SYNTHESIS, ELECTRONIC STRUCTURE, AND PHYSICOCHEMICAL CHARACTERISTICS OF PYRAZOLO[1,2-*a*]PYRIDAZINIUM

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The interaction of 1-methallylpyrazoles with acetic or propionic anhydride in the presence of perchloric acid forms products of acylation at the double bond and subsequent heterocyclization – pyrazolo[1,2-a]pyridazinium salts – that are representatives of a new heteroaromatic system. Analogous cyclization is observed in the acylation of 3-(2-hydroxy-2-methylpropyl-pyrazole.

In an attempt at the synthesis of pyrazolylmethylpyrylium salts IV by bis-acylation of the methallylpyrazoles Ib, c by anhydrides of carboxylic acids in the presence of perchloric acid, the first representatives of a new heteroaromatic system were obtained: pyrazolo[1,2-*a*]pyridazinium salts IXc-e [1, 2].

In the present work, in studying the relationships governing the formation of pyrazolo[1,2-*a*]pyridazinium salts, the series of these salts was extended; also, a quantum-chemical calculation of the new system was performed in order to compare these calculated data with experimental results, in particular with the phenomenal resistance of the salts IX to the action of bases.

The optimal conditions for the formation of the salts IX are achieved by 12-h holding at room temperature, with a reaction mixture obtained by the addition of 2 equivalents of perchloric acid to a solution of 1 equivalent of the methallylpyrazole I in an excess of the carboxylic acid anhydride. Extending the reaction time does not give any appreciable increase in the yield of compounds IX, and the products become more contaminated with tar. When the reaction temperature is increased to 60°C with the aim of accelerating the reaction, the yield of salts IX drops to 5%, and a large quantity of tarry resin is formed. At 100°C, the reaction mixture is completely resinified.

The reaction proceeds through addition of the acylium cation to the compound I to form the carbocation II; the deprotonation of II may proceed in different directions, and it may lead to the synthesis of unsaturated ketones VI. Upon subsequent protonation of the carbonyl group, the hydroxycarbocations VIIa, b are formed; these are cyclized to the bicyclic cations VIII, which are then aromatized with the splitting out of water, to obtain the pyrazolo[1,2-*a*]pyridazinium IX. Also possible is the formation of structures VIIc. This reaction is analogous to syntheses of pyrylium salts by bis-acylation of olefins [3] and the monoacylation of aromatic ketones [4], with the weakly basic nitrogen atom in this case acting as an analog of the carbonyl oxygen.

It is interesting that, upon acylation of 1-methallyl-3-tert-butylpyrazole Id by acetic anhydride in the presence of perchloric acid, instead of the expected pyrazolo[1,2-*a*]pyridazinium, along with the product of splitting of the original Id – 1-acetyl-3-tert-butylpyrazole perchlorate – we find small amounts of 2,6-dimethyl-4-(3-tert-butylpyrazolyl-1-methyl)pyrylium perchlorate IV. The bulky tert-butyl substituent in position 3 of the pyrazole ring in this case apparently prevents heterocyclization to pyrazolo[1,2-*a*]pyridazinium, and this leads to the result of ordinary bis-acylation of olefins (see scheme on following page).

The structure of the salts IX was confirmed by ^{1}H NMR spectroscopic data (Table 1). In the IR spectra of the compounds that are described, the vibrations of the stretching bonds of the heterocyclic system are manifested as low-intensity bands at 1655 and 1560 cm^{-1}.

The pyrazolo[1,2-*a*]pyridazinium salts IX are distinguished by unusual stability; they do not react with caustic or with alkali metal alcoholates. The alkyl substituents in these salts do not enter into reactions of condensation with aldehydes.

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TABLE 1. Characteristics of Compounds I, IV, V, IX, XI, and XII

