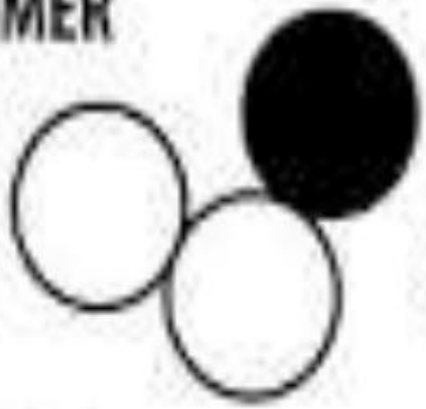
There are 4 major macromolecules (polymers) in the cell formed by condensation of smaller building blocks (monomers) by the removal of H_2O (dehydration):

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

CHNOPS vs monomer vs macromolecules

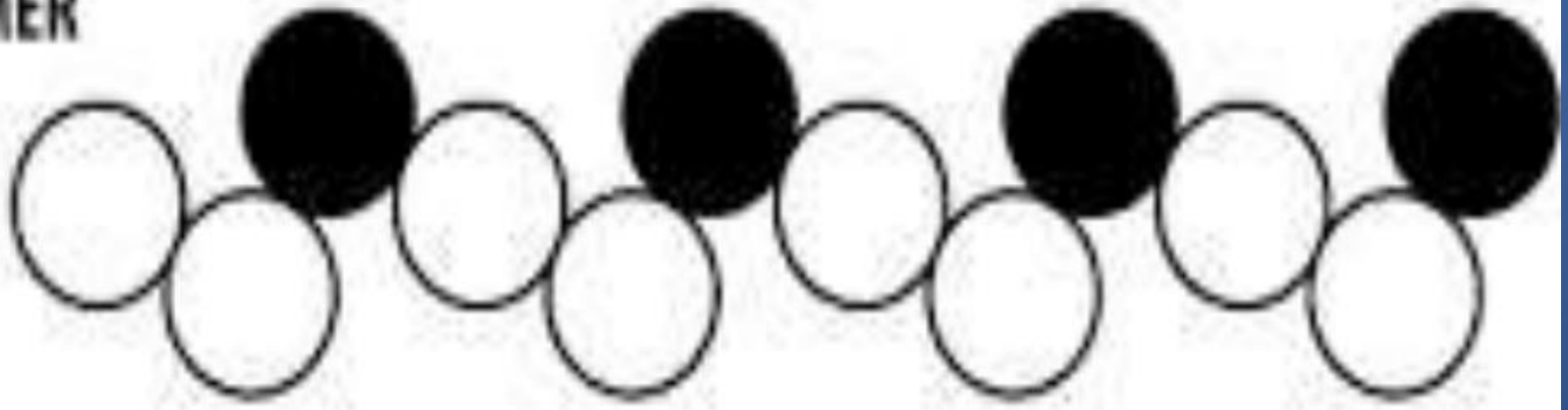


MONOMER



A monomer is a small molecule.

POLYMER



A polymer is a long-chain molecule made up of a repeated pattern of mon

* Many Important Biomolecules are Polymers

	lipids	proteins	carbo	nucleic acids
monomer	fatty acid	amino acid	glucose	nucleotide
polymer	phospholipid	protein subunit	cellulose	DNA
supramolecular structure	membrane	protein complex	cell wall	chromosome

Biomolecules

Carbohydrates are made from monomers called monosaccharides.

- Examples of this monosaccharide include

glucose ($C_6H_{12}O_6$)

fructose ($C_6H_{12}O_6$)

Sugars

- Carbohydrates most abundant organic molecule found in nature.
- Initially synthesized in plants from a complex series
- of reactions involving photosynthesis.
- Basic unit is monosaccharaides.
- Monosaccharaides can form larger molecules e.g. glycogen, plant starch or cellulose.
- Functions
- Store energy in the form of starch (photosynthesis in plants) or glycogen (in animals and humans).
- Provide energy through metabolism pathways and cycles.
- Supply carbon for synthesis of other compounds.
- Form structural components in cells and tissues.

Lipids

Lipids are usually made from one molecule of glycerol combined with other molecules.

- For example in triglycerides, the main group of bulk lipids, there is one molecule of glycerol and three fatty acids.

Fatty acids

- Are monocarboxylic acid contains even number C atoms
- Two types: saturated (C-C sb) and unsaturated (C-C db)
- Fatty acids are components of several lipid molecules.
- E,g. of lipids are triacylglycerol, streiods (cholestrol, sex hormones),

fat soluble vitamins.

