PMR SPECTRA OF 2-SUBSTITUTED PYRAZINES AND THE CORRESPONDING PYRAZINE N-OXIDES AND N,N'-DIOXIDES

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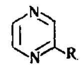
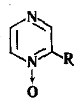
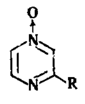
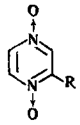
The PMR spectra of pyrazine, its 2-substituted derivatives, and the corresponding N-oxides and N,N'-dioxides were investigated. The character of the change in the chemical shifts in the N-oxides and N,N'-dioxides of unsubstituted pyrazine indicates the electron-donor effect of the N→O group. An additive effect of the N→O groups on the chemical shifts of the ring protons is observed in pyrazine N,N'-dioxide. An appreciable interaction of the substituent with the $N_{(1)} \rightarrow O$ group and a weak interaction with the $N_{(4)} \rightarrow O$ group occur in N-oxides and N,N'-dioxides of 2-substituted pyrazines. A significant increase in the ortho and meta spin–spin coupling constants of the ring protons is noted when the nitrogen atoms are oxidized. The sign of the spin–spin coupling constant (J_{35}) through the N→O group was determined.

The PMR spectra of aromatic nitrogen-containing heterocycles and their N-oxides are of interest as a source of information regarding the electronic structures of molecules of these compounds and the character of the transfer of electronic effects in them. A complete analysis of the spectra has been carried out for some 2-substituted pyrazines [1]. The chemical shifts (CS) and spin–spin coupling constants (SSCC) of eight pyrazine derivatives were compared with the analogous parameters in series of monosubstituted benzenes and 2-substituted pyrazines [2, 3]. It seemed of interest to us to compare the PMR spectra of pyrazine (Ia), 2-substituted pyrazine derivatives (Ib-k) and the corresponding N-oxides and N,N'-dioxides (IIIc-g, IIIc-j, and IVa-g).


Ia-h


IIa, c-g


IIIa, c-j


IVa-g

a R=H, b CH_3, c NH_2, d $NHCOCH_3$, e F, f Cl, g OCH_3, h $CONH_2$, i COOH, j $COOCH_3$, k CN

The CS of the ring protons of pyrazine (Ia) depend only slightly on the nature of the solvent (Table 1). However, transition from slightly polar solvents of the $CDCl_3$ type to the more polar dimethyl sulfoxide (DMSO) and, particularly, to proton-donor solvents D_2O and CD_3OD leads to more appreciable differences in the CS of N-oxides and N,N'-dioxides of unsubstituted pyrazines (IIa and IVa), which is apparently associated with the pronounced tendency of N-oxides to form hydrogen bonds in D_2O and CD_3OD or associates in DMSO. In addition, the changes in the CS in the investigated compounds, which are caused by intermolecular interactions with the solvents, are small, and this makes it possible to compare the results obtained in various solvents.

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TABLE 1. Chemical Shifts* of the Ring Protons of Ia, IIa, and IVa

Solvent	Ia	IIa		IVa
	$\delta_{H_{(2)}}=\delta_{H_{(3)}}==\delta_{H_{(5)}}=\delta_{H_{(6)}}$	$\delta_{H_{(2)}}=\delta_{H_{(6)}}$	$\delta_{H_{(3)}}=\delta_{H_{(5)}}$	$\delta_{H_{(2)}}=\delta_{H_{(3)}}==\delta_{H_{(5)}}=\delta_{H_{(6)}}$
$CDCl_3$	8,62	8,12	8,50	8,02
CH_3CN	8,59	8,10	8,43	8,00
CH_2Cl_2	—	—	—	8,01
CD_3OD	8,64	8,33	8,60	8,29
D_2O	8,58	8,32	8,62	8,37
$(CH_3)_2SO$	8,63	8,32	8,62	8,24
0,1 *N* NaOD	8,57	8,34	8,64	8,42
0,2 *N* NaOD	8,57	8,34	8,64	8,39
0,1 *N* DCl	—	8,39	8,72	8,39
0,2 *N* DCl	—	8,46	8,69	8,38
CF_3COOH	9,40	8,83	8,95	8,82

* δ in parts per million.

