

MINISTRY OF HEALTH OF THE REPUBLIC OF BELARUS
Educational Institution
BELARUSIAN STATE MEDICAL UNIVERSITY



APPROVED

by Rector of the Educational
Institution «Belarusian State
Medical University»

S.P.Rubnikovich

26.06.2024

Reg. # UD-091-096/2425/edu.

ORGANIC CHEMISTRY

**Curriculum of the educational institution
in the academic discipline for the specialty**

7-07-0912-01 «Pharmacy»

Curriculum is based on the educational program «Organic Chemistry», approved 26.06.2024, registration # УД-091-096/2425/уч.; on the educational plan in the specialty 7-07-0912-01 «Pharmacy», approved 15.05.2024, registration # 7-07-0912-01/2425/mf.

COMPILERS:

T.T.Lakhvich, Associate Professor of the Department of General Chemistry of the educational institution «Belarusian State Medical University», PhD, Associate Professor;

O.N.Ryneiskaya, Associate Professor of the Department of General Chemistry of the Belarusian State Medical University, PhD, Associate Professor

RECOMMENDED FOR APPROVAL:

by the Department of General Chemistry of the Educational Institution «Belarusian State Medical University»
(protocol # 1 of 22.05.2024);

by the Scientific and Methodical Council of the educational institution «Belarusian State Medical University»
(protocol # 18 of 26.06.2024)

EXPLANATORY NOTE

«Organic Chemistry» – the academic discipline of the Chemistry Module, which contains systematized scientific knowledge about the relationship between the structure of organic substances and their chemical, physicochemical and biological properties, as well as methods of their synthesis, isolation, purification and identification.

The aim of the discipline «Organic Chemistry» is to develop basic competencies by providing students with the scientific knowledge the relationship between the structure and properties of organic substances, as well as modern methods for their study, that is required for professional carrier of the pharmacist awarded with the university degree.

The objectives of the discipline «Organic Chemistry» are to develop students' scientific knowledge about the classification, nomenclature, structure and properties of the main classes of mono-, poly- and heterofunctional organic compounds, mechanisms of organic reactions, natural biologically important compounds, methods for studying organic compounds; properties and reactivity of organic compounds, including those that perform certain biological functions in the body and (or) are used as medicines, the principles of synthesis and self-organization of biological macromolecules; skills and abilities necessary for predicting the structure and properties of organic compounds, the direction and result of their chemical transformations, predicting and interpreting the spectral characteristics of organic compounds, planning and performing a scientific experiment on the synthesis, isolation and identification of organic substances, including the instrumental methods and qualitative.

The knowledge, skills, and abilities acquired during the study of the academic discipline «Organic Chemistry» are necessary for successful mastering of the academic disciplines «Biological Chemistry», «Pharmacology», «Industrial Technology of Drugs», «Pharmacy Technology of Drugs», as well as a module «Pharmaceutical Chemistry and Pharmacognosy».

Studying the academic discipline «Organic Chemistry» should ensure the development of students' basic professional competence: apply knowledge of the basic physical, chemical and biological laws for quality control of medicines and medicinal plant.

As a result of studying the discipline «Organic Chemistry» the student should know:

- nomenclature of organic compounds and processes;
- the basic concepts of structure and reactivity of organic compounds;
- transformations between different classes of organic compounds, the nature and mechanisms of typical organic reactions;
- chemical tests on functional groups and structural fragments;
- the basics of instrumental and functional analysis of organic compounds;
- the role and application of the classes of organic compounds in medicine and pharmacy;

be able to:

- classify organic compounds according to their structure;

write down the chemical formulas of compounds according to their systematic names, compile the systematic names of compounds according to their formulas;

predict and interpret the features of the structure, properties and spectral characteristics of organic compounds;

model the structures of biologically important compounds and drugs using visualization simulation programs; converting their trivial and systematic names;

interpret and predict the spectral data (IR, ^1H and ^{13}C NMR) of organic compounds;

master:

converting chemical formulas into names and chemical names into formulas, including the application of ChemOffice software package);

skills in working with reference and educational literature, chemical and biochemical databases, compiling abstract reviews, and reports on experiments.

skills of identification of organic compounds, in particular, biologically important, using functional qualitative analysis;

skills of using databases to assess the structure and functionality of biological macromolecules; conversion macromolecule visualization formats

skills of modelling the structures of biologically important compounds and drugs using visualization simulation programs; converting their trivial and systematic names

skills of carrying out safe work in a chemical laboratory: handling chemical glassware, burners, toxic and volatile substances safe operation.

skills in predicting the reactivity of organic compounds and their affinity to biological targets;

methodology for planning and performing an organic synthesis, methods of isolation/purification and identification of organic compounds (including instrumental technique and functional analysis).

Total number of hours for the study of the discipline is 363 academic hours, of which 186 classroom hours and 177 hours of student independent work. Classroom hours according to the types of studies: lectures – 24 hours (including 6 hours of supervised student independent work (SSIW)), laboratory classes – 186 hours.

Intermediate assessment is carried out according to the syllabus of the specialty in the form of a credit (3^d semester), and exam (4th semester).

Form of higher education – full-time.

**ALLOCATION OF ACADEMIC TIME
ACCORDING TO SEMESTERS OF STUDY**

Code, name of the specialty	semester	Number of academic hours						Form of intermediate assessment
		total	in-class	including			out-of-class self-studies	
				lectures	supervised student independent work	laboratory studies		
7-07-0912-01 «Pharmacy»	3	165	87	12	3	72	78	credit
	4	198	99	6	3	90	99	examination
Total hours		363	186	18	6	162	177	

THEMATIC PLAN

Section (topic) name	Number of class hours	
	lectures (incl. SSIW)	laboratory
1. Structure and bonding. Spectroscopic methods of organic substances identification	6	28
1.1. Introduction to Organic Chemistry. Classification and nomenclature of organic compounds	-	4
1.2. Chemical bonding and distribution of electrons in molecules	1,5	4
1.3. Stereoisomerism and stereochemistry	1,5	4
1.4. Spectroscopic methods of organic substances identification	1,5	8
1.5. Chemical reactivity. Acidic/basic and nucleophilic/electrophilic properties of organic compounds	1,5	8
2. The main classes of mono- and polyfunctional organic compounds: structure, nomenclature, reactivity and identification	9	44
2.1. Hydrocarbons	1,5	12
2.2. Hydrocarbon halides	1,5	4
2.3. Alcohols, phenols, thiols, ethers, sulphides	1,5	4
2.4. Amines. Azo, diazo compounds	1,5	4
2.5. Oxo compounds	1,5	8
2.6. Carboxylic acids and their functional derivatives	1,5	4

Section (topic) name	Number of class hours	
	lectures (incl. SSIW)	laboratory
2.7. Functional derivatives of carbonic acid. Sulfonic acids and their functional derivatives		8
3. Heterofunctional organic compounds. Peptides and proteins	1,5	10
3.1. Hydroxy-, phenol- and oxocarboxylic acids	1,5	5
3.2. Amino acids. Peptides and proteins. Aminoalcohols and aminophenols		5
4. Carbohydrates	1,5	15
4.1. Monosaccharides	1,5	5
4.2. Oligosaccharides and polysaccharides		10
5. Lipids and isoprenoids	1,5	10
5.1. Lipids	-	3
5.2. Terpenes and terpenoids	-	2
5.3. Steroids	1,5	5
6. Heterocyclic compounds. Nucleosides, nucleotides, nucleic acids	1,5	20
6.1. Classification and nomenclature of heterocyclic compounds. Five-membered heterocyclic compounds	1,5	5
6.2. Six-membered heterocyclic compounds	-	5
6.3. Fused heterocycles. Alkaloids	-	3
6.4. Nucleosides, nucleotides. Nucleic acids	-	7
7. Synthesis. Isolation and purification. Physical constants of substance as criteria of purity and identification	3	35
7.1. Bioactive small molecules of natural and synthetic origin	1,5	-
7.2. Isolation and purification		5
7.3. Molecular design and <i>in silico</i> modeling of organic compounds	-	5
7.4. Methodology and methods of modern organic synthesis	1,5	15
7.5. Polymers in medicine and pharmacy	-	5
7.6. Modern organic synthesis and rational drug design		5
Total hours	24	162

CONTENT OF THE EDUCATIONAL MATERIAL

1. Structure and bonding. Spectroscopic methods of organic substances identification

1.1. Introduction to Organic Chemistry. Classification and nomenclature of organic compounds

Organic chemistry as fundamental discipline in the system of pharmaceutical education.

Classification of organic compounds. Functional group and the structure of the carbon skeleton as characteristic lattice for naming of organic compounds. The main classes of organic compounds.

Naming (nomenclature) of organic compounds. Common (historic, trivial) names. The IUPAC (International Union of Pure and Applied Chemistry) systematic approach to nomenclature: substitutive and radical functional approaches. Basics of special nomenclature (spiro-, bi-, and polycycles; lipids, steroids, etc.).

