Danylo Halytsky Lviv National Medical University

Department of Pharmaceutical, Organic and Bioorganic chemistry

APPROVED
First pro-rector
for the Academic Work
Danylo Halytsky Lviv National
Medical University
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THE EDUCATIONAL PROGRAM IN THE DISCIPLINE
"BIOORGANIC CHEMISTRY"
ОК 9

Second (master's) educational level
Field: 22 "Health"
Specialty 222 "Medicine"
for first-year students of medical faculty

Discussed and approved
Department of Pharmaceutical, Organic
and Bioorganic chemistry
Proceedings No 22
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Head of Department
Prof. Roman LESYK

Approved
Methodical Commission
of Chemical and Pharmaceutical
Disciplines
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Head of the Methodical Commission
Prof. Svitlana BILOUS

The educational program in the discipline "Bioorganic chemistry" for 1st year english medium students of medical faculty, specialty: 222 " Medicine". Authors: ScD, PhD, prof. V. Muzychenko, PhD, associat. prof. N. Shtoiko, PhD, associate prof. N. Zelisko. in accordance with the educational and professional program "Medicine" of the second (master's) level, Knowledge 22 "Health", Specialty 222 "Medicine", approved by the Academic Council of Danylo Halytsky Lviv National Medical University (proceeding №1 15.02.2023)

Changes and additions to the curriculum for the 2023-2024 academic year

№	The content of the changes made	Date and proceedings number of the department meeting	Notes
1.	Changing the code of the educational program from OK 11 to OK 9	Proceeding №22 26.06.2023	

Head of Department of Pharmaceutical, Organic and Bioorganic chemistry — prof. Roman LESYK

INTRODUCTION

The syllabus of subject matter "Biorganic Chemistry"
in accordance with the Standard of Higher Education of *the second (master's) level*
Knowledge 22 *"Health"*
Specialty _222 "Medicine"
Master's Degree Program in Medicine

Description of the discipline (abstract)

The subject matter "Bioorganic Chemistry" studies the structure and reactivity of various classes of organic substances, and on their basis are the most important biologically active substances that are part of living organisms - low molecular biomolecules, biopolymers (proteins, nucleic acids, polysaccharides), natural and synthetic physiologically active compounds (hormones, vitamins, medicines, toxic substances, etc.). The tasks of bioorganic chemistry are to determine the structure of biomolecules, natural and synthetic bioregulators, to identify the relationship between their molecular, electronic structure and physiological, in particular, pharmacological effects, and reveal the patterns of their transformations.

The structure of the subject matter	**The number of credits, hours, of which**				**Year of study**	**Type of control**
	Total Credit hours	**Auditorium**		**Self-study**		
		Lectures	**Practical classes**			
The name of the subject matter: Bioorganic Chemistry *4 thematic modules*	3.0 credits ECTS / 90 hours	10	30	50	1st year (II semester)	exam
Per semester						
1-4 thematic modules	3.0 credits ECTS / 90 hours	10	30	50	2nd semester	exam

The subject of the study of the discipline is

1. molecular structure of organic compounds;
2. physical and chemical properties of bioorganic compounds;
3. biological activity of organic compounds;
4. the relationship between the structure and properties of organic compounds, including metabolites and drugs;

Interdisciplinary connections: - General and Inorganic chemistry; Biophysics; Biology; Biological chemistry; Normal physiology; Pharmacology; Histology; Therapia.

1.The objectives and tasks of the "Bioorganic Chemistry" course

1.1 **objectives** ***of teaching of the "Bioorganic Chemistry" course are:***

- mastering regularity concerning chemical properties of organic compounds in relation to their structure and based on this understanding of biochemical processes that occur in biological systems.
- becoming familiar with basic methods of organic compounds identification as basic prerequisite for the principles understanding of laboratory methods of diagnosis and understanding of many pathological processes in the human body;
- Organic chemistry practical aspects disclosure, methods and ways of usage its achievements in the medical practice.

1.2 Tasks of the "Bioorganic Chemistry" course are:

- to teach students the general principles of the chemical reactions passing of bioorganic compounds, as the basis of biochemical processes in the human body;
- the formation the understanding of the relationship between the structure and function of bioorganic compounds;
- reveal of the Bioorganic chemistry practical aspects, the ways and methods of use its achievements in the medical practice.

*1.3 **Competence and learning outcomes that are formed by this subject matter*** (the relationship with the normative content of the training of higher education graduates, formulated in terms of learning outcomes in the Standard of Higher Education)

In accordance with the requirements of the Standard of Higher Education, discipline ensures students' acquisition of **competences**:

-general: "ЗК 1"; "ЗК 2"; "ЗК 3"; "ЗК 4"; "ЗК 5"; "ЗК 6"; "ЗК 7"; "ЗК 8"; "ЗК 11"; "ЗК 12"; "ЗК 15";

-special (professional, subject): "ФК 2"; "ФК 5"; "ФК 17".

Detail of competencies according to the descriptors of the "НРК" in the form of "Matrix of competencies".

