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Layered Compounds. XXXV.[1] Syntheses of Triple-layered Metaparacyclophanes

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Six triple-layered [2.2]metaparacyclophanes have been prepared using general synthetic methods such as the Stevens rearrangement-Raney nickel desulfurization method, pyrolysis of bissulfone, and photo-induced desulfurization. The pyrolysis of bissulfone has turned out to be the most useful and convenient method for preparation of the intermediate double-layered [2.2]metaparacyclophanes because of simple experimental process and excellent yields. The unexpected formation of compound **9** during the photo-induced desulfurization of **7** was explained by a unique skeletal rearrangement of the intermediate **8** on irradiation.

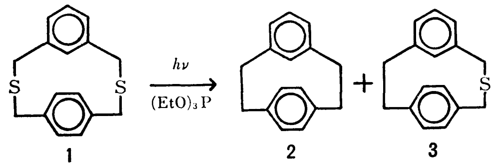
Since [2.2]metaparacyclophane **2** in which meta-substituted benzene is stacked at some angle on the para-substituted benzene by double methylene bridges was first synthesized in 1966,[2] its unique structure has become of great interest. Earlier efforts were made to study the NMR spectrum which showed temperature-dependence due to the flipping of the meta-ring.[2–5] On the other hand, as observed in the electronic spectra, there are few unambiguous evidences supporting the originally expected trans-annular electronic interaction between two benzene rings. In earlier papers of this series, multilayered para- and meta-cyclophanes were reported to exhibit stronger electronic interactions in their physical and chemical properties than the corresponding double-layered cyclophanes.[6]

One may expect that, in the same manner as multilayered meta- and para-series, multilayered meta-paracyclophanes should offer further informations concerning the interaction between meta- and para-rings. However, there are a number of possible structual isomers according to the combination modes of meta- and para-rings in this series of multilayered cyclophanes. The present paper describes the syntheses of six triple-layered metaparacyclophanes containing a durene ring as the inner benzene nucleus along with several [2.2]metaparacyclophane derivatives.[7]

The nomenclature of cyclophanes proposed by Hirayama[8] is very useful also for the present series of multilayered cyclophanes, but not so familiar with us. Therfore, in this paper, we tentatively call the triple-layered cyclophanes as derivatives of double-layered one. For example, the compound **8** is regarded as a metacyclo derivative of [2.2]paracyclophane. In addition, we use a brief and convenient notation affixed after the name of compounds, *e.g.*, m-p,p-p for **8**, where m and p indicate meta and para bridging of methylene chains, respectively.

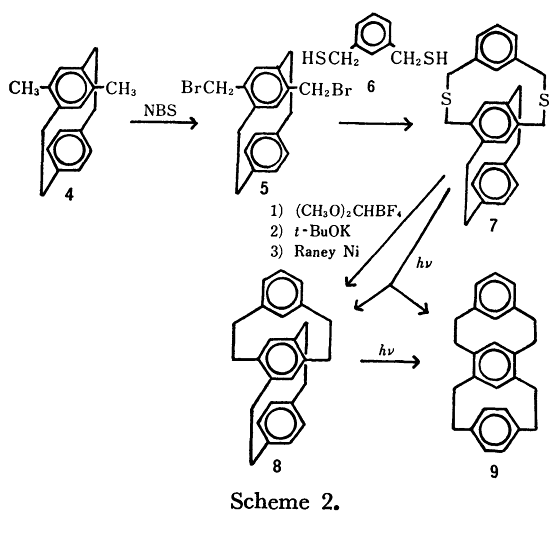
Results and Discussion

Synthesis: *[2.2]Metaparacyclophane (**2**).* From acid-catalyzed rearrangement of [2.2]paracyclophane, [2.2]-metaparacyclophane **2** was first prepared by Cram and his co-workers.[2] As alternate routes, Boekelheide and his co-workers developed the Stevens rearrangement-Hofmann elimination method and dithiane alkylation-Raney nickel desulfurization method.[9] Also Vögtle obtained the same compound **2** by pyrolysis of bissulfone.[3] We investigated photo-induced desulfurization according to Jenny and his co-workers[10] as an alternate synthetic method of **2**. On irradiation of 2,11-dithia-[3.3]metaparacyclophane **1**[9] in triethyl phosphite with a 400w high pressure mercury lamp, **2** was obtained in 40% yield together with a by-product, 2-thia[3.2]metaparacyclophane **3** in 9% yield.



Scheme 1.

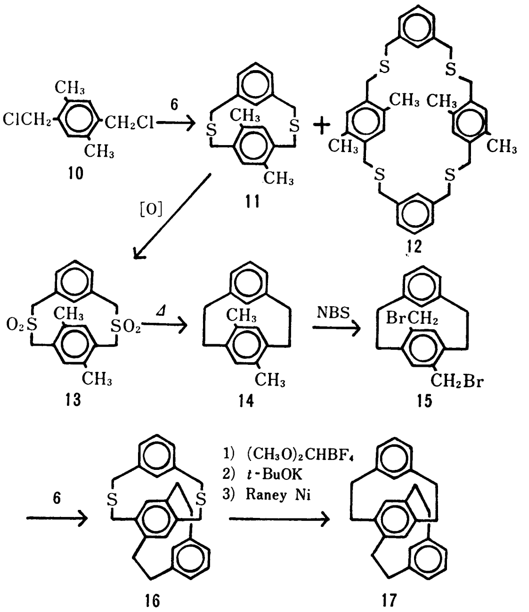
[2.2]Metacyclo(4,7)[2.2]paracyclophane (m-p,p-p) *(**8**).* Treatment of 4,7-dimethyl[2.2]paracyclophane **4**[6a] with *N*-bromosuccinimide (NBS) gave the corresponding bis(bromomethyl) compound **5** in 76% yield. Condensation of **5** with 1,3-bis(mercaptomethyl)benzene **6** smoothly afforded 18,27-dithia[3.3]metacyclo(4,7)[2.2]-paracyclophane **7** in 56% yield. The desired triple-layered metaparacyclophane (m-p,p-p) **8** was obtained in only 12% yield by the Stevens rearrangement of **7** followed by desulfurization with Raney nickel. On the other hand, direct photodesulfurization of **7** in triethyl phosphite gave **8** in 26% yield together with a small amount of another isomer (m-m,m-p) **9**. The structure of **9** was confirmed by comparison with the authentic sample synthesized by alternate routes as described later. The unexpected formation of **9** provides an interesting problem whether **9** is formed



Scheme 2.

