[3.2]Paracyclophane-10-enes and [3.2.3.2]Paracyclophane-10,27-dienes: A Convenient Synthesis by the McMurry Reaction and Dynamic Stereochemistry

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The 1,3-bis(4-acylphenyl)propanes **2**, **3**, **9**, **12**, and **15** were subjected to a cyclization by reductive coupling with low-valent titanium (McMurry reaction). **2** and **3** are converted into the corresponding 10,11-dialkyl[3.2]paracyclophane-10-enes **4** and **5**, respectively, under carefully controlled conditions in good yields. By the same method the dialdehydes **12** and **15** give rise to [3.2]paracyclophane-10-ene **13** and [3.2]metacyclophane-10-ene **16**. However, the ditoluoyl derivative **9** gives rise only to the macrocyclic cyclophane **10** by dimerization. The corresponding macrocyclic cyclophanes **6** and **7** were also obtained from **2** and **3**, respectively. The conformational mobility of the cyclophanes **4**, **5**, and **13** was studied by variable-temperature ^{1}H-NMR, and $\Delta G^{\neq} = 48-51$ kJ/mol was determined for the wobbling motion of the propano bridges.

[3.2]Paracyclophan-10-ene und [3.2.3.2]Paracyclophan-10,27-diene: Eine einfache Synthese mit Hilfe der McMurray-Reaktion und dynamische Stereochemie

Die 1,3-Bis(4-acylphenyl)propane **2**, **3**, **9**, **12** und **15** wurden einer Cyclisierung durch reduktive Kupplung mit niedervalentem Titan (McMurry-Reaktion) unterworfen. **2** und **3** werden unter sorgfältig kontrollierten Bedingungen mit guten Ausbeuten in die 10,11-Dialkyl[3.2]paracyclophan-10-ene **4** und **5** umgewandelt. Die beiden Dialdehyde **12** und **15** liefern nach der gleichen Methode ebenfalls [3.2]Paracyclophan-10-en **13** bzw. [3.2]Metacyclophan-10-en **16**. Das Ditoluoyl-Derivat **9** bildet dagegen durch eine Dimerisierung nur das makrocyclische Cyclophan **10**. Die entsprechenden makrocyclischen Cyclophane **6** und **7** lassen sich auch aus **2** und **3** erhalten. Die konformative Beweglichkeit der Cyclophane **4**, **5** und **13** wurde mit Hilfe von ^{1}H-NMR bei verschiedenen Temperaturen untersucht und $\Delta G^{\neq} = 48-51$ kJ/mol für das Durchschwingen der Propano-Brücke bestimmt.

The properties of the [3.2]cyclophanes have not been studied as extensively as those of the [2.2]cyclophanes, very likely because of the lack of a simple synthesis of the former. The asymmetrically bridged [3.2]cyclophanes cannot be prepared by the simple dimerization of a dihalide, and the usual synthetic routes are the desulfuration of a thia-[3.3]cyclophane[1], a cyclization by the geminal dialkylation of diethyl malonate[2], a ring expansion of [2.2]cyclophanes[3], and an intramolecular Wurtz coupling of suitable precursors[4]. These preparations require many synthetic steps and the total yields are usually low. Hence, a convenient and efficient synthesis of [3.2]cyclophanes is of particular interest.

In the course of our studies of "twinned" cyclophanes[5] a synthesis producing [3.2]paracyclophane-10-enes in high yields was needed, and it appeared that the titanium-induced reductive coupling of appropriate diketones – the McMurry reaction[6] – could be a suitable method. It is well known[7] that the McMurry reaction is one of the best possibilities to synthesize sterically hindered alkenes. Furthermore, highly strained cyclic compounds were prepared by this method[8] also, but so far only the formation of additional bridges in cyclophanes[9a] and the syntheses of macrocyclic cyclophanes[9b] were performed by the McMurry reaction. We now report the preparation of 10,11-dimethyl-[3.2]paracyclophane-10-ene (**4**), 10,11-diethyl[3.2]paracyclophane-10-ene (**5**), [3.2]paracyclophane-10-ene (**13**), and [3.2]-metacyclophane-10-ene (**16**) by the McMurry reaction with moderate to excellent yields. By varying slightly the reaction conditions the macrocyclic cyclophanes 10,11,27,28-tetramethyl[3.2.3.2]paracyclophane-10,27-diene (**6**), 10,11,27,28-tetraethyl[3.2.3.2]paracyclophane-10,27-diene (**7**), and 10,11,27,28-tetrakis(4-methylphenyl)[3.2.3.2]paracyclophane-10,27-diene (**10**) are also obtained with an acceptable yield. Finally, the conformational mobility of the [3.2]paracyclophanes **4**, **5**, and **13** has been studied by variable-temperature ^{1}H-NMR.

Synthesis

In effect, the starting material for the synthesis of [3.2]-paracyclophane-10-enes by the titanium-induced reductive coupling is the easily available 1,3-diphenylpropane[10] (**1**). The twofold and regioselective Friedel-Crafts acylation of **1** with acetyl chloride and propionyl chloride under optimized reaction conditions gave satisfactory yields of the corresponding 1,3-bis(4-acylphenyl)propane **2** and **3**[10], respectively. The reversible acylation reaction strongly prefers a substitution at the *para* position of each of the phenyl groups, and no contamination with the sterically hindered

