Tetrahedron. Vol 31, pp. 1837 to 1840. Pergamon Press 1975. Printed in Great Britain

NMR EXPERIMENTS ON ACETALS—56

CONFORMATIONAL STUDY OF 1,3-DIOXENE

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(*Received in UK* 17 *July* 1974; *Accepted for publication* 24 *March* 1975)

Abstract—From the ^{1}H-NMR parameters, extracted from the spectra of 1,3-dioxene, 5-Me-1,3-diox-4-ene, 4,5-diMe-1,3-diox-4-ene and of 2,4,5-triMe-1,3-diox-4-ene, it follows that the preferred conformations are the 1,2-diplanar (sofa) C_2 form (Fig. 1B). The barrier to ring reversal in 5-Me-1,3-dioxene was found to be 7·2 ± 0·2 kcal/mole at −123° (in freon-21).

INTRODUCTION

In 1941 Lister proposed[1] that the main conformation of cyclohexene is the half-chair (monoplanar form), and Pitzer's first calculations[2,3] have confirmed his view. Others[4–7] have recalculated the energies of a series of possible geometric forms, and they all come to the same conclusion. Experimental evidence, obtained from ^{1}H-NMR,[8] X-ray,[9] microwave,[10] Raman and IR[11] and electrondiffraction,[12] are convincing criteria in this respect, so that relatively precise molecular data have become available.[10,12] Thus, the dihedral angles between the π-lobes and the σ_{C-H} bonds of the α-methylene groups are resp. 225° and 345° and in the ring-inversed conformation they are resp. 195° and 315°.[14]

The next-most stable characteristic conformer is the 1,2-diplanar (sofa) form, less stable by some 1·2[6] – 1·8 kcal/mole.[7] The characteristic dihedral angles between the π-lobes and $\alpha-\sigma_{C-H}$ bonds are 210° and 330° and between the π-lobes and $\alpha'-\sigma_{C-H}$ bonds they are 237° and 357° or 183° and 303°.[14]

The sofa, however, is not a minimum energy conformation and neither is the 1,3-diplanar (boat or half-boat) form (having 5·1 to 5·3 kcal/mole strain[6,7] with respect to the half-chair).

Both of these conformations lie on the topomerization path, the itinerary being characterized by a unique top of about ~5·3 kcal/mole, as ascertained by ^{1}H-NMR experiments,[8] thus the critical conformation is very similar to the 1,3-diplanar form.[13]

RESULTS

We have measured the ^{1}H-NMR parameters at 300 MHz of a series of four 1,3-dioxenes, and the extracted data are gathered in Table 1. 2,4,5-TriMe-1,3-diox-4-ene is believed to exist preponderantly in an anancomeric form, where the 2-Me has a (quasi)equatorial orientation.[†]

Because $^2J6$ in this model compound is found to be −15·0 Hz, whereas in 1,3-dioxane it is only *ca.* −(11–12) Hz,[17] the dihedral angles between the π-lobes and the $\alpha-\sigma_{C-H}$ bonds are very near to 30°(330°) and 210°, according to the Barfield-Grant effect.[18] This statement accords only with a sofa form. In both 4,5-diMe- and 2,4,5-triMe-1,3-diox-4-ene a homoallylic coupling of 2·0 Hz is found between both H-6 protons and Me-4. Recent INDO-MO reconsiderations[19,cf 20] about the quantitative values for homoallylic coupling, involving a free rotating Me group, suggest that for a transoïd coupling, as in the present case, the ϕ's must be close to 120° and 240°. This does not agree with a half-chair form (ϕ (idealized): 255° (2·8 Hz) and 135° (1·5 Hz)) nor with a half-boat form (where the ϕ values would give rise to 2·3 and 0·2 Hz), but only with a C_2 sofa-form[‡] as depicted in Fig. 1B. Here the plane going through O_3–C_4–C_5–C_6 bisects the CH_2–6 moiety, giving rise to ϕ-values of 120° and 240°. The O_1 sofa-form (Fig. 1A) on the contrary is characterized by ϕ-values of 147° and 267°, resulting in values[19] 0·94 and 3·15 Hz, respectively, for homoallylic coupling. The O_1-sofa furthermore would show up a value for $^2J6$ of −12·5 to −13·0 Hz,[18] which is not substantiated by our findings. Finally the fact that we observe a value ~6·0 Hz for $^2J2$ in 5-Me-1,3-diox-4-ene favours decisively the C_2-sofa. The normal value in 1,3-dioxanes being $^2J2$ = 6·1 Hz, this geminal coupling constant in a XCH_2Y moiety is dominated by the electron density and the direction of the p-X and p-Y lobes, and emperical rules with respect to idealized orientations have been developed,[21] e.g. as a function of the torsion angles between X–CH_2 and CH_2–Y. Taking as a good guess the torsion angles observed in the different forms in cyclohexene, then we predict[§] as $^2J2$ for a half-chair a value of −5·1 Hz,[cf 22] for the O_1-sofa a value of −3·5 Hz, but as present data shows, almost a normal value[§] for the C_2-sofa form.

