ELECTRON DENSITY DISTRIBUTION IN HETEROCYCLIC SYSTEMS WITH TWO ADJACENT NITROGEN ATOMS

V. Dipole Moments of Some Halogeno, Amino, and Hydroxy Derivatives of Pyrazole*

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The dipole moments of 19 pyrazole derivatives are determined. Comparing measured dipole moments with those calculated by vector addition, differences in polarization of the pyrazole ring are considered as functions of the natures and positions of substituents. The inadequacy of a symmetrical structure for pyrazole, with a hydrogen linked to both nitrogens, is demonstrated. Comparison of experimentally determined dipole moments with those calculated by the vector method makes it possible to choose between tautomeric structures of 3, 4-dibromopyrazole.

Previous papers [2, 3] gave information about dipole moments of pyrazole (I) and some of its alkyl, aryl, and nitro derivatives. The dipole moment of I as determined experimentally was compared with that calculated vectorially, on a basis of the valence states of the nitrogen atoms in the molecule, and X-ray measurements of the molecule's geometry [4].

In the present paper we have determined the dipole moments of some halogeno, amino, and hydroxy pyrazoles.

I

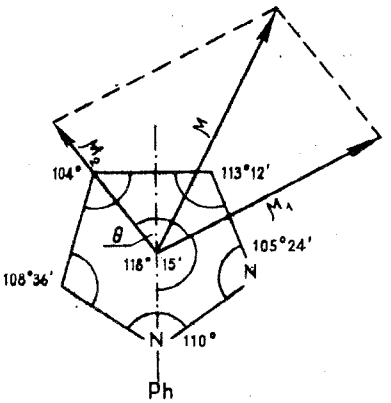
To elucidate peculiarities in the interaction of substituents with the pyrazole ring, the measured dipole moments were compared with those calculated vectorially. In the calculations we used the vector addition formula

$$\mu^2=\mu_1^2+\mu_2^2+2\mu_1\mu_2\cos\Theta.$$

The angle Θ between the dipole moment of the substituents and the pyrazole ring was calculated from the pyrazole valence angles as determined by X-ray analysis [4], also the angle which the dipole moment of the pyrazole ring forms with the N—H bond, i.e., 118° 15' [2]. As the found dipole moment of 1-phenylpyrazole, 2.00 D [3], is, within the limits of error, equal to that for unsubstituted pyrazole, 2.06 D [2], the direction of dipole moment of 1-phenylpyrazole was assumed to be the same as that of pyrazole, i.e., 118° 15'. The following dipole moments were assumed for substituents:

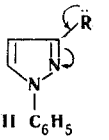
$\mu(-Cl) = -1.58\ D$, $\mu(-Br) = -1.55\ D$, $\mu(-NH_2) = +1.55\ D$, $\Theta = 142°$, $\mu(-NO_2) = -4.00\ D$, $\mu(-CH_3) = +0.37\ D$, $\mu(-OH) = +1.60\ D$, $\Theta = 62°$ [5].

The figure gives the pyrazole valence angles and an example of vector addition.



Example of vector addition of dipole moment components: μ_1) Dipole moment of 1-phenylpyrazole; μ_2) dipole moment of substituent; μ) total dipole moment of molecule.

The table gives measurement data, calculated dipole moments, and dipole moments due to interaction between substituents and the pyrazole ring $\mu_{inter} = \mu_{exp} - \mu_{calc}$.



II C_6H_5

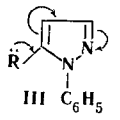
The tabulated data show that substituents with a +T effect (amino, halogen) at position 3 give rise to a positive μ_{inter}. A positive μ_{inter} is characteristic of the interaction between two substituents in the ortho or para positions in the benzene ring when one substituent has a +T effect, and the other a –T effect, e.g., p-nitroaniline, and also of interaction between an ortho or para substituent with a +T effect and the nitrogen atom in pyridine, e.g., 4-chloropyridine. In the cases of 1-phenyl-3-aminopyrazole and 1-phenyl-3-chloropyrazole, the positive value of μ_{inter} indicates, as in the above examples, displacement of electrons from substituent R to the electron acceptor, a nitrogen atom at position 2 (II, R = NH_2, Cl, Br).