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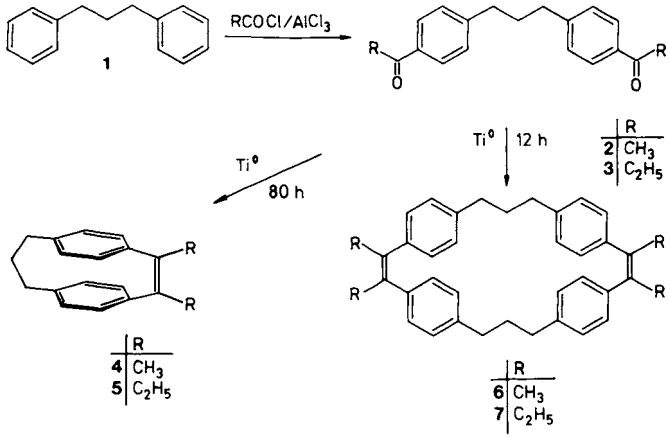
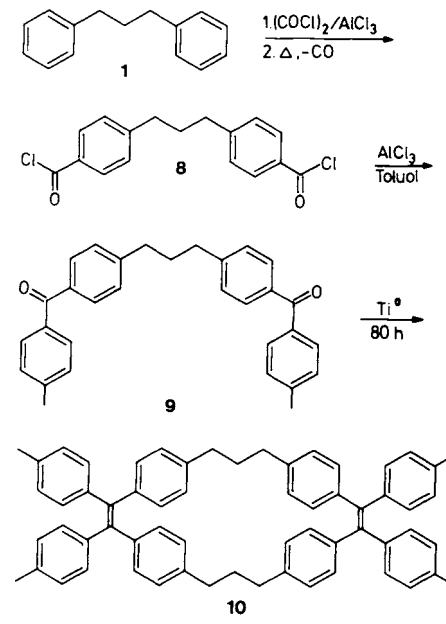
ortho-substituted isomers is detected in the ^{1}H-NMR spectra of **2** and **3**. The diketones **2** and **3** are suitable substrates for a cyclization to [3.2]paracyclophanes by the McMurry reaction. Mass spectral studies of 1,ω-diphenylalkanes have indicated[11] that **1** can adopt a conformation with a *face-to-face* orientation of the two aromatic rings quite easily during its reactions. Assuming a similar conformational situation for the *para*-substituted derivatives **2** and **3** one would anticipate a facile cyclization to the [3.2]paracyclophanes **4** and **5**. However, the yields were very low under the standard conditions of the McMurry reaction[6] even when dilution techniques were used. Only if a very large molar excess (>20:1) of the titanium reagent was used and by slow addition (ca. 80 h) of the diketone **2** and **3** to the Ti slurry, suspended in a large volume of THF or DME, the [3.2]-paracyclophanes **4** and **5** respectively, were obtained in about 80% yield.

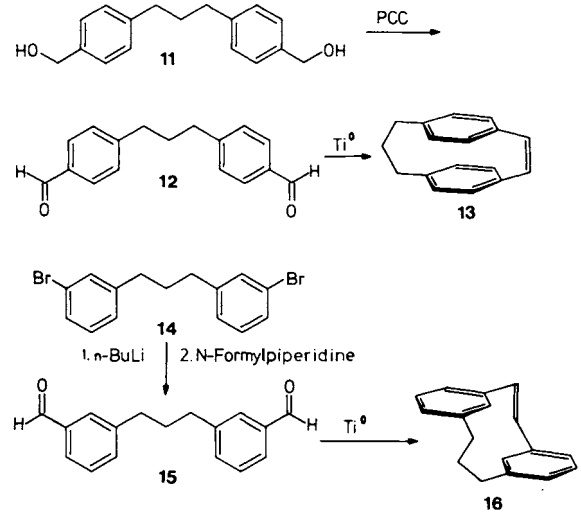


The macrocyclic [3.2.3.2]paracyclophane-10,27-dienes **6** and **7** were formed as byproducts (<5%) under these reaction conditions and were separated from the corresponding monomeric coupling products **4** and **5** respectively, by flash chromatography. However, if the diketones **2** or **3** were added to the McMurry reagent within 12 h but with otherwise identical reaction conditions, the dimeric coupling products **6** or **7** were the main products.

The cyclization of 1,3-bis(4-aroylphenyl)propanes by the McMurry reaction should give rise to [3.2]paracyclophane-10-enes substituted with aryl groups at the unsaturated bridge. A direct double aroylation of **9** by benzoyl chloride and p-toluoyl chloride was not successful. In contrast, 1,3-bis(4-chloroformylphenyl)propane (**8**) obtained from **1** by the reaction with $(COCl)_2/AlCl_3$ and subsequent decarbonylation reacted smoothly with toluene to produce 1,3-bis(4-methylbenzoyl)propane **9** under Friedel-Crafts conditions. However, the cyclization of **9** to the 10,11-bis(4-methylphenyl)[3.2]paracyclophane-10-ene failed even if extremely slow addition to the McMurry reagent and long reaction times were used. Instead, the dimeric coupling product, 10,11,27,28-tetrakis(4-methylphenyl)[3.2.3.2]paracyclophane-10,27-diene (**10**) was obtained with excellent yields. The formation of tetraarylethenes by the McMurry reaction is known[5a,6], but obviously in the present case the result is due to severe steric effects in the conformation necessary for the formation of the monomeric product and shows the limits of an intramolecular McMurry reaction for the synthesis of cyclophanes.



The [3.2]paracyclophane-10-ene **13** and the corresponding metacyclophane **16**, both unsubstituted at the unsaturated bridge, should arise from the dialdehydes 1,3-bis(4-formylphenyl)propane (**12**) and 1,3-bis(3-formylphenyl)propane (**15**), respectively, by the intramolecular McMurry reaction. A direct Rieche formylation of **1** in the *meta* positions of the aromatic rings to obtain **15** is not possible, and the corresponding reaction in the *para* positions to prepare **12** failed. Hence, both dialdehydes had to be prepared by rather elaborate synthetic routes[5c,12]. The best results for **12** were obtained by PCC oxidation of the 1,3-bis(4-hydroxymethylphenyl)propane (**11**) [$LiAlH_4$ reduction of 1,3-bis(4-ethoxycarbonylphenyl)propane via **8**] and for **15** by formylation of the 1,3-bis(3-bromophenyl)propane (**14**) (via the



corresponding chalcone) with *N*-formylpiperidine/*n*BuLi. The intramolecular coupling of the *para*-dialdehyde **12** by the McMurry reaction using the same conditions as for **2** and **3** provided the [3.2]paracyclophane-10-ene **13**, albeit in a rather poor yield of 8%, together with the macrocyclic dimer (11%). Better results were obtained for the corresponding cyclization of the *meta*-dialdehyde **15** which generated the [3.2]metacyclophane-10-ene **16** in 58% yield. In this case only a trace of the dimer was isolated.

