Synthesis of novel mono- and diaryl-substituted [2.2]paracyclophanes

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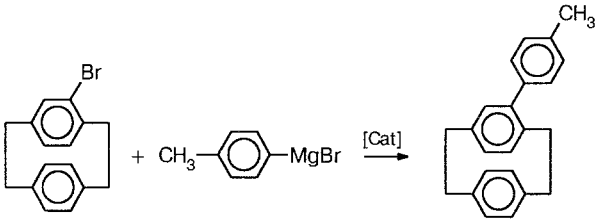
The cross-coupling reactions of 4-bromo[2.2]paracyclophane with *p*-tolylmagnesium bromide in the presence of various palladium and nickel complexes have been studied. It was found that [1,1'-bis(diphenylphosphinoferrocene)]palladium dichloride ($PdCl_2 \cdot$ dppf) shows the highest catalitic activity in this reaction. A series of new mono- and diaryl [2.2]paracyclophane derivatives with various substituents in the arene ring have been synthesized using this catalyst. It was shown that it is possible to cross-couple organozinc [2.2]paracyclophane derivatives with aromatic bromides. The composition and structure of the compounds obtained have been established on the basis of elemental analysis and spectral data. Some correlations between the structure and spectral parameters of mono- and diaryl-substituted [2.2]paracyclophanes have been found.

Key words: 4-bromo[2.2]paracyclophane; cross-coupling, catalysts; arylsubstituted [2.2]paracyclophanes.

[2.2]Paracyclophane (**1**) and some of its simplest derivatives can form mono- and binuclear π-complexes incorporating a chromotricarbonyl moiety.[1—3] It was of interest to develop this work further by studying the comparative π-complexing ability of the aromatic rings of [2.2]paracyclophane and of usual arenes.[4] In order to find ways of solving this problem, it was necessary to synthesize ligands of the [2.2]paracyclophane series containing various aromatic substituents. Several methods have been reported in the literature for the synthesis of aryl-substituted derivatives of [2.2]paracyclophane **1**. The first method[5] involves a radical reaction of compound **1** with *N*-acetyl-*N*-nitrosoaniline to give 4-phenyl[2.2]paracyclophane in only 5 % yield. There have been several examples showing the possibility of the synthesis of diphenyl derivatives (the 4,7- and 4,15-isomers) of **1** by the cleavage of the respective dithia[3.3]paracyclophanes.[6] The last and most general method[7] involves the cross-coupling of monobrominated [2.2]paracyclophane with arylmagnesium bromides catalyzed by phosphine complexes of nickel. This approach has been used to obtain derivatives of compound **1** with phenyl, 2-methylphenyl, and 2,4,6-trimethylphenyl substituents in 9—60 % yields.

In the present work we used the cross-coupling reaction to synthesize novel derivatives of **1** containing various aryl substituents. For this purpose, we optimized the reaction conditions to increase the yield of the target products. We also studied whether it is possible to introduce two aryl substituents into a molecule of **1**. Furthermore, we studied the comparative catalytic activity of Ni and Pd complexes in a model reaction of the cross-coupling of 4-bromo[2.2]paracyclophane (**2**) with 4-tolylmagnesium bromide (Scheme 1).

Scheme 1



2 **5a**

The phosphine complex of Pd^0 displayed the lowest activity (the yield of the product was 65 % after 12 h). When the phosphine complex of nickel was used as the catalyst, the same yield was attained in 4 h (Table 1). The highest catalytic efficiency was shown by the diphenylphosphinoferrocene complex of palladium dichloride, which provided a yield of 67 % in 30 min almost without side products of homo-coupling. Thus, it was shown that $PdCl_2 \cdot$ dppf is the most promising catalyst for the synthesis of arylcyclophanes. Therefore we used this catalyst in the subsequent study.

