

**Federal State Autonomous Educational Institution of Higher Education "Moscow
Institute of Physics and Technology
(National Research University)"**

APPROVED
**Head of the Phystech School of
Biological and Medical Physics**
D.V. Kuzmin

Work program of the course (training module)

course: Organic Chemistry/Органическая химия
major: Biotechnology
specialization: Biomedical Engineering/Биомедицинская инженерия
Phystech School of Biological and Medical Physics
Department of Molecular and Biological Physics
term: 2
qualification: Bachelor

Semester, form of interim assessment: 4 (spring) - Exam

Academic hours: 120 AH in total, including:

lectures: 30 AH.

seminars: 30 AH.

laboratory practical: 60 AH.

Independent work: 120 AH.

Exam preparation: 30 AH.

In total: 270 AH, credits in total: 6

Number of course papers, tasks: 4

Authors of the program:

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The program was discussed at the Department of Molecular and Biological Physics 04.06.2020

Annotation

The course of organic chemistry is designed to form students studying in the direction of "Biotenology" the ideas about the basic concepts and laws of chemistry, chemical reactions and properties of organic substances. The course is the basics of chemical literacy, shows the place of chemistry in modern natural sciences, especially the chemical approach to the study of the world, gives an idea of the methodology and approaches of chemistry to the study of chemical properties of matter, makes it clear that chemistry, being closely related to physics and biology, is an independent science.

The peculiarity of this course is that it is taught in the forth semester and is based only on the knowledge that students have received in the previous semester of the course of General chemistry. The course consists of lectures, seminars and laboratory work. This makes it possible to fully develop the curriculum and the active use of knowledge for the development of further training in such disciplines as chemical physics, biochemistry and biophysics.

Theoretical and practical exploration of fundamental topics of organic chemistry in light of modern trends of development of chemical science that is necessary for a deeper understanding of the possible chemical approach to the study of the world, general regularities of structure of matter and its transformations in nature.

1. Study objective

Purpose of the course

The course of organic chemistry is designed to form students studying in the direction of "Biotenology" the ideas about the basic concepts and laws of chemistry, chemical reactions and properties of organic substances. The course is the basics of chemical literacy, shows the place of chemistry in modern natural sciences, especially the chemical approach to the study of the world, gives an idea of the methodology and approaches of chemistry to the study of chemical properties of matter, makes it clear that chemistry, being closely related to physics and biology, is an independent science.

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Theoretical and practical exploration of fundamental topics of organic chemistry in light of modern trends of development of chemical science that is necessary for a deeper understanding of the possible chemical approach to the study of the world, general regularities of structure of matter and its transformations in nature.

Tasks of the course

- familiarity with the internal logic of organic chemistry as a science; formation of ideas about the mechanisms of organic reactions;
- study of the main classes of organic compounds; formation of ideas about the relationship of the reactivity of organic molecules with their structure;
- study of laws of interaction of various organic substances with objects of environment, their physiological and pharmacological action, biological role, application in practical activity of the person; formation of representations about the ecological problems connected with use of organic substances.

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
Gen.Pro.C-1 Apply knowledge of mathematical, physical, chemical, biological laws, patterns, and interrelation to study, analyze, and utilize biological objects and processes	Gen.Pro.C-1.1 Analyze the task in hand, outline the ways to complete it
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology

(in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.7 Follow the basic rules of conduct in a modern scientific laboratory
Pro.C-3 Select the necessary devices, tools, and research methods for problem-solving in a selected subject area	Pro.C-3.1 Apply functional principles and operating ranges of scientific equipment

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

- basic concepts of organic chemistry;
- basic properties of the most important classes of organic compounds and their application;
- basic mechanisms of organic reactions;
- basic methods of chemical and spectral identification of organic substances;
- basic methods of work in the laboratory of organic chemistry.

be able to:

- depict the structure of typical representatives of the classes of organic compounds by name and call them by structural formulas based on knowledge of the principles of nomenclature and isomerism;
- to isolate the reaction centers in the molecule, to predict the behavior of the organic compound under specific conditions, based on its structure and knowledge of the typical reactivity of functional groups;
- to carry out a simple chemical experiment for the synthesis, isolation, purification and chemical identification of the substance;
- draw up reports of laboratory work.

master:

- methods for determining the possibility of chemical transformations of the main classes of organic compounds in different conditions;
- methods of safe handling of combustible and toxic substances and laboratory equipment;
- methods of preparation of solutions of the set concentration.

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	General ideas about the structure and reactivity of organic compounds.	2	2		8
2	Saturated hydrocarbons. Homology. Isomers, types of isomerism	2	2	6	8
3	Unsaturated hydrocarbons (Alkenes and alkynes). Geometric isomerism (concepts CIS -, TRANS-and Z -, E-nomenclature)	2	2	6	8
4	Functional derivatives with a simple C-Hal bond.	2	2	6	8
5	Functional derivatives with more than one multiple bond. Alkadiene. Mesomeric effect	2	2		8
6	Cycloalkane. Strain energy. Conformations of cyclohexane	2	2		8
7	Aromatic hydrocarbon. Aromaticity. Substitution reactions in the aromatic series.	2	2	6	8

8	Methods of analysis of organic compounds.	2	2	6	8
9	Carbon-metal compounds (organometallic compounds)	2	2		7
10	Functional derivatives with a simple C-O bond. Alcohols and esters	2	2	6	8
11	Functional derivatives with one multiple bond C=O. Aldehydes and ketones.	2	2	6	8
12	Functional compounds with carboxyl group. Carboxylic acid. Derivatives of carboxylic acids, halides, esters	2	2	6	8
13	Nitrogen-containing compounds. Nitroalkanes, amines, diazo compounds	2	2	6	8
14	Heterocyclic compound. Five-membered and six-membered aromatic heterocycles with one heteroatom	2	2		8
15	Multifunctional, including natural (biologically important) compounds.	2	2	6	9
AH in total		30	30	60	120
Exam preparation		30 AH.			
Total complexity		270 AH., credits in total 6			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 4 (Spring)