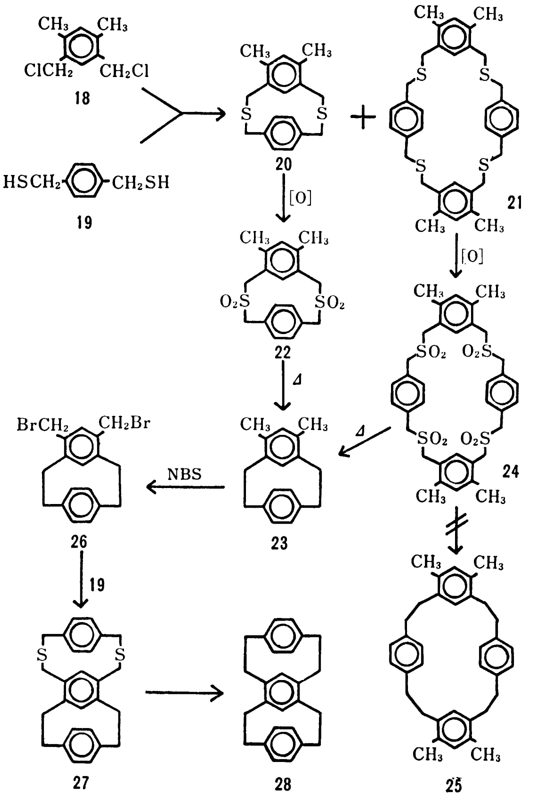
directly from **7** or through the main product **8**. A plausible mechanism is that the initially produced **8** isomerizes to **9** by exchanging the bridge positions at the inside benzene ring during irradiation. This assumption was supported by the facts that prolonged irradiation of **7** resulted in an increased yield (23%) of **9** with a decreased yield of **8** and that irradiation of **8** in degassed cyclohexane produced the isomer **9**.

[2.2]Metacyclo(12,15)[2.2]metaparacyclophane (m-p,p-m) *(**17**).* Condensation of 2,5-bis(chloromethyl)-*p*-xylene **10** with **6** gave 14,17-dimethyl-2,11-dithia[3.3]metaparacyclophane **11** in a good yield (71%) together with its dimer **12** in 6% yield. Pyrolysis of bissulfone **13** at about 900 °C, which was derived by oxidation of the dithiacyclophane **11** in a quantitative yield, afforded 12,15-dimethyl[2.2]metaparacyclophane **14** in an excellent yield (86%). Treatment of **14** with NBS gave the corresponding bis(bromomethyl) compound **15** in 88% yield. As usual, 18,27-dithia[3.3]metacyclo(12,15)[2.2]metaparacyclophane **16** was obtained by condensation of **15** with **6** in 32% yield and then converted to the desired cyclophane (m-p,p-m) **17** in a low yield (9.4%) by the Stevens rearrangement-Raney nickel desulfurization method. Direct photodesulfurization of **16** to **17** was unsuccessful.



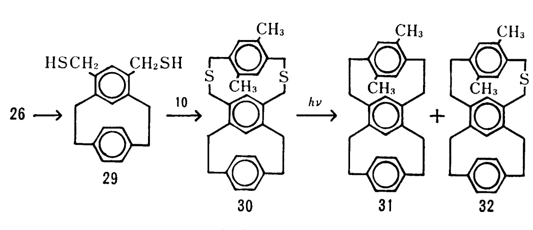
Scheme 3.

[2.2]Paracyclo(4,6)[2.2]metaparacyclophane (p-m,m-p) *(**28**).* Condensation of 4,6-bis(chloromethyl)-*m*-xylene **18** with 1,4-bis(mercaptomethyl)benzene **19** gave 5,6-dimethyl-2,11-dithia[3.3]metaparacyclophane **20** and its cyclic dimer **21** in 68 and 18% yields, respectively. Oxidation of **20** and pyrolysis of the resulting bissulfone **22** afforded 4,6-dimethyl[2.2]metaparacyclophane **23** in a satisfactory yield (91%). Surprisingly, pyrolysis of tetrakissulfone **24** derived from **21** produced rather strained metaparacyclophane **23** in 74% yield instead of the expected [2.2.2.2]metaparametaparacyclophane **25**. 4,6-Bis(bromomethyl)[2.2]metaparacyclophane **26**, which was derived from bromination of **23** with NBS in 78% yield, was coupled with dimercaptan **19** to give 18,27-dithia[3.3]paracyclo(4,6)[2.2]metaparacyclophane **27** in 35% yield. The Stevens rearrangement-Raney nickel desulfurization treatment of **27** afforded the desired cyclophane (p-m,m-p) **28** in only 6.8% yield. On the other hand, direct photodesulfurization of **27** in triethyl phosphite under a nitrogen atmosphere provided the same cyclophane **28** in a better yield of 55%.



Scheme 4.

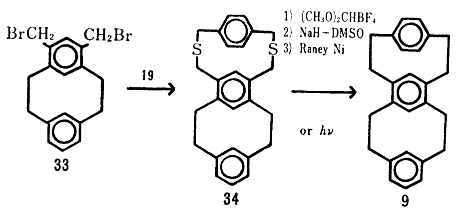
12,15-Dimethyl[2.2]paracyclo(4,6)[2.2]metaparacyclophane (dimethyl p-m,m-p) *(**31**).* 4,6-Bis(bromomethyl)[2.2]metaparacyclophane **26** was converted to the corresponding bis(mercaptomethyl) compound **29** in 96% yield in the usual way. The reaction of **29** with **10** gave dimethyl dithia compound **30** in 70% yield. Irradiation of **30** in triethyl phosphite under bubbling nitrogen afforded the desired dimethylcyclophane **31** in 60% yield and half-desulfurized cyclophane **32** in 24% yield.



Scheme 5.