IUPAC substitution nomenclature in naming of pharmaceutical drug components. The use of other nomenclature systems and common names in pharmaceutical chemistry. Transliteration of systematic and common drug names.

Types of chemical formulas. Software packages for 2D visualizing the structure of molecules and using 3D models (Chem Office, etc.). Using the Chem Office software package for structure-name interconversion.

1.2. Chemical bonding and distribution of electrons in molecules

Electronic configuration of the carbon atom and organogenic heteroatoms in the molecules of organic compounds. Orbital hybridization concept in the explanation of molecular geometry and atomic bonding properties

Different types of bonding in organic compounds. Covalent σ - and π - bonds. Multiple bonding: double ($C=C$, $C=O$, $C=N$) and triple ($C\equiv C$, $C\equiv N$) bonds; their main characteristics (length, energy, polarity, polarizability). The role of the mutual influence of atoms in a molecule on biological activity and/or bioavailability of substances.

Delocalized chemical bond. Conjugation (π, π - and p, π - conjugation). Conjugation in cyclic molecules: partly and completely conjugated systems. Aromaticity of carbocyclic and heterocyclic compounds. Concepts of aromaticity. Characteristics of aromatic compounds according to *Hückel's* rule. Annulenes, completely conjugated monocyclic hydrocarbons alternating (possessing alternating single and double bonds), with aromatic, non-aromatic or anti-aromatic properties.

Types of weak interactions. Hydrogen bonding. Halogen bond. Ion-dipole interactions. Hydrophobic interactions. The role of weak interactions in the formation of affinity of biogenic agonists and exogenous agents (drugs and toxicants) with biological macromolecules (proteins, nucleotides and other targets).

The charge distribution in a molecule. Electronic effects. Mesomerism. Induction. Electron donor and electron acceptor substituents. Steric, stereoelectronic and solvent effects. Distribution of electron density in functional groups and hydrocarbon skeleton, graphic representation of of bond polarization.

Influence of functional groups on reactivity and physicochemical properties (hydrophilicity/hydrophobicity; lipophilicity/lipophobicity), connection with biological activity and bioavailability. The concept of bioisosteric groups.

1.3. Stereoisomerism and stereochemistry

The three dimensional shape or configuration of a molecule. Molecular conformations. Presentation of three dimensional shape: molecular models, perspective drawings, *Fischer* and *Newman* projections. Stereochemistry of organic compounds and their biological activity.

Stereoisomerism. Configurational and conformational stereoisomers. Diastereomers and enantiomers, differentiation of their physical and chemical properties. Structure of σ - and π - diastereomers. Diastereotopic and enantiotopic atoms (groups) and sides.

Chirality and symmetry. Symmetry elements and their association with chiral and achiral objects. Types of chirality (centre, axis and plane). Chirality centre, asymmetric atoms. Prochirality concept.

Enantiomers as optical antipodes. Optical activity of the chiral substances and its measuring. Polarimetry, rotation angle, specific rotation. *Levo*- and *Dextro* rotating substances.

Racemates. Racemic crystal, conglomerate, racemic mixture. Methods of racemate resolution and separation.

The concept of stereodifferentiation of atoms (groups of atoms) in molecule. Diastereotopic, enantiotopic and homotopic atoms (groups) and sides.

Conformational analysis. Torsional angle. Angular, torsional and *van der Waals* interactions in the molecule. Conformational isomers, or rotamers. Conformations. Eclipsed and staggered conformations and their nomenclature for acyclic and cyclic compounds. Conformational isomers, or rotamers.

Conformations of alkanes and hydrocarbon substituents, their energy characteristics. Zigzag and claw-like conformation of alkanes.

Conformations of cycloalkanes. Tension of small cycles. Conformations of cyclopentane and cyclohexane. Energy characteristics of chair and boat conformations of cyclohexane. Axial and equatorial substituents. Inversion of the cycle. 1,3-Diaxial interaction in cyclohexane derivatives. Free energy and equilibria of conformational isomers. The influence of the substituent on the state of axial-equatorial equilibrium; the other reasons for shift of the conformational equilibrium. Conformational analysis of heteroanalogues of cycloalkanes: tetrahydropyran, tetrahydrofuran and piperidine.

The role of weak interactions and solvents on the state of conformational equilibrium. Stabilization of conformations due to the formation of intra- and intermolecular hydrogen bonds.

Stereochemical nomenclature. Cahn-Ingold-Prelog rules for ranking substituents. R, S- and D, L-conventions for designation of configuration; E, Z-convention for designation of configuration of relative configuration of substituents. Outdated and previous systems of stereoisomer nomenclature used in biochemistry, pharmacology (D, L, cis, trans, etc.), relation to topical systematic nomenclature.

Stereochemistry and nomenclature of medicines. ChemOffice software package for determination the stereochemistry of compounds. Representation of 3D structure in 2D modelling (chemical drawing); mutual transformation of 2D and 3D models.

1.4. Spectroscopic methods of organic substances identification

The electromagnetic spectrum. Different parts of the total radiation spectrum. Gamma and X rays, visible (UV and IR), microwave and radio regions. The ground and excited states of a molecule. Excitation energy. Selectivity of energy absorption by a molecule. The nature of the excitation of a molecule upon absorption of energy in the UV, IR and radio-frequency regions of the spectrum.

UV-visible absorption spectroscopy (electron spectroscopy), spectrum recording range. The *Beer-Lambert-Bouguer* law. Absorbance and molar Absorbancy. Representation of the spectrum. Molecular orbitals of electrons, types of electronic transitions (excitations) in a molecule. The energies which are sufficient to promote or excite a molecular electron to a higher energy orbital. Absorption bands and their parameters in the spectrum. Correlation between the UV spectrum and the structure of the compound. Chromophore and auxochromic groups. Bathochromic and hypsochromic shifts, hyperchromic and hypochromic effects of the absorption band, the importance of conjugation. Solvents for UV spectroscopy.

Optical absorption spectroscopy in the infrared spectrum (infrared, vibrational spectroscopy), spectrum recording range. Representation of the spectrum. Absorption bands and their parameters in the spectrum. Types of vibrations of atoms in a molecule. The energy of stretching and bending vibrations, the values of the corresponding absorption bands in the spectrum. Typical infrared absorption Frequencies. The fingerprint range. The influence of the conjugation and hydrogen bond formation and on the spectral characteristics. The influence of the polarity of a bond in a characteristic group to the intensity of an absorption band in spectrum. Databases of characteristic group frequencies of organic compounds. Different techniques of IR spectroscopy (liquid and solid sampling, attenuated total reflection (ATR) sampling, Fourier-transform infrared spectroscopy (FTIR), Solvents in IR spectroscopy.

Nuclear magnetic resonance spectroscopy (NMR spectroscopy). Representation of the spectrum. Nuclear magnetic resonance, resonance energy, resonant frequency. NMR techniques on different chemical nuclei.

Proton NMR spectroscopy. (NMR- ^1H). Fourier transform technique for NMR. Effect of screening of hydrogen nuclei in a molecule. Determination of magnetically equivalent (homotopic and enantiotopic) and magnetically nonequivalent (diastereotopic and structurally distinct) atoms and groups. Chemical shift and its correlation with the structure of substances (influence of the nature of atoms and spatial effects). Intensity and multiplicity of signals. J-coupling and constants of spin-spin interaction. Scales and standards in NMR. Delta scale (δ), tetramethylsilane as internal standard for calibrating NMR spectra. Spectra interpretation. NMR- ^1H spectra simulation with the aid of ChemOffice software package.

^{13}C NMR spectroscopy: range of spectrum, chemical shifts and J-coupling. Basics of nuclear magnetic resonance spectroscopy on the nuclei of other elements (P, N, F, etc.). Transition metal compounds as shifting reagents. Chiral shifting reagents, chiral NMR spectrometry.

Solvents for NMR spectroscopy.

Mass spectrometry, the nature of the spectrum. Molecular ion, fragmentation ions. The main directions of fragmentation of the molecule. Determination of molecular weight and molecular formula. Chromato-mass spectrometry, its combination with other physical research methods for the identification of drugs and impurities.

Chiroptical methods in the identification of the structure of organic compounds, including natural and synthetic biologically active substances and their precursors.

Simulation of spectra of biologically active substances and their precursors in silico (Chem Office software package, etc.).

1.5. Chemical reactivity. Acidic/basic and nucleophilic/electrophilic properties of organic compounds

General definitions: reactants, substrate, reagent, reaction product; the reaction center (cite) of the molecule; reactivity of the compound; reaction mechanism. Reaction classification: on the structural change occurring in the reactant molecules; on the mechanism of bond break/formation; on the type of the reagent, on the molecularity.

Reaction classification on the structural change occurring in the reactant molecules: addition, elimination, substitution, redox, pericyclic rearrangements, Acid-base interactions.