Compound	Empirical formula	T_b, °C (mm Hg) [T_m, °C]	IR spectrum, cm^{-1}	^1H NMR spectrum, δ, ppm (I, Hz)	Yield, %
Ia	$C_7H_{10}N_2$	75(25)		1,48 (3H, s, CH_3); 4,25 (2H, s, NCH_2); 4,47 (2H, d, CH_2); 5,92 (1H, t, J=2,0 Hz, 4-H); 7,15 (2H, t, J=2,0 Hz, 3-H and 5-H)	85
Ib*	$C_8H_{12}N_2$	77 ... 90(23)		1,58 (3H, s, CH_3—C=); 2,18 (3H, s, 3-CH_3); 4,48 (2H, s, NCH_2); 4,65 (2H, d, =CH_2); 5,95 (2H, d, J=2,0 Hz, 4-H); 7,22 (1H, d, J=2,0 Hz, 5-H)	83
Ic**	$C_9H_{14}N_2$	100(20)	2985, 2930, 1675 (C=C), 1565 (C=N), 1465, 1430, 1390, 910, 785	1,51 (3H, s, CH_3—C=); 2,0 (2H, s, 5-CH_3); 2,05 (3H, s, 3-CH_3); 4,42 (2H, s, NCH_2); 4,58 (2H, d, =CH_2); 5,73 (1H, s, 4-H)	89
Id	$C_{11}H_{18}N_2$	75(1)		1,25 [9H, s, —$C(CH_3)_3$]; 1,50 (3H, s, CH_3—C=); 4,45 (2H, s, NCH_2); 4,67 (2H, d, =CH_2); 6,10 (1H, d, J=2,0 Hz, 4-H); 7,17 (1H, d, J=2,0 Hz, 5-H)	75
IV	$C_{15}H_{21}N_2ClO_5$	[173 ... 174]	1640 (pyrylium), 1536 (C=N), 1290, 1245, 1100 (ClO_4), 805, 615	1,45 [9H, s, $C(CH_3)_3$]; 2,94 (6H, s, $2CH_3$); 6,17 (2H, s, CH_2); 7,17 (1H, d, J=3,0 Hz, 4-H pyrazoles); 7,63 (2H, s, 3-H and 5-H pyrylium); 8,40 (1H, d J=3,0 Hz, 5-H pyrazole)	6
V	$C_{15}H_{21}N_3$	[86 ... 87]	3400, 2955, 2910, 1605, 1510, 1450, 1430, 1240, 835, 770	1,15 [9H, s, $C(CH_3)_3$]; 2,33 (6H, s, 2-CH_3); 5,03 (2H, s, CH_2); 6,0 (1H, d, J=2,0 Hz, 4-H pyrazole); 6,58 (2H, s, 3-H and 5-H pyridine); 7,11 (1H, d, J=2,0 Hz, 5-H pyrazoles);	58
IXa	$C_9H_{11}ClN_2O_4$	[172 ... 173]	3130, 3070, 1635, 1525, 1100 (ClO_4^-), 765	2,35 (3H, s, 7-CH_3); 2,70 (3H, s, 5-CH_3); 6,45 (1H, s, 6-H); 7,35 (1H, t, J=3,5 Hz, 2-H); 8,16 (1H, s, 8-H); 8,3 (1H, d, J=3,5 Hz, 1-H); 8,43 (1H, d, J=3,5 Hz, 3-H)	28
IXb	$C_{10}H_{13}ClN_2O_4$	[247 ... 248]	3120, 3080, 1445, 1100 (ClO_4^-), 765, 620	1,51 (3H, t, J=8,0, CH_3CH_2); 2,38 (3H, s, 7-CH_3); 3,0 (2H, q, J=8 Hz, CH_3CH_2); 6,77 (1H, s, 6-H); 7,33 (1H, t, J=3,0 Hz, 2-H); 8,18 (1H, s, H-8); 8,37 ... 8,68 (2H, m, 1-H and 3-H)	25
IXc	$C_{10}H_{13}ClN_2O_4$	[146 ... 147]	3135, 3120, 3075, 1670, 1585, 1520, 1490, 1450, 1390, 1250, 1100 (ClO_4^-), 840, 805, 620	2,23 (3H, s, 7-CH_3); 2,92 (3H, s, 3-CH_3); 3,02 (3H, s, 5-CH_3); 6,43 (1H, s, 6-H); 6,97 (1H, d, J=3,0 Hz, 2-H); 7,9 (1H, s, 8-H); 8,2 (1H, d, J=3,0 Hz, 1-H)	33***

