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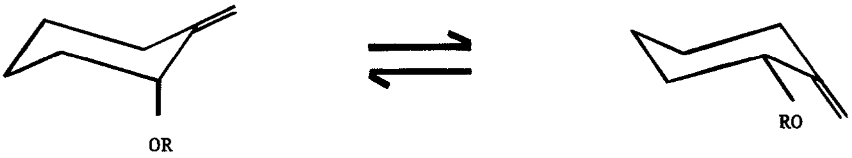
UNEXPECTED CONFORMATIONAL PROPERTIES OF 2-VINYLOXY-, 2-PHENOXY- AND 2-ACETOXY-METHYLENECYCLOHEXANES

Minh Tan Phan Viet, Jean Lessard*, and John K. Saunders
Département de chimie, Université de Sherbrooke, Sherbrooke,
Québec, Canada, J1K 2R1.

The preference of polar groups to exist in the axial rather than the equatorial orientation in 2-substituted oxanes is known as the anomeric effect (1). This anomaly has been explained (2) in terms of an overlap of the oxygen n electrons with the vacant antibonding C(2)-X orbital when the C-X bond is in the axial orientation thus stabilizing this orientation. This can be visualized in terms of the "double bond - no bond resonance" concept.

In an earlier publication (3), we reported that the methoxy group in 2-methoxy-methylenecyclohexane exists preferentially in the axial orientation and that this preference is increased upon introduction of a methoxy group on the double bond. These observations were explained by the "double bond - no bond resonance" interaction with the overlap being between the Π electrons of the double bond and the σ^* orbital of the C-X bond. More recently, Zefirov and his co-workers (4) have reported that oxygenated substituents at C-4 in spiro[5.2]octane derivatives prefer the axial orientation. They suggested that the interaction between the electrons of one of the two degenerate orbitals of e-type symmetry of the cyclopropane ring and the σ^* orbital of the adjacent axial C-O bond could be responsible, at least in part, for this axial preference.

We have determined the conformational equilibria of 2-methoxy-(1a), 2-propyloxy-(1b), 2-isopropyloxy-(1c), 2-vinyloxy-(1d), 2-phenoxy-(1e), and 2-acetoxy-(1f) methylenecyclohexane by dynamic ^{13}Cmr spectroscopy using 3% solutions in $CHFCl_2$ - CD_2Cl_2 (4:1, v/v). The chemical shifts



of C-4 in the axial and equatorial orientations, δ_{ax} and δ_{eq} respectively, were obtained at -110°C, well below the coalescence temperature. Carbon 4 is shielded by 4.5 ppm in the axial relative to the equatorial conformer by the well known γ effect (5). The chemical shifts are virtually independent of substituent. The proportion of equatorial conformer, x, was determined at 0°C from $\delta_m = x\delta_{eq} + (1-x)\delta_{ax}$, where δ_m is the C-4 chemical shift at 0°C (6). The results are recorded in Table 1. The proportion of equatorial conformer increases from 1a to 1f as does the carbon 4 chemical shift in both $CHFCl_2$ and the less polar CCl_4.

TABLE 1

Conformational equilibria and C-4 chemical shifts of 2-substituted methylenecyclohexanes

Substituent OR		% of equatorial conformer[a] ($CHFCl_2$-CD_2Cl_2, 0°C)	C-4 chemical shift in ppm[b] ($CHFCl_2$-CD_2Cl_2, 0°C)	(CCl_4, 30°C)
OCH_3	(1a)	41	22.6	21.6
$OCH_2CH_2CH_3$	(1b)			21.8
$OCH(CH_3)_2$	(1c)	56	23.4	22.0
$OCH=CH_2$	(1d)	61	23.3	22.2
OC_6H_5	(1e)	74	23.9	23.1
$OCOCH_3$	(1f)	80	23.9	23.1

[a] See the text.

[b] Downfield from TMS.

The interesting feature of these results is the siginficantly higher proportion of the equatorial orientation for unsaturated substituents (1d, 1e, and 1f) as compared to saturated substituents (1a, 1b, and 1c). According to the "double bond - no bond resonance" concept, the proportion of axial conformer should increase with increasing substituent electronegativity since an increase in substituent electronegativity should decrease the energy level of the σ^* orbital of the C-O bond and hence lead to a better orbital interaction in the axial orientation. This has indeed been observed in 2-substituted oxanes (7) and 4-substituted spiro[5.2]octanes (4) where the population of the axial conformer increases when a methoxy is replaced by an acetoxy group. In Table 2, we give the chemical shifts of carbon 4 of 2-substituted oxanes. This carbon is γ with respect of the oxygenated substituent and is more shielded in the case of an unsaturated substituent than for a saturated substituent indicating a greater preference of the former for the axial orientation as expected. In 2-substituted methylenecyclohexanes, the greater preference for the equatorial orientation of unsaturated oxy substituents as compared to alkoxy substituents is therefore unexpected.

This "unsaturation effect" cannot be attributed to solvation effects since it has been observed in two solvents of different polarity ($CHFCl_2$ and CCl_4) (8) nor can it be due to steric factors since a vinyloxy group (1d) should be sterically comparable to a propyloxy group (1b), and the phenoxy (1e) and acetoxy (1f) groups comparable to the isopropyloxy group (1c). In fact, examination of molecular models of 1e indicates that, in the axial conformer, there are two more or less equivalent orientations around the C–O bonds which appear sterically identical with the unique orientation around the same bonds in the equatorial conformer.

TABLE 2

C-4 chemical shifts of 2-substituted oxanes

Substituent	δ^a
OCH_3	19.4
$OCH(CH_3)_2$	20.0
$OCH = CH_2$	18.7
OC_6H_5	18.8
$OCOCH_3$	18.8

[a] In carbon tetrachloride at ca. 30°C, downfield from TMS.

Other factors which could be responsible for the observed "unsaturation effect" are interactions between the Π electrons of the exo methylene group and the Π electrons of the unsaturated oxy substituent, and/or electrostatic interactions between the C–O bonds and the exo methylene group. The Π-Π electron interactions can probably be discarded from inspection of molecular models of 1e. In one of the two sterically favored orientations around the C–O bonds for the axial conformer (see above) there could be a repulsive Π-Π interaction but this interaction is absent in the other orientation. For the equatorial conformer, there exist orientations in which Π-Π attraction could be envisaged. However these orientations possess severe steric interactions which would more than counterbalance any gain by electronic stabilization. Simple electrostatic calculations on 1a implied that the dipole-dipole and the dipole-quadrupole interactions between the C–O bonds and the exo methylene group would favor the axial conformation relative to the equatorial conformation (3). An unsaturated system attached directly to the oxygen could modify the orientation and the moment of the dipole of the C–O bonds such that the electrostatic interactions would now favor the equatorial conformer over the axial conformer.

Thus the unexpected conformational properties of 2-unsaturated oxy methylenecyclohexanes are not a consequence of A and $A^{1,3}$ interactions nor orientations about the C-O bonds.

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6. Calculation of ΔG^o at various temperatures gave the same value within experimental error for a given substituent.

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8. In fact, the C-4 chemical shift difference between OCH_3 (1a) and OC_6H_5 (1e), for example, varies only slightly with solvent at ca. 30°C as can be observed from: $\Delta\delta = 1.5$ (CCl_4), 1.3 (C_6D_6, $CDCl_3$, $CHFCl_2$, CD_3OD), 1.0 (CD_3CN). It appears that there is a greater preponderence of the axial conformer in non polar solvents.

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