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INTRAMOLECULAR INTERACTIONS IN SERIES OF OXAZOLE, OXADIAZOLE, AND TRIAZOLE DERIVATIVES

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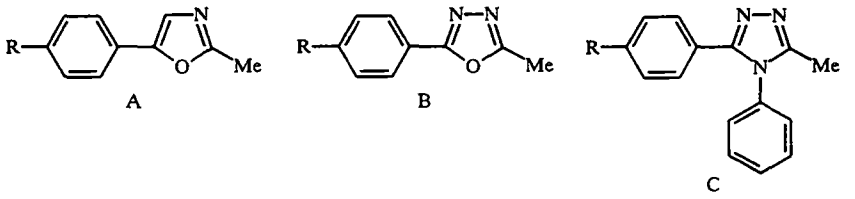
A comparison of the PMR spectra of 5-phenyl-2-methyl derivatives of oxazole, 1,3,4-oxadiazole, and 1,3,4-triazole with the spectrum of toluene leads to the conclusion that the electron-acceptor character of the heterocycles drops off in the order oxadiazole > oxazole > triazole. The conduction of electronic effects of the substituents by the oxazole ring is at the level of benzene; the 1,3,4-oxadiazole ring accomplishes the transmission somewhat better, and the 1,3,4-triazole ring more weakly, than in the case of benzene. The formation of H-complexes with a 1:1 composition in a system consisting of the azole, phenol, and carbon tetrachloride was investigated by means of IR spectroscopy. The relative n-donor strength of the heterocycles decreases in the series triazole > oxazole > oxadiazole. The effectiveness of transmission of electronic influence of the substituents in the phenyl radical on the pyridine nitrogen atom, which is the center of complexation, decreases in the series oxazole > oxadiazole > triazole.

One of the critical needs in the development of organic liquid dye lasers is a substantial improvement of the coherent radiation parameters in the violet and ultraviolet regions.

Structural-chemical modeling of the luminophores that are the most effective for this region, aimed at discovering new molecules with improved parameters, requires a knowledge of the relationships involved in the intramolecular electronic interactions in the base molecules. In this connection, the present work was aimed at investigating intramolecular interactions of fragments in molecules of derivatives of oxazole (A), 1,3,4-oxadiazole (B), and 1,3,4-triazole (C):



For these comparisons we used the chemical shifts of the protons of the compounds (Tables 1 and 3) and the shift of stretching vibration frequency for the hydroxyl group of phenol, which forms a hydrogen bond with nitrogen atoms (in the state of sp^2 hybridization) of the heterocycles (Table 2).

Results from measurements of the chemical shifts of protons of the methyl and phenyl groups are presented in Table 1. In 1,5-diphenyl-2-methyltriazole, the ortho protons of the phenyl are shielded less than the meta protons by 0.12 ppm. In 2-methyl-5-phenyloxazole, this difference amounts to 0.24 ppm, and in 2-methyl-5-phenyloxadiazole it amounts to 0.52 ppm; here, the signal of the ortho protons is observed at 8.03 ppm, that of the meta protons at 7.5 ppm. Such a position of the signals of the aromatic protons reflects the electron-acceptor nature of the heterocycle, owing to which the shielding of the protons closest to the heterocycle is reduced. The acceptor influence of the heterocycles on the benzene ring increases in the order triazole < oxazole < oxadiazole.

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TABLE 1. Chemical Shifts of Protons in PMR Spectra of Compounds, δ, ppm

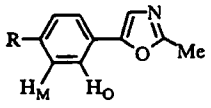
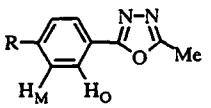
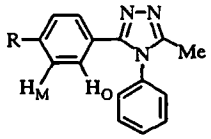
R	 A			 B			 C		
	H_{CH3}	H_o	H_M	H_{CH3}	H_o	H_M	H_{CH3}	H_o	H_M
NO_2	2,575	7,75	8,27	2,673	8,21	8,36	2,372	7,60	8,13
Cl	2,542	7,51	7,34				2,353	7,43	7,33
Br				2,637	7,88	7,61			
H	2,524	7,60	7,36	2,625	8,03	7,51	2,347	7,48	7,36
Me							2,340	7,31	7,11
OMe	2,509	7,54	6,93	2,606	7,93	6,96	2,330	7,35	6,78
NMe_2	2,488	7,48	6,73	2,572	7,84	6,70			

