MINISTRY OF HEALTH OF UKRAINE

ODESSA NATIONAL MEDICAL UNIVERSITY

Faculty of Pharmacy

Department of Pharmaceutical Chemistry and Drug Technology

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_____, 202_

METHODOLOGICAL DEVELOPMENT
TO THE LECTURES ON THE EDUCATIONAL DISCIPLINE

Faculty, course Pharmaceutical, II year

Academic discipline Organic chemistry

(name of academic discipline)

Approved:

The meeting of the department Pharmaceutical chemistry

Odesa National Medical University

Minutes № _ dated _____

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Lecture No. 1

Topic: The subject of organic chemistry. Classification and nomenclature of organic compounds.Types of chemical bonds and mutual influence of atoms in organic molecules

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselveswith types of chemical bonds and eelectronic effects in organic compounds,interpret the featureinfluence of atoms in organic compounds.

Basic concepts: Development of theoretical ideas about the structure of organic compounds.Chemical bond. Types of chemical bonds. Valence states of the carbon atom. Covalent σ- and π-bonds. Electronic effects in organic compounds.

Plan and organizational structure of the lecture:

1. Development of theoretical ideas about the structure of organic compounds.
2. Chemical bond. Types of chemical bonds.
3. Valence states of the carbon atom.
4. Covalent σ- and π-bonds.
5. Electronic effects in organic compounds.

Content of lecture material (lecture text)

Organic chemistry studies the compounds of carbon with other elements. Carbon forms a particularly large number of compounds with the so-called organogen elements – H, O, N, S, P, halides. These compounds are more common in nature and a greater number of them are obtained artificially - by synthesis.

Some organic compounds in a more or less pure state have been known since time immemorial (vinegar is an aqueous solution of acetic acid, many organic dyes). A number of organic compounds, such as urea, diethyl ether ("sulfur ether"), were

obtained by alchemists. Many substances, especially organic acids (oxalic, citric, tartaric, lactic, etc.) and organic bases (alkaloids) were isolated from plants and objects of animal origin in the second half of the 18th century and the beginning of the 19th century. This time should be considered the beginning of scientific organic chemistry, although the term "organic chemistry" arose later.

Since the beginning of the 19th century, more and more substances common to the animal world and the plant world began to be discovered (starting with acids such as oxalic and formic, ending with fats and proteins), the boundaries between plant and animal chemistry gradually blurred. Organic chemistry included not only substances released directly from objects of plant or animal origin (which, according to the ideas of that time, could not be obtained by synthesis), but also the products of their chemical transformations. In 1824, the German chemist F. Wöhler, who was considered a representative of mineral chemistry, obtained oxalic acid by hydrolysis of dicyan.(CN)2 → HOOC–COOH.

The critical date, however, is considered to be 1828, when the same F. Wöhler transformed "inorganic" ammonium cyanate into the well-known organic compound - urea:

NH4CNO → NH2–CO–NH2.

It was this discovery that eliminated the prejudice that separated organic and mineral chemistry, demonstrating the possibility of obtaining organic substances artificially, without the participation of a hypothetical life force.

Already in the 1930s, it became clear that a different definition than the chemistry of substances of organic origin should be sought for organic chemistry. Then the German chemist H. Hmelin (1848) gave the definition of organic chemistry as the chemistry of carbon compounds, which is still accepted today. With such a definition of organic chemistry, the question arises, however, why carbon has such a dominant position out of all the hundreds of known elements? That this special position is natural is clear from a comparison of some facts from the fields of organic and inorganic chemistry. First of all, the number of currently known carbon compounds is approximately 10 times greater than the number of inorganic compounds. But even more than five million currently studied organic compounds do not exhaust the practically limitless possibilities of designing organic molecules. Taking into account the fact that there are a number of carbon compounds belonging to inorganic substances (CO, CO2, salts of carbonic and hydrocyanic acids), K. Schorlemmer proposed a more precise definition of organic chemistry: the science that studies hydrocarbons and their derivatives.

In organic chemistry, the phenomenon of isomerism discovered by Berzelius, common to all chemistry, but most widespread in organic chemistry, is extremely important. The essence of the phenomenon is that there can be several (in organic

chemistry - many) different substances that have the same composition and molecular weight, but differ in the structure of the molecule from the same set of atoms. Among simple inorganic compounds, it is not so easy to cite a case of isomerism (isomers, for example, are ammonium hydrosulfate (NH4)HSO4 and hydroxylammonium hydrosulfite (NH3OH)HSO3). At the same time, in organic chemistry, even in substances of the simplest composition - hydrocarbons, the phenomenon of isomerism leads to the existence of a huge number of different chemical species.

The second factor that provides a huge number of organic compounds is the phenomenon of homology established by S. Gerard - the existence of chemically similar series of substances, the composition of successive members of which differs from each other by the CH2 group - the homologous difference.

The third factor is the existence of isological series of compounds, that is, series of substances built from the same number of carbon atoms, but differing in composition in such a way that each subsequent member contains two hydrogen atoms less than the previous one (for example, ethane C2H6, ethylene C2H4, acetylene C2H2). Even for hydrocarbons, which are simple in composition of organic compounds, due to these factors there are strictly systematized series, forming in principle an infinite number of substances.

It should be noted the fundamentally important role of organic chemistry in the system of pharmaceutical education - about 90% of medicines consist of organic compounds. In this regard, the development and industrial production of medicinal products, their quality control are largely based on the methods and techniques of organic chemistry.

1. Development of theoretical ideas about the structure of organic compounds.

At the beginning of the 19th century, during the study of organic compounds, attention was drawn to the fact that in a number of chemical transformations, individual groups of atoms, so-called radicals, pass unchanged from one substance to another. Based on the one created in 1812 by Y.Ya. Berzelius of the electrochemical theory, which asserted that all chemical compounds are made of electropositive and electronegative atoms or atomic groups held together by electrostatic forces, a number of scientists created the first theory in organic chemistry - the theory of radicals (Y. Liebich, F. Völer, Y. J. Berzelius).

The authors of this theory believed that if radicals do not change during chemical transformations, just as inorganic substances are composed of atoms, organic substances are composed of radicals.

However, in 1833-1834, the French chemist J. Dumas, while studying the effect of chlorine on organic compounds, established that in organic radicals, hydrogen atoms can be replaced by chlorine, that is, the radical can change. These works led to the need for a critical revision of the theory of radicals.

In the 40s of the XIX century, the theory of radicals was replaced by a more advanced theory of types, the founder of which is the French chemist S. Gerard. In contrast to the theory of radicals, which focuses attention in chemical transformations on the fixed part of the molecule - radicals, the theory of types appeared as a result of the generalization of observations on the variable part of the molecule (what we call today a functional group). These observations formed the basis of the classification of organic compounds by types of chemical transformations. First, analogues (types) of water, hydrogen chloride, ammonia, and hydrogen were distinguished, then the type of methane appeared.

Type of water	N AT N	C2H5 AT N	C2H5 AT C2H5
	water	ethanol	diethyl ether
Type hydrogen chloride	N Cl	CH3 Cl	C2H5 Cl
	hydrogen chloride	methyl chloride	ethyl chloride
Typeammonia	H HN H	CH3 HN H	CH3 CH3 N H
	ammonia	methylamine	dimethylamine
Typehydrogen	H H	CH3 H	C2H5 N
	hydrogen	methane	ethane

The given typical formulas show, for example, that when replacing one hydrogen atom in a water molecule with a C2H5 residue, ethyl alcohol is formed, two - diethyl ether, etc.

By the middle of the 19th century, as a large amount of experimental material was accumulated, the theory of types was no longer able to explain many facts. The further development of organic chemistry demanded the creation of a new, more modern theory. The creation of such a theory, which laid the scientific foundations of organic chemistry, belongs to the Russian scientist A. M. Butlerov. Using the discovery of the German chemist F. Kekule about the four valences of the carbon atom (1857) and the Scottish chemist A. Cooper about the ability of carbon atoms to combine into long chains (1858), Cooper also proposed a modern representation of formulas in which the sign of the element was accompanied number of dashes equal to its valence), A. M. Butlerov created a theory of the chemical structure of organic compounds. Its main principles were outlined in the report "On the theory of chemical structure" at the International Congress of Naturalists and Physicians in Speyer (Switzerland) on September 19, 1861.

The main provisions of the theory are summarized as follows:

1. The atoms of the organic compound that make up the molecule are connected to each other in a strictly defined order according to their valency. The sequence of bonding atoms in a molecule is called a chemical structure.
2. The properties of a substance depend not only on which atoms and in what quantity are part of the molecule, but also on the sequence in which they are connected, that is, on the chemical structure of the molecule.
3. Molecules are formed by atoms or groups of atoms, connected directly or through other atoms, mutually influencing each other, which depends on the reactivity of the molecule.
4. Having studied the reactivity of a substance, its structure can be established and, conversely, its properties can be judged from the structure of a substance.

A. M. Butlerov's theory of chemical structure made it possible not only to systematize the enormous experimental material accumulated at that time in organic chemistry, but also to predict the existence of new compounds and indicate the ways of their synthesis.

The theory of chemical structure received further development in the works of the Dutch chemist J. Van Hoff and the French chemist J. Le Bel (1874), who proposed the stereochemical theory - an idea of the spatial arrangement of atoms in a molecule. These authors independently came to the conclusion about the tetrahedral directional bonds of the carbon atom in space.

Taking into account the above, the following general characteristics of inorganic and organic chemistry can be given.

Inorganic chemistry is the chemistry of mainly polar compounds and polar chemical bonds, organic chemistry is the chemistry of mainly non-polar compounds and non-polar chemical bonds. The specificity of carbon is that it easily forms strong non-polar bonds with both electropositive and electronegative elements.

The theory of chemical structure received its further development with the introduction of electronic concepts into organic chemistry. In 1916, the American scientist J. Lewis proposed an electronic theory of chemical bonding (the so-called theory of electron pairs), according to which a chemical bond in organic compounds is carried out by a pair of electrons supplied one by one to each of the bonded atoms. In addition, J. Lewis suggested that the electron pair participating in the formation of a chemical bond can move to one of the atoms. This idea turned out to be very important and was laid at the basis of the theory of electronic displacements. In the works of R. Robinson (1922), and later K. Ingold (1926 - 1934), ideas about the displacement of electrons in simple connections (inductive effect) and multiple connections (mesomer effect) were introduced and developed. The theory of electronic displacements has become widespread in organic chemistry, as it allows establishing the relationship between the electronic structure and the reactivity of organic compounds.

A new, fundamentally important stage in the development of the theory of chemical structure was the introduction of ideas of quantum mechanics into organic chemistry in the 30s of the 20th century. At that time, quantum mechanical methods of describing the structure of molecules were developed - the method of molecular orbitals (J. Lennard-Jones, R. Mulliken, F. Hund, 1928-1932) and the method of valence bonds (L. Pauling, J. Slater, 1931-1934). Using the ideas of the method of valence bonds, L. Pauling developed the theory of resonance, which made it possible to explain many properties of aromatic systems. Using the method of molecular orbitals, E. Hückel proposed an explanation of the stability of aromatic systems and formulated a theoretically based rule that allows predicting whether the system will be aromatic or not (Hückel's rule). The intensive development of quantum mechanical ideas was stimulated by the appearance of electronic computing technology in the 60s of the 20th century.

2. Chemical bond. Types of chemical bonds.

According to the ideas of the electronic theory of J. Lewis and St. Kossel (1916), a chemical bond is considered as the result of the interaction of the outer electron shells (valence electrons) of atoms. Each atom, forming a chemical bond, receives, gives or localizes valence electrons in such a way that its outer electron

shell corresponds to the configuration of a noble gas. This principle of filling the valence shells was called the "octet rule".

Depending on the method of formation, two main types of chemical bonds are distinguished: ionic and covalent.

An ionic bond is formed between atoms that differ significantly in electronegativity (EN). The electronic configuration of a noble gas is achieved in this case by the transfer of an electron to a more electronegative atom, the resulting ions are electrostatically bonded:

$$Na+ : \dot{\underset{\cdot\cdot}{Cl}} : \rightarrow Na+Cl–.$$

Compounds with an ionic bond, as a rule, have high melting points, dissolve well in polar solvents (water, alcohols, etc.), dissociate into ions in aqueous solutions. Their solutions and melts conduct electric current.

Covalent bond is the main type of chemical bond in organic compounds. It is formed between atoms that are equal or close in EN. The electronic configuration of a noble gas in this case is achieved due to delocalized valence electrons and the formation of one or more shared electron pairs:

H

$$\cdot \dot{\underset{\cdot}{C}} \cdot + 4H\cdot \rightarrow H : \ddot{\underset{\cdot\cdot}{C}} : H$$

H

When a covalent bond is formed between atoms with the same EH, the common electron pair is located symmetrically with respect to the centers of both atoms - this is a nonpolar covalent bond.

If atoms with different EN are involved in the formation of a covalent bond, the shared electron pair shifts to the atom with a larger EN. In this case, the bond is called a covalent polar bond and is depicted as an arrow pointing to the atom with a higher EN:

$$H3C : Cl \equiv H3C\delta+ \rightarrow Cl\ \delta–$$

The letter δ denotes fractional (partial) charges on atoms; δ+ reflects reduced, and δ– – increased electron density. Depending on the number of common electron pairs that arise between atoms during the formation of a bond, single and multiple covalent bonds are distinguished:

simple covalent bond

↓

H–C≡C–H

↑

multiple covalent bond

Atoms of nitrogen, oxygen, sulfur, halogens and some other elements when forming covalent bonds form an octet shell by delocalization of not all outer electrons. Some of the electrons do not participate in the formation of chemical bonds - these are the so-called indivisible electron pairs (NEP).

A donor-acceptor bond is a type of covalent bond and differs from the latter only in the mechanism of its formation: if a covalent bond is formed by a delocalized pair of electrons, one from each atom, then a donor-acceptor bond is formed due to the NEP provided by one of the atoms. This atom is called a donor, and an atom that accepts electrons is called an acceptor. The acceptor can be a proton or another atom that lacks two electrons to form an octet (there is a vacant orbital). For example, the formation of an ammonium ion occurs under the donor-acceptor mechanismNH4+:

H3N: +□H+ → NH4+

donor acceptor

The covalent bond formed in the ammonium ion by the donor-acceptor mechanism is no different from the other three bonds.

Other names of the donor-acceptor bond are coordination, because during its formation, the process of NEP coordination takes place.

In some cases, the donor-acceptor bond is semipolar. It is formed by the interaction of atoms that have NEP (donors) with electroneutral particles that contain a sextet of electrons (acceptors). As a result, the donor atom acquires a positive charge, and the acceptor atom acquires a negative charge, i.e. these atoms are connected by covalent and ionic bonds:

$$(CH_3)_3N: + \ddot{O}: \rightarrow (CH_3)_3\overset{+}{N}-\overset{-}{O}$$

trimethylamine trimethylammonium oxide

Despite the fact that in heptipolar bonds, along with the covalent bond, there is an ionic interaction, the compounds built according to this type do not conduct an electric current.

It is customary to denote a semipolar bond as follows:

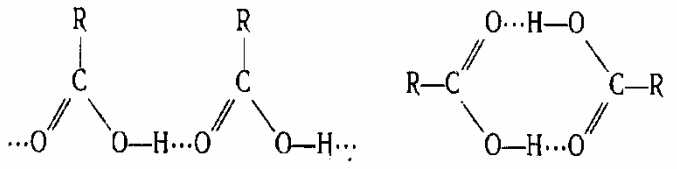
$(CH3)3\,\overset{+}{N}-\overset{-}{O}$ or $(CH3)3N\rightarrow O$

A hydrogen bond (H-bond) is formed as a result of electrostatic interaction between "mobile" hydrogen atoms in a molecule and atoms with NEP (oxygen, nitrogen, fluorine, rarely sulfur, chlorine) in the same or another molecule. Hydrogen atoms connected in the molecule by a strongly polar covalent bond, for example, –O←H, N←H, S←H, etc., are called "mobile". Graphically, a hydrogen bond is indicated by three dots

–N←H···N

The H-bond energy is usually small (10 – 40 kJ/mol) compared to the covalent bond energy (340 – 360 kJ/mol). However, examples of so-called strong H-bonds are known. As a rule, this is an H-bond with the participation of fluorine, for example, in the hydrodifluoride ion HF2– (~220 kJ/mol) and in the complex HCOOH•••F– (~250 kJ/mol); the energies of these H-bonds are values of the same order as the energies of covalent bonds.

Intramolecular and intermolecular H-bonds are distinguished. Intramolecular H-bonds are realized within one molecule with the formation of five-, six- or seven-membered chelate-like structures (from the Latin chela – claw). Intermolecular H-bonds are realized between two or several molecules with the formation of dimers or associates:



The presence of H-bonds affects the physical (melting and boiling points, solubility, viscosity, spectral characteristics) and chemical properties of organic compounds. The realization of intermolecular H-bonds is accompanied by an increase in the boiling point, and often the melting of substances.

For example, due to the formation of associates, the boiling point of ethanol C2H5OH (78 ° C) is much higher than that of the isomeric dimethyl ether CH3–O–

CH3 (-24 °C) with the same molecular weight, but which is not capable of forming H-bonds. Similarly, the higher melting point of meta-nitrophenol (97 ºC) and para-nitrophenol (114 ºC) compared to ortho-nitrophenol (45 ºC) is explained by the formation of intermolecular H-bonds in the case of the first two compounds.

The formation of an H-bond between the solute and the solvent significantly increases the solubility of the substance.

It is possible to establish the presence of an H-bond using the methods of IR, MR and NMR spectroscopy. In particular, in the IR spectra of hydroxyl-containing compounds (alcohols, phenols), there is an absorption band of free OH groups in the region of 3650 – 3590 cm–1; under the condition of participation of OH groups in H-bonds, the absorption band shifts to the low-frequency region of 3400 – 3200 cm–1.

H-bonds play an important role in the course of various biochemical processes in the body, in particular, they form the spatial structure of proteins, polysaccharides, participate in the formation of the double helix of DNA, etc.

3. Valence states of the carbon atom

A carbon atom in the ground state has two unpaired electrons, and its ability to form four covalent bonds in organic compounds is explained by the transition of one electron from 2s-electrons to a vacant 2pz-orbital:

s	s	px	nd year	years
↓	↓			

s	s	px	nd year	years
↓				

ground state of carbon excited state of carbon

In this excited state, the carbon atom has four (one s- and three p-) one-electron orbitals. The equivalence of all four bonds in the methane molecule is explained by the effect of hybridization of atomic orbitals (AO) with the formation of four hybrid sp3-AOs, which are asymmetric volumetric eights. Compared to non-

hybridized hybrid AOs, they are more advantageous geometrically and, as a result of greater overlap with AOs of other atoms, form stronger bonds.

The carbon atom is characterized by three types of hybridization involving s- and p-orbitals, each of which corresponds to a specific valence state of the atom.

sp3-Hybridization of carbon (first valence state) - from one s - and three p-AO, four qualitatively new equivalent sp3-hybrid orbitals are formed, directed in space at an angle of 109º28 (from the center of a regular tetrahedron to its vertices, tetrahedral hybridization). In this valence state, the carbon atom forms only simple covalent bonds.

sp2-Hybridization of carbon(second valence state) - is carried out as a result of the interaction of one s - and two p-AO (px, py). At the same time, three equivalent sp2-hybrid orbitals are formed, lying in one plane at an angle of 120º (trigonal hybridization). The remaining non-hybridized pz-AO is located in a plane perpendicular to the plane of the hybrid orbitals. A carbon atom in sp2-hybridization forms a double bond.

sp-Hybridization of carbon(third valence state) - arises as a result of the interaction of one s - and one p-AO (px). As a result, two sp-hybrid orbitals located at an angle of 180 º are formed (linear hybridization). Unhybridized ru and pz are located in two mutually perpendicular planes and at right angles to the sp-hybrid orbitals. In the state of sp-hybridization, the carbon atom forms a triple bond.

4. Covalent σ- and π-bonds

Depending on the method of AO superimposition, two types of covalent bonds are distinguished: σ-bonds and π-bonds. σ-bonds are formed as a result of overlapping of two different AOs - s-, p-, d - and hybrid ones - sp3-, sp2-, sp - along the line connecting the nuclei of atoms.

Along with the overlap of AO along the axis connecting the nuclei of atoms, there is a so-called lateral overlap of AO. Only parallel p-AO - π-overlaps take part in it, a bond - π-bond is formed. The maximum electron density of the π-bond is concentrated in two regions - above and below the axis connecting the nuclei of atoms, and therefore the π-bond is less strong than the σ-bond. A π-bond is formed between atoms that are in sp2 and sp-hybrid states.

In the ethylene molecule, the carbon atoms are sp2-hybridized. σ-Superposition of three hybrid AOs of each carbon atom gives two C–H and one C–C σ-bond, π-overlapping gives a C–C π-bond. At the same time, the π-bond is located in a plane perpendicular to the plane of σ-bonds.

In the acetylene molecule, the carbon atoms are in sp-hybridization and form a triple bond between themselves, consisting of one σ - and two π-bonds: the σ-bond arises due to the overlap of sp-hybrid AOs, and four p -orbitals form two π-bonds located in mutually perpendicular planes.

Depending on the number of binding electron pairs involved in the formation of a chemical bond between two atoms, single and multiple covalent bonds are distinguished. Simple (single) bonds are always represented by a σ-bond, multiple bonds include a π-bond along with a σ-bond. There are double and triple multiple bonds.

5. Electronic effects in organic compounds

In organic chemistry, two types of electronic effects are distinguished: displacement of the electron density along the chain of σ-bonds – inductive effect; shift along the system of π-bonds is a mesomeric effect.

The transfer of electronic influence of substituents along the chain of σ-bonds is called the inductive effect. The inductive effect is denoted by the letter "I". The direction of displacement of the electron density of σ-bonds is represented by an arrow (→). The action of the inductive effect is most strongly manifested on the two nearest σ-bonds; due to the weak polarizability of σ-bonds, the inductive effect through 3-4 bonds fades.

Depending on the direction of the electronic influence of the substituents, positive (+I) and negative (–I) inductive effects are distinguished. To estimate the direction of the I-effect of the substituent, the I-effect of the H atom is taken as a standard, which is considered to be zero due to the small dipole moment of the C–H bond.

Substituents that attract electrons of σ-bonds to themselves to a greater extent than a hydrogen atom, showing a negative electronic effect (–I), and substituents that repel bond electrons more strongly than a hydrogen atom, show a positive inductive effect (+ I).

– I-effect	+I effect
– OR2+, –NR3+, – NO2, –C≡N, – COOH, –F, –Cl, –	– NR–, –O–, Alk (– CR3, –CHR2,

Br, –I, – COOR, –OR, –COR, –SR, – OH, –NH2, –C≡CR, –Ar, – CH=CR2	– CH2R, –CH3)

–I-The effect of the substituent, as a rule, is greater, the higher the EN of the atom connected to the carbon chain. Groups carrying a positive charge show the greatest -I-effect.

Substituents that carry a negative charge show the largest +I effect. Among alkyl groups, tertiary radicals possess great electron-donating properties, followed by secondary and, finally, primary radicals:

(CH3)3C– > (CH3)(C2H5)CH– > CH3(CH2)3–

In a series of primary alkyl radicals, the +I effect increases with the increase of the carbon chain:

C4H9– > C3H7– > C2H5– > CH3–.

In a way that differs from the inductive effect, the electronic influence of the substituent is transmitted through the combined system of π-bonds. A system consisting of alternating single and multiple bonds, or when next to a carbon atom forming a multiple bond, there is an atom with an unshared pair of p-electrons or an atom with a vacant p-orbital, for example:

CH2=CH–CH=CH2 CH2=CH–Cl: CH2=CH–CH2+

butadiene-1,3 chloride vinyl allyl cation

Connected systems are divided into open-loop and closed-loop systems. In conjugated systems, there is an additional overlap of π- and p-orbitals, which is called conjugation. A distinction is made between π-π-combination and p-, π-combination. The combination is possible only in case of parallelism of the axis of symmetry, which overlap the orbitals. As a result, a single π-electron system is formed and the π-electron density is redistributed (delocalized). Coupling is an energetically beneficial process and is accompanied by a decrease in system energy.

The process of transferring the electronic influence of a substitute for a combined system of π-bonds is called the mesomeric effect (M) or the coupling effect. The mesomeric effect is manifested only in the case when the sleeper is included in the conjugated system of molecules.

The positive mesomeric effect (+M) is revealed by substituents that supply electrons to the conjugated system. They include atoms containing NEP or negative charge, as well as atomic groups that have NEP or negative charge on the first atom.

The negative mesomeric effect (–M) is revealed by the substituents, which attract the electron density of the conjugated system.– The M-effect is possessed by substituents whose first atom carries a positive charge, as well as atomic groups in which the first atom is linked by a multiple bond to an atom more EO than itself. The direction of displacement of the electron density of π-bonds and NEP is indicated by a bent arrow.

Below are some substitutes, arranged in order of decreasing –M - and +M effects.

- M-effect	+M-effect
– OR2+, –NR3+, –NO2, –C≡N, > C=O,–COOR,–COOH, –CONH2, –COO–	– O–, –N(CH3)2, –HHCH3, – HH2, –OCH3, –OH, –F, -Cl, -Br

Substituents that carry a positive charge show the greatest M-effect; – The M-effect of unsaturated groups is greater, the greater the difference in EH of atoms connected by a multiple bond. Atoms that carry a negative charge have the largest +M-effect. The +M-effect of particles containing atoms with NEP is greater, the smaller it is within the EN period of the atom carrying NEP, for example:

–HH2 > –OH > –F.

Within the group of the periodic system +M-the effect of the shutters weakens from top to bottom:

–F > –Cl > –Br.

In contrast to the inductive effect, the transmission of the electronic influence of the deputy in the coupled system occurs over a much greater distance without fading.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control:

1.Types of chemical bonds in organic molecules.

2. Ionic, covalent, coordination, seven-polar bond.

3. Hydrogen bond. Quantum mechanical foundations of the theory of chemical bonding.

3. Types of hybridization of atomic orbitals of carbon, nitrogen, and oxygen.

4. Covalent σ- and π-bonds, their characteristics from the standpoint of the molecular orbital (MO) method.

5. Electronic structure of double and triple carbon-carbon bonds and their characteristics (length, energy, polarity, polarizability).

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Lecture No. 2

Topic: Isomerism of organic compounds. Acidic and basic properties of organic compounds.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves with isomerism of organic compounds, types of reaction mechanisms and reagents. They should know the acidic and basic properties of organic compounds, interpret the peculiarity of the influence of atoms in organic compounds and analyze their reactivity.

Basic concepts: Isomerism of organic compounds.Reaction mechanisms and their types. Types of organic reactions. Acidic and basic properties of organic compounds. Types of organic acids. Lewis acids and bases.

Plan and organizational structure of the lecture:

1. Isomerism of organic compounds. Spatial structure of molecules.
2. Types of reaction mechanisms and reagents.
3. Types of organic reactions.
4. Methods of determining the structure of organic compounds.
5. Acidic and basic properties of organic compounds.

Content of lecture material (lecture text).

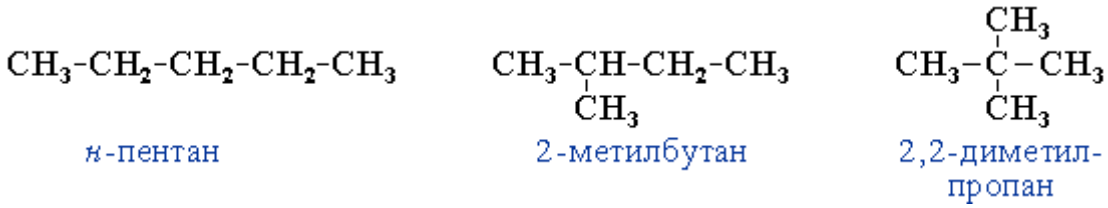
1. Isomerism of organic compounds. Spatial structure of molecules.

Isomerism is a phenomenon that consists in the existence of compounds that are identical in qualitative and quantitative composition, but differ in the order of

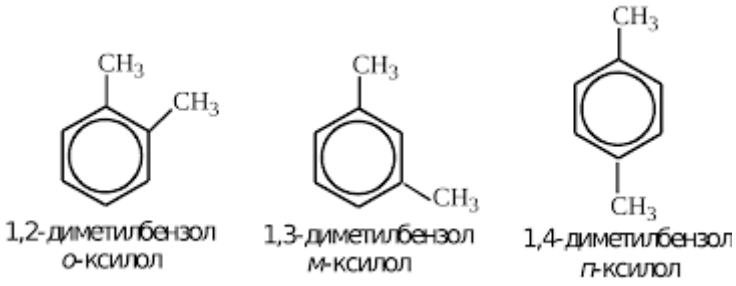
bonding of atoms in the molecule or their location in space, and as a result have different physical and chemical properties.

Structural isomerism is divided into:

carbon chain isomerism (for example, C5H12 – n-pentane, 2-methylbutane, 2,2-dimethylpropane):



positional isomerism(for example, C3H7Cl – 1-chloropropane and 2-chloropropane; C6H4(CH3)2 – 1,2-dimethylbenzene, 1,3-dimethylbenzene, 1,4-dimethylbenzene):



isomerism of functional groups (C2H6O– ethanol and dimethyl ether):

CH3—CH2—OH CH3—O—CH3

The case when two structural isomers are in dynamic equilibrium with each other is called tautomerism, and structural isomers are tautomers (for example, acetoneC3H6Oin ketone (CH3)2C=Oand enolCH3C(OH)=CH2forms).

Substances that have the same composition and order of bonding of atoms in a molecule, but differ from each other in their location in space, are called spatial isomers or stereoisomers.

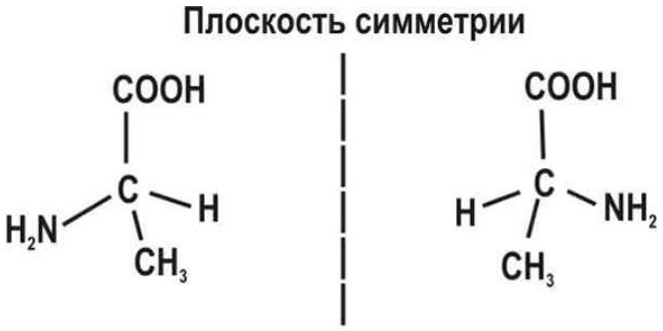
A configuration is a relative arrangement of atoms in space. For example, in the methane molecule, the carbon atom has a tetrahedral configuration; the angle between the bonds of methane H–C–H, equal to 109º28, is called normal or tetrahedral. In ethyleneCH2=CH2the carbon atom has a planar configuration (valence angle 120º), in the acetylene molecule H–C≡C–H – linear (valence angle 180°).

Conformation is a different spatial arrangement of atoms or atomic groups in molecules of a certain configuration, due to rotation around σ-bonds.

For example, in the ethane moleculeH3C–CH3as a result of rotation around the C–C bond, the spatial position of one methyl group relative to another changes. At the same time, the molecule takes many conformations.

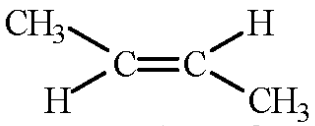
Organic compounds that differ from each other only in the configuration of molecules are called configurational isomers. There are configurational optical and geometric isomers.

Stereoisomers, having a different spatial arrangement of atoms or atomic groups due to rotation around a simple carbon-carbon bond, are called conformational isomers.

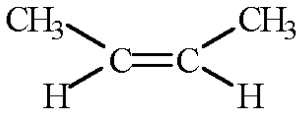


Molecules that have at least one element of symmetry are always identical with their mirror image and are called achiral. Examples can be chloroform CHCl3 or bromochloromethaneCH2BrCl, have a plane of symmetry.

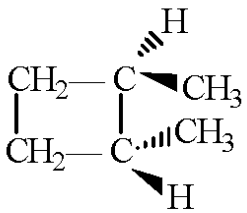
Geometric isomers are substances that have the same composition and sequence of bonding of atoms in the molecule, but a different arrangement of substituents in space relative to the plane of the double bond or the plane of the cycle:



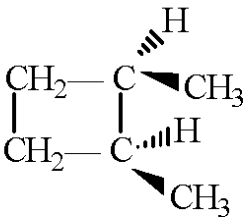
транс-бутен-2



цис-бутен-2



транс-1,2-диметилциклобутан



цис-1,2-диметилциклобутан

The appearance of this type of isomerism is due to the impossibility of free rotation around the double bond in the molecule and the σ-bonds forming the cycles.

To indicate the configuration of geometric isomers, use the cis-, trans- (identical substituents) and Z, E-system

(various substitutes).

2. Types of reaction mechanisms.

The reaction mechanism is the general path along which the transition from the starting substances to the final products of the reaction is carried out. For convenience, one of the reactants is conventionally called a substrate, and the other an attacking reagent.

Depending on the method of breaking bonds in the attacking reagent and substrate, three types of reaction mechanisms are distinguished: hemolytic (radical), heterolytic (ionic), and pericyclic (molecular). A homolytic or free radical mechanism is called a mechanism in which, when bonds in the reacting molecules are broken, one electron remains in each of the formed fragments. Such particles are called radicals:

$$A\cdot\,|\,\cdot B \rightarrow A\cdot + B\cdot$$

The free radical mechanism is denoted by the symbol "R".

*Heterolytic or ionic*is called a mechanism in which, when bonds are broken in the reacting molecules, both electrons remain on one of the resulting fragments. Such particles are called ions:

$$\text{AND:}\,|\,B \rightarrow A^- + B^+$$

Depending on the electronic nature of the attacking reagent, the reactions proceeding through the ionic mechanism are divided into nucleophilic (symbol "N") and electrophilic (symbol "E"). In nucleophilic reactions, the attacking reagent is a nucleophile (Nu–), and in electrophilic reactions, it is an electrophile (E+).

Nucleophilic (which seek nuclei) are reagents that donate an electron pair when forming a chemical bond with a substrate.

Nucleophilic reagents include: molecules containing one or more NEP; ions carrying a negative charge (anions); molecules having centers with increased electron density.

Below are the most important nucleophilic reagents.

1. Neutral molecules that have NEP:HH3, PHH2, R2HH, R3N, H2O, POH, ROP.

2. Anions:OH–, CN–, RO–, NN2–, RCOO–, RS–, SH–, Cl–, Br–, I–, HSO3–, CNS–.

3. Compounds containing centers with increased electron density:>C=C<, –C≡C–, C6H6.

Nucleophiles are able to form a covalent bond with the substrate, attacking centers with reduced electron density in its molecule.

Reactants that accept an electron pair from a substrate when a chemical bond is formed from them are called electrophilic (electron-seeking).

Electrophilic reagents include neutral molecules that have a vacant orbital or centers with reduced electron density.

Typical electrophilic reagents are:

1. Neutral molecules with a vacant orbital (Lewis acids):
SO3, AlCl3, FeBr3, SnCl4, BF3BF3, etc.
2. Cations: proton H+, metal ions (Mep+), aryldiazonium cations (Ar–N2+),

protonated sulfur trioxide (SO3H+), nitrosonium ion (NO+), etc

2. molecules with centers with reduced electron density:
halogen derivatives of hydrocarbons (R→Hal), compounds with a carbonyl group R–C(O)H, R–C(O)R, R–C(O)BH, R–C(O)OP, R–C(O)Hal, etc., halogens(Cl2, Br2, J2).

Electrophilic reagents are able to form a covalent bond with the substrate, attacking centers with increased electron density in its molecule.

In addition to homo - and heterolytic reactions, which proceed according to the so-called pericyclic (molecular) mechanism, are known. The molecular mechanism is characterized by the simultaneous (coordinated) breaking and formation of bonds in the reacting molecules. Molecular reactions proceed without the formation of ions or radicals, they are accompanied by the synchronous movement of electrons in the substrate and reagent. A typical example of a molecular reaction is the addition of dienes to alkenes (Diels-Alder reaction).

3. Types of organic reactions.

Organic reactions can be divided into several main types.

1. *Addition reactions*(denoted by the symbol "A"):

$$A{=}B + X{-}Y \rightarrow \begin{matrix} A{-}B \\ | \; | \\ X \quad Y \end{matrix}$$

Addition reactions can occur by the following possible mechanisms:

a) electrophilic addition (symbol AE);

b) nucleophilic addition (AH);

c) free radical addition (AR);

d) molecular (synchronous) joining.

2. Substitution reactions (denoted by the symbol "S"):

$$A{-}B + X{-}Y \rightarrow A{-}X + B{-}Y$$

Substitution reactions can take place according to the following mechanisms:

a) electrophilic substitution (symbol CE);

b) nucleophilic substitution (SN);

c) free radical substitution (SR).

3. Cleavage (elimination) reactions (denoted by the symbol "E"):

$$A{-}B \rightarrow A{=}B + X{-}Y$$

| |

X Y

Such substances as water, hydrogen halides, and ammonia are most often separated from organic compounds.

4. Regrouping:

$$A{-}B \rightarrow \begin{matrix} A{-}B \\ | \; | \\ X \quad X \end{matrix}$$

Rearrangements include the transition (migration) of individual atoms or groups of atoms from one fragment of a molecule to another. In particular, non-limiting compounds are prone to them.

5. Oxidation and reduction reactions are accompanied by a change in the degree of oxidation of the carbon atom, which is the reaction center.

According to the number of molecules involved in the stage that determines the reaction rate, monomolecular and bimolecular reactions are distinguished, which are denoted by indices 1 and 2, respectively. Molecules of one reagent participate in the limiting (slow) stage of a monomolecular reaction, and molecules of two reagents participate in a bimolecular reaction.

4. Methods of determining the structure of organic compounds.

Along with chemical methods of identification of organic compounds, based on the use of qualitative reactions to functional groups,multiplicity of connection, etc., as well as destruction reactions, currently physical (instrumental) methods are widely used.

Spectral methods– vibrational spectroscopy, including IR and Raman spectroscopy, UV spectroscopy and spectroscopy in the visible region of the spectrum, NMR spectroscopy, mass spectrometry.

Diffraction methods– X-ray structural analysis (XRA), electronography, neutronography.

Each of the listed methods has its limitations, and therefore a complex of physical methods is used to study the structure. Optimal is the joint use of NMR, IR, UV spectroscopy and mass spectrometry.

5. Acidic and basic properties of organic compounds.

To evaluate the acid-base properties of organic compounds, two approaches are used - the protolytic theory of Brønsted and the electronic theory of Lewis.

According to Brønsted's ideas, an acid is any substance that can donate a proton (a proton donor), and a base is a substance that can add a proton (a proton acceptor). In general, the acid-base process consists in the transfer of a proton from an acid to a base and can be represented by the following scheme:

$$A–H + + B \rightleftarrows A– + B+–H.$$

acid base conjugate base acid

Many organic compounds can simultaneously have the properties of acids and bases. Such compounds are called amphoteric.

The measure of the strength of A–H acid is the acidity constant Ka, which is usually determined in relation to the standard base - water:

A–H + H2O⇄A– + H3O+; Ka = [A–][H3O+]/[A–H].

The higher the value of Ka, the stronger the acid. Since the acidity constants are very small, the values of pKa are usually used, where pKa = –lg Ka. The lower the pKa value, the stronger the acid.

Similarly, the strength of the underbase is quantitatively expressed by the basicity constant Kb, which is determined from equilibrium:

B + H2O⇄B+–H + HO–; Kb = [B+H][HO–]/[B].

The greater the Kb, the stronger the base. For convenience, the strength of the bases is usually expressed by the value pKb, where pKb = –lg Kb. At the same time, the smaller rKb, the stronger the base. However, most often the strength of the base is estimated by the acidity constant of the conjugate base of the acid BH+, denoted as pKB+H. The greater the pKV+H value, the stronger the base.

Types of organic acids

Depending on the nature of the acid center, organic acids are divided into four main types:

1. OH-acids, carboxylic acids, alcohols, phenols, H2O, etc

2. SH-Acids: thiols, thiol acids, etc

3. NH-acids: amines, acid amides, imides.

4. CH-Acids: compounds containing strongly polar C–H bonds.

` The strength of organic acids is determined by the stability of the formed anion (conjugate base): the stronger the conjugate base, the stronger the acid. All other factors being equal, the stability of anions (and acidity) increases with increasing electronegativity (EN) and polarizability of the atoms of the acidic center. Since within the period EH of atoms increases from left to right (polarizability does not change), then OH-acids are stronger than the corresponding NH-acids, and those, in turn, are stronger than CH-acids:

CH3C(O)OH CH3C(O)NH2 CH3C(O)CH3

acetic acid, acetone acetamide

pKa = 4.7 pKa = 15.1 pKa = 20.0

Within the group of the periodic system, the EN of atoms decreases from top to bottom, but their volume and polarizability increase, i.e., delocalization of the external electron cloud is possible. This leads to an increase in the stability of the anion to an increase in acidity. Therefore, SH-acids have higher acidity than their OH-analogues, for example:

CH3—CH2—OH CH3—CH2—SH

ethanol (pKa = 18.0) ethanethiol (pKa = 10.5)

Thus, depending on the nature of the acid center, organic acids with the same radicals can be arranged in the following series in order of increasing acidity:

CH-acids NH-acids OH-acids SH-acids.

Within this type of acids, the acidity depends on the structure of the radical bound to the acid center. For example, in the aliphatic series, the strongest influence on acidity is exerted by substituents located closer to the acid center; substituents in radicals affect acidity due to their manifestation of electronic effects - inductive and mesomeric. Electron-donating substituents (+I +M) reduce acidity, and electron-accepting ones (–I, –M) increase it, as, for example, in the case of chlorine derivatives of acetic acid:

Сила кислот

Кислота	Возрастание силы кислоты	$K_{дисс}$
$CCl_3 — COOH$		$2{,}0 \cdot 10^{-1}$
$CHCl_2 — COOH$		$5{,}0 \cdot 10^{-2}$
$CH_2Cl — COOH$		$1{,}4 \cdot 10^{-3}$
$CH_3 — COOH$		$1{,}8 \cdot 10^{-5}$

Types of organic bases

Depending on the nature of the main center (an NEP atom or π-bond electrons), organic bases are divided into n-bases and π-bases.

In n-bases, the center of basicity is an atom with NEP. According to the nature of the center of basicity, n-bases are classified into the following types:

ammonium(center of basicity –N =N–, ≡N); they include amines, azomethines (RCH=NR), nitriles (R–C≡N), nitrogen-containing heterocycles.

oxonium(center of basicity –O–, =O); include alcohols, ethers, aldehydes, ketones, esters, acid amides, etc.;

sulfonium(center of basicity –S–); include thioalcohols (R–SH) and thioethers (R–S–R).

When the n-base interacts with a proton as a conjugate acid, the corresponding cation is formed:

B + H+ B+–H

n-base conjugate acid

In π-bases, the center of basicity is the electrons of π-bonds (in alkenes, alkadienes, arenes). Compared to n-bases, these are very weak bases, in the process of interaction of a proton with a π-base, a so-called π-complex is formed:

>C=C<

↓

H+

Depending on the nature of the main center, organic bases can be arranged in the following series in order of increasing basicity:

π-bases > sulfonium > oxonium > ammonium.

The nature of the substituent associated with the main center has a great influence on the basicity of organic compounds. Electron-donating substituents lead to an increase in basicity, and electron-withdrawing substituents reduce basicity. For example, due to the +I influence of alkyl groups, the basicity of alkylamines is noticeably higher than that of arylamines (due to the effect of NEP pairing with the π-electron system of the ring).

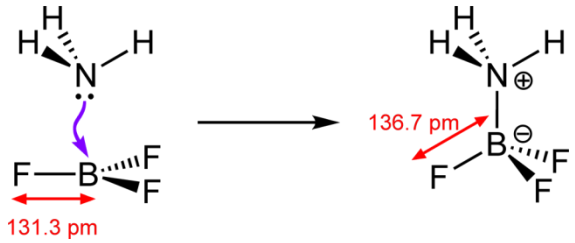
Lewis acids and bases

In 1923, the American researcher JN Lewis proposed a more general (compared to Brønsted's ideas) electronic theory of acids and bases. According to Lewis:

A base is any particle (atom, molecule, or anion) capable of donating an electron pair (NEP) to form a covalent bond, and an acid is any particle (atom, molecule, cation) capable of accepting a pair of electrons to form a covalent bond. connection

Lewis bases correspond to Brønsted bases, but Lewis acids cover a wider range of organic compounds. Any particle with a vacant orbital, including a proton, is considered a Lewis acid. Lewis acids are, for example, such compounds asBF3, SiF4, AlCl3, FeCl3, SbCl3, ZnCl2, HgCl2 andothers

The acid-base process according to Lewis is the formation of a covalent bond between a base and an acid due to the NEP of the base and the vacant orbital of the acid:



The ease of the acid-base interaction is determined by the strength of the acid and base, as well as the "hardness" or "softness" of the acid and base. The concept of "hard" and "soft" acids and bases (HMB), introduced by the American inorganic chemist R. Pearson in 1963, is a certain development of Lewis's theory. According to the concept of ЖМКО, Lewis acids and bases are divided into "hard" and "soft".

"*Hard" acids*– Lewis acids, in which the acceptor atoms have a small volume and carry a high positive charge (they have a high EN and low polarization): H+, Li+, Na+, K+, Mg2+, Ca2+, Al3+, Fe3+, AlCl3, Sif 4, etc. . The lowest free molecular orbital (BMO) in hard acids has low energy.

"Soft" acids– Lewis acids, in which the acceptor atoms have a large volume and carry a low positive charge (have a low EN and high polarization):Cu+, Ag+, Hg2+, Pt2+, I2, Br2etc. HBMO in "soft" acids has high energy.

"Hard" foundations– Lewis bases, in which donor atoms have high EN and low polarization:H2O, OH–, F–, Cl–, CH3COO–, SO42–, CO32–, NO3–, R–OH, RO–, R–O–R, NH3, R–NH2, NH2NH2, NH2–etc. The upper occupied molecular orbital (UEM) in "hard" bases has low energy.

"Soft" foundations– Lewis bases, in which the donor atoms have low EN and high polarization:, RS–, R–S–R, HS–, I–, CN–, R–CN, C2H4, C6H6, H–, R–etc. VZMO in "soft" bases has high energy.

Since the interaction between orbitals with similar energies is more effective, "hard" acids preferentially react with "hard" bases, and "soft" acids - with "soft" bases (principle of ЖМКО).

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control:

1. Isomerism of organic compounds. Spatial structure of molecules.
2. Structural isomerism (isomerism of carbon chain, isomerism of position and isomerism of functional groups).
3. Spatial isomerism (stereoisomers; their classification).
4. Optical isomerism. Optical activity and specific rotation.
5. Geometric isomerism. Optical isomerism. Optical activity and specific rotation.
6. Nomenclature of optical isomers (D, L and R, S configuration notation systems).

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Lecture No. 3

Topic: Alkanes. Cycloalkanes.Alkenes. Alkadienes. Alkynes.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical propertiesalkanes, cycloalkanes,alkenes, alkadienes, alkynes.

Basic concepts: Alkanes. Cycloalkanes. Alkenes. Alcodienes. Alkynes

Plan and organizational structure of the lecture:

1. Classification of hydrocarbons.
2. Alkanes.
3. Cycloalkanes.
4. Alkenes.
5. Alkadienes.
6. Alkynes.

Content of lecture material (lecture text).

1. Classification of hydrocarbons.

Ulehydrogens are organic compounds whose molecules consist only of carbon and hydrogen atoms.

Depending on the structure of the carbon skeleton, hydrocarbons are divided into acyclic (aliphatic), alicyclic and aromatic.

Aliphatic carbohydrates have an open (unclosed) carbon chain. According to the degree of saturation of C–C bonds, aliphatic hydrocarbons are divided into alkanes (limiting hydrocarbons), alkenes (hydrocarbons with a double bond), alkodienes (with two double bonds), and alkynes (with a triple bond).

Aromatic and alicyclic hydrocarbons have a closed carbon chain. Aromatics include hydrocarbons containing one or more benzene rings. Depending on the number of benzene rings, they are divided into mononuclear and polynuclear.

2. Alkanes.

*Alkanes are hydrocarbons of the aliphatic series, in the molecules of which carbon atoms are connected only by simple covalent bonds (σ-bonds).*Synonyms are marginal or saturated hydrocarbons, paraffins.

The general formula of alkanes is $S_pH2п+2$, the progenitor of the homologous series is CH4 methane. Starting with the C4H10 hydrocarbon, alkanes can have both straight and branched chains. The first are called normal, or n-alkanes. The first four members of the homologous series of alkanes have trivial names - methane, ethane, propane, butane, the names of the following hydrocarbons with an n-carbon chain are formed from the Greek. or Latin numerals (indicate the number of carbon atoms in the molecule) with the addition of suffixes -an, for example, pentane, hexane.

Building

Carbon atoms in alkanes have a tetrahedral configuration (sp3-hybridization), valence angles between bonds equal to 109º28. In cases where the carbon atom is connected to different substituents, the angles deviate slightly from the tetrahedral angle. The length of the C-C bond in alkanes is 0.154 nm, the length of the C-H bond is 0.110 nm. According to X-ray diffraction data, alkanes of the n-structure in the crystalline state have a zigzag conformation, which is the most advantageous in terms of energy.

Isomerism

*Structural isomerism*of alkanes (chain isomerism) is possible, starting with butane C4H10 (isomers - n-butane and isobutane). Starting with the C7H16 hydrocarbon, optical isomerism is possible for alkanes.

Methods of obtaining

Natural sources

The main natural sources are oil (a complex mixture of organic compounds with a predominance of alkanes) and natural gas (gaseous alkanes, mainly methane (up to 95%), ethane, propane and butane).

As a result of fractional distillation of oil, several fractions are obtained (petroleum ether, gasoline, kerosene, diesel fuel, fuel oil), each of which is a mixture of hydrocarbons boiling in a certain temperature range. Diesel oil, lubricating oils, petroleum jelly, and paraffin are obtained from fuel oil by distillation under vacuum or with steam.

Natural gas is separated into components by atomization followed by fractional distillation.

Synthetic methods of obtaining

1. Fischer-Tropsch synthesis (catalytic hydrogenation of carbon monoxide):

$CO + H2 \xrightarrow{Fe(Co)} CnH2n+2 + H2O$ (n = 6 – 10).

2. Wurtz reaction (discovered by Sh. Wurtz in 1854):

$2CH3I + 2Na \rightarrow CH3–CH3 + 2NaI$.

3. Catalytic hydrogenation of alkenes and alkynes (catalyst – platinum metals or Raney nickel, the reaction proceeds at normal pressure and temperature):

$CH3–C\equiv C–CH3 \xrightarrow{H_2} CH3–CH=CH–CH3 \xrightarrow{H_2} CH3–CH2–CH2–CH3$.

4. Fusion of salts of carboxylic acids with alkalis:

$CH3CH2COONa + NaOH \rightarrow CH3–CH3 + Na2CO3$.

5. Hydrolysis of organometallic compounds:

$CH3CH2MgI + H2O \rightarrow CH3–CH3 + Mg(OH)I$.

6. Effect of water on aluminum carbide:

$$Al_4C_3 + 12H_2O \rightarrow 3CH_4 + 4Al(OH)_3.$$

7. Electrolysis of aqueous solutions of salts of carboxylic acids:

$$2CH_3COONa + H_2O \xrightarrow{электролиз} CH_3–CH_3 + 2NaOH + H_2.$$

Physical and chemical properties

Under normal conditions, the first four members of the homologous series of alkanes are gaseous substances, n-alkanes from C5 to C17 are liquids, > C17 are solid substances. As M increases in the homologous series, the melting and boiling points, t boil. isomers with a branched chain are lower than those of n-alkanes. All alkanes are lighter than water and practically do not dissolve in it; dissolve well in non-polar organic solvents($(C_2H_5)_2O$, CCl_4,benzene, etc.), and as M increases, solubility decreases.

Under normal conditions, alkanes are poorly reactive, resistant to the action of acids, alkalis, and oxidants, which is due to the high strength of C–C and C–H σ-bonds. C–C and C–H bonds are practically nonpolar and are not prone to heterolytic cleavage, but are capable of homolysis with the formation of free radicals, that is, alkanes are characterized by substitution reactions that proceed by the radical mechanism (S_R).

*Halogenation.*According to the reactivity with respect to alkanes, halogens are arranged in the following order: $F_2 > Cl_2 > Br_2$. The reaction with fluorine has the nature of an explosion and is accompanied by the breaking of C–C bonds. Therefore, special methods are used for fluorination of alkanes (for example, dilution of reagents with nitrogen). A less exothermic reaction of chlorination occurs under UV irradiation or heating by a free-radical mechanism:

$$CH_4 + nCl_2 \rightarrow CH_{4-n}Cl_n + nHCl \ (n = 1 – 4).$$

*Sulfochlorination.*It is carried out under UV irradiation, the reaction proceeds according to the SR radical mechanism:

$$R–H + SO2 + Cl2 \rightarrow R–SO2Cl + HCl.$$

The reaction of sulfochlorination is important in the production of SMZ.

*Nitration.*It is carried out by heating alkanes with diluted HNO3 at t ~ 140 ºC and increased pressure (M. I. Konovalov, 1888):

$$R–H + HNO3 \rightarrow R–NO2 + H2O.$$

As in the case of halogenation, hydrogen is preferably substituted for the tertiary carbon atom during nitration.

Oxidation of alkanes

Combustion:

$$CH4 + 2\ O2 \rightarrow CO2 + 2H2O\ (+ 882\ kJ/mol).$$

Catalytic oxidation. Flows in the presence of catalysts (manganese, chromium, lead salts, etc.) at 150-200°C with the formation of mainly carboxylic acids, aldehydes, ketones and alcohols, for example:

$$CH3–CH2–CH3 \xrightarrow{O_2} CH3COON + HCOOH + CH3CON + (CH3)2CO + CH3OH.$$

The oxidation reaction is used in industry to obtain methanol, formaldehyde, acetaldehyde and acetic acid from propane and butane, as well as higher fatty acids from alkanes with a chain length > $C_{25.}$

Cracking of alkanes

There is a distinction between thermal cracking (at t ≥ 800 ºC) and catalytic cracking (at t = 450 – 550 C in the presence of aluminosilicate catalysts), for example:

$$2CH4 \xrightarrow{1400–1500°C} HC{\equiv}CH + 3H2.$$

Higher alkanes under thermal cracking conditions decompose to form a complex mixture of lower alkanes and alkenes; the reaction proceeds by a radical mechanism.

During catalytic cracking (proceeds according to the ionic mechanism), the cleavage of C–C bonds is mainly accompanied by the isomerization of n-alkanes into branched chain alkanes:

$$CH3(CH2)4CH3 \rightarrow CH3–CH(CH3)–CH(CH3)–CH3 + (CH3)3CCH2CH3.$$

The cracking process has important industrial importance and is widely used to produce high-octane gasoline, unsaturated and aromatic hydrocarbons.

3. Cycloalkanes.

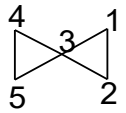
Cycloalkanes are called alicyclic hydrocarbons, in which all the carbon atoms forming the cycle are in the sp3-hybridized state.

Cycloalkanes are classified by the size of the ring, the number of rings and the way the rings are joined.

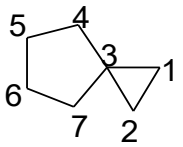
Cycloalkanes are distinguished by the size of the rings*small cycles*(3- and 4-membered), ordinary cycles (5-, 6- and 7-membered), medium cycles (8-11-membered) and macrocycles (12-membered and more).

Depending on the number of cycles included in the molecule, cycloalkanes are divided into*monocyclic, bicyclic and polycyclic.*

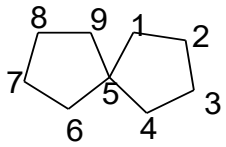
Bicyclic cycloalkanes are divided into spirans (two rings with a common C atom) based on the method of joining the rings.*condensed*(two rings with two common C atoms) and bridging (two rings with three or more common C atoms):



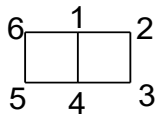
спиро [2,2] пентан



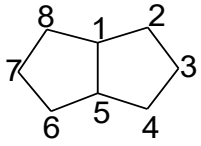
спиро [2,4] гептан



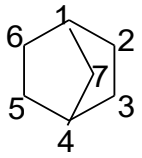
спиро [4,4] нонан



бицикло [2,2,0] гексан



бицикло [3,3,0] октан

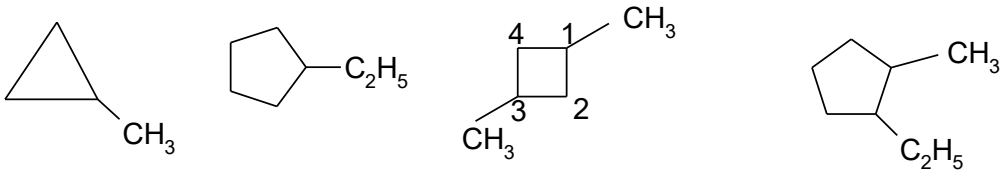


бицикло [2,2,1] гептан

In accordance with the rules of IUPAC, the names of monocyclic cycloalkanes are formed from the names of alkanes with the appropriate number of C atoms, adding the prefix cyclo-:

циклопропан циклобутан циклопентан циклогексан

The positions of the substituents in the ring are indicated by numbers: the numbering begins with the atom that has the substituent and is carried out in such a way that the other substituents receive possibly smaller numbers:



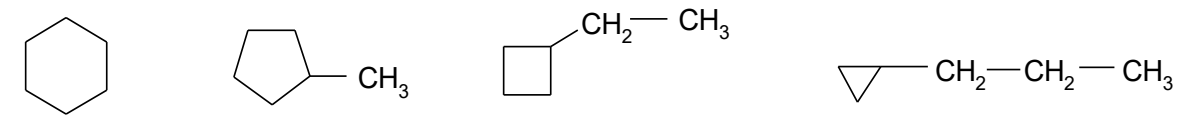
метилциклопропан этилциклопентан 1,3-диметилциклобутан 1-метил-2-этил-циклопентан

Isomerism

Cycloalkanes are characterized by structural, geometric, and optical isomerism.

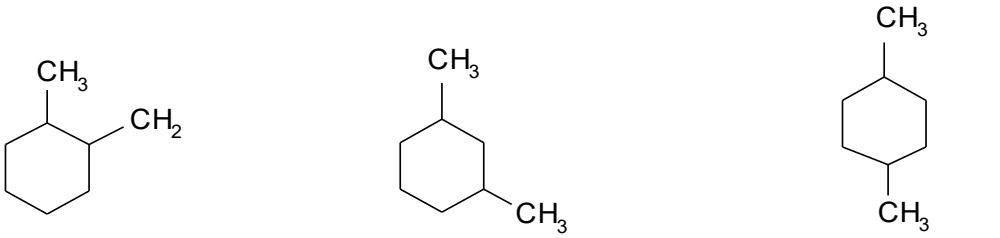
Structural isomerism can be caused by:

a) different size of the cycle:



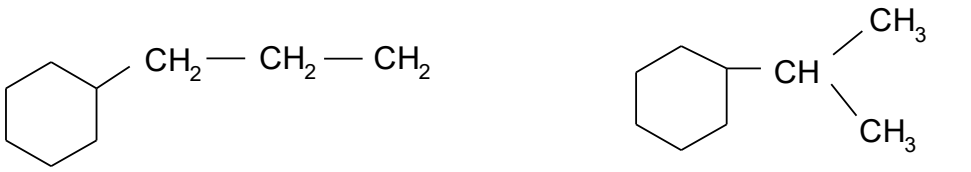
циклогексан метилциклопентан этилциклобутан пропилциклопропан

b) different positions of substituents in the cycle:



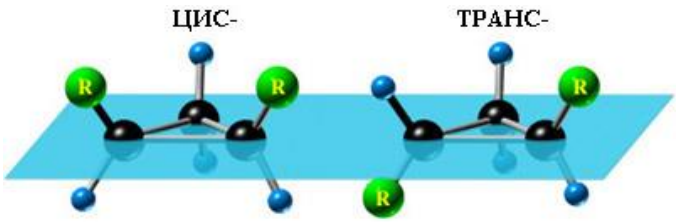
1,2-диметилциклогексан 1,3-диметилциклогексан 1,4-диметилциклогексан

c) different structure of side chains:

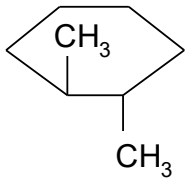


пропилциклогексан изопропилциклогексан

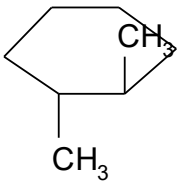
Geometric isomerism caused by different positions of substituents relative to the cycle plane:



Optical isomerism is characteristic of cycloalkanes, the molecules of which do not have a plane of symmetry, in particular, in the cyclohexane series, this is the case with the 1,2- and 1,3-trans position of the substituents:



транс-1,2-диметилциклооксан



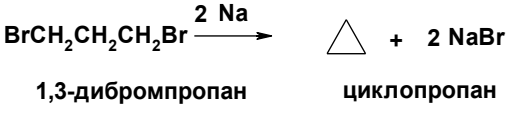
транс-1,3-диметилциклогексан

Methods of obtaining

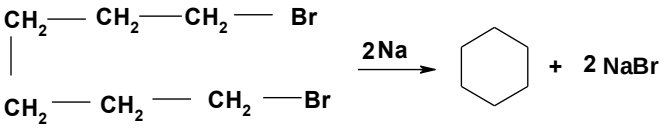
Individual cycloalkanes (cyclopropane, cyclohexane and their homologues) can be isolated from some types of oil.

Synthetic methods of obtaining

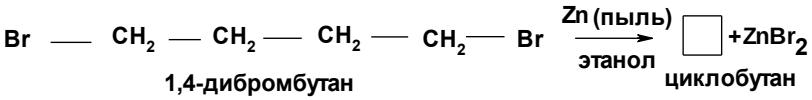
1. Interaction of α, ω-dihaloalkanes with metallic sodium or zinc:



1,3-дибромпропан — циклопропан

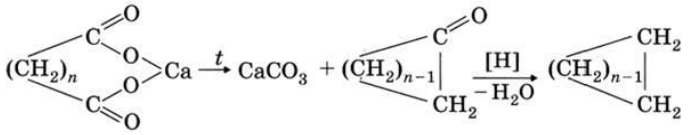


1,6-дибромгексан — циклогексан

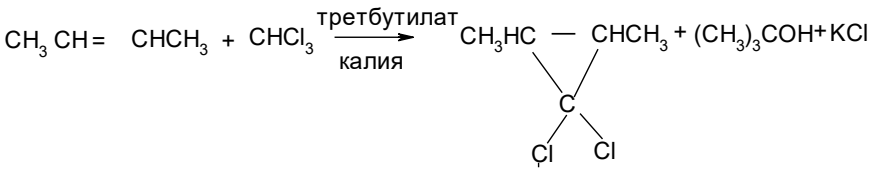


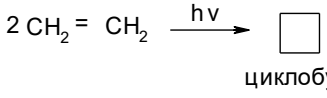
1,4-дибромбутан — циклобутан

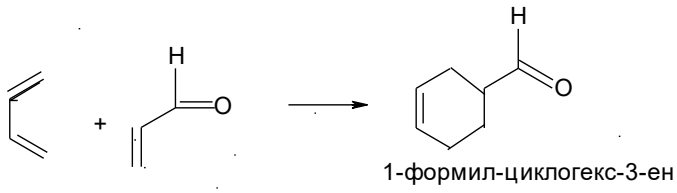
2. Pyrolysis of salts of dicarboxylic acids:



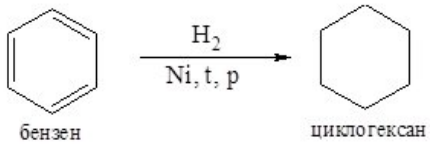
3. Cycloaddition reactions:





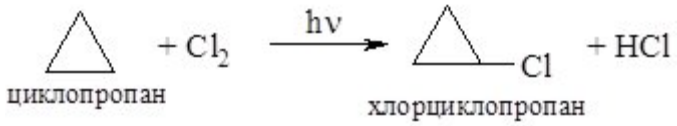


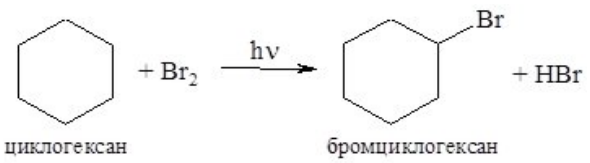
4. Cyclohexane can be obtained by hydrogenation of benzene:

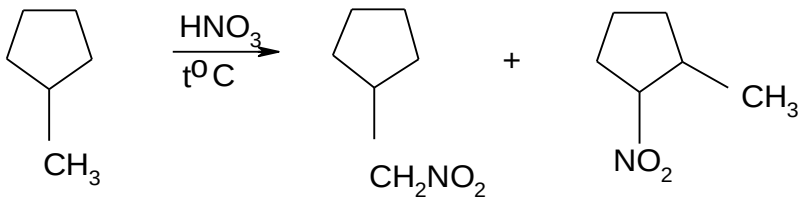


Chemical properties

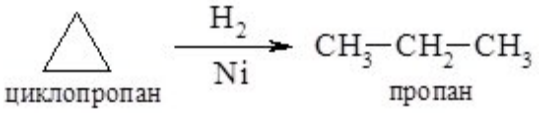
Chemically, cycloalkanes behave in many ways like alkanes, in particular, they are characterized by substitution reactions from the radical S_R-mechanism:

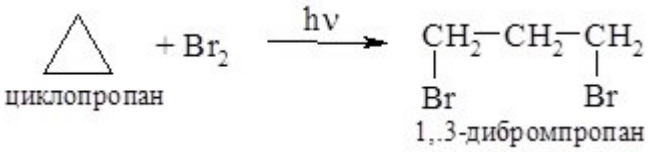




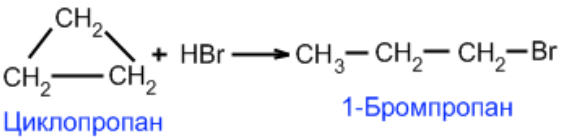


Along with this, cycloalkanes with small rings (3-, 4-membered), unstable due to angular and torsional stresses, enter into addition reactions with opening of the ring:





Гидрогалогенирование:



4. Alkenes.

Aliphatic hydrocarbons containing one double bond are called alkenes. The general formula of alkenes is СПН2п.

Other names are ethylene hydrocarbons, olefins (that is, those that form oils - a historically formed name, since lower homologues of this group of compounds form oily liquids when interacting with chlorine or bromine).

Nomenclature

According to the rules of IUPAC, the names of alkenes are formed from the names of the corresponding alkanes with the suffix -an replaced by -en and the position of the double bond in the chain of carbon atoms indicated. For example, ethene, propene, butene-1, etc.

Isomerism

Alkenes are characterized by structural and geometric isomerism. Structural isomerism is due to isomerism of the chain and isomerism of the position of the double bond:

CH2=CH–CH2–CH3 CH3–C=CH2 CH3–CH=CH–CH3

butene-1 ı 2-methylpropene butene-2

CH3

In addition, geometric or cis-, trans-isomerism occurs in a number of alkenes. For example, butene-2 can exist as*cis*-butene-2 and trans-butene-2.

Methods of obtaining

Alkenes can be obtained by thermal cracking of alkanes. Basically, the methods of synthesis of alkenes are based on the elementalization of atoms (atomic groups) from molecules of alkanes, haloalkanes and alcohols.

1. Dehydration of saturated alcohols:

$CH3CH2OH \xrightarrow{H2SO4,t} CH2=CH2 + H2O.$

$SN_3CH2CH2OH \xrightarrow{Al2O3,t} CH3–CH=CH2 + H2O.$

2. Dehydrohalogenation of monohaloalkanes:

$CH3CH2CH2Br \xrightarrow{NaOH\ ,cnupm} CH3–CH=CH2 + NaBr + H2O.$

3. Dehalogenation of dihalides:

$SN_3–CHBr–CHBr–CH3 + Zn \rightarrow CH3–CH=CH–CH3 + ZnBr2.$

4. *Dehydrogenation of alkanes*(industrial method, t = 300 – 500 ºC, Ni catalysts,Cr2O3etc):

$CH3–CH2–CH3 \xrightarrow{Ni} CH3–CH=CH2 + H2.$

5. *Selective hydrogenation of alkynes*(in the presence of catalysts with reduced activity – Fe, deactivation of Pd, Pt, etc.):

R–C≡C–R + H2→R–CH=CH–R.

Physical and chemical properties

Similarly to alkanes, the first four representatives of the homologous series of alkenes with n. in. - gases, S_5– C17 – liquids, > C17 – solids.

All alkenes are practically insoluble in water,dissolve well in organic solvents. The boiling points of n-alkenes are generally higher than their branched-chain isomers. Cis isomers generally have higher boiling points and lower melting points than trans isomers.

The specificity of the reactivity of alkenes is determined by the presence of a double –C=C– bond in their structure. Alkenes relatively easily participate in addition reactions, which in most cases follow an ionic mechanism (electrophilic addition reactions of AE).

At the 1st stage, the electrophilic reagent $X_{\delta+}$→Uδ– forms a π-complex with an alkene, which then turns into a carbocation; at the 2nd stage, the carbocation interacts with the nucleophilic part of U– released from the electrophilic reagent and the final addition product is formed:

>C=C< + Xδ+→Уδ–⇄ >C=C< → >C–C+< + У–

↓ ׀

Xδ+→Уδ– X carb cation

>C–C+< + У– → >C–C<

׀ ׀

X X

*Addition of halogens (halogenation).*Alkenes relatively easily add chlorine and bromine to a double bond, iodine is more difficult to form dihalogen derivatives containing halogen atoms at neighboring C atoms:

SN_2=CH2 + Br2 → CH2Br–CH2Br.

Addition of hydrogen halides:

CH2=CH2 + HBr → CH3–CH2–Br.

The reactivity of hydrogen halides with respect to alkenes increases in the following order: HF < HCl < HBr < HI.

Markovnikov's rule(1869): during the interaction of hydrogen halides and related compounds with unsymmetrical alkenes, a hydrogen atom joins a double bond to a more hydrogenated carbon atom.

Example:

CH3–C(CH3)=CH2 + HBr → CH3–C(CH3)Br–CH3.

Deviations from Markovnikov's rule are observed in cases where the addition of hydrogen halide is carried out by a free radical mechanism (for example, in the presence of peroxides).

Addition of concentrated sulfuric acid:

CH3–CH=CH2 + H2SO4 → CH3–CH–CH3.

| isopropyl ether

OSO3H of sulfuric acid

When heated with water, monoalkyl sulfates form alcohols:

CH3–CH–CH3 + H2O → CH3–CH(OH)–CH3 + H2SO4.

|

OSO3H

In industry, this reaction is used to produce ethanol and isopropanol.

*Addition of water (hydration).*In the presence of mineral acids, alkenes add water to form the corresponding alcohols. The reaction is subject to Markovnikov's rule:

(CH3)2C=CH2 + H2O → (CH3)3COH.

*Addition of hypohalic acids.*Alkenes join HOX (X = Cl, Br, I) with the formation of halohydrins; joining is carried out according to the Markovnikov rule:

CH3–CH=CH2 + HOCl → CH3–CH(OH)–CH2Cl.

