Synthesis and conformational studies of 9-methoxy- and 9-methyl-2,11-dithia[3.3]metacyclophanes

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A series of 9-methoxy- and 9-methyl-2,11-dithia[3.3]metacyclophanes are obtained by the coupling reaction of the corresponding 1,3-bis(bromomethyl)benzenes and bis(sulfanylmethyl)benzenes in ethanol under the high dilution conditions. The conformational studies of 2,11-dithia[3.3]metacyclophanes as well as the ring current interactions derived from benzene ring are also described.

Keywords: cyclophanes, dithia[3.3]metacyclophanes, conformations, ring current effect, charge transfer complex

For many years, various research groups have been attracted by the structures of the [3.3]MCP ([3.3]MCP = [3.3]metacyclophane) skeleton.[1–4] When both internal substituents of a [3.3]phane such as **1** are H, the molecule may be mobile. Mitchell and his coworkers demonstrated that 9,18-dimethyl-2,11-dithia[3.3]MCP exists in *syn*- (*syn*-**2b**) and *anti*- (*anti*-**2b**) conformers, which do not interconvert below 200 °C.[6–9] As in the case of the [2.2]phanes,[2–4] the internal methyl protons of *anti*-**2b** are shielded at δ 1.30 ppm by 1.24 from those of *syn*-**2b** (δ 2.54 ppm), which is relatively normal for a toluene derivative.

Even one internal methyl substituent is sufficient to allow the isolation of a discrete *syn* or *anti* isomer; for example, in *anti*-**2a** the internal proton (H^i) appears at δ 5.50 ppm and the internal methyl protons (Me^i) at δ 2.18 ppm. The reduced shielding of Me^i relative to *anti*-**2b** indicates that **2a** adopts a different geometry from that of *anti*-**2b**.

Vögtle *et al*.[10] have made extensive studies of *syn*-*anti* conversions in other dithia[3.3]MCPs, especially in relation to the size of the substituents. When electron-withdrawing groups such as halo, nitro, and cyano are present, the yields of the *syn* isomers increase substantially. Very bulky groups, such as *tert*-butyl, decrease the yields of *syn* isomers. Although the effect on the ratio of *syn* and *anti* conformers of dithia[3.3]MCPs was reported, it is still not clear what the effects are, not only properties of the internal substituents, but also having unsymmetrically substituted benzene rings arising from charge-transfer-type interactions between two benzene rings as well as steric effects of substituents at the 6 and 15-positions.

All of the previous compounds are internally unsubstituted or methyl-substituted dithia[3.3]MCPs and it is surprising that there are very few reports on the preparation of 9-methoxy analogues. We report here the synthesis and stereochemical assignments of 9-methoxy- and 9-methyl-2,11-dithia[3.3]MCPs using the above method, as well as studies of their conformation by the ring current interactions derived from benzene ring.

Results and discussion

2,6-Bis(sulfanylmethyl)anisoles **4** were prepared by treatment of the corresponding 2,6-bis(bromomethyl) 4-substituted anisoles **3** with thiourea and potassium hydroxide in ethanol.[11–15] 5-*tert*-Butyl-1,3-bis(bromomethyl)benzene **5** was prepared by bromination of 5-*tert*-butyl-1,3-dimethylbenzene with *N*-bromosuccinimide in the presence of 2,2'-azobis(2,4-dimethylpentanenitrile) in a methylene dichloride solution according to our reported procedure.[11,13]

The cyclisations of 5-*tert*-butyl-1,3-bis(bromomethyl) benzene **5** and 2,6-bis(sulfanylmethyl)anisoles **4** were carried out under high-dilution conditions in 10% ethanolic KOH in the presence of a small amount of $NaBH_4$,[11–15] giving *syn*-9-methoxy-2,11-dithia[3.3]MCPs **6a–e** in 16–60% yields, respectively (Scheme 1).

