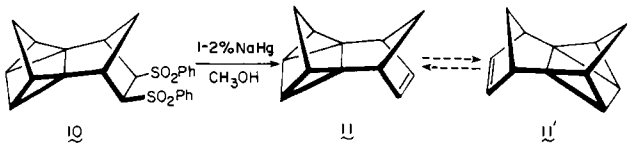

10 11 11'

to fit quite well with the absence of any obvious reason to deform additionally the hybridization of these atomic centers, quite unlike the situation in **3**. The interesting question of whether **11** and the corresponding anti isomer are capable of unprecedented degenerate quadricyclane–quadricyclane rearrangement is currently under active investigation.

Acknowledgment. We are grateful to the National Institutes of Health for the financial support of this work (Grant CA-12115) and Prof. Harald Günther for a helpful exchange relating to ^{13}C NMR shift theory.

Synthesis of 1,2:7,8-Dibenzo[2.2]paracyclophane and 1,2-Benzo-7,8-naphtho[2.2]paracyclophane[1]

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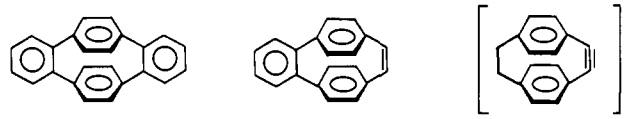
Received April 2, 1985

1,2:7,8-Dibenzo[2.2]paracyclophane (**1**) has attracted attention



1 2 3

as a theoretically interesting but unknown substance.[3] Structurally, cyclophane **1** possesses orthogonal benzene rings and therefore is expected to exhibit interesting chemical as well as physical properties. Moreover, it may serve as a novel ligand for metal complexation and it is also possible that it may behave as a host molecule in clathrate inclusion phenomenon.[4]

In 1978, Jacobson and Boekelheide reported the isolation and characterization of **2**,[5] and in 1982, Psiorz and Hopf reported the identification of an elusive intermediate **3**.[6] On the basis of their strategies, we here report the successful synthesis of **1** as well as 1,2-benzo-7,8-naphtho[2.2]paracyclophane (**11**).

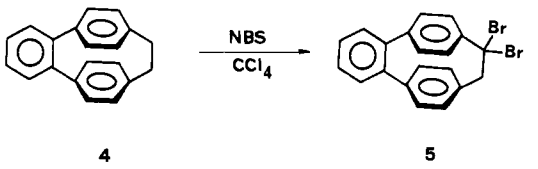
Treatment of the known cyclophane **4**[5-8] with a large excess of *N*-bromosuccinimide gave the dibromide **5** in 30% yield (Scheme I), isolated as white crystals,[9] mp 223–225 °C; ^1H NMR δ 4.71 (s, 2 H), 6.50–6.70 (m, 4 H), 6.70–7.30 centered at 7.00 (AA′XX′, 4 H), 7.30–7.70(A_2B_2, 4 H).

Dehydrobromination of **5** with KO-*t*-Bu in THF led presumably to the fugitive cyclophyne **6** which was trapped in situ with furan (**7**) to yield the endoxide **8** in 15% yield (Scheme II): mp 203–205 °C, ^1H NMR δ 5.83 (s, 2 H), 6.10–6.60 centered at 6.36 (AA′XX′, 4 H), 6.55 (AA′XX′, 4 H), 7.40–7.60 (A_2B_2, 4 H), 7.49 (s, 2 H).[9] Similarly, cyclophyne **6** underwent the Diels–Alder reaction with isobenzofuran (**9**)[10] to provide the endoxide **10** in 70% yield: mp 247–249 °C; ^1H NMR δ 5.70–6.50 centered at 6.08 (AA′XX′, 4 H), 6.10 (s, 2 H), 6.71 (s, 4 H), 7.05–7.55 (m, 8 H).[9] Reaction of **6** with 2,5-diphenylisobenzofuran (**12**) yielded **13** in 47% yield: mp 270 °C dec; ^1H NMR δ 6.61–6.80 (m, 8 H), 7.20–7.80 (m, 18 H).[9] Ketone **15** was isolated as a side product in every dehydrobromination reaction (Scheme III). We anticipated that the strained cyclophyne **6** would react with *t*-BuOH during the dehydrobromination step and provide the enol–ether **14**, which was hydrolyzed to the ketone **15** during acidic workup of the reaction mixture.[11]

The intermediacy of **6** is indirectly confirmed by the fact that **2** gave no Diels–Alder adduct with furan (**7**) at room temperature. Thus the alternative mechanism which involves the initial cycloaddition between furan (**7**) and the vinyl bromide (generated by eliminating one molecule of HBr from **5**) and the subsequent elimination of the second HBr to give **8** is rather unlikely, although further confirmation is necessary.