The tetrasubstituted double bond in the bridge of **4** and **5** is resistant towards catalytic hydrogenation, while **13** and **16** can be converted quantitatively into the saturated [3.2]paracyclophane and [3.2]metacyclophane, respectively, by $Pd(C)/H_2$. However, all cyclophanes **4**, **5**, **13**, and **16** react readily by the electrophilic addition of bromine.

Dynamic Stereochemistry of the Paracyclophanes 4, 5, and 13

The conformations and the conformational mobilities of the [3.2]paracyclophanes are of some interest in comparison to their next lower and higher homologues[13]. The [2.2]paracyclophanes are rigid and strained molecules, while the unsubstituted [3.3]paracyclophane is a mobile molecule exhibiting a wobble motion of the bridges, and probably also a ring rotation[14]. The conformational isomerism observed for [3.3]metacyclophanes is also attributed to a wobbling of the bridges of the *syn* conformer[15] giving rise to an interconversion between chair-chair, chair-boat, and boat-boat forms. This conformational interchange depends in some cases on the presence of heteroatoms in and substituents at the bridges[14,16]. A wobbling of the propano bridge can be expected also for the [3.2]paracyclophanes **4**, **5**, and **13** and may be effected by the substituents at the C_2 bridge. In order to analyze the dynamic processes, these cyclophanes were studied by variable-temperature ^{1}H-NMR spectroscopy at 300 MHz over the temperature range of 303 to 193 K.

Above room temperature quite simple NMR spectra are obtained. The 300-MHz ^{1}H-NMR spectrum of the 10,11-diethyl[3.2]paracyclophane-10-ene (**5**) is shown in Figure 1 as a typical example. The NMR spectra of the other [3.2]paracyclophanes differ qualitatively only by the signals due to the different substituents at the etheno bridge. The ^{1}H-NMR spectrum ($CDCl_3$) of **5** exhibits at 302 K (Figure 1a) the signals of an AA'BB' spin system for the arene ring protons at $\delta = 6.4-6.7$, showing a small upfield shift compared to the reference compound **1** as usual for cyclophanes with a *face-to-face* orientation of the aromatic groups[14]. The protons at the trimethylene bridge give rise to a broad unstructured signal at $\delta = 2.71$ for the two benzylic CH_2 groups and to a not completely resolved quintuplet at $\delta = 2.10$ for the central CH_2. The remaining sharp signals at

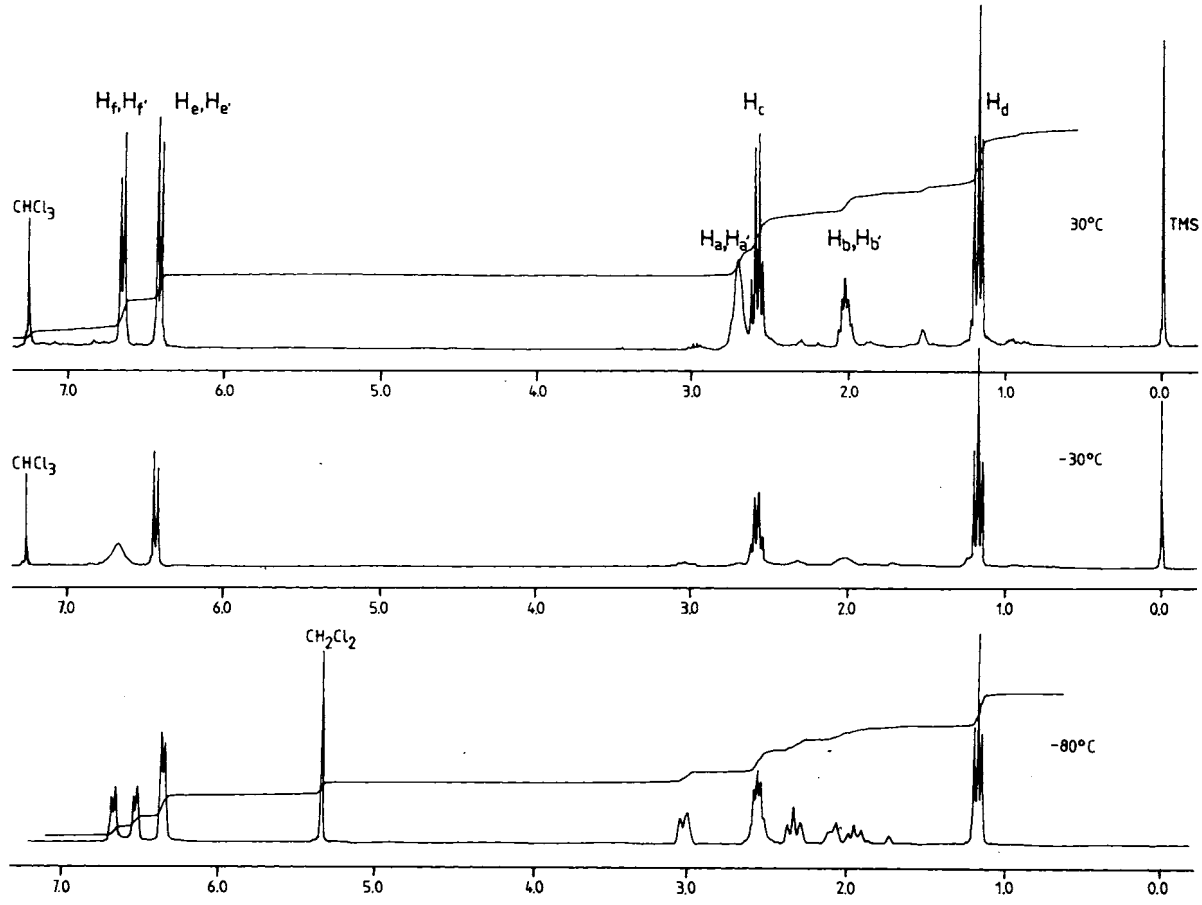
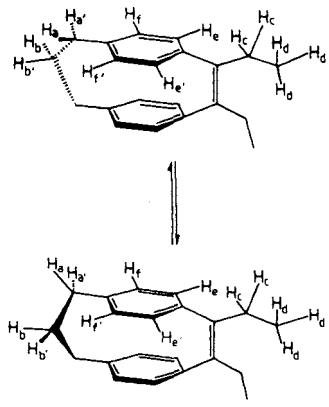