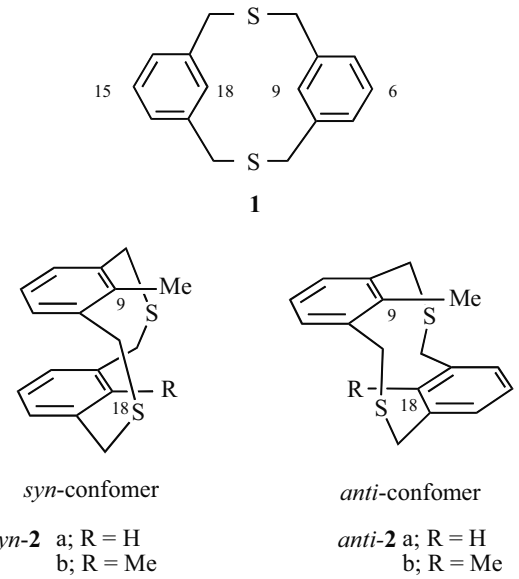

Fig. 1 *syn*- and *anti*-Conformers of dithia[3.3]metacyclophane **2**.

The structures of **6** were established on the basis of the base peak molecular ions in their mass spectra, and they were assigned the *syn*-stereochemistry *syn*-**6** on the basis of their ^{1}H NMR spectra by comparison with the known *syn*-cyclophane **2a**, since the 9-proton of *syn*-**6** appears at around δ 6.9 ppm (that for *syn*-**2a** is at δ 6.82 ppm),[5,7,8] *i.e.* relatively normal for a benzene, whereas if **6** existed as the *anti* conformers they might be expected to be shielded by the opposite ring to *ca* δ 5 ppm. The same shift of the internal methoxy protons at around δ 3.66–3.68 ppm as that of an anisole was observed in *syn*-**6**. Further, the other aryl hydrogens can clearly be seen to be shielded at δ 6.87–6.90 ppm by the adjacent ring, a common consequence of a face-to-face benzene ring.[7] Also the *tert*-butyl protons of *syn*-**6a**–**6d** were observed at higher field, δ 1.08–1.19 ppm due to the strong shielding effect of the benzene ring except *syn*-**6e** (δ 1.25 ppm). These observations strongly suggest that compounds **6a–e** all adopt *syn*-conformations. The chemical shifts (δ) of the internal methoxy protons, the aromatic internal protons at the 18-position and the *tert*-butyl protons of *syn*-9-methoxy-2,11-dithia[3.3]MCPs *syn*-**6a–e** are com piledin Table 1. All the bridged CH_2SCH_2 protons of the above-prepared cyclophane **6b** are observed as a pair of doublets at δ 3.42, 4.22 ppm (J = 14.3 Hz) and δ 3.70, 3.79 ppm (J = 14.5 Hz) in ^{1}H NMR spectra at room temperature. With increasing temperature in DMSO-d_6,

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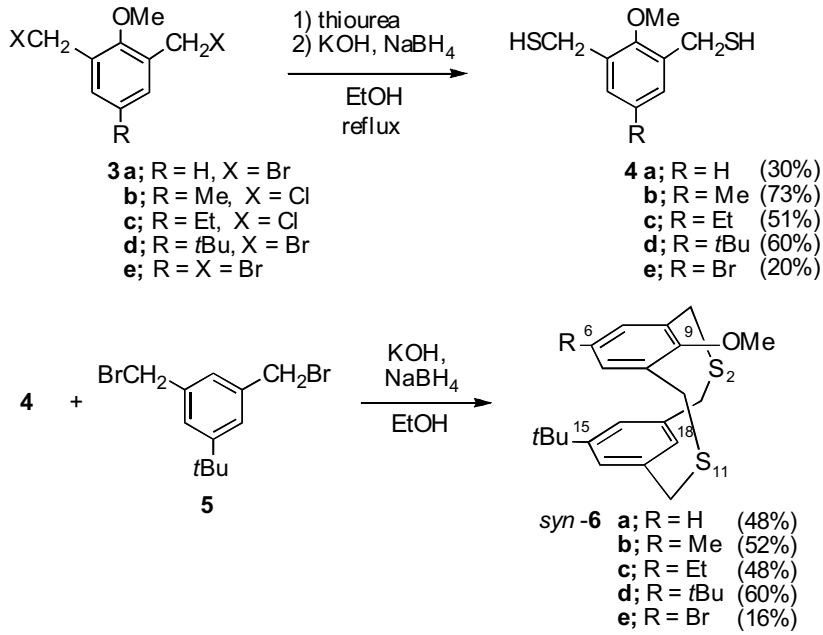
Table 1 Chemical shifts (δ) of the internal methoxy protons, aromatic internal proton at 18 position and *tert*-butyl protons of *syn*-9-methoxy-2,11-dithia[3.3]MCPs *syn*-**6a–e** and *anti*-9-methyl-2,11-dithia[3.3]MCPs *anti*-**8a–b**[a]