The possibility of partial protonation of pyrazine N-oxides in proton-donor solvents is apparently excluded, since IIa and IVa are very weak bases. The absence of protonation is experimentally confirmed by the fact that the CS of the ring protons of pyrazine N-oxides in proton-donor solvents and in aqueous NaOD solutions practically coincide. A substantial change in the CS is observed in aqueous DCl and trifluoroacetic acid solutions.

The introduction of an N-oxy group into the pyrazine ring leads to a pronounced positive* shift of the signal of the α protons and to a considerably smaller positive or even small negative shift of the signals of the β protons (Table 2, IIa and IVa). Similar data are also presented in the literature for the N-oxides of pyridine [4], pyrimidine [5], and pyridazine [6]. In the case of these N-oxides, a proton is also available in the γ position: for it, the effect is similar in character to that observed for the α proton but somewhat lower in magnitude. In all cases, the magnitude of the positive contribution to the CS of the protons due to the effect of the N→O group increases as the solvent polarity decreases. This sort of effect in general indicates electron-donor character of the N→O group, but the possibility of a contribution of magnetic anisotropy to the observed CS and of the effect of the electric field of the N-oxy group cannot be excluded. An increase in the polarization of the N→O bond in polar solvents, which occurs due to intermolecular interactions, apparently leads primarily to a decrease in the electron-donor effect of the N→O group. This is in agreement with the direction of the shift of the CS and the retention of their sequence in all solvents $(\delta_{H_\alpha} > \delta_{H_\gamma} > \delta_{H_\beta})$

Additivity of the effect of the N→O groups on the CS of ring protons is observed in IVa: the overall effect of two N→O groups in IVa on each proton coincides with the sum of the effects of each N→O group on this proton, which are found from the CS of IIa. This apparently attests to extremely weak interaction of the N→O groups in the compound under consideration.

The relative CS of the ring protons in Ib-k (Table 2) reflect the effect of the substituent on the CS of the protons of the pyridine ring $-H_{(3)}$, $H_{(6)}$, and $H_{(5)}$ (o-, m-, and p-protons with respect to the substituent). These effects are generally in good agreement with the donor-acceptor properties of the substituent. They have positive signs for donor substituents and negative signs for acceptor substituents, precisely as is observed in other aromatic systems. A comparison of the effect of the substituents on the CS for a number of pyrazines with similar effects in a series of monosubstituted benzenes [8] and 2-substituted pyrazines [9] demonstrates that the effects on $H_{(5)}$ are closest in all three rings; the effects on $H_{(3)}$ coincide to almost the same degree, while $H_{(6)}$ experiences the greatest deviations in the magnitudes of the effects.

The observed considerable shift to weak field of the $H_{(3)}$ signal (o-proton with respect to the $-NHCOCH_3$ substituent) in Id cannot be explained from the point of view of the donor-acceptor properties of this group. On the basis of the available literature data, this effect should be associated with the effect of the anisotropy of the carbonyl group [7]. The same sort of deshielding effect is also observed in IId, IIId, and IVd, which contain an $NHCOCH_3$ group as a substituent.

The CS of N-oxides and N,N'-dioxides (II-IV) and of the 2-substituted pyrazines themselves (Ib-g) relative to the CS of Ia characterize the experimental additive effect of the substituent and the N→O group

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*We will call the shift of the proton signal to strong field a positive shift, and a shift to weak field with respect to the signals of unsubstituted pyrazine will be called a negative shift.

on the CS of the ring protons (Table 2). If one proceeds from the assumption of independent action of the N → O group and of the substituent on the ring protons, the additive effect can be calculated on the basis of data obtained from the spectra of Ib–j and IIa. The values calculated according to this additive scheme are compared with the experimental values in Table 2. An examination of the results demonstrates that general good agreement between the experimental and additively calculated data is observed for all of the protons in IIIc–j. This fact reflects the slight interaction of the $N_{(4)} \rightarrow O$ group and the substituent in the 2-position.