Reaction classification on the reagent type and the mechanism of bond break/formation. Homolytic/heterolytic bond break and homogenic/heterogenic bond formation. Structure and stability of reaction intermediate: free radicals, carbocations and carboanions.

Radical and polar (nucleophiles and electrophiles) reagents. Types of nucleophiles and electrophiles. Electrophilic and nucleophilic reaction centers of the molecule.

Mono- and bimolecular reactions.

Kinetically and thermodynamically controlled reactions. Regio- and stereoselective (stereospecific) reactions.

The role of solvents in the chemical reactivity. Classification of solvents by polarity / non-polarity; protonity/aprotonity; relation to water.

Brønsted-Lowry acids and bases. Conjugated acids and bases. Acidity and basicity constants. Organic OH, SH, NH and CH acids. Organic π - and n-bases (Ammonium, oxonium, sulphonium).

Acid-base catalysis.

Lewis acids and bases. Aidity/basicity vs electrophility/nucleophility. Hard and soft acids and bases. *Pearson*, or HSAB (Hard and soft Acid/Base) concept.

The factors which influence the acidity and basicity of the compound (electronegativity and polarizability of the atom in the reaction center, the electronic effects of substituents on the reaction center, the stability of the corresponding acids and bases conjugated to the substrate, the solvent effects).

2. The main classes of mono- and polyfunctional organic compounds: structure, nomenclature, reactivity and identification

2.1. Hydrocarbons

Alkanes. Structure. Nomenclature. Physical properties. Reactions of radical substitution. Mechanism S_R and regioselectivity of halogenation. Oxidation of alkanes.

Vaseline oil, paraffin.

Cycloalkanes. Structure, classification and nomenclature. Special chemical properties of small cycles. Structure, stereochemistry and nomenclature of bi- and polycyclic systems.

Cyclopropane, cyclopentane, cyclohexane.

Identification of alkanes and cycloalkanes, spectral characteristics.

Alkenes. Structure. Nomenclature. Physical properties. Reactions of allylic substitution (Halogenation and oxidation). Hydrogenation. Reactions of electrophilic addition A_E : mechanism and selectivity. Hydrogenation, halogenation, hydrohalogenation, hydration, addition of alcohols, hydroxylation (hydroxylation, ozonization, epoxidation). Acidic catalysis. Regio- and stereoselectivity of addition. *Markovnikov* rule, contemporary concepts of regioselectivity. Radical addition. *Kharasch* addition. Oxidative cleavage of double bond. Coupling (*Heck* reaction).

Alkadiene. Structure. Classification and nomenclature. Physical properties. Reactions of electrophilic addition (hydrohalogenation, halogenation). 1,2- and 1,4-Addition to conjugated dienes. Reactions of *Diels-Alder* cycloaddition (diene synthesis).

Buta-1,3-diene, isoprene.

Alkynes. Structure. Nomenclature. Physical properties. Hydrogenation. Reactions of electrophilic addition (hydrohalogenation, halogenation, hydration, interaction with alcohols). Reactions of nucleophilic addition. Reaction of vinylation. Formation of metal acetylides. Oxidation reactions. Coupling (*Sonogashira* reaction).

Identification of unsaturated hydrocarbons. Spectral characteristics.

Polymerization of unsaturated hydrocarbons and their functionally substituted derivatives. Natural and synthetic polymers based on unsaturated organic compounds. Polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyvinyl alcohol, Teflon, rubbers. Polymers, their classification. Synthetic polymers. Polymerization reactions, polymerization mechanisms. Stereoregular polymers. The main polymers used in medicine and pharmacy.

Arenes. Structure and classification.

Monocyclic arenes. Nomenclature and physical properties. Benzylic substitution (halogenation, oxidation). Reactions of benzene ring. Hydrogenation and oxidation. Reactions of electrophilic substitution in the aromatic ring, mechanism S_EAr . Halogenation, nitration, sulfonation, alkylation, acylation of arenes. The influence of substituents on the regioselectivity and the rate of reaction. Thermodynamically and kinetically controlled processes. Activating and deactivating groups, *Ortho* / *para* and meta-directors. Directing effect on multiple substituents.

Arenes with isolated cycles: biphenyl, diphenylmethane, triphenylmethane. Fused arenes. Nomenclature and physical properties. Reactions of electrophilic substitution, the influence of substituents on the regioselectivity and rate of reaction. Specific character of additions to fused analogues of benzene.

Hydrogenation and oxidation of benzene and their fused analogues.

Carbon skeleton of tetracene as a structural base of tetracycline antibiotics.

The concept of non-benzoic carbocyclic aromatic compounds.

Identification of arenes. Spectral characteristics.

Influence of the hydrocarbon skeleton and hydrocarbon substituents on the lipophilicity of organic compounds, their role in biological (pharmacological) activity and availability.

2.2. Hydrocarbon halides

Influence of the halogen on the electron density distribution in organic compounds. The ability of a halogen atom to form intra- and intermolecular weak interactions (halogen bond). Hydrophilicity/hydrophobicity and lipophilicity/lipophobicity of organic compounds containing halogen atom, influence on biological (pharmacological) activity and availability. Bioisostericity of fluorine and hydroxyl group.

Structure. Classification and nomenclature. Physical properties. Typical chemical reactivity.

Saturated alicyclic and cyclic halides. Characteristics of carbon-halogen bond (length, energy, polarity, polarizability), reactivity of halides. Nucleophilic substitution reactions. Mechanisms of mono- and bimolecular substitution S_N1 and S_N2 . Interaction of halogen derivatives with O-, S-, C- and N-nucleophiles. Synthesis of alcohols, ethers and esters, thiols, sulfides, sulfonium salts, amines, nitro derivatives, nitriles based on halogen derivatives of hydrocarbons. Elimination reactions. Mechanisms of mono- and bimolecular elimination of E_1 and E_2 . *Zaitsev's* rule. Competitiveness of reactions of nucleophilic substitution and elimination. Reactions of alkyl halides with metals. Magnesium (Grignard) and Lithium organic reagent and their application in synthesis.

Specific reactivity of allyl and benzyl halides in substitution reactions.

Specific reactivity of vinyl and aryl halides in substitution reactions.

Specific physical and chemical properties of organic fluorides, their application in medicine and pharmacy.

Identification of organic halides. Spectral characteristics.

2.3. Alcohols, phenols, thiols, ethers, sulphides

The structure of the hydroxyl group. Influence of the hydroxyl group on the electron density distribution in organic compounds. The ability of a hydroxyl group to form intra- and intermolecular hydrogen bonds. Hydrophilicity/hydrophobicity and lipophilicity/lipophobicity of organic compounds containing a hydroxyl group, influence on biological (pharmacological) activity and availability.

Alcohols. Structure. Classification and nomenclature. Physical properties. Acidic properties, formation of alkoxides (alcoholates). Basic properties, formation of oxonium salts. Intra- and intermolecular hydrogen bond in alcohols. Nucleophilic properties of alcohols; formation of ethers and esters, esters of inorganic acids (sulfates, phosphates, di- and triphosphates). Nucleophilic substitution and elimination reactions: activation of poor leaving hydroxyl group (acid catalysis, ester formation with inorganic and organic acids). Reactions of nucleophilic substitution of non-activated alcohols with hydrogen halides, phosphorus halides, thionyl chloride; activated alcohols (sulfonates) with O-, S-, C- and N-nucleophiles.

Intramolecular dehydration of alcohols. Oxidation of alcohols *in vitro* and *in vivo*.

Methanol, ethanol, propanols, butanols, benzyl alcohol.

Polyhydric alcohols. Chemical properties: general and specific reactions. Acidity. Cyclization and formation of chelate complexes.

Ethylene glycol, glycerin.

Identification of alcohols. Spectral characteristics.

Phenols and naphthols. Structure. Classification and nomenclature. Physical properties. Acidic properties, formation of phenoxides (phenolates). Nucleophilic properties: phenols and phenoxides as nucleophiles (substitution and addition reactions – formation of ethers and esters, addition to multiple bond). Reactions of electrophilic substitution in the aromatic ring of phenols: halogenation, nitration, sulfonation, nitration, carboxylation, formylation, hydroxymethylation, alkylation, acylation. Reduction and oxidation of phenols. Phenolic antioxidants.

Phenolic compounds in plants and animals, their application in medicine.

Phenol, 2,4,6-trinitrophenol (picric acid); 1- and 2-naphthols, catechol (pyrocatechin), resorcinol, hydroquinone, phloroglucinol, pyrogallol.

Identification of phenols. Spectral characteristics.

Ethers. Structure. Classification and nomenclature. Physical and chemical properties and their application as solvents. Basic properties, formation of oxonium salts. Ether cleavage by hydrogen halides. Oxidation, formation of organic peroxides. Oxiranes (1,2-epoxides), structure and reactivity, cycle cleavage with the formation of vicinal diols and heterofunctional alcohols. Oligo and polyethers: their structure and application. Crown-ethers.

