Tetrahedron. Vol. 26, pp. 1261 to 1265. Pergamon Press 1970. Printed in Great Britain

INTRAMOLECULAR HYDROGEN BONDS

INFRARED SPECTRA OF THIOPYRIDINECARBOXY-ANILIDES AND OF THIOBENZAMIDO-PYRIDINES

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Received in the UK 2 *May* 1969; *Accepted for publication* 29 *October* 1969

Abstract—The difference in frequencies ($\Delta\nu$) between the absorption of free and intramolecularly bonded N—H groups has been given for (3- and 4-thiopyridinecarboxy) anilides, thiobenzamido-pyridines, and (2-thiopyridinecarboxy) anilides. The geometry of the 5-membered chelate ring of N-oxides of 2-acylamino-pyridines; and S-oxides of thiobenzanilides, (2-pyridinecarboxy) anilides and (2-thiopyridinecarboxy) anilides is discussed.

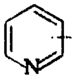
INFRARED spectra of organic compounds with intramolecular H-bonds generally reveal two bands in the proton-donor stretching vibration range. One of the bands is related to a free proton donating group A—D—H and the other to an intramolecular H-bond $\overline{\text{D—H}\cdots\text{A}}$.[1, 2] If only one band occurs, it can be attributed to either cause, as the other is probably absent.[3–5] In order to avoid wrong conclusions, the spectra of isomeric or related compounds (Tables 1 and 2) should be analysed. For example Glaznewa *et al.*[6] claim that no H-bond exists in (2-thiopyridinecarboxy) anilides but this is probably incorrect as a comparative study in the present work leads to a different result.

The difference $\Delta\nu$ between the position of the bands is a well known measure of the H-bond strength and depends on the size of the chelate ring.[1, 2, 7, 8] For example

TABLE 1. $\nu_{\text{N H}-}$ DATA FOR MOLECULES WITH AN INTRAMOLECULAR HYDROGEN BOND AND A SINGLE BAND IN THE $\nu_{\text{N H}-}$ REGION (B) AND FOR RELATED MOLECULES WITH NO INTRAMOLECULAR HYDROGEN BONDS (F).

Compound	ν N—H cm^{-1}	$\Delta\nu$ N—H cm^{-1} between compounds (F) and (B)	Ref.
2-Acylamino-pyridine (F) 1-Oxide-4-acylamino-pyridine (F)	3410–3440	~145	3
1-Oxide-2-acylamino-pyridine (B)	3280		
(3- or 4-Pyridinecarboxy)-anilides (F) 2-, 3- or 4-Benzamido-pyridines (F)	3424–3442	~ 95	5
(2-Pyridinecarboxy)-anilides (B)	3325–3350		
(3- or 4-Thiopyridinecarboxy)-anilides (F) 2-, 3- or 4-Thiobenzamido-pyridines (F)	3366–3388	~140	this work
(2-Thiopyridinecarboxy)-anilides (B)	3234–3242		
Thiobenzanilides (F)	3383–3385	~140	4
S-oxides of thiobenzanilides (B)	3245		

Table 2. IR spectral data and the results of analyses for thiopyridinecarboxy-anilides and for thiobenzamido-pyridines.