A different situation is observed for IIIc–g and IVb–g. In these compounds, significant deviations from additivity occur for the $H_{(3)}$ and $H_{(6)}$ protons – the experimental effects are less than the values cal-

TABLE 2. Chemical Shift (CS) of the Protons of I–IV Relative to the CS of Ia

Solvent	R	I			II					
					$\Delta\delta_{H_{(3)}}$		$\Delta\delta_{H_{(5)}}$		$\Delta\delta_{H_{(6)}}$	
		$H_{(3)}$	$H_{(5)}$	$H_{(6)}$	exptl.	add.	exptl.	add.	exptl.	add.
D_2O	H	0,00	0,00	0,00	−0,04		−0,04		+0,26	
$(CH_3)_2SO$	H	0,00	0,00	0,00	+0,10		+0,10		+0,31	
$CDCl_3$	H	0,00	0,00	0,00	+0,12		+0,12		+0,50	
D_2O	CH_3	+0,15	+0,24	+0,19						
$(CH_3)_2SO$	CH_3	+0,07	+0,23	+0,16						
D_2O	NH_2	+0,74	+0,91	+0,76	+0,33	+0,66	+0,81	+0,80	+0,56	+0,97
$(CH_3)_2SO$	NH_2	+0,69^1	+0,92^1	+0,73^1	+0,47	+0,79	+0,90	+1,03	+0,49	+1,04
D_2O	$NHCOCH_3$	−0,42	+0,30	+0,28	−0,83	−0,46	+0,33	+0,27	+0,28	+0,55
$(CH_3)_2SO$	$NHCOCH_3$	−0,72	+0,34	+0,34	−0,81	−0,68	+0,42	+0,30	+0,25	+0,60
$(CH_3)_2SO$	F	−0,10^1	−0,07^1	+0,21^1						
D_2O	Cl	−0,03	+0,04	+0,17	−0,23	−0,07	+0,16	+0,01	+0,08	+0,43
$(CH_3)_2SO$	Cl	−0,08^1	+0,03^1	+0,17^1	−0,25	+0,02	+0,13	+0,13	+0,08	+0,36
$CDCl_3$	Cl	−0,01	+0,20	+0,10	+0,02	+0,11	+0,25	+0,32	+0,38	+0,60
D_2O	OCH_3	+0,38	+0,47	+0,47	+0,03	+0,39	+0,37	+0,44	+0,29	+0,48
$(CH_3)_2SO$	OCH_3	+0,32^1	+0,41^1	+0,41^1	+0,14	+0,42	+0,46	+0,51	+0,28	+0,68
$CDCl_3$	OCH_3	+0,32	+0,48	+0,50	+0,35	+0,51	+0,44	+0,62	+0,46	+1,03
D_2O	$CONH_2$	−0,51	−0,18	−0,11						
$(CH_3)_2SO$	$CONH_2$	−0,63^1	−0,27^1	−0,12^1						
D_2O	COOH	−0,65	−0,22	−0,18						
$(CH_3)_2SO$	COOH	−0,55	−0,19	−0,15						
D_2O	$COOCH_3$	−0,59	−0,21	−0,11						
$(CH_3)_2SO$	$COOCH_3$	−0,59^1	−0,31^1	−0,23^1						
$CDCl_3$	$COOCH_3$	−0,71	−0,18	−0,12						
D_2O	CN	−0,44	−0,25	−0,20						
$(CH_3)_2SO$	CN	−0,35	−0,28	−0,22						
$CDCl_3$	CN	−0,34	−0,30	−0,13						

TABLE 2. (Continued)