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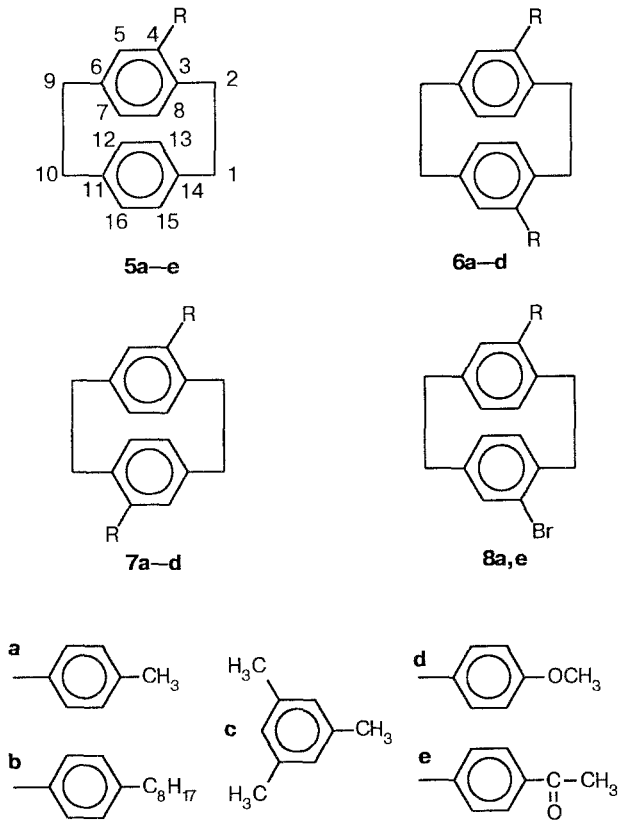
Table 1. Conditions of the reaction of 4-bromo[2.2]paracyclophane **2** with 4-tolylmagnesium bromide (RMgX) and the yield of 4-(4-methylphenyl)-[2.2]paracyclophane (**5a**) (THF, 64 °C)

[Cat] (1 mol.%)	Ratio RMgX/(**2**)	Reaction time /h	Degree of conversion(%)	Yield (%)
$NiBr_2(PPh_3)_2$	2.0	4	100	65
$Pd(PPh_3)_4$	2.5	2	44	11
$Pd(PPh_3)_4$	3.0	12	98	65
$PdCl_2$dppf*	1.5	0.5	100	67

* dppf indicates [1,1'-bis(diphenylphosphino)ferrocene].

We used 4-bromo- (**2**) as well as isomeric 4,15-dibromo-(*pseudo-meta*)- (**3**) and 4,16-dibromo-(*pseudo-para*)- (**4**) derivatives of [2.2]paracyclophane as substrates, which we converted by cross-coupling with the corresponding arylmagnesium bromides into a series of aryl[2.2]paracyclophanes (**5—8**) (Scheme 2).

Scheme 2



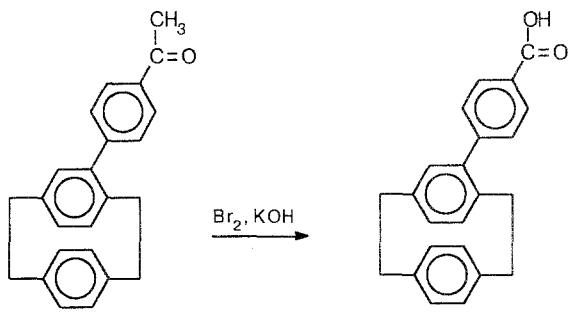
For the reactions with dibromides **3** and **4**, at least a 1.5-molar excess of the Grignard reagents was required in order to replace each of the two bromine atoms. The end of the reaction was determined using TLC on SiO_2 by the disappearance of the spot of the starting dibromide. Table 2 presents the conditions of the cross-coupling of various Grignard reagents with bromides **2—4** and the yields of the products, **5—8**.

As follows from our results, the reactions of almost all organomagnesium reagents with bromides **2—4** are completed within 0.5—3.5 h and give 47—87 % yields. It should be noted that the isolation of the target products formed from dibromide **4** (the more symmetric *pseudo-para* isomer) is much easier due to their precipitation from the reaction mixture as poorly soluble solids (except for compound **7b**).

The considerable duration (up to 20 h) of the cross-coupling of aromatic and aliphatic bromides with 2,4,6-trimethylphenylmagnesium bromide has already been observed previously.[8] In particular, compound **5c** has been obtained in 12.3 % yield by boiling the reaction mixture for 20 h and using a fivefold excess of a Grignard reagent.[7] We used a more efficient catalyst, which made it possible to increase the yield of compound **5c** to 85 % while the duration of the process decreased to 11 h. To diminish the time of the reaction with dibromides **3** and **4**, the molar fraction of the catalyst was increased 2—3 times.