IXd	$C_{11}H_{15}ClN_2O_4$	[175 ... 176]	1670, 1560, 1100 (ClO_4^-)	2,30 (3H, s, 7-CH_3); 2,68 (3H, s, 1-CH_3); 2,90 (3H, s, 3-CH_3); 3,0 (3H, s, 5-CH_3); 6,53 (1H, s, 6-H); 6,90 (1H, s, 2-H); 7,76 (1H, s, 8-H)	32
IXc	$C_{12}H_{17}ClN_2O_4$	[171 ... 172]		1,30 (3H, t, J=8,0 Hz, CH_3CH_2); 2,30 (3H, s, 7-CH_3); 2,68 (3H, s, 1-CH_3); 2,90 (3H, s, 3-CH_3); 3,30 (2H, q, J=8,0 Hz, CH_3, CH_2), 6,53 (1H, s, 6-H); 6,90 (1H, s, 2-H); 7,76 (1H, s, 8-H)	23
XIa	$C_9H_{11}ClN_2O_4$	[208 ... 209]		2,54 (3H, s, 5-CH_3); 2,85 (3H, s, 7-CH_3); 6,99 (1H, d, J=3,5 Hz, 3-H); 7,24 (1H, s, 6-H); 7,72 (1H, s, 4-H); 8,28 (1H, d, J=3,5 Hz, 2-H)	24
XIb	$C_{10}H_{13}ClN_2O_4$	[176 ... 180] (dec.)]		1,10 (3H, t, J=7,0 Hz, CH_3CH_2); 2,15 (3H, s, 5-CH_3); 2,74 (2H, q, J=7,0 Hz, CH_3CH_2); 6,55 (1H, d, J=3,0 Hz, 3-H); 6,79 (1H, s, 6-H); 7,26 (1H, s, 4-H); 7,8 (1H, d, J=3,0 Hz, 2-H)	5
XIIa**	$C_9H_{10}N_2$	82(2)	2950, 2920, 1650, 1550, 1525, 1453, 1385, 1345, 1315, 1220, 1200, 1050, 920, 864, 830, 765, 728, 650, 470	1,90 (3H, s, 5-CH_3); 2,45 (3H, s, 7-CH_3); 5,92 (1H, s, 6-H); 6,26 (1H, d, J=3,0 Hz, 3-H); 6,81 (1H, s, 4-H); 7,95 (1H, d, J=3,0 Hz, 2H)	95
XIIb	$C_{10}H_{12}N_2$	85(2)		1,13 (3H, t, J=7,0 Hz, CH_3CH_2); 1,91 (3H, s, 5-CH_3); 2,91 (2H, q, J=7,0 Hz, CH_3CH_2); 5,95 (1H, s, 6-H); 6,16 (1H, d, J=2,0 Hz, 3-H); 6,78 (1H, s, 4-H); 7,85 (1H, d, J=2,0 Hz, 2-H)	93

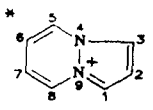
*Compound Ib contains 30% admixture of the isomer 1-methallyl-5-methylpyrazole. Yields listed are for mixture of isomers. In ^{1}H NMR spectrum, owing to the admixture of the isomer, a weak peak of 5-CH_3 is present, δ 2.15 ppm.

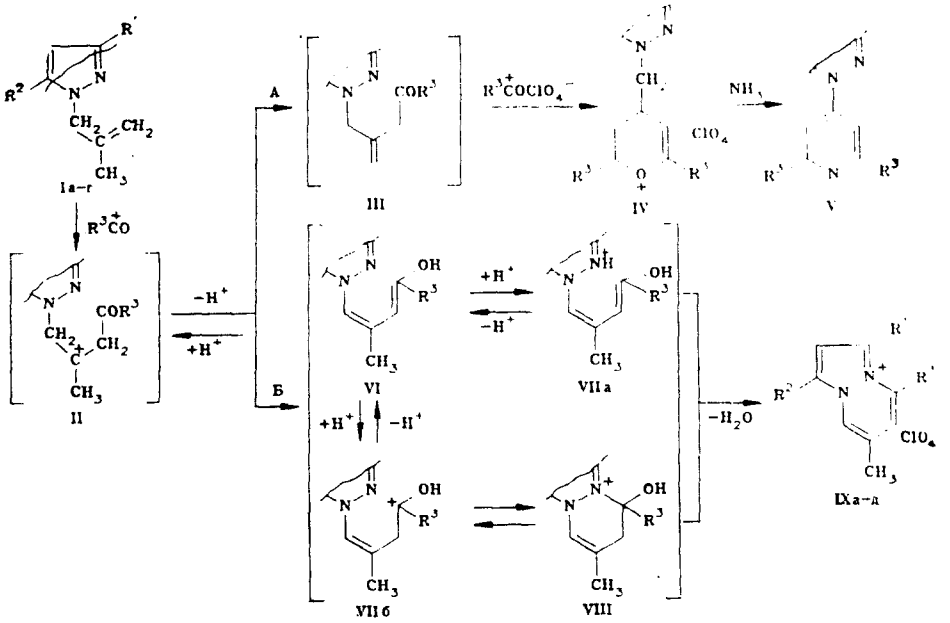
**IR spectrum was taken in a thin layer.

