Preparation and structural properties of dithia[3.3.1]-metacyclophanes

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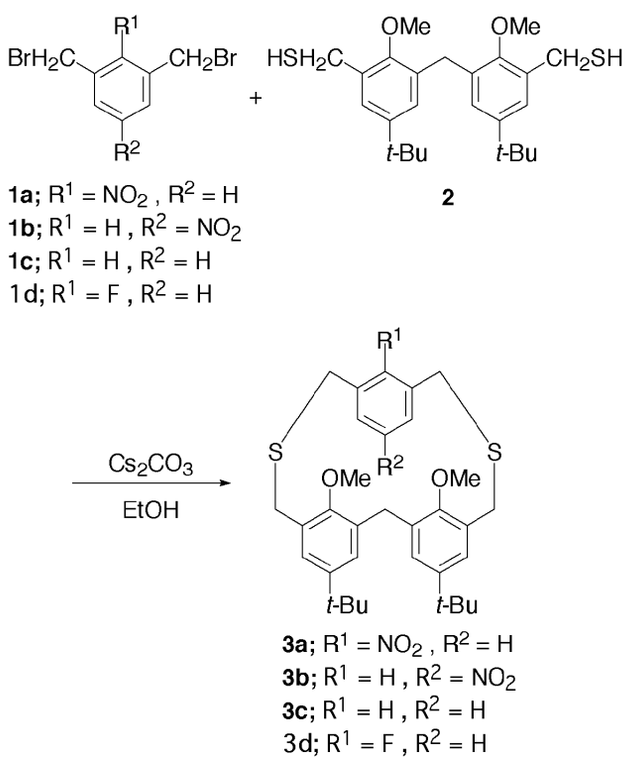
Various substituents have been introduced into the inner or the outer position of the dithia[3.3.1]metacyclophanes (MCPs). Conformational properties of these MCPs are evaluated by variable temperature ^{1}H-NMR spectral measurements, IR measurements, computer calculation and X-ray structural analyses. It has been found that the conformations of dithia[3.3.1]MCPs are affected by not only the steric effect of the inner or the outer substituent but also by the electronic nature of the component aromatic ring. Furthermore, a weak interaction such as NH–π interaction or hydrogen-bonding also regulates their conformation.

Introduction

Weak interactions such as hydrogen-bonding, π–π interaction, charge-transfer, *etc.* are highlighted by many researchers because they play very important roles *in vivo* and *in vitro*. On the other hand, NH–π interaction has not been studied extensively because of difficulties in evaluating this weak interaction.[1] Conformational properties and a transannular interaction in the medium-sized metacyclophane compounds have been attracting great interest from organic and physical organic chemists.[2] We have already reported the conformational properties of [3.3.*n*]metacyclophanes (MCPs),[3] which have been discussed only in terms of bulkiness of the inner substituent. We have also reported that intra- and intermolecular weak interactions play very important roles in regulating the crystal and the molecular structure in dithia[3.3]MCPs.[4] Thus, we show here the preparation and the conformational properties of dithia[3.3.1]MCPs which have various substituents at their inner or outer position in order to clarify the influence of weak interactions, that is to say, NH–π interaction and hydrogen-bonding, by variable temperature ^{1}H-NMR spectral measurements, IR measurements, computer calculation and X-ray structural analyses.



1a; $R^1 = NO_2$, $R^2 = H$
1b; $R^1 = H$, $R^2 = NO_2$
1c; $R^1 = H$, $R^2 = H$
1d; $R^1 = F$, $R^2 = H$

2

3a; $R^1 = NO_2$, $R^2 = H$
3b; $R^1 = H$, $R^2 = NO_2$
3c; $R^1 = H$, $R^2 = H$
3d; $R^1 = F$, $R^2 = H$

Scheme 1

Results and discussion

Bis(halomethyl)arenes **1a**–**d**[5] and bis(5-*tert*-butyl-3-mercaptomethyl-2-methoxyphenyl)methane **2**[6] were prepared according to the previously outlined procedures. Dithia[3.3.1]MCPs **3a**–**d** were prepared from the corresponding halomethyl (**1a**–**d**) and mercaptomethyl compounds (**2**) under highly dilute conditions by using Cs_2CO_3 as an alkaline catalyst (Scheme 1).[7] NitroMCPs **3a** and **3b** were readily reduced with hydrogen gas in the presence of 10% Pd/C as a catalyst to give the corresponding aminoMCPs **4a** and **4b** in excellent yields (Scheme 2).