Matrix of competencies

No	Competence	Knowledge	Scill	Communication	Autonomy and responsibility
1	"ЗК 1". Ability to abstract thinking, analysis and synthesis.	**Зн1**	**Ум1**	**К1**	**АВ1**
2	"ЗК 2". Ability to learn and master modern knowledge	**Зн1**	**Ум3**	**К2**	**АВ3**
3	"ЗК 3". Ability to apply knowledge in practical situations	**Зн1**	**Ум2**	**К1**	**АВ1**
4	"ЗК 4". Knowledge and understanding of the subject area and understanding of professional activity	**Зн2**	**Ум2**	**К2**	**АВ2**
5	"ЗК 5". Ability to adapt and act in a new situation		**Ум3**		**АВ2**
6	"ЗК 6". Ability to make informed decisions	**Зн1**	**Ум3**	**К1**	**АВ1**
7	"ЗК 7". Ability to work in a team	**Зн2**	**Ум3**	**К1**	**АВ2**
8	"ЗК 8". Ability to interpersonal interaction	**Зн1**	**Ум3**	**К1**	**АВ2**
9	"ЗК 11". Ability to search, process and analyze information from various sources	**Зн2**	**Ум2**	**К2**	**АВ2**
10	"ЗК 12". Definiteness and persistence in terms of tasks and responsibilities	**Зн2**	**Ум3**		**АВ3**
11	"ЗК 15". Ability to preserve and multiply moral, cultural, scientific values and achievements of society based on understanding the history and patterns of development of the subject area, its place in the general system of knowledge about nature and society and in the development of society, technics and technology, use various types and forms of physical activity for active recreation and a healthy lifestyle.	**Зн2**	**Ум3**		**АВ3**
12	"ФК 2". Ability to determine the required list of laboratory and instrumental studies and evaluate their results	**Зн2**	**Ум3**		**АВ1**
13	"ФК 5". Ability to determine the nature of nutrition in the treatment of diseases	**Зн2**	**Ум1**	**К1**	**АВ1**
14	"ФК 17". Ability to assess the impact of the environment, socio-economic and biological determinants on the health of the individual, family, population	**Зн2**	**Ум3**	**К1**	**АВ1**

“Зн1” Specialized conceptual knowledge, which includes modern scientific achievements in the field of professional activity or field of knowledge and is the basis for original thinking and research.
“Зн2” Critical understanding of problems in the field and on the borders of knowledge fields.
“Ум1” Specialized problem-solving skills required for research and / or innovation in order to develop new knowledge and procedures.
“Ум2” Ability to integrate knowledge and solve complex problems in broad or multidisciplinary contexts..
“Ум3” Ability to solve problems in new or unfamiliar environments with incomplete or limited information, taking into account aspects of social and ethical responsibility.
“К1” Clear and unambiguous communication of one's own knowledge, conclusions and arguments to specialists and non-specialists, in particular to students.
“К2” Use of foreign languages in professional activities.
“АВ1” Management of work or learning processes that are complex, unpredictable and require new strategic approaches.
“АВ2” Responsibility for contributing to professional knowledge and practice and / or evaluating the performance of teams and teams.
“АВ3” Ability to continue learning with a high degree of autonomy.

Learning outcomes:
Integrative final program learning outcomes, the formation of which is facilitated by the discipline:
“ПРН 2”. Understanding and knowledge of basic and clinical biomedical sciences, at a level sufficient to solve professional problems in the field of health care.
“ПРН 3”. Specialized conceptual knowledge, which includes scientific achievements in the field of health and is the basis for research, critical thinking in the field of medicine and related interdisciplinary issues.
“ПРН 5”. Collect complaints, life history and disease, assess the psychomotor and physical development of the patient, the state of organs and systems of the body, based on the results of laboratory and instrumental studies to assess information about the diagnosis, taking into account the patient's age.
“ПРН 7”. Prescribe and analyze additional (mandatory and optional) methods of examination (laboratory, functional and / or instrumental), patients with diseases of organs and systems of the body for the differential diagnosis of diseases.

Learning outcomes for discipline:
- Be able to determine the organic compound's class based on the structure of the carbon skeleton and the nature of the functional group.
- To know the spatial structure of organic compounds and its influence on biological activity.
- Learn the principles of the substitute and radical-functional IUPAC nomenclature.
- To interpret the dependence of the bioorganic compounds reactivity on the nature of the chemical bonds and the electronic effects of substituents.
- Explain the mechanisms of chemical reactions of different classes of organic compounds having analogies in vivo.
- To be familiar with individual representatives of hydrocarbons, alcohols, phenols, thiols, aldehydes and ketones and carboxylic acids, which are metabolites or drugs.
- To understand the general and specific properties of heterophunctional compounds.
- To interpret the peculiarities of the structure of α-amino acids as the basis of biopolymers - proteins, which are structural components of all tissues of an organism.
- Make conclusions about the variants of transformations in the organism of α-amino acids and analyze the dependence of the formation of physiologically active compounds (FAS) from them on the structure and reactivity.
- Explain the mechanism of the biogenic amines formation and their influence on the physiological functions of the organism.
- Explain the dependence of the physical and chemical properties of proteins from their amino acid composition.
- Be able to conduct qualitative α-amino acid reactions to determine the amino acid composition of proteins and use them for the quantitative determination of proteins.
- To make conclusions about the existence of monosaccharides in various tautomeric forms, which affects on their reactivity and make the possibility for the laboratory study of monosaccharides in biological fluids.

- To interpret the peculiarities of the structure and transformations in the body of homopolysaccharides as nutrients - sources of energy for the processes of life.
- Analyze the principles of methods for the detecting and the quantitative monosaccharides assay in the blood, urine, saliva.
- Explain the mechanisms of the biological role of heteropolysaccharides (glycosaminoglycans) in biological liquids and tissues.
- Explain the dependence of the reactivity of heterocyclic compounds on their structure, in the context of their biosynthesis and laboratory synthesis for the purpose of obtaining medical preparations.
- To draw conclusions on the biological activity of heterophunctional heterocyclic compounds depending on their specific structure and chemical behavior.
- Understand the importance of mononucleotides for the construction of nucleic acids and the activity of nucleotide coenzymes.
- To interpret the mechanisms of participation of vitamins in the construction of coenzymes that catalyze biochemical reactions in the body.

