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# Layered Compounds. LXIII.[1] Bromination of Double- and Triple-layered Paracyclophanes

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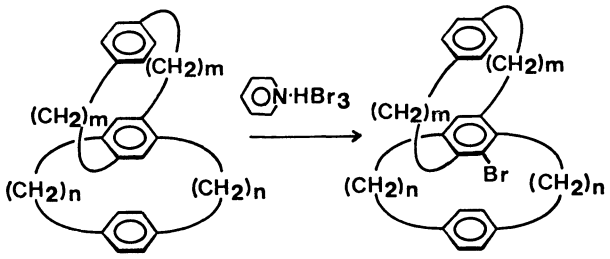
[*m.m*][*n.n*]Triple-layered paracyclophanes underwent bromination to give exclusively monobromo derivatives substituted to the inner benzene. The reactions were markedly accelerated by the transannular electronic interaction as compared to [*n*]- and double-layered paracyclophanes, and their enhanced reactivities were demonstrated by some competitive reactions. The relative rates of [2.2] and [3.3]systems are in reverse order for the triple-layered and double-layered series. Their reaction mechanisms were discussed.

It is well-known that layered compounds exhibit unique properties originated from the transannular π-electronic interaction of the faced benzene rings.[2] The enhancement in chemical reactivities based on the interaction was observed in some studies on the electrophilic aromatic substitution of double-layered compounds such as [*n.n*]paracyclophanes[3] and janucene.[4] Since multilayered cyclophanes show a stronger π-electronic interaction than double-layered series,[2] it is very interesting to study their chemical properties. Multilayered [2.2]paracyclophanes are expected to be highly reactive for electrophilic aromatic substitutions. However, their severe strain prevents normal Friedel-Crafts reaction and leads to unusual reactions such as skeletal rearrangement.[5]

[3.3]Paracyclophane and its derivatives are expected to show a reactivity reflecting the transannular π-electronic interaction alone because they have far less strain than those of the corresponding [2.2]phane systems. In addition, they may give some of the information on the reactions, in which the formation of π-complex is an important step of aromatic substitution, since [3.3]paracyclophane show a strong π-basicity.[6] In these regards we have investigated the bromination of double and triple-layered paracyclophanes with [2.2] and [3.3]types of bridging chains and related cyclophanes.

## Results and Discussion

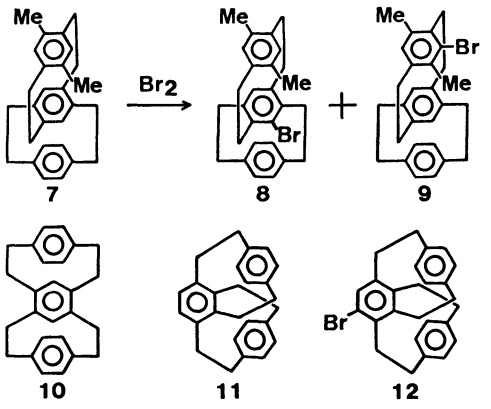
*Bromination.* Triple-layered paracyclophanes **1**—**3**[1,7,8] gave easily the corresponding monobromo derivatives **4**—**6** as a sole product by non-catalytic bromination. In the reactions, pyridinium hydrobromide perbromide afforded the bromides in better yields than with bromine alone. These brominations were complete in a shorter time than for [*n*]paracyclophane or double-layered paracyclophane, indicating an acceleration of the reaction based on strong transannular electronic stabilization in the transition state. No dibromo derivative was formed even if an excess of the reagent was used or the reaction time was prolonged. The first-introduced bromine substituent may prevent the following substitution because the steric requirement and the inductive effect of the very bromo group probably makes difficult the formation of the second σ-complex at the inner benzene.




1, m = n = 2
2, m = 2, n = 3
3, m = n = 3
4, m = n = 2
5, m = 2, n = 3
6, m = n = 3

Scheme 1.

On the other hand, bromination of 4,7-dimethyl-[2.2][2.2]paracyclophane **7**[7] afforded an equimolar mixture of inner-bromo derivative **8** and outer-bromo derivative **9**. Both reaction sites, the inner and the dimethylated outer benzenes, are in a similar electronic state with regard to alkyl substituent effect, but the outer benzene is of greater advantage than the inner with regards to steric surroundings. This sterical disadvantage for bromo-substitution at the inner benzene must be compensated by a stabilization of the intermediate due to a larger transannular electronic interaction to yield an equal amount of **8** and **9**.




Scheme 2.