The aminoMCP **4a** was converted into the corresponding MCPdiazonium salt **5** by using $NaNO_2$ in aqueous media. The salt **5**, which has a diazonio group on its inner position, was so unstable that it readily decomposed to the corresponding hydroxyMCP **6** (Scheme 2). The structures of these MCPs, except for MCPdiazonium salt **5**, were confirmed by the ^{1}H-NMR, IR and MS spectra and elemental analysis.

Conformational properties of the substituted MCPs **3**, **4** and **6** were studied by variable temperature ^{1}H-NMR measurements (Table 1). MCPs **3**, **4** and **6** show quite broad peak patterns at room temperature. At 213 K in $CDCl_3$, two pairs of two doublets for their bridge protons appeared. In detail, one of the coupling constants (J = 14.0 Hz) in nitroMCP **3a** is the same as the constant in hydroxyMCP **6**. The other coupling constant (J = 13.7 Hz) is also similar to that of hydroxyMCP **6**. In

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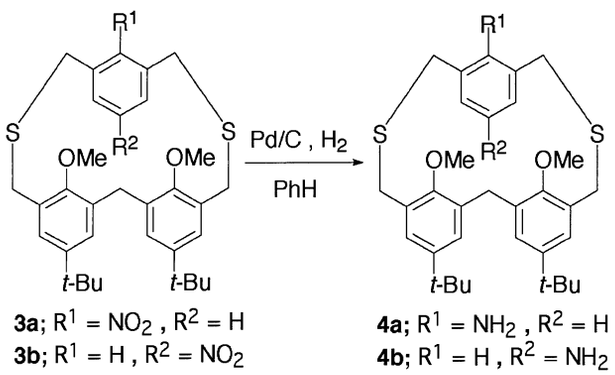
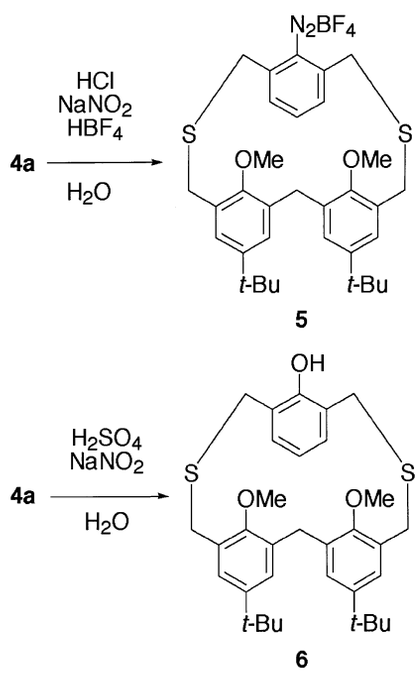
Table 1 Selected spectral data for dithia[3.3.1]MCPs **3**, **4** and **6**

MCP	Chemical shift[a] (ppm) Bridge-H	Ar-H	ν[b]/cm^{-1}
3a	3.53 (d, J = 13.7 Hz), 3.56 (d, J = 13.7 Hz), 4.03 (d, J = 14.0 Hz), 4.10 (d, J = 14.0 Hz)	6.12	—
3b	3.17 (d, J = 13.6 Hz), 3.29 (d, J = 13.6 Hz), 3.45 (d, J = 14.1 Hz), 3.87 (d, J = 14.1 Hz)	5.74	—
3c	3.14 (d, J = 14.0 Hz), 3.26 (d, J = 13.7 Hz), 3.39 (d, J = 14.0 Hz), 3.90 (d, J = 13.7 Hz)	5.52	—
3d	3.32 (d, J = 14.0 Hz), 3.42 (d, J = 14.0 Hz), 3.50 (d, J = 13.7 Hz), 3.81 (d, J = 13.7 Hz)	6.89	—
4a	3.48 (d, J = 13.7 Hz), 3.58 (d, J = 14.4 Hz), 3.66 (d, J = 13.7 Hz), 3.82 (d, J = 14.4 Hz)	6.47	3432, 3363[c]
4b	3.04 (d, J = 13.9 Hz), 3.27 (d, J = 13.9 Hz), 3.27 (d, J = 14.2 Hz), 3.92 (d, J = 14.2 Hz)	4.98	3449, 3367[c]
6	3.44 (d, J = 13.7 Hz), 3.48 (d, J = 13.7 Hz), 3.65 (d, J = 14.0 Hz), 3.96 (d, J = 14.0 Hz)	6.75	3399[d]

[a] In $CDCl_3$ at 213 K. [b] KBr method. [c] NH_2 stretching. [d] OH stretching.