Diethyl ether, anisole, phenetol. Dioxane, tetrahydrofuran. Polyethylene glycol.

Identification of ethers. Spectral characteristics.

Thiols. Nomenclature. Physical properties. Acidic properties, the formation of thiolates and salts with cations of heavy metals. Nucleophilic properties: the formation of sulfides and sulfur analogues of esters. Nucleophilic properties: formation of sulfides and sulfur analogues of esters. Reduction and oxidation. Biologically important thiols: Coenzyme A, Glutathione. Thiolic antioxidants.

Sulfides. Structure. Classification and nomenclature. Physical and chemical properties. Nucleophilic properties, formation of sulfonium salts. Oxidation in sulfoxides and sulfones; reduction.

Application of thiols, sulfides, sulfoxides and sulfones in organic chemistry and medicine.

Dimethyl sulfoxide, its application as a solvent and drug. Omeprazole as an example of a substance with a stereogenic sulfur atom.

Identification of thiocompounds. Spectral characteristics.

2.4. Amines. Azo, diazo compounds

The structure of the amino group. Influence of the amino group on the electron density distribution in organic compounds. The ability of an amino group to form intra- and intermolecular hydrogen bonds. Hydrophilicity/hydrophobicity and lipophilicity/lipophobicity of organic compounds containing an amino group, influence on biological (pharmacological) activity and availability.

Classification and nomenclature of amines, azo and diazo compounds, their typical reactivity.

Structure and physical properties of amines. The basic properties of aliphatic and aromatic amines, ammonium salts. Acidic properties of amines, formation and application of metal amides. Amines as nucleophiles: substitution reactions and addition

to multiple bonds. Carbylamine (isonitrile) reaction. Synthesis of amines and quaternary ammonium salts, organic amides. Elimination of quaternary ammonium salts, regioselective pathways to *Hoffman* and *Zaitsev* alkenes from halides. Reactions of electrophilic substitution in aromatic amines: halogenation, sulfonation, nitration, alkylation and acylation.

Nitroization of primary, secondary and tertiary aliphatic and aromatic amines. Mechanisms of diazotization reaction. Formation and structure of diazonium salts. Application of diazonium salts in organic synthesis and analysis.

The structure of aromatic diazonium salts. The reaction of diazotization, its mechanism, conditions of conduct. Substitution on N₂-group by halogens and hydrogen; hydroxy, cyano, nitro group and alkoxy groups. Azo-coupling reactions: mechanism and application in synthesis and analysis. Aza-dyes, structure and their industrial and analytical application. Aza-indicators. Diazotization in chemical tests and spectroscopy.

Aliphatic diazo compounds. Diazomethane, its structure and alkylating properties.

Ethyl-, diethyl-, triethylamines, ethylenediamine, hexamethylenediamine, aniline, N-methylaniline, N,N-dimethylaniline, toluidines, phenetidines, diphenylamine, phenylenediamines (o-, m-, n-), naphthylamines. Nitrozoarea and its derivatives as drugs.

Identification of amines, azo and diazo compounds. Spectral characteristics.

2.5. Oxo compounds

The structure of the carbonyl group in oxo compounds. Influence of the oxo group on the electron density distribution in organic compounds. The ability of an oxo group to form intra- and intermolecular hydrogen bonds. Hydrophilicity / hydrophobicity and lipophilicity / lipophobicity of organic compounds containing an oxo group, influence on biological (pharmacological) activity and availability.

Structure. Nomenclature. The physical and physico-chemical properties, their typical reactivity.

Nucleophilic addition: reversibility and mechanisms. Acid catalysis of nucleophilic addition. Interaction of oxo compounds with O-, S-, C- and N- and Halogen nucleophiles.

Water addition (formation and (un)stability of hydrated forms of aldehydes and ketones). Addition of alcohols and thiols (formation of hemiacetals and acetals; thiacetals). Application of acetals and thioacetals for protection, deoxygenation and ampouling (polarity) inversion of carbonyl group. Formation of aminals (synthesis of Urotropin).

Interaction with carbon nucleophiles (hydrocyanation and cyanosilylation, interaction with organometallic compounds and acetylides, *Wittig* olefination).

Interaction with halogen nucleophiles (phosphorus halides and sulfur halides, etc.).

Addition-elimination reactions: interaction with nitrogen nucleophiles (primary and secondary amines, hydroxylamine, hydrazine and their derivatives): mechanism, influence of the nature of the reactants on product formation. Formation of imines (Schiff bases), enamines, aminals, oximes, hydrazones, semicarbazones, thiosemicarbazones and their application in synthesis and medicine.

Reactions on CH-acid center of the α -carbon atom of aldehydes and ketones. Enolization, the structure of the enolate ion, keto-enol tautomerism. Substitution reactions in the α -position to the oxo group (alkylation, α -halogenation, haloform

reactions; iodoform test, aminoalkylation). Aldol addition, aldol-croton condensation. Retro-aldol reaction; lab- and biosynthetic contexts.

Oxidation and reduction of aldehydes and ketones: reagents and scope. *Baeyer-Villiger* rearrangement. Oxidation of oxo compounds by metal compounds and peroxide compounds. Reduction of oxo compounds with hydrogen hydrides and complex metal hydrides. Methods for deoxygenation of aldehydes and ketones (Kishner-Wolf and Clemmensen reactions, reduction of thioacetals). Hydride transfer reaction *in vitro* and *in vivo*. *Cannizzaro* and *Meerwein-Ponndorf-Verley* reductions, interaction with *tert*-butylmagnesiumchloride: scope, mechanisms and factors stabilizing the transition state. Enzymatic reduction with NADH: mechanism and biological role.

Polymerization with oxo compounds.

Aza analogues of oxo compounds (imines, enamines, oximes, hydrazones and semicarbazones); their application in chemical analysis and for preparation of convenient dosage forms. Reactivity of aza analogues with O-, S-, C- and N-nucleophiles. Addition reactions: hydrolysis, hydrogenation, hydrocyanation, interaction with organometallic compounds. α -Substitution reactions: halogenation, C-alkylation and acetylation; *Stork* reaction. Specific reactions. The *Wolff-Kishner* reduction: mechanism and application to convert carbonyl functionalities into methylene group. *Beckmann* rearrangement and degradation of oximes: mechanism and application in drug synthesis. Synthesis of caprolactame and their polymers.

Formaldehyde (formalin), acetaldehyde, chloral (chloral hydrate), acrolein, benzaldehyde, acetone, cyclohexanone, acetophenone, urotropin.

Quinones. Structure. Nomenclature. The physical and physico-chemical properties. π -Acceptor properties. Oxidative properties of quinones. Addition reactions. Anthraquinone and ubiquinons. Vitamin K.

Identification of oxo compounds. Spectral characteristics.

2.6. Carboxylic acids and their functional derivatives

The structure of functional groups in carboxylic acids and their functional derivatives; their influence on the distribution of electron density in organic compounds and their ability to form intra- and intermolecular hydrogen bonds. Hydrophilicity/hydrophobicity and lipophilicity/lipophobicity of organic compounds containing these groups; influence on biological (pharmacological) activity and availability.

Structure. Classification and nomenclature. The physical and physico-chemical properties. Typical reactivity: reactions of nucleophilic substitution at the carbonyl group and substitution reactions of the α -hydrogen atom. Reactions of nucleophilic substitution at the sp^2 -hybrid carbon atom; addition-elimination mechanism through a tetrahedral intermediate. O-, C- and N acylation reactions in synthesis and *in vivo*. Transformation of hydroxy- and amine-containing pharmaceutical substances into more bioavailable prodrugs. Comparative characteristics of the acylating reactivity. Occurrence and biological role in nature. Halogenation of aliphatic carboxylic acids according to Gell-Volhard-Zelinsky; the use of α -halo-substituted acids for the synthesis of α -hydroxy-, α -amino- and α,β -unsaturated acids.

Specific reactivity of carboxylic acids and their salts. The structure of the carboxylic group and carboxylate ion. Acidity of carboxylic acids: effect of substituents

on pKa, general and specific acidic catalysis. Synthesis and application of salts (*Kolbe* and *Hunsdiecker-Borodin* reactions, pyrolysis). Anhydride formation from mono and dicarboxylic acids. Decarboxylation. Polycondensation of dicarboxylic acids with diamines as a method for obtaining polyamides. Nylon. Polymerization of ϵ -caprolactam. Polycondensation of dicarboxylic acids with glycols. Formic, acetic, propionic, butyric, isovaleric, acrylic, methacrylic, benzoic and cinnamic acids, oxalic, malonic, succinic, glutaric, adipic, maleic, fumaric, phthalic acids.

Specific reactions of esters and thioethers. *Claisen* and *Dieckmann* condensations: mechanism, application *in vitro* and biological role *in vivo*. examples used in organic synthesis. Malonic ester, CH-acidity. Malonic ester synthesis of substituted carboxylic acid derivatives.

