Medium-Sized Cyclophanes. 43.[1] First Evidence for *anti*−*syn*-Ring Inversion under the Nitration of 5,13-Di-*tert*-butyl-8,16-dimethoxy[2.2]metacyclophane

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Received February 3, 1997 (Revised Manuscript Received July 22, 1997[⊗])

Nitration of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (metacyclophane = MCP) (**1**) with various nitrating reagents led to *ipso*-nitration at the *tert*-butyl group to give 5-*tert*-butyl-8,16-dimethoxy-13-nitro[2.2]MCP (**2**), as well as the corresponding 8,16-epoxy[2.2]MCP (**4**) arising from intramolecular condensation reaction via *anti*−*syn*-ring inversion of the nitration intermediate. This novel intramolecular condensation reaction to afford 8,16-epoxy[2.2]MCP (**4**) was also observed in the presence of Nafion-H under chlorobenzene reflux. The mechanism of the *ipso*-nitration as well as the present novel intramolecular condensation reaction is also discussed.

Introduction

For many years various research groups have been attracted by the chemistry and spectral properties of the [2.2]metacyclophane ([2.2]MCP) skeleton.[2,3] Its conformation, which was elucidated by X-ray measurements,[4] is apparently frozen into a chair-like nonplanar form. The two halves of the molecule form a stepped system. The benzene rings are not planar but have a boat conformation, with the result that the molecule avoids the steric interaction of the central carbon atoms C-8 and C-16 and of the attached hydrogen atoms. The C(8)−C(16) distance is 2.689 Å. The increased strain in the molecule 8,16-dimethyl[2.2]MCP as compared with that in the parent hydrocarbon can be seen in particular in the distance between C-1 and C-2 (1.573 Å). It is also remarkable that the two methyl carbon atoms lie in one plane together with the carbon atoms 8, 7, and 3 and 16, 11, and 15. The C(8)−C(16) distances are increased from 2.689 Å in [2.2]MCP to 2.819 Å in 8,16-dimethyl-[2.2]MCP.[5] On the basis of the temperature-independence of the methylene resonances of [2.2]MCP between −80 and 190 °C,[6] the molecule is rigid in solution; in agreement with molecular model considerations, ring inversion can be ruled out. The [2.2]MCPs described so far, according to the spectroscopic findings, have the *anti* conformation with staggered benzene rings, but the existence of a *syn* form for a [2.2]MCP has also been detected.[7]

Due to electronic interaction between the two benzene rings, the proximity of the 8,16-positions, and the considerable strain energy, [2.2]MCP is prone to give transannular reaction products[5] under the electrophilic,[8] radical,[9] and photolytic[10] reaction conditions together with other transformation products derived from tetrahydropyrene. These have usually been rationalized as involving initial dehydrogenation to 4,5,9,10-tetrahydropyrene. Allinger and his co-workers have reported[11] that the nitration of 8,16-unsubstituted [2.2]MCP with fuming HNO_3 affords 2-nitro-4,5,9,10-tetrahydropyrene *via* the addition−elimination mechanism.

Subsequently, we reported that[12] nitration of 8,16-dimethyl[2.2]MCP with fuming HNO_3 afforded only 5-nitro-8,16-dimethyl[2.2]MCP but not 5,13-dinitro-8,16-dimethyl[2.2]MCP and that similar reaction of 5,13-di-*tert*-butyl-8,16-dimethyl[2.2]MCP gave a different type of product, 2,7-di-*tert*-butyl-4,9-dinitro-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene.

Although the replacement of a *tert*-butyl group by a nitro group in electrophilic aromatic substitutions has frequently been described in the literature,[13,14] generally the yields are modest because of the accompanying side reactions.[15] Only in activated compounds are better yields obtained. More recently, Reinhoudt *et al.* reported[16] the high-yield 4-fold *ipso*-nitration of *p-tert*-butylcalix[4]arenes.

However, the mechanistic aspects for *ipso*-attack in electrophilic aromatic substitutions having more than

[⊗] Abstract published in *Advance ACS Abstracts,* October 1, 1997.