Scheme 2

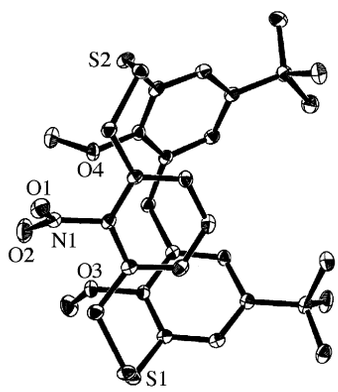


Fig. 1 Molecular structure of nitrodithia[3.3.1]MCP **3a**. Hydrogen atoms are omitted for clarity.

contrast, aminoMCP **4a** exhibits a different coupling pattern and different coupling constants from those of nitroMCP **3a** and hydroxyMCP **6**. Such differences in the peak patterns and the coupling constants of their bridge protons of MCPs could be ascribed to the difference in their conformational properties. The outer aryl proton of aminoMCP **4a** appeared in a downfield region (δ = 6.47 ppm) compared with that of nitroMCP **3a** (δ = 6.12 ppm). Furthermore, internal NH_2 protons were observed at 3.52 ppm. These results indicate that the outer aryl proton of aminoMCP **4a** is not affected by the ring current effect of the two opposite aromatic rings, suggesting that the conformation of aminoMCP **4a** does not assume the "Cone" structure.

On the other hand, the coupling pattern for the bridge protons of nitroMCP **3b** and aminoMCP **4b** appeared as two pairs of two doublets, but their pattern was quite different from those of nitroMCP **3a** and aminoMCP **4a**. The inner aryl protons of nitroMCP **3b** and aminoMCP **4b** (δ = 5.70, 4.98 ppm, respectively) seem to be affected by the ring current effect of the two opposite aromatic rings. From this tendency the conformations of nitroMCP **3b** and aminoMCP **4b** are similar to neither nitroMCP **3a** nor aminoMCP **4a**, however their exact conformations cannot be determined by the NMR data.

From the data for hydroxyMCP **6**, the conformation is assumed to be "Cone" form because the coupling constants (J = 14.0, 13.7 Hz) and patterns are quite similar to those of nitroMCP **3a**. As the outer aryl proton of fluoroMCP **3d** (δ = 6.89 ppm) is not affected by the ring current effect of the two opposite aromatic rings, the conformation could be considered as the "Folded-Inward" form.

Finally, the coupling patterns and the coupling constants for MCP **3c** are different from those of other MCPs.

In order to confirm the conformation, we performed X-ray structural analyses of MCPs **3**, **4** and **6** except for aminoMCP **4b**, because a crystal of **4b** suitable for the X-ray analysis was not obtained. Analytical data are given in the Experimental section. The molecular structures for MCPs **3a**, **3b**, **3c**, **3d**, **4a** and **6** are shown in Figs. 1, 2, 3, 4, 5 and 6, respectively. The structure of nitroMCP **3a** is "Cone" form, that is, the nitro substituent on the nitrobenzene unit is oriented in the same

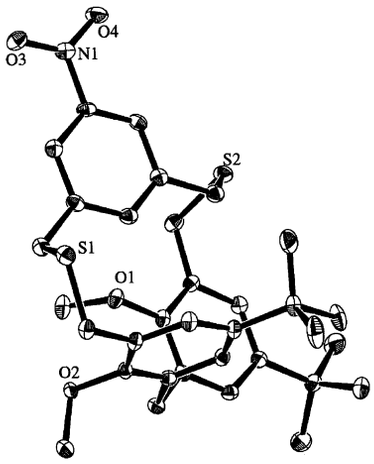


Fig. 2 Molecular structure of nitrodithia[3.3.1]MCP **3b**. Hydrogen atoms are omitted for clarity.

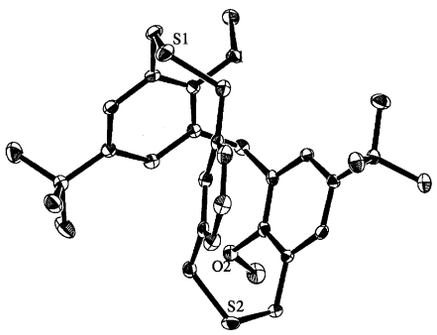


Fig. 3 Molecular structure of dithia[3.3.1]MCP **3c**. Hydrogen atoms are omitted for clarity.