In order to carry out the reaction with 4-bromoacetophenone, we first obtained the corresponding ketal,[9] which was then transformed to the Grignard reagent. The ketal protection was removed without isolating the dioxolane derivative of [2.2]paracyclophane formed in the reaction mixture. The 4-(4-acetylphenyl)[2.2]paracyclophane **5e** was oxidized to the corresponding carboxylic acid (**9**) in quantitative yield (Scheme 3).

Scheme 3



In the attempt to obtain the bis-acetylphenyl derivative from dibromide **3** the only product which could be isolated from the reaction mixture in the pure state was 4-(4-acetylphenyl)-15-bromo[2.2]paracyclophane (**8e**). It should be noted that this reaction also affords a mixture of two other compounds, which we could not separate and identify due to their extremely low solubility. However, it cannot be ruled out that the reaction mixture

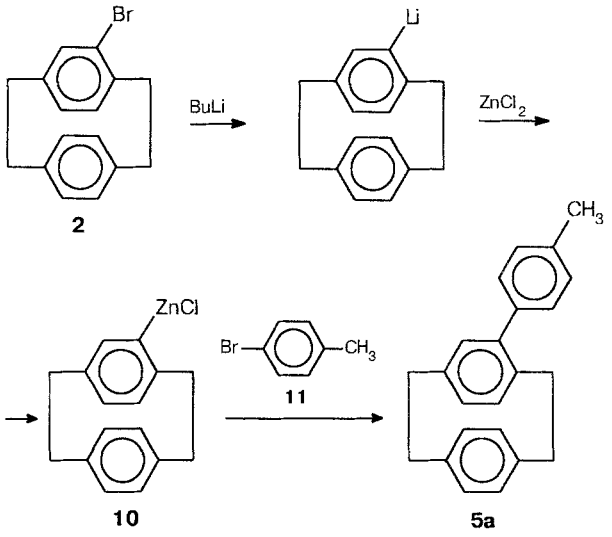
Table 2. The reaction of brominated [2.2]paracyclophanes **2—4** with arylmagnesium bromides RMgBr (for R see Scheme 2), in THF at 64 °C

Ratio RMgX/(**2—4**)	[Cat] (mol. %)	Reaction time /h	Product	Yield (%)
3.4	1	1.5	**6a**	65
3.4	1	1.5	**7a**	70
1.5	1	0.6	**5в**	50
3.0	2	1.5	**6в**	47
3.0	2	1.5	**7в**	48
4.5	2	11.0	**5c**	85
7.0	6	20.0	**6c**	75
7.0	4	16.0	**7c**	56
1.5	1	3.0	**5d**	87
3.0	2	2.0	**6d**	61
3.0	2	2.0	**7d**	78
1.7	1	3.5	**5e**	53
2.2	1	4.5	**6e**	28
2.0	1	0.7	**6a**	25
			8a	35

contains a product of diarylation. We believe that the decrease in the reaction rate can be explained by the increased steric hindrance due to the presence of a bulky group (just like in the case of compounds **5—7c**) at the reaction center of the Grignard reagent. These observations lead us to believe that cross-coupling reactions involving dibromides **3** and **4** can make the directed isolation of type **8** monoaryl derivatives possible. In fact, when a twofold excess of 4-tolylmagnesium bromide was used in the reaction with bromide **3** and the reaction time was decreased to 40 min, only the product corresponding to the substitution of one bromine atom, 4-(4-methylphenyl)-15-bromo[2.2]paracyclophane (**8a**), was isolated in 35 % yield along with product **6a** (yield 25 %). Thus, varying the cross-coupling conditions provides a way to synthesize [2.2]paracyclophane derivatives with two different aryl substituents in a molecule.