Compound	Methoxy and methyl protons	Aromatic proton at 18-position	*tert*-Butyl protons	Assignment
6a	3.68	6.90	1.18	*syn*
6b	3.66	6.93	1.19	*syn*
6c	3.67	6.93	1.10	*syn*
6d	3.66	6.87	1.08, 1.14	*syn*
6e	3.67	6.90	1.25	*syn*
8a	2.17	5.65	1.31	*anti*
8b	2.00	5.00	1.24, 1.28	*anti*

[a]Determined in $CDCl_3$ by using $SiMe_4$ as a reference and expressed in ppm.

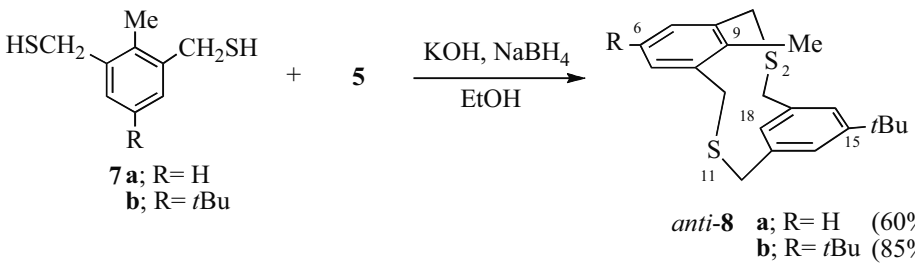


Scheme 1

the doublets do not coalescenc below 150 °C, respectively, and the energy barriers of flipping are both above 25 kcal mol^{-1}.[8,9,10] Similar findings were obtained in dithia[3.3]MCPs **6a, 6c**–**6e**. These observations strongly suggest that compounds **6** adopt rigid *syn*-conformation.

In contrast, the cyclisation of 1,3-bis(bromomethyl)-5-*tert*-butylbenzene **5** and 2,6-bis(sulfanylmethyl)toluenes **7a** and **7b** were carried out under high dilution conditions in 10% ethanolic KOH in the presence of a small amount of $NaBH_4$, giving exclusively *anti*-9-methyl-2,11-dithia[3.3]MCPs *anti*-**8a** and *anti*-**8b** in 60 and 85% yields, respectively (Scheme 2). The assignments of structure for the *anti* and *syn* conformers were readily apparent from their ^{1}H NMR spectra (Table 1). The ^{1}H NMR spectra of conformer *anti*-**8a** and *anti*-**8b** show the internal aromatic proton at the 18-position at δ 5.65 and 5.00 ppm, respectively. Thus, the internal aromatic proton of the *anti* conformers shows an upfield shift due to the ring current of the opposite aromatic ring.[3,4] However, the internal methyl protons appeared at δ 2.18 and 2.00 ppm different from those observed in 9,18-dimethyl-2,11-dithia[3.3]MCP *anti*-**2b** (δ 1.33 ppm). No ring current effects of the opposing benzene was observed. These findings might be attributable to the different structure between *anti*-**8** and *anti*-**2b**. The internal aromatic proton at the 18-position of *anti*-**8** is observed at δ 5.00–5.65 ppm. The *tert*-butyl protons of *anti*-**8** was also observed at much lower field (δ 1.24–1.31 ppm) than that of *syn*-**6d** at δ 1.08 ppm. These observations strongly suggest compounds *anti*-**8a** and *anti*-**8b** adopt an *anti*-conformation. Dependent on the OMe and Me substitution, different yields (inversion of selectivity) of *anti*- and *syn*-conformers were formed. Thus 9-methoxy analogues are exclusively formed as *syn*-conformers, but other 9-methyl analogues are exclusively formed as *anti*-conformers.