Figure 1. ^{1}H-NMR spectrum of 10,11-diethyl[3.2]paracyclophane-10-ene at 302 K (a), 242 K (b), 192 K (c)

δ = 2.60 and 2.01 are due to the ethyl substituents at the etheno bridge.



In particular the signals of the methylene protons at the propano bridge are broadened even at room temperature. On cooling the solution, a further broadening and eventually a coalescence is observed for these signals as well as for the low-field component of the aromatic AA'BB' spin system (Figure 1b). At 192 K the spectrum shown in Figure 1c was observed. The AA'BB' spin system of the protons at the aromatic rings has changed into an ABCC' system with an unequal pair of protons (H_f and $H_{f'}$, see formula in Figure 1) at the one *ortho* position giving rise to two doublets at δ = 6.54 and 6.69, respectively, while the signal of the other pair of protons (H_e and $H_{e'}$) remains unchanged. The protons H_a and $H_{a'}$ at the benzylic positions of the propano bridge now appear as an AB spin system with a slightly diffuse doublet at δ = 2.99 ($^2J_{aa'}$ = −14.8 Hz) and a triplet at δ = 2.29. This latter signal arises by a coincidence of the magnitude (ca. 14.5 Hz) of the geminal coupling constant $^2J_{aa'}$ and the vicinal coupling constant $^3J_{ab}$ of $H_{a'}$ to $H_{b'}$ at the central methylene group. This specifies a dihedral angle of almost 180° between these two protons in a frozen propano bridge. Finally, H_b and $H_{b'}$ appear as a broad doublet at δ = 2.03 and a broad triplet at δ = 1.90, respectively. Not only the pattern for the signals of the propano bridge in the low-temperature ^{1}H-NMR spectrum but also the unusual splitting of the low-field signal of the *ortho* protons is in accord with a frozen trimethylene bridge, in which only the *endo*-oriented $H_{b'}$ interferes with the neighboring proton of the aromatic ring. Additionally, the splitting of the *ortho* protons adjacent to the trimethylene bridge documents that the rings do not rotate at least at 192 K, if at all. The conformations derived from the ^{1}H-NMR spectra of **4**, **5**, and **13** agree very well with the conformations calculated by the MMPMI program[17]. The dihedral angle $H_{a'}-C(1)-C(2)-H_{b'}$ within the propano bridge is calculated to be 179.7° for all three cyclophanes. The distortion of the [3.2]paracyclophanes is seen from the *endo* and *exo* angles at the etheno bridges which are 116° and 125°, respectively, deviating from the normal bond angle of 120°. Similarly the benzene rings are distorted into a boat form, and the bonds to the etheno bridge are bent additionally out of the plane of the rings in these calculated models.

Table 1. Coalescence temperature ($H_e/H_{e'}$) and ΔG^* for the conformational motion of **4**, **5**, and **13** (300-MHz ^{1}H NMR, CD_2Cl_2)

compound	T_c [K]	ΔG^* [kJ/mol]
13	248	50.7 ± 1.0
4	243	48.7 ± 1.0
5	243	49.5 ± 1.0

ΔG^* of the wobble motion of the trimethylene bridge was determined by the coalescence temperature method for the cyclophanes **4**, **5**, and **13**, and the results are presented in Table 1. The values obtained vary slightly between 49 and 51 kJ/mol but show no systematic effect of the substituents at the etheno bridge. Furthermore, ΔG^* for the wobble motion of the propano bridges of **4**, **5**, and **13** is not significantly different from the ΔG^* values of 48–49 kJ/mol observed for the same motion within [3.3]paracyclophane[15] and [3.3]metacyclophane[16]. Obviously, the steric situation at the trimethylene bridges of the [3.2]cyclophanes and [3.3]cyclophanes is very similar in spite of the distortion of the former cyclophanes by the unsymmetrical bridges. This agrees with the assumption that the conformations of these cyclophanes and in particular the preference of the *syn* form of the [3.3]metacyclophanes is determined by the torsional strain (Pitzer strain) within the propano chains[16].

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Experimental

Melting points, uncorrected: Electrothermal melting point apparatus. – Infrared spectra: Perkin-Elmer Infrared Spectrophotometer 377 and 883. – UV spectra: Beckman Spectralphotometer UV 5240. – ^{1}H-NMR spectra: Bruker AM 300 and Bruker WP 80; TMS as internal standard. – Mass spectra: Varian MAT 311 A, direct insertion probe, 70 eV; high-resolution mass determinations with the same instrument at mass resolution $m/\Delta m$ = 8000. – Thin layer chromatography: Merck silical gel DC 60 F 254. – Column chromatography: Merck silical gel 60 (70–230 mesh/0.063–0.2 mm).

