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DNMR ANALYSIS OF RING INVERSION IN anti-1,5-BISHOMOCYCLOOCTATETRAENES

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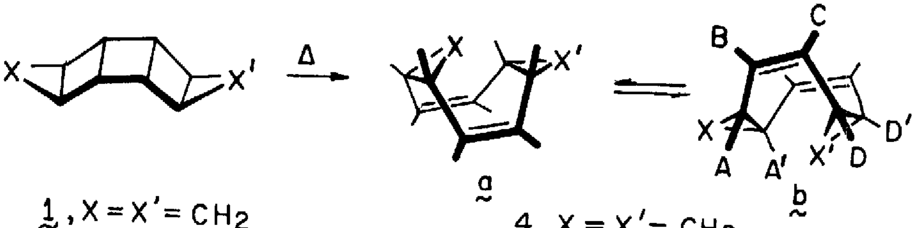
The recently developed synthetic entry to 1,2,3,4- and 1,2,3,8-tetraalkyl cyclooctatetraenes[1] has established that the ring inversion process characteristic of the parent hydrocarbon ($\Delta G^{\ddagger} \approx 13.7$ kcal/mol)[2] can be greatly impeded by steric constraints external to the medium ring (isolation of stable bond shift isomers becomes possible). Such a disposition of substituents arrests attainment of the planar transition state believed necessary for interconversion of the tub conformers.[3] The activation energy for ring inversion in these examples must also contain a term for increased strain within the eight-membered ring, but this contribution is not readily determinable. In an attempt to develop a greater appreciation of such internal, necessarily less overwhelming, strain contributions, the variable temperature NMR behavior of the anti-1,5-bishomocyclooctatetraenes **4**-**6** has now been quantitatively assessed.



1, X = X' = CH_2
2, X = CH_2, X' = O
3, X = X' = O

4, X = X' = CH_2
5, X = CH_2, X' = O
6, X = X' = O

The desired tetracyclic compounds were available by suitable thermolysis[4] of pentacyclo$[5.3.0.0^{2,6}.0^{3,5}.0^{8,10}]$decanes **1**-**3**.[5] As concerns **4** and **6**, the ring inversions are seen to be degenerate, returning identical molecules in which the chemical environments of all constituent carbon atoms and attached protons have been reciprocally interchanged.[6] Passage through the coalescence temperature is therefore tantamount to altering the effective shape of these molecules from static C_s to dynamic C_{2h}. In the case of **5**, this unique situation does not obtain. Rather, competition between epoxide oxygen and the cyclopropyl methylene group for the ''inside'' and ''outside'' positions gains importance.

Table I. Thermodynamic Data and Activation Parameters for the Ring Inversions in **4**-**6**.

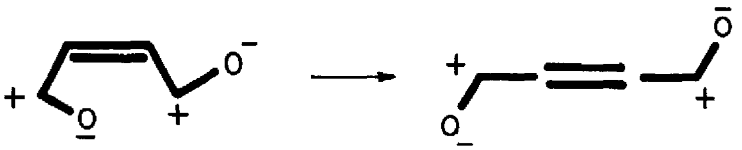
	4	**5**	**6**
E_a, kcal/mol	16.41 ± 0.72	16.77 ± 0.75	18.81 ± 0.85
log A	14.08 ± 0.56	13.11 ± 0.53	12.03 ± 0.49
$\Delta H^{\ddagger}$, kcal/mol	16.17 ± 0.58	16.40 ± 0.73	18.17 ± 0.76
$\Delta S^{\ddagger}$, eu	-5.21 ± 2.05	-0.05 ± 2.00	-5.69 ± 2.00

At -45° and below, the proton decoupled ^{13}C NMR spectrum of **4** ($CDCl_3$ solution) consists of 6 lines: 128.35, 126.90, 22.71, 17.80, 16.51, and 14.02 ppm. As the temperature is raised, these signals broaden and then sharpen to generate above +41° a triad of singlets at 127.62, 20.55, and 15.26 ppm. This mutual averaging of peaks shows that rapid equilibration between **4a** and **4b** leads to total environmental exchange between the four methine, four olefinic, and two methylene carbons. Matching of calculated (DNMR 2)[7] and observed methylene and olefinic segments of these spectra provided a series of rates from which the data in Table I were obtained.

