^{15}N NMR SPECTRA AND SPECIFIC INTRAMOLECULAR INTERACTIONS IN N-VINYLAZOLES

A. V. Afonin, V. K. Voronov, E. S. Domnina,
L. A. Es'kova, L. V. Baikalova,
B. V. Trzhtsinskaya, E. I. Enikeeva,
and A. V. Vashchenko

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The factors that affect the chemical shifts in the ^{15}N NMR spectra of N-vinylazoles were investigated. It was shown that an additional positive contribution to the shielding constant of the "pyridine" nitrogen atom occurs in the s-cis-($N_{(2)}$) conformation of N-vinylpyrazoles due to overlapping of the electron cloud of its unshared electron pair and the s-orbital of the vinyl group hydrogen β-cis-atom.

The PMR and ^{13}C NMR spectra of N-vinylazoles have been well studied [1-4]. It was found that the spatial proximity of the unshared pair of electrons of a "pyridine" nitrogen atom to the vinyl group significantly affects its spectral parameters. At the same time, the ^{15}N NMR spectroscopic data for N-substituted azoles are very limited [5, 6]. The parameters of the ^{15}N NMR spectra of a wide number of N-vinylazoles I-XXII were obtained for the first time in the present study (see Table 1).

The ranges of the change in the CS of "pyrrole" ($N_{(1)}$ or $N_{(2)}$) and "pyridine" ($N_{(2)}$ or $N_{(3)}$) atoms overlap in these N-vinylazoles. The first one resonates at 122.0-269.9, and the second resonates at 241-372.4 ppm. However, the "pyrrole" atom resonates in a stronger field for each real molecule in the series of substances (I-XXII) (see Table 1).

The strong changes in the chemical shifts (CS) of the ^{15}N nuclei are observed in going to compounds with the "pyrrole" and "pyridine" nitrogen atoms positioned adjacently. For example, the CS of the "pyrrole" nitrogen atom in compounds IX, XX, XXI, and XXII is increased by 40-70 ppm relative to compounds I, IV, XI, and X, respectively. The CS of the "pyridine" nitrogen atom increases by 40-60 ppm in azoles II and IX in comparison to the shifts of azoles XI and XIV (see Table 1).

It is impossible to compare the CS of "pyrrole" and "pyridine" nitrogen atoms in N-vinylazoles and in unsubstituted azoles because of averaging of the CS of these atoms in the unsubstituted azoles due to tautomerism [5]. At the same time, the "pyrrole" nitrogen atom in N-methylazoles also resonates in a stronger field than the "pyridine" atom [5, 6]. Substitution of a methyl group by a vinyl group causes a stable weak-field shift of the signal of the "pyrrole" nitrogen atom (Table 1). This could be the consequence of either $p-\pi$ conjugation of the unshared pair of nitrogen atom electrons with the π-electrons of the vinyl group or an increase in the nitrogen—carbon bond order with a change in the hybridization.

When a substituent is added to other positions of the azole ring, relatively small changes in the CS of the ^{15}N nuclei not exceeding 15 ppm are observed (Table 1). The effect of the substituents in the ring on the CS of "pyrrole" and "pyridine" nitrogen atoms is symbatic. The signal of the $N_{(1)}$ nitrogen atom is shifted by 3.6-5.9 ppm to the strong field and the signal of the $N_{(2)}$ (or $N_{(3)}$) atom is shifted by 0.3-13.5 ppm due to the electronic effect of $-SCH=CH_2$ and $-CH_3$ donor groups [7] (compounds II and III, II and VI, XI and XII, XIV and XV, XVI and XVIII, XVII and XIX). The presence of an electron-acceptor bromine atom in vinylpyrazole V causes the complete shift of the signal of "pyridine" and "pyrrole" nitrogen atoms by 8.4 and 5.6 ppm, respectively. At the same time, the presence of a nitro group in position 4 of the pyrazole ring has almost no effect on the position of the signals of $N_{(1)}$ and $N_{(2)}$ atoms (compounds II and IV, VII and VIII, see Table 1). This is probably due to mutual compensation of the σ-acceptor and π-acceptor effects of the substituents [8].