DISCUSSION

The postulation that in 1,3-dioxenes the sofa form would be stabilized with respect to the half-chair, seems

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[†] In 1,3-dioxanes a 2-Me group is a "biasing" (anancomerizing) group, as its conformational energy amounts to 4·1–4·3 kcal/mole.[15] This tendency to occupy exclusively the equatorial position is believed to be so pronounced, that in whatever form dioxene may occur, this group will still prefer to a great extent the (quasi)equatorial position. This is especially true if one notes that even in 4-Me-*c*.hexene the conformational energy of a Me substituent amounts to 1·0–1·1 kcal/mole.[6,16]

[‡] In other compounds where ϕ amounts to 120° and 240°, experimental values near 2·0 Hz have indeed been reported[cf 19]: e.g. 1-propylidene-indane (1·94 Hz), 4-ϕ-2-Me-*c*.pentenone (2·0 Hz) and propylidene *c*.propane (2·0 Hz). Also in 6-Me-3,4-dihydro-2H-pyrane, $^5J(Me_{4,6})$ = 2 Hz[29] (vide infra for a discussion of this compound).

[§] Because the electron density of the 0–3 lobes may have been decreased through mesomeric overlap with the double bond, in fact the reported values may become slightly more negative.[cf 22] Thus in 4-oxo-1,3-dioxane (half-chair[37]) $^2J2$ = −(5·2–5·6) Hz.

Table 1. ^1H-NMR parameters of 1,3-dioxenes obtained at 300 MHz (5 vol % in CCl_4, TMS internal)

	δ-values (in ppm)						
	H_2	H_4	H_5	H_6	Me_2	Me_4	Me_5
1,3-Dioxene (1)	$4{\cdot}90_5$	$6{\cdot}42_7$	$4{\cdot}77_9$	$4{\cdot}10_9$	—	—	—
5-Methyl-1,3-dioxene (2)		$6{\cdot}27_6$	—	4·02	—	—	$1{\cdot}51_8$
4,5-Dimethyl-1,3-dioxene (3)	$4{\cdot}85_3$	—	—	$3{\cdot}92_3$	—	$1{\cdot}72_6$	$1{\cdot}50_4$
2,4,5-Trimethyl-1,3-dioxene (4)	$4{\cdot}78_5$	—	—	$4{\cdot}05_2$ $3{\cdot}80_2$[a]	$1{\cdot}30_0$	$1{\cdot}70_0$	$1{\cdot}49_4$

	J-values (in Hz)									
	$^{4t}JH_4,H_6$	$^3JH_5,H_6$	$^{5t}JMe_4,H_6$	$^5JMe_4,Me_5$	$^4JMe_5,H_6$	$^4JMe_5,H_4$	$^3JH_4,H_5$	$^2JH_6$	$^3JMe_2,H_2$	$^2J_2$
1,3-Dioxene (1)	−1·9	$2{\cdot}5_6$	—	—	—	—	$6{\cdot}3_5$	—	—	~ −6·0[a]
5-Methyl-1,3-dioxene (2)	−1·7	—	—	—	−1·2	−1·5	—	—	—	
4,5-Dimethyl-1,3-dioxene (3)	—	—	2·0	0·95	−0·95	—	—	—	—	
2,4,5-Trimethyl-1,3-dioxene (4)	—	—	2·0 & 2·0	1	−1·4	—	—	−15·0	5·1	

[a] Approximated value obtained at −150° in freon-21 at 100 MHz.

