

**Questions to exam for students  
in the educational discipline ORGANIC CHEMISTRY  
for the specialty:  
1-79 01 08 «Pharmacy»**

**Introduction to structure and reactivity of organic compounds**

1. Classification and main classes of organic compounds. Functional group and the structure of the carbon skeleton as basic principles for naming organic compounds.
2. Naming (nomenclature of) organic compounds. Common (trivial) names. The IUPAC (International Union of Pure and Applied Chemistry) systematic approach to nomenclature: substitutive and radical functional approaches.
3. 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
4. Different types of bonding in organic compounds. Covalent  $\sigma$ - and  $\pi$ - bonds,  $\tau$ - («banana»,  $\tau$ - («bent»)) bonds as representation of electron density in small ring molecules. 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).
5. Delocalized chemical bond. Conjugation ( $\pi, \pi$ - and  $p, \pi$ - 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.
6. The charge distribution in a molecule. Electronic effects. Mesomerism. Induction. Electron donor and electron acceptor substituents. Steric, stereoelectronic and solvent effects.
7. The three dimensional shape or configuration of a molecule Molecular conformations. Presentation of three dimensional shape: molecular models, perspective drawings, Fischer and Newman projections.
8. Stereochemistry of organic compounds and their biological activity.
9. Chirality and symmetry. Symmetry elements and their association with chiral and achiral objects. Types of chirality (centre, axis and plane). Chirality centre, asymmetric atoms.
10. Optical activity of the chiral substances and its measuring. Polarimetry, rotation angle, specific rotation. Levo and Dextro rotating substances.
11. Stereoisomerism. Configurational and conformational stereoisomers. Configurational stereoisomers: enantiomers, diastereomers ( $\sigma$ -,  $\pi$ -). Stereochemical nomenclature: R, S- and D, L-conventions for designation of configuration; E, Z-convention for designation of relative configuration of substituents.
12. Conformational analysis. Torsional angle. Angular, torsional and van der Waals interactions in the molecule.
13. Conformational isomers, or rotamers. Conformations. Eclipsed and staggered conformations and their nomenclature for acyclic and cyclic compounds.
14. Conformations of cycloalkanes. Chair and bath conformations of cyclohexane. Axial and equatorial substituents. Inversion of the cycle. 1,3-Diaxial interaction in cyclohexane derivatives.
15. Reaction classification on the structural change occurring in the reactant molecules: addition, elimination, substitution, redox, pericyclic rearrangements. Acid-base interactions.
16. Reaction classification on the reagent type and the mechanism of bond break/formation. Homolytic/heterolytic bond break and homogenic/heterogenic bond formation.
17. 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.
18. Brønsted-Lowry acids and bases. Conjugated acids and bases. Acidity and basicity constants. Organic OH, SH, NH and CH acids. Organic  $\pi$ - and n-bases (Ammonium, oxonium, sulphonium).
19. 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).

20. Lewis acids and bases. Acidity/basicity vs electrophilicity/nucleophilicity. Hard and soft acids and bases. *Pearson*, or HSAB concept.
21. UV-visible absorption spectroscopy (electron spectroscopy), spectrum recording range, 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.
22. Optical absorption spectroscopy in the infrared spectrum (infrared, vibrational spectroscopy), spectrum recording range. Representation of the spectrum. The energy of stretching and bending vibrations, the values of the corresponding absorption bands in the spectrum. Solvents for IR spectroscopy.
23. Nuclear magnetic resonance spectroscopy (NMR spectroscopy). Representation of the spectrum. Proton NMR spectroscopy. (NMR-1H). Chemical shift and its correlation with the structure of substances (the 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. Solvents for NMR spectroscopy.
24. 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.
25. Functional analysis and identification of organic compounds. Application of chemical tests and spectral methods in pharmacy.