Treatment of **1** with bromine in the presence of iron powder gave skeletal rearrangement products **10**—**12**[5] together with **4**. Our previous papers reported that **1**

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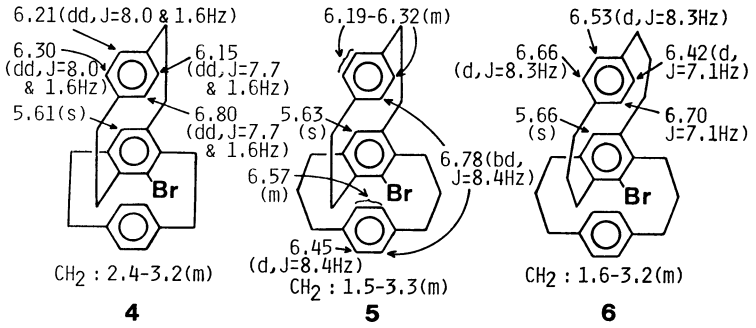
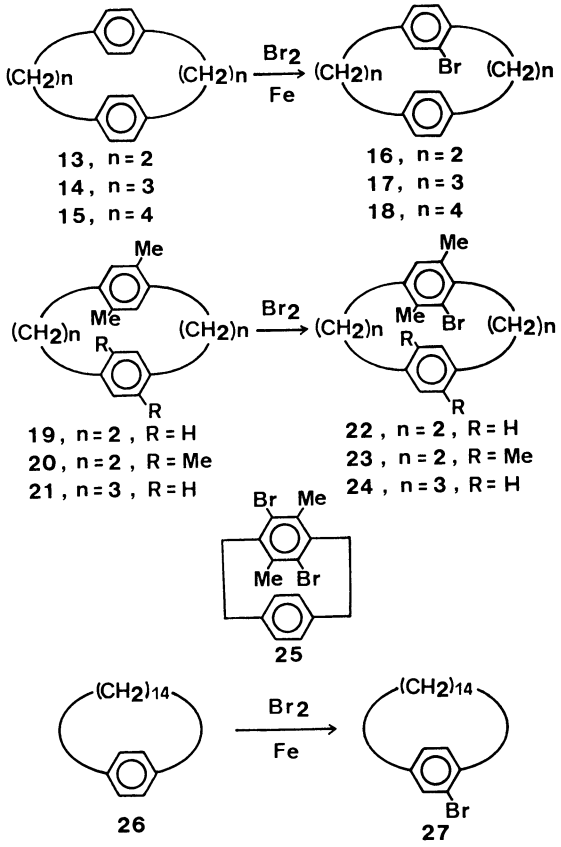



Fig. 1. NMR data of monobromo triple-layered paracyclophanes **4**—**6** in deuteriochloroform ($\delta$, 100 MHz).

underwent the same skeletal rearrangement by catalysis of a variety of Brønsted acids such as tin(IV) chloride–hydrogen chloride.[5] So, it can be presumed that a similar acid, *e.g.*, iron(III) bromide–hydrogen bromide, was formed in the bromination reaction and acted as a catalyst for the rearrangement.




Scheme 3.

Monobromination of [*n.n*]paracyclophanes, **13**,[9] **14**,[10] and **15**, and [14]paracyclophane **26** was accomplished by bromine and iron catalyst. Methyl substituted [*n.n*]paracyclophanes **19**—**21**, on the other hand, were readily brominated by bromine alone. In this case, use of excess reagent provided dibromo derivative as represented by **25**, and pyridinium hydrobromide perbromide was less reactive.

*Physical Properties of Bromo Derivatives.* The structures of all the bromo derivatives were confirmed by NMR and mass spectra and elemental analyses. The NMR spectra of bromo triple-layered paracyclophanes show a characteristic pattern (Fig. 1). The aromatic signals of the parent triple-layered compounds appear at higher field due to the anisotropic effect of the faced aromatic rings,[11] but the introduction of bromine atom gives rise to a considerable downfield shift of the proton pseudo-gem to the bromine (0.65 ppm for the [2.2][2.2]system and 0.30 ppm for the [3.3][3.3]-system).[10,12] This may be explained in terms of steric compression effect of the bromine atom.

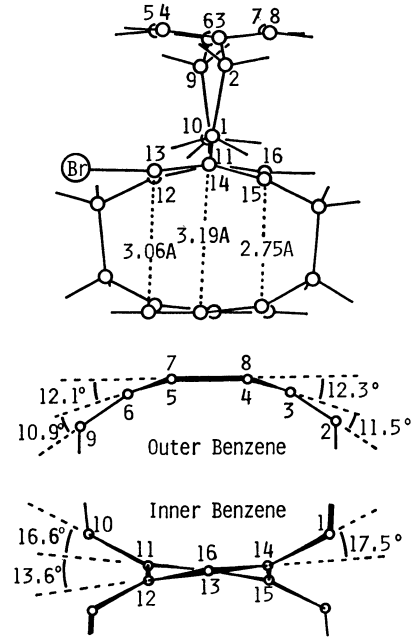



Fig. 2. Molecular structure of monobromo triple-layered [2.2]paracyclophane **4**.

