Intramolecular OH - - - π Hydrogen Bonding in 6- and 7-Hydroxy-5,6,7,8-tetrahydro-5,8-methanoisoquinolines and their *N*-Oxides

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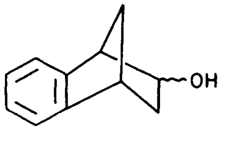
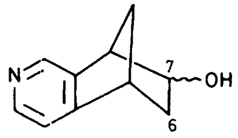
I.r. spectral measurements gave the frequency shift and integrated intensity of the hydroxy stretching band for the title compounds in dilute solutions of carbon tetrachloride and chloroform. Intramolecular OH - - - π hydrogen bondings with characteristic differences were found.

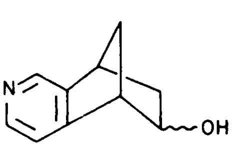
Intramolecular OH - - - π hydrogen bondings between the hydroxy group and the π-electron on olefins and aromatic compounds have been extensively studied by i.r. spectroscopy, because the hydroxy stretching bands provide much information on the molecular conformation and the electronic structure.[1-7] However, no data have been reported for pyridine and its *N*-oxide, which are typical heteroaromatic compounds, with attention focused on the π-electron distribution effect. In intermolecular hydrogen bonding between alcohols and pyridines or their *N*-oxides, OH - - - N or OH - - - O ⟵ N hydrogen bonding is preferred and OH - - - π does not exist, because the proton-accepting ability of the π-electron in the rings is much weaker than those of N and N ⟶ O. Thus, we studied the hydroxy stretching bands of bicyclic alcohols (**2a**)—(**5b**), the recently prepared norbornenols condensed with a pyridine ring,[8] which have a conformation incapable of forming the intramolecular hydrogen bonding between the hydroxy group and N or N ⟶ O. The results were compared with i.r. data of benzo analogues, benzonorbornen-2-ols (**1a**) and (**1b**).



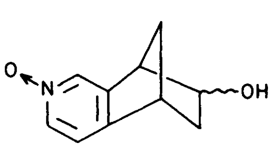
exo (**1a**)
endo (**1b**)



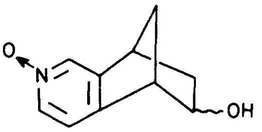
exo (**2a**)
endo (**2b**)



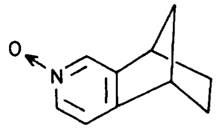
exo (**3a**)
endo (**3b**)



exo (**4a**)
endo (**4b**)



exo (**5a**)
endo (**5b**)



(**6**)

Experimental

I.r. spectra were recorded on a magnified wavenumber scale (× 50 and × 20) with a JASCO A-702 i.r. spectrophotometer calibrated according to the absorption bands of atmospheric water. Compounds (**1**)—(**6**) were synthesized as reported elsewhere.[8,9] The solvents carbon tetrachloride and chloroform were purified by distillation. Compounds (**1a**)—(**3b**) and (**4a**)—(**5b**) were dissolved in carbon tetrachloride at a concentration (c) of 0.0040—0.0039 mol dm^{-3} (cell length l 2 cm) and below 0.0001 mol dm^{-3} (l 10 cm), respectively, and at c 0.0090—0.0073 mol dm^{-3} in chloroform (l 0.5 cm). The integrated intensity (A) was calculated by Ramsay's method,[10] defined as $A = (\pi/2)[\ln (I_0/I)/c\cdot l]\cdot\Delta\nu_{1/2}$ (mol^{-1} dm^3 cm^{-2}), where $\ln (I_0/I)/c\cdot l$ is the absorption coefficient (mol^{-1} dm^3 cm^{-1}) at the band maximum and $\Delta\nu_{1/2}$ is the band width (cm^{-1}) at half intensity. The accuracies of frequency (ν_{OH}) and integrated intensity (A_{OH}) of the hydroxy stretching band (ν_{OH} band) for (**1a**)—(**3b**) were within ±1.0 cm^{-1} and ±5%, respectively. Since the ν_{OH} bands of (**4a**)—(**5b**) in CCl_4 were very weak because of their low solubilities and those of (**4b**) and (**5b**) in $CHCl_3$ overlapped each other, the accuracies of ν_{OH} and A_{OH} were poorer than in the above case. All measurements were carried out at room temperature (*ca.* 27 °C).

Results and Discussion

The i.r. parameters obtained for (**1a**)—(**5a**) in CCl_4 and $CHCl_3$ are shown in the Table.

