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THE CONFORMATIONAL EQUILIBRIA OF PIPERIDINE AND MORPHOLINE FROM INFRARED SPECTRA

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The conformational equilibrium of piperidine has been the subject of considerable controversy (1). Lambert et al. (2) have emphasized the "danger of obtaining misleading conclusions based on experimental variables that must be of the highest accuracy in order to be significant, but which are still quite sensitive to substrate purity" and have concluded from NMR results that piperidine exists with the NH predominantly axial. We believe these conclusions themselves fall in the misleading category and similar doubts are eloquently expressed by Robinson (3); before the piperidine NH-axial doctrine is canonized by general acceptance (4), we wish to present further contrary evidence.

Whereas the gas-phase infrared spectra of several acyclic aliphatic secondary amines disclose only one broad band in the 6500 cm.$^{-1}$ region, eleven piperidines and morpholines showed two well-resolved bands. For piperidine itself, the Q-branch maxima occured at 6577 and 6499 cm.$^{-1}$, displaced by N-deuteration to 4906 and 4842 cm.$^{-1}$ The spectrum of the deuterium compound confirmed that no other bands occured in the 6500 cm.$^{-1}$ region. The bands centred at 6577 and 6499 cm.$^{-1}$ were assigned to the first overtone NH-stretching frequencies of the NH-equatorial and NH-axial conformers, respectively, by band shape criteria (5, 6). Geometrically, piperidine closely resembles the oblate symmetric top cyclohexane $\left[I_A = I_B = 117.1;\ I_C = 205.1;\ \beta = (I_A/I_C) - 1 = -0.43\right]$ (7). The NH-axial bond is almost parallel to I_C and gives a parallel band (Q-branch strong, P and R weak).

The NH-equatorial bond is at 111° to I_C and is expected to have $(\cos 69^{\circ})/(\cos 69^{\circ} + \cos 21^{\circ}) = 27.7\%$ parallel character. A perpendicular band with $\beta = 0.5$ has P, Q and R branches of equal intensity; here, the 28% parallel character increases the strength of the Q-branch. The spectrum (FIG.) clearly shows the expected differences in band shapes.