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S0022-3263(97)00192-8 CCC: $14.00

Table 1. Nitration of 5,13-Di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (1) at Room Temperature[a]

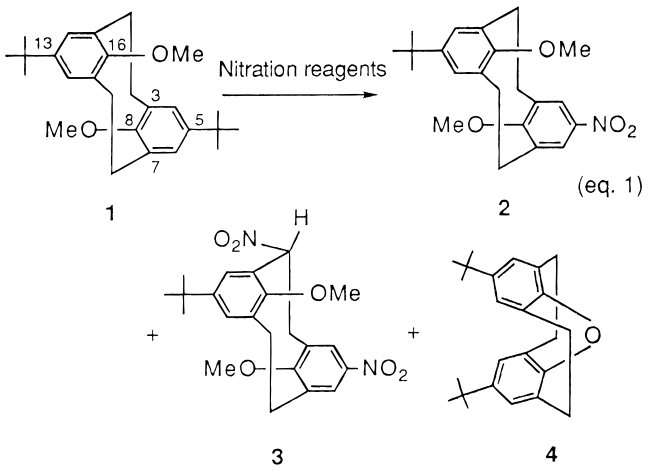
run	reagent	1/reagent [mol/mol]	reaction time [h]	products [% yield][b]
1	$Cu(NO_3)_2$	2.2	**24**	**2** (50), **3** (25), **4** (12)
2	$Cu(NO_3)_2$	4.2	**24**	**2** (40), **3** (41), **4** (5)
3	63% NHO_3	excess	**1**	**2** (22), **3** (57), **4** (5)
4	Fuming HNO_3	excess	**1**	**2** (74), **3** (9) **4** (0)

[a] The detailed reaction conditions are shown in the Experimental Section. [b] Yields determined by GLC analysis.

two aromatic rings are still not clear in spite of the possibility of through-space electronic interactions among the other benzene rings.[17] Thus there is substantial interest in investigating the nitration of the internally methoxy-substituted [2.2]MCPs, which might afford single mono- and dinitrated products because conformational ring rotation of the meta-bridged benzene ring is impossible at room temperature, in contrast to the case of tetramethoxy-*p*-*tert*-butylcalix[4]arene. We report here on the through-space electronic interaction among the two benzene rings and evidence for *anti*−*syn*-ring inversion under the nitration of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**).

Results and Discussion

Nitration of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**)[18] with 2.2 equiv. of copper(II) nitrate in acetic anhydride led to *ipso*-nitration at just one *tert*-butyl group to give **2** in 50% yield along with 9-*endo*-nitro[2.2]MCP (**3**) and 8,16-epoxy[2.2]MCP (**4**) in 25 and 12% yields, respectively (eq 1, Table 1). Increasing the amount of

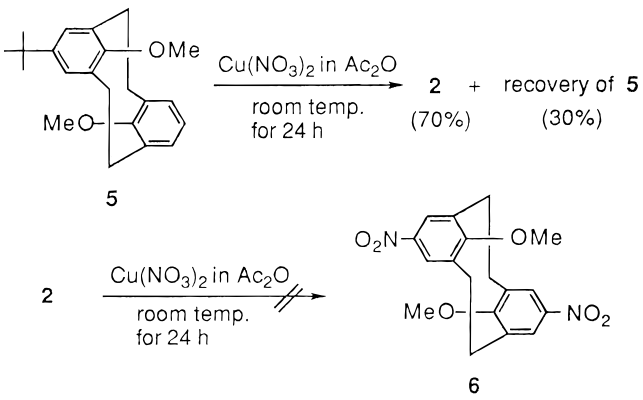


copper(II) nitrate ratio to 4.2 equiv increased the yield of 1-*endo*-nitro[2.2]MCP (**3**).

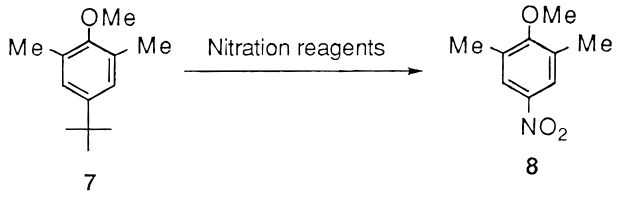
Similar treatment of 5-*tert*-butyl-8,16-dimethoxy[2.2]-MCP (**5**) with 2.2 equiv of copper(II) nitrate in acetic anhydride under the same conditions afforded **2** in 70% yield and recovered **5**.