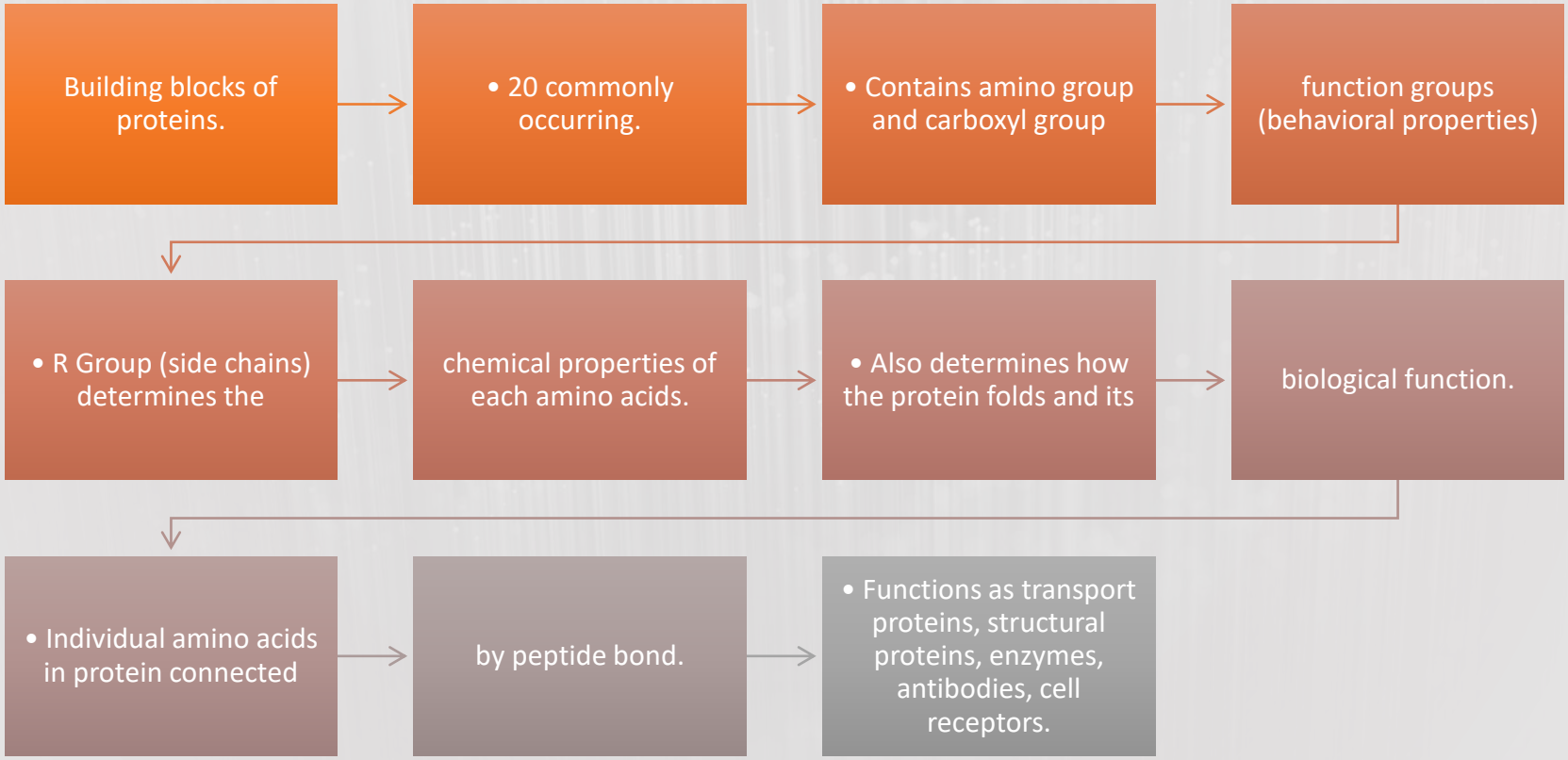
- Functions
- Storage of energy in the form of fat
- Membrane structures
- Insulation (thermal blanket)
- Synthesis of hormones

