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PREDICTION OF ROTAMERIC PREFERENCES IN 9-(1-METHOXYETHYL)TRIPTYCENE DERIVATIVES BY MOLECULAR FORCE FIELD CALCULATIONS

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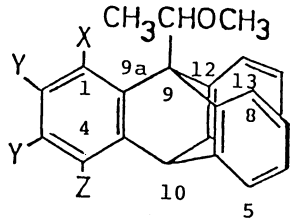
The rotamer distributions and the optimized geometries of peri-substituted 9-(1-methoxyethyl)triptycene derivatives were determined by means of molecular force-field calculations (MM2). The results agreed well with those from the NMR experiments except for the derivative containing the intramolecular hydrogen bonding.

We recently reported on the rotamer equilibria in 9-(1-methoxyethyl)triptycene derivatives 1-6 carrying several types of substituents at one peri-position studied by NMR spectroscopy,[1,2] which revealed an intriguing dependence of the rotamer distribution on the peri-substituent. It seemed desirable to investigate in detail the factors which govern the rotamer distribution by some theoretical means. We therefore carried out empirical molecular force-field calculations on these compounds to obtain the optimized geometries and the steric energies of the rotamers. In this letter the results are discussed in comparison with those experimentally obtained.[1,2]

The calculations were performed by use of the revised MM2 program originally written by Allinger[3] and modified by Ōsawa.[4] The relative steric energies of the rotamers and the populations obtained therefrom by the Boltzmann's theorem neglecting the entropy differences among the rotamers are given in Table 1. The total steric energy and the energies of the component terms for each rotamer are compiled in Table 2.



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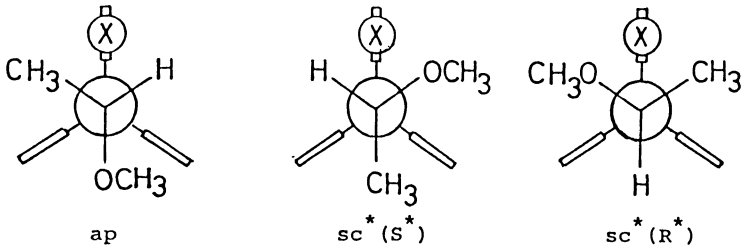
	X	Y	Z
1	F	F	F
2	Cl	Cl	Cl
3	Br	Br	Br
4	CH_3	H	CH_3
5	OCH_3	H	OCH_3
6	OH	H	OCH_3



ap sc*(S*) sc*(R*)

Substituted 9-(1-methoxyethyl)triptycenes

As revealed by Table 1, the MM2 calculations properly reproduce the rotamer distributions obtained by NMR except for that in compound 6. In compounds 1-4, the steric

energy increases in the order of sc*(S*)< ap<sc*(R*),[5] which is in agreement with the prediction on the basis of the group bulkiness concept (CH_3>OCH_3>H) and we ascribed the steric effect as the principal factor ruling the rotamer distribution.[1] Inspection of Table 2 reveales that the preference for the sc*(S*) rotamer in the 1,4-dimethyl derivative 4 is derived from the contribution of the component terms which are mainly steric in origin (EC+EB+ESB+EV+ET). The electrostatic term (ED) also contributes significantly to the rotamer equlibria in the tetrahalo compounds 1-3. The sc*(R*) rotamer in any compound is disfavored both sterically and electrostaticaaly.

Table 1. Populations on Rotamers Determined by MM2 Calculations and NMR Experiments [a]

Compd	Rotamer	MM2 E [b] /KJ mol^{-1}	MM2 Pop/%	NMR Pop/%
1	ap	+ 0.38	45	39
	sc*(S*)	0.	52	55
	sc*(R*)	+ 7.41	3	6
2	ap	+ 1.92	32	24
	sc*(S*)	0.	68	76
	sc*(R*)	+ 18.24	0	0
3	ap	+ 2.51	27	22
	sc*(S*)	0.	73	78
	sc*(R*)	+ 24.77	0	0
4	ap	+ 3.51	20	22
	sc*(S*)	0.	80	78
	sc*(R*)	+ 19.71	0	0
5	ap	0.	57	75
	sc*(S*)	+ 0.71	43	25
	sc*(R*)	+ 10.38	0	0
6	ap	+ 9.70 (0.)[c]	2 (70)[c]	0 (62)[d]
	sc*(S*)	0. (+ 2.22)	86 (29)	25 (18)
	sc*(R*)	+ 4.93 (+ 11.26)	12 (1)	75 (20)

a) NMR measurements were carried out in $CDCl_3$.
b) Relative steric energy.
c) Calculated values without taking into account the contribution by hydrogen bond.
d) Populations in DMSO-d_6.

Careful examinations of the optimized geometries disclose the way in which steric congestion around the 9-substituent is relieved. Noteworthy is the out-of-plane deformation of the peri-substituent X from the plane of the benzene ring to which it is attached.[6] In the sc*(S*) and ap rotamers in which one of the sc-sites to the peri-substituent is occupied by a hydrogen atom, the peri-substituent tilts toward the hydrogen as manifested by dihedral angle C_9-C_{9a}-C_1-X : ap-1, 2.0°; sc*(S*)-1, -3.1°; ap-2, 7.0°; sc*(S*)-2, -7.4°; ap-3, 10.5°; sc*(S*)-3, -10.5°; ap-4, 4.9°; sc*(S*)-4, -3.5°. On the other hand, in the sc*(R*) rotamers in which both of the sc-sites are occupied by bulky groups, methyl and methoxyl, the out-of-plane bending of the peri-substituent X is very small, suggesting the inhibition of the steric relief by the out-of-plane deformation. The high steric energy in the sc*(R*) rotamers should partly be ascribed to this factor.