+T effect substituents at position 4, unlike the same substituents when at position 3, give rise to a negative μ_{inter} (see table, Nos. 3, 6, 8), but a nitro group,

*For Part IV see [1].

with a –T effect, at position 4 gives rise to a positive μ_{inter}. Evidently in 1-phenyl-4-nitropyrazole, there is additional shift of negative charge from ring to nitro group. If the substituent at position 4 is an amino group or halogen, the shift in the reverse direction (from substituent to ring) appears less marked, than if that substituent were at position 3. For 1-phenyl-4-aminopyrazole the calculated dipole moment of the amino group is +1.10 D, which is close to the value of the dipole moments of aliphatic amines (for isopropylamine μ = = 1.20 D [6]), where there is no +T effect. Negative values of μ_{inter} are also characteristic of 1-phenyl-4-chloropyrazole and 1-phenyl-4-bromopyrazole. Obviously the large electron density at carbon atom 4 hinders marked electron shift, due to the +T effect, from substituent (amino group or halogen) to ring, and conversely promotes shift from ring to substituent (nitro group).

Positive μ_{inter} is also found with 1-phenyl-5-chloropyrazole and 1-phenyl-5-bromopyrazole. Obviously this is due to shift of the negative charge to N atom 2 (see III, R = Cl, Br).



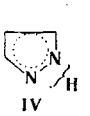
III C_6H_5

Within the limits of experimental error the found and vectorially calculated dipole moments of 1-phenyl-5-aminopyrazole agree.

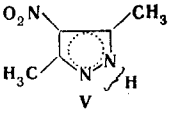
The difference of 0.32 D between the dipole moments of 3,5-diphenyl-4-bromopyrazole (2.62 D) and 3,5-diphenylpyrazole (2.30 D) is practically the same as the difference of 0.28 D between the dipole moments of 1-phenyl-4-bromopyrazole (2.28 D) and 1-phenylpyrazole (2.00 D) [3]. Obviously the polarity of bromine situated between two phenyl groups does not differ appreciably from the polarity of bromine in the previously considered 1-phenyl-4-bromopyrazole.

The dipole moment of 3,3-dimethyl-4-iodopyrazole is less than the dipole moment of 3,5-dimethyl-4-chloropyrazole by 0.24 D. Probably what takes place here is partial decrease in dipole moment with formation of a fractional positive charge on the iodine atom, and of a fractional negative charge on the ring.

The experimental data for the dipole moments of 4-substituted pyrazoles makes it possible to settle the question of the appearance of so-called meso-hydrogen tautomerism in pyrazole [7]. According to this view, the hydrogen atom in pyrazoles is not fixed at a definite nitrogen atom, but bound to both nitrogen atoms [8] (IV).



IV



V

Under such circumstances the dipole moment of pyrazole, 3,5-dimethylpyrazole, and 3,5-diphenylpyrazole must be directed along the axis of symmetry of the molecule. The additivity of dipole moments should be approximately conserved on introducing a substituent at position 4. The calculated dipole moment of 3,5-dimethyl-4-nitropyrazole (V), is found as the sum of the dipole moments of the nitro group 4.00 D and 3,5-dimethylpyrazole 2.31 D [3], μ = 4.00 + 2.31 = 6.31 D, if the dipole moment of the pyrazole ring is directed along an axis of symmetry from the heteroatoms to the center of the ring. The dipole moment of V is determined as the difference between the dipole moments of nitro group and 3,5-dimethylpyrazole ring, with the dipole moment of the pyrazole ring directed in a direction opposite to that stated above: μ = 4.00 – 2.31 = = 1.69 D.

The experimentally found dipole moment of this compound, 3.88 D, does not even approximately agree with one of the calculated values, though it differs by only 0.34 D from the dipole moment calculated for a structure with a fixed hydrogen atom (see table, no. 14).

Dipole Moments of Pyrazole Derivatives

Experiment No.	Compound	Solvent	μ_{found} D	μ_{calc} D	μ_{inter} = μ_{found} – μ_{calc}
1	1-Phenyl-3-aminopyrazole	b*	1.85	1.44	+0.41
2	1-Phenyl-4-aminopyrazole	b	2.36	2.68	–0.32
3	1-Phenyl-5-aminopyrazole	b	3.34	3.41	–0.07
4	1-Phenyl-3-chloropyrazole	b	3.76	3.49	+0.27
5	1-Phenyl-4-chloropyrazole	b	2.28	2.38	–0.10
6	1-Phenyl-5-chloropyrazole	b	1.25	0.51	+0.74
7	1-Phenyl-4-bromopyrazole	b	2.28	2.36	–0.08
8	1-Phenyl-5-bromopyrazole	b	1.33	0.48	+0.85
9	3,5-Diphenyl-4-bromopyrazole	b	2.62	2.49	+0.13
10	3,5-Dimethyl-4-iodopyrazole	b	2.19	2.21	–0.02
11	3,5-Dimethyl-4-chloropyrazole	b	2.43	2.51	–0.08
12	3,4-Dibromopyrazole	b	4.66	3.96	+0.70
13	3,4,5-Tribromopyrazole	b	2.48	3.05	–0.57
14	3,5-Dimethyl-4-nitropyrazole	b	3.88	3.54	+0.34
15	1-Phenyl-3-hydroxypyrazole	d	2.18	—	—
16	1-Phenyl-4-hydroxypyrazole	d	2.43	—	—
17	1-Phenyl-5-hydroxypyrazole	d	3.41	—	—
18	1-p-Aminophenylpyrazole	b	2.97	3.00	–0.03
19	1-p-Hydroxyphenylpyrazole	d	2.71	2.72	–0.01

