ISSN 1070-3632, Russian Journal of General Chemistry, 2012, Vol. 82, No. 2, pp. 226–229. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © V.V. Kuznetsov, 2012, published in Zhurnal Obshchei Khimii, 2012, Vol. 82, No. 2, pp. 230–233.

Conformational Composition of the 2,4,6-Trimethyl-1,3,2-dioxaborinane Stereoisomers

V. V. Kuznetsov[a,b]

[a] *Institute of Physics of Molecules and Crystals, Ufa Scientific Center, Russian Academy of Sciences,*
pr. Oktyabrya, 71, Ufa, 250054 Russia
e-mail: kuz@anrb.ru

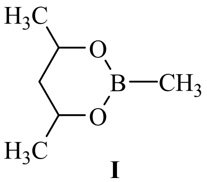
[b] *Ufa State Petroleum Technical University*

Received December 2, 2010

Abstract—A study of conformational transformations of 2,4,6-trimethyl-1,3,2-dioxaborinane *cis*- and *trans*-isomers in non-empirical quantum-chemical HF/6-31G (d) and PBE/3z approximations showed that the transformation routes include the *sofa* conformers with different orientations of the substituents at the ring atoms C^4 and C^6 through the transition states corresponding to *diequatorial*, *axial-equatorial*, and *dixial* conformations of the 2,5-*twist* form. The calculation and ^1H NMR data show that the conformational equilibrium of *cis*-isomer is almost entirely shifted to *diequatorial sofa*, and the *trans*-form is characterized by the interconversion between the two *axial-equatorial sofa* conformers.

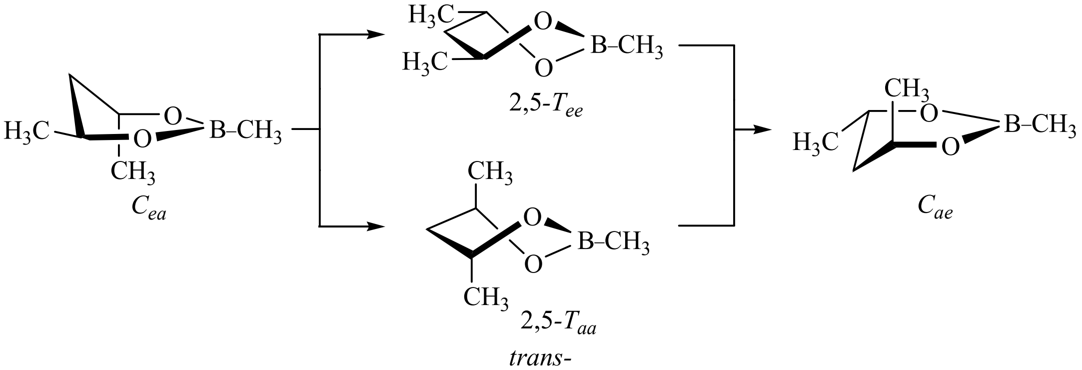
DOI: 10.1134/S1070363212020119

An interest in 1,3,2-dioxaborinanes is due to their widespread application in fine organic synthesis [1–9], and by a complex of their practically useful properties and structural features [1, 10–15]. We have studied previously in detail the relative conformational stability of the stereoisomers of 2,4,5-substituted 1,3,2-dioxaborinanes [16, 17]. The aim of this study is to analyze the routes of conformational transformations of the *cis*- and *trans*-isomers of 2,4,6-trimethyl-1,3,2-dioxaborinane molecule (**I**) using a nonempirical quantum-chemical approximations HF/6-31G (d) and PBE/3z within the HyperChem [18] and PRIPODA [19] software.

