EVIDENCE FOR THE PRESENCE OF CONTACT TERM CONTRIBUTION TO LANTHANIDE INDUCED SHIFTS IN ^{1}H AND ^{13}C NMR SPECTRA OF PYRIDINE N-OXIDES

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In a number of papers dealing with applications of lanthanide shift reagents (1), the pseudocontact interaction has been accepted as a main contributor to lanthanide-induced NMR shifts (1,2). Several authors ascribed anomalous ^{1}H shifts induced by some shift reagents to the possible contribution of the contact term (1,3,4). Furthermore, abnormal behaviours that should be attributed to the contact-term contribution were observed for ^{14}N (5), ^{31}P (1,6), ^{13}C (7-10), and ^{19}F (10) NMR shifts in various compounds with some lanthanide reagents. Thus, we wish to report here further evidence for the presence of the contact-term contribution in the induced shifts observed for ^{1}H and ^{13}C NMR spectra of pyridine N-oxide (I) and its alkyl derivatives (II-VI) complexed with Ln(FOD)$_3$, Eu(PTA)$_3$, and Ln(DPM)$_3$ (Ln = Eu and Pr),[†] having been prompted by a recent communication (11) which reported ^{1}H NMR results very similar to those presented here.

The variation in ^{1}H NMR shifts induced by Ln(FOD)$_3$ and Eu(PTA)$_3$ for all protons in compounds I-VI in CDCl$_3$ was not linear but very complicated against molar ratios of Ln/substrate, this implies that the stoichiometry for binding of substrates I-VI to Ln(FOD)$_3$ and Eu(PTA)$_3$ is not simple (1,12). On the interaction of I-VI with Ln(DPM)$_3$, the induced-shift variations were almost linear up to 0.8 molar ratios of Ln/substrates. Thus, Table 1 lists the slopes of initial and linear parts of the shift curves as S-values

Apparent <u>upfield</u> shifts for β-H signals in I, II, and V and those for γ-Me signals in II, IV, and V with

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[†] HFOD, HPTA, and HDPM represent 1,1,1,2,2,3,3-heptafluoro-7,7-dimethyloctane-4,6-dione, pivaloyltrifluoroacetone, and dipivaloylmethane, respectively.

Eu(FOD)$_3$ and Eu(PTA)$_3$ can hardly be explained by the angle dependence in the so-called geometric factor

of the pseudocontact interaction (2). However, these upfield shifts can well be interpreted as resulting from

the contribution of the contact term, Eu^{3+} (Pr^{3+}) may induce negative (positive) spin density on the oxygen

atom (4), which delocalises onto all atoms in the ring including methyl groups with an alternative change in

sign as shown in FIG. 1. This inference is based on ^{1}H contact-shift studies on several methyl derivatives of

pyridine N-oxide complexed with Ni(AA)$_2$ (13) and hexakis(γ-picoline N-oxide)nickel(II) perchlorate (14).

Thus, the upfield contact-shift effects exerted on the β-H in I, II, and V and γ-Me in II, IV, and V by

Eu(FOD)$_3$ and Eu(PTA)$_3$ overcome the downfield pseudocontact shifts to produce the observed u̲p̲f̲i̲e̲l̲d̲ shift.

The contact interaction seems weaker with Pr(FOD)$_3$ than with Eu(FOD)$_3$, and also weaker with

Ln(DPM)$_3$ than with Ln(FOD)$_3$, as seen from Table 1. In the latter case this may be due partly to the stronger

Lewis acidity (15) of Ln(FOD)$_3$ than that of Ln(DPM)$_3$ (1, 11), because the contact interaction depends on the

degree of covalent character of the metal-ligand bonding (4). However, a loosing of the metal-ligand bond-

ing by steric hindrance (16, 17) may also be responsible for the weak contact interaction of Ln(DPM)$_3$, which

has two bulky t̲-butyl groups, whereas Ln(FOD)$_3$ has one t̲-butyl. This idea is supported by the fact that β-H

did not show an upfield shift with Eu(FOD)$_3$ and Eu(PTA)$_3$ in substrate IV, whose two α-Me groups have a

steric effect on the complex formation. Thus, the results that Eu(PTA)$_3$ exerts contact effects similar to those

by Eu(FOD)$_3$, can be explained by the fact that, although Eu(PTA)$_3$ has a weaker Lewis acidity, it causes

less steric hindrance than Eu(FOD)$_3$ (15). On the other hand, the S-values observed for β-Me in III and β-Et

in VI were generally small as relative values, and further, even their signals were shifted u̲p̲f̲i̲e̲l̲d̲ by Eu(PTA)$_3$

(see Table 1). These results may be due to the angular dependence of the geometric factor (1, 2, 16)