Solvent	R	III					
		$\Delta\delta_{H_{(3)}}$		$\Delta\delta_{H_{(5)}}$		$\Delta\delta_{H_{(6)}}$	
		exptl.	add.	exptl.	add.	exptl.	add.
D_2O	H	+0,26		+0,26		−0,04	
$(CH_3)_2SO$	H	+0,31		+0,31		+0,10	
$CDCl_3$	H	+0,50		+0,50		+0,12	
D_2O	CH_3						
$(CH_3)_2SO$	CH_3						
D_2O	NH_2	+0,90	+0,96	+1,03	+1,17	+0,60	+0,72
$(CH_3)_2SO$	NH_2	+1,16	+1,00	+1,27	+1,23	+0,83	+0,83
D_2O	$NHCOCH_3$	−0,35	−0,11	+0,54	+0,56	+0,33	+0,24
$(CH_3)_2SO$	$NHCOCH_3$	−0,28	−0,41	+0,65	+0,65	+0,39	+0,44
$(CH_3)_2SO$	F						
D_2O	Cl	+0,02	+0,23	+0,32	+0,30	+0,12	+0,13
$(CH_3)_2SO$	Cl						
$CDCl_3$	Cl	+0,45	+0,49	+0,62	+0,70	+0,36	+0,22
D_2O	OCH_3	+0,63	+0,64	+0,68	+0,73	+0,42	+0,42
$(CH_3)_2SO$	OCH_3	+0,65	+0,32	+0,68	+0,72	+0,52	+0,52
$CDCl_3$	OCH_3	+0,87	+0,82	+0,91	+0,98	+0,65	+0,62
D_2O	$CONH_2$	−0,21	−0,25	+0,13	+0,08	−0,09	−0,16
$(CH_3)_2SO$	$CONH_2$						
D_2O	COOH	−0,25	−0,39	+0,13	+0,04	−0,11	−0,22
$(CH_3)_2SO$	COOH	+0,05	−0,30	+0,18	+0,12	+0,00	−0,05
D_2O	$COOCH_3$	−0,32	−0,33	+0,07	+0,05	−0,14	−0,16
$(CH_3)_2SO$	$COOCH_3$	−0,03	−0,28	+0,09	+0,00	−0,01	−0,13
$CDCl_3$	$COOCH_3$	−0,13	−0,21	+0,41	+0,32	+0,07	+0,00
D_2O	CN						
$(CH_3)_2SO$	CN						
$CDCl_3$	CN						

TABLE 2. (Continued)

Solvent	R	IV								
		$\Delta\delta_{H(3)}$			$\Delta\delta_{H(5)}$			$\Delta\delta_{H(6)}$		
		exptl.	add.	add.A	exptl.	add.	add. A	exptl.	add.	add.A
D_2O	H	+0,21	+0,22		+0,21	+0,22		+0,21	+0,22	
$(CH_3)_2SO$	H	+0,40	+0,41		+0,40	+0,41		+0,40	+0,41	
$CDCl_3$	H	+0,61	+0,62		+0,61	+0,62		+0,61	+0,62	
D_2O	CH_3	+0,12	+0,38		+0,33	+0,50		+0,20	+0,45	
$(CH_3)_2SO$	CH_3	+0,19	+0,46		+0,47	+0,63		+0,34	+0,56	
D_2O	NH_2	+0,51	+0,95	+0,59	+0,88	+1,12	+1,07	+0,41	+0,97	+0,51
$(CH_3)_2SO$	NH_2	+0,85	+1,09	+0,78	+1,06	+1,32	+1,21	+0,50	+1,13	+0,60
D_2O	$NHCOCH_3$	−0,70	−0,21	−0,57	+0,47	+0,51	+0,59	+0,16	+0,49	+0,24
$(CH_3)_2SO$	$NHCOCH_3$	−0,37	−0,30	−0,50	+0,56	+0,74	+0,73	+0,21	+0,74	+0,35
$(CH_3)_2SO$	F									
D_2O	Cl	−0,22	+0,18	+0,03	+0,25	+0,25	+0,42	+0,08	+0,38	+0,04
$(CH_3)_2SO$	Cl	−0,29	+0,32	+0,06	+0,36	+0,43	+0,44	+0,16	+0,57	+0,18
$CDCl_3$	Cl									
D_2O	OCH_3	+0,15	+0,59	+0,29	+0,41	+0,68	+0,73	+0,18	+0,68	+0,25
$(CH_3)_2SO$	OCH_3									
$CDCl_3$	OCH_3									
D_2O	$CONH_2$									
$(CH_3)_2SO$	$CONH_2$									
D_2O	COOH									
$(CH_3)_2SO$	COOH									
D_2O	$COOCH_3$									
$(CH_3)_2SO$	$COOCH_3$									
$CDCl_3$	$COOCH_3$									
D_2O	CN									
$(CH_3)_2SO$	CN									
$CDCl_3$	CN									

TABLE 3. Spin–Spin Coupling Constants in I–IV (Hz)