The degree of the strong-field shift of the signals of $N_{(1)}$ and $N_{(3)}$ atoms on incorporation of a methyl group in position 2 of the benzimidazole ring (compounds XIV and XV) is almost the same as for the imidazole ring (compounds XI and XII, Table 1). However, in contrast to compound XIV, departure of the vinyl group from the plane of the heterocycle is observed for compound XV [4], while incorporation of a methyl group in position 2 of

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Institute of Organic Chemistry, Siberian Branch, Academy of Sciences of the USSR, Irkutsk 664033.
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TABLE 1. ^{15}N NMR Spectra of Some N-Vinylazoles

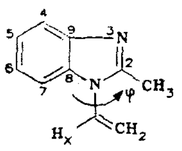
Compound	Name	Chemical shifts, δ, ppm*			
		$N_{(1)}$	$N_{(2)}$	$N_{(3,4)}$	NO_2
I	1-Vinylindole	122,0	—	—	—
II	1-Vinylpyrazole	220,0 (199,4)	301,6 (301,7)	—	—
III	1-Vinyl-3-methylpyrazole	215,3	297,1	—	—
IV	1-Vinyl-4-nitropyrazole	219,9	301,3	—	358,9
V	1-Vinyl-4-bromopyrazole	225,6	310,0	—	—
VI	1-Vinyl-5-methylpyrazole	216,4	289,1	—	—
VII	1-Vinyl-3,5-dimethylpyrazole	211,5	290,6	—	—
VIII	1-Vinyl-3,5-dimethyl-4-nitropyrazole	211,8	288,0	—	363,5
IX	1-Vinylindazole	194,7 (177,4)	308,9 (323,7)	—	—
X	2-Vinylindazole	277,0 (287,6)	229,2 (219,3)	—	—
XI	1-Vinylimidazole	183,9 (158,3)	—	260,7 (252,2)	—
XII	1-Vinyl-2-methylimidazole	179,3	—	257,6	—
XIII	1-Vinylimidazole·HCl	187,7	—	179,2	—
XIV	1-Vinylbenzimidazole	164,0 (149,3)	—	245,1 (245,8)	—
XV	1-Vinyl-2-methylbenzimidazole	160,3	—	241,1	—
XVI	1-Vinyl-1,2,4-triazole	230,4 (228,3)	290,7 (329,5)	257,5 (261,1)	—
XVII	1-Vinyl-5-methyl-1,2,4-triazole	224,5	290,4	257,6	—
XVIII	1-Vinyl-3-vinylthio-1,2,4-triazole	225,9	277,2	249,5	—
XIX	1-Vinyl-3-vinylthio-5-methyl-1,2,4-triazole	.220,5	275,8	249,7	—
XX	2-Vinyl-5-nitro-1,2,3-triazole	331,6	258,9	317,4	351,7
XXI	1-Vinylbenzotriazole	232,7	372,4	342,3	—
XXII	2-Vinylbenzotriazole	309,2	269,9	309,2	—

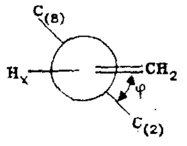
*The ^{15}N chemical shifts for the corresponding N-methylazoles are indicated in parentheses [1, 2].

TABLE 2. Parameters of the PMR and ^{13}C and ^{15}N NMR Spectra of N-Vinylazoles

Compound	$\Delta\delta_N$	$\Delta\delta_H$	$^2J_{AB}$	ΔJ	$^1J\ C_\alpha C_\beta$	$r_{N\cdots H}$	$\int N_\delta H_B$
s-cis- II	81,6	0,67	−1,2	4,6	77,7	2,72	0,025
s-trans- II						4,12	0,001
III	81,8	0,69	−1,1	4,9	—	—	—
IV	81,4	0,64	−1,7	4,6	—	—	—
V	84,4	0,69	−1,5	4,9	—	—	—
VI	72,7	0,85	−0,3	1,6	—	2,78	0,022
VII	79,1	0,84	−0,3	1,5	79,7	—	—
VIII	76,2	0,77	−0,6	1,3	—	—	—
s-cis-XI	76,8	0,41	−1,6	7,4	76,8	4,16	0,001
s-trans- XI						4,84	0
XII	78,3	0,31	−1,3	7,0	77,3	4,91	0
XVI	60,3	0,73	−1,2	3,4	77,8	—	—
XVII	65,9	0,74	−0,8	1,5	79,0	—	—
XVIII	51,3	0,72	−1,3	3,0	—	—	—
XIX	55,3	0,73	−0,9	1,6	—	—	—

the imidazole ring virtually does not perturb the coplanar position of the vinyl group and heterocycle [9]. As a consequence, the CS of the "pyrrole" $N_{(1)}$ atom is insensitive (or not very sensitive) to a change in the torsion angle φ at the N—C_α bond.