1,3-Bis(4-acetylphenyl)propane (**2**): 12.6 g (94.5 mmol) of anhydrous $AlCl_3$ is suspended in 50 ml of anhydrous 1,2-dichloroethane. 7.04 g (89.7 mmol) of acetyl chloride is added within 10 min to the stirred and cooled suspension followed by the addition of a solution of 5.50 g (28.1 mmol) of **1** in 50 ml of anhydrous 1,2-dichloroethane over a period of 50 min. After stirring for 40 h at room temp. the reaction mixture is poured onto 500 g of ice. The aluminum hydroxide is dissolved by adding dropwise 2 N HCl. The organic layer is separated, and the aqueous residue is extracted twice with 100 ml of dichloromethane. The combined organic layers are dried with Na_2SO_4 and evaporated under reduced pressure. The residue is recrystallized from ethanol. – Yield 6.40 g (81%). – M.p. 84°C

(ref.[4]) 85–86.5°C). – R_f [petroleum ether/ethyl acetate (1:1)] = 0.42. – IR (KBr): $\tilde{\nu}$ = 3030 cm^{-1}, 3000, 2930, 2910, 2860 (C–H), 1675 (C=O), 1600, 1570 (C–$C_{arom.}$), 1440, 1415, 1360, 850, 835, 815. – ^1H NMR ($CDCl_3$): δ = 2.03 (m, 2H, $CH_2CH_2CH_2$), 2.57 (s, 6H, CH_3), 2.70 (t, ^3J = 6.8 Hz, 4H, $CH_2CH_2CH_2$), 7.15–7.95 (AA'BB', 8H, aromatic H). – MS (70 eV): *m/z* (%) = 280 (46) [$M^{+\cdot}$], 265 (100) [$M^{+\cdot}$ – CH_3], 147 (12), 134 (23), 105 (15), 43 (66).

1,3-Bis(4-propionylphenyl)propane (**3**): 12.2 g (91.4 mmol) of anhydrous $AlCl_3$ is suspended in 50 ml of anhydrous 1,2-dichloroethane, and 7.45 g (80.5 mmol) of propionyl chloride is added within 10 min to the cooled mixture. Then, a solution of 5.00 g (25.5 mmol) of **1** in 50 ml of 1,2-dichloroethane is added slowly within 45 min. After stirring for 60 h at room temp. the reaction mixture is poured onto 500 g of ice. The workup occurs as with **2**, but recrystallization from methanol/ethanol/acetone (1:1:1). – Yield 5.10 g (65%). – M.p. 41°C (ref.[4] 42.4–44°C). – R_f [petroleum ether/ethyl acetate (1:1] = 0.55. – IR (KBr): $\tilde{\nu}$ = 2980 cm^{-1}, 2940, 2860 (C–H), 1680 (C=O), 1605 (C–$C_{arom.}$), 1450, 1410, 1375, 1350, 850, 790. – ^1H NMR ($CDCl_3$): δ = 1.15 (t, ^3J = 7.1 Hz, 6H, CH_2CH_3), 1.99 (m, 2H, $CH_2CH_2CH_2$), 2.67 (t, ^3J = 7.4 Hz, 4H, $CH_2CH_2CH_2$), 2.91 (q, ^3J = 7.1 Hz. 4H, CH_2CH_3), 7.12–7.95 (AA'BB', 8H, aromatic H). – MS (70 eV): *m/z* (%) = 308 (14) [$M^{+\cdot}$], 279 (100) [$M^{+\cdot}$ – C_2H_5], 91 (7), 57 (8).

10,11-Dialkyl[3.2]cyclophane-10-enes **4** *and* **5**. – *General Procedure:* 24.2 g (127.4 mmol) of $TiCl_4$ is added dropwise in a stream of nitrogen to 500 ml of dry THF at 0°C. After the addition of 23.9 g (365.0 mmol) of Zn dust and 1.00 g (12.60 mmol) of dry pyridine the mixture is stirred and refluxed for 2 h. A solution of 2.00 mmol of **2** (**3**) in 100 ml of dry THF is added dropwise within 80 h to this black reaction mixture using high-dilution techniques under continuous refluxing and stirring. The solution is refluxed for further 10 h (12 h) and then cooled to room temp. Hydrolysis is achieved by addition of 250 ml of a 10% K_2CO_3 solution. The insoluble residue is removed by filtration after the addition of 200 ml of dichloromethane and extracted twice with 100 ml of dichloromethane. The combined organic layers are dried with Na_2SO_4 and evaporated under reduced pressure. The resulting residue is recrystallized from ethanol.

4: Yield 0.41 g (82%). – M.p. 147–149°C. – R_f (CH_2Cl_2) = 0.80. – IR (KBr): $\tilde{\nu}$ = 3010 cm^{-1}, 2970, 2840 (C–H), 1605 (C=C, C–$C_{arom.}$), 1440. – UV (*n*-heptane): λ_{max} (lgε) = 214 nm (4.138), 272 (2.952). – ^1H NMR ($CDCl_3$): δ = 2.01 (m, 2H, $CH_2CH_2CH_2$), 2.19 (s, 6H, CH_3), 2.70 (s, 4H, $CH_2CH_2CH_2$), 6.40–6.70 (AA'BB', 8H, aromatic H). – MS (70 eV): *m/z* (%) = 248 (100) [$M^{+\cdot}$], 233 (51) [$M^{+\cdot}$ – CH_3], 218 (24), 203 (10), 141 (5), 129 (11), 91 (6).

$C_{19}H_{20}$ (248.4) Calcd. C 91.88 H 8.12
Found C 90.93 H 8.03
Calcd. 248.1565 Found 248.1564 (MS)

5: Yield 0.33 g (60%). – M.p. 190°C. – R_f (CH_2Cl_2) = 0.81. – IR (KBr): $\tilde{\nu}$ = 3020 cm^{-1}, 2960, 2870, 2850 (C–H), 1595 (C=C), 1460. – UV (*n*-heptane): λ_{max} (lgε) = 215 nm (4.217), 274 (3.053). – ^1H NMR ($CDCl_3$): δ = 1.18 (t, ^3J = 7.4 Hz, 6H, CH_2CH_3), 2.10 (m, 2H, $CH_2CH_2CH_2$), 2.60 (q, *J* = 7.4 Hz, 4H, CH_2CH_3), 2.71 (s, 4H, $CH_2CH_2CH_2$), 6.39–6.70 (AA'BB', 8H, aromatic H). – MS (70 eV): *m/z* (%) = 276 (100) [$M^{+\cdot}$], 247 (39) [$M^{+\cdot}$ – C_2H_5], 218 (24), 203 (10), 141 (5), 129 (11), 91 (6).