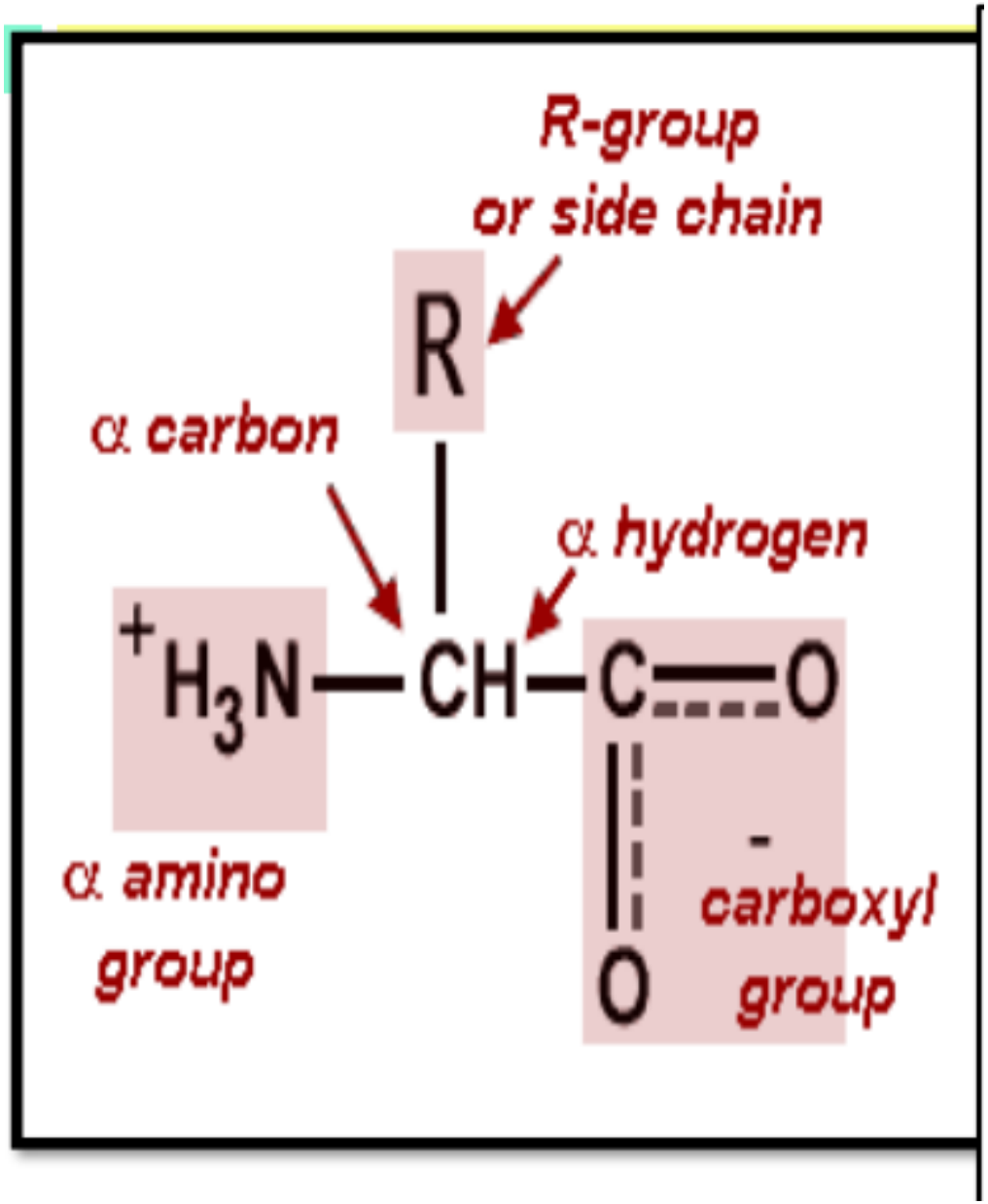
Proteins

Proteins are very large molecules made from monomers called amino acids.

- There are 20 standard amino acids.
- When amino acids combine, they form a special bond called a peptide bond and become a polypeptide, or protein.

Amino Acids


Building blocks of proteins.
• 20 commonly occurring.
• Contains amino group and carboxyl group
function groups (behavioral properties)
• R Group (side chains) determines the
chemical properties of each amino acids.
• Also determines how the protein folds and its
biological function.
• Individual amino acids in protein connected
by peptide bond.
• Functions as transport proteins, structural proteins, enzymes, antibodies, cell receptors.