Specific reactions of amides. The structure of the amide group. Basic and acidic properties. Dehydration to nitriles. Nitrosation. *Hofmann* rearrangement (degradation) of amides in synthesis of primary amine and in chemical tests. Dehydration to nitriles. Ethanamide, benzamide. Imides, their alkylation, hydrolysis. N-bromosuccinimide (NBS) and its application in synthesis.

Hydrolysis and reduction of nitriles. Addition of nucleophiles (carbocations and hydroperoxide anion). Ethannitrile, benzonitrile.

Anhydrides and acid halides as active acylating agents. Acetic anhydride. Acetyl chloride. Acetic anhydride. Phthalic anhydride. Phenolphthalein, synthesis, indicator properties.

Acid hydrazides and hydroxamic acids, their use in chemical analysis and pharmacy.

Identification of carboxylic acids and their functional derivatives. Spectral characteristics.

Polysiloxanes. The structure of the siloxane bond, the properties of polysiloxanes (thermal stability, hydrophobicity, biological inertness).

2.7. Functional derivatives of carbonic acid. Sulfonic acids and their functional derivatives

Structure, classification and nomenclature of functional derivatives of carbonic acid. Phosgene and chloroformates: their application in synthesis and analysis; protection of hydroxyl and amino groups. Carbamic acid and its esters (urethanes), their biological and application. Carbamide (urea): hydrolysis, basic and nucleophilic properties. Acyl ureas (ureides), ureido acids. Interaction of urea with nitrous acid and hypobromites. Biuret formation; Biuret test. Guanidine, its basic properties. Urea, guanidine and their derivatives in nature, their application in medicine.

Classification and nomenclature of sulfonic acids and their derivatives. Acidic properties of sulfonic acids, formation of salts. Desulphurization of aromatic sulfonic acids. Nucleophilic substitution in Arene sulfonic acids. Application of functional derivatives of sulfonic acids (esters, amides, acid chlorides) in chemistry and medicine. Sulfonic esters in nucleophilic substitution (conversion of hydroxyl to good leaving group): interaction with halogen, carbon, oxygen and sulfur nucleophiles.

Sulfanilic acid. Sulfanilamide (streptocid). General principle of the structure of sulfonamide drugs. Sulfonamides as pharmaceutical drugs.

3. Heterofunctional organic compounds. Peptides and proteins

3.1. Hydroxy-, phenol- and oxocarboxylic acids

Hydroxycarboxylic acids. Classification. Nomenclature. Physical and physico-chemical properties. Chemical properties as heterofunctional compounds. Typical reactions of acids and alcohols. Specific reactions of α -, β -, γ -, δ -hydroxy acids. Lactones, lactides. Mono, di and tricarboxylic acids.

Phenolcarboxylic acids. Salicylic acid: chemical properties as a hetero-functional compound. Salicylic acid esters (methyl and phenyl salicylates, acetylsalicylic acid). The basics of the pro-drug concept. N-Aminosalicylic acid (PAS). Coumaric and gallic acids. Tannins.

Dicarbonyl compounds. Classification. Structure. Nomenclature. The physical and physico-chemical properties. Chemical properties as heterofunctional compounds. Occurrence and biological role in nature.

Chemical properties β -dicarbonyl compounds. Keto-enol tautomerization. Factors influencing the state of equilibrium, C-H and O-H acidity of β -dicarbonyl compounds. Keto-enol tautomerization: stabilization of enol form; C-H and O-H acidity. Interaction β -dicarbonyl compounds with nucleophiles and bases. Reaction selectivity of two carbonyl groups. Formation of enolate anions under thermodynamic and kinetic control. Reactions of enolic and enolate forms: C- alkylation, aldol (*Knoevenagel*) condensation. Acetoacetic ester synthesis strategy. Acetoacetic and malonic ester synthesis of substituted alicyclic and cyclic ketones and acid derivatives.

Glyoxylic, pyruvic, acetoacetic, oxaloacetic, α -ketoglutaric acids. Ketone bodies.

3.2. Amino acids. Peptides and proteins. Aminoalcohols and aminophenols

Classification and nomenclature of amino acids. Chemical properties as heterofunctional compounds. Typical reactions of acids and amines. Specific reactions of α -, β -, γ -, δ -aminocarboxylic acids. Lactams, diketopiperazines. Structure and application of β -lactam antibiotics.

Structure and classification of proteinogenic α -amino acids. Stereoisomerism. Physical properties. Amphoteric properties, isoelectric point. Formation of chelate compounds. Biologically important reactions of proteinogenic amino acids: carboxylation and decarboxylation; hydroxylation, transamination, oxidative and non-oxidative deamination, retro-aldol degradation. Identification of α -amino acids.

Peptides and proteins. The amide nature of the peptide bond. Primary structure of peptides and proteins. Partial and complete hydrolysis. Amphoterism of peptides and proteins. Principles of peptide identification and synthesis. Four distinct aspects of a protein's structure (primary, secondary, tertiary and *quaternary structure*).

Examples of peptide hormones (oxytocin, vasopressin, insulin) and medicinal substances (*Enalapril*).

γ -Aminobutyric acid (GABA). Piracetam.

N-Aminobenzoic acid. Benzocaine, procaine, procainamide. O-Aminobenzoic acid (anthranilic acid).

Sulfanilic acid. Sulfanilamide (streptocide). The general principle of the structure of sulfanilamide medicinal substances.

p-Aminophenol, its derivatives used in medicine (paracetamol). Catecholamines. Epinephrine (adrenaline), norepinephrine.

Biogenic amines: 2-aminoethanol (colamine), choline, acetylcholine, tryptamine, serotonin, GABA, tyramine, DOPA, their roles. The basics of the secondary messengers and receptor concept.

4. Carbohydrates

4.1. Monosaccharides

Structure. Classification and nomenclature. Occurrence and biological role in nature. Aldoses and ketoses; pentoses and hexoses; deoxy- and amino sugars. Stereochemistry. D- and L- series, Epimers. Oxo and cyclic forms (furanose, pyranose). *Haworth* and *Fisher* projections. Conformations of cyclic forms. Ring-straight chain isomerism. Mutarotation in solutions.

The physical and physico-chemical properties. Chemical properties as heterofunctional compounds. Typical reactions of oxo compounds and alcohols. Formation of ethers and esters. Reduction of monosaccharides to polyols (aldites). Specific reactions of monosaccharides. Epimerization reactions. Reactions of the acetal hydroxyl. Glycation in normal and pathologic metabolism. Oxidation of monosaccharides. Glyconic, glycaric and glycuronic acids. the formation of glycosides. O-, N- and S-glycosides, their nomenclature, hydrolysis, biological role and application in medicine. «C-glycosides».

Pentoses: D- and L-arabinose, D-xylose, D-ribose, D-ribulose. Hexoses: D-glucose, D-galactose, D-mannose, D-fructose, L-rhamnose, D-fucose. 2-Deoxy-D-ribose, D-glucosamine, D-galactosamine, D-sorbitol, xylitol. D-Glucuronic, D-galacturonic, D-gluconic acid. Ascorbic acid (vitamin C).

4.2. Oligosaccharides and polysaccharides

The structure of reducing and non-reducing disaccharides. Nomenclature of oligosaccharides. Tautomerism of reducing disaccharides. Hydrolysis, methanolysis. Esters and ethers. Oxidation. Maltose, cellobiose, lactose, lactulose, sucrose, rutinose.

Classification and nomenclature of polysaccharides. Homoglycans and heteroglycans. Esters and ethers of polysaccharides: acetates, nitrates, methyl-, carboxymethyl- and diethylaminoethylcellulose. Starch (amylose, amylopectin), glycogen, cellulose, chitin, dextrans, inulin, pectin substances, chondroitin sulfate, hyaluronic acid, heparin, alginic acids. Hydrolysis of polysaccharides and their derivatives.

Structure of aminoglycoside antibiotics and glycopeptides.

5. Lipids and isoprenoids

5.1. Lipids

Structure, classification and nomenclature. Monocomponent lipids (lipid monomers): fatty acids and alcohols. Saturated and unsaturated higher fatty acids, features of structure and nomenclature, omega acids. Palmitic, stearic, oleic, linoleic, linolenic, arachidonic, mycolic acids. Fatty alcohols: cetyl, stearyl, myristyl alcohols, glycerol, sphingosine. Multicomponent lipids: simple and complex lipids.

Waxes. Beeswax. Spermaceti. Lanolin.

Fats, oils (triacylglycerols). Nomenclature.

Phospholipids. L-Glycerol-3-phosphate, phosphatidic acids. Phosphatidylcholines, phosphatidylcolamines, phosphatidylserines. Diphilic structure.

Sphingosine based lipids.