### **Main classes of organic compounds**

26. Alkanes. Structure. Nomenclature. Physical properties. Reactions of radical substitution. Mechanism SR and regioselectivity of halogenation. Oxidation of alkanes.
27. Alkenes. Structure. Nomenclature. Physical properties.
28. Reactions of allylic substitution.
29. Addition to alkenes. Hydrogenation. Reactions of electrophilic addition AE: mechanism and selectivity.
30. Alkadiene. Structure. Classification and nomenclature. Physical properties.
31. 1,2- and 1,4- Addition to conjugated dienes. Reactions of Diels-Alder cycloaddition (diene synthesis).
32. Alkynes. Structure. Nomenclature. Physical properties.
33. Addition to alkynes. Hydrogenation. Reactions of electrophilic addition (hydrohalogenation, halogenation, hydration, interaction with alcohols). Reactions of nucleophilic addition.
34. Reaction of vinylation. Formation of metal acetylides.
35. Arenes. Structure and classification.
36. Arenes: benzylic substitution (halogenation, oxidation).
37. Arenes: reactions of electrophilic substitution in the aromatic ring, mechanism SEAr. Halogenation, nitration, sulfonation, alkylation, acylation of arenes. The influence of substituents on the regioselectivity and rate of reaction.
38. Hydrogenation and oxidation of benzene and their fused analogues.
39. Identification of Hydrocarbons. Spectral characteristics.
40. Structure. Classification and nomenclature of Hydrocarbon halides. Physical properties.
41. Nucleophilic substitution reactions. Mechanisms of mono- and bimolecular substitution SN1 and SN2.
42. Synthesis of alcohols, ethers and esters, thiols, sulphides, sulfonium salts, amines, nitro derivatives, nitriles from halides.
43. Reactions of elimination in halide series. Zaitsev's rule. Competitiveness of reactions of nucleophilic substitution and elimination. Reactions of alkyl halides with metals. Grignard reagent and their application in synthesis.
44. Specific reactivity of allyl and benzyl halides in substitution reactions.
45. Specific reactivity of vinyl and aryl halides in substitution reactions.
46. Specific physical and chemical properties of organic fluorides, their application in medicine and pharmacy.
47. Structure, classification and nomenclature of alcohols. Physical properties. Acid/base properties of alcohols, formation of alkoxides (alcoholates). Inter- and intramolecular hydrogen bond in alcohols.

48. Nucleophilic properties of alcohols; formation of ethers and esters, esters of inorganic acids (sulfates, phosphates, di- and triphosphates)
49. Nucleophilic substitution and elimination reactions of alcohols: activation of poor leaving hydroxyl group. Reactions with inorganic halides and thionyl chloride. General scheme of nucleophilic substitution of activated hydroxyl group with halogen, O-, N-, S- and C-nucleophiles.
50. Oxidation of alcohols in vitro and in vivo.
51. Polyhydric alcohols. Chemical properties: general and specific reactions. Acidity. Cyclization and formation of chelate complexes.
52. Structure, classification and nomenclature of phenols and naphthols. Acidic properties, formation of phenoxides.
53. 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.
54. Structure, classification, nomenclature and application of Ethers.
55. Structure, classification, nomenclature and application of Thiols and Sulfides.
56. Structure, classification and nomenclature of amines, azo and diazo compounds.
57. The basic and acidic properties of aliphatic and aromatic amines, ammonium salts. Acidic properties of amines, formation and application of metal amides.
58. Amines as nucleophiles: substitution reactions and addition to multiple bonds. 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.
59. Nitrosation of amines. Mechanisms of diazotization reaction. Formation and structure of diazonium salts. Application of diazonium salts in organic synthesis and analysis.
60. Structure, classification and nomenclature of oxo-compounds.
61. The structure of the carbonyl groups. Comparative reactivity of aldehydes and ketones. Nucleophilic addition to the carbonyl groups, mechanism and catalysis.
62. Hydride exchange reaction in vitro and in vivo (Cannizzaro and Meerwein-Ponndorf-Verley reductions, interaction with *tr*-butylmagnesiumchloride): scope, mechanisms and factors stabilizing the transition state. Enzymatic reduction with NADH: mechanism and biological role.
63. Interaction of oxo-compounds with carbon nucleophiles (hydrocyanation, interaction with organometallic compounds and acetylide, Wittig olefination). Interaction with halogen nucleophiles (phosphorus halides and sulfur halides, etc.).
64. Interaction of oxo-compounds with oxygen and Sulfa nucleophiles: reagents and catalysis.
65. Oxidation of aldehydes and ketones. Reagents and scope. Baeyer-Villiger rearrangement.
66.  $\alpha$ -Substitution. Halogenation. Haloform reaction. Aldol addition/condensation and Mannich reaction: mechanism, biological role and application in synthesis.
67. Reactions of aza-analogues of oxo compounds (imines, enamines, oximes, hydrazones and semicarbazones).
68. Quinones. Structure. Nomenclature. Physical and physico-chemical properties.  $\pi$ -Acceptor properties. Oxidative properties of quinones. Addition reactions. Anthraquinone and ubiquinons. Vitamin K.
69. Structure, classification and nomenclature of carboxylic acids and their derivatives.
70. The structure of the carboxyl, carboxylate, amide, ester, anhydride and acyl halide functional groups. Comparative electrophilicity of carbonyl group in carboxylic acids and their derivatives. Nucleophilic substitution in tetrahedral carbon atom: mechanisms, formation of acids and their functional derivatives (hydrolysis, alcoholysis, amination).
71.  $\alpha$ -Substitution of carboxylic acids and their derivatives. Halogenation. C-alkylation and Cleisen reaction.
72. 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. Anhydride formation from mono and dicarboxylic acids. Decarboxylation.

