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BIOLOGICAL AND BIOORGANIC Chemistry

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BIOORGANIC CHEMISTRY

National textbook

Third edition

Approved by the Ministry of Education and Science of Ukraine
as a textbook for students of higher medical education establishments

Published pursuant to the Order of the Ministry of Health of Ukraine
No. 502 as of 22 June 2010 as a national textbook for students
of higher medical education establishments

Recommended by the Academic Council of Bogomolets National
Medical University as a textbook for students of higher medical
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The textbook contains the information about the structure, chemical properties and biological role of organic compounds which take part in human metabolic processes: low-molecular bioregulators (vitamins, hormones, other natural and synthetic biologically active compounds, including certain medications and toxic compounds) and biopolymers (carbohydrates, proteins and nucleic acids).

This textbook is recommended for students and teachers of higher medical education establishments.

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ABBREVIATIONS

ACE — Angiotensin-converting enzyme
AIDS — Acquired immune deficiency syndrome
ADP — Adenosine diphosphate
AMP — Adenosine monophosphate
ATP — Adenosine triphosphate
ASA — *n*-Aminosalicylic acid
API — Active pharmaceutical ingredients
BAL — British anti-Lewisite
CDI — 1,1-Carbonyl-dimidazole
DDT — Dichlor-diphenyl-trichlor-methyl-methane
DMSO — Dimethyl sulfoxide (Dimexidum)
DNA — Deoxyribonucleic acid
DNFB — 2,4-Dinitrofluorobenzene
DNP-derivative — Dinitrophenyl-derivative
FAD — Flavin adenine dinucleotide
GABA — gamma-Aminobutyric acid
HIL — Human immunodeficiency virus
HFA — Higher fatty acids
IAA — Indoleacetic acid
IEP — Isoelectric point
IPA — Indolepyruvic acid
IUPAC — International Union of Pure and Applied Chemistry
iRNA — Informational ribonucleic acid
LPO — Lipid peroxidation
mRNA — Messenger ribonucleic acid
NAD⁺ — Nicotinamide adenine dinucleotide
PABA — Para-aminobenzoic acid
PAS — Para-aminosalicylic acid
PG — Prostaglandin
PTH-derivative — 3-Phenyl-2-thiohydantoin derivative
PUFAs — Polyunsaturated fatty acids
SPSP — Solid-phase synthesis of polypeptides
TAC — tricarboxylic acid cycle (the Krebs' cycle)
tRNA — Transfer ribonucleic acid

PREFACE

The academic discipline “Biological and Bioorganic chemistry” for students of medical and stomatological faculties is structured into three modules. The first involves the study of Bioorganic chemistry, which creates the necessary theoretical base for successful learning of Biological chemistry. The study of these two disciplines will help students at the molecular level to learn such medico-biological and medical subjects as “Physiology”, “Pharmacology”, “Internal medicine”, “Genetics”, “Allergology” and others. In recent years the teaching in higher medical institutions was transferred to the credit-modular system, therefore the curriculum in all disciplines was radically changed. So, the creation of the new national textbooks is important.

“Bioorganic chemistry” by B.S. Zimenkovsky, V.A. Muzychenko was taken into consideration when writing this tutorial, and it was created in accordance with modern pedagogical technologies.

In the textbook the presentation of factual material is preceded by the consideration of the theoretical aspects regarding nomenclature, structural and spatial isomerism of bioorganic compounds, electronic submissions in bioorganic chemistry, nature of chemical bonds, acidity and basicity of bioorganic compounds, classification of reagents and chemical reactions and, on the basis of this knowledge, about their mechanisms. This approach was suggested by Professor N.A. Tyukavkina (“Bioorganic chemistry”. — M. : Medicine, 1985). As evidenced by years of teaching experience of bioorganic chemistry, this sequence of presentation is fully justified, because it facilitates the student to learn the material on the structure and chemical behavior of metabolic products.

With the aim of creating the necessary theoretical base to explore these such important and difficult to study bioorganic compounds, as heterofunctional, heterocyclic compounds, carbohydrates, proteins, nucleic acids, terpenes, carotenoids, steroids etc. at the beginning of the textbook there are more simple classes of organic compounds — hydrocarbons, their halogen and hydroxyl derivatives, aldehydes, ketones, carboxylic acids, and so on.

For increasing the professional motivation of students to master the knowledge of bioorganic chemistry in the textbook the medical terminology is often used with brief explanations; considerable attention is paid to the consideration of structures that are not only conventional representatives of a certain class of organic compounds, but also active participants in metabolic processes or important medicines. In this aspect chemical properties of all classes of organic compounds are represented. The maximal attention is paid to the reactions and chemical properties of compounds, which take place in the human body. In order to increase the professional interest of students in studying such important

ABBREVIATIONS

chapters as “Proteins”, “Lipids” and “Nucleic acids” at the beginning of each chapter there are data on the biological role of these compounds in the body.