Physical and chemical properties of saponified lipids. Hydrolysis, transesterification, hydrogenation, addition of halogens, oxidation. Lipid peroxidation. peroxides or lipid oxidation products (LOPs).

Classification, properties and application of surfactants (surfactants).

Arachidonic acid and products of its metabolism. Basics of the classification and biological role of eicosanoids. Prostaglandins, Prostocyclins. Thromboxanes. Leukotrienes. Formation of the eicosanoids by action of the cyclooxygenase (COX), the biological role and application of drugs affecting the COX activity.

5.2. Terpenes and terpenoids

Isoprenoids. Classification. Physical properties. Occurrence, biological role and application.

Structure, classification and nomenclature of terpenes and terpenoids. Typical reactivity. Parent monoterpene hydrocarbons (2,6-dimethyloctane, menthane, pinan, bornan). Acyclic monoterpenes (citral), monocyclic monoterpenes and monoterpenoids (limonene, menthol, terpin), bicyclic monoterpenes and monoterpenoids (α -pinene, borneol, camphor). Diterpenoids (retinol, retinal), vitamin A. Tetraterpenes (β -carotene), provitamin A.

5.3. Steroids

The structure of gonan (cyclopentanoperhydrophenanthrene): structure, numbering of carbon atoms, A, B, C, D rings); Stereoisomerism, *cis* and *trans*-forms of bicyclic fragments, α , β -convention for designating the configuration of chirality centers. Configuration of cycles A, B, C, D in molecules of natural steroids, 5α - and 5β -stereochemical series of steroids.

Classification and nomenclature of natural steroid compounds. Types by structure and function. Parent hydrocarbons, gonane homologs: estran, androstane, pregnan, cholan, cholestane, cordane. Types by function: sterols, bile acids, corticosteroids, androgenic hormones, estrogen hormones, aglycones of cardiac glycosides.

Sterols (cholesterol, ergosterol). Isomerization of ergosterol to vitamin D₂, cholesterol to vitamin D₃.

Bile acids (cholate, deoxycholic, glycocholic, taurocholic). Emulsifying action.

Corticosteroids (hydrocortisone, deoxycorticosterone, prednisolone).

Androgenic hormones (testosterone, androsterone).

Estrogenic hormones (estradiol, estrone, estriol).

Structure and nomenclature of cardiac glycosides. Hydrolysis. Aglycones of cardiac glycosides: cardenolides (digitoxigenin, strophanthidine) and bufadienolide.

6. Heterocyclic compounds. Nucleosides, nucleotides, nucleic acids

6.1. Classification and nomenclature of heterocyclic compounds. Five-membered heterocyclic compounds

Classification and nomenclature of heterocyclic compounds. Parent heterocyclic compounds. Principles of systematic nomenclature and common names.

The structure of five- and six-membered aromatic heterocyclic compounds, electron-rich and electron-deficient heterocycles. Aromatic heterocycles and their stability.

Five-membered heterocycles with one heteroatom. Aromatic heterocycles: pyrrole, thiophene, furan, indole. Acidic properties of pyrrole and indole.

Acidophobicity of pyrrole and furan. Reactions of electrophilic substitution, the use of special reagents for halogenation, nitration, sulfonation and acylation. Reduction and oxidation. Hydrogenated analogues.

Furfural, semicarbazone of 5-nitrofurfural. Nitrofurans antibacterials. Cyanocobalamin – vitamin B₁₂. β -indolylacetic acid. Porphin: aromaticity and occurrence, structure of chlorophyll and hemoglobin.

Classification and nomenclature of five-membered heterocycles with two heteroatoms. Aromatic heterocycles: pyrazole, imidazole, thiazole, oxazole, isoxazole. Acid-base properties, the formation of associates. Nucleophilic properties. Reactions of electrophilic substitution in pyrazole and imidazole. Tautomerism of pyrazole and imidazole.

Pyrazolones and their tautomerism. Medications based on pyrazolone (Metamizole, phenylbutazone).

Imidazole derivatives: histidine, histamine, benzimidazole. Imidazole based medications.

Thiazolidine.

6.2. Six-membered heterocyclic compounds

Six-membered heterocycles with one heteroatom. Aromatic heterocycles: pyridine, quinoline, isoquinoline. Basic properties. Reactions with electrophiles (addition to nitrogen and S_EAr). Reactions of nucleophilic substitution (amination, hydroxylation). Tautomerism of hydroxy derivatives and amino derivatives of pyridine. Nucleophilic properties of pyridine. Oxidation and reduction of pyridine and its fused analogues, application of pyridinium oxides. Alkylpyridinium ion and its interaction with hydride ion as the chemical basis of the redox system coenzyme NAD⁺/NADH (nicotinamide adenine dinucleotide). Hydrogenated analogues (piperidine, perhydroquinoline), properties as amines and application in medicine.

α -, β - и γ -picolines. CH-acidity. α -Substitution: alkylation, condensation and oxidation. Nicotinic and isonicotinic acids. Nicotinamide (vitamin PP), isonicotinic acid hydrazide (isoniazid) and its derivatives: synthesis and application as TB drugs. Piperidine, quinuclidine: basic properties. Piperidine based opioid receptor agonists (Fentanyl, Promedol, Loperamid).

Pyridoxal, pyridoxal phosphate. Structure and properties of compounds of the vitamin B₆ group. Structure and properties of compounds of the vitamin B₆ group.

8-Hydroxyquinoline, quinolin-4-one and their derivatives used in medicine.

Piran and its analogues. Nonaromatic α - and γ -pyrans, α - and γ -pyrones. Pyrilium salts, aromaticity of the pyrilium cation. Cyanidine test. Benzopyran derivatives: chroman, chromene, chrome, benzopyrones. Flavan, flavanone, flavone, their hydroxy derivatives (catechins, flavonoids). Classification of phenylpropanoids and basic principles of flavonoid chemistry (occurrence and structure). Luteolin, quercetin, rutin. Tocopherols (vitamins of group E).

Classification and nomenclature of six-membered heterocycles with two heteroatoms. Aromatic diazines: pyrimidine, pyrazine, pyridazine. Pyrimidine, its hydroxy and amino derivatives: uracil, thymine, cytosine, their tautomerism. 5-fluorouracil. Barbituric acid: lactim-lactam and keto-enol tautomerism, acidic

properties. Derivatives of barbituric acid (barbiturates): barbitol, phenobarbital. Thiamine (vitamin B₁). Oxazine, phenoxazine. Thiazine, phenothiazine.

Seven-membered heterocycles. Diazepine, benzodiazepine. Structure of medications of the benzodiazepine series.

6.3. Fused heterocycles. Alkaloids

Purin. Acidic and basic properties, tautomerism. Reactions of halogenated derivatives of purine with nucleophilic reagents. Hydroxy derivatives of purine: hypoxanthine, xanthine, uric acid, their tautomerism. Acidic properties of uric acid, acid and average urate. N-Methylated xanthines (caffeine, theophylline, theobromine), acidic and basic properties, electrophilic substitution reactions. Murexide test. Amino derivatives of purine (adenine, guanine): tautomerism, reactions with nitrous acid.

Pteridine and isoalloxazine. Folic acid. Methotrexate as chemotherapy and agent and immune system suppressant. Flavin. Riboflavin. Flavin adenine dinucleotide (FAD) as redox cofactor.

Alkaloids. Chemical classification. Basic properties, formation of salts. Reactions with alkaloid precipitation reagents. Alkaloids of the pyridine group: nicotine, anabasine. Alkaloids of the quinoline group: quinine. Alkaloids of benzyloquinoline and phenantrenoquinoline groups: papaverine, morphine, codeine. Alkaloids of the benzyloquinoline and phenanthrenoquinoline groups: papaverine, morphine, codeine. Synthetic analogues of morphine based on piperidine skeleton. Alkaloids of the tropane group: atropine, cocaine. Protoalkaloids and pseudoalkaloids. Polyamine and Peptide and cyclopeptide alkaloids. Antibiotic, antiviral and antitumor alkaloids.

6.4. Nucleosides, nucleotides. Nucleic acids

Structure and nomenclature of Nucleosides as N-glycosides. Ribonucleosides and deoxyribonucleosides. Pyrimidine and purine nucleic bases. Nomenclature of nucleosides. Conformational structure. Hydrolysis. Pyrimidine and purine nucleic antimetabolites as antiviral and cytostatic drugs. 3-Azidothymidine.

Structure and nomenclature of nucleotides. Ribonucleotides and deoxyribonucleotides. Hydrolysis.

Nucleoside polyphosphates. Nicotinamide adenine dinucleotides.

Nucleic acids. Ribonucleic (RNA) and deoxyribonucleic (DNA) acids. Primary structure of nucleic acids as polynucleotides with phosphodiester bonds. The concept of the secondary structure of nucleic acids.