An exact molecular structure of **4** was determined by X-ray crystallographic analysis (Fig. 2).[13] Its structural features are described below. The bending of the outer benzenes are almost the same as those of [2.2]paracyclophane **13**[14] and tetramethyl quadruple-layered [2.2]-paracyclophane,[15] and the inner benzene is twisted by a nearly equal twisting angle, *ca.* 13°, as that of the quadruple-layered paracyclophane. The non-bonding distance between the bromine and the pseudo-gem proton is an unexpectedly large value, 3.218 Å which is equal to or rather longer than ordinary van der Waals

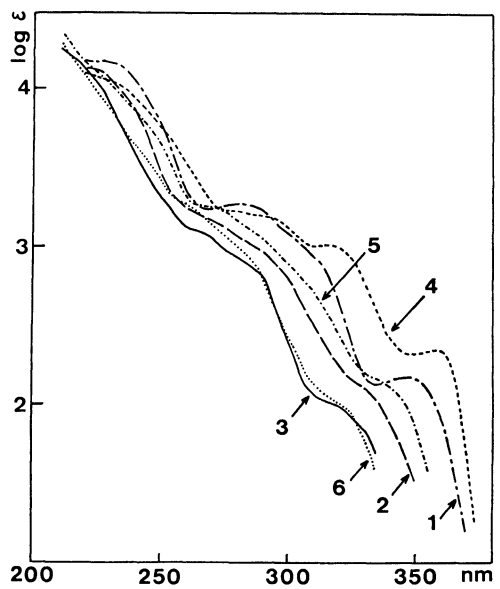



Fig. 3. The electronic spectra of triple-layered [*m.m*]-[*n.n*]paracyclophanes **1**—**3** and their monobromo derivatives **4**—**6** in tetrahydrofuran.

contact. Accordingly, it is concluded that the introduction of a bromine atom exerts less influence on the original structure of the parent hydrocarbon than expected from NMR analysis.

As shown in Fig. 3, the strong transannular electronic interactions of triple-layered paracyclophanes are indicated by marked bathochromic shifts of bands in their electronic spectra.[7,16] Although the spectrum of benzene itself is little affected by bromo substituent,[17] the substitution to triple-layered paracyclophanes gives rise to further bathochromic shifts of the longer wavelength bands except the [3.3][3.3]system. Thus, the substituent effect is dependent on the interplanar distance in the parent compounds, *viz.*, [2.2][2.2]PC **1**>[2.2][3.3]PC **2**>[3.3][3.3]PC **3** (PC=paracyclophane). Figure 4 shows the electronic spectra of monobromo dimethyl derivatives **8** and **9**. The inner bromo derivative **8** exhibits a significant red shift, whereas the outer bromo derivative **9** a hypsochromic shift of the longest wavelength band, supporting a much larger transannular electronic interaction due to the bromo substitution at the inner benzene as described above.

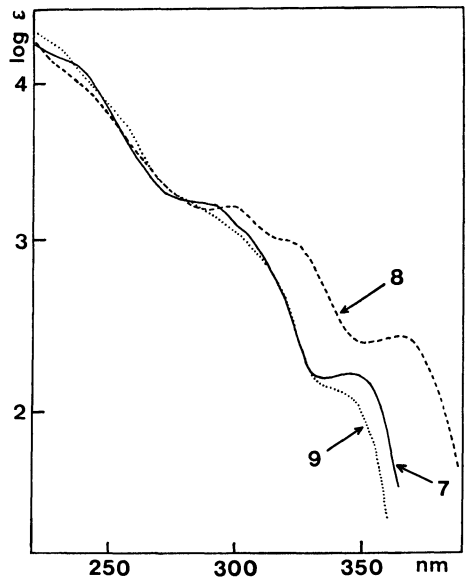



Fig. 4. The electronic spectra of dimethyl triple-layered [2.2]paracyclophane **7** and its monobromo derivatives **8** and **9** in tetrahydrofuran.