(*a*) *Frequency Shift.*—Intramolecular OH - - - π hydrogen bonded ν_{OH} bands appeared at 3 592—3 569 cm^{-1} for the *endo*-epimers (**1b**)—(**5b**), which have a conformation capable of intramolecular hydrogen bonding, but not for the *exo*-epimers (**1a**)—(**5a**), which are incapable of it, in both CCl_4 and $CHCl_3$. In (**1b**)—(**5b**), the parameter $\Delta\nu_{OH}$ represents the magnitude of the shift to a lower wavenumber from free ν_{OH} bands. The $\Delta\nu_{OH}$ values are strongly influenced by the π-electron systems; their magnitudes decrease in the order benzene > pyridine > pyridine *N*-oxide. This is the order of proton acceptors of the π-electron systems examined. Interestingly, in the pyridine system, the ν_{OH} value of 7-ol (a *quasi-meta* derivative) (**2b**) is larger than that of 6-ol (a *quasi-para* derivative) (**3b**), but *vice versa* in the pyridine *N*-oxide system [(**4b**), (**5b**)]. The larger values imply higher proton acceptabilities. The results are not inconsistent with the positional selectivity in nitration reactions of pyridines and with the relative solvolysis rates of the arenesulphonates of *exo*-alcohols (**2a**)—(**5a**). The nitration of pyridine proceeds with the formation of the β-nitro derivative, but that of the *N*-oxide gives the γ-nitro derivative.[11] Hydrolysis of the *quasi-meta* arenesulphonate [of (**2a**)] in 50% (v/v) aqueous t-butanol at 50 °C proceeds at a rate 33 times faster than that of *quasi-para* (**3a**), while the reaction of the *quasi-meta N*-oxide (**4a**) proceeds at a rate 100 times slower than that of the *quasi-para N*-oxide (**5a**).[8] Molecular orbital treatments of pyridine *N*-oxide have given the same prediction.[12]

Table. I.r. spectral data for the ν_{OH} band for bicyclic alcohols

	CCl_4					$CHCl_3$					
Compound	ν_{OH}/ cm^{-1}	$\Delta\nu_{OH}$/ cm^{-1}	ε/ mol^{-1} dm^3 cm^{-1}	10^{-4} A_{OH}/ mol^{-1} dm^3 cm^{-2}	Concentration ($\times 10^{-3}$) (mol dm^{-3})	ν_{OH}/ cm^{-1}	$\Delta\nu_{OH}$/ cm^{-1}	ε/ mol^{-1} dm^3 cm^{-1}	10^{-4} A/ mol^{-1} dm^3 cm^{-2}	ε(3 200 cm^{-1})^a/ mol^{-1} dm^3 cm^{-1}	Concentration ($\times 10^{-3}$) (mol dm^{-3})
(1a)	3 623.3		91.8	0.60	3.9833	3 611.2		93.6	0.92	0	8.2748
(1b)	3 623.3		16.0	0.14	3.9921	3 611.5		20.9	0.21	0	7.9257
	3 577.7	45.6	63.7	0.38 (0.50)^b		3 569.0	42.5	39.6	0.45 (0.58)^b		
(2a)	3 622.4		102.7	0.67	3.9906	3 611.0		99.8	1.01	0	7.6183
(2b)	3 623.4		23.7	0.20	3.9676	3 611.8		33.3	0.34	0	7.7862
	3 584.7	38.7	55.8	0.30 (0.43)^b		3 580.0	31.8	40.9	0.42 (0.63)^b		
(3a)	3 622.6		104.9	0.68	3.9639	3 611.3		99.0	1.00	0	7.8479
(3b)	3 624.3		28.0	0.22	3.9602	3 612.2		38.6	0.38	0	8.9743
	3 588.0	36.3	54.9	0.29 (0.43)^b		3 582.7	29.5	36.4	0.37 (0.59)^b		
(4a)	3 621.2			*c*	<0.1	3 610.3		102.5	1.05	10	7.3972
(4b)	3 622.2			*c*	<0.1	3 613.2		33.7	0.35	62	7.4636
	3 590.7	31.5				3 588.8	24.4	16.2	0.18		
(5a)	3 621.8			*c*	<0.1	3 610.7		108.8	1.11	10	7.7244
(5b)	3 623.2			*c*	<0.1	3 612.5		60.0	0.64	17	7.8212
	3 589.4	33.8				3 587.0	25.5	22.5	0.23		

[a] The ε value is the absorption coefficient at 3 200 cm^{-1} at the concentration shown, because the absorption maximum could not be measured due to solvent absorption. [b] Based on A_{OH} values of the corresponding *exo*-epimers, the A_{OH} values given in parentheses were estimated by extrapolation to 100% formation of the OH - - - π hydrogen bonding. [c] The A_{OH} values of **(4a)**—**(5b)** were not obtained, because of their low solubilities.