These findings suggest that in the case of 9-methoxy analogue the through-space interaction between the non-bonding electron pairs of the oxygen atom of the methoxy



Scheme 2

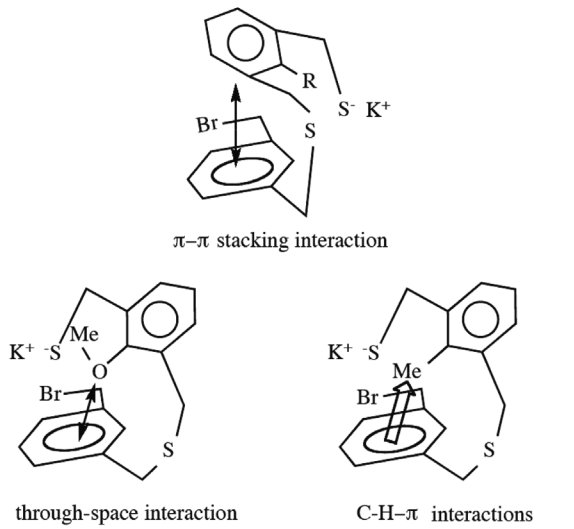


Fig. 2 Reaction intermediate for the cyclisation to form dithia[3.3]MCPs.

group and the opposite aromatic π-electrons of the *anti*-conformer may disfavour the formation of the latter as shown in Fig. 2. In contrast, in the case of a 9-methyl analogue the aromatic π–π interaction between the two opposite benzene rings and the steric crowding at the internal positions 9 and 18 may inhibit the formation of the *syn*-conformer in the [3.3]MCP system and that in turn the C–H–π interaction[16] between the methyl and the opposite aromatic π-electrons may favour the formation of an *anti*-conformer during the cyclisation process. C–H–π interactions involving aliphatic CH moieties are well documented[16] as being either conformation controlling intramolecular processes or involving crystal-structure controlling intermolecular forces, especially for inclusion complexes of calixarene derivatives.[17–23]

A solution of 15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]MCP (*syn*-**6a**) and TCNE in CH_2Cl_2 presents a reddish brown colour and the charge-transfer band at 521 nm (log ε = 1.307) was observed in its UV spectrum. This absorption is due to the formation of 1 : 1 charge-transfer complex among the electron donor, *syn*-**6a** and the electron acceptor, TCNE. The position of absorption maximum and the shape of absorption curve remain unchanged when a 4–12-fold excess of TCNE was added. The charge transfer band positions of other 15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]MCPs (*syn*-**6b**, *syn*-**6c** and *syn*-**6e**), 2,6-dimethylanisole **9** and 5-*tert*-butyl-1,3-dimethylbenzene **10** with TCNE complexes are summarised in Table 2.

TCNE complexes have often been used in studies on the relative π-base strength of various methyl-substituted benzenes.[24] The π-basicity of the donor molecules increases with an increase in the number of substituted methyl groups and/or stacking benzene rings and an increase in the face-to-face overlapping between aromatic nuclei. In contrast to the

Table 2 Charge-transfer bands of π–π salts of *syn*-**6a**, **b**, **c**, **e** and reference compounds **9**, **10** with TCNE in CH_2Cl_2[a]

Compounds	R	λ_{CT} (nm)	log ε
syn-**6a**	H	521	1.307
syn-**6b**	Me	520	1.364
syn-**6c**	Et	522	1.414
syn-**6e**	Br	470	1.386
9	–	455	1.287
10	–	422	1.364

[a]The complexes were prepared in CH_2Cl_2 using equimolar quantities of substrate and TCNE at 25 °C.

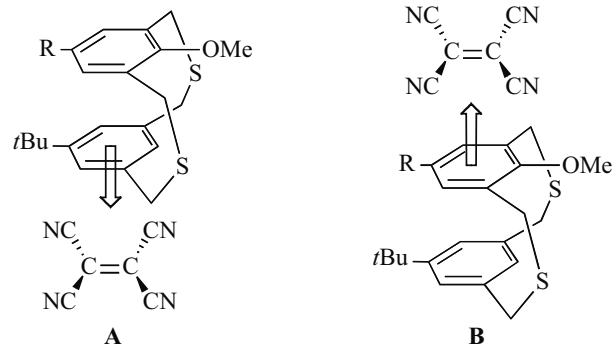


Fig. 3 Possible structures of charge-transfer complex for *syn*-15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]MCPs *syn*-**6a–e** with TCNE.

cyclophanes having symmmetric donor-sites, unsymmetric cyclophanes containing non-equivalent donor-sites such as 4-acetyl- and 4-methoxy[2.2]paracyclophanes[25] can be expected to form two isomeric one-to-one complexes with TCNE, *i.e.*, pseudo-configurational isomers.[26] An important factor for determining which isomeric compex is more predominant or exclusive is the magnitude of ionisation potentials of the constituent donor moieties. Similarly, two possible pseudo-configurational isomers **A** and **B** are also expected for the one-to-one complex of *syn*-15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]MCPs *syn*-**6** as shown in Fig. 3.