Table 1. Competitive reactions of paracyclophanes

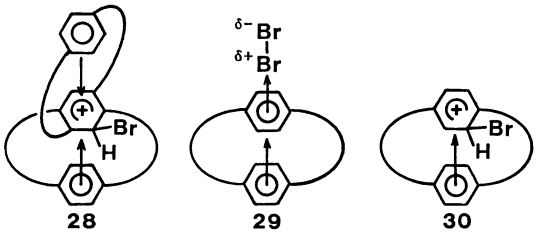
| Run | Compounds | Reagent[a] | Product ratio |
|---|---|---|---|
| 1 | **1** and **2** | A or B | **4** : **5**=20 : 1 |
| 2 | **2** and **3** | A | **5** : **6**= 3 : 1 |
| 3 | **7** | B | **8** : **9**= 1 : 1 |
| 4 | **1** and **7** | B | **4** : **8**+**9**= 1.5 : 1 |
| 5 | **13** and **14** | C | **16** : **17**= 1 : 2 |
| 6 | **13** and **15** | C | **16** : **18**= 9 : 1 |
| 7 | **15** and **26** | C | **18** : **27**= 1.4 : 1 |
| 8 | **19** and **20** | B | **22** : **23**= 1 : 3 |
| 9 | **19** and **21** | B | **22** : **24**= 1 : 1.2 |
| 10 | **1** and **19** | B | **4** : **22**= 1 : 0 |
| 11 | **1** and **20** | B | **4** : **23**= 1 : 0 |
| 12 | **2** and **19** | B | **5** : **22**= 1 : 0 |
| 13 | **3** and **21** | B | **6** : **24**= 1 : 0 |
| 14 | **7** and **20** | B | **8**+**9** : **23**= 1 : 0 |

a) A: Pyridinium hydrobromide perbromide. B: Bromine. C: Bromine and iron powder.

*Competitive Reactions.* The bromination of layered paracyclophanes is surely accelerated by the transannular electronic interaction in the transition state. The magnitude of the acceleration was estimated by competitive reactions summarized in Table 1. The reactions are obviously speeded up with an increase of the layer number regardless of kinds of reagent. Especially the reactions of triple-layered series are overwhelmingly faster than those of double-layered series (Runs 10—14). The relative rate of triple-layered series is [2.2][2.2]PC **1**: [2.2][3.3]PC **2**: [3.3][3.3]PC **3**=60: 3: 1 (Runs 1 and 2). This order is in accord with the relative strength of transannular electronic interaction above-stated in the electronic spectra.

On the other hand, the relative rate of double-layered series using [14]paracyclophane **26** as a standard is as follows; [3.3]PC **14**: [2.2]PC **13**: [4.4]PC **15**: [14]PC **26**=29: 13: 1.4: 1 (Runs 5—7). The rather higher reactivity of [3.3]system **14** than [2.2]system **13** is particularly surprising and in conflict with the results of triple-layered series. The difference between iron-catalytic and non-catalytic conditions can be ruled out for interpretation of the above problem because a non-catalyzed competitive reaction of the dimethyl series, **19** and **21**, gave also the same order, although the advantage of [3.3]system becomes relatively smaller in the presence of methyl groups having a large substituent effect.

The difference in relative rates of the two series may be explained by a mechanism described below. In the substitution reaction of triple-layered cyclophanes **1**—**3**, the formation of $\pi$-complex on the inner benzenes is




Scheme 4.

sterically impossible although their $\pi$-basicities are increased by four alkyl substituents. Therefore, the electrophile must directly attack the inner benzenes to form $\sigma$-complex **28** which is stabilized by transannular charge delocalization to both outer benzenes. Since the transition state resembles the $\sigma$-complex, the relative rate of triple-layered series reflects the transannular electronic interaction of $\sigma$-complex. On the other hand, the reactions of double-layered paracyclophanes are expected to proceed *via* the formation of $\pi$-complex **29** followed by $\sigma$-complex **30** like an ordinary electrophilic aromatic substitution. The transannular electronic interaction must be more effective in the $\sigma$-complex having ionic structure than in the $\pi$-complex having charge-transfer character. When the $\sigma$-complex is highly stabilized by such an interaction, its potential energy may be at lower level than that of the $\pi$-complex. This consideration is consistent with Olah's proposal that in highly exothermic electrophilic aromatic substituion the reaction state with the highest energy leads to the formation of a $\pi$-complex.[18] On taking account of a noticeable property that [3.3]paracyclophane **14** interacts as a much stronger $\pi$-base than [2.2]paracyclophane **13**,[6] the reaction pathways are understood by the diagram shown in Fig. 5. The figure reveals that the formation of $\pi$-complex is rate-determining and the [3.3]system takes a lower energy path than the [2.2]system. Thus, the rate-determining step resembles $\sigma$-complex for triple-layered series and $\pi$-complex for double-layered series, respectively.