Solvent	R	I			II			III			IV		
		J_{35}	J_{36}	J_{56}	J_{35}	J_{36}	J_{56}	J_{35}	J_{36}	J_{56}	J_{35}	J_{36}	J_{56}
$CDCl_3$	H	0,5[6]	1,8[6]	1,8[6]	0,38[3]	0,83[3]	4,1[3]	1,75[3]	0,83[3]	4,1[3]			
D_2O	CH_3	<0,5	1,5	2,6							2,5	0,8	5,6
$(CH_3)_2SO$	CH_3		1,5	2,6							2,5		5,6
$CDCl_3$	CH_3	−0,20[1]	1,48[1]	2,56[1]									
D_2O	NH_2	<0,5	1,3	2,8	<0,5	0,8	4,2	1,8	0,8	4,0	2,5		5,5
$(CH_3)_2SO$	NH_2	−0,21[1]	1,54[1]	2,77[1]	<0,5	0,8	4,2	1,8	0,8	4,2	2,5		5,5
D_2O	$NHCOCH_3$		1,1	2,5	<0,5	0,5	4,0	1,6	0,8	4,1	2,5		6,0
$(CH_3)_2SO$	$NHCOCH_3$				<0,5	0,5	4,0	1,6	0,6	4,2	2,6		5,5
$(CH_3)_2SO$	F	−0,46[1]	1,33[1]	2,67[1]									
D_2O	Cl	0,3	1,2	2,4	<0,5	0,8	4,5	1,4	0,7	4,2	2,7	0,5	5,8
$(CH_3)_2SO$	Cl	−0,40[1]	1,43[1]	2,61[1]		0,7	4,0	1,5	0,6	4,2	2,7	0,5	5,8
$CDCl_3$	Cl					0,6	4,0						
D_2O	OCH_3				<0,5	0,7	4,0	1,5	0,7	4,2	2,4	0,5	5,5
$(CH_3)_2SO$	OCH_3	−0,35[1]	1,40[1]	2,86[1]		0,7		1,5	0,8	4,0			
$CDCl_3$	OCH_3		1,0	2,3			4,0	1,6	0,8	4,2			
D_2O	$CONH_2$		1,5	2,5									
$(CH_3)_2SO$	$CONH_2$	−0,01[1]	1,51[1]	2,49[1]									
D_2O	COOH							1,5		4,0			
$(CH_3)_2SO$	COOH		1,3	2,5				1,8	0,7	4,2			
D_2O	$COOCH_3$		1,3	2,5				1,7	0,8	4,0			
$(CH_3)_2SO$	$COOCH_3$	−0,30[1]	1,49[1]	2,43[1]				1,7	0,8	4,0			
$CDCl_3$	$COOCH_3$		1,3	2,5				1,7	0,8	4,0			
D_2O	CN		1,3	2,7									
$(CH_3)_2SO$	CN		1,3										
$CDCl_3$	CN		1,3	2,3									

culated from the additive scheme. This result can be explained by interaction of the substituent in the 2 position with the N→O group. In the series of compounds that we investigated, there were only substituents that interacted with the N→O group as electron donors, and the latter was an acceptor. Owing to this, the electron-donor effect of substituents on the ring protons was weakened. It can be expected that a similar interaction should also occur in the case of electron-acceptor substituents, and, in this case, the N→O group, which is known to have dual character in electron interactions, will be a donor.

It is interesting to note that the agreement between the calculated and experimental data for the cis proton in the investigated compounds continues to remain quite satisfactory. This circumstance may indicate a change primarily in the inductive properties of the groups that interact with one another and a relatively small change in their resonance action. Moreover, the protons in the 3 and 6 positions, which are in direct proximity to the interacting groups, should experience a greater deviation from additivity than the protons in the 5 position, for which the resonance effect predominates. In addition, one should