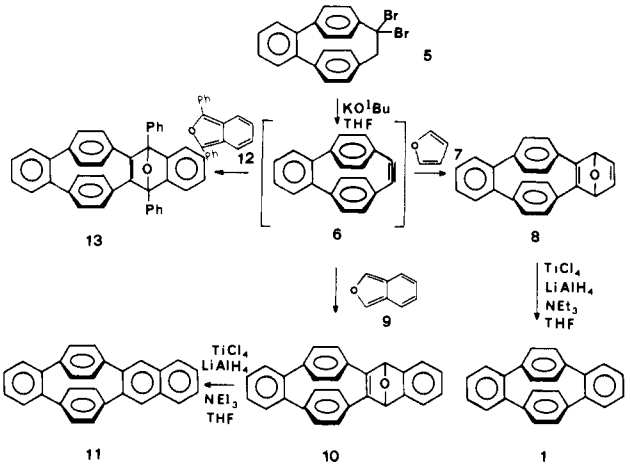
Deoxygenation of **8** by low valent titanium generated by reducing $TiCl_4$ with $LiAlH_4$[12-14] gave a 15% yield of **1**, which sublimed at 275 °C: ^1H NMR δ 6.69 (s, 8 H), 7.42–7.70 (A_2B_2, 8 H).[9] Similarly, **10** was converted to **11** in 17% yield: mp 278 °C dec; ^1H NMR δ 6.65–6.80 (A_2X_2, 8 H), 7.45–7.62 (A_2B_2, 4 H), 7.65–8.00 (A_2B_2, 4 H), 8.10 (s, 2 H).[9] The endoxide **13** resists deoxygenation; hence no reasonable product has been isolated.

Scheme I

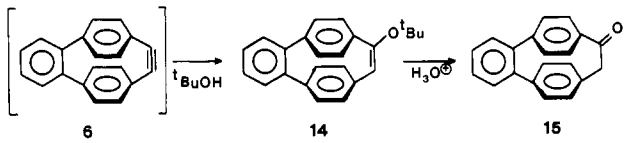


4 5

Scheme II



Scheme III



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The X-ray diffraction study of **1** and **11** is in progress. We are currently studying various physical and chemical properties of **1** and **11**.[15]

Acknowledgment. We thank Y. H. Law for measuring the accurate masses for all new compounds. This work was partially supported by a Messrs. Ho Tim & Ho Yin Research Grant administered by the Chinese University of Hong Kong.

(15) The less descriptive IUPAC names for **1**, **6**, and **11** are 5,8:13,16-diethenodibenzocyclododecene, 9,10-didehydro-5,8:11,14-diethenobenzocyclododecene, and 5,8:15,18-diethenobenzonaphthocyclododecene, respectively.

Transition-State Conformations of a Lewis Acid Catalyzed Diels–Alder Reaction. The Low-Temperature Cycloaddition of 1-(1-Oxo-2-propenyl)-2-(3-isopropenyl-4-methyl-3-pentenyl)benzene

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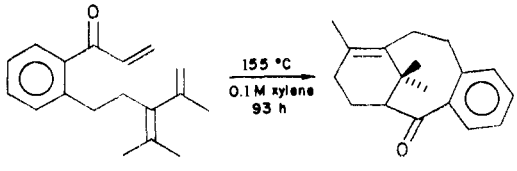
Received March 18, 1985

An analysis of various transition-state conformations is the organic chemists modus operandi for predicting product outcome and evaluating the relative merits of competing reaction pathways. This is particularly true in intramolecular Diels–Alder chemistry where issues of regio- and stereochemistry are determined by subtle conformational factors.[1] Unfortunately it is often impossible to relate the transition-state analysis to the resultant product molecules since under normal conditions the conformational isomer populations do not remain under kinetic control.

We report in this paper a rather unique opportunity to probe the relationship between transition-state conformation and product outcome in a Lewis acid catalyzed intramolecular Diels–Alder reaction. Our results establish that the relative stability of the conformational isomers of the product are amplified slightly in the transition states that lead to them.

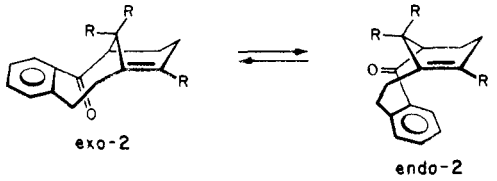
The thermal cycloaddition of trienone **1** (toluene, 155 °C, 0.1 M xylene, 93 h) affords a single cycloadduct in 70–80% isolated yield.[2] The gross structure of the tricyclo[9.3.1.0^{3,8}]pentadecane



1 2

ring system was established by a combination of ^{1}H and ^{13}C NMR spectroscopy.