2. Information volume of subject matter

To study the academic discipline 3.0 credits ECTS, 90 hours are given.

Structure of the discipline according to the thematic modules:

Thematic module 1. Theoretical aspects of bioorganic chemistry. Hydrocarbons and their mono-functional derivatives.

Topic 1. Introduction. Classification and nomenclature of the bioorganic compounds. Classification of the chemical reactions and reagents. Structure of chemical bonds.

The main provisions of the theory of chemical structure of organic compounds and its significance for the development of organic chemistry.Classification of organic compounds by the structure of the carbon skeleton and the nature of the functional group. Fundamental concepts of organic chemistry: homology, isomerism, radical, substituent, functional group, ancestral structure, poly- and heterofunctionality. Nomenclature systems in organic chemistry - trivial, rational, radical-functional, substitute. Types of hybridization of the carbon atom. The structure of σ- and π-bonds. Classification of chemical reactions by direction (substitution, addition, cleavage, isomerization, oxidation, reduction). Classification of chemical reactions by the method of disconnection (homolytic and heterolytic). Intermediate reaction particles are intermediates (carbocations, carbanions and free radicals). Electrophiles and nucleophiles. Reagent and substrate. The concept of mechanisms of chemical reactions and their designation.

Topic 2. Structure of bioorganic compounds. Conjugated systems. Electron effects (mesomeric and inductive effects). Reactivity of hydrocarbons.

Configurations and conformations of molecules. Conformations of ethane, n-butane, ethylene glycol, cyclohexane. Geometric (cis, trans) and mirror isomerism. Stereochemical formulas. Chirality of molecules. Enantiomers and diastereomers. The relative configuration of chiral molecules. D- and L- stereochemical series of chiral molecules. Optical activity and racemates. Mesoforms. Relationship of spatial structure with biological activity. Conjugate systems. Interaction of atoms in molecules: induction and mesomeric effects. Electron-donor and electron-acceptor substituents. Aromatic conditions. Hückel's rule. Alkanes, cycloalkanes, alkadienes and arenes, their structure, isomerism, chemical properties and medical and biological significance. Reactions of free radical substitution (S_R), electrophilic addition (A_E) and electrophilic substitution (S_E). Markovnikov's rule and its modern interpretation. Approximate action of substituents in the benzene nucleus.

Topic 3. Acidic and basic properties of organic compounds. Reactivity of hydroxy derivatives of hydrocarbons, thiols, amines and carbonylic compounds.

Acid and basic properties of organic compounds. Bransted and Lewis theories. Types of organic acids (OH-, SH-, NH- and CH-acids). The concept of pKa.Factors affecting the acidity and basicity of organic compounds.Alcohols, their classification, nomenclature, isomerism, properties and medical and biological significance.Chemical properties of alcohols. Oxidation reactions, intermolecular and intramolecular dehydration. Zaitsev's rule. Nucleophilic substitution reactions at a tetragonal carbon atom and their pathways (S_N1, S_N2).Qualitative reaction to polyhydric alcohols.Phenols, their classification, nomenclature, isomerism, properties and medical and biological significance.Identification of phenolic hydroxyl.Acidic properties of phenols.Quinones. Ubiquinone. Vitamin K.The concept of thiols and their derivatives (sulfides, disulfides).Chemical properties of thiols (acidity, oxidation, formation of thioesters).Amines, their classification, nomenclature, isomerism, properties and medical and biological significance.Chemical properties of amines. Basicity, nucleophilicity, interaction with nitric acid, isonitrile reaction and its practical application.Aldehydes and ketones. Classification, nomenclature and isomerism.Electronic structure of

carbonyl group. Nucleophilic addition (A_N) reactions for aldehydes and ketones - formation of hydrates, hemiacetals, cyanhydrins, hydrogen sulfite derivatives. Aldol condensation reaction and its biochemical significance. Interaction of carbonyl compounds with amino derivatives - formation of Schiff bases, oximes, phenylhydrazones, semicarbazones. Oxidation and reduction of carbonyl compounds.Some representatives: monohydric (methanol, ethanol) and polyhydric (ethylene glycol, glycerol, xylitol, sorbitol) alcohols, monohydric (phenol, cresol) and diatomic (pyrocatechol, resorcinol, hydroquinone) phenols, amines (methylamine, aniline).

Topic 4. Biologically important carboxylic acids and their derivatives. Control work "Theoretical aspects of bioorganic chemistry. Structure and properties of the hydrocarbons and their monofunctional derivatives.

Classification, nomenclature and isomerism of monocarboxylic acids. The structure of the carboxyl group and the carboxylate anion. Acidic properties of carboxylic acids. The concept of the mechanisms of nucleophilic substitution reactions. Esterification reaction. Reactions for the formation of amides, anhydrides, acid halides. Decarboxylation reactions of monocarboxylic acids. Reactions involving the radical of saturated, unsaturated and aromatic acids. Properties of formic acid. Dicarboxylic acids, their structure, nomenclature, isomerism. Specific reactions of dicarboxylic acids (decarboxylation, formation of cyclic anhydrides). Medico-biological significance of carboxylic acids.