1. General ideas about the structure and reactivity of organic compounds.

Subject and tasks of organic chemistry. Carbon and organic matter in nature. A brief excursion into the structure of the electron shells of the atom, the example of the carbon atom. Types of chemical bonds and methods of their graphical representation. The concept of hybridization. Methods of imaging molecules of organic compounds (structural formulas, abbreviated structural formulas, Lewis formulas, resonance structures). Mapping a graphical model to a real structure (dashes and arrows). The concept of a functional group, the relationship with chemical properties, the main classes of organic compounds (relationship with functional groups, basic functional groups). Interconversion of connections with different functional groups. Principles of construction of names of organic compounds, systematic and trivial. Homology. Isomerism (skeletal, position). Spatial isomerism. Configuration, unlike conformation. Asymmetric carbon atom, optical activity. Enantiomers and diastereomers. Racemates. Chirality. Different types of chirality. The principle of R, S-nomenclature. Compounds with two asymmetric carbon atoms. Construction of Fisher projections.

2. Saturated hydrocarbons. Homology. Isomers, types of isomerism

Saturated hydrocarbons – alkanes. Structure concept of conformations and conformers of alkanes. Obstructed, hindered, beveled conformation. Newman projection formulas. Conformations of ethane, butane, their energy diagrams. Chemical properties of alkanes: halogenation (chlorination, bromination) with the formation of halogenoalkanes. Energy of chain free radical halogenation reactions. Nitration. Relative stability of various alkyl radicals. Thermal cracking of alkanes.

Classification of mechanisms of chemical reactions in organic chemistry. Concepts nucleophile, electrophile. Classification of chemical reactions by result: addition, cleavage, substitution, rearrangement, classification by the nature of the reagent and the type of bond break: heterolytic (nucleophilic, electrophilic), homolytic: (radical), molecular.. The energy profile of the reaction.

3. Unsaturated hydrocarbons (Alkenes and alkynes). Geometric isomerism (concepts CIS -, TRANS-and Z -, E-nomenclature)

The nature of the double bond in alkenes. Geometric isomerism-definitions and concepts of CIS-, TRANS - and Z-, E - nomenclature.

Catalytic hydrogenation of alkenes. Thermodynamic stability of alkenes based on hydrogenation heats.

Electrophilic double bond connection (Ade). Reaction mechanism, π - and σ -complexes, reaction energy profile, bromonium ions. Markovnikov's Rule. Halogenation, hydro-halogenation. Hydration. Conjugate connection. Oxidation of alkenes to diols and oxiranes. Ozonolysis of alkenes, oxidative and reductive cleavage of ozonides. Radical reactions of alkenes: HBr joining in Karasu. Carbenes. Reactions of addition of carbenes to alkenes.

Electronic structure of triple bond in alkynes. Electrophilic addition to alkynes. Reactivity of alkynes. Halogenation, hydrohalogenation, hydration (Kucherov). Reduction of alkynes to CIS - and TRANS-alkenes. C-H acidity of acetylene. Sodium, magnesium and copper acetylenides, their preparation and use in organic synthesis.

4. Functional derivatives with a simple C-Hal bond.

Halogenoalkane, alkenylamine and arylalane the most important examples. Features of the electronic structure of C-Hal bond. Inductive effect. (Graphical representations of electron density transfer). Common methods of obtaining halogenoalkanes, -alkenes, -alkynes.

Nucleophilic substitution in saturated carbon atom. The concept of nucleophilicity, nucleophiles. Classification of mechanisms of nucleophilic substitution reactions. Main characteristics of SN1 and SN2 reactions. SN2-type reactions. Energy profile of reactions. Kinetics, stereochemistry, Walden circulation. Influence of the nature of the substituent and the outgoing group, the nature of the nucleophilic agent and solvent on the rate of SN2 reactions. SN1-type reactions, dependence on the nature of the radical, the outgoing group, the solvent. Carbocations, their stability. Elimination reactions, α - and β -elimination. Classification of elimination mechanisms: E1, E2. Zaitsev's Rule. Sin - and anti-elimination. The influence of the nature of the base and the outgoing group on the direction of elimination. Competition of E2 and SN2, E1 and SN1 processes. Halogen derivatives of alkenes.

5. Functional derivatives with more than one multiple bond. Alkadiene. Mesomeric effect

1,2 -, 1,3-diene. Butadiene-1,3, structural features, conjugation of double bonds. Galogenirovannami and hydrohalogenation 1,3-dienes. 1,2 - and 1,4-joining.

Diene synthesis as an example of pericyclic reaction. Diels-Alder Reaction. Influence of diene and dienophile structure on regio- and stereo-selectivity of the process. The use of diene synthesis for synthetic purposes. Thermal and photochemical reactions of cycle closure and opening in dienes and polyenes.

6. Cycloalkane. Strain energy. Conformations of cyclohexane

Classification of alicycles. Energy tension. Structure of cyclopropane, cyclobutane, cyclopentane, cyclohexane. Conformations of cyclohexane. Axial and Equatorial bonds in the chair conformation of cyclohexane. Conformations of mono- and disubstituted cyclohexane derivatives and conformational transition barriers. Features of chemical properties of compounds with three-membered cycle.

7. Aromatic hydrocarbon. Aromaticity. Substitution reactions in the aromatic series.

Structure of benzene. Kekule Formula. Molecular orbitals of benzene. Frost Circle. The concept of aromaticity, resonance energy. Hückel's Rule. Aromatic cations and anions. Condensed aromatic hydrocarbons: naphthalene, phenanthrene, anthracene, azulene and other Heterocyclic aromatic compounds.