$C_{21}H_{24}$ (276.4) Calcd. C 91.25 H 8.75
Found C 90.33 H 8.77
Calcd. 276.1878 Found 276.1876 (MS)

10,11,27,28-Tetraalkyl[3.2.3.2]paracyclophane-10,27-dienes **6** *and* **7**. – *General Procedure:* 30.0 ml (270 mmol) of $TiCl_4$ is added dropwise at 0°C to 1.5 l of absolute THF under nitrogen. After the addition of 22.0 g (340 mmol) of Zn dust and 1.00 g (12.6 mmol) of dry pyridine the mixture is refluxed for 2 h, and a solution of 14.0 mmol of **2** (**3**) in 50 ml of absolute THF is added dropwise to this black reaction mixture within 12 h (10 h) using high-dilution techniques under continuous stirring and refluxing. Then, the reaction mixture is cooled and hydrolyzed with 300 ml of a 10% K_2CO_3 solution. After filtration the organic layer can be separated by addition of diethyl ether, and the insoluble residue is extracted twice with diethyl ether. The organic layers are washed with water, dried with Na_2SO_4, and evaporated under reduced pressure. The colourless residue is recrystallized from toluene.

6: Yield 1.12 g (32%). – M.p. 192°C. – R_f [petroleum ether/ethyl acetate (1:1)] = 0.79. – IR (KBr): $\tilde{\nu}$ = 3019 cm^{-1}, 2993, 2924, 2850 (C–H), 1608, 1506 (C=C, C–$C_{arom.}$), 1435, 1019, 844, 828, 812, 726. – UV (*n*-heptane): λ_{max} (lgε) = 278 nm (4.853). – ^1H NMR ($CDCl_3$): δ = 1.68 (quint, ^3J = 7.3 Hz, 4H, $CH_2CH_2CH_2$), 2.16 (s, 12H, CH_3), 2.35 (t, ^3J = 7.3 Hz, 8H, $CH_2CH_2CH_2$), 6.80 (s, 16H, aromatic H). – MS (70 eV): *m/z* (%) = 496 (100) [$M^{+\cdot}$], 219 (23), 205 (21), 129 (22), 117 (18), 91 (28).

$C_{38}H_{40}$ (496.7) Calcd. C 91.88 H 8.12
Found C 91.80 H 8.56
Calcd. 496.3130 Found 496.3130 (MS)

7: Yield 2.24 g (58%). – M.p. 209°C. – R_f [petroleum ether/ethyl acetate (1:1)] = 0.81. – IR (KBr): $\tilde{\nu}$ = 3017 cm^{-1}, 2969, 2939, 2861 (C–H), 1508 (C–$C_{arom.}$), 1454, 1321, 1122, 1022, 838, 818, 790. – UV (*n*-heptane): λ_{max} (lgε) = 272 nm (4.762). – ^1H NMR ($CDCl_3$): δ = 0.98 (t, ^3J = 7.4 Hz, 12H, CH_2CH_3), 1.64 (quint, ^3J = 6.9 Hz, $CH_2CH_2CH_2$), 2.31 (t, ^3J = 6.9 Hz, 8H, $CH_2CH_2CH_2$), 2.55 (q, ^3J = 7.4 Hz, 8H, CH_2CH_3), 6.77 (s, 16H, aromatic H). – MS (70 eV): *m/z* (%) = 552 (100) [$M^{+\cdot}$), all signals of fragment ions > 14%.

$C_{42}H_{48}$ (552.8) Calcd. C 91.25 H 8.75
Found C 91.30 H 8.78
Calcd. 552.3756 Found 552.3756 (MS)

1,3-Bis(4-chloroformylphenyl)propane (**8**): A solution of 9.50 g (75.0 mmol) of oxalyl chloride in 25 ml of dry dichloromethane is added dropwise to a stirred suspension of 10.0 g (75.0 mmol) of anhydrous $AlCl_3$ in 100 ml of dry dichloromethane at –15°C. The reaction mixture is stirred for further 30 min at this temp., and a solution of 4.00 g (20.4 mmol) of **1** in 50 ml of dry dichloromethane is added at –15°C within 30 min. The reaction mixture is stirred for 5 h at –15°C and then poured onto 500 g of ice. The organic phase is separated, and the aqueous phase is extracted with three portions of 100 ml of diethyl ether/dichloromethane (1:1). The combined organic phases are dried with Na_2SO_4. After evaporation of the solvent the yellow product is suspended in 100 ml of anhydrous chlorobenzene and refluxed for 5 h. The solvent is evaporated under reduced pressure, and the yellow crude material is used without further purification. – Yield 5.24 g (80%).