Thematic module 2. Heterofunctional bioorganic compounds. Biopolymers and bioregulators.

Topic 5. Heterofunctional bioorganic compounds.

Amino alcohols - colamine, choline, acetylcholine. Structure, chemical properties and biological significance. n-Aminophenol and its derivatives - paracetamol, phenacetin. Extraction and medical and biological significance. Catecholamines - dopamine, norepinephrine, adrenaline, their synthesis and biological role. Hydroxy and oxo acids, their structure, classification, nomenclature. Spatial (configurational) isomerism of hydroxy acids (enantiomeric and diastereomeric, meso-forms, racemates). Optical activity, relative configuration, D- and L-stereochemical series. Fisher projections. Chemical properties of hydroxy acids with the participation of the hydroxyl group. Chemical properties of hydroxy acids with the participation of the carboxyl group. Specific properties of α, β and γ-hydroxy acids. Aromatic hydroxy acids. Salicylic acid, aspirin, methyl salicylate, salol. Chemical properties of oxoacids as bifunctional compounds. Specific properties of oxoacids: decarboxylation reactions, keto-enol tautomerism. Medico-biological significance of hydroxy and oxo acids. Amino acids. Spatial structure, acid-base properties, specific properties of α-, β- and γ-amino acids.Sulfanilic acid and its amides. White streptocide.

Topic 6. Amino-acids, peptides, proteins.

Structure and classification of natural (proteinogenic) amino acids. Stereoisomerism of α-amino acids. D- and L-Stereochemical series. Bipolar structure of α-amino acids. Isoelectric point. Biologically important reactions of α-amino acids (deamination, decarboxylation, transamination). Chemical properties of proteinogenic amino acids. Primary structure of peptides, proteins. Peptide bond. Its electronic structure. The concept of secondary, tertiary and Quaternary structure of proteins. The concept of peptide synthesis (protection of amino and carboxyl groups, carboxyl group activation). Analysis of peptides (determination of the N-terminus, C-terminus, amino acid sequence). Partial and complete hydrolysis of proteins. Qualitative reactions to natural amino acids, proteins.

Topic 7. Saponifiable lipids.

Lipids and their classificationHigher fatty carboxylic acids are important structural components of saponifying lipids, their structure, stereoisomerism, properties.The concept of biosynthesis of higher fatty carboxylic acids.Fats (triacylglycerols) as representatives of simple saponifying lipids, their structure, propertiesThe concept of lipid peroxidation (LPO).Complex saponifying lipids, their structure, classification.Glycerophosphatides - derivatives of phosphatidic acids, their structure and properties. Representatives of glycerophosphatides - lecithin, cephalins, phosphatidylserines, plasmogen.Structure of sphingolipids: ceramides and sphingomyelins.Glycolipids. The concept of the structure of cerebrosides and gangliosides.Medico-biological significance of saponifying lipids.

Topic 8. Nonsaponifiable lipids. Control work "Heterofunctional bioorganic compounds. Lipids"

Terpenes, their classification. Isoprene rule.Acyclic monoterpenes (geraniol, citral).Monocyclic monoterpenes (limonene, menthol), their medical value.Bicyclic monoterpenes (α-pinene).Camphor, structure, optical activity, properties and medical value.Carotenoids, their structure, biological significance. Retinol (vitamin A), β-carotene (provitamin A)Chemistry of the process of light perception in the body.

Steroids, general characteristics, classification. The structure of the steran. Stereoisomerism.Conformations of cyclohexane rings; cis-, trans-articulation of nuclei in the structure of steran; 5α- and 5β- steroids.The structure of hydrocarbons underlying the classification of steroids (estrane, androstane, pregnane, holan, cholestan).Derivatives of cholesterol (sterols): cholesterol, ergosterol, vitamin D2.Derivatives of cholan (bile acids): cholic, deoxycholic, glycocholic acids.Derivatives of estrone (female sex hormones): estrone and estradiol. Their structure and biological role.Androstane derivatives (male sex hormones): androsterone and testosterone. Structure and biological role.Derivatives of pregnane (corticosteroids): corticosterone, deoxycorticosterone, hydrocortisone.Cardiac glycoside aglycones: digitoxygenin; strophanthidine.
Prostaglandins, their structure and medical and biological significance

Thematic module 3. Structure and functions of carbohydrates.

Topic 9. Structure, chemical properties and functions of monosaccharides.

Monosaccharides, their structure, classification and nomenclature. Stereoisomerism. D- and L-Stereochemical series. Cyclo-oxo-tautomerism. Furanose and pyranose forms, α- and β-anomers. Haworth's formulas. The phenomenon of mutarotation. Conformations of cyclic forms of monosaccharides. Chemical properties of monosaccharides (reactions involving hemiacetal hydroxyl, esterification and esterification, oxidation and reduction). Types of fermentation of monosaccharides. Monosaccharide identification reactions. Representatives: pentoses (D-xylose, D-ribose, L-arabinose), hexoses (D-glucose, D-galactose, D-mannose, D-fructose), deoxy sugars (2-deoxyribose, D-digitoxose), amino sugars (glucosamine). Neuraminic acid. Ascorbic acid.

Topic 10. Structure, chemical properties and functions di- and polysaccharides.

