Biochemistry

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Water: The Solvent for Biochemical Reactions

Introduction:

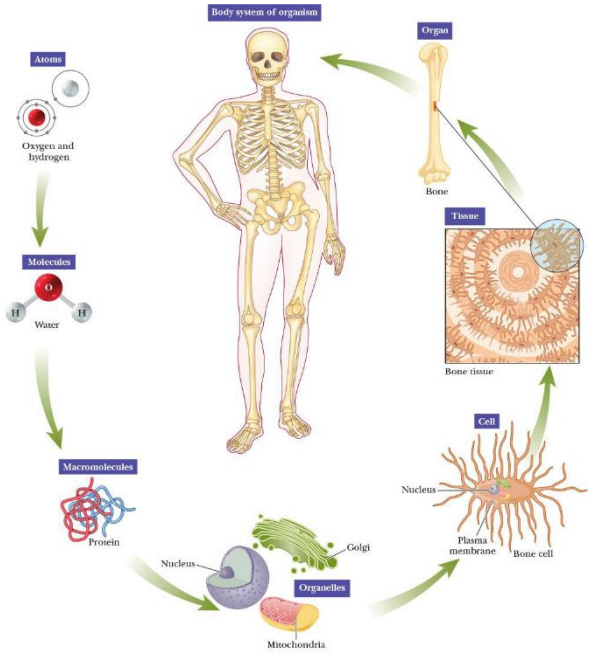
- **Biology**: Natural science is concerned with the study of life and living organisms, including their structure, function, growth, evolution, distribution, identification and taxonomy.

- **Chemistry**: Natural science that studies non-living systems, including their:
  - The composition, structure, properties and change of matter.
  - Properties of individual atoms.
  - How atoms form chemical bonds to create chemical compounds.
  - The interactions of substances through intermolecular forces that give matter its general properties.
  - The interactions between substances through chemical reactions to form different substances.

- **Biochemistry/Biological chemistry**
  - Combines biology and chemistry
  - Chemistry of life
    ➔ It is the scientific discipline that seeks to explain life at the molecular level.
  - It uses the tools and terminology of chemistry to describe the various attributes of living organisms.

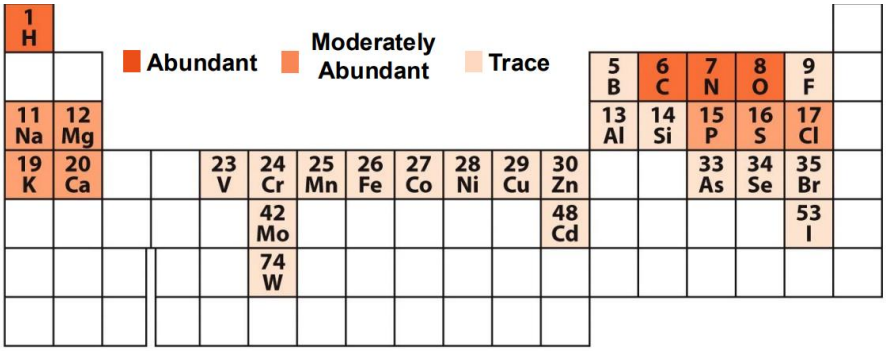
Biochemistry and Life

- Organism can be studied using the methods of chemistry and physics as all living things (from simplest bacterium to the human being.
- Biochemistry - Multidisciplinary in nature
  - Biology and chemistry
  - Uses results from many sciences to answer questions about the molecular nature of life processes
- Levels of Structural Organization in the Human Body



Elements Found in Biological Systems

- Biological molecules are mainly composed of **H, C, N, and O**.
- Other elements are also necessary for life.



- Most of the essential elements in biological systems are nonmetals.
- General properties of nonmetals
  - H, O, N, F, Cl are gases in the elemental state.
  - All nonmetallic elements are poor conductors of heat and electricity, i.e., exhibit both positive and negative oxidation numbers.
  - More electronegative than metals
  - Concentrated in the upper right-hand corner of the periodic table (except for H).
  - Compounds formed by the combination of metals and nonmetals tend to be ionic, having a metallic cation and a nonmetallic anion.

- **Abundance of Important Elements**
  - Oxygen is the most abundant element by mass in biological systems, making up about 65% of the human body → followed by carbon (18.5%), → hydrogen (9.5%), → and nitrogen (3.2%).
  - Together, these four elements constitute over 95% of the mass in living organisms.

Oxygen:

- ${}_8O$: [He] $2s^2\ 2p^4$
- Diatomic molecules O_2
- By mass, oxygen is the third-most abundant element in the **universe**, after hydrogen and helium.
- Only 21% of the air we breathe is oxygen, nitrogen and other gasses make up the majority.
- Highly reactive nonmetal, and a strong oxidizing agent that readily forms oxides with most elements as well as with metabolic breakdown of food molecules
- Oxygen is normally found in an oxidation state of -2.
- Without oxygen a human being cannot survive for more than a few minutes.