In spite of all the merits of the cross-coupling of [2.2]paracyclophane bromides with the Grignard reagents, this method does not permit the synthesis of compounds containing reactive functional groups without introducing protective groups. A method reported earlier[10] for the synthesis of an organomagnesium compound from bromide **2** involves refluxing **2** for 16 h with Mg (activated by first transforming it to $MgCl_2$ and then reducing the latter with metallic potassium). Diaryls with reactive functional groups can be synthesized using the reactions of bromides with organotin[11] or organozinc[12] compounds. However, we have shown previously[13] that the cross-coupling of 4-trimethylstannyl[2.2]paracyclophane with *p*-nitroiodobenzene catalyzed by $PdCl_2(CH_3CN)_2$ involves the transfer of the methyl moiety, rather than the paracyclophane moiety, to the aryl, which results in *p*-nitrotoluene. Therefore, it seemed interesting to carry out the coupling of the organozinc paracyclophane derivative **10** with aromatic bromide **11** (Scheme 4).

Scheme 4



The $PdCl_2 \cdot$ dppf complex showed no catalytic activity. However, the corresponding cross-coupling product was obtained in 33 % yield in the presence of $Pd(PPh_3)_4$. Thus, we demonstrated that it is possible to perform the cross-coupling using a paracyclophane-derived organometallic reagent.

Except for **6b**, all of the compounds obtained are colorless crystals having distinct melting points. It is convenient to determine the structures of aryl-substituted [2.2]paracyclophanes by NMR spectroscopy, since the chemical shifts of the protons lie within definite ranges and have typical multiplicity. The signals of the aromatic protons of [2.2]paracyclophane are shifted 1.0—1.5 ppm upfield in comparison with the aromatic protons of the aryl substituent, which simplifies the assignment of signals in the spectra. This upfield shift is due to the mutual anisotropic effect of the aromatic rings located close to one another in the molecule. In the case of mono-substituted derivatives, **5a—e**, the aromatic protons of the cyclophane rings (PCR) manifest themselves as a complex multiplet, whose relative integral intensity corresponds to seven protons. The spectra of the aromatic protons in the bis-arylated compounds **6a—d** and **7a—d** are more informative: the six protons of these rings are pairwise equivalent and form an ABX spin system with the coupling constants ^3J = 7.8 Hz, ^4J = 1.6 Hz.

The two ABX-systems of the aromatic cyclophane rings in the spectra of compound **8e** overlap, which considerably hampers the assignment of each signal. The signal of the proton located just under the bromine atom

(the *pseudo-gem*-position) is shifted 0.7 ppm downfield. Such an effect of bromine atoms on the *pseudo-gem*-position has been reported previously.[13,14] The signals of the aromatic protons of the substituents in compounds **5—7a,b,d** form an AA'BB' spin system and appear in the spectra as two doublets in the range 7.45—7.5 ppm. For the acetyl- (**5e**, **8e**) and carboxyphenyl (**9**) derivatives, these signals are shifted downfield by 7.6—8.2 ppm. The two nonequivalent protons in the mesitylene substituent in compounds **5—7c** appear as singlets at 6.9 and 7.1 ppm.

Interesting behavior was observed for the aliphatic bridge protons. In the spectra of 4-aryl- (**5a—d**) and 4,16-diaryl[2.2]paracyclophanes **7a—d**, the signals of one or two protons, respectively, stood out of the overall complex multiplet. Probably, this effect can be attributed to the fact that the bridge proton is located in the zone of the ring current of the aryl substituent, which results in the downfield displacement of its signal. A similar simultaneous effect of both the magnetic contributions and electric field on the chemical shifts of bridge protons has been reported previously for acetyl-, carboxymethyl-, and nitro[2.2]paracyclophanes,[15] where it was attributed to the location of the bridge protons in the deshielding cone of the C=O and N=O bonds.

The methyl protons of the mesitylene substituents in compounds **5—7c** display three different singlet signals, which indicates that the mesitylene moiety slowly rotates (on the NMR time scale) around the C—C bond relative to the [2.2]paracyclophane frame.

The elemental analysis and mass-spectral data also fully confirm the structures of the compounds obtained. In all cases, the mass spectra contain molecular ion peaks and display fragmentation patterns typical of the [2.2]paracyclophane series.

Experimental

All reactions were carried out in dry solvents under argon. NMR spectra were recorded on a Bruker-WP-200SY spectrometer (200 MHz) in $CDCl_3$ using Me_4Si as the internal standard.