73. Specific reactions of esters. Claisen and Dieckmann condensations: mechanism, application *in vitro* and biological role *in vivo*. Application in organic synthesis. Malonic ester, CH-acidity. Malonic ester synthesis of substituted carboxylic acid derivatives.
74. 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.
75. Hydrolysis and reduction of nitriles. Addition of nucleophiles (carbocations and hydroperoxide anion).
76. Structure, classification and nomenclature of functional derivatives of carbonic acid.
77. Phosgene and chloroformates: their application in synthesis and analysis; their use for protection of hydroxyl and amino groups.
78. Carbamic acid and its esters (urethanes), their biological and industrial role. Carbamide (urea): hydrolysis, basic and nucleophilic properties. Guanidine, its basic properties. Urea and guanidine in nature, their application in medicine.
79. Structure, classification and nomenclature of sulfonic acids and their derivatives.
80. Chemical properties and application of sulfonic acids and their derivatives.
81. Sulfanilic acid. Sulfanilamide (streptocid). General principle of the structure of sulfonamide drugs. Sulfonamides as pharmaceutical drugs.
82. Structure, classification and nomenclature of hydroxy-, phenol- and oxocarboxylic acids
83. Chemical properties of hydroxy-, phenol- and oxocarboxylic acids.
84. Chemical properties  $\beta$ -dicarbonyl compounds. Keto-enol tautomerization. Acetoacetic and malonic ester synthesis of substituted alicyclic and cyclic ketones and acid derivatives.

### **Small molecules and polymers in pharmacy and medicine**

85. Structure, classification and nomenclature of amino acids
86. Classification and nomenclature of amino acids. Chemical properties as heterofunctional compounds. Typical reactions of acids and amines. Specific reactions of  $\alpha$ -,  $\beta$ -,  $\gamma$ -,  $\delta$ -aminocarboxylic acids. Lactams, diketopiperazines. Structure and application of  $\beta$ -lactam antibiotics.
87. Structure and classification of proteinogenic  $\alpha$ -amino acids. Stereoisomerism. Physical properties. Amphoteric properties, isoelectric point. Formation of chelate compounds. Identification of  $\alpha$ -amino acids.
88. 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).
89. Biogenic amines.
90. Structure. Classification and nomenclature of monosaccharides. 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 of solutions.
91. Chemical properties of monosaccharides as heterofunctional compounds.
92. 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".
93. Pentoses: D- and L-arabinose, D-xylose, D-ribose. 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).
94. The structure of reducing and non-reducing disaccharides. Nomenclature of oligosaccharides. Tautomerism and reactivity of reducing disaccharides.
95. Classification and nomenclature of polysaccharides. Homoglycans and heteroglycans. Starch (amylose, amylopectin), glycogen, cellulose, chitin, dextrans, inulin, pectin substances, Chondroitin sulfate and hyaluronic acid. Hydrolysis of polysaccharides and their derivatives.