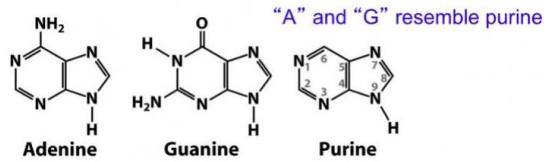


Nucleic acids

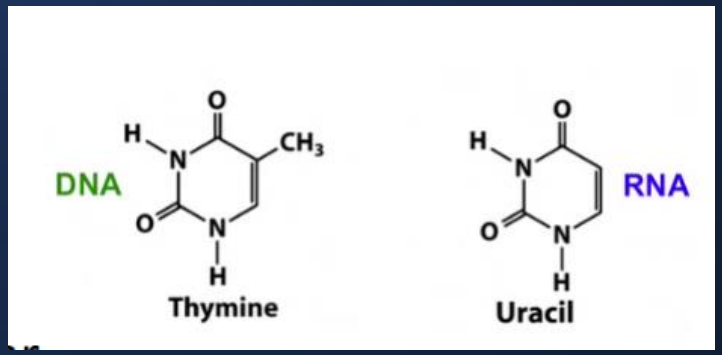
- Nucleic acids are the molecules that make
- up DNA, (to store their genetic information).
- • The most common nucleic acids
- are Deoxyribonucleic acid (DNA)
- and Ribonucleic acid (RNA).

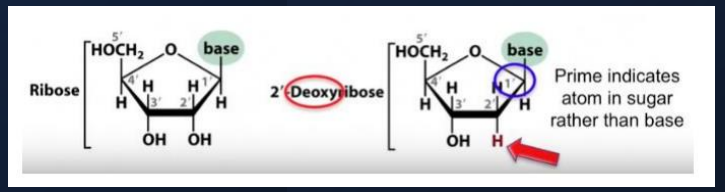
Nucleotides

- Nucleic acids are polymers of nucleotides
- • Identity of nucleotide determined by base