***Yield of salt IXc is calculated on 1,3-isomer of Ib.

TABLE 2. Residual π-Electron Charges P_{kk}, Bond Orders P_{ik}, and Atom–Atom and Atom–Bond Self- and Manual Polarizabilities $\pi_{j,ik}$ (eV^{-1}) of Pyrazolo[1,2-*a*]pyridazinium

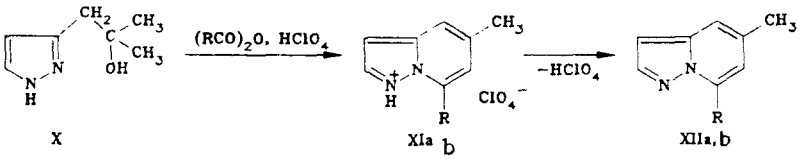
i–*k*	P_{ik}	$\pi_{1,ik}$	$\pi_{2,ik}$	$\pi_{5,ik}$*	$\pi_{6,ik}$
1—1	0,1084	−0,1273			
2—2	−0,0580	+0,0525	−0,1153		
3—3	0,1084	−0,0031	+0,0525		
4—4	0,3801	+0,0168	+0,0023		
5—5	0,0076	+0,0058	+0,0007	−0,1419	
6—6	0,0330	+0,0096	+0,0021	+0,0794	−0,1202
7—7	0,0330	+0,0069	+0,0021	−0,0066	+0,0272
8—8	0,0076	−0,0161	+0,0007	+0,0389	−0,0066
9—9	0,3801	+0,0227	+0,0023	−0,0022	+0,0034
1—2	0,6789	−0,0146	−0,0093	0,0093	0,0075
2—3	0,6789	0,0179	−0,0107	−0,0107	−0,0073
3—4	0,5522	−0,0129	0,0144	0,0179	−0,0064
4—5	0,3710	0,0147	−0,0048	−0,0199	−0,0016
5—6	0,8022	−0,0145	0,0034	0,0068	−0,0028
6—7	0,5148	0,0135	−0,0040	−0,0085	0,0008
7—8	0,8022	−0,0117	0,0034	0,0064	0,0056
8—9	0,3710	0,0245	−0,0048	0,0002	0,0096
4—9	0,2222	0,0197	−0,0041	0,0003	−0,0029
1—5	0,1546	0,0135	0,0083	0,0046	0,0027
1—9	0,5522	0,0060	0,0144	−0,0040	0,0076

* 



Ia, IXa,b $R^1=H$, $R^2=H$; Ib IXc $R^1=CH_3$, $R^2=H$; Ic, IXd,e $R^1=CH_3$, $R^2=CH_3$; Id, IV V $R^1=C(CH_3)_3$, $R^2=H$; IV, V, IXa,c,d $R^3=CH_3$; IXb,e $R^3=C_2H_5$

The fact of formation of pyrazolo[1,2-*a*]pyridazinium salts upon acylation of 1-methylallylpyrazoles I suggests that analogous heterocyclization is possible in the case of 3-methallylpyrazole. In fact, from 3-(2-hydroxy-2-methylpropyl)pyrazole (X), used as a predecessor of the 3-methallylpyrazole, under the conditions for acylation of the 1-methallylpyrazoles I, what are actually formed are perchlorates of pyrazolo[1,5-*a*]pyridines ÙÈ in mixture with the product of dehydration – 3-isobutenylpyrazole. By treatment of the perchlorates XI with aqueous caustic or a sodium carbonate solution, the free bases XII were obtained.



X XIa b XIIa,b

XI, XII a $R=CH_3$; b $R=C_2H_5$

The original pyrazole X was synthesized by the interaction of hydrazine hydrate with 2,2-dimethyl-2,3-dihydropyranone-4, obtained in turn from 2-methyl-6-butoxyhexen-5-yn-3-ol-2 [5].

It was found that, in order to accomplish the heterocyclization that has been described, catalysis by a strong protic acid is necessary, specifically perchloric acid. In the presence of sulfuric acid, methanesulfonic acid, or boron fluoride, the acylation does not take place; from the reaction mixture, after its decomposition, the original methallylpyrazole I is recovered, or 3-isobutenylpyrazole if the original material is the pyrazole X. Acylation of methallylpyrazoles by a mixture of antimony pentasulfide and benzoyl chloride in nitromethane leads only to resinification of the reaction mixture. We were also unsuccessful in an attempt to obtain a pyrazolo[1,2-*a*]pyridazinium salt unsubstituted in position 7 by acylation of 1-allyl-3,5-dimethylpyrazole; this failure is apparently related to the lower reactivity of the allyl group in comparison with methallyl.