The room temperature ^{1}H NMR spectrum of **6** (o-dichlorobenzene solution, 90 MHz) consists of a downfield AB quartet (547.3 and 499.3 Hz), an upfield pseudodoublet (338.8), and a broadened pseudosinglet (325.5). As judged from Dreiding models, the exo orientation of an oxirane ring causes the >CHO- hydrogens to adopt a dihedral angle of ~ 90° with the adjacent olefinic protons and consequent low spin-spin interaction. Inner folding of the epoxide moiety decreases this angle to ~ 40° and is therefore expected to measurably enhance coupling. By standard LAOCOON techniques for AA'BB' systems, the relevant coupling constants were determined to be: $J_{AA'} = J_{DD'} = 4.10$, $J_{AB} = 0.50$, $J_{AB'} = -0.29$, $J_{BB'} = J_{CC'} = 0.01$, and $J_{CD} = 2.74$ Hz. Upon gradual heating of **6**, the oxirane protons were seen to become fully isochronous only at 150°. Under these limiting conditions, the chemical shift of the >CHO- singlet (332.1 Hz) appeared midpoint between those in the static structure. Complete line shape analysis according to the DNMR 3 method of Binsch[8] throughout the entire temperature range provided the activation parameters listed in Table I.

The ^{1}H NMR spectrum of static **5** (-20°, $Cl_2C{=}CCl_2$ solution)[9] is very similar to that of **6** in the oxiranyl proton region except that the singlet (304.3 Hz) is now diminished in intensity. The pseudodoublet appears at 324.4 Hz. Upon slow heating to 71°, these signals broadened and then coalesced at a chemical shift (318.8 Hz) which proved to be a linear combination of the shifts of conformers 5a and 5b. The 5a:5b ratio (1:2.58) therefore gives no indication of meaningful alteration with temperature, the concentration imbalance representing a ΔG^{0}_{298} value of 0.56 kcal/mol. Mean lifetimes as a function of temperature were determined by computer simulation of the oxiranyl proton signals as before; use of a relaxation time of 0.250 sec afforded optimal results (Table I).

Our findings disclose that diepoxide 6 undergoes tub-to-tub interconversion with less facility than hydrocarbon 4. Since the $\Delta S^{\ddagger}$ components of these processes are closely similar, the 2.5 kcal/mol difference likely finds its origin in those factors which directly affect enthalpy. The behavior of 5 provides important clues. Firstly, replacement of one cyclopropyl methylene by oxygen lowers the free energy of 5b relative to 5a by approximately 0.5 kcal/mol, a likely consequence of the smaller space filling demands of the oxygen lone pair relative to a cyclopropyl hydrogen. In actuality, the somewhat reduced conformational mobility of 5 relative to 4 (ca 0.25 kcal/mol) can be viewed to arise chiefly because of this added ground state stabilization. It is not known to what degree the shorter C-C bond of an oxirane ring (1.472 Å for the parent heterocycle)[10] as compared to cyclopropane (1.510 Å)[11] directly affects the attainment of the planar or nearly planar fused 1,5-cyclooctadiene ring necessary for inversion.[12] Notwithstanding, bond length factors alone cannot account for the $\Delta\Delta H^{\ddagger}$ gap of 2.0 kcal/mol separating 4 and 6. However, as shown schematically in Figure 1, dipolar interactions can gain importance in the folded conformation of the diepoxide (7), internal solvation of the ''inner'' oxygen lone pair by the transannular oxiranyl carbons leading to enhanced ground state stabilization. In progressing to the ring inversion transition state, such interactions must not only be decoupled, but an adverse dipole-dipole situation develops which is perhaps accentuated by the interconnective double bonds (see 8). The abnormally high $\Delta H^{\ddagger}$ for 8 is therefore viewed to be the result of combined steric and dipolar electronic ground state stabilization in tandem with some dipole-induced transition state destabilization.