Carbon

- $_6C$: $1s^2\ 2s^2\ 2p^2$
- Is the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen.
- Has the unique ability to form long chains (consisting of more than 50 C atoms) and stable rings with five or six members.
- Forms unusually strong C-C single bonds, C=C double bonds, and carbon-carbon triple bonds.
- The electronegativity of carbon is too small to allow carbon to form C^{4-} ions with most metals and too large for carbon to form C^{4+} ions when it reacts with nonmetals.
    - ➔ Carbon therefore forms covalent bonds with many other elements.
- Forms strong double and triple bonds with several other nonmetals, including N, O, P, and S.
    - This versatility (ability to form many bonds)
        - ➔ Enables carbon to form the many different shapes adopted by the complex organic compounds that make up the bodies of animals and plants.
        - ➔ Some of the carbon chains needed for life are millions of atoms long.
            - ⇨ such as the glucose ring (along with a single oxygen molecule),
            - ⇨ the backbone of the polypeptide chains that form the different proteins in the bodies of living things
- Carbon's versatility is the basis of many of the complex organic compounds vital to life.

Hydrogen

- $_1H$: $1s^1$.
- It contains only one proton and one electron.
- Elemental hydrogen is diatomic molecule (H2)
- Is a colorless, odorless, and nonpoisonous gas
- It is the most abundant element in the universe
- It is an important constituent of water, proteins, carbohydrates, fats etc.
- At 1 atm, liquid hydrogen gas has a boiling point of -252.9 °C
- Have three oxidation states:
    - H+ ion, oxidized by losing electrons.
    - Neutral H: found in elemental hydrogen (H_2 gas).
    - H- (hydride ion): reduced by gaining an extra electron.

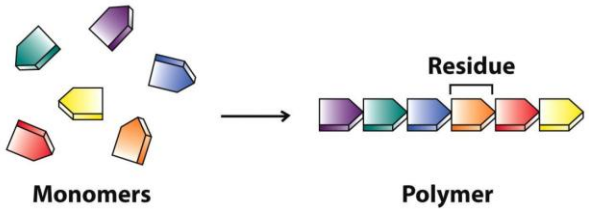
- Is found in many covalent compounds: CH_4 (methane), H_2O (water), NH_3 (ammonia), HCl.
- It has a unique capacity for hydrogen-bond formation.

Nitrogen

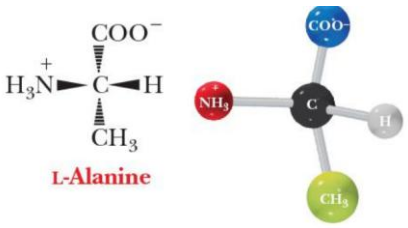
- $_7N$: $1s^2\ 2s^2\ 2p^3$
- About 78% of air by volume is nitrogen
- It is a component of proteins and nucleic acids
- N_2 molecule contains triple bond and very stable with respect to dissociation into atomic species.
- Nitrogen forms many compounds with hydrogen and oxygen in which the oxidation number varies from -3 to +5.
- Elemental nitrogen in the atmosphere cannot be used directly by either plants or animals and must be converted into a reduced (or 'fixed') state to be useful for higher plants and animals **(Nitrogen Fixation).**

Major Groups of Biochemicals

- Living cells include large molecules, such as proteins, nucleic acids, polysaccharides, and lipids.
- Polymers: Poly = many, meros = parts.
  - Macromolecules formed by the bonding of smaller units
- Monomers: Mono + meros, single + part
  - Small molecules that may bond to many others to form a polymer
    - ➔ Amino acids ⟶ Proteins
    - ➔ Nucleotides ⟶ Nucleic acids
    - ➔ Monosaccharides ⟶ Polysaccharides
    - ➔ Glycerol and 3 fatty acids ⟶ Lipids

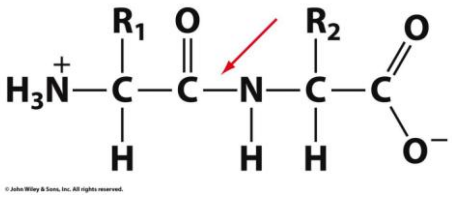


- Biochemistry involves the study of 4 types of molecules.
  - Proteins.
  - Nucleic Acids
  - Carbohydrates
  - Lipids