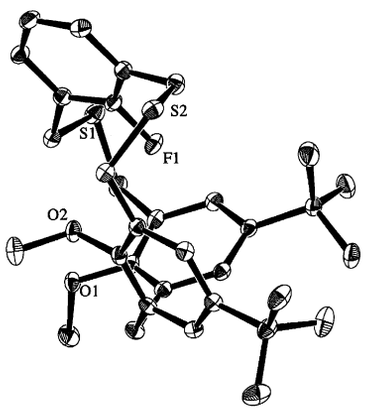


Fig. 4 Molecular structure of fluorodithia[3.3.1]MCP **3d**. Hydrogen atoms are omitted for clarity.

direction as the two methoxy groups on the diphenylmethane unit. This can be explained by the bulkiness of the nitro group. On the other hand, nitroMCP **3b** is neither "Cone" form nor "Folded-Inward" form. The inner aryl proton (R^1) on the nitrobenzene unit is directed toward the center of one aromatic ring of the diphenylmethane unit. This fact implies the existence of a weak CH–π interaction but the average lengths between the proton and the aromatic carbons (*ca.* 2.8 Å) are slightly longer than the sum of these van der Waals radii. The conformation of MCP **3c** is quite different from those of the other MCPs. The two anisole rings orient in the opposite direction and the phenyl ring is directed perpendicular to the two anisole rings. FluoroMCP **3d** seems to be in the "Folded-Inward" form. Although the internal fluoro atom is oriented toward the center of one aromatic ring of the diphenylmethane unit, F–π interaction cannot be confirmed because the long

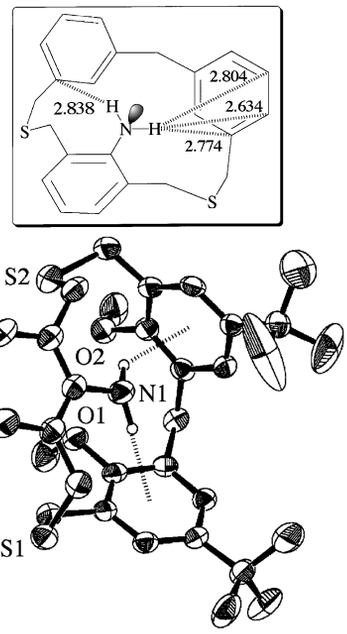


Fig. 5 Molecular structure of aminodithia[3.3.1]MCP **4a**. Hydrogen atoms are omitted for clarity except for amino protons. NH–π interactions are shown by dotted lines. Distances (Å) between the amino protons and the opposite aromatic carbons in aminodithia[3.3.1]MCP **4a** are shown in the insert.

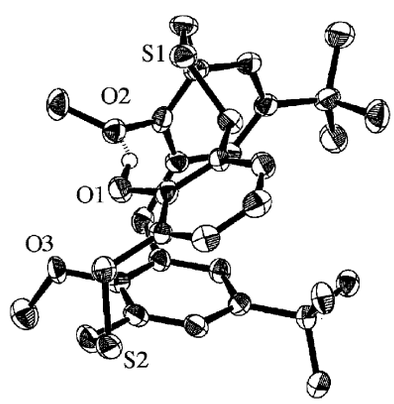


Fig. 6 Molecular structure of hydroxydithia[3.3.1]MCP **6**. Hydrogen atoms are omitted for clarity except for the hydroxy proton and the hydrogen-bonding is shown by a dotted line.

distances between the fluoro atom and the aromatic carbons (*ca.* 2.9 Å) are much longer than the sum of these van der Waals radii.

The conformation of aminoMCP **4a** is not "Cone" form but "Folded-Inward" form. Lengths between amino protons and the two opposite aromatic carbon atoms in aminoMCP **4a** are also shown in Fig. 5. Some of these values are smaller than the sum of the van der Waals radii of the proton and carbon (2.90 Å). This result strongly suggests the existence of two NH–π interactions between the two amino protons and the two opposite aromatic rings in this system. Intramolecular NH–π interactions between the two amino protons and the opposite two aromatic rings and hydrogen-bonding are indicated from the X-ray analyses, and are shown by dotted lines.

Interestingly, the conformation of hydroxyMCP **6** is found to be "Cone" form. This can be explained by the intramolecular hydrogen-bonding (*ca.* 1.92 Å) between the hydroxy proton and the oxygen atom of the methoxy group of the opposite aromatic ring, which seems to restrict the ring inversion of the opposite aromatic ring.

In the IR spectra, wavenumbers of symmetric and asymmetric