# STEREOCHEMISTRY OF 2,3-DISUBSTITUTED
1,3,2-DIOXABORINANES

**V. V. Kuznetsov, E. A. Alekseeva, E. G. Pykhteeva,
I. S. Rublev, and A. I. Gren'**

According to ^1H NMR spectroscopic data, molecules of 2,4-disubstituted 1,3,2-dioxaborinanes exist in the preferred sofa conformation with equatorial alkyl groups at $C_{(4)}$. This conclusion has been confirmed by calculation of the optimal geometry of the ring of the cyclic boron esters by the MM2 molecular mechanics method.

The preferred conformation of the ring of 1,3,2-dioxaborinanes is determined by the partial double bond nature of the B–O, the consequence of which is that for molecules with 2,5-, various forms of 2,5,5-, trans-2,4,5, and cis-2,4,5-substituents the semiplanar or sofa conformation is observed [1-7]. At the same time the conformation of cis-2,4,5-trialkyl-1,3,2-dioxaborinanes is distorted towards one of the twisted forms [5] and molecules of most of the 2,5,5- and 2,4,4-substituted derivatives are mixtures of invertomers at room temperature [2, 8]. Because of this and the absence of systematic literature data it seemed interesting to estimate the effect of alkyl substituents at $C_{(4)}$ on the nature of the preferred conformation of six-membered cyclic esters of boric acid. The present paper is concerned with a study of the conformational properties of 2,4-disubstituted 1,3,2-dioxaborinanes (compounds I-VI) by ^1H NMR spectroscopy and molecular mechanics.

The cyclic boric acid esters I and III-VI were made by the reaction of the corresponding 1,3-diols with boric acid or an alkylboric acid [2] (Table 1).

R – CH₃, C₅H₁₁, C₆H₁₃; R^1 – OH, i-C₃H₇, i-C₄H₉; R^2 – H, C₃H₇, i-C₄H₉
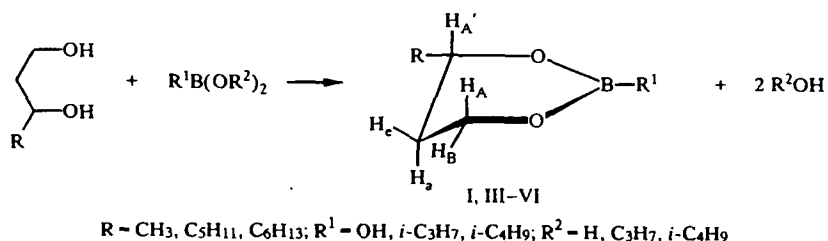
2-Phenoxy-4-methyl-1,3,2-dioxaborinane (II) was synthesized by transesterification of the 2-butoxy derivative with phenol.

The parameters of the ^1H NMR spectra of the compounds studied are given in Table 1. The methyl-substituted compounds (compounds I-IV) have a noticeable nonequivalence ($\Delta\delta$ 0.21-0.25 ppm) of the methylene protons at $C_{(5)}$ of the ring. The chemical shifts of the protons on $C_{(6)}$ are found in the expected range [2], but their nonequivalence is notably smaller than in the corresponding 1,3-dioxanes (Δ δ_{AB} in the spectra of the latter is 0.32-0.48 ppm [9, 10]). The chemical shift of the protons of the methyl group at $C_{(4)}$ (1.25 ppm) does not differ from that observed in the spectrum of cis-4,6-dimethyl-1,3,2-dioxaborinane, the molecules of which exist in the sofa conformation with diequatorial orientation of the substituents, no matter what the substituent on boron [2, 5, 6]. In the spectrum of compound II the protons of this group show anisochronicity ($\Delta\delta$ 0.05 ppm). An interesting peculiarity of the spectrum of compound III is that the signal of the protons of the isopropyl group on the boron atom appears as a singlet. The reason for this effect has already been explained in detail [2, 11, 12].

TABLE 1. Parameters of the ^{1}H NMR Spectra of 2,4-Disubstituted 1,3,2-Dioxaborinanes I-VI

Compound	R	R^1	Chemical shifts, ppm						Coupling constants, Hz					
			H$_A$	H$_B$	$\Delta\delta_{AB}$	H$_a$	H$_e$	$\Delta\delta_{ae}$	$^2J_{AB}$	$^2J_{ae}$	$^3J_{Aa}$	$^3J_{Ba}$	$^3J_{Ae}$	$^3J_{Be}$
I	Me	OH	3,81	3,93	0,12	1,69	1,90	0,21	10,7	14,0	11,1	4,7	3,7	3,7
II	Me	PhO	3,96	4,05	0,09	1,62	1,87	0,25	10,7	14,3	11,0	4,8	3,4	3,5
III	Me	i-Pr	3,94	4,03	0,09	1,63	1,86	0,23	10,7	14,0	11,2	4,7	3,5	3,7
IV	Me	i-Bu	3,93	4,02	0,09	1,65	1,89	0,24	10,7	14,0	11,2	4,7	3,5	3,7
V	Am	i-Bu	3,92	4,01	0,09	1,68	1,89	0,21	10,7	14,0	11,2	4,9	3,4	3,7
VI	Hex	i-Bu	3,92	4,01	0,09	1,68	1,89	0,21	10,7	14,0	11,2	4,9	3,4	3,7