Disaccharides, their structure and nomenclature.Reducing disaccharides (maltose, cellobiose, lactose), the relationship between monosaccharide residues and its spatial orientation.Cyclo-oxo-tautomerism and mutarotation of reducing disaccharides.Chemical properties of reducing disaccharides.Non-reducing disaccharides (sucrose) and the type of bond between monosaccharide residues.Chemical properties of non-reducing disaccharides.Sucrose inversion.Polysaccharides, their classification and the principle of construction.Homopolysaccharides: starch (amylose, amylopectin), glycogen, cellulose, dextrans. Spatial structure of amylose and cellulose.Heteropolysaccharides, their structure. Structure and biomedical significance of glycosaminoglycans (mucopolysaccharides) - chondroitin sulfates, hyaluronic acid, heparin. Mixed biopolymers (glycoproteins, proteoglycans, glycolipids). The concept of blood group substances.

Topic 11. Control work “Carbohydrates”.

Generalization, systematization and consolidation of knowledge about the structure, isomerism, chemical properties and related biological activity of carbohydrates.

Thematic module 4. Structure and biological properties of heterocyclic compounds, alkaloids, nucleotides, nucleosides and nucleic acids

Topic 12. Biologically active 5-membered heterocyclic compounds.

Heterocyclic compounds, their classification and nomenclature. Five-membered heterocycles with one heteroatom. Aromatic character. The structure of the pyrrole atom of Nitrogen. π-Excess aromatic systems. Acidophobicity of pyrrole and furan. Chemical properties of five-membered heterocycles with one heteroatom. Features of halogenation, sulfonation and nitration reactions of acidophobic heterocycles. NH-Acidity of pyrrole. Addition reactions. Indole, structure, aromatic character, chemical properties. Tetrapyrrole systems (porphins, porphyrins), their structure. Five-membered heterocycles with two heteroatoms. Aromaticity. Electronic structure of the pyridine nitrogen atom. Acid-base properties of five-membered heterocycles with two heteroatoms.

Topic 13. Biologically active 6-membered heterocyclic compounds.

Six-membered heterocyclic compounds, their classification and nomenclature.Six-membered heterocycles with one nitrogen atom: pyridine, quinoline, isoquinoline, acridine. Their structure, aroma.Chemical properties of pyridine: basicity, nucleophilic, electrophilic and nucleophilic substitution reactions. Redox reactions.Quinoline, isoquinoline, acridine, their chemical properties.Six-membered heterocycles with one oxygen atom: α- and γ-pyran and their derivatives.Medico-biological significance of six-membered heterocyclic compounds.Six-membered heterocycles with two nitrogen heteroatoms, their structure and properties.Hydroxy derivatives of pyrimidine (uracil, thymine, cytosine, barbituric acid) and their tautomeric forms.Six-membered heterocycles with heteroatoms of Nitrogen and Sulfur, their structure.Medico-biological significance of six-membered heterocycles with two heteroatoms.

Topic 14. Biologically active fused heterocyclic compounds. Alkaloids. Nucleic acids.

Classification and nomenclature of condensed heterocyclic compounds.Purine (structure, aromaticity, tautomerism, amphotericity).Hydroxy derivatives of purine: hypoxanthine, xanthine, uric acid. Their tautomerism and acid-base propertiesAmino derivatives of purine (adenine, guanine), their tautomeric forms, biochemical significance in the formation of nucleotides and coenzymes.Methylated derivatives of xanthine (caffeine, theophylline, theobromine) as physiologically active compounds with action on the central nervous and cardiovascular systems.Murexide test is a qualitative reaction to compounds containing a purine nucleus.Pteridine. Folic acid. Its antagonism with sulfonamides.Alkaloids (definition, their value as biologically active substances and drugs).Representatives of alkaloids: pyridine groups (nicotine, lobeline), quinoline (quinine), isoquinoline (morphine, papaverine), tropane (atropine), indole (reserpine).Nucleic bases: purine, pyrimidine, minor.Lactime-lactam tautomerism of nucleic bases. Complementarity.Nucleosides, nomenclature and structure. Pseudouridine.Nucleotides. Their structure, nomenclature and properties.Classification and primary structure of nucleic acids.Higher structural organization of nucleic acids.Biological role of nucleic acids.ATP is an energy accumulator in biological systems, its structure, properties and role.Nucleotide coenzymes (NAD +, NADH, FAD, FADN, coenzyme A), structure and participation in metabolic processes.

Topic 15. Control work "Heterocyclic compounds, alkaloids, nucleic acid".
Generalization, systematization and consolidation of knowledge about the structure, chemical properties and biological activity of the most important heterocyclic compounds, alkaloids, nucleic acids.