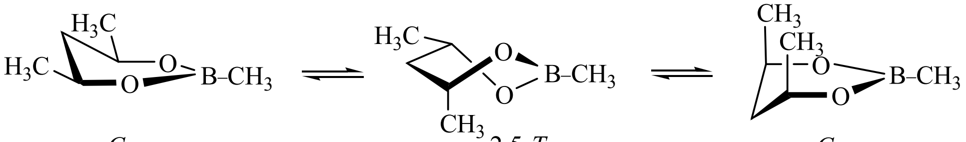


I

We found that, like in the case of 4- and 2,4-substituted 1,3,2-dioxaborinanes [13–15], the conformational transformation of the *trans*-isomer of ether **I** molecule can take place by two routes, including the 2,5 T_{ee}-and 2,5-T_{aa} transition states (TS).



trans-



C_{ee} 2,5-T_{ea} *cis*- C_{aa}

The difference in energy between the 2,5-T_{ee} and 2,5-T_{aa} transition states is 2.0–2.4 kcal mol^{-1} (Table 1). The process of the conformational transformation is characterized by a negative $\Delta S^{\neq}$ value, indicating a more compact nature of both transition states compared with the invertomers C_{ea} and C_{ae}. According to the ^{1}H NMR data, the molecule of *trans*-**I** at room temperature is in a state of fast ring interconversion [20]. The estimated $\Delta G^{\neq}$ value coincides with that experimentally observed for 1,3,2-dioxaborinanes [21].

According to the ^{1}H and ^{13}C NMR data, the molecules of the *cis*-isomer are conformationally uniform [20]. The results of calculations confirm this conclusion: for the $C_{ee} \leftrightarrow C_{aa}$ interconversion a sufficiently high ΔG^0 value is obtained (Table 1). The route of the conformational transformations in this case includes only one transition state, 2,5-T_{ea}, which is characterized by a negative activation entropy.

It should also be noted that the conformer C_{4e6e} *cis*-**I** is more stable than the form *trans*-C_{4e6a} by 1.3–1.1 kcal mol^{-1} (Table 1).

Calculation of the relative content of the conformers C_{ee} and C_{aa} *cis*-**I** by an independent method requires an approach that takes into account the experimental (from ^{1}H NMR spectrum: $^3J_{\mathrm{AX}}$ and $^3J_{\mathrm{BX}}$ [20]) and theoretical (J_{aa}, J_{ae}, and J_{ee}) vicinal spin-spin coupling constants of alternative conformers with relative content N and 1–N, respectively [22]:

$$^3J_{\mathrm{AX}} + {}^3J_{\mathrm{BX}} = N(J_{aa} + J_{ae}) + (1 - N)(J_{ae} + J_{ee}),$$

$$\Delta G^0 = -RT\ln N/(1 - N).$$

The theoretical coupling constants can be determined in turn with the modified Karplus equation [23], using torsion angles between the protons in the conformers involved in the binary equilibrium (data of the optimum geometry). The HF/6-31G (d) and PBE/3z approximations resulted in the fairly close geometrical parameters of the conformers: the maximum difference in the values of torsion angles is 1.6°. Therefore, for the determination of vicinal coupling constants we used only the results of the PBE/3z method.

The data in Table 2 indicate that the content N of the *diequatorial cis*-**I** C_{ee} form is close to 100% confirming the validity of the high value of the calculated conformational free energy for the $C_{ee} \leftrightarrow C_{aa}$ equilibrium (Table 1: at ΔG^0 = 4.6 kcal mol^{-1} $N/(1–N) >$ 2200).

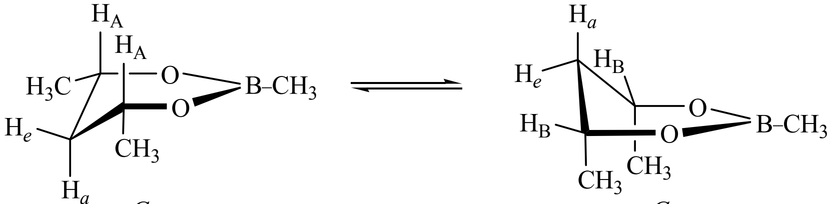
These results indicate a relatively larger conformational rigidity of the *cis*-**I** molecules com-pared with *cis*-2,4,5-trimethyl-1,3,2-dioxaborinane, whose molecules are conformationally nonuniform [17]. This is due to stronger repulsion of the two *axial*

Table 1. Relative stability of minima and maxima on the potential energy surface (PES) of the individual stereoisomers of ether **I** (ΔH, ΔS^0, $\Delta H^{\neq}$, and $\Delta G^{\neq}$ in kcal mol^{-1}, ΔS and $\Delta S^{\neq}$ in cal mol^{-1} K)

Isomer and the minima and maxima forms on the PES	Parameters (T, K)	Methods	
		HF/6-31G(d)	PBE/3z
trans-**I**			
2,5-T_{ee}[a]	$\Delta H^{\neq}$ (0)	6.2	5.6
	$\Delta H^{\neq}$ (298)	–	5.1
	$\Delta G^{\neq}$ (298)	–	6.7
	$\Delta S^{\neq}$ (298)	–	–5.3
2,5-T_{aa}[a]	$\Delta H^{\neq}$ (0)	8.2	8.0
	$\Delta H^{\neq}$ (298)	–	7.5
	$\Delta G^{\neq}$ (298)	–	9.0
	$\Delta S^{\neq}$ (298)	–	–4.8
cis-**I**			
C_{4a6a}[b]	ΔH (0)	5.1	4.9
	ΔH (298)	–	4.9
	ΔG^0 (298)	–	4.6
	ΔS (298)	–	1.1
2,5-T_{ea}[b]	$\Delta H^{\neq}$ (0)	8.7	8.3
	$\Delta H^{\neq}$ (298)	–	7.8
	$\Delta G^{\neq}$ (298)	–	8.9
	$\Delta S^{\neq}$ (298)	–	–3.7
	$\Delta E_{cis\text{-}trans}$ (0 K)	1.3	1.3
	$\Delta H_{cis\text{-}trans}$ (298 K)	–	1.3
	$\Delta G^0_{cis\text{-}trans}$ (298 K)	–	1.1

[a] Relatively to C_{4e6a} form. [b] Relatively to C_{4e6e} form.

Table 2. Relative content of the conformers of ester **I** *cis*-isomer



C_{4e6e} *cis*- C_{4a6a}

Conformer	Torsion angles, deg[a]		Spin–spin coupling constant, Hz		N[b]
	$\varphi_{aa(ea)}$	$\varphi_{ae(ee)}$	$^3J_{aa(ea)}$	$^3J_{ae(ee)}$	
C_{4e6e}	175.7	58.0	11.6	2.4	1.0
C_{4a6a}	40.2	75.7	6.8	2.1	

[a] Geometry optimizing by the PBE/3z method; *a* and *e* indicate *axial* and *equatorial* orientations of the hydrogen atoms in the corresponding ethane fragment. [b] Relatively to the prevailing conformer, by the data of spin–spin coupling constants.

substituents at the atoms C^4 and C^6 compared with the destabilizing interaction between the *axial* methyl group at the C^4 or C^5 atom with a heteroatomic ring fragment in the case of *cis*-2,4,5-trimethyl-1,3,2-dioxaborinane.

EXPERIMENTAL

Individual stereoisomers of the ether **I** have been described in [24], and their NMR spectral features, in [20]. Conformational transformations were simulated by means of the geometry optimization of the molecules of the compounds varying the endocyclic OCCC torsion angle in the range of ±50°. The route of interconversion and the value of the potential barriers were revealed using the procedure of finding transition states in the framework of the HyperChem [18] and PRIRODA [19] software. The assignment of a stationary point of potential energy to a peak was checked by the presence of one imaginary frequency, and to a minimum, by the lack of imaginary frequencies in the corresponding Hessian.

The modified Karplus equation has the form [23]:

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

where $\Delta\chi_i$ is the difference in electronegativity of the substituent at the corresponding ethane fragment and hydrogen, φ is the calculated torsion angles between the interacting protons, ξ_i takes the values ±1 depending on the orientation of substituents at the carbon atoms of ethane fragment, P_1–P_6 are the parameters depending on the degree of substitution of this fragment. At solving this equation we used the numerical values of the parameters P_1–P_6 for the fragments with three substituents [calculation of $^3J_{aa(ea)}$ $^3J_{ae(ee)}$ spin–spin coupling constants]: P_1 = 13.22, P_2 = –0.99, P_3 = 0, P_4 = 0.87, P_5 = –2.46, and P_6 = 9.19°, and the values of electronegativity from [25]. The numerical values of the experimental coupling constants for *cis*-**I** are: $^3J_{AX}$ = 10.6 Hz, $^3J_{BX}$ = 3.4 Hz [20]. The ΔG^0 value was determined for the temperature of 298 K, at which the ^1H NMR spectra were recorded.