TABLE 2. Optimal Geometric Parameters for the Molecules of 4-Methyl- and 4-Hexyl-1,3,2-dioxaborinanes (R' = H)
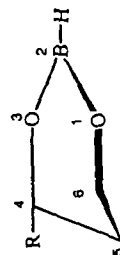
Compound	R	Bond angle, deg			Torsion angle, τ, deg						τ av, deg
		1–2–3*	6–1–2	2–3–4	1–2–3–4	2–3–4–5	3–4–5–6	4–5–6–1	5–6–1–2	6–1–2–3	
VII	CH$_3$	121,2	122,2	122,4	–4,5	29,9	–53,8	54,0	–30,2	4,6	29,5
VIII	C$_6$H$_{13}$	121,1	122,0	122,1	–5,8	32,5	–56,3	55,4	–30,2	4,5	30,8

*Numbers correspond to the atoms in the ring. Bond lengths: B–O 1.35 Å, C–O 1.41 Å, C–C 1.53-1.54 Å. Intracyclic angles at carbon atoms 108.4-109.6°.

TABLE 3. Values of the Torsion Angles between Protons and the Vicinal Coupling Constants for the Molecules of the Model Compounds VII and VIII (R' = H) Compared with Experimental Values for Compounds IV and VI

Com-pound	Calculated value φ, deg				Calculated values of $^3J_{HH}$, Hz				Equation used to calculate coupling constants	$*\sum |\delta J|$, Hz
	H_ACCH_a	H_ACCH_e	H_BCCH_a	H_BCCH_e	$^3J_{Aa}$	$^3J_{Ae}$	$^3J_{Ba}$	$^3J_{Be}$		
VII	175.1	57.1	52.3	65.7	11.5	2.2	5.3	3.6	(1)	0.3 + 1.3 + + 0.6 + 0.1 − 2.3
					11.9	4.1	4.8	3.1	(2)	0.7 + 0.6 + + 0.1 + 0.6 − 2.0
					10.2	3.1	3.7	2.3	(3)	1.0 + 0.4 + + 1.0 + 1.4 − 3.8
VIII	175.0	55.8	53.3	65.8	11.5	2.4	5.1	3.6	(1)	0.3 + 1.0 + + 0.2 + 0.1 − 1.6
					11.9	4.3	4.6	3.1	(2)	0.7 + 0.9 + + 0.3 + 0.6 − 2.5
					10.2	3.2	3.5	2.3	(3)	1.0 + 0.2 + + 1.4 + 1.4 − 4.0

*Sum of the absolute values of the differences between the corresponding experimental (Table 1) and calculated values of $^3J_{HH}$.

The values of the spin-spin coupling constants in the spectra of 4-methyl-1,3-dioxanes, which exist in the preferred chair form, fall within the ranges: $^3J_{Aa} = 11.0$-11.7, $^3J_{Ba} = 4.5$-5.3, $^3J_{Ae} = 2.9$-3.5, and $^3J_{Be} = 1.6$-2.0 Hz [9, 10]. The analogous spin-spin coupling constants, apart from $^3J_{Be}$, also fall in this range, which shows that the carbon part of the ring is not distorted. In the case of compound II as the result of suppression of the methyl proton signals it was possible to obtain the values of the constants $^3J_{A'a} = 7.3$ and $^3J_{A'e} = 2.9$ Hz. All of these observations indicate that the methyl group on $C_{(4)}$ is equatorial and that the molecules of compounds I-IV exist in the preferred sofa conformation, no matter what the substituent on boron. These conclusions are confirmed by comparison of the experimental and theoretical spectra of the 4-methyl analogs. The calculation was carried out using the PANIC program for a six-spin system (H_A, H_B, $H_{A'}$, H_a, H_e, and CH_3). The AB part of the $AB_{ae}A'$ spin system consists of a characteristic triplet of doublets for H_A and a quartet of doublets for H_B. A multiplet signal for $H_{A'}$ is superimposed on the weak field part of the latter. The ea part of the spectrum consists of a doublet of quartets from H_e and a quartet of doublets for H_a.