Reduction and oxidation reactions

Alkenes are hydrogenated in the presence of catalysts (Pd, Pt, Ni) to form alkanes:

$$CH_3–CH=CH_2 + H_2 \rightarrow CH_3–CH_2–CH_3.$$

*Oxidation of alkenes.*A dilute aqueous solution of $KMnO_4$ in a neutral or alkaline medium oxidizes alkenes to glycols (E. E. Wagner, 1888):

$$3CH_2=CH_2 + 2KMnO_4 + 4H_2O \rightarrow 3CH_2(OH)–CH_2(OH) + 2KOH + 2MnO_2.$$

*Ozonation of alkenes*leads to addition products - ozonides, the decomposition of which during treatment with $ZnCH_3COOH$is accompanied by the formation of aldehydes or ketones, depending on the structure of the alkene. The ozonation reaction is used to determine the position of the double bond.

Oxidation of alkenes with air oxygen and peroxyacids leads to the formation of epoxides:

$$2CH_2=CH_2 + O_2 \xrightarrow{Ag,300°C} 2CH_2–CH_2.$$

A

Polymerization of alkenes

Polymerization is the process of connecting molecules of low-molecular substances (monomers) with each other to form high-molecular compounds (polymers):

$$nCH_2=CH_2 \rightarrow (CH_2–CH_2)_n.$$

A polymer consisting of the same monomers is called a homopolymer, and a polymer consisting of two or more different monomers is called a homopolymer.*copolymer*.

The number of repeating monomer units n is called the degree of polymerization. The polymerization process is carried out in the presence of catalysts (initiators) and includes three main stages: chain nucleation (initiation), chain growth, and chain breakage.

Polymerization of alkenes can occur by radical and ionic (cationic) mechanisms. If*radical polymerization*initiators are peroxide compounds (acetyl, benzoyl peroxides, etc.), cationic polymerization is initiated by Brønsted or Lewis acids (AlCl3, BF3, etc.).

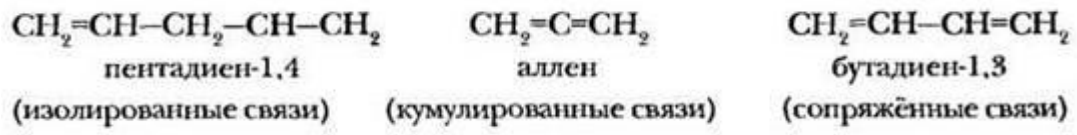
*Coordination polymerization*occurs in the presence of complex organometallic catalysts (Ziegler-Natta catalysts, for example Al(C2H5)3•TiCl4).

5. Alkadienes.

Aliphatic hydrocarbons containing two double bonds are called alkadienes.
General formula of alkadienes*CnH2n–2*.

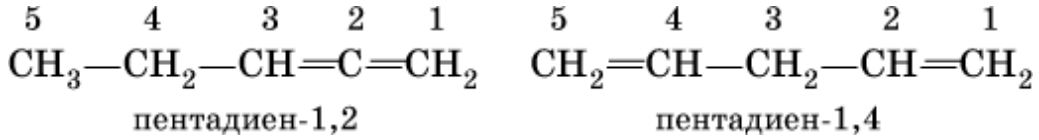
According to the mutual arrangement of double bonds in the molecule, three main types of alkadienes are distinguished.

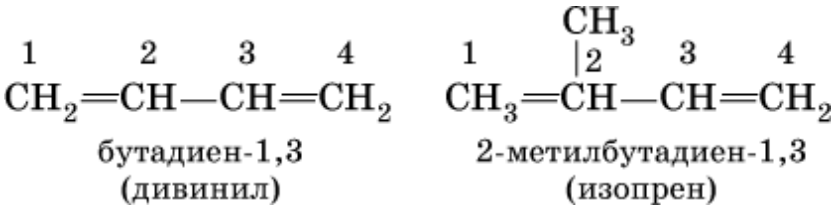
1. With cumulated double bonds (allenes);
2. With conjugated double bonds;
3. With isolated double bonds:



Nomenclature

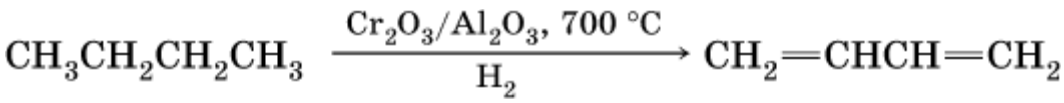
According to the IUPAC nomenclature, the names of alkadienes are formed similarly to alkenes, the presence of two double bonds is indicated by the suffix -diene indicating the position of each of them in the main carbon chain, for example:



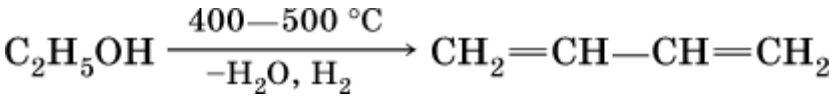


Methods of obtaining

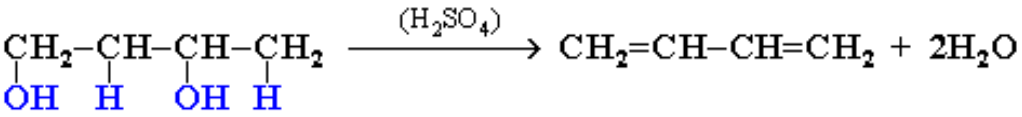
1. *Catalytic dehydrogenation of alkanes:*



2. *Synthesis of butadiene-1,3 (S. V. Lebedev, 1928):*

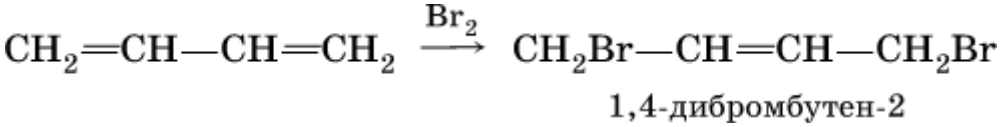


3. *Dehydration of diols (glycols):*

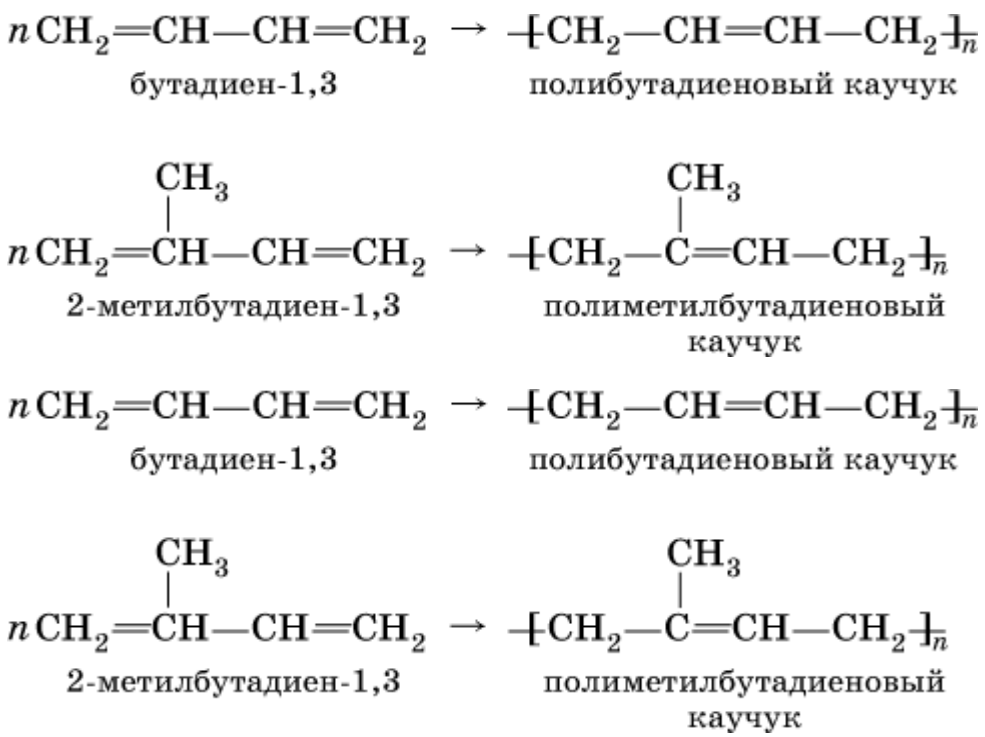


Chemical properties

Alkadienes with conjugated bonds, like alkenes, are characterized by addition and polymerization reactions. However, conjugated dienes show higher reactivity compared to alkenes, and, in addition, in electrophilic addition reactions, two products are most often formed - as a result of 1,2-addition (at the site of the double bond) and 1,4-addition (at the ends connected system):

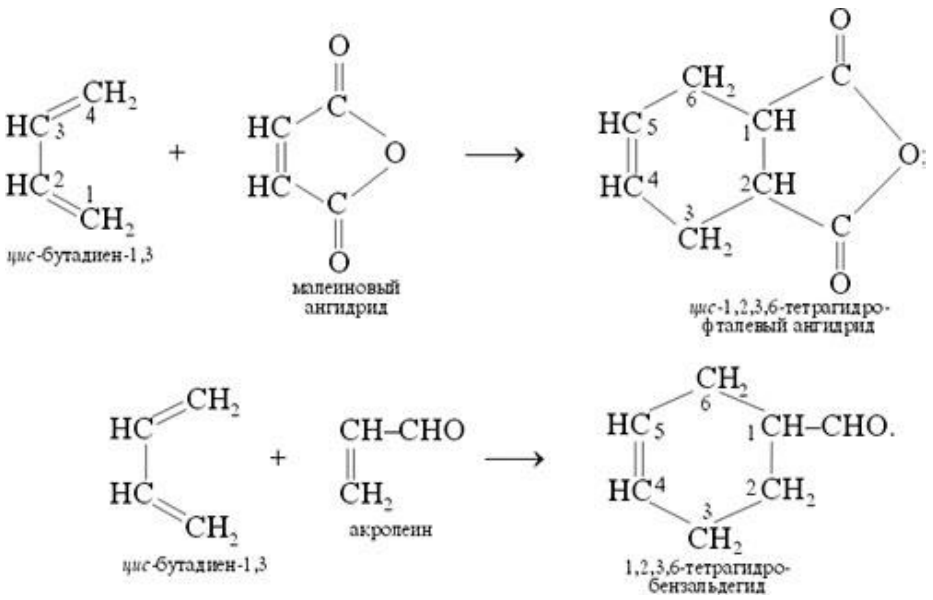


Polymerization reactions of dienes with conjugated bonds lead to synthetic analogues of natural rubber, cis-polyisoprene, which have different physicochemical characteristics:



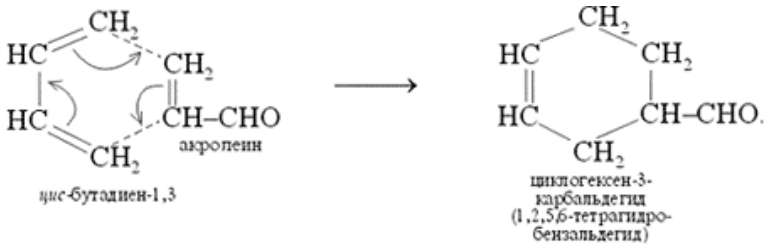
For the first time, synthetic rubber based on 1,3-butadiene was obtained in the USSR in 1932 by S. V. Lebedev.

Diels-Alder reaction (diene synthesis). Conjugated dienes interact with substances containing a double or triple C–C bond to form cyclic structures. This reaction is especially easy with dienophiles containing an activated double bond (when the double bond is combined with an electron-accepting or electron-donating group: CN, NO2, CHO, COR, COOH, COOR, OR, etc.):



This reaction belongs to the [4 + 2]-cycloaddition reactions, as it involves the 4π-electron system of the diene and the 2π-electron system of the dienophile. Diene synthesis is widely used for the synthesis of polycyclic compounds, including biologically active compounds.

The Diels-Alder reaction mechanism involves the simultaneous breaking of multiple π-bonds and the formation of new –σ-bonds and π-bonds:



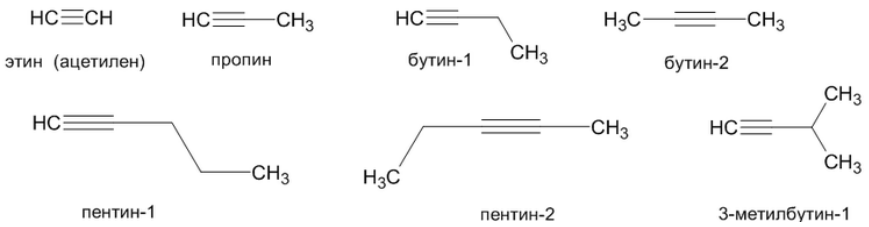
6. Alkynes.

Aliphatic hydrocarbons containing one triple bond are called alkynes. The general formula of alkyneCnH2n–2.

The simplest representative of this series of compounds is acetylene C2H2, which is why alkynes are also called acetylene hydrocarbons.

Nomenclature and isomerism

According to the IUPAK nomenclature, the names of alkyne are formed from the names of the corresponding alkanes with the replacement of the suffix -an with -in indicating the position of the triple bond of the chain of carbon atoms:



Along with the IUPAC nomenclature, rational names are often used for the simplest hydrocarbons, considering them as derivatives of acetylene, in which hydrogen atoms are replaced by hydrocarbon radicals:

CH3–C≡CH CH3CH2–C≡CH CH3–C≡C–CH3

methylacetylene ethylacetylene dimethylacetylene

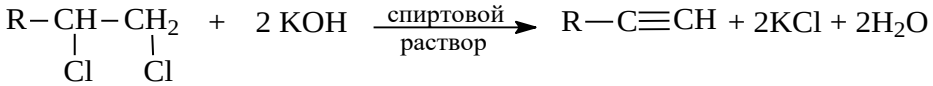
Alkynes are characterized by structural isomerism caused by a different structure of the carbon chain (chain isomerism) and a different position of the triple bond (positional isomerism):

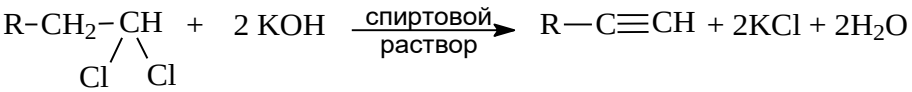
CH3–CH(CH3)–C≡CH CH3–CH2–CH2–C≡CH CH3–C≡C–CH2–CH3

3-methylbutyn-1 pentyne-1 pentyne-2

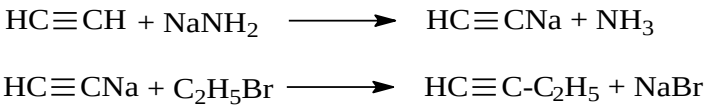
Methods of obtaining

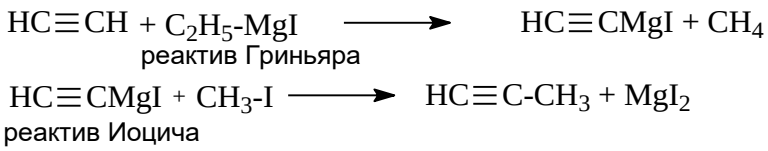
1. Dehydrohalogenation of vicinal and geminal dihaloalkanes:



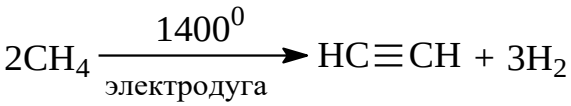


2. Alkylation of acetylene:





3. Production of acetylene from methane (industrial method):

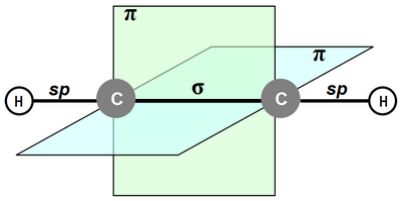


4. *Production of acetylene from calcium carbide (industrial method):*

Physical and chemical properties

The first three members of the series are gases, C5 - C15 - liquids, starting with C16 - solids.

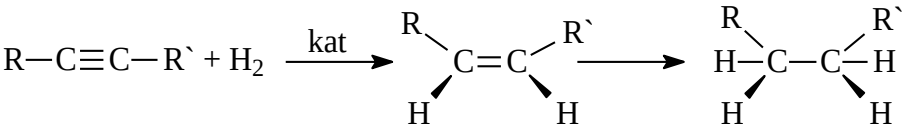
The reactivity of alkynes is determined by the presence of a triple –C≡C– bond in their structure:



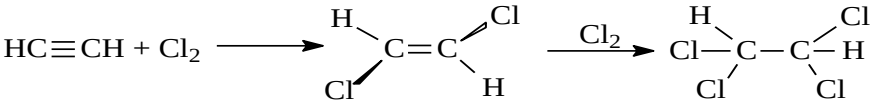
Alkynes, like alkenes, are characterized by electrophilic addition reactions due to the breaking of π-bonds, but alkynes are somewhat less active in such reactions. Alkynes with a terminal triple bond R–C≡CH have a weak CH acidity and are capable of substituting a hydrogen atom for metals and other groups.

Reactions of electrophilic addition

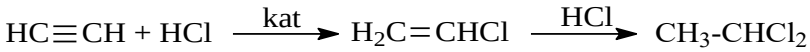
Hydrogenation:



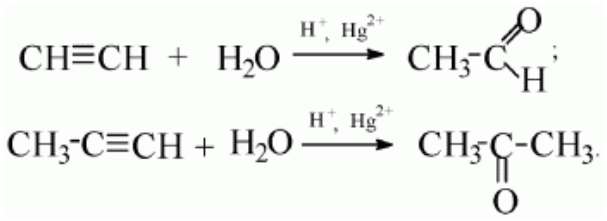
Halogenation:



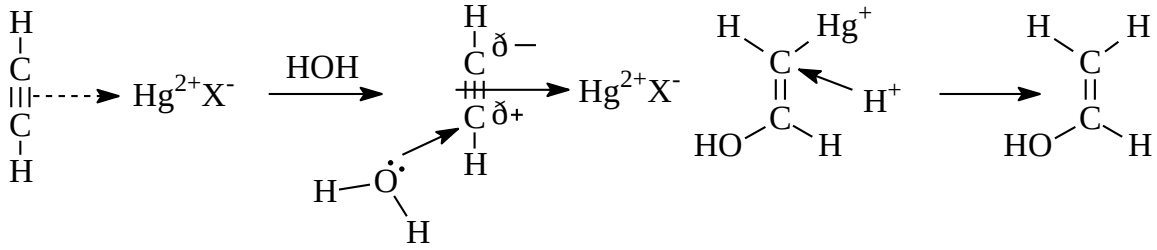
Hydrohalogenation (follows Markovnikov's rule):



Hydration (Kucherov reaction, 1881, an industrial method of obtaining acetaldehyde):

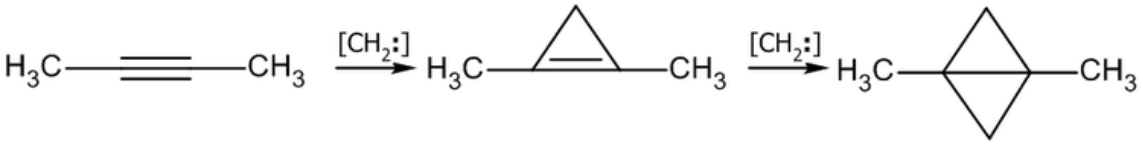


The probable mechanism of the Kucherov reaction:



The intermediate products of the reaction are unsaturated alcohols with a hydroxyl at the C-atom double bond, unstable and isomerized into carbonyl compounds (aldehydes, ketones). This regularity was called Eltekov's rule (1877).

Addition of carbynes to alkynes (radical addition):



Substitution reactions

Characteristic of acetylenes with a terminal triple bond R–C≡CH, reactions with silver and copper ammonias are qualitative for the presence of a terminal triple bond (silver salts – white precipitates, copper – yellow or red precipitates):

$$CH_3–C\equiv CH + Ag(NH_3)_2OH \rightarrow CH_3–C\equiv C–Ag\downarrow + 2NH_3 + H_2O$$

$$CH_3–C\equiv CH + Cu(NH_3)_2OH \rightarrow CH_3–C\equiv C–Cu\downarrow + 2NH_3 + H_2O$$

$$HC\equiv CH + 2Cu(NH_3)_2OH \rightarrow 2Cu–C\equiv C–Cu\downarrow + 4NH_3 + 2H_2O$$

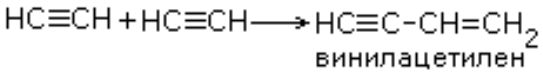
Oxidation and reduction reactions

$$SN_3–CH2–C\equiv C–CH3 \xrightarrow{KMnO_4,OH^-} CH3–CH2–COOH + CH3–COOH.$$

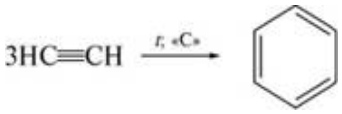
$$SN_3–CH2–C\equiv CH \xrightarrow{KMnO_4,OH^-} CH3–CH2–COOH + CO2.$$

$$SN_3–C\equiv CH \xrightarrow{H_2,Ni} CH3–CH=CH2 \xrightarrow{H_2,Ni} CH3–CH2–CH3.$$

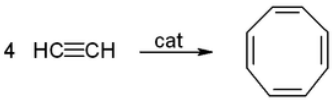
*Dimerization, trimerization and tetramerization of alkynes*The dimerization reaction of acetylene in the presence of CuCl and NH4Cl is of important industrial importance (vinyl acetylene is a semi-product in the production of synthetic rubber):



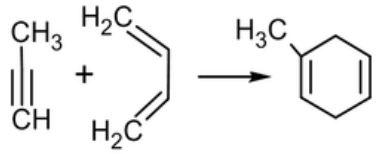
Cyclotrimerization of alkynes in the presence of activated carbon or complex organo-nickel catalysts leads to benzene and substituted benzenes:



Cyclotetramerization of acetylene in the presence of Ni(CN)2 leads to cyclooctatetraene:



An important feature of alkynes is their ability to undergo the Diels-Alder reaction:



» bases, and "soft" acids - with "soft" bases (principle of ЖМКО).

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control:

1.Classification of hydrocarbons (acyclic (aliphatic), alicyclicand aromatic).

2. Alkanes (nomenclature, isomerism, structure, production methods, chemical and physical properties, reactivity).

3. Cycloalkanes (nomenclature, isomerism, structure, production methods, chemical and physical properties, reactivity).

4. Alkenes (nomenclature, isomerism, structure, production methods, physical and chemicalproperties, reactivity).

5. Alkodienes (nomenclature, isomerism, structure, production methods, physical and chemicalproperties, reactivity).

6. Alkynes (nomenclature, isomerism, structure, production methods, physical and chemicalproperties, reactivity).

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1. Chernykh V.P., Zimenkovskyi B.S., Hrytsenko I.S. Organic chemistry: In 3 books/ Ed. V.P. Chernykh - Kharkiv.: View of the NfaU; Original, 2008. – 752 p.

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Lecture No. 5

Topic: Halogen derivatives of hydrocarbons. Halogen-alkanes. Haloalkenes.Halogenarenes and arylalkyl halides.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical halogenated hydrocarbons.

Basic concepts: Halogenalkanes. Halogenalkenes. Aromatic halogen derivatives.

Plan and organizational structure of the lecture:

1. Halogenalkanes.

2. Halogenalkenes.

3. Aromatic halogen derivatives.

Content of lecture material (lecture text)

Halogen derivatives of hydrocarbons are products of substitution of one or more hydrogen atoms by halogen atoms in hydrocarbons.

Depending on the nature of the hydrocarbon radical, halogen derivatives are divided into aliphatic,

alicyclic, aromatic. Among the aliphatics, saturated (haloalkanes) and unsaturated (haloalkenes, haloalkynes) are distinguished. Aromatic halogen derivatives are divided into haloarenes (the halogen atom is directly connected to the aromatic nucleus) and arylalkyl halides (the halogen atom is in the side chain). According to the number of halogen atoms in the molecule, mono-, di-, tri-, and polyhalo derivatives of hydrocarbons are distinguished.

According to the substitute nomenclature of IUPAC, the names of halogenated hydrocarbons are composed by adding the name of the parent structure to the name of the halogen atoms. The main carbon chain is taken as the parent structure in aliphatic halogen derivatives, and the cycle in alicyclic and aromatic ones.

Isomerism

Halogenated hydrocarbons are characterized by structural, geometric and optical isomerism.

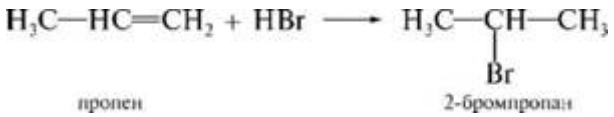
1. Halogenalkanes.

Methods of obtaining

1. *Halogenation of alkanes*(with UV irradiation, chloro- and bromoalkanes are obtained by this method):

CH4 + nCl2 → CH4–nCln + nHCl (n = 1 – 4).

2. *Addition of hydrogen halides to alkenes*(you can get fluoro-, chlorine-, bromo-, iodoalkanes):



3. *Getting from*alcohols:

3C2H5OH + PCl3 → 3C2H5Cl + H3POC

3C2H5OH + PCl5 → 2 HC5Cl + POCl3 + HCl C

C2H5OH + SOCl2 → 2 HC5Cl + SO2↑ + HCl ↑.

4. *Interaction of haloalkanes with salts of hydrohalic acids*(Finkelstein's reaction, usually used to obtain iodalkanes):

C2H5Br + NaI $\xrightarrow{ацетон}$ C2H5I + NaBr.

5. *Preparation of perfluoroalkanes by direct fluorination*alkanes:

C2H6 + F2 $\xrightarrow{N_2,64°C}$ C2F6 (83%).

*6.*Preparation of perfluoroalkanes by fluorination of alkanes using CoF3 and KCoF4:

C7H16 $\xrightarrow{CoF_3,150–300°C}$ C7F16 (91%).

Physical and chemical properties

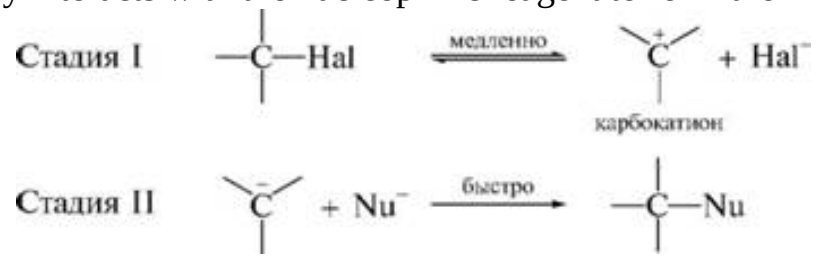
Under normal conditions, lower haloalkanes are colorless gases or liquids with a peculiar sweet smell, medium ones are liquids, and higher ones are solid substances. The boiling point increases with an increase in the atomic mass of the halogen, the number of halogen atoms (with the exception of fluorine derivatives) and the length of the carbon chain of the molecule. Some of the haloalkanes are good solvents; many have a narcotic effect.

Nucleophilic substitution reactions are most typical for haloalkanes(SN)and splitting(IS).Depending on the structure of haloalkanes, the nature of the nucleophile and the solvent, nucleophilic substitution reactions proceed according to two main mechanisms:$\boldsymbol{S_N2}$(bimolecular nucleophilic substitution)$\boldsymbol{S_N1}$(monomolecular nucleophilic substitution).

By mechanismS_N2 the reaction proceeds in one stage through a trigonal-bipyramidal transition state, which is formed from a haloalkane molecule and a nucleophilic reagent:

It is important when implementing the mechanismS_N2 have steric effects of the substituents at the carbon atom connected to the halogen (difficulty in the formation of the transition state due to spatial obstacles), so according to the mechanismS_N2 primary and somewhat more difficult - secondary alkyl halides react easily. Tertiary derivatives do not participate in the substitution reaction according to the specified mechanism. Another important factor is the nucleophilicity of the reagent: the higher the nucleophilicity, the easier the reaction proceeds according to the mechanismS_N2.

By mechanismS_N1 the reaction proceeds in two stages: in the first stage, ionization of the haloalkane molecule occurs with the formation of a carbocation and halide ion (determines the reaction rate), in the second stage, the formed cation quickly interacts with the nucleophilic reagent to form the final reaction product:



To the factors contributing to the course of the reaction according to the mechanismS_N1**,**include the ability of the compound to form stable carbcations and the high ionizing and solvating ability of the solvent. By mechanism$S_N1$nucleophilic substitution occurs under theoretical conditions and under certain conditions - in secondary haloalkanes.

Halogenalkanes enter into a variety of nucleophilic substitution reactions, many with

which have important synthetic value.

*Hydrolysis*haloalkanes:

C2H5Br + H2O⇄ C2H5OH + HBr,

WITH$_2$H5Br + NaOH → C2H5OH + NaBr.

*Interaction with alcoholates and phenolates (reaction*Williamson):

C2H5Br + C2H5OHa → C2H5–O–C2H5 + NaBr,

WITH$_2$H5Br + C6H5OHa → C2H5–O–C6H5 + NaBr.

*Interaction with carboxylic salts*acids:

2 HC5Br + CH3COONa → CH3COOS2H5 + NaBr.

*Interaction with ammonia, alkyl- and*arylamines:

C2H5Br + NH3 → [C2H5NH3]+Br– $\xrightarrow{+NH_3}$ C2H5NH2 + NH4Br.

*Interaction with cyanide salts*acids:

2 HC5Br + NaCN → 2 HC5-C≡N + NaBr.

Interaction with salts of nitric acid:

C2H5Br + NaNO2 → C2H5–NO2 + NaBr.

Interaction with salts of hydrohalic acids (Finkelstein reaction- is of practical importance for obtaining primary fluoro- and iodoalkanes from more available chloro-bromo derivatives).

*Interaction with hydrosulfide and alkali sulfides*metals:

2 HC5I + NaSH → 2 HC5SH + NaI,

2C2H5I + Na2S → 2 HC5-S-C2H5 + 2NaI.

Schedule reaction

CH3–CH2–Cl $\xrightarrow{NaOH\ ,cnupm}$ CH2=CH2 + NaCl + H2O.

Interaction with metals

Obtaining Grignard reagents:

C2H5Cl + Mg $\xrightarrow{(C_2H_5)_2O}$ C2H5MgCl.

2. Halogenalkenes.

Alkene derivatives in which one or more hydrogen atoms are replaced by halogen atoms are called haloalkenes.

According to the mutual location of the double bond and the halogen atom, haloalkyls can be conditionally divided into three groups:

1. *Vinyl halides*- compounds containing a halogen atom in carbon, which forms a double bond:

CH2 = CH-Cl CH3-CH = CH-Br CH2 = CCl-CH3
vinyl chloride 1-bromopropene 2-chloropropyl

2. *Allyl halides*- compounds in which the halogen atom is in the α-position to carbon, a double bond is formed:

CH2 = CH-CH2-Cl CH3-CHCl-CH = CH2
allyl chloride 3-chlorobutene-1

3. Compounds in which a halogen atom and a carbon atom, which forms a double bond, are separated by two simpler C-C bonds:

CH2= CH-CH2-CH2-Br CH3-CH = CH-CH2-CH2-Cl
4-bromobutene-1 5-chloropentene-2

Methods of obtaining

*Hydrohalogenation*Alkynov:

HC≡CH + HCl → CH2= CH-Cl.

*Halogenation of alkenes into allylic ones*position:

$CH_2=CH–CH_3 + Cl_2 \xrightarrow{500–600°C} CH_2=CH–CH_2Cl + HCl.$

*Action of halogenating agents*reagents (PCl3, PCl5, SOCl2) to unlimited alcohols:

CH2=CH–CH2–OH + PCl3 → CH2=CH–CH2–Cl + POCl3 + HCl.

Chemical properties

The reactivity of haloalkenes largely depends on the mutual location of the double bond and the halogen atom in the molecule: if they are far enough from each other (separated by two or more C-C bonds), then each of these groups behaves independently of each other . At the same time, due to the mutual influence of C=C and C-Hal bonds, vinyl halides are characterized by low reactivity: addition reactions of electrophilic reagents and reactions of nucleophilic halogen substitution are more difficult. The addition of hydrogen halides follows Markovnikov's rule:

CH2=CH–Cl + HCl → CH3–CHCl2.

In the presence of catalysts, vinyl halides are easily polymerized, which is used in the production of polymeric materials:

nCH2=CH–Cl → (–CH2–CHCl–)n.

Allyl halides undergo nucleophilic substitution reactions more easily than haloalkanes, which is explained by their tendency to ionize with the formation of a very stable allyl cation:

CH2=CH–CH2Br⇄ CH2=CH–CH2+ + Br–.

The addition of hydrogen halides to allyl halides follows Markovnikov's rule:

CH2=CH–CH2–Cl + HCl → CH3–CHCl–CH2Cl.

3. Aromatic halogen derivatives.

Aromatic halogen derivatives are derivatives of aromatic hydrocarbons in which one or more hydrogen atoms are replaced by halogen atoms.

Depending on the position of the halogen atoms, aromatic halogen derivatives are divided into haloarenes - compounds in which the halogen atoms are directly connected to the aromatic nucleus, and arylalkyl halides - compounds containing halogen atoms in the side chain.

Methods of obtaining

Two methods of obtaining haloarenes are most often used:

Direct halogenation of aromatic hydrocarbons(mechanism$\boldsymbol{S_E}$, with an excess of halogen, di- and trihalogenarenes are formed):

$$C_6H_6 + Cl_2 \xrightarrow{FeCl_3} C_6H_5–Cl + HCl.$$

*Substitution of the diazo group in aryldiazonium salts by a halogen (reaction*Sandmeyer):

$$[C_6H_5–N^+\equiv N]Cl^- \xrightarrow{CuCl_2} C_6H_5–Cl + N_2.$$

To obtain aryl fluorides, the Schiemann reaction is usually used, which is a halogen substitution reaction with the participation of aryl halides activated by electron-withdrawing groups of the -NO2 type.

Shiman's reaction(one of the most convenient and common methods of obtaining aryl fluorides):

$$C6H5–NH2 \xrightarrow{NaNO_2+HX} [C6H5–N+\equiv N]X– \xrightarrow{NaBF_4} [C6H5–N+\equiv N]BF4– \xrightarrow{t}$$

$$WITH_6H5–F + BF3\uparrow.$$

Substitution of halogens(carried out in an environment of aprotic polar solvents):

$$n\text{-}O2N–C6H4–Cl \xrightarrow{KF} p\text{-}O2N–C6H4–F.$$

*Halogenation*alkylarenes Halogenation of the side chain of alkylarenes is carried out without a catalyst at high temperature or UV irradiation - mechanism$\boldsymbol{S_R}$:

$$C6H5–CH3 + Cl2 \xrightarrow{h\nu} C6H5–CH2Cl + HCl.$$

*Chloromethylation reaction*used to obtain arylmethyl chlorides:

$$WITH_6H6 + CH2O + HCl \rightarrow C6H5–CH2Cl + H2O.$$

Physical and chemical properties

Aryl halides are liquids or crystalline substances. Boiling temperatures increase in a number of fluorine, chlorine, bromine, and iodine derivatives. All aryl halides are not soluble in water, but easily dissolve in organic solvents. Halogen derivatives with a halogen atom in the α-position of the side chain have an irritating effect on mucous membranes, causing lacrimation.

Aryl halides are characterized by nucleophilic substitution reactions involving the C-Hal reactions of electrophilic substitution on the aromatic nucleus and reactions with metals.

Nucleophilic substitution reactions

Reactions of nucleophilic substitution of the halogen directly connected to the benzene ring occur under harsh conditions due to the combination of the NEP of the halogen with the π-electron system of the ring:

$$C6H5–Cl + NaOH \xrightarrow{300°C,150amu} C6H5–OH + NaCl.$$

$$WITH_6H5–Cl + 2NH3 \xrightarrow{300°C,Cu} C6H5–NH2 + NH4Cl.$$

The mobility of the halogen atom in aryl halides increases sharply in the presence of strongly electronegative substituents in the ortho- or para-position to the halogens, for example,NO2, CN, COOH, SO3H.

Reactions of electrophilic substitution on the aromatic nucleus

$$C6H5–Cl + HNO3 \xrightarrow{H_2SO_4} o\text{-}, p\text{-}O2N–C6H4–Cl + H2O,$$

$$WITH_6H5–Cl + H2SO4 \rightarrow o\text{-}, p\text{-}HO3S–C6H4–Cl + H2O.$$

Metallization reactions

Obtaining Grignard reagents:

$$C6H5Cl + Mg \xrightarrow{(C_2H_5)_2O} C6H5MgCl.$$

In the reaction with sodium, an organometallic compound is formed as an intermediate product (Wurtz-Fittig reaction):

$$C6H5Br + 2Na \rightarrow C6H5Na + NaBr,$$

$$WITH_6H5Na + C6H5Br \rightarrow C6H5–C6H5 + NaBr.$$

Individual representatives of halogenated hydrocarbons

Chloroethane(Ethyl chloride) C2H5Cl is a low-boiling liquid (boiling point 12 ºC), has a strong narcotic effect. Upon contact with the skin, due to rapid evaporation, it causes strong cooling of the skin area and loss of pain sensitivity, which allows the use of chloroethane in medicine for local anesthesia.

Chloroform(trichloromethane) CHCl3 is a colorless liquid with a characteristic sweet smell (boiling point 61.2 ºC). It is widely used as a solvent and extractant. It has a strong narcotic effect. Previously, it was used in medicine to enhance the effect of nitrous oxide in combined inhalation anesthesia, but it is not used at present due to its high toxicity.

Iodoform(triiodomethane) CHИ3 - a crystalline substance of lemon-yellow color with a sharp characteristic smell (bp. 116 ºC). Iodoform is traditionally used as an antiseptic agent in dentistry, as well as in the form of powders and ointments for the treatment of infected wounds and ulcers.

FluoroethaneCФ3-CNBrCl is a colorless, mobile liquid with an odor resembling the smell of chloroform (b.p. 49 - 51 ºC). It has a strong narcotic effect and low toxicity. It is widely used in medical practice as a means for combined inhalation anesthesia.

Difluorodichloromethane(freon-12) CF2Cl2 - under normal conditions, an odorless gaseous substance, non-flammable, non-explosive, non-toxic, does not cause metal corrosion. It is used as a refrigerant in refrigeration units, as well as as a propellant in the production of aerosol medicines and cosmetics. In recent years, the

use of freon-12 for these purposes has been limited due to the problem of the destruction of the ozone layer.

Difluorochlorobromethane, difluorodibromoethane CF2ClBr, CF2Br2 - fire extinguishers.

ChlorobenzeneC6H5Cl is a colorless liquid with a peculiar smell (boiling point 132 ºC). It is used in the production of phenol, aniline, and medicines.

5. Materials for students' activation during the lecture

Question:

1. Halogen derivatives of hydrocarbons.
2. Production methods, physical and chemical properties, reactivity and recovery

haloalkanes.

3.Production methods, physical and chemical properties, reactivity

haloalkenes.

4.Methods of obtaining, physicochemical properties, reactivity of aromatic halogen derivatives.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

and). on the topic of the lecture;

1. Halogenalkanes.

2. Methods of obtaining,physical and chemicalproperties, reactivityand recovery.

3. Halogenalkenes.

4. Methods of obtaining,physical and chemicalproperties, reactivity.

5. Aromatic halogen derivatives.

6. Methods of obtaining,physical and chemicalproperties, reactivity.

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Lecture No. 6

Topic: Nitro compounds.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical properties of nitro compounds.

Basic concepts: Nitroalkanes. Nitroarenes.

Plan and organizational structure of the lecture:

1. Nitroalkanes.

2.Aromatic nitro compounds.

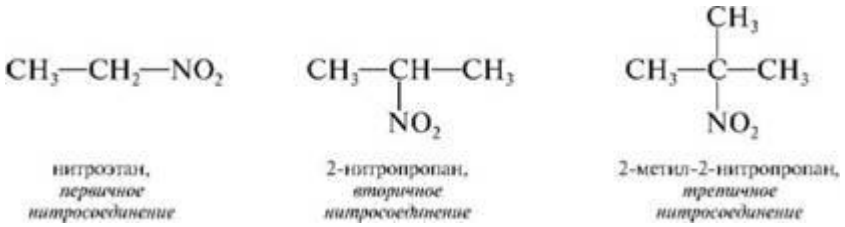
Content of lecture material (lecture text).

1. Nitroalkanes.

Nitrocompounds are derivatives of hydrocarbons containing one or more nitro groups - NO2.

The nitro group has a planar structure; nitrogen and oxygen atoms are in a statesp^2-hybridization. The electronic structure of the nitro group can be represented with the help of two boundary structures, in which one of the oxygen atoms forms a double bond with the nitrogen atom, and the other forms a seven-polar bond.

Depending on the nature of the hydrocarbon radical to which the nitro group is connected, aliphatic and aromatic nitro compounds are distinguished. Aliphatic can be saturated (nitroalkanes) and unsaturated (nitroalkenes, nitroalkynes). Aromatic nitro compounds can contain a nitro group directly connected to the benzene nucleus (nitroarenes) and a nitro group in the side chain (nitroalkylarenes). According to the location of the nitro group in the carbon chain, nitroalkanes and nitroarenes with a nitro group in the side chain are divided into secondary, primary, and tertiary:



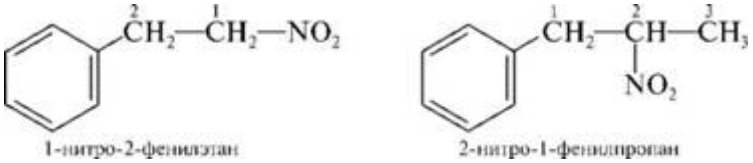
Nomenclature, isomerism

According to the substitute nomenclature, the names of nitroalkanes and nitro compounds with a nitro group in the benzene ring are formed by adding the prefix nitro- to the name of the parent hydrocarbon, indicating the position of the nitro group in the carbon chain, for example:

CH3–CH(NO2)–CH2–CH3 CH3–CH(NO2)–CH(CH3)–CH3 C6H5–NO2

2-nitrobutane 2-methyl-3-nitrobutane nitrobenzene

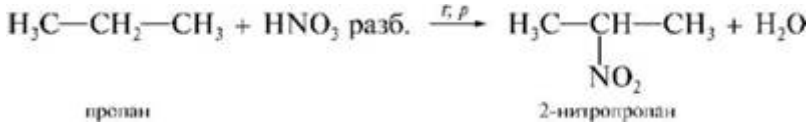
Nitro compounds with a nitro group in the side chain are considered as derivatives of nitroalkanes containing an aromatic radical as a substituent, for example:



Isomerism of nitro compounds can be caused by a different structure of the carbon skeleton (chain isomerism) and a different position of the nitro group in the carbon chain (positional isomerism).

Methods of obtaining

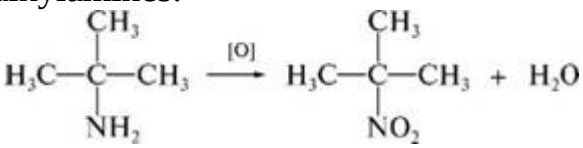
1. *Nitration of alkanes*(Konovalov reaction), is carried out by the action of diluted nitric acid (10 - 25%) on alkanes at elevated temperature and pressure:



2. *Interaction of haloalkanes with salts of nitric acid*(in the environment of aprotic solvents):

C2H5I + NaNO2 → C2H5NO2 + NaI.

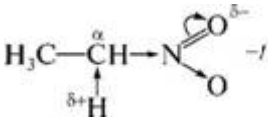
3. *Oxidation*tert-alkylamines:



Nitroalkanes are colorless or slightly yellowish liquids with a pleasant smell, poisonous. Slightly soluble in water, soluble in most organic solvents, they are polar compounds with large dipole moments (3.15 - 3.7 D).

Chemical properties

Chemical transformations of nitroalkanes occur with the participation of the nitro group and the α-carbon atom:



*Tautomerism and formation*of salt

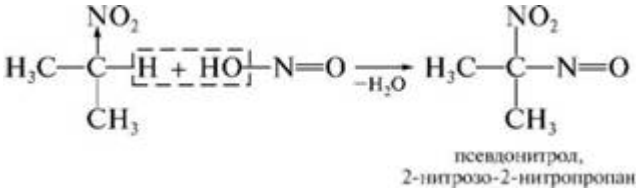
Primary and secondary nitroalkanes are tautomeric substances in which the nitro form (nitroalkane) is in equilibrium with the aci-nitro form (nitroic acid):

Such tautomerism is called azi-nitro-tautomerism. In a neutral environment, the equilibrium is usually almost completely shifted towards the nitro form, in an alkaline environment, the equilibrium is shifted towards the aci-nitro form:

R–CH=N(→O)OH + NaOH → R–CH=N(→O)O–Na+.

*Reaction with nitrogen*acid Primary nitroalkanes react with nitrous acid to form alkylnitrolic acids:

Secondary nitroalkanes give pseudonitroles with nitrous acid (dissolved melts are colored blue):



Tertiary nitroalkanes do not react with nitrous acid.

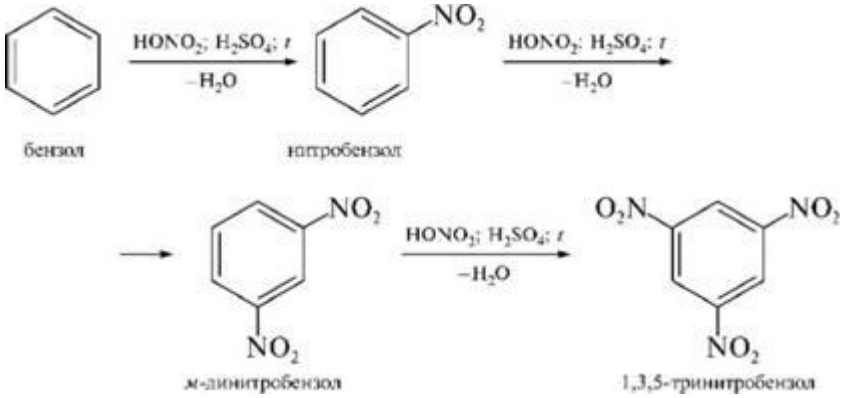
Reduction of nitroalkanes(reducing agents - stannous chloride (II), iron + HCl, sulfides of alkali metals):

R–NO2 + 6[H] → R–NH2 + 2H2O.

2. Aromatic nitro compounds.

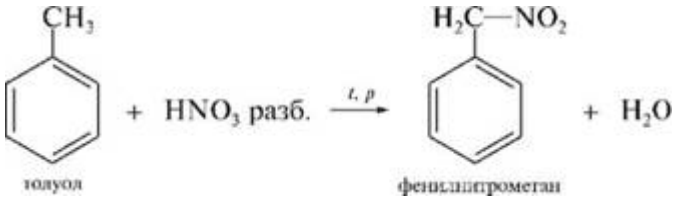
Methods of obtaining

*1. Nitration*arenas:



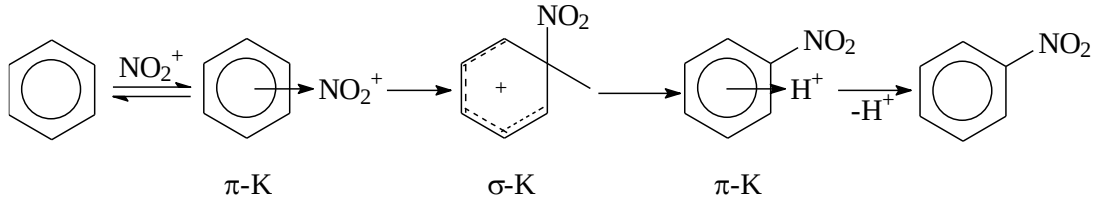
The introduction of the second nitro group requires stricter conditions: high temperature, concentrated acids, prolonged heating. The introduction of the third nitro group occurs with great difficulty.

The introduction of a nitro group into the arene side chain is carried out by the Konovalov reaction:



In the presence of electron-donating substituents in the nucleus, the nitration reaction is greatly facilitated, which illustrates the synthesis of 2,4,6-trinitrotoluene under normal conditions.

The nitration reaction mechanism is electrophilic substitution(SE):



π-K σ-K π-K

Nitroarenes are liquids or crystalline substances, colorless or pale yellow, insoluble in water, with the smell of bitter almonds.

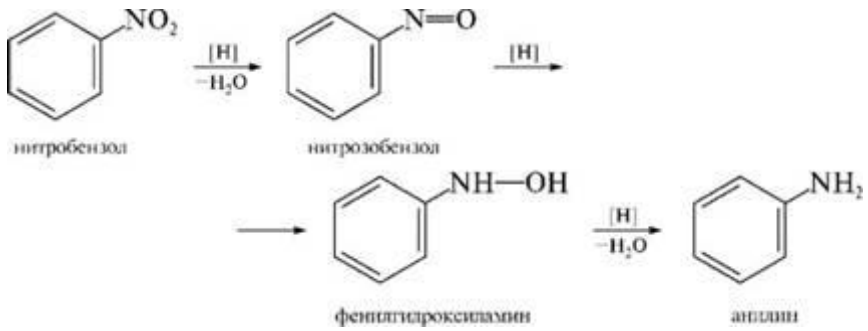
Nitroarenes containing several nitro groups are yellow, explosive crystalline substances.

Chemical properties

*Reduction of nitroarenes (reaction*Zenina):

$$C6H5NO2 + 6[H] \rightarrow C6H5NH2 + 2H2O.$$

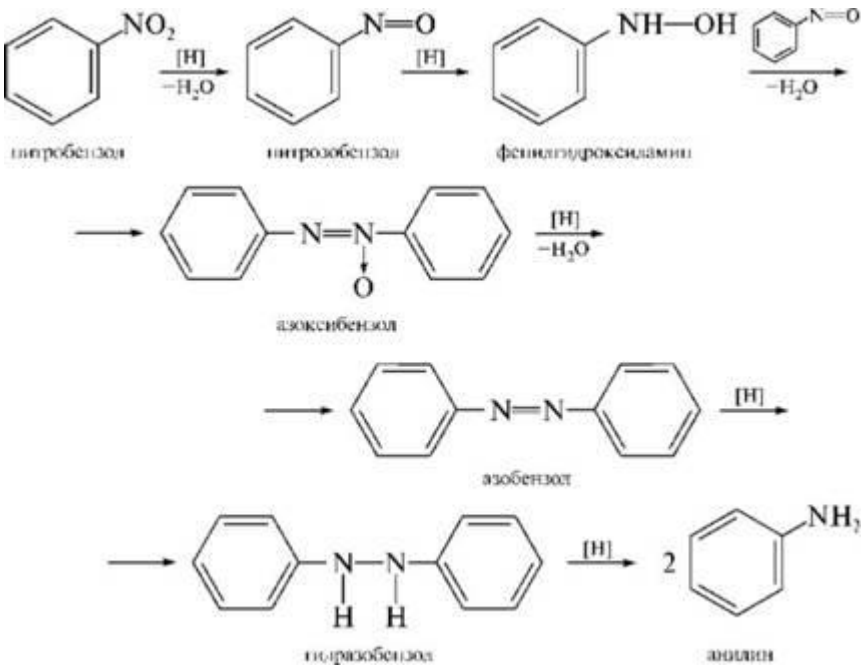
Depending on the pH of the reaction medium, the recovery process can follow two directions. In a neutral and acidic medium:



нитробензол нитрозобензол фенилгидроксиламин анилин

When reconstitution in a neutral environment, the reaction can be stopped at any stage. In an acidic environment, it is impossible to isolate intermediate products.

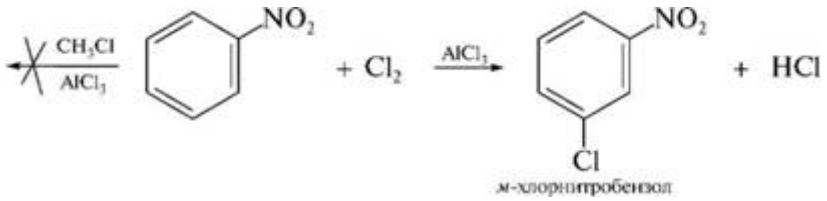
In an alkaline environment:



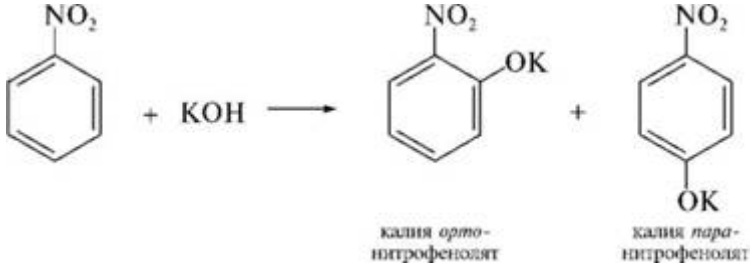
The reduction reaction of nitroarenes in an alkaline medium can be stopped at any of the following stages. It serves as the main method of obtaining azo and hydrazo compounds.

Reactions on the aromatic nucleus

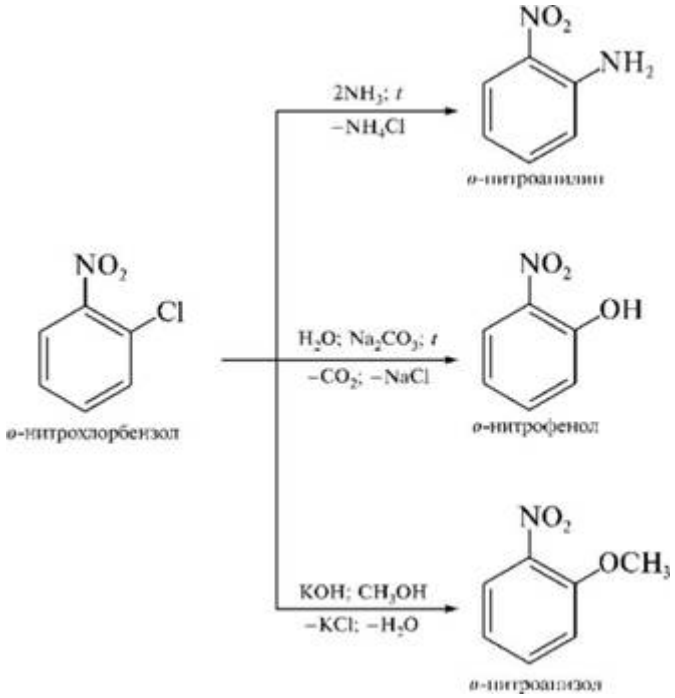
Reactions of electrophilic substitution (SE).The nitro group, possessing electron-acceptor properties, deactivates the benzene nucleus inS_N-reactions Thus, nitrobenzene is not alkylated under the conditions of the Friedel-Crafts reaction, but it can undergo nitration, sulfonation, and halogenation reactions with the formation of the corresponding meta-substituted ones, for example:



Nucleophilic substitution reactions(SN).The electron-withdrawing effect of the nitro group creates an opportunity for flowS_N -reactions, and the nitro group directs the substituent to the ortho- and para-positions. For example, when nitrobenzene is heated with solid KOH, a mixture is obtained -*at*- and p-nitrophenolatespotassium:



By reducing the electron density in the nucleus, the nitro group increases the mobility of the substituents that are in the ortho- or para-position in relation to it. This makes it possible to obtain various nitroderivatives of the aromatic series:



Individual representatives

NitromethaneCH3-NO2 is the simplest representative of nitroalkanes. Colorless liquid (b.p. 101.2 ºC), used as a solvent.

NitrobenzeneC6H5-NO2 - liquid (b.p. 210 ºC), used to obtain aniline, benzidine, in the production of dyes, as a mild oxidant in chemical reactions, as a solvent.

NitrotoluenesCH3C6H4NO2. They are used for the synthesis of dyes and other aromatic compounds.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1. Isomerism and nomenclature of nitro compounds.

2. Nitroalkanes.

2. Methods of obtaining,physical and chemicalproperties, reactivity.

3. Aromatic nitro compounds. 4. Methods of obtaining,physical and chemicalproperties, reactionsaromatic core.

5. Nitroarenes.

6. Methods of obtaining,physical and chemicalproperties, reactivity.

7. Identification of nitro compounds.

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Lecture No. 7

Topic: Aliphatic amines.Aromatic amines. Diamines. Identification of amines.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical properties of aliphatic amines, aromatic amines and diamines

Basic concepts: Amen.Alkylamines. Arylamines Diamines.

Plan and organizational structure of the lecture:

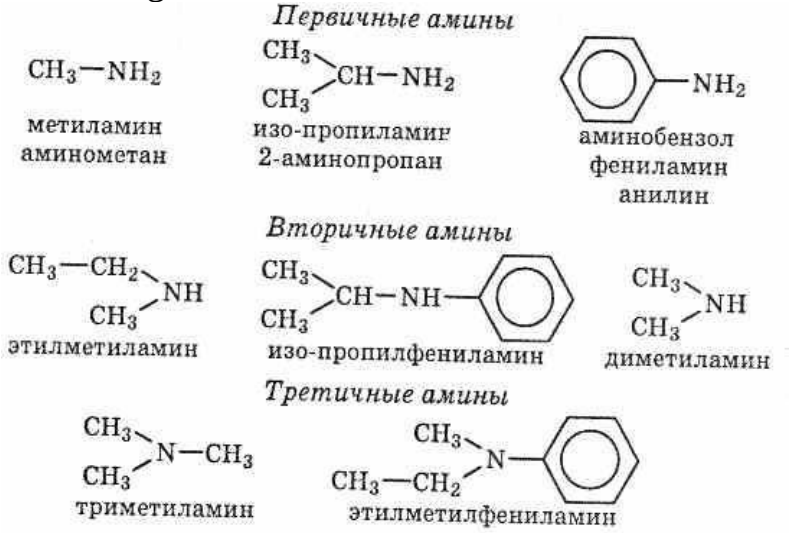
1. Classification, nomenclature, isomerism.
2. Alkylamines.
3. Arylamines.
4. Diamines.

Content of lecture material (lecture text).

1. Classification, nomenclature, isomerism.

Amines are ammonia derivatives, in the molecule of which one, two or three hydrogen atoms are replaced by hydrocarbon radicals.

According to the number of hydrocarbon radicals, primary, secondary and tertiary amines are distinguished:



Depending on the nature of the hydrocarbon radicals at the N-atom, amines are divided into aliphatic, alicyclic, and aromatic; amines in which the nitrogen atom is connected to an aliphatic and aromatic hydrocarbon radical are called mixed.

Nomenclature, isomerism

According to the substitute nomenclature of IUPAC, the names of primary amines are formed by adding the suffix -amine to the name of the hydrocarbon followed by the indication of the position of the amino group in the carbon chain. When compiling the names of secondary and tertiary amines, they are considered as derivatives of the primary amine with substituents at the nitrogen atom. In this case, the most structurally complex radical associated with a nitrogen atom is taken as the original primary amine. If the compound contains two or three amino groups, then in the name they are indicated by the multiplying prefixes -di or three - which are placed before the suffix -amine:

H2N-CH2-CH2-CH2-CH2-NH2
butanediamine-1,4

The names of primary aromatic amines, as well as mixed amines, are usually formed on the basis of the name of the parent representative - aniline.

Toluene derivatives containing an amino group in the benzene nucleus are called toluidines (o-, m-, p-toluidine).

Aromatic diamines are usually called phenylenediamines (o-, m-, p-phenylenediamine).

The isomerism of amines is due to the different structure of hydrocarbon radicals, the different position of the amino group and metamerism. The essence of metamerism is that amines with the same gross formula can be primary, secondary and tertiary. Yes, metamers are:

CH3CH2CH2-NH2	CH3-NH2-CH2CH3	(CH3)3N
n-propylamine	methylethylamine	trimethylamine

2. Alkylamines.

Alkylamines are products of substitution of one, two or three hydrogen atoms in ammonia by alkyl groups.

Methods of obtaining

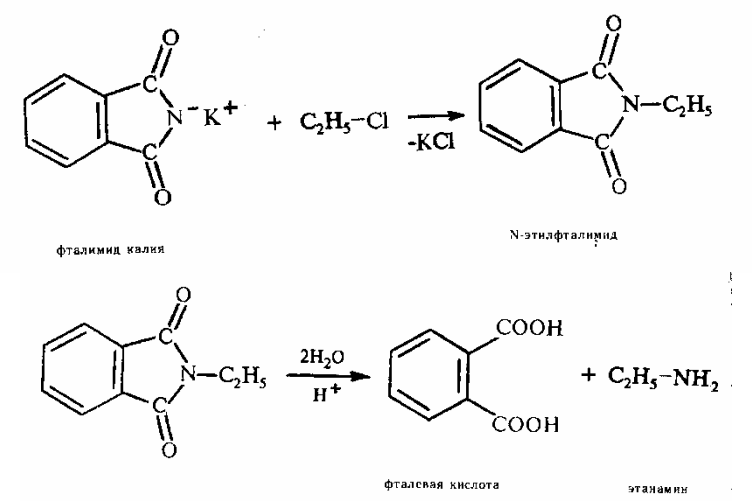
Interaction of haloalkanes with ammonia (Hoffman reaction). When heating an alcoholic solution of ammonia with haloalkanes, a mixture of primary, secondary and tertiary amines is formed, as well as a quaternary ammonium salt:

$$CH3I + NH3 \rightarrow [CH3NH3+]I- \xrightarrow{+NH_3} CH3NH2 + NH4I,$$

$$CH_3NH2 + CH3I \rightarrow [(CH3)2NH2+]I- \xrightarrow{+NH_3} (CH3)2NH + NH4I,$$

$$(CH_3)2NH + CH3I \rightarrow [(CH3)3NH+]I- \xrightarrow{+NH_3} (CH3)3N + NH4I.$$

Synthesis of Gabriel. It allows to obtain primary alkylamines by the interaction of potassium phthalimiu and haloalkanes with subsequent hydrolysis to form N-alkylphthalimide:



Reduction of nitroalkanes and nitriles:

$$R–NO2 + 3H2 \xrightarrow{Ni} R–NH2 + 2H2O,$$

$$R–C\equiv N + 2H2 \xrightarrow{Ni} RCH2–NH2.$$

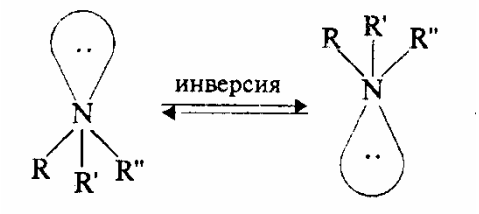
Hofmann rearrangement - cleavage of sodium hypobromite amides of carboxylic acids. At the same time, primary amines containing one less carbon atom than the original amide are formed:

$$CH3CH2–C(O)NH2 + NaOBr \rightarrow CH3CH2–NH2 + CO2 + NaBr.$$

Physical and chemical properties

Under normal conditions, methyl-, dimethyl- and trimethylamine are gases, alkylamines withC4 - C15- liquids, higher amines - solids. Lower amines are well soluble in water, with increasing M solubility decreases. Gaseous amines have the smell of ammonia, liquid amines have a sharp unpleasant smell, solid ones have no smell. Primary and secondary amines are associated due to H-bonds NH ⋯ N.

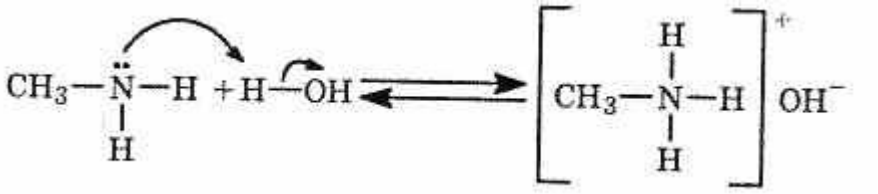
Alkylamines have a pyramidal structure - at the top of the pyramid is the N atom, the angles between bonds are ~ 107 - 108 ºC. Taking into account the stereoactivity of NEP, amines of the R1R2R3N type can exist in the form of optical isomers, however, due to the inversion process - the rapid mutual transformation of one tetrahedral configuration into another, the separation of optical isomers, as a rule, is not possible:



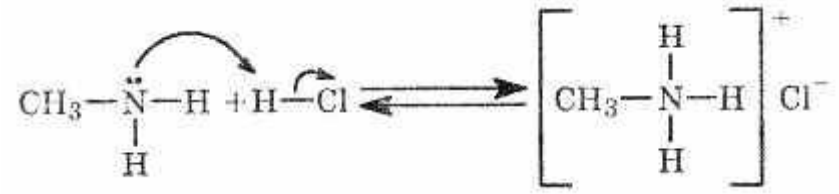
However, such examples are known.

The presence of NEP at the N atom provides nucleophilic properties of amines. Alkylamines are stronger bases compared to ammonia due to the +I effect of alkyl groups. The basicity of alkylamines in the gas phase and medium of the above solvents increases in the order: primary < secondary < tertiary. In aqueous solutions, the basicity of theoretical amines is, as a rule, lower than the basicity of primary and secondary due to the implementation of solvation effects.

Aqueous solutions of alkylamines have an alkaline environment:



With acids, alkylamines form alkylammonium salts:



When strong bases act on alkylammonium salts, the original amine is released:

$$[R–NH3]+Cl– + NaOH \rightarrow R–NH2 + NaCl + H2O,$$

which is used to purify amines.

Alkylation reaction:

$$RNH2 + R'I \rightarrow RR'NH + НИ.$$

Acylation:

$$RNH2 + R'–C(O)Cl \rightarrow RNH–C(O)–R' + HCl.$$

Interaction with nitrous acid (obtained directly in the reaction process by the interaction of $NaNO2$ or $KNO2$ with a strong mineral acid). The products of the reaction of primary alkylamines with $HNO2$ are alcohols and free nitrogen:

RNH2 + HNO2 + HCl → [R-N+≡N] Cl+ -2H2O,
[R-N+≡N] Cl+ -H2O → ROH + N2 + HCl.

Secondary alkylamines react with HNO2 to form N-nitrosoamines - yellow or orange oily liquids:

R2NH + HNO2 → R2N–N=O + H2O.

Tertiary amines do not react with nitrous acid under normal conditions.

The isonitrile reaction is characteristic only for primary amines. When primary alkylamines are heated with chloroform in the presence of alkalis in an alcoholic medium, isonitriles (isocyanides) are formed, which have a very strong unpleasant smell:

RNH2 + CHCl3 + 3KOH → R-N+≡C+ -3KCl + 3H2O.

The use of the isonitrile reaction for qualitative detection of primary amines is based on this property.

3.Arylamines.

Arylamines are ammonia derivatives, in the molecule of which one, two or three hydrogen atoms are replaced by residues of aromatic hydrocarbons.

Methods of obtaining

Reduction of nitroarenes (Zinin reaction):

$$C_6H_5–NO_2 + [H] \rightarrow C_6H_5–NH_2 + H_2O.$$

Interaction of haloarenes with ammonia and amines (harsh conditions - high pressure and temperature, catalysis by copper and its salts):

$$C_6H_5–Cl + 2NH_3 \xrightarrow{200°C;P;Cu} C_6H_5–NH_2 + NH_4Cl,$$

$$C_6H_5–Cl + 2NH_3 + Cu_2O \xrightarrow{200°C;P} C_6H_5–NH_2 + 2CuCl + H_2O.$$

Schmidt's reaction

$$C_6H_5–COOH + HN_3 \xrightarrow{H_2SO_4} C_6H_5–NH_2 + N_2 + CO_2.$$

Direct amination (the method has limited value for synthesis, as it is implemented under very harsh conditions):

$$C_6H_6 + NH_3 \xrightarrow{MoS_3,CuO,30атм,400°C} C_6H_5–NH_2.$$

Alkylation of primary arylamines (the method makes it possible to obtain mixed N-alkyl- and N, N-dialkylarylamines; haloalkanes or alcohols are usually used as alkylating agents in the presence of acids:

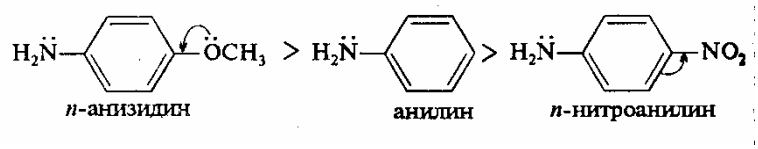
C6H5–NH2 + CH3I → C6H5–NH–CH3 + HI,

WITH$_6$H5–NH–CH3 + CH3I → C6H5–N(CH3)2 + HI.

Physical and chemical properties

Under normal conditions, arylamines are colorless high-boiling liquids or crystalline substances with a weak unpleasant odor; sparingly soluble in water, highly toxic, oxidized by oxygen in the air (due to which they acquire a yellowish color during storage).

The basicity of arylamines is noticeably lower than the basicity of alkylamines (for example, the pKa of CH3NH2 and C6H5NH2 is 10.6 and 4.6, respectively), which is due to the combination of NEP nitrogen with the π-electron system of the ring. Substituents in the benzene ring have a significant effect on the basicity of arylamines: electron-donating substituents increase basicity, and electron-accepting ones decrease it. For example, aniline is a stronger base than p-nitroaniline, but less strong than p-anisidine:



The basicity of arylamines strongly decreases in the series ArNH2 > Ar2NH > Ar3N. For example, triphenylamine has practically no basic properties.

Arylamines are characterized by reactions involving the nitrogen atom and carbon atoms of the aromatic cycle.

Reactions involving the nitrogen atom

Alkylation reactions:

C6H5NH2 + C2H5I → C6H5NH–C2H5 + HI,
N-ethylaniline

C6H5NH–C2H5 + C2H5I → C6H5N(C2H5)2 + HI. N, N-diethylaniline

Acylation reactions:

C6H5NH2 + (CH3CO)2O → C6H5NH–C(O)–CH3 + CH3COOH.

Carboxylic acid amides are easily hydrolyzed in an acidic or alkaline environment with the formation of the original amine and carboxylic acid:

$$C_6H_5NH–C(O)–CH_3 + H_2O \xrightarrow{H^+} C_6H_5NH_2 + CH_3COOH$$

Formation of isocyanides. Similarly to alkylamines, primary aromatic amines when heated with chloroform and alkali in an alcoholic medium form isocyanides - substances with an unpleasant, nauseating smell:

$$C_6H_5NH_2 + CHCl_3 + 3NaOH \rightarrow C_6H_5N^+{\equiv}C^- + 3NaCl + 3H_2O.$$

To detect primary aromatic amines, along with the isonitrile reaction, a diazotization reaction with subsequent condensation of a diazonium salt with β-naphthol (azo coupling reaction) is used. At the same time, a red azo dye is formed.

Interaction with nitric acid:

$$C_6H_5NH_2 + HNO_2 + HCl \rightarrow [C_6H_5–N^+{\equiv}N]Cl^- + 2H_2O.$$

Secondary arylamines and N-alkylarylamines upon interaction with nitrous acid, like alkylamines, form N-nitrosoamines:

$$C_6H_5–NH–C_6H_5 + HO–NO \rightarrow C_6H_5–N(NO)–C_6H_5 + H_2O.$$

Tertiary N, N-dialkylarylamines under the action of nitrous acid undergo nitration in the para-position of the benzene ring, and if it is occupied - in the ortho-position:

$$C_6H_5–N(CH_3)_2 + HO–N=O \rightarrow O=N–C_6H_4–N(CH_3) + H_2O.$$

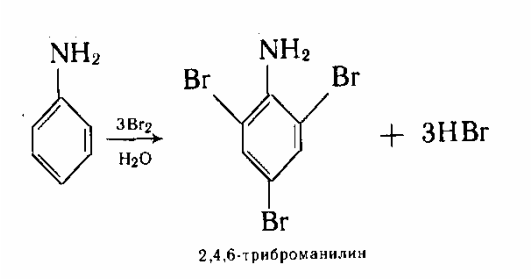
Interaction with aromatic aldehydes (azomethines are formed - Schiff bases):

$$C_6H_5–NH_2 + C_6H_5–C(O)H \rightarrow C_6H_5–N=CH–C_6H_5 + H_2O.$$

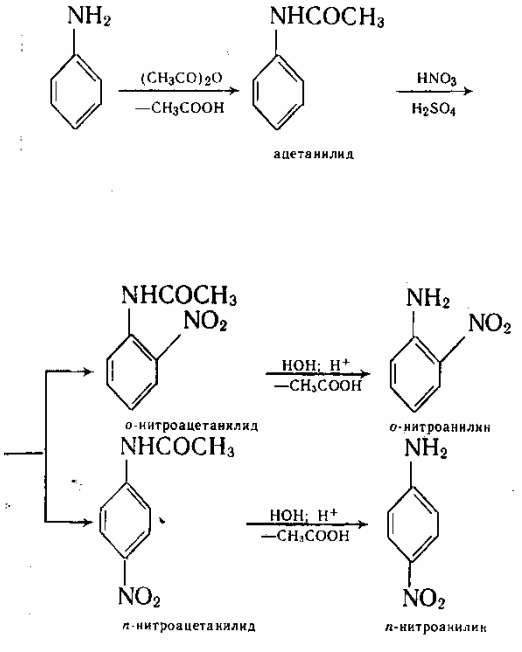
Reactions involving carbon atoms of the cycle

Arylamines are characterized by reactions of electrophilic substitution along the aromatic cycle, in which the amino group as an orientant of the first kind directs the substituents to the ortho- and para-positions.