Apparently the *ipso*-nitration of **1** at the *tert*-butyl group is much faster than the normal nitration of **5** at the 13 position. This might be explained by the higher π-density on the benzene rings of **1** (cf. **5**) due to the two electron-releasing *tert*-butyl groups. This is precedented in the *ipso*-nitration of 2,4,6-tri-*tert*-butylaniline, which

Scheme 1



Scheme 2



i) $Cu(NO_3)_2$ in Ac_2O, room temp. for 24 h: no reaction
ii) 70% HNO_3 in HOAc, room temp. for 24 h: no reaction
iii) 70% HNO_3 in HOAc, 50°C for 24 h: **8** (40%)
iv) Fuming HNO_3 in HOAc, room temp. for 0.5 h: **8** (97%)

has been explained, in addition to steric reasons, by activation of the concerned *tert*-butyl group by the electron-releasing amino group (Scheme 1).[19]

Attempted further nitration of **2** with copper(II) nitrate failed. No formation of dinitro compound **3** or **6** was observed; starting compound **2** was recovered quantitatively. These results demonstrate that **2** is not an intermediate leading to **3**. Rather, competition between *ipso*-nitration at the *tert*-butyl group and substitution on the ethylene bridge could occur in the nitration of **1**.

Similarly, 4-*tert*-butyl-2,6-dimethylanisole (**7**) with excess copper(II) nitrate in an acetic anhydride solution or with 70% HNO_3 in acetic acid at room temperature only gave a quantitative recovery of starting compound. Raising the reaction temperature to 50 °C afforded the product **8** from *ipso*-nitration at the *tert*-butyl group in 40% yield, along with recovered **7**. When nitration of **7** with fuming HNO_3 in an acetic acid solution was carried out at room temperature for 30 min, 2,6-dimethyl-4-nitroanisole (**8**) was obtained in quantitative yield (Scheme 2).

In contrast with **7**, nitration of [2.2]MCP **1** with excess copper(II) nitrate in an acetic anhydride solution or with 70% HNO_3 led to *ipso*-nitration only at one of the *tert*-butyl groups to give **2** and **3** in moderate yields. We previously reported[12] that nitration of 5,13-di-*tert*-butyl-8,16-dimethyl[2.2]MCP with copper(II) nitrate afforded only 2,7-di-*tert*-butyl-4,9-dinitro-*trans*-10b,10c-dimethyldihydropyrene. No products arising from *ipso*-nitration were observed. This result seems to indicate that the methoxy group in **1** plays an important role in the present *ipso*-nitration reaction. The *ipso*-nitration of **1** is attributed to the highly activated character of the aryl ring and the increased stabilization arising from dienone character made possible by the methoxy substituent.

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Chart 1

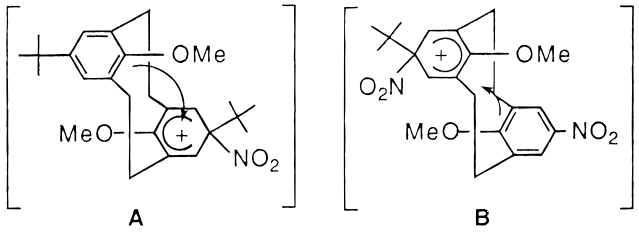
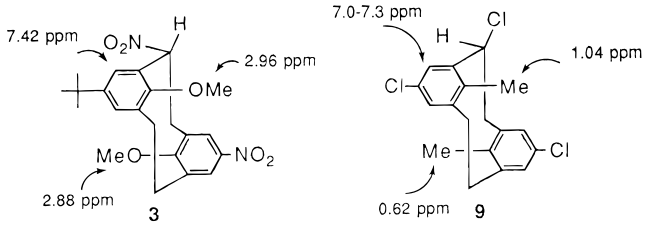


Chart 2



Quite recently, Cacace *et al.* reported[20] the intramolecular proton shift, namely, ring-to-ring proton migration in (*β*-phenylethyl)arenium ions from the higher cationic alkylation rate of 1,2-diphenylethane than that of toluene in the gas phase. Thus in the present system, *σ*-complex intermediate **A** would be stabilized by a through-space electronic interaction through intraannular 8,16-positions with the opposing benzene ring, therefore accelerating the reaction (like the formylation of *tert*-butyl[n.2]-MCPs[21]). However, only one *tert*-butyl group is *ipso*-nitrated because of deactivation of the second aromatic ring by the nitro group introduced (structure **B**) (Chart 1).