7. Synthesis. Isolation and purification. Physical constants of substance as criteria of purity and identification

7.1. Bioactive small molecules of natural and synthetic origin

Classification of natural and synthetic bioactive small molecules. Characteristics for synthetic small molecules affording their biological activity and bioavailability. The concept of prodrug.

The main classes of natural small molecules: isoprenoids (terpenes and terpenoids, steroids), iridoids, flavonoids, vitamins, eicosanoids. The role of glycosides in plant biochemistry.

Chemical classification of synthetic bioactive small molecules, which are used as pharmaceutical substances.

7.2. Isolation and purification

Apparatus for the synthesis and purification of substances. Isolation from mixtures, purification of substances by filtration, extraction, distillation, recrystallization, sublimation. Physicochemical principles of methods. Methodology. Equipment.

Basics of the one phase and two-phase extraction: solvents, techniques, application in pharmacognosy, analytical and pharmaceutical chemistry.

7.3. Molecular design and *in silico* modeling of organic compounds

Modelling and *in silico* simulation of potential leader compounds as a key element of rational drug design. 2D and 3D visualization of the structure of organic compounds. Chemical formula types. Software packages for 2D and 3D structure visualization (Chem Office and others).

Mutual influence of atoms in a molecule as a basis for decreasing or increasing biological activity and/or bioavailability. The role of weak interactions in the formation of affinity of biogenic agonists and exogenous agents (drugs and toxicants) with biological macromolecules (proteins, nucleotides and other targets). Influence of functional groups on reactivity and physicochemical properties (hydrophilicity/hydrophobicity; lipophilicity/lipophobicity), their influence on biological activity and bioavailability.

Models on the plane taking into account the need for correct representation of the compound configuration; mutual transformation of planar and three-dimensional models. Study of the binding energy of a modeled ligand with a protein by using the molecular docking technique. Structure design using a software package Chem Office. Conversion of models from graphic format (Chem Draw, *.cdx) to molecular descriptor format (MDL Molfile, *.mol; Protein Data bank, *.pdb, *.pdbqt, etc.). Selection of the target macromolecule from the Protein Data Bank online resource (or an analogous resource). *In silico* simulation for prediction of pharmacological properties and molecular docking. Carrying out SAR-analysis (structure/activity relationship).

7.4. Methodology and methods of modern organic synthesis

Synthesis design. Retrosynthetic analysis. Synthons, rethrons and synthetic equivalents. Convergent and linear synthetic strategies. Cascade reactions.

Selectivity of chemical reactions. Examples of regio- and stereoselective processes in the laboratory (industry) and *in vivo*. General approaches to stereoselective synthesis of organic compounds.

Basics of the modern organic synthesis. Comparative analysis of industrial and laboratory synthesis. Examples of pharmaceutical drug and their precursor synthesis.

Methods of carbon skeleton formation and functionalization reactions. Methods of functionalization and refunctionalization. Methods for introducing multiple bonds, functional groups of halogen derivatives of hydrocarbons, alcohols, phenols, amines, aldehydes, ketones, carboxylic acids, esters, amides. Protection of functional groups in organic synthesis and synthesis of biologically important compounds.

Condition of the reaction. Substances for synthesis. Equipment and glassware for synthesis. Isolation from mixtures, purification of the substance by filtration, extraction, distillation, recrystallization, sublimation.

Measuring of the boiling point, melting point, refractive index, chromatographic characteristics and optical activity. Equipment and techniques. Empirical correlations between structure of physical constants of a substance. Application of physical constants of a substance for its identification.

Determination of boiling point, melting point, refractive index. Capillary work. Devices. Equipment. Method of work. The main empirical patterns of the influence of the composition and structure of molecules on the boiling and melting points of a substance. The use of physical constants of matter for its identification. Mixed sample melting point method. Reference literature. Chromatographic characteristics for the identification of substances.

7.5. Polymers in medicine and pharmacy

Structure and physico-chemical properties of natural and synthetic polymers. Polymerization reactions, understanding of polymerization mechanisms. Stereoregular structure of polymers. The application of polymeric materials as pharmaceutical substances and additives in pharmacy.

7.6. Modern organic synthesis and rational drug design

Strategy and tactics of rational drug design in the context of organic synthesis. Steps and perspectives of the modern organic synthesis in the preparation of pharmaceutical drugs

ACADEMIC DISCIPLINE CURRICULAR CHART

Section, topic #	Section (topic) name	Number of class hours		Supervised student independent work	literature	Practical skill	Form of control	
		lectures	laboratory				of practical skill	of current / intermediate assessment
3 ^d semester								
	Lectures	12	-	6				
1.	Structure of organic molecules. Stereoisomerism	1,5	-	1,5	1-5			Electronic tests
2.	Separation and identification of organic compounds	1,5	-	1,5	2-5			Electronic tests
3.	Reactivity of organic compounds	1,5	-	-	1-5			
4.	Hydrocarbons	-	-	1,5	1-5			Electronic tests
5.	Halogen derivatives. Nucleophilic substitution and elimination reactions	1,5	-	-	1-5			
6.	Hydroxy and thio derivatives of organic compounds	1,5	-	-	1-5			
7.	Amine derivatives of organic compounds. Azo and diazo compounds	1,5	-	-	1-5			
8.	Carbonyl compounds I	1,5			1-5			
9.	Carbonyl compounds II	1,5	-	1,5	1-5			Electronic tests
	Laboratory classes	-	72	-				
1.	Introduction to Organic Chemistry. Classification and nomenclature of organic compounds	-	4	-	1-5	Modelling organic compound structures using visualization/simulation programs; inter-convert systematic/trivial/pharmaco peia names and molecular models	Resolving a situational problem	Express-interview, electronic tests
2.	Chemical bonding and distribution of electrons in molecules	-	4	-	1-5		Resolving a situational problem	
3.	Stereoisomerism and stereochemistry	-	4	-	1-5		Resolving a situational problem	

4.	Spectral methods. UV and IR spectroscopy	-	4	-	2-5	Interpreting spectra of organic compounds, predicting/simulating spectral data	Resolving a situational problem, including the case with the application of Chem office software package	
5.	NMR spectroscopy	-	4	-	2-5			
6.	Reactivity of organic compounds	-	4	-	1-8	Modelling organic compound structures and reactions using visualization/simulation programs; inter-convert systematic/trivial/ pharmacopeia names and molecular models	Resolving a situational problem	
7.	Continuous assessment No 1 «Structure, classification and nomenclature of organic compounds»	-	4	-	1-8	Classifying compounds by the structure of the carbon skeleton and the nature of the functional groups	Resolving a situational problem, including the case with the use of catalogues with formulas of medications *	Situation problem resolving *
						Interpreting spectra of organic compounds, predicting/simulating spectral data	Resolving a situational problem, including the case with the application of Chem office software package *	
8.	Structure and properties of hydrocarbons and hydrocarbon fragments in organic compounds. Non-aromatic hydrocarbons I.	-	4	-	1-8	Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc.	Resolving a situational problem	Electronic tests
9.	Non-aromatic hydrocarbons II.	-	4	-			Resolving a situational problem	Electronic tests
10.	Aromatic hydrocarbons	-	4	-			Resolving a situational problem	Electronic tests

11.	Halogen derivatives. Reactions of nucleophilic substitution and elimination	-	4	-			Resolving a situational problem	Electronic tests
12.	Hydroxy and thio derivatives. Ethers and sulfides	-	4	-			Resolving a situational problem	Electronic tests
13.	Amino derivatives. Azo, diazo compounds	-	4	-			Resolving a situational problem	Electronic tests
14.	Continuous assessment No 2 «Structure, reactivity and identification of hydrocarbons and their halogen-, hydroxy-, thio- and amino derivatives, ethers and sulfides»	-	4	-	1-8	Identifying organic compounds using functional qualitative analysis	Lab report	Written control test*, control questioning
15.	Оксосоединения. Альдегиды и кетоны	-	4	-	1-8	Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc.	Resolving a situational problem	Express-interview, electronic tests
16.	Карбоновые кислоты, функциональные производные карбоновых кислот	-	4	-			Resolving a situational problem	
17.	Функциональные производные угольной кислоты. Сульфокислоты и их функциональные производные	-	4	-			Resolving a situational problem	
18.	Continuous assessment No 3 «Carbonyl compounds. Derivatives of carbonic and sulfonic acids»	-	4	-	1-8	1. Identifying organic compounds using functional qualitative analysis. 2. Applying Chem office software package, online resources and visualization programs to design the structure of an organic compound for in silico research	Lab report * Resolving a situational problem *	Situation problem resolving * Credit
4th semester								
	Lectures	6	-	3				
1.	Heterofunctional compounds	1,5	-	1,5	1-8			Electronic tests
2.	Carbohydrates	1,5	-	1,5	1-8			Electronic tests
3.	Bioactive small molecules	1,5	-	-	1-8			
4.	Methodology and methods of modern organic synthesis	1,5		-	1-8			