Halogenation:



Nitration. Arylamines are easily oxidized by concentrated nitric acid; to protect the amino group from oxidation, arylamines are pre-acylated. The acetylamino group directs the nitration process to ortho- and para-positions. After nitration, N-acyl derivatives are hydrolyzed in an acidic or alkaline medium to obtain ortho- and para-nitroaniline in*at*-O2NC6H2NH2 and p-O2NC6H2NH2:



Sulfation:

C6H5NH2 $\xrightarrow{H_2SO_4}$ C6H5NH3+HSO4– $\xrightarrow{180–200°C}$ *couple*-HO3S–C6H4–NH2 + H2O

sulfanilic acid

The presence of acidic (-SO3H group) and basic (-NH2 group) centers in the sulfanilic acid molecule determines its existence in the form of an internal salt (bipolar ion):

H3N+–C6H4–SO3–

Sulfanilic acid is a fairly strong acid that easily reacts with bases to form salts:

H3N+–C6H4–SO3– + NaOH → H2N–C6H4–SO3Na + H2O.

Due to its bipolar structure, sulfanilic acid does not form salts with mineral acids, that is, despite the presence of an amino group, it does not have basic properties.

Sulfanilic acid is widely used in the production of dyes and medicines. It is a structural fragment of a large group of drugs - sulfonamides. The progenitor of sulfonamides is the amide of sulfanilic acid - streptocide: para-H2N-C6H4-SO2NH2.

Unlike sulfanilic acid, its amide is an amphoteric compound capable of forming salts with both mineral acids and alkalis:

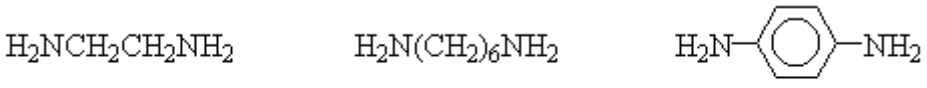
H2N–C6H4–SO2NH2 + HCl → H3N+–C6H4–SO2NH2Cl–,

H2N–C6H4–SO2NH2 + NaOH → H2N–C6H4–SO2NH–Na+ + H2O.

3. Diamines.

Compounds containing two amino groups connected to a hydrocarbon radical are called diamines.

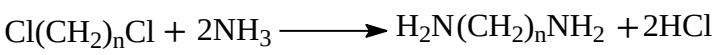
Depending on the nature of the radical, aliphatic and aromatic diamines are distinguished. The names of diamines are formed from the names of the corresponding divalent radicals or the name of the parent structure with the addition of the suffix "diamine":



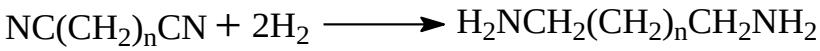
этилендиамин, этандиамин	гексаметилендиамин, 1,2-гександиамин	п-фенилендиамин

Methods of obtaining

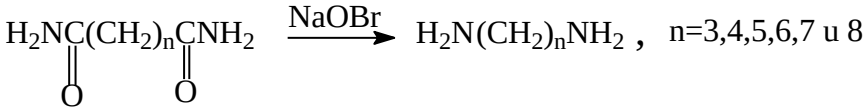
Ammonolysis of dihaloalkanes:



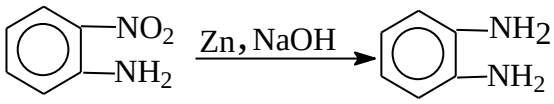
Reduction of dinitriles:

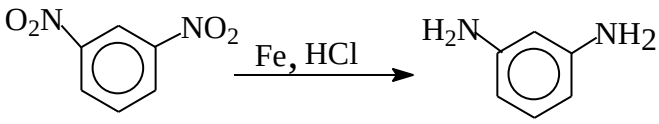


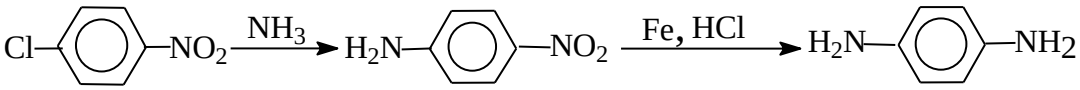
Decomposition of DIAMID according to Hoffmann:



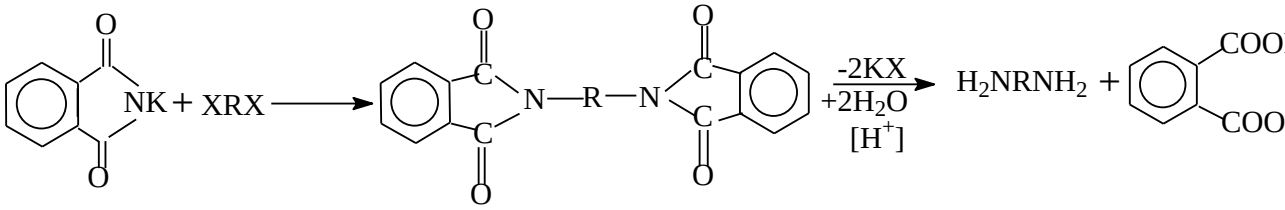
Reduction of nitroaniline or dinitrobenzene:







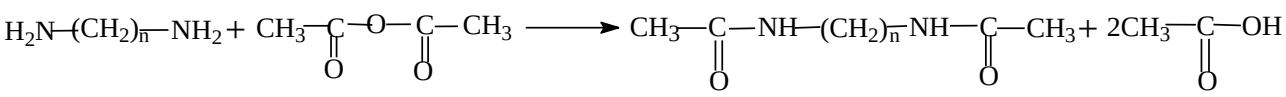
Synthesis according to Gabriel:

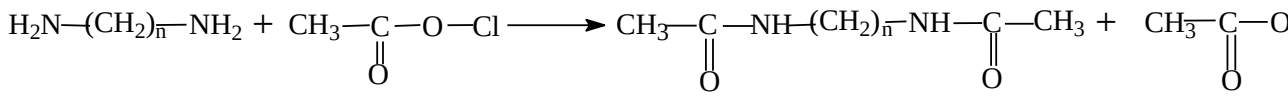


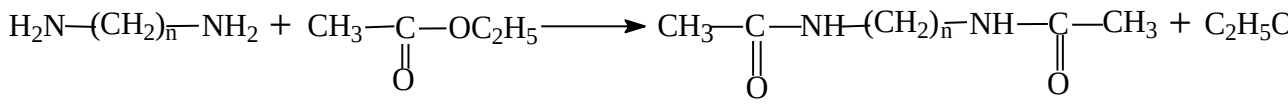
Chemical properties

In terms of chemical properties, diamines are similar to monoamines, the peculiarity of their behavior is only the possibility of the reaction taking place on one or two amino groups.

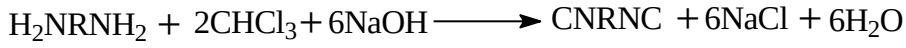
Aliphatic diamines undergo acylation reactions with carboxylic acids, acid anhydrides, acid chlorides, and esters:



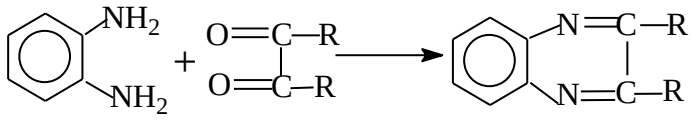


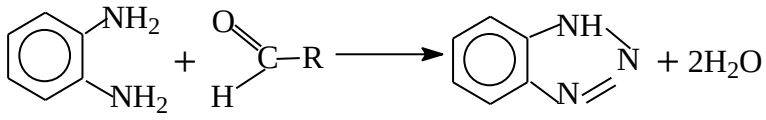


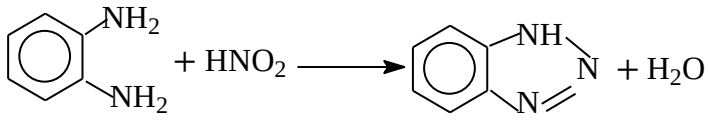
Primary diamines when heated with chloroform in an alcoholic alkali form diisonitriles:



The peculiarity of the chemical behavior of ortho-phenylenediamine is its tendency to enter into condensation reactions with α-dialdehyde, diketones, aldehyde- and ketoacids, carboxylic acids with the formation of heterocyclic structures:







Individual representatives

Aniline6 HC5NH2 is a colorless liquid with a peculiar smell (boiling point 184.4 ° C), easily oxidized by air oxygen, acquiring a red-brown color. Toxic. It is produced in large quantities, used in the synthesis of dyes, plastics, medicines, photographic materials, etc.

phenomenon,1-phenylpropanamine-2 6 HC5-CH2-CH (NH2)-CH3 - a white crystalline substance, slightly soluble in drinking water. In the form of a sulfuric acid salt, it is used in medicine as a stimulant of the central nervous system.

Ortho-phenylenediamine- orthoC6H5(NH2)2 - a colorless crystalline substance (m.p. 102 - 104 ° C), well soluble in water. It is used in the production of medicines (dibazole, etc.), dyes, pesticides.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1. Classification, nomenclature, isomerism of amines.

2.Production methods, physical and chemical properties, spatial structure, reactivity of alkylamines.

3. Preparation methods, physicochemical properties, structure, reactivity and oxidation of arylamines.

4. Classification, nomenclature, isomerism. Methods of extracting aromatic amines.

5.Physico-chemical properties. The effect of the amino group in aromatic amines on

undergoing electrophilic substitution (SE) reactions: halogenation, sulfonation, nitration, nitrosation.

6. Sulfanilamide preparations, methods of extraction and chemical properties of diamines.

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Lecture No. 8

Topic: Diazo-, azo compounds.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical properties of diazo and azo compounds.

Basic concepts: Diazo compounds. Azo compounds.

Plan and organizational structure of the lecture:

1. Diazo compounds.

2. Azo compounds.

Content of lecture material (lecture text).

1. Diazo compounds.

Diazo compounds are organic substances containing in their structure a group of two nitrogen atoms connected to a hydrocarbon radical and a mineral acid residue.

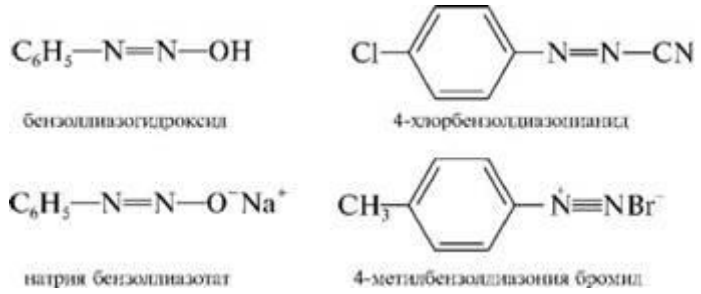
According to the nature of the hydrocarbon radical, aliphatic and aromatic diazo compounds are distinguished.

Aromatic diazo compounds have the general formula ArN2X, where Ar is an aromatic radical, X is an acidic residue. If X is the residue of a strong mineral acid(Cl–, Vg–, HSO4–, NO3–),diazo compounds have an ionic structure and are called diazonium salts(Ar–N+≡NX–),and if X is the residue of a weak mineral acid(CN–, HSO3–, OH–, SH–),then they have the covalent structure Ar-N = NX. Diazo compounds of the general formulaAr–N=N–O–M+,where M is a metal, are called diazotates.

Depending on the pH of the medium, these forms can interconvert. In an acidic environment, diazo compounds exist in the form of diazonium salts, in an alkaline environment - in the form of diazotates, in a close to neutral environment - in the form of isomeric diazohydrates.

Nomenclature. Isomerism.

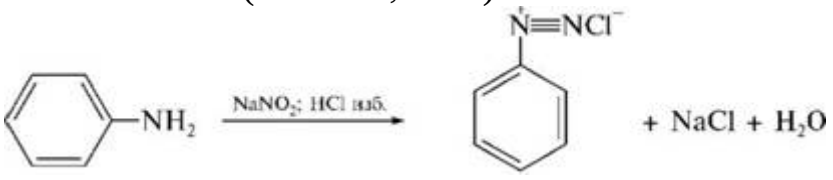
According to the IUPAC nomenclature, the names of aromatic diazo compounds are formed by adding the suffix -diazo to the name of the hydrocarbon, and the names of diazonium salts are formed by adding the ending -diazonium followed by the indication of the anion:



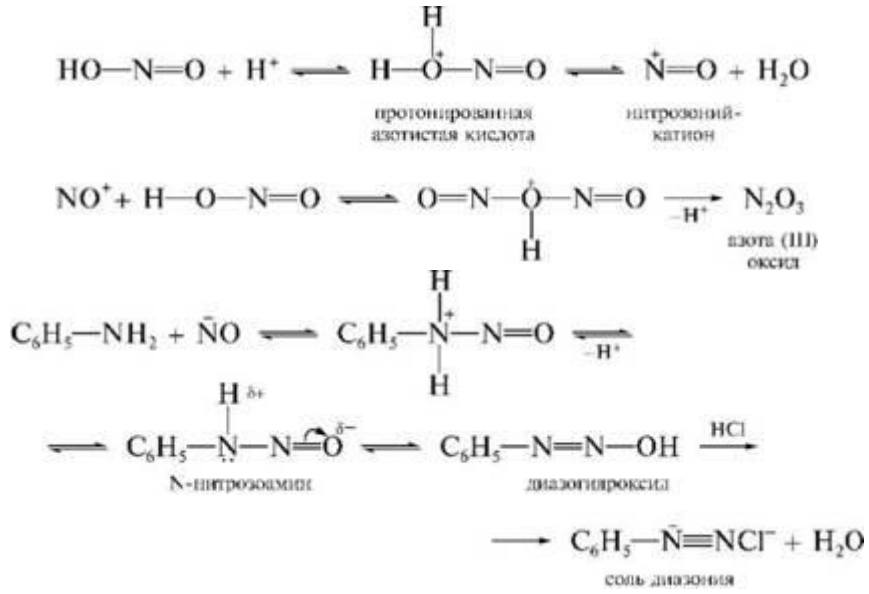
Since covalently constructed diazo compounds contain a double bond in their composition, they are characterized by geometric isomerism, or the so-called syn- (cis-) and anti- (trans-) isomerism, for example:

Methods of obtaining

Diazotization reaction (P. Griess,1858.):



Mechanismreactions Ingold's kinetic studies showed that the reaction proceeds by an ionic mechanism. The diazotizing agent is not nitrous acid, but the formed nitrosonium cation. First, the nitrosonium cation forms nitrosoamine with an aromatic amine, which in an acidic environment changes into the tautomeric form - diazohydroxide. At the final stage, diazohydroxide is transformed into an aryldiazonium salt:



Physical and chemical properties

Diazonium salts are colorless crystalline substances, easily soluble in water, unstable, decompose with an explosion when heated and mechanically affected. Their freshly obtained aqueous solutions are usually used in reactions.

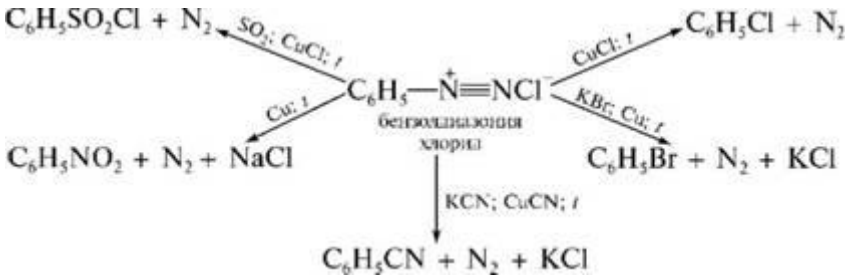
Diazonium salts are very reactive compounds. Their activity in chemical transformations is related to the presence of a diazo cation. The nitrogen atoms in the diazo cation are in a state of sp-hybridization. One of them has an NEP, and the second contains a positive charge, which is distributed mainly between two nitrogen atoms and partially over the π-electron system of the benzene ring. Due to delocalization, each nitrogen atom acquires a partial positive charge, which can be represented in the form of resonance structures:

All reactions of diazonium salts can be divided into two groups: with and without nitrogen release.

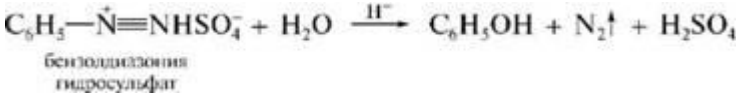
Reactions with the release of nitrogen

These reactions are accompanied by the breaking of the C-N bond and the replacement of the diazo group with other atomic groups.

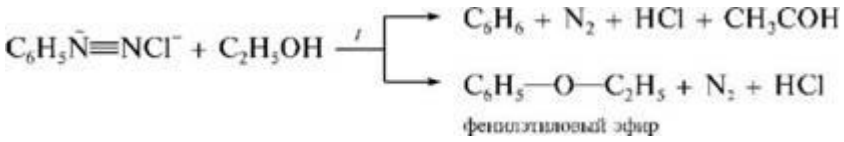
Sandmeyer reaction (catalyzed by copper (I) salts, the diazo group is replaced by chlorine, bromine, nitro-, cyano, chlorosulfonyl and other groups):



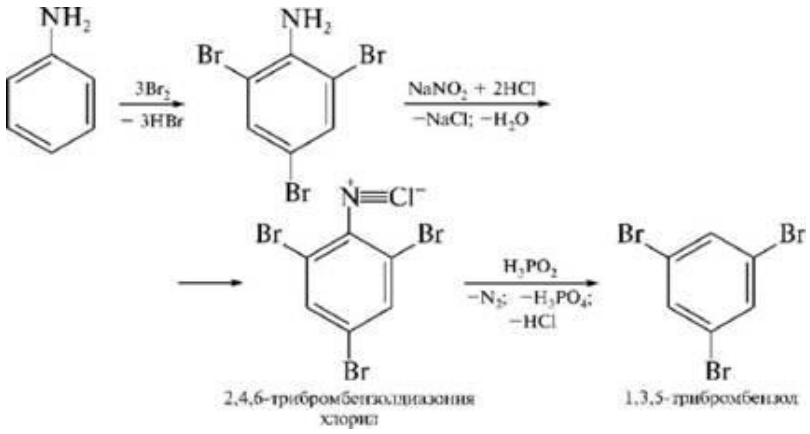
Substitution of a diazo group for a hydroxyl group (leads to the formation of phenols):



Substitution of a diazo group by a hydrogen atom (in the presence of reducing agents). When alcohols are used as a reducing agent, along with the reduction, a side process occurs with the formation of simple ethers:

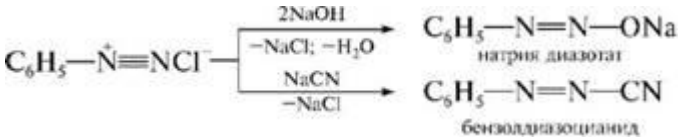


The reaction of the substitution of a diazo group on a hydrogen atom is used for the synthesis of benzene derivatives that cannot be obtained by other means. Example:

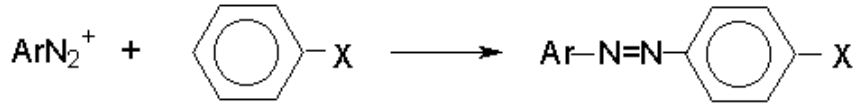


Reactions without nitrogen release

Formation of diazo derivatives. Being electrophilic reagents, diazonium salts react with nucleophilic reagents, forming diazo derivatives, for example:

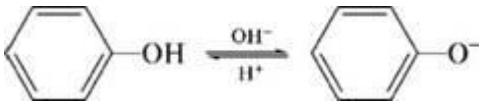


Azo coupling reaction. Aryldiazonium salts interact with phenols and aromatic amines, forming azo compounds of the general formula Ar-N = N-Ar. These reactions are called azo coupling reactions and proceed by the mechanism of electrophilic substitutionSE:

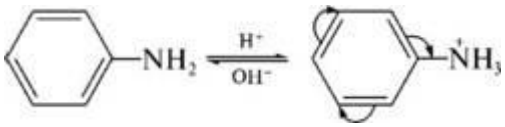


X = OH, NH_2.

Azo compounds with phenols are carried out in a slightly alkaline environment, where they are transformed into more reactive phenolates:



With aromatic amines, the reaction is carried out in a weakly acidic environment (pH 5 - 7). In a strongly acidic environment, the reaction does not proceed, because in this case the amino group turns into an ammonium group, which deactivates the benzene nucleus in the reactionsSE:



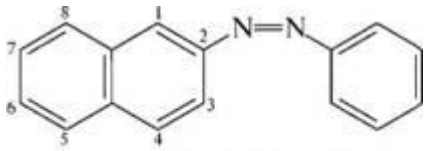
2. Azo compounds.

Organic substances containing the group -N = N- (azo group) connected to two hydrocarbon radicals are called azo compounds.

Depending on the nature of the hydrocarbon radical, aliphatic and aromatic azo compounds are distinguished. The latter are the most important.

The names of azo compounds with the same radicals consist of the prefix azo- and the name of the hydrocarbon. The position of the substitutes is indicated by numbers or locants ortho-, meta-, para-.

In the case of various radicals, azo compounds are considered as derivatives of a hydrocarbon with a more complex structure, which contains the arenazo group Ar-N = N- as a substituent:



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Methods of obtaining

Azo-compound reaction (the most important method of obtaining azo compounds, widely used in industry).

Reduction of nitroarenes in an alkaline environment.

Chemical properties

The reactivity of azo compounds is due to the presence of the azo group -N = N- in their structure. Due to the presence of NEP on nitrogen atoms, azo compounds exhibit weak basic properties:

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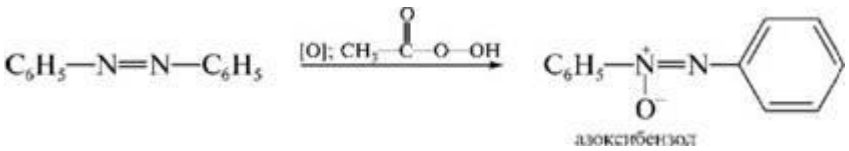
With the participation of the azo group, azo compounds undergo oxidation and reduction reactions. Thus, under the action of peroxyacid, oxidation occurs with the formation of an azoxy compound:



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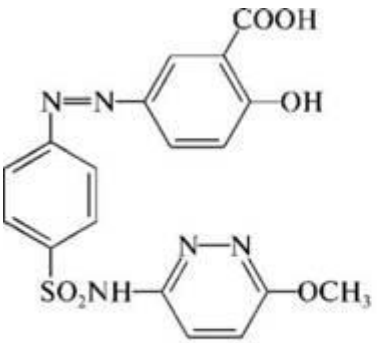
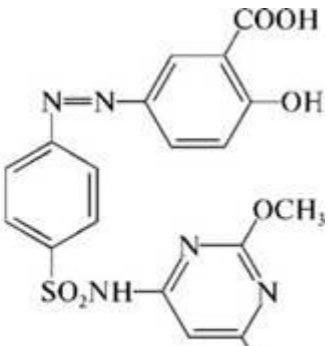
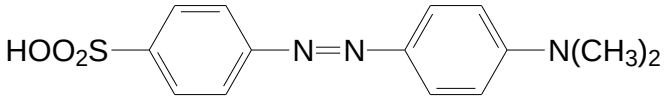
Reduction under mild conditions leads to the formation of hydrazo compounds, and by the action of tin (II) chloride in hydrochloric acid, arylamines are obtained.

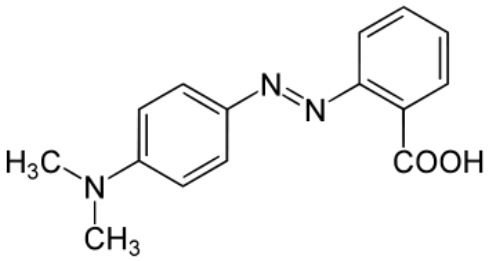
Azo compounds are colored (yellow, orange, red, blue, etc.) crystalline substances, used as dyes and medicinal preparations:

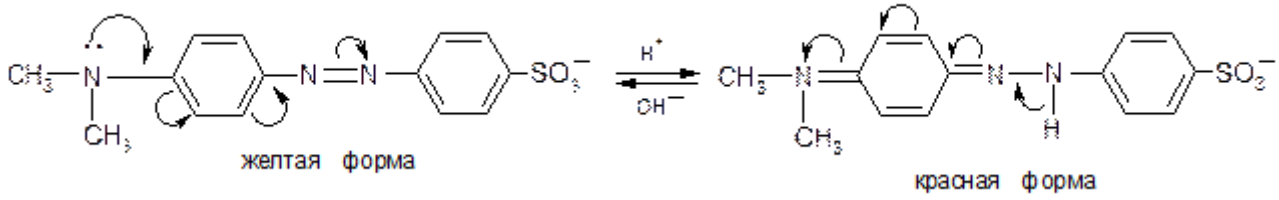




Azo compounds as indicators. Many azo dyes, depending on the pH of the medium, change their structure and, therefore, their color. Such azo dyes are used as indicators (methyl orange, Congo red, β-naphthol orange, methyl red):







In neutral and alkaline environments, methyl orange is in the form of a yellow azo form, and in acidic environments it turns into a red quinoid form.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks

- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1.Classification, nomenclature, diazotization reaction, its conditions, mechanism. Structure of diazonium salts.

2.Reactions of diazonium salts without nitrogen release, azo-compound reaction. Physical foundations of color theory.

3.Concept of chromophores and auxochromes. Azo dyes (methyl orange, methyl red), indicator properties.

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Lecture No. 9

Topic: Alcohols, phenols. Simple ethers. Thioalcohols and thioethers.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, isomerism, extraction methods, physical and chemical properties of alcohols and phenols, mercaptans, ethers and sulfides

Basic concepts:ATbottom-,di-, tri- and polyatomic alcohols.Phenols.Thio-alcohols (thiols, mercaptans).Thioethers (sulfides). Simple ethers.

Plan and organizational structure of the lecture:

1. Classification.
2. Monoatomic alcohols.
3. Di-, tri- and polyatomic alcohols.
4. Phenols. Monoatomic phenols.
5. Mercaptans.
6. Simple ethers and sulfides.

Content of lecture material (lecture text).

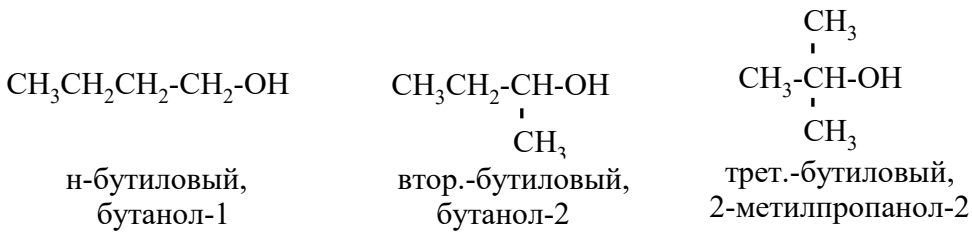
1. Classification.

Hydroxyl derivatives are hydrocarbon derivatives in which one or more hydrogen atoms are replaced by a hydroxyl group.

Depending on the type of hybridization of the carbon atom directly connected to the OH group, hydroxyl derivatives are divided into**alcohols**(The OH group is located at the C atom insp^3-hybridizationand phenols (the OH group is located at the sp2-hybridized C atom, which is part of the aromatic system). Compounds with an OH group at an sp2-hybridized C atom that is not part of the aromatic system are called enols. Such substances are usually unstable

Depending on the number of OH groups in the molecule, they are distinguished**one-,**di-, tri- and polyatomic alcohols and phenols.

Alcohols are classified according to the location of the OH group in the carbon chain**primary (group**-OH is located at the primary C atom), secondary (the -OH group is located at the secondary C atom), tertiary (the -OH group is located at the tertiary C atom):



When the O atom of hydroxyl derivatives of hydrocarbons is replaced by an S atom, sulfur analogues of hydroxyl derivatives are formed, which are called**thiols**(thioalcohols and thiophenols). These compounds are also called mercaptans. The -SH functional group, which is part of thiols, is called a thiol or mercapto group.

Monoatomic alcohols are called hydroxyl derivatives of hydrocarbons containing one hydroxyl group connected to a carbon atom in sp3-hybridization.

According to the nature of the carbohydrate radical, alcohols are divided into three groups:

saturated(alkanols and cycloalkanols) - OH derivatives of alkanes and cycloalkanes;

unsaturated(alkenols, alkynols, cycloalkenols, etc.) - OH-derivatives of unsaturated hydrocarbons in which the hydroxyl group is not present in a multiple bond;

aromatic(arylalkanols) - OH derivatives of aromatic hydrocarbons with a hydroxyl group in the side chain.

2. Monoatomic alcohols.

It is most often used to name alcohols**substitute**and the radical-functional nomenclature of IYUPAK. According to the substitute nomenclature, the name of the alcohol is formed from the name of the hydrocarbon, the corresponding main hydrocarbon chain, to which the suffix -ol is added indicating the position of the OH group in the chain of carbon atoms. The numbering of the main carbon chain begins with the end to which the OH group is closest, for example:

CH3-CH (OH)-CH3 - C propanol-2, 6H5-CH2-CH2-OH - 2-phenylethanol.

Onin the radical-functional nomenclature, the name of alcohol is formed from the name of the hydrocarbon radical bound to the OH group, to which -ov and alcohol are added, for example C2H5-OH - ethyl alcohol, (CH3)3C-OH - tert-butyl alcohol, C6H5- CH2--OH - benzyl alcohol, etc.

Isomerism

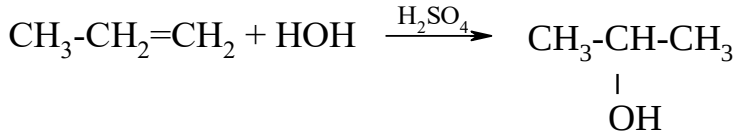
Alcohols are characterized by structural, geometric and optical isomerism.

Methods of obtaining

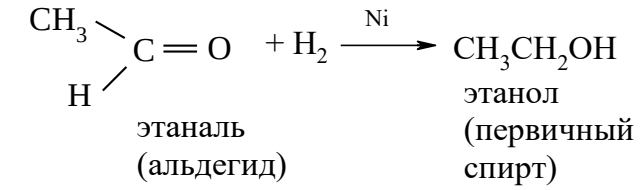
1. Hydrolysis of haloalkanes:

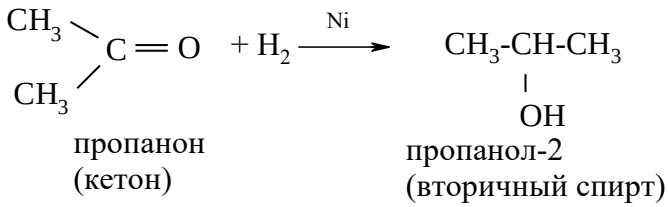
$WITH_2H5\text{-}Cl + NaOH \rightarrow C2H5OH + NaCl.$

2. Hydration of alkenes:

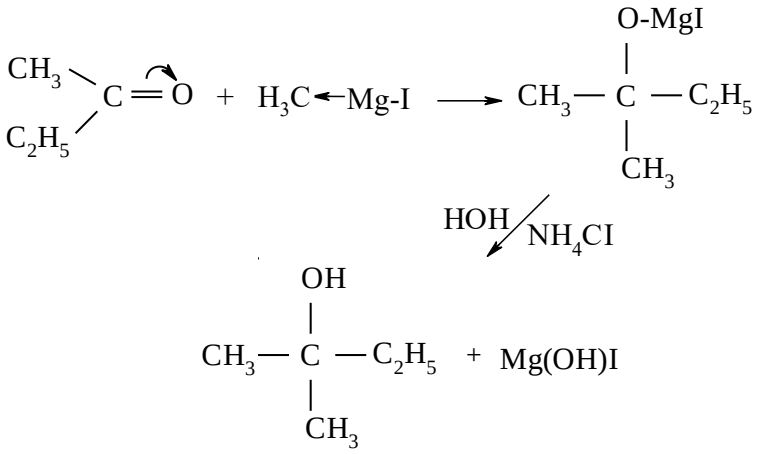


3.Recovery of carbonyl compounds - aldehydes, ketones, carboxylic acids and esters:





4.Interaction of carbonyl compounds with Grignard reagents:



5. Oxidation of trialkylboranes with hydrogen peroxide in an alkaline environment:

$$R3B + 2H2O2 + NaOH \rightarrow 3ROH + NaBO2.$$

6.Oxidation of trialkylalanines and subsequent hydrolysis of alcoholates:

$$R3Al \xrightarrow{O_2} (RO)3Al \xrightarrow{+3H_2O} 3ROH + Al(OH)3.$$

Physical and chemical properties

Saturated alcohols are, as a rule, colorless liquids or crystalline substances with a specific smell. Lower members of the series have a characteristic "alcohol" smell; butanol and pentanol have an unpleasant "smelly" smell, higher alkanols have a pleasant smell.

Alcohols have higher melting and boiling points, greater solubility in water than the corresponding hydrocarbons. Such a sharp difference between the physical properties of alcohols and alkanes is due to the fact that alcohols are polar compounds and form H-bonds (association of alcohols).

Alcohols are characterized by reactions involving O-H, C-O bonds and oxidation reactions.

Acid-base properties. Alcohols exhibit weak acidic and weak basic properties, that is, they are amphoteric compounds. The acidic properties of alcohols are due to the mobility of the hydrogen atom of the OH group (the H atom has a

partial positive chargeOδ–←Hδ+);under the influence of strong bases, alcohols detach a proton from the OH group, i.e., they reveal the properties of OH acids. However, alcohols are weaker OH acids than water due to the +I effect of the hydrocarbon radical at the OH group, which leads to a decrease in the polarity of the OH bond. Therefore, when passing from primary alcohols to secondary and tertiary alcohols, the acidic properties decrease.

Alcohols as acids react with alkali metals to form alcoholates:

$2C_2H5OH + 2Na \rightarrow 2C2H5\text{-}OHa + H2\uparrow.$

In an alcoholic environment, alcohols undergo ionization with the formation of an alkoxide anion, which exhibits strong nucleophilic and basic properties:

$C2H5–OHa \rightleftarrows C2H5–O– + Na+.$

Alcohols are easily decomposed under the influence of water to original alcohols, which confirms the lower acidity of alcohols against water:

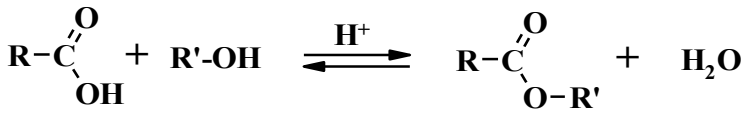
$C2H5–OHa + H2O \rightarrow C2H5–OH + NaOH.$

With strong acids, primary alcohols as bases due to the NEP of the oxygen atom form low-stable alkyloxonium salts in the cold:

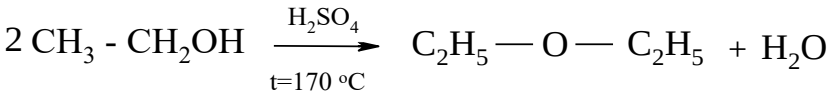
$WITH_2H5–OH + HBr \rightleftarrows [C2H5–OH2]+Br–.$

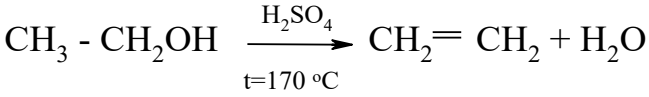
Interaction with mineral and organic acids. Alcohols react with mineral (sulfuric, nitric, nitrous, etc.) and organic acids to form esters - the esterification reaction:

$$C_2H_5OH + HOSO_3H \rightleftharpoons C_2H_5OSO_3H + H_2O$$



Dehydration of alcohols is carried out by heating in the presence of concentrated sulfuric acid, anhydrous phosphoric acid or by passing acid vapors over the catalyst -Al2O3. Depending on the nature of the alcohol and the reaction conditions, dehydration can occur intermolecularly and intramolecularly. In the first case, simple ethers are formed, in the second - alkenes:





Intermolecular and intramolecular dehydration of alcohols are competing processes: the first dominates when heating alcohols in the presence of catalytic amounts of mineral acid (alcohol in excess) at 140 - 160 ºC (mechanism **-S_N1 or SN2),**the second - when heating alcohols with an excess of mineral acid at a temperature > 170 ºC (E1 or E2 mechanism). Intramolecular dehydration occurs especially easily in the case of tertiary alcohols.

Interaction with hydrohalic acids (reactivity to alcohols changes in the order HCl <HBr <HI, mechanism NS1 or NS2):

2 NS_5OH +⇄HI 2 HC5-I + H2O.

Primary and secondary alcohols react with HCl only in the presence of Lewis acid - ZnCl2.

Interaction with halogen anhydrides of inorganic acids (PCl3, PCl5, SOCl2, etc.):

3C2H5OH + PCl3 → 3C2H5Cl + H3PO3,

C2H5OH + PCl5 → C2H5Cl + POCl3 + HCl↑,

$C_2H_5OH + SOCl_2 \rightarrow C_2H_5Cl + SO_2\uparrow + HCl\uparrow.$

Oxidation. During oxidation, primary alcohols first form aldehydes, which, in turn, can be further oxidized to carboxylic acids:

$CH_3–CH_2–CH_2–OH \xrightarrow{[O]} CH_3–CH_2–C(O)H \xrightarrow{[O]} CH_3–CH_2–C(O)OH.$

propanol-1 propanal propanoic acid

Secondary alcohols upon oxidation form ketones:

$(CH_3)_2CH–OH \xrightarrow{[O]} (CH_3)_2C=O.$

Tertiary alcohols are resistant to oxidation, but in harsh conditions they oxidize with the breakdown of the carbon skeleton and the formation of a mixture of ketones and carboxylic acids.

Identification of alcohols is carried out using the reaction of the formation of complex esters RC (O) OR', which, as a rule, have a characteristic pleasant smell.

Alcohols with a -CH (CH3)OH fragment in the molecule give a positive iodoform test: when alcohol is treated with iodine and NaOH, a yellow precipitate of iodoform $CHNI_3$ with a sharp characteristic odor is formed.

Individual representatives

MethanolCH_3OH is a colorless flammable liquid (b.p. 64.7 ºC) with a smell reminiscent of the smell of ethanol, miscible with water in all proportions, poisonous. When oxidized in the body, it turns into formaldehyde and formic acid. It is used as a starting compound in organic synthesis and as a solvent. Obtained by catalytic hydrogenation of carbon monoxide.

EthanolC_2H_5OH is a colorless flammable liquid (boiling point 78.3 ºC) with a burning taste and a characteristic smell, it is mixed with water in all proportions. Gives an intoxicating effect. In the body, it is oxidized to acetaldehyde, and then to carbon dioxide and water. It is widely used as a raw material and solvent in organic synthesis, as fuel, in pharmacy and medicine (preparation of tinctures, extracts, solutions), as a disinfectant, for preservation of anatomical preparations, etc. The basis of alcoholic beverages. Obtained by enzymatic hydrolysis of carbohydrates and hydration of ethylene.

Allyl alcoholCH2=CH–CH2–OH –colorless liquid with a pungent odor (boiling point 96.9 ºC), miscible with water. It is used in the production of glycerin. Obtained from 3-chloropropyl.

Propargyl alcoholCH≡C–CH2–OH –colorless liquid with the smell of geranium (b.p. 115 ºC), miscible with water in all ratios. Used in organic synthesis, obtained from acetylene and formaldehyde.

Benzyl alcohol6 HC5-CH2-OH is a colorless liquid, poorly soluble in water, better in organic solvents (bp. 15 ºC, boiling point 205 ºC). It is contained in essential oils and balms. It belongs to fragrant substances and is used in perfumery as a fixative of smell, as well as a solvent for dyes, ink pastes, casein, waxes, etc.

3. Di-, tri- and polyatomic alcohols.

Diatomic alcohols (containing two hydroxyl groups) are called diols or glycols. Depending on the position of the OH groups in the carbon chain, glycols are divided into α-glycols (OH groups are in the neighboring C atoms, i.e. in the 1,2 position), β-glycols (OH groups in the 1,3 position), γ -glycols (1,4-position), etc.:

R–CH(OH)–CH(OH)–RR–CH(OH)–CH2–CH(OH)–R

α-glycol β-glycol

According to the IUPAC systematic nomenclature, the names of glycols are formed from the name of the corresponding hydrocarbon, adding the suffix -diol and indicating the position of the OH groups in the carbon chain. According to the radical-functional nomenclature, the names of α-glycols are derived from the name of the corresponding divalent radical, to which the suffix -glycol is added.

Triatomic alcohols (containing three OH groups) are called triols or glycerol. According to the substitute nomenclature, the names of triatomic alcohols are formed by adding the suffix -triol to the name of the corresponding hydrocarbon:

CH2(OH) -CH (OH) -CH2(OH) - propanetriol-1,2,3 or glycerol.

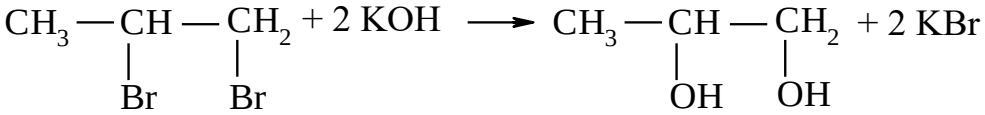
Alcohols containing more than three OH groups are called polyol or simply polyhydric alcohols. Four-atom alcohols have a common name - erythritol, five-atom - pentite, six-atom - hexites, etc.

The structural isomerism of di-, tri-, and polyhydric alcohols is due to the different structure of the carbon skeleton and the different arrangement of OH groups.

Polyatomic alcohols are characterized by optical isomerism due to the appearance of asymmetric carbon atoms in their structure.

Methods of obtaining

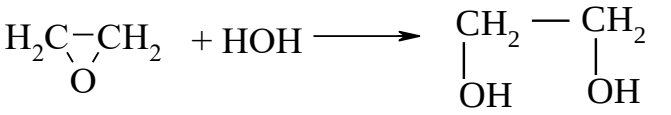
1. Hydrolysis of dihalogen derivatives:



2. Hydroxylation of alkenes:

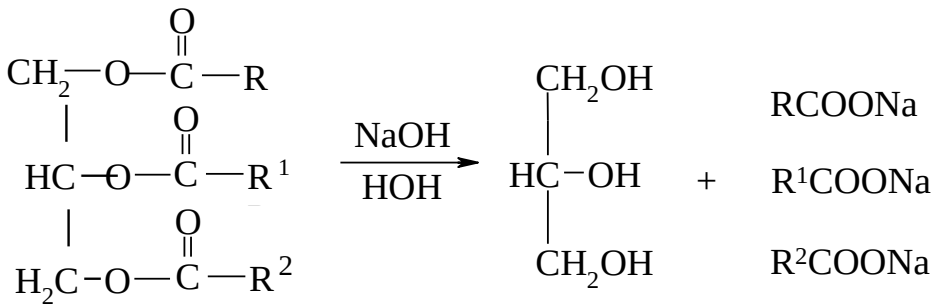
3CH3–CH=CH2 + 2KMnO4 + 4H2O → 3CH3–CH(OH)–CH2(OH) + 2KOH + 2MnO2.

3. Hydration of oxiranes - this method is used in industry to obtain ethylene glycol:



этиленгликоль

The most important representative of triols - glycerol can be obtained by acid or alkaline hydrolysis of fats:



Industrial synthesis of glycerol is carried out using propylene:

$$CH2{=}CH{-}CH3 \xrightarrow{Cl_2} CH2{=}CH{-}CH2Cl \xrightarrow{NaOH} CH2{=}CH{-}CH2OH \xrightarrow{HOCl}$$

$$CH2Cl{-}CH(OH){-}CH2OH \xrightarrow{NaOH} CH2(OH){-}CH(OH){-}CH2(OH).$$

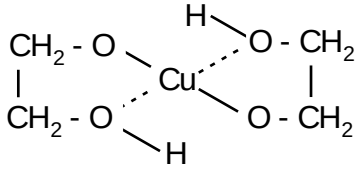
Physical and chemical properties

The lower members of the homologous series of diols are viscous liquids, the higher members are crystalline substances. Liquid glycols dissolve well in water. Triatomic alcohols are viscous liquids or hard-to-crystallize solids. Viscosity, solubility in water, melting and boiling points of OH-derived aliphatic hydrocarbons increase in the order: monoatomic alcohols < glycols < glycerin. This is a consequence of strengthening the association of molecules due to the formation of intermolecular H-bonds.

Formation of alcoholics. Glycols and glycerol are stronger OH-acids than monoatomic alcohols due to the influence of one OH-group on others (-I effect). With an increase in the number of OH groups in the molecule, the acidic properties of the compound increase. When interacting with active metals (alkaline, Al, Mg, etc.), glycols form complete and incomplete glycolates:

$$2CH2(OH){-}CH2(OH) \xrightarrow{+2Na} 2CH2(OH){-}CH2ONa \xrightarrow{+2Na} 2CH2ONa{-}CH2ONa.$$

With Cu (OH)2, glycols and glycerol form blue complex compounds - copper glycolate and glycerate:



Interaction with hydrogen halides (chloro- or bromohydrins are formed):

$$CH2(OH)–CH2(OH) \xrightarrow{+HHal} CH2(OH)–CH2Hal.$$

The second OH group is more difficult to replace (it is better to use PCl5 or SOCl2):

$$CH2(OH)–CH2(OH) \xrightarrow{+SOCl_2} CH2Cl–CH2Cl.$$

Formation of simple and complex esters. When interacting with alcohols, mineral or organic acids, glycols form two series of derivatives, and glycerin - three series:

$$CH2(OH)–CH2(OH) \xrightarrow{+HNO_3} CH2(OH)–CH2ONO2 \xrightarrow{+HNO_3} CH2ONO2–CH2ONO2.$$

Glycerin under harsh conditions forms glycerol trinitrate (nitroglycerin):

$$CH2(OH)–CH(OH)–CH2(OH) \xrightarrow{+3HNO_3} CH2ONO2–CHONO2–CH2ONO2.$$

Similarly, under harsh conditions, the full acetic acid ester of glycerol - glycerin triacetate - is obtained.

Oxidation of di-, tri- and polyatomic alcohols. When glycols are oxidized, a mixture of oxidation products is formed:

$$CH2(OH)–CH2(OH) \xrightarrow{[O]} CH2(OH)–C(O)H \xrightarrow{[O]} [\ H(O)C–C(O)H +$$

glycol aldehyde glyoxal

$$CH2(OH)–C(O)OH\ ] \xrightarrow{[O]} CH(O)H–C(O)OH \xrightarrow{[O]} OH(O)C–C(O)OH.$$

glycolic acid, glyoxylic acid, oxalic acid

The oxidation of glycerol takes place in several stages: in the first stage, dioxyacetone is formed, and the final product is mesoxalic acid:

$$CH2(OH)–CH(OH)–CH2(OH) \xrightarrow{[O]} CH2(OH)–C(O)–CH2(OH) \xrightarrow{[O]}$$

dioxyacetone

$$C(O)OH–C(O)–C(O)OH.$$

mesoxalic acid

Dehydration of hydroxyl compounds with several OH groups. When heating ethylene glycol in the presence of concentrated H2SO4, a cyclic simple ether - 1,4-dioxane is formed, intramolecular dehydration of butanediol-1,4 leads to the formation of tetrahydrofuran.

The product of the intramolecular dehydration of glycerol when it is heated with potassium hydrosulfate is the nonlimiting aldehyde - acrolein:

$$CH2(OH)–CH(OH)–CH2(OH) \xrightarrow{KHSO_4} CH2=CH–C(O)H.$$

Polycondensation of diatomic alcohols. Polycondensation product of ethylene glycol - polyethylene glycol:

$$n CH2(OH)–CH2(OH) \xrightarrow{H2SO4,t} HO–[–CH2–CH2–O–]n–H.$$

Polyethylene glycol with M up to 400 is used in pharmacy as a solvent for medicinal substances, bases for ointments, and also as a binder in the production of tablets.

Identification of diols and triols can be carried out by reaction withCu(OH)2,which leads to the formation of blue-colored solutions of Cu (II) complex salts.

Individual representatives

Ethylene glycol- colorless viscous liquid (boiling point 197.6 ºC, melting point -11.5 ºC), hygroscopic, miscible with water and ethanol. Very toxic. It strongly lowers the freezing point of water and is used to prepare antifreeze. It is widely used for obtaining synthetic fibers.

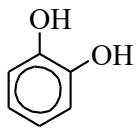
Glycerin- a colorless, syrupy, odorless liquid with a sweet taste (p.p. 18 ºC, boiling point 290 ºC with decomposition), hygroscopic, miscible with water and ethanol in all ratios. It is used as a base for ointments and pastes, an additive to soaps, and in large quantities is used to obtain nitroglycerin.

Nitroglycerin- a heavy oily liquid with a sweetish burning taste, explodes when heated or hit, used to make dynamite. In the form of diluted alcohol solutions or tablets, it is used in medicine as a vasodilator (for angina pectoris).

4. Phenols.

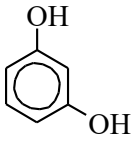
Hydroxyl derivatives of hydrocarbons in which the OH group is located at the carbon in*sp2-hybridization,*which is included in the aromatic cycle, are called phenols (arenols).

According to the number of OH groups, phenols are divided into monoatomic (arenols), diatomic (arenediols), triatomic and polyatomic (arenetriols, arenepolyols):

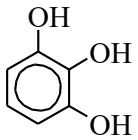


1,2-диоксибензол,
пирокатехин

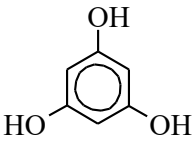
1,4-диоксибензол,
гидрохинон



1,3-диоксибензол,
резорцин



1,2,3-триоксибензол,
пирогаллол



1,3,5-триоксибензол,
флороглюцин

Monoatomic phenols

Phenols differ significantly from alcohols in terms of their physical and chemical properties, which is due to the different nature of electronic interactions of OH groups with the hydrocarbon radical. In phenols, the OH group reveals–I- and +M(mesomeric) effects, and + M> -I. Therefore, the total partial charge on the O-atom of the phenolic hydroxyl is positive, while the O-atom of the alcohol hydroxyl has a partial negative charge. The second set of differences is related to the different reactivity of radicals in alcohols ROH and phenols ArOH.

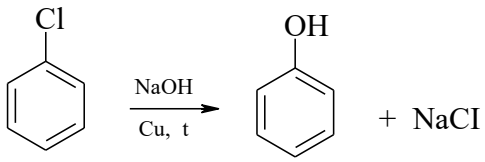
According to the substitute nomenclature of IUPAC, the names of phenols are formed from the names of the corresponding arenes with the addition of the prefix hydroxy-. The word - phenol is most often used as the basis for the names of phenol homologues.

The structural isomerism of phenols is due to the isomerism of the position of the substituents, as is the case with the three isomeric cresols o-, m-, n-CH3C6H4OH. Another option is also possible, when the isomerism is caused by structural changes of the substituents, for example, CH3-CH2-CH2-C6H4-OH - propylphenol and (CH3)2CH-C6H4-OH - isopropylphenol.

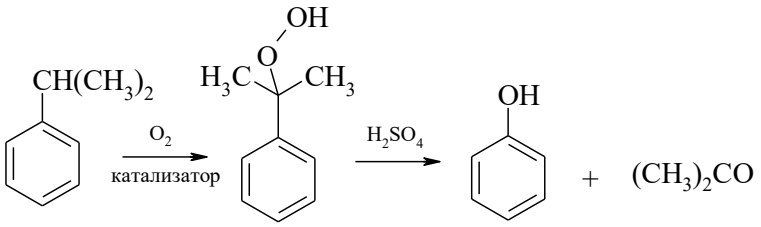
Methods of obtaining

Natural sources are coal tar, from which F. Runge isolated phenol for the first time in 1834; cresols are also released. Phenol and cresols are also formed during the cracking of oil. However, phenol is mainly obtained by synthetic methods.

Synthesis of phenol by hydrolysis of chlorobenzene:



Synthesis of phenol from isopropylbenzene (cumene):



Oxidative decarboxylation of aromatic carboxylic acids:

$$C6H5–C(O)OX \xrightarrow{O_2, H_2O, 200–300°C, Cu^{2+}} C6H5–OH + CO2.$$

Obtaining from aryldiazonium salts:

$$[C6H5–N+\square N]Cl– + H2O \rightarrow C6H5–OH + N2 + HCl.$$

Physical and chemical properties

The simplest phenols are viscous liquids or low-melting solids with a specific persistent smell ("carbolic smell"). Phenol is soluble in water, other phenols are sparingly soluble in water. Most phenols are colorless substances, but due to oxidation by oxygen in the air, they can acquire a dark color.

All possible reactions of phenols are divided into reactions involving O-H, C-O bonds, aryl radical, as well as reduction and oxidation reactions.

Acid properties. Phenols are stronger OH-acids than alcohols as a result+ **M**- effect of the OH group; in addition, phenolate -C6H5–O–has increased stability due to the delocalization of the negative charge along the aromatic radical. Electron-accepting substituents in the ring (-NO2,-CN, Hal, etc.), especially in the para position, enhance the acidic properties of phenol, electron-donating substituents (-NH2,-OCH3, etc.) - reduce it. Unlike alcohols, phenols react with alkali solutions:

$$C6H5–OH + NaOH \rightleftarrows C6H5–ONa + H2O.$$

Formation of simple and complex esters:

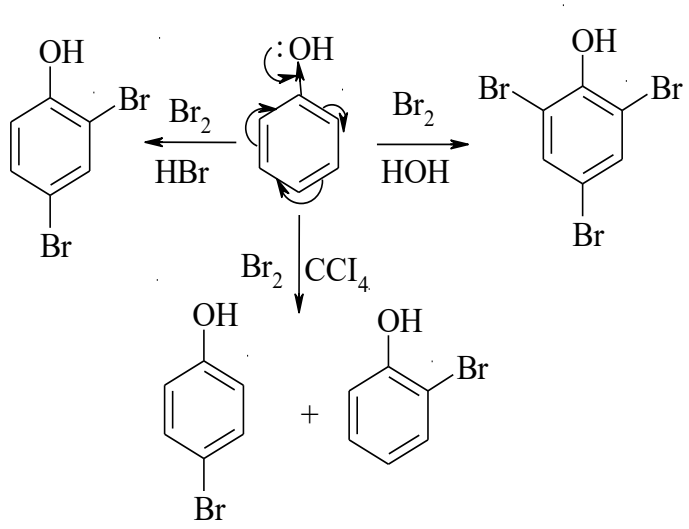
C6H5–ONa + C2H5–Br → C6H5–O–C2H5 + NaBr,

C6H5–OHa + (CH3)2SO4 → C6H5–O–CH3 + CH3OSO3Na.

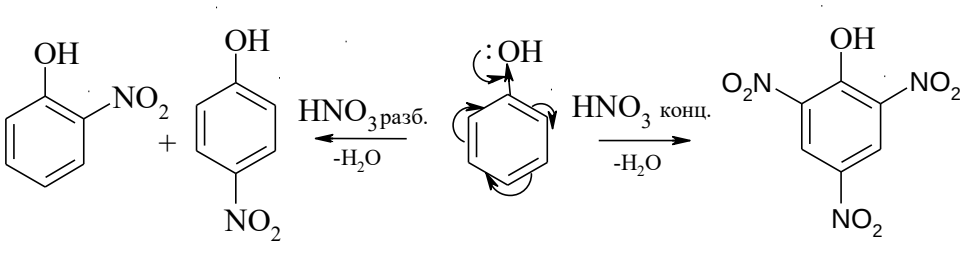
C6H5–ONa + CH3–C(O)Cl → C6H5–O–(O)C–CH3 + NaCl,

C6H5–OH + (CH3CO)2O → C6H5–O–(O)C–CH3 + CH3C(O)OH.

Reactions of electrophilic substitution in an aromatic ring(SE)

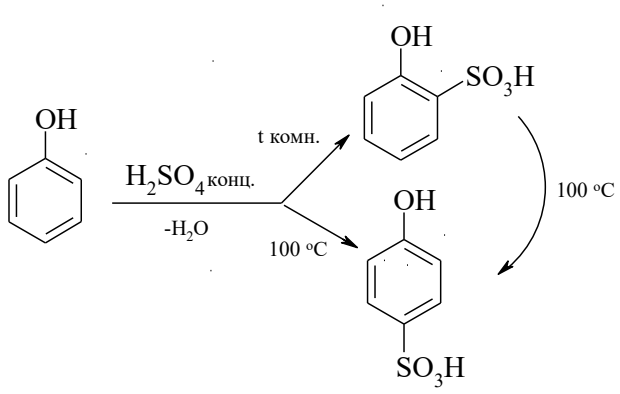


Halogenation:



Nitration:

Sulfation:



Nitrosation:

2C6H5–OH+2NaNO2+2HCl $\xrightarrow{20°C}$ 2-C6H4NO(OH)+4-C6H4NO(OH)+2NaCl+2H2O.

Alkylation and acylation:

2C6H5–OH + 2CH3OH $\xrightarrow{BF_3}$ 2-C6H4CH3(OH) + 4-C6H4CH3(OH) + 2H2O,

2C6H5–OH+2CH3C(O)Cl $\xrightarrow{AlCl_3}$ 2-C6H4C(O)CH3(OH)+4-C6H4CH3(OH)+2HCl.

Azo compounds:

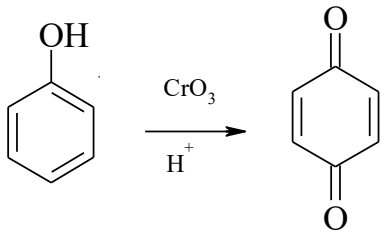
[C6H5–N+□N]Cl– + C6H5–OH $\xrightarrow{NaOH}$ C6H5–N=N–C6H4–OH + NaCl + H2O.

Synthesis of phenolcarbolic acids (Kolbe reaction):

C6H5–ONa + O=C=O $\xrightarrow{125°C,P}$ *at*-NaOOC–C6H4–OH $\xrightarrow{HCl}$ *at*-HOOS–C6H4–OH.

Reduction and oxidation reactions:

$$WITH_6H5–OH \xrightarrow{H_2,Ni} C6H11–OH,$$



$$C6H5–OH \xrightarrow{K_2S_2O_8,OH^-} n\text{-}HO–C6H4–OH.$$

Identification of monoatomic phenols - color reaction with FeCl3 (purple for phenol, blue for cresols); reaction of azo coupling with diazonium salts (formation of azo dyes).

The most important representatives of phenols

Phenol- colorless crystals that turn pink in air (bp. 43 ºC, boiling point 182 ºC), dissolves in water (at 15 ºC - about 8%), toxic, causes burns. It has antiseptic properties, in the form of a 5% aqueous solution it is used as a disinfectant. It is widely used in the production of plastics, dyes, explosives, and medicines.

o-, m-, p-Cresols- used for obtaining plastics, dyes, etc. A mixture of isomeric cresols is used in veterinary practice as a disinfectant (Lysol, Creolin).

Thymol(2-isopropyl-5-methylphenol) - a crystalline substance (p.p. 50 ºC, boiling point 232.9 ºC), well soluble in ethanol, diethyl ether, benzene. It is used in medicine as an antiseptic and anthelmintic, used in the production of menthol.

Pyrocatechin(o-dihydroxybenzene) - a crystalline substance (b.p. 105 ºC, b.p. 245 ºC), soluble in water and alcohols, acquires a brown color in light and air. Has antiseptic properties, is used as a starting substance in the synthesis of adrenaline; used in photography as a developing substance.

Resorcinol(m-dihydroxybenzene) is a crystalline substance (m.p. 110 ºC, boiling point 178 ºC), soluble in water. A good antiseptic in the treatment of skin diseases (as part of lotions and ointments), used in the production of dyes, resorcinol-formaldehyde resins.

Pyrogallol(1,2,3-trihydroxybenzene) - a white crystalline substance (m.p. 134 ºC, m.p. 309 ºC), soluble in water, alcohols; it gets darker in the light. A strong reducing agent, it reacts extremely quickly with oxygen in an alkaline solution, therefore it is used to absorb 2O in gas analyzers. It is used in the production of dyes, as a reducing agent in organic synthesis, and a developer in photography.

5. Mercaptans.

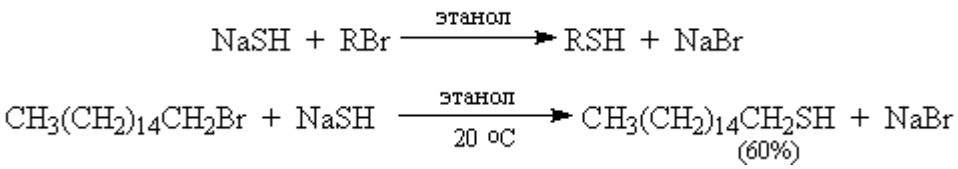
Thiols are derivatives of hydrocarbons in the molecules of which one or more hydrogen atoms are replaced by the -SH mercapto group.

Compounds of this class are also called mercaptans. The nomenclature of thiols is similar to the nomenclature of alcohols; instead of the suffix -ol, the suffix -thiol is used, or instead of the prefix hydroxy-, the prefix mercapto- is used, for example: CH3SH - methanethiol (methyl mercaptan), C6H5SH - mercaptobenzene (thiophenol).

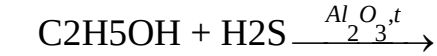
Thiols, with the exception of methanethiol, are liquid or solid substances, their boiling and melting points, as a rule, are lower than OH analogues, which is due to the lower EO of the sulfur atom compared to the oxygen atom and, accordingly, less tendency to form H-bonds. Mercaptans dissolve worse in water than alcohols and phenols, are poisonous and have an extremely unpleasant smell.

Methods of obtaining

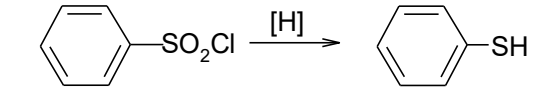
1. *Interaction of haloalkanes with hydrosulfide of alkali metals:*



2. *Interaction of primary alcohols with hydrogen sulfide:*



3. *Reduction of arenesulfonic acids and arenesulfonic chlorides:*



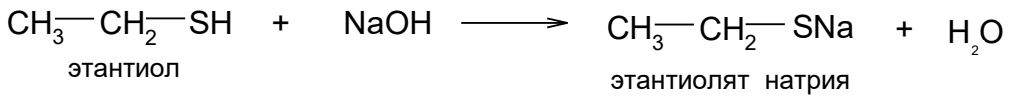
бензолсульфонил хлорид бензолтиол
тиофенол

Zinc in sulfuric acid solution or lithium aluminum hydride LiAlH4 are used as reducing agents.

Chemical properties

Mercaptans are somewhat similar to OH-derivatives of hydrocarbons, but differ from them in that the strength of the SH bond is reduced compared to OH in alcohols and phenols. Therefore, mercaptans have more pronounced acidic properties; reactions of thiols are mainly caused by the ionization of the SH bond and the nucleophilic properties of the S atom.

Formation of thiolates:



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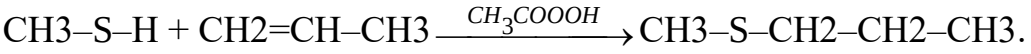
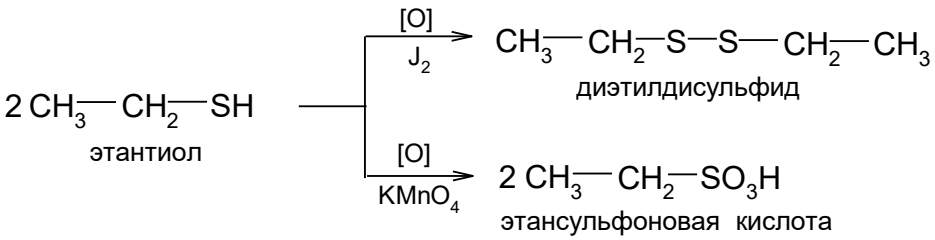
The interaction of thiols with alkenes:



Acylation of thiols:

Oxidation of thiols:



6. Simple ethers and sulfides.

Simple ethers ROR' and sulfides RSR' can be considered as derivatives of alcohols, phenols (thiols), formed as a result of replacing the hydrogen atom of the OH- (SH-) group with a hydrocarbon residue.

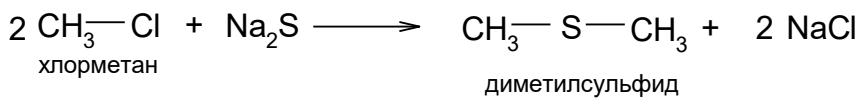
Sulfides (thioethers) are thioanalogues of ethers.

Methods of obtaining

Interaction of alcoholates (thiolates) with alkyl halides:

R–O(S)Na + R′–Br → R–O(S)–R′ + NaBr.

Symmetric sulfides are obtained by the interaction of alkyl halides with sodium sulfide:



Intermolecular dehydration of alcohols:

2C2H5–OH $\xrightarrow{t,H^+}$ C2H5–O–C2H5 + H2O.

Interaction of sulfur halides with arenes:

Chemical properties

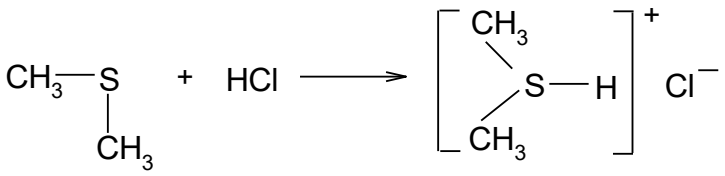
Chemically, ethers are inert substances. Due to the NEP of the O atom, ethers exhibit weak basic properties, forming oxonium salts with strong mineral acids. Concentrated hydroiodic acid splits the ether bond:

CH3–O–CH3 + HI → CH3OX + CH3I.

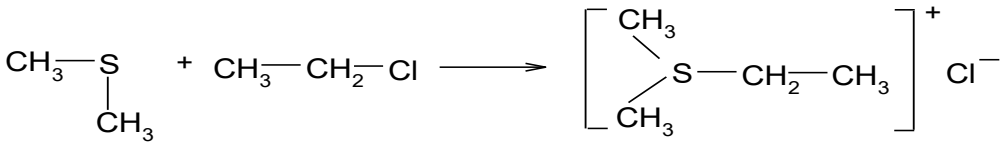
Concentrated mineral acids (HCl, H2SO4, HNO3, etc.) form oxonic compounds with simple ethers; the center of protonation is the oxygen atom:

CH3CH2–O–CH2CH3 + HCl → [CH3CH2–OX–CH2CH3]+Cl–.

Sulfides, like simple ethers, exhibit the properties of weak bases and are protonated in an acidic environment with the formation of sulfonium salts, for example:



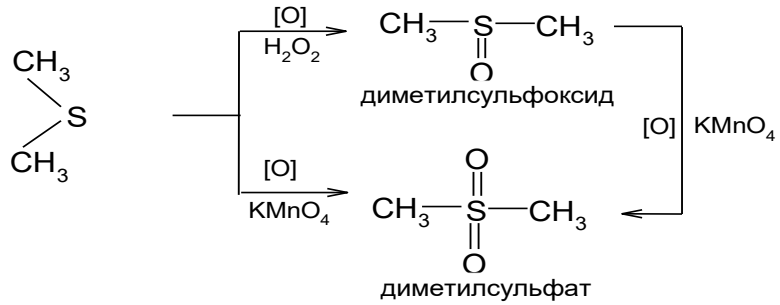
Alkylation of sulfides with alkyl halides leads to the formation of fairly stable trialkylsulfonium salts:



хлористый диметилэтил сульфоний

Oxidation of ethers. With prolonged exposure to air, simple ethers are oxidized to form explosive hydroperoxides RO-OH and peroxides ROOR, which prevents the distillation of ethers dry due to the danger of explosions. To destroy peroxides, the ether is treated with a reducing agent. Store peroxide-free ethers over metallic sodium or calcium hydride.

Oxidation products of sulfides, depending on the use of oxidizing agents and reaction conditions, are sulfoxides or sulfones:



диметилсульфоксид

диметилсульфат

Reactions with salts of heavy metals. Sulfides easily react with salts of heavy metals to form complexes, for example:

$$R2S + HgCl2 \rightarrow R2S \cdot HgCl2.$$

This reaction is used in analysis to identify sulfides. In addition, the use of some sulfides as antidotes for poisoning by heavy metal salts is based on this reaction.

Individual representatives

Diethyl ether(ethoxyethane)C2H5–O–C2H5.Colorless, volatile, flammable liquid with a specific smell (boiling point 36.5 ºC), which forms an explosive mixture with air. Miscible with most organic solvents, immiscible with

water, much lighter than the latter. Widely used as a solvent; in medicine - as a drug for general anesthesia.

Dioxane(1,4-dioxane). Transparent colorless liquid, miscible with water. Effective solvent of organic compounds.

Anisole(methoxybenzene, methyl phenyl ether)C6H5–O–CH3.Liquid, miscible with organic solvents, immiscible with water. Irritates mucous membranes. It is used in the production of aromatic substances.

Phenetol(ethoxybenzene, phenylethyl ether)C6H5–O–C2H5. Colorless liquid, miscible with ethanol, ether and other organic solvents, practically immiscible with water. It is used as a solvent and in the production of aromatic substances.

Dimethyl sulfideCH3-S-CH3. A colorless liquid with an unpleasant odor, used for the production of dimethyl sulfoxide.

Yperite(β, β'-dichlorodiethyl sulfide)ClCH2CH2–S–CH2CH2Cl.Colorless crystalline substance, poorly soluble in water, well - in organic solvents (b.p. 157 ºC). Technical mustard is a brownish liquid with a mustard smell. Extremely poisonous - combat toxic substance (BOV) of skin-irritating and general toxic effect. The lethal concentration of mustard gas in contact with the skin is 70 mg/kg. Chlorinating and oxidizing agents are used for degassing.

Diaphenyl sulfone(4,4' diaminodiphenylsulfone)H2NC6H5–SO2–C6H5NH2.It is used in medicine as a drug for the treatment of leprosy.

Dimexide(dimethyl sulfoxide, DMSO)(CH3)2S=O.Colorless liquid (bp. 189 ºC). Organic solvent, widely used in organic synthesis, industry. It is used as a drug with anti-inflammatory, analgesic and antimicrobial effects. It is mainly used for external use (lotions, ointments, solutions, etc.).