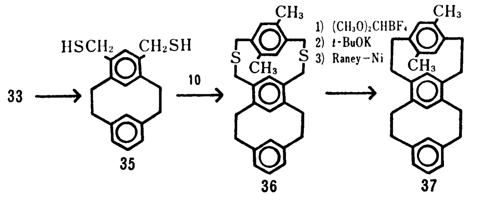
[2.2]Metacyclo(4,6)[2.2]metaparacyclophane (m-m,m-p) *(**9**).* Treatment of 4,6-bis(bromomethyl)[2.2]metacyclophane **33**[6b] with dimercaptan **19** gave 18,27-dithia[3.3]paracyclo(4,6)[2.2]metacyclophane **34** in 34%

yield. Then **34** was led to the desired cyclophane **9** by the Stevens rearrangement-Raney nickel method (19%) or the photochemical method (35%).



Scheme 6.

12,15-Dimethyl[2.2]metacyclo(4,6)[2.2]metaparacyclophane (dimethyl m-m,m-p*)* (**37**). The above dibromide **33** was transformed to the corresponding dimercaptan **35** in 85% yield. As usual, the reaction of **35** with **10** smoothly gave dimethyl dithia compound **36** in 74% yield. Desulfurization of **36** was carried out using the Stevens rearrangement-Raney nickel reaction to prepare the desired cyclophane **36** in 15% yield, while photochemical desulfurization of **35** failed to provide **37** because of a large amount of oily contaminant.



Scheme 7.

Experimental

Mps are uncorrected. All solvents are of reagent grade unless otherwise specified. Photodesulfurizations were carried out in triethyl phosphite degassed or under nitrogen bubbling at room temp using a quartz tube and a 400 W high pressure mercury lamp. PMR spectra were taken with a Hitachi-Perkin Elmer R-20 spectrometer (60 MHz) using TMS as an internal std, and MS with a Hitachi RMU-7 spectrometer at 70 eV using a direct insertion technique.

*Photodesulfurization of 2,11-Dithia[3.3]metaparacyclophane (**1**).* A soln of 250 mg (0.93 mmol) of 2,11-dithia[3.3]metaparacyclophane **1** in 6 ml of triethyl phosphite purified by distillation over sodium metal was degassed by the freeze-pump-thaw method in a quartz tube and then the tube was sealed. The soln was irradiated with a 400 W high pressure mercury lamp for 7 days at room temp. The solvent was evaporated and the residue was chromatographed on neutral alumina (40 g, Woelm activity I-II). First elution with hexane gave [2.2]metaparacyclophane **2** (79 mg, 40%), then with hexane-benzene (1 : 1) a mixture of 2-thia[3.2]metaparacyclophane **3** and *O,O,O*-triethyl phosphorothioate, and finally with benzene **1** (20 mg) was recovered. [2.2]Metaparacyclophane was recrystd from methanol to give colorless fine crystals, mp 79—80 °C [lit, 79—81 °C (Cram,[2] Vögtle[3])), 81—81.5 °C (Boekelheide[9])]. The compd **3** was purified by rechromatography on silica gel (30 g, Merck activity I-II) using hexane-benzene (4 : 1) (20 mg, 9%). Recrystallization from ethanol gave colorless plates, mp 224—224.5 °C.

Found: C, 80.22; H, 6.66; S, 13.19%. Calcd for $C_{16}H_{16}S$: C, 79.95; H, 6.71; S, 13.34%. PMR (CCl_4, δ) 2.67 (A_2B_2, 4H, CH_2), 3.26 (s, 2H, CH_2), 3.70 (s, 2H, CH_2), 5.32 (bs, 1H, meta internal ArH), 6.34 (d, J=9 Hz, 2H, para ArH), 6.82 (d, J=9 Hz, 2H, para ArH). MS *m/e* 240 (M^+), 104.

*4,7-Bis(bromomethyl)[2.2]paracyclophane (**5**).* A mixture of 4,7-dimethyl[2.2]paracyclophane **4** (4.72 g, 20 mmol) and *N*-bromosuccinimide (7.12 g, 40 mmol) was refluxed in 100 ml of carbon tetrachloride for 4 h. After removal of succinimide by filtration, the filtrate was evaporated and the residue was recrystd from carbon tetrachloride to give the desired dibromide **5** (5.95 g, 76%), colorless prisms, mp 166—168 °C.

Found: C, 54.62; H, 4.67; Br, 40.23%. Calcd for $C_{18}H_{18}Br_2$: C, 54.85; H, 4.60; Br, 40.55%. PMR (CCl_4, δ) 2.6—3.6 (m, 8H, bridged CH_2), 4.16 and 4.40 (A_2B_2, 4H, CH_2Br), 6.29 (s, 2H, ArH). MS *m/e* 396, 394, 392 (M^+), 315, 313, 234, 104.

*18,27-Dithia[3.3]metacyclo(4,7)[2.2]paracyclophane (**7**).* A soln of 1,3-bis(mercaptomethyl)benzene **6** (0.90 g, 5.3 mmol) and sodium hydroxide (0.43 g, 11 mmol) in 35 ml of 95% ethanol, and a soln of the dibromide **5** (1.97 g, 5 mmol) in 35 ml of benzene were added dropwise and simultaneously over a period of 4 h to refluxing and stirring abs ethanol (100 ml) placed in a 300 ml three necked flask under a nitrogen atmosphere. Refluxing was continued for additional 12 h. The mixture was concd and the residue was extracted with chloroform. The extract was washed, dried, and evaporated. The residual solid was chromatographed on neutral alumina (Woelm act. II) with hexane-benzene (1 : 1) to give the dithia compd (1.12 g, 56%). Recrystallization from benzene-ethanol (1 : 1) afforded colorless fine crystals, mp 163—164 °C.

Found: C, 77.49; H, 6.37; S, 15.74%. Calcd for $C_{26}H_{26}S_2$: C, 77.55; H, 6.52; S, 15.92%. PMR ($CDCl_3$, δ) 2.1—4.0 (m, 16H, CH_2) 5.39 (bs, 1H, meta inner ArH), 5.89 (s, 2H, ArH of inner benzene), 6.34 and 6.50 (A_2B_2, 4H, para ArH), 6.9 (m, 3H, meta ArH). MS *m/e* 402 (M^+), 104.