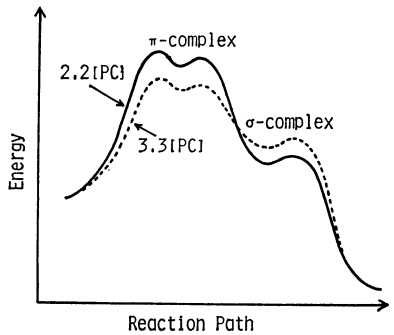



Fig. 5. A reaction diagram for bromination of [2.2]- and [3.3]paracyclophanes.

The above explanation is also supported from a viewpoint of steric effect. The introduction of methyl groups at the outer benzene of triple-layered [2.2][2.2]-paracyclophane **1** results in a 66% reduction of the rate for the inner substitution (Run 4). The methyl group must block the formation of $\sigma$-complex or the elimination of proton from $\sigma$-complex. On the other hand, such a steric blocking of pseudo-methyl group is not recognized in the reactions of double-layered cyclophanes. In a competitive reaction of **19** and **20**, (Run 8), **20** having pseudo-gem methyl group is rather more reactive than **19**. This also confirms that the formation of $\pi$-complex is rate-determining because the pseudo-gem methyl group does not sterically prevent the formation of $\pi$-complex but accelerates it due to larger stabilization resulted from an increased transannular electron release of the attached, non-complexed benzene.

## Experimental

Melting points are uncorrected. All the solvents are of reagent grade unless otherwise stated. NMR spectra were taken with Hitachi Perkin-Elmer R-20 (60 MHz) and JEOL FX-100 (100 MHz) spectrometers using TMS as an internal standard, MS with Hitachi RMU-7 spectrometer at 70 eV using a direct insertion technique, and UV with Hitachi EPS-3T spectrophotometer.

The syntheses of all the starting material except **21** were reported in the previous papers.[7,8,19,20] 5,8-Dimethyl[3.3]-paracyclophane **21** was prepared in the same way as that used for [3.3]paracyclophane **14**;[19] colorless scales from hexane, mp 119—120.5 °C, MS *m/e* 264 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 1.8—2.3 (m, 4H, $CH_2$), 2.17 (s, 6H, $CH_3$), 2.4—2.9 (m, 8H, benzylic $CH_2$), 6.38 (s, 2H, ArH), 6.65 (dd, $J$=7.8 and 1.8 Hz, 2H, ArH), 6.89 (dd, $J$=7.8 and 1.8 Hz, ArH).

*12-Bromo[2.2][2.2]paracyclophane* **4**. *a) With Pyridinium Hydrobromide Perbromide*: A mixture of [2.2][2.2]paracyclophane **1**[7] (1 g, 2.95 mmol) and pyridinium hydrobromide perbromide (2.36 g, 7.39 mmol) in 80 ml of dry dichloromethane was stirred for 2.5 h at 0 °C. The reaction mixture was filtered through a column of neutral alumina and recrystallized from benzene to give colorless prisms, 0.909 g (74%), mp 236 °C (dec. in sealed tube), MS *m/e* 416, 418 ($M^+$). Found: C, 74.82; H, 5.86; Br, 18.73%. Calcd for $C_{26}H_{25}Br$: C, 74.82; H, 6.04; Br, 19.14%.

*b) With Bromine–Iron*: Into a solution of **1** (100 mg, 0.30 mmol) in 15 ml of dry dichloromethane was dropwise added bromine (101 mg, 0.63 mmol) in 2.8 ml of carbon tetrachloride. The mixture was stirred for 20 min at room temperature and filtered through a short column of neutral alumina. Recrystallization of the eluted product from benzene gave colorless prisms, 44 mg (36%).

*c) With Bromine–Iron*: Iron powder (11 mg) was stirred with 4 ml of dichloromethane and 0.5 ml of a solution of bromine (133 mg, 0.83 mmol) in 4 ml of carbon tetrachloride for 2.5 h at 25 °C. Dichloromethane (18 ml) was added and the resulting mixture was brought to reflux. [2.2][2.2]-Paracyclophane **1** (245 mg, 0.72 mmol) was added in one portion and the remaining bromine solution was added dropwise within 10 min to the refluxing, stirred solution. The mixture was stirred under reflux for 30 min and quenched with 10% $NaHSO_3$ solution. The organic layer was separated and washed with water, sat. $NaHCO_3$ solution, and water, successively. After dryness over anhyd magnesium sulfate, the solvent was condensed and the remainder was chromatographed on alumina with 1:9 dichloromethane–hexane. The main fraction consisted of a mixture of four products **4**, **10**, **11**, and **12**. Careful rechromatography on silica gel with 1: 50 benzene-hexane gave first **4** (14.4 mg,

4.8%), secondly **11**[5] (23.0 mg, 9.4%), and finally a mixture of **10** and **12**. Separation of the mixture was accomplished by gel permeation liquid chromatography, **10**[5] (8.4 mg, 3.4%) and **12**[5] (9.2 mg, 3.1%).