For better understanding by students the biological role of various metabolites the Introduction contains a brief summary of some bioregulators (vitamins, hormones, enzymes, and coenzymes) to master certain classes of bioorganic compounds.

The chemical classification of bioorganic compounds is the basis used to installate this tutorial. In this regard such typical for the customary publications themes as “Vitamins”, “Coenzymes” and “Antibiotics” were omitted. Some information about these metabolites was included into the chapters describing the corresponding classes of bioorganic compounds. This order of presentation will facilitate a deeper and more complete understanding of biochemical processes occurring in the body.

To avoid the fragmentation of knowledge the individual chapters were interconnected by numerous links to previous or next material. This will help the students to learn Bioorganic chemistry as a subject in general.

Due to the wide use of computer technology a simplified way of writing structural formulae has increasingly adopted in modern chemical literature. That’s why the quantity of simplified formulae were being expanded gradually from section to section to adapt the student for modern requirements.

There are also models of the key molecules of biological structures that will help students to solve the issues concerning their structure. In connection with the transition to the credit-modular system of teaching after each chapter there are tasks and tests for self-control. It will facilitate the student adaptation to the test form of checking the knowledge in practical classes and during compilation of the final modules.

INTRODUCTION

THE SUBJECT, HISTORY OF BIOORGANIC CHEMISTRY DEVELOPMENT, ITS VALUE AS A SCIENCE

All bioorganic compounds can be divided into biopolymers and bioregulators.

Biopolymers include complex carbohydrates, proteins and nucleic acids. Vitamins, hormones, some synthetic and natural biologically active compounds, including medicines, belong to **bioregulators**.

Vitamins are bioorganic compounds found in food in very small quantities. They are not a source of energy, but without them the normal functioning of the body is impossible. The lack of vitamins in the body causes metabolic disorders called **hypovitaminosis**, and decrease of necessary amount of vitamins is called **avitaminosis**, or **vitamin deficiency**. Vitamins are divided into water- and fat-soluble.

Hormones are biologically active compounds that are produced and secreted into the bloodstream by the endocrine glands. They affect the functions of the corresponding organs, activating or inhibiting their enzymatic processes. There are about 30 hormones produced by the human or mammal organism.

Biopolymers and **bioregulators** are involved in the processes of substances exchange, the so-called **metabolism**. Metabolism occurs with the participation of enzymes.

Enzymes perform the role of biocatalysts in the body. The flow of vital biochemical processes in the body is impossible without them.

An attacked by any enzyme substance is called **substrate**.

Metabolites take part in the metabolic processes. Also there are **antimetabolites**; these compete with metabolites.

The processes occurring in the organism are called **in vivo**, and out of it — **in vitro**.

PART I

THEORETICAL BASIS OF ORGANIC AND BIOORGANIC CHEMISTRY. THE STRUCTURE OF ORGANIC AND BIOORGANIC COMPOUNDS

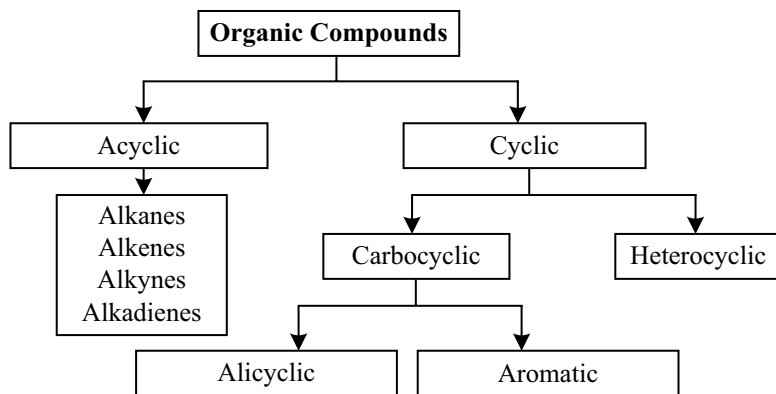
CHAPTER 1 CLASSIFICATION AND NOMENCLATURE OF ORGANIC COMPOUNDS

1.1. CLASSIFICATION OF ORGANIC COMPOUNDS

- Structure of the Carbon Chain
- Nature of the Functional Group

1.1.1. Classification Based on the Carbon Chain Structure

The diagram below shows the division of organic compounds on the structure based on the carbon skeleton.