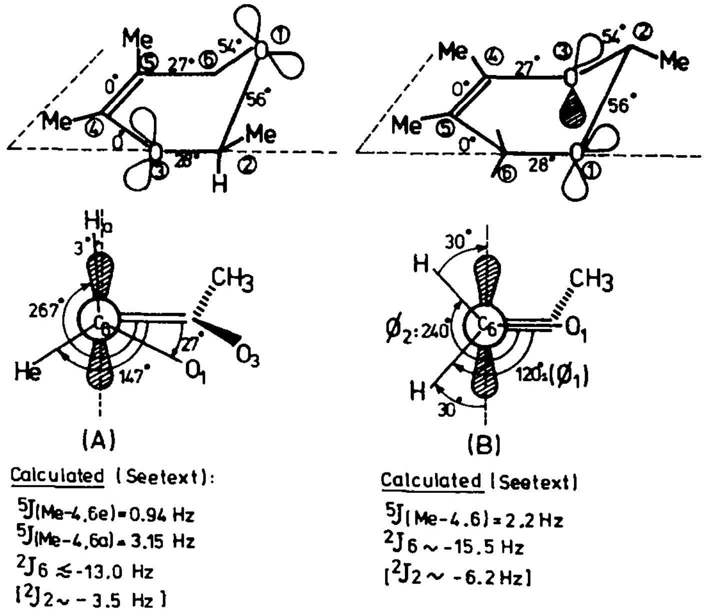

Fig. 1.

reasonable. From inspection of ^3J, ^4J and ^5J values in 3,4-dihydro-2H-pyrane, the main conformation here also seems to be[23] the 1,2-diplanar form. The main reason may reside in the fact that overlap of the p-O π-system is maximal in this conformation.*

However, other considerations agree with the expectation that in 1,3-dioxene the sofa form becomes more stabilized in comparison with the half-chair form, in contrast with the situation in cyclohexene. In the latter, a sofa form suffers from some strain by an approach down to 2·55 Å of the 3,5 H nuclei. In the C_2-sofa O-atoms are put into these positions (a similar situation can be traced in the 2H-pyrane nucleus).

1,4-Dioxene is believed to exist in a half-chair form,[26] but here two ring O-atoms are equivalent to the π-orbital, and this may result in an "in-between" maximal stabilisation where both O-atoms physically indeed become equivalent in a static fashion, and not in a dynamic fashion (e.g. by equilibration between two equivalent sofa forms).

Basic conformation and topomerization phenomena. As pointed out, the basic conformation in cyclohexene is the half-chair, while the 1,2-diplanar form lies on the route of ring reversal.[13] The fact that in 3,4-dihydro-2H-pyrane and 1,3-dioxene the basic conformation has now become the 1,2-diplanar form, has an influence on the barrier to topomerization. For c.hexene $\Delta G^{*} = 5{\cdot}3$ kcal/mole,[8] in 3,4-dihydro-2H-pyrane it is increased to 6·6 kcal/mole,[27] in 1,4-dioxene it is still higher, i.e. 7·3 kcal/mole.[28] We have now found for 1,3-dioxene a coalescence temperature of −123° ± 1, corresponding to $\Delta G \neq \sim 7{\cdot}2$ kcal/mole. The increase in topomerization barrier may be rationalized, if one accepts that in the critical conformation during inversion the proposed p.O-π stabilisation would be lost. As the relative orientation between the p and π-lobes must change during the process for reversal then the increase in $\Delta G \neq$ might be accounted for an extra stabilization of the ground state. It is nevertheless possible that this stabilization is apparent and that in the real situation a destabilization phenomenon occurs in the transition state.†