TLC analyses were performed on Silufol UV-254 plates from Chemapol (pentane : benzene, 5 : 1). Chromatographic separation of reaction mixtures was carried out on silica gel Chemapol L 40/100 and Merck 70/230 using pentane : ether (7 : 1) as the eluent.

The synthesis of ArMgX. The Grignard reagents were obtained by treatment of activated (I_2) magnesium strips with an aryl bromide (ArBr; 10 mmol) in THF (10 mL).

The general procedure for the synthesis of compounds 5—7a,b. The ArMgX reagent (at least 1.5 mmol per Br atom) was added with stirring to a mixture of bromide **2—4** (2 mmol) and the catalyst ($PdCl_2$ · dppf) (1—2 mol. %). The reaction mixture was heated for 0.5—1.5 h, diluted with saturated aqueous NH_4Cl, washed with H_2O, and dried with $MgSO_4$. The solvent was distilled off, and the residue was recrystallized or purified by column chromatography on silica gel.

4-(4-Tolyl)-[2.2]paracyclophane (5a). Yield 67 %, m.p. 108.5—109 °C (from EtOH). Found (%): C, 92.25; H, 7.47. $C_{23}H_{22}$. Calculated (%): S, 92.56; H, 7.43. ^1H NMR ($CDCl_3$), δ: 2.32 (s, 3 H, CH_3); 2.52—3.12 (m, 7 H, bridge); 3.28—3.47 (m, 1 H, bridge); 6.38—6.55 (m, 7 H, paracyclophane); 7.20 (d, 2 H, Ar); 7.36 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 298 [M^+] (35), 194 (40), 193 (100), 179 (58), 178 (38), 104 (20).

4,15-Bis(4-tolyl)-[2.2]paracyclophane (6a) was obtained by recrystallization of the residue after the solvent was distilled off, yield 65 %, m.p. 187—188.5 °C (from EtOH). Found (%): C, 92.44; H, 7.51. $C_{30}H_{28}$. Calculated (%): C, 92.74; H, 7.26. ^1H NMR ($CDCl_3$), δ: 2.45 (s, 6 H, $2CH_3$); 3.22 (m, 8 H, bridge); 6.61 (dd, 2 H, ^3J = 7.6 Hz, ^4J = 1.6 Hz, H-7, H-12); 6.76 (d, 2 H, ^3J = 7.6 Hz, H-8, H-13); 6.77 (d, 2 H, ^4J = 1.6 Hz, H-5, H-16); 7.34 (d, 4 H, Ar); 7.46 (d, 4 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 388 [M^+] (42), 195 (90), 194 (52), 193 (100), 179 (77), 178 (50), 165 (10).

4,16-Bis(4-tolyl)-[2.2]paracyclophane (7a) was obtained by recrystallization of the precipitate that formed after the work-up with ether; yield 70 %, m.p. 288—289.5 °C (from toluene). Found (%): C, 92.44; H, 7.24. $C_{30}H_{28}$. Calculated (%): C, 92.74; H, 7.26. ^1H NMR ($CDCl_3$), δ: 2.46 (s, 6 H, $2CH_3$); 2.75—3.10 (m, 6 H, bridge); 3.47—3.58 (m, 2 H, bridge); 6.59 (dd, 2 H, ^3J = 7.6 Hz, ^4J = 1.6 Hz, H-7, H-13); 6.65 (d, 2H, ^3J = 7.6 Hz, H-8, H-12); 6.65 (d, 2 H, ^4J = 1.6 Hz, H-5, H-15); 7.32 (d, 2 H, Ar); 7.43 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 388 [M^+] (25), 195 (100), 194 (30), 193 (30), 179 (62), 178 (39), 165 (8).

4-(4-Octylphenyl)-[2.2]paracyclophane (5b). Yield 50 %, m.p. 30 °C (from EtOH). Found (%): C, 90.63; H, 9.28. $C_{30}H_{36}$. Calculated (%): C, 90.85; H, 9.15. ^1H NMR ($CDCl_3$), δ: 0.92 (m, 3 H, CH_3); 1.25—1.82 (m, 12 H, $6CH_2$); 2.59—3.24 (m, 2 H, $C_6H_4C\underline{H}_2$, 7 H, bridge); 3.32—3.58 (m, 1 H, bridge); 6.42—6.68 (m, 7 H, paracyclophane); 7.27 (d, 2 H, Ar); 7.38 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 396 [M^+] (42), 291 (88), 193 (27), 179 (100), 178 (40), 165 (10), 105 (21), 104 (20).