[2.2]Metacyclo(4,7)[2.2]paracyclophane (m-p,p-p) *(**8**).*
a) By the Stevens Rearrangement-Raney Nickel Desulfurization. A mixture of the above dithia compd **7** (0.40 g, 1 mmol) and dimethoxycarbonium fluoroborate[11] (0.65 g, 4 mmol) was refluxed with magnetic stirring in 30 ml of dichloromethane for 6 h. After evaporation of the solvent and decomposition of the excess reagent, the residual solid was powdered and then refluxed with potassium *t*-butoxide (1.1 g, 10 mmol) in 30 ml of dry tetrahydrofuran for 16 h. The mixture was filtered and the filtrate was evaporated. The resulting rearrangement product was refluxed with Raney nickel (6 ml) in 50 ml of abs ethanol for 19 h. Raney nickel was removed by filtration and washed with benzene. The filtrate and the washings were combined and evaporated. The residue was chromatographed on neutral alumina (50 g, Woelm act. II) eluted with hexane-benzene (9 : 1) to give the desired triple-layered metaparacyclophane **8** (40 mg, 12%). For analysis, **8** was recrystd from ethanol, colorless plates, mp 144—145 °C.

Found: C, 92.40; H, 7.68%. Calcd for $C_{26}H_{26}$: C, 92.24; H, 7.76%. PMR ($CDCl_3$, δ) 1.5—3.6 (m, 16H, CH_2), 4.90 (s, 1H, ArH of inner benzene), 5.12 (bs, 1H, meta inner ArH), 6.17 (s, 1H, ArH of inner benzene), 6.30 (bs, 4H, para benzene), 6.6 (m, 3H, meta benzene). MS *m/e* 338 (M^+), 234, 104.

b) By Photodesulfurization. The dithia compd **7** (95 mg, 0.24 mmol) was dissolved in 10 ml of freshly distd triethyl phosphite in a quartz tube and the tube was externally irradiated for an hour bubbling a slow stream of nitrogen through the soln. The solvent was evaporated and the residue was chromatographed over silica gel (40 g, Merck act. II-III) with hexane-benzene (4 : 1) to give 23 mg (28%) of **8**. When the irradiation was continued for 15 h, an isomeric triple-layered metaparacyclophane **9** was obtained in 23% yield, accompanied with **8** and an unknown oily substance. A 98 h irradiation produced **9** in the highest yield (34%). A soln of **8** (43 mg) in 10 ml of freshly purified cyclohexane was irradiated in a quartz tube for 28 h under an argon atmosphere and worked up in the usual way to give a mixture of **8** and **9** (26 mg).

*14,17-Dimethyl-2,11-dithia[3.3]metaparacyclophane (**11**) and 14,17,32,35-Tetramethyl-2,11,20,29-tetrathia[3.3.3.3]metaparametaparacyclophane (**12**).* A soln of 1,3-bis(mercaptomethyl)benzene **6** (3.40 g, 20 mmol) and sodium hydroxide (1.60 g, 40 mmol) in a mixture of water (5 ml) and ethanol (245 ml) and a soln of 2,5-bis(chloromethyl)-*p*-xylene **10** (4.06 g, 20 mmol) in 250 ml of benzene-ethanol (1 : 1) were added dropwise and simultaneously over a period of 4 h with stirring to refluxing alcohol (1 l) in a nitrogen atmosphere. Refluxing was continued for additional 12 h. The solvent was evaporated and the residue was extracted with benzene. The benzene extract was condensed and chromatographed over silica gel (100 g, Merck act. II-III). Elution with hexane-benzene (1 : 1) gave the dithia compd **11** (4.72 g, 71%), colorless columns from benzene-ethanol (1 : 1), mp 130—131 °C.

Found: C, 71.84; H, 6.79; S, 20.94%. Calcd for $C_{18}H_{20}S_2$: C, 71.94; H, 6.72; S, 21.34%. PMR ($CDCl_3$, δ) 2.16 (s, 6H, CH_3), 3.48 (s, 4H, CH_2), 3.71 and 3.96 (A_2B_2, 4H, CH_2), 5.63 (bs, 1H, ArH), 6.69 (s, 2H, ArH), 7.03 (m, 3H, ArH). MS *m/e* 300 (M^+).

Then elution with benzene gave the tetrathia compd **12** (0.36 g, 5.5%), which was recrystd from hexane-benzene (1 : 1), colorless fine crystals, mp 206—207 °C.

Found: C, 71.77; H, 6.60; S, 21.05%. Calcd for $C_{36}H_{40}S_4$: C, 71.94; H, 6.70; S, 21.34%. PMR ($CDCl_3$, δ) 2.13 (s, 12H, CH_3), 3.59 (s, 8H, CH_2), 3.61 (s, 8H, CH_2), 6.89 (bs, 4H, ArH), 7.08 (bs, 2H, ArH), 7.32 (m, 6H, ArH). MS *m/e* 600 (M^+), 132.

*12,15-Dimethyl[2.2]metaparacyclophane (**14**).* To a suspension of 15 g (50 mmol) of the above dithia compd **11** in 100 ml of acetic acid was added slowly an excess (30 ml, 0.34 mol) of hydrogen peroxide (35%) with stirring and then the soln was warmed at 100 °C for 5 h. The resulting ppt was filtered, washed repeatedly with water, and dried to give a quantitative yield of the corresponding bissulfone **13**. Pyrolysis of the bissulfone **13** to the corresponding [2.2]cyclophane **14** was carried out according to the general method described below. The bissulfone **13** (2.0 g) was placed into a Pyrex bulb and plugged lightly with glass wool. In order to prevent a loss of the product, some absorbent cotton was placed near the end of a glass tube which was connected to an aspirator to absorb sulfur dioxide generated. The Pyrex bulb was inserted into a furnance pre-heated at 900 °C and the reaction was completed within 1 min. The trapped product **14** was chromatographed over neutral alumina (10 g, Woelm act. II) with hexane (1.12 g, 86% based on **11**), colorless plates from pentane, mp 65—66 °C.

Found: C, 91.25; H, 8.68%. Calcd for $C_{18}H_{20}$: C, 91.45; H, 8.55%. PMR ($CDCl_3$, δ) 1.65 (s, 3H, CH_3), 1.9—3.4 (m, 8H, CH_2), 2.43 (s, 3H, CH_3), 5.51 (s, 1H, meta inner ArH), 5.69 (s, 1H, para ArH), 6.78 (s, 1H, para ArH), 6.86 (m, 3H, meta ArH). MS *m/e* 236 (M^+), 104.