*12-Bromo[2.2][3.3]paracyclophane* ***5***. A mixture of [2.2]-[3.3]paracyclophane **2**[19] (25.2 mg, 0.07 mmol) and pyridinium hydrobromide perbromide (43.5 mg, 0.14 mmol) in 2.5 ml of dry dichloromethane was stirred for one hour at room temperature. The solution was washed with dil sodium sulfite solution and then sat sodium chloride solution. After drying over anhyd magnesium sulfate, the solvent was evaporated. The residue was chromatographed on silica gel with benzene and the eluted product was recrystallized from hexane–benzene to give colorless plates, 22.6 mg (74%), mp 186—188 °C, MS *m/e* 444, 446 ($M^+$). Found: C, 75.31; H, 6.41; Br, 17.92%. Calcd for $C_{28}H_{29}Br$: C, 75.50; H, 6.56; Br, 17.94%.

*14-Bromo[3.3][3.3]paracyclophane* ***6***. [3.3][3.3]Paracyclophane **3**[8] (9.6 mg, 0.024 mmol) was treated with pyridinium hydrobromide perbromide (15 mg, 0.047 mmol) in 2 ml of dry dichloromethane for 7 h at room temperature. The mixture was worked up as described for **5**. Recrystallization from hexane gave colorless prisms, 5.0 mg (44%), mp 207—208 °C, MS *m/e* 472, 474 ($M^+$). Found: C, 75.93; H, 7.08; Br, 16.64%. Calcd for $C_{30}H_{33}Br$: C, 76.10; H, 7.02; Br, 16.88%.

*12-Bromo- and 5-Bromo-4,7-dimethyl[2.2][2.2]paracyclophanes* ***8*** *and* ***9***. Into a stirred solution of bromine (116 mg, 0.73 mmol) in 3 ml of carbon tetrachloride and 20 ml of dichloromethane was added 4,7-dimethyl[2.2][2.2]paracyclophane **7**[7] (100 mg, 0.27 mmol) in one portion. The mixture was stirred for 30 min at 19 °C. After evaporation of the solvents, the residue was chromatographed on silica gel with hexane, 1: 50 benzene–hexane, and 1: 20 benzene–hexane, successively. From the first eluate was obtained one isomer **9**, 9.9 mg (8%), colorless prisms from benzene–hexane, mp 193—194 °C, MS *m/e* 444, 446 ($M^+$). NMR ($CDCl_3$, 60 MHz): $\delta$ 1.92 (s, 3H, $CH_3$), 1.97 (s, 3H, $CH_3$), 2.1—3.5 (m, 16H, $CH_2$), 5.68 (s, 1H, inner ArH), 5.72 (s, 1H, inner ArH), 5.91 (s, 1H, outer ArH), 6.24 (s, 4H, outer ArH). Found: C, 75.24; H, 6.43; Br, 18.14%. Calcd for $C_{28}H_{29}Br$: C, 75.50; H, 6.56; Br, 17.94%.

From the second eluate was obtained another isomer **8**, 9.9 mg (8%), colorless prisms from hexane, mp 172—173 °C, MS *m/e* 444, 446 ($M^+$). NMR ($CDCl_3$, 60 MHz): $\delta$ 1.97 (s, 3H, $CH_3$), 2.15 (s, 3H, $CH_3$), 2.3—3.4 (m, 16H, $CH_2$), 5.79 (s, 1H, inner ArH), 5.92 (s, 1H, outer ArH), 5.94 (s, 1H, outer ArH), 6.14 (dd, $J$=8 and 2 Hz, 1H, outer ArH), 6.25 (dd, $J$=9 and 2 Hz, 1H, outer ArH), 6.36 (dd, $J$=9 and 2 Hz, 1H, outer ArH), 6.87 (dd, $J$=8 and 2 Hz, 1H, outer ArH). Found: C, 75.57; H, 6.46; Br, 17.90%. Calcd for $C_{28}H_{29}Br$: C, 75.50; H, 6.56; Br, 17.94%.

*Bromination of [n.n]paracyclophanes*. The preparation of 4-bromo[2.2]paracyclophane **16**[9] is described below as a typical experiment.