The increase of the bond angle C_{9a}-C_9-C_α is observed (116-122°) as the peri-substituent becomes bulkier in any of the rotamers, which may also be due to the relaxation of the local steric congestion.[7]

In the 1,4-dimethoxy compound 5, the ap rotamer was found to be more populous

Table 2. Calculated Steric Energies of Rotamers

	Compd 1			Compd 2			Compd 3		
	ap	sc*(S*)	sc*(R*)	ap	sc*(S*)	sc*(R*)	ap	sc*(S*)	sc*(R*)
E	138.07	137.70	145.10	182.67	180.75	198.99	212.59	210.08	234.85
EC	12.51	12.34	13.14	19.87	19.54	22.51	26.78	26.36	31.71
EB	46.48	47.15	48.38	52.59	54.81	59.08	55.60	58.62	64.39
ESB	-0.50	-0.50	-0.42	-0.25	-0.25	0.13	-0.04	-0.08	0.54
EV	70.79	70.26	71.81	102.55	101.71	109.45	122.97	121.96	134.38
ET	-33.43	-33.14	-32.21	-29.62	-31.38	-31.30	-25.52	-28.12	-30.54
ED	42.22	41.59	44.40	37.53	36.32	39.12	32.80	31.34	34.35
μ	1.83	3.13	3.65	2.15	3.50	3.94	2.14	3.51	3.88

	Compd 4			Compd 5			Compd 6		
	ap	sc*(S*)	sc*(R*)	ap	sc*(S*)	sc*(R*)	ap	sc*(S*)	sc*(R*)
E	124.60	121.09	140.79	137.74	138.45	148.11	120.79	111.09	116.02
EC	17.61	17.36	20.32	16.77	16.69	17.87	14.81	18.03	17.66
EB	59.26	60.49	66.35	66.22	66.99	69.74	58.70	70.24	71.30
ESB	-0.21	-0.25	0.17	-0.13	-0.17	0.13	-0.46	0.00	-0.04
EV	81.89	81.49	87.60	96.85	95.30	97.98	86.23	83.00	83.71
ET	-37.41	-41.16	-36.37	-42.05	-42.93	-41.63	-38.24	-47.04	-43.18
ED	3.51	3.18	2.72	0.08	2.55	4.02	-0.25	-13.14	-13.43
μ	1.33	1.30	1.24	3.24	2.30	1.49	3.74	1.41	1.54

E; Steric energy, EC; Compression, EB; Bending, ESB; Stretch bend, EV; van der Waals ET; Torsion, ED; Dipole (KJ/mol), μ ; Dipole moment (debye).

than sc*(S*): the predominance of the electrostatic repulsion between the methoxyl groups suggested for the phenomenon.[2] The MM2 calculation reproduces the situation fairly well and the energy component analysis (Table 2) clearly indicates that ED term overweighs the steric terms favoring the ap rotamer.

The detailed studies by NMR and IR spectroscopies showed that 6 exists sololy as the intramolecularly hydrogen-bonded rotamers, sc*(S*) and sc*(R*), in $CDCl_3$.[2] The calculation which did not take the intramolecular hydrogen-bonding into account naturally failed to reproduce the observed results, predicting ap to be the most stable rotamer similarly as in 5. The calculation which included the hydrogen bonding as the electrostatic interactions considerably decreased the steric energies of sc*(S*) and sc*(R*), rendering ap the least stable. But optimized geometries therefrom were the unreasonable ones because the OH···O angle was unrealistic. The best results so far were obtained when the OH···O hydrogen bonding was treated as a weak covalent bond between the hydrogen and one of the oxygen lone pairs, regarding the lone pair as a divalent phantom atom. In this calculation, the hydrogen and the lone pair should be redefined as divalent connected atoms with proper force constants.[8] Although the calculation afforded the proper geometries with the reasonable orientation of the OH group, it still failed to reproduce the relative stabilities of the rotamers as shown in Table 1. Refinement of the force field parameters for the hydrogen bond system may improve

the situation and the effort is now in progress.

In conclusion, the molecular force field calculation can actually be a powerful tool to investigate the conformational behavior of complex organic molecules with more than one polar functional groups and to analyze the factors governing the behavior. In order to improve the accuracy of calculations and to extend the applicability of the force field to even more complex polyfunctional molecules, the force field should be further modified so that it can correctly evaluate the intramolecular electrostatic effects[9] including hydrogen bonding.

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5) For the nomenclature of rotamers, see: M. Oki, *Top. Stereochem.*, 14, 1 (1983).
6) The benzene ring itself slightly deforms out-of-plane to be boat-shaped, the dihedral angles in the ring being ± 2-3°.
7) Many of the structural features obtained from the calculations for these triptycenes are also found in the X-ray crystallographic data of some related 9-substituted triptycenes : M. Ōki, G. Izumi, G. Yamamoto, and N. Nakamura, *Bull. Chem. Soc. Jpn.*, 55, 159 (1982); N. Nogami, M. Ōki, S. Sato, and Y. Saito, *Bull. Chem. Soc. Jpn.*, 55, 3580 (1982).
8) The details of the calculations will be reported elsewhere. The force field parameters concerning the hydrogen bond are as follows when the divalent OH proton and lone pair are symbolized as HB and AH respectively.

(1) van der Waals parameters

	R*(Å)	ESP(kcal/mol)
HB	0.90	0.015
AH	1.20	0.036

(2) Stretching parameters

	k(mdyne/Å)	L(Å)
O-HB	7.2	0.972
HB-AH	5.0	1.16
AH-O	4.6	0.60

(3) Bending parameter

	k(mdyne Å/rad^2)	θ(deg)
O-HB--AH	o.50	180

(4) Torsional parameters

$(V_1, V_2, V_3, V_4)=0$

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