Cystamine dihydrochloride(bis-β-aminoethyl disulfide dihydrochloride) H2N-CH2CH2-SS-CH2CH2-NH2·2HCl. It is used as a medicine for the prevention of radiation sickness.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1.Classification,.methods of obtaining, properties, structure, reactivity of one-,di-, tri- and polyatomic alcohols.

2. Classification, production methods, properties, structure, reactivity of mono-, di-, tri- and polyatomic phenols.

3.Thio-alcohols (thiols, mercaptans). Nomenclature, extraction methods, physical and chemical properties.

4. Thioethers (sulfides). Nomenclature, extraction methods, physical and chemical properties.

5.Simple ethers. Nomenclature,isomerism, production methods, physical and chemical properties, reactivity.

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2. General workshop on organic chemistry / V.P. Chernykh, I.S. Hrytsenko, M.O. Lozinskyi, Z.I. Kovalenko; Under the editorship V.P. Black people – Kh.: NfaU Publishing House; Golden Pages, 2003. – 592 p.

3. Biological and bioorganic chemistry: teaching. study guide universities/A.A. Mardashko, L.M. Myronovych, G.F. Stepanov. - K.: Caravella, 2008. - 248 p.

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5. Grandberg I.O., Nam N.L. Organic chemistry. Textbook for universities. - K.: Drofa, 2009. - 375 p. 6. State Pharmacopoeia of Ukraine. - 1st ed., Addendum 3. - Kh.: State enterprise "Ukrainian Scientific Pharmacopoeia Center for the Quality of Medicinal Products", 2009. - 280 p.

7. State Pharmacopoeia of Ukraine. - 1st ed., Addendum 2. - Kh.: State enterprise "Scientific-expert pharmacopoeial center", 2008. - 620 p.

8. State Pharmacopoeia of Ukraine. – 1st ed., Addendum 1. – Kh.: RIREG, 2004. – 494 p.

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Lecture No. 10

Topic: Aldehydes and ketones.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, means of extraction, physical and chemical propertiesaldehydes and ketones.

Basic concepts: Aldehydes. Ketones.Dialdehydes.Diketones.

Quinones.

Plan and organizational structure of the lecture:

1. Saturated aldehydes and ketones.
2. Dialdehydes and diketones.
3. Aromatic aldehydes and ketones.
4. Quinones.

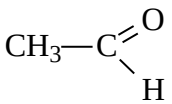
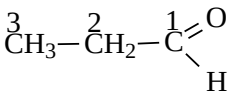
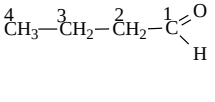
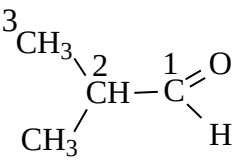
Content of lecture material (lecture text)

*Aldehydes and ketones are derivatives of hydrocarbons containing a carbonyl group > C = O.*Therefore, they are also called carbonyl compounds. The general formulas of aldehydes and ketones are RC (= O) H and RC (= O) -R, respectively; the group -C (O) H was called an aldehyde group, the carbonyl group in ketones is often called a keto group.

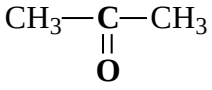
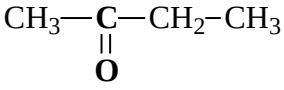
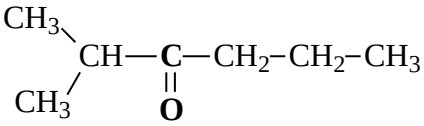
Depending on the structure of the hydrocarbon radical, aldehydes and ketones are divided into aliphatic, alicyclic, and aromatic. Among aliphatic aldehydes and ketones, saturated and unsaturated are distinguished.

1. Saturated aldehydes and ketones.

Trivial and systematic names are used in the nomenclature of aldehydes and ketones: the trivial names of aldehydes come from the name of the acids into which they turn during oxidation. According to the substitute nomenclature of IUPAC, the names of aldehydes are formed from the name of a hydrocarbon with the same number of carbon atoms (including the carbon of the aldehyde group), adding the suffix -al. The numbering of the main carbon chain begins with the C atom of the aldehyde group, for example: H-C (O) H - formic aldehyde, methanal; CH3-C (O) H - acetaldehyde, ethanal, etc.:

			
ethanal	propanal	butanal	2-methylpropanal

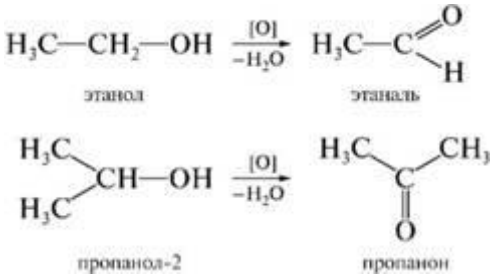
Radical-functional nomenclature is widely used for the names of ketones, according to which the suffix -ketone is added to the names in alphabetical order of hydrocarbon radicals with a carbonyl group, for example:

1	2	3
		
dimethyl ketone	methyl ethyl ketone	propyl isopropyl ketone

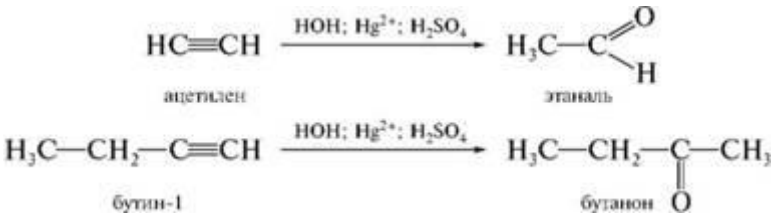
Carbonyl compounds are characterized by structural isomerism. Aldehydes and ketones containing the same number of carbon atoms are isomers. For example, propanone CH3-C(O)-CH3 and propanal CH3-CH2-C(O)H are structural isomers. The isomerism of aldehydes and ketones can be associated with a different structure of the carbon chain.

Methods of obtaining

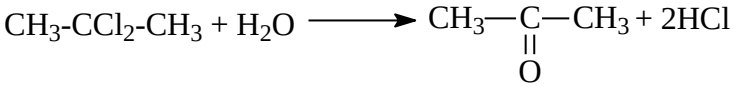
1. Oxidation of alcohols - primary alcohols are oxidized to aldehydes, secondary alcohols to ketones:



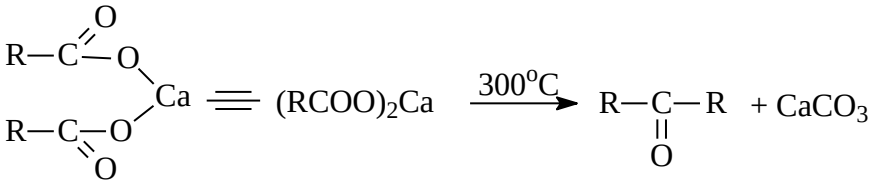
2. Hydration of alkynes (Kucherov reaction):



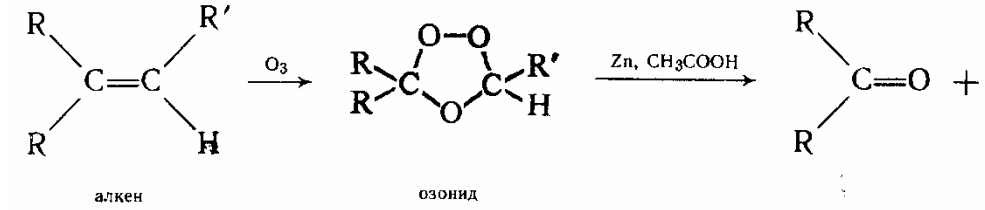
3. Hydrolysis of geminal alkyl dihalides:



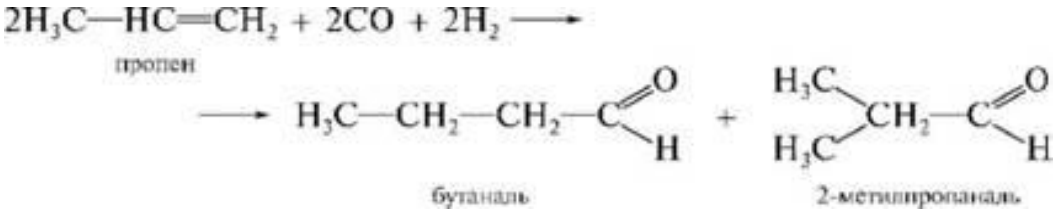
4. Pyrolysis of salts of carboxylic acids:



5. Ozonolysis of alkenes:



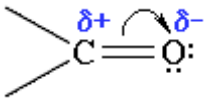
6. Oxosynthesis:
7.



Physical and chemical properties

Formic aldehyde is a gas, lower aldehydes and ketones are volatile liquids that boil at a lower temperature than the corresponding alcohols, due to the lack of ability to form H-bonds. Aldehydes and ketones dissolve well in organic solvents, lower - soluble in water. Most aldehydes and ketones have a characteristic smell.

The chemical properties of aldehydes and ketones are determined by the presence in their molecules of the aldehyde group > C = Oδ, the double bond of which is strongly polarized:



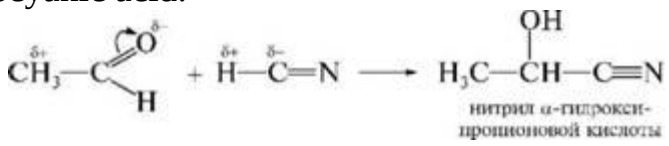
Thanks to such polarization, aldehydes and ketones are able to react with nucleophilic reagents that attack the C atom of the carbonyl group. Aldehydes, as a rule, are more reactive than ketones due to a more significant reduction of the effective charge δ+ on the C atom of the carbonyl group of the latter as a result of the +I effect of two alkyl radicals. In addition, alkyl radicals in the ketone molecule make it more difficult for the nucleophile to approach the carbonyl group.

All reactions of aldehydes and ketones can be divided into the following groups:

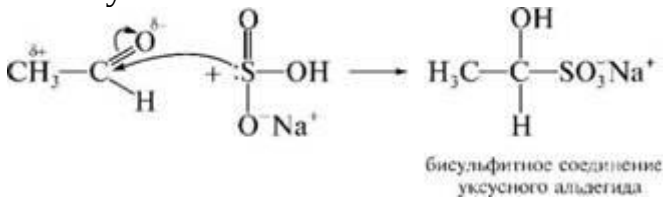
· nucleophilic addition;
· joining-splitting;
· condensation;
· with the participation of an α-carbon atom;
· polymerization;
· oxidation-reduction.

Nucleophilic addition reactions(AN)

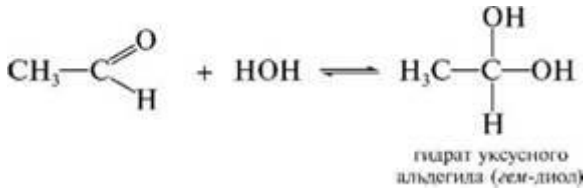
Addition of hydrocyanic acid:



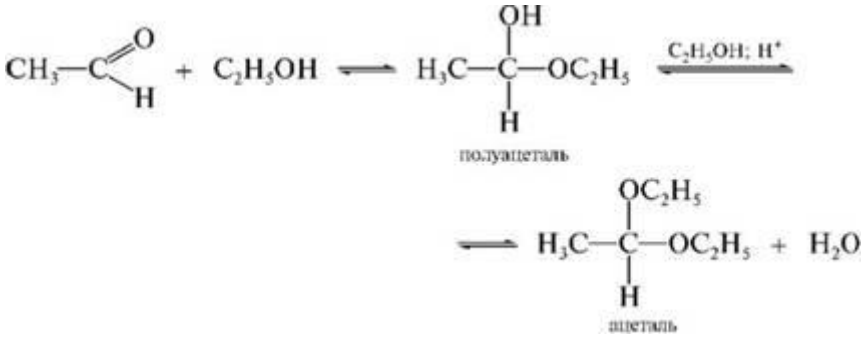
Addition of sodium hydrosulfite:



Adding water:



Addition of alcohols:



Interaction with Grignard reagents is one of the important ways of synthesizing alcohols:

CH3–C(O)H+C2H5–MgBr→(CH3)2(C2H5)C–OMgBr $\xrightarrow{+H_2O}$ (CH3)2(C2H5)C–OH.

Addition-cleavage reactions

Aldehydes and ketones interact with nitrogenous bases H2N-X (X = H, Alk, Ar, OH, NH2, etc.) with the formation of unstable products of nucleophilic addition, which are stabilized by splitting off a water molecule.

Interaction with ammonia:

CH3–C(O)H + NH3 ⇄ CH3–CH(OH)–NH2 ⇄ CH3–CH=NH + H2O.
acetaldehyde

Aldimines are unstable compounds; their spontaneous cyclization leads to the formation of six-membered rings.

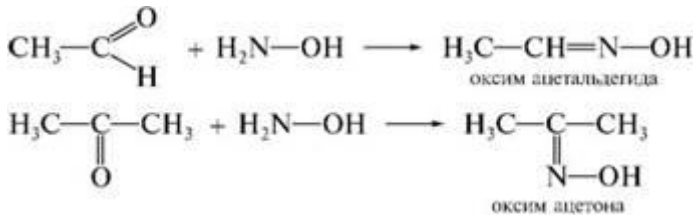
Interaction with amines:

R–C(O)H + R′–HH2 ⇄ R–CH=N–R′ + H2O.

Names

If R' is an alkyl radical, then such imines are easily decomposed or polymerized, if R' is an aryl radical, then imines are stable. Substituted imines are also called Schiff bases.

Interaction with hydroxylamine. Condensation products of aldehydes and ketones with hydroxylamine are called aldoximes and ketoximes, respectively:



Aldoximes and ketoximes are crystalline substances with a clear melting point, easily hydrolyzing in an acidic environment with the formation of starting compounds. Therefore, the reaction of the formation of oximes is used for the isolation and identification of aldehydes and ketones.

Interaction with hydrazine and its derivatives. Aldehydes and ketones react with hydrazine, phenylhydrazine, semicarbazide, and thiosemicarbazide to form hydrazones, phenylhydrazones, semicarbazones, and thiosemicarbazones, respectively:

RR′C=O + H2N–HH2 → RR′C=N–HH2 + H2O,

RR′C=O + H2N–C6H5 → RR′C=N–HH–C6H5,

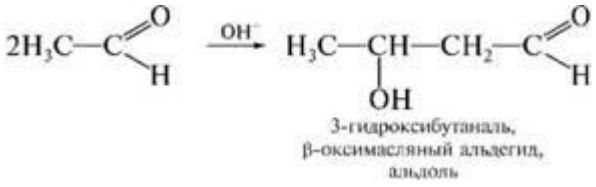
RR′C=O + H2HH–C(O)–HH2 → RR′C=NNH–C(O)–HH2 + H2O,

RR′C=O + H2NNH–C(S)–HH2 → RR′C=NNH–C(S)–NN2 + H2O.

The products of these reactions, like oximes, crystallize well and are used for the identification of aldehydes and ketones, as well as their isolation from mixtures.

Condensation reactions

Aldol condensation:



Complex ether condensation (Tishchenko reaction):

$$2CH3–C(O)H \xrightarrow{Al(OC_2H_5)_3} CH3–C(O)–OCH2CH3.$$

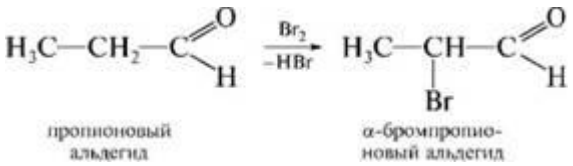
Ethyl acetate

In this reaction, one aldehyde molecule is reduced to an alcohol, and the second is oxidized to an acid (disproportionation reaction).

Reactions involving the α-carbon atom

The carbonyl group as an electron-withdrawing substituent increases the mobility of hydrogen atoms at the α-carbon atom (CH-acidity).

Halogenation reaction:

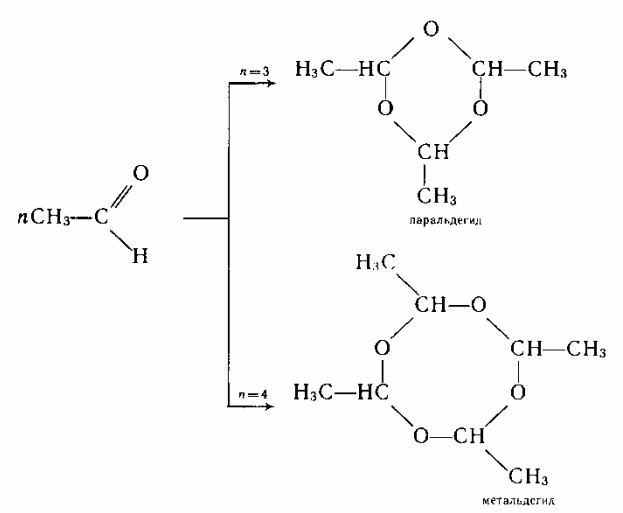


α-Halogen derivatives of aldehydes and ketones have a lachrymatory effect and are called a lacrimator (from the Latin lacrima - tear).

Polymerization reactions:

*n*H2C=O + H2O → OH–CH2–(OSH2)n–OH. Paraform

Cyclic products of acetaldehyde polymerization are paraldehyde (trimer, reaction is carried out at 20 ºC) and metaldehyde (tetramer, reaction at 0 ºC). Metaldehyde is a solid substance used as a dry fuel under the name "dry alcohol".

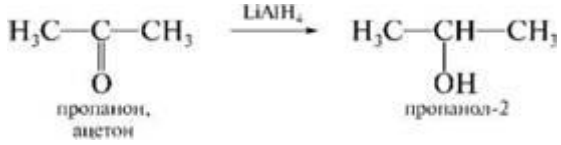


The polymerization reaction is reversible, when polymer products are heated with mineral acids, their depolymerization occurs.

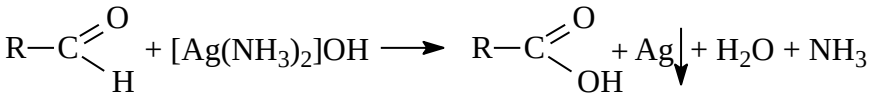
Reduction and oxidation reactions

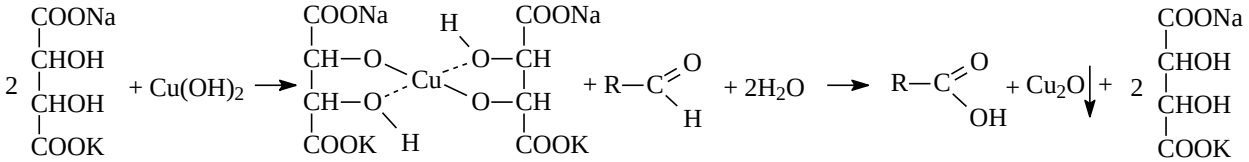
Recovery reactions:

$$R–C(O)H \xrightarrow{H_2,kat} R–CH2OH,$$



Oxidation reactions:





Oxidation reactions of aldehydes[Ag(NH3)2]OHand Fehling's reagent are used in analytical practice to detect the aldehyde group. Ketones are not oxidized under these conditions, so these reactions can be used to distinguish aldehydes from ketones.

Oxidation of ketones occurs only in the presence of strong oxidants, such as KMnO4 or K2Cr2O7. At the same time, C-C bonds between the carbon atoms of the carbonyl group and the hydrocarbon radical are broken, as a result of which a mixture of acids is formed:

$$CH3–C(O)–CH2–CH3 \xrightarrow{[O]} H–C(O)OH + 2CH3–C(O)OH + CH3–CH2–C(O)OH.$$

Individual representatives

Formic aldehyde(formaldehyde, methanal) CH2O is a colorless gas with a pungent odor, soluble in water. A 37-40% aqueous solution of CH2O, to which 6-15% methanol is added as a polymerization inhibitor, is called formalin. Formalin is used as a disinfectant, tanning agent and preservative for anatomical preparations. In medicine, the condensation product of formaldehyde and ammonia is used - hexamethylenetetramine (the drug urotropin). In industry, formaldehyde is used in the production of phenol-formaldehyde, urea-formaldehyde, melamino-formaldehyde resins, and polyformaldehyde.

Acetic aldehyde(acetaldehyde, ethanal)CH3CHO- colorless liquid with a pungent odor (boiling point 20 ºC), miscible with water, ethanol, diethyl ether in all proportions. It is used to obtain acetic and peracetic acids, acetic anhydride, ethyl acetate, chloral.

Acetone(dimethyl ketone, propanone) CH3COCH3 is a colorless liquid (b.p. 56.2 ºC), miscible with water and organic solvents. It is used as a solvent for organic substances (varnishes, nitrocellulose), in the production of methyl methacrylate, methyl isobutyl ketone, isophorone, and as a starting material in the synthesis of some medicines, for example, iodoform.

2. Dialdehyde and wild tones.

The simplest representative of dialdehyde is glyoxal or ethanedial, and diketones are diacetyl or butanedione:

OHC–CHO CH3–C(O)–C(O)–CH3
glyoxal diacetyl

Glyoxal is a crystalline substance, and diacetyl is a liquid, both substances are colored yellow. Glyoxal and diacetyl can be obtained by careful oxidation of the corresponding diatomic alcohols: ethylene glycol and butanediol-2,3. They have all the properties of carbonyl compounds; one or two carbonyl groups can react.

When glyoxal is oxidized, oxalic acid is formed:

$$OHC\text{-}CHO \xrightarrow{[O]} NOOS\text{-}SOON.$$

Under the conditions of the Cannizzaro reaction, glyoxal turns into glycolic acid, that is, an intramolecular oxidation-reduction reaction occurs:

$$OHC\text{-}CHO \xrightarrow{KOH} NOSN2C–SOOK.$$

When interacting with hydroxylamine, depending on the ratio of reagents, mono- or dioximes are formed:

$$OHC–CHO + H2N–OH \rightarrow OHC–CH=N–OH + H2O,$$

$$OHC–CH=N–OH + H2N–OH \rightarrow HO–N=CH–CH=N–OH + H2O.$$

Due to its ability to form intracomplex compounds with a number of metal cations, dimethylglyoxime has found application in analytical practice as a reagent for detecting nickel (+2) - Chugaev's reagent (with Ni2+ salts it forms a red-violet precipitate of a chelate complex).

Glyoxal and diacetyl are used in the synthesis of various heterocycles. Diacetyl is contained in butter and determines its smell, therefore it is used in the food industry as a flavoring agent for butter, margarine, and cheese.

3. Aromatic aldehydes and ketones.

Aromatic aldehydes are divided into two groups: containing an aldehyde group in the benzene nucleus and in the side chain. The simplest representative of the first group is benzaldehydeC6H5–CHO, which got its name from the acid it turns into during oxidation.

Aldehydes, in which the aldehyde group is in the side chain, are called fatty aldehyde derivatives. The position of the phenyl radical is usually indicated by letters of the Greek alphabet, for exampleC6H5–CH2–CHO –phenylacetaldehyde, C6H5-CH2-CH2-CHO - β-phenylpropionic aldehyde.

Aromatic ketones are also divided into two groups: purely aromatic and fatty-aromatic. The first one includes ketones in which the carbonyl group is connected to two aryl radicals; if one of the radicals is aliphatic, then such ketones are classified as fatty-aromatic.

For the names of aromatic ketones, the radical-functional nomenclature is most often used. Trivial names are also widely used, for exampleC6H5–C(O)–CH3 – acetophenone (methylphenylketone), C6H5-C (O)-C6H5 - benzophenone (diphenylketone).

Methods of obtaining

Aromatic aldehydes and ketones can be obtained using the methods used for the synthesis of their aliphatic analogues - oxidation reactions of the corresponding alcohols, saponification of geminal dihalogen derivatives, pyrolysis of calcium salts of carboxylic acids, etc. At the same time, there are a number of specific methods for obtaining aromatic aldehydes and ketones.

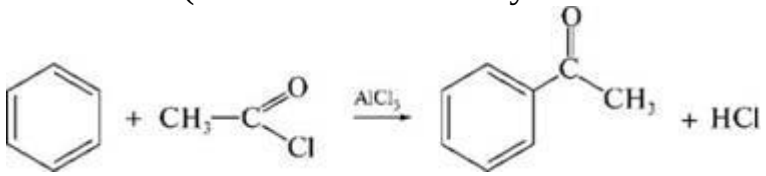
Oxidation of aromatic hydrocarbons:

$$C6H5–CH3 \xrightarrow{CrO_3,(CH_3CO)_2O} C6H5–CH(OCOCH3)2 \xrightarrow{+H_2O,H^+} C6H5–CHO.$$

Gutterman-Koch reaction (formulation reaction):

$$WITH_6H5–CH3 + CO + HCl \xrightarrow{Cu_2Cl_2,AlCl_3} n\text{-}CH3C6H4–CHO.$$

Friedel-Crafts reaction (the main method of synthesis of aromatic ketones):



Physical and chemical properties

Aromatic aldehydes and ketones are liquids or solids that are insoluble in water. Aromatic aldehydes have the smell of bitter almonds, with the removal of the aldehyde group from the benzene nucleus, the smell becomes sharper. Acetophenone has a sour cherry smell.

In terms of chemical properties, aromatic aldehydes and ketones in some ways resemble aliphatic analogues. Aromatic aldehydes give a "silver mirror" reaction, form acetals, cyanohydrins, hydrosulfite compounds, aldoximes, hydrazones, azomethines. However, they do not undergo aldol condensation, polymerize with great difficulty, and react with ammonia in other ratios.

Aromatic ketones are less reactive than fatty ketones: they do not form hydrosulfite compounds, benzophenone does not react with hydrocyanic acid.

In addition, aromatic aldehydes and ketones give a number of specific reactions.

Cannizzaro reaction (discovered in 1853 by the Italian chemist S. Cannizzaro):

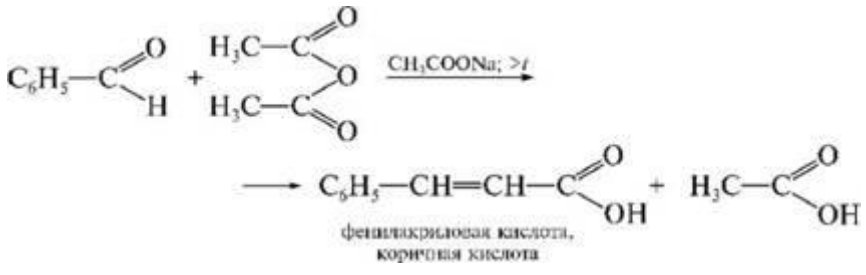
$$2C6H5–CHO \xrightarrow{KOH} C6H5–COOK + C6H5–CH2OH.$$

Cross aldol condensation. In the presence of bases, aromatic aldehydes are capable of entering into a condensation reaction with aldehydes containing mobile hydrogen atoms at the α-carbon atom:

$$C6H5–CHO + CH3–CHO \rightarrow C6H5–CH=CH–CHO + H2O.$$

cinnamic aldehyde

Perkin condensation (reaction of aromatic aldehydes with anhydrides of aliphatic carboxylic acids, which leads to unsaturated acids):



Benzoic condensation:

$$2C6H5–CHO \xrightarrow{CN^-} C6H5–CH(OH)–C(O)–C6H5.$$

Halogenation:

$$C6H5–CHO + Cl2 \rightarrow C6H5–C(O)Cl + HCl.$$

Benzoic acid chloride

In the case of aliphatic aldehydes, the reaction proceeds along the alkyl radical.

Electrophilic substitution reactions in the benzene ring(sulfonation, nitration, etc.; the aldehyde group orients the substituent in the m-position):

$$C6H5–CHO + HNO3 \xrightarrow{H_2SO_4} m\text{-}H(O)C–C6H4–NO2 + H2O.$$

In reaction$S_E$aromatic aldehydes are less active compared to arenes, which is due to the electron-withdrawing effect of the aldehyde group on the benzene nucleus.

Individual representatives

Benzaldehyde C6H5–CHO –colorless liquid with the smell of bitter almonds (boiling point 179.2 ºC), formed during the hydrolysis of amygdalin glycoside contained in almonds, peach pits, apricots. Soluble in alcohol, practically insoluble in water. In air, benzaldehyde is easily oxidized to benzoic acid. It is used as a fragrant substance in perfumery and the food industry, as a raw material for obtaining arylmethane dyes and some fragrant substances (jasminaldehyde, cinnamic aldehyde, etc.).

Vanillin(4-hydroxy-3-methoxybenzaldehyde) - a crystalline substance (m.p. 81 - 83 ºC), well soluble in alcohol, ether, slightly soluble in water. Vanillin as a fragrant substance is used in the food and perfume industry, it is a starting substance in the synthesis of ftivazide - an anti-tuberculosis drug.

Acetophenone(methylphenyl ketone)C6H5–C(O)–CH3 –crystalline substance (p.p. 19.6 ºC, boiling point 202.3 ºC), soluble in alcohol, ether, benzene, insoluble in water. It is used as a fragrant substance in perfumery (the smell of cherry), as well as in the synthesis of some medicines.

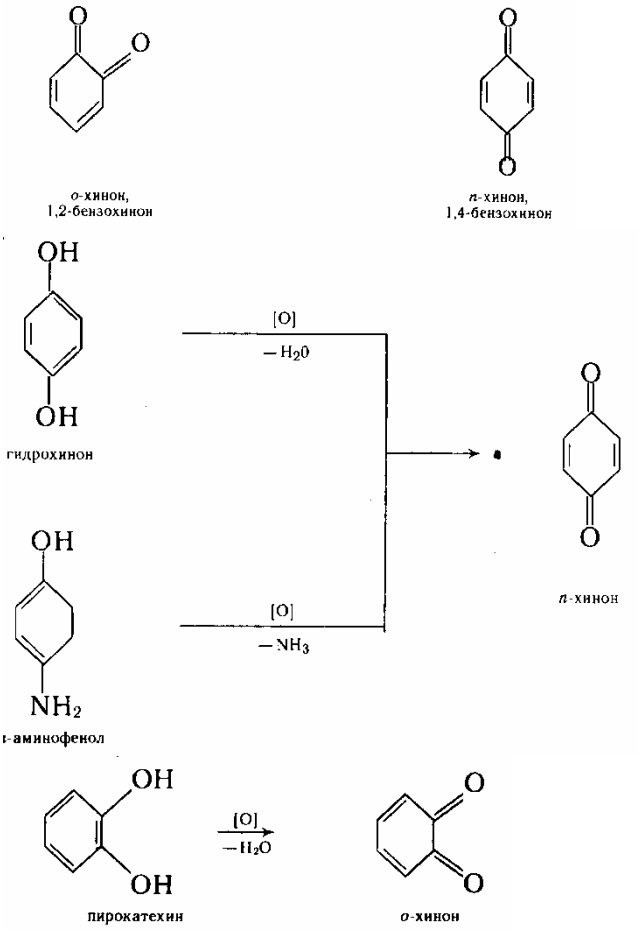
ChloracetophenoneC6H5–C(O)–CH2Cl –crystalline substance (p.p. 59 ºC, boiling point 245 ºC), poorly soluble in water, well - in organic solvents. A poisonous substance with a strong lachrymatory effect; intolerable concentration of 0.005 mg/l at exposure of 2 min. Protection against chloracetophenone - gas mask.

Benzophenone(diphenyl ketone)C6H5–C(O)–C6H5 –crystalline substance, soluble in ether, alcohol, benzene, insoluble in water. It was used in the production of aromatic substances and in the synthesis of dyes.

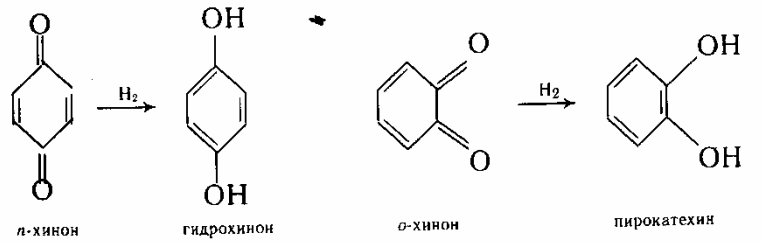
4. Quinones.

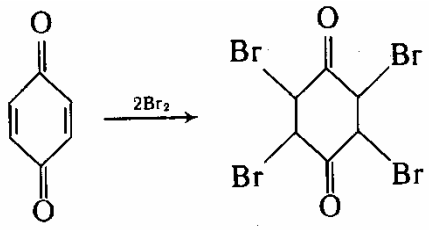
Quinones- *cyclic unsaturated diketones*

The simplest representatives of this class of compounds are o-quinone and p-quinone - crystalline substances of bright red and yellow color, obtained by oxidation of the corresponding diatomic phenols or aminophenols:

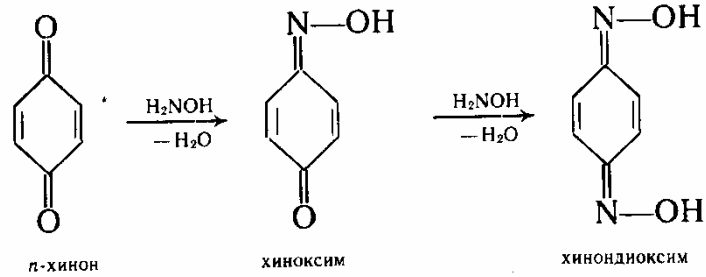


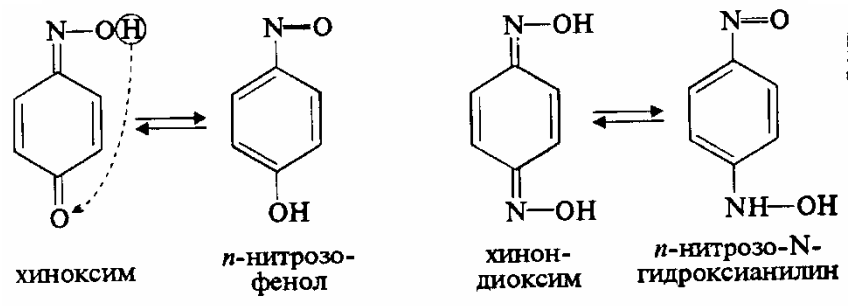
The chemical properties of quinones are due to the presence of multiple bonds of carbonyl groups in their structure: quinones are easily reduced to diatomic phenols, as unsaturated compounds they easily add bromine:



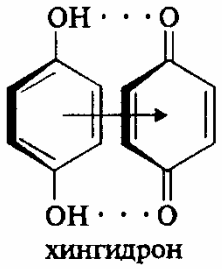


When p-quinone interacts with hydroxylamine, depending on the ratio of reagents, monooxime (quinoxime) or diox (quinodioxime) is formed:





With phenols, quinones form strong complexes with charge transfer. For example, with hydroquinone, p-quinone forms a stable compound (1:1) known as quinhydrone:



General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1.Classification, nomenclature, isomerism, methods of obtaining aliphatic and aromatic oxo compounds, physical and chemical properties.

2. Physical properties, electronic structure of the carbonyl group. Influence of the nature of the hydrocarbon radical on the reactivity of oxo compounds. Chemical properties.

3. Oxidation and reduction of oxo compounds. Specific reactions of aldehydes of aliphatic and aromatic series.

4. Concept of dialdehydes, diketones, quinones.Classification, nomenclature, physical and chemical properties,identification of oxo compounds.

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Lecture No. 11

Topic: Monocarboxylic acids.Dicarboxylic acids.Functional derivatives of carboxylic acids.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, means of extraction, physical and chemical propertiescarboxylic acids,functional derivatives of carboxylic acids.

Basic concepts: Monocarboxylic acids. Dicarboxylic acids. Acid properties.Unsaturated carboxylic acids.Aromatic monocarboxylic acids. Halide anhydrides of carboxylic acids. Anhydrides of carboxylic acids. Complex esters of carboxylic acids. Amides of carboxylic acids. Hydrazides of carboxylic acids. Nitriles.

Plan and organizational structure of the lecture:

1. Classification.

2. Saturated monocarboxylic acids.

3. Unsaturated monocarboxylic acids.

4. Aromatic monocarboxylic acids.

5. Saturated, unsaturated and aromatic dicarboxylic acids.

6. Halide anhydrides of carboxylic acids.

7. Anhydrides of carboxylic acids.

8. Complex esters of carboxylic acids.

9. Amides of carboxylic acids.

Content of lecture material (lecture text).

1. Classification.

Carboxylic acids are derivatives of hydrocarbons containing the carboxyl group -COOH.

Depending on the nature of the hydrocarbon radical to which the carboxyl group is connected, aliphatic alicyclic and aromatic carboxylic acids are distinguished. According to the number of carboxyl groups, acids are divided into monocarboxylic (one group -COOH), dicarboxylic (two), tricarboxylic (three) and polycarboxylic (more than three). Aliphatic carboxylic acids are classified according to the degree of saturation of the hydrocarbon radical into saturated and unsaturated.

2. Saturated monocarboxylic acids.

Trivial nomenclature is very widely used in the names of carboxylic acids. For example, HCOOH - formic acid, CH3COOH - acetic acid, CH3-CH2-COOH - propionic acid, etc. The position of the substituents in relation to the -COOH group in trivial names is denoted by the Greek letters α-, β-, γ-, etc., for example Br-CH2-CH2-COOH - β-bromopropionic acid.

According to the substitute nomenclature of IUPAC, the names of carboxylic acids are formed from the names of the original hydrocarbons with the same number of carbon atoms, including the carbon atom of the -COOH group, to which -ova and acid are added. The numbering of the main carbon chain begins with the C atom of the -COOH group:

H–COOH CH3–CH2–COOH CH3–CH(CH3)–COOH methanoic acid propanoic acid 2-methylpropanoic acid

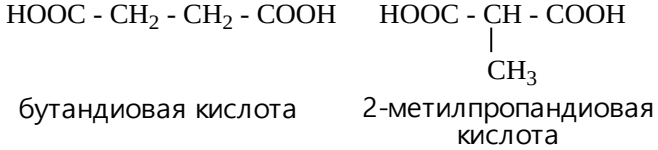
According to the rational nomenclature, saturated monocarboxylic acids are considered as derivatives of acetic acid, for example:

CH3-CH2-COOH CH3(C2H5)CH-COOH

methyl acetic acid methyl ethyl acetic acid

The residue of a carboxylic acid formed after the removal of a hydrogen atom from a carboxyl group is called an acyloxy group (R-COO-), and the residue formed after the removal of a hydroxyl group is called an acyl group (R-CO-).

The isomerism of saturated monocarboxylic acids is due to the different structure of the carbohydrate radical connected to the -COOH group. The first three representatives of the homologous series do not have isomers, the fourth homolog exists in the form of two isomers:



With an increase in the number of carbon atoms in a carboxylic acid molecule, the number of structural isomers increases sharply.

Methods of obtaining

1. Oxidation of primary alcohols and aldehydes:

$$R–CH2–OH \xrightarrow{[O]} R–COH \xrightarrow{[O]} R–COOH.$$

2. Oxidation of alkanes:

$$CH3–CH2–CH2–CH3 \xrightarrow{+O_2(катализ.)} 2CH3–COOH.$$

3. Hydrolysis of geminal trihalohydrocarbons:

$$R–CCl3 \xrightarrow{+H_2O(OH^- или H^+)} R–COOH.$$

4. Hydrolysis of nitriles:

$$R–C\equiv N \xrightarrow{+H_2O(OH^- или H^+)} R–C(O)NH2 \xrightarrow{+H_2O(OH^- или H^+)} R–COOH.$$

5. Interaction of Grignard reagents with*CO2*:

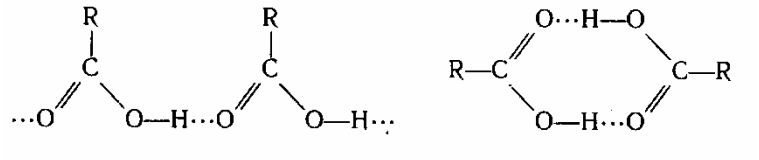
$$R–MgCl + CO2 \rightarrow R–COOMgCl \xrightarrow{+HCl} R–COOH + MgCl2.$$

6. Reppe reaction (hydrocarboxylation of alkenes, oxosynthesis):

$$CH2=CH2 + CO + H2O \xrightarrow{H_3PO_4,325°C,700am} CH3–CH2–COOH.$$

Physical and chemical properties

Lower carboxylic acids(C1 - C3)under normal conditions - easily mobile liquids with a sharp smell; acids from C4 - C9 - oily liquids with an unpleasant smell, reminiscent of the smell of sweat; acids from≥ C10 –solid substances. Formic acid, acetic acid and propionic acid are mixed with water in any ratio. As M acid increases, solubility in water decreases significantly. Higher carboxylic acids are insoluble in water. The boiling points of acids are much higher than the boiling points of alcohols with the same number of C atoms, indicating that acids are more associative than alcohols. Unlike alcohols, which are characterized only by linear associates, carboxylic acids form both linear and cyclic associates (dimers) due to H-bonds:



The reactivity of carboxylic acids is determined mainly by the presence in their structure of the -COOH group - a connected system in which the NEP of the O atom of the OH group pairs with the π-electrons of the C=O group (p, π-conjugation). As a result of the +M effect on the part of the OH group, the electron density shifts towards the O atom of the carbonyl NEP group, which is not involved in the coupling. As a result of the shift in electron density, the O-H bond turns out to be highly polarized, which leads to the appearance of an OH-acidic center in the carboxyl group. In addition, as a result of the -I effect of the carboxyl group in the

carboxylic acid molecule, the electron density is shifted from the hydrocarbon radical, which leads to the appearance of a C-H acid center at the α-carbon atom.

The main reactions of carboxylic acids, taking into account the peculiarities of their structure, can be conditionally divided into four groups:

· with the participation of the O-H bond (acidic properties);
· nucleophilic substitution involving the C atom of the carbonyl group;
· substitution of H atoms at the α-carbon atom;
· oxidation and reduction.

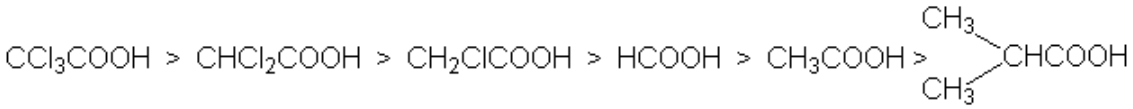
Acid properties

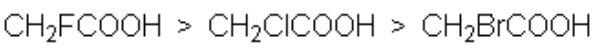
In aqueous solutions, carboxylic acids dissociate according to the scheme:

R–COOH + H2O ⇄ R–COO– + H3O+.

In the carboxylate ion, both O atoms are equivalent, and the negative charge is uniformly delocalized between them, which causes the high stability of the anion. Since the strength of acids is determined by the stability of the formed anion, carboxylic acids are superior to alcohols and phenols in their acidic properties, where the possibility of charge delocalization in the anion is less.

The strength of carboxylic acids is also influenced by the structure of the hydrocarbon radical bound to the -COOH group. Electron-donating substituents weaken the acidic properties (destabilization of the anion), while electron-accepting substituents, on the contrary, increase the stability of the anion, which leads to increased acidity. As the substituent moves away from the -COOH group, its influence on acid properties weakens. Acidity series of carboxylic acids:





Formation of salts:

2CH3–COOH + Zn → (CH3–COO)2Zn + H2,

2CH3–COOH + MgO→ (CH3–COO)2Mg + H2O,

SN3–COOH + NaOH → CH3–COOHa + H2O,

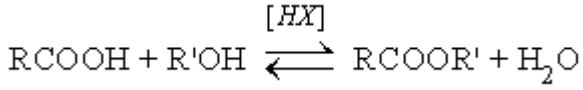
CH3–COOH + NaHCO3 → CH3–COOHa + CO2 + H2O.

Trivial Latin names of acids are often used in the names of salts of carboxylic acids. Formic acid salts have a common name - Formate, acetic - acetate, propionic - propionate, butyrate - butyrate, isobutyrate - isobutyrate.

Nucleophilic substitution reactions

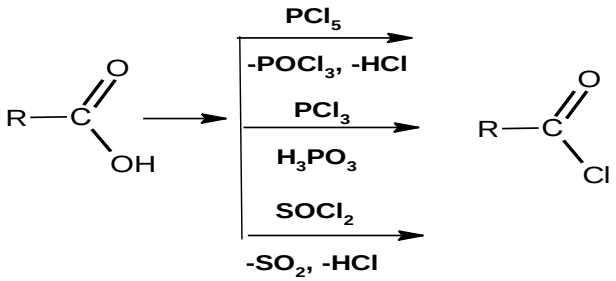
The carbon atom of the carboxyl group, which carries a partial positive charge, is an electrophilic center in the carboxylic acid molecule and can be attacked by a nucleophilic reagent. During the attack, the OH group is replaced by a nucleophilic particle.

Esterification reaction:



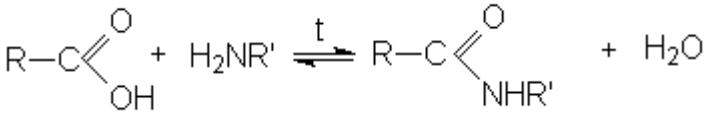
To shift the equilibrium towards the formation of a complex ether, either an excess of one of the reagents (usually alcohol) is used, or water is removed from the reaction medium. The easiest reaction of esterification is carried out with primary alcohols and lower carboxylic acids. Secondary alcohols and higher acids react more slowly, tertiary alcohols react with great difficulty due to steric hindrances. In addition, under the action of mineral acids, they easily undergo intramolecular dehydration with the formation of alkenes.

Interaction with halogenated reagents (PCl3, PCl5, SOCl2, etc.):

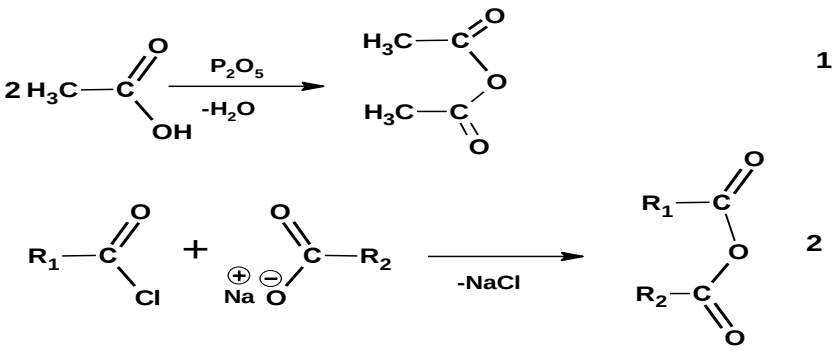


Interaction with ammonia and amines:

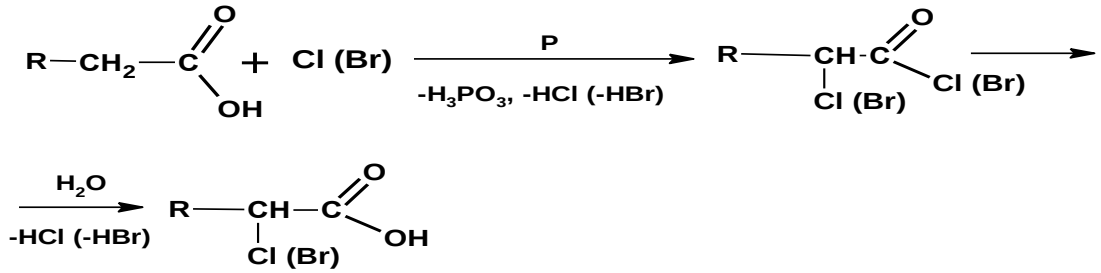
$$R–COOH + NH3 \rightleftarrows R–COONH4 \xrightarrow{200°C} R–CONH2 + H2O,$$



Formation of acid anhydrides:



Substitution of hydrogen at the α-hydrogen atom:



Oxidation and reduction

Monocarboxylic acids, with the exception of formic acid, are quite resistant to oxidation. Formic acid is easily oxidized by KMnO4 and other oxidizing agents to form carbonic acid, which decomposes into carbon monoxide (IV) and water:

$$HCOOH \xrightarrow{[O]} CO2\uparrow + H2O.$$

Upon reduction, monocarboxylic acids form, depending on the conditions, aldehydes or primary alcohols.

Individual representatives

Antacid (methanoic acid) HCOOH - a colorless liquid with a pungent odor (p.p. 8.4 ºC, boiling point 100.8 ºC), soluble in water, ethanol, ether. In a free state, it is contained in secretions of ants' glands, in nettles. In industry, they receive according to the scheme:

$$CO + NaOH \xrightarrow{p,t} NSOONa \xrightarrow{HCl} HCOOH.$$

When heated with concentrated sulfuric acid, formic acid decomposes into carbon dioxide (II) and water.

Formic acid is used in organic synthesis to produce pesticides and solvents (such as DMF), as a mordant in textile and paper dyeing, leather processing, fruit juice preservation, and beer and wine barrel disinfection. In medicine, formic acid is used in the form of a 1% alcohol solution (formic alcohol) for neuralgia, myositis, etc.

Vinegaracid (ethanoic acid) CH3COOH is a colorless liquid with a pungent odor, miscible with water, ethanol, ether. Anhydrous (glacial) acetic acid has a T. Pl. 16 ºC, t. Kip. 118 ºC. It is widely used as a reagent and solvent in organic synthesis, 3-6% solutions are used as a flavoring and preservative. In large quantities, acetic acid is used in the production of artificial fibers based on cellulose, as well as in the synthesis of medicinal products (acetylsalicylic acid, phenacetin).

Propionovaacid (propanoic acid) CH3CH2COOH is a colorless liquid (b.p. 141.1 ºC), miscible with water and organic solvents. Obtained by oxidation of propionic aldehyde. It is used in the production of vitamins, medicines, aromatic substances, herbicides; to prevent grain, cheese and bread from becoming moldy.

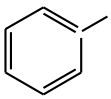
3. Unsaturated monocarboxylic acids.

Unsaturated carboxylic acids include carboxylic acids containing a multiple bond in the hydrocarbon radical.

In the nomenclature of unsaturated acids, trivial names are widely used:

$CH_2 = CH - COOH$
акриловая кислота

$CH_3 - CH = CH - COOH$
кротоновая кислота


$CH = CH - COOH$
коричная кислота

$CH_3 - CH = CH - CH = CH - COOH$
сорбиновая кислота

$HOOC - CH = CH - COOH$
малеиновая кислота

$CH_3 - (CH_2)_7 - CH = CH - (CH_2)_7 - COOH$
олеиновая кислота

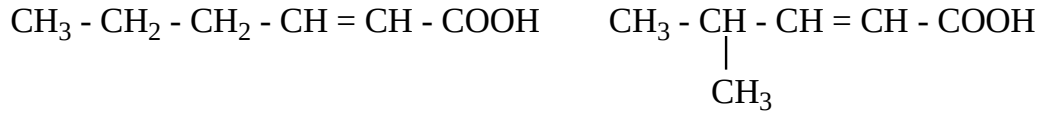
According to the substitute nomenclature of IUPAC, the names of unsaturated acids are formed similarly to saturated ones, using the suffix -en to denote a double bond and the suffix -in to denote a triple bond, indicating the position of the multiple bond in the carbon chain. Depending on the position of the multiple bond in relation to the -COOH group, α, β- are distinguished; β, γ-; γ, δ- and other unsaturated acids, for example:

β α γ β α

CH2=CH–COOH CH2=CH–CH2COOH

α, β-unsaturated acid β, γ-unsaturated acid

Unsaturated monocarboxylic acids are characterized by structural isomerism due to the different structure of the hydrocarbon radical and the position of the multiple bond, as well as geometric isomerism associated with the different arrangement of substituents relative to the plane of the double bond:



2-гексеновая кислота 4-метил-2-пентеновая кислота

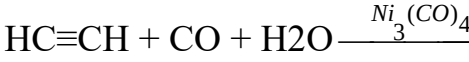
2-гексеновая кислота 3-гексеновая кислота

цис-кротоновая кислота транс-кротоновая кислота

Methods of obtaining

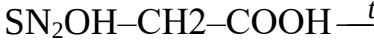
Many of the methods for the synthesis of saturated carboxylic acids can be used. Unsaturated compounds are used as starting materials, for example, oxidation of unsaturated primary alcohols and aldehydes under mild conditions, hydrolysis of nitriles, etc. In addition, there are specific methods of synthesis.

Hydrocarboxylation of alkynes (Reppe reaction):



Acrylic acid

Elimination of β-halo- and β-hydroxycarboxylic acids:



Physical and chemical properties

Under normal conditions, unsaturated monocarboxylic acids are colorless liquids or crystalline substances. Lower representatives dissolve well in water, have a sharp, irritating smell; with an increase in M acid, the solubility in water decreases. Higher acids do not dissolve in water and dissolve well in organic solvents.

The reactivity of unsaturated monocarboxylic acids is due to the presence of a carboxyl group and a multiple bond in their structure.

Due to the carboxyl group, unsaturated acids undergo reactions characteristic of saturated acids: they form salts, halides, anhydrides, esters, amides. Due to the multiple bond in the hydrocarbon radical, unsaturated acids exhibit the properties of alkenes (alkynes). Thus, they are characterized by reactions of addition, oxidation and polymerization.

The addition of hydrogen halides to α, β-unsaturated acids proceeds against Markovnikov's rule due to the electron-accepting effect of the carboxyl group due to the M- and -I-effect:

$CH_2=CH–COOH + HBr \rightarrow CH_2Br–CH_2–COOH.$

α, β-Unsaturated acids, especially with a triple bond, are stronger acids compared to the corresponding saturated ones. This is explained by an increase in the stability of the anion due to delocalization of the charge along the conjugated system. Below are the pKa values in water of some unsaturated acids and propionic acid.

Acid	pKa (H_2O), 25 ºC
$CH_3–CH_2–COOH$	4.87
$CH_2=CH–COOH$	4.26
$CH_2–C\equiv C–COOH$	2.60
$CH\equiv C–COOH$	1.84

Individual representatives

Acrylic acidCH_2= CH-COOH is a colorless liquid (b.p. 13 ºC, b.p. 141 ºC) with a pungent odor, well soluble in water, easily polymerizes with the formation of polyacrylic acid. Polymers based on esters of acrylic acid - polyacrylates - are of great practical importance. In medicine, polyacrylates are used for the manufacture of dental prostheses.

Methacrylic acid$CH_2=C(CH_3)$-COOH is a colorless liquid (boiling point 160.5 ºC), easily polymerizes. It is used in the production of carbosilicate rubbers, ion exchange resins, and polyacrylic adhesives. The methyl ether of methacrylic acid - methyl methacrylate, whose polymerization produces polymethyl methacrylate - organic glass (Plexiglas), is of great importance.

Oleic acidCH3–(CH2)7–CH=CH–(CH2)7–COOH(cis-9-octadecenoic acid) is a colorless oily liquid without taste or smell. In the form of glycerin esters, it is part of vegetable oils and animal fats. Being a cis-isomer, under the action of nitric acid or under UV irradiation, oleic acid is isomerized into trans-isomeric elaidic acid. It is used in the production of synthetic rubber, flotation reagents, defoamers, plasticizers, wetting agents for dyeing with disperse dyes

A mixture of ethyl esters of oleic (~ 15%), linoleic (~ 15%) and linolenic (~ 57%) acids are part of the medicinal preparation linetol, used in medicine for the prevention and treatment of hypertension and atherosclerosis, as well as for burns and radiation sickness.

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4. Aromatic monocarboxylic acids.

Organic acids in which the carboxyl group is directly connected to the aromatic nucleus are called aromatic carboxylic (arene carboxylic) acids.

The simplest representative of arene carboxylic acids is benzoic acid. According to the IUPAC nomenclature rules, other homologues of this series are considered as benzoic acid derivatives.

Methylbenzoic acids have a trivial name - toluic acid: o-CH3-C6H4-COOH - o-toluic acid, m-CH3-C6H4-COOH - m-toluic acid, p-CH3-C6H4-COOH - p-toluic acid.

The names of carboxylic acids of the naphthalene, anthracene and other series are formed from the name of the corresponding hydrocarbon with the addition of the words carboxylic acid.

Carboxylic acids, in which the carboxyl group is located in the side carbon chain of an aromatic hydrocarbon, are considered as derivatives of aliphatic acids.

Methods of obtaining

1. *Oxidation of alkylarenes (one of the most frequently used methods):*

C6H5–CH3 $\xrightarrow{[O]}$ C6H5–COOH.

2. *Hydrolysis of trihalogenated aromatic hydrocarbons:*

WITH$_6$H5–CCl3 + 3NaOH → C6H5–COOH + 3NaCl + H2O.

3. *Hydrolysis of nitriles:*

$$C6H5–C\equiv N \xrightarrow{H_2O, H_2SO_4} C6H5–COOH + (NH4)2SO4.$$

4. *Friedel-Crafts synthesis:*

$$Ar–H + O=CCl2 \xrightarrow{AlCl_3} Ar–COCl \xrightarrow{+H_2O} Ar–COOH.$$

5. *Organometallic synthesis:*

$$C6H5–MgBr + CO2 \rightarrow C6H5–COOMgBr \xrightarrow{+HCl} C6H5–COOH + MgBrCl,$$

$$C6H5–Br + 2Li \rightarrow C6H5–Li + LiBr,$$

$$C6H5–Li + CO2 \rightarrow C6H5–COOLi.$$

Physical and chemical properties

Aromatic monocarboxylic acids are colorless crystalline substances, some of them have a weak pleasant smell. Lower homologues are sparingly soluble in water and are distilled with steam. Arene carboxylic acids dissolve well in ethanol and ether.

The reactivity of arene monocarboxylic acids is due to the presence of a carboxyl group and a benzene nucleus in their structure.

According to the carboxyl group, they are characterized by reactions characteristic of saturated monocarboxylic acids:

$$C6H5–COOH + NaOH \rightarrow C6H5–COOHa + H2O,$$

$$C6H5–COOH + C2H5OH \xrightarrow{H^+} C6H5–COOC2H5 + H2O,$$

$$C6H5–COOH + PCl5 \rightarrow C6H5–COCl + POCl3 + HCl\uparrow,$$

$$2C6H5–COOH + (CH3CO)2O \xrightarrow{H^+} (C6H5CO)2O + CH3–COOH.$$

Aromatic monocarboxylic acids show stronger acidic properties compared to saturated (except formic) and unsaturated monocarboxylic acids of the aliphatic series. This is due to an increase in the stability of the anion due to delocalization of the charge along the conjugated system of the benzene ring.

When arene carboxylic acids are heated above 200 ºC in the presence of copper powder or copper salts, they undergo decarboxylation:

$$C6H5–COOH \xrightarrow{t,Cu} C6H6 + CO2.$$

After the benzene ring, arenemonocarboxylic acids undergo electrophilic substitution reactions (nitration, sulfonation, halogenation), characteristic of aromatic hydrocarbons. The carboxyl group, exhibiting -I- and -M-effects, deactivates the benzene ring in relation to electrophilic reagents, so electrophilic substitution reactions are much more difficult than for unsubstituted benzenes. Being an orientant of the II kind, the -COOH group directs substitution to meta-positions:

$$C6H5–COOH + HNO3 \xrightarrow{H_2SO_4} m\text{-}O2N–C6H4–COOH + H2O,$$

$$C6H5–COOH + H2SO4 \rightarrow m\text{-}HO3S–C6H4–COOH + H2O,$$

$$C6H5–COOH + Br2 \xrightarrow{FeBr_3} m\text{-}Br–C6H4–COOH + HBr.$$

Individual representatives

Benzoic acidC6H5–COOH –white crystalline substance (b.p. 122 ºC), easily distilled, poorly soluble in water, well - in ethanol and benzene. In the form of esters, it is contained in some natural oils, for example, in clove oil. Benzoic acid is used as a raw material in the production of dyes, fragrances, medicines, as well as as a preservative, antiseptic and antifungal agent in medicine. The sodium salt of benzoic acid (sodium benzoate) is used as an expectorant for bronchitis. Phenylacetic acidC6H5–CH2–COOH –white crystalline fragrant (smell of honey) substance (b.p. 77 ºC). Due to the presence of an activated methylene group, it easily enters into condensation reactions with aldehydes, ketones, acid anhydrides, etc. It is used in organic synthesis to obtain aromatic substances and medicines.

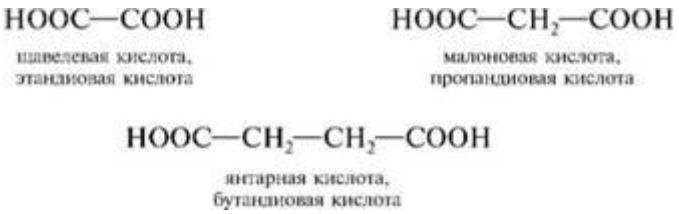
Cinnamic acidC6H5–CH=CH–COOH (trans-3-phenylpropenoic acid) - a white crystalline substance (m.p. 133 ºC). It is contained in the form of esters in essential oils, resins, balms. It is used in the synthesis of aromatic substances and medicines.

5. Saturated, unsaturated and aromatic dicarboxylic acids.

Dicarboxylic acids are derivatives of hydrocarbons containing two carboxyl groups.

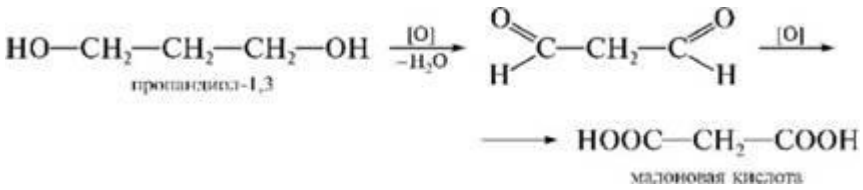
Saturated dicarboxylic acids

In the nomenclature of dicarboxylic acids, trivial names are widely used. According to the substitute nomenclature of IUPAC, the names of dicarboxylic acids are formed from the names corresponding to the number of atoms in the main chain of monocarboxylic acids with the addition of the multiplying prefix -dy. More commonly used trivial names:

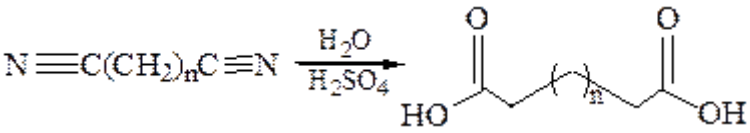


Methods of obtaining

1. Oxidation of two primary glycols, dialdehydes and hydroxy acids:



2. Hydrolysis of dinitriles:



Physical and chemical properties

Dicarboxylic acids - white crystalline substances, well soluble in water. The melting points of acids with an even number of carbon atoms are higher than the melting points of neighboring acids with an odd number of carbon atoms. Dicarboxylic acids dissociate stepwise, forming an anion(pKa1)and the dianion(pKa2):

NOOS-SOON⇄NOOS–SOO– + H+,

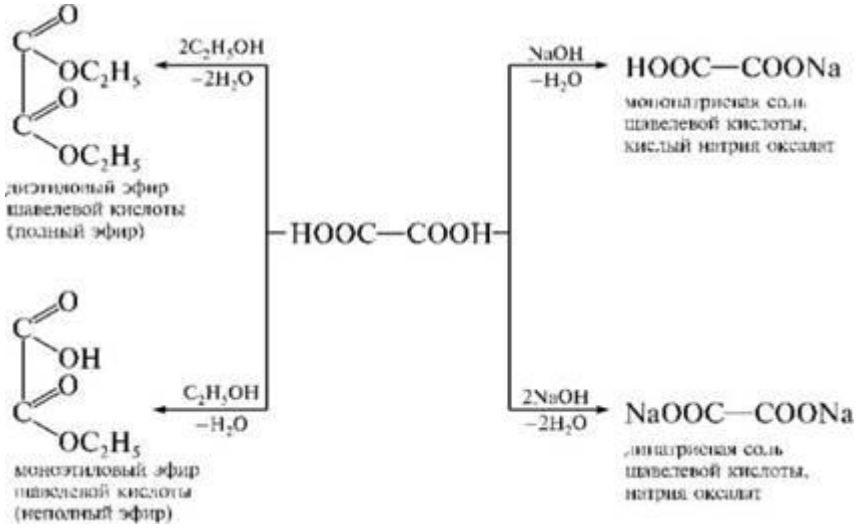
NOOS–SOO–⇄–OOC–COO– + H+.

According to the first degree, carboxylic acids have stronger acidic properties than monocarboxylic acids with the same number of C atoms due to the mutual influence of -COOH groups. As the carboxyl groups move away from each other, their mutual influence weakens, as a result of which the acidity of the first degree decreases. The detachment of a proton from the second group -COOH is much more difficult due to the low stability of the dianion, and the acidity of the second degree of dicarboxylic acids is much lower than that of the first, especially for oxalic and malonic acids. Below are the valuespKa in water for some dicarboxylic acids.

Acid	pKa1 (H2O)	pKa2 (H2O)
NOOS-SOON	1.27	4.27

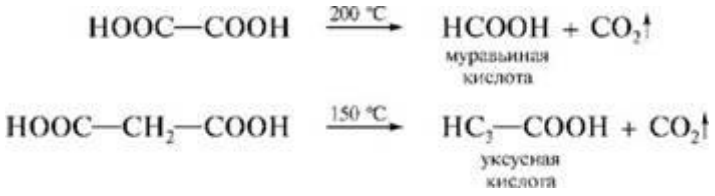
NOOS–CH2–COOH	2.86	5.70
NOOS–(CH2)2–COOH	4.21	5.64
NOOS–(CH2)3–COOH	4.34	5.27
NOOS–(CH2)4–COOH	4.41	5.28

In terms of chemical properties, dicarboxylic acids are similar to monocarboxylic acids: they form the same functional derivatives, with the only difference that reactions can take place with the participation of one or two -COOH groups:



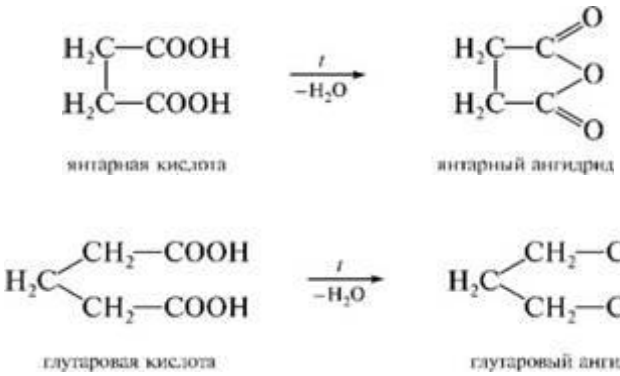
Along with this, dicarboxylic acids exhibit a number of specific properties, in particular, they react differently to heating.

Reaction of dicarboxylic acids to heating. Oxalic and malonic acids when heated above tpl. undergo decarboxylation by one -COOH group and turn into monocarboxylic acids:

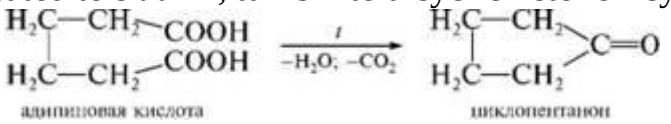


Mono- and dialkyl-substituted malonic acids behave similarly when heated.

The following two representatives of the homologous series of dicarboxylic acids will form cyclic anhydrides when heated:



Adipic acid, when heated to 300 ºC, turns into a cyclic ketone - cyclopentanone:



Individual representatives

Oxalic acidHOOC–COOH is a white crystalline substance (m.p. 189 ºC), easily soluble in water and alcohols. It is contained in the form of salts in many plants (sorrel, rhubarb, etc.). Oxalic acid salts are oxalates. Calcium oxalate crystals are difficult to dissolve in water and can be deposited in pathological conditions in the kidneys in the form of stones (nephrolithiasis). In industry, oxalic acid is obtained from sodium formate:

$$2HCOOHa \xrightarrow{400°C} NaOOC–COOHa \xrightarrow{+2HCl} NOOS\text{-}SOON.$$

Oxalic acid is used to clean metals from rust and scale, as well as as a mordant in leather production.

Malonic acidHOOC–CH2–COOH is a white crystalline substance (m.p. 135 ºC), soluble in water, ethanol, ether. It is contained in sugar beet juice. Obtained by hydrolysis of cyanoacetic acid. An important derivative of malonic acid is its diethyl ether - malonic ether, used in organic synthesis to obtain mono- and dicarboxylic acids. Malonic ether is widely used in the synthesis of heterocyclic compounds and medicines.

Succinic acidHOOC–(CH2)2–COOH is a white crystalline substance (m.p. 152 ºC), soluble in water and ethanol. In industry, succinic acid is obtained by catalytic hydrogenation of maleic acid:

$$HOOC–CH=CH–COOH \xrightarrow{H_2,Ni} HOOC–CH2–CH2–COOH.$$

Salts of succinic acid are called succinates. Succinic acid, its esters and amide are widely used in organic synthesis.

Adipic acidHOOC–(CH2)4–COOH is a white crystalline substance (m.p. 185 ºC), sparingly soluble in water. Salts - adipinates. It is used mainly in the production of synthetic fiber - nylon, as well as in the food industry and organic synthesis.

Unsaturated carboxylic acids

*Unsaturated carboxylic acids contain two carboxyl groups and a multiple C = C bond.*The simplest representatives of unsaturated dicarboxylic acids are maleic and fumaric acids - cis- and trans-isomers of butenedic acid HOOC–CH=CH–COOH – white crystalline substances. Maleic acid is easily soluble in water and alcohols, fumaric acid is difficult to dissolve in water. In industry, maleic acid is obtained by hydration of maleic anhydride - a product of catalytic oxidation of benzene or butene-2 with air oxygen. Fumaric acid is obtained by thermal isomerization of maleic acid. Unsaturated dicarboxylic acids show more pronounced acidic properties compared to saturated ones, since the mutual influence of two carboxyl groups is more effectively transmitted through the combination of the π-bond system. At the same time, maleic acid is much stronger than fumaric acid.

Acid	pKa1 (H2O)	pKa2 (H2O)
Maleic acid	1.92	6.23
Fumaric acid	3.02	4.32

The increased acidity of malonic acid in the first degree and low in the second degree is due to the implementation of an intramolecular H-bond between ionized and non-ionized carboxyl groups: the H-bond, on the one hand, increases the stability of the anion, and on the other hand, it complicates the separation of a proton from the second carboxyl groups The reactivity of unsaturated dicarboxylic acids is due to the presence of two -COOH groups and a multiple bond in their structure. Addition reactions (hydrogenation, halogenation, hydrohalogenation, hydration) take place with the participation of a multiple bond, acidic and medium salts, incomplete and complete esters, amides are formed on the carboxyl group. Maleic acid easily forms a cyclic anhydride when heated, fumaric acid does not form an anhydride due to the spatial distance of the -COOH groups. Maleic acid, being a cis isomer, is more labile than fumaric acid, and under the influence of various reagents it is easily isomerized into a more stable form - fumaric acid.

The most important functional derivatives of carboxylic acids include halides, anhydrides, esters, amides, hydrazides, hydroxamic acids, nitrile, etc.

6. Halide anhydrides of carboxylic acids.

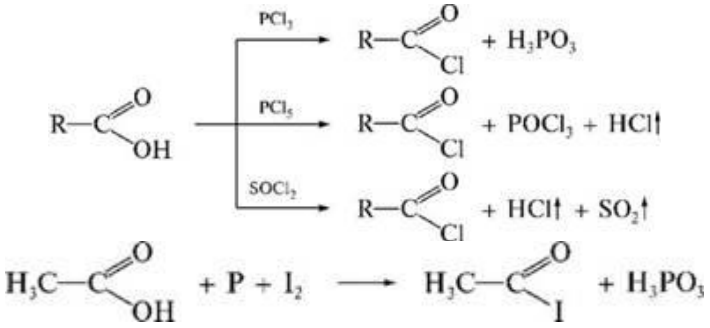
Halogenanhydrides of carboxylic acids are their derivatives in which the hydroxyl group, which is part of the carboxyl group, is replaced by a halogen atom (chlorine, bromine, less often - fluorine and iodine).