3. The structure of the discipline "Biorganic Chemistry"

Theme	Lectures	Practical classes	Self-study	Individual work
Thematic module 1. **Theoretical aspects of bioorganic chemistry. Hydrocarbons and their mono-functional derivatives.**				
Topic 1. Introduction. Classification and nomenclature of the bioorganic compounds. Classification of the chemical reactions and reagents. Structure of chemical bonds.		2	2	-
Topic 2. Structure of bioorganic compounds. Conjugated systems. Electron effects (mesomeric and inductive effects). Reactivity of hydrocarbons.	1	2	3	
Topic 3. Acidic and basic properties of organic compounds. Reactivity of hydroxy derivatives of hydrocarbons, thiols, amines and carbonylic compounds.	1	2	2	
Topic 4. Biologically important carboxylic acids and their derivatives. Control work "Theoretical aspects of bioorganic chemistry. Structure and properties of the hydrocarbons and their monofunctional derivatives.	1	2	3	
Total for the thematic module 1	3	8	10	
Thematic module 2. **Heterofunctional bioorganic compounds. Biopolymers and bioregulators.**				
Topic 5. Heterofunctional bioorganic compounds.	1	2	3	-
Topic 6. Amino-acids, peptides, proteins.	1	2	2	
Topic 7. Saponifiable lipids.	1	2	3	
Topic 8. Nonsaponifiable lipids. Control work "Heterofunctional bioorganic compounds. Lipids"		2	4	
Total for the thematic module 2	3	8	12	
Thematic module 3**. Structure and functions of carbohydrates.**				
Topic 9. Structure, chemical properties and functions of monosaccharides.	1	2	4	-
Topic 10. Structure, chemical properties and functions di- and polysaccharides.	1	2	5	
Topic 11. Control work "Carbohydrates".	-	2	1	
Total for the thematic module 3	2	6	10	
Thematic module 4. **Structure and biological properties of heterocyclic compounds, alkaloids, nucleotides, nucleosides and n*ucleic acids*.**				
Topic 12. Biologically active 5-membered heterocyclic compounds.	1	2	5	-

Topic 13. Biologically active 6-membered heterocyclic compounds.	1	2	2	
Topic 14. Biologically active fused heterocyclic compounds. Alkaloids. Nucleic acids.		2	9	
Topic 15. Control work "Heterocyclic compounds, alkaloids, nucleic acid".	-	2	2	
Total for the thematic module 4	2	8	18	
Total hours 90 / 3.0 ECTS credits	**10**	**30**	**50**	
Final assessment				**Exam**

4. Topics of lectures

No	Theme	Hours
1	Bioorganic chemistry. Classification of the chemical reactions. Reactivity of the hydrocarbons. Hydroxy- derivatives of the hydrocarbons. Thioles. Amines.	2
2	Carbonyl-containig compounds. Carboxylic acids. Heterofunctional compounds	2
3	Lipids. Proteinogenous amino-acids. Peptides & proteins.	2
4	Carbohydrates	2
5	Heterocyclic compounds. Alkaloids. Nucleic acids.	2
TOTAL		10

5. Topics of practical classes

No	Theme	Hours
Thematic module 1. **Theoretical aspects of bioorganic chemistry. Hydrocarbons and their mono-functional derivatives**		
1	Introduction. Classification and nomenclature of the bioorganic compounds. Classification of the chemical reactions and reagents. Structure of chemical bonds.	2
2	Structure of bioorganic compounds. Conjugated systems. Electron effects (mesomeric and inductive effects). Reactivity of hydrocarbons.	2
3	Acidic and basic properties of organic compounds. Reactivity of hydroxy derivatives of hydrocarbons, thiols, amines and carbonylic compounds.	2
4	Biologically important carboxylic acids and their derivatives. Control work "Theoretical aspects of bioorganic chemistry. Structure and properties of the hydrocarbons and their monofunctional derivatives".	2
TOTAL		8
Thematic module 2. ***Heterofunctional bioorganic compounds. Biopolymers and bioregulators***		
5	Heterofunctional bioorganic compounds	2
6	Amino-acids, peptides, proteins	2
7	Saponifiable lipids	2
8	Nonsaponifiable lipids. Control work "Heterofunctional bioorganic compounds. Lipids"	2
TOTAL		8
Thematic module 3. **Structure and functions of carbohydrates**		
9	Structure, chemical properties and functions of monosaccharides.	2
10	Structure, chemical properties and functions di- and polysaccharides	2
11	Control work "Carbohydrates"	2
TOTAL		6
Thematic module 4. **Structure and biological properties of heterocyclic compounds, alkaloids, nucleotides, nucleosides and nucleic acids.**		
12	Biologically active 5-membered heterocyclic compounds	2
13	Biologically active 6-membered heterocyclic compounds	2
14	Biologically active fused heterocyclic compounds. Alkaloids. Nucleic acids.	2
15	Control work "Heterocyclic compounds, alkaloids, nucleic acids"	2
TOTAL		**8**
Number of practical classes hours on discipline		**30**

6. Out of class works

No	Topic	Hours	Type of control
1	Types of hybridisation of Carbon. Electronic structure of chemical bonds. Conjugated and aromatic systems. Reactivity of arens, alkanes, alkenes and cycloalkanes.	5	Verification in the practical classes
2	Reactions of polymerization and polycondensation of aldehydes and carboxylic acids	5	
3	Transformation of keto- and hydroxyacids (reactions of oxidation, reduction, decarboxylation, aldol condensation). Keto-enol tautomerism	5	
4	Simple and complex saponifiable lipids. Low-molecular weight bio-regulators – terpenes, carotenoids, steroids, prostaglandins	7	
5	Stereo-isomerism and tautomerism of monosaccharides. D & L row of monosaccharides. Enantiomers and diastereomers. Anomers and epimers. Synthesis and hydrolysis of glicosides, ether and esters of monosaccharides.	5	
6	Reducing and nonreducing sugars. Structure and properties of homo- (starch, celulouse, inulin) and heteropolysacharides (Hyaluronic acid, chondroitin sulfate, heparin)	5	
7	Biologically active 5-membered heterocyclic compounds. Aromaticity. Reaction of nucleophilic and electrophilic substitution. Lactam-lactim and azole tautomerisms.	5	
8	Pyridine-carboxylic acids based drugs	2	
9	Alakoilds: structure, classification, properties	6	
10.	Nucleotides, nucleosides and nucleic acids. The structure of viruses, Coronaviruses in particular.	5	
TOTAL		**50**	

7. Individual tasks

(history of diseases, forensic medical certificates, acts of toxicological research, courseworks and diploma, master's works)

There is not any in working curriculum.