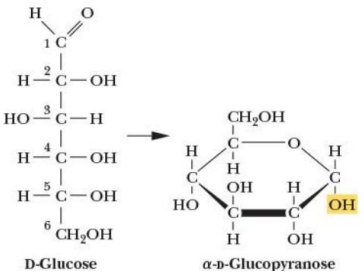
Protein

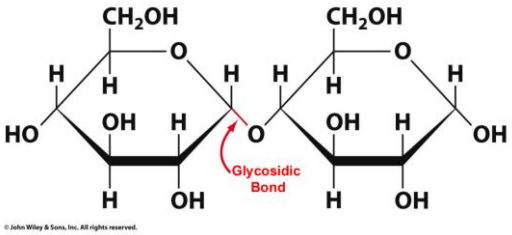
- Amino acid:
  - Structure:
    - ➔ Central carbon atom is bonded to a carboxyl group, an amino group, a hydrogen, and the R group (variable group).
  - They get their name from the fact that they all contain an amino group and carboxyl group.
  - It is the differences between the R groups that make each amino acid unique.
  - Amino acids link to form polypeptides and proteins
  - Amino acid residues are connected via peptide bonds.
  - Polypeptide sequences are always read from the N terminus to the C terminus



Carbohydrates

- Compounds made up of carbon, hydrogen, and oxygen
- General formula of (CH2O)n , where n is at least 3
- Simple form are called monosaccharides, or sugars
- Glucose is the most common monosaccharide
- Simple sugars make up larger polymers (energy storage and structural components).





Nucleotides

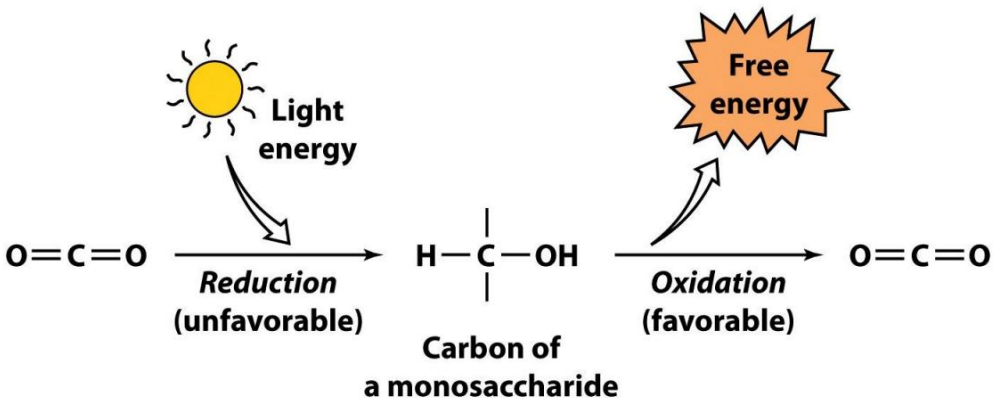
- Basic unit of the hereditary materials DNA and RNA
- Form the molecular currency of the cell, adenosine triphosphate (ATP)
- Composed of a five-carbon sugar, a nitrogen-containing ring, and one or more phosphate groups
- Nucleotide residues link via phosphodiester bonds.
- Polymers of nucleotides yield nucleic acids.

Lipids

- Lipids (fats) have a variety of structures.
- Poorly soluble in water because they are composed of long chains of hydrocarbons
- Example of a simple lipid - Palmitic acid, which has 16C

Source of Energy in Life Processes

- All cells require energy to function
- Sun - Ultimate source of energy for all life on Earth
- Photosynthetic organisms use light energy to drive the energy-requiring synthesis of carbohydrates from carbon dioxide and water (reduction)
- Nonphotosynthetic organisms consume carbohydrates and use them as energy sources (oxidation)
- Hydrolysis of ATP is a part of many biochemical processes



Reduction = gain of electrons **Oxidation = loss of electrons**

Basics of Thermodynamics:

- The energy relevant to biochemical systems is called the Gibbs free energy (G) is determined by its enthalpy and entropy.

🔹 1. Enthalpy (H)

- **التعريف :**كمية الحرارة أو المحتوى الحراري للنظام.(total heat content)
- **المعنى :**تقيس الطاقة الحرارية الكامنة في الروابط الكيميائية والحرارة الممتصة أو المنبعثة أثناء التفاعل.
- **الوحدة** : $J \cdot mol^{-1}$

🔹 2. Entropy (S)

- **التعريف :**مقياس لدرجة **العشوائية أو الاضطراب (disorder)** في النظام.
- **المعنى :**كلما زادت العشوائية زادت قيمة الإنتروبيا.(S)
- **الوحدة** : $J \cdot K^{-1} \cdot mol^{-1}$

🔹 3. Gibbs Free Energy (G)

- **التعريف :**مقياس للطاقة الحرة التي يمكن للنظام استخدامها لإجراء عمل.(work)
- **العلاقة :**تعتمد على كل من **H**و **S**من خلال المعادلة:

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

- **الوحدة** : $J \cdot mol^{-1}$
- **المعنى:**
  - إذا ⟶ **ΔG < 0** التفاعل تلقائي.(spontaneous)
  - إذا ⟶ **ΔG > 0** غير تلقائي.
  - إذا ⟶ **ΔG = 0** في حالة توازن.