The structures of **2** and **3** were assigned on the basis of elemental analyses and spectral data. Thus, we previously assigned[22] the ^{1}H-NMR signals of 1-*exo*-1,5,-13-trichloro-8,16-dimethyl[2.2]MCP (**9**). We have assigned the ^{1}H-NMR signals of **3** in a similar fashion (Chart 2). For example, the ^{1}H-NMR spectrum of **3** shows two internal methoxy resonances as singlets at δ 2.88 and 2.96, a bridge methine signal as a doublet at δ 5.56 (J = 1.95 Hz), and two aromatic protons as two sets of doublets at δ 7.11, 7.42 (J = 2.44 Hz) and 8.05, 8.14 (J = 2.45 Hz); the latter protons are strongly deshielded by the nitro group. We observed one methoxy signal not to be deshielded by the *endo*-nitro group on the ethylene bridge, resulting in a downfield shift (δ 0.08) considerably less than the δ 0.42 shift observed in 1-*exo*-1,5,13-trichloro-8,16-dimethyl[2.2]MCP (**9**) (Chart 2). These data strongly support the *endo*-arrangement for the nitro group. An aromatic proton in the ^{1}H NMR spectrum of **3** at δ 7.42 was observed which is similar to one in the *endo*-Br analog (δ 7.69).[23] Thus **3** is assigned the structure 9-*endo*-5-*tert*-butyl-8,16-dimethoxy-9,13-dinitro-[2.2]MCP.

The ratio of (**2** + **3**)/**4** varied with the reactivity of the nitrating reagents. Increasing the reactivity of the nitration reagents (from 61% HNO_3 to fuming HNO_3) increased the yields of **2** and **3**. Thus, the positional selectivity for the nitration of **1** was strongly affected by the reactivity of the nitration reagents (as reported in normal aromatic systems[24]). However, the formation of the 2-fold *ipso*-nitration product, 8,16-dimethyl-5,13-dinitro[2.2]MCP (**6**) was not observed under these reaction conditions. This result strongly suggests that in the first step *ipso*-nitration at the *tert*-butyl group competes with the substitution reaction at the benzylic position. Nitration with mixed acid, however, led only to an intractable mixture. No di-*ipso*-nitration was detected.

Table 2. Nafion-H catalyzed intramolecular condensation reaction of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP 1[a]

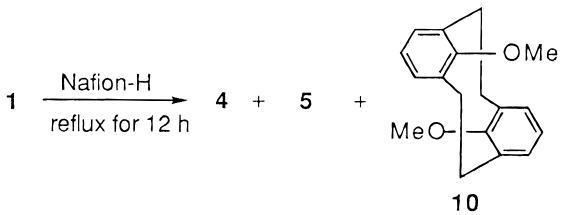
		product yields (%)			
run	solvent	4	5	10	recovd 1
1	benzene	3	12	4	70
2	toluene	9	23	9	10
3	chlorobenzene	34	15	4	14

[a] The detailed reaction conditions are shown in the Experimental Section. [b] Yields determined by GLC analysis.

Nitration of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**) with various nitrating agents led to an intramolecular condensation reaction at the intraannular 8,16-positions to give 5,13-di-*tert*-butyl-8,16-epoxy[2.2]MCP (**4**) in 5−12% yield along with *ipso*-nitration products **2** and **3**. The present novel intramolecular condensation reaction of two methoxy groups might be similar to the protic-acid catalyzed condensation of 2,2′-dihydroxybiphenyls to afford dibenzofurans at high temperatures (above 200 °C).[25] Thus, attempted condensation of **1** to afford **4** in the presence of protic acids, such as sulfuric acid, trifluoroacetic acid, trifluoromethanesulfonic acid, and Lewis acids, such as titanium tetrachloride and aluminum chloride−nitromethane, under various conditions failed. No formation of the desired **4** was observed under the conditions used.