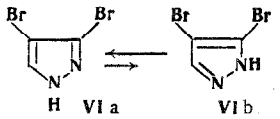
*b – benzene; d – dioxane

The dipole moments calculated in this way for the symmetrical structure 3,5-diphenyl-4-bromopyrazole are 2.30 − 1.55 = 0.75 D (when the dipole moment of the pyrazole ring is directed from the hetero atoms to the ring center), or 2.30 + 1.55 = 3.85 D (when the dipole moment is in an opposite direction). The experimental value is 2.62 D.

Correspondingly the calculated dipole moments for 3,5-dimethyl-4-chloropyrazole are 2.31 − 1.58 = = 0.73 D and 2.31 + 1.58 = 3.89 D. The experimental value is 2.43 D.

Comparison of calculated dipole moments for symmetrical structures and structures with a fixed hydrogen atom (table, Nos. 9, 11, 14), with experimental values, shows the existence of a structure with a hydrogen atom fixed at one nitrogen atom, and hence the nonequivalence of the hydrogen atoms at the nitrogen in the pyrazole ring.

Due to possible exchange of protons between the nitrogen atoms of 3,4-dibromopyrazole, it can exist as the tautomeric structures VIa and VIb. Vectorial calculation gives a dipole moment 3.96 D for structure VIa, and 1.85 D for structure VIb. The experimental value of 4.66 D indicates that here tautomeric equilibrium is completely displaced over to the side of formation of structure VIa.

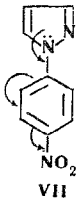


VI a VI b

For structure VIa, the experimentally found dipole moment exaltation 0.72 D above that calculated is obviously due to additional polarization of the pyrazole ring due to the action of two adjacent bromine atoms.

From what has been said above it is evident that determination of dielectric constant can prove serviceable for settling a problem of the predominance of one of the tautomeric structures of substituted pyrazoles when there is sufficiently great difference between vectorially calculated values of dipole moments of the structures.

In a paper [3] we pointed out the strong polarization of the pyrazole ring under the action of the nitro group in 1-p-nitrophenylpyrazole, due to which the experimentally found dipole moment for that compound is greater by 2D than that calculated vectorially.



VII

It is characteristic that introduction of an amino or hydroxyl group in the para position of the phenyl ring of 1-phenylpyrazole does not give rise to additional polarization, and that within the limits of experimental error, the experimentally found dipole moment agrees with that calculated vectorially. Obviously in polarization of the pyrazole ring of 1-phenylpyrazole by a substituent at the para position in the N-phenyl ring, or at position 4 in the pyrazole ring, the conjugation effect is the most important one: the −T effect of the nitro group brings about a powerful charge shift, and conversely the +T effect of an amino or hydroxyl group does not evoke such a shift.

The close agreement between the experimental dipole moment and that calculated vectorially in the cases of 1-p-aminophenylpyrazole and 1-p-hydroxyphenylpyrazole confirms the hypothesis of the coplanarity of the phenyl and pyrazole rings, due to hybridization of the nitrogen atom 1 valence electrons [9].

In conclusion we consider it necessary to mention that determining dipole moments does not make it possible to decide the problem of keto-enol tautomerism for isomeric 1-phenyl-X-hydroxypyrazoles, as successfully as the solution of the problem of the position of the tautomeric equilibrium of 3,4-dibromopyrazole was possible.

Apart from the equilibrium between keto and enol forms, the experimental dipole moments for these compounds can also depend on rotational isomerism of the hydroxyl enol form, and on polarization of the pyrazole ring under the action of a substituent, a hydroxyl or carbonyl group. Vectorial calculation of dipole moments is complicated by the electron densities at the various carbon atoms of the pyrazole ring in these compounds differing greatly, as calculations by the MO method has shown [10].

Possible superposition of these factors made it impossible to obtain clear-cut results in considering the dipole moments of 1-phenyl-X-hydroxypyrazoles.

Dipole moments were determined in benzene or dioxane solution at 25°. The measurement procedure and methods of purifying the solvents were described in [11]. The table gives the experimental data.

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