1,3-Bis[4-(4-methylbenzoyl)phenyl]propane (**9**): 4.00 g (12.50 mmol) **8** is suspended in 100 ml of anhydrous toluene. At 0°C a suspension of 6.50 g (48.74 mmol) of anhydrous $AlCl_3$ in 100 ml of dry toluene is added cautiously. The reaction mixture is stirred for 1 h at 0°C and 18 h at room temp. The mixture is poured onto 400 g of ice, the organic phase is separated, and the aqueous layer is extracted twice with 100 ml of dichloromethane. The combined organic phases are dried with Na_2SO_4 and purified by filtration through a 2.5-cm layer of silica gel. The silica gel layer is extracted with petroleum ether/ethylacetate (1:1). The combined organic phases are evaporated, and the slighly pink residue is recrystallized

from ethyl acetate. – Yield 2.25 g (42%). – M.p. 143–144°C. – R_f [petroleum ether/ethyl acetate (1:1)] = 0.56. – IR (KBr): $\tilde{\nu}$ = 3050 cm^{-1}, 2940, 2880 (C–H), 1675 (C=O), 1605, 1570 (C–$C_{arom.}$), 1415, 1360, 815, 800. – ^1H NMR ($CDCl_3$): δ = 1.99 (m, 2H, $CH_2CH_2CH_2$), 2.38 (s, 6H, CH_3), 2.70 (t, ^3J = 7.2 Hz, 4H, $CH_2CH_2CH_2$), 7.10–7.85 (2 AA'BB', 16H, aromatic H). – MS (70 eV): *m/z* (%) = 432 (70) [$M^{+\cdot}$], 341 (16), 223 (12), 210 (22), 119 (100), 91 (29).

10,11,27,28-Tetrakis(4-methylphenyl)[3.2.3.2]paracyclophane-10,27-dien (**10**): 20.7 g (109.2 mmol) of $TiCl_4$ is added dropwise under nitrogen within 30 min at 0°C to 400 ml of anhydrous dioxane. After the addition 14.0 g (214.0 mmol) of Zn dust is added, and the mixture is refluxed for 2 h. A solution of 0.65 g (1.500 mmol) of **9** in 100 ml of anhydrous dioxane is added dropwise to the black reaction mixture over 80 h using high-dilution techniques continuing the refluxing and stirring. After the addition the mixture is further refluxed for 10 h to complete the reaction and then cooled and hydrolized with 300 ml of 10% aqueous solution of K_2CO_3. 200 ml of dichloromethane is added, the unsoluble residue filtered off and extracted twice with 100 ml of dichloromethane. The combined organic layers are dried with Na_2SO_4 and evaporated under reduced pressure. The residue is purified by column chromatography on silica gel using dichloromethane as eluent. – Yield 0.09 g (6.6%). – M.p. 355°C. – R_f (CH_2Cl_2) = 0.81. – IR (KBr): $\tilde{\nu}$ = 3080 cm^{-1}, 3050, 3020, 2990, 2930, 2860 (C–H), 1610, 1510, 1440, 1410 (C=C, C–$C_{arom.}$), 840, 820, 810. – UV (*n*-heptane): λ_{max} (lgε) = 212 nm (4.453), 248 (4.302), 290 (3.952), 320 (4.034). – ^1H NMR ($CDCl_3$): δ = 1.73 (m, 4H, $CH_2CH_2CH_2$), 2.28 (s, 12H, CH_3), 2.41 (t, 8H, $CH_2CH_2CH_2$),-6.85 (AA'BB', 16H, aromatic H, endocyclic), 6.93 (AA'BB', 16H, aromatic H, exocyclic). – MS (70 eV): *m/z* (%) = 800 (100) [$M^{+\cdot}$], 400 (21), 105 (8).

$C_{62}H_{56}$ Calcd. 800.4382 Found 800.4384 (MS)

1,3-Bis(4-formylphenyl)propane (**12**): 2.80 g (8.2 mmol) of 1,3-bis(4-ethoxycarbonylphenyl)propane in 100 ml of dry THF is added slowly to a suspension of 3.00 g (78 mmol) of $LiAlH_4$ in 100 ml of dry THF and eventually refluxed for ca. 12 h. The reaction mixture is hydrolyzed and acidified with dilute HCl and thoroughly extracted with dichloromethane. The organic extracts are dried with Na_2SO_4, and the crude *1,3-bis(4-hydroxymethylphenyl)propane* (**11**) 1.80 g, 86%) is used without further purification.

1.80 g (7.0 mmol) of **11** is redissolved in 50 ml of dichloromethane and treated with 43.4 g of PCC/Al_2O_3 (1 g ≙ 1 mmol of PCC) for 2 h at room temp. The reaction mixture is filtered, and the residue is rinsed with dichloromethane. The combined organic filtrates are evaporated under reduced pressure. The crude product **12** (1.30 g) is purified by column chromatography using ethyl acetate as the eluent. – Yield 1.30 g (71%). – M.p. 252°C. – R_f (ethyl acetate) = 0.68. – IR (KBr): $\tilde{\nu}$ = 3031 cm^{-1}, 2940, 2858 (C–H), 1697 (C=O), 1605, 1576 (C–$C_{arom.}$). – ^1H NMR (CD_3Cl): δ = 2.10 (m, 2H, $CH_2CH_2CH_2$), 2.75 (t, 4H, $CH_2CH_2CH_2$), 7.26–7.87 (AA'BB', 8H, aromatic H), 9,99 (s, 2H, HCO). – MS (70 eV): *m/z* (%) = 252 (14) [$M^{+\cdot}$], 133 (23), 120 (19), 105 (44), 103 (19), 92 (73), 91 (100), 79 (12), 77 (43).

[3.2]Paracyclophane-10-ene (**13**): 19.0 g (100 mmol) of $TiCl_4$ is slowly added in a stream of nitrogen to 1000 ml of absolute dimethoxyethane at –20°C using an apparatus for high dilution. After stirring for additional 30 min, 13.3 g (200 mmol) of Zn(Cu) and 1.4 ml of pyridine are added, and the black-greenish mixture is refluxed for 2 h. Then, 1.20 g (4.70 mmol) of **12** in 100 ml of absolute dimethoxyethane is added continuously within 60 h followed by refluxing of the mixture for further 12 h. After cooling to room temp. the mixture is hydrolyzed carefully by the addition of 300 ml of a 10% K_2CO_3 solution and stirring for 4 h. The residue formed is filtered off, and the residue and the filtrate are extracted with diethyl ether. The combined organic solutions are dried with Na_2SO_4, concentrated under reduced pressure, and filtered through a layer of silica gel. After evaporation the crude material (300 mg) is purified by column chromatography using CCl_4 as eluent. – Yield 0.14 g (14%). – R_f (CCl_4) = 0.68. – A sample is further purified by HPLC (Milton Roy, Model III; column RP 18, 10μ; eluent CH_3OH). – IR (KBr): $\tilde{\nu}$ = 3018 cm^{-1}, 2932, 2848 (C–H), 1597, 1511 (C=C,C–$C_{arom.}$), 1437, 1400, 1109, 963, 888, 803, 779, 708. – ^1H NMR ($CDCl_3$): δ = 2.03 (quint, 2H, $CH_2CH_2CH_2$), 2.71 (m, not resolved, 4H, $CH_2CH_2CH_2$), 6.43–6.68 (AA'BB', 8H, aromatic H), 7.21 (s, 2H, CH=CH). – MS (70 eV): *m/z* (%) = 220 (100) [$M^{+\cdot}$], 219 (17), 205 (20), 191 (17), 189 (16), 178 (14), 165 (16), 115 (29), 91 (9), 89 (13).