4,15-Bis(4-octylphenyl)-[2.2]paracyclophane (6b). Yield 47 %. An oil. Found (%): C, 90.26; H, 9.35. $C_{44}H_{56}$. Calculated (%): C, 90.35; H, 9.65. ^1H NMR ($CDCl_3$), δ: 0.85 (m, 6 H, 2 CH_3); 1.25—1.87 (m, 24 H, 12 CH_2); 2.42—2.55 (m, 4 H, $C_6H_4C\underline{H}_2$); 2.69—3.38 (m, 8 H, bridge); 6.52 (dd, 2 H, ^3J = 7.6 Hz, ^4J = 1.6 Hz, H-7, H-12); 6.68 (d, 2 H ^3J = 7.6 Hz, H-8, H-13); 6.68 (d, 2 H, ^4J = 1.6 Hz, H-5, H-16); 7.25 (d, 2 H, Ar); 7.45 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 585 [M^+] (25), 584 (60), 290 (60), 291 (78), 193 (50), 179 (100), 178 (40).

4,16-Bis(4-octylphenyl)-[2.2]paracyclophane (7b). Yield 48 %, m.p. 70 °C (from toluene : EtOH). Found (%): C, 90.34; H, 9.87. $C_{44}H_{56}$. Calculated (%): C, 90.35; H, 9.65. ^1H NMR ($CDCl_3$), δ: 0.82 (m, 6 H, 2 CH_3); 1.15—1.75 (m, 24 H, 12 CH_2); 2.60 (m, 4 H, $C_6H_4C\underline{H}_2$, 2 H, bridge); 2.68—3.05 (m, 4 H, bridge); 3.30—3.48 (m, 2 H, bridge); 6.63 (dd, 2 H, ^3J = 7.6 Hz, ^4J = 1.6 Hz, H-7, H-13); 6.70 (d, 2 H ^3J = 7.6 Hz, H-8, H-12); 6.71 (d, 2 H, ^4J = 1.6 Hz, H-5, H-15); 7.22 (d, 2 H, Ar); 7.40 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 585 [M^+] (10), 584 (22), 293 (32), 193 (35), 179 (100), 177 (52).

Synthesis of compounds 5c—7c: general procedure. The $PdCl_2$ · dppf complex (2—6 mol. %) was added to a solution of bromide **2—4** (2 mmol) in THF (5 mL), then the Grignard reagent was added (3 mmol per Br atom). The reaction mixture was refluxed for 11—20 h with stirring, worked up with saturated aqueous NH_4Cl, washed with H_2O, and dried with $MgSO_4$. The solvent was removed and the residue was recrystallized or purified by column chromatography using hexane : benzene (6 : 1) as the eluent.

4-(2,4,6-Trimethylphenyl)-[2.2]paracyclophane (5c). Yield 85 %, m.p. 102—104 °C (from EtOH) (*cf.* Ref. 7: 104—106 °C). ^{1}H NMR ($CDCl_3$), δ: 1.8 (s, 3 H, CH_3); 2.36 (s, 3 H, CH_3); 2.82 (s, 3 H, CH_3); 2.60—3.38 (m, 8 H, bridge); 6.26—6.58 (m, 5 H, paracyclophane); 6.68 (s, 1 H, Ar); 6.78 (s, 2 H, paracyclophane); 7.08 (s, 1 H, Ar).