Recently, we have found Nafion-H, a perfluorinated resin sulfonic acid,[26] catalyzed condensation of 2,2′-dihydroxybiphenyl to afford dibenzofurans under relatively mild conditions (Table 2).[27]

Condensation reaction of **1** in the presence of Nafion-H as a catalyst was carried out in boiling benzene or toluene to afford the desired 8,16-epoxy[2.2]MCP (**4**) in 3−9% yield along with the trans-*tert*-butylated products **5** and **10** (eq 2). Benzene or toluene could be an acceptor for



(eq. 2)

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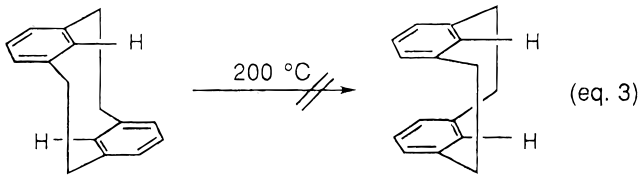
the *tert*-butyl group under the reaction used. In contrast, the reaction carried out in boiling chlorobenzene for 12 h afforded 8,16-epoxy[2.2]MCP (**4**) in 34% yield.

The synthesis and stereochemical aspects of conformationally mobile [*m.n*]MCPs have been of interest for the past decade, particular attention being paid to [2.2]-MCPs, which possess an *anti*-stepped conformation. Although the parent [2.2]MCP was first reported as early as 1899 by Pellegrin,[28] the synthesis of *syn*-[2.2]MCP was not realized until 85 year later. Mitchell *et al.*[7a] have successfully prepared *syn*-[2.2]MCP at low temperature by using (arene)chromiumcarbonyl complexation to control the stereochemistry. However, *syn*-[2.2]MCP isomerizes readily to the *anti*-isomer above 0 °C. More recently, Itô *et al.*[7b] have isolated and characterized *syn*-[2.2]MCP without complexation. However, a ring inversion of *anti*-[2.2]MCPs to the corresponding *syn*-[2.2]MCPs has not yet been published. The meta-bridged benzene ring has not been shown to undergo conformational flipping above 200 °C (eq 3). A great part of this high-energy barrier is



(eq. 3)

believed to arise from steric destabilization of the transition state in which the 8 or 16 hydrogen to each meta-bridged ring impinges into the π-electron cloud of the opposing benzene ring. Therefore, the cleavage of the ethylene bridge must be necessary for the ring inversion.

On the other hand, we have reported[29] that the novel intramolecular dehydration of hydroxyl groups in the *syn*-intraannular positions of *syn*-6,14-di-*tert*-butyl-9,17-dihydroxy[3.2]MCP (**11**) occurred easily under $AlCl_3$–$MeNO_2$-catalyzed trans-*tert*-butylation reaction conditions to afford 9,17-epoxy[3.2]MCP (**12**) in 76% yield, attributable to the release of strain in **11** leading to the more strainless 9,17-epoxy[3.2]MCP (**12**) containing an ether linkage.

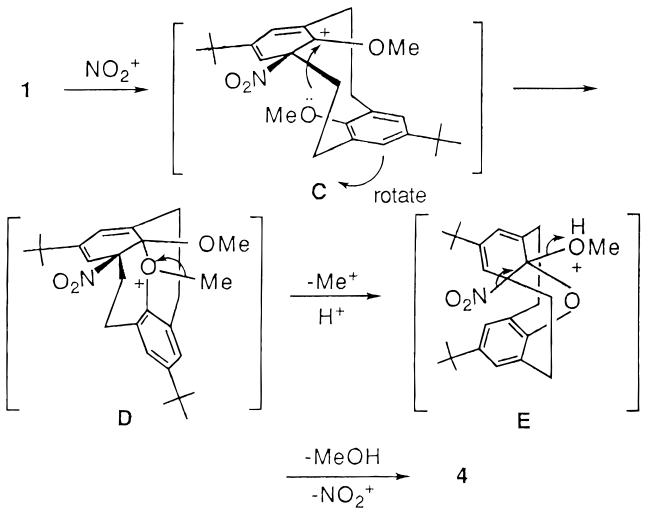
This result strongly suggests that the formation of 8,-16-epoxy[2.2]MCP (**4**) might have arisen from *syn*-8,16-dimethoxy[2.2]MCP.