96. Structure of aminoglycoside antibiotics and glycopeptides.
97. Classification and nomenclature of heterocyclic compounds.
98. The structure and reactivity of five-membered aromatic heterocyclic compounds. Aromatic heterocycles and their stability.
99. The structure and reactivity of six-membered aromatic heterocyclic compounds, electron-rich and electron-deficient heterocycles.
100. Alkylpyridinium ion and its interaction with hydride ion as the chemical basis of the redox system coenzyme NAD<sup>+</sup>/NADH (nicotinamide adenine dinucleotide). Hydrogenated analogues (piperidine, perhydroquinoline), properties as amines and application in medicine.
101.  $\alpha$ -,  $\beta$ - and  $\gamma$ -Picolines. CH-acidity.  $\alpha$ -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.
102. Piran and its analogs. Nonaromatic  $\alpha$ - and  $\gamma$ -pyrans,  $\alpha$ - and  $\gamma$ -pyrones. Pyrilium salts.
103. Benzopyran derivatives: chroman, chromene, chrome, benzopyrones. Flavan, flavanone, flavone, their hydroxy derivatives (catechins, flavonoids).
104. Classification of phenylpropanoids and basic principles of flavonoid chemistry (occurrence and structure). Luteolin, quercetin, rutin. Tocopherols (vitamins of group E).
105. Basic knowledge of seven-membered heterocycles. Diazepine, benzodiazepine. Structure of medications of the benzodiazepine series.
106. Classification and nomenclature of five-membered and six-membered heterocycles with two heteroatoms. Acid-base properties, the formation of associates.
107. Pyrazolones and their tautomerism. medications based on pyrazolone (Metamizole, phenylbutazone).
108. Reactivity of five-membered and six-membered heterocycles with two heteroatoms.
109. Imidazole derivatives: histidine, histamine, benzimidazole.
110. Pyrimidine, its hydroxy and amino derivatives: uracil, thymine, cytosine, their tautomerism. Barbituric acid. Oxazine, phenoxazine. Thiazine, phenothiazine.
111. Purin. Acidic and basic properties, tautomerism. Reactions of halogenated derivatives of purine with nucleophilic reagents. Amino and hydroxy derivatives of purine: tautomerism, chemical and biological activity.
112. Pteridine and isoalloxazine. Folic acid. Methotrexate as chemotherapy and agent and immune system suppressant. Flavin. Riboflavin. Flavin adenine dinucleotide (FAD) as redox cofactor.
113. Alkaloids. Chemical classification. Basic properties, formation of salts. Reactions with alkaloid precipitation reagents.
114. Alkaloids of the pyridine group: nicotine, anabasine. Alkaloids of the quinoline group: quinine.
115. Alkaloids of benzyloisoquinoline and phenantrenoisoquinoline groups: papaverine, morphine, codeine.
116. Alkaloids of the tropane group: atropine, cocaine.
117. Protoalkaloids and pseudoalkaloids. Polyamine and Peptide and cyclopeptide alkaloids. Antibiotic, antiviral and antitumor alkaloids.
118. Structure and nomenclature of Nucleosides as N-glycosides. Ribonucleosides and deoxyribonucleosides. Pyrimidine and purine nucleic bases. Nomenclature of nucleosides. Conformational structure. Hydrolysis. 3-Azidothymidine.
119. Structure and nomenclature of nucleotides. Ribonucleotides and deoxyribonucleotides. Hydrolysis. Nucleoside polyphosphates. Nicotinamide adenine dinucleotides.
120. 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.
121. Structure, classification and nomenclature of Saponified lipids. Simple and complex saponifiable lipids. Saturated and unsaturated higher fatty acids, features of structure and nomenclature, omega acids. Acyl and alcoholic fragments. Waxes. Beeswax. Spermaceti. Lanolin.
122. Fats, oils (triacylglycerols). Nomenclature.