TABLE 2. Values of $\Delta\nu_{O-H}$ for Complexes of Azoles with Phenol

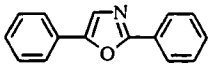
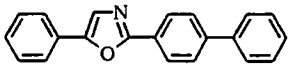
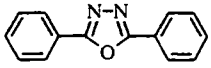
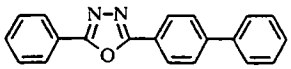
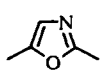
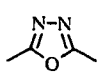
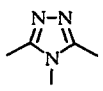
R	$\Delta\nu C-H$, cm^{-1}			Compound	$\Delta\nu O-H$, cm^{-1}
	A	B	C		
NO_2	375	307	430		410
Cl	410	320	445		
H	424	340	451		405
Ph	421	339	458		
Me			456		
OMe	435	354	461		325
NMe_2	462	375			
					311

TABLE 3. Results from Correlation Analysis of Spectral Quantities δ_{CH3} and $\Delta\nu_{O-H}$ with δ-Constants of Substituents

Index			
ρ	0,053	0,061	0,040
r	0,973	0,997	0,990
π'	0,25	0,29	0,18
m	-54	-44	-29
t	0,994	0,98	0,97

In order to elucidate the question of interaction of the heterocycles and the methyl group, let us compare the chemical shifts of the methyl group in these compounds with the chemical shifts for toluene (δ_{CH3} 2.33 ppm). As can be seen from Table 1, the signals of the methyl-group protons are shifted downfield by 0.02-0.259 ppm in comparison with signals for the model compound; in the case of the 1,3,4-oxadiazole, this is manifested to a significant degree. The heterocycles, in terms of their deshielding effect on the methyl-group protons, are ranked in an order analogous to that for the influence on the phenyl (C < A < B). It is evident that such deshielding of protons proceeds as a consequence of the influence of the pyridine nitrogen atom (A < B) and also the influence of the type of heteroatom in position 1 of the heterocycle. This effect is predominant (B >> C).

Now examining the electronic interaction of these heterocycles with the methyl group, the protons of which are located closer to the heterocycle in comparison with the protons of the benzene ring, we should consider that the shielding of the CH_3 group may be definitely affected by the ring current, shifting the signals of the protons located in the plane of the heterocycle, also giving a downfield shift. However, since the aromaticity of the rings decreases in the indicated series, then, if the influence of ring currents on shielding of the methyl group were primary, the heterocycles would be ranked in the reverse order. Consequently, the downfield shift of the methyl signal indicates an electron-acceptor influence of the heterocycles in comparison with the benzene ring. Obviously, deshielding of the protons proceeds mainly at the expense of the induction effect of the heteroatoms, and hence the observed ranking of the heterocycles can be explained from the standpoint of an increase of the acceptor influence of the heterocycles in this series.

It was of interest to evaluate the transmission of electronic effects of the substituents through the heterocycle to the CH_3 group, by using its chemical shifts as an indicator of the change of electron density on carbon atoms of the heterocycles connected to the methyl group. To this end, the chemical shifts of the CH_3 group were compared with the σ-constants of the substituents in accordance with the equation $\delta = \rho\sigma + \delta_0$. In all of the series, we observe an increase of the shielding of the methyl-group protons with increasing electron-donor strength of the substituents. In Table 3 we present results from correlation analysis for these compounds. A comparison of values obtained for the slope (ρ) with the values for toluene (ρ = 0.213) [1] enabled us to evaluate the transmission factor of these heterocycles, as listed in Table 3. It should be noted that the conduction of electronic effects of the substituents by the oxazole ring is approximately at the level of that of the benzene ring (π' = 0.26) [2]. The oxadiazole transmits the influence of the substituents somewhat better, while the triazole is poorer in this respect. This behavior of the triazole may be related to a greater disruption of planarity of the triazoles that were investigated, in comparison with the oxazoles and oxadiazoles, as a result of repulsion of the benzene rings located alongside.

It was also of interest to estimate the relative n-donor strength of the compounds, to track the influence of substituents in the phenyl radical on this donor strength, and to explain the efficiency of transmission of substituent influence on the pyridine nitrogen atom of the heterocycles. This would make it possible to evaluate the intramolecular interactions in these systems.

It is known from the literature that azoles, like other nitrogen-containing heterocyclic bases, are capable of forming n- and π-type complexes, with their n-donor properties predominating [3-7]. In the course of investigating various azoles [4-6], it was established that the center of H-complexation is the pyridine nitrogen atom. This conclusion is further supported by the results of quantum-chemical calculations of azoles using the index Φ_D [8-9]. For the substituted oxadiazoles and triazoles, there are two possible donor centers of this type. In the works cited, it was shown for derivatives of 1,2,4-triazole that the center of basicity is the pyridine nitrogen atom in position four of the heterocycle.