Although the detailed mechanism of formation of 8,-16-epoxy[2.2]MCP (**4**) is not clear from the available results, one might assume the reaction pathway shown in Scheme 3.

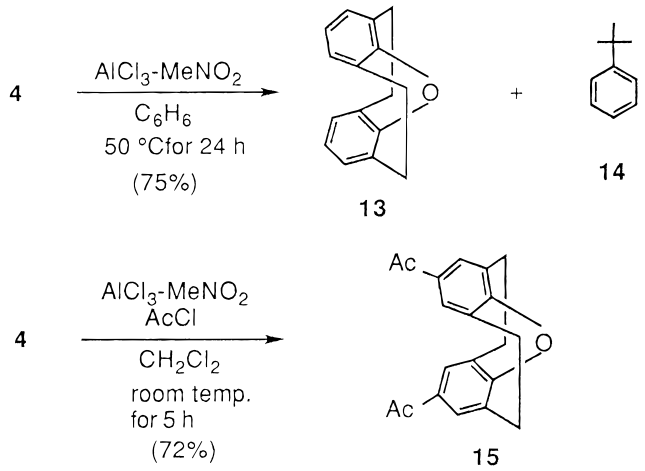
Although it is well-recognized that the anti–syn-ring inversion is inhibited, that of the intermediate **C** arising from *ipso*-attack by nitro group at the ethylene bridge might be possible. This phenomenon is strongly supported by the molecular models. Subsequently the intramolecular nucleophilic aromatic substitution might proceed to form the intermediate **D**. Elimination of methanol would afford 8-epoxy[2.2]MCP **4** *via* the intermediate **E**.

The present novel intraannular condensation reaction is the first evidence for anti–syn-ring inversion under the nitration of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**).

Scheme 3



Scheme 4



The structure of **4** was assigned on the basis of elemental analysis and spectral data. The ^1H NMR spectrum of **4** in $CDCl_3$ shows the disappearance of two internal methoxy protons and *tert*-butyl protons as a singlet at δ 1.21, a bridged methylene protons as a multiplet at δ 2.64–3.66, and aromatic protons as a singlet at δ 6.85.

The $AlCl_3$–$MeNO_2$-catalyzed trans-*tert*-butylation of **4** was carried out in benzene at 50 °C to afford 8-epoxy-[2.2]MCP (**13**) in 75% yield (Scheme 4). The physical properties and spectral data were identical with those of the sample which was already prepared by Boekelheide *et al.*[30] Attempted nitration of **4** with copper(II) nitrate under the conditions mentioned above resulted only in the recovery of starting compound; with fuming HNO_3 the intractable mixture only was afforded. No formation of *ipso*-nitrated product was observed. In contrast, acetylation of **4** with acetyl chloride carried out in the presence of $AlCl_3$–$MeNO_2$ afforded the desired *ipso*-acetylated product, 5,13-diacetyl-8,16-epoxy[2.2]MCP (**15**), in 72% yield. These results strongly support the 8,16-epoxy[2.2]MCP structure of **4**.

We conclude that the *ipso*-nitration reactions of **1** lead to the first-reported direct introduction of one nitro group. The selective *ipso*-nitration of **1** is attributed to the highly activated character of the aryl ring and the increased

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stabilization of the σ-complex intermediate arising from dienone character made possible by the methoxy substituent. And we have observed that the first σ-complex intermediate, (β-phenylethyl)arenium ion, would be stabilized by the through-space electronic interaction with the other benzene ring in nitration reactions like the electrophilic aromatic substitution of MCPs. The presently developed novel intramolecular condensation reaction to afford 8,16-epoxy[2.2]MCP will open up new mechanistic aspects for cyclophane chemistry. Further studies on *ipso*-nitration are currently in progress in our laboratory.