It is of interest to examine the electronic structure of the new heterocation IX and to compare physicochemical characteristics obtained in quantum-chemical calculations with the experimentally measured characteristics. To this end, within the framework of previously developed calculational methods and parametrization [6], we calculated the residual π-electron charges, bond orders, and self-consistent atom–atom and atom–bond self- and mutual polarizabilities (Table 2). It can be seen from these data that the positive charge is localized mainly on the nitrogen atoms, and for the carbon atoms at positions 1 and 3. Excess electron density is found only on the $C_{(2)}$ atom in the five-membered ring, which is strongly polarized in this connection, whereas the charges on the carbon atoms of the six-membered ring are small (Table 2). The strongest bonds are the $C_{(5)}$–$C_{(6)}$ [$C_{(7)}$–$C_{(8)}$], the π-electron orders of which are maximal; the weakest bonds are the $C_{(5)}$–$N_{(4)}$ [$(C_{(8)}$–$N_{(9)}$].

As in the case of indolizine [7], the presence of a large positive long-range order of the bonds $P_{15}(0) = 0.1546$, together with the relatively small order of the bond $P_{45} = 0.3710$ (for indolizine, $P_{15} = 0.1571$ and $P_{45} = 0.3890$), indicates the possibility of thermal rearrangement of the cation IX to pyrazolo[1,5-*a*]pyridinium XI.

IX XI

At the same time, nucleophilic attack, in accordance with the redistribution of charges in the cation IX, should be accomplished at the $C_{(1)}$ atom, which cannot lead to rupture of the weakest bond $N_{(4)}$–$C_{(5)}$ and recyclization to pyrazolo[1,5-*a*]pyridinium XI. Along with this, the $C_{(1)}$–$N_{(9)}$ and $C_{(1)}$–$C_{(2)}$ bonds are quite strong; and this evidently explains the resistance of the cations IX to alkalis.

In Table 2 we have listed atom–atom and atom–bond polarizabilities. On the basis of these values, it is easy to find the redistribution of electron density in the substituted cations IX by the use of the formulas

$$q_i = q_i^0 + \sum_j \pi_{j,ii}\Delta\alpha_j;\ P_{ih} = P_{ih}^0 + \sum_j \pi_{j,ik}\Delta\alpha_j, \quad (1)$$

where q_i, q_i^0 (P_{ik}, P_{ik}^0) are the changes (and bond orders) in the substituted and unsubstituted molecules; $\pi_{j,ii}$ and $\pi_{j,ik}$ are the atom–atom and atom–bond mutual polarizabilities; $\Delta\alpha_j$ is a parameter characterizing the substituent; the summation is performed over all substituting groups ($\Delta\alpha_{CH_3} = -3.50$ eV, $\Delta\alpha_{C_2H_5} = -3.70$ eV [8]). From an analysis of the mutual polarizabilities, we can see that the introduction of methyl or ethyl groups into position 1 or 5 generally lowers the positive charges on the unsubstituted carbon atoms and thereby increases the resistance of the cations IX to alkalis. From the calculation it follows that, in order to facilitate recyclization to the pyrazolo[1,5-*a*]pyridinium XI, it is necessary to introduce donor substituents into position 1 and acceptor substituents into position 5 and/or 6, which should weaken the $N_{(4)}$–$C_{(5)}$ bond and increase the long-range order $P_{15}(0)$ [the introduction of a donor substituent into position 1, according to the calculation, weakens both the $N_{(4)}$–$C_{(5)}$ and $C_{(1)}$–$C_{5)}$ bonds].

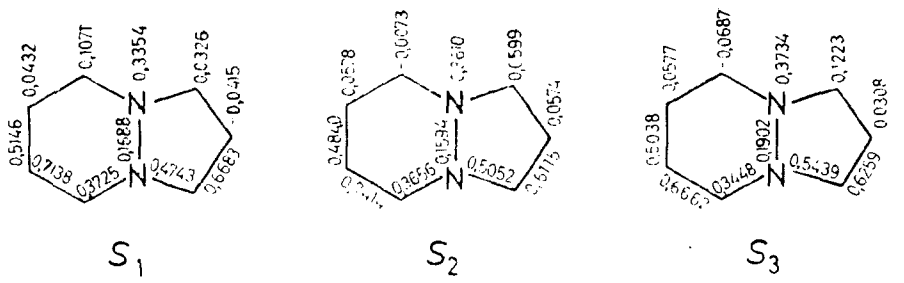


Fig. 1. Residual π-electron charges and bond orders of excited states of cation IX.

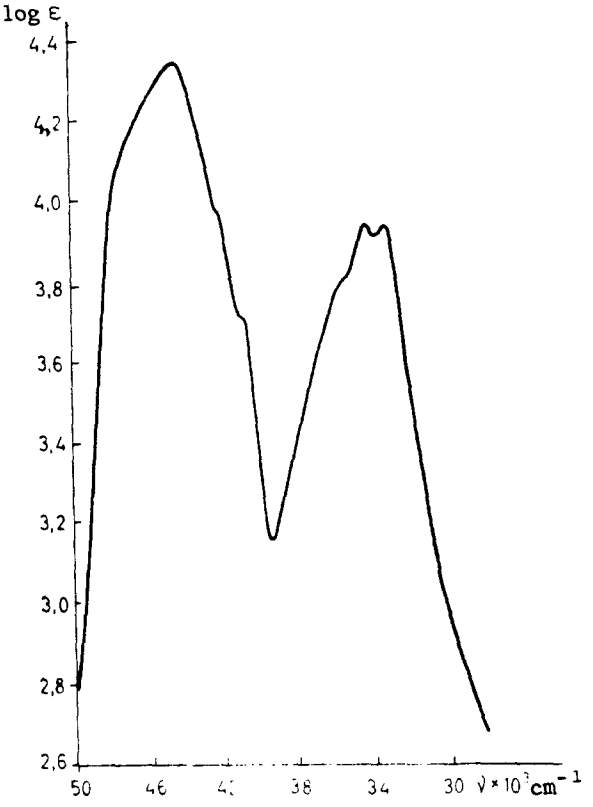


Fig. 2. UV spectrum of 1,3,5,7-tetramethylpyrazolo[1,2-*a*]pyridazinium perchlorate (methanol solvent).

Since the aromaticity of conjugated molecules (and cations) is rated according to the values of the relative diamagnetic susceptibility $\chi' = \chi^{\pi}/\chi_{C_6H_6}{}^{\pi}$, and the aromaticity of one ring or another is rated according to the induced ring current, we have calculated these values, using a procedure given in [9], in order to rate the aromaticity of the cation IX. The calculation showed that the diamagnetic current in the five-member ring $i_1 = 0.920$, and in the six-membered ring $i_2 = 0.639$, whereas $\chi' = 1.248$. Upon comparing these values with the results obtained for indolizine [7] ($i_1 = 1.026$, $i_2 = 0.801$, $\chi' = 1.481$), it will be seen that the introduction of the second nodal atom of nitrogen leads to decreases of the ring currents in both the five-membered and six-membered rings, i.e., to a drop in χ'. Comparing the values of χ' for a series of azoles [9] with the values for the cations IX, we find that the aromaticity of the IX is lower (if we eliminate the comparison with pyrrole).

On the basis of calculated values of the induced π-electron currents and charges, it is not difficult to obtain [6, 7, 9] calculated values of the chemical shift of protons and ^{13}C and ^{14}N nuclei for the cation IX. The calculation gives the following values:

$$\delta_{H_{(1)}} = 8{,}11;\ \delta_{H_{(2)}} = 7{,}63;\ \delta_{H_{(5)}} = 8{,}02;\ \delta_{H_{(6)}} = 7{,}61 \text{ ppm}.$$

$$\delta_{C_{(1)}} = 144{,}6;\ \delta_{C_{(2)}} = 119{,}5;\ \delta_{C_{(5)}} = 130{,}8;\ \delta_{C_{(6)}} = 133{,}7 \text{ and } \delta_N = 217 \text{ ppm}.$$

No experimental data are thus far available for the unsubstituted cation IX. Also, any accounting for the influence of substituents on the chemical shifts of protons in the case of charged heterocations is difficult because of the difference in solvation effects for different substituted cations IX; another complicating factor is the interaction of substituents, which is not taken into account within the framework of the scheme that has been developed, and which is substantial in the present case because of the change in ring currents upon introduction of substituting groups. However, it should be kept in mind that the main contributions of the substituent to the chemical shift of ^1H nuclei is due to σ-currents of the substituents. As previously, when we account for these contributions on the basis of an additive scheme, adding to the chemical shifts of the protons adjacent to a methyl group the value $\gamma_{CH_3} = -0.4$ ppm (see [10]), we can describe the chemical shifts of methyl-substituted cations IX only by means of this constant and by calculation of the unsubstituted system. However, this does not pretend to any exact interpretation of the ^1H NMR spectra. Thus, the calculation gives for 5,7-dimethylpyrazolo[1,2-*a*]pyridazinium the values 1-H 8.11 (8.43), 2-H 7.67 (7.35), 3-H 6.81 (6.45); 8-H 7.62 (8.16); for the 1,6,8-trimethyl-substituted derivative the values 2-H 7.27 (6.97), 3-H 8.11 (8.20), 5-H 7.62 (7.90), 7-H 6.81 (6.43); and for the 1,3,5,7-tetramethyl-substituted derivative the values 2-H 6.87 (6.90), 6-H 6.81 (6.53), 8-H 7.62 (7.76) ppm (the values shown in parentheses are experimental data from the present work). It will be seen that the calculation is generally in fairly good agreement with the experimental data.

The energies of the lowest singlet–singlet transitions were determined as the eigennumbers of the matrix of stability of the Hartree–Fock ground state [11]. For the cation IX, we calculated the following energies of the singlet transitions: λ_1 3.82 eV (324.5 nm), λ_2 4.72 eV (262.7 nm), λ_3 5.71 eV (217.1 nm). The first and third transitions are symmetric relative to the plane of symmetry of the cation; the second transition is antisymmetric. From the molecular diagrams of the cation IX in the excited states (Fig. 1) it can be seen that, along with a general weakening of the valence bonds upon excitation, there is a substantial redistribution of electron density. Thus, whereas in the ground state the negative π-electron charge is localized at the $C_{(2)}$ position, and the picture remains unchanged upon transition of the molecule into the lowest singlet state, we find that in the S_2 and S_3 states there is a deficiency of electron density on the $C_{(2)}$ atom, and the negative charge is now localized on the $C_{(5)}$ ($C_{(8)}$) atom.

Since the shifts of absorption bands under the influence of substituents is determined by the change in residual π-electron charge upon excitation of the molecule [12], we can write

$$\Delta\lambda_i = (P^*_{ii} - P_{ii})\,\Delta\alpha_R, \tag{2}$$

where P_{ii}^* and P_{ii} are the residual π-electron charge in the i-th position of the heterocycle in the particular excited state. Then, from the results of the calculation (compare the data of Fig. 1 and Table 2), it can be seen that the introduction of substituents of the same nature into position $C_{(2)}$ ($C_{(3)}$) of the five-membered ring and into any position of the six-membered ring, must shift the long-wave band in different directions. Position 2 should have the maximum sensitivity to substitution for states S_2 and S_3, and position 5 (8) for state S_1.

For the 1,3,5,7-tetramethylpyrazolo[1,2-*a*]pyridazinium perchlorate, we obtained an experimental UV spectrum (Fig. 2). The results from a calculation of the energy of π–π* transitions by the use of Eq. (2) are generally in satisfactory agreement with the experimental data. Thus, for the cation IXd we obtain 3.98 (4.12), 5.02 (5.07), and 5.78 (5.54) eV (the experimental data are listed in parentheses; the maximum at λ 4.29, 4.46, and 5.25 eV can be attributed to vibrational levels). As previously, the accuracy in describing the experimental data is no better than 0.1-0.2 eV; and a study of the influence of substituents can pretend only to a qualitative picture. In the calculations, the influence of the counterion and the solvent was ignored.

In conclusion, let us dwell briefly on the quantum-chemical description of the heterocyclization leading to the cation IX. As the object of calculation we used the conjugated intermediate structures VIIc, d. As previously [13], the rating of the capability for cyclization was determined by the long-range orders of the bonds $P_{ik}(0)$, with positive values signifying the possibility of forming an aromatic heterocycle, with the magnitude of the bond order characterizing the ease of this process. Let us note that even in the molecule of 1-(4-hydroxybutadien-1,3-yl-1)pyrazole VIIc, the calculation gives a rather large positive order of the newly formed bond ($P_{N_{(2)}-C_{(4')}} = 0.087$). Protonation of the $N_{(2)}$ atom gives only a slight decrease in this value (to 0.073). The introduction of substituents does not have any significant effect on the values of $P_{N_{(2)}-C_{(4')}}$.

Thus, the calculation does not negate the possibility of forming the cation IX through the intermediate VIIc, d. Any quantum-chemical description of other possible reaction pathways requires going beyond the bounds of the π-electron approximation; this has not been done in the present work, although it is of undoubted interest.

EXPERIMENTAL

The IR spectra were taken in an IR-20 instrument in white mineral oil. The ^1H NMR spectra were taken in a Tesla BS-467 instrument (60 MHz) (compounds I and XII without solvent; IV, IX, and XI in trifluoroacetic acid; V in carbon tetrachloride); internal standard TMS.

The 1-methallylpyrazoles Ia-e that were used as starting materials were obtained by alkylating the corresponding pyrazoles with methallyl chloride, following procedures described in [14]. Compound Id was obtained by alkylating 3-tert-butylpyrazole, following procedures analogous to those described in [15].

