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INFLUENCE OF LONE-PAIR ELECTRONS ON THE SIGN OF $^2J(^{13}C-^{15}N)$. SIGNS OF THE $^{13}C-^{15}N$ COUPLING CONSTANTS IN ^{15}N-PYRIDINE AND ITS DERIVATIVES

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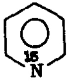
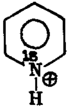
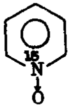
The importance of the effects of proximity and orientation of lone-pair electrons on the magnitudes and signs of $^1H-^{15}N$, $^1H-^{31}P$, $^{13}C-^{15}N$, and $^{13}C-^{31}P$ nuclear spin-spin coupling constants has been well-documented in recent experimental and theoretical studies [1]. Special attention has been focused on the effect on two-bond couplings which appear to show the largest relative variations in such a geometrical dependence. The results for these couplings have demonstrated that lone-pair electron proximity makes a positive contribution to the reduced coupling constants $^2K_{ij} = 4\pi^2 J_{ij}/h\gamma_i\gamma_j$. Reports on the magnitudes of two-bond $^{13}C-^{15}N$ couplings have shown a larger magnitude for $^2J_{CN}$ when the carbon is cis to the nitrogen lone-pair electrons than when it is in the trans configuration [1h]. Although the absence of experimental sign determinations of long-range $^{13}C-^{15}N$ couplings prevented any detailed comparison with INDO-FPT calculated values [1h], it was pointed out that $^2J_{CN}$ in *e.g.* the E-acetaldoxime isomer (carbon cis to the nitrogen lone-pair) is probably negative. However, whether there is a reversal in sign for $^2J_{CN}$ from the E- to Z-isomer was not discussed although a lone-pair induced sign change has been observed for $^2J_{HN}$ in aldoximes [1a] and aldimines [1g] and for $^2J_{CP}$ in some aromatic phosphines [1d]. We report here on the determination of signs for some one-, two-, and three-bond $^{13}C-^{15}N$ couplings, which indicates that a sign change is most likely to occur for $^2J_{CN}$ in isomers of a geometrically rigid CCN fragment.

In connection with current studies on signs and magnitudes of $^{13}C-^{31}P$ couplings in phosphorins (phosphabenzenes) [2] we have determined experimentally [3] the signs of all $^{13}C-^{15}N$ coupling constants in ^{15}N-pyridine, 1, the ^{15}N-pyridinium ion, 2, and pyridine-^{15}N-oxide, 3. The magnitudes and signs of the $^{13}C-^{15}N$ couplings (Table 1) were determined from $^{13}C-\{^1H\}$ noise and off-resonance (selective) decoupled spectra, respectively, using 95% ^{15}N-enriched samples. Excellent agreement is observed with the magnitudes of the $^{13}C-^{15}N$ couplings reported earlier for 1 and 2 [1c].

The signs of the $^{13}C-^{15}N$ couplings in 1, 2, and 3 were determined relative to those for the $^1H-^{15}N$ couplings using the earlier reported off-resonance or selective proton decoupling technique [4] which in general allowed the sign of $^{n}J_{C-N} \times {}^{n+1}J_{H-N}$ to be obtained directly from the observed spectra. However, in order to interpret unambiguously the off-resonance $^{13}C-\{^{1}H\}$ spectra these experiments were simulated (e.g. for ^{15}N-pyridine, Figures 1-3) by means of the double resonance computer program HETDR [5]. The simulations, performed using the signs and magnitudes reported earlier [1c,6-9] or determined here for the $^{13}C-^{1}H$, $^{15}N-^{1}H$, and $^{1}H-^{1}H$ couplings, the spectrometer controlled parameters (i.e. decoupling frequencies and amplitudes), and correct signs for the $^{13}C-^{15}N$ couplings, show excellent agreements (Figures 1-3) with the experiments. However, rather large deviations were observed between some of the ^{1}H chemical shifts required to simulate the $^{13}C-\{^{1}H\}$ spectra and those estimated qualitatively from the apparent best decoupling frequencies (up to 6 Hz for C3 in 1; see Figure 2). Thus the ^{1}H NMR spectrum was reinvestigated for the present sample of 1 for (i) comparison with precise values for these shifts and (ii) for determination of the sign for $^{4}J_{H4-N}$.

The coupling constants obtained from analysis of the extremely well-resolved ^{1}H spectrum of 1 are within error limits with earlier reported values [1c, 6,7]. Furthermore, a positive sign could be determined for $^{4}J_{H4-N}$ (= +0.27 Hz) when a negative sign was used for both $^{2}J_{H2-N}$ and $^{3}J_{H3-N}$ [1c,8] in the analysis (LAOCN3, 106 assigned lines, rms error = 0.007 Hz). All other relative sign combinations for the $^{1}H-^{15}N$ couplings gave slightly larger rms errors (0.011-0.013 Hz). Since this increase in rms errors reflects <u>large</u> deviations for only a <u>few</u> (4-6) lines, the sign determination is unambiguous. Finally, the negative sign suggested earlier [6] for $^{5}J_{H2-H6}$ (= -0.11 Hz) is fully confirmed from the anal-

TABLE 1. Comparison of Signs and Magnitudes of $^{13}C-^{15}N$ and $^{1}H-^{15}N$ Coupling Constants in ^{15}N-Pyridine Derivatives.[a]

	 1	 2	 3
$^{1}J_{C2-N}$	+ 0.62 (- 1.54)	-11.85 (-27.5)	-15.23
$^{2}J_{C3-N}$	+ 2.53 (+ 6.03)	+ 2.01 (+ 7.38)	+ 1.43
$^{3}J_{C4-N}$	- 3.85 (- 6.60)	- 5.30 (- 8.72)	- 5.17
$^{2}J_{H2-N}$	-10.93 (-16.98)	- 3.01 (+ 0.47)	+ 0.47
$^{3}J_{H3-N}$	- 1.48 (- 0.59)	- 3.98 (- 7.51)	- 5.32
$^{4}J_{H4-N}$	+ 0.27 (+ 0.54)	+ 0.69 (+ 1.73)	+ 1.11

[a] In Hz with errors within ± 0.03 Hz. INDO-FPT MO calculated values from refs. [1f] and [1h] are given in parentheses. Solutions are: 1: 2.0 Molar in $(CD_3)_2CO$; 2: 2.0 Molar in CD_3OH; 3: 1.0 Molar in $CDCl_3$. $^{1}H-^{15}N$ Coupling constants in 2 and 3 are taken from refs. [1c] and [9], respectively.

FIGURES 1, 2, and 3. Experimental (upper parts) and simulated (lower parts) $^{13}CX-\{^{1}HX\}$ double resonance spectra of the C2, C3, and C4 carbons in ^{15}N-pyridine, 1. The ^{1}H chemical shifts (relative to internal TMS at 100.1 MHz) and ^{1}H-^{1}H coupling constants used in the simulations and obtained from the ^{1}H NMR analysis are: ν_{H2} = 860.07 Hz, ν_{H3} = 734.21 Hz, ν_{H4} = 774.65 Hz, J_{23} = 4.90 Hz, J_{24} = 1.84 Hz, J_{25} = 1.01 Hz, J_{26} = -0.11 Hz, J_{34} = 7.68 Hz, and J_{35} = 1.37 Hz. ^{13}C-^{1}H coupling constants are from ref. [7]. Decoupling frequencies, ν_2 (on the TMS-scale), and amplitudes $\gamma H_2/2\pi$, are both in Hz.

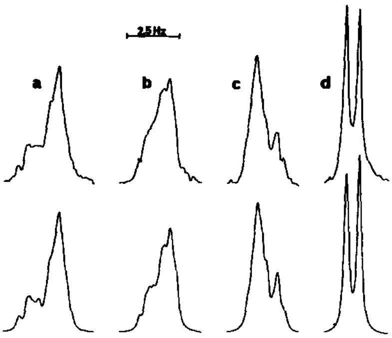


FIG. 1. C2 carbon spectra. ν_2: 866.0(a), 861.1(b), 856.1(c), and 861.1(d). $\gamma H_2/2\pi$: 1200(a, b,c) and noise decoupled (d).

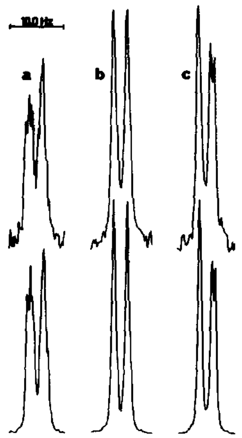


FIG. 2. C3 carbon spectra. ν_2: 746.0 (a), 740.8(b), and 736.6(c). $\gamma H_2/2\pi$ = 950(a,b,c).

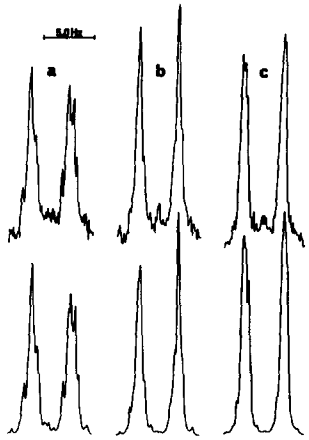


FIG. 3. C4 carbon spectra. ν_2: 783.0(a), 780.1 (b) and 777.1(c). $\gamma H_2/2\pi$ = 850(a,b,c).

ysis. The proton chemical shifts are identical with those required for simulation of the $^{13}C-\{^{1}H\}$ spectra and thus differ from e.g. the H3 proton decoupling frequency giving the best multiplet collapse in the C3-$\{H3\}$ spectra of Figure 2. This indicates that the $^{13}C-\{^{1}H\}$ methods for accurate determination of proton chemical shifts, as reported recently [10], may give erroneous results in certain strongly coupled systems without the use of $^{13}C-\{^{1}H\}$ double resonance simulations.

A positive sign has been proposed for $^{4}J_{H4-N}$ in 2 [1c,1f] although it was not verified experimentally. This suggestion is confirmed from the present results without reanalysis of its ^{1}H NMR spectrum. For both 2 and 3 the $^{13}C-\{^{1}H\}$ double resonance experiments gave $^{3}J_{C4-N} \times {}^{4}J_{H4-N} < 0$. Analysis of the ^{1}H spectrum for the same sample of 3 showed that $^{4}J_{H4-N} > 0$ for this compound [9]. Thus $^{3}J_{C4-N}$ is negative for 3 and also for 2, since a change in sign for this coupling is unlikely for the two compounds. It follows that $^{4}J_{H4-N}$ is positive in 2. The positive sign and relative order determined experimentally for $^{4}J_{H4-N}$ in 1 and 2 agree with the results obtained from INDO-FPT calculations [1f].

Comparisons of the $^{13}C-^{15}N$ coupling constants (Table 1) for the ^{15}N-pyridine derivatives show that the $^{2}J_{C3-N}$'s are all positive ($^{2}K_{C3-N} < 0$) and decrease slightly with increasing electronegativity of the nitrogen substituent, i.e. within the series 1 > 2 > 3. The determination of $^{2}J_{C3-N} > 0$ for 1 demonstrates that nitrogen lone-pair electrons affect not only the relative magnitudes of two-bond $^{13}C-^{15}N$ couplings but may also induce a reversal in sign for $^{2}J_{C-N}$ in certain CCN fragments of fixed geometry. Furthermore, this sign dependence observed for $^{2}J_{C-N}$ is in accord with the signs predicted for $^{2}J_{C3-N}$ (> 0), $^{2}J_{C10-N}$ (> 0), and $^{2}J_{C8-N}$ (< 0) in quinoline from INDO-FPT calculations [1h].

In general the INDO-FPT calculations for the $^{13}C-^{15}N$ couplings in 1 and 2 [1h] agree fairly well with the experimental results (Table 1) as far as the signs and general trends of the couplings are concerned. Only the sign for $^{1}J_{C2-N}$ in 1 has been wrongly predicted. Poorer agreement is observed for the magnitudes of the couplings. However, it is noteworthy that the determination of opposite signs for $^{1}J_{C-N}$ in 1 and 2 confirms the suggestion [1c] made on the basis of solvent effects.

Obviously, the determination of signs of two-bond $^{13}C-^{15}N$ couplings may provide a useful method for assigning stereochemistry in compounds possessing a nitrogen lone-pair of electrons, especially since the range of magnitudes for $^{2}J_{C-N}$ is rather small (< 10 Hz).

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