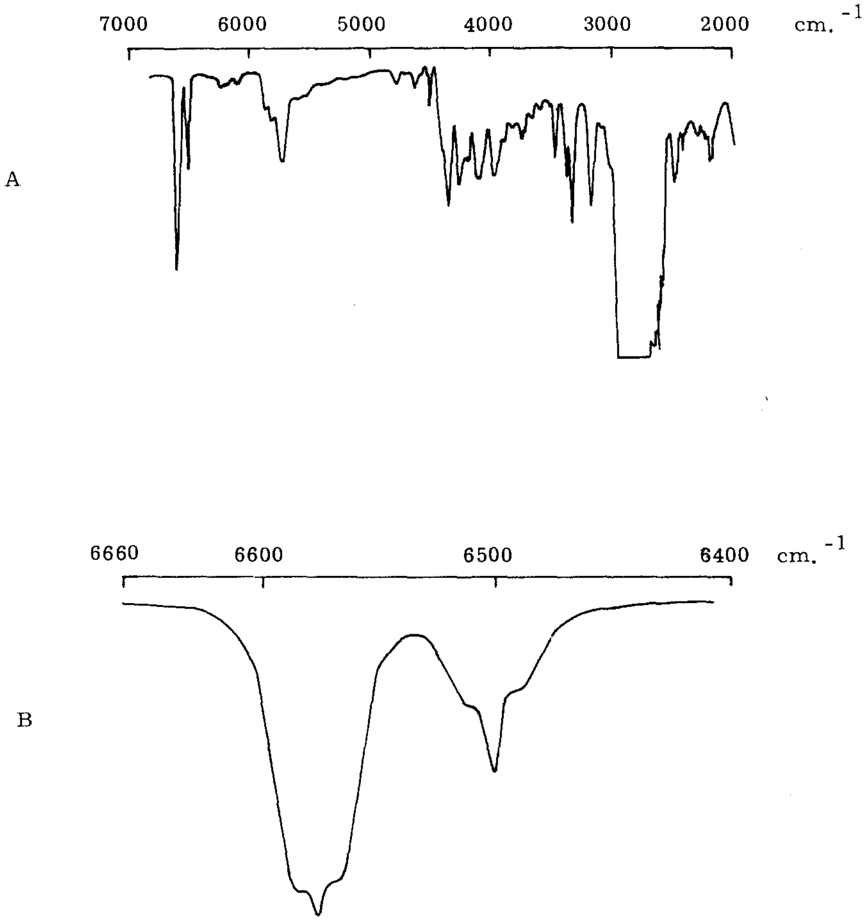

FIG. Infrared spectra of gaseous piperidine at 90° (A) 7000 - 2000 cm.$^{-1}$ region, (B) NH-first overtone region, expanded scale.

Fair quantitative agreement is also found: for the NH-equatorial parallel band the PR-branch separation observed is 17.5 ± 1 cm.$^{-1}$ and that calculated is 18.3 ± 1.5 cm.$^{-1}$ For the NH-axial band of composite character, the PR-branch separation is observed as 24 ± 4 cm.$^{-1}$ and calculated as 25 ± 2 cm.$^{-1}$.

The spectrum of morpholine in the NH-first overtone region is similar to that of piperidine and similarly assigned. The results for the several substituted piperidines and morpholines that we have also studied will be discussed in detail in our full publication (8). At present, we wish merely to state that the effect of methyl substituents on the moments of inertia, and thus on the band contours, can be calculated and that the results are in good agreement with the predictions. Thus, for example, the asymmetric top cis-2, 6-dimethylmorpholine is predicted to have an NH-axial band of type C(strong Q-branch, no distinct P, R maxima) and an NH-equatorial band of 67% type B and 33% type C character with a calculated PR-branch separation of 7.9 ± 0.8 cm.$^{-1}$ (observed: 9 ± 1 cm.$^{-1}$).

To obtain the conformational equilibrium constants K for piperidine and morpholine we plotted the logarithmic ratios of the band intensities against the reciprocal of the absolute temperature (9). Provided ΔH, ΔS, and $\varepsilon_e / \varepsilon_a$ are all temperature independent, the slope is $-\Delta H/R$. As measures of the band intensity we have used (i) Q-branch maxima, (ii) the mean of the P- and R-branch maxima, and (iii) integrated band areas. Experiments extended over temperature ranges of 50-210° for piperidine and 70-220° for morpholine. The correlation coefficient r was >0.99 for each plot (see Table).

The results and a detailed consideration of the errors involved (8), indicate that in the gas phase the equatorial NH-form predominates with $\Delta H = 0.53 \pm 0.13$ kcal. for piperidine and $\Delta H = 0.48 \pm 0.13$ kcal. for morpholines(68% confidence limits).

The NH-bands broaden in solution and band-overlap makes precise intensity measurements somewhat more difficult; however determinations for both piperidine and morpholine in carbon tetrachloride solution indicate that the equatorial NH-form predominates with $\Delta H = 0.6 \pm 0.2$ kcal. in each case. Full details will be reported later (8).

Consideration of differential rotational and vibrational entropy contributions to the NH-equatorial and axial conformers indicate (8) that these are small and that the ΔH values given are close to ΔG values for both morpholine and piperidine.

TABLE

ΔH Values for NH-Equatorial Preference (Gas Phase)

Method (see text)	Piperidine		Morpholine	
	ΔH	r	ΔH	r
(i)	0.44 ± 0.03	0.999	0.43 ± 0.03	0.998
(ii)	0.64 ± 0.03	0.999	0.57 ± 0.03	0.998
(iii)	0.53 ± 0.03	0.991	0.44 ± 0.03	0.998

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