In studying the electron spectra of *syn*-**6**–TCNE complexes, it is advantageous also to examine the spectra of TCNE complex of 6,15-di-*tert*-butyl-9,18-dimethoxy-2,11-dithia-[3.3]MCP (**11**). In contrast to 15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]MCP (*syn*-**6a**), which exhibits a charge-transfer absorption band with TCNE at 521 nm (log ε = 1.307), a mixture of TCNE and **11** exhibits no band in the visible region. However, the charge-transfer absorption band of the reference compound 2,6-dimethylanisole (**9**) with TCNE was observed at 455 nm (log ε = 1.287).[27] Complexing with TCNE is considered to be difficult in the case of **11** owing to the cyclophane structure as well as the steric hindrance of the methoxy group at the 8-position, in spite of the increased π-basicity of the benzene ring due to the methoxy groups. Thus the observed charge-transfer bands of the *syn*-**6**–TCNE complexes should be attributed to the internally unsubstituted benzene-site one. Although the charge-transfer of the 5-*tert*-butyl-1,3-dimethylbenzene **10**–TCNE complex exhibits an absorption peak at 422 nm, that of *syn*-**6a** is shifted to 521 nm. Such a red shift could be due to the benzene ring at the other side of the molecule which tends to work as a π-electron donor.

Similar redshifts were observed in the 15-*tert*-butyl-8-methoxy-6-substituted-2,11-dithia[3.3]MCPs *syn*-**6b** and *syn*-**6c**, each of which possesses an electron-donating group,

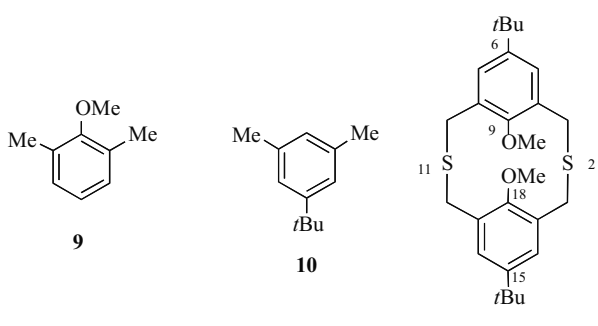


Fig. 4 Reference compounds **9**, **10** and **11**.

such as a methyl or ethyl group at the 6-position, respectively, due to the increased transannular π-electron donation from the non-complexed to the complexed benzene ring. In contrast, the charge-transfer band of *syn*-**6e**, having an electron-withdrawing bromine atom at the 6-position, would certainly be shifted less than that of *syn*-**6a**, so that the overall transannular effect of the uncomplexed ring would be electron withdrawing. These findings strongly support the attribution of the observed charge-transfer bands of the *syn*-8-methoxy[3.3]MCP (*syn*-**6**)–TCNE complexes to the internally unsubstituted benzene-site complex.

Conclusions

In conclusion, we have demonstrated for the first time a through-space interaction between the non-bonding electron pairs of the oxygen atom of the methoxy group and the opposite aromatic π-electrons which may disfavour formation of the *anti*-conformer during the coupling reaction of the corresponding 5-*tert*-butyl-2,6-bis(bromomethyl)benzene **5** and 4-*tert*-butyl-2,6-bis(sulfanylmethyl)anisole **4** to afford *syn*-9-methoxy-2,11-dithia[3.3]MCPs *syn*-**6** exclusively. In contrast, the corresponding 9-methyl analogues *anti*-**8** are exclusively formed as *anti*-conformers. Dependent on the OMe and Me substitution, different yields (inversion of selectivity) of *syn*- and *anti*-conformers were formed. The substituent effect at the 6-position does exist in the complexation of *syn*-8-methoxy-2,11-dithia[3.3]MCPs (*syn*-**6**) with TCNE and that a through-space electronic interaction of the opposite uncomplexed benzene ring must be considered. Further chemical properties and the charge-transfer complexes of the present novel unsymmetrically substituted *syn*-[3.3]MCP derivatives are currently under study in our laboratory.