*12,15-Bis(bromomethyl)[2.2]metaparacyclophane (**15**).* By the usual way from **14** (1.00 g, 4 mmol), *N*-bromosuccinimide (1.51 g, 8 mmol), and a small amount of benzoyl peroxide in 20 ml of carbon tetrachloride, 1.46 g (88%) of **15** was obtained as an yellow oil. The dibromide was used in the next coupling reaction without purification.

PMR ($CDCl_3$, δ) 2.0—4.5 (m, 8H, CH_2), 4.60 (s, 4H, CH_2), 5.55 (bs, 1H, meta ArH), 5.82 (s, 1H, para ArH), 6.9 (m, 3H, meta ArH), 7.22 (s, 1H, para ArH). MS *m/e* 396, 394, 392 (M^+), 315, 313.

*18, 27 - Dithia [3,3] metacyclo (12, 15) [2.2] metaparacyclophane (**16**).* A soln of the dibromide **15** (1.46 g, 3.7 mmol) in 35 ml of benzene and a soln of 1,3-bis(mercaptomethyl)benzene **6** (0.63 g, 3.7 mmol) and sodium hydroxide (0.30 g, 7.5 mmol) in a mixture of 2 ml of water and 33 ml of ethanol were added dropwise and simultaneously to 100 ml of refluxing ethanol for 4 h in a nitrogen atmosphere and refluxing was continued for additional 12 h. The solvent was evaporated and the residue was chromatographed on neutral alumina (60 g, Woelm act. II) with hexane-benzene (1 : 1). The initial eluate gave 0.47 g (32%) of **16** as an oil.

PMR ($CDCl_3$, δ) 1.5—4.3 (m, 16H, CH_2), 5.22 (bs, 1H, ArH of [2.2]bridged *m*-xylene moiety), 5.42 (s, 1H, ArH of durene moiety), 5.53 (bs, 1H, ArH of S-bridged *m*-xylene moiety), 6.54 (s, 1H, ArH of durene moiety), 6.5—7.2 (m, 6H, ArH of both *m*-xylene moieties). MS *m/e* 402 (M^+).

[2.2]Metacyclo(12,15)[2.2]metaparacyclophane (m-p,p-m) *(**17**).* The synthesis of **17** was carried out in the same manner as that of **8**. The reaction conditions were as follows; methylation of the dithia compd **16** (1.10 g, 2.7 mmol) with the Borch reagent[11] (2.30 g, 14 mmol) in dichloromethane (20 ml) under reflux for 15 h; the Stevens rearrangement with potassium *t*-butoxide (3.50 g, 31 mmol) in 25 ml of dry tetrahydrofuran under reflux for 4 h; desulfurization with Raney nickel (6 ml) in 60 ml of benzene-ethanol (1 : 5) under reflux for 15 h. The desired cyclophane **17** was purified by column chromatography over silica gel (50 g, Merck act. II) using hexane-benzene (9 : 1) (87 mg, 9.4%) and recrystd from benzene-ethanol (1 : 1), colorless plates, mp 170—171 °C.

Found: C, 92.04; H, 7.67%. Calcd for $C_{26}H_{26}$: C, 92.24; H, 7.76%. PMR ($CDCl_3$, δ) 1.5—3.5 (m, 32H, CH_2), 4.39 (s, 1H, ArH of durene moiety), 5.28 (bs, 1H, meta ArH), 5.37 (bs, 1H, meta ArH), 5.60 (s, 2H, ArH of durene moiety), 6.4—7.1 (m, 12H, meta ArH), 6.87 (s, 1H, ArH of durene moiety). MS *m/e* 338 (M^+).

*5,7-Dimethyl-2,11-dithia[3.3]metaparacyclophane (**20**) and 5,7,23,25-Tetramethyl-2,11,20,29-tetrathia[3.3.3.3]metaparametaparacyclophane (**21**).* A soln of 4,6-bis(chloromethyl)-*m*-xylene **18** (10.15 g, 50 mmol) in 250 ml of benzene-alcohol (1 : 4) and a soln of 1,4-bis(mercaptomethyl)benzene **19** (8.50 g, 50 mmol) in 10 ml of water and 240 ml of alcohol were added dropwise and simultaneously over a period of 4 h to boiling ethanol (1 l) with stirring under a nitrogen atmosphere and refluxing was continued for additional 12 h. After removal of the solvent the residue was extracted with chloroform and the extract was evaporated to dryness. The resulting solid was chromatographed over silica gel (200 g, Merck act. II). Elution with benzene-hexane (1 : 1) gave the dithia compd **20** (10.14 g, 68%), which was recrystd from benzene, colorless columns, mp 215—216 °C.

Found: C, 71.90; H, 6.85; S, 21.08%. Calcd for $C_{18}H_{20}S_2$: C, 71.94; H, 6.72; S, 21.34%. PMR ($CDCl_3$, δ) 2.15 (s, 6H, CH_3), 3.42 (s, 4H, CH_2), 3.86 (s, 4H, CH_2), 5.30 (s, 1H, ArH of durene moiety), 6.92 (bs, 1H, ArH of durene moiety), 7.00 (s, 4H, ArH of *p*-xylene moiety). MS *m/e* 300 (M^+).

Elution with benzene gave the tetrathia compd **21** (2.76 g, 18%) which was recrystallized from toluene, colorless needles, mp 235—236 °C.

Found: C, 72.02; H, 6.69; S, 21.08%. Calcd for $C_{36}H_{40}S_4$: C, 71.94; H, 6.72; S, 21.34%. PMR ($CDCl_3$, δ) 2.37 (s, 12H, CH_3), 3.55 (s, 8H, CH_2), 3.63 (s, 8H, CH_2), 6.87 (bs, 2H, ArH), 7.04 (bs, 2H, ArH). MS *m/e* 600 (M^+).