	 ZR				Analyses	
No.	Z = CSNH-	ν N—H cm^{-1}	I[a]	M.p. C°	% N calc.	% N obt.
I	2-Z-C_6H_5	3236[b] 3236[c, d]	192 ± 2	52[6]	13·07	13·15
II	2-Z-$C_6H_4OCH_3$ (*p*)	3242[b] 3240[c]	210 ± 2	102[6, 9]	11·47	11·51
III	2-Z-$C_6H_4OC_2H_5$ (*m*)	3234[b]	200 ± 2	52– 53	10·86	11·02
IV	2-Z-$C_6H_4OC_2H_5$ (*p*)	3242[b] 3240[c]	210 ± 3	83[6, 9]	10·86	10·91
V	2-Z-C_6H_4Cl (*p*)	3235[b] 3235[c]	201 ± 1	88– 89	11·26	11·32
VI	2-Z-C_6H_4Br (*p*)	3234[b] 3232[c]	202 ± 2	95	9·56	9·67
VII	3-Z-C_6H_5	3387[b]	104 ± 3	124–125	13·07	13·20
VIII	3-Z-$C_6H_4OC_2H_5$ (*o*)	3368[b]	104 ± 2	112–113	10·87	11·12
IX	3-Z-$C_6H_4OC_2H_5$ (*m*)	3388[b] 3388[c]	110 ± 2	83– 84	10·86	11·01
X	4-Z-$C_6H_4OCH_3$ (*p*)	3386[b] 3386[c]	100 ± 2	167–168[9]	11·47	11·59
	Z = -NHCS-					
XI	2-Z-C_6H_5	3370[b] 3368[c]	100 ± 3	147–148	13·07	13.25
XII	2-Z-$C_6H_4OCH_3$ (*p*)	3373[b] 3372[c]	104 ± 2	137–139	11·47	11·70
XIII	2-Z-$C_6H_4OC_2H_5$ (*m*)	3366[b] 3366[c]	101 ± 2	112–113	10·86	10·98
XIV	2-Z-$C_6H_4OC_2H_5$ (*p*)	3373[b]	99 ± 3	123	10·86	10·93
XV	2-Z-C_6H_4Cl (*p*)	3369[b] 3369[c]	110 ± 2	127	11·26	11·52
XVI	3-Z-$C_6H_4OC_2H_5$ (*o*)	3370[b] 3369[c]	108 ± 3	112–113	10·86	11·03
XVII	4-Z-$C_6H_4OC_2H_5$ (*m*)	3370[d]	103 ± 2	163–164	10·86	10·89

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[a] An average of six integrations by a planimeter.

[b] Concentration $-5\cdot10^{-3}$ mole/litre in chloroform; NaCl cell; thickness of layer – 1·02 mm; temp – 30°.

[c] Concentration $-5\cdot10^{-5}$ moles in 0·5 ml $CHCl_3$; cell length – 0·27 mm.

[d] Concentration $-5\cdot10^{-5}$ moles in 2 ml $ChCl_3$; cell length – 0·27 mm.

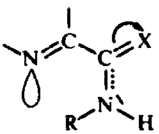
molecules with a 6-membered chelate ring show a larger difference $\Delta\nu$ than 5-membered rings,[1, 2] although there are exceptions to this rule.[8] Very detailed studies are known for the case of an OH as the proton donating group. In the present work we are concerned with thiopyridinecarboxy-anilides and thiobenzamido-pyridines. (2-Thiopyridinecarboxy) anilides can form a 5-membered ring which involves an H-bond (Table 3). In this case the N—H group is the proton-donor whereas pyridine nitrogen is the acceptor.

RESULTS AND DISCUSSION

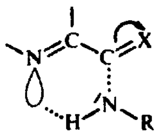
Spectra of all the compounds studied show, at a concentration of 0·005 mole/litre, a single and almost symmetrical band (Table 2). At higher concentrations (ca. 0·1 mole/litre), the spectra of compounds VII–XVII reveal a new flat and broad band (3190–3210 cm^{-1}). The additional band is certainly related to the intermolecular H-bond.

The compounds I–XVII in Table 2 have been divided into two groups, the first involves the compounds I–VI, in which $\nu_{N-H} \sim 3237 \pm 5\ \text{cm}^{-1}$ and $I \sim 201 \pm 9$, and for the second group, $\nu_{N-H} \sim 3377 \pm 11\ \text{cm}^{-1}$ and $I \sim 111 \pm 12$. The first group consists of molecules with an H-bond closing a 5-membered chelate ring and in the second group, no intramolecular H-bond seems to be possible. The difference, $\Delta\nu_{N-H} \sim 140\ \text{cm}^{-1}$, agrees well with that observed for other series (Table 1).

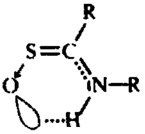
Several correlations have been made between the basicity of the proton acceptor and $\Delta\nu$ which serves as a measure of the H-bond strength.[1, 8b, 10] For intramolecular H-bonding, however, added complications due to steric effects have to be considered.[2, 8] The N-derivatives of amides and thioamides can have both a *cis* (1) and a *trans* (2) configuration. In the case of thioamides the *trans* form is predominant.[11] The intramolecular H-bonding stabilizes the *trans* form (2) of (2-pyridinecarboxy) anilides and (2-thiopyridinecarboxy) anilides, but the *cis* form (3) stabilizes the S-oxides of thiobenzanilides.[4]