Experimental

All melting points are uncorrected. ^{1}H NMR spectra were recorded at 300 MHz on a Nippon Denshi JEOL FT-300 NMR spectrometer in deuteriochloroform with Me_4Si as an internal reference. UV-vis spectra were recorded on a Perkin Elmer Lambda 19 UV/VIS/NIR spectrometer. Mass spectra were obtained on a Nippon Denshi JMS-HX110A Ultrahigh Performance Mass Spectrometer at 75 eV using a direct-inlet system. Elemental analyses were performed by Yanaco MT-5.

Materials

Preparations of 2,6-bis(halomethyl)-4-substituted anisoles **3a–e**, 2,6-bis(sulfanylmethyl)-4-substituted anisoles **4a**, **4b**, **4d**[28] and 5-*tert*-butyl-1,3-bis(bromomethyl)benzene **5** were previously described.[11,13] The TCNE was recrystallised twice from chlorobenzene and sublimed twice at 125 °C (4 mmHg).

2,6-*Bis(sulfanylmethyl)*-4-*ethylanisole (***4c***)*. A solution of **3c** (1.20 g, 5.1 mmol) and thiourea (854 mg, 11.22 mmol) in ethanol (18 mL) was refluxed for 8 h under an atmosphere of nitrogen. After the reaction mixture was cooled to room temperature and KOH (858 mg, 15.3 mmol) and $NaBH_4$ (38.6 mg, 1.02 mmol) was added. The solution was refluxed for 10 h, acidified with aqueous 10% HCl and extracted with CH_2Cl_2 (100 mL × 2). The CH_2Cl_2 extract was washed with water (100 mL) followed by saturated aqueous NaCl (100 mL), and dried (Na_2SO_4) and evaporated *in vacuo* to leave a colourless solid. Recrystallisation from hexane gave the **4c** as a colourless liquid (592 mg, 51%), b.p.133–134 °C/3 torr; ν_{max}/cm^{-1} (NaCl) 3040, 2924, 2540, 1428, 1216, 1122, 994 and 870; δ_H ($CDCl_3$) 1.22 (3H, t, *J* = 7.5 Hz, CH_2CH_3), 1.90 (2H, t, *J* = 7.4 Hz, *SH*), 2.59 (2H, q, *J* = 7.5 Hz, CH_2CH_3), 3.75 (4H, t, *J* = 7.4 Hz, CH_2SH), 3.87 (3H, s, OCH_3) and 7.06 (2H, s, Ar*H*); *m/z* 228 (M^{+}); HRMS (CI): *m/z* Calcd for $C_{11}H_{16}OS_2$ (M^{+}) 228.06427. Found 228.06387 (Found: C, 57.74; H, 7.03. $C_{11}H_{16}OS_2$ (228.37) requires C, 57.86; H, 7.06%).

Compound **4e** was prepared in the same manner as described for **4c** in 20% yield.

2,6-*Bis(sulfanylmethyl)*-4-*bromoanisole* (**4e**): Colourless liquid, b.p.165–167 °C/10 torr; ν_{max}/cm^{-1} (NaCl) 3040, 2912, 2540, 1570, 1420, 1202, 984 and 848; δ_H ($CDCl_3$) 1.91 (2H, t, *J* = 7.7 Hz, *SH*), 3.72 (4H, d, *J* = 7.7 Hz, CH_2SH), 3.87 (3H, s, OCH_3) and 7.38 (2H, s, Ar*H*); *m/z* 278, 280 (M^{+}); HRMS (CI): *m/z* Calcd for $C_9H_{11}BrOS_2$ (M^{+}) 277.94348. Found 277.94333 (Found: C, 38.84; H, 3.85. $C_9H_{11}BrOS_2$ (279.21) requires C, 38.72; H, 3.97%).

Cyclisation reaction of **4** *and* **5** *to give dithia[3.3]metacyclophanes* **6**; *typical procedure*