In order to resolve this question, we brought in results obtained by IR spectroscopy. In order to reduce the probability of forming complexes with a 1:2 composition [10], we used a weak proton-donor, namely phenol; the measurements were performed under conditions of excess base. To evaluate the relative n-donor strength of the azoles, we measured frequency shifts for stretching vibrations of the hydroxyl group of phenol $\Delta\nu OH = \nu OH^{free} - \nu OH^{comp}$ upon formation of H-complexes. Under the particular conditions of experiment (system consisting of the azole, phenol, and carbon tetrachloride), all of the IR spectra exhibit a single broad absorption band, both for the oxazoles and for the oxadiazoles and triazoles, suggesting that complexes with a 1:1 composition are formed in all cases. This conclusion also follows from the similar values of half-width of the absorption bands, averaging 327 cm^{-1} in all cases, corresponding to the complex O-H···N≡.

From a comparative analysis of our data, we can conclude that the relative n-donor strength of the heterocycles decreases in the series triazole > oxazole > oxadiazole. Also, replacement of the N_1 atom by O_1 in the heterocycle leads to a substantial reduction of n-donor strength (triazole > oxadiazole); an analogous relationship is manifested upon introduction of a second pyridine nitrogen atom (oxazole > oxadiazole). Thus, the same is indicated by the PMR data, the heteroatom in position 1 plays the decisive role. The observed changes in n-donor strength of these heterocycles fit completely into the previously known analogous relationships (imidazole > oxazole; imidazole > 1,2,4-triazole) [4, 9, 11]. From a comparison of results obtained by IR and PMR spectroscopy, we can conclude that in the series of heterocycles we have investigated, their n-donor strength increases with increasing electron-donor character of the heterocycle (as observed on the basis of PMR data). Since the n-donor strength in our similarly constructed systems is determined mainly by their electronic structure, the symbaticity in changes of properties enables us to conclude that the electronic nature of the heterocycle is the predominant factor determining the magnitude of δ_{CH3}.

As described in [4-7, 9, 11], benzannelation results in weakening of the n-donor properties of the heterocycle and a decrease of basicity. In this connection, it was of interest to track the effects on these properties due to increasing the extent of the π-system of the molecule. To this end, we investigated 2,5-diphenyl- and 2-phenyl-5-biphenyl-substituted oxazole and oxadiazole. These data are presented in Table 2. A decrease of the values of $\Delta\nu_{OH}$ is noted as benzene rings are accumulated, indicating a weakening of the n-donor properties of the heterocycles.

From the standpoint of investigating intramolecular electronic interactions, it was of interest to determine the efficiency of transmission of the electronic influence of substituents in the 5-phenyl radical on the pyridine nitrogen atom of the heterocycle. With this aim, we carried out a correlation analysis of the results, indicating good correlation (r from 0.97 to 0.99) of values of $\Delta\nu_{OH}$ with Hammett δ-constants, in accordance with the equation $\Delta\nu_{OH}{}^{R} = m\delta + \Delta\nu_{OH}{}^{H}$. The reaction constants m obtained by this analysis are listed in Table 3. Here we observe a drop of conduction in the series oxazole > oxadiazole > triazole. The sharp drop that is observed upon transition from oxygen-containing to nitrogen-containing series is probably related to the greater degree of aplanarity of the triazole derivatives.

EXPERIMENTAL

PMR spectra were recorded on a Tesla B-487B spectrometer (80 MHz) in deuterochloroform, internal standard TMS. IR spectra were measured in a Specord IR-75 spectrophotometer in a ternary system consisting of the base, phenol, and carbon tetrachloride. The individuality of the compounds that were obtained was monitored by means of TLC on Silufol UV-254 plates in benzene (development in UV light).

Elemental analyses of the synthesized compounds for C, H, and N matched the calculated values.

The synthesis, purification, and spectral characteristics of functionally substituted 2-methyl-5-phenyl-1,3,4-oxadiazoles have been described in [12]. The substituted 1,3,4-triazoles were obtained by a procedure given in [13].

General Method for Obtaining Functionally Substituted 2-Methyl-5-phenyl Oxazoles. A solution of 0.01 mole of the appropriate hydrochloride of an α-aminoaryl methyl ketone is refluxed with a fivefold excess (by weight) of acetic anhydride, after which the reaction mixture is poured into water and neutralized with a 10% sodium carbonate solution; the precipitate is filtered off and washed to neutral reaction. The product is purified chromatographically on aluminum oxide (heptane eluent). Yield 60%. The melting points of the synthesized compounds are consistent with the literature data [14, 15].

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