Force-field calculations[3] and molecular models reveal two plausible low-energy conformations of the cycloadduct, *endo*- and *exo*-**2**. At room temperature, the rate of interconversion of the



exo-2 endo-2

(1) For recent reviews, see: (a) Taber, D. F., "Intramolecular Diels–Alder and Ene Reactions"; Springer-Verlag, Berlin, 1984. (b) Ciganik, E. *Org. React.* **1984**, *32*, 1. (c) Fallis, A. *Can. J. Chem.* **1984**, *62*, 183.

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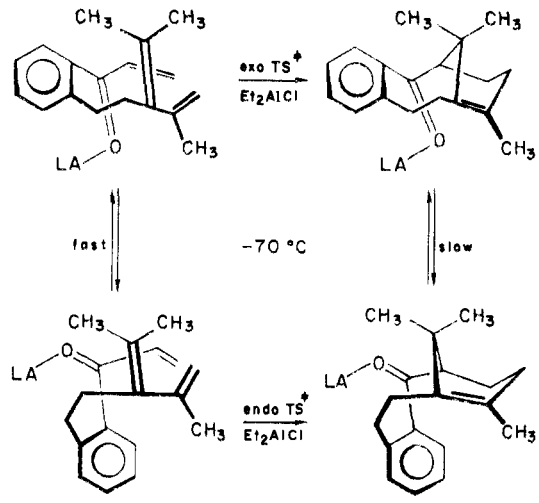
(3) Allinger, N. L. *J. Am. Chem. Soc.* **1977**, *99*, 8127.

Scheme I



two conformational isomers is slow on the NMR time scale; thus, at 250 MHz, the ^{1}H NMR consists of a superimposition of the spectra of *endo*- and *exo*-**2**.

Analysis of the spectra utilizing NOE and saturation transfer NMR spectroscopy permitted unambiguous assignment of the two isomers.[4] Our results can be summarized as follows: at 25 °C *endo*-**2** is the major conformational isomer in solution (*endo*-**2**/*exo*-**2** = 89:11), the free energy difference calculated from the experimentally observed ratios is $\Delta\Delta G°_{25\,°C}$ = 1.24 ± 0.15 kcal/mol. The equilibrium ratio was found to be insensitive to temperature over a 75-deg range (45 to −30 °C).[5] Variable-temperature NMR revealed the barrier height separating the two conformational isomers is quite high; analysis of site exchange of two methyl resonances (Me_{16} and Me_{18}) yields an average single point free energy barrier $\Delta G^‡$ = 16.5 ± 0.1 kcal/mol.[4]

We have also reported that type II intramolecular Diels–Alder cycloadditions are amenable to Lewis acid catalysis.[6] Trienone **1** is particularly responsive to catalysis by diethylaluminum chloride. For example, after 1 h in the presence of 0.3 equiv of Et_2AlCl in CD_2Cl_2 at −70 °C, trienone **1** gives cycloadduct **2** in 90% isolated yield.

The low-temperature reaction conditions provide a rare opportunity to establish the *conformational selectivity* of the Lewis acid catalyzed intramolecular Diels–Alder reaction. Scheme I summarizes the various competing reactions involved in the experiment.

At −70 °C interconversion of the conformational isomers of **1** is fast.[7] Interconversion of the conformational isomers of cycloadduct **2**, however, is slow.[8] Based upon the experimentally measured free energy of activation we estimate $t_{1/2} \approx 6$ h at −70 °C.

Under the Lewis acid catalyzed reaction conditions the ratio *endo*-**2**/*exo*-**2** represents the *kinetically controlled* rate of *conformational isomer formation*, thus k_{endo}/k_{exo} = 70 (−70 °C), from which the difference in free energy of activation for the two competing reactions can be computed, $\Delta\Delta G^‡_{-70°C}$ = 1.70 ± 0.02

(4) Shea, K. J.; Gilman, J. W. *Tetrahedron Lett.* **1984**, *24*, 2451.

(5) The variation in the ratio of *endo*-**2**/*exo*-**2** between 25 and −40 °C falls within the experimental uncertainty of the integrated peak intensities (4%). At room temperature this ratio is not influenced by the presence 0.3 equiv of diethylaluminum chloride.

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(8) The conformational integrity of **2** at −70 °C in the presence of Lewis acids was established in the following manner. A single crystal of pure *endo*-**2** was dissolved at −100 °C in CD_2Cl_2, warmed to −70 °C, and then treated with 0.3 equiv of Et_2AlCl. *exo*-**2** could not be detected after 1 h (*endo*-**2**/*exo*-**2** > 250:1 at −70 °C). Upon warming the equilibrium ratio of the two conformations was readily achieved.

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