4,15-Bis(2,4,6-trimethylphenyl)-[2.2]paracyclophane (6c). Yield 75 %, m.p. 213—215 °C (from EtOH : toluene = 1 : 7). Found (%): C, 92.00; H, 8.15. $C_{34}H_{36}$. Calculated (%): C, 91.84; H, 8.16. ^{1}H NMR ($CDCl_3$), δ: 1.87 (s, 6 H, 2 CH_3); 2.32 (s, 6 H, 2 CH_3); 2.52—2.76 (m, 2 H, bridge); 2.85 (s, 6 H, 2 CH_3); 2.89—3.1 (m, 4 H, bridge); 3.37—3.56 (m, 2 H, bridge); 6.36 (s, 4 H, paracyclophane); 6.78 (s, 2 H, paracyclophane); 6.88 (s, 2 H, Ar); 7.01 (s, 2 H, Ar).

4,16-Bis(2,4,6-trimethylphenyl)-[2.2]paracyclophane (7c) was obtained by recrystallization of the precipitate that formed from the reaction mixture. Yield 56 %, m.p. 330—332 °C (from toluene). Found (%): C, 92.17; H, 8.15. $C_{34}H_{36}$. Calculated (%): C, 91.84; H, 8.16. ^{1}H NMR ($CDCl_3$), δ: 1.95 (s, 6 H, 2 CH_3); 2.42 (s, 6 H, 2 CH_3); 2.90 (s, 6 H, 2 CH_3); 2.58—3.00 (m, 4 H, bridge); 3.15—3.48 (m, 4 H, bridge); 6.32 (d, 2 H, paracyclophane); 6.57 (d, 2 H, paracyclophane); 6.77 (s, 2 H, paracyclophane); 6.95 (s, 2 H, Ar); 7.15 (s, 2 H, Ar).

Synthesis of compounds 5d—7d: general procedure. The Grignard reagent (1.5 mmol per a Br atom) was added with stirring to a mixture of bromide **2**—**4** (2 mmol) and $PdCl_2$ · dppf (1—2 mol. %). The reaction mixture was heated for 2—3 h, diluted with THF (15 mL), worked up with saturated aqueous NH_4Cl, washed with H_2O, and dried with $MgSO_4$. The solvent was distilled off, and the residue was recrystallized.

4-(4-Methoxylphenyl)-[2.2]paracyclophane (5d). Yield 87 %, m.p. 80.5—81.5 °C (EtOH). Found (%): C, 88.18; H, 7.16. $C_{23}H_{22}O$. Calculated (%): C, 87.86; H, 7.05. ^{1}H NMR ($CDCl_3$), δ: 2.55—3.22 (m, 7 H, bridge); 3.36—3.54 (m, 1 H, bridge); 3.90 (s, 3 H, OCH_3); 6.41—6.67 (m, 7 H, paracyclophane); 7.02 (d, 2 H, Ar); 7.42 (d, 2 H, Ar).

4,15-Bis(4-methoxylphenyl)-[2.2]paracyclophane (6d). Yield 61 %, m.p. 160.5—162.0 °C (from EtOH : toluene = 5 : 1). Found (%): C, 86.18; H, 6.71. $C_{30}H_{28}O_2$. Calculated (%): C, 85.68; H, 6.71. ^{1}H NMR ($CDCl_3$), δ: 2.3—3.34 (m, 8 H, bridge); 3.88 (s, 6 H, 2 OCH_3); 6.49—6.81 (m, 6 H, paracyclophane); 7.01 (d, 4 H,Ar); 7.45 (d, 4 H, Ar).

4,16-Bis(4-methoxylphenyl)-[2.2]paracyclophane (7d). Yield 78 %, m.p. >370 °C (from toluene). Found (%): C, 85.66; H, 6.82. $C_{30}H_{28}O_2$. Calculated (%): C, 85.68; H, 6.71. ^{1}H NMR ($CDCl_3$), δ: 2.68—3.06 (m, 6 H, bridge); 3.38—3.52 (m, 2 H, bridge); 3.89 (s, 6 H, 2 OCH_3); 6.52—6.64 (m, 6 H, paracyclophane); 7.04 (d, 4 H, Ar); 7.45 (d, 4 H, Ar).

Synthesis of a magnesium derivative of 2-(4-bromophenyl)-2-methyl-1,3-dioxolane was carried out by adding a solution of 2-(4-bromophenyl)-2-methyl-1,3-dioxolane (15 mmol) in THF (15 mL) to magnesium turnings (15.75 mmol) activated by I_2.