Substitution reactions in the aromatic series. Classification of aromatic electrophilic substitution reactions. Ideas about the mechanism of reactions, π - and σ -complexes. Resonance structure. The energy profile of the reaction. Arenonium ions in electrophilic substitution reactions. Influence of the substituent on the rate and direction of electrophilic substitution, connection with the electron density distribution. Orientation of the first and second kind. Nitration of benzene, reaction mechanism. Getting polynitroalkanes. Halogenation, reaction mechanism of halogenation of arenes, catalysis by Lewis acids. Sulfonation, reaction mechanism, kinetic and thermodynamic control in sulfonation reaction on the example of naphthalene. The concept of ipso attack and ipso substitution. Friedel-Crafts alkylation of arenes, polyalkylation, side processes - isomerization of alkylating agent and final products. Friedel-Crafts acylation of arenes. Acylating agents. Reaction mechanism. Regioselectivity of acylation. Gatterman-Koch formylation and related reactions.

Nucleophilic aromatic substitution. General ideas about the mechanism of nucleophilic substitution. The mechanism of cleavage-addition on the example of conversion of halobenzenes into phenols and aromatic amines. The mechanism of joining-splitting. Meisenheimer Complex.

Reactions with the destruction of the aromatic system. Catalytic hydrogenation of arenes, restoration of arenes by Birch.

Reactions not affecting the aromatic system. Oxidation of alkylbenzenes to carboxylic acids, aldehydes and ketones. Oxidation of condensed aromatic hydrocarbons. Substitution of hydrogen in the side chain of alkylbenzenes by halogen. Benzyl radical. Allyl radical. Allyl halogenation. π -Orbitals of the allylic system.

8. Methods of analysis of organic compounds.

Ideas about physical and chemical methods of analysis of organic compounds. Electron absorption spectra of organic compounds in the UV region. Ground and electron-excited States of molecules. Allowed and forbidden transitions. Chromophores and auxochromes. Relation of the position of absorption maxima and intensities with the structure of organic compounds.

Fundamentals of IR spectroscopy - vibrational spectroscopy in the IR region. Origin of vibrational spectra. Selection rules in IR spectroscopy. The intensity of the absorption signals. Characteristic frequencies of functional groups in organic molecules. Detection of compounds with different functional groups and structural analysis of organic compounds using IR spectroscopy.

Concepts of NMR spectroscopy, fundamentals of the method and applications, application for the analysis of organic compounds. General principles of modern pulse NMR spectrometers. Conditions of observation of high-resolution NMR spectra in liquids and gases and rules of sample preparation for measurements. Chemical shifts and spin-spin interaction constants in the ^1H -NMR and ^{13}C -NMR spectra of organic compounds. Connection of these parameters with the structure of molecules. Determination of the structure of organic compounds by NMR.

9. Carbon-metal compounds (organometallic compounds)

Lithium- and magnesium-organic compounds, the electronic structure of the carbon-metal bond. Receiving by means of the interaction of the metal with alkyl halides, transmetalation. Structure of Grignard reagents in solution. Schlenk's Equilibrium. Reactions with hydrocarbons (C-H acids). The use of lithium- and magnesium-organic compounds in the synthesis of hydrocarbons, alcohols, aldehydes, ketones, carboxylic acids. Dialkylamide, their synthetic use.

10. Functional derivatives with a simple C-O bond. Alcohols and esters

Monatomic alcohols, thiols. Properties of alcohols, hydrogen bond. Substitution of hydroxyl group in alcohols for halogen (under the action of halides, phosphorus halides, thionyl chloride). Dehydration of alcohols. Oxidation of primary alcohols to aldehydes and carboxylic acids, secondary alcohols to ketones. Oxidation reagents based on chromium anhydride and manganese dioxide. Diatomic alcohols. Ethylene glycol and glycerin. Pinacolada regrouping. Ether. Properties of esters: formation of oxonium salts, cleavage by acids, formation of hydroperoxides. Oxiranes. Disclosure of the oxirane ring under the action of electrophilic and nucleophilic agents. Cyclic ethers, crown ethers. Phenols. Phenols as OH-acids, the effect of substituents on the acidity of phenols. Cumene process. Electrophilic substitution reactions in the aromatic phenols nucleus: halogenation (mechanism), sulfonation, nitration, nitrosation and alkylation. Carboxylation of alkali metal phenolates by Kolbe. Formation of phenols by Reimer-Tiemann, and Vilsmeier. Vries regrouping. The rearrangement of allyl ethers of phenols (Claisen). Oxidation of phenols. The concept of hydroxyl radicals.

11. Functional derivatives with one multiple bond C=O. Aldehydes and ketones.

Electronic structure of the carbonyl group, its polarity and polarizability. The most important aldehydes and ketones. Formaldehyde, acetaldehyde, acetone, aromatic aldehydes and ketones. Concepts of the mechanism of nucleophilic addition on carbonyl group. Acid and basic catalysis. Accession of water, alcohols, thiols. Acetals and semiacetals, dioxolane. Getting bisulfite derivatives and cyanhydrines. Interaction of aldehydes and ketones with phosphorus ylides (Wittig). Interaction of aldehydes and ketones with nitrogenous bases. Oximes, hydrazones, phenylhydrazones. Schiff bases, methenamine. The Beckmann Rearrangement. Reactions of aldehydes and ketones with organometallic compounds. Keto-enol tautomerism. Enolization of aldehydes and ketones in halogenation reactions. The influence of structural factors and the nature of the solvent on the position of keto-enol equilibrium and its dependence on the ratio of CH - and OH-acidity of ketone and enol. Dual reactivity of enolate ions. Aldol-Croton condensation of aldehydes and ketones in acid and alkaline medium, reaction mechanism. Benzoin condensation. Aminomethylation of aldehydes and ketones, Mannich reaction.

Reduction reactions of carbonyl compounds. Reduction of aldehydes and ketones to alcohols, reduction reagents; reduction of carbonyl group to CH₂-group; Kishner-Wolf and Clemmensen reactions. Reductive dimerization of aldehydes and ketones. Oxidation of aldehydes, oxidation reagents. Reductive amination of carbonyl compounds. The interaction of aldehydes and ketones with ammonium formate (Lacerta reaction). Disproportionation of aldehydes by Cannizzaro.