123. Phospholipids. L-Glycerol-3-phosphate, phosphatidic acids. Phosphatidylcholines, phosphatidylcolamines, phosphatidylserines. Diphilic structure.
124. Physical and chemical properties. Hydrolysis, transesterification, hydrogenation, addition of halogens, oxidation. Lipid peroxidation. peroxides or lipid oxidation products (LOPs).
125. Structure, classification and nomenclature of terpenes and terpenoids. Typical reactivity. Parent monoterpenes. Acyclic and cyclic monoterpenes and monoterpeneoids, bicyclic monoterpenes and monoterpeneoids
126. The structure of gonane (cyclopentanoperhydrophenanthrene): structure, numbering of carbon atoms, A, B, C, D rings). Stereoisomerism, cis and trans-forms of bicyclic fragments,  $\alpha$ ,  $\beta$ -convention for designating the configuration of chirality centers. Configuration of cycles A, B, C, D in molecules of natural steroids,  $5\alpha$ - and  $5\beta$ - series of steroids.
127. Classification and nomenclature of natural steroid compounds. Types by structure and function. Parent hydrocarbons, gonane homologs: estrane, androstane, pregnane, cholane, cholestane. Types by function: sterols, bile acids, corticosteroids, androgenic hormones, estrogen hormones, aglycones of cardiac glycosides.
128. Sterols (cholesterol, ergosterol). Isomerization of ergosterol to vitamin D<sub>2</sub>, cholesterol to vitamin D<sub>3</sub>.
129. Bile acids (cholate, deoxycholic, glycocholic, taurocholic). Emulsifying action.
130. Corticosteroids (hydrocortisone, deoxycorticosterone, prednisolone).
131. Androgenic hormones (testosterone, androsterone).
132. Estrogenic hormones (estradiol, estrone, estriol).
133. Structure and nomenclature of cardiac glycosides. Hydrolysis. Aglycones of cardiac glycosides: cardenolides (digitoxigenin, strophanthidine) and bufadienolides.
134. Synthesis design. Retrosynthetic analysis. Synthons, rethrons and synthetic equivalents. Convergent and linear synthetic strategies. Cascade reactions. Examples of pharmaceutical drug synthesis.
135. Methods of carbon skeleton formation and functionalization /transfunctionalization reactions.
136. Conditions of reaction. Substances for synthesis. Equipment and glassware for synthesis.
137. Separation from mixtures, purification of the substance by filtration, extraction, distillation, recrystallization, sublimation. Physicochemical principles of methods. .
138. 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.
139. Aglycones of cardiac glycosides: cardenolides, bufadienolides; the general principle of structure and the reactivity of cardiac glycosides. Application in the medicine and pharmacy
140. Structure and properties of steroid saponins. Application in the medicine and pharmacy
141. Structure of vitamins and their application in medicine and pharmacy: vitamin A (retinol, retinal, retinoic acid) and its precursor  $\beta$ -carotene, vitamins of group E (tocopherols), vitamins of group D, vitamins of group K, ubiquinones, vitamin C (ascorbic acid), vitamin B<sub>1</sub> (thiamine), vitamin B<sub>6</sub> (pyridoxol, pyridoxal, pyridoxamine), vitamin H (biotin), vitamin B<sub>12</sub> (cyanocobalamine), vitamin PP (nicotinic acid), vitamin P (rutin), vitamin U.
142. General characteristics of polymers. Classification by origin; topology of polymer chains; the composition of the chain; number of types of monomers, spatial isomerism; in relation to heating.
143. Synthesis of polymers: chain and step polymerization. Types of chain polymerization. The mechanism of the reaction of free-radical chain polymerization. Initiators. Inhibitors.
144. Textiles, polypropylene, polystyrene, polyvinyl chloride, polytetrafluoroethylene, polymers based on acrylates, polyethylene, polymers obtained in the chain polymerization reaction.
145. Stepw polymerization: polycondensation and polyaddition. Structure of polymers, their application in medicine and pharmacy: lavsan, nylon, kapron, kevlar, polycarbonates, polyurethanes, epoxy resins, polysiloxanes.
146. Structure, properties and application in the medicine and pharmacy of natural polymers: starch, dextran, alginic acids, natural rubber, gutta-percha.