4,6-Dimethyl[2.2]metaparacyclophane (23). The cyclophane **23** was synthesized from **20** by the same method as **14.** Thus a suspension of the dithiacyclophane **20** (3.0 g, 10 mmol) in 20 ml of acetic acid was oxidized with 10 ml of hydrogen peroxide (35%) at 100 °C for 5 h with stirring to give the bissulfone **22** in a quantitative yield. Pyrolysis of the bissulfone **22** at 900 °C under 0.1 mmHg followed by chromatography gave **23** (91% based on **20**), colorless plates from pentane, mp 63—64 °C. On the other hand, the same cyclophane **23** was obtained in a good yield of 74% by oxidation-pyrolysis of the tetrathiacyclophane **21**.

Found: C, 91.25; H, 8.63%. Calcd for $C_{18}H_{20}$: C, 91.45; H, 8.55%. PMR ($CDCl_3$, δ) 2.22 (s, 6H, CH_3), 1.7—3.3 (m, 8H, CH_2), 5.22 (s, 1H, ArH of durene moiety), 5.83 (d, $J=1$ Hz, 2H, ArH of *p*-xylene moiety), 6.65 (bs, 1H, ArH of durene moiety), 7.16 (d, $J=1$ Hz, 2H, ArH of *p*-xylene moiety). MS *m/e* 236 (M^+), 132, 104.

4,6-Bis(bromomethyl)[2.2]metaparacyclophane (26). A mixture of **23** (0.50 g, 2 mmol), *N*-bromosuccinimide (0.76 g, 4 mmol), and a small amount of benzoyl peroxide in 20 ml of carbon tetrachloride was refluxed for 3.5 h and worked up in the usual way. The resulting crystals were washed with methanol to give 0.65 g (78% yield) of **26**, colorless plates from carbon tetrachloride, mp 151—152 °C.

Found: C, 55.02; H, 4.51; Br, 40.14%. Calcd for $C_{18}H_{18}Br_2$: C, 54.85; H, 4.60; Br, 40.55%. PMR ($CDCl_3$, δ) 1.8—3.4 (m, 8H, CH_2), 4.46 (s, 4H, CH_2Br), 5.45 (s, 1H, ArH of durene moiety), 6.14 (d, $J=2$ Hz, 2H, ArH of *p*-xylene moiety), 7.12 (s, 1H, ArH of durene moiety), 7.24 (d, $J=2$ Hz, 2H, ArH of *p*-xylene moiety). MS *m/e* 396, 394, 392 (M^+), 315, 313, 104.

18,27-Dithia[3.3]paracyclo(4,6)[2.2]metaparacyclophane (27). A soln of the dibromide **26** (0.6 g, 1.7 mmol) in 35 ml of benzene and a soln of 1,4-bis(mercaptomethyl)benzene **19** (0.28 g, 1.6 mmol) and sodium hydroxide (0.14 g, 3.5 mmol) in water (2 ml) and alcohol (35 ml) were added dropwise and simultaneously to 100 ml of boiling ethanol for 4 h under a nitrogen atmosphere. The mixture was refluxed for 12 h and worked up in the usual way. The desired dithiacyclophane **27** was purified by column chromatography (0.30 g, 35%) and recrystd from benzene, colorless prisms, mp 265—266 °C (sealed tube).

Found: C, 77.71; H, 6.35; S, 15.74%. Calcd for $C_{26}H_{26}S_2$: C, 77.55; H, 6.52; S, 15.92%. PMR ($CDCl_3$, δ) 1.0—4.0 (m, 16H, CH_2), 5.01 (s, 1H, ArH of durene moiety), 5.14 (s, 1H, ArH of durene moiety), 5.91 (bs, 2H, ArH of [2.2]bridged *p*-xylene moiety), 7.02 (bs, 2H, ArH of S-bridged *p*-xylene moiety), 7.14 (bs, 2H, ArH of [2.2]-bridged *p*-xylene moiety), 7.30 (bs, 2H, ArH of S-bridged *p*-xylene moiety). MS *m/e* 402 (M^+), 104.

[2.2]Paracyclo(4,6)[2.2]metaparacyclophane (p-m,m-p) *(28). a) By the Stevens Rearrangement-Raney Nickel Desulfurization.* In the same manner as the synthesis of **8**, 1.53 g (3.8 mmol) of the dithiacyclophane **27** and 1.50 g (9.3 mmol) of the Borch reagent[11)] in 20 ml of dichloromethane were refluxed with stirring for 15 h. The resulting ppt was filtered and then refluxed with 2.0 g (18 mmol) of potassium *t*-butoxide in 30 ml of dry tetrahydrofuran for 5 h. The mixture was filtered and the filtrate was condensed. The residue was refluxed with Raney nickel (10 ml) in benzene (5 ml) and ethanol (60 ml) for 17 h. After removal of Raney nickel the soln was worked up in the usual way. Chromatography over silica gel (50 g, Merck act. II) gave **28** (87 mg, 6.8%) from hexane-benzene (9 : 1) eluate. The cyclophane **28** was recrystd from toluene, colorless plates, mp 259—260 °C (sealed tube).

Found: C, 92.20; H, 7.73%. Calcd for $C_{26}H_{26}$: C, 92.24; H, 7.76%. PMR ($CDCl_3$, δ) 1.5—3.3 (m, 16H, CH_2), 4.94 (s, 2H, ArH of durene moiety), 5.66 (bs, 4H, ArH of *p*-xylene moiety), 7.12 (bs, 4H, *p*-xylene moiety). MS *m/e* 338 (M^+), 104.

b) By Photodesulfurization. A suspension of the dithiacyclophane **27** (30 mg, 0.075 mmol) in 15 ml of freshly distd triethyl phosphite was placed in a quartz tube and the tube was externally irradiated with a 400 W high pressure mercury lamp under bubbling of nitrogen for 13 h. After removal of the solvent the residue was adsorbed on silica gel (15 g, Merck act. II) and eluted with hexane–benzene (4 : 1) to give **27** (15 mg, 55%).