8. Methods of studies

In the process of"Bioorganic Chemistry"disciplines studying the following teaching methods are usedfor students:

- by the cognitiveactivitytype:
  – explanatory-illustrative;
  – reproductive;
  – problematic presentation;
  – the logic of cognition;
  – analitical;
  – inductive;
  – deductive;
- according to the main stages of the process:
  – knowledgeformation;
  – skills and abilitiesformation;
  – knowledge application;
  – generalization;
  – fixing;
  – assesment;
- by thesystem approach:
  – stimulation and motivation;
  – assessment and self-assesment;
- by sources of knowledge:
  – verbal – lecture, explanation;
  – visual – demonstration, illustration;
- according to the individual mental activity level:

– problematic;
– partially discovering;
– explorative;
– the method of problematic teaching.

In the study of Bioorganic Chemistry, students use textbooks, lecture notes, methodological guidelines, chemical computer programs, molecular models, laboratory devices and glassware necessary for performing experiments.

According to the syllabus, methods for organization and accomplishment of studies are:

a) lectures

b) practical classes

c) students' independent study.

The topics of the lecture course reveal the problematic issues of the appropriate sections of Bioorganic Chemistry.

Practical classes are organized as laboratory classes. These classes include: laboratory studies on production and detection of specific classes of organic compounds according to their functional groups, performing specific reactions and organic compounds synthesis, its obtaining, purification and physicochemical constants detection.

Students are recommended to write short-term protocols of performed research in laboratory studies, indicating the purpose of the study and the conclusions.

The students also perform educational exercises and solve situational problems. ISIS DRAW, Chemistry in motion, HyperChem computer programs, videos and models of molecules made by department`s chair all of these materials are used in practical classes.

The structure of practical classes organization includes:

- Discussion and explanation of the most complicated issues of the topic;
- Written test;
- Performance of practical (laboratory) work.
- Filling in a practical lesson protocol.
- Summary of the lesson.

9. Methods of control

Types of control: current (routine) and final.

The current control is a regular check of educational trained achievements, fulfiled by the teacher according to syllabus of the discipline. It is carried out on each practical class according to the specific objectives, during the individual work of the teacher with the student for those topics which are not part of the structure of practical classes. The objective (standardized) control of theoretical and practical knowledge and skills of students is used. The following means of the level of students' knowledge assessment are used: testing, situational problems solving, laboratory research activities and their results interpreting and evaluating, practical skills evaluation. At each practical class the student gives answers on 10 questions (multiple choice questions on the topic of the practical classes, standardized questions, knowledge of which is necessary for understanding the current topic, the issue of a lecture course and individual work related to the current class, demonstrates knowledge and skills of practical abilities in accordance with the topic of the practical class).

The exam is the form of ***final control*** for the discipline " Bioorganic Chemistry" studying.Students, who completed all types of activities provided by the syllabus, attended all practical classesand were scored with thepoints number not less than the minimum.

10. The current control

The curren tcontrol is realized during the practical classes and aims at checking the learning of educational material. It is recommended to apply objective (standardized) kind of control to check theoretical and practical knowledge of students.

When evaluating the educational activitees achievements of each topic for the current educational activity, the student is assessed with grades in the 4-graiding scale (national). It takes into account all types of activities provided for by the discipline sullabus. A student should gain an assessment from each topic for further conversion of 4- grading scale points into 200-grading scale points. The standardized control of the theoretical part includes 10 tasks. Five of them are the first level tests question, and another five are referred to the tasks of the second level and must be given a written response in addition to the test response. Theoretical students' self-preparation control is performed in writing by answering 10 questions. A correct answer to guestions 1-5 is valued at 1 point, guestions 6-10 valued at 2 point The

maximum score for the entire test is 15 points.The minimum score points number a student must gain for the successful assessment of the theoretical part is 8 points.

Assessment of practical skills of students - as a result of the implementation of the practical part - is formalized in the form of a protocol.

Criteria of assessment of current educational activity:

"Excellent" mark receives a student who actively participated in the discussion of the most difficult issues of the topic, gave at least 90% of correct answers to standardized tests, responded to written tasks without any mistake, performed practical work and filled in the protocol.

"Good" mark gets a student who participated in the discussion of the most difficult issues of the topic, gave at least 75% of correct answers to standardized tests, responded to written tasks with some insignificant mistakes, performed practical work and filled in the protocol.

"Satisfactory" mark receives a student who did not take part in the discussion of the most difficult issues of the topic, gave at least 60% of correct answers to standardized tests, responded to written tasks with a lot of mistakes, performed practical work and made the protocol.

"Unsatisfactory" mark receives a student who did not take part in the discussion of the most difficult issues of the topic, gave less than 60% of correct answers to standardized tests, responded to written tasks with gross mistakes or did not give answer, didn't perform practical work and didn't make the protocol.

The students' individual work issues and achievements which are provided by the syllabus in the content of practical training practical class activities, are evaluated during the current control of the topic at the appropriate practical class. The evaluation of the topics submitted for individual study and not included into the content of the practical class training is monitored during the final control.

11. Form of final control of study success

The final control is carried out upon completion of the study of the discipline in the form of the exam.