The names of halogen anhydrides are formed from the names of the corresponding acids or acyl groups and the name of the halogen:

acetic acid chloride benzoic acid chloride

acetyl chloride benzoyl chloride.

Methods of obtaining

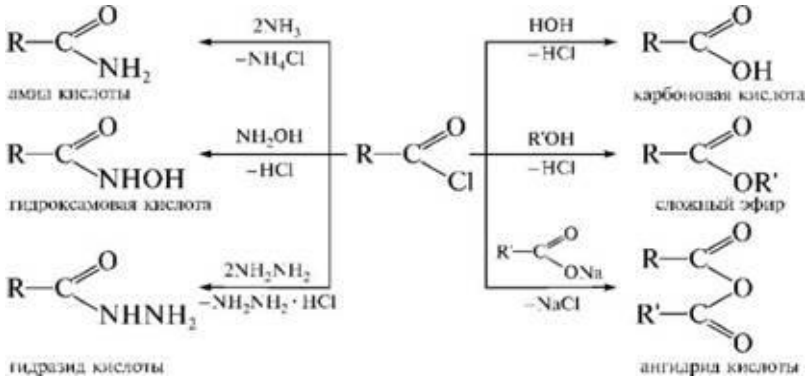


Physical and chemical properties

Halogenanhydrides of carboxylic acids are colorless liquids or crystalline substances with a pungent odor, volatile, irritating mucous membranes and skin.

Halide anhydrides are quite active electrophilic reagents, due to the presence of a small positive charge on the C atom of the carbonyl group. As a result of the electron-accepting properties of the halogen atom (-I effect) on the carbon atom of the carbonyl group, the electron density is significantly reduced, so halogen anhydrides are stronger electrophilic reagents than carboxylic acids.

Acyl halides easily undergo various reactions of nucleophilic substitution:



In the process of nucleophilic substitution reactions, an acyl group is introduced into the molecule of the nucleophilic reagent, therefore, halides are an acylating reagent, and the reactions are called acylation reactions.

Halide anhydrides react with weak nucleophilic reagents, such as arenes, in the presence of Lewis acids (AlCl3, FeBr3, SnCl2, etc.). In this case, Lewis acids activate the acyl halide molecule due to the formation of a donor-acceptor complex (n-complex) or an acyl ion:

R–COCl + AlCl3 ⇄ R–COCl:→AlCl3 ⇄[R–CO]+[AlCl4]–.

Individual representatives

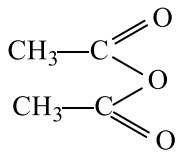
Acetyl chlorideCH3-C (O) Cl is a colorless liquid with a pungent odor (boiling point 51.8 ºC), quickly hydrolyzes with water, dissolves in most organic solvents. It is used as an acylating reagent in the production of dyes and medicines.

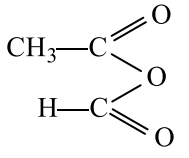
Benzoyl chlorideC6H5–C(O)Cl- a colorless liquid with a pungent odor (b.p. 197.2 ºC), irritates the mucous membranes of the respiratory tract and eyes, is well soluble in ether, benzene, carbon disulfide, hydrolyzes with water. It is used for the introduction of the benzoyl group in the synthesis of indigo dyes and medicines, a reagent for the identification of amines and amino acids.

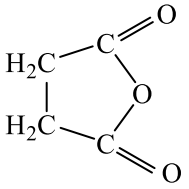
7. Anhydrides of carboxylic acids.

Derivatives of carboxylic acids in which the hydrogen atom of the carboxylic acid group is replaced by an acyl group are called anhydrides.

Anhydrides are products of dehydration of carboxylic acids. Linear and cyclic anhydrides of carboxylic acids are distinguished; linear anhydrides, the molecules of which contain residues of various acids, are called mixed anhydrides:


уксусный ангидрид


муравьиноуксусный ангидрид


янтарный ангидрид

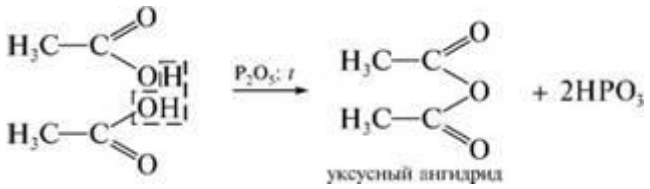
The names of anhydrides are formed from the trivial names of the corresponding acids, for example:

CH3–C(O)–O–C(O)–CH3 C6H5–C(O)–O–C(O)–C6H5

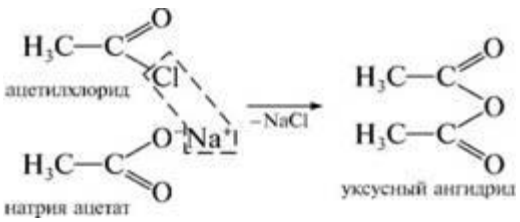
acetic anhydride, benzoic acid anhydride,
acetic anhydride benzoic anhydride

Methods of obtaining

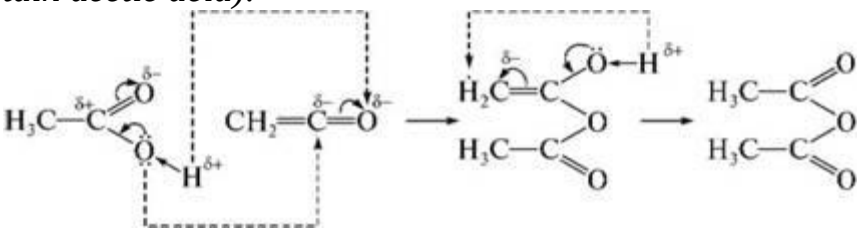
1. *Dehydration of carboxylic acids:*



2. *Interaction of halogen anhydrides with anhydrous salts of carboxylic acids*:



3. *Interaction of carboxylic acids with ketenes (the method is used in industry to obtain acetic acid):*

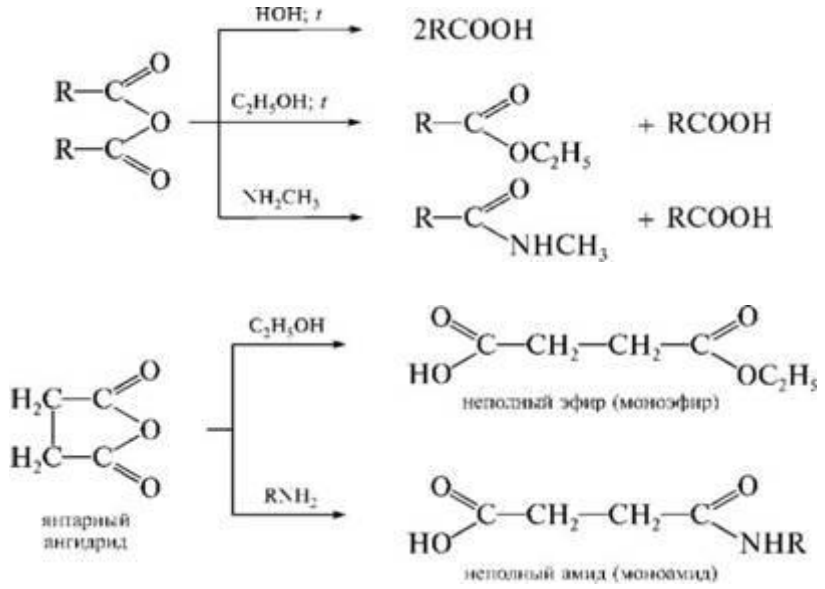


Physical and chemical properties

Anhydrides of carboxylic acids are colorless liquids or crystalline substances, sparingly soluble in water and slowly reacting with it. Lower representatives have an irritating smell.

Anhydrides of carboxylic acids, like halogen anhydrides, are quite active electrophilic reagents. Due to the smaller value of the small positive charge on the C-atom of the carbonyl group, carboxylic acid anhydrides have a less pronounced electrophilic character than halogen anhydrides, but show greater electrophilicity compared to carboxylic acids, since they have an oxygen atom that exhibits +M-effect attributed to two acyl groups.

Like halogen anhydrides, carboxylic acid anhydrides easily react with various nucleophilic reagents and are used to introduce acyl groups into their structure; during the reaction, carboxylic acid is released:



In the molecules of anhydrides, as in carboxylic acids, hydrogen atoms at the α-carbon atom have mobility. Anhydrides in the presence of bases (salts of carboxylic acids, tertiary amines) enter into condensation reactions with aromatic aldehydes, forming unsaturated arenecarboxylic acids (Perkin reaction):

$$C6H5–CHO + (CH3CO)2O \xrightarrow{CH_3COONa} C6H5–CH=CH–COOH + CH3COOH.$$

Individual representatives

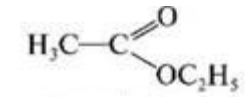
Acetic anhydride(CH3CO)2O is a colorless liquid with a pungent odor (b.p. 140 ºC), irritates the mucous membranes of the eyes and respiratory tract, causes skin burns. Reacts slowly with water to form acetic acid, dissolves in ethanol, ether, benzene, acetic acid. It is used as an acylating and dehydrating agent in the production of acetyl cellulose, vinyl acetate, dimethylacetamide, medicines (for example, acetylsalicylic acid).

Phthalic anhydride- white crystalline substance (b.p. 130.8 ºC), easily distilled, soluble in ethanol. It is used in the synthesis of medicines (phthalazole, phtazine, etc.), in the production of alkyd resins, plasticizers (dioctyl, dimethyl and diethyl phthalate), dyes, insecticides; reagent for detection and titrimetric determination of lower primary and secondary aliphatic alcohols, identification of phenols and phenolic resins.

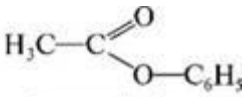
8. Complex esters of carboxylic acids.

Complex esters are functional derivatives of carboxylic acids in which the hydroxyl group is replaced by an alcohol or phenol residue - OR.

Usually, esters are named after the original acid and alcohol or phenol. According to the substitute nomenclature of IUPAC, their names are formed from the name of the hydrocarbon radical of alcohol or phenol and the systematic name of the carboxylic acid, in which -ova acid is replaced by the suffix -OAT, for example:



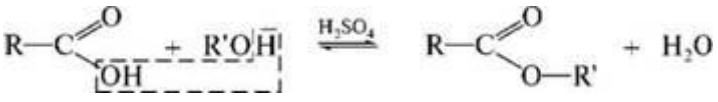
этиловый эфир
уксусной кислоты,
уксусноэтиловый эфир,
этилацетат, этилэтаноат



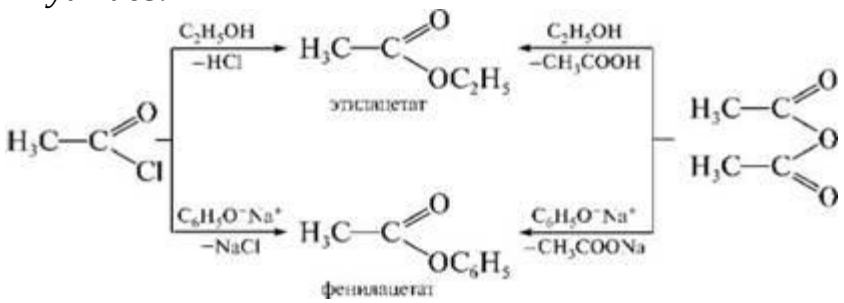
фениловый эфир
уксусной кислоты,
фенилацетат,
фенилэтаноат

Methods of obtaining

1. *Interaction of carboxylic acids with alcohols:*



2. *Interaction of alcohols and phenols with halogen anhydrides and carboxylic acid anhydrides:*



3. *Alkylation of salts of carboxylic acids with haloalkanes:*

CH3COOHa + C2H5–Cl → CH3–C(O)–OC2H5 + NaCl.

Physical and chemical properties

Complex esters of carboxylic acids are colorless volatile liquids, less often - crystalline substances with a pleasant smell. As a rule, they are poorly soluble in water, they dissolve well in most organic solvents. The boiling points of esters are usually below the boiling point of the carboxylic acids included in their composition due to the absence of association due to H-bonds.

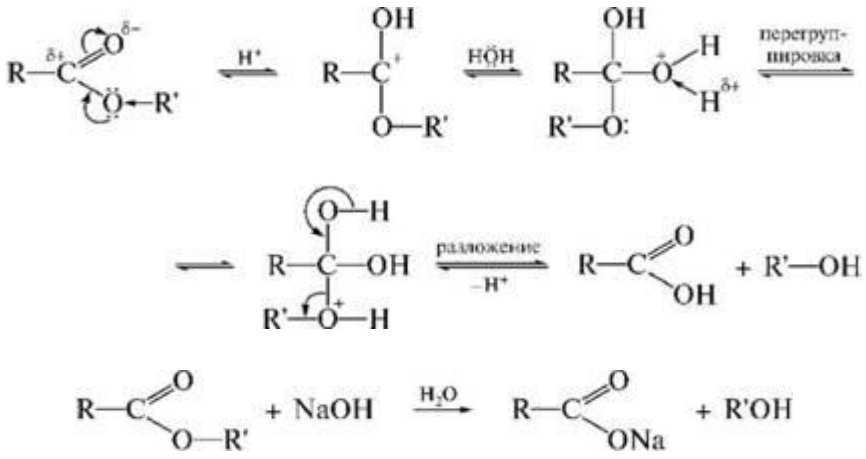
Like halogen anhydrides and carboxylic acid anhydrides, esters are electrophilic reagents. The C atom of the carbonyl group serves as an electrophilic center. However, due to the +M effect of the O atom connected to the hydrocarbon radical, esters show a less pronounced electrophilic character in comparison with halogen anhydrides and anhydrides of carboxylic acids.

The nature of the hydrocarbon radical at the O atom also affects the electrophilic properties of esters. The electrophilicity of ethers increases if the hydrocarbon radical forms a system connected to the O atom, as, for example, in aryl or vinyl ethers of carboxylic acids:

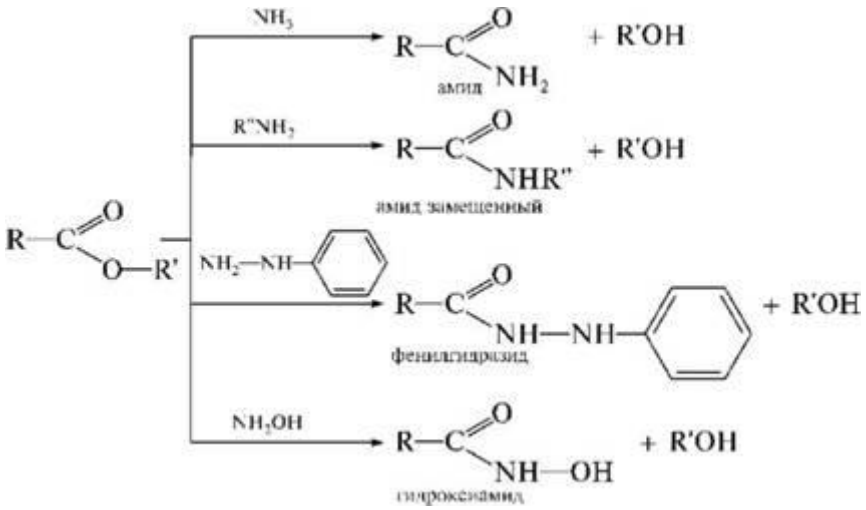
These esters are called activated esters.

Being electrophilic reagents, esters enter into nucleophilic substitution reactions. In particular, they react with water (hydrolysis), alcohols (alcohololysis), hydrazines (hydrazinolysis), etc.

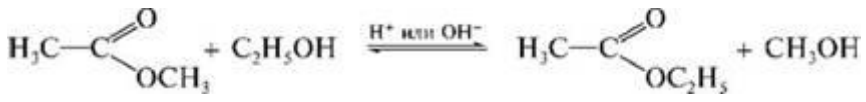
Hydrolysis of esters:



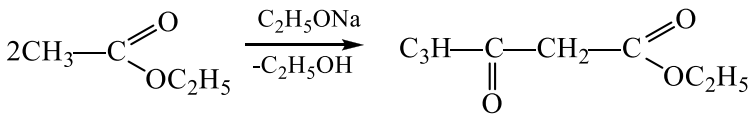
Interaction with ammonia, primary and secondary amines, hydrazine and hydroxylamine:



Interaction with alcohols (transesterification reaction):



Ester condensation (Claisen condensation):



этилацетат ацетоуксусный эфир

Individual representatives

Ethyl formateHCOOC2H5 is a colorless liquid (bp. 54.3 ºC), soluble in ethanol, ether, sparingly soluble in water. It is used in the production of vitamin B1, as well as as a perfume for soap and a component of fruit essences.

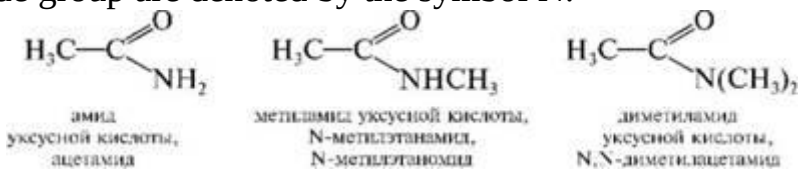
Ethyl acetateCH3-COOK2H5 is a colorless liquid with a pleasant smell (boiling point 77.1 ºC), sparingly soluble in water, soluble in organic solvents. It is used as a solvent for ethers, cellulose, chlorinated rubber, vinyl polymers, fats, waxes. It is used to obtain acetoacetic ether, as a fragrance for soap in perfumery, it is part of food essences.

Benzyl benzoateC6H5COOCH2C6H5- light yellow liquid (boiling point 323 - 324 ºC), insoluble in water, soluble in ethanol. Contained in many essential oils, Peruvian balsam. It has a toxic effect on scabies mites and is used to treat scabies.

9. Amides of carboxylic acids.

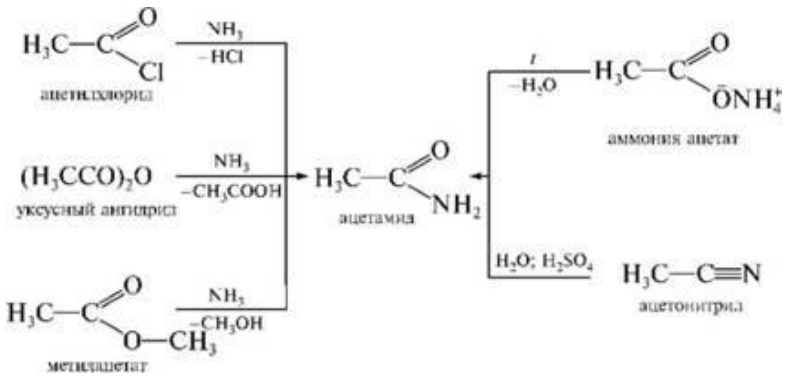
Amides are derivatives of carboxylic acids in which the carboxyl carboxyl group is replaced by an amino group.

The names of amides are most often formed from the names of the corresponding carboxylic acids and amines. In many cases, trivial names of acid residues are used - acyl, replacing suffixes in them -**fig**on –amide**.**According to the replacement nomenclature of IUPAC, the names of amides are composed of the names of acids, replacing part of their name -ova acid with the suffix -amide. In the names of substituted amides, the positions of the substituents located at the nitrogen atom of the amide group are denoted by the symbol N:



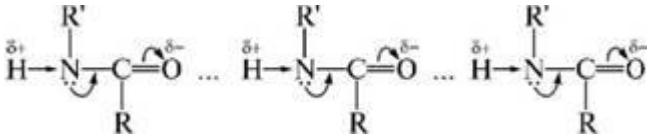
Methods of obtaining

Interaction of halogen anhydrides, anhydrides or complex esters of carboxylic acids with ammonia, primary or secondary amines, heating of ammonium salts of carboxylic acids, hydrolysis of nitriles:



Physical and chemical properties

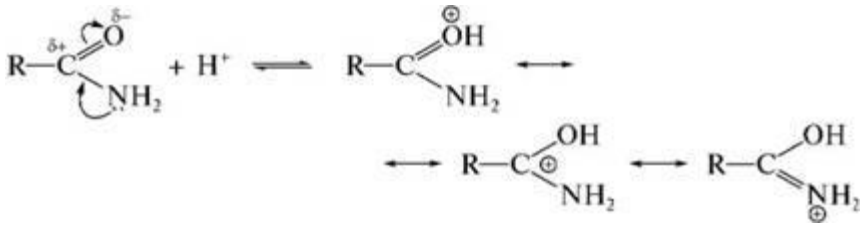
Amides of carboxylic acids are crystalline substances or liquids, soluble in water and organic solvents. Amides containing an NH bond form strong intermolecular H-bonds and have higher melting and boiling points compared to carboxylic acids:



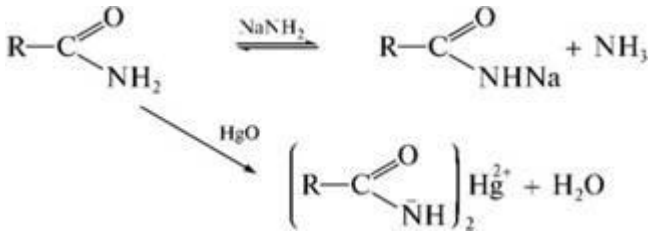
The reactivity of amides is due to the presence in their structure of the amide group -C (O) -N <. NEP nitrogen atom is combined with π-electrons of the carbonyl group (p-, π-conjugation), as a result of which the bond C-N becomes shorter, and the C = O bond becomes somewhat longer compared to the non-conjugation of the bond. Due to the strong NEP shift of the N-atom (+M-effect) to the C = O group, the δ+ charge on the C-atom of the carbonyl group in the amide is less than that of halogen anhydrides, anhydrides, and esters.

As a result of this electronic structure, amides practically do not react with nucleophilic reagents and, unlike amines, are very weak bases. Amides that have an NH bond in their structure are weak NH-acids.

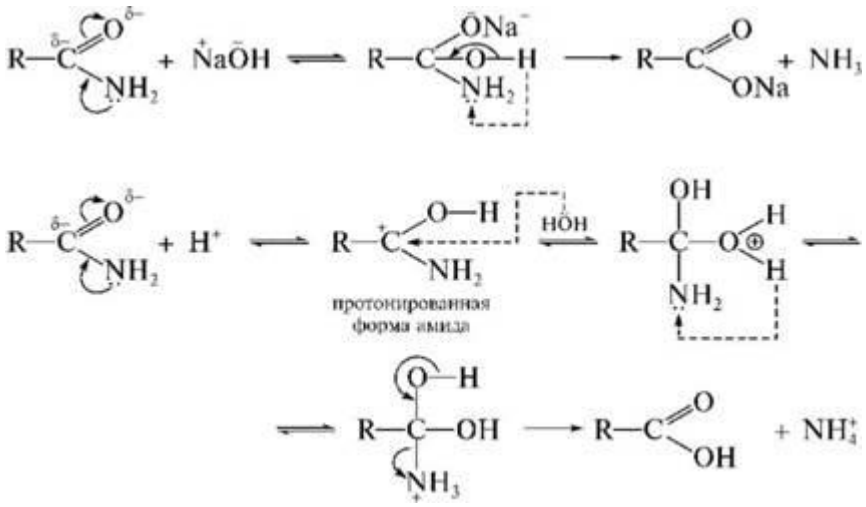
Acid-base reactions. As weak bases, amides form salts only with strong mineral acids, and the center of protonation in the ambidentate amide group is the O atom, since the resulting cation is stabilized by coupling:



Protonated forms of amides are strong OH-acids. As a result of conjugation, H atoms of NH bonds acquire mobility, that is, amides exhibit the properties of weak NH acids and form salts:



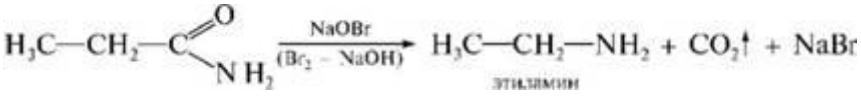
Hydrolysis of amides is much more difficult than that of other functional derivatives of carboxylic acids. In a neutral environment, hydrolysis proceeds very slowly, it proceeds quite easily in the presence of mineral acids or alkalis:



Dehydration of unsubstituted amides:

$$R–C(O)NH2 \xrightarrow{P_2O_5,t} R–C\equiv N + H2O.$$

Cleavage of amides according to Hoffmann:



Restoration:

$$R–C(O)NH2 \xrightarrow{[H],LiAlH_4} R–CH2–NH2.$$

N-Substituted amides similarly give secondary or tertiary amines.

Individual representatives

FormamideH–CONH2colorless liquid(boiling point 210.5 ºC), soluble in water and alcohols. It is used as a solvent and reagent in organic synthesis.

N, N-Dimethylformamide (DMF) H–COH(CH3)2 is a colorless liquid with a weak odor (boiling point 153 ºC), miscible with water and alcohols. DMF is widely used as an aprotic solvent in the production of synthetic fibers, paint materials, artificial leather, etc.; as a reaction medium with catalytic properties during halogenation and hydrohalogenation of non-limiting compounds; as a reagent for the introduction of a formyl group; in the pharmaceutical industry for the purification of medicinal products.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1.Classification, nomenclature, isomerism, extraction methods, physical and chemical properties, reaction, oxidation and reduction,reactivity. Electronic structure of carboxyl group and carboxylate anion.

2. Monocarboxylic acids: chemical properties, formation of salts, reactions

nucleophilic substitution (formation of functional derivatives of carboxylic acids),oxidation and reduction.

3. Unsaturated carboxylic acids, chemical properties, addition of hydrogen halides

against Markovnikov's rule in a series of α,β-unsaturated acids.

4. Aromatic carboxylic acids:extraction methods, physical and chemical properties.Orienting action of the carboxyl group in SE reactions.

5. Properties of dicarboxylic acids as bifunctional compounds. Specific

properties of dicarboxylic acids.

6.Halide anhydrides and anhydrides of carboxylic acids, nomenclature, methods

extraction, physical and chemical properties. Synthesis of phenolphthalein.

7. Complex ethers, nomenclature, extraction methods. Acidic and alkaline hydrolysis of esters.

8. Amides of carboxylic acids. Nomenclature, extraction methods, acid-base properties, hydrolysis of amides, acid and alkaline catalysis. Cleavage of amides with hypobromites, dehydration.

9. Hydrazides, hydroxamic acids, nitriles. Structure, nomenclature, extraction methods, physical and chemical properties. Acetonitrile. Identification of functional derivatives of carboxylic acids.

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Lecture No. 12

Topic: Halocarbon, hydroxy and phenolic acids.Oxo- and amino acids. Sulfuric acids. Carbonic acid and its functional derivatives.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withnomenclature, means of extraction, physical and chemical propertiesheterofunctional carboxylic acids.

Basic concepts: Halocarbon acids. Aliphatic hydroxy acids. Phenolic acids. Amino acids.

Plan and organizational structure of the lecture:

1. Halocarbon acids
2. Aliphatic hydroxy acids.
3. Phenolic acids.
4. Oxoacids.
5. Amino acids.

6. Derivatives of carbonic acid.

Content of lecture material (lecture text)

Heterofunctional carboxylic acids include derivatives of carboxylic acids, in the hydrocarbon radical of which one or more hydrogen atoms are replaced by other atoms or groups of atoms - a halogen, a hydroxy group, an amino group, a carbonyl group, etc.

The most important heterofunctional carboxylic acids are halocarboxylic acids (haloacids), hydroxycarboxylic acids (hydroxyacids), oxocarboxylic acids (aldehyde- and ketoacids), and aminocarboxylic acids (amino acids).

1. Halocarbon acids.

Halocarboxylic acids are derivatives of carboxylic acids, in the hydrocarbon radical of which one or more hydrogen atoms are replaced by halogen atoms.

According to the nature of the hydrocarbon radical, aliphatic, alicyclic, and aromatic halocarboxylic acids are distinguished. Aliphatic halogen acids are divided into α-, β-, γ-, etc. according to the relative position of the halogen atom and the carboxyl group:

α β α γ

R–CHHal–COOH R–CHHal–CH2–COOH R–CHHal–CH2–CH2–COOH

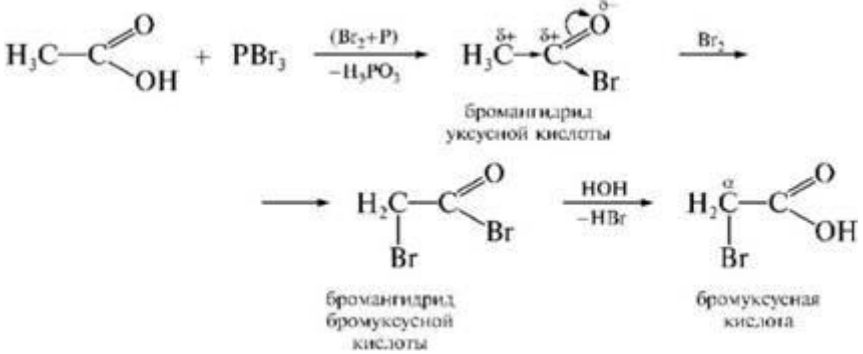
The nomenclature of halocarboxylic acids is similar to the nomenclature of carboxylic acids. According to the substitute nomenclature of IUPAC, the name is usually formed from trivial names of carboxylic acids. The position of the halogen atom is indicated by the Greek letters α-, β-, γ-, etc. According to the IUPAC systematic nomenclature, the name consists of the systematic names of carboxylic acids, indicating the position of the halogen atom with numbers:

Cl–CH2–COOH CH3–CHBr–COOH Cl–CH2–CH2–CH2–COOH*chloroacetic acid, α-bromopropion acid, γ-chlorobutyric acid,*

chloroethane k-ta 2-bromopropane k-ta 4-chlorobutane k-ta

Methods of obtaining

1. Halogenation of carboxylic acids (Gell-Volgard-Zelinsky reaction):



2. *Addition of hydrogen halide to α, β-unsaturated acids (proceeds against Markovnikov's rule):*

$$CH2= CH\text{-}COOH + HCl \rightarrow Cl\text{-}CH2\text{-}CH2\text{-}COOH.$$

3. *Halogenation of arene carboxylic acids:*

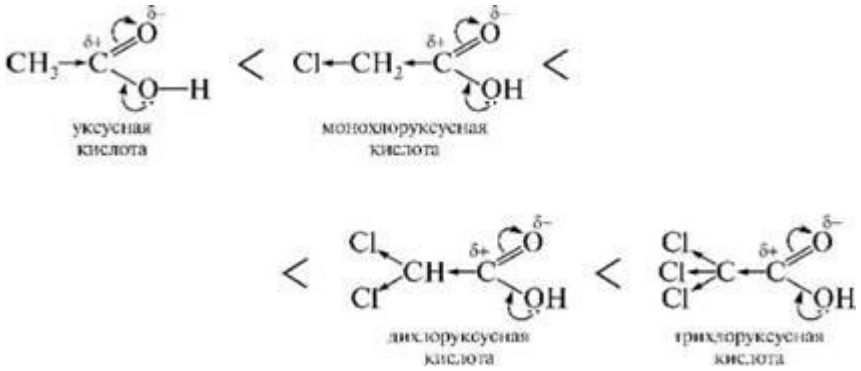
$$C6H5\text{–}COOH + Cl2 \xrightarrow{AlCl_3} m\text{-}C6H4Cl\text{–}COOH + HCl.$$

Physical and chemical properties

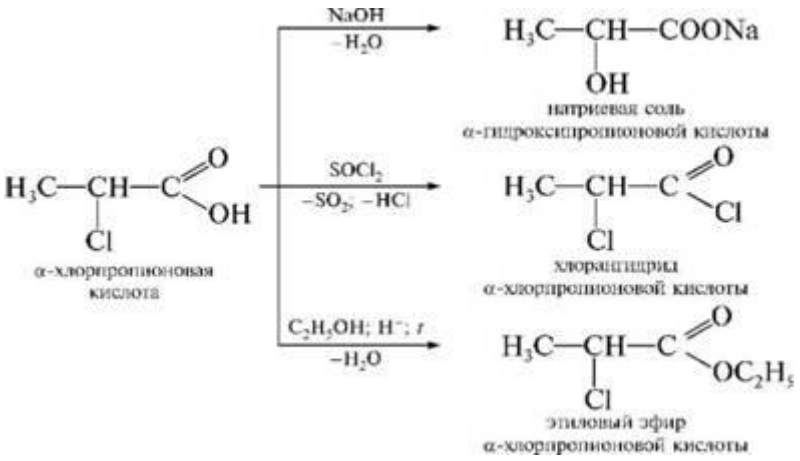
Halocarbon acids are colorless liquids or crystalline substances, soluble in water. They are characterized by reactions involving the group -COOH and reactions involving halogen.

Reactions on the carboxyl group. The introduction of a halogen atom into the R-radical of the acid leads to an increase in acidic properties, which is due to the -I effect of the halogen atom, and, as a result, a shift in the electron density from the C atom of the -COOH group and an increase in the stability of the anion. For example, the pKa acidity constant of acetic acid in an aqueous solution is 4.76, and that of chloroacetic acid is 2.86. As the halogen atom moves away from the -COOH group, the inductive effect fades and the strength of acids decreases in the order: α> β> γ, etc.

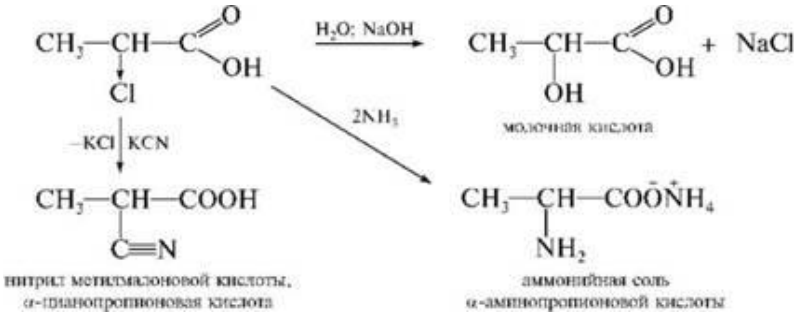
When transitioning to di- and polyhalocarboxylic acids, the acidity increases. The strongest carboxylic acid is CF3-COOH (pKa 0.23):



Halic acids form all functional derivatives - salts, halides, esters, amides, etc.:



Reactions involving the halogen atom. Aliphatic halocarboxylic acids undergo various reactions of nucleophilic substitution with the participation of a halogen atom; α-substituted acids are much more reactive than haloalkanes. This is due to the electron-accepting effect of the -COOH group, which increases the mobility of the halogen atom due to the -I effect. Substitution, as a rule, proceeds according to the mechanism**SN2**:



The attitude of aliphatic halogen acids to aqueous alkali solutions depends on the relative location of the halogen atom and the -COOH group.

α-Halocarboxylic acids under the action of aqueous alkalis form α-hydroxy acids:

CH3-CHCl-COOH + NaOH → CH3-CH (OH) -COOH + NaCl.

β-Halocarboxylic acids in the presence of aqueous alkalis form β-hydroxy acids, which at elevated temperatures split off water and turn into α, β-unsaturated acids:

$$Cl–CH2–CH2–COOH \xrightarrow{NaOH} HO–CH2–CH2–COOH \xrightarrow{t} CH2=CH2–COOH + H2O.$$

γ- and δ-Haloacids under these conditions first form γ- or δ-hydroxy acids, which, when heated, cleave water with the formation of γ- or δ-lactones - cyclic esters:

$$Cl–CH2–CH2–CH2–COOH \xrightarrow{NaOH} HO–CH2–CH2–CH2–COOH \xrightarrow{t}$$

CH2–CH2–CH2–C=O

|————O———— |

γ-butyrolactone

In a number of aromatic halocarboxylic acids, the nucleophilic substitution of the halogen atom occurs under stricter conditions. Halogen atoms located in the ortho- or para-position in relation to the -COOH group are more reactive. Thus, o-chlorobenzoic acid when heated with aniline in the presence of CuO and K2CO3 forms N-phenylanthranilic acid:

$$\textit{at}\text{-ClC6H4COOH+C6H4NH2} \xrightarrow{CuO,K_2CO_3} \textit{at}\text{-HOOC–C6H4–NH–C6H5+KCl+CO2+H2O.}$$

Individual representatives

***H*Loroctova**acid. Monochloroacetic acid ClCH2-COOH - cryst. substance (b.p. 62 ºC), used in the production of carboxymethyl cellulose, herbicides (2,4-dichloro- and 2,4,6-trichlorophenoxyacetic acids), complexones (for example, ethylenediaminetetraacetic acid, EDTA).

Dichloroacetic acid Cl2CH-COOH is a low-melting substance (p.p. 13ºC, boiling point 194ºC), used in organic synthesis.

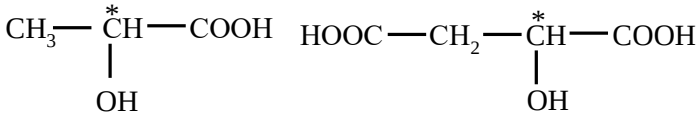
Trichloroacetic acid Cl3C-COOH is a hygroscopic substance (b.p. 58 ºC), used in organic synthesis, its sodium salt is used as a herbicide.

2. Hydroxy acids.

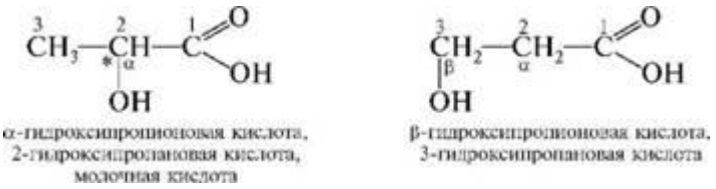
Derivatives of carboxylic acids containing one or more hydroxyl groups in the hydrocarbon radical are called hydroxy acids.

Depending on the nature of the hydrocarbon radical, aliphatic and aromatic hydroxy acids are distinguished (alcoholic acids, phenolic acids, respectively). Aliphatic hydroxy acids are divided into α-, β-, γ-, etc. based on the relative position of the -COOH and -OH groups.

The number of -COOH groups in a hydroxy acid molecule determines the basicity, and the number of OH groups, including hydroxyls included in the -COOH groups, characterizes valence. Thus, lactic acid CH3-CH (OH) -COOH is a monobasic diatomic acid, and malic acid isПООС–CH2–CH(OH)–COOH- dibasic triatomic acid:



Trivial names are widely represented in the nomenclature of hydroxy acids. According to the substitute nomenclature of IUPAC, the trivial or systematic name of the carboxylic acid is taken as the original name. The hydroxyl group is denoted by the prefix hydroxy- (rarely oxy-). When using the trivial name of the parent structure, the position of the OH group in the hydrocarbon chain is indicated by the letters of the Greek alphabet α-, β-, γ-, etc., and when using the systematic name of the parent structure, the position of the OH group is indicated by numbers:



Hydroxy acids are characterized by structural isomerism due to the different structure of the hydrocarbon radical to which the -COOH group is connected and the different position of the OH group in the chain. For example, structural isomers are:

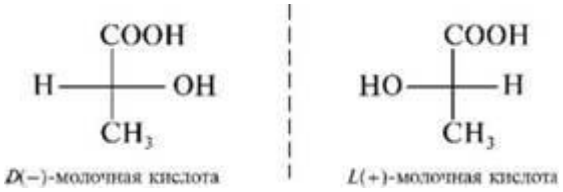
CH3–CH2–CH(OH)–COOH (CH3)2CH(OH)–COOH

2-hydroxybutane k-ta 2-hydroxy-2-methylpropane k-ta

CH3–CH(OH)–CH2–COOH

3-hydroxybutanic acid

In addition, optical isomerism is often found in a series of hydroxy acids. For example, dairyacid CH3–C*H(OH)–COOHcontains an asymmetric carbon atom in its structure and exists in the form of two optical isomers (enantiomers):



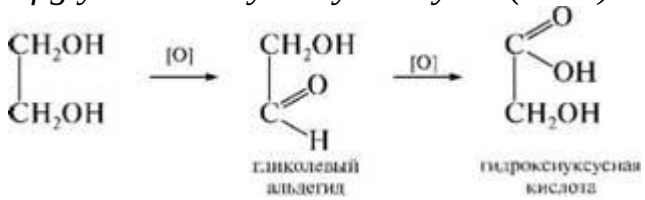
Aliphatic hydroxy acids

Methods of obtaining

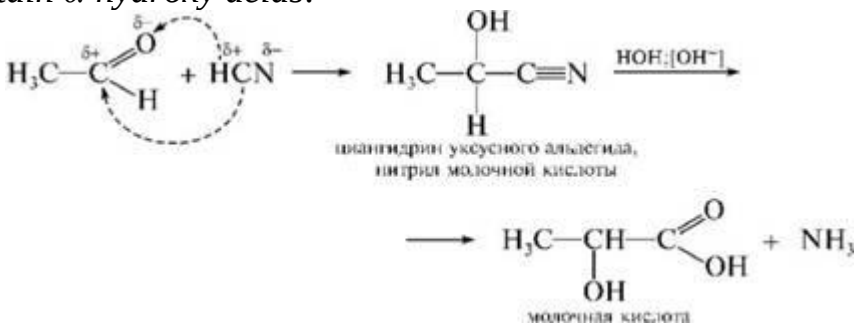
1. Hydrolysis of α-halocarboxylic acids:

$$CH3–CHBr–COOH \xrightarrow{H_2O,NaOH} CH3–CH(OH)–COOH + NaBr.$$

2. *Oxidation of glycols and hydroxyaldehydes (aldol):*



3. *Hydrolysis of hydroxynitriles (cyanohydrins). The method is used to obtain α-hydroxy acids:*



4. *Hydration of α-, β-unsaturated carboxylic acids:*

$$CH2{=}CH{-}COOH + H2O \xrightarrow{H^+} HO{-}CH2{-}CH2{-}COOH.$$

5. *Interaction of esters of α-halocarboxylic acids with carbonyl compounds (Reformatsky reaction):*

$$Br{-}CH2{-}COOC2H5 + Zn + CH3{-}C(O)H \rightarrow CH3{-}CH(OZnBr){-}CH2{-}COOC2H5$$

$$\xrightarrow{2H_2O,H^+} CH3{-}CH(OH){-}CH2{-}COOH + Zn(OH)Br + C2H5OH.$$

Physical and chemical properties

Hydroxycarboxylic acids are colorless liquids or crystalline substances, soluble in water. Many hydroxy acids have optical activity.

The reactivity of hydroxy acids is due to the presence of two functional groups in their structure - carboxylic and hydroxyl.

According to the -COOH group, all reactions characteristic of carboxylic acids are given: they form salts, esters, halides, amides, etc. In some of these reactions, the OH group can simultaneously enter, for example:

$$HO{-}(CH2)2{-}COOH + 2PCl3 \rightarrow Cl{-}(CH2)2{-}C(O)Cl + 2POCl3 + 2HCl.$$

β-chloropropionic acid chloride

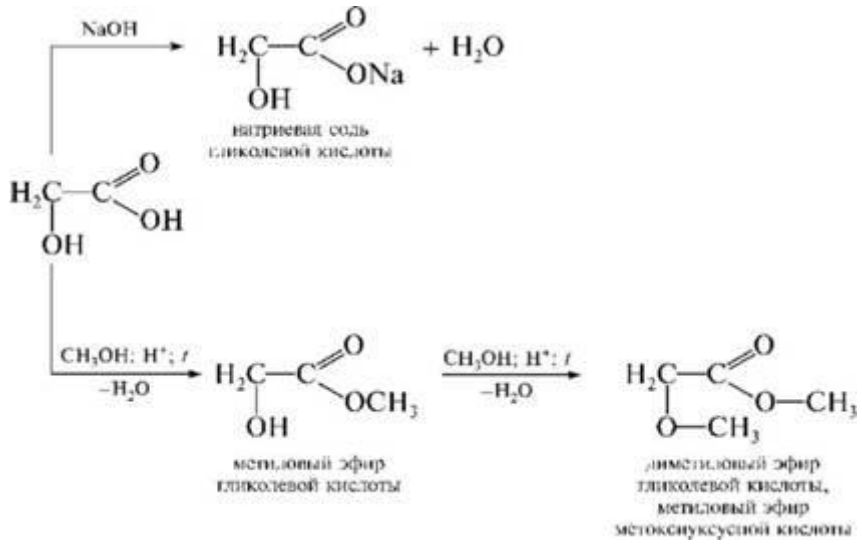
$$HO–(CH2)2–COOH \xrightarrow{CH_3OH,H^+} HO–(CH2)2–COOCH3 \xrightarrow{CH_3OH,H^+}$$

$SN_3O–(CH2)2–COOCH3$

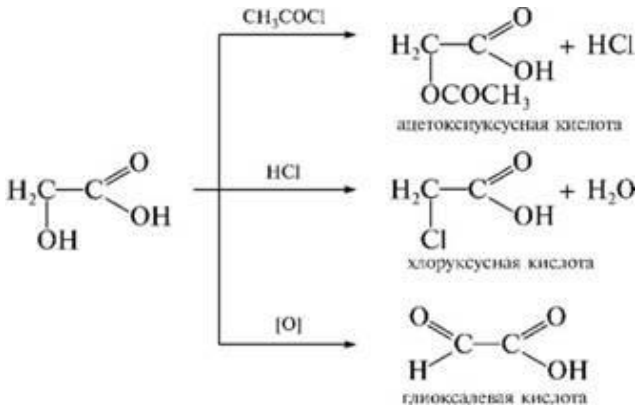
methyl ether of 3-methoxypropane k-ty

Compared with the corresponding unsubstituted acids, hydroxy acids show more pronounced acidic properties. This is due to the electron-accepting effect of the OH group, which, showing the -I effect, additionally stabilizes, is formed in the process of ionization of the carboxylate anion. As the OH group moves away from the carboxyl, the strength of hydroxy acids decreases (α <β <γ, etc.).

With the participation of the -COOH group, aliphatic hydroxy acids undergo reactions characteristic of carboxylic acids: for example, they form salts and esters.

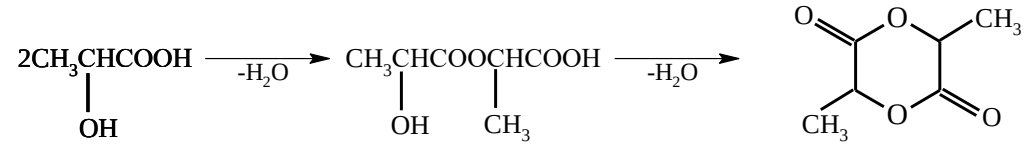


With the participation of OH groups, hydroxy acids undergo reactions characteristic of alcohols. When interacting with hydrogen halides (HCl, HBr), nucleophilic substitution of the OH group for a halogen atom occurs. When hydroxy acids are oxidized, they turn into aldehyde or keto acids:



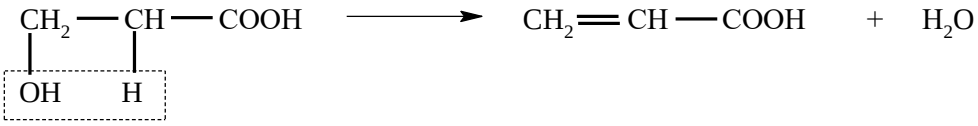
At the same time, aliphatic hydroxy acids are characterized by a number of specific properties due to the mutual influence of -COOH and OH-groups.

In relation to heating. α-Hydroxy acids, when heated, undergo intermolecular dehydration with the formation of cyclic esters - lactides:

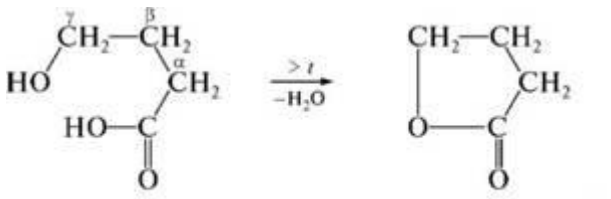


молочная кислота лактид

β-Hydroxy acids undergo intramolecular dehydration upon heating with the formation of α-, β-unsaturated acids:

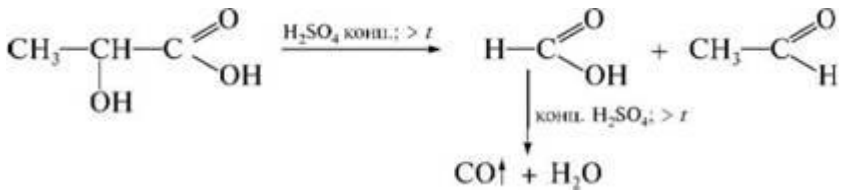


γ- and δ-Hydroxy acids already at room temperature or slightly heated undergo intramolecular dehydration with the formation of cyclic esters - lactones:



γ-гидроксимасляная кислота лактон гидроксимасляной кислоты

Cleavage of α-hydroxy acids:

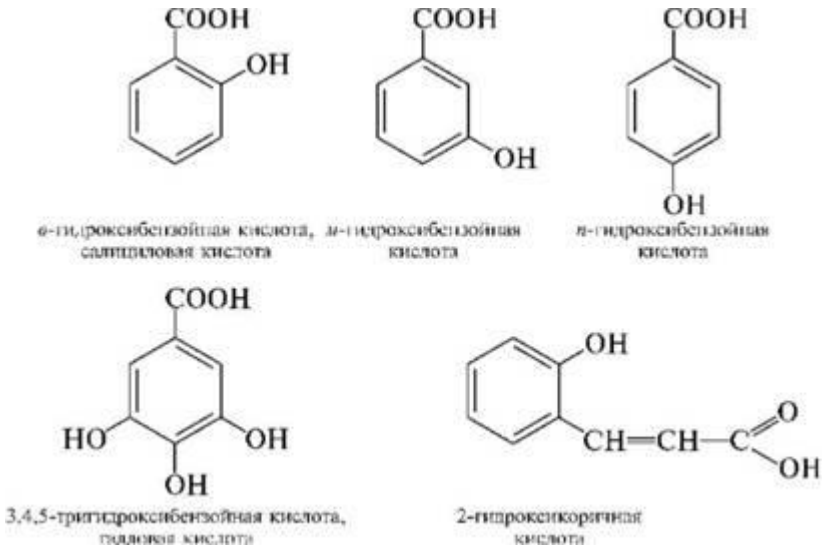


This reaction can be used to identify α-hydroxy acids.

3. Phenolic acids.

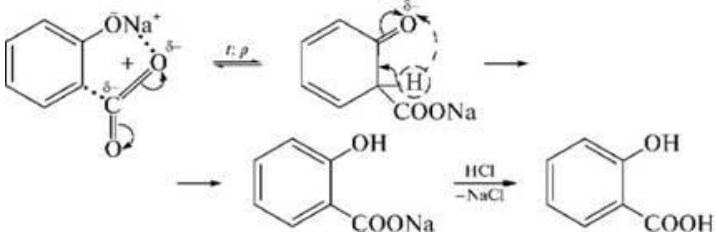
Phenolic acids are derivatives of arenecarboxylic acids in which one or more hydrogen atoms in the aromatic ring are replaced by hydroxyl groups.

The most important representatives of phenolic acids are: salicylic acid (2-hydroxybenzoic acid), 3-hydroxybenzoic acid, 4-hydroxybenzoic acid, gallic acid (3,4,5-trihydroxybenzoic acid), o-hydroxycinnamic acid:



Methods of obtaining

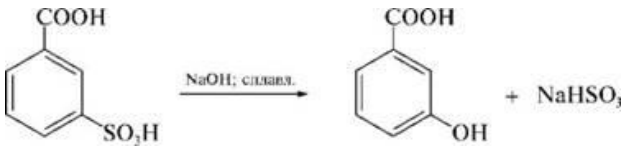
1. *Carboxylation of phenols with carbon dioxide (IV) (Kolbe-Schmidt reaction, proceeds according to the mechanism* S_E*:*



2. *Hydroxylation of arene carboxylic acids:*

$$C6H5–COOHa \xrightarrow{Cu(OH)_2,t} C6H5–COOCuOH \xrightarrow{t} at\text{-}HOOS–C6H4–OH + Cu.$$

3. *Fusion of sulfobenzoic acids with alkalis:*

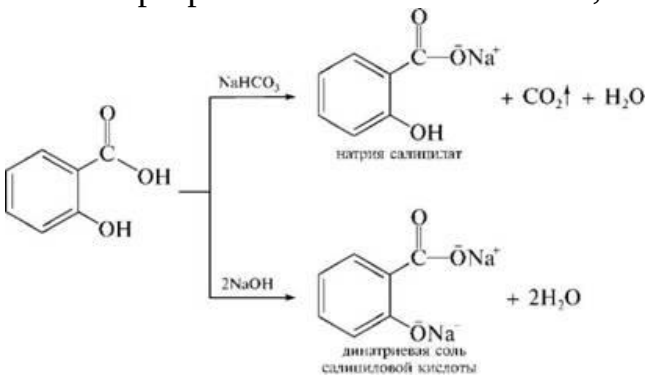


Chemical properties

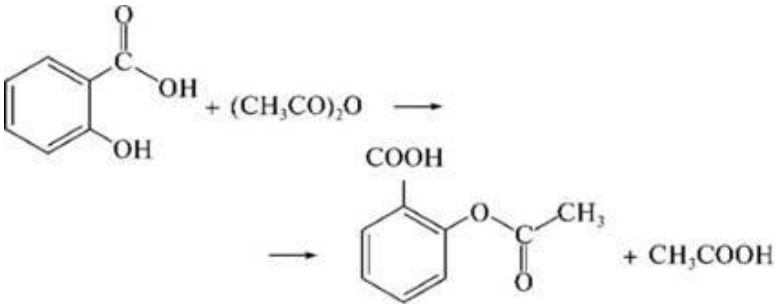
The reactivity of hydroxy acids is due to the presence of a carboxyl group, phenolic hydroxyl and an aromatic nucleus in their structure.

With the participation of the -COOH group, they form various functional derivatives - salts, halides, esters, etc. When alkalis act on hydroxy acids, salts are formed both on -COOH and on phenolic hydroxyl. Only the -COOH group reacts

with carbonates or bicarbonates of alkali metals; phenolic hydroxyl, which has weaker acidic properties than carbonic acid, is not able to displace it from salts:



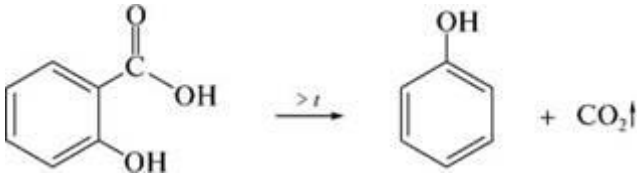
Due to phenolic hydroxyl, phenolic acids are able to form simple and complex esters, for example:



Like phenols, the interaction of phenolic acids with FeCl3 leads to products with a purple color.

Phenolic acids enter into reactions of electrophilic substitution on the aromatic nucleus, characteristic of areamn.

When heated, phenolic acids are easily decarboxylated, for example:



Individual representatives

Salicylic acid(o-hydroxybenzoic acid) is a white crystalline substance (b.p. 159 ºC), easily distilled, decarboxylated with strong rapid heating, soluble in hot water. It is used in medicine in the form of alcohol solutions and ointments as an antiseptic; serves as a raw material for the synthesis of other medicines: sodium salicylate, methyl salicylate, phenylsalicylate (salol), salicylamide, oxaphenamide, acetylsalicylic acid (aspirin).

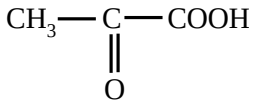
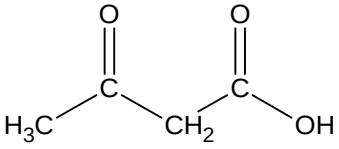
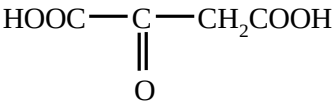
Headacid (3,4,5-trihydroxybenzoic acid) is a white crystalline substance (m.p. 220 ºC), dissolves well in water, undergoes decarboxylation when heated to form pyrogallol, easily oxidizes in air, acquiring a dark color. It is part of the tannins

contained in oak bark, tea leaves and a number of other plants. The main component of tannins are tannins - glycosides of gallic acid.

Gallic acid is used in the synthesis of dyes, and is also used in the synthesis of pyrogallol and as an analytical reagent.

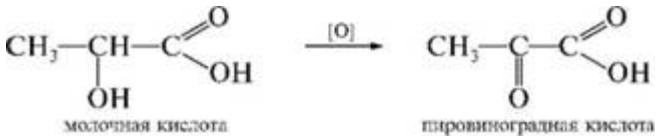
4. Oxoacids.

*Oxoacids include aldehyde and keto acids, these compounds contain a carboxyl group and an aldehyde or ketone group.*According to the relative location of the functional groups, they are divided into α-, β-, γ-oxocarboxylic acids, etc. Trivial names are widely used for many oxoacids:

		
Pyruvic acid, oxoethanoic acid	*Acetoacetic acid, 3-oxobutanoic acid*	*oxalic acid, oxobutanoic acid*

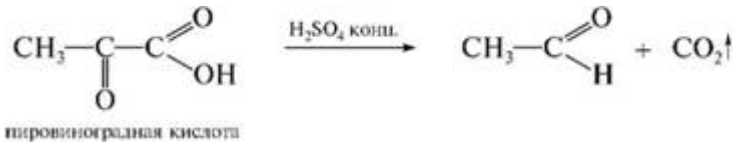
Methods of obtaining

Oxidation of hydroxy acids:

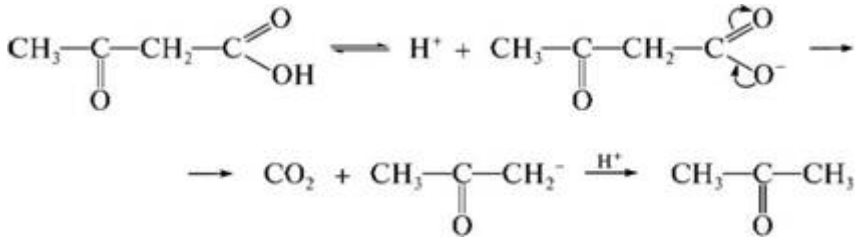


Chemical properties

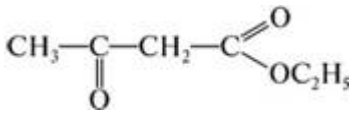
α-oxo acids are easily decarboxylated in the presence of concentrated sulfuric acid, turning into aldehydes:



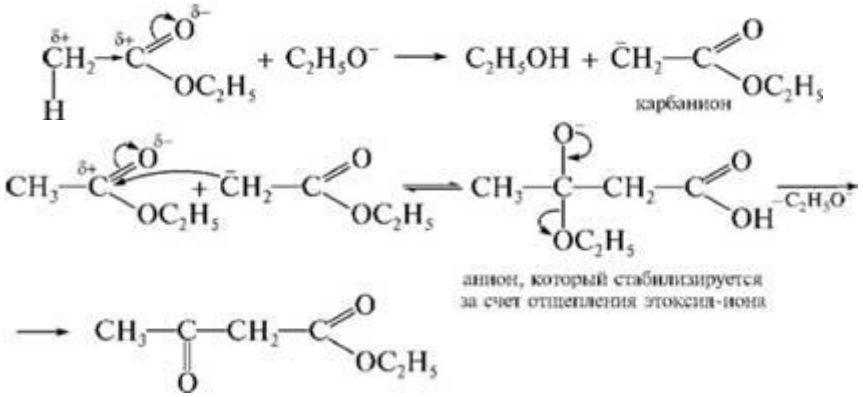
Decarboxylation of β-oxo acids occurs already at room temperature or with slight heating:



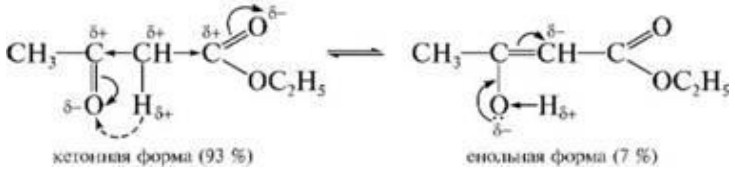
The ethyl ester of acetoacetic acid - acetoacetic ether - is of great importance in organic synthesis:



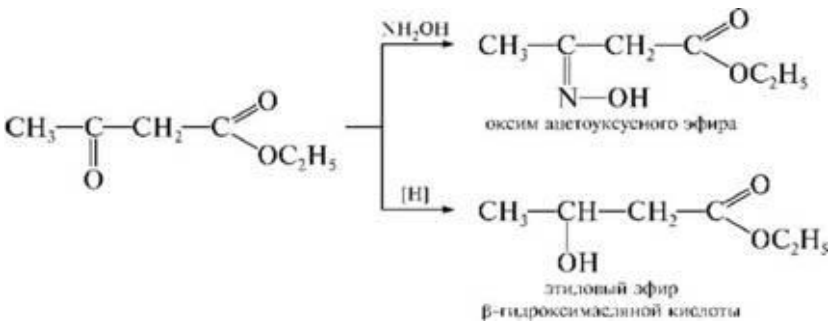
Acetoacetic ether is obtained by ester condensation of ethyl acetate:



Acetoacetic ether is a tautomeric compound, it is characterized by ketoenol tautomerism, which is due to the presence of mobile hydrogen atoms of the methylene group:



The keto form of acetoacetic ether reacts with hydroxylamine to form an oxime; is regenerated by hydrogen at the moment of separation and gives other reactions of ketones:



The existence of the enol form is proved by the formation of a red color with FeCl3 and the discoloration of bromine water:

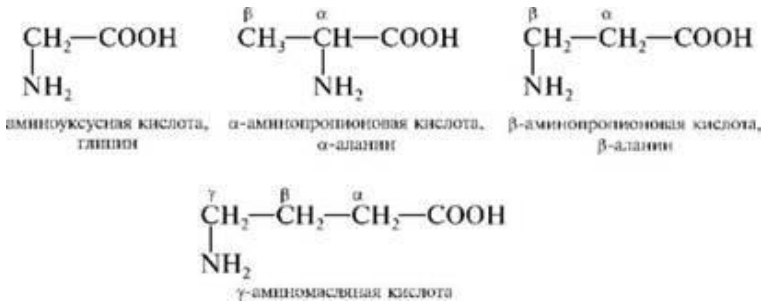
Acetoacetic ether is widely used to obtain various ketones and carboxylic acids.

5. Amino acids.

Derivatives of carboxylic acids, in the hydrocarbon radical, in which one or more hydrogen atoms are replaced by an amino group, are called amino acids.

Depending on the nature of the hydrocarbon radical to which the -COOH group is connected, amino acids are divided into aliphatic and aromatic. Aliphatic amino acids are divided into α-, β-, γ-amino acids, etc. based on the relative position of the amino group and the carboxyl group. The most common in nature are α-amino acids, which are part of proteins.

According to the substitute nomenclature of IUPAC, the names of amino acids are formed from the trivial or systematic names of the corresponding carboxylic acids and the prefix amino-. When using the trivial names of carboxylic acids, the position of the amino group is indicated by the letters of the Greek alphabet α-, β-, γ-, etc.:



Trivial names are often used for amino acids that are part of proteins. Aromatic amino acids of the benzene series are considered as derivatives of benzoic acid:

n-аминобензойная кислота, 4-аминобензойная кислота

антрамиловая кислота, *o*-аминобензойная кислота, 2-аминобензойная кислота

The isomerism of amino acids is similar to the isomerism of hydroxy acids: it can be due to the different structure of the hydrocarbon radical to which the -COOH group is connected, and the different position of the amino group in the carbon chain (structural isomerism); for amino acids containing an asymmetric carbon atom, isomerism is associated with a different arrangement of substituents in space (optical isomerism).

Methods of obtaining

1. *Action of ammonia on halocarboxylic acids:*

CH3-CHCl-COOH + 2NH3 → CH3-CH (NH2)-COOH + NH4Cl.

2. *The effect of ammonia and senile acid on aldehydes (Strecker synthesis):*

CH3-C (O) H + NH3 + HCN + 2H2O → CH3-CH (NH2)-COOH.

3. *Addition of ammonia to α, β-unsaturated acids (addition proceeds against Markovnikov's rule):*

CH2= CH-COOH + 2NH3 → NH2-CH2-CH2-COOH.
B-aminopropion k-ta

4. *Reduction of nitrobenzoic acid:*

p-O2N–C6H4–COOH $\xrightarrow{[H]}$ *p*-H2N–C6H4–COOH.

Physical and chemical properties

Amino acids are white crystalline substances with high melting points, well soluble in water. Due to the presence in the structure of an acidic (group -COOH) and a basic center (group - NH2) amino acids crystallize from neutral aqueous solutions in the form of internal salts - bipolar ions or zwitterions: R-CH (NH3+)-COO-.

Chemically, amino acids exhibit the properties of primary amines and carboxylic acids: according to the -COOH group, they form functional derivatives of carboxylic acids - salts, esters, amides, halides.

With the participation of the amino group, amino acids form salts with mineral acids, enter into alkylation, acylation reactions, react with nitrous acid, and also give

other reactions characteristic of primary amines. Amino acids have amphoteric properties, forming salts with mineral acids and bases.

Some chemical transformations of amino acids are presented in the diagram:

Reactions on the amino group

R–CH(NH2)–COOH + HCl→ R–CH(NH3+Cl–)–COOH,

R–CH(NH2)–COON + R´I→ R–CH(NHR´)–COON + НИ,

R–CH(NH2)–COON + R´COCl → R–CH(NHCOR´)–COON + HCl,

R–CH(NH2)–COON + HNO2 → R–CH(OH)–COON + N2↑ + H2O.

Reactions on the carboxyl group

R–CH(NH2)–COON + NaOH→R–CH(NH2)–COONa + H2O,

R–CH(NH2)–COON + R´OH→R–CH(NH2)–COOR´ + H2O,

R–CH(NH2)–COON + R´NH2→R–CH(NH2)–CONHR´ + H2O,*

R–CH(NH2)–COOH + PCl5→R–CH(NH2)–COCl + POCl3 + HCl.*

**Reactions are carried out after preliminary protection of the amino group.*

Along with this, amino acids have some specific properties due to the mutual influence of carboxyl and amino groups.

Attitude of amino acids to heating. When α-, β-, γ- and δ-amino acids are heated, various products are formed. α-Amino acids, when heated, undergo intermolecular dehydration with the formation of cyclic DIAMIDE - diketopiperazines.

β-Amino acids when heated split off the ammonia molecule, forming α-, β-unsaturated acids:

$$CH_3–CH(NH_2)–CH_2–COOH \xrightarrow{t} CH_3–CH=CH–COOH + NH_3.$$

When heated, γ- and δ-amino acids undergo intramolecular dehydration with the formation of cyclic amides - lactams:

$$NH_2–CH_2–CH_2–CH_2–COOH \xrightarrow{t} CH_2–CH_2–CH_2–C=O + H_2O.$$

|————NH—— |

γ-aminobutyric acid *γ-lactam*

Interaction of α-amino acids with ninhydrin. When ninhydrin acts on α-amino acids, a blue-violet dye is formed. The ninhydrin reaction is used for the qualitative determination of α-amino acids.

Individual representatives

γ-aminobutyric acid(GABA) NH2- (CH2)3-COOH is a white crystalline substance (m.p. 202 ºC), dissolves well in water. GABA is formed in living organisms during the decarboxylation of glutamic acid. It is a neurotransmitter involved in metabolic processes of the brain. GABA under the name aminalon or gammalon is used in medicine for the treatment of neuropsychiatric diseases, memory impairment, disorders of cerebral circulation, etc. GABA is used in the synthesis of other drugs, such as piracetam, phenibut, etc.

E-Aminocapronovaacid (6-aminohexanoic acid) NH2-(CH2)5-COOH is a white crystalline substance (m.p. 372 ºC), easily soluble in water. It is used in medicine as a hemostatic agent.

Anthranilic acid(o-aminobenzoic acid)o-H2N–C6H4–COOH –white crystalline substance (b.p. 145 ºC), practically insoluble in water. It is used in the production of dyes and medicines.

P-Aminobenzoinacid (PABA) is a white crystalline substance (bp. 186 ºC), sparingly soluble in drinking water. It is part of folic acid, which acts as a growth factor for some microorganisms.

Complex esters of PABA are widely used in medicine as local anesthetic agents, for example anesthesin (ethyl ester of PABA) and novocaine (β-diethylaminoethyl ester of PABA hydrochloride):

p-H2H–C6H4–COOC2H5 anesthesin
p-H2N–C6H4–COOCH2CH2N(C2H5)2·HCl novocaine

6. Derivatives of carbonic acid.

Carbonic acid can formally be considered as a carboxylic acid that contains a hydroxyl group instead of a hydrocarbon residue. Carbonic acid and its derivatives perform important functions in the body, are used in synthetic practice, some of them are used as medicines.

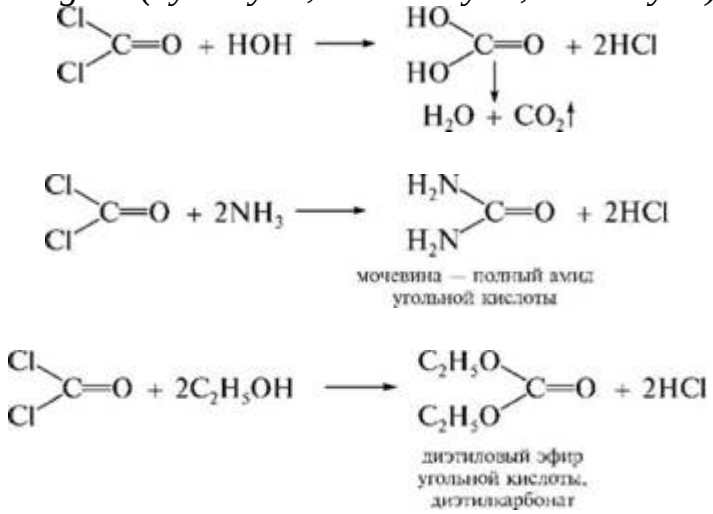
Carbonic acid chlorides

Monochloroanhydride (chlorocarbonic acid) HO-C (O) -Cl does not exist in the free state (decomposes into CO2 and HCl), but carbonic acid esters are relatively stable.

Dichloroanhydride of carbonic acid (phosgene) O = CCl2 is a gaseous substance with the smell of old hay, toxic (hazard class II), used as an explosive device in the First World War.

The synthesis of phosgene is carried out by the interaction of carbon dioxide (II) with chlorine in the light.

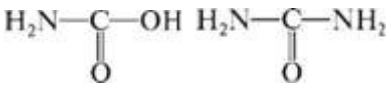
Some reactions of phosgene (hydrolysis, ammonolysis, alcoholysis):



In industry, phosgene is used in the synthesis of medicines, dyes, and plastics.