12. Functional compounds with carboxyl group. Carboxylic acid. Derivatives of carboxylic acids, halides, esters

Features of the electronic structure of the carboxyl group. Effect of substituents in an organic radical on the acidity of carboxylic acids. Halogenation of acids by Hell-Volhard-Zelinsky. Pyrolytic ketonization, Kolbe reaction, Borodin-Hunsdiecker reaction.

Derivatives of the carboxylic acids. Halides. Properties: interaction with nucleophilic reagents (water, alcohols, ammonia, amines, hydrazine, organometallic compounds). Reduction by Rosenmund and complex metal hydrides. Interaction of diazomethane with halides of carboxylic acids (reaction Arndt-Eistert). Anhydrides. Reactions of anhydrides of acids. The ketene, properties. Esters, esterification reaction. Reactions of esters: hydrolysis (mechanism of acid and basic catalysis), ammonolysis, transesterification. Ester condensation (Claisen), the interaction with magnesium - and organolithium compounds, the recovery of esters to alcohols and aldehydes with complex metal hydrides, the restoration of Buvo-Blanc, acyloin condensation. Reaction of esters with diazomethane. Esters of polyatomic alcohols. Fats, lipids, triglycerides, phospholipids. Amides. Hydrolysis, reduction to amines, dehydration of amides. The concept of sextet rearrangements. Rearrangements Of Hoffmann, Curtius. Nitriles. Hydrolysis, ammonolysis, reduction by complex metal hydrides to amines, interaction with magnesium - and lithium-organic compounds. Dibasic acids. Oxalic, malonic, succinic acid. Diethylxalate in ester condensation. Syntheses and malonic ether, the Michael reaction, condensation with aldehydes and ketones (Knoevenagel condensation).

13. Nitrogen-containing compounds. Nitroalkanes, amines, diazo compounds

Nitroalkanes. Electronic structure of NO₂-group. Acidity and tautomerism of nitroalkanes. Condensation with carbonyl compounds. Restoration of nitro compounds to amines.

Amines. Amines as bases. Alkylation and acylation of amines. Protecting the amino group. Decomposition of tetraalkylammonium hydroxides (Hoffmann elimination).

Aromatic amines. Reduction of aromatic nitro compounds in acid and alkaline medium. Benzidine rearrangement. Comparison of the basic properties of aliphatic and aromatic amines. Effect of substituents amines in the aromatic nucleus on the basicity. Electrophilic substitution reactions in the benzene core of aromatic amines. Oxidation and halogenation of amines.

Diazo compounds. Aromatic diazocompounds. The reaction of diazotization of primary aromatic amines. Mechanism, nature of nitrosing agent. Structure and stability of diazonium salts. Reactions of diazo compounds with nitrogen release: replacement of diazogroup with hydroxyl-, halogen-, cyano -, nitrogroup and hydrogen. Reactions of diazo compounds without nitrogen release: reduction to arylhydrazines, azo combination. The azo coupling reaction electrophilic substitution. Azo - and datastudio, conditions for the combination of amines and phenols. Azo dyes, chromaticity of azo dyes. Aliphatic diazo compounds. The electronic structure of diazomethane, its reaction with carboxylic acids, diazomethane as a source of carbene.

14. Heterocyclic compound. Five-membered and six-membered aromatic heterocycles with one heteroatom

Electronic structure of heterocyclic five-and six-membered aromatic compounds (pyrrole, furan, thiophene, indole, azoles, pyridine, quinoline).

Five-membered aromatic heterocycles with one heteroatom(heterocyclisation). Furan, thiophene, pyrrole.(Electron excess). Acidophobicity of furan and pyrrole. Electrophilic substitution reactions in five-membered aromatic heterocycles (analogy with the reactivity of benzene): nitration, sulfonation, halogenation, formylation, acylation. Orientation of electrophilic substitution. Indole. Electrophilic substitution reactions in the indole pyrrole ring.

Six-membered aromatic heterocycles with one heteroatom. Pyridine and quinoline, electronic structure, comparison with heterocyclization. The basicity of pyridine. Pyridine reactions with alkyl halides. Oxidation and reduction of pyridine. Electrophilic substitution reactions in pyridine and quinoline: nitration, sulfonation, halogenation. N-Oxides of pyridine and quinoline and their use in the nitration reaction. Nucleophilic substitution of hydrogen atoms in pyridine in reactions with sodium amide (the Chichibabin) and phenyllithium.

15. Multifunctional, including natural (biologically important) compounds.

Hydroxo- and oxo- acids, the most important examples, α - β -nomenclature. Acetoacetic ether and its use in synthesis. Keto-enol tautomerism of β -ketoacids esters, ambident character of enolate ion. Dieckmann condensation as a variant of the condensation of Clausen. Acyclic condensation of dicarboxylic acid esters in the synthesis of medium and macrocycles. α - β -Unsaturated acids. Fumaric and maleic acids, their esters, maleic anhydride, use in organic synthesis.

Amino acid. Structure and properties of amino acids. α -amino acids, β -amino acids (β -alanine, asparagine). Essential amino acids, stereochemistry of amino acids, D-L-nomenclature. Synthesis of amino acids by Gabriel, Strecker. Separation of racemic amino acid mixtures. Peptides and proteins. Peptide bond. Examples of di - and tri-peptides. Synthesis of peptides. Structure of proteins.