4,6-Bis(mercaptomethyl)[2.2]metaparacyclophane (29). 4,6-Bis(bromomethyl)[2.2]metaparacyclophane **26** (6.61 g, 17 mmol) was added portionwise to a warm soln of thiourea (2.60 g, 34 mmol) dissolved in 50 ml of ethanol and then the mixture was refluxed for 3 h. The solvent was evaporated and the residual thiouronium salt was refluxed with 85% potassium hydroxide (18 g) in 50 ml of water for 8 h. The cold soln was filtered and acidified with hydrochloric acid to ppt the dithiol **29**. The mixture was extracted with chloroform and the extract was washed with water, dried over anhyd sodium sulfate, and evaporated to dryness. The resulting solid was chromatographed on neutral alumina (20 g) using hexane-benzene (1 : 1) to give the desired thiol **29** (4.83 g, 96%), colorless fine crystals from hexane–benzene (1 : 1), mp 112—113 °C.

Found: C, 72.23; H, 6.68; S, 21.08%. Calcd for $C_{18}H_{20}S_2$: C, 71.94; H, 6.72; S, 21.34%. PMR ($CDCl_3$, δ) 1.78 (t, $J=8$ Hz, 2H, SH), 1.7—3.3 (m, 8H, CH_2), 3.70 (d, $J=8$ Hz, 4H, CH_2), 5.36 (s, 1H, ArH of durene moiety), 6.03 (d, 2H, ArH of *p*-xylene moiety), 6.97 (s, 1H, ArH of durene moiety), 7.23 (d, 2H, ArH of *p*-xylene moiety). MS *m/e* 300 (M^+).

21,24-Dimethyl-18,27-dithia[3.3]paracyclo(4,6)[2.2]metaparacyclophane (30). A soln of 2,5-bis(chloromethyl)-*p*-xylene **10** (1.02 g, 5 mmol) in 40 ml of benzene and a soln of the above dithiol **29** (1.50 g, 5 mmol) and 85% potassium hydroxide (0.66 g, 10 mmol) in 40 ml of 80% aq ethanol were added dropwise and simultaneously over a period of 3 h to 300 ml of boiling ethanol under a nitrogen atmosphere. The mixture was refluxed for additional 12 h and worked up in the same manner as the synthesis of **7**. Chromatography of the product over silica gel (50 g, Merck act. II) with hexane-benzene (1 : 1) gave the dithiacyclophane **30** (1.44 g, 70%), colorless plates from ethanol, mp 201—202 °C.

Found: C, 78.14; H, 6.91; S, 14.84%. Calcd for $C_{28}H_{30}S_2$: C, 78.23; H, 6.98; S, 14.90%. PMR ($CDCl_3$, δ) 1.96 (s, 3H, CH_3), 2.45 (s, 3H, CH_3), 2.5—4.4 (m, 16H, CH_2), 4.89 (s, 1H, ArH), 5.08 (s, 1H, ArH), 5.76 (bs, 2H, ArH of *p*-xylene moiety), 6.76 (s, 1H, ArH), 7.00 (s, 1H, ArH), 7.10 (bs, 2H, ArH of *p*-xylene moiety). MS *m/e* 430 (M^+).

12,15-Dimethyl[2.2]paracyclo(4,6)[2.2]metaparacyclophane (31) and 21,24-Dimethyl-18-thia[3.2]paracyclo(4,6)[2.2]metaparacyclophane (32). A suspension of the above dithiacyclophane **30** (100 mg, 0.2 mmol) in 14 ml of purified triethyl phosphite was externally irradiated in a quartz tube under bubbling of nitrogen at room temp for 8.5 h. The solvent was evaporated and the residue was chromatographed over silica gel (20 g, Merck act. II) with hexane–benzene (4 : 1). The initial eluate gave the desired product **31** (55 mg, 63%), colorless fine crystals from toluene, mp 192—193 °C.

Found: C, 91.79; H, 8.17%. Calcd for $C_{28}H_{30}$: 91.73; H, 8.27%. PMR ($CDCl_3$, δ) 1.44 (s, 3H, CH_3), 1.7—3.2 (m, 16H, CH_2), 2.39 (s, 3H, CH_3), 4.90 (s, 1H, ArH), 5.05 (s, 1H, ArH), 5.48 (s, 1H, ArH), 5.63 (d, J=1 Hz, 2H, ArH), 6.79 (s, 1H, ArH), 7.09 (d, J=1 Hz, 2H, ArH). MS m/e 366 (M^+).

The second eluate gave the monosulfur compd **32** (22 mg, 24%), colorless plates from ethanol, mp 187—188 °C.

Found: C, 84.63; H, 7.62; S, 8.17%. Calcd for $C_{28}H_{30}S$: C, 84.37; H, 7.59; S, 8.04%. NMR ($CDCl_3$, δ) 1.71 (s, 3H, CH_3), 2.2—3.6 (m, 16H, CH_2), 2.37 (s, 3H, CH_3), 4.92 (s, 1H, ArH), 5.11 (s, 1H, ArH), 5.49 (s, 1H, ArH), 5.60 (d, J=1 Hz, 2H, ArH), 6.87 (s, 1H, ArH), 7.10 (d, J=1 Hz, 2H, ArH). MS m/e 398 (M^+).

*18,27-Dithia[3.3]paracyclo(4,6)[2.2]metacyclophane (**34**).* A soln of 4,6-bis(bromomethyl)[2.2]metacyclophane **33**[6b] in 35 ml of benzene and a soln of 1,4-bis(mercaptomethyl)-benzene **19** (0.31 g, 1.8 mmol) and sodium hydroxide (0.15 g, 3.8 mmol) in a mixture of water (2 ml) and ethanol (33 ml) were added dropwise and simultaneously over a period of 4 h to boiling ethanol (100 ml) with stirring in a nitrogen atmosphere. The mixture was refluxed for additional 12 h and worked up in the usual way. Chromatography of the product over neutral alumina (30 g, Woelm act. II) using hexane-benzene (1 : 1) gave the desired dithiacyclophane **34** (0.31 g, 34%), colorless needles from benzene-alcohol (1 : 1), mp 238—239 °C.

Found: C, 77.80; H, 6.36; S, 15.78%. Calcd for $C_{26}H_{26}S_2$: C, 77.55; H, 6.52; S, 15.92%. PMR ($CDCl_3$, δ) 1.5—4.0 (m, 17H, CH_2 and one ArH), 4.54 (bs, 1H, ArH), 5.43 (s, 1H, ArH), 7.13 (bs, 4H, ArH), 7.21 (m, 3H, ArH). MS m/e 402 (M^+), 104.