Amides of carbonic acid

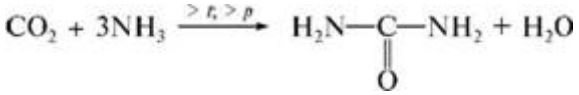
Incomplete amide of carbonic acid - carbamic acid, complete - urea (urea):



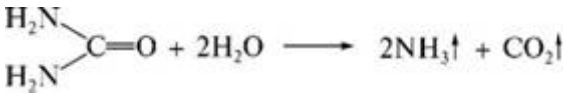
Carbamic acid is unstable and does not occur in the free state, as it easily decomposes at room temperature:

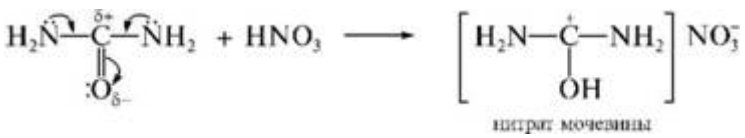
Urea - diamide of carbonic acid, is the end product of the breakdown of proteins, has great biochemical significance. For the first time, urea was obtained by F. Weller in 1828 by isomerization of the ammonium salt of cyanic acid:

Industrial synthesis of urea:

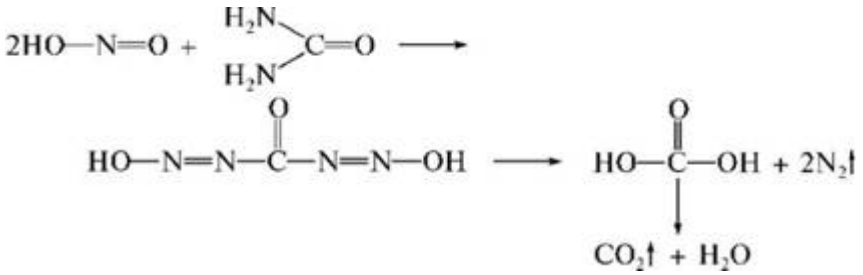


Some reactions of urea (hydrolysis, interaction with mineral acids):



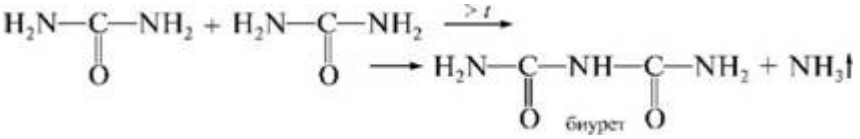


Under the action of nitric acid, urea decomposes according to the following scheme (A.P. Borodin, 1875):

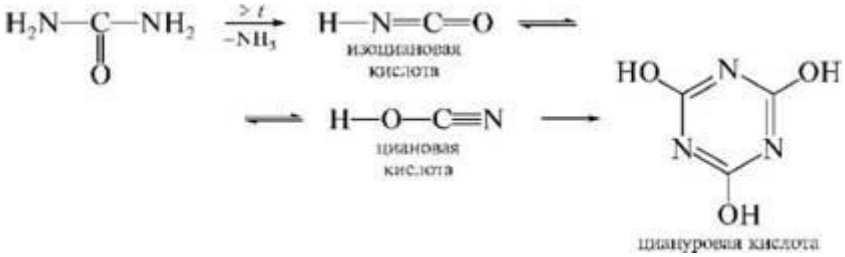


This reaction can be used for the quantitative determination of urea by the volumetric method (measurement of the volume of released nitrogen).

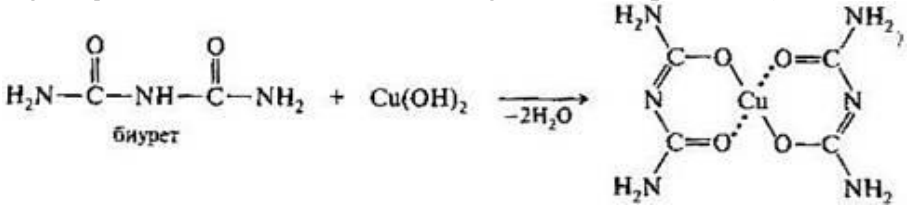
When urea is heated, a biuret is formed, which is well soluble in water:



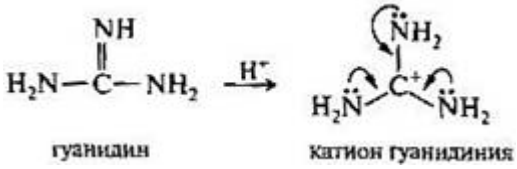
Further heating leads to the formation of cyanuric acid:



Biuret forms a red-violet complex compound with copper (II) ions (biuret reaction, used for qualitative determination of urea and proteins):

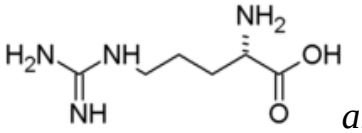


An important nitrogen derivative of urea is guanidine - a strong monoacidic base (pKVN + 13.5), which forms with acids salts that are resistant to hydrolysis:

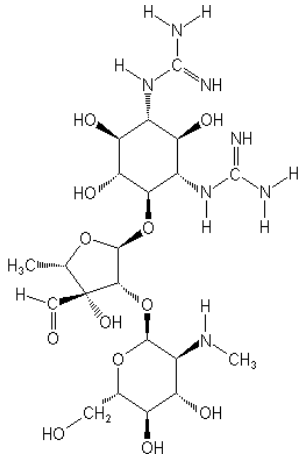


гуанидин катион гуанидиния

The guanidine residue is a structural fragment of the nucleic acid base guanine, it is included in the structure of the amino acid arginine and the antibiotic streptomycin:



arginine



streptomycin

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1. Halocarbon acids. Nomenclature, isomerism, extraction methods, acidic properties, physical and chemical properties, reactivity.
2. Hydroxy acids.Nomenclature, isomerism,Aliphatic hydroxy acids,extraction methods, physical and chemical properties, reactivity...

3.Hydroxy and phenolic acids.Nomenclature, extraction methods, chemical properties.

4. Amino acids.Nomenclature, isomerism, extraction methods, physical and chemical

properties, reactivity.

references

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Lecture No. 13

Topic: General characteristics of heterocyclic compounds. Three- and four-membered heterocycles with one heteroatom. Five-membered heterocyclic compounds with one heteroatom.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withclassification, nomenclature, aromatic character, method of extraction, physical and chemical properties of the most important heterocyclic compounds with one heteroatom.

Basic concepts: Three-membered heterocycles..Four-membered heterocycles. Five-membered heterocycles. Five-membered heterocycles with two heteroatoms.

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Plan and organizational structure of the lecture:

1. Classification and nomenclature of heterocyclic compounds.

2. Three- and four-membered heterocycles with one heteroatom.

3. Five-membered heterocycles with one heteroatom (pyrrole, furan, thiophene).

4. General ideas about five-membered heterocyclic compounds with two heteroatoms.

Content of lecture material (lecture text)

Heterocyclic are organic substances containing cycles, the composition of which, in addition to carbon atoms, includes one or more atoms of other elements - heteroatoms.

Often heteroatoms**isoxygen, nitrogen, and sulfur**, although in principle a heteroatom can be an atom of any element with a valence of at least two.

1. Classification and nomenclature of heterocyclic compounds.

Heterocyclic compounds are classified depending on the size of the ring, the nature and number of heteroatoms, as well as the degree of saturation of the ring. Three-, four-, five-, six-, and seven-membered heterocycles are distinguished by the size of the cycle. According to the degree of saturation, all heterocyclic compounds are classified into saturated, unsaturated and aromatic.

Trivial and systematic names are used for heterocyclic compounds. Trivial names are adopted by the IUPAC nomenclature and in most cases are more commonly used. When constructing the systematic names of heterocycles, the IUPAC rules take into account the nature and number of heteroatoms, as well as the size of the cycle and the degree of its saturation. At the same time, the nature of the heteroatom is reflected in the prefix, the size of the cycle - in the root, and the degree of saturation - in the suffix of the name. Prefixes are used to designate heteroatoms O, S, and N**ox**- (O), thia- (S) and -azo(N). The size of the cycle is indicated by the roots -ir- (three-), -et- (four-), -ol- (five-), in -(six-), -ep- (seven-membered), and the degree of saturation - by the suffixes - idine (saturated cycle with N-atom), -ane (saturated cycle without N-atom), -ene (unsaturated cycle). The suffix is not indicated in the name of heterocycles with the maximum possible number of double bonds in the

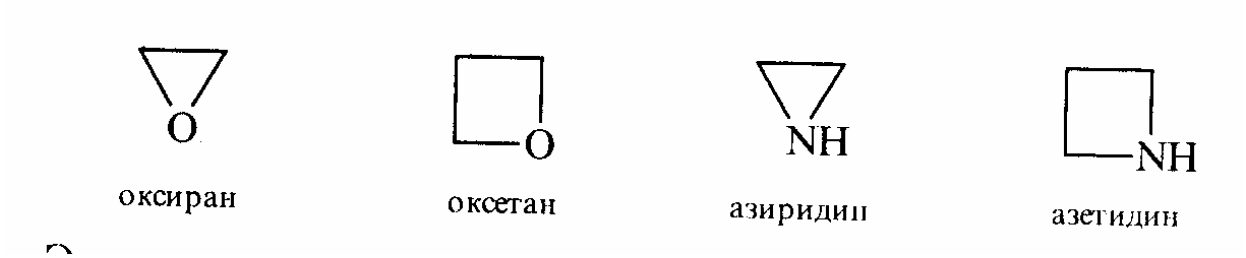
cycle. For partially hydrogenated compounds, prefixes dihydro-, tetrahydro- are used, indicating the numbers of atoms to which hydrogen is attached. If a hydrogen atom is attached to only one atom of the cycle, then the number of the hydrogenated atom and the letter H are indicated in the name. In six- and seven-membered N-containing heterocycles, complete saturation of the cycle is indicated by the prefix perhydro-. The number of heteroatoms of the same type is indicated in the name by the multiplying prefixes di-, tri-, tetra-, etc. If the heterocycle

contains several different heteroatoms, then they are called in a certain sequence: oxa-, thia-, azo -.

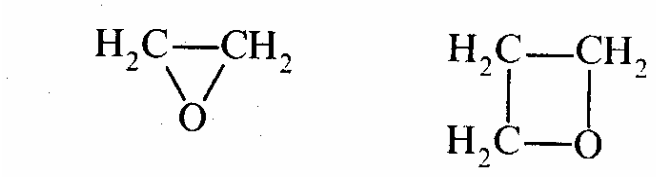
A number of simplifications are allowed when compiling the name in general. Below are examples of the construction of systematic names, as well as trivial names of some heterocycles.

2. Three- and four-membered heterocyclic compounds with one heteroatom.

Three- and four-membered heterocycles with one heteroatom can be considered as derivatives of cyclopropane and cyclobutane, in which one group -**CH2**- substituted by a heteroatom. Compounds with O- and N-heteroatoms are considered below:



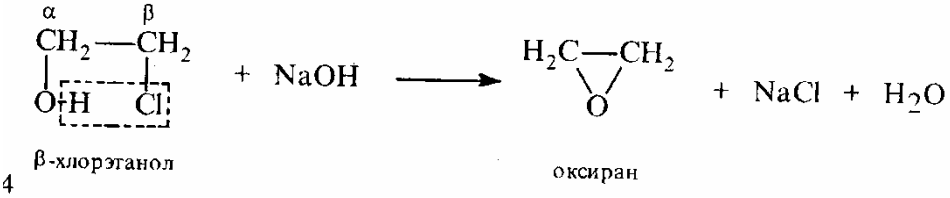
These heterocycles have a number of common methods of preparation and have similar reactivity due to the presence of strained three- and four-membered rings in the structure. The listed compounds are prone to addition reactions that proceed with the breaking of the "heteroatom - carbon" bond. Three-membered heterocycles are less stable (more reactive) than four-membered ones.



Oxirane and oxetane

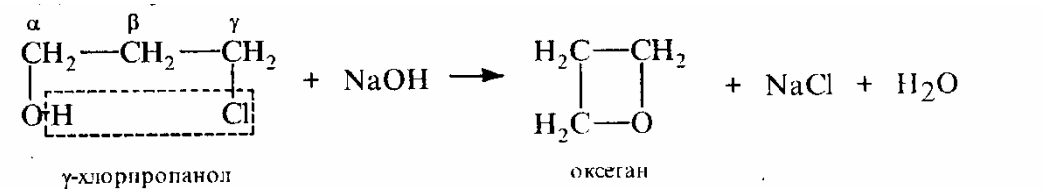
Methods of obtaining

1. The general method of oxirane and oxetane synthesis is dehydrohalogenation of β- and γ-haloalcohols, respectively, accompanied by cyclization:



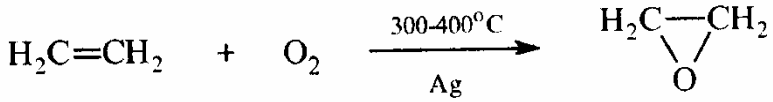
β-хлорэтанол оксиран

4



γ-хлорпропанол оксетан

2. In industry, oxirane is mainly obtained by oxidizing ethylene with air oxygen at a temperature of 300-400 ºC over a silver catalyst:



Physical and chemical properties

Oxirane- colorless gas with an ethereal smell, i.e. Boil. 10.7 ºC, dissolves well in water and organic solvents.

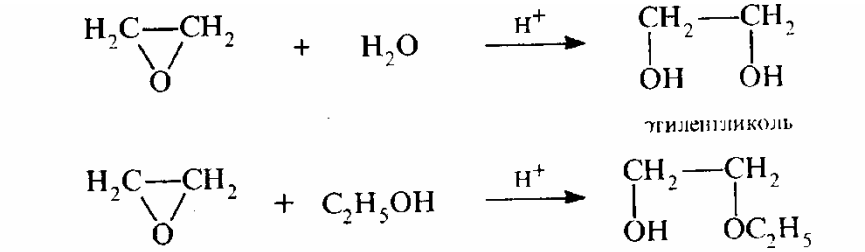
Oxetane- liquid with t. Kip. 47.8 ºC, well soluble in water, ethanol and diethyl ether.

Oxirane and oxetane are relatively reactive compounds, which is related to the angular and torsional stress of the cycles (similar to cyclopropane and cyclobutane) and the presence of polar C-O bonds.

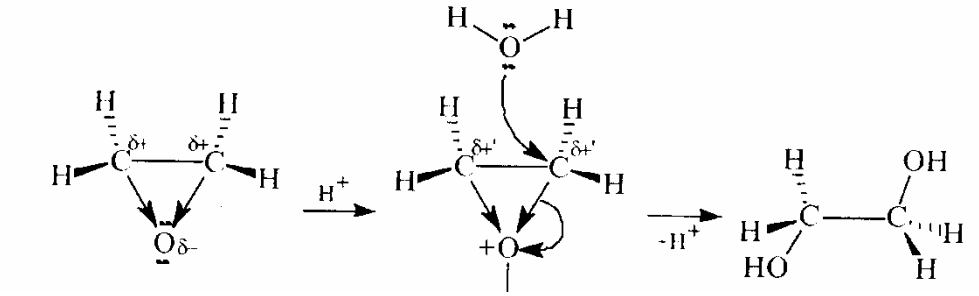
Cyclic ether	Stress energies, kJ/mol	
	according to measurement data heat of formation	according to measurement data heat of combustion
(CH2)2O	117.2	114.1
(CH2)3O	–	106.7
(CH2)4O	28.0	23.6
(CH2)5O	9.2	4.9

Under the action of electrophilic and nucleophilic reagents, the C-O bond is broken and the reagent molecule is joined at the site of the cycle break. These reactions proceed especially easily under conditions of acid catalysis.

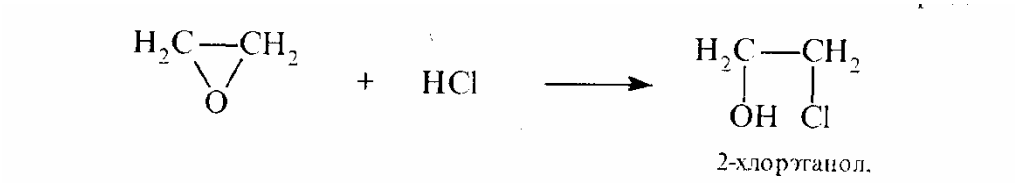
So, in the presence of sulfuric or phosphoric acids, oxirane easily adds water and alcohols:



The mechanism of the above reactions involves the formation of an oxonium compound, which is much more easily attacked by nucleophilic reagents than oxirane itself (δ + '> δ +):

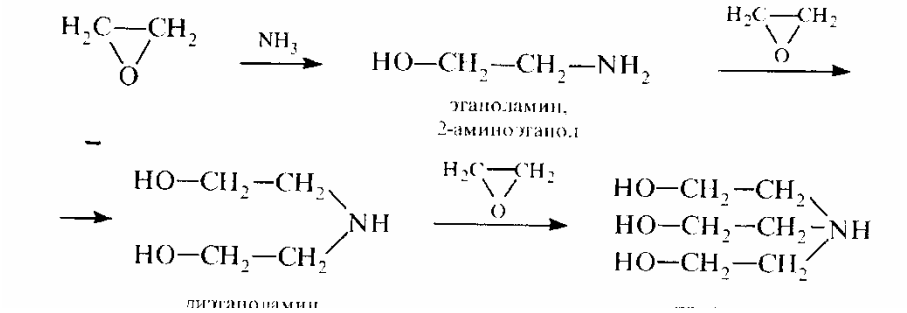


Similarly, oxirane attaches halogens:



Oxiran relatively easily attaches strong nucleophiles, such as ammonia, amines, organometallic compounds.

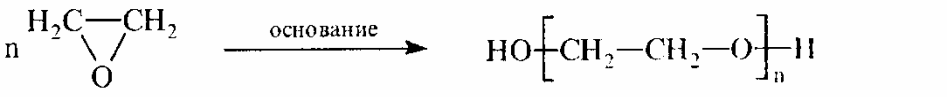
When oxirane interacts with ammonia, depending on the ratio of reagents, mono-, di-, and triethanolamines are formed:



When acting on the oxirane of aliphatic amines, N-alkylaminoethanols are formed in a similar way:

(CH2)2O + R–NH2 → HO–CH2–CH2–NH–R.

In the presence of strong bases, oxirane polymerizes with the formation of polyethylene oxide (polyethylene glycol):

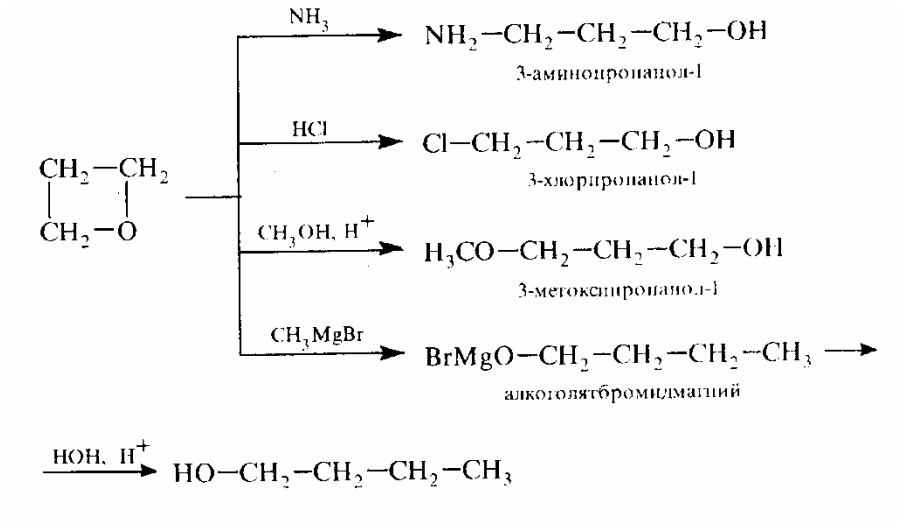


Polyethylene glycol, depending on the molecular weight, has a different state of aggregation. Do M 400 is a liquid that is well soluble in many organic solvents. It

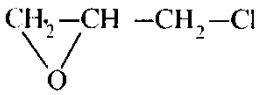
is used in pharmacy as a solvent for medicinal substances, bases for ointments and suppositories, and also as a binder in the production of tablets.

Oxetane, like oxirane, is characterized by ring-opening addition reactions, but the lower degree of stress in four-membered rings contributes to the slower progress of such reactions.

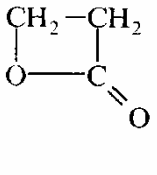
Many oxetane reactions lead to the formation of 1,3-disubstituted propane derivatives:



The most important derivatives of oxirane and oxetane

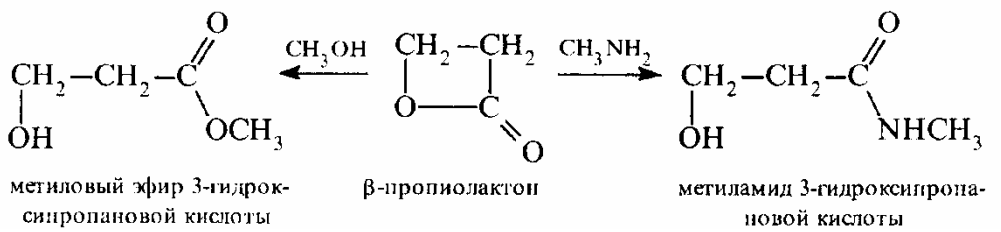


Epichlorohydrin(3-chloro-1,2-epoxypropane). Colorless liquid with the smell of chloroform, t. Boil. 116.1 ºC. Well soluble in organic solvents, it is used in the production of epoxy resins, ion-exchange fibrous materials, for the production of glycerol and as a solvent for cellulose esters.

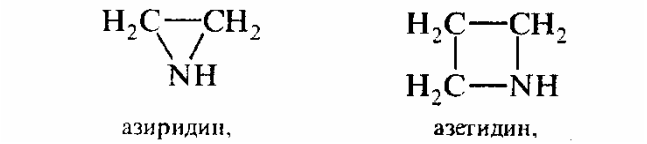


β-propiolactone(β-hydroxypropionic acid lactone). liquid with a sharp smell, t. Boil. 155 ºC, dissolves in organic solvents, easily hydrolyzes in water to β-hydroxypropionic acid.

B-propiolactone easily interacts with amines and alcohols with opening of the cycle:

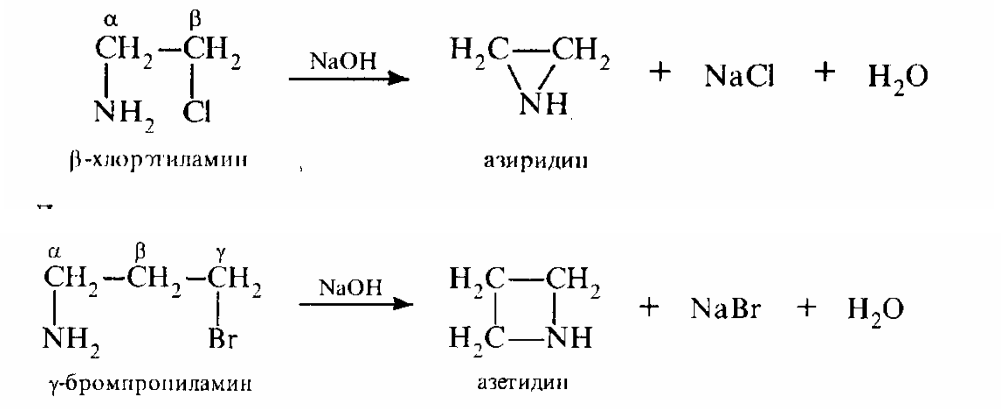


Aziridine and Azetidine

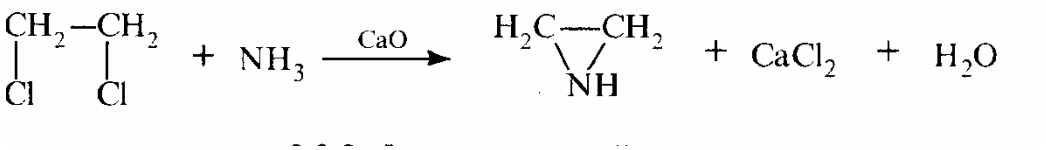


Methods of obtaining

The general method of obtaining aziridine and azetidine consists in the cyclization of halogenamines (β-haloethylamines and γ-halopropylamines, respectively) in the presence of alkali:



In industry, aziridine is obtained by reacting 1,2-dichloroethane with ammonia in the presence of calcium oxide:



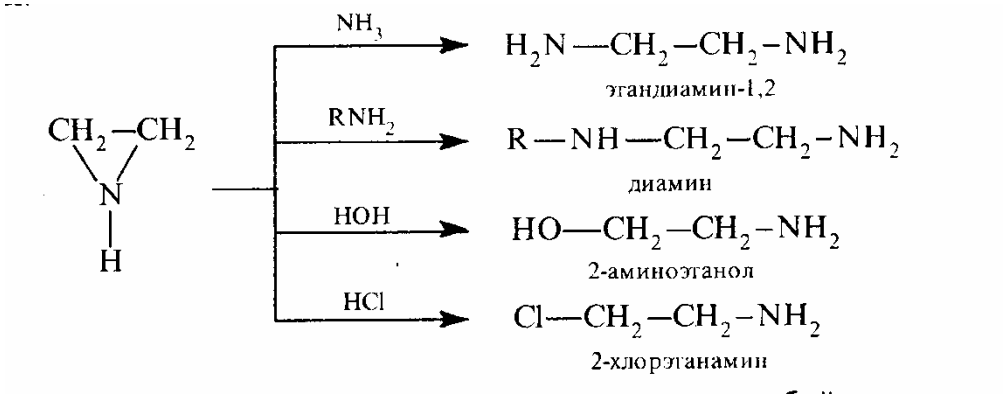
Physical and chemical properties

Aziridine- colorless liquid with t. Kip. 55 ºC, dissolves well in water and organic solvents.

Azetidine- a colorless liquid with an ammoniacal smell, i.e. Boil. 63 ºC, dissolves well in water and alcohols.

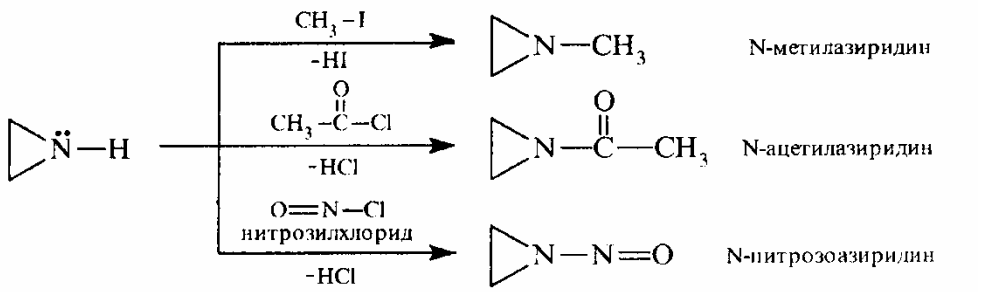
Chemical properties

Aziridine and Azetidine are somewhat similar to the properties of O-containing heterocycles of oxirane and oxetane. Thus, aziridines and azetidines are characterized by addition reactions with ring opening:



Along with this, aziridine and azetidine, being secondary cyclic amines, show basic properties (pK_{and}7.48 and 11.29, respectively).

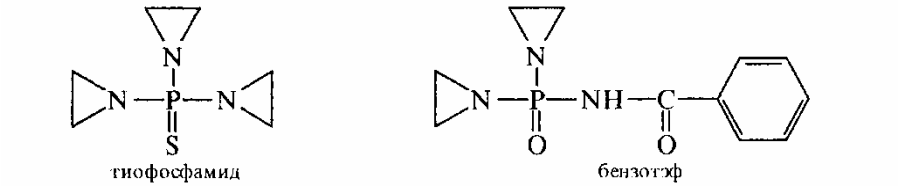
Like other secondary amines, they undergo alkylation, acylation, nitrosation and other reactions, for example:

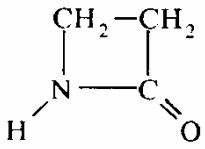


These reactions are usually carried out in the presence of bases (an excess of triethylamine is often used) to bind the released hydrogen halide or other acidic products capable of opening the cycle.

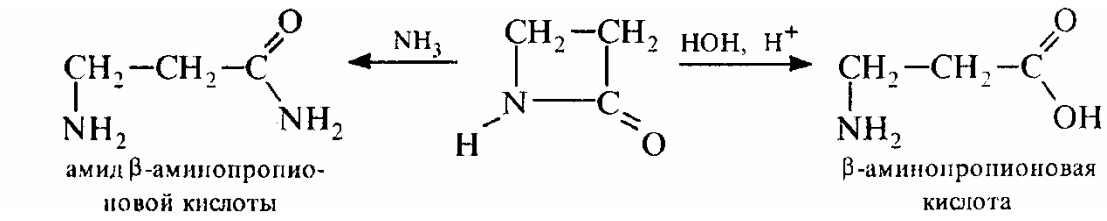
The most important derivatives of aziridine and azetidine

Among the aziridine derivatives, substances with cytostatic activity were found, on the basis of which a number of antitumor drugs were createddrugs (thiophosphamide, benzotef, fluorobenzotef, etc.). All of them contain, as a rule, residues of phosphoric and thiophosphoric acids:

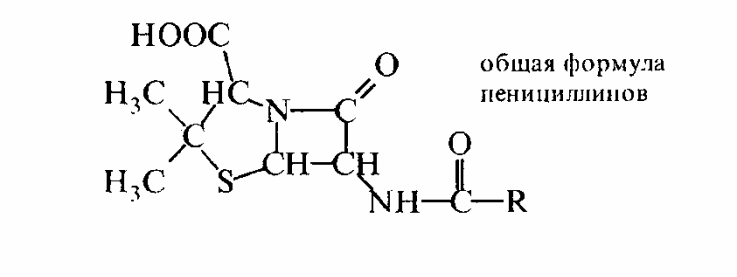




Of the azetidine derivatives, azetidinone-2 (β-lactam) is important. This is a cyclic amide of β-aminopropionic acid. It is obtained by thermal cyclization of β-aminopropionic acid. Under the action of aqueous solutions of acids and alkalis, ammonia and amines, the β-lactam ring opens:



Azetidione-2 is part of penicillin group antibiotics:



5. Five-membered heterocyclic compounds with one heteroatom.

The subject of this lecture is five-membered N-, O- and S-containing heterocycles with aromatic properties. Such substances in their stability and chemical properties resemble benzene in many ways and are called heteroaromatic compounds; according to their properties, they are significantdiffer from the previously considered three- and four-membered N-, O-containing heterocycles.

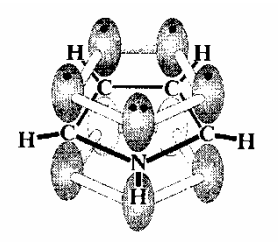
Aromaticity of five-membered heterocycles

As is known, according to Hückel, a sign of aromaticity is the presence of a planar cyclic system, which includes a closed chain of coupling with the participation of (4n + 2) π-electrons.

The aromaticity of five-membered heterocycles with two π-bonds is due to the fact that in pairing with the π-electrons of double bonds,**NEP**hetero atomO:, N: or S:.As a result, a closed conjugated system is formed, in which the number of π-electrons corresponds to Hückel's rule 4n + 2; n = 1.

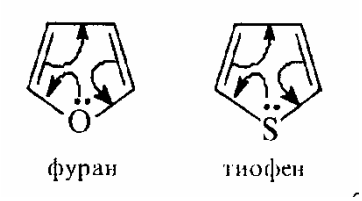
In a molecule**pyrrole**carbon and nitrogen atoms are in a state of sp2 hybridization. Due to sp2-hybrid AO, each atom of the cycle forms three σ-bonds located in the plane of the cycle. At the same time, each C-atom and nitrogen atom has one unhybridized p-AO, which are located parallel to each other and perpendicular to the plane of the cycle. Each of p-AO, C-atom has one electron, and NEP is located on p-AO, N-atom. When overlapping r-AO

a single 6π-electron cloud of the cycle is formed.



The nitrogen atom in sp2-hybridization with an electronic configuration in which NEP occupies unhybridized p-AO was named pyrrolic.

Similarly, a conjugated system is formed in other five-membered heterocycles with two π-bonds, in particular, in furan and thiophene molecules.



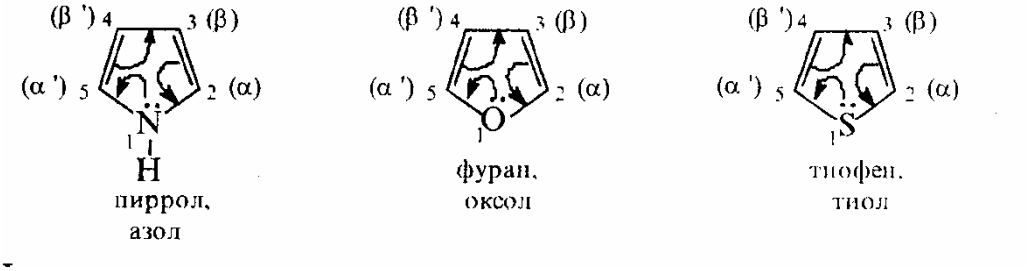
Here, as in pyrrole, the heteroatom contributes to the aromatic sextet of NEP. By analogy with pyrrole, a heteroatom that contributes to the π-electron system of NEP on p-AO and forms only σ-bonds with other atoms is called a pyrrole-type heteroatom.

Heterocycles in the molecules of which a heteroatom is a donor**NEP**and, therefore, increases the electron density on the carbon atoms of the aromatic ring, called π-excess.

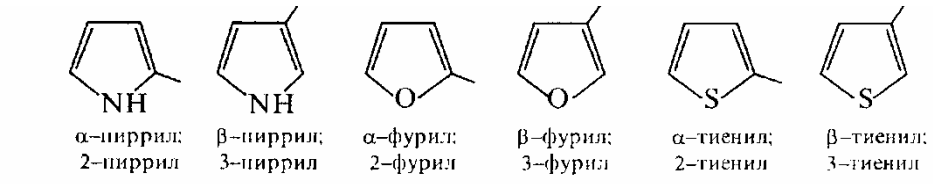
They include five-membered heteroaromatic compounds containing pyrrole-type heteroatoms (pyrrole, furan, thiophene, etc.).

Non-condensed five-membered heterocyclic compounds with one heteroatom

The most important representatives of these heterocycles are**pyrrole, furan and thiophene**:

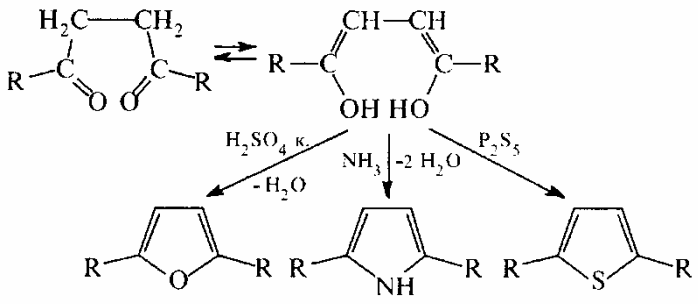


The names of the monovalent residues of the given heterocycles are formed with the help of the suffix -**silt,**indicating the position of the free valency by a number or letter of the Greek alphabet:

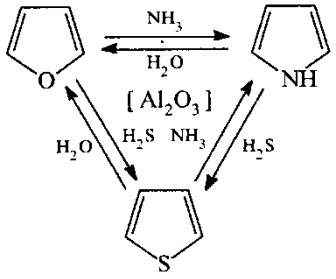


Methods of obtaining

1. Cyclization of 1,4-dicarbonyl compounds (Paal-Knorr synthesis):



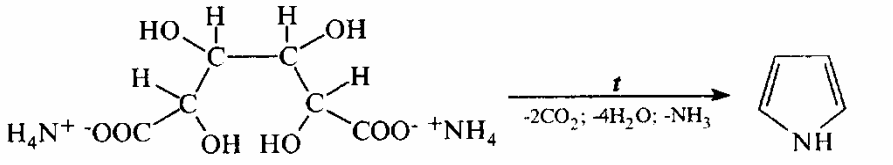
2. Mutual transformations of furan, pyrrole and thiophene (Yuriev reactions). Discovered by the Soviet chemist Yu.K. Yuryev in 1936, are carried out under catalytic action and heating (~ 450 ºC):



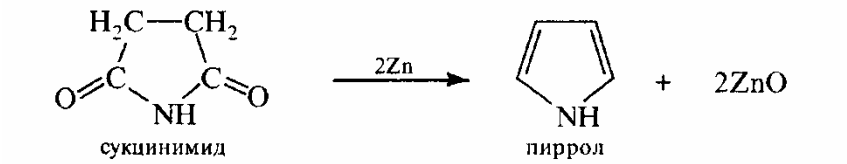
Of the above reactions, only the transformation of furan into pyrrole and thiophene proceeds with good yield.

Specific methods of obtaining

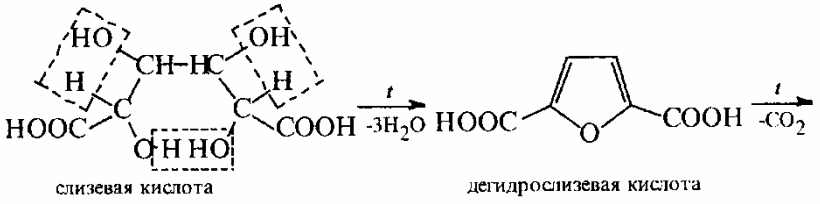
1. Obtaining pyrrole - by heating the diammonium salt of mucous acid:

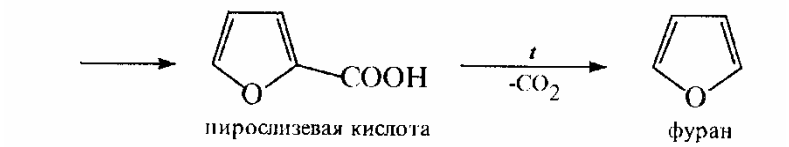


Another method consists in the distillation of succinimide with zinc dust:

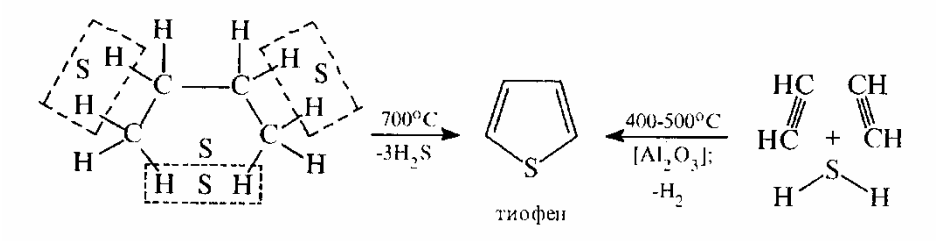


2. Obtaining furan - by dry distillation of mucoid acid:





3. Obtaining thiophene (first isolated in 1882 by V. Meyer from coal tar) - by vapor-phase cyclization of butane with sulfur or by the Chichibabin reaction when a mixture of acetylene and hydrogen sulfide is passed over a catalyst (Al2O3):



Physical and chemical properties

Pyrrole is a colorless liquid; the smell resembles the smell of chloroform; t. kip 130 ºC; sparingly soluble in water, well soluble in ethanol and benzene. It's getting dark in the air.

Furan is a colorless liquid with a peculiar smell, reminiscent of the smell of chloroform, i.e. Kip. 32 ºC; soluble in water, well soluble in ethanol and diethyl ether.

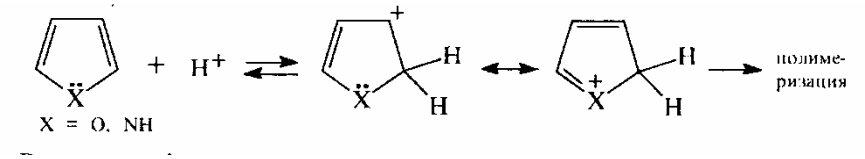
Thiophene is a colorless liquid with a weak smell of sulfur compounds; t. kip 84 ºC; soluble in water, well soluble in ethanol, diethyl ether and benzene. Resistant to high temperature, oxidizes in the light.

The reactivity of pyrrole, furan, and thiophene is determined by the presence of a π-electron excess aromatic system in their ring structure (6 p-electrons per 5 ring atoms). However, the degree of aromaticity of these heterocycles is lower than that of benzene and depends on the nature of the heteroatom. Because**EO**The S-atom is less than the EO of N- and O-atoms, the share of NEP participation of the S-atom in the formation of the aromatic sextet of the thiophene molecule is greater than that of the N-atom in pyrrole and the O-atom in furan. Thus, if for benzene the energy of coupling is ~ 150 kJ/mol, then in the series of thiophene, furan, and pyrrole it decreases as the EO of the heteroatom increases: ~ 130, ~ 110, ~ 90 kJ / mol, respectively. Therefore, of the given heterocycles, thiophene in its chemical behavior is most similar to benzene, and furan has the least pronounced aromatic character, so that in some reactions furan behaves as an unsaturated compound.

Because of**EO**heteroatoms in pyrrole, furan, and thiophene molecules, in contrast to benzene, the electron density is unevenly distributed, in particular, electron density is higher on C atoms in the α-position than in the β-position, which determines the directionality of electrophilic substitution reactions.

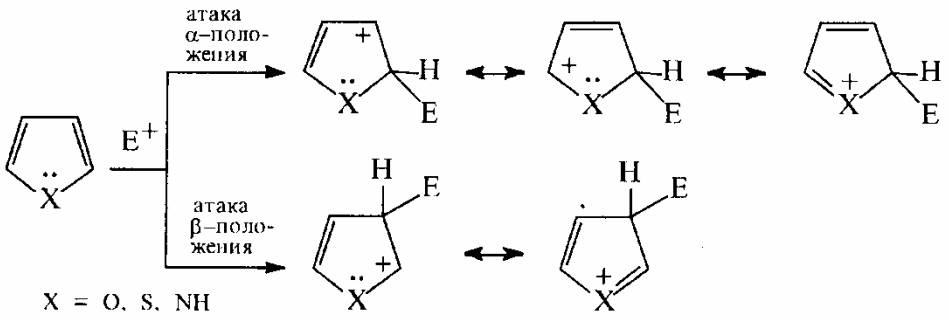
General chemical properties of pyrrole, furan and thiophene

1. Interaction with mineral acids. In the presence of strong mineral acids, pyrrole and furan tarnish, forming dark-colored polymer products (acidophobic from Latin - acidum - "Acid" and Greek. Phobos - "fear"). Acidophobicity is due to the addition of a proton mainly to the α-C atom of the ring, which leads to a violation of the aromaticity of the ring. Then there is either a rupture of the cycle with the formation of a polymer (the most likely process for furan), or the polymerization of the formed diene structure with the preservation of the cycle:

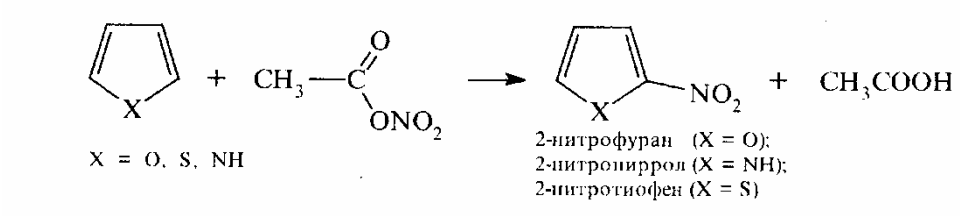


Introduction of electron-withdrawing substituents (-NO_2,-COOH, -CH = O) leads to a decrease in the acidophobicity of these compounds. Thiophene, unlike furan and pyrrole, is not acidophobic, so it has a stable aromatic structure that is not destroyed by strong mineral acids.

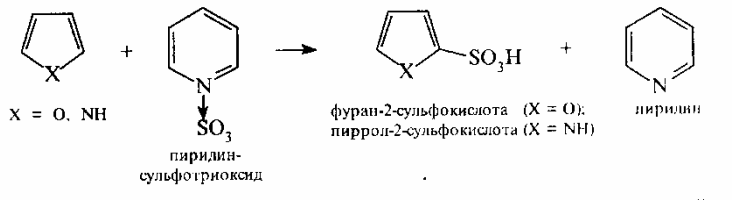
2. Reactions of electrophilic substitution. Pyrrole, furan, and thiophene easily undergo electrophilic substitution reactions characteristic of aromatic compounds, which proceed much more easily than in benzene. According to activity in reactions with electrophilic reagents, these heterocycles are located in the series: pyrrole > furan > thiophene. First of all, a hydrogen atom is replaced at the α-C atom, and only if this position is occupied, the substitution is carried out at the β-position. Such directionality of substitution is due to the fact that with the participation of the α-C atom, a more stable σ-complex is formed (a great opportunity for the delocalization of the positive charge):



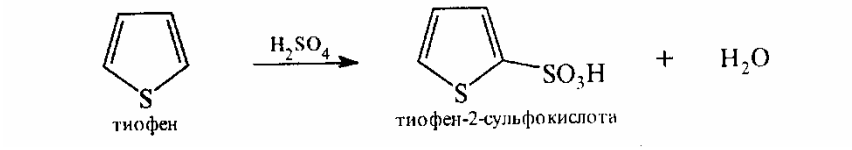
Nitration. Taking into account the acidophobicity of furan and pyrrole, their nitration is carried out not with nitric acid itself, but with the reaction product $HNO_3$with acetic anhydride - acetyl nitrate. Thiophene can be nitrated with HNO3 under mild conditions, however, acetyl nitrate is also often used. As a result of nitration, α-nitro compounds are formed:



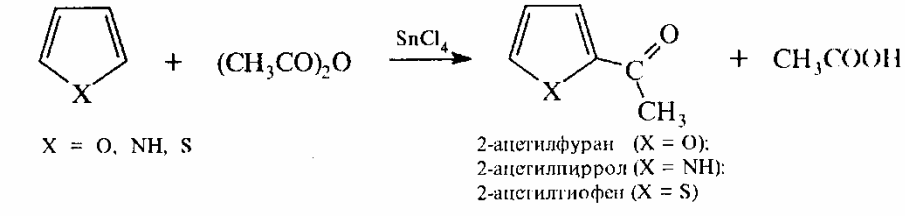
Sulfation. For sulfonation of acidophobic furans and pyrroles instead of sulfuric acid. A complex of pyridine with sulfur oxide (VI) C is used$_5$H5N·SO3. This sulfonating reagent BUV was proposed in 1947 by the Soviet chemist A.P. Terentyev. Reaction products are α-sulfonic acids:



Thiophene is easily sulfonated with concentrated sulfuric acid in the cold in almost quantitative yield. Since benzene under these conditions with H_2SO4 does NOT react, this reaction is used in the purification of technical benzene from thiophene admixture:

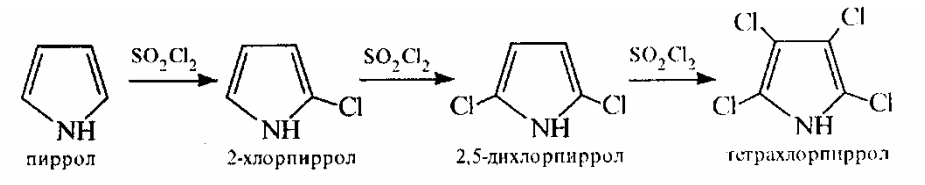


Acylation. For the acylation of furan and pyrrole, acid anhydrides are used as reagents in the presence of Lewis acids, more often $SnCl_4$and ZnCl2. Thiophene acylated with both anhydrides and acid chlorides in the presence of AlCl3. Substitution is carried out in the α-position:



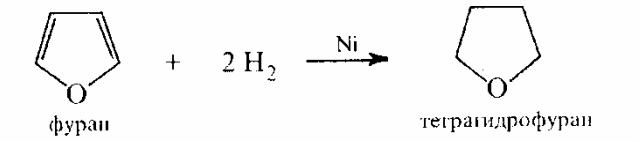
Halogenation. Halogenation of furan is quite complicated: along with replacement of H atoms by halogen, depending on the reaction conditions, 2,5-

addition products are also formed. Pyrrole reacts very easily with halogens, forming tetrahalopyrroles. Special conditions are used to obtain monosubstituted pyrrole derivatives. For example, when sulfur chloride SO acts on pyrrole$_2$Cl2 there is a stepwise replacement of H atoms by halogen:



Halogenation of thiophene is carried out directly by the action of halogen (chlorine or bromine) in the cold, while mono-, di-, tri- and tetra-substituted derivatives of thiophene are formed.

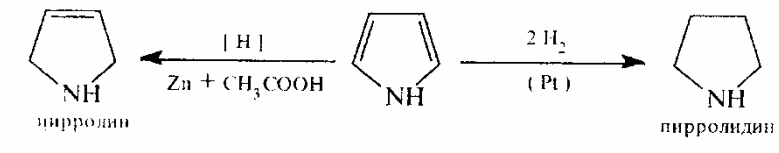
3. Recovery reactions. Furan is hydrogenated at high temperature (140 ºC) and pressure (100 - 150 atm.) in the presence of a catalyst (Raney nickel, palladium) with the formation of tetrahydrofuran (THF):



THF is a cyclic simple ether, low-reactivity, widely used in organic chemistry as a solvent.

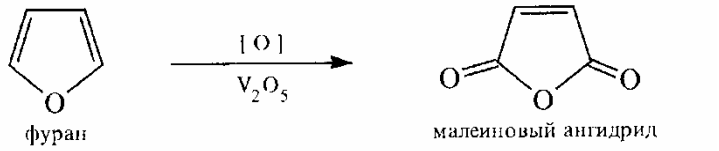
Hydrogenation of thiophene in the presence of a Pd catalyst to form tetrahydrothiophene is much easier than that of furan (room temperature, P = 2-4 atm).

Pyrrole, unlike furan and thiophene, is hydrogenated by hydrogen at the moment of separation (Zn + CH_3COOH) with the formation of unsaturated 2,5-dihydropyrrole (pyrroline). During hydrogenation over a Pt or Pd catalyst, tetrahydropyrrole (pyrrolidine) is formed:

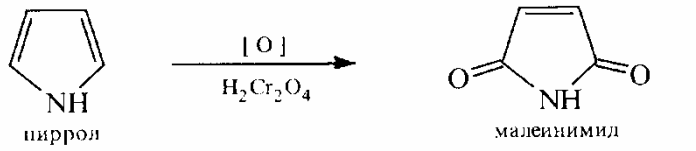


Pyrroline and pyrrolidine are cyclic amines and differ significantly in their chemical properties from pyrrole. In the pyrroline molecule**NEP**is not combined with the π-electrons of the double bond, therefore it exhibits the properties of amines and non-limiting compounds. Pyrrolidine is a typical representative of secondary cyclic amines. The pyrrolidine cycle is part of many natural compounds, such as alkaloids nicotine, cocaine, atropine, etc.

4. Oxidation reactions. Furan and pyrrole are very sensitive to the action of oxidizing agents and are already oxidized by air oxygen with the destruction of the cycle and the formation of polymer compounds. Passing a mixture of furan and air over a V2O5 catalyst at a temperature of 320 ºC leads to the formation of maleic anhydride:



When pyrrole is oxidized with chromic acid, maleic acid imide is formed:

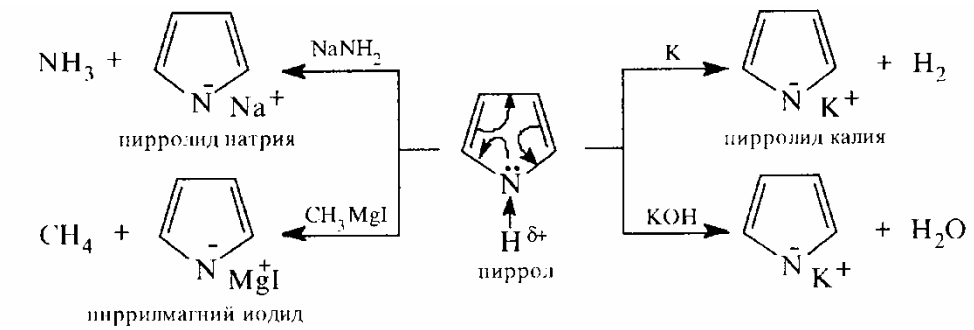


Thiophene is oxidized with great difficulty.

5. Mutual transformations of furan, pyrrole and thiophene - the reaction takes place at a temperature of 450 ºC in the presence of a catalystAl2O3.

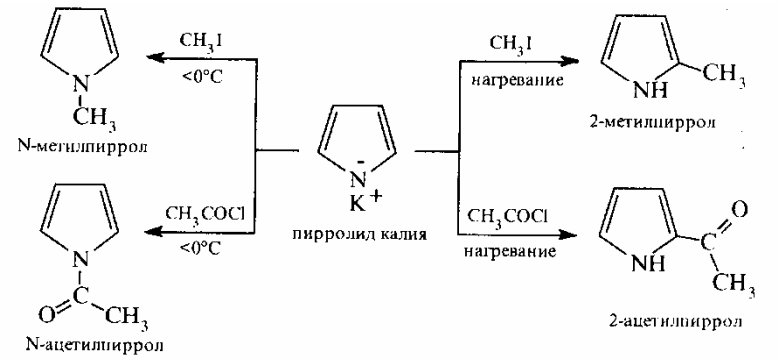
Specific chemical properties of pyrrole and furan

1. Pyrrole and its derivatives. Being a weak NH-acid, pyrrole reacts with potassium metal, anhydrous NaOH, sodium and lithium in liquid ammonia, with sodium and potassium amides, as well as organomagnesium compounds, forming salts:

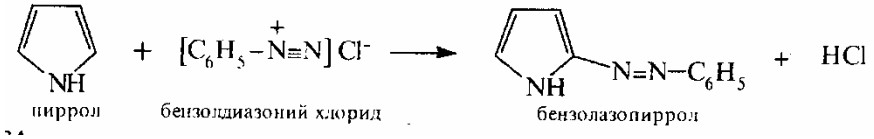


The pyrrolide anion included in the composition of the salts is quite stable due to the delocalization of the negative charge along the pyrrole cycle.

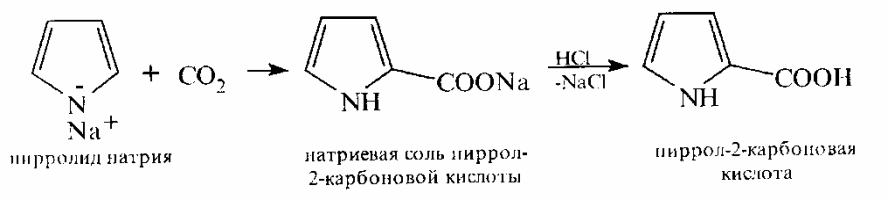
Salts of pyrrole are reactive and are widely used in organic synthesis to introduce alkyl and acyl substituents into the pyrrole molecule, and the direction of introduction of the substituents depends on the temperature:



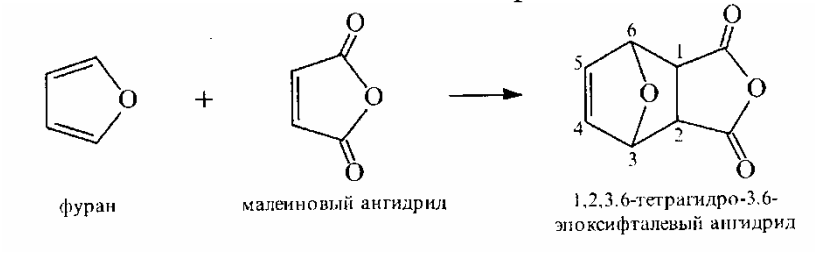
In some reactions of electrophilic substitution, pyrrole resembles phenol, and its N-metal derivatives are phenolates of alkali metals. In particular, pyrrole, like phenol, undergoes an azo coupling reaction:



Sodium pyrrolide is carboxylated by the action of CO_2similar to the Kolbe-Schmidt reaction for phenol:

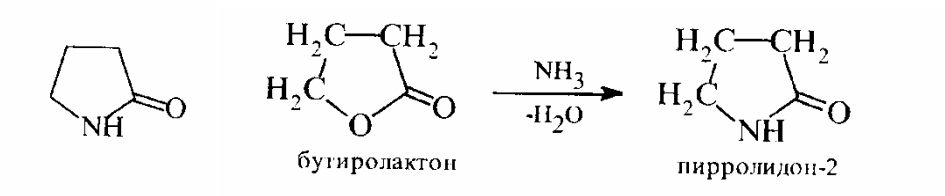


2. Furan and its derivatives. Occupying an intermediate position between aromatic compounds and 1,3-dienes, furan undergoes a Diels-Alder reaction characteristic of related dienes, for example, with maleic anhydride:

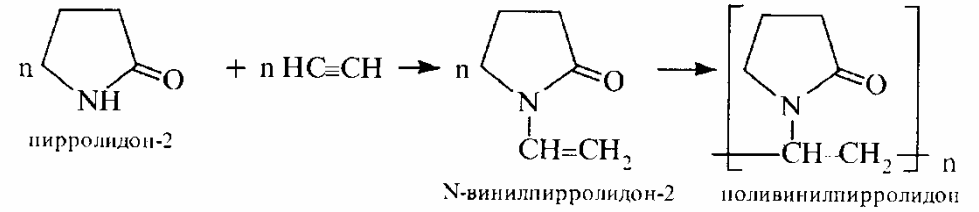


The most important derivatives of pyrrole, furan and thiophene

Pyrrole derivatives.**Pyrrolidone-2-** γ-aminobutyric acid lactam, obtained in industry by the interaction of butyrolactone with ammonia:

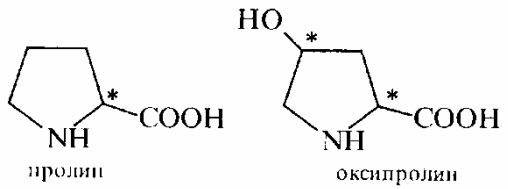


Condensation of pyrrolidone-2 with acetylene leads to N-vinylpyrrolidone-2, which easily polymerizes to form**polyvinylpyrrolidone**(PVP):



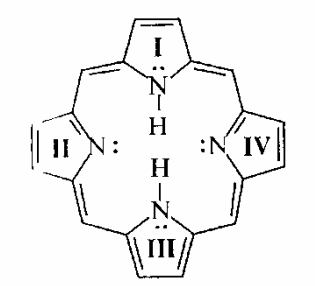
Low-molecular PVP (M = 12,000 - 13,000) forms colloidal solutions in water and is used to prepare the blood substitute "Hemodez", medium-molecular PVP (M = 35,000 - 40,000) is used in the pharmaceutical industry as binders in the production of tablets.

Proline(pyrrolidine-2-carboxylic acid) and oxyproline (4-hydroxypyrrolidine-2-carboxylic acid) - α-amino acids of the heterocyclic series, in which the common α-amino acid fragment -NH-CH (-COOH) - is included in the pyrrolidine cycle. L-Proline and L-oxyproline are part of proteins. Collagen is especially rich in them.



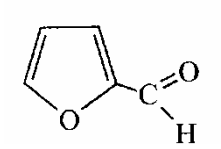
пролин оксипролин

Porfin- a dark red crystalline substance, is a macrocyclic linked system consisting of pyrrole (III), pyrroline (I) and two isopyrrole (II, IV) nuclei connected to each other by methine groups = CH-.

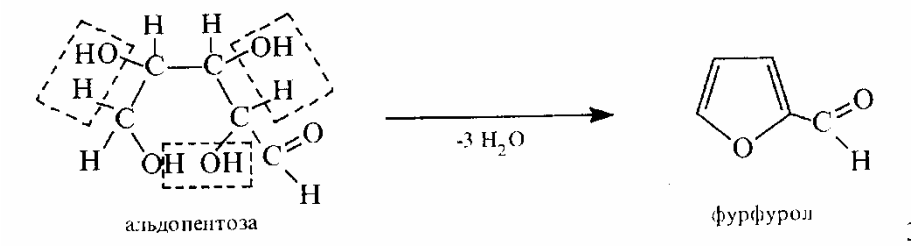


Porphine is an aromatic compound: it has a planar structure, contains a closed connected system with 26 π-electrons (11 π-bonds and two NEP pairs at nitrogen), which corresponds to Hückel's rule. Porphin derivatives have received the common name of porphyrins. In the form of complexes with metals, porphyrins are part of such important natural compounds as hemoglobin and chlorophyll.

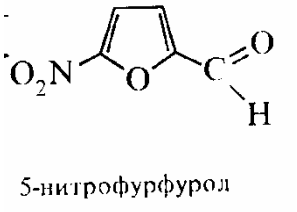
Furan derivatives. The most important derivative of furan is furfural (furan-2-carbaldehyde), a colorless or slightly yellowish oily liquid (boiling point 162 ºC), which has the smell of freshly baked rye bread:



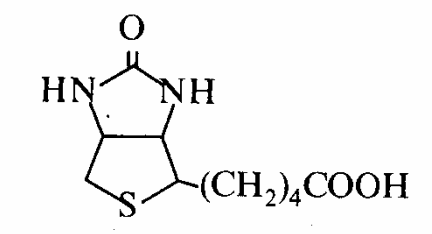
In industry, furfural is obtained by acid hydrolysis of pentosan polysaccharides contained in agricultural waste (straw, sunflower husks, corn cobs, cotton bolls, etc.):



A derivative of furfural - 5-nitrofurfural, is a starting material for the synthesis of a number of drugs (furacilin, furadonin, furazolidone) with high antibacterial activity. They are used in medicine to treat purulent and inflammatory processes.

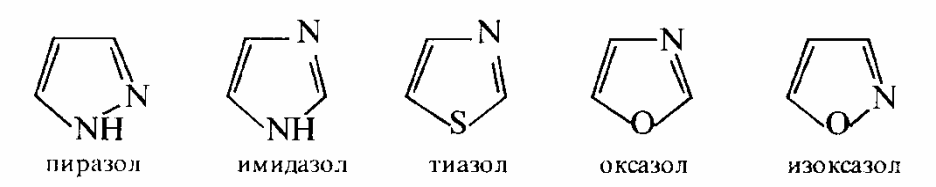


Thiophene derivatives. Biotin (vitamin H). The heterocyclic part of the biotin molecule consists of fully hydrogenated thiophene and imidazole rings, and the side chain is represented by a valeric acid residue. Biotin was first isolated in 1935 from egg yolk. Kidneys, liver, peas, beans, and potatoes are especially rich in biotin. Biotin is part of the active center of enzymes involved in the synthesis of higher fatty acids, proteins, nucleic acids, etc. With a lack of biotin in the body, inflammatory skin diseases (dermatitis) develop, accompanied by hair loss and nail damage.



4. Five-membered heterocyclic compounds with two heteroatoms.

The most important representatives of a large class of five-membered heterocycles with two heteroatoms are pyrazole, imidazole, thiazole, oxazole, and isoxazole:

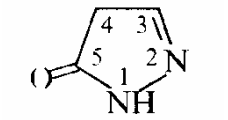


Since in these compounds, at least one of the heteroatoms is nitrogen, they received the general name of azoles.

All the given heterocycles are aromatic.**NEP**the nitrogen atom of the pyridine type does not participate in the formation of an aromatic sextet and adds the main properties with heterocycles. In addition, the N-atom of the pyridine type, having a greater EO than the C-atom, reduces the π-electron density on the C-atoms of the ring and thereby reduces the reactivity of these heterocycles in electrophilic substitution reactions compared to furans, pyrroles, and thiophenes.

In nonpolar solvents, pyrazole exists in the form of cyclic dimers and trimers due to the formation of intermolecular H-bonds NH ⋯ N; imidazole forms H-bonded associates of a linear structure.

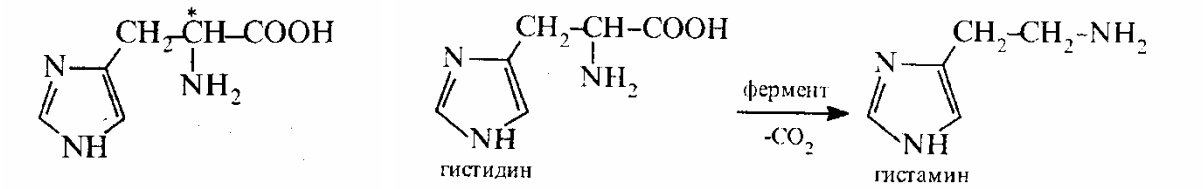
The most important pyrazole derivative is**pyrazolone-5**, the kernel of which is included in the structure of the series



medicines, in particular, antipyrine, amidopyrine and analgin.

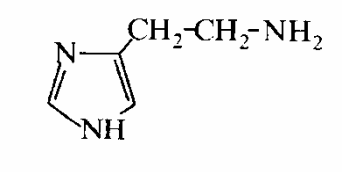
The most important derivatives of imidazole are such natural compounds as an alkaloid**pilocarpine,**α-amino acid, histidine and biogenic amine histamine.

Histidinein the L-configuration is part of many proteins. The hydrochloride salt of histidine is used in medicine for the treatment of hepatitis, peptic ulcer disease of the stomach and duodenum.

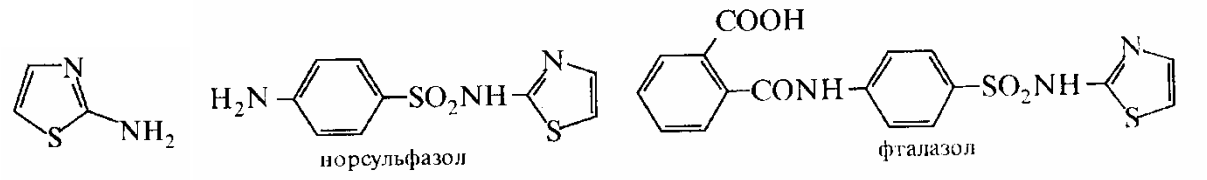


During enzymatic decarboxylation, histidine turns into histamine.

Histamine[4-(2'-aminoethyl) imidazole] is a biogenic amine that is involved in the regulation of vital body functions.

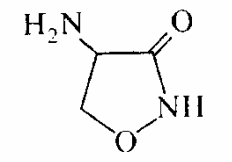


The most important thiazole derivatives are 2-aminothiazole, widely used in the production of medicines. Derivatives of 2-aminothiazole are sulfonamide drugs norsulfazole and phthalazole, which have an antibacterial effect.



Among the oxazole derivatives, substances with antipyretic, analgesic, antibacterial and hypnotic effects are known.

The isoxazole ring is part of the structure of a number of drugs, in particular, the antibiotics oxacillin Dicloxacillin, the antituberculosis drug cycloserine:



General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline

- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1. Basic principles of the nomenclature of heterocyclic compounds. Aromatic nature of the most important heterocyclic compounds.

2. Preparation methods, properties and reactivity of three- and four-membered heterocycles with one heteroatom.

3. Five-membered heterocycles with one heteroatom (pyrrole, furan, thiophene).

Aromaticity of five-membered heterocycles. Preparation methods, properties, reactivity. Specific chemical properties of pyrrole and furan.

4. Five-membered heterocycles with two heteroatoms.

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Lecture No. 14

Topic: Six-membered heterocycles with one heteroatom. Azines with condensed rings: quinoline, isoquinoline, acridine. Heterocycles of the pyran group. Six-membered heterocycles with two heteroatoms. Seven-membered heterocycles. Condensed systems of heterocycles.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal: As a result of the lecture, students should familiarize themselves withclassification, nomenclature, aromatic character, extraction method, physical and chemical properties of the most important six-membered heterocyclic compounds with one heteroatom, six-membered heterocyclic compounds with two heteroatoms, seven-memberedheterocyclesand condensedheterocycles.

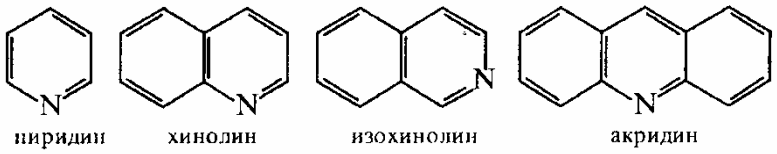
Basic concepts: Pyridine and alkylpyridines. Azines. Heterocycles of the pyran group.

Plan and organizational structure of the lecture:

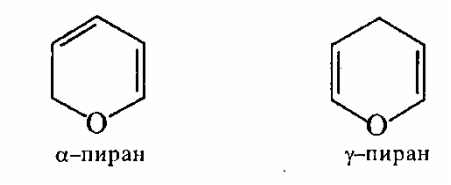
1. Aromaticity of pyridine and its derivatives.
2. Pyridine and alkylpyridines.
3. Azines with condensed rings: quinoline, isoquinoline, acridine.
4. Heterocycles of the pyran group.
5. Six-membered heterocycles with two heteroatoms.
6. Seven-membered heterocycles.
7. Purine and its derivatives.

Content of lecture material (lecture text)

The most important representatives of this group of compounds with one heteroatom are N-containing heterocycles - pyridine, quinoline, isoquinoline, acridine:

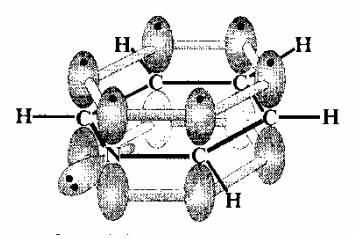


and heterocycles with an oxygen atom - α-pyran and γ-pyran:



1. Aromaticity of pyridine and its derivatives.

In a molecule**pyridine**all carbon atoms and the nitrogen atom are in the state of sp2 hybridization. A closed 6 π-electron system is formed by five p-AO C atoms (one from each) and a p-AO N atom. That is, in the pyridine molecule, as well as in the benzene molecule, each ring atom contributes one p-electron to the aromatic sextet. The NEP of the N atom in the pyridine molecule, unlike the pyrrole molecule, occupies an sp2-hybrid AO and does not participate in the formation of an aromatic sextet.



Nitrogen atom in sp^2-hybridization, which has an electronic configuration in which NEP occupies an sp2-hybrid orbital and does not participate in the formation of an aromatic sextet, was named pyridine (pyridine-type heteroatom).

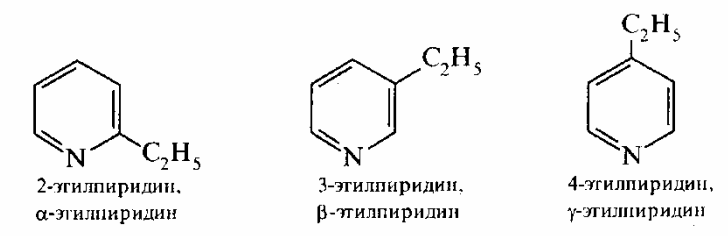
Heteroatom of the pyridine type, possessing a larger**EO**compared to carbon, reduces the electron density on the C atoms of the aromatic ring.

Heterocycles in the molecules of which the heteroatom reduces the electron density on the carbon atoms of the aromatic ring are called π-deficient.

2. Pyridine and alkylpyridines.

Pyridine(azine) can be considered as an analogue of benzene, in the molecule of which the CH group is replaced by a nitrogen atom.

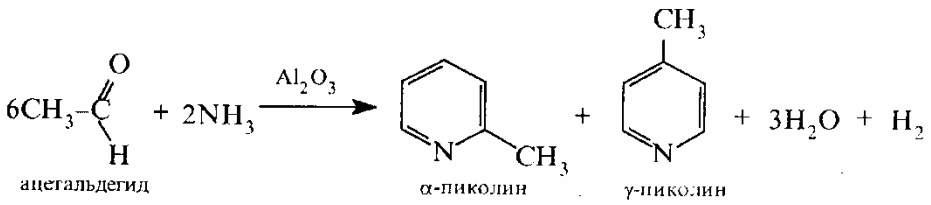
For the name of pyridine derivatives, the numbering of the atoms of the cycle is used or they are denoted by Greek letters. Positions 2, 6 are called α, α '; position 3, 5 - β, β '; position 4 - γ:



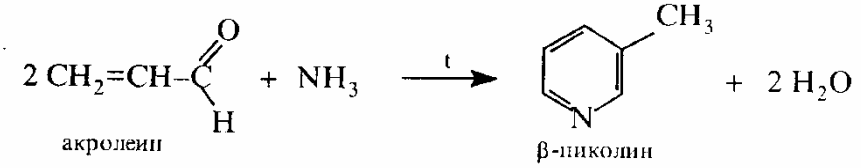
Methods of obtaining

Pyridine and its monomethyl derivatives - α-, β- and γ-picolines, are contained in small quantities in coal tar (a product of dry distillation of coal), from which they are isolated individually. In addition, there are a large number of methods for the synthesis of pyridine and its homologues, mainly based on the condensation reaction of aldehydes with ammonia.