7 8

Figure 1. Sideview schematic of 6 and its transition state for ring inversion.

The differential response of **4**-**6** to the input of thermal energy nicely illustrates the sensitivity of medium ring inversion energetics to subtle structural factors. Curiously, as in several carefully studied Cope rearrangement reactions of divinylcyclopropanes and epoxides,[13] the sequencing of $\Delta H^{\ddagger}$ bears no direct relationship to relative heats of formation computed by summation of bond increments.[14]

References and Footnotes

(1) (a) L. A. Paquette, J. M. Photis, K. B. Gifkins, and J. Clardy, *J. Am. Chem. Soc.*, **97**, 536 (1975); (b) L. A. Paquette, J. M. Photis, and G. D. Ewing, *ibid.*, **97**, 3538 (1975); (c) L. A. Paquette and J. M. Photis, *ibid.*, **98**, in press.

(2) F. A. L. Anet, *J. Am. Chem. Soc.*, **84**, 671 (1962).

(3) For a recent review, see L. A. Paquette, *Tetrahedron*, **31**, 2855 (1975).

(4) M. J. Carmody and L. A. Paquette, submitted for publication.

(5) Previously unreported **2** was prepared by monoperphthalic acid epoxidation of tetracyclo-$[4.3.0.0^{2,5}.0^{7,9}]$non-3-ene (77%).[4] Heating **2** dissolved in benzene at 125° for 12 hr in a sealed tube proved adequate for efficient conversion to **4** (57% after vpc isolation).

(6) Both D. P. Mullis [Ph.D. Thesis, UCLA (1970)] and A. G. Anastassiou and E. Reichmanis [*J. Org. Chem.*, **38**, 2421 (1973)] previously recognized the temperature-dependent behavior of **6**. Their approximations of $\Delta H^{\ddagger}$ were *ca* 20.5 kcal/mol.

(7) G. Binsch and D. A. Kleier, Program 140, QCPE, Indiana University (1969).

(8) D. A. Kleier and G. Binsch, Program 165, QCPE, Indiana University (1969).

(9) The use of three different solvent systems for the study of **4**, **5**, and **6** was made necessary because of the widely divergent temperature ranges needed to achieve rapid ring inversion. However, their uniform chlorocarbon nature does minimize possible wide variations in solvent polarity.

(10) C. L. Cunningham, Jr., A. W. Boyd, R. J. Meyers, W. D. Gurin, and W. I. LeVan, *J. Chem. Phys.*, **19**, 676 (1951).

(11) O. Bastiansen, F. N. Fritsch, and K. Hedberg, *Acta Cryst.*, **17**, 538 (1964); R. M. Schwendeman, G. D. Jacobs, and T. M. Krigas, *J. Chem. Phys.*, **40**, 1022 (1964).

(12) For cyclooctatetraene, the C=C bond length is 1.340 Å: M. Traetteberg, *Acta Chem. Scand.*, **20**, 1724 (1966).

(13) J. C. Pommelet and J. Chuche, *Tetrahedron Lett.*, 3897 (1974); J. C. Pommelet, N. Manisse, and J. Chuche, *Tetrahedron*, **28**, 3929 (1972); J. M. Brown, B. T. Golding, and J. J. Stofko, *JCS Chem. Commun.*, 319 (1973); W. Grimme and K. Seel, *Angew. Chem. Intern. Ed. Engl.*, **12**, 507 (1973).

(14) S. W. Benson, F. R. Cruickshank, D. M. Golden, G. R. Haugen, H. E. O'Neal, A. S. Rodgers, R. Shaw, and R. Walsh, *Chem. Revs.*, **69**, 279 (1969).