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ELECTROSTATIC FIELD EFFECTS AND THE P.M.R. SPECTRA OF PYRIDINE DERIVATIVES IN HYDROGEN BONDING SOLVENTS

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Solvent effects on the p.m.r. spectra of pyridine derivatives have been the subject of several investigations, and evidence for specific solvent-solute association in acetone and benzene solutions has been presented (1,2). Few solvent studies have been concerned with the effect of hydrogen bonding solvents which produce relatively large selective shifts between the resonances of the heterocyclic ring protons compared with the values in an inert solvent. In this communication we report the chemical shift data for a number of methyl substituted pyridines in solvents of varying dielectric constant, including two hydrogen bonding solvents (methanol and deuterium oxide). The results are, we believe, best interpreted in terms of the electrostatic field effect of the nitrogen lone-pair and the variation in the effective electrostatic dipole with the nature of the solvent, a phenomenon which has been well established in the determination of dipole moments (3).

The dipole moment of pyridine in an inert solvent is 2.15 D (4) of which approximately 0.45 D derives from the π-electron moment and the moment of the C-4 - H bond (5). The remaining 1.7 D may reasonably be ascribed to the moment of the nitrogen lone-pair, and calculation of the effect of this electrostatic dipole at the ring protons using the expression given by Musher (6) gives a contribution to the chemical shift of 0.43 ppm. (α), 0.20 ppm. (β), and 0.15 ppm. (γ), the shifts all being paramagnetic. Similar values have been reported by Gill and Murrell (7).

The contributions to the chemical shifts are appreciable and a reduction in the effective dipole moment of the nitrogen lone-pair in more polarizable solvents should be accompanied by a decrease in the difference in chemical shift between the α protons, where the dipole electrostatic field is most strongly deshielding, and the β and γ protons.

The chemical shift data given in Table 1 for α-, β- and γ-picoline and 2,6-dimethylpyridine show clear evidence for this effect. The separation between H-5 and H-6, and between H-4 and H-6, in the three picolines is virtually the same in carbon tetrachloride and deuterochloroform, decreasing by approximately 0.1 - 0.12 ppm. in acetone, and by 0.25 - 0.28 ppm. in deuterium oxide, with the separation in methanol slightly larger than that in deuterium oxide. By contrast, the change in chemical shift difference between protons symmetrically situated with respect to nitrogen is approximately 0.01 ppm. in α-picoline and β-picoline, and the difference in chemical shift between H-4 and H-5 in α-picoline, β-picoline, and 2,6-dimethyl-pyridine has a range of only 0.05 ppm., with the separation consistently lower in deuterochloroform.

The decrease in separation between H-4 and H-6, and H-5 and H-6 in the hydrogen bonding solvents methanol and deuterium oxide is surprisingly close to the value attributed to the electrostatic field of the nitrogen lone-pair, and it seems that the formation of a strong hydrogen bond between the solvent and the solute effectively removes the entire contribution of this effect. The p.m.r. spectra of 2,2'-bipyridyl (I) provides striking evidence for the almost complete removal of the electrostatic field effect in

TABLE 1

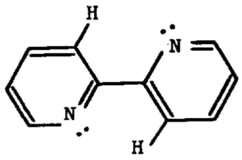
Chemical Shifts in Methyl Substituted Pyridines

(δ in ppm. from TMS)*

	Solvent	H-2	H-3	H-4	H-5	H-6
2-Me	CCl_4	-	7.00	7.46	6.95	8.39
	$CDCl_3$	-	7.12	7.55	7.07	8.48
	$(CH_3)_2CO$	-	7.18	7.62	7.13	8.44
	CH_3OH	-	7.27	7.74	7.21	8.41
	D_2O	-	7.28	7.75	7.21	8.40
3-Me	CCl_4	8.34	-	7.38	7.06	8.31
	$CDCl_3$	8.45	-	7.46	7.16	8.41
	$(CH_3)_2CO$	8.41	-	7.54	7.27	8.37
	CH_3OH	8.37	-	7.63	7.29	8.33
	D_2O	8.32	-	7.64	7.30	8.29
4-Me	CCl_4	8.35	6.98	(2.32)		
	$CDCl_3$	8.45	7.09	(2.34)		
	$(CH_3)_2CO$	8.41	7.15	(-)		
	CH_3OH	8.38	7.20	(2.35)		
	D_2O	8.42	7.31	(2.33)		
2,6-diMe	CCl_4	-	6.83	7.35		
	$CDCl_3$	-	6.95	7.48		
	CH_3OH	-	7.06	7.59		
	D_2O	-	6.05	7.60		

* Determined in 0.08 M solutions on Varian DP60 and DA60-IL instruments

deuterium oxide. H-3 and H-5 are symmetrically situated with respect to the



(I)

nitrogen atom in one ring, but H-3 is in close proximity to the nitrogen lone-pair of the neighbouring ring in the trans coplanar conformation (8,9) and the chemical shift difference between these two protons decreases from 1.28 ppm. in carbon tetrachloride to 0.52 ppm. in deuterium oxide (10). The ultraviolet absorption spectra in the two solvents are virtually identical, and conformational changes cannot, therefore, be responsible for this remarkable change in chemical shift. In fact, the calculated effect of the electrostatic field due to the nitrogen lone-pair electrons at H-3 and H-5 for the trans coplanar conformation is 0.5 ppm. with the dipole located 0.4 Å from the nitrogen along the C-4 - N axis, and 0.8 ppm. when it is located 0.8 Å from the nitrogen.

Variations in the reaction field (11) would be quite ineffective in explaining this large change in relative shifts, and the small variation in the positions of the methyl group resonances for γ picoline (Table 1) with changing solvent is in much better agreement with a decrease in the effective dipole of the nitrogen lone-pair. Further evidence for an effect involving the nitrogen lone-pair electrons in hydrogen bonding solvents can be inferred from the appearance of clearly resolved fine structure for the α protons in deuterium oxide. The broadening of the α-proton multiplets associated with the nitrogen quadrupole moment is removed in methanol and deuterium oxide, strongly suggesting that the electric field gradient at the nitrogen has been reduced by hydrogen bonding of the nitrogen lone-pair.

We conclude that the p.m.r. spectra of nitrogen heterocycles in hydrogen bonding solvents may be of considerable value in comparisons with predicted electron densities and "ring current" effects, and may also simplify the problems of spectral analysis by removing the quadrupolar broadening of spectral lines. Further investigations of lone-pair dipolar effects in other heterocyclic compounds are in progress.

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