(*b*) *Integrated Intensity*.—Spectra of the *exo*-epimers (**1a**)—(**3a**) showed only free ν_{OH} bands. The A_{OH} ($\times 10^{-4}$ mol^{-1} dm^3 cm^{-2}) of these bands are in the range 0.60—0.68 in CCl_4 and greater than those of the saturated alcohols; the A_{OH} values of free ν_{OH} bands in saturated alcohols have been reported to be in the range 0.32—0.54 in CCl_4.[6,13-15] Spectra of the *endo*-epimers (**1b**)—(**3b**) showed free and OH - - - π hydrogen bonded ν_{OH} bands, so that their A_{OH} values were estimated by extrapolation to 100% formation of the OH - - - π hydrogen bonding. The A_{OH} values estimated are in the range 0.43—0.50 in CCl_4 which are smaller than those for the free ν_{OH} of the *exo*-epimers (**1a**)—(**3a**) and of almost the same order as those for the free ν_{OH} of saturated alcohols, in spite of the fact that A_{OH} generally increases with hydrogen bond formation.[6,13-17]* The behaviour of A_{OH} for (**2**) and (**3**) strongly resembles that of (**1**), indicating that in (**2**) and (**3**), through-space interaction takes place between the π-electron and the sp^3-hybridized carbon atom bearing the hydroxy groups, as we reported earlier for (**1**).[6] For (**1a**)—(**3b**), the spectra obtained in $CHCl_3$ show a strong resemblance to the characteristic A_{OH} behaviour in CCl_4, although they had been altered by the solvent effects; the A_{OH} values for the free ν_{OH} bands of the saturated alcohols are in the range 0.59—0.68 in $CHCl_3$.[14]

Since the A_{OH} values for (**4a**)—(**5b**) having the *N*-oxide group could not be obtained due to their low solubilities in CCl_4, their determinations were carried out in $CHCl_3$. At the concentration used for the determination, these compounds exhibited broad bands below 3 200 cm^{-1} where the band maximum could not be measured because of the solvent absorption, except for the ν_{OH} bands in the range 3 614—3 569 cm^{-1}. This bond was assigned to the intermolecular hydrogen-bonded ν_{OH} band between the hydroxy and the *N*-oxide groups, because its band did not appear in (**6**) which does not bear the hydroxy group. For the broad bands, the absorption coefficient (ε) at 3 200 cm^{-1} of the *endo*-epimers (**4b**) and (**5b**) is larger than those of the *exo*-epimers (**4a**) and (**5a**) and the value of (**4b**) is the largest in this series. This suggests the formation of a dimer in the *endo*-epimer (**4b**) and (**5b**) system series. The A_{OH} values of (**4a**)—(**5b**) are not absolute because of the formation of intermolecular hydrogen bonding. However, the A_{OH} values of free ν_{OH} bands for the *exo*-epimers (**4a**) and (**5a**) are somewhat greater than those for the *exo*-epimers (**1a**)—(**3a**) in $CHCl_3$, and they are also greater than those for the free ν_{OH} of saturated alcohols. The results suggest that in (**4**) and (**5**), a through-space interaction exists between the π-electron and the sp^3-hybridized carbon atom bearing the hydroxy group as in the case of benzo derivatives (**1**).

The information obtained here should be useful for understanding i.r. behaviour in related systems and for investigating intramolecular interactions.

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* We found that, as far as our previous[6] and present compounds are concerned, A_{OH} for the intramolecular OH - - - π bond is lower than A_{OH} for the unbonded form. We considered this finding as anomolous: however, a referee commented as follows: 'This value assumes that A_{OH} for the unbonded forms is unaffected by the change in configuration between the *exo*- and *endo*-isomers. This assumption is not necessarily correct, since i.r. intensity depends indirectly on the alignments of the molecular dipole, which will not be the same for these two isomers. The authors have already observed that A_{OH} for the *exo*-epimer is anomalously high. If unbonded A_{OH} for the *endo*-epimer were to be anomalously low, then the extent of intramolecular hydrogen bonding will be less than the authors assume and A_{OH} for the bonded form will be correspondingly higher. Anomalously high A_{OH} for one epimer could well be accompanied by anomalously low A_{OH} for the other, both resulting from the change in alignment of the molecular dipole. In this case, A_{OH} for the bonded form could be quite normal.'