^{13}C Nuclear Magnetic Resonance Spectra of *NN*-Dimethylformamide in Aqueous Acid Solution. Evidence for Predominant *O*-Protonation at all Acidities

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Summary The observation of a doublet methyl signal in the ^{13}C n.m.r. spectrum of *NN*-dimethylformamide from 0—100% H_2SO_4 demonstrates that the predominant protonated form at all acidities is the *O*-protonated amide.

ALTHOUGH there is general agreement that amides are oxygen-protonated in strongly acidic solutions[1,2] a controversy has arisen over the predominant protonation site in dilute and moderately concentrated aqueous acids.[2—4] The primary basis of this controversy lies in the ^1H n.m.r. spectra of amides in these solutions, which give an ambiguous answer for the structure of the protonated species. For example, although the *N*-Me protons of *NN*-dimethylamides appear as two distinct resonances in very dilute acids and in very concentrated acids, these signals coalesce in the region of intermediate acidity.[5] This has been explained in terms of predominant *N*-protonation,[2,5] or alternatively in terms of predominant *O*-protonation, with a minor amount of the *N*-protonated amide being responsible for the isomerisation.[4]

We report that in the ^{13}C n.m.r. spectra of *NN*-dimethylformamide in aqueous sulphuric acids, such coalescence does not occur. ^{13}C Chemical shifts as well as representative *N*-methyl spectra are shown in the Figure. Although there are changes in the position of the peaks associated with protonation and medium effects, *at all acidities* there are two distinct signals associated with the two methyl groups.

The non-equivalence of the methyl signals is clearly inconsistent with appreciable *N*-protonation at any acidity since this should lead to coalescence of the methyl peaks to a singlet. However, it is entirely consistent with a steady progression from neutral to *O*-protonated dimethylformamide with increasing acidity.

Slight additional broadening of the methyl signals is noted in the region of intermediate acidity which can be attributed

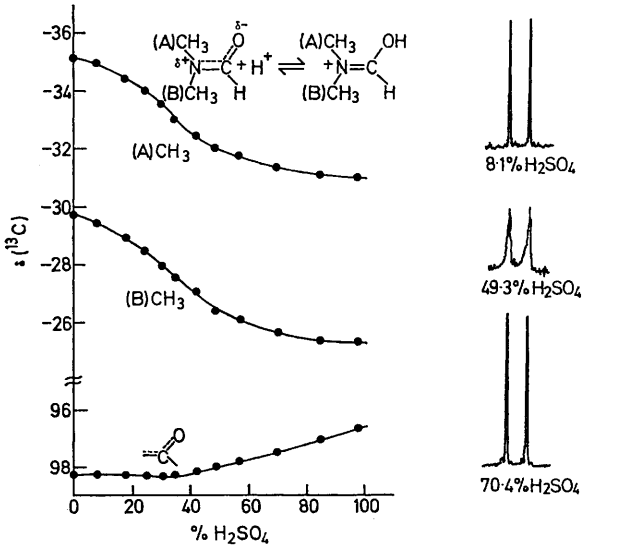

FIGURE. Plots of ^{13}C chemical shifts for *NN*-dimethylformamide *v.* concentration of H_2SO_4. (Chemical shifts relative to external dioxan in D_2O with low-field shifts positive. Methyl assignment is that given by W. McFarlane, *Chem. Comm.*, 1970, 418). Proton-decoupled ^{13}C spectra obtained on a Varian CFT-20 at 20 MHz, using 15 vol.% solutions. Representative spectra of *N*-methyl groups on the right.

to isomerization *via* *N*-protonation. However, the maximum broadening of 10 Hz (at 45% H_2SO_4) corresponds to a rate of isomerization of only 3×10^1 l mol^{-1} s^{-1} ($\pi\Delta\nu$, where $\Delta\nu$ = line width at half height). Since the reverse (deprotonation) reaction should be very rapid, perhaps even diffusion-controlled (*k ca.* 10^{10}),[4,6] the slow rate of isomerization requires an extremely small fraction of the *N*-protonated species, even though the amide is substantially protonated in 45% H_2SO_4 (*ca.* 85%).[5] Because of the smaller methyl chemical shift difference in the ^{1}H spectrum (*ca.* 8 Hz at 60 MHz)[5] than the ^{13}C spectrum (*ca.* 110 Hz at 20 MHz), this rate of isomerization is sufficient to coalesce the ^{1}H methyl signals while the ^{13}C spectrum shows a broadened doublet. Thus the ^{13}C spectra confirm previous interpretations of the ^{1}H spectra in terms of dominant *O*-protonation with isomerisation *via* a very small fraction of the *N*-protonated species.[6]

Variations in chemical shifts with acidity are less informative than the spectral pattern, because of pronounced medium effects on the protonated amide. However, there is a low-field shift of the methyl signals on protonation. This suggests *O*-protonation since *N*-protonation generally causes *high* field shifts of α-carbon atoms.[7]

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