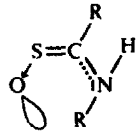
cis
1



trans
2



cis
3



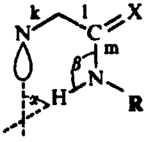
trans
4

In all cases the chelate ring is likely to be planar, favouring the quantitative formation of a 5-membered ring. A further stabilization of the ring is caused by the contribution of the resonance structure (5), as is the case in *o*-hydroxyacetophenone.[12, 13] An eventual increase in the basic character of the pyridine N atom would result in tautomeric equilibrium (5) ⇄ (6), in a close anology to formazanes.[14]

5 6

An increase in the difference Δν from 95 cm^{-1} for X = O to 140 cm^{-1} for X = S supports this viewpoint. Sulphur, being less electronegative than oxygen does not lower the basicity of the pyridine nitrogen as much as does oxygen. On the other hand, owing to its greater polarizability, it favours the contribution of the resonance structure (5).

The estimated geometry of chelate rings of the compounds listed in Table 1 are given in Table 3.



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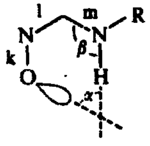

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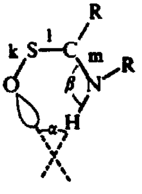

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Although the data in Table 3 are based on bond lengths and bond angles measured for simple molecules, the calculated A..H—N distances are all quite close to each other and correspond to a strong H-bond.[1, 2, 8, 13] However, the orientation of the nonbonding acceptor orbital is important.[2, 8a] In the cases of (2-pyridinecarboxy) anilides the orientation is disadvantageous and the CO group does not favour the resonance effect, hence the shift is small. A replacement of oxygen by sulphur does not change the orientation of this orbital. It favours, however, the resonance effect, leading thus to an increase of Δν. In the case of the other two groups the orientation of the acceptor orbital is more advantageous (greater angle of O..H—N) and hence the differences Δν are large.

TABLE 3. THE GEOMETRY OF THE 5-MEMBERED CHELATE RINGS.

Scheme	k Å	1 Å	m Å	A..H—N Å	∢ kl degr.	∢ lm degr.	∢ α degr.	∢ β degr.
7, X = O	1·34[a]	1·52[b]	1·33[c]	~2·73	118[a]	116[b]	~65	120[e]
7, X = S	1·34[a]	1·50[b]	1·32[b]	~2·75	118[a]	118[b]	~63	120[e]
8	1·44[d]	1·34[a]	1·44[e]	~2·76	121,5[a]	118[a]	~75	120[e]
9	1·53[f]	1·71[b]	1·32[b]	~2·90	107[f]	122[b]	~87	120[e]

[a] As in pyridine.[15]
[b] As in thioacetamide.[16]
[c] As in α-picolinamide.[16]
[d] As in trimethylamine N-oxide.[17]
[e] The assumed length differs from the sum of atomic radii of C and N by 0·03 Å; ∢ β assumed.
[f] As in dimethysulphoxide.[18]

EXPERIMENTAL

IR measurements. All measurements were carried out with the use of the UR 10 spectrophotometer in $CHCl_3$ as solvent (purified according to Vogel[19]) and dried over $CaCl_2$. A good reproducibility of the results was obtained, equal to ±2 cm^{-1}.

Synthesis of thioamides. All the compounds were prepared by a standard method[20] by heating the amides and P_2S_5 in pyridine (0·002:0·002 moles in 20 ml). During synthesis of compounds I–VI the reactants were heated under reflux for 15 min. A longer time resulted in darkening of the mixture. Compounds VII–XVII were synthesized by heating under reflux for 80 min. The mixtures were then cooled and poured into cold water to which 2 ml 0·1 N HaOH had been added. The next day the ppt was filtered off (or the mother liquor decanted if the oil did not crystalize). The material was then dissolved in 20 ml 1N NaOH and the soln filtered. The filtrate was neutralized with HCl and extracted with benzene (about 200 ml) until decolourization and dried with $MgSO_4$. The benzene extract was concentrated to $\frac{1}{5}$ of the starting volume and chromatographed on Al_2O_3 Woelm (compounds I–VI on Al_2O_3 of activity I and compounds VII–XVII on Al_2O_3 of activity III). All the compounds were crystallized from aqueous MeOH. Compounds I–VI were obtained in a yield of 30–40% and compounds VII–XVII in a yield of 55–70%. Other properties of the compounds are given in Table 2.

Acknowledgement—We are indebted to Miss A. Zacny for the infrared measurements.

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