Experimental Procedure

All melting points are uncorrected. ^{1}H NMR spectra were recorded at 270 MHz in $CDCl_3$. Mass spectra were obtained at 75 eV using a direct-inlet system.

Materials. The preparations of *anti*-5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**) and *anti*-5-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**5**) were previously described.[18]

Nitration of 5,13-Di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (1) with $Cu(NO_3)_2$ in Acetic Anhydride. Copper(II) nitrate trihydrate (150 mg, 0.62 mmol) was added at 0 °C to a solution of 5,13-di-*tert*-butyl-8,16-dimethoxy[2.2]MCP (**1**) (110.6 mg, 0.289 mmol) in a mixture of CH_2Cl_2 (2.5 mL) and acetic anhydride (50 mL). The mixture was stirred at room temperture for 24 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with hexane, hexane−benzene (1:1), and benzene afforded **4** (11 mg, 12%), **2** (53 mg, 50%), and **3** (30 mg, 25%), respectively.

5-*tert*-Butyl-8,16-dimethoxy-13-nitro[2.2]metacyclophane (2): pale yellow prisms (hexane); mp 241−243 °C; ^{1}H NMR ($CDCl_3$) δ 1.32 (9 H, s), 2.61−2.89 (8 H, m), 2.93 (3 H, s), 3.02 (3 H, s), 7.06 (2 H, s), 7.97 (2 H, s); MS (*m*/*e*) 369 (M^+). Anal. Calcd for $C_{22}H_{27}O_4N$: C, 71.52; H, 7.37; N, 3.79. Found: C, 71.52; H, 7.37; N, 3.79.

9-*endo*-5-*tert*-Butyl-8,16-dimethoxy-9,13-dinitro[2.2]metacyclophane (3): pale yellow prisms (hexane:benzene 5:1); mp 110−113 °C; ^{1}H NMR ($CDCl_3$) δ 1.31 (9 H, s), 2.42−2.64 (2 H, m), 2.81−3.33 (3 H, m), 2.88 (3 H, s), 2.96 (3 H, s), 3.85 (1 H, d, J = 1.95 Hz), 5.56 (1 H, d, J = 1.95 Hz), 7.11 (1 H, d, J = 2.44 Hz), 7.42 (1 H, d, J = 2.44 Hz), 8.05 (1 H, d, J = 2.45 Hz), 8.14 (1 H, d, J = 2.45 Hz); MS (*m*/*e*) 414 (M^+). Anal. Calcd for $C_{22}H_{26}O_6N_2$: C, 63.75; H, 6.32; N, 6.76. Found: C, 64.18; H, 6.53; N, 6.57.

5,13-Di-*tert*-butyl-8,16-epoxy[2.2]metacyclophane (4): colorless prisms (methanol); mp 207−209 °C; ^{1}H NMR ($CDCl_3$) δ 1.21 (18 H, s), 2.64−3.66 (8 H, m), 6.85 (4 H, s); MS (*m*/*e*) 334 (M^+). Anal. Calcd for $C_{24}H_{30}O$: C, 86.17; H, 9.04. Found: C, 86.05; H, 8.89.

Nitration of 1 with 63% Nitric Acid. HNO_3 (63%, 1.8 mL) was added at 0 °C to a solution of **1** (110.6 mg, 0.289 mmol) in a mixture of CH_2Cl_2 (2.5 mL) and acetic acid (4 mL). The mixture was stirred at room temperture for 1 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with hexane, hexane−benzene (1:1) and benzene afforded **4** (5 mg, 5%), **2** (26 mg, 22%), and **3** (61 mg, 57%), respectively.

Nitration of 1 with Fuming Nitric Acid. Fuming HNO_3 (1.8 mL) was added at 0 °C to a solution of **1** (110.6 mg, 0.289 mmol) in a mixture of CH_2Cl_2 (2.5 mL) and acetic acid (4 mL). The mixture was stirred at room temperture for 1 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with hexane−benzene (1:1) and benzene afforded **2** (79 mg, 74%) and **3** (10 mg, 9%), respectively.