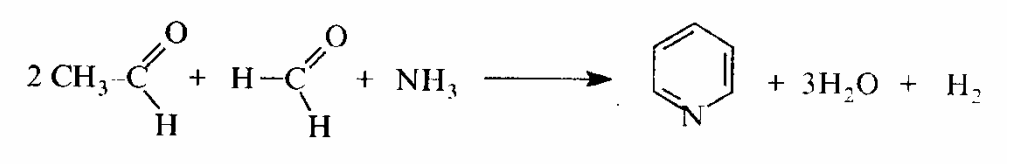
Thus, the interaction of acetaldehyde and ammonia at 400 ºC in the presence of an Al catalyst$_2$O3 leads to a mixture of products consisting mainly of 2- and 4-methylpyridine:



When acrolein is heated with ammonia, β-picoline is mainly formed:



Condensation of acetaldehyde and formaldehyde with ammonia is accompanied by the formation of unsubstituted pyridine:

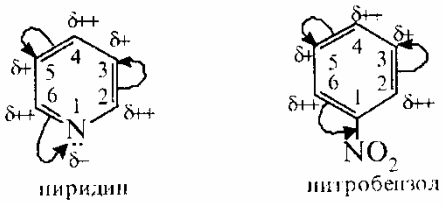


Structure, physical and chemical properties

Pyridine is a colorless liquid (bp. 115 ºC) with a characteristic unpleasant smell, miscible with water, ethanol and most organic solvents.

Pyridine is structurally similar to benzene: it is an aromatic compound with a 6 π-electron system.**NEP**nitrogen atom does not participate in the formation of an aromatic sextet and determines the main properties of pyridine. However, unlike benzene, the electron density in the Ru molecule is unevenly distributed, which confirms the relatively large dipole moment (2.26 D). As a result of the electron-accepting effect of the N atom in the pyridine ring on all C atoms, the electron density is reduced, and to a greater extent in positions 2, 4 and 6 (α- and γ-positions), to a lesser extent - in positions 3 and 5 (β-positions) . That is, pyridine is a π-deficient aromatic system.

The influence of the N atom on the electron density of the pyridine ring is comparable to the influence of NO_2-groups on the benzene ring in the nitrobenzene molecule:



Reactions characteristic of pyridine can be conditionally divided into three groups:

- reactions taking place with the participation of a heteroatom;
- reactions of substitution of hydrogen atoms of the pyridine cycle;
- reduction and oxidation reactions.

Reactions taking place with the participation of a heteroatom

1. Interaction with acids. Pyridine is a relatively weak base: the basicity of pyridine is close to the basicity of aniline (pK_{and}Ru 5:25; pKa 6 HC5NH2 4.6). Aqueous solutions of Roux turn red litmus paper blue. When interacting with strong mineral and organic acids (hydrochloric, hydrobromic, sulfuric, picric), pyridine forms well-crystallizing pyridine salts:

Ru + HCl → RuH+Cl–

pyridine chloride

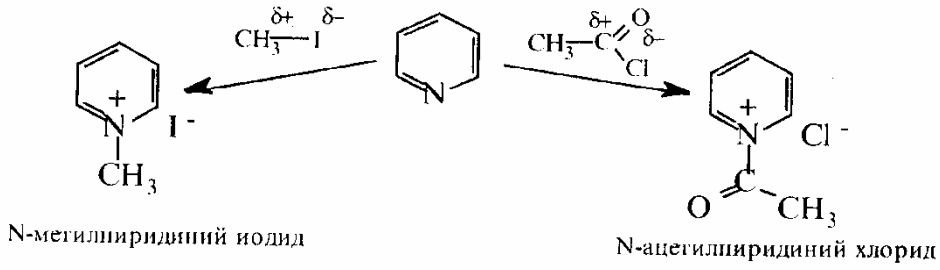
Salt formation with picric acid is used to identify pyridine.

2. Interaction with sulfur oxide (VI):

Ru + SO3 → Ru·SO3

The donor-acceptor complex - pyridinesulfotrioxide, is used in organic synthesis as a mild sulfonating reagent in the sulfonation of acidophobic heterocycles.

3. Interaction with alkyl and acyl halides:



N-метилпиридиний иодид

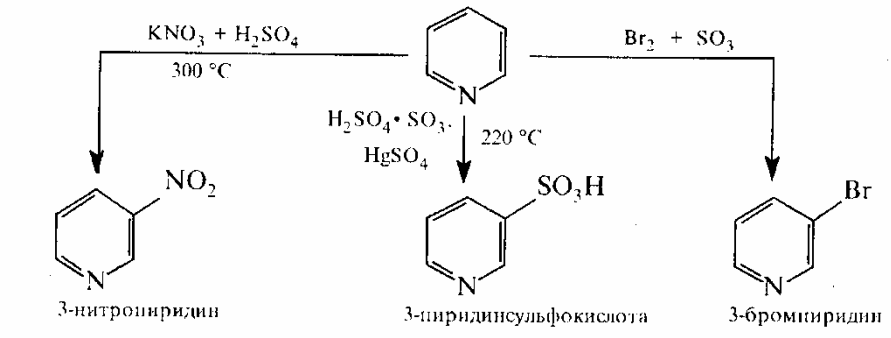
N-ацетилпиридиний хлорид

The products of the reactions - quaternary salts of N-alkyl- and N-acylpyridine, are distinguished by the high reactivity of the acyl fragment in relation to the nucleophile and are therefore very effective acylating reagents.

Hydrogen atom substitution reactions of the pyridine cycle.

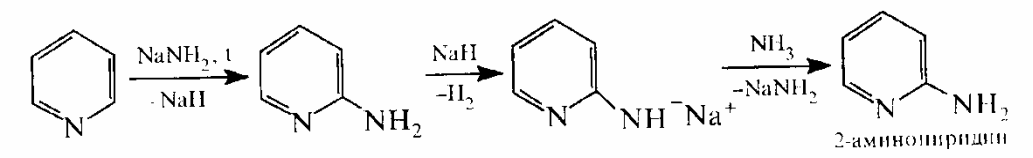
Electrophilic and nucleophilic substitution reactions can occur along the pyridine cycle.

1. Reactions of electrophilic substitution in the pyridine cycle proceed with great difficulty. Nitration, sulfonation, and halogenation of pyridine is carried out only under harsh conditions: nitration proceeds with low yield when heating Ru with KNO3 in fuming sulfuric acid at 300 ºC; sulfonation occurs when heated with oleum at (220 - 270 ºC) in the presence of a catalyst - mercury sulfate; bromination is possible by the action of bromine with oleum. The electrophilic substituent is directed to the β-position of the cycle:

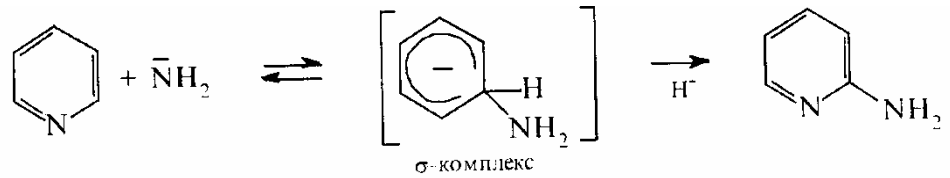


Friedel-Crafts alkylation and acylation reactions are not typical for pyridine. The low reactivity of the Ru-cycle in electrophilic substitution reactions and the orientation of the substitution in the β-position are due to the electron-accepting properties of the N-atom, which, reducing the electron density on all C-atoms of the cycle, affects the β-position to a lesser extent, which determines the place of attack of the electrophilic reagent.

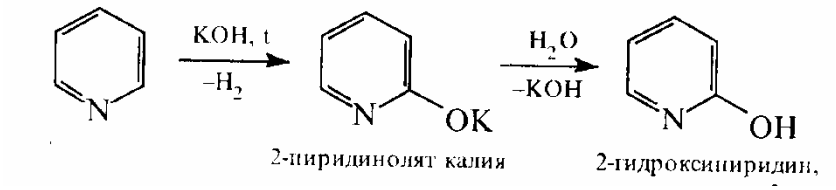
2. Reactions of nucleophilic substitution as a result of a decrease in electron density on the C atoms of the pyridine ring are facilitated. Unlike benzene, Ru reacts quite easily with nucleophilic reagents, forming substitution products in positions 2, 4, or 6 (α- and γ-positions). In particular, during amination according to Chichibabin (A.E. Chichibabin, 1914) by the interaction of Ru with sodium amide during heating, 2-aminopyridine is formed:



The reaction proceeds according to the mechanism$S_N2$through the intermediate formation of a σ-complex:

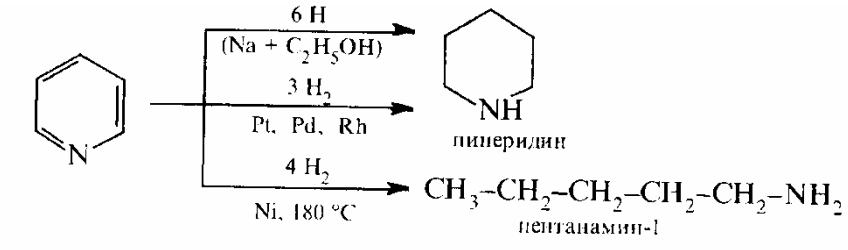


Hydroxylation of pyridine occurs similarly to amination: when Ru vapor is passed over dry KOH at 300 - 320 ºC, 2-hydroxypyridine is formed:

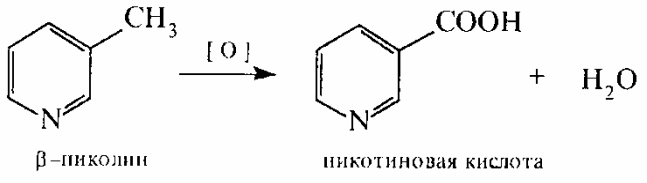


Reduction and oxidation reactions

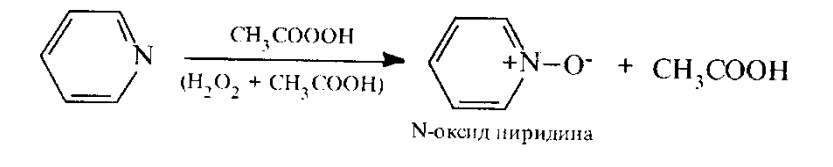
1. Restoration. Ru-cycle is reduced more easily than benzene, and depending on the nature of the reducing agent and the reaction conditions, different products are formed:



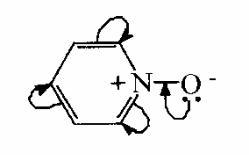
2. Oxidation. Ru-cycle is resistant to oxidizing agents. Alkylpyridine, like alkylbenzene, is quite easily oxidized to form the corresponding pyridinecarboxylic acids:



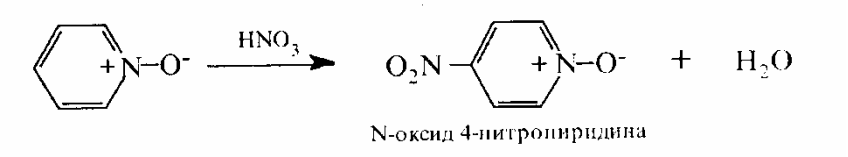
Under the action of peroxyacid, oxidation occurs along the N atom with the formation of N-oxides:



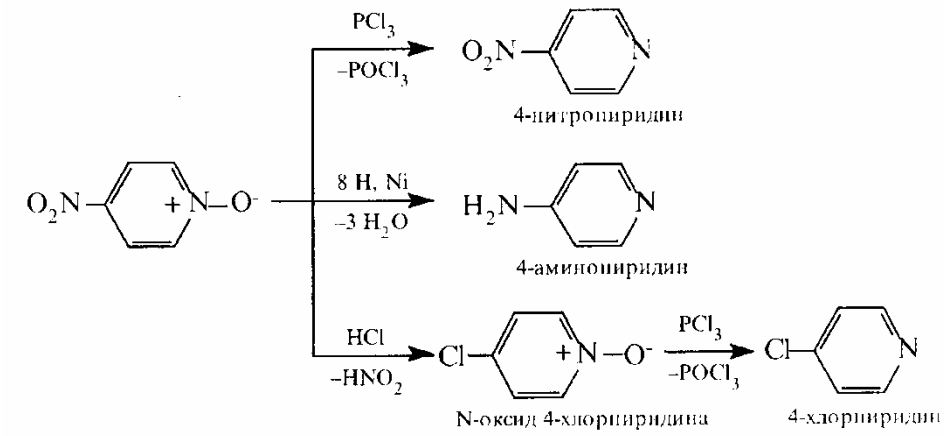
Pyridine N-oxide, unlike pyridine, is more active in nucleophilic substitution reactions, which is due to some electron-donatingeffect of the O atom. As a result of the shift of the electron density from the O atom to the ring on the C atoms α- and γ-positions of the N-oxide of pyridine, the electron density is increased compared to Ru:



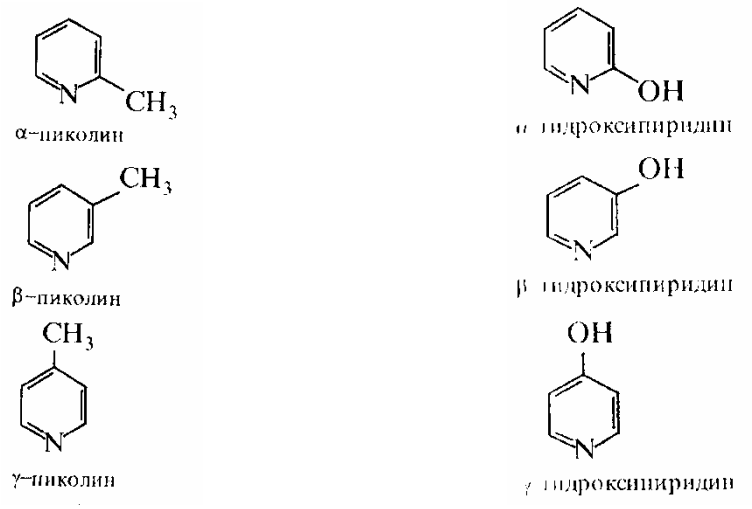
Thus, the N-oxide of pyridine enters into the nitration reaction much more easily than Ru, with the formation, with a high yield, of the N-oxide of 4-nitropyridine:



Since the substituted N-oxide can be reduced to the corresponding pyridine, this reaction is used to obtain γ-derivatives of pyridine:



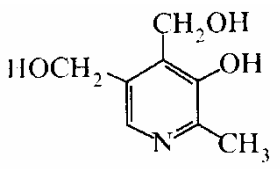
The most important pyridine derivatives



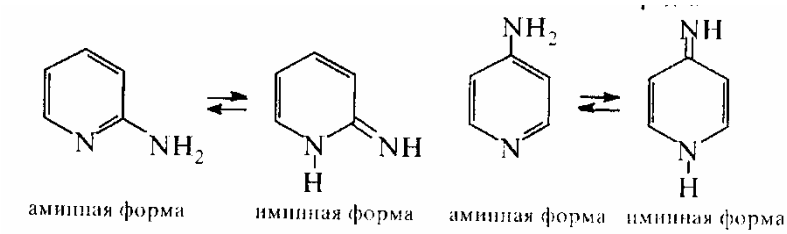
Picolini(monomethyl derivatives of Ru) - colorless liquids, well soluble in water and organic solvents. The boiling points of α-, β-, and γ-picoline are 129.5, 144, and 145.4 ºC, respectively. Like Ru, methylpyridine forms salts with strong acids and alkyl halides, peroxyacids are oxidized to N-oxides, and are reduced by hydrogen in the presence of Pt or Pd to form piperidine derivatives. Under the action of oxidizing agents, picolines are oxidized to the corresponding pyridinecarboxylic acids. Picolines are used in organic synthesis: α-picoline - in the production of pesticides, β- and γ-picolines - to obtain nicotinic and isonicotinic acids, respectively.

Hydroxypyridines(oxypyridines) - white crystalline substances, easily soluble in ethanol, acetone, moderately - in water, limited - in diethyl ether and benzene. α- and γ-Hydroxypyridines are tautomeric compounds (hydroxy-oxo-tautomerism). Hydroxypyridines are bifunctional compounds - on the heteroatom they show the properties of Ru, on the OH group - the properties of phenol. The phenolic character is most pronounced in 3-hydroxypyridine, the OH group of which is not combined with a heteroatom.

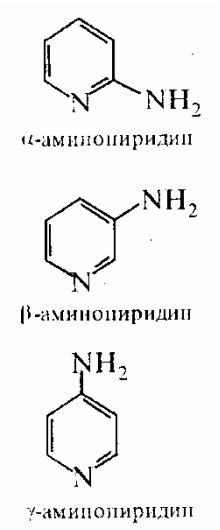
Various hydroxypyridine derivatives are used in medicine, for example, pyridoxine (vitamin B6) is found in unrefined cereal grains, vegetables, meat, fish, milk, egg yolk, etc. It plays an important role in metabolism, is used in the form of a salt with HCl for B6-hypovitaminosis, toxicosis, anemia, leukopenia, and diseases of the nervous system.



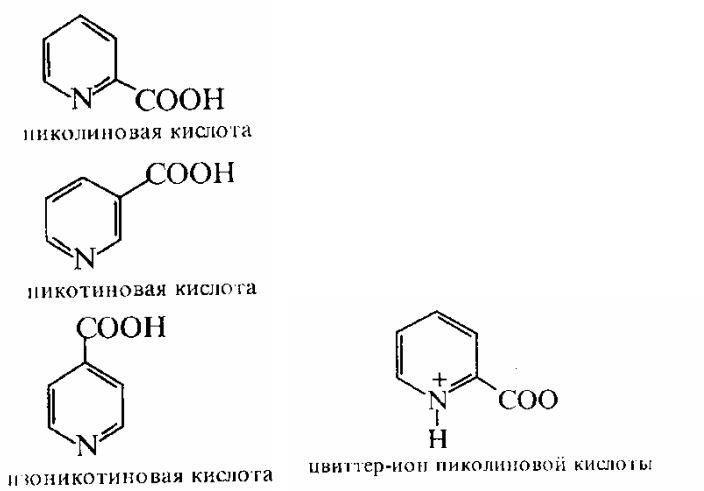
Aminopyridines- white crystalline substances, easily soluble in water, ethanol, diethyl ether and other organic solvents, are stronger bases compared to pyridine and aniline. α- and γ-aminopyridines form salts with only one equivalent of a mineral acid (heteroatom protonation). α- and γ-aminopyridines exist in two tautomeric forms - amine and imine; the amine form is more stable:



Aminopyridines are used in the synthesis of medicinal substances.



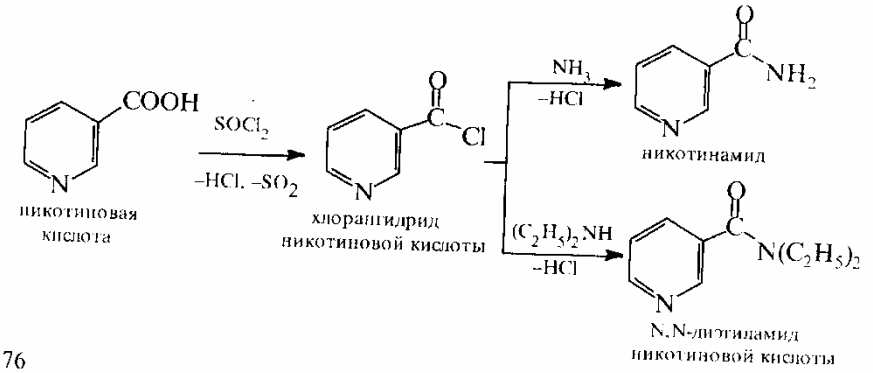
Pyridinecarbonsacids - white crystalline substances, are bifunctional compounds. According to the -COOH group, they form salts, halides, esters, amides, hydrazides, and other functional derivatives; reactions characteristic of pyridine occur behind the pyridine ring. Being amphoteric substances, in the crystalline state and partially in solutions, they exist in the form of zwitterions:



When heated, pyridinecarboxylic acids are decarboxylated. As a result of the electron-accepting effect of the heteroatom, pyridinecarboxylic acids are stronger acids than benzoic acid.

Pyridinecarboxylic acids are widely used in the synthesis of medicinal products. Thus, nicotinic acid and its amide are known in medical practice as two forms of vitamin PP (the acid is a provitamin, and the amide is vitamin PP).

N, N-Diethylamide of nicotinic acidin the form of a 25% aqueous solution (cordiamine) is used as a means that stimulates the central nervous system, excites the respiratory and vascular centers of the brain. Nicotinic acid amide and N,N-diethylamide of nicotinic acid are obtained from nicotinic acid:



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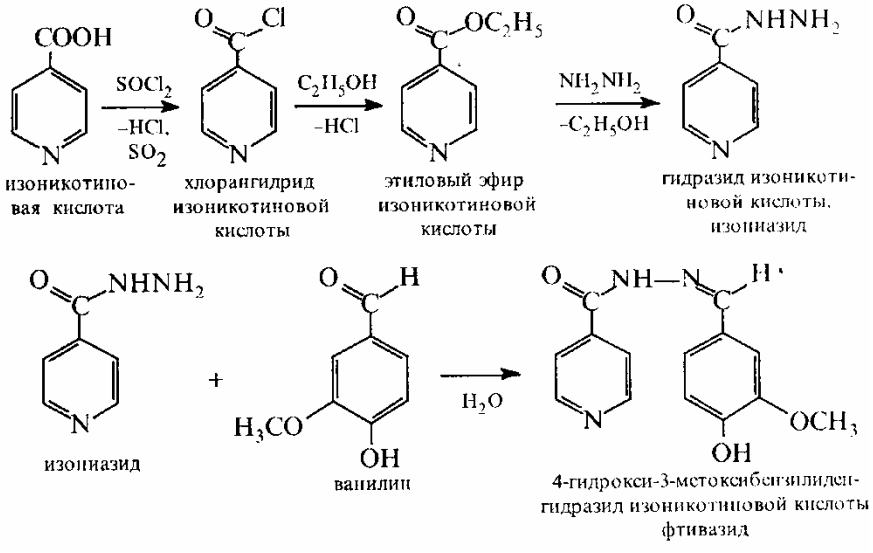
Derivatives of isonicotinic acid - its hydrazide and the condensation product of hydrazide with vanillin, under the names isoniazid and ftivazid, are used in the treatment of tuberculosis.



3. Azines with condensed rings: quinoline, isoquinoline, acridine.

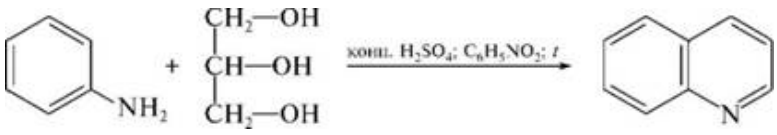
Quinoline

Methods of obtaining

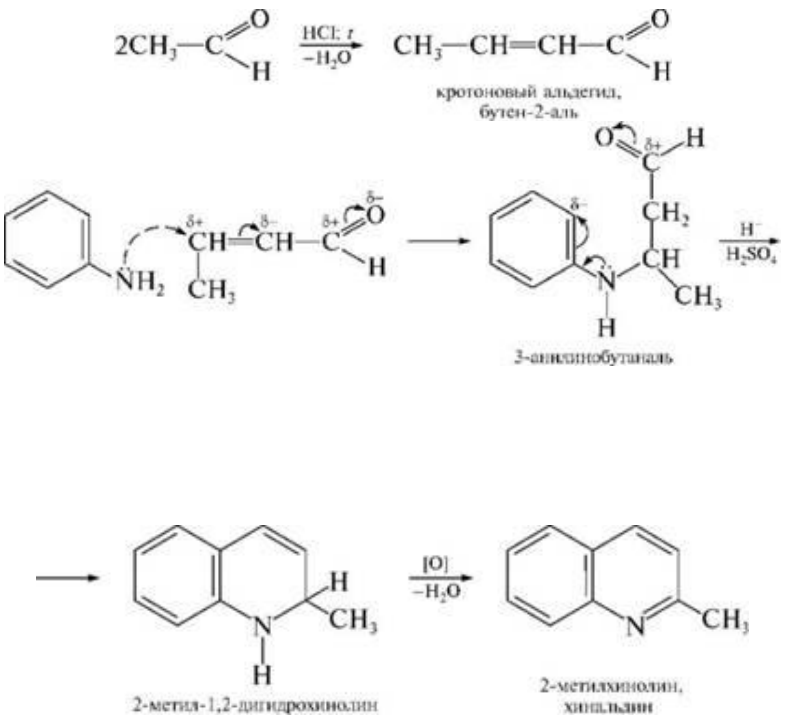
Quinoline and its methyl derivatives are obtained from coal tar distillation products.

Among the synthetic methods of obtaining quinoline and its derivatives, the most important are the Scroup synthesis and the Debner-Miller synthesis.

Scroup's Synthesis:



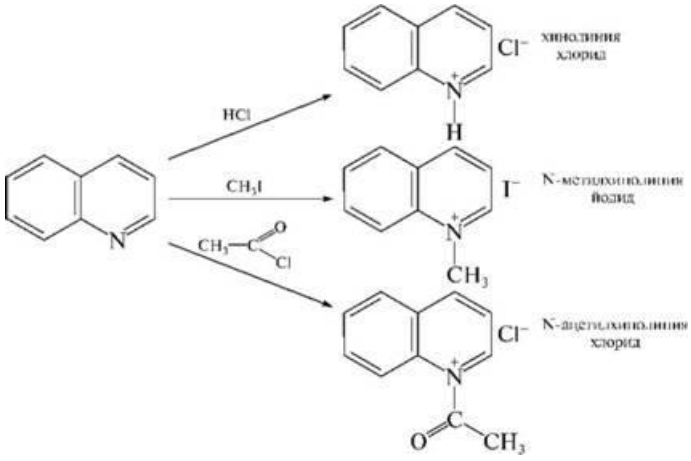
The Debner-Miller synthesis is used to obtain quinoline derivatives containing an alkyl substituent in the pyridine ring:



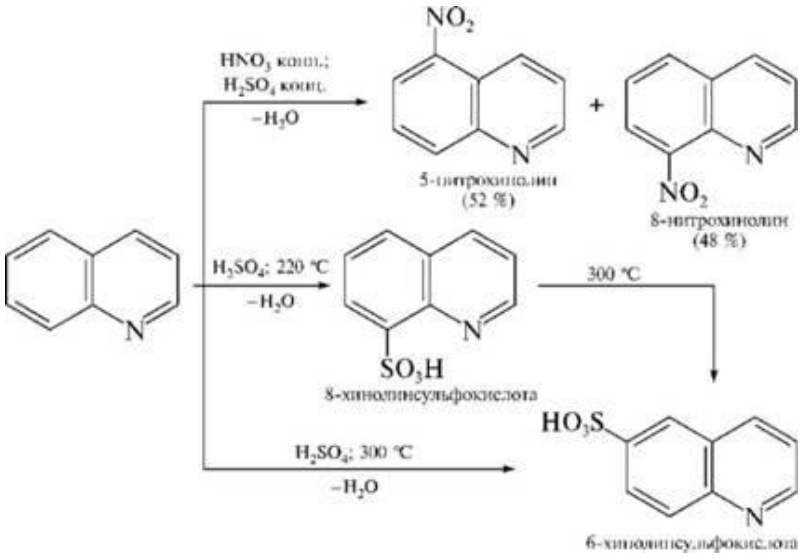
In terms of chemical properties, quinoline is similar to pyridine. It is characterized by reactions:

- with the participation of a heteroatom;
- electrophilic and nucleophilic substitution;
- oxidation;
- restoration.

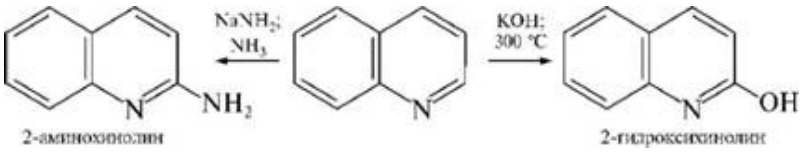
Heteroatom reactions



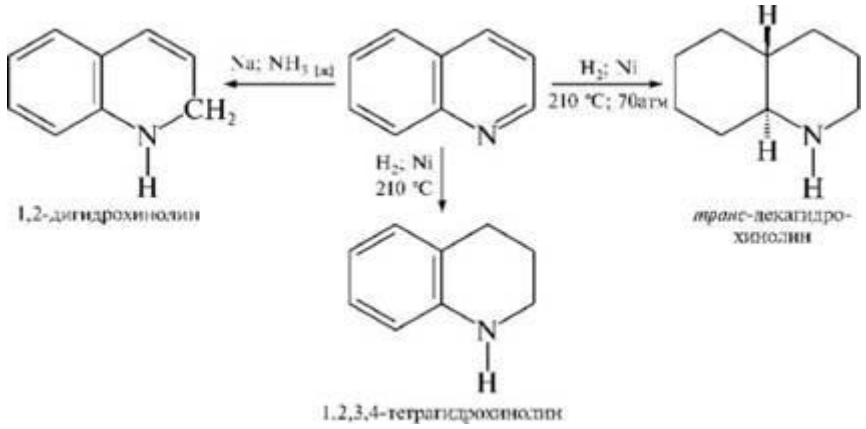
Electrophilic and nucleophilic substitution reactions. As a result of the electron-accepting effect of the heteroatom, the electron density in the quinoline molecule is unevenly distributed: it is lower in the pyridine ring than in the benzene ring. Therefore, under the action of electrophilic reagents, substitution occurs along the benzene ring, and nucleophilic substitution occurs along the pyridine ring:



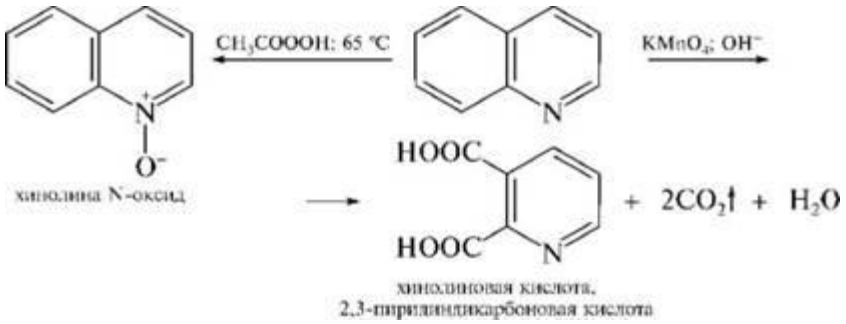
In the reaction of nucleophilic substitution, quinoline enters much easier than pyridine. At the same time, the reactions proceed according to position 2:



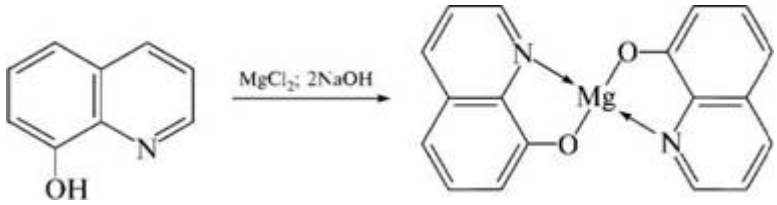
When reducing quinoline, the pyridine nucleus is first of all restored. The formation of reaction products depends on the catalyst and conditions:



Oxidation of quinoline with potassium permanganate in an alkaline environment leads to the splitting of the benzene ring and the formation of quinoline (2,3-pyridine dicarboxylic acid). In the presence of peroxyacid, quinoline forms N-oxide:

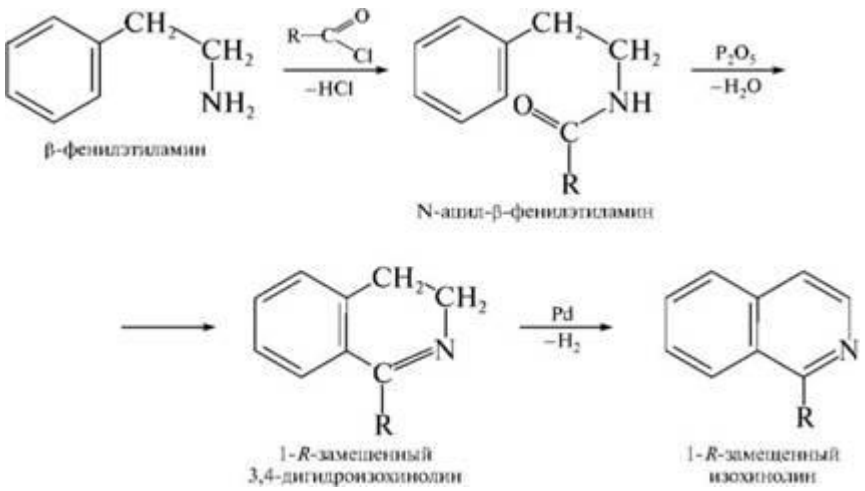


The quinoline nucleus is a structural fragment of many alkaloids and drugs. Quinoline derivative - 8-hydroxyquinoline is able to form insoluble chelate complexes with metal cations, used in qualitative analysis:

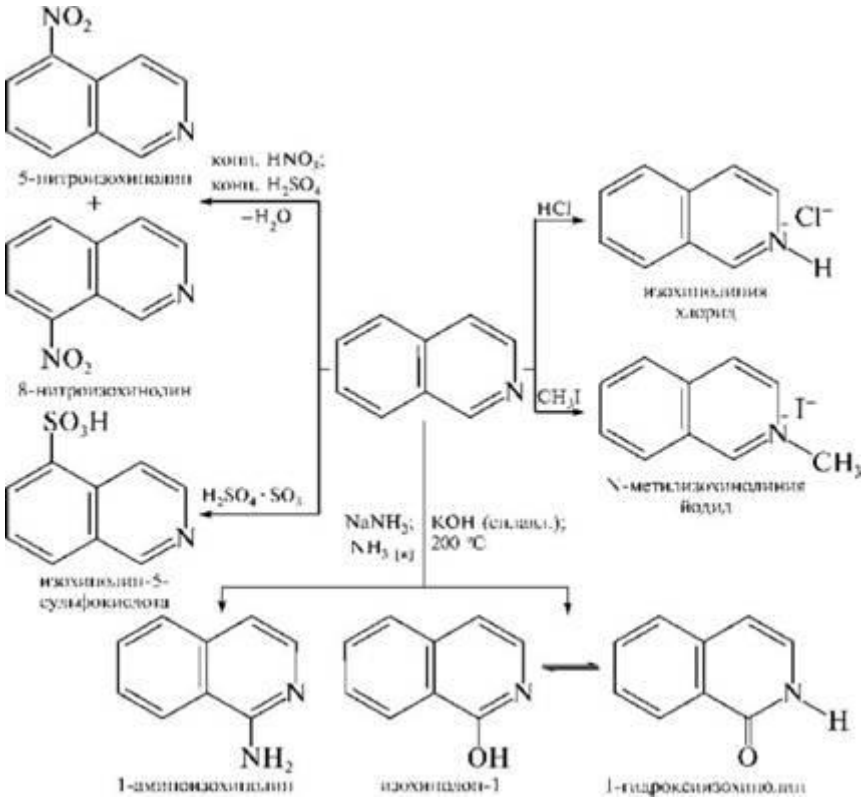


Isoquinoline

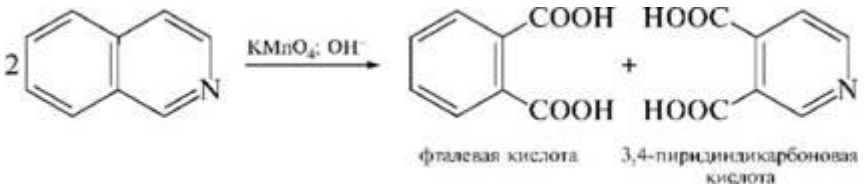
Isoquinoline is an isomer of quinoline. Isoquinoline is contained in the quinoline fraction of coal tar (1%). The synthesis of isoquinoline and its derivatives is carried out by the Bishler-Napiralsky reaction:



In terms of chemical properties, isoquinoline resembles quinoline in many ways. Due to the heteroatom, it exhibits weakly basic properties, interacting with strong acids. As a base, isoquinoline is slightly stronger than quinoline, alkylation and acylation proceed along the heteroatom with the formation of salt-like addition products. Isoquinoline undergoes electrophilic substitution reactions, like quinoline, in positions 5 and 8 of the benzene ring.



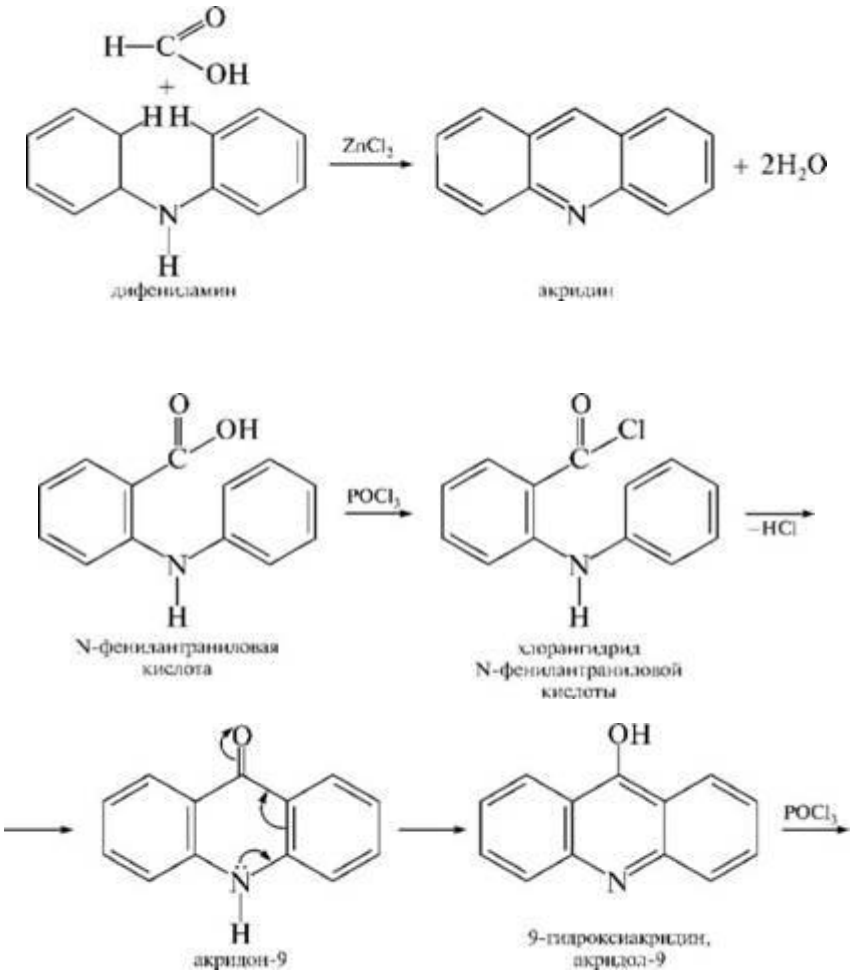
When isoquinoline is oxidized with an alkaline solution of potassium permanganate, both nuclei undergo oxidation, and as a result, a mixture of phthalic and 3,4-pyridinedicarboxylic acids is formed:

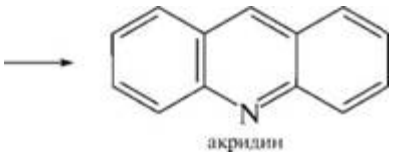


Derivatives of isoquinoline are many alkaloids of the isoquinoline series - morphine, papaverine, narcotine, etc.

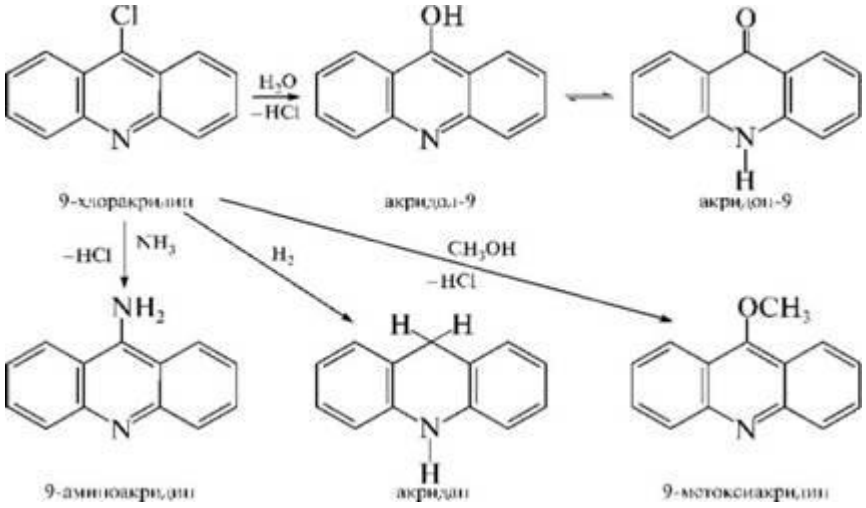
Acridine

Acridine is isolated from the anthracene fraction of coal tar. It is obtained synthetically using condensation and cyclization reactions.

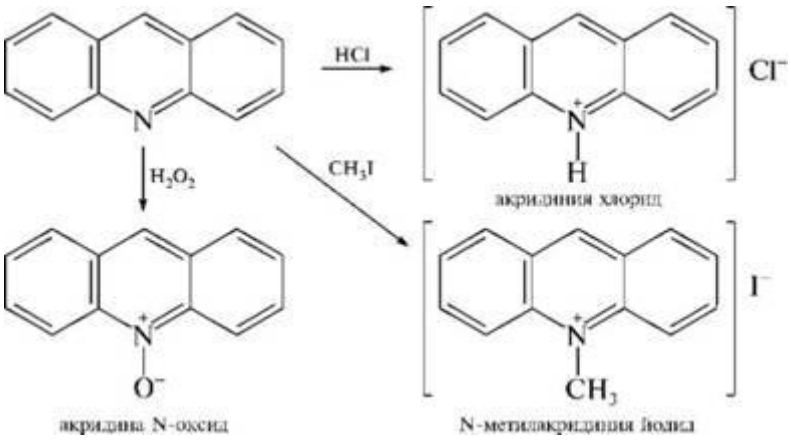




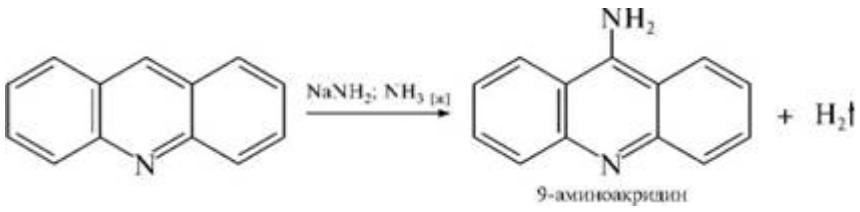
In the 9-chloroacridine molecule, the chlorine atom exhibits great mobility, so it is used to obtain derivatives in position 9:



Acridine, like pyridine, reacts with acids, forming salts called acridine salts. With peracids, acridine N-oxide forms:

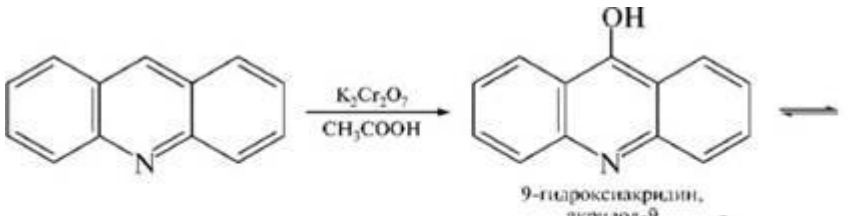


Reactions of nucleophilic substitution for acridine proceed quite easily at position 9. For example, when sodium amide acts on acridine, 9-aminoacridine is formed:

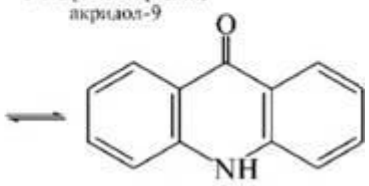


9-аминоакридин

Under the action of potassium dichromate in acetic acid, acridine is oxidized to acridone-9, which is a tautomeric substance:

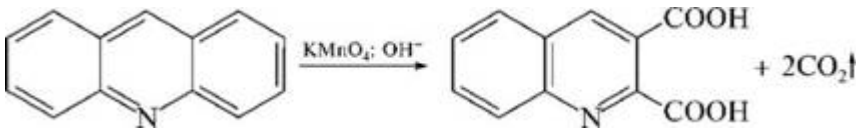


9-гидроксиакридин, акридол-9

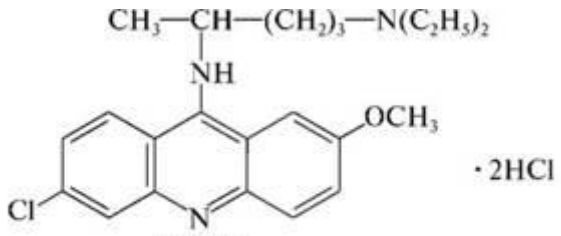


9-оксоакридин, акридон-9

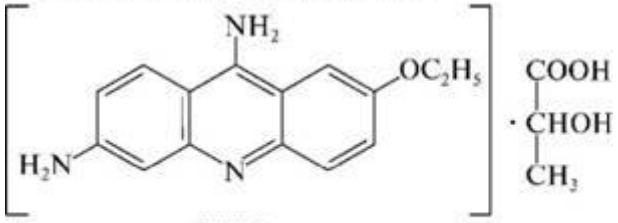
When acridine is oxidized under harsh conditions, one of the benzene nuclei is affected with the formation of quinoline-2,3-dicarboxylic acid:



Among the derivatives of acridine, we should note the drugs acriquine and rivanol: acriquine is used in the treatment of malaria, rivanol is a bactericidal drug.



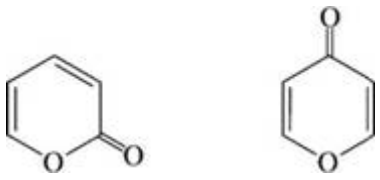
акрихин, 9(4'-диэтиламино-1'-метилбутиламино)-2-метокси-6-хлоракридина дигидрохлорид



риванол, 6,9-диамино-2-этоксиакридина лактат, этакридина лактат

4. Heterocycles of the pyran group.

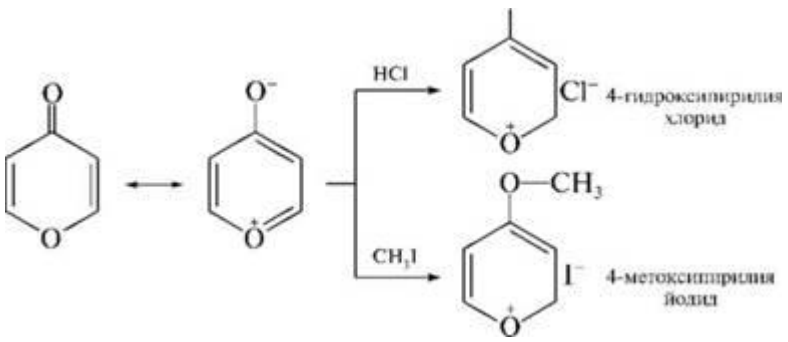
Six-membered O-containing heterocycles, α- and γ-benket, are unstable compounds. Unlike α- and γ-pyran, their oxo derivatives are quite stable aromatic compounds:



α-Pyrone is a colorless liquid with the smell of fresh hay, γ-Pyrone is a colorless crystalline substance.

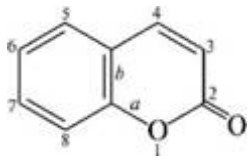
In the molecules of α- and γ-pyrones, the lone pair of electrons of the cyclic oxygen atom is combined with the π-electrons of the double bond of the oxo group.

γ-Pyrone exhibits weak basic properties and upon interaction with mineral acids and alkyl halides forms pyrylium salts:

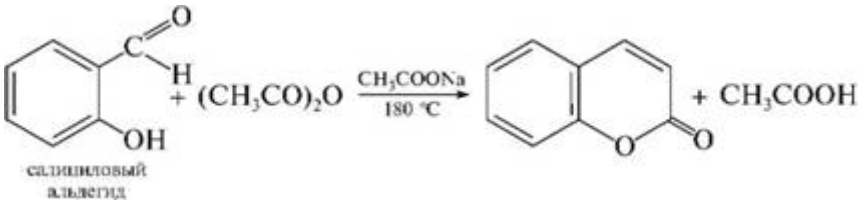


The pyrylium cation contains a closed π-electron system of six electrons and has an aromatic character. γ-Pyrone does not enter into reactions characteristic of ketones.

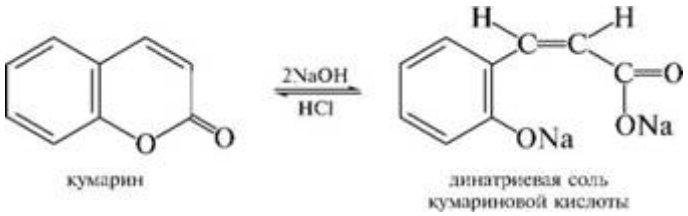
Coumarin (benzopyrone-2) is a condensed system consisting of benzene and α-pyrone rings. By structure, it is a lactone of cis-o-hydroxycinnamic acid (coumaric acid):



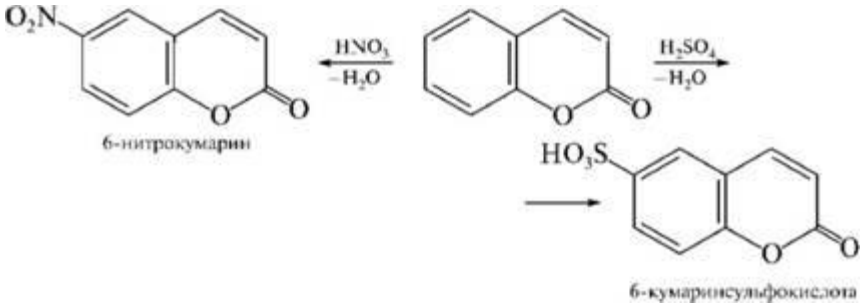
Synthetic coumarin is obtained by the Perkin reaction from salicylic aldehyde:



When coumarin is heated with alkalis, a salt of o-hydroxycinnamic acid is formed, which, when acidified, quickly recycles into coumarin:



Behind the benzene ring, coumarin undergoes electrophilic substitution reactions (nitration, sulfonation) at position 6:



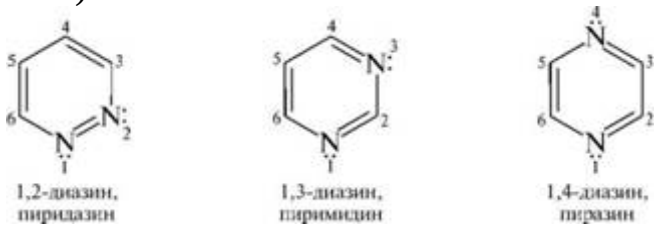
Based on coumarin derivatives, drugs with anticoagulant activity have been created - neodicumarin, fepromaron, syncoumar, etc.

5. Six-membered heterocycles with two heteroatoms.

Diazine

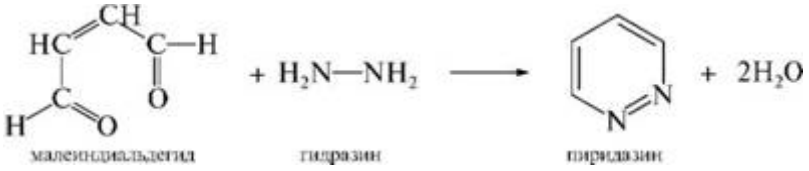
Six-membered heterocycles containing two nitrogen atoms as hetero atoms are called diazines.

There are three diazine isomers - pyridazine (1,2-Diazine), pyrimidine (1,3-Diazine) and pyrazine (1,4-Diazine):

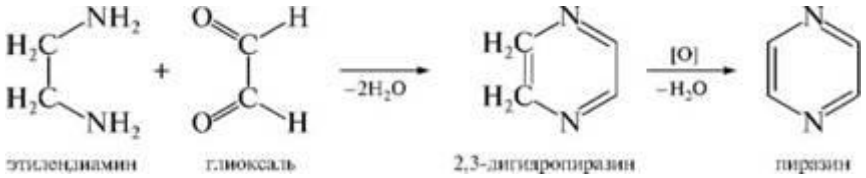


Methods of obtaining

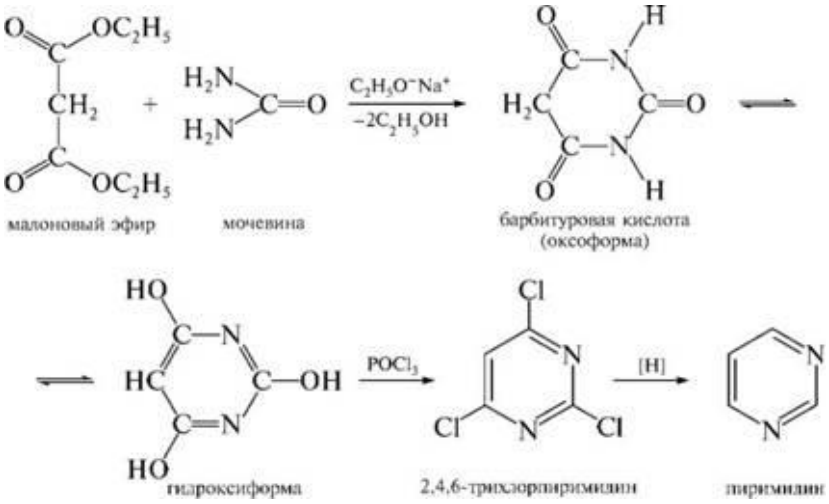
Pyridazine and its derivatives are obtained by the condensation reaction of hydrazine from 1,4-dicarbonyl compounds (limiting or non-limiting):



Pyrazine and its derivatives are obtained by the condensation reaction of 1,2-diamine with 1,2-dicarbonyl compounds:

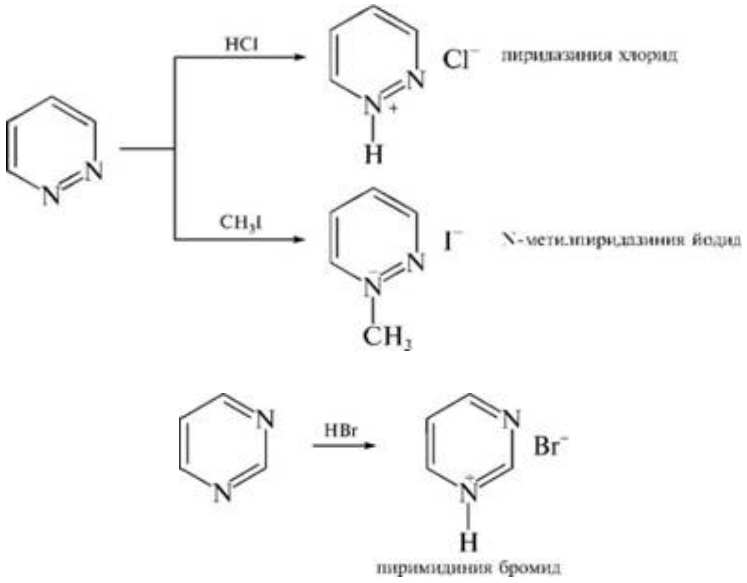


Pyrimidine is obtained by reacting urea with malonic ether according to the following scheme:

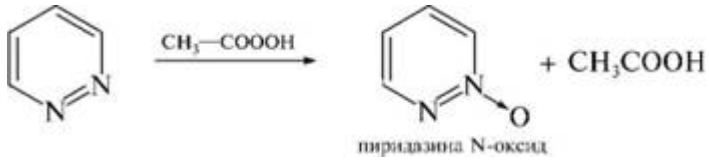


Structure and chemical properties

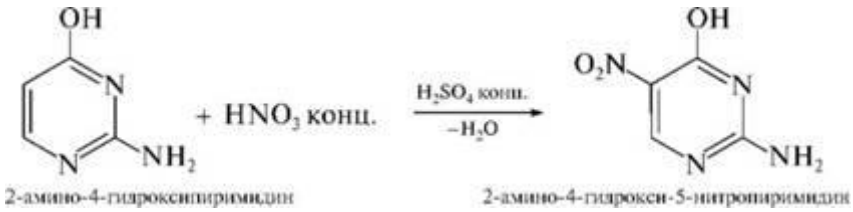
In terms of structure and properties, these compounds resemble pyridine in some respects. Like pyridine, diazine molecules have a closed conjugated 6 π-electron system in their composition and have an aromatic character. NEP of nitrogen atoms do not participate in the combination and give diazine the main properties. Due to the deactivating effect of the nitrogen atoms on each other, diazine is a weaker base than pyridine. For this reason, despite the presence of two main centers, diazine forms salts with only one equivalent of a mineral acid and an alkyl halide:



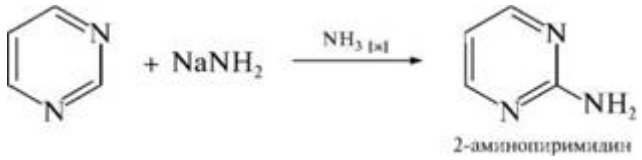
The interaction with peroxyacids is also carried out one nitrogen atom at a time:



The presence of two pyridine-type N-atoms in the structure of diazine molecules leads to a significant decrease in the electron density on the carbon atoms of the diazine cycle. Therefore, diazines are characterized by very low reactivity in reactions$S_E$and, conversely, high activity in reactionsS_N. Electrophilic substitution reactions are possible only when the diazine cycle is activated by electron-donating groups, for example, -NH2, -OH, etc.:

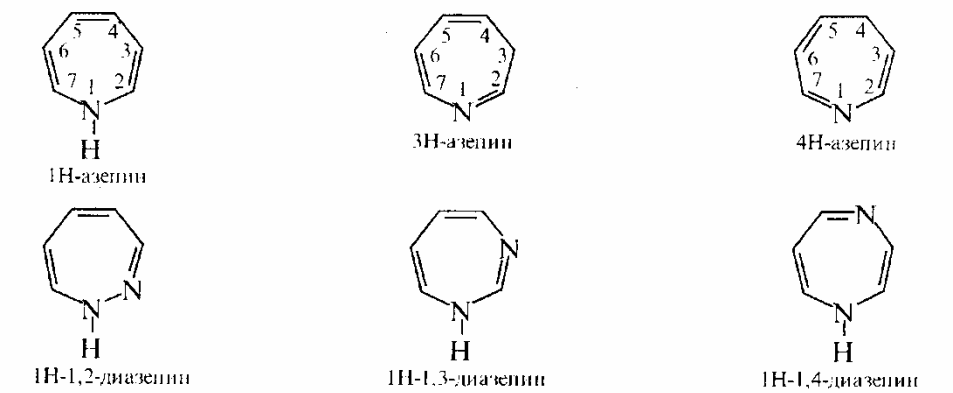


Nitrogen atoms of the pyridine type, as a result of the electron-accepting action, cause a general decrease in the electron density, primarily in positions 2, 4, 6, which contributes to the course of nucleophilic substitution reactionsS_N:



6. Seven-membered heterocycles.

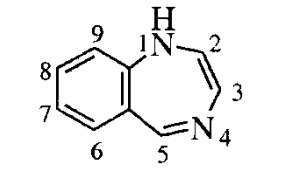
Seven-membered heterocyclic compounds with one nitrogen atom, containing the maximum number of double bonds in the cycle, are called azepine, similar heterocycles with two nitrogen atoms are called diazepines. Representatives of azepine and diazepine are:



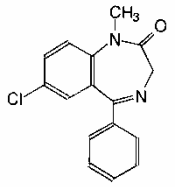
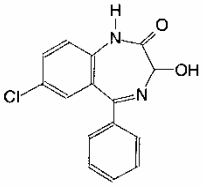
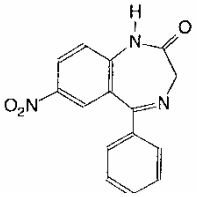
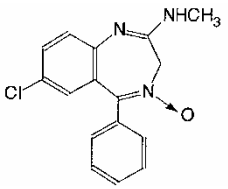
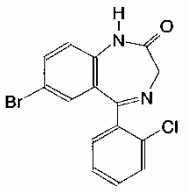
None of the above heterocycles has been obtained in free form to date, but their numerous derivatives are known.

Azepine and diazepine have a non-planar structure and exhibit the properties of polyenes. As a result of the deformation of valence angles, seven-membered rings are less stable than six-membered rings. The main method of azepine synthesis is ring expansion reactions using both the starting compounds of benzene and its derivatives.

The increased interest in the synthesis of 1,4-benzodiazepine derivatives (a condensed system of 1,4-diazepine with benzene) is due to the manifestation of some of them tranquilizing (relieves overexcitation of the central nervous system, fear, anxiety, tension), antidepressant, analeptic (increasing the tone of the central nervous system) and anticonvulsant properties properties



The first works on the synthesis and study of the pharmacological action of 1,4-benzodiazepines were performed by LH Sternbach in the USA in the late 1950s. Effective drugs of the benzodiazepine series are Elenium, Nitrazepam (Radedorm), Diazepam (Seduxen), Phenazepam, etc.:

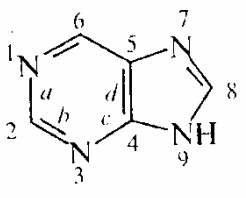
				
diazepam	**oxazepam**	**nitrazepam**	**elenium**	**phenazepam**

The first domestic tranquilizer - phenazepam, obtained by a group of chemists at the Institute of Physics and Chemistry of the Academy of Sciences of the Ukrainian SSR under the leadership of Academician of the Academy of Sciences of the Ukrainian SSR A.V. Bogatsky. Works in this field were awarded the State Prize of the USSR in the field of science and technology in 1980 (together with S.A. Andronati and others).

1,4-Benzodiazepines and their dihydro-derivatives exhibit weakly basic properties due to the pyridine-type N-atom in position 4. Compounds with the lactam group -NN-ZI- also exhibit weakly acidic properties, forming salts with alkali metals, that is, they are amphoteric.

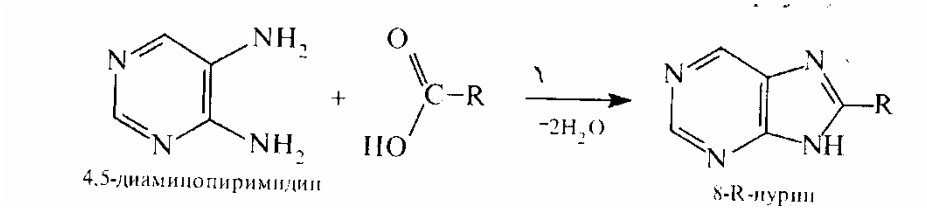
7. Purine and its derivatives.

Purine (imidazo [4,5-d] pyrimidine) is a condensed heterocyclic system consisting of pyrimidine and imidazole rings. Historically, the numbering of the atoms of the purine nucleus has developed, which does not correspond to the general rules for numbering condensed systems, but is generally accepted:



Methods of obtaining

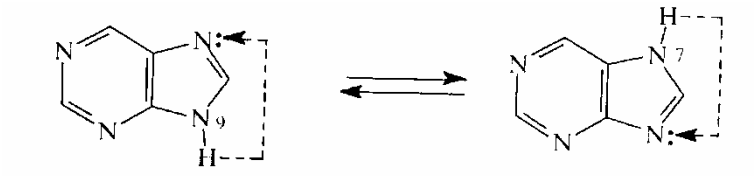
Purine and its derivatives are usually obtained by condensation of 4,5-diaminopyrimidine with carboxylic acids (Traube method):



Structure, physical and chemical properties

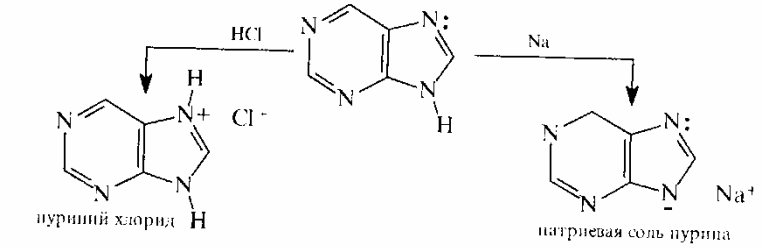
Purine is a colorless crystalline substance (m.p. 217 ºC), well soluble in water, poorly soluble in acetone, diethyl ether, chloroform.

Purine is an aromatic compound: the purine molecule is planar and contains a bonded system of 10 π-electrons, including the NEP of the N-atom in position 9, which corresponds to Hückel's rule (4n + 2, n = 2). The presence of an imidazole ring in a purine molecule gives it a number of properties characteristic of imidazole. Thus, purine is characterized by azole tautomerism:



In the crystalline state, the hydrogen atom is more characteristically located in position 7.

Similarly to imidazole, purine is an amphoteric compound and forms salts with strong acids and bases:

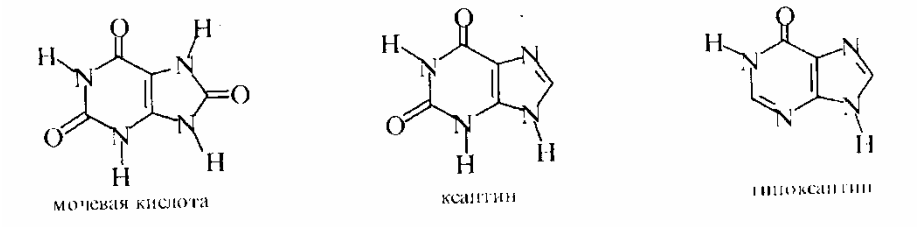


Nitrogen atoms of the pyrimidine cycle, as a result of the electron acceptor effect on each other and participation in the delocalization of the positive charge of purine cations, which are not protonated by strong acids.

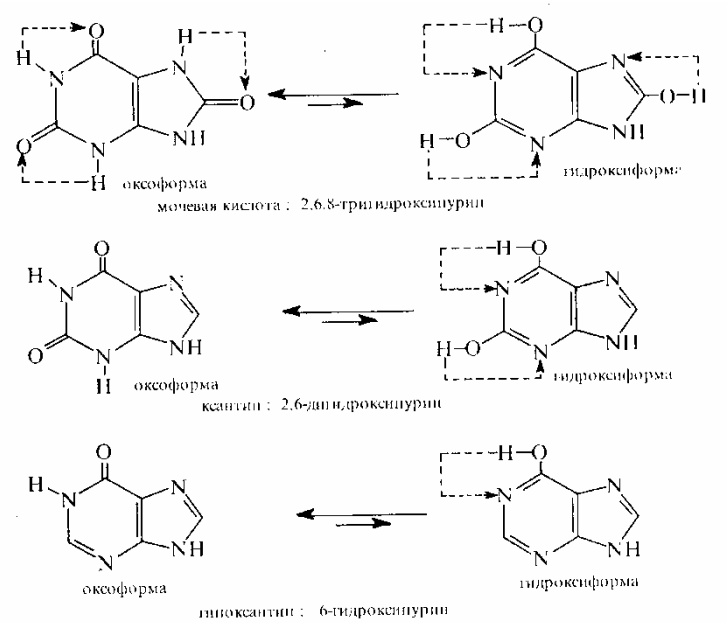
The most important purine derivatives

The most important purine derivatives are oxo- and amino derivatives.

*Oxopurines.*Representatives of oxopurines are uric acid, xanthine and hypoxanthine.



These compounds are formed in the body during the transformation of nucleic acids. Uric acid, xanthine and hypoxanthine are tautomeric substances. As a result of lactam-lactim tautomerism, they exist in two tautomeric forms - oxoform (lactam form) and hydroxyform (lactim form). Therefore, in the chemical literature, oxopurines are often called hydroxypurines.



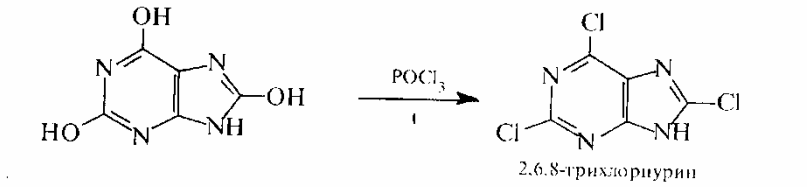
In the crystalline state, uric acid, xanthine and hypoxanthine are in the oxo form; in solutions, they exist as an equilibrium mixture of tautomeric oxo- and hydroxyl forms, in which the oxo form predominates.

Sechovaacid- colorless crystalline substance (b.p. 400 ºC), poorly soluble in water, ethanol, diethyl ether, soluble in dilute solutions of alkalis and glycerin. Uric acid is the final product of the exchange of purine compounds in the body and is excreted in human urine in the amount of 0.5 - 1 g per day.

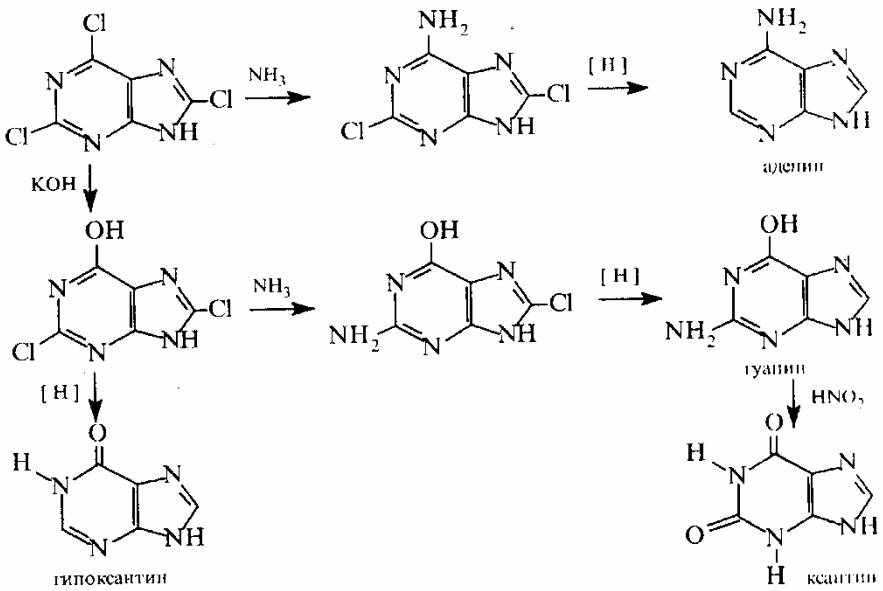
Uric acid is a dibasic acid and upon interaction with aqueous alkali solutions forms acidic and medium salts:

Salts of uric acid - urates. Acid urates, with the exception of lithium salts, are sparingly soluble compounds. With some diseases, in particular, gout, they are deposited in the joints, with kidney stone disease - accumulate in the kidneys in the form of kidney stones. The main component of kidney stones is the monosodium salt of uric acid.