[2.2]Metacyclo(4,6)[2.2]metaparacyclophane (m-m, m-p) *(**9**). a) By the Stevens Rearrangement-Raney Nickel Desulfurization.* A mixture of the above dithiacyclophane **34** (0.60 g, 1.5 mmol) and the Borch reagent[11] (1.00 g, 6.2 mmol) in 20 ml of dichloromethane was refluxed with stirring for 15 h. The resulting ppt was filtered and stirred with sodium hydride (0.12 g, 4.8 mmol), washed with dry ether, in dry dimethyl sulfoxide (10 ml) at 20 °C under a nitrogen atmosphere for 1.5 h. The mixture was poured into ice-water to quench the reaction. The resulting ppt was filtered, dried, and then refluxed with 7 ml of Raney nickel (W-II) in benzene (5 ml) and ethanol (50 ml) for 15 h. Raney nickel was filtered and washed with benzene. The filtrate and the washings were combined and concentrated, and then the residue was chromatographed on silica gel (40 g, Merck act. II) using hexane-benzene (9 : 1). The first eluate gave the desired cyclophane **9** (96 mg, 19%), colorless prisms from toluene, mp 209—210 °C.

Found: C, 92.08; H, 7.75%. Calcd for $C_{26}H_{26}$: C, 92.24; H, 7.76%. PMR ($CDCl_3$, δ) 1.5—3.5 (m, 16H, CH_2), 3.66 (s, 1H, ArH), 5.62 (s, 1H, ArH), 5.70 (bs, 1H, ArH), 6.48 (d, J=2 Hz, 2H, ArH), 7.3 (m, 3H, ArH), 7.46 (d, J=2 Hz, 2H, ArH). MS m/e 338 (M^+), 234, 104.

b) By Photodesulfurization. In the same manner as **8** b), irradiation of a soln of **34** (60 mg, 0.15 mmol) in triethyl phosphite (20 ml) for 15 h and purification by column chromatography gave the same compd **9** (19 mg, 35%).

*4,6-Bis(mercaptomethyl)[2.2]metacyclophane (**35**).* A mixture of 4,6-bis(bromomethyl)[2.2]metacyclophane **33** (2.36 g, 6 mmol) and thiourea (1.0 g, 13 mmol) was refluxed in 50 ml of ethanol for 3 h and concd to dryness. The thiouronium salt was hydrolyzed by refluxing with 85% potassium hydroxide (7.30 g) in 50 ml of water for 7.5 h and worked up as usual. The crude product was filtered through a short column of neutral alumina with hexane–benzene (1 : 1) to afford pure dithia compound **35** (1.53 g, 85%), colorless prisms from hexane–benzene, mp 92—93 °C.

Found: C, 71.97; H, 6.71; S, 21.11%. Calcd for $C_{18}H_{20}S_2$: C, 71.94; H, 6.72; S, 21.34%. PMR ($CDCl_3$, δ) 1.80 (t, J=7 Hz, 2H, SH), 3.0—3.5 (m, 8H, CH_2), 3.81 (d, J=7 Hz, 4H, SCH_2), 4.17 (s, 1H, ArH), 4.43 (bs, 1H, ArH), 7.0—7.5 (m, 4H, ArH). MS m/e 300 (M^+).

*21,24-Dimethyl-18,27-dithia[3.3]paracyclo(4,6)[2.2]metacyclophane (**36**).* A soln of 2,5-bis(chloromethyl)-*p*-xylene **10** (1.02 g, 5 mmol) in 40 ml of benzene and a soln of 4,6-bis(mercaptomethyl)[2.2]metacyclophane **35** (1.50 g, 5 mmol) in 40 ml of 80% ethanol were added dropwise and simultaneously over a period of 3.5 h to boiling ethanol (100 ml) under nitrogen and the refluxing was continued for 12 h. The mixture was worked up in the usual way. The crude product was purified by chromatography over alumina (Woelm act. II) with hexane-benzene (4 : 1) to give the pure dithiacyclophane **36** (1.62 g, 74%), colorless fine crystals from ethanol, mp 165—166 °C.

Found: C, 78.23; H, 7.17; S, 14.85%. Calcd for $C_{28}H_{30}S_2$: C, 78.23; H, 6.98; S, 14.90%. PMR ($CDCl_3$, δ) 2.22 (s, 3H, CH_3), 2.32 (s, 3H, CH_3), 2.9—4.0 (m, 16H, CH_2), 4.09 (bs, 1H, ArH), 4.34 (s, 1H, ArH), 5.46 (s, 1H, ArH), 6.9—7.5 (m, 5H, ArH). MS m/e 430 (M^+).

*12,15-Dimethyl[2.2]metacyclo(4,6)[2.2]metaparacyclophane (**37**).* The Stevens rearrangement-Raney nickel desulfurization method was carried out as in the synthesis of **8**. The following conditions were used; methylation of **36** (1.10 g, 2.6 mmol) with the Borch reagent (1.66 g, 10 mmol) in dichloromethane (20 ml) under reflux for 3.5 h, the Stevens rearrangement with potassium *t*-butoxide (3.0 g, 27 mmol) in dry tetrahydrofuran (25 ml) under reflux for 5 h, and desulfurization with Raney nickel (6 ml) in 60 ml of benzene-ethanol (1 : 5) under reflux for 15 h. After chromatography, the desired product **37** was obtained as an oil, which was solidified when treated with a small amount of pentane (141 mg, 15%), colorless fine crystals from toluene, mp 131—132 °C.

Found: C, 91.51; H, 8.06%. Calcd for $C_{28}H_{30}$: C, 91.73; H, 8.27%. PMR ($CDCl_3$, δ) 1.7—3.4 (m, 32H, CH_2), 1.49 (s, 3H, CH_3), 1.98 (s, 3H, CH_3), 2.44 (s, 3H, CH_3), 2.58 (s, 3H, CH_3), 3.71 (s, 2H, ArH), 4.20 (s, 1H, ArH), 5.07 (bs, 1H, ArH), 5.39 (s, 1H, ArH), 5.60 (s, 1H, ArH), 5.80 (bs, 1H, ArH), 6.21 (s, 1H, ArH), 6.87 (s, 1H, ArH), 6.9—7.3 (m, 7H, ArH). MS m/e 366 (M^+).

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