	Laboratory classes	-	90	-				
1.	Proteinogenic amino acids. Peptides, proteins. Biogenic amines	-	5	-	1-8	1. Work with databases to evaluate the structure and functionality of biological macromolecules; to interconvert macromolecular visualization formats. 2. Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc.	Resolving a situational problem	Express-interview, electronic tests
2.	Hydroxy-, phenol- and oxocarboxylic acids	-	5	-			Resolving a situational problem	
3.	Monosaccharides	-	5	-			Resolving a situational problem	
4.	Carbohydrates	-	5	-			Resolving a situational problem	
5.	Continuous assessment No 4 «Heterofunctional compounds and carbohydrates»	-	5	-	1-8	Identifying organic compounds using functional qualitative analysis	Lab report	Written control test *
6.	Lipids. Lipid monomers and multicomponent lipids. Isoprenoids. Terpenes and terpenoids	-	5	-	1-5	1. Work with databases to evaluate the structure and functionality of biological macromolecules; to convert macromolecular visualization formats. 2. Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc.	Resolving a situational problem	Express-interview, electronic tests
7.	Steroids	-	5	-	1-8		Resolving a situational problem	
8.	Classification and nomenclature of heterocyclic compounds. Five-membered heterocyclic compounds	-	5	-	1-5		Resolving a situational problem	
9.	Six-membered heterocyclic compounds with one heteroatom	-	5	-			Resolving a situational problem	
10.	Fused heterocycles. Alkaloids. Nucleosides, nucleotides. Nucleic acids	-	5	-			Resolving a situational problem	
11.	Continuous assessment No 5 «Heterofunctional compounds and carbohydrates». Lipids, isoprenoids and heterocyclic compounds	-	5	-	1-5		Lab report	Written control test *
12.	Separation and purification of organic substances. Extraction of biologically active	-	5	-	2,3	1. Carrying out safe work in a chemical laboratory,	Lab report with defense (experiment)*	

	substances					including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc. 2. Carrying out a designed chemical experiment followed by analysis and presentation of the results		
13.	Molecular design and <i>in silico</i> modeling of organic compounds	-	5	-	3	1. Work with databases to evaluate the structure and functionality of biological macromolecules; to convert macromolecular visualization formats. 2. Work with the Chem office software package, online resources and visualization programs. Design the structure of an organic compound for in silico research	Resolving a situational problem * Carrying out practical skills using simulation resources (Chem office software package, online resources and visualization programs)*	Assessment using virtual simulators
14.	Organic synthesis I	-	5	-	2, 3	1. Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc. 2. Carrying out a designed chemical experiment followed by analysis and presentation of the results 3. Work with the software package Chem office. 4. Interpreting spectra of organic compounds,	Lab report with defense (experiment)*	
15.	Organic synthesis II	-	5	-				
16.	Organic synthesis III	-	5	-			Resolving a situational problem *	
17.	Polymers in medicine and pharmacy	-	5	-	1-5		Resolving a situational problem	
18.	Continuous assessment No 6 «Modern organic synthesis and rational drug design»	-	5	-	2-4		Lab report with defense (experiment)* Resolving a situational problem *	Situation problem resolving *, final test

					predicting/simulating spectral data. 5. Modelling the structures and reactions of organic compounds using simulation/visualization programs; interconvert systematic/trivial/pharmaceutical names and molecular models		
	Total hours	18	162	6			Exam

*This is a mandatory form of current certification

INFORMATION AND INSTRUCTIONAL UNIT

LITERATURE

Basic (relevant):

1. Bioorganic Chemistry : textbook for international students / O. N. Ryneiskaya [et al.]. – 2nd edition – Minsk : New knowledge, 2020. – 174 p.

Additional:

2. Lakhvich, T. T., Ryneyskaya, O. N., Fando, G. P. Organic chemistry. Part I : handbook – Minsk : BSMU, 2025. – 210 p.
3. Lakhvich, T. T., Ryneyskaya O.N., Fando, G.P. Oorganic chemistry. Part II : handbook – Minsk : BSMU, 2025. – 216 p.
4. Klein, D. R. Organic Chemistry / D. R. Klein. – New York : Wiley, 2015. – 1648 p.
5. Organic chemistry. Tests with explanations : the study manual for students of higher schools. – Kh.: NUPh, 2015.
6. Loudon, Marc Organic Chemistry, 6th edition / Marc Loudon, James Parise- New York : W. H. Freeman and Company, 2015. – 1648 p.

Normative regulatory acts:

7. European Pharmacopoeia 9th edition in 3 volumes / Council of Europe, Strasbourg, 2016.

Electronic courseware for the academic discipline «Organic Chemistry»

8. <https://etest.bsmu.by/course/view.php?id=189>.

LIST OF AVAILABLE DIAGNOSTIC TOOLS

The following forms are used for competences assessment:

express-interview;
tests; electronic tests;
control questioning;
final tests;
lab report;
accounts of classroom and home practical exercises with oral defense;
lab report with oral defense;
situation problems;
assessment using virtual simulators.

LIST OF AVAILABLE TEACHING METHODS

Traditional method;
active (interactive) methods:
Problem-Based Learning (PBL);
Team-Based Learning (TBL);
Research-Based Learning (RBL);
Simulation-based learning (SBL).

LIST OF PRACTICAL SKILLS

Name of practical skills	Form of practical skills control
1. Classifying compounds by the structure of the carbon skeleton and the nature of the functional groups	Resolving a situational problem, that includes the case with the use of catalogues with formulas of medications
2. Work with the Chem office software package, online resources and visualization programs. Design the structure of an organic compound for in silico research	Resolving a situational problem. Carrying out practical skills using simulation resources
3. Modelling the structures and reactions of organic compounds when using simulation/visualization programs; interconvert systematic/trivial/pharmacopeial names and molecular representations	(Chem office software package, online resources and visualization programs)
4. Interpreting spectra of organic compounds, predicting/simulating spectral data	
5. Identifying organic compounds using functional qualitative analysis	Lab report
6. Carrying out a designed chemical experiment followed by analysis and presentation of the results	Lab report (experiment)
7. Work with databases to evaluate the structure and functionality of biological macromolecules; interconverting macromolecular visualization formats	Resolving a situational problem. Carrying out practical skills using simulation resources
8. Carrying out safe work in a chemical laboratory, including toxic and volatile substances: handling chemical glassware, burners, stirrer, hot plate, etc.	(Chem office software package, online resources and visualization programs)
	Lab report with oral defense

LIST OF SIMULATION EQUIPMENT USED

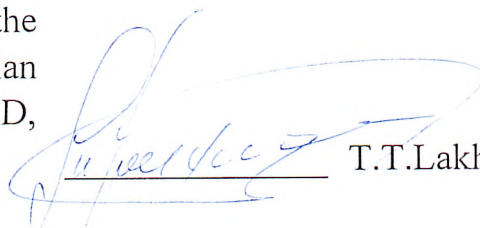
The simulation equipment located at the department of General Chemistry and in computer classes 305, 309, 311, 601 (Building 15) and includes personal computers with installed Chem office program pocket, Autodock for molecular docking visualization services Protein plus and PLIP.

**PROTOCOL OF THE CURRICULUM APPROVAL
BY OTHER DEPARTMENTS**

Title of the discipline requiring approval	Department	Amendments to the curriculum in the academic discipline	Decision of the department, which designed the curriculum (date, protocol #)
1. General and inorganic chemistry	Department of General Chemistry	No proposals	protocol # 6 dated 22.05.2024
2. Biological Chemistry	Department of Biological Chemistry	No proposals	protocol # 6 dated 22.05.2024
3. Pharmaceutical Chemistry	Department of Pharmaceutical Chemistry	No proposals	protocol # 6 dated 22.05.2024

COMPILERS/AUTHORS:

Associate professor of the Department of General Chemistry of the Educational Institution «Belarusian State Medical University», PhD, Associate Professor



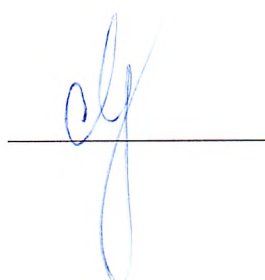
T.T.Lakhvich

Associate professor of the Department of General Chemistry of the Educational Institution «Belarusian State Medical University», PhD, Associate Professor



O.N.Ryneiskaya

Head of the Department of General Chemistry of the Educational Institution «Belarusian State Medical University», PhD, Associate Professor



M.M.Kauhanka

Curriculum content, composition and accompanying documents comply with established requirements.

Head of the Office of Educational Activities of the Educational Institution «Belarusian State Medical University»

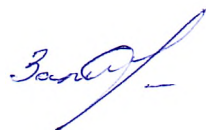
24. 06. 2024



I.L.Kotovich

Methodologist of the Educational and Methodological Department of the Office of Educational Activities of the Educational Institution «Belarusian State Medical University»

24. 06. 2024



S.V.Zaturanova