Nitration of 5-*tert*-Butyl-8,16-dimethoxy[2.2]MCP (5) with $Cu(NO_3)_2$ in Acetic Anhydride. Copper(II) nitrate (250 mg, 0.492 mmol) was added at 0 °C to a solution of **5** (149.0 mg, 0.461 mmol) in a mixture of CH_2Cl_2 (2.5 mL) and acetic anhydride (50 mL). The mixture was stirred at room temperture for 24 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with hexane and hexane−benzene (1:1) and benzene afforded **5** (32 mg, 30%) and **2** (61 mg, 70%), respectively.

Nitration of 7 with Fuming Nitric Acid. Typical Procedure. Fuming HNO_3 (0.83 mL) was added at 0 °C to a solution of 4-*tert*-butyl-2,6-dimethylanisole (**7**) (55.6 mg, 0.289 mmol) in a mixture of CH_2Cl_2 (2.5 mL) and acetic acid (2.5 mL). The mixture was stirred at room temperture for 0.5 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo* to give 2,6-dimethyl-4-nitroanisole (**8**) (53.3 mg, 97%) as pale yellow prisms (hexane): mp 91−92 °C; ^{1}H NMR ($CDCl_3$) δ 2.36 (6 H, s), 3.79 (3 H, s), 7.91 (2 H, s).

Trans-*tert*-butylation of 4. To a solution of **4** (30.0 mg, 0.09 mmol) in benzene (3 mL) was added a solution of $AlCl_3$ (200 mg, 1.50 mmol) in nitromethane (1.0 mL) at 0 °C. The mixture was stirred at room temperature for 24 h, poured into ice−water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with hexane afforded 8,16-epoxy[2.2]metacyclophane (**13**) (15 mg, 75%) as colorless prisms (methanol): mp 91−94 °C (lit.[30] mp 94−95 °C); ^{1}H NMR ($CDCl_3$) δ 2.52−2.69 (4 H, m), 3.52−3.65 (4 H, m), 6.79 (6 H, s); MS (*m*/*e*) 222 (M^+). Anal. Calcd for $C_{16}H_{14}O$: C, 86.45; H, 6.35. Found: C, 86.39; H, 6.54.

***ipso*-Acetylation of 4.** To a solution of **4** (40.0 mg, 0.12 mmol) and acetyl chloride (0.034 mL, 0.48 mmol) in CH_2Cl_2 (2 mL) was added a solution of $AlCl_3$ (96.0 mg, 0.72 mmol) in nitromethane (0.2 mL) at 0 °C. The mixture was stirred at room temperature for 5 h, poured into ice-water, and extracted with CH_2Cl_2. The extracts were washed with water and then 10% sodium bicarbonate, dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Chromatography on silica gel (Wako, C-300; 100 g) eluting with benzene afforded 5,13-diacetyl-8,16-epoxy[2.2]metacyclophane (**15**) (24 mg, 72%) as colorless prisms (chloroform): mp 177−179 °C; IR (KBr) 1683 (C=O) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.48 (6 H, s), 2.75−2.83 (4 H, m), 3.69−3.78 (4 H, m), 7.79 (4 H, s); MS (*m*/*e*) 306 (M^+). Anal. Calcd for $C_{20}H_{18}O_3$: C, 78.41; H, 5.92. Found: C, 78.39; H, 5.84.

The formation of *tert*-butylbenzene (**14**) was confirmed by GLC. GLC analyses were performed by a Shimadzu gas chromatograph (GC-14A) with Silicone OV-1 (2 m), a programmed temperature rise of 12 °C/min, and nitrogen carrier gas as (25 cm^3/min).

Nafion-H-Catalyzed Intramolecular Condensation Reaction of 1. Typical Procedure. To a solution of **1** (110.4 mg, 0.289 mmol) in chlorobenzene (4 mL) was added Nafion-H (110 mg, 100 wt %) at room temperature. After stirring the reaction mixture had been refluxed for 12 h, it was cooled to room temperature. The solid resinsulfonic acid was then filtered off and the filtrate analyzed by GLC.

The results are compiled in Table 2. The formation of **10** was confirmed by the comparison of the retention time in GLC with that of an authentic sample.[31]

JO970192P

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