A solution of 1,3-bis(bromomethyl)-5-*tert*-butylbenzene **5** (2.0 g, 4.5 mmol) and 2,6-bis(sulfanylmethyl)anisole **4a** (811 mg, 4.5 mmol) in benzene (100 mL) was added dropwise from a Hershberg funnel with stirring under nitrogen to a solution of potassium hydroxide (700 mg, 12.4 mmol) and sodium borohydride (100 mg, 2.5 mmol) in ethanol (3.0 L). When addition was complete (6 h), the reaction mixture was concentrated *in vacuo* and the residue was extracted with CH_2Cl_2 (500 mL). The CH_2Cl_2 extract was washed with water and dried (Na_2SO_4), and concentrated. The residue was chromatographed over silica gel (Walo, C-300; 100 g) with hexane–CH_2Cl_2 1:1 as eluent to give a colourless solid, which was recrystallised from hexane to yield the desired 15-*tert*-butyl-9-methoxy-2,11-dithia[3.3]metacyclophane (*syn*-**6a**) (773 mg, 48%) as prisms (from hexane), m.p. 103–105 °C; ν_{max}(KBr)/cm^{-1} 2900, 1590, 1430, 1166, 1008; δ_H($CDCl_3$) 1.18 (9H, s, *tBu*), 3.46 (2H, d, *J* = 14.1 Hz, 1,12-CH_2), 3.68 (3H, s, O*Me*), 3.69 (2H, d, *J* = 14.4 Hz, 3,10-CH_2), 3.79 (2H, d, *J* = 14.4 Hz, 3,10-CH_2), 4.25 (2H, d, *J* = 14.1 Hz, 1,12-CH_2), 6.60 (1H, t, *J* = 7.8 Hz, 15-Ar*H*), 6.90 (1H, s, 9-Ar*H*), 6.91 (2H, d, *J* = 7.8 Hz, 14,16-Ar*H*) and 6.92 (2H, s, 5,7-Ar*H*); *m/z* 358 (M^{+}); HRMS (CI): *m/z* Calc. for $C_{21}H_{26}OS_2$ (M^{+}) 358.1425; Found 358.1431 (Found: C, 70.47; H, 7.38. $C_{21}H_{26}OS_2$ (358.56) requires C, 70.34; H, 7.31%).

Compounds *syn*-**6b**–*syn*-**6e** were prepared in the same manner as described for *syn*-**6a**. The yields are compiled in Scheme 1.

15-*tert-Butyl*-9-*methoxy*-6-*methyl*-2,11-*dithia*[3.3]*metacyclophane* (*syn*-**6b**). Prisms (from hexane), m.p. 110–112 °C; ν_{max}(KBr)/cm^{-1} 2930, 1590, 1160 and 898; δ_H ($CDCl_3$) 1.19 (9H, s, *tBu*), 1.99 (3H, s, *Me*), 3.42 (2H, d, *J* = 14.3 Hz, 3,10-CH_2), 3.66 (3H, s, O*Me*), 3.70 (2H, d, *J* = 14.5 Hz, 1,12-CH_2), 3.79 (2H, d, *J* = 14.5 Hz, 1,12-CH_2), 4.22 (2H, d, *J* = 14.3 Hz, 3,10-CH_2), 6.70 (2H, s, 14,16-Ar*H*) and 6.93 (3H, s, 5,7,18-Ar*H*); *m/z* 372 (M^{+}); HRMS (CI): *m/z* Calcd for $C_{22}H_{28}OS_2$ (M^{+}) 372.1582. Found 372.1568 (Found: C, 70.74; H, 7.65. $C_{22}H_{28}OS_2$ (372.59) requires C, 70.92; H, 7.57%).

syn-15-*tert-Butyl*-6-*ethyl*-9-*methoxy*-2,11-*dithia*[3.3]*metacyclophane* (*syn*-**6c**): Prisms (from hexane), m.p. 70–72 °C; ν_{max}(KBr)/cm^{-1} 2904, 1592, 1432, 1208, 1116, 1002 and 870; δ_H ($CDCl_3$) 1.02 (3H, t, *J* = 7.7 Hz, CH_2CH_3), 1.17 (9H, s, *tBu*), 2.30 (2H, q, *J* = 7.7 Hz, CH_2CH_3), 3.45 (2H, d, *J* = 14.4 Hz, 3, 10-CH_2), 3.67 (3H, s, O*Me*), 3.68 (2H, d, *J* = 14.7 Hz, 1,12-CH_2), 3.79 (2H, d, *J* = 14.7 Hz, 1,12-CH_2), 4.22 (2H, d, *J* = 14.4 Hz, 3,10-CH_2), 6.72 (2H, s, 14,16-Ar*H*), 6.91 (2H, s, 5,7-Ar*H*) and 6.93 (1H, s, 18-Ar*H*); *m/z* 386 (M^{+}); HRMS (CI): *m/z* Calcd for $C_{23}H_{30}OS_2$ (M^{+}) 386.1738. Found 386.1723 (Found: C, 71.64; H, 7.83. $C_{23}H_{30}OS_2$ (386.62) requires C, 71.45; H, 7.82%).