Increasing the length of the chain of the substituent at C_4 in compounds V and VI did not change the character of the spin interactions in the carbon part of the ring (Table 1). The values of the spin-spin coupling constants indicate the preference for the sofa conformation.

We have carried out the optimization of the geometry of models 4-methyl- (VII) and 4-hexyl- (VIII) -1,3,2-dioxaborinanes using the strong field MM 2 method with standard parametrization in order to investigate in greater detail the effect of substituents at $C_{(4)}$ on the preferred conformation of 1,3,2-dioxaborinane molecules. The resultant potential energy surface shows a minimum corresponding to the sofa conformer with an equatorial orientation of the substituent at $C_{(4)}$. The optimized geometric parameters of the conformers of compounds (VII) and (VIII) are given in Table 2.

The B−O and C−O bond lengths correspond to experimental values for molecules with six-membered cyclic esters of boric acid [2, 6]. The bond angles in the heteroatomic unit are close to 120° and the intracyclic bonds at the carbon atoms of the ring are close to 109°. The intracyclic torsion angles, τ, are close in both compounds. It should be noted, however, that the ring in compound VIII is slightly distorted on the side of the substituted carbon atom. At the same time comparison of the values of τ_{mean} shows that the increase in length of the substituent at $C_{(4)}$ has practically no effect on the compression of the ring.

To estimate the reliability of our results we have compared the experimental (compounds IV and VI) with the theoretical (compounds VII and VIII) vicinal spin-spin coupling constants. The latter were obtained by several methods based on the optimal calculation of the values of the torsional angles φ between the corresponding protons (Table 3). In the first place we used the known relationship between the angle φ and the values of the spin-spin coupling constants [14]:

$$^3J_{HH} = P_1\cos^2\varphi + P_2\cos\varphi + P_3 + \sum\Delta\chi_i\left\{P_4 + P_5\cos^2(\xi_i\varphi + P_6\,|\Delta\chi_i|)\right\} \tag{1}$$

where P_1 to P_6 are empirical parameters, $\Sigma\Delta\chi_i$ is the sum of the differences in electronegativity between substituents on the corresponding ethane fragment and hydrogen (see [15]), and ξ_i is a parameter with the value $+1$ or -1, depending on the orientation of the substituent on the carbon containing the vicinal protons. The following simpler formula was also used [16]:

$$^3J_{HH} = (7.8 - 1.0\cos\varphi + 5.6\cos2\varphi)(1 - 0.1\sum\Delta\chi_i), \tag{2}$$

where the value of $\Delta\chi_i$ is analogous to that in Eq. (1). The Karplus equation [17] was also used with parameters from [14]:

$$^3J_{HH} = 7.76\cos^2\varphi - 1.10\cos\varphi + 1.40. \tag{3}$$

It is not difficult to see that the closest agreements between the experimental and theoretical coupling constants (smallest sum $|\Delta J|$) were obtained using Eqs. (1) and (2). At the same time the calculated values of individual coupling constants, particularly $^3J_{Ae}$, obtained using these equations differ noticeably from the experimental values. In our view the probable reason for this is not connected with a notable contribution of other conformers (e.g., twisted) because of the considerable stabilization of the sofa conformer by p-π interactions in the heteroatom fragment [2]. In other words the molecules can be discussed as conformationally homogeneous. The remaining suggestion for the differences in the coupling constants is that it results from distortion of the real molecule (corrugation) toward the side of the substituted carbon atom because of interaction of the substituent with one of the n-electron pairs of a ring oxygen atom.

EXPERIMENTAL

^1H NMR Spectra of 10% solutions in $CDCl_3$ with TMS as internal standard were recorded with a Bruker AM-250 spectrometer (250 MHz). Theoretical spectra were obtained using the PANIC program for a six-spin system with parameters analogous to those in Table 1; $^3JCH_3H_A = 6.5$ Hz.

Compound I has been described previously [18]. Compound II was obtained in 68% yield by transesterification of 2-butoxy-4-methyl-1,3,2-dioxaborinane [19] with an equimolar amount of phenol, bp 130°C (6 mm Hg). Compounds III and IV have been described previously [20]. The cyclic esters V and VI were obtained by interaction of esters of alkylboric acids [21] with the corresponding 1,3-diols by a standard method [2, 22]: dioxaborinane V, yield 73%, bp 95-96°C (5 mm Hg), n^D_{20} = 1.4339; dioxaborinane VI, yield 64%, bp 111-113°C (5 mm Hg), n^D_{20} = 1.4360. The 1,3-octane- and 1,3-nonanediol starting materials were synthesized by the Prins reaction of the corresponding alkenes with paraformaldehyde followed by methanolysis of the 1,3-dioxane intermediates by a literature method [23].

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