Acyclic compounds are also called *aliphatic* and include substances with an open carbon chain. Acyclic compounds are divided into saturated (alkanes, paraffins) and unsaturated.

Cyclic compounds contain the rings (cycles) in their structure. If the cycle contains only the carbon atoms, then such compounds are called **carbocycles**. If the rings are built from other atoms, such compounds are called **heterocyclic** (from Greek *heteros* — *different*).

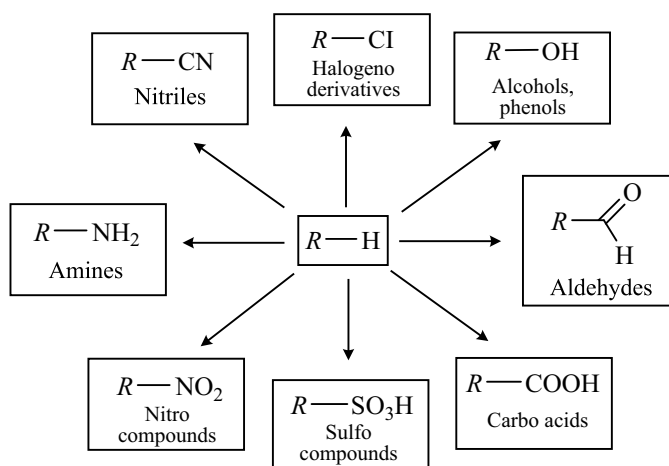
In turn, the carbocyclic compounds are divided into alicyclic and aromatic. *The saturated alicyclic hydrocarbons* (cycloalkanes) include *cyclopropane* and its homologues — cyclobutane, cyclopentane, cyclohexane, etc.

1.1.2. Classification Based on the Nature of the Functional Group

The functional group is a structural fragment of the molecule that determines its belonging to a particular class of organic compounds and characterizes its chemical properties. According to the functional group nature all organic compounds are divided into classes (Table 1.1).

Table 1.1. The Most Important Functional Groups and the Corresponding Classes of Organic Compounds

Functional Group	The Name of the Group	The Class of Substances
–Hal (–F, –Cl, –Br, –I)	Halogeno	Halogeno derivatives of hydrocarbons
–OH	Hydroxy	Alcohols, phenols
–SH	Thio, mercapto	Thio alcohols
–OR	Alkoxy	Esters
>C=O	Carbonyl	Aldehydes, ketones
–COOH	Carboxyl	Carboxylic acids
–SO ₃ H	Sulfo	Sulfonic acids
–COOR	Alkoxycarbonyl	Esters
–C(O)NH ₂	Amide	Amides of acids
–NO ₂	Nitro	Nitro compounds
–NH ₂	Amino	Amines



Classes of organic compounds

Substitution of hydrocarbon molecules of hydrogen atoms by a functional group a certain class of organic compounds is formed.

Based on the number of functional groups the organic compounds are divided into mono - and polyfunctional derivatives. *The monofunctional compounds* contain one functional group; the *polyfunctional ones* have two and more. In addition, polyfunctional organic compounds are divided into homo- and heterofunctional. Molecules of the *homo-functional compounds* contain the same functional groups, and *heterofunctional* — different.

1.2. NOMENCLATURE OF ORGANIC COMPOUNDS

The most important nomenclature systems include the common (trivial empirical) names, rational and the IUPAC (International Union of Pure and Applied Chemistry) nomenclature.

The common (trivial empirical) names of organic compounds are random. The most often it indicates the source of obtaining a compound (malic acid, ethyl alcohol). In addition, the common name is often an indication of a specific property of a compound: fluorescein fluoresces, glycerol possesses the sweet taste (*glycys* means *sweet*). The common name also refers to a method of obtaining a compound (pyruvic (*pyros* means *heat*) acid is the grape acid after heat treatment), or application (the ascorbic acid, which is used against the scorbutus (scurvy)).

The Rational Nomenclature: *For successful learning the basis* of chemical nomenclature of organic compounds it's necessary to know such concept as radical. Hydrocarbon radicals are formed during the removal of the hydrogen atom from hydrocarbon molecules. Alkanes form *alkyl radicals*, and arenes form *aryl radicals*. During the creation of the names of alkyl radicals, the suffix *-ane* is replaced by *-yl*. **Radicals are denoted by the letter R.** To distinguish the *alkyl* radicals from others *Alk* is often used. The aromatic (aryl) radicals are **the symbol Ar**. The radicals may be *primary*, *secondary*, and *tertiary*. Let's show them on examples of the propane and butane radicals:

