UDC 543.5 + 547.79

ELECTRON DENSITY DISTRIBUTION IN HETEROCYCLIC SYSTEMS WITH TWO ADJACENT NITROGEN ATOMS

IV. Dipole Moments of Some 1, 2, 4-Triazole Derivatives*

I. B. Mazheika, G. I. Chipen and S. A. Hiller

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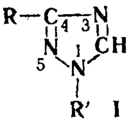
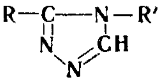
A comparison is given between the dipole moments found experimentally for 1, 2, 4-triazole and its derivatives and those computed vectorially. In 1, 2, 4-triazoles unsubstituted on nitrogen, the hydrogen is attached at N_1 in the majority of cases. The 1, 2, 4-triazoles undergo acylation on N_1. Under the influence of a strong electron acceptor (a p-nitrophenyl substituent), the electron cloud of the triazole ring is highly polarized.

Continuing our study of the dipole moments of nitrogen-containing aromatic heterocycles [1-3], we have investigated some 1, 2, 4-triazole derivatives.

When there are no substituents on nitrogen in 1, 2, 4-triazole derivatives, tautomeric forms (Ia, IIa, IIIa) are possible, depending on the position of the hydrogen atom; however, these compounds are known in only one form.


I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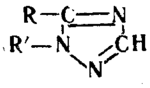

III

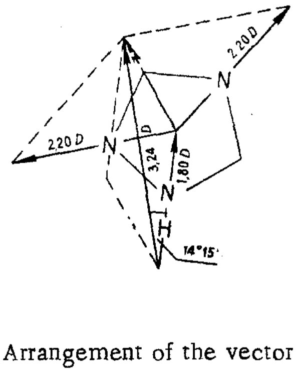

IV

a $R=R'=H$
b $R=Cl$; $R'=H$
c $R=NH_2$; $R'=H$
d $R=4\text{-}NO_2=C_6H_4$; $R'=H$
e $R=H$; $R'=CH_3$
f $R=C_6H_5$; $R'=H$
g $R=H$; $R'=4\text{-}NO_2=C_6H_4$

Despite isolated attempts to determine the position of the hydrogen atom in 1, 2, 4-triazole [4-7], there is still no unanimity on this question. The hypothesis [4] that there is no fixed hydrogen atom in the 1, 2, 4-triazole molecule and that the ring possesses a "smeared" negative charge as in formula IV is as yet unproven. The most reliable information has been obtained by comparison of the dipole moments of 1, 2, 4-triazole and its N_1- and N_4-phenyl derivatives [8]. The value of 3.17 D found for the dipole moment of 1, 2, 4-triazole is close to the dipole moment of the N_1 substituted compound (2.88 D) and differs greatly from the dipole moment of the N_4 substituted compound (5.63 D). Hence one may draw the conclusion that, in triazole, the hydrogen is on the N_1 nitrogen atom.

In order to determine the structure of 1, 2, 4-triazole and some of its derivatives, we have compared the dipole moment values found experimentally with those calculated by vector addition and with the dipole moments of some model substances.

In the vector calculation of the dipole moments of 1, 2, 4-triazoles, we have made certain simplifying assumptions. Two of the nitrogen atoms in 1, 2, 4-triazole, like the nitrogen atom in pyridine, have two endocyclic σ-bonds and no exocyclic σ-bonds, and contribute their third valence electron to the sextet of the molecule. Thanks to the presence of an unshared electron pair, these two nitrogen atoms come to carry fractional negative charges relative to the rest of the molecule. In the vector calculation, the components of the molecular dipole moment associated with the presence of these nitrogen atoms have been taken equal to the dipole moment of pyridine (2.20 D), directed from the center of the ring toward the nitrogen atoms.



Arrangement of the vector components of the dipole moment of 1, 2, 4-triazole.

The nitrogen atom which has one exocyclic σ-bond in addition to the two endocyclic ones, like the nitrogen atom in pyrrole, contributes its unshared electron pair to the aromatic sextet and

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* For communication III see [1].

carries a fractional positive charge. In the vector calculation, the component of the dipole moment which depends on the presence of this nitrogen atom in the molecule was taken equal to the dipole moment of pyrrole (1.80 D), directed from the nitrogen atom toward the center of the ring (see figure).

Table 1

Dipole Moments of 1,2,4-Triazole Derivatives

No.	Compound	μ, D
1	1,2,4-Triazole (Ia)	3.29
2	1-Methyl-1,2,4-triazole (Ie)	3.50
3	3-Chloro-1,2,4-triazole (Ib)	4.25
4	3-Amino-1,2,4-triazole (IIIc $\rightleftarrows$ Ic)	3.38
5	3-Phenyl-1,2,4-triazole (If)	3.10
6	3-(4-Nitrophenyl)-1,2,4-triazole (Id)	6.60
7	1-(4-Nitrophenyl)-1,2,4-triazole (Ig)	2.23
8	1-Methyl-5-amino-1,2,4-triazole (Va)	4.04
9	3-Phenyl-5-amino-1,2,4-triazole (Vb)	3.57
10	1-Methyl-3-phenyl-5-amino-1,2,4-triazole (Vc)	4.01
11	1-Acetyl-3-phenyl-1,2,4-triazole (VII)	1.98
12	1-Benzoyl-5-amino-1,2,4-triazole (IXa)	1.58
13	1-Acetyl-3-phenyl-5-amino-1,2,4-triazole (IXc)	1.13
14	1-Benzoyl-3-phenyl-5-amino-1,2,4-triazole (IXb)	0.84
15	1-Benzoyl-3-methyl-5-amino-1,2,4-triazole (IXd	1.23

In the calculations, we used the well-known formula for vector addition:

$$\mu^2 = \mu_1^2 + \mu_2^2 + 2\mu_1\mu_2 \cos \Theta \,. \tag{1}$$

The dipole moments of the substituents and the angles between a bond and the moment of its substituent were taken as follows: $-Cl = -1.55$ D, $-CH_3 = +0.37$ D, $-NH_2 = +1.53$ D, $\varphi = 142°$, $-COCH_3 = -2.89$ D, $\varphi = 57°$, $-NO_2 =$ $= -3.98$ D [11]. The 1,2,4-triazole molecule was considered to be a regular plane pentagon. The mutual influence of the nitrogen atoms and the different effect of the carbon atoms on the dipole moments in the pyridine, pyrrole, and triazole molecules were disregarded in the calculations.

In our view, such a calculation is permissible as a first approximation and can solve the question of whether the compounds under consideration exist in the form of a particular tautomer or isomer. The validity of this contention is confirmed by the good agreement of the calculated and experimental dipole moments for model substances of known structure (see below) and is evidently explained by the fact that the dipole moment value for aromatic nitrogen-containing heterocycles is mainly determined by the participation of the unshared electron pairs in the conjugated π-electron system (the same thing happens when compounds of the pyrazole series are examined) [1, 2].

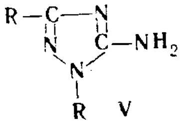
For 1,2,4-triazole, the dipole moment found experimentally (3.29 D) differs only slightly from that calculated for 1-H-1,2,4-triazole (Ia), 3.24 D, while the calculated moment for 4-H-1,2,4-triazole (IIa) equals 5.36 D. Consequently, unsubstituted triazole exists mainly in the form Ia. This is also confirmed by the closeness of the experimental dipole moment value for the model compound 1-methyl-1,2,4-triazole (Ie), 3.50 D, to the dipole moment of Ia.

The dipole moment of the methyl group in Ie, calculated vectorially, equals +0.27 D. This is somewhat less than the dipole moment of the methyl group in pyrazole (+0.41 D) and in toluene (+0.37 D).

The vector calculation made it possible to compute the angle between the total dipole moment of the 1,2,4-triazole molecule and the N—H bond, which proved to equal 14°15'. The marked polarizability of the 1,2,4-triazole ring does not permit one to determine the direction of the total moment by measuring the dipole moment of 1,2,4-triazole itself and that of any of its derivatives with a known substituent moment, since with different substituents the angle thus determined varies within wide limits on account of the varying degree of polarization of the ring. Similar polarization is also observed in pyrazole [1] and imidazole [12] derivatives.

The dipole moment value found experimentally for 3-amino-1,2,4-triazole (3.38 D) differs considerably from those calculated vectorially ($\mu_{Ic} = 1.89$ D, $\mu_{IIc} = 6.03$ D, $\mu_{IIIc} = 4.27$ D) but is closest to the value for the structure 3-amino-2-H-1,2,4-triazole (IIIc). The possibility is not excluded that an equilibrium between forms Ic and IIIc exists in solution.

In 1-methyl-5-aminotriazole (Va), where such an equilibrium is impossible, the dipole moment value calculated vectorially, 4.51 D, differs by only 0.47 D from the value found experimentally 4.04 D; to some degree this favors the existence, in 3-amino-1,2,4-triazole, of the equilibrium just mentioned.



V

a $R=H$; $R'=CH_3$
b $R=C_6H_5$; $R'=H$
c $R=C_6H_5$; $R'=CH_3$

In aminotriazoles not substituted on nitrogen, amino-imino tautomerism is also possible, but we have succeeded in demonstrating convincingly, by spectroscopy, that only the amino form exists [13, 14].

A phenyl group in the 3 position of the triazole ring (If) lowers the dipole moment of the triazole by 0.19 D. However, this change does not make it possible to determine whether the phenyl radical in this case possess electron-accepting or electron-donating properties relative to the triazole ring. From the orientation of the moment of the 1, 2, 4-triazole ring (see figure), one can see that the introduction of an electron-donating substituent in position 3, like the introduction of an electron-accepting substituent in position 5, should cause a decrease in the dipole moment; but, on account of the rapid proton exchange between the ring nitrogen atoms, positions 3 and 5 in N-unsubstituted triazoles are indistinguishable.

The dipole moment found experimentally for 3-(4-nitrophenyl)-1, 2, 4-triazole (Id, IId, IIId) is 6.60 D. The data obtained by vector computation, namely $\mu_{Id} = 7.18$ D, $\mu_{IId} = 5.60$ D, $\mu_{IIId} = 3.55$ D, differ markedly from the experimental value, but the latter is nevertheless closest to the value for structure Id. The cause of the marked decrease in the observed dipole moment as compared with that calculated for Id may possibly be an interaction among the closely spaced negative charges on N_2, N_4, and the 4-nitrophenyl radical, each of which draws electrons toward itself; but the existence of a tautomeric equilibrium is not excluded.

The introduction of a 4-nitrophenyl substituent in position 1 of the triazole ring (Ig) is apparently the cause of the great decrease in the dipole moment of 1-(4-nitrophenyl)-1, 2, 4-triazole (Ig) (in comparison with Id) and the change of its direction toward the strongly electron-accepting substituent. As a result of the high polarization of the 1, 2, 4-triazole ring, the value found experimentally for Ig, 2.23 D, markedly exceeds the computed dipole moment, 1.09 D. Such a polarization also takes place in the pyrazole ring [1].

Depending on the nature of the other substituents, a phenyl radical in position 3 of the triazole ring acts differently on the total molecular moment. In the 3-amino-1,2,4-triazole molecule, which has no substituent on a ring nitrogen atom, the phenyl increases the dipole moment somewhat: $\mu_{Ib} - \mu_{Ic} = 3.57 - 3.38 = 0.19$ D. When an electron-donating substituent is present on N_1, for example, a methyl group, the introduction of a phenyl radical causes practically no change in the dipole moment value: $\mu_{Va} - \mu_{Vc} = 4.04 - 4.01 = 0.03$ D. On the other hand, when a strongly electron-accepting radical (an acyl group) is present on N, the introduction of a phenyl radical markedly decreases the dipole moment of the compound: $\mu_{IXb} - U_{IXa} = 0.84 - 1.58 = -0.74$ D.

According to the vector computation, the phenyl ring in IXb is electron-donating relative to the rest of the molecule and has a dipole moment of 0.85 D, directed from the phenyl ring toward the triazole ring. The dipole moment of the methyl group in IXc, computed vectorially, equals 0.40 D. Such a large difference between the moments of the methyl and phenyl groups testifies to the very high mobility of the π-electron cloud of the entire conjugated system of 3-phenyl-1, 2, 4-triazole and the strong polarizing influence of the substituent on N_1.

On acylation of 3-amino-1, 2, 4-triazoles, the formation of four different isomers is possible in principle. IR and UV spectra, as well as certain chemical properties of these compounds, give evidence that the acyl radical is in the α-position relative to the amino group, i.e., on N_1 or N_4 [15–17]. Furthermore, it has been established on the basis of Raman spectra that the acyl group is on the first nitrogen atom in the acyl derivatives of 3-phenyl-5-amino-1, 2, 4-triazole [18]. So far, however, it has remained unknown whether the point of acylation changes depending on the nature of the substituents on the carbon atoms of the triazole ring.

We have attempted to obtain an answer to this question by means of dipole moments. Measurement and calculation of the dipole moment of the acetyl derivatives of 3-phenyl-1, 2, 4-triazole favor N_1 substitution. The vectorially computed dipole moment values for structures VI, VII, and VIII (3.71, 2.35, and 4.70 D, respectively), when compared with the experimentally established value of 1.98 D, allow us to consider structure VII as most probable, with the acyl group on N_1 in the trans position relative to the negatively charged nitrogen atom N_2.