Only thouse students who completed all types of works provided by syllabus and during study scored points not less than the minimum, and don't have any undone lectures and practical classes are allowed to put the exam. The standardized form of the exam includes control of theoretical and practical knowledge.

The exam is performed during the examination session according to the schedule and includes:

Written answers to 20 standard test tasks, each of which has one correct answer from the five proposed formats A (rated at 1 point);

Written answers to 20 standard test tasks, the solution of which involves both an alphabetic response and a written assignment. It is rated from 0 to 3 points. Thus, a student can score a maximum of 80 points. ***The maximum number of points*** a student can score for an exam is 80.

12. Scheme of accrual and distribution of scores received by students is as follows:

The maximum number of points that a student can get for current educational activity during study is 120 points.

The minimum number of points that a student must get to pass the test on the discipline is 72 points.

Calculating the number of points is performed by the way of calculating the arithmetical average (AA) of student's received marks by traditional rate during the semester the discipline is studied, and rounded to two decimal places. The received value is converted into points by multi-point rate as follows:

$$xX = (AA \times 120)/5$$

For convenience, there is a table of conversion to 200-point rate:

Recalculation of the average mark for current activity into multi-point rate for disciplines, ending with exam.

4-point rate	200- point rate
5	120
4.95	119
4.91	118
4.87	117
4.83	116
4.79	115
4.75	114
4.7	113
4.66	112
4.62	111
4.58	110
4.54	109
4.5	108

4-point rate	200- point rate
4.45	107
4.41	106
4.37	105
4.33	104
4.29	103
4.25	102
4.2	101
4.16	100
4.12	99
4.08	98
4.04	97
3.99	96
3.95	95

4-point rate	200- point rate
3.91	94
3.87	93
3.83	92
3.79	91
3.74	90
3.7	89
3.66	88
3.62	87
3.58	86
3.54	85
3.49	84
3.45	83

4-point rate	200- point rate
3.41	82
3.37	81
3.33	80
3.29	79
3.25	78
3.2	77
3.16	76
3.12	75
3.08	74
3.04	73
3	72
Less then 3	Insuffi-cient

Students out-of classes works is assessed during the current verification of topic on the lesson.

The maximum number of points that a student can get on the exam is 80 points.

The minimum number of points during the examination - 50.

A mark on a discipline is defined as the sum of points for the current educational activity (not less than 72) and marks for the exam (not less than 50).

Points from discipline are converted into ECTS rate, and 4-point (national) rate.

Points from ECTS rate can't be converted into 4-point rate and vice versa. Marks of students, who study in one specialty, and taking into account the number of points gained by him/her in the discipline are ranked by ECTS rate as follows:

ECTS Mark	Statistical index
A	Top 10% of students
B	Next 25% of students
C	Next 30% of students
D	Next 25% of students
E	Last 10% of students

A, B, C, D, E rankings are awarded to students of actual course, who study in one specialty and successfully completed the study of the discipline. Students who received FX, F ("2") ratings are not included in the list of ranked students. Students with an FX score after repassing the exam receive an "E" score automatically.

Score points for students who have successfully completed the program are converted to the traditional 4-point scale by the absolute criteria listed in the table below:

Points from discipline	Mark by 4-point rate
From 170 to 200 points	5
From 140 to 169 points	4
From 139 to the minimum number of points which student must get	3
Below the minimum number of points which student must get	2

Mark written by ECTS can't be converted into traditional scale because the ECTS scale and 4-point scale are independent (do not coincide).

Objectivity of assessment students` educational activities is checked by statistical methods (correlation coefficient between the ECTS mark and mark by national scale).

13. Methodical support

Bioorganic Chemistry Methodical Guide for Practical Classes on Bioorganic Chemistry for the First Year English-Medium Students of the Department of Medicine, Lviv -2011, 123 p., that includes:

- plan of lectures,
- plans of practical classes,

- tasks for laboratory work, out-of class work,
- questions, tasks and test tasks for current and final control of knowledge and skills of students, after attestation monitoring of acquired knowledge and skills in the discipline.

14. Suggested Reading References

The main literature

1. Zimenkovsky B.S., Muzychenko V.A., Nizhenkovskaya I.V. Biological and bioorganic chemistry:in 2 books: textbook. Book I: - Kyiv: AUS Medicine Publishing, 2018: 288p.
2. J. Komarytsia. Organic Chemistry. Handbook for medical students. Lviv 2005.-74 p.
3. Stoker, H.S. (2001). Organic and biological chemistry. Houghton Mifflin. 2001. 556p.

The additionary literature

1. L.G. Wade Jr. Organic Chemistry. 8th edition. - Pearson. 2013. - 547p.
2. T. Graham Solomons, Craig B. Fryhle. Organic Chemistry. Tenth edition. Hoboken, NJ. – 2011. - John Willey and Sons, Inc.- 1218 p.
3. David C. Eaton. Laboratory investigation in Organic Chemistry. – McGRAW-HILL BOOK COMPANY. – New York – Toronto. – 893 p.

15. Information resources

1. www.ncbi.nlm.nih.gov/PubMed – free access to the database of scientific research in the field of biomedical sciences.
2. https://pubchem.ncbi.nlm.nih.gov/ free access to the database of scientific data in the field of biomedical sciences.
3. http://www.orgsyn.org - has provided the chemistry community with detailed, reliable, and carefully checked procedures for the synthesis of organic compounds.
4. http://www.organic-chemistry.org - offers an overview of recent topics, interesting reactions, and information on important chemicals for organic chemists.