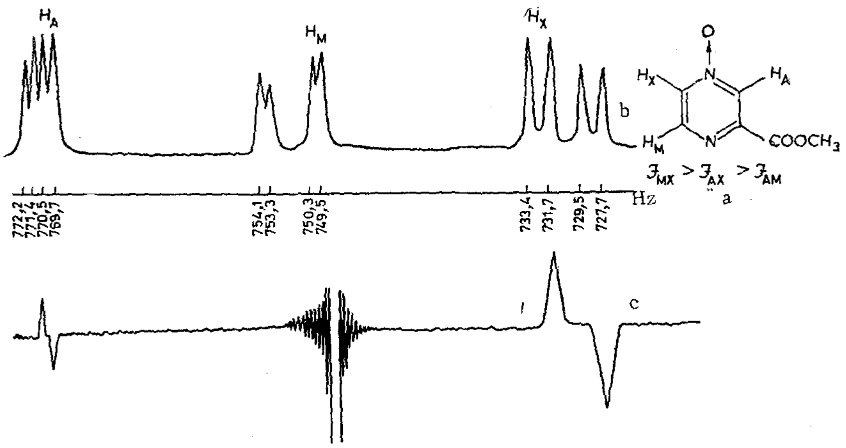

Fig. 1. Assignment of the lines in the PMR spectrum of 2-carbomethoxypyrazine 4-N-oxide (IIIj) (a, b); INDOR spectrum of IIIj (c).

bear in mind that the CS of the $H_{(3)}$ and $H_{(5)}$ protons may also be partially determined by the change in the magnetic anisotropy of the N→O group and of the substituents in the 2 position as a result of a change in the electron distribution in these groups during their interaction. It is obvious that an influence of this type should primarily affect the CS of the protons in the 3 and 6 positions and, to a small degree, the far-removed proton in the 5 position.

A somewhat different approach to an evaluation of the overall effects can be used in IVb-f. Using the experimental additive effects of the substituent and the $N_{(1)} \rightarrow O$ group on the ring protons in IIb-f and the effects of the N→O group on the ring protons as a basis, from the PMR data on IIa one can calculate the overall effect of the N→O groups and the substituent via a new additive scheme (additive A), in which the interacting R and $N_{(1)} \rightarrow O$ groups are considered to be a single substituent. This sort of approach leads to a considerable improvement in the agreement between the effects for $H_{(3)}$ and $H_{(6)}$. The effects calculated by both additive schemes do not differ too much for $H_{(5)}$. In addition, it is necessary to note that, for general satisfactory agreement between the experimental and additively calculated values in 4-N-oxides, there are some deviations that, in individual cases, exceed the experimental error. Thus the additive effects are somewhat lower for all −C substituents in D_2O, and somewhat lower than the experimental values for +C substituents. This attests to weak interaction of the $N_{(4)} \rightarrow O$ group with the 2-substituent and dual character of this group: when there is a donor substituent in the ring, $N_{(4)} \rightarrow O$ acts as a weak acceptor, but when there is an acceptor substituent in the ring, this group acts as a weak donor. (It should be noted that when DMSO is used as a solvent, this effect is completely absent in the case of donor substituents.) In the case of the available +C substituents, an interaction of this sort is also noted in N,N'-dioxides.

Effects of quadrupole broadening of the lines due to interaction with the nitrogen atom are observed in all of the spectra of I-IV; in a number of cases, this reduces the accuracy in the measurement of the spin–spin splittings of the protons in direct proximity to the nitrogen. The presence of an oxygen atom attached to nitrogen to a considerable extent eliminates this quadrupole broadening. Resolution made it possible to determine the SSIC starting at 0.5 Hz.

An examination of our results and the literature data [1, 6, 3] (Table 3) demonstrates that the ortho constant (J_{56}), which is 2.5-2.7 Hz in Ib-k, increases to 4.2-4.5 Hz when one N→O group is introduced into the ring and to 5.0-6.0 Hz in the presence of two N→O groups. The constant through the heteroatom (J_{35}) ranges from 0 to 0.5 Hz in Ib-k and IIc-g, increases to 1.5-1.8 Hz in IIIc-j, and increases to 2.5 Hz in IVb-g. The para constant (J_{36}), which ranges from 1.3-1.5 Hz in Ia-k, decreases to 0.5-0.8 Hz in IIIc-g and apparently remains the same in IVb-g. The same character in the change in analogous constants on passing from nonoxidized to N-oxidized rings is observed also in the pyridine [4], pyridazine [6], and pyrimidine [5] series.