Carbohydrates. Classification and nomenclature of carbohydrates. Monosaccharides and polysaccharides. Types of monosaccharides: trioses, tetroses, pentoses, hexoses (aldoses and ketoses). Spatial structure of monosaccharides, an example of glycerol aldehyde. L - and D-carbohydrates. The formula of Fischer and Hawara. Glucopyranose and glucofuranose. Ring-chain tautomerism of monosaccharides. Conversion of aldose to 2-ketose (mutarotation). The most important reactions of monosaccharides. Synthesis of monosaccharide esters and complex esters. Oxidation of aldose to aldonic acids. Oxidative cleavage. Lengthening and shortening of the carbohydrate chain. Disaccharides (BIOS): maltose, cellobiose, lactose, sucrose. α - and β -disaccharides. Structural features of natural polysaccharides on the example of cellulose and starch.

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

- Specialized laboratories equipped with fume hoods.
- Laboratory equipment for the workshop.
- Chemical reagents.
- For lectures-classrooms equipped with a projector.
- For practical training-the necessary computer equipment with Internet access.

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

Recommended additional literature:

1. McMurry J.E. Organic Chemistry with Biological Applications. – 3rd Edition – Cengage Learning, 2015.

Additional literature

Recommended additional literature:

1. McMurry J.E. Study Guide with Solutions Manual for McMurry's Fundamentals of Organic Chemistry, 7th, McMurry. – Cengage Learning, 2015. 464 p.
2. McMurry J.E. Organic Chemistry. – 8th Edition – Cengage Learning, 2011.

7. List of web resources that are necessary for the course (training module) mastering

www.chem.msu.su/rus/elibrary/edu_organic.html

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

MS Office program package.

9. Guidelines for students to master the course

The student studying the discipline, on the one hand, must master the General conceptual apparatus, and on the other hand, must learn to apply theoretical knowledge in practice.

As a result of studying the discipline, the student must know the basic definitions of the discipline, be able to apply this knowledge to solve various problems.

Successful completion of the course requires:

- attendance of all classes provided by the curriculum of the discipline;
- introduction of abstract classes;
- intense independent work of the student.

Independent work includes:

- reading recommended literature;
- study of educational material, preparation of answers to questions intended for self-study;
- solving problems offered to students in the classroom;
- preparation for performance of tasks of the current and intermediate certification.

Indicator of ownership of the material is the ability to answer questions without synopsis on topics of discipline.

It is important to achieve an understanding of the studied material, rather than mechanical memorization. If it is difficult to study certain topics, questions, you should seek advice from the teacher.

Intermediate control of students' knowledge is possible in the form of problem solving in accordance with the subject of classes.

Assessment funds for course (training module)

major: Biotechnology
specialization: Biomedical Engineering/Биомедицинская инженерия
Phystech School of Biological and Medical Physics
Department of Molecular and Biological Physics
term: 2
qualification: Bachelor

Semester, form of interim assessment: 4 (spring) - Exam

Authors:

D.M. Roytershteyn, candidate of chemical sciences, associate professor, associate professor
S.V. Silkin, candidate of chemical sciences

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
Gen.Pro.C-1 Apply knowledge of mathematical, physical, chemical, biological laws, patterns, and interrelation to study, analyze, and utilize biological objects and processes	Gen.Pro.C-1.1 Analyze the task in hand, outline the ways to complete it
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology
	Pro.C-1.7 Follow the basic rules of conduct in a modern scientific laboratory
Pro.C-3 Select the necessary devices, tools, and research methods for problem-solving in a selected subject area	Pro.C-3.1 Apply functional principles and operating ranges of scientific equipment

2. Competency assessment indicators

As a result of studying the course the student should:

know:

- basic concepts of organic chemistry;
- basic properties of the most important classes of organic compounds and their application;
- basic mechanisms of organic reactions;
- basic methods of chemical and spectral identification of organic substances;
- basic methods of work in the laboratory of organic chemistry.

be able to:

- depict the structure of typical representatives of the classes of organic compounds by name and call them by structural formulas based on knowledge of the principles of nomenclature and isomerism;
- to isolate the reaction centers in the molecule, to predict the behavior of the organic compound under specific conditions, based on its structure and knowledge of the typical reactivity of functional groups;
- to carry out a simple chemical experiment for the synthesis, isolation, purification and chemical identification of the substance;
- draw up reports of laboratory work.

master:

- methods for determining the possibility of chemical transformations of the main classes of organic compounds in different conditions;
- methods of safe handling of combustible and toxic substances and laboratory equipment;
- methods of preparation of solutions of the set concentration.

3. List of typical control tasks used to evaluate knowledge and skills

1. On the basis of acetone, propanol and inorganic agents will receive 1-bromopentane.
2. For each pair of compounds, specify whether they are enantiomers, diastereomers, structural isomers, or identical.
3. For the tartaric acid isomer below, draw the projection formulas of Newman and Fisher and specify the configuration of all chiral centers
4. Explain why isobutane containing isobutene, under the action of excess dinitrogen tetroxide acid (D_2SO_4) becomes nondeteriorated $(\text{CD}_3)_3\text{CH}$?
5. From acetylene and other necessary reagents get CIS- and TRANS-hexenes-3. What is the stereochemical result of the interaction of these compounds:
 - a) with an aqueous solution of KMnO_4 at room temperature
 - b) with a 50% aqueous solution of hydrogen peroxide in formic acid?Give wedge-shaped projections and Fischer's formula of reaction products. Specify (R, S) - notation for asymmetric centers.

6. How can the different pathways of the reactions below be explained:
7. From p-cresol, isobutylene and inorganic reagents get food preservative (antioxidant) 2,6-di-tert-butyl-4-METHYLPHENOL.
8. Which of the following compounds can be attributed to aromatic, nonaromatic, antiaromatic?
9. Complete the diagram below:
10. Offer the conditions for the following transformations:
11. Insert missing structure, hiraldo if the connection is M?
12. Compare the reactivity of pyridine and pyridine N-oxide in the electrophilic substitution reaction.
13. Compare the basicity of aniline, p-nitroaniline, cyclohexylamine, diethylamine, piperidine.
14. To β -Natalians from benzene and naphthalene
15. Offer a way to obtain pyridone-2 from pyridine.
16. From m-anisidine and aniline will receive secretely H. On the key during Assembly of the skeleton use the benzidine rearrangement.