In order to confirm the above results, we have further examined the ^{13}C NMR spectra of I and II com-

plexed with Ln(FOD)$_3$ and Ni(AA)$_2$, since a relatively stronger contact interaction is known to be observed

on carbon atoms (9, 10) and since the sign of ^{13}C contact shift for each carbon atom in pyridine N-oxides is

readily predictable, as indicated in FIG. 1. The results are summarised in Table 2. The feature of the con-

tact interaction expected by a π spin delocalisation mechanism (13, 14) was clearly seen with substrate II

complexed with Ni(AA)$_2$. With Eu(FOD)$_3$, an upfield shift of the α-C signal was observed as expected, but

the γ-C signal still showed a downfield shift. A little surprisingly, Pr(FOD)$_3$ induced a downfield shift on

γ-C, but the α-C signal was still shifted upfield though to a reduced extent. A diamagnetic correction to

Table 1 Lanthanide-induced ^{1}H Shift (S) Values in CDCl$_3$ (ppm)[a]

Compound	Shift reagent	S-value α-H (α-Me)	β-H (β-Me)	γ-H (γ-Me)
(I)	Eu(FOD)$_3$	+4.50	-0.05	+2.40
	Eu(PTA)$_3$	+5.35	-0.20	+2.25
	Eu(DPM)$_3$	+14.2	+3.84	+3.84
	Pr(FOD)$_3$	-11.8	-3.50	-3.50
	Pr(DPM)$_3$	-19.1	-5.83	-5.46
	[Ni(AA)$_2$	-1.00	+0.54	-1.27][b]
(II)	Eu(FOD)$_3$	+3.20	-0.30	(-0.80)
	Eu(PTA)$_3$	+4.45	-0.60	(-1.00)
	Eu(DPM)$_3$	+12.5	+2.93	(+1.46)
	Pr(FOD)$_3$	-9.95	-3.00	(-1.65)
	Pr(DPM)$_3$	-15.7	-4.63	(-2.68)
	[Ni(AA)$_2$	-1.00	+0.53	+1.35][b]
(III)	Eu(FOD)$_3$	+2.95	(+0.40)	+1.95
	Eu(PTA)$_3$	+6.25	(-0.90)	+3.30
	Eu(DPM)$_3$	+12.1	(+1.87)	+3.07
	Pr(FOD)$_3$	-9.40	(-1.95)	-2.90
	Pr(DPM)$_3$	-15.8	(-2.67)	-3 88
(IV)	Eu(FOD)$_3$	(+6.90)	+1.15	(-0.30)
	Eu(PTA)$_3$	(+6.90)	+0.80	(-0.70)
	Eu(DPM)$_3$	(+7.00)	+2.55	(+0.95)
	Pr(FOD)$_3$	(-15.4)	-3.40	(-1.00)
	Pr(DPM)$_3$	(-13.6)	-4.67	(-2.16)
(V)	Eu(FOD)$_3$	(+4.20) +2.95	-0.02 -0.40	(-0.90)
	Eu(PTA)$_3$	(+5.00) +3.90	+0.10 -0.45	(-1.05)
	Eu(DPM)$_3$	(+5.80) +11.1	+3.00 +2.40	(+1 15)
(VI)	Eu(FOD)$_3$	(+5.10) +5.10	+0.65 (+0.20, CH$_2$) (+0.05, Me)	+2 40
	Eu(PTA)$_3$	(+5.10) +4.00	+0.50 (-0.10, CH$_2$) (-0.30, Me)	+2.40
	Eu(DPM)$_3$	(+6.15) +9.95	+2.45 (+0.86, CH$_2$) (+0.45, Me)	+2.50

[a] Plus sign denotes a downfield shift. ^{1}H NMR spectra were taken with a Varian A-60A spectrometer using an internal TMS standard at 38°C. Substrate concentrations were about 0.4-0.7 mole/l. Accuracies for S-values are about 5% or less (see text) [b] Relative values taken from ref. 13.

Table 2. Lanthanide-induced ^{13}C Shift (S) Values in CDCl$_3$ (ppm)[a]

Compound	Shift reagent	S-value α-C	β-C	γ-C (γ-Me)
(I)	Eu(FOD)$_3$	-2.0	+6.0	+2.3
	Pr(FOD)$_3$	-12.6	-11.3	+5.6
(II)	Eu(FOD)$_3$	-0.8	+6.5	+5.3 (+3.6)
	Pr(FOD)$_3$	-5.4	-8.1	+10.8 (-2.3)
	[Ni(AA)$_2$	+260	-130	+190 (-70)]

[a] Plus sign denotes a downfield shift. Substrate concentrations were about 1-2 mole/l. ^{13}C NMR spectra were recorded on a Varian XL-100 spectrometer in the frequency-swept and deuteron-locked mode at ordinary probe temperature, using an observed frequency of 25.2 MHz, a C-1024 time-averaging device, and the proton noise-decoupling technique. The assignment of ^{13}C signals was carried out by the off-resonance single-frequency decoupling technique. S-values were obtained in the same way with ^{1}H S-values, accuracies, about 5% or less.
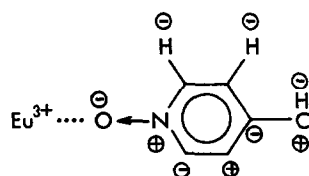
FIG. 1. Sign of spin densities on the atoms in γ-picoline N-oxide induced by Eu^{3+} (Pr^{3+} and Ni^{2+} induce spin densities of opposite signs; positive spin causes a downfield contact shift).

the induced shifts, using such a diamagnetic complex as $La(FOD)_3$, may be necessary before more detailed

discussion of the above results can be made. However, the presence of the contact-term contribution to

lanthanide-induced shifts observed for pyridine N-oxide derivatives has clearly been established, and we

would suggest that caution be exercised in applications of shift reagents solely using the pseudocontact term.

We have further studied lanthanide-induced ^1H and ^{13}C shifts in other aromatic systems, the contact-

shift contribution observed with anilines is very similar to that obtained here with pyridine N-oxides (11),

a fairly small but clearly discernible contribution is seen with phenols; and pyridines show somewhat different

features from those with other aromatic compounds (3,8,9). These results will be published elsewhere, and

further investigations on the problem are now in progress at these laboratories.

REFERENCES

(1) For a leading reference, see J.K.M. Sanders, S.W. Hanson and D.H. Williams, J. Amer. Chem. Soc. 94, 5325 (1972).

(2) Origin of lanthanide-induced shifts has recently been a problem of controversy, see, B. Bleaney, J. Magn. Resonance 8, 91 (1972), C.L Honeybourne, Tetrahedron Lett. 1095 (1972), W DeW. Horrocks, Jr. and J.P. Sipe, III, Science 177, 994 (1972); A.D. Buckingham and P.J. Stiles, Mol. Phys. 24, 99 (1972), J.M. Briggs, G.P. Moss, E.W. Randall and K.D. Sales, J.C.S. Chem. Commun. 1180 (1972), and references therein.

(3) A.M. Grotens, J. Smid and E. de Boer, Tetrahedron Lett. 4863 (1971), and references therein, R.K. Mackie and T.M. Shepherd, Org. Magn. Resonance 4, 557 (1972).

(4) E.R. Birnbaum and T. Moeller, J. Amer. Chem. Soc. 91, 7274 (1969); F.A. Hart, J.E Newbery and D. Shaw, J. Inorg. Nucl. Chem. 32, 3585 (1970).

(5) M. Witanowski, L. Stefaniak, H. Januszewski and Z.W. Wolkowski, Tetrahedron Lett. 1653 (1971); Chem. Commun. 1573 (1971).

(6) J.K.M. Sanders and D.H. Williams, Tetrahedron Lett. 2813 (1971).

(7) R.J. Cushley, D.R. Anderson and S.R. Lipsky, J.C.S. Chem. Commun. 636 (1972).

(8) A.A. Chalmers and K.G.R. Pachler, Tetrahedron Lett. 4033 (1972).

(9) M. Hirayama, E Edagawa and Y. Hanyū, J.C.S. Chem. Commun. 1343 (1972).

(10) M. Kainosho, K. Ajisaka and K. Tori, Chemistry Lett. 1061 (1972).

(11) B.F.G. Johnson, J. Lewis, P. McArdle and J.R. Norton, J.C.S. Chem. Commun. 535 (1972).

(12) N.H. Andersen, B.J. Bottino and S.E. Smith, J.C.S. Chem. Commun. 1193 (1972), B.L. Shapiro and M.D. Johnston, Jr., J. Amer Chem. Soc. 94, 8185 (1972); and references therein.

(13) R.W Kluiber and W. DeW. Horrocks, Jr., J. Amer. Chem. Soc. 87, 5350 (1965).

(14) W.D. Perry, R.S. Drago, D.W. Herlocker, G.K. Pagenkopf and K. Czworniak, Inorg. Chem. 10, 1087 (1971)

(15) H.E. Francis and W.F. Wagner, Org. Magn. Resonance 4, 189 (1972), and references therein.

(16) Y. Yoshimura, Y. Mori and K. Tori, Chemistry Lett. 181 (1972).

(17) L. Ernst and A Mannschreck, Tetrahedron Lett. 3023 (1971)