Iron powder (8 mg) was added in a solution of bromine (156 mg, 1 mmol) in 3.8 ml of carbon tetrachloride and stirred for one hour at room temperature. [2.2]Paracyclophane **13** (166 mg, 0.8 mmol) in 20 ml of dry dichloromethane was added, and the stirring was continued for 4 h. The reaction was quenched with dil sodium hydrogensulfite soln, washed with sat. aq sodium chloride soln, and dried over magnesium sulfate. After evaporation of the solvents, the residue was chromatographed on silica gel with benzene and recrystallized from hexane to give almost pure 4-bromo[2.2]-paracyclophane **16**, 167 mg (73%). An analytical sample was purified by gel permeation liquid chromatography and again recrystallization from hexane, colorless plates, mp 133—134 °C, MS *m/e* 286, 288 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 2.6—3.7 (m, 8H, $CH_2$), 6.48 (dd, $J$=7.9 and 2.0 Hz, 1H, pseudo-ortho ArH), 6.50 (m, 4H, ArH), 7.14 (dt, $J$=7.9, 2.0, and 2.0 Hz, 1H, pseudo-gem ArH). Found: C, 66.69; H, 5.04; Br, 27.81%. Calcd for $C_{16}H_{15}Br$: C, 66.91; H, 5.26; Br, 27.82%.

*5-Bromo[3.3]paracyclophane* ***17***: Yield 73%, colorless crystals from hexane, mp 149—150 °C (lit,[10] mp 153—154 °C), MS *m/e* 314, 316 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 1.7—3.2 (m, 12H, $CH_2$), 6.61 (s, 2H, meta and para ArH), 6.66 (d, $J$=8.4 Hz, 1H, pseudo-ortho ArH), 6.75 (s, 2H, pseudo-meta and -para ArH), 6.90 (s, 1H, ortho ArH), 7.03 (d, $J$=8.4 Hz, 1H, pseudo-gem ArH).

*6-Bromo[4.4]paracyclophane* ***18***: Yield 81%, colorless plates from pentane, mp 89—89.5 °C, MS *m/e* 342, 344 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 1.1—3.0 (m, 16H, $CH_2$), 6.58 (dd, $J$=7.6 and 1.5 Hz, 1H, para ArH), 6.6—6.9 (m, 5H, ArH), 6.96 (d, $J$=1.5 Hz, ortho ArH). Found: C, 69.85; H, 6.67; Br, 23.00%. Calcd for $C_{20}H_{23}Br$: C, 69.97; H, 6.75; Br, 23.27%.

*5-Bromo-4,7-dimethyl[2.2]paracyclophane* ***22*** *and 5,8-Dibromo-4,7-dimethyl[2.2]paracyclophane* ***25***. Into a solution of 4,7-dimethyl[2.2]paracyclophane **19**[7] (300 mg, 1.27 mmol) was added bromine (234 mg, 1.46 mmol) in 6 ml of carbon tetrachloride. The mixture was stirred for 2.5 h at 35 °C, and worked up as described in the bromination of [*n.n*]paracyclophanes. Chromatography of the crude product on silica gel with hexane gave dibromo product **25** from the first eluate and monobromo derivative **22** from the following few fractions.

**22**: yield 310 mg (78%), colorless plates from hexane, mp 97.5—98.5 °C, MS *m/e* 314, 316 ($M^+$). NMR ($CDCl_3$, 60 MHz): $\delta$ 2.11 (s, 3H, $CH_3$), 2.15 (s, 3H, $CH_3$), 2.4—3.5 (m, 8H, $CH_2$), 6.14 (s, 1H, ArH), 6.44 (dd, $J$=8 and 2 Hz, 1H, ArH), 6.68 (dd, $J$=8 and 2 Hz, 1H, ArH), 6.80 (dd, $J$=8 and 2 Hz, 1H, ArH), 6.95 (dd, $J$=8 and 2 Hz, 1H, ArH). Found: C, 68.50; H, 5.97; Br, 25.05%. Calcd for $C_{18}H_{19}Br$: C, 68.56; H, 6.08; Br, 25.36%.

**25**: yield 30 mg (6%), colorless scales from benzene–hexane, mp 168.5—169.5 °C, MS *m/e* 392, 394 ($M^+$). NMR ($CDCl_3$, 60 MHz): $\delta$ 2.21 (s, 3H, $CH_3$), 2.8—3.6 (m, 8H, $CH_2$), 6.64 (dd, $J$=8 and 2 Hz, 2H, ArH), 6.91 (dd, $J$=8 and 2 Hz, 2H, ArH). Found: C, 54.67; H, 4.43; Br, 40.06%. Calcd for $C_{18}H_{18}Br_2$: C, 54.83; H, 4.61; Br, 40.56%.