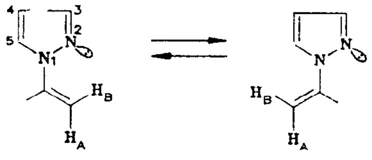




It follows from the data from comparing the CS of the $N_{(2)}$ atom in pyrazoles II and VI and III and VII that the methyl group in position 5 of the ring significantly affects the resonance of this atom through two bonds (strong-field shift of 7-12 ppm). In isostructural triazoles XVI-XIX, this group causes a shift of only the resonance of the

$N_{(1)}$ atom to the strong field, while the signal of the $N_{(2)}$ atom is shifted insignificantly (< 1.5 ppm, Table 1). The effect of the methyl group in pyridine and its derivatives on the CS of the nitrogen atom through two bonds (from the *meta* position) is also small (≤ 0.3 ppm) [6].

There is consequently a specific factor that affects the position of $N_{(2)}$ atom resonance in pyrazoles II-VIII. We previously showed that compounds II-V, unsubstituted in position 5, existing in a mixture of *s-cis-* and *s-trans-*conformers (A and B) relative to the $N_{(2)}$ atom. The steric effect of the methyl group in position 5 of the pyrazole ring shifts the conformational equilibrium to the *s-cis*-form [1, 2].



A B

The spatial proximity of the unshared pair of nitrogen atom electrons and the $C_\beta—H_B$ bond in the *s-cis*-conformation induces a change in the spectral parameters, which are a function of the stereoelectronic state of the $C_\beta—H_B$ bond: the CS of the H_B atom, SSCC $^2J_{AB}$, $^1J_{C_\beta H_B}$ and $^1J_{C_\alpha H_\beta}$ [1-4]. It is logical to predict that the *s-cis*-conformations of 1-vinylpyrazoles II-VIII in the ^{15}N NMR spectra exhibit the reverse effect: additional contribution to shielding of the $N_{(2)}$ atom due to the spatial proximity of the $C_\beta—H_B$ bond. For this reason, the increase in the population density of the *s-cis*-conformation in 5-methyl-substituted pyrazoles VI-VIII will decrease the CS of the $^{15}N_{(2)}$ nucleus. This is not observed for triazole derivatives XVI-XIX, since the conformational equilibrium is shifted toward the *s-cis*-form in 5-unsubstituted triazoles [7].

It is convenient to use the relative spectral characteristics to detect small contributions to the parameters of the NMR spectra. The relative CS of the "pyridine" and "pyrrole" nitrogen atoms ($\Delta\delta_N = \delta_{N_{(2)}} - \delta_{N_{(1)}}$) for 5-unsubstituted 1-vinylpyrazoles II-V varies from 81 to 84 ppm (see Table 2). In going to 5-methyl-substituted 1vinylpyrazoles VI-VIII, $\Delta\delta_N$ decreases to 73-79 ppm. $\Delta\delta_N$ increases by 1.5 ppm on incorporation of a methyl group in ring position 2 in 1-vinylimidazoles XI and XII, where the $N_{(3)}$ atom is spatially distant from the vinyl group (Table 2). In vinyltriazoles XVI-XIX, which primarily exist in the *s-cis*-conformation [7], incorporation of a methyl group in ring position 5 is also accompanied by an increase in $\Delta\delta_N$ by 4-5 ppm.

In comparing the $\Delta\delta_N$ parameters in azoles II-VIII, XI, XII, and XVI-XIX with the relative CS of the vinyl group β protons ($\Delta\delta_H = \Delta_{H_A} - \delta_{H_B}$), the difference in the $^{13}C—^1H$ SSCC lines of these protons ($\Delta J = {}^1J_{C_\beta H_A} - {}^1J_{C_\beta H_B}$), geminal SSCC between them ($^2J_{AB}$), and SSCC $^1J_{C_\alpha C_\beta}$, i.e., the parameters subject to the effect of the unshared electron pair of the nitrogen atom, the correlation of the change in these values is seen. An increase in $\Delta\delta_H$ by 0.15-0.20 ppm, a decrease in SSCC $^2J_{AB}$ by 1 Hz, in ΔJ by 3.0-3.5 Hz, and an increase in SSCC $^1J_{CC}$ by 2 Hz correspond to a decrease in $\Delta\delta_N$ by 5-8 ppm in going from pyrazoles II-V to 5-methylpyrazoles VI-VIII (Table 2).