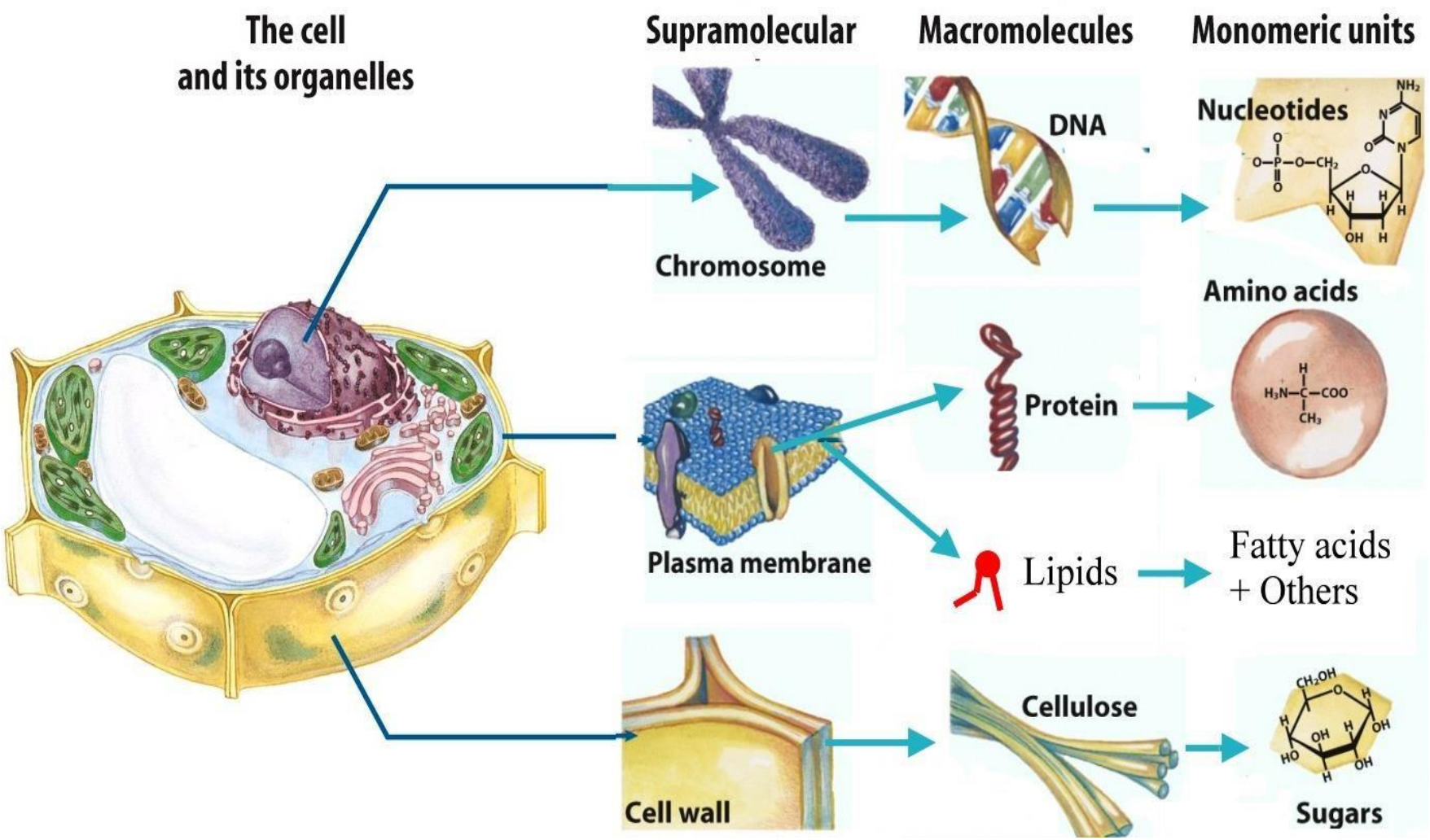


DNA&RNA


DNA
Thymine
RNA
Uracil


Ribose
base
2' Deoxyribose
base
Prime indicates atom in sugar rather than base

Structural Levels of Cell Molecules



Biochemical Reactions

- Metabolism: total sum of the chemical reaction happening in a
- living organism (highly coordinated and purposeful activity)

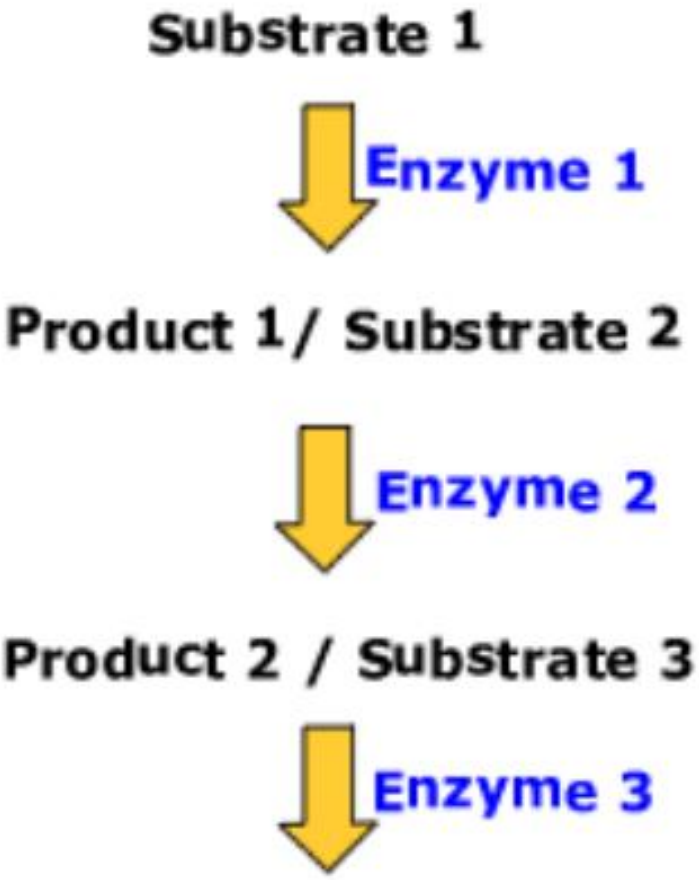
- a. Anabolism- energy requiring biosynthetic pathways
- b. Catabolism- degradation of fuel molecules and the production of
- energy for cellular function

All reactions are catalyzed by enzymes

- • The primary functions of metabolism are:
- a. acquisition & utilization of energy
- b. Synthesis of molecules needed for cell structure and
- functioning (i.e. proteins, nucleic acids, lipids, & CHO
- c. Removal of waste products

Metabolism

- It is a series of chemical reactions inside the cell with the help of different types of enzymes. The
- chemical compounds involved in this process known as metabolites. This process can be linier
- (Glycolysis), cyclic (Krebs cycle) or spiral (Fatty acid synthesis).
- It’s divided in two pathways on the basis of synthesis and breakdown of compounds.
- (1) Anabolic pathway: It’s involve synthesis of compounds and usually endergonic in nature.
- (2) Catabolic pathway: Its involve breakdown of compounds and usually exergonic in nature.



Characteristics of metabolic pathway are:

(1) They are usually irreversible.

(2) Those in eukaryotic cells occurs in specific cellular locations.

(3) Each one has a first committed step.

(4) They are regulated. Regulation occurs in following different ways :

(i) Availability of substrate, the rate of reaction depends on substrate concentration.

(ii) Allosteric regulation of enzyme by a metabolic intermediate or co-enzyme.