4. Evaluation criteria

Sample questions for exam tickets:

1. The concept of a functional group. Interconversion of connections with different functional groups. Homology. Isomerism (skeletal, position). Spatial isomerism. Configuration, unlike conformation. Asymmetric carbon atom, optical activity.
2. Enantiomers and diastereomers. Racemates. Chirality. The principle of R, S-nomenclature. Compounds with two asymmetric carbon atoms. Fischer Projection.
3. Limit hydrocarbons, structure concept of conformations and conformers of alkanes. Obstructed, hindered, beveled conformation. Newman projection formulas. Conformations of ethane, butane, their energy diagrams.
4. Types of organic reactions. Concepts nucleophile, electrophile. Classification of chemical reactions by result: addition, cleavage, substitution, rearrangement, classification by the nature of the reagent and the type of bond break: heterolytic (nucleophilic, electrophilic), homolytic: (radical), molecular. The energy profile of the reaction. Examples of reactions.
5. Chemical properties of alkanes: galogenirovannami (chloration, bromation) with the formation of halogenoalkanes. Mechanism and energy of chain free radical halogenation reactions. Nitration of alkanes. Relative stability of various alkyl radicals. Thermal cracking of alkanes.
6. Alkenes. The nature of the double bond in alkenes. Geometric isomerism (definitions and concepts of CIS-, TRANS - and Z-, E - nomenclature). Catalytic hydrogenation of alkenes. Thermodynamic stability of alkenes based on hydrogenation heats.
7. Electrophilic double bond connection (Ade). Reaction mechanism, π - and σ -complexes, reaction energy profile, bromonium ions. Markovnikov's Rule. Halogenation, hydro-halogenation. Hydration.
8. Conjugate connection. Oxidation of alkenes to diols and oxiranes. Ozonolysis of alkenes, oxidative and reductive cleavage of ozonides. Radical reactions of alkenes: HBr joining in Karasu. Carbenes. Reactions of addition of carbenes to alkenes.
9. Alkynes. Electronic structure of triple bond in alkynes. Electrophilic addition to alkynes. Reactivity of alkynes. Halogenation, hydrohalogenation, hydration (Kucherov). Reduction of alkynes to CIS - and TRANS-alkenes. C-H acidity of acetylene. Sodium, magnesium and copper acetylenides, their preparation and use in organic synthesis.
10. Halogen-containing compounds. Halogenoalkane, the most important examples. Features of the electronic structure of C-Hal communication. Inductive effect. Nucleophilic substitution in saturated carbon atom the Concept of nucleophilicity, nucleophiles.
11. Classification of mechanisms of nucleophilic substitution reactions. Main characteristics of SN1 and SN2 reactions. SN2-type reactions. Energy profile of reactions. Waldenesque treatment.
12. Nucleophilic substitution reactions of SN1-type, dependence on the nature of radical, outgoing group, solvent. Examples of reactions. Carbocations, their stability.
13. Elimination reactions, α - and β -elimination. Classification of elimination mechanisms: E1, E2. Zaitsev's Rule. Sin - and anti-elimination. The influence of the nature of the base and the outgoing group on the direction of elimination. Competition of E2 and SN2, E1 and SN1 processes.
14. Alkadiene. 1,2 -, 1,3-diene. Butadiene-1,3, structural features, conjugation of double bonds. Galogenirovannami and hydrohalogenation 1,3-dienes. 1,2 - and 1,4-joining.

15. Cycloalkane. Classification of alicycles. Energy tension. Structure of cyclopropane, CYCLOBUTANE, cyclopentane, cyclohexane. Conformations of cyclohexane. Axial and Equatorial bonds in the chair conformation of cyclohexane. Conformations of mono- and disubstituted cyclohexane derivatives. Features of chemical properties of compounds with three-membered cycle.
16. Aromatic hydrocarbon. Structure of benzene. Kekule Formula. Molecular orbitals of benzene. Frost Circle. The concept of aromaticity, resonance energy. Hückel's Rule. Aromatic cations and anions. Condensed aromatic hydrocarbons: naphthalene, phenanthrene, anthracene, azulene and other Heterocyclic aromatic compounds.
17. Electrophilic substitution in the aromatic series. Classification of aromatic electrophilic substitution reactions. Ideas about the mechanism of reactions, π - and σ -complexes. Resonance structure. The energy profile of the reaction.
18. Influence of the substituent on the rate and direction of electrophilic substitution, connection with the electron density distribution. Orientate the first and second kind. Nitration of benzene, reaction mechanism. Getting polynitroalkanes.
19. Electrophilic substitution in the aromatic series: Halogenation, reaction mechanism of halogenation of arenes, catalysis by Lewis acids. Sulfonation, reaction mechanism, kinetic and thermodynamic control in sulfonation reaction on the example of naphthalene. The concept of ipso attack and ipso substitution.
20. Electrophilic substitution in the aromatic series: alkylation of arenes by Friedel-Crafts, polyalkylation, side processes - isomerization of the alkylating agent and final products. Friedel-Crafts acylation of arenes. Acylating agents. Reaction mechanism. Regioselectivity of acylation. Guttmann-Koch formylation and related reactions.
21. Nucleophilic aromatic substitution. General ideas about the mechanism of nucleophilic substitution. The mechanism of cleavage-addition on the example of conversion of halobenzenes into phenols and aromatic amines. The mechanism of joining-splitting. Meisenheimer Complex.
22. Aromatic hydrocarbon. Reactions with the destruction of the aromatic system. Catalytic hydrogenation of arenes, restoration of arenes by Birch. Reactions that do not affect the aromatic system. Oxidation of alkylbenzenes to carboxylic acids, aldehydes and ketones. Oxidation of condensed aromatic hydrocarbons. Substitution of hydrogen in the side chain of alkylbenzenes by halogen. Benzyl radical. Allyl radical. Allyl halogenation. π -Orbitals of the allylic system.
23. Carbon-metal compounds (ORGANOMETALLIC compounds). Lithium and magyarkanizsa compounds, electronic structure of connected M-S. the Receipt by the interaction of the metal with alkyl halides, Parametrierung. Schlenk's Equilibrium. Reactions with hydrocarbons (C-H acids).
24. Alcohols and esters. Monatomic alcohols, thiols. Properties of alcohols, hydrogen bond. Substitution of hydroxyl group in alcohols for halogen. Dehydration of alcohols. Oxidation of primary alcohols to aldehydes and carboxylic acids, secondary alcohols to ketones. Oxidation reagents based on chromium anhydride and manganese dioxide.
25. Diatomic alcohols. Ethylene glycol and glycerin. Pinacolada regrouping. Ether. Properties of esters: formation of oxonium salts, cleavage by acids, formation of hydroperoxides. Oxiranes. Disclosure of the oxirane ring is studied cycle under the action of electrophilic and nucleophilic agents. Cyclic ethers, crown ethers.
26. Phenols. Phenols as OH-acids, the effect of substituents on the acidity of phenols. Cumene process. Electrophilic substitution reactions in the aromatic phenols nucleus (mechanism): halogenation sulfonation, nitration, alkylation.
27. Carboxylation of alkali metal phenolates by Kolbe. Formirovanie phenols by Reimer-the Timan, and Vilsmaier. Regrouping Vries. The rearrangement of allyl ethers of phenols (Claisen). Oxidation of phenols.
28. Aldehydes and ketones. Electronic structure of the carbonyl group, its polarity and polarizability. The most important aldehydes and ketones. Formaldehyde, acetaldehyde, acetone, aromatic aldehydes and ketones. Representations about the mechanism of nucleophilic addition on carbonyl group. Acid and basic catalysis
29. Aldehydes and ketones, addition of water, alcohols. Acetals and semi-acetals. Preparation of cyanhydrins. Interaction of aldehydes and ketones with phosphorus ilides (Wittig).
30. Interaction of aldehydes and ketones with nitrogenous bases. Oximes, hydrazones, phenylhydrazones. Schiff bases, methenamine. Reactions of aldehydes and ketones with ORGANOMETALLIC compounds.