The slight increase in $\Delta\delta_N$ in imidazole XI and triazoles XVI and XVIII in comparison to $\Delta\delta_N$ in their 2(5)-methyl-substituted analogs is accompanied by significantly smaller changes in $\Delta\delta_H$, $^2J_{AB}$, ΔJ, and $^1J_{CC}$ (Table 2). These changes could be related to an increase in the torsion angle φ at the $N—C_\alpha$ bond caused by the steric effect of the methyl group [10, 11].

The data presented suggest the positive contribution ($\sim$ 5-8 ppm) to the shielding constant of the $N_{(2)}$ atom with an increase in the population density of the *s-cis*-conformation of compound II-VIII due to the spatial proximity of the $C_\beta—H_B$ bond. This contribution could be the consequence of the specific reaction of the unshared electron pair of the $N_{(2)}$ atom and the H_B atom. A similar effect was observed in a series of vinyl ethers and sulfides of the pyridine series (quinolines) in [12, 13]. Changes in the chemical shift one order of magnitude greater were obtained in quaternization of the "pyridine" nitrogen atom in [14]. The signal of the $N_{(3)}$ atom is shifted to the strong field by 81.5 ppm in vinylimidazole hydrochloride XIII relative to the signal of imidazole XI, with shifting of the signal of the $N_{(1)}$ atom by only 3.8 ppm to the weak field (Table 1).

We performed a quantum chemical calculation of molecules II, VI, XI, and XII by the AM-1 method in [15] to establish the nature of the effect observed in the ^{15}N NMR spectra of 1-vinylpyrazoles II-VIII. According to the calculated data, two planar conformations — *s-cis-* and *s-trans-* (the energy of the first is 0.4 kcal/mole less) — are energetically advantageous for pyrazole II. In the *s-trans*-conformation of pyrazole II, the $H_B...N_{(2)}$ distance is 4.12 Å ($r_{N...H_B}$, Table 2). It decreases to 2.72 Å in the *s-cis*-conformation and becomes equal to the sum of the van der Waals radii of the hydrogen and nitrogen atoms (2.75 Å [16]). The uneven increase in the integral of overlap ($\int N_\delta H_H$) of the *s*-, p_x-, and p_y-orbitals of the $N_{(2)}$ atom, forming its unshared electron pair [17], and the *s*-orbital of the H_B atom from 0.001 to 0.025 (Table 2) corresponds to this. The electron cloud of the unshared pair of the $N_{(2)}$ atom in the *s-cis*-conformation of compound II is thus perturbed by overlapping with the *s*-orbital of the H_B atom, which should cause a change in the CS of the nucleus of the $^{15}N_{(2)}$ atom.

The equilibrium values of $r_{N...H_B}$ and $\int N_\delta H_B$ in methylpyrazole VI and in the *s-cis*-conformation of vinylpyrazole II are close, and the transition from molecule II to molecule VI can be considered equivalent to an increase in the population density of the *s-cis*-conformation in compound II.

The $N_{(3)}$ and H_B atoms in vinylimidazole XI are distant in both the *s-trans* ($N_{(3)}$) and in the *s-cis*($N_{(3)}$) conformations, while the value of the integral of overlapping is close to zero and virtually does not change (Table 2). A zero value of $\int N_\delta H_B$ was also obtained for methylimidazole XII. In agreement with this, no additional contribution to shielding of the $N_{(3)}$ atom is observed for imidazoles XI and XII.

It was thus found that the electronic effect of the substituent in the ring and the specific intramolecular interactions primarily act on the CS in the ^{15}N NMR spectra of N-vinylazoles.

EXPERIMENTAL

The ^{15}N NMR spectra of samples with a natural concentration of the isotope were recorded on a Bruker WP 200 SY spectrometer (20.28 MHz) (80% solution in $CDCl_3$ with addition of $Cr(acac)_3$ as a relaxation oscillator). The standard was 1 *M* $H^{15}NO_3$ in D_2O. The values of the CS are reported on the NH_3 scale. From 5000 to 15,000 free induction decay accumulations were required for obtaining the ^{15}N NMR spectrum. Synthesis of the N-vinylazoles investigated is described in [17, 18].

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