$C_{17}H_{16}$ Calcd. 220.1252 Found 220.1252 (MS)

During the column chromatography 0.11 g (8.1%) of the macrocyclic dimer has been isolated from the fractions after the elution of **13**. However, the dimer is contaminated with about 10% of an impurity of higher molecular weight, which could not be separated by chromatography. – MS (70 eV): *m/z* (%) = 440 (100) [$M^{+\cdot}$], 220.5 (2.5) [$^{13}M^{2+}$], 220 (13) [M^{2+}], 219 (18), 207 (15), 206 (10), 193 (12), 191 (11), 178 (6), 165 (4), 129 (7), 117 (12), 105 (8), 91 (16).

$C_{34}H_{32}$ Calcd. 440.2503 Found 440.2504 (MS)

1,3-Bis(3-formylphenyl)propane (**15**): 56.0 ml (89.0 mmol) of *n*-BuLi is added slowly to a solution of 10.0 g (28.2 mmol) of **14** in 200 ml of absolute diethyl ether at 0–5°C in a stream of nitrogen. The mixture is stirred at 0°C for 4 h yielding an intensively red solution. After cooling to –5°C 12.4 ml (112 mol) of *N*-formylpiperidine is added within 90 min; during this time the colour of the suspension changes from red to pale yellow. Stirring is continued over night at room temperature. The reaction mixture is acidified with dilute HCl and extracted with several portions of dichloromethane. The combined organic phases are washed successively with 10% $NaHCO_3$ solution and H_2O and evaporated under reduced pressure. The residue is redissolved in diethyl ether and again extracted three times with H_2O, dried with Na_2SO_4, and then evaporated. The crude product is purified by column chromatography using dichloromethane as eluent giving a colourless oil. – Yield 3.40 g (49%). – R_f (CH_2Cl_2) = 0.32. – IR (KBr): $\tilde{\nu}$ = 3030 cm^{-1}, 2932, 2664 (C–H), 1693 (C=O), 1606, 1588 (C–$C_{arom.}$). – ^1H NMR ($CDCl_3$): δ = 2.10 (q, 2H, $CH_2CH_2CH_2$), 2.78 (t, 4H, $CH_2CH_2CH_2$), 7.25–7.75 (m, 8H, aromatic H), 9.90 (s, 2H, HCO). – MS (70 eV): *m/z* (%) = 252 (94) [$M^{+\cdot}$], 133 (60), 120 (49), 119 (62), 105 (66), 103 (20), 92 (100), 91 (91), 79 (23), 77 (28).

[3.2]Metacyclophane-10-ene (**16**): 11.6 ml (100 mmol) of $TiCl_4$ is added dropwise in a stream of nitrogen to 300 ml of absolute dimethoxyethane at –70°C, followed by the slow addition of 13.3 g (200 mmol) of Zn(Cu) and 1.4 ml of pyridine. The mixture is refluxed for 1 h. Then, 0.50 g (1.98 mmol) of **15** in 100 ml of absolute dimethoxymethane is added to the black-greenish slurry using high-dilution techniques within 60 h under continuous refluxing and stirring. The reaction is completed by further refluxing for 12 h. The workup followed the procedure given for **13** and the crude material (0.45 g) was purified twice by column chromatography using petroleum ether/ethyl acetate (9:1) and *n*-heptane as the eluents giving a colourless oil. – Yield 0.25 g (58%). – R_f [petroleum ether/ethyl acetate (9:1)] = 0.46. – IR (KBr): $\tilde{\nu}$ = 3050 cm^{-1}, 3008, 2913, 2855 (C–H), 1600, 1576 (C=C, C–$C_{arom.}$), 1475, 1450, 1430, 955, 820, 752, 718. – ^1H NMR (CCl_4): δ = 1.92 (q, 2H, $CH_2CH_2CH_2$), 2.43 (t, 4H, $CH_2CH_2CH_2$), 6.05 (s, 2H, aromatic H_i,

anti conformation), 6.65 (s, 2H, C*H*=C*H*), 6.8–7.3 (m, 6H, aromatic H). – MS (70 eV): *m/z* (%) = 220 (100) [$M^{+\cdot}$], 219 (32), 218 (13), 205 (45), 203 (32), 192 (54), 191 (91), 190 (20), 178 (29), 165 (12). $C_{17}H_{16}$ Calcd. 220.1252 Found 220.1252 (MS)

From a later fraction during the column chromatography 10 mg (2.3%) of the macrocyclic dimer have been obtained. – MS (70 eV): *m/z* (%) = 440 (100) [$M^{+\cdot}$], 220.5 (2.3) [$^{13}M^{2+}$], 220 (15) [M^{2+}], 208 (14), 205 (19), 203 (12), 193 (19), 191 (18), 179 (13), 178 (19), 165 (10), 129 (16), 117 (17), 105 (17), 91 (24).

$C_{34}H_{32}$ Calcd. 440.2303 Found 440.23 (MS)

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