

An NMR and *Ab Initio* MO Study of the Effect of β -Oxygen in 1,3-Dioxanes

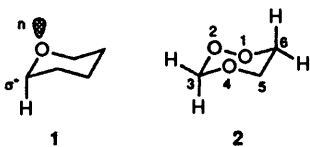
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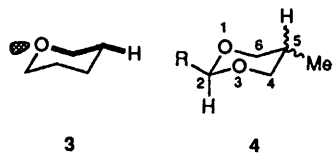
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NMR Measurements and *ab initio* calculations suggest that in 1,3-dioxanes the β -oxygen atoms have the effect of weakening the equatorial CH bond at the 5-position.

At the methyne group adjacent to oxygen in pyranoses the one-bond NMR coupling constants, $^1J_{C-H}$, are greater for the equatorial than the axial hydrogen atoms (*ca.* 170 and 160 Hz respectively).¹ This effect has been named after its discoverer as the Perlin effect,² and it has been ascribed to the anomeric $n-\sigma^*$ interaction between the axially directed non-bonding electron pair on the α -oxygen and the antiperiplanar axial C-H bond as shown in 1;²⁻⁴ this lengthens and weakens the bond, and attenuates the Fermi coupling. This model is supported by *ab initio* calculations on acyclic model compounds.²



We recently reported⁵ that in 1,2,4-trioxanes (2), the methylene groups at the 3- and 6-positions show a reversed Perlin effect, *i.e.* $^1J_{C-H(ax)} > ^1J_{C-H(eq)}$; this appears to be the first example of this effect in oxygen heterocycles. We suggested that this might be due to the fact that both these methylene groups have oxygen in the β -position. A homoanomeric interaction between a pseudo-equatorial non-bonding electron pair on β -oxygen, and the equatorially directed CH bond as shown in 3 might weaken the equatorial CH bond, and if the effect of β -oxygen were greater than the counteracting anomeric effect of α -oxygen, $^1J_{C-H(eq)}$ might be reduced below $^1J_{C-H(ax)}$. Similar W-plan interactions are often invoked in both NMR⁶ and EPR⁷ spectroscopy.



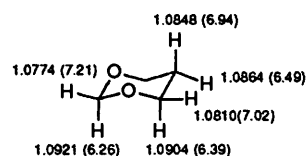
Alternatively the effect of the β -oxygen might be ascribed to the antiperiplanar arrangement of the O-C and C-H bonds. Of course, both mechanisms may contribute. Juaristi has shown that a reversed Perlin effect is observed at all methylenic positions in some 1,3-dithianes,⁸ and at some positions in 1,3-oxathianes,⁹ and has preferred this second explanation.

In order to separate the effect of α -oxygen from that of β -oxygen, we have now studied the NMR spectra of a series of 1,3-dioxanes 4 ($R = \textit{tert}$ -butyl, 4- $\text{NO}_2\text{C}_6\text{H}_4$, 2- MeOC_6H_4 , 4- MeC_6H_4 or 3- ClC_6H_4), which are provided with a conformation-holding *tert*-butyl or aryl group at C(2), and a *cis* or *trans* methyl group at C(5) to aid the analysis of the spectra.

The dioxanes were prepared from 2-methylpropan-1,3-diol and the appropriate aldehyde. In each case this gave two isomers which were identified by ^1H NMR spectroscopy, which showed that the *trans* isomer was always the principal component. In all these compounds, the hydrogen at the C(5) position shows a reversed Perlin effect, with $^1J_{C-H(eq)}$ (125.0–126.0 Hz) $<$ $^1J_{C-H(ax)}$ (131.2–132.3 Hz). In 2-*tert*-butyl-1,3-dioxane itself, the values are $^1J_{C-H(eq)}$ 125.2 Hz, $^1J_{C-H(ax)}$ 130.7 Hz.

This confirms that the effect is due to the presence of the β -oxygen atoms. At C(4), and C(6), which have oxygen in the α -position, the normal Perlin sequence holds, with $^1J_{C-H(eq)} > ^1J_{C-H(ax)}$. The combination of the effects of α -oxygen in weakening the axial CH bond, and β -oxygen in weakening the equatorial CH bond shows up in the value of $^3J_{H(4ax)H(5eq)}$ (1.2–1.3 Hz) (which is subject to both effects), being consistently smaller than $^3J_{H(4eq)H(5ax)}$ (4.5–4.8 Hz) (which is subject to neither). This is despite the fact that molecular mechanics calculations show that the former dihedral angle (129.6°) is greater than the latter (120.6°), and, by the Karplus equation, should lead to the larger coupling. This effect has been noted previously by Anteunis¹⁰ who pointed out the W-arrangement of bonds and non-bonding electrons.

This qualitative model of the interactions of the non-bonding electron pairs on α - and β -oxygen is open to the criticism that these electrons do not occupy pure tetrahedrally-directed sp^3 orbitals, the axial orbital having enhanced p character and the equatorial orbital having enhanced s-character.² We have therefore supplemented these NMR measurements with *ab initio* (RHF/6-31G*) calculations using the Gaussian 92 system of programs.¹¹ The results for 1,3-dioxane are shown in 5.



5 *Ab initio* bond lengths (Å). Stretching force constants (mD/Å) are given in parentheses.

Our calculations predict that at the 2-, 4- and 6-positions, the α -oxygen lengthens and weakens the axial CH bonds [$\text{C}(2)\text{-H(ax)} = 1.0921$ Å, $\text{C}(2)\text{-H(eq)} = 1.0774$ Å; $\text{C}(4)\text{-H(ax)} = 1.0904$ Å, $\text{C}(4)\text{-H(eq)} = 1.0810$ Å], but at the 5-position, the presence of the β -oxygen lengthens and weakens the equatorial bond [$\text{C}(5)\text{-H(ax)} = 1.0848$ Å, $\text{C}(5)\text{-H(eq)} = 1.0864$ Å]. The inclusion of electron correlation in the optimization procedure (MP2/6-31G*) reinforces the trend observed at the lower level of theory [*viz.* $\text{C}(2)\text{-H(ax)} = 1.1060$ Å, $\text{C}(2)\text{-H(eq)} = 1.0896$ Å;

C(4)–H(ax) = 1.1026 Å, C(4)–H(eq) = 1.0922 Å; C(5)–H(ax) = 1.0940 Å, C(5)–H(eq) = 1.0968 Å].

The difference between calculated equatorial and axial bond lengths at the 5-position, while being too small to be conclusive, is consistent with the experimental coupling constants, and with the contrasting results for cyclohexane, where $^1J_{C-H(ax)} > ^1J_{C-H(eq)}$.

This effect of β -oxygen should be detectable by other methods. The differences in bond lengths might be measurable by microwave spectroscopy, and the differences in bond strengths by IR spectroscopy. One might also expect the difference in bond strengths to manifest itself in a difference in heterolytic and homolytic reactivity, as has been shown to occur with oxygen in the α -position.¹²⁻¹⁵ It would be interesting to design and study compounds which could show whether an antiperiplanar configuration of the O–C and C–H bonds is sufficient, or whether a W-configuration which includes also the orbital of the non-bonding electrons is necessary to show the effect.

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