General Method of Synthesis of Compounds IV, IX, and XI. To a mixture of 0.01 mole of the pyrazole I or X and 0.15 mole of the carboxylic acid anhydride, 1 ml (0.025 mole) of 70% perchloric acid was added dropwise. The mixture was held for 12 h at room temperature, after which the reaction product was precipitated by diluting with 100-ml of ether. In the case of formation of the salt IV, the product that separated was a mixture of the desired compound and the perchlorate of 1-acetyl-3-tert-butylpyrazole. This mixture was filtered off and washed on the filter with isopropyl alcohol, which completely removed the byproduct. The salts IX and XI came out of solution in the form of resinous precipitates, which were segregated by decantation and then mixed with 5-10 ml of isopropyl alcohol; the crystalline precipitate was filtered off and washed on the filter with 2-3 ml of isopropyl alcohol. The salts IX were purified by recrystallization from 50% aqueous methanol.

2,6-Dimethyl-4-(3-tert-butylpyrazolyl-1-methyl)pyridine (V). To a suspension of 3.4 g (~0.01 mole) of the salt IV in 15 ml of alcohol, 10 ml of 25% aqueous ammonia was added; the mixture was refluxed for 5 min, then poured into 300 ml of water. The resulting precipitate was filtered off, washed with water, dried, and crystallized from octafluorotoluene.

3-(2-Methyl-2-hydroxypropyl)pyrazole (X). To a mixture of 15 ml of hydrazine hydrate and 25 ml of methanol, a solution of 14.5 g (0.115 mole) of 2,2-dimethyl-2,3-dihydropyranone-4 [5] in 20 ml of methanol was added while stirring. Upon completion of the exothermic reaction, the mixture was refluxed for 1 h, after which the methanol, water, and excess hydrazine were taken off under vacuum. The residue was crystallized by grinding in 5 ml of a 1:1 mixture of ether and hexane. Yield 11.9 g (74%), mp 85-86°C (according to [16], mp 85-86°C).

Pyrazolo[1,5-*a*]pyridines (XIIa, b). A mixture of 0.01 mole of the perchlorate XI and 100 ml of a 10% sodium carbonate solution was shaken for 10 min, after which the mixture was extracted with two 30-ml portions of ether. The extract was dried with potassium carbonate, the ether was driven off, and the residue was vacuum-distilled.

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NITROAZINES 11.*

STRUCTURE OF PRODUCTS OF TRANSFORMATION OF 6-NITROAZOLO-[1,5-*a*]PYRIMIDINES UNDER THE INFLUENCE OF CYANOACETIC ESTER

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The interaction of 6-nitroazolo[1,5-a]pyrimidines with ethyl cyanoacetate is accompanied by transformation of the pyrimidine ring, forming derivatives of 2-azolylaminopyrimidine. The structure of the transformation products has been investigated in crystals and in solution.

In an earlier communication [2], we described briefly the transformation of 6-nitroazolo[1,5-*a*]pyrimidines under the influence of ethyl cyanoacetate.

The present work has been aimed at determining the limits of applicability of this reaction by varying the type of ring annelated to the pyrimidine ring; the work was further aimed at following the influence of substituents and establishing the structure of the transformation products.

Upon interaction with ethyl cyanoacetate, the 2-R-6-nitro-1,2,4-triazolo- and 3-R-6-nitropyrazolo[1,5-*a*]pyrimidines Ia-i are converted to the 2-(5-azolylamino)-3-carbethoxy-5-nitropyridines IIa-i. The reaction proceeds without any additional activation by charging the reagent and substrate.

The capability of the azolo[1,5-*a*]pyridimines Ia-k to participate in reaction depends on the degree of π-deficiency of the system. The triazolylaminopyridines IIa-e are readily formed by 30-min refluxing of compounds Ia-e with cyanoacetic ester in alcohol. The introduction of donor substituents such as CH_3 or SCH_3 into the azole part does not hinder the reaction. However, groups having a significant +M-effect, such as $N(CH_3)_2$ or NH_2, deactivate the substrate; and the transformation products can be obtained only by heating to 100°C in DMSO.

A different sort of behavior in these conversions is exhibited by the desaza analogs of compounds Ia-g, i.e., the pyrazolo[1,5-*a*]-pyrimidines in Ih-k. They can be made capable of reacting with cyanoacetic ester by introducing acceptor substituents such as NO_2 or $COOC_2H_5$ into the pyrazole fragment. The 6-nitropyrazolo[1,5-*a*]pyrimidine itself (Ij), and all the more the 2-methyl-6-nitropyrazolo[1,5-*a*]pyrimidine (Ik) are incapable of such conversion (see scheme on page 1359).

With the aim of establishing the molecular-crystal structure of the transformation products, we carried out an x-ray structural study of compound IIb (Table 1 and Fig. 1).

*For Communication 10, see [1].

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