EXPERIMENTAL

Samples for ^{1}H-NMR spectra were purified previously by GC on QF_1 and Carbowax. ^{1}H-NMR spectra were obtained at 18° with a Varian HR-300 spectrometer, the double resonance and INDOR with a Varian HA-100, equipped with Muirhead-Wigan-D 980-B decade oscillators. Low temperature studies were done in freon-21 with a Varian XL-100 (12 in.). The temps were measured with a calibrated Iron-Constantan thermocouple. All spectral analyses were checked afterwards by simulations on a Varian 620-i computer with the aid of the SIMEQ 16/II program.[32]

1,3-Dioxene. (a) Glycerol was acetalated with formaldehyde in acidic medium according to the method of Hibbert and Tritser.[33] The mixture of 5-HO-1,3-dioxane and 4-$HOCH_2$-1,3-dioxolane was equilibrated with a trace of *p*-toluenesulfonic acid at 70° for 24 hr. The crude mixture was tosylated in pyridine conventionally and the tosylated mixture dissolved in a minimum of boiling benzene. After cooling the crystallized 5-TsO-1,3-dioxane was collected (yield 40%).

(b) Elimination of TsOH was performed in DMSO with the aid of KOt-Bu according to the procedure of Snyder and Soto.[34] The volatile fraction was collected and redistilled, b.p. 78°, yield 74%. (Found C 56·0, H 6·8. Calc.: C 55·8$_5$, H 6·98%).

4,5-Dimethyl-1,3-dioxene (3) *and 2,4,5-trimethyl-1,3-dioxene* (4). These compounds were obtained as by-products during the reduction study of 4 - Me - 5 - methylidene - 1,3 - dioxane and 2,4 -

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*It may be noted that the C_2-sofa possesses parallel p-orbitals for both oxygen atoms while the O_1-sofa does not. This paralellity, occasionally called "rabbit-ear effect"[24] was for some time believed to cause strain. It is not at all clear whether this is indeed the case. 1,3-Dioxane is, however, less stable than 1,4-dioxane.[25]

†In 1,4-dioxene (a half-chair conformation),[26] one might advance a stabilization per oxygen of $\frac{1}{2}(7{\cdot}3 - 5{\cdot}3) = 1$ kcal/mole for the ground state. One would then expect a ΔG^{*} value of $5{\cdot}3 + 1{\cdot}0 = 6{\cdot}3$ kcal/mole for 3,4-dihydro-2H-pyrane in the half-chair form. It is 6·6 kcal/mole as the basic conformation is the sofa. Taking the values for c.hexene as an approximate measure of the intrinsic destabilisation between sofa and half-chair (with $\Delta\Delta G^{*} = 1{\cdot}2 - 1{\cdot}8$ kcal/mole[6,7]), the overall stabilisation by the pO–π overlap should therefore amount to some $1{\cdot}0 + 0{\cdot}3 + 1{\cdot}2$ à $1{\cdot}8 = 2{\cdot}5$ à 3·2 kcal/mole. This is a very reasonable value and in fact is almost exactly the difference in rotational barrier between that observed in propenyl methyl ether (3·83 kcal/mole)[30] and *cis*-butene (0·65 kcal/mole).[31]

diMe - 5 - methylidene - 1,3 - dioxane.[35] The isolation of the reaction mixture[35] was performed by GC on Carbowax, yield[35] of the crude mixture: 16% (3) and 19% (4).

5 *-Me* -1,3 *-Diox* -4 *-ene.* 5 - Me - 5 - I - 1,3 - dioxane[36] (1·5 g) was refluxed for 30 min in 10 ml EtOH, after 0·3 g Na had been dissolved. Fractionation of the crude mixture gave a fraction (63°–81°) that was subsequently purified by GC (Gm Carbowax, 80°C). Two fractions (61 : 39; respectively 5 - Me - 1,3 - diox - 4 - ene and 5 - methylidene - 1,3 - dioxane) were obtained. (Found: (main fraction): C 60·2, H $7{\cdot}8_8$; Calc. C $60{\cdot}1_5$, H $7{\cdot}9_7$%). (minor fraction) C $60{\cdot}3_5$%, H $7{\cdot}7_5$%.

Acknowledgements—We thank the Ministry for Scientific Programming for funds for the continuation of our research using a superconducting 300 MHz spectrometer. The IWONL is thanked for a grant to one of us (R.C.).

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