The transfer of spin–spin coupling through both σ and π bonds should be taken into account in considering the SSIC between protons in aromatic rings. The theoretical calculations of MacConnell for benzene and naphthalene result in the fact that transfer of the interaction along the σ bonds predominates for the ortho and meta constants, while transfer by means of π bonds is characteristic for the para constant [10, 11]. From this point of view, the considerable increase in J_{56} in II and III and of J_{35} in III (in comparison with I), as well as the absence of changes in J_{35} in II, can be considered to be an indication of the strong perturbation of the σ framework of the molecule by the $N \rightarrow O$ group in direct proximity to the latter. When a second $N \rightarrow O$ group is added to the pyrazine ring, the J_{35} and J_{56} constants increase more, and J_{36}, like the para constant, decreases. The latter may be evidence for a decrease in the delocalization of the π electrons in the ring in the order pyrazine > N-oxide > N,N'-dioxide. It is possible that these effects are also partially associated with a change in the geometry of the molecules in connection with the presence of $N \rightarrow O$ groups.

The effect of the $N \rightarrow O$ group on the SSIC is manifested not only in the magnitude of the constants but also in their signs. The determination of the signs of the constants in benzene demonstrated that the signs of J_{HH}^{ortho} and J_{HH}^{meta} are the same in all cases and are positive. In 2-substituted pyrazines the J_{35} constant through the nitrogen atom has a negative sign [1], just as J_{26} in pyridine [3]. In the present paper, we determined the sign of J_{35} in IIIj, the signals of the protons of which form a degenerate AMX system. The INDOR method [12] was used to determine the signs of the constants in IIIj. The assignment of the lines in the PMR spectrum of IIIj and the INDOR spectrum of this compound are shown in Fig. 1. The interpretation of the results obtained on the basis of an examination of the AMX energy levels and the results of INDOR demonstrates that a set of SSCC with the same signs is realized ($\pm J_{56} \pm J_{35} \pm J_{36}$). Taking into account the usual assumption of the positive sign of the vicinal J_{56} constant, it can be concluded that the sign of J_{35} is positive. These results confirm the assumption of the positive sign of the constant through the $N \rightarrow O$ group that was made on the basis of an analysis of the spectrum of pyrazine N-oxide [3]. Thus the oxidation of the ring nitrogen leads to reversal of the sign of the J_{35} constant through the nitrogen atom.

EXPERIMENTAL

The PMR spectra of up to 5% solutions of the investigated compounds were obtained with a JNM-4H-100 spectrometer with an operating frequency of 100 MHz. The solvents were D_2O and perdeuterated dimethyl sulfoxide (d_6-DMSO). The internal standard in D_2O and NaOD and DCl solutions was dioxane [δ 3.70 ppm relative to tetramethylsilane (TMS)], and the internal standard in DMSO was TMS.

The CS relative to TMS are presented in Table 1. The spectra of Ib-j, IIc-g, and IIIb-g are readily interpreted as an ABX or AMX system. The spectra of Ia and IVa give singlet signals. The spectrum of IIa is interpreted as an AA'XX' system in which the centers of the multiplets corresponding to the AA' and XX' portions of the spectra are taken as the CS of the protons. The mean-experimental errors in the determination of the CS and SSIC were ± 0.05 ppm and ± 0.2 Hz, respectively.

A change in the intensity of the component of the quartet corresponding to the $H_{(6)}$ signal at ν_1 4749.5 Hz was observed in the spectrum obtained as a result of INDOR. The double resonance frequency (ν_2) changed synchronously with time with the scanning of the recording device. An increase in intensity was observed at distances of +17.8 and −21.0 Hz, while a decrease in intensity was observed at distances of +21.8 and −20.2 Hz from the central beat, which corresponds to a line position of 749.5 Hz.

The results of chemical analysis of the previously unreported compounds, the synthesis of which will be described in subsequent papers, are presented below. 2-Chloropyrazine 1,4-N,N'-dioxide had mp 191-192°C (dec.). Found: C 32.4; H 2.1; N 19.1%. $C_4H_3ClN_2O_2$. Calculated C 32.7; H 2.1; N 19.1%. 2-Methoxypyrazine 1-N-oxide had mp 150-151°. Found: C 47.9; H 4.74; N 22.1%. $C_5H_6N_2O_2$. Calculated: C 47.6; H 4.8; N 22.2%. 2-Methoxypyrazine 1,4-N,N'-dioxide had mp 181.5-182.0° (violent decomposition). Found: C 42.4; H 4.4; N 19.7%. $C_5H_6N_2O_3$. Calculated: C 42.2; H 4.2; N 19.7%.

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