syn-6,15-*Di-tert-butyl*-9-*methoxy*-2,11-*dithia*[3.3]*metacyclophane* (*syn*-**6d**): Prisms (from hexane), m.p. 115–117 °C; δ_H($CDCl_3$) 1.08 (9H, s, *t*Bu), 1.14 (9H, s, *tBu*), 3.46 (2H, d, *J* = 15.0 Hz, CH_2), 3.60 (2H, d, *J* = 15.0 Hz, CH_2), 3.66 (3H, s, O*Me*), 3.78 (2H, d, *J* = 15.0 Hz, CH_2), 4.19 (2H, d, *J* = 15.0 Hz, CH_2) and 6.84–6.90 (5H, m, Ar*H*); *m/z* 414 (M^{+}) (Found: C, 72.19; H, 8.17. $C_{25}H_{34}OS_2$ (414.67) requires C, 72.41; H, 8.27%).

syn-6-*Bromo*-15-*tert-butyl*-9-*methoxy*-2,11-*dithia*[3.3]*metacyclophane* (*syn*-**6e**): Prisms (from hexane), m.p. 153–154 °C; ν_{max}(KBr)/cm^{-1} 2908, 1574, 1420, 1200, 1002 and 846; δ_H ($CDCl_3$) 1.25 (9H, s, *tBu*), 3.40 (2H, d, *J* = 14.3 Hz, 3,10-CH_2), 3.67 (3H, s, O*Me*), 3.70 (2 H, d, *J* = 14.6 Hz, 1,12-CH_2), 3.77 (2H, d, *J* = 14.6 Hz, 1,12-CH_2), 4.19 (2H, d, *J* = 14.3 Hz, 3,10-CH_2), 6.90 (1H, s, 18-Ar*H*), 6.98 (2H, s, 14,16-ArH) and 7.02 (2H, s, 5,7-ArH); *m/z* 436, 438 (M^{+}); HRMS (CI): *m/z* Calcd for $C_{21}H_{25}BrOS_2$ (M^{+}) 436.05303. Found 436.05179 (Found: C, 57.49; H, 5.67. $C_{21}H_{25}BrOS_2$ (437.46) requires C, 57.66; H, 5.76%).

Similarly, compounds *anti*-**8a** and *anti*-**8b** were synthesised in the same manner as described in 60 and 85% yields, respectively.

anti-15-*tert-Butyl*-9-*methyl*-2,11-*dithia*[3.3]*metacyclophane* (*anti*-**8a**): 60% as *prisms* (from hexane); m.p. 83–84 °C; δ_H ($CDCl_3$) 1.31 (9H, s, *tBu*), 2.17 (3H, s, *Me*), 3.55 (2H, d, *J* = 15.0 Hz, CH_2), 3.71 (2H, d, *J* = 15.0 Hz, CH_2), 3.78 (2H, d, *J* = 13.8 Hz, CH_2), 3.94 (2H, d, *J* = 13.8 Hz, CH_2), 5.65 (1H, broad s, internal-H_{18}), 6.78 (2H, t, *J* = 7.5 Hz, Ar*H*), 6.84 (2H, s, Ar*H*) and 6.97 (1H, t, *J* = 7.5 Hz, Ar*H*); *m/z* 342 (M^{+}) (Found: C, 73.91; H, 7.53. $C_{21}H_{26}S_2$ (342.56) requires C, 73.63; H, 7.65%).

anti-6,15-*Di-tert-butyl*-9-*methyl*-2,11-*dithia*[3.3]*metacyclophane* (*anti*-**8b**): 85% as *prisms* (from hexane); m.p. 101–102 °C; δ_H ($CDCl_3$) 1.24 (9H, s, *tBu*), 1.28 (9H, s, *tBu*), 2.00 (3H, s, *Me*), 3.54

(2H, d, J = 15.0 Hz, CH_2), 3.70 (2H, d, J = 15.0 Hz, CH_2), 3.77 (2H, d, J = 15.0 Hz, CH_2), 3.93 (2H, d, J = 15.0 Hz, CH_2), 5.00 (1H, broad s, internal-H_{18}), 6.88 (2H, s, ArH) and 7.08 (2H, s, ArH); m/z 398 (M^+) (Found: C, 75.19; H, 8.53. $C_{25}H_{34}S_2$ requires C, 75.32; H, 8.60%).

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