31. Keto-enol tautomerism. Enolization of aldehydes and ketones in halogenation reactions. The influence of structural factors and the nature of the solvent on the position of keto-enol equilibrium and its dependence on the ratio of CH - and OH-acidity of ketone and enol. Aldol-Croton condensation of aldehydes and ketones in acid and alkaline medium, reaction mechanism. Benzoin condensation. Aminomethylation of aldehydes and ketones (Mannich).
32. Reduction reactions of carbonyl compounds. Reduction of aldehydes and ketones to alcohols, reduction reagents; reduction of carbonyl group to CH₂-group; Kizhner-wolf and Clemensen reactions. Reductive dimerization of aldehydes and ketones.
33. Aldehyde oxidation reactions, oxidation reagents. Disproportionation of aldehydes by Cannizaro. Reductive amination of carbonyl compounds. The interaction of aldehydes and ketones with ammonium formate (reaction Lacerta).
34. α,β -Unsaturated aldehydes and ketones. Acrolein. Mesomeric effect, conjugation of C=O and C=C bonds. Reactions of 1,2-and 1,4-addition of lithium-organic compounds. Reduction of unsaturated carbonyl compounds.
35. Nitroalkanes. Electronic structure of the nitro group. Restoration of nitro compounds to amines. Amines. Amines as bases. Alkylation and acylation of amines. Decomposition of tetraalkylammonium hydroxides (Hoffmann elimination).
36. Aromatic amines. Reduction of aromatic nitro compounds in acid and alkaline medium. Comparison of the basic properties of aliphatic and aromatic amines. Effect on the basicity of substituents amines in the aromatic nucleus. Electrophilic substitution reactions in the benzene core of aromatic amines. Oxidation and halogenation of amines.
37. Diazo compound. Aromatic diazocompounds. The reaction of diazotization of primary aromatic amines. Mechanism, nature of nitrosing agent. Structure and stability of diazonium salts. Reactions of diazo compounds with nitrogen release: replacement of diazogroup with hydroxyl, halogen -, cyano - group and hydrogen.
38. Reactions of diazo compounds without nitrogen release: reduction to arylhydrazines, azo combination. The azo coupling reaction electrophilic substitution. Azo - and datastudio, conditions for the combination of amines and phenols. Aliphatic diazo compounds.
39. Carboxylic acid. Electronic structure of the carboxyl group. Effect of substituents in an organic radical on the acidity of carboxylic acids. Galogenirovannami acids in Hello Folgard-Zelinsky. Pyrolytic ketonization, Kolbe reaction, Borodin-Hunsdiecker.
40. Derivatives of carboxylic acids. Halides. Galogenidov reactions with nucleophilic reagents (water, alcohols, ammonia, amines, hydrazine, ORGANOMETALLIC compounds). Reduction by Rosenmund and complex metal hydrides. Interaction diazomethane with halides of carboxylic acids.
41. Esters, esterification reaction. Reactions of esters: hydrolysis (mechanism of acid and basic catalysis), ammonolysis, transesterification. Ester condensation (condensation of Clausena), the interaction with magnesium - and organolithium compounds, the recovery of esters to alcohols and aldehydes with complex metal hydrides, the restoration of Buvo-Blanc, allinova condensation.
42. Carboxylic acid amides. Hydrolysis, reduction to amines, dehydration of amides. The concept of sextet rearrangements. Rearrangements Of Hoffmann, Curtius. Nitriles. Hydrolysis, ammonolysis, reduction by complex metal hydrides to amines, interaction with magnesium - and lithium-organic compounds.
43. Carboxylic acid anhydrides. Reactions of anhydrides of acids. Dibasic carboxylic acids. Oxalic, malonic, succinic acid. Aromatic dicarboxylic acids.
44. electrophilic substitution. Indole. Electrophilic substitution reactions in the indole pyrrole ring.
45. Heterocyclic compound. Five-membered aromatic heterocycles with one heteroatom (heterocyclisation). Furan, thiophene, pyrrole. Altofonte of furan and pyrrole. Electrophilic substitution reactions in five-membered aromatic heterocycles: nitration, sulfonation, halogenation, formylation, acylation. Orientation
46. Six-membered aromatic heterocycles with one heteroatom. Pyridine and quinoline, electronic structure, comparison with comparison with five-membered heterocycles. The basicity of pyridine. Pyridine reactions with alkyl halides. Oxidation and reduction of pyridine. Electrophilic substitution reactions in pyridine and quinoline: nitration, sulfonation, halogenation.
47. N-Oxides of pyridine and quinoline and their use in the electrophilic substitution reaction. Nucleophilic substitution of hydrogen atoms in pyridine in reactions with sodium amide (the Chichibabin), sodium hydroxide. Heterocycles with two heteroatoms in a cycle (imidazole, pyrazole, pyrimidine, purine).