REFERENCES

1. Gren', A.I. and Kuznetsov, V.V., *Khimiya tsiklicheskikh efirov bornykh kislot* (Chemistry of Cyclic Esters of Boron Acids), Kiev: Naukova Dumka, 1988.
2. Murata, M., Oda, T., Watanabe, S., and Masuda, J., *Synthesis*, 2007, no. 3, p. 351.
3. Praveen, G.N. and Chavant, P.J., *Eur. J. Org. Chem.*, 2008, no. 27, p. 4690.
4. Woods, W.G. and Strong, P.L., *J. Am. Chem. Soc.*, 1966, vol. 88, no. 20, p. 4667.
5. Smith, H.D. and Brotherton, R.J., *Inorg. Chem.*, 1970, vol. 9, no. 11, p. 2443.
6. Fish, R.H., *J. Am. Chem. Soc.*, 1968, vol. 90, no. 16, p. 4435.
7. Lightfoot, A.P., Twiddle, S.J.R., and Whiting, A., *Org. Biomol. Chem.*, 2005, vol. 3, no. 17, p. 3167.
8. Lightfoot, A.P., Twiddle, S.J.R., and Whiting, A., *Synlett.*, 2005, no. 3, p. 529.

9. Kuznetsov, V.V., *Izv. Ross. Akad. Nauk, Ser. Khim.*, 2005, no. 7, p. 1499.
10. Rossi, K. and Pihlaya, K., *Acta Chem. Scand. B*, 1985, vol. 39, no. 8, p. 671.
11. Kliegel, W., Preu, L., Rettig, S.J., and Trotter, J., *Can. J. Chem.*, 1986, vol. 64, no. 9, p. 1855.
12. Kuznetsov, V.V., *Uspekhi organicheskogo kataliza i khimii geterotsiklov* (Progress in Organiccatalysis on Chemistry of Heterocycles), Moscow: Khimiya, 2006, p. 336.
13. Valiakhmetova, O.Yu., Bochkor, S.A., and Kuznetsov, V.V., *Khim. Geterotsikl. Soedin.*, 2009, no. 6, p. 925.
14. Valiakhmetova, O.Yu., Bochkor, S.A., and Kuznetsov, V.V., *Khim. Geterotsikl. Soedin.*, 2010, no. 8, p. 1245.
15. Valiakhmetova, O.Yu. and Kuznetsov, V.V., *Zh. Obshch. Khim.*, 2008, vol. 78, no. 12, p. 2007.
16. Kuznetsov, V.V., Alekseeva, E.A., Khudyakov, V.V., and Levshov, Yu.A., *Zh. Obshch. Khim.*, 2002, vol. 72, no. 3, p. 429.
17. Valiakhmetova, O.Yu., Bochkor, S.A., and Kuznetsov, V.V., *Zh. Obshch. Khim.*, 2009, vol. 79, no. 6, p. 930.
18. *HyperChem 7.01. Trial version, www.hyper.com.*
19. Laikov, D.N., Ustynyuk, Yu.A., *Izv. Ross. Akad. Nauk, Ser. Khim.*, 2005, no. 3, p. 804.
20. Kuznetsov, V.V. and Gren', A.I., *Zh. Obshch. Khim.*, 1984, vol. 54, no. 10, p. 2263.
21. Carton D, Pontier A, Ponet M, Soulie, J., and Cadiot, P., *Tetrahedron Lett.*, 1975, no. 28, p. 2333.
22. Zefirov, N.S., Blagoveshchenskii, V.S., Kazimirchik, I.V., and Yakovleva, O.P., *Zh. Org. Khim.*, 1971, vol. 7, no. 3, p. 594.
23. Haasnoot, C.A.G., de Leeuw, F.A.A.M., and Altona, C., *Tetrahedron.*, 1980, vol. 36, no. 19, p. 2783.
24. Kuznetsov, V.V., Gren', A.I., and Bubker Sh., *Reaktivy i osobo chistye veshchestva* (Chemicals and Extra Pure Substances), Moscow: IREA, 1982, no. 3, p. 15.
25. Huggins, M.L., *J. Am. Chem. Soc.*, 1953, vol. 75, no. 17, p. 4123.