Tetrahedron Letters No. 10, pp 879 - 882, 1972. Pergamon Press. Printed in Great Britain.

DEUTERIUM ISOTOPE EFFECTS OBSERVED IN NMR SHIFTS INDUCED BY LANTHANIDE COMPLEXES

C. C. Hinckley, W. A. Boyd, and G. V. Smith
Department of Chemistry and Biochemistry
Southern Illinois University
Carbondale, Illinois 62901

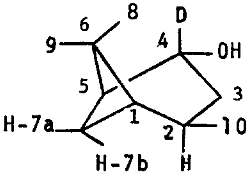
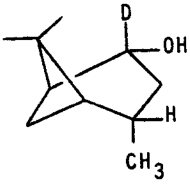
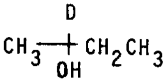
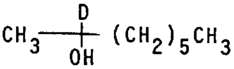
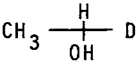
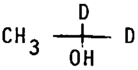
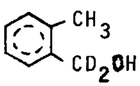
(Received in USA 20 January 1972; received in UK for publication 31 January 1972)

A deuterium isotope effect has been observed in the shifts induced by lanthanide complexes in the nmr spectra of alcohols in which deuterium is substituted for hydrogen geminal to the hydroxyl group.[1] In such cases, proton resonances of the deuterium substituted alcohol are shifted further than those of the unsubstituted alcohol. The effect is readily observed in mixtures of deuterium substituted (labeled) and unsubstituted (unlabeled) alcohols as a doubling of all resonance peaks concomitant with the shifts induced by the lanthanide complex. Similar effects have not been reported for alcohols in which the deuterium substitution is remote from the hydroxyl group. In this paper we report data obtained from additional systems.

Appropriately labeled compounds were prepared as part of a study designed to test for the occurence of [1,3] sigmatropic shifts during catalytic hydrogenation.[2,3] PMR spectra of 1:1 mixtures of labeled and unlabeled compounds were obtained with and without added shift reagent, using either a Varian HA100 or A56-60 nmr spectrometer. Enough shift reagent was added to allow observation of the splittings induced in the most prominent resonances. Though splittings were observed in all resonances of the substrates, multiplet structure and overlap prevented confident measurement of differences for every absorption.

In Table I, shifts induced by the dipyridine adduct of tris(dipivalomethanato) europium(III), $Eu(DPM)_3 \cdot 2py$, are reported for proton resonance of the unlabeled substrate. Listed percentage differences between resonances for labeled and unlabeled substrate are calculated relative to the shifts observed for unlabeled substrate. The percentage differences appear to be independent of the concentrations of substrate, metal complexes, and pyridine. This suggests that the

Table I. Isotope Effects on N.M.R. Shifts Induced by $Eu(DPM)_3 \cdot 2Py$

Labelled Compound	Resonance Observed	Chemical Shift[a]	Induced Shift[b]	% Difference[c]
 isoverbanol	Methyl-8	99	- 97	1.8
	Methyl-9	126	- 80	1.9
	Methyl-10	100	- 86	
	H-1	180	-137	
	H-2	200[f]	-220	
	H-3a	200[f]	-220	
	H-3b	200[f]	-480	
	H-5	200[f]	-386	
	H-7a	200[f]	-220	
	H-7b	124	-411	1.7
 verbanol	Methyl-8	80	-122	
	Methyl-9	126	-104	1.3
	Methyl-10	91	-150	1.3
	H-1	163	-173	
	H-2	200[f]	-180	
	H-3a	200[f]	-410	
	H-3b	200[f]	-590	
	H-5	200[f]	-544	
	H-7a	200[f]	-260	
	H-7b	145	-492	1.4
 $CH_3-\overset{D}{\underset{OH}{\vert}}-CH_2CH_3$	Methyl-1	67[d]	-184[d]	
	Methyl-2	55[d]	-113[d]	2.4[e]
 $CH_3-\overset{D}{\underset{OH}{\vert}}-(CH_2)_5CH_3$	Methyl-1	67[d]	-70[d]	2.7
	Methyl-2	54[d]	- 3[d]	
 $CH_3-\overset{H}{\underset{OH}{\vert}}-D$	Methyl-1	118	-229	1.3
 $CH_3-\overset{D}{\underset{OH}{\vert}}-D$	Methyl-1	118	-332	2.5
	Methyl-1	133[d]	- 73[d]	3.4
	H-3,4,5	424[d]	- 36[d]	
	H-6	424[d]	-150[d]	
	Methylene	265[d]	-239[d]	

See Footnotes in Table II

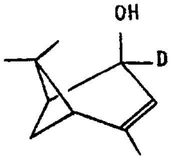
splittings arise out of differences in the metal complex-substrate association constants for labeled and unlabeled compounds.

Table II contains the results of studies using pyridine free Eu(DPM)$_3$, Pr(DPM)$_3$, and solutions containing tris(dibenzoylmethanato)europium(III), Eu(DBM)$_3$, and tris(1-benzoyl acetonato)europium(III), Eu(BAT)$_3$, as shift reagents. Eu(DBM)$_3$ is relatively insoluble in carbon tetrachloride[4] but may be dissolved by the addition of a few drops of pyridine. Resonances due to the metal complexes were observed in solutions of Eu(DBM)$_3$, and similarly treated Eu(BAT)$_3$, but did not interefere.

Analyses of shift magnitudes indicate that the alcohol hydroxyl group coordinates with the metal chelate in a nearly eclipsed conformation relative to the geminal hydrogen. This conformation facilitates hydrogen bonding between the geminal H (or D) and the ring oxygens of the metal chelate ligands. Such secondary hydrogen bonding could contribute to differences in association of the labeled and unlabeled alcohols. Alternatively, or concurrently, geminal deuterium substitution may alter the basicity of the hydroxyl oxygen. Comparisons of europium induced shifts in the nmr spectra of ethanol, 1-deuterioethanol and 1,1-dideuterioethanol (Table I) demonstrate the additive nature of a second deuterium substitution and suggest that changes in bacisity on deuterium substitution may be the dominant effect in these cases.

The effect is general and has been observed in lanthanide induced shifts of an appropriately substituted aldehyde and amine as well as alcohols. It is likely that the effect will also be found in other systems, such as mercaptans and ethers, where geminal substitution is possible.

Table II. Comparison of Isotope Effects Produced by Different Shifts Reagents on Mixtures of Labeled and Unlabeled Alcohols

Compound	Shift Reagent	Resonance Observed	Induced Shift^{b}	% Difference^{c}
	Pr(DPM)$_3$	Methyl-8	306	2.5
		Methyl-9	130	2.6
		H-7b	172	2.6
		Olefinic	404	2.5
Cis-Verbenol	Eu(DPM)$_3$	Methyl-8	-187	2.0
		Methyl-9	- 75	3.2
		H-7b	- 98	2.6
		Olefinic	-238	2.6
Sec-Butanol	Eu(DPM)$_3$	Methyl-1	- 79^{d}	2.2
Sec-Butanol	Eu(DBM)$_3$	Methyl-1	- 77	2.9
Sec-Butanol	Eu(BAT)$_3$	Methyl-1	- 62	2.2
Sec-Butanol	Pr(DPM)$_3$	Methyl-1	215^{d}	1.7

[a] Initial chemical shifts are the same for both labeled and unlabeled compounds;

[b] Induced changes in shifts are reported for unlabeled material;

[c] (induced shift of labeled compound - induced shift of unlabeled compound) X100/induced shift of unlabeled compound;

[d] 60 MHz;

[e] Identical % difference obtained at 100 MHz with various concentrations;

[f] Center of multiple resonance band;

[g] Because accurate shift change measurements for certain resonances were unaccessible due to line width, complex patterns, or overlapping resonances; % difference was not calculated for all groups.

1. Gerard V. Smith, Walter A. Boyd, and C. C. Hinckley, J. Amer. Chem. Soc., 93, 6319 (1971).
2. Gerard V. Smith and J. R. Swoap, J. Org. Chem., 31, 3904 (1966).
3. F. D. Mango, Advan. Catalysis, 20, 291 (1969).
4. J. K. M. Sanders and D. H. Williams, J. Amer. Chem. Soc., 93, 641 (1971).