(iii) By extra cellular signal such as growth factors and hormones that act from outside the

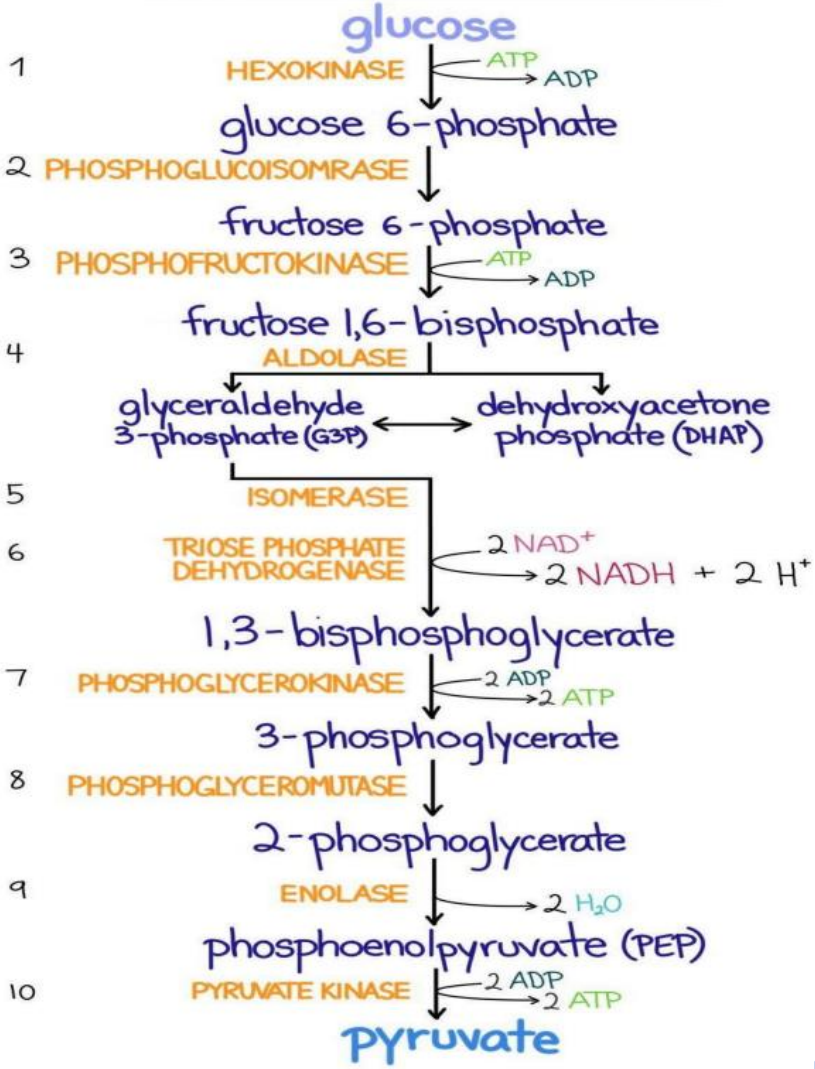
cell in multicellular organisms changes the cellular concentration of a enzyme by

altering the rate of its synthesis or degradation

Glycolysis

- Glycolysis means lysis or breakdown of sugar (Glucose).it's also known as Embden-Meyerhof pathway.
- Glycolysis is a catabolic process which take place inside the cytosol of the cell.
- Glycolysis is anoxidative process in which one mole of glucose is partially oxidized in to two mole of pyruvate in a series reactions
- It is a unique pathway that occurs in both aerobic and anaerobic condition.
- On the basis of energy utilization and energy production further classified in two phase
- (1) Preparatory phase: The first to five steps are included in this phase because in these steps utilization of
- energy take place.
- (2) Payoff phase: Six to last steps are included in this phase because in these steps generation of energy
- take place