The synthesis of 4-acetylphenyl[2.2]paracyclophane (5e). The Grignard reagent (6 mmol) was added with stirring and heating to a mixture of bromide **2** (3.48 mmol) and $PdCl_2$ · dppf (1 mol. %). The reaction mixture was refluxed for 3.5 h, treated with saturated aqueous NH_4Cl, and washed with H_2O. The organic layer was concentrated, dissolved in a mixture of methanol (10 mL) and benzene (5 mL), refluxed for 1 h with 5 *M* HCl (10 mL), treated with 5 % alkali and water, and dried with Na_2SO_4. The solvent was distilled off, and the residue was separated by column chromatography using benzene as the eluent to give compound **5e**, yield 53 %, m.p. 147—149 °C (from EtOH). Found (%): C, 88.24; H, 7.08. $C_{24}H_{22}O_1$. Calculated (%): C, 88.31; H, 6.79. ^{1}H NMR ($CDCl_3$), δ: 2.65 (s, 3 H, CH_3); 2.7—3.7 (m, 8 H, bridge); 6.6 (m, 7 H, paracyclophane); 7.6 (d, 2 H, Ar); 8.2 (d, 2 H, Ar).

4-(4-Carboxyphenyl)[2.2]paracyclophane (9). A solution of compound **5e** (1 mmol) in dioxane (10 mL) was added at 0 °C to a freshly-prepared solution of KOBr (3 mmol). The mixture was stirred for 0.5 h at 20 °C and heated to 60 °C. Then $CHCl_3$ was added, and the reaction mixture was decomposed with $Na_2S_2O_5$ and saturated with KCl to induce the separation of the organic and aqueous phases. Then former was washed with H_2O. The aqueous layer was acidified with HCl until compound **9** formed. The organic phase was dried with $MgSO_4$, and the solvent was evaporated. The acid was distributed as follows: inorganic phase, 5 %; organic phase, 95 %. The overall yield of **9** was 90 %, m.p. 210—212 °C. ^{1}H NMR ($CDCl_3$), δ: 2.6—3.6 (m, 8 H, bridge); 6.6 (m, 7 H, paracyclophane); 7.6 (d, 2 H, Ar); 8.1 (d, 2 H, Ar); MS (EI, 70 eV), *m/z* (I_{rel} (%)): 328 [M^+] (1.4), 179 (49), 165 (26), 105 (100), 104 (93).

15-Bromo-4-(4-methylphenyl)[2.2]paracyclophane (8a). M.p. 145—147 °C (from EtOH). Found (%): C, 73.33; H, 5.36; $C_{23}H_{21}Br$. Calculated (%): C, 71.21; H, 5.61; ^{1}H NMR ($CDCl_3$), δ: 2.65 (s, 3 H, CH_3); 2.5—3.5 (m, 8 H, bridge); 6.6—7.3 (m, 7 H, paracyclophane); 7.6 (d, 2 H, Ar); 8.1 (d, 2 H, Ar).

4-(4-acetylphenyl)-15-bromo[2.2]paracyclophane (8e). Yield 28 %, m.p. 128—130 °C (from EtOH). Found (%): C, 71.35; H, 5.98; Br, 19.77. $C_{24}H_{21}BrO$. Calculated (%): C, 71.12; H, 5.22; Br, 19.71. ^{1}H NMR ($CDCl_3$), δ: 2.65 (s, 3 H, CH_3); 2.5—3.5 (m, 8 H, bridge); 6.6—7.3 (m, 7 H, paracyclophane); 7.6 (d, 2 H, Ar); 8.1 (d, 2 H, Ar).

Cross-coupling of organozinc compound 10 with aromatic bromide 11. BuLi (5.25 mmol) was added dropwise to a solution of compound **2** (5 mmol) in ether (25 mL); 30 min later, a solution of $ZnCl_2$ (5.25 mmol) in THF (15 mL) was added, and the mixture was stirred for 45 min. Then a solution of compound **11** (2.125 mmol) in THF (10 mL) and $PdCl_2(PPh_3)_4$ were added, the mixture was refluxed for 2 h, treated with saturated aqueous NH_4Cl, and washed with H_2O. The solvent was distilled off, and the residue was separated by column chromatography to give compound **5a** in 33 % yield.

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