*5-Bromo-4,7,12,15-tetramethyl[2.2]paracyclophane* ***23***. 4,7,12,15-Tetramethyl[2.2]paracyclophane **20**[7] (246 mg, 0.93 mmol) in 20 ml of dry dichloromethane was treated with bromine (151 mg) in 5 ml of carbon tetrachloride at 28 °C. After 60 min from the start, the mixture was worked up as usual. The main product **23** was purified by column chromatography on silica gel with hexane and recrystallization from hexane, 237 mg (74%), colorless plates, mp 159.5—160 °C, MS *m/e* 342, 344 ($M^+$). NMR ($CDCl_3$, 60 MHz): $\delta$ 2.03 (s, 3H, $CH_3$), 2.12 (s, 3H, $CH_3$), 2.18 (s, 3H, $CH_3$), 2.28 (s, 3H, $CH_3$), 2.4—3.8 (m, 8H, $CH_2$), 6.40 (bs, 3H, ArH). Found: C, 69.93; H, 6.78; Br, 22.97%. Calcd for $C_{20}H_{23}Br$: C, 69.97; H, 6.75; Br, 23.28%.

*6-Bromo-5,8-dimethyl[3.3]paracyclophane* ***24***. 5,8-Dimethyl[3.3]paracyclophane **21** (26.4 mg, 0.10 mmol) in 3 ml of dry dichloromethane was treated with bromine (20 mg, 0.13 mmol) in 0.5 ml of carbon tetrachloride at room temperature. After 4 h, the mixture was worked up as usual. The main product **24** was purified by gel permeation liquid chromatography and then column chromatography on silica gel with hexane, 16 mg (46%), colorless scales from ethanol, mp 108—109 °C, MS *m/e* 342, 344 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 1.7—3.2 (m, 12H, $CH_2$), 2.18 (s, 3H, $CH_3$),

2.29 (s, 3H, $CH_3$), 6.27 (s, 1H, ArH), 6.71 (ABd, $J$=9 Hz, 1H, ArH), 6.75 (ABd, $J$=9 Hz, 1H, ArH), 6.91 (ABbd, $J$=9 Hz, 2H, ArH). Found: C, 69.73; H, 6.61; Br, 23.09%. Calcd for $C_{20}H_{23}Br$: C, 69.97; H, 6.75; Br, 23.27%.

*16-Bromo[14]paracyclophane* **27**. Bromine (20 mg, 0.13 mmol) in 0.5 ml of carbon tetrachloride was stirred with iron powder (5 mg) for 30 min at room temperature. [14]Paracyclophane **26**[20] (29 mg, 0.105 mmol) in 5 ml of dry dichloromethane was added at once. The mixture was stirred for 1.5 days and worked up in the usual way. The main product **27** was purified by column chromatography on silica gel with hexane and gel permeation liquid chromatography, 15 mg (40%), colorless oil, MS *m/e* 350, 352 ($M^+$). NMR ($CDCl_3$, 100 MHz): $\delta$ 0.6—1.8 (m, 24H, $CH_2$), 2.4—3.0 (m, 4H, benzylic $CH_2$), 7.01 (dd, $J$=7.7 and 0.5 Hz, 1H, ArH), 7.08 (d, $J$=7.7 Hz,1H,ArH),7.33 (d, $J$=0.5 Hz,1H,ArH). Found: C, 68.14; H, 9.11; Br, 23.04%. Calcd for $C_{20}H_{31}Br$: C, 68.37; H, 8.89; Br, 22.74%.

*Competitive Reactions*. An equimolar mixture of two cyclophanes (2 mol) was treated with a reagent (1 mol) indicated in Table 1. The reaction conditions were essentially the same as in the experimental part above-stated for the bromination of each cyclophane. The reaction time was controlled in such a way that about one-half amount of the more reactive component was consumed. Analysis of the reaction mixture was carried out by proton NMR measurement. The product ratio was determined on the basis of the integration of the isolated, appropriate peaks. On the other hand, carbon NMR analysis was performed for Run 6 alone, because nothing was clearly isolated peaks in the PMR spectrum of the products.[21]

CMR datum of **16** ($CDCl_3$, TMS standard, JEOL FX-100):[22] $\delta$ 33.477 (C-1), 34.793 (C-2), 35.475 and 35.816 (C-9,10), 126.941 (C-4), 128.648 (C-13), 131.424 (C-7), 132.203, 132.835, and 133.225 (C-12,15,16), 134.980 (C-8), 137.170 (C-5), 139.026 (double) and 139.268 (C-6,11,14), 141.513 (C-3).

CMR datum of **18**:[22] $\delta$ 26.460 (C-3), 28.458, 28.653, and 28.848 (C-2,12,13), 34.842 (C-1), 35.134 (double) and 35.280 (C-4,11,14), 123.386 (C-6), 127.186 (C-17), 128.063 (C-9), 128.352 (double) and 128.843 (C-16,19,20), 130.839 (C-10), 132.936 (C-7), 137.809 (C-8), 139.026 and 139.268 (C-15,18), 141.607 (C-5).

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