Table 2
Data for Determining the Dipole Moments of 1, 2, 4-Triazole Derivatives*

No.	f mole fraction	ε	d	P_{total}, cm³	MR, см³	P_{av}, cm³	μ, D
1	2	3	4	5	6	7	8
1	0.006928	2.3130	1.0291	241.49	16.51	224.98	3.29
	0.005890	2.3015	1.0293				
	0.004962	2.2792	1.0284				
	0.003397	2.2657	1.0286				
	0.003370	2.2631	—				
2	0.006435	2.3597	1.0253	275.71	21.13	254.58	3.50
	0.005883	2.3042	1.0250				
	0.002639	2.2492	1.0279				
	0.002441	2.2466	—				
	0.002161	2.2937	1.0251				
	0.001214	2.2792	—				
3	0.008061	2.3368	1.0282	397.65	21.32	376.33	4.25
	0.001721	2.3036	1.0257				
	0.001370	2,2933	1.0256				
4	0.002777	2.2550	1.0288	257.85	19.85	238.00	3.38
	0.001369	2.2313	1.0283				
	0.001135	2.2266	1.0275				
5	0.003772	2.3138	1.0260	240.77	40.38	200.39	3.10
	0.002781	2.2988	1.0256				
	0.001721	2.2834	1.0254				
	0.001349	2.2803	1.0255				
	0.000943	2.2736	—				
6	0.001001	2.2990	1.0251	903.95	45.56	858.39	6.60
	0.000797	2.2814	—				
	0.000539	2.2689	1.0280				
	0.000476	2.2705	1.0247				
	0.000432	2.2560	—				
7	0.003217	2.2395	1.0290	148.96	45.56	103.40	2.23
	0.002264	2.2322	1.0286				
	0.001212	2.2208	—				
8	0.002370	2.2638	1.0289	361.90	26.52	335.38	4.04
	0.001973	2.2556	1.0285				
	0.000821	2.2282	1.0283				
9	0.002178	2.2461	1.0286	310.40	44.44	265.96	3.57
	0.001185	2.2308	1.0286				
	0.001169	2.2280	1.0285				
	0.000835	2.2230	1.0284				
	0.000646	2.2202	1.0283				
10	0.001298	2.2390	1.0284	383.34	48.64	334.70	4.01
	0.001033	2.2323	1.0283				
	0.000759	2.2261	1.0283				
11	0.005878	2.2948	1.0265	131.39	50.07	81.32	1.98
	0.005471	2.2917	1.0264				
	0.004098	2.2788	1.0261				
	0.003432	2.2793	1.0256				
12	0.007863	2.2887	1.0310	106.09	54.33	51.76	1.58
	0.005775	2.2741	1.0298				
	0.003847	2.2685	1.0289				
	0.002867	2.2622	1.0278				

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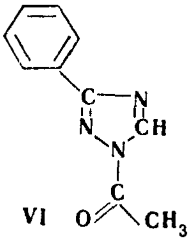
* The numbering of the derivatives corresponds to Table 1.

[Table 2 completed on next page]

[continuation of Table 2]

1	2	3	4	5	6	7	8
13	0.004875	2.2684	—	80.22	53.48	26.75	1.13
	0.004656	2.2684	1.0271				
	0.002792	2.2638	1.0259				
14	0.010630	2.2425	1.0352	88.99	74.38	14.61	0.84
	0.008798	2.2347	1.0335				
	0.002604	2.2129	1.0296				
15	0.009915	2.2839	1.0293	84.83	53.48	31.35	1.23
	0.004974	2.2715	1.0272				
	0.003240	2.2658	1.0264				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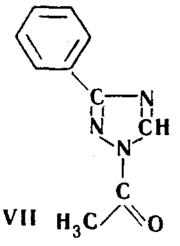
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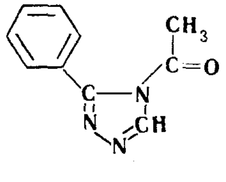
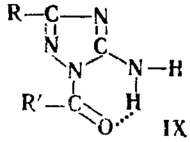

VIII

The experimentally found value for the dipole moment of N-benzoyl-3-amino-1, 2, 4-triazole (1, 58 D) agrees comparatively well with the value calculated for 1-benzoyl-5-amino-1-2, 4-triazole (IXa), 1.78 D. On the other hand, vector calculation of the dipole moments for the isomers Xa and XIa leads to results differing widely from the experimental values (2.71 and 4.77 D); this speaks convincingly in favor of N_1 substitution.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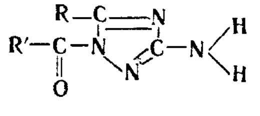
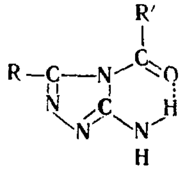

X


XI

a $R=H$; $R'=C_6H_5$
b $R=R'=C_6H_5$
c $R=C_6H_5$; $R'=CH_3$
d $R=CH_3$; $R'=C_6H_5$

The introduction of a phenyl or methyl substituent in position 3 (IXb and IXd), like the replacement of a benzoyl radical on nitrogen by an acetyl (cf. compounds IXb and IXc), does not substantially change the dipole moment values. This is possible if the acylation takes place at N_1 in all the cases mentioned.

The dipole measurements were performed in dioxane solution at 25° C. The measuring procedure and solvent purification method have been previously described [2, 3].

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Institute of Organic Synthesis
AS Latvian SSR, Riga