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NEW DIMENSIONS IN LANTHANIDE SHIFT REAGENT-PMR ANALYSIS OF ORGANIC COMPOUNDS: $Eu(tfn)_3$

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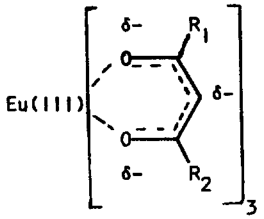
Despite the utility of lanthanide shift reagents for spreading the signals of the proton magnetic resonance (PMR) spectra of organic compounds,[1] limitations in the application of such shift reagents have been reported.[2] Investigations in our laboratory[2] demonstrated that PMR spectra (CCl_4 solvent) of bivalent organosulfur compounds were only slightly altered upon addition of Siever's[3] reagent: $Eu(fod)_3$, (I); the shifts were even smaller when the "nonbonded pair" of electrons on sulfur was formally conjugated with a π-system. These substrates thus represented a challenge and it seemed appropriate for us to initiate experiments that would allow organic chemists to carry out shift reagent studies on these and other weakly basic substrates. We felt that the additional electron-withdrawing fluorines of the new, more highly fluorinated shift reagent $Eu(tfn)_3$, II, (compared to I) would enhance the Lewis acidity of the lanthanide atom, in turn, increasing the interaction[5] of this shift reagent with weakly basic substrates. The greater effectiveness of $Eu(tfn)_3$, compared to $Eu(fod)_3$, is indeed illustrated in Table I, Experiments 1-4; the more fluorinated shift reagent results in gradients (G)[1] on common organic substrates that are at least an order



I, R_1 = t-butyl, R_2 = $CF_3CF_2CF_2$-, $Eu(fod)_3$, (Ref. 1,3)

II, R_1 = R_2 = $CF_3CF_2CF_2$-, $Eu(tfn)_3$, (Ref. 4)

tris[1,1,1,2,2,3,3,7,7,8,8,9,9,9]tetradecafluoro-4,6-nonanedionato europium (III)

III, R_1 = R_2 = CF_3CF_2-, $Eu(fhd)_3$, (Ref. 7)

tris[1,1,1,2,2,6,6,7,7,7]decafluoro-3,5-heptanedionato europium (III)

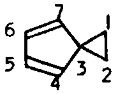
IV, R_1 = R_2 = t-butyl $Eu(dpm)_3$, (Ref. 1)

Table I: EUROPIUM TRIS(DIKETONATE) INDUCED GRADIENTS IN THE PMR SPECTRA OF VARIOUS ORGANOSULFUR AND ETHER COMPOUNDS

Experiment	Substrate	Shift Reagent[a]	G[b]	(LSR)/(S) max[c]	Reference
1	butyl disulfide	Eu(tfn)$_3$[d]	2.2	0.23	this work
2	butyl disulfide	Eu(fod)$_3$	0.07	---	Ref. 2
3	methyl phenyl sulfide	Eu(tfn)$_3$	2.5	0.14	this work[e]
4	methyl phenyl sulfide	Eu(fod)$_3$	0.04	---	Ref. 2
5	n-butyl ether	Eu(tfn)$_3$	9.0	0.55	this work
6	n-butyl ether	Eu(fhd)$_3$	6.7	---	Ref. 7
7	n-butyl ether	Eu(dpm)$_3$	10	---	Ref. 7
8	n-butyl ether	Eu(fod)$_3$	10	---	Ref. 7

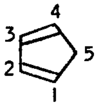
Table II: EUROPIUM AND BENZENE SHIFT REAGENT STUDIES[a] ON HYDROCARBONS

Experiment	Proton(s)	G,[b,f]Eu(tfn)$_3$	G,Eu(fod)$_3$[g]	G,C_6H_6
1	H_1,H_2 , V	2.10	0.00	0.054
	H_4,H_7 , V	2.76	0.00	0.04
	H_5,H_6 , V	2.62	0.00	0.02
2	H_1-H_4, VI	0.99	---	---
	H_5 , VI	0.89	---	---



V

Va



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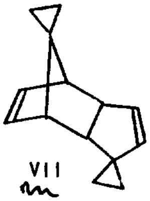

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a) All studies carried carried out in CCl_4 (Table I) solvent or $CDCl_3$ (Table II) solvent at ambient instrument temperature 60 MHz; TMS, δ = 0.00.

b) G = gradients[1] (slopes) of plots of chemical shift (ppm) vs. mole ratio of shift reagent to substrate. All studies were carried out at sufficiently low mole ratios such that linear plots were expected[1] and realized. All gradients refer to the aliphatic protons on the carbon attached to the heteroatom.

c) Maximum ratio studied; samples homogeneous at this ratio.

d) This shift reagent, as commercially available,[4,12] occurs as an oil or a solid. Drying over anhydrous P_2O_5 for 2-2.5 hrs. did not change the original phase of the sample. All shift reagents used were dryed and stored over P_2O_5.

e) A repeat using another vial of the same shift reagent, resulted in a gradient of 1.3. A revealing statement as to the variability of reported gradients is made on p. 89 of reference 7. A similar study carried out on benzyl 2,4-dinitrophenyl sulfide was not successful in shifting the PMR signals; mixing of homogeneous solutions of each of II and of this substrate resulted in a precipitate.

f) Maximum [shift reagent]/[substrate] ratio utilized = 0.05; samples remained homogeneous at this point.

g) Maximum [shift reagent]/[substrate] ratio utilized = 0.7; samples homogenous at this point.

of magnitude larger than gradients from the $Eu(fod)_3$ reagent. It is interesting, however, to note (Table I, Experiments 5-8) that a more basic substrate (aliphatic ether oxygen) apparently induces a leveling effect; in view of the known variable purity of shift reagents,[1,2,6] the four gradients listed for *n*-butyl ether must be regarded as virtually equal. Thus we attribute no special significance to our slightly larger gradient (9.0) observed for $Eu(tfn)_3$ compared to the gradient (6.7) arising from $Eu(fhd)_3$ (shift reagent III) reported by Burgett and Warner.[7] One would expect[8] that the minor structural changes in $Eu(tfn)_3$ vs. $Eu(fhd)_3$ would result in neglible differences in the shift reagent properties of these two compounds. Thus, with weakly basic organic substrates, the following order of effectiveness seems apparent:

$$Eu(tfn)_3 \sim Eu(fhd)_3 > Eu(fod)_3 > Eu(dpm)_3 \text{ (IV)}$$

To further test the effectiveness of the $Eu(tfn)_3$ shift reagent, a study of the possible alterations of the PMR spectra of cyclic hydrocarbons V and VI was carried out (Table II). Spiro[2.4]hepta-4,6-diene, V, showed no significant lanthanide induced shifts due to $Eu(fod)_3$, but the high solubility of this shift reagent (0.7 moles per mole of substrate) implied an interaction between this shift reagent and V; the polar character of V, e.g. Va, has been discussed elsewhere.[9,10] The more acidic character of $Eu(tfn)_3$ and the polar character of V seem to be supported by the substantial gradients listed for the II/V mixtures described on Table II. The highly acidic character of II, but less basic character of VI (relative to V), is indicated by the results of Experiment 2 (Table II). This to our knowledge is the first report of lanthanide induced shifts with hydrocarbon substrates.

It is tempting to propose complexes of the shift reagent with the electron rich five membered ring (relative to the three membered ring) of V; although this is consistent with the greater shift of the protons on the five membered ring, geometry postulates are tenuous since the magnitudes of these induced gradients involve angle as well as distance considerations.[1] A qualitative interpretation of these results does implicate a psuedo-contact interaction and the greater magnitude of the lanthanide induced shifts, relative to the solvent (benzene) induced shifts (Table II), is consistent with a psuedo-contact mechanism.[1]

We would like to point out a result that demonstrates significant Lewis Acid strength for the title shift reagent: a sample of V and $Eu(tfn)_3$, shift reagent:substrate mole ratio = 0.05, after seven days at *ca.* 5°(refrig.) showed only Diels-Alder dimer VII in the PMR spectrum. Since analogous conditions, in the absence of shift reagent, are not sufficient to induce Diels-Alder dimerization of **V**[10] and since Lewis Acid catalysis of Diels-Alder reactions is well documented,[11] it seems that the shift reagent is catalyzing chemical conversion of the substrate.

In summary, it is clear that Eu(tfn)$_3$ is a shift reagent that should be very useful for analyzing the PMR spectra of weakly basic organic substrates. Unpublished results[12] suggest that aliphatic nitro and aliphatic cyano compounds are significantly shifted with Eu(tfn)$_3$. PMR spectra in Eu(tfn)$_3$ studies are not complicated with the (upfield) diketonate ligand resonances that often interfere in analogous studies using shift reagents **I** and **IV**.[1] We intend to further investigate the utility of this shift reagent on other weakly basic substrates.

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* Author to whom inquiries should be sent.

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