In the hydroxyform, uric acid undergoes a nucleophilic substitution reaction, for example, interaction with POCl3 leads to 2,6,8-trichloropurine:



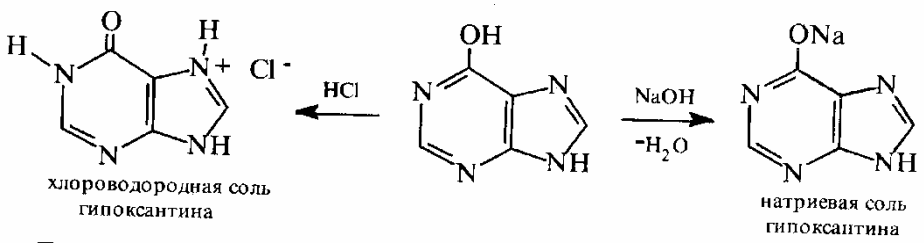
Due to the high mobility of chlorine atoms, 2,6,8-trichloropurine is widely used in the synthesis of purine derivatives - adenine, guanine, hypoxanthine, xanthine, etc. Activity of chlorine atoms in different positions of the purine nucleus in reactions$S_N$is not the same and decreases in the series 6 > 2 > 8, for example:



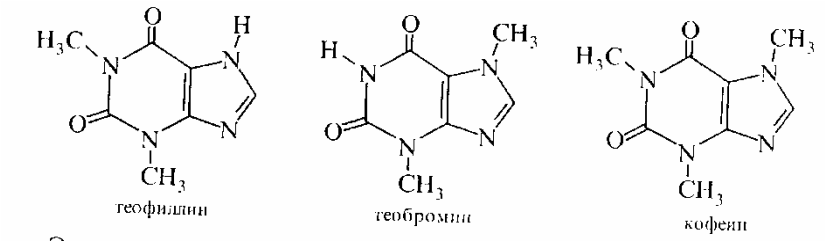
When uric acid is heated with nitric acid and then added to the reaction mixture of ammonia, a purplish-violet color appears, associated with the formation of the ammonium salt of purpuric acid, called murexide. This reaction, called the murexide reaction, is used for the qualitative detection of uric acid and other compounds containing a purine nucleus.

Hypoxanthine(6-hydroxypurine) and xanthine (2,6-dihydroxypurine) are chemically similar to uric acid. They exist in two tautomeric forms - lactam and

lactim, forming salts when interacting with alkalis. Hypoxanthine and xanthine, exhibiting amphoteric properties, also form salts with strong mineral acids:

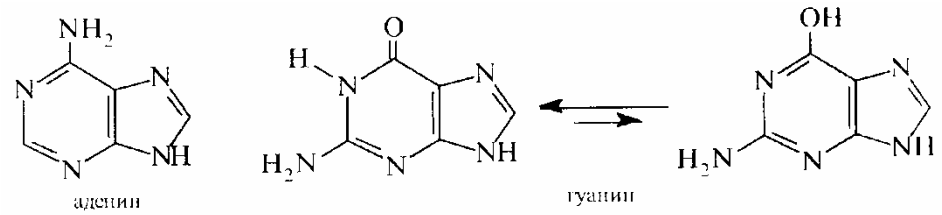


Hypoxanthine and xanthine are widely distributed in the plant and animal world. N-methyl derivatives of xanthine are important in pharmacy - alkaloids theophylline (1,3-dimethylxanthine), theobromine (3,7-dimethylxanthine), caffeine and (1,3,7-trimethylxanthine). Theophylline is found in tea leaves, theobromine in cocoa beans, caffeine in tea leaves and coffee beans.



Theophylline, theobromine and caffeine are obtained from natural raw materials or synthetically - by methylation of xanthine. The listed compounds are colorless crystalline substances, well soluble in hot water, poorly soluble in cold water. Theophylline and theobromine are amphoteric compounds: their acidic properties are due to the mobility of the H atom in the NN fragment of the molecules, the basic properties are due to the presence of the pyridine nitrogen atom N9. Caffeine exhibits only weak basic properties due to the presence of the N9 atom. Theophylline and theobromine have a diuretic effect, caffeine has stimulating effect on the central nervous system. In medical practice, caffeine is usually used in the form of a double salt with sodium benzoate - caffeine-sodium benzoate.

Aminopurine. The most important amino derivatives of purine are adenine (6-aminopurine) and guanine (2-amino-6-hydroxypurine), which are part of nucleic acids as purine bases. Guanine exists in two tautomeric forms - lactam and lactim. A more stable lactam form, in the form of which the guanine fragment is found in nucleic acids.



Adenine and guanine are colorless crystalline substances, hardly soluble in water, well soluble in alkalis. They are formed during the hydrolysis of nucleic acids.

In the body, adenine and guanine undergo deamination with the formation of hypoxanthine and xanthine, which are oxidized to uric acid.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1. Azines: pyridine, quinoline, isoquinoline, acridine. Nomenclature, structure, physical and chemical properties, methods of obtaining, aromaticity.

2. Pyridine.Extraction methods, physicochemical properties, reactions involving a hetero atom, hydrogen atom substitution reactions of the pyridine cycle. The main properties, the most important derivatives of pyridine.

3. Azines with condensed rings: quinoline, isoquinoline, acridine. Nomenclature, structure, physical and chemical properties, methods of obtaining, aromaticity. Heterocycles of the group

piranha

4. Six-membered heterocycles with two heteroatoms. Diazines: pyrimidine (1,3-diazine), pyrazine (1,4-diazine), pyridazine (1,2-diazine). Nomenclature, structure, extraction methods, aromaticity, physicochemical properties, basicity, reactivity.

5. Condensed systems of heterojunctions. Purine: nomenclature, structure,extraction methods, physical and chemical properties, the most important purine derivatives,aromaticity. Azole tautomerism. Amphoteric character.

6. Seven-membered heterocycles. 1,4-Benzodiazepines.

7. Macroheterocyclic compounds. Crown and azacrown ethers.

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Lecture No. 15

Topic: General characteristics of carbohydrates. Monosaccharides. Di- and polysaccharides.

Actuality of theme: The organic chemistry course is also an introduction to some aspects of the physical and colloid chemistry, chemical technology, and biochemistry courses and includes a description of classes of organic compounds, including polymers and biologically active organic compounds.

Goal:as a result of the lecture, students should familiarize themselves with the classification, nomenclature, method of extraction, physical and chemical properties of the most important monosaccharides, di- and polysaccharides."
Basic concepts: Monosaccharides. Disaccharides. Polysaccharides.

Plan and organizational structure of the lecture:

1. Monosaccharides.
2. Disaccharides.
3. Polysaccharides.

Content of lecture material (lecture text).

1. Monosaccharides.

The term "carbohydrates" was proposed in 1844 by the Russian chemist K.G. Schmidt on the basis of elemental analysis data of the first representatives of this class of compounds, since it was established that their molecules consist of carbon, hydrogen and oxygen atoms in the ratio[Cx(H2O)y]. Further study of the structure of these compounds and the discovery of substances with a composition that does not correspond to the specified empirical formula showed that their classification as "carbon hydrates" is only formal, but the accepted name "carbohydrates" has been preserved.

Currently, carbohydrates include a large group of natural and synthetic compounds that are polyhydroxyl substances that contain aldehyde or ketone groups, or form them during hydrolysis.

Carbohydrates (sugar) make up the bulk of organic matter on our planet. In nature, carbohydrates are formed as a result of photosynthesis carried out by plants with the participation of carbon dioxide, water and sunlight-absorbing pigments (chlorophyll, etc.).

In the body, starch, disaccharides, and in some cases - cellulose are broken down under the influence of enzymes with the formation, mainly, of glucose, which is oxidized in the tissues to carbon dioxide and water with the release of energy. Excess glucose is converted into glycogen, which is stored in the liver and muscles. Glycogen supplies the body with glucose during exercise, as well as when there is a lack or absence of food. Carbohydrates are a raw material base for the textile, pulp and paper, food, woodworking and other industries.

Depending on the number of monosaccharide units connected in a molecule, carbohydrates are divided into simple and complex.

Simple carbohydrates, or monosaccharides, cannot be hydrolyzed. Complex carbohydrates form monosaccharides during hydrolysis. Complex carbohydrates are classified into oligosaccharides, which form during hydrolysis from two to ten molecules of monosaccharides, and polysaccharides, (polyoses), hydrolyzing with the formation of more than ten molecules of monosaccharides.

Monosaccharides

Monosaccharides are polyhydroxy compounds containing aldehyde or ketone groups. They are also called monoses or simple carbohydrates (sugars).

Depending on the presence of an aldehyde or ketone group in the monosaccharide structure, they are divided into aldoses and ketoses. According to the number of C atoms in the molecule, monosaccharides are classified into trioses (C3), tetroses (C4), pentoses (C5), hexoses (C6), etc. Monosaccharides, the composition of which includes more than six C-atoms, are called higher sugars. Most natural monosaccharides are pentoses and hexoses. Usually, both classification features are taken into account during classification, for example, aldopentose, aldogexose, ketopentose, ketohexose:

5 4 3 2 1

$NOSN_2$–CHOH–CHOH–CHOH–C(O)H aldopentose

6 5 4 3 2 1

$NOSN_2$–CHOH–CHOH–CHOH–CHOH–C(O)H aldohexose

6 5 4 3 2 1

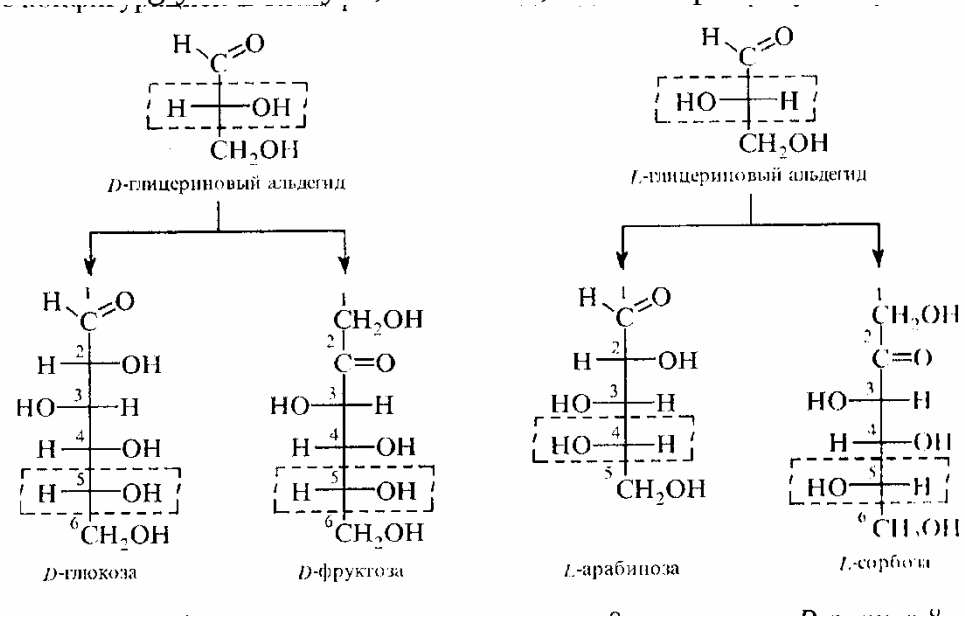
$NOSN_2$–CHOH–CHOH–CHOH–C(O)–CH2OH ketohexose

As a rule, trivial nomenclature is used in the names of monosaccharides. All trivial names end in -ose, for example, glucose, fructose, galactose, ribose, etc. The IUPAC nomenclature is practically not used in the names of carbohydrates.

Stereoisomerism

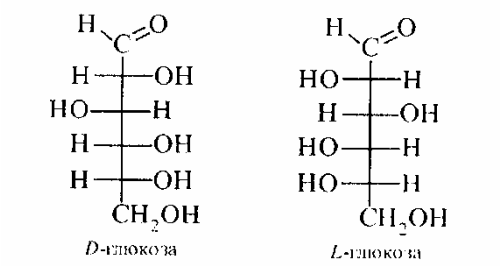
Monosaccharide molecules contain several asymmetric C atoms and therefore exist in the form of various spatial isomers. For example, aldopentose has 3 asymmetric C-atoms, and therefore 8 stereoisomers (2+3) correspond to the same structural formula, aldohexose contains 4 asymmetric C-atoms and can exist in the form of 24 = 16 stereoisomers.

Fisher's projection formulas are used to represent stereoisomers on a plane. All isomers of monosaccharides are divided into D- and L-stereochemical series, belonging to which is determined by the configuration of the asymmetric C atom, the most distant from the carbonyl group (for pentoses - C4, for hexoses - C5). If the configuration of this chiral C atom coincides with the configuration of D-glyceraldehyde, then the monosaccharide belongs to D. Next to it, if with the configuration of L-glyceraldehyde, then to L-, for example:

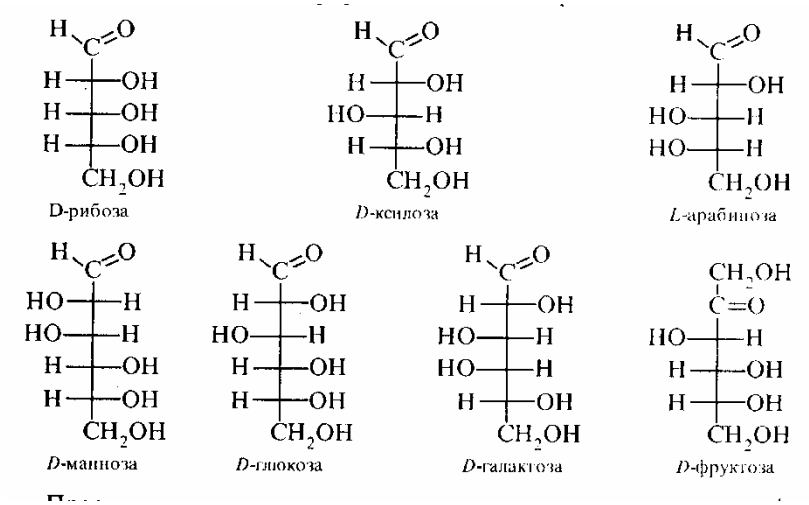


So, out of 16 stereoisomers of aldohexoses, 8 belong to D- and 8 to L-. Representatives of the D-series are optical antipodes of the L-series, that is,

aldohexose exists in the form of 8 pairs of enantiomers. For example, enantiomers are D- and L-glucose:



The vast majority of natural monosaccharides belong to D-. The most important natural monosaccharides are:



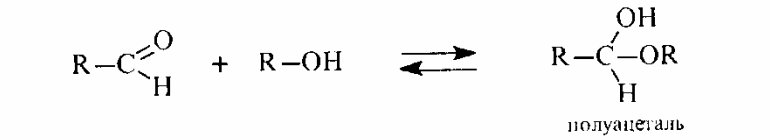
Spatial isomers of monosaccharides that differ in the configuration of one or more C atoms and that are not mirror isomers (enantiomers) are called diastereomers. Thus, D-glucose and -galactose, -mannose and DD -glucose, -mannose and D-galactose form pairs of diastereomers. Diastereomers that differ in the configuration of only one asymmetric C atom are called epimers.
For example, D-glucose and D-galactose, as well as D-glucose and D-mannose, form pairs of epimers. Thus, epimers are a special case of diastereomers.

The structure of monosaccharides

For a long time, it was believed that monosaccharides are compounds with an open carbon chain containing an aldehyde or ketone group and several alcohol hydroxyls. However, a deeper study of their structure showed that a number of properties of monosaccharides do not agree with existing ideas. So, monosaccharides, being aldehydes, do not give some reactions to the aldehyde group. When monosaccharides are heated with alcohols in the presence of dry HCl, only the OH group of the carbohydrate reacts, although, based on the linear structure, under these conditions, a compound of the simple ether type should be formed by all OH groups. The phenomenon of mutarotation, a change in the amount of optical rotation of freshly prepared solutions, characteristic of monosaccharides, has no small explanation. To explain these facts, the Russian chemist A.A. Kolli (1870) and the

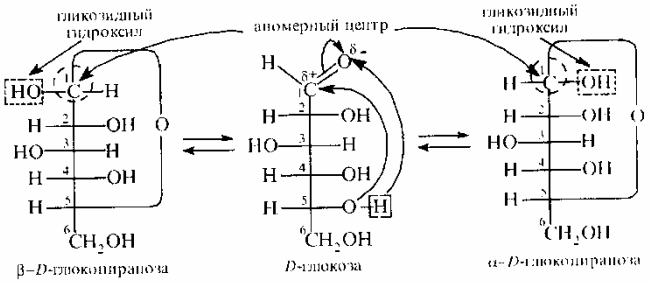
German chemist B. Tollens (1883) suggested the cyclic structure of monosaccharides.

As you know, aldehydes react with alcohols to form a hemiacetal:



Similarly, monosaccharides, being polyhydroxyaldehydes or polyhydroxyketones, form cyclic hemiacetals as a result of the intramolecular interaction of the carbonyl and spatially close to it OH group. Moreover, in accordance with the theory of stress cycles, the most favorable interaction leads to the formation of five- or six-membered cycles. A six-membered ring is formed by the interaction of an oxo group with an OH group at C5 aldohexose or C6 ketohexose. It is called pyranose (from the six-membered heterocycle of pyran).

When an oxo group interacts with an OH group at C4 aldohexose or C5 ketohexose, a five-membered cycle called furanose (from the five-membered heterocycle of furan) is formed.



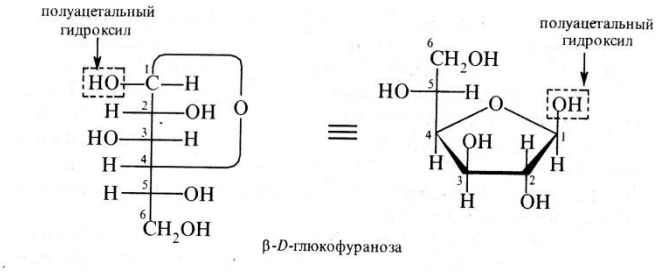
The intramolecular formation of hemiacetal leads to the fact that the C atom of the carbonyl group becomes asymmetric. This new chiral center is called anomeric, and the corresponding two new stereoisomers are α- and β-anomers. The newly formed OH group at the anomeric center is called hemiacetal or glycosidic. In the projection formulas of D-series monosaccharides, the glycosidic hydroxyl in the α-anomer is located to the right of the vertical line of the carbon chain, and to the left in the β-anomer.

The above images of cyclic forms of monosaccharides are called Collie-Tollens formulas. Since Colli-Tollens formulas are cumbersome and inconvenient for depicting cyclic structures, the English chemist H. Heworths in the 20s of the 20th century proposed to depict cyclic forms of monosaccharides in the form of flat polygons; The O atom in the pyranose ring is located in the right corner, the substituents are located above and below the plane of the ring.

These formulas were called Heworth's formulas.

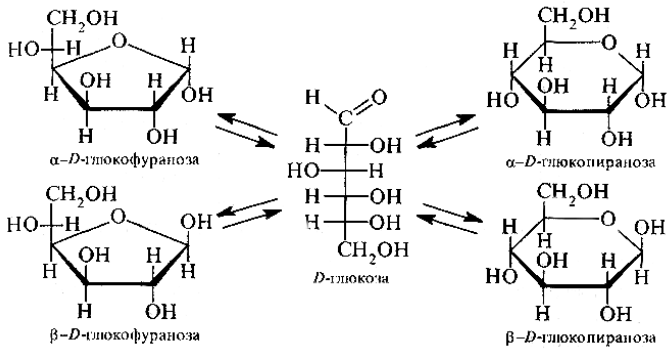
The following rules are used to convert from Collie-Tollens formulas to Heworths formulas:

1. The substituents located in the Collie-Tollens fl to the left of the vertical line of the carbon chain are depicted in the Heworths fl above the plane of the cycle, and the substituents located to the right - below the plane. This means that in the α-anomer of D-series monosaccharides, the hemiacetal hydroxyl is below the cycle plane, and in the β-anomer - above the plane.
2. In D-series aldohexoses, the -CH2OH group in the pyranose form, and the -CH(OH)CH2OH group in the furanose form, is always located above the cycle plane.



When depicting the racemic form of α- and β-anomers in Heworth's graph, the symbol of the H atom at the glycosidic C atom is omitted, and the location of the OH group is indicated by a wavy line.

Tautomerism.Monosaccharides are tautomeric substances. In the crystalline state, they have a cyclic structure (yes, D-glucose is in the form of Dα-glucopyranose); in an aqueous solution, the cyclic form under the influence of the solvent is transformed through the open oxoform into other cyclic forms - pyranose and furanose with α- and β-configuration of the anomeric center. Thus, in aqueous solutions, monosaccharides exist in the form of five tautomeric forms - open, α- and β-pyranose, and α- and β-furanose.



This type of tautomerism is called cyclo-oxo-tautomerism, or ring-chain tautomerism.

The mutual transition of forms leads to the fact that after a certain time a dynamic equilibrium is established in the solution, in which the number of all forms remains constant. In the equilibrium mixture of aldohexose tautomers, pyranose forms predominate. Analogous tautomeric transformations occur in aqueous solutions

of ketoses. Furanose forms predominate in the equilibrium mixture of D-fructose tautomers.

The ability of monosaccharides to undergo cyclo-oxo-tautomerism explains the phenomenon of mutarotation discovered long before their structure was established.

Mutatorations (from the Latin muto - "betray" and rotatio - "rotation") - an involuntary change in the amount of optical rotation of freshly prepared solutions of optically active substances.

Conformationsmonosaccharides. Furanose forms of monosaccharides have an almost flat spatial structure, and therefore, the substituents in the five-membered ring are forced to be in an unstable conformation.

For pyranose cycles, the most favorable, corresponding to the minimum energy, is the armchair form, in which the substituents are in a conformation close to the inhibited one. Therefore, furanose forms of monosaccharides are thermodynamically less advantageous than pyranose forms.

It should be noted that of the two possible types of chair conformation of pyranose forms, the one with the maximum number of bulky substituents (group -OH and especially-CH2OH) is in the equatorial position.

Methods of obtaining

Carbohydrates are formed in the green parts of plants from carbon dioxide and water in the process of photosynthesis:

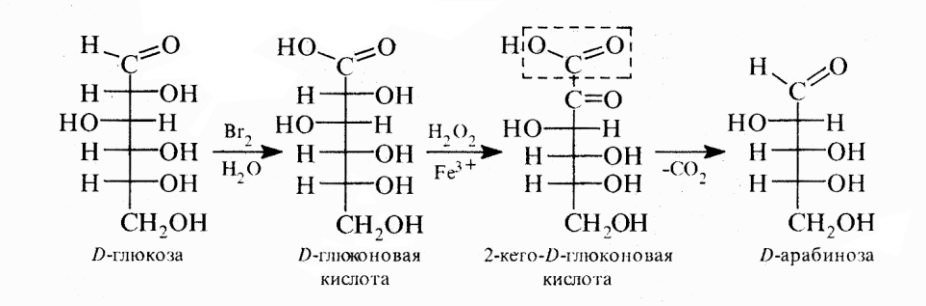
$$n\mathrm{CO2} + \mathrm{nH2O} \xrightarrow{h\nu} \mathrm{CnH2nOn} + \mathrm{nO2}.$$

The most important method of obtaining monosaccharides is acid hydrolysis of natural di- and polysaccharides. Thus, D-glucose is obtained by hydrolysis of starch, a mixture of D-glucose and D-fructose by hydrolysis of sucrose, etc.

Synthetic methods are used, as a rule, to obtain scarcely available monosaccharides.

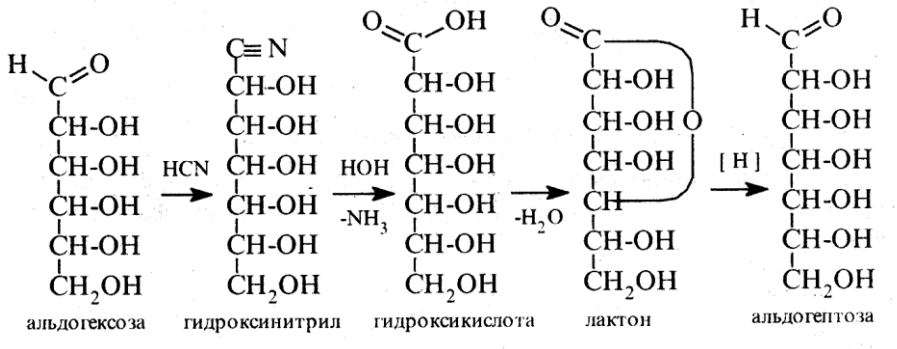
These methods are based on the transformation of monosaccharides, easily isolated from natural sources (D-glucose, etc.), and other monosaccharides by shortening or lengthening the carbon chain.

Ruff decomposition- one of the classic methods of shortening the carbon chain, based on the oxidation of monosaccharides:



First, the monosaccharide is oxidized under mild conditions to aldonic acid; the acid is oxidized by H2O2 in the presence of Fe3+ salts to 2-ketoaldonic acid, which, as a result of decarboxylation, turns into a monosaccharide containing one less C atom than the original.

Cyanhydricsynthesis.The essence of the method is the addition of hydrogen cyanide through the double bond of the carbonyl group of the aldose followed by the hydrolysis of the formation of hydroxynitrile to the hydroxy acid, which, through the stage of lactonization and reduction, turns into an aldose containing one more C atom than the original:



Cyanohydrin synthesis allows the carbon chain to be extended and is used to obtain higher aldoses from lower aldoses.

Physical and chemical properties

Monosaccharides are solid hygroscopic substances, easily soluble in water, difficult - in ethanol and practically insoluble in diethyl ether, dioxane, benzene. A significant part of monosaccharides are crystalline substances. Their aqueous solutions usually have a sweet taste and a neutral reaction. In solutions, monosaccharide molecules are strongly solvated, which leads to the formation of narrow "syrups", from which the crystallization process is carried out with difficulty.

This is explained, on the one hand, by the slow formation of crystallization centers due to difficulty in the orientation of molecules in viscous solutions, and on the other hand, by the establishment of a tautomeric equilibrium with a low concentration of the tautomer most prone to crystallization.

Solutions of monosaccharides are optically active.

Being polyhydroxycarbonyl compounds, monosaccharides exhibit the chemical properties of carbonyl compounds, polyhydric alcohols, and cyclic hemiacetal.

Chemical transformations in a number of monosaccharides can be conditionally divided into two groups:

reactions involving open forms and reactions involving cyclic forms of monosaccharides.

Reactions involving open forms

Restoration. During the reduction of monosaccharides H2 (in the presence of Ni, Pd), NaBH4, Na / Hg in diluted H2SO4 polyatomic alcohols are formed:

$$HOCH2–(CHOH)4–C(O)H \xrightarrow{[H]} HOCH2–(CHOH)4–CH2OH.$$

D-glucose produces D-sorbitol, D-xylose produces D-xylitol, etc. D-xylitol and D-sorbitol are crystalline substances with a sweet taste and are used in diabetes as sugar substitutes.

Oxidation.Monosaccharides are easily oxidized; depending on the nature of the oxidant and the reaction conditions, different products are formed.

Oxidation in acidic and neutralenvironment. When using weak oxidizing agents (bromine water, diluted HNO3), aldoses are oxidized with the formation of monobasic polyoxyacids - aldonic acids. D-glucose under these conditions gives D-gluconic acid. Calcium salt of D-gluconic acid - calcium gluconate [HOCH2-(CHOHN)4-COO]2Ca · 2 OH is used in medicine for allergic diseases, toxic liver damage, etc.

Strong oxidizing agents, for example, concentrated HNO3, oxidize aldehyde and primary OH groups in aldose molecules with the formation of dicarboxylic acids, which have received the common name sugar acids:

$$HOCH2–(CHOH)4–C(O)H \xrightarrow{[O]} HO(O)C–(CHOH)4–C(O)OH.$$

glucosaccharic acid

Oxidationin an alkaline environment. Like aldehydes, monosaccharides are oxidized with an ammonia solution of AgNO3 (Tollens' reagent, the "silver mirror" reaction) and Cu (OH)2 in an alkaline medium (or Fehling's reagent, a red-orange precipitate is formed). These reactions involve both aldoses and ketoses, therefore, in an alkaline medium, ketoses are isomerized into aldoses:

Fehling's reagent

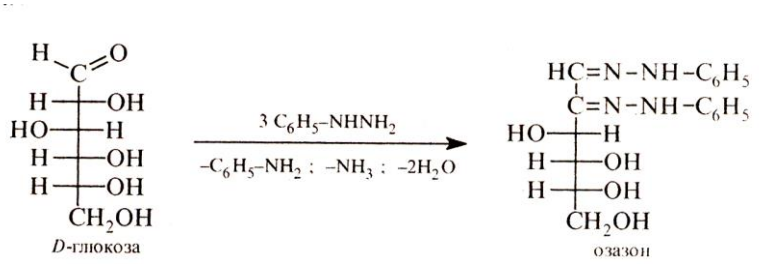
R–C(O)H + [Ag(NH3)2]NO3 → Ag↓ + oxidation products

R–C(O)H + Cu2+(complex) → Cu2O↓ + oxidation products

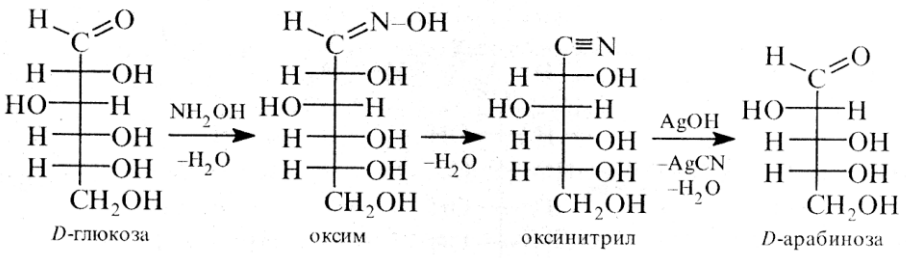
These reactions are qualitative for aldoses and ketoses.

Transformation of monosaccharides under the action of alkalis*(epimerization*). In dilute alkali solutions at room temperature, monosaccharides undergo isomerization with the formation of an equilibrium mixture of monoses that differ in the configuration of carbon atoms and C-C2. Thus, D-glucose, kept in NaOH solution (8 10-3) at 35 °C for 4 days, turns into a mixture of D-fructose (~ 28%), D-mannose (~ 3%) and D-glucose (~ 69%). Ketoses, for example, fructose, undergo a similar isomerization. Isomeric transformations of monosaccharides under the action of alkalis are called epimerization, because they lead to the formation of epimers, for example, glucose and mannose.

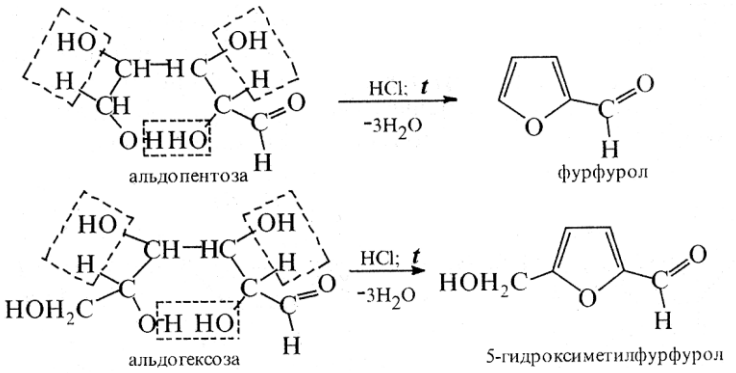
Formation of ozazones. When monosaccharides are heated with phenylhydrazine in a molar ratio of 1:3, bis-phenylhydrazones are formed, which are called ozazones:



Interaction withhydroxylamine.Aldoses easily react with hydroxylamine, forming oximes. In the presence of dehydrating reagents, oximes can be transformed into the corresponding oxynitriles, which, under the action of Ag+ ions, detach HCN and form oxyaldehydes containing one less C atom than in the original aldose. With the help of this reaction, you can make a transition from higher aldoses to lower ones:



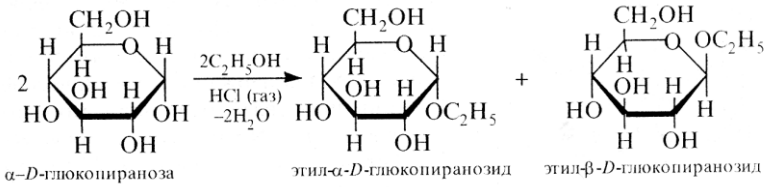
Intramoleculardehydration. When heated with mineral acids (HCl, H2SO4), pentoses undergo intramolecular dehydration with the formation of furfural, and hexoses - 5-hydroxymethylfurfural:



This reaction makes it possible to distinguish hexoses from pentoses.

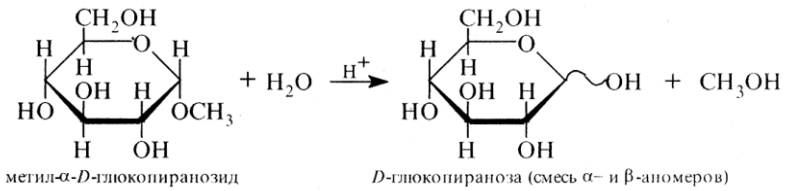
Reactions involving cyclic forms

Formation of glycosidesin.Monosaccharides as cyclic hemiacetals react with alcohols and phenols in the presence of an acid catalyst to form cyclic acetals - glycosides. Regardless of the initial form of the monosaccharide, a mixture of α- and β-glycosides is formed during the reaction:



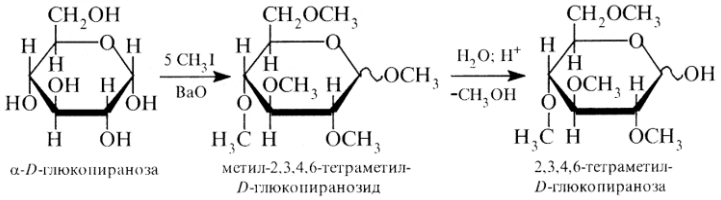
The names of glycosides are formed from the names of monosaccharides, replacing the suffix -ose with -ozide. The non-carbohydrate part of the glycoside molecule is called an aglycone. The chemical bond between the anomeric C atom of the monosaccharide and the aglycon in the glycoside is called glycosidic. Due to the fact that the molecules of glycosides lack a free hemiacetal OH group, they, unlike monosaccharides, are not capable of tautomerism in aqueous solutions, which do not mutate and do not exhibit reducing properties.

Glycosides are easily hydrolyzed in an acidic environment with the formation of a mixture of α- and β-anomers of the corresponding monosaccharide:

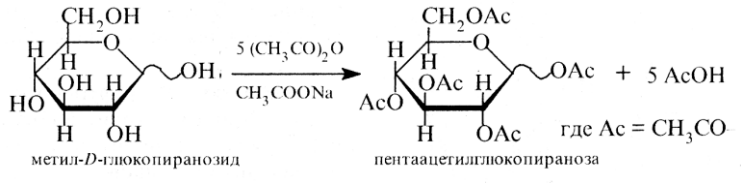


Glycosides are very common in nature. Phenols and steroids often act as aglycons in natural glycosides. Since the connection of the aglycon with the anomeric C-atom in these compounds is carried out through the O-atom, such glycosides are called O-glycosides. In addition to O-glycosides, N-glycosides and S-glycosides are known.

Alkylation.When monosaccharides interact with alkylating agents (CH3I, (CH3)2SO4), all OH groups, including hemiacetal hydroxyl, react:



Acylation.The interaction of monosaccharides with carboxylic acid anhydrides is carried out by all OH groups with the formation of the corresponding complex esters:



Individual representatives of monosaccharides

D- Ribose. In the β-furanose form, it is part of RNA, a number of coenzymes, glycosides and antibiotics.

D-glucose(dextrose). In a free state, it is found in plants, honey, blood; is part of many disaccharides (lactose, sucrose, etc.), polysaccharides (starch, fiber, glycogen, etc.). Glucose is the main source of energy for most organisms. Obtained by hydrolysis of starch or cellulose in the presence of mineral acids.

Glucose is used as a raw material for the production of vitamin C and medicinegluconatecalcium; in medicine, it is used in the form of solutions for intravenous administration in hypoglycemia, infectious diseases, liver diseases, etc.; is a component of various blood substitutes and anti-shock fluids. Under the action of

enzymes, glucose undergoes fermentation processes (alcoholic, lactic acid, butyric acid, citric acid, etc.), the most important of which is alcoholic fermentation:

$$C_6H_{12}O_6 \xrightarrow{дрожжи} 2C_2H_5OH + 2CO_2.$$

This type of fermentation is used in industry to obtain ethanol, as well as in winemaking and brewing.

L-Sorbose. Obtained by microbiological oxidation of D-sorbitol. This process is an important intermediate stage in the synthesis of vitamin C.

D- fructose(fruit or fruit sugar). In a free state, it is found in fruits, honey; is part of a number of oligosaccharides (sucrose, raffinose) and polysaccharides (inulin). D-fructose phosphates are intermediate products of energy metabolism of carbohydrates in living organisms. Fructose is sweeter than glucose and sucrose. Fructose is obtained by hydrolysis of inulin contained in dahlia tubers and chicory roots.

2. Disaccharides.

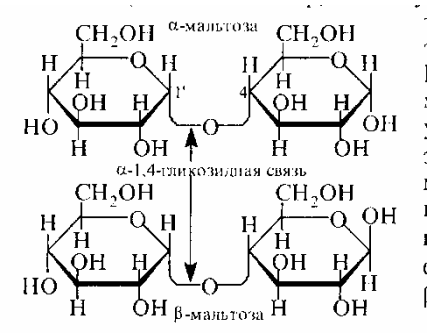
Carbohydrates are called disaccharides, the molecules of which consist of two residues of monosaccharides of the same or different nature, connected to each other by a glycosidic bond.

Being O-glycosides, disaccharides are easily hydrolyzed in an acidic environment with the formation of two molecules of monosaccharides. Depending on the methodformation of a glycosidic bond, disaccharides are divided into two groups - reducing and non-reducing.

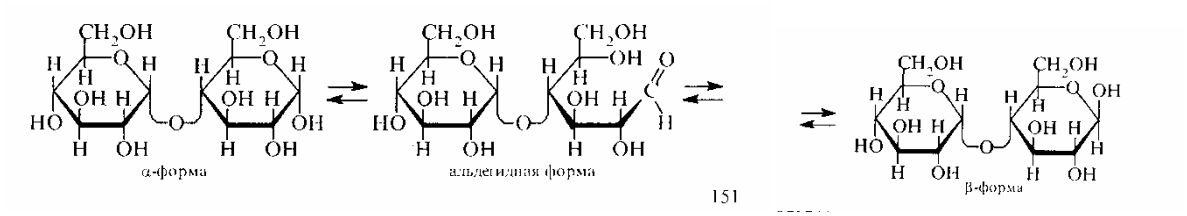
Regenerating disaccharides

In reducing disaccharides, the glycosidic bond is formed due to the hemiacetal (glycosidic) OH group of one or any OH group (more often $C^{4)}$another monosaccharide. At the same time, one free semi-acetal hydroxyl group remains in the molecule, as a result of which the disaccharide retains the ability for cyclo-oxo-tautomerism and, therefore, has reducing properties. In freshly prepared solutions of such disaccharides, the phenomenon of mutarotation is observed. Representatives of reducing disaccharides are maltose, cellobiose, lactose.

Maltose(malt sugar). The maltose molecule consists of two D-glucopyranose residues connected by a 1,4-glycosidic bond. At the same time, the glucose residue, whose anomeric C atom participates in the formation of a glycosidic bond, is in the α-form, and the glucose residue with a free hemiacetal OH group can have an α-configuration (α-maltose) or a β-configuration (β -maltose).



Maltose is a reducing disaccharide. In solution, it exists in several tautomeric forms - α- and β-cyclic and aldehyde:



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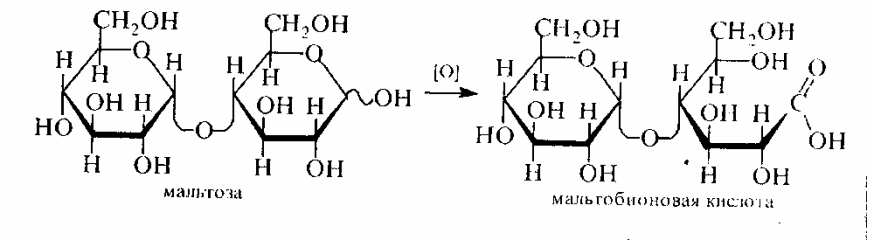
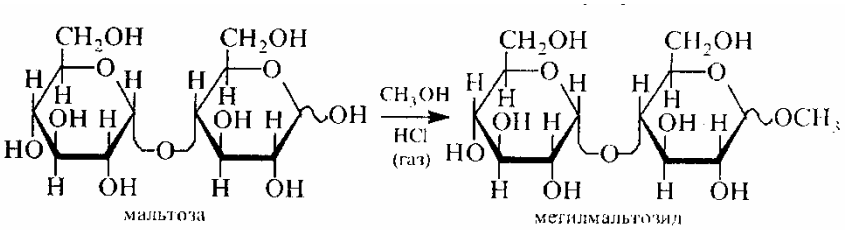
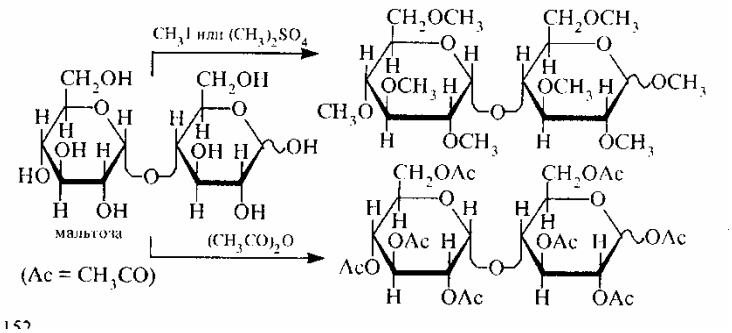
Maltose solutions mutarotate and give a positive reaction with Tollens' and Fehling's reagents. With the participation of the aldehyde form, maltose enters into reactions characteristic of monosaccharides with phenylhydrazine, hydroxylamine, hydrocyanic acid. When oxidized under mild conditions, for example, with bromine water, maltose turns into maltobionic acid:



Due to the hemiacetal hydroxyl, maltose forms glycosides.

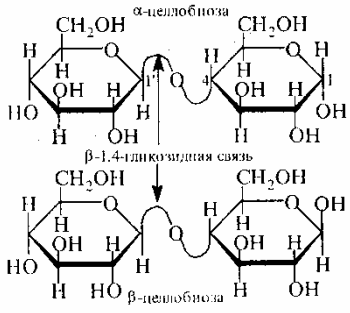


With the participation of cyclic forms of maltose, similar to monosaccharides, it forms simple and complex esters with all OH groups.



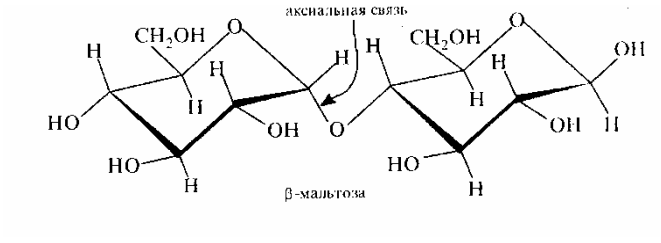
Maltose is found in small amounts in some plants and is formed during the enzymatic hydrolysis of starch. Easily dissolves in water, aqueous solutions have a sweet taste. In the human body, maltose is broken down toD-glucose.

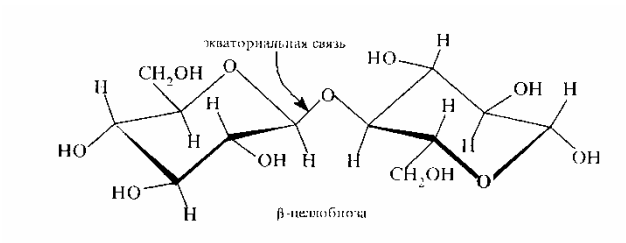
Cellobiose. The cellobiose molecule, like maltose, consists of two D-glucopyranose residues connected by a 1,4-glycosidic bond. But, unlike maltose, in the cellobiose molecule, the residue of glucose, the hemiacetal hydroxyl of which participates in the formation of a glycosidic bond, has a β-configuration. The remainder of glucose with a free hemiacetal group, similar to maltose, can have α- and β-configuration. Accordingly, α- and β-cellobioses are distinguished.



Cellobiose is a reducing disaccharide. Its solutions exhibit mutarotation, give a positive reaction with Tollens' and Fehling's reagents. When cellobiose is oxidized under mild conditions, cellobionic acid is formed. Cellobiose is also involved in many other reactions characteristic of regenerating disaccharides (see above).

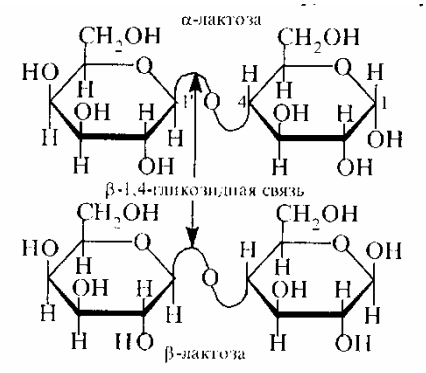
Cellobiose and maltose have a different spatial structure. In the maltose molecule, the α-glycosidic bond is located axially, and in the cellobiose molecule, the β-glycosidic bond is equatorial.



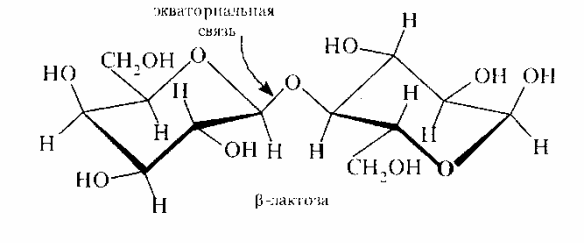


Cellobiose is a colorless crystalline substance that dissolves easily in water. It is not broken down in the human body and therefore cannot be used as a food product.

(Lactose is milk sugar). The lactose molecule consists of D-galactopyranose and D-glucopyranose residues connected by a 1,4-glycosidic bond. In the formation of a glycosidic bond, the naviacetal hydroxyl of D-galactopyranose, which has a β-configuration, takes part. The residue of D-galactopyranose can have α- and β-configuration, in connection with which α- and β-lactose are distinguished.



The spatial structure of lactose is similar to the structure of cellobiose, that is, the β-glycosidic bond is located equatorially.



Lactose is a reducing disaccharide. In solution, it exists in several tautomeric forms - aldehyde, α- and β-cyclic. In this regard, lactose solutions mutate and give a positive reaction with Tollens and Fehling's reagents. When lactose is oxidized in mild conditions, lactobionic acid is formed.

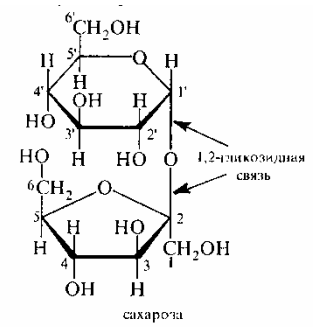
Lactose is found in milk. It does not undergo alcoholic fermentation, has 4.5 times less sweetness than sucrose. During acid or enzymatic hydrolysis of lactose, D-glucose and D-galactose are formed. Lactose has low hygroscopicity, it is used in pharmacy in the manufacture of powders and tablets.

Non-reducing disaccharides

In the molecules of non-reducing disaccharides, the glycosidic bond is formed due to hemiacetal OH groups of both monosaccharides. Such disaccharides do not have a free hemiacetal hydroxyl in their composition,therefore, in solutions they exist only in cyclic form, their solutions do not mutate and do not have reducing properties. Non-reducing disaccharides do not give reactions on the aldehyde group and the glycosidic hydroxyl. They are only capable of forming simple and complex esters. Sucrose is a representative of non-reducing disaccharides.

Saccharose(cane or beet sugar). The sucrose molecule consists of D-glucose and D-fructose residues. At the same time, D-glucose is part of sucrose in the form of D-α-glucopyranose, and D-fructose in the form of D-β-fructofuranose. The glycosidic bond between D-α-glucopyranose and D-β-fructofuranose is formed due to hemiacetal hydroxyls of both molecules. Based on the chemical structure, sucrose can be named as D-α-D-glucopyranosido-β-fructofuranoside.

Sucrose is a colorless crystalline substance, well soluble in water, and has a sweet taste. Sucrose solutions are optically active [α^{20D}+66.5 °], which do not mutate and do not show reducing properties.



сахароза

Under the action of mineral acids, when heated, sucrose is hydrolyzed with the formation of a mixtureD-glucose and D-fructose. At the same time, there is a change in the sign of the specific rotation, i.e., the rotation of the polarization plane to the right [α20D +66.5 °] characteristic of sucrose changes to a left rotation [α20D -39.5 °]. Due to the change in the sign of the specific rotation in the process of sucrose

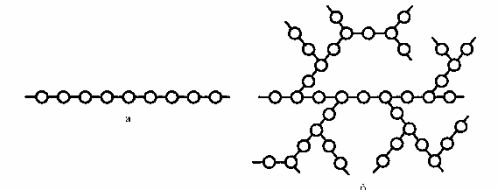
hydrolysis, the hydrolysis of sucrose was called inversion. Hence, the mixture of equal amounts of D-glucose and D-fructose formed during hydrolysis is called invert sugar. Invert sugar is the main component of bee honey. The reason for the inversion of sucrose is a relatively large specific rotation of D-fructose to the left [α20D -92 °] than that of D-glucose to the right [α20D +52.5 °], because a mixture with left rotation is formed during hydrolysis.

Sucrose is found in sugar cane and sugar beet (17-20%), from which it is obtained in industry. In pharmacy, sucrose is used to prepare powders, syrups, mixtures, etc.

3. Polysaccharides.

Polysaccharides include compounds whose molecules contain more than ten monosaccharide units linked by an O-glycosidic bond.

Most often, polysaccharides consist of several hundreds and even thousands of monosaccharide residues forming linear (a) or branched (b) polymer chains:



Glycosidic bonds in polysaccharide molecules are formed, as a rule, due to the glycosidic hydroxyl of one and the alcohol hydroxyl of another monosaccharide residue. Most of these connections arise between $S^{2,}$C1 and C3 or C1 and C6.

At the end of the polysaccharide chain there is a reducing monosaccharide residue, but since its share in the molecule is insignificant, polysaccharides with a large molecular weight practically do not have reducing ability. If the structure of polysaccharides includes the remains of only one monosaccharide, then they are called**homopolysaccharides.**Polysaccharides consisting of different monosaccharide units are called heteropolysaccharides.

Homopolysaccharides

Homopolysaccharides built from pentose residues are called**pentosans,**and from hexose residues - hexosans. The general formula of pentosans is (C5H8O4)n, and that of hexosans is (C6H10O5)n. The vast majority of natural polysaccharides are hexosans; they include: starch, cellulose, glycogen, dextrans, etc.

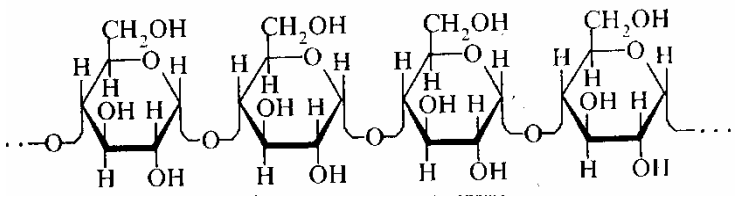
Starch. Starch serves as the main source of reserve energy in plants; occurs mainly in seeds, tubers, roots.

Starch contains ~ 20% of the water-soluble fraction, called**amylose,**and about ~80% of the insoluble fraction called amylopectin. With gradual acid and enzymatic hydrolysis, amylose and amylopectin are split into dextrins (a mixture of polysaccharides with a lower molecular weight), further hydrolysis of which leads to maltose, and then to D-glucose:

$$(C_6H_{10}O_5) \rightarrow n(C_6H_{10}O_5) \rightarrow C\ x_{12}H_{22}O_{11} \rightarrow C_6H_{12}O_6.$$

The difference in the structure of amylose and amylopectin is due to the nature of glycosidic bonds.

Amylose is a linear polymer in whichD-glucopyranose residues are linked by an α-1,4-glycosidic bond; consist of 200 - 350 monomer units:

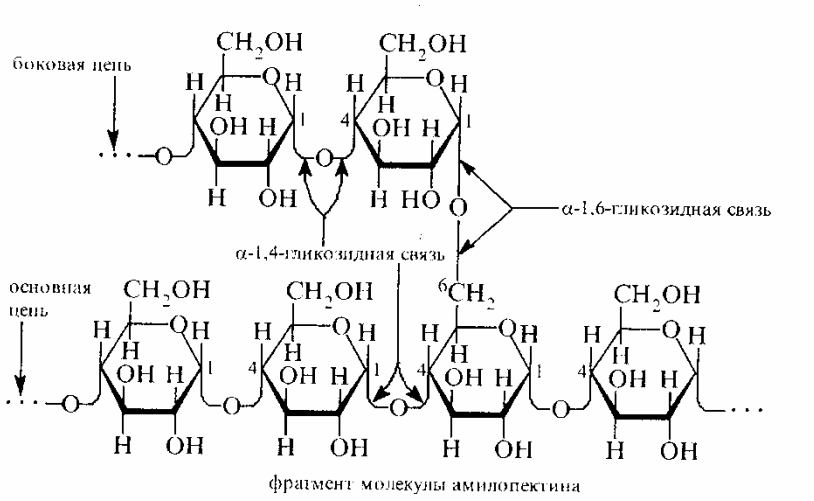


a fragment of the amylose molecule

The molecular weight of amylose is ~ 40,000. Its molecules are flexible and can take different spatial forms. In the presence of complexing agents, for example, iodine, it can exist in the form of a spiral, each turn of which contains six glucose residues. The size of the inner cavity of the spiral allows the placement of an iodine molecule in it, which leads to the formation of a complex colored in blue. Its use in pharmaceutical analysis as an indicator is based on this property of starch.

Amylopectin is a polymer with a branched structure that can contain 1000 or more residuesD-glucose in the molecule. The molecular weight of amylopectin reaches 1 - 6 million. All polysaccharide chains - the main and side chains - are built

in the same way: glucose residues in them are connected by an α-1,4-glycosidic bond. The side branches are connected to the main chain by an α-1,6-glycosidic bond. Between two adjacent branching points, the main chain contains 20-25 monosaccharide residues:



фрагмент молекулы амилопектина

Due to the presence of a large number of branches, the amylopectin molecule is unable to adopt a helix conformation and binds iodine only in small amounts with the formation of a red color.

Starch is the main source of carbohydrates in the human diet. The enzyme amylase, contained in saliva, cleaves the α-Glycosidic bond of starch to dextrins and partially to maltose, the further breakdown of which into glucose occurs in the intestines. In pharmacy, starch is used in the production of tablets, as well as for the preparation of powders and pastes.

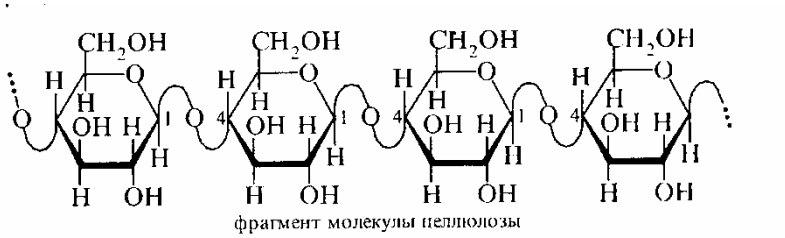
Glycogen (animalstarch). If starch is the reserve polysaccharide in most plants, glycogen performs this function in animal organisms. This polysaccharide supplies the body with glucose during increased physical activity and between meals.

Glycogen is built similarly to amylopectin, but is an even more branched structure. The connection of glucopyranose residues in the main and side chains α-1,4, and in the places of branching - α-1,6. Between the branching points there are 10 - 12, less often - 2 - 4 monosaccharide residues.The molecular weight of glycogen varies and can reach several million. Unlike most other reserve polysaccharides, glycogen is well soluble in water.

The strong branching of glycogen chains contributes to its attack by enzymes from different sides at the same time. This circumstance leads to an extremely high rate of polysaccharide splitting and, therefore, the possibility of almost instantaneous mobilization of energy reserves imprisoned in it.

The liver and muscles are the richest in glycogen.

Cellulose. Cellulose is a polysaccharide widely distributed in nature, which is a component of plant cell membranes. The composition of wood includes from 50 to 70%, and the composition of cotton - up to 98% cellulose. The cellulose molecule is a linear chain consisting of D-glucopyranose residues connected by a β-1,4-glycosidic bond:


фрагмент молекулы целлюлозы

The molecular weight of cellulose ranges from 250,000 to 1,000,000 with a content of at least 1,500 glucose residues.

Cellulose does not dissolve in water and ordinary organic solvents, but dissolves in ammonia solution $Cu(OH)_2$(Schweizer's reagent) and a concentrated solution of zinc chloride.

Cellulose absorbs water vapor, ammonia and aliphatic amines and swells in liquid water and a number of organic solvents, which is accompanied by a change in its structural characteristics while maintaining a fibrous form. It is obvious that the interaction of cellulose with ammonia and amines is accompanied by the replacement of H-bonds OH ⋯ O, which stabilize the original structure of cellulose, with stronger H-bonds of the type OH⋯N.

When heated with mineral acids, cellulose is hydrolyzed according to the scheme:

$$(C6H10O5) \rightarrow n(C6H10O5) \rightarrow C\ x12H22O11 \rightarrow C6H12O6.$$

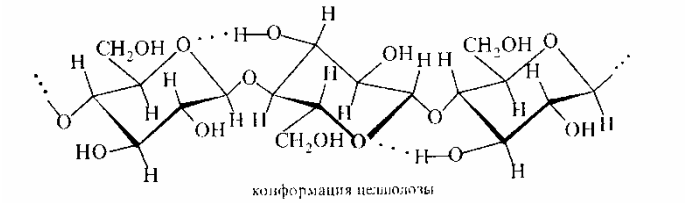
cellulose amyloid cellobiose D-glucose

$$(x < n)$$

The process of cellulose hydrolysis is the basis of the hydrolysis industry. Wood is practically subjected to hydrolysis; the main product of hydrolysis is D-glucose, which is fermented and ethyl alcohol is obtained. Therefore, this process is also called "sugaring of wood." At the same time, other valuable products are formed, for example, nutritional yeast, lignin.

Humans and higher animals do not have an enzyme that hydrolyzes the β-Glycosidic bond of cellulose, but it is a necessary ballast component of food that improves digestion.

The cellulose molecule has a strictly ordered "rigid rod" conformation, in which glucopyranose residues are arranged linearly:


конформация целлюлозы

This arrangement of residues in space is due to the fact that the glycosidic oxygen atom and the O atom at C^4connected to the pyranose cycle equatorially. The linear conformation of the molecule is fixed by intramolecular H-bonds.

The parallel polysaccharide chains are held together by the formation of intermolecular H-bonds. Due to this structure, cellulose is chemically relatively inert (insoluble in water, hardly hydrolyzed) and has high mechanical strength. Cellulose is not broken down by enzymes of the gastrointestinal tract and is therefore not absorbed, but it is a necessary ballast component of food for normal nutrition.

They have important practical significancederivativescellulose The presence of three free OH groups in each glucoside residue of cellulose makes it possible to obtain its complex esters and the so-called alkaline (mercerized) cellulose.

The interaction of cellulose with solutions of NaOH alkali (mercerization) leads to alkaline cellulose, which has the structure of an alcoholate or a molecular complex:

$$[C6H7O2(OH)3]n + nNaOH \rightarrow [C6H7O2(OH)2OHa]n + nH2O,$$

$$[C6H7O2(OH)3]n + nNaOH \rightarrow [C6H7O2(OH)3 \cdot NaOH]n.$$

Most likely, the ionic (alcoholic) form of alkaline cellulose is in equilibrium with the molecular form. The mercerization process is widely used in the isolation of cellulose from various plant materials, as well as as an intermediate stage in the synthesis of cellulose ethers and xanthogenates, in the formation of viscous solutions and the formation of artificial fibers and hydrated cellulose films from them, in the mercerization of textile materials.

When cellulose is treated with a mixture of nitric and sulfuric acids, cellulose nitrates are formed, the properties and application possibilities of which depend on the degree of nitration:

$$[C_6H_7O_2(OH)_3]_n \xrightarrow{+HNO_3\,(H_2SO_4)} [C_6H_7O_2(OH)_2ONO_2]_n.$$

A mixture of mono- and dinitrate is called collodion or koloxylun cotton wool. It is used to make collodion, which is used in medicine to fix bandages. The product of complete nitration of cellulose (cellulose trinitrate, trinitrocellulose, pyroxylin $[C_6H_7O_2(ONO_2)_3]_n$) is an explosive used in the production of smokeless powder. Smokeless powders are obtained by gelatinizing pyroxylin with the addition of up to 30% nitroglycerin in the presence of a stabilizer, such as diphenylamine.

Acetic acid esters of cellulose - acetyl cellulose - are obtained in technology by the interaction of cellulose with acetic anhydride in the presence of acetic and sulfuric acids:

$$[C_6H_7O_2(OH)_3]_n \xrightarrow{+(CH_3CO)_2O} [C_6H_7O_2(OCOCN_3)_3]_n.$$

triacetyl cellulose

When heated with acids, triacetyl cellulose is partially hydrolyzed to form a mixture of triacetyl cellulose and diacetyl cellulose, which is used for the manufacture of acetate silk and plastics.

When carbon disulfide acts on alkaline cellulose, the sodium salt of the ether of xanthogenic acid is formed - cellulose xanthogenate:

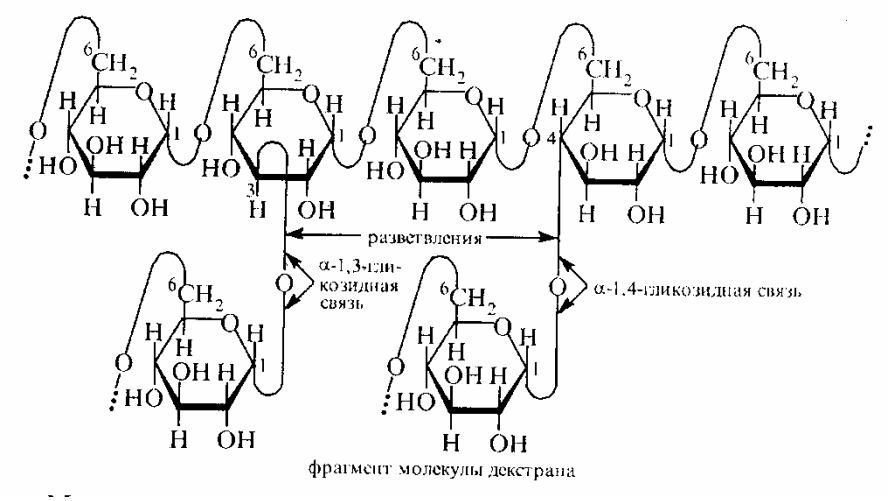
$$[C_6H_7O_2(OH)_2ONa]_n \xrightarrow{+CS_2} [C_6H_7O_2(OH)_2OC(S)SNa]_n.$$

Cellulose xanthogenate has the ability to dissolve in alkalis; such a solution is called viscose. Acids decompose viscose to form regenerated cellulose.

When viscose is pressed into acid through filters, strands of fiber called viscose fiber or viscose silk are formed. Although this fiber is chemically cellulose, it has greater strength and heat resistance compared to the original cellulose, which is explained by the parallel orientation of molecules during the formation and drawing of the fiber during its formation.

Viscose fiber is quite common among chemical fibers mainly due to its cheapness. If viscose is pressed into acid through thin slits, cellophane is formed - a cheap packaging material.

Dextrins. Dextrins are polysaccharides of bacterial origin, built from D-α-glucopyranose residues. They are obtained from sucrose with the participation of Leuconostocmesenteroides bacteria. The main type of bond in dextrins is an α-1,6-glycosidic bond, and at the branching points - α-1,4- and α-1,3-glycosidic bonds :

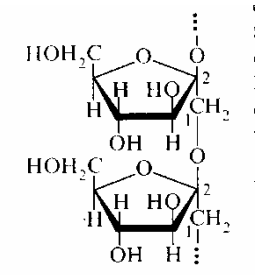


фрагмент молекулы декстрана

The molecular weight of dextrins is several million. Partially hydrolyzed dextrins M = (40000 - 800000) are used in pharmacy in the production of plasma substitutes***"polyglucin"and "rheopolyglukin".***

Inulin. Insulin is a reserve polysaccharide contained in the tubers of complex flowers and other plants. The inulin molecule has a linear structure and consists of D-β-fructofuranose residues connected by 2,1-glycosidic bonds, and ends with a D-α-glucopyranose residue (as in sucrose). M is usually no more than 6,000.

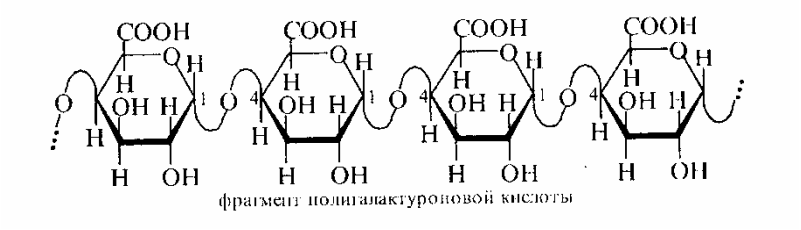
Inulin is obtained from dahlia tubers by hot water extraction. Used to receiveD-fructose.



PectinsubstancesPectin substances (pectins) include polysaccharides whose structure is based on polygalacturonic acid (pectic acid), built from D-α-galacturonic

acid residues linked by 1,4-glycosidic bonds. Part of the carboxyl groups of polygalacturonic acid is esterified and is in the form of methyl ether.

Aqueous solutions of pectins are able to form strong gels.



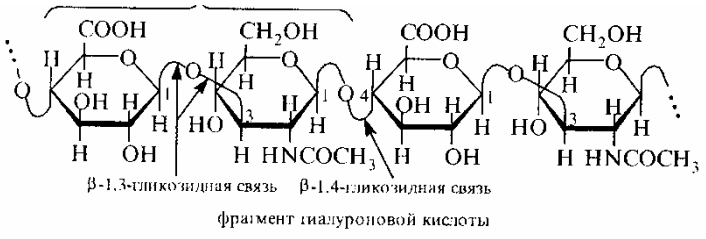
Pectins are found in almost all land plants and some algae. They are widely used in the food industry for the production of jellies and marmalades, so they form jellies with sucrose in the presence of organic acids.

Some pectin substances have an anti-ulcer effect and are the basis of a number of medicines.

Heteropolysaccharides

*Heteropolysaccharides include polysaccharides consisting of residues of various monosaccharides.*Such polysaccharides include polysaccharides of connective tissue - hyaluronic acid, chondroitin sulfate, heparin. All of them have a linear carbon chain and a disaccharide fragment called a repeat link is regularly repeated throughout the chain.

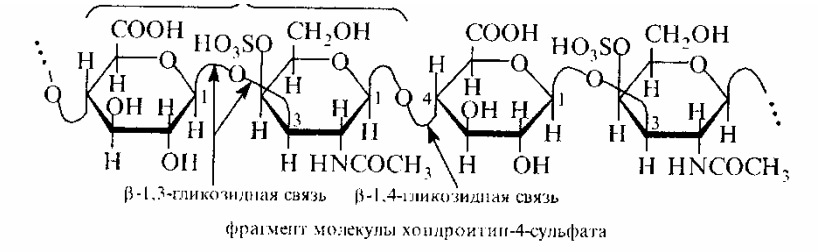
Hyaluronic acid. ISone of the most common polysaccharides of connective tissue, found in cartilage, umbilical cord, joint (synovial fluid), vitreous body. The repeating link of hyaluronic acid is D-glucuronic acid and N-acetylD-glucosamine, connected by a β-1,3-glycosidic bond. The relationship between disaccharide fragments - β-1,4:



The molecular weight of hyaluronic acid varies from 1600 to 6400. This polysaccharide has high viscosity, which ensures the impermeability of connective tissue to bacteria.

In tissues, hyaluronic acid is complexed with protein due to H-bonds.

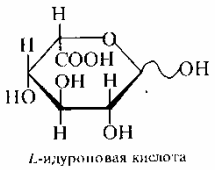
Chondroitin sulfate -one of the main components of cartilage. They are also found in the skin, tendons, sclera, and bones. The repeating link of chondroitin sulfates is D-glucuronic acid and N-acetylD-galactosamine, which contains a sulfate group. Inside the disaccharide fragment is a β-1,3 bond, and between the fragments - β-1,4. The sulfate group forms an ether bond with the OH group of N-acetylD-galactosamine either in position 4 (chondroitin-4-sulfate) or in position 6 (chondroitin-6-sulfate).



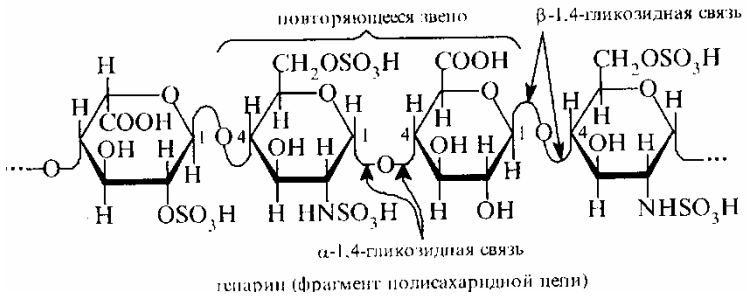
фрагмент молекулы хондроитин-4-сульфата

Carbohydrate chains of chondroitin sulfates contain up to 150 disaccharide residues, attached in the body by O-glycosidic bonds to OH-groups of amino acid residues, which are part of the protein part of the molecule, has not yet been sufficiently studied.

Heparin. It is produced in the body of humans and animals, it is contained in large quantities in the liver and lungs; in smaller ones - in skeletal muscles, spleen, heart muscle. The periodic link in the structure of heparin consists of D-glucosamine and uronic acid connected by α-1,4-glycosidic bonds. L-induronic acid and, less often, D-glucuronic acid act as uronic acids:


L-идуроновая кислота

Remains of glucosamine andL-induronic acid in heparin is partially sulfonated. The molecular weight of heparinM = 16,000 - 20,000. As with hyaluronic acid and chondroitin sulfates, the carbon chains of heparin are connected in tissues with the protein part of the molecule.



гепарин (фрагмент полисахаридной цепи)

Heparin prevents blood clotting, participates in the exchange of lipids, fats and cholesterol. It is used in medicine as an anticoagulant.

VegetablegumIt is a branched heteropolysaccharide containing residues of neutral monosaccharides (DD-galactose, L-glucose, L-rhamnose, arabinose, etc.) and uronic acids in the form of salts. Gums are released when plants are damaged in the form of viscous liquids.

Arabic gum (gum arabic) includes the remains of carbohydratesLD-arabinose,-galactose, methylpentose and D-glucuronic acid; is used in medicine as an emulsifier in the production of emulsions.

General material and bulk-methodological support of the lecture:

- Working program of the academic discipline
- Syllabus of the academic discipline
- Textbooks:
- Multimedia presentations
- Situational tasks
- Methodical development of practical classes
- Electronic bank of test tasks by subdivisions of the discipline.

Questions for self-control

1.Classification, production methods, properties, reactivity, structure and nomenclature (aldo-, ketopentoses and hexoses). Stereoisomerism. D- and L-. Stereochemical series.

2. Disaccharides. Renewable and non-renewable disaccharides: maltose, cellobiose, lactose, sucrose. Structure, nomenclature, chemical properties.

3. Polysaccharides. Homopolysaccharides: starch (amylose, amylopectin), glycogen, cellulose, dextrans, inulin. Spatial structure of amylose and cellulose. Complex and simple esters of polysaccharides.

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