48. Hydroxo - and oxo-acids, major examples, α/β -nomenclature. Acetoacetic ether and its use in synthesis. Keto-enol tautomerism of β -ketoacids esters, ambident character of enolate ion. α , β -unsaturated acids. Fumaric and maleic acids, their esters, maleic anhydride.

49. Amino acid. Structure and properties of amino acids. α -amino acids, β -amino acids (β -alanine, asparagine). Essential amino acids, stereochemistry of amino acids, D/L-nomenclature. Synthesis of amino acids. Separation of racemic amino acid mixtures. Peptides and proteins. Peptide bond. Examples of di- and tripeptides. Synthesis of peptides, protective groups in the synthesis of peptides.

50. Carbohydrates. Classification and nomenclature of carbohydrates. Monosaccharides and polysaccharides. Types of monosaccharides. Spatial structure of monosaccharides. L- and D-carbohydrates. The formula of Fischer and Hawara. Ring-chain tautomerism of monosaccharides, mutarotation. Epimerization (conversion of aldose to 2-ketose). The most important reactions of monosaccharides. Oxidation of aldose to aldonic and aldaric acids. Oxidative cleavage.

51. Carbohydrates. Lengthening and shortening of the carbohydrate chain. Disaccharides (BIOS): maltose, cellobiose, lactose, amigdalota, sucrose. Glucose and fructose anomers, α - and β -disaccharides. Reducing and non-reducing carbohydrates. Structural features of natural polysaccharides on the example of cellulose and starch.

Example of the examination ticket:

1. Types of organic reactions. Concepts nucleophile, electrophile. Classification of chemical reactions by result: addition, cleavage, substitution, rearrangement, classification by the nature of the reagent and the type of bond break: heterolytic (nucleophilic, electrophilic), homolytic: (radical), molecular. The energy profile of the reaction. Examples of reactions.

2. Amino acid. Structure and properties of amino acids. α -amino acids, β -amino acids (β -alanine, asparagine). Essential amino acids, stereochemistry of amino acids, D/L-nomenclature. Synthesis of amino acids. Separation of racemic amino acid mixtures. Peptides and proteins. Peptide bond. Examples of di- and tripeptides. Synthesis of peptides, protective groups in the synthesis of peptides.

Assessment excellent 10 points-exposed to the student who showed a comprehensive, systematic, in-depth knowledge of the curriculum discipline, showing interest in the subject area, demonstrated the ability to confidently and creatively apply them in practice in solving specific problems, free and correct justification of decisions.

Assessment excellent 9 points-exposed to the student, who showed a comprehensive, systematic, in-depth knowledge of the curriculum discipline and the ability to confidently apply them in practice in solving specific problems, free and correct justification of decisions.

Assessment is excellent 8 points-exposed to the student, who showed a comprehensive, systematic, in-depth knowledge of the curriculum discipline and the ability to confidently apply them in practice when solving specific problems, the correct justification of the decisions, with some shortcomings.

Score well 7 points is assigned to the student if he knows the material, competently, and essentially presents it, is able to apply the acquired knowledge in practice, but has not been properly justifies the results obtained.

Score well 6 points is assigned to the student if he knows the material, competently, and essentially presents it, is able to apply the acquired knowledge in practice, but admits in the answer or in the task some inaccuracies.

Score well 5 points is assigned to the student if he basically knows the material, competently, and essentially presents it, is able to apply the acquired knowledge in practice, but admits in the answer or in the task of quite a number of inaccuracies.

The satisfactory rating of 4 points is assigned to the student who showed the fragmented, piecemeal nature of the knowledge is not enough for the correct formulation of the basic concepts, disorders of logical sequence in the presentation of program material, but he mastered parts of the curriculum necessary for further learning, and can apply the knowledge modeled in the standard situation.

Rating satisfactory 3 points - is given for student, who showed the fragmented, piecemeal nature of knowledge makes a mistake in the formulation of the basic concepts of violation of logical sequence in the presentation of program material, has little major parts of the curriculum necessary for further studies and work applies the knowledge gained even in the standard situation.

Assessment unsatisfactory 2 points-exposed to the student who does not know most of the basic content of the curriculum discipline, makes blunders in the wording of the basic principles and does not know how to use the knowledge in solving typical problems.

Assessment unsatisfactory 1 point-exposed to the student who does not know the basic content of the curriculum discipline, makes gross errors in the wording of the basic concepts of discipline and does not have the skills to solve typical practical problems.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

In the theoretical part of the course, an oral exam is conducted with the affixing of the grades "excellent", "good", "satisfactory", "unsatisfactory", as well as the corresponding score in a ten-point scale. During the oral examination, the student is given one academic hour (45 minutes) to prepare. Questioning of the student on the ticket at the oral exam is carried out until the examiner is convinced of the objectivity of the assessment, but should not exceed one astronomical hour.