GLYCOLYSIS

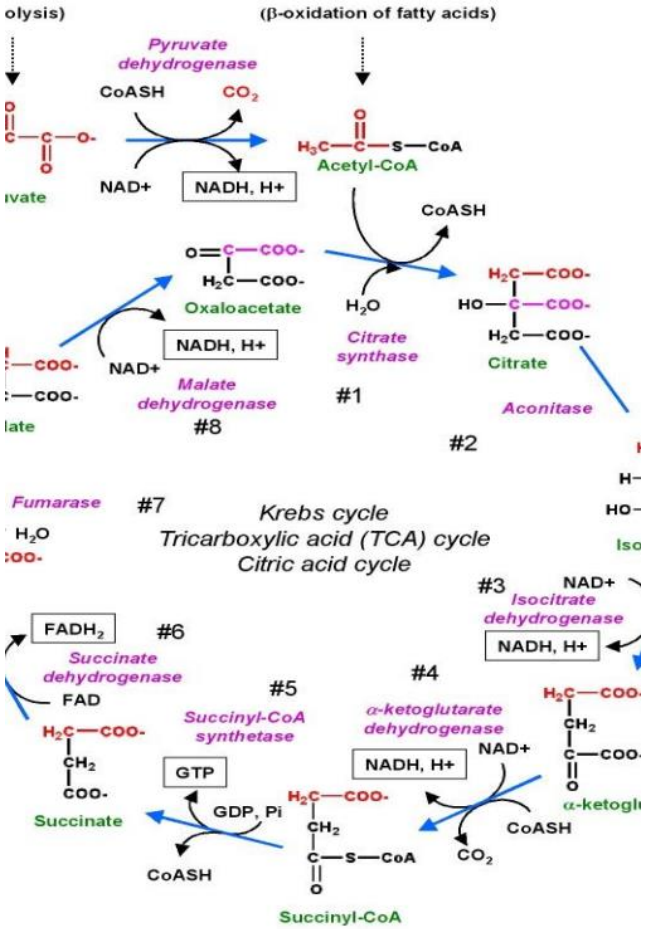


Formation of Acetyl CoA:

- Pyruvate formed in glycolysis enters the mitochondrial matrix. It undergoes oxidative
- decarboxylation to form two molecules of Acetyl CoA. The reaction is catalysed by pyruvate
- dehydrogenase enzyme.

$$2Pyruvate + 2NAD^{+} + 2CoA \xrightarrow{Pyruvate\ dehydrogenase} 2AcetylCoA + 2NADH + CO_2$$

Krebs cycle (TCA or Citric Acid Cycle)

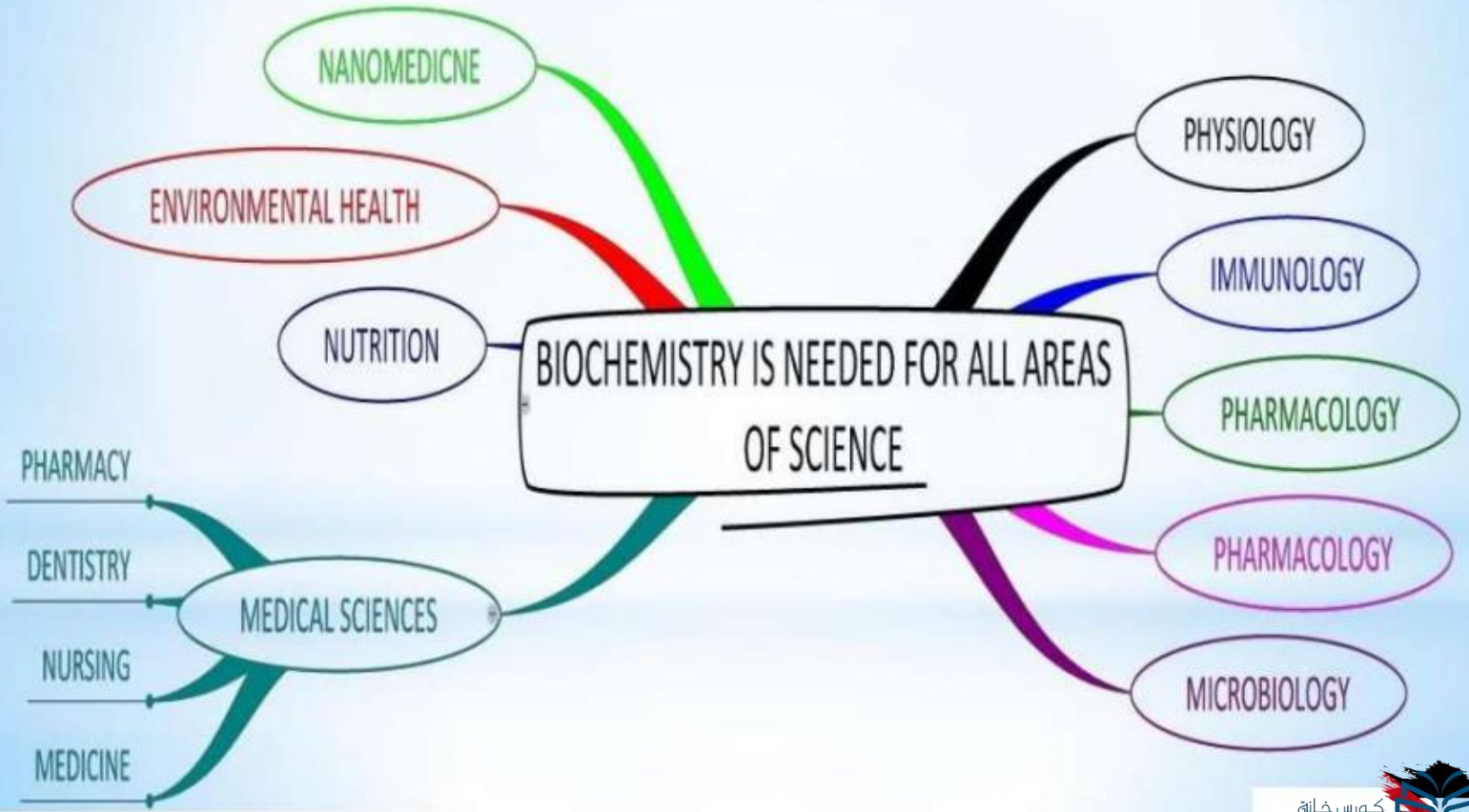


Summary

کورس خانہ
Course Khana

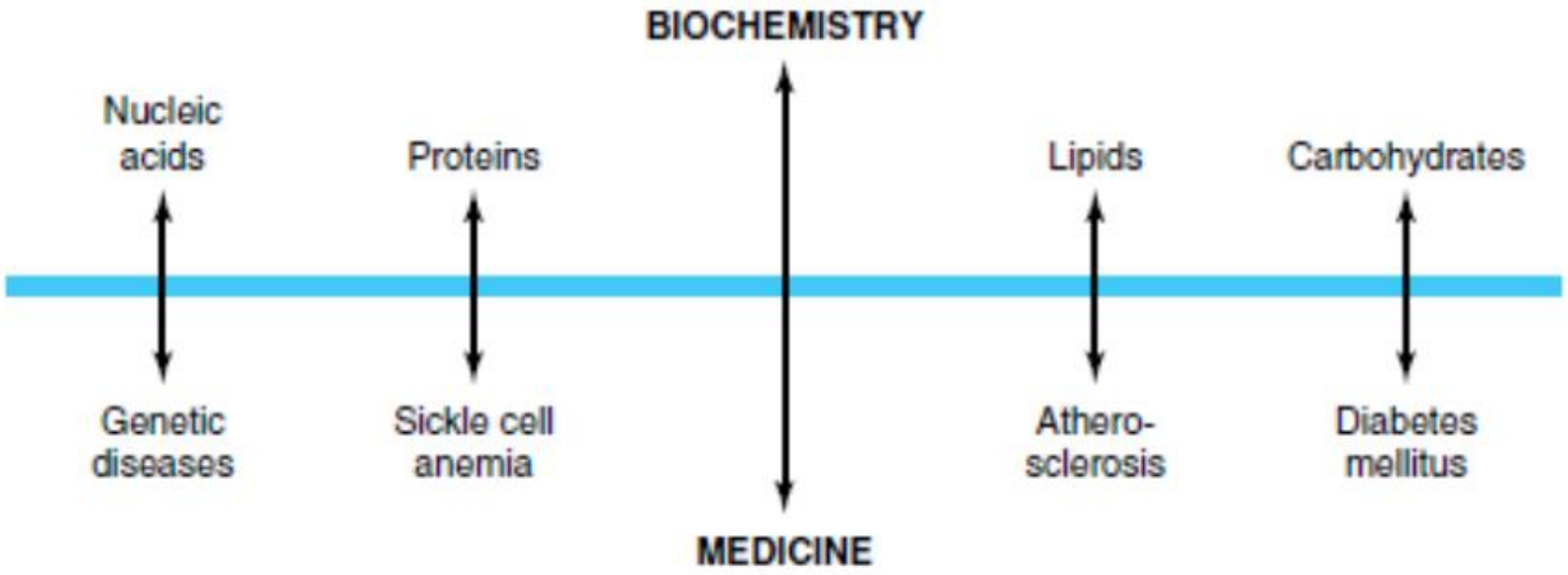
- Scop and Applications of Biochemistry

BIOCHEMISTRY IS NEEDED FOR ALL AREAS OF SCIENCE



Relationship between biochemistry & medicine

- The interrelationship of biochemistry and
- medicine is a wide, two-way street.
- Biochemical studies have illuminated many aspects of health and disease, and conversely, the study of various aspects of health and disease has opened up new areas of biochemistry.



Examples of the two-way street connecting biochemistry and medicine. Knowledge of the biochemical molecules shown in the top part of the diagram has clarified our understanding of the diseases shown in the bottom half—and conversely, analyses of the diseases shown below have cast light on many areas of biochemistry. Note that sickle cell anemia is a genetic disease and that both atherosclerosis and diabetes mellitus have genetic components.

Most & perhaps all disease has a biochemical basis

THANK YOU