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STERIC FACTORS AND BENZENE SOLVENT SHIFTS IN NMR SPECTROSCOPY

J. Edgar Anderson
Institut de Chimie, Université de Strasbourg,
Boîte Postale 296, Strasbourg, France.

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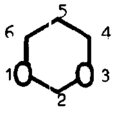
There has been a recent revival of interest in the effects of solvents on chemical shifts in nmr spectroscopy. As pointed out by Bhacca and Williams[1)], the interaction of aromatic solvents with polar functions in the solute can simplify complex spectra in many cases. For cyclic ketones, the size and sign of the effect $\Delta\delta$ (the difference in chemical shift of a signal in the interacting solvent and in an inactive solvent) has been linked with the position of the protons relative to the carbonyl function[2,3)].

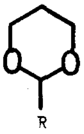
In the case of steroidal sapogenins, where the principal polar function is an R—O—C(R_2)—O—R group, Williams and Bhacca[4)] have concluded, from comparisons of spectra in deuteriochloroform and benzene solutions, that "The solvent shift for a given proton is approximately constant provided that the position of the proton relative to polar sites in the molecule is unchanged in the various compounds".

The 1,3-dioxanes I, whose preferred conformation is a chair[5)] have a similar polar function to that of the steroidal sapogenins, though the steric environment is clearly different. These dioxanes show large solvent shifts, and have two other features which make them attractive for solvent effect studies. Firstly, it is usually possible to identify every proton in the molecule, and secondly, one obtains a wide range of solvent shifts, from -0.25 to +0.6ppm, in each molecule, so that there results a precise picture of the effect of the solvent. Changes brought about by substituents are readily observed, and in the present study, steric factors affecting the size and nature of the interaction are demonstrated, so that the conclusion of Williams and Bhacca quoted above is true only within the limits of the examples they considered.

Spectra were measured on a Varian A60 spectrometer operating at 60Mcs. Solutions were about 0.4M in solute. Carbon tetrachloride and

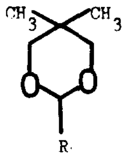


I



II

R = a) t-Bu.
b) i-Pr.
c) Et.
d) Me.

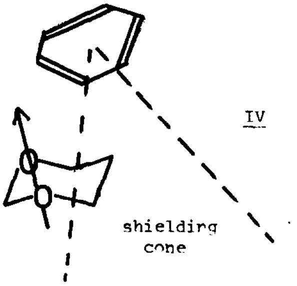


III

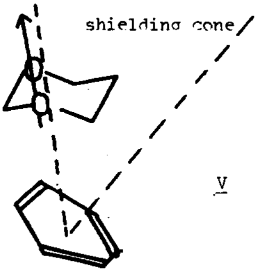
benzene were the 'inactive' and 'active' solvents respectively. A plot of the solvent shift against the mole fraction of benzene in carbon tetrachloride is a straight line$^{6)}$, which indicates a 1:1 complex. The equilibrium constant for complex formation is obtained from a plot of (mole fraction benzene/fraction of the total solvent shift) against the mole fraction benzene$^{7)}$, but such plots for the series II and III are very nearly horizontal. This indicates that the equilibrium constant for complex formation is much less than 1, i.e. the complex is less stable than the dissociated state of the two molecules.

Thus benzene and 1,3-dioxanes interact to give very weak 1:1 complexes. Since it is difficult to conceive a barrier of great magnitude to complex formation, there will be a rapid exchange of the particular benzene molecule involved in complexing with any one dioxane molecule.

The solvent shifts $\Delta\delta^{CCl_4}_{C_6H_6}$ for a series of 1,3-dioxanes are presented and discussed below. In the series II and III, there is at equilibrium, more than 95% of the conformation with the 2-alkyl group equatorial$^{8)}$. Solvent shifts for the series II are shown in Table 1. The 4-, 5-, and 6-positions are shielded, the 5-position particularly so: the 2-axial position is little affected, while the protons at the 2-equatorial position are deshielded. This is compatible with location of the benzene molecule as in IV or V. The dipole of the



IV



V

COMPOUND	5-eq-H	5-ax-H	4,6-eq-H	4,6-ax-H	2-ax-H	2-eq-subst.	
						-C-Ring H	C-C-Ring H
IIa R=t-Bu	+.59	+.24	+.24	+.32	-.01	---	-.27
IIb R=i-Pr	+.55	*	+.19	+.28	-.02	*	-.19
IIc R=Et	+.55	*	+.19	+.27	0	*	-.14
IId R=Me	+.54	+.29	+.18	+.28	+.05	-.16	--

TABLE 1

COMPOUND	5-eq-Me	5-ax-Me	4,6-eq-H	4,6-ax-H	2-ax-H	2-eq-subst.	
						-C-Ring H	C-C-Ring H
IIIa R=tBu	+.36	0	+.07	+.17	-.06	--	-.24
IIIb R=iPr	+.35	-.01	+.02	+.16	-.04	-.26	-.19
IIIc R=Et	+.34	-.01	+.05	+.13	-.03	-.21	-.13
IIId R=Me	+.33	-.03	+.01	+.09	-.04	-.16	--

TABLE 2

Solvent shift values are in ppm

*The shift of the signal could not be determined because of overlap with other signals

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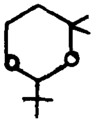
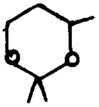
dioxanes is as shown in IV and V, so that if the interaction with benzene is of the type dipole-induced dipole, the nucleophilic benzene molecule would be expected to prefer position V.

The introduction of axial methyl groups into the dioxane molecule produces marked effects. The series III comprises compounds with axial and equatorial methyl groups in position 5, and the solvent shifts observed for this series are in Table 2. All the protons in the 4,5, and 6-positions are less shielded by .15 to .30 ppm than those in the corresponding compounds in the series II, though in the 5-position the change from hydrogen to methyl substituent prevents a direct comparison. These changes could be explained on the basis of diagram IV, with the axial methyl group now in position 5, tipping the end of the benzene molecule away from the dioxane ring, with the result that the protons at positions 4, 5, and 6 would be nearer the edge of the shielding cone of the benzene ring.

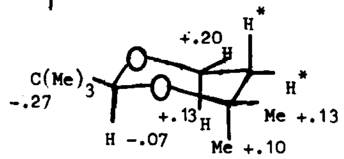
Axial groups on the other side of the molecule however, have a similar but less marked effect, see VI and VII. Compared with the compounds in series II, the 6-axial proton is much less shielded. Similarly, the

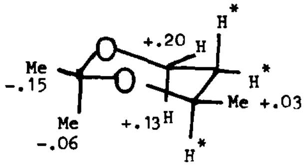


VI



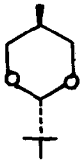
VII



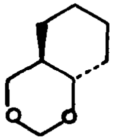


2-axial proton and, in VII, the 6-equatorial proton are less shielded.

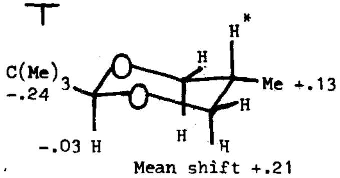
That equatorial substituents have little effect is shown by the compounds VIII and IX. In VIII the protons in the 4,6-positions have almost identical chemical shifts, but their mean solvent shift and that of the 2-axial hydrogen and the t-butyl group compare well with those in series II. In IX, all the shifts observed agree well with those found in series II.

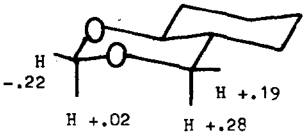


VIII



IX





Thus, although the benzene dioxane complex is specific, it is not possible to say at present on which side of the dioxane ring the benzene molecule is located, since axial groups on either side of the dioxane molecule change the effect of the solvent. It is clear however that steric factors can invalidate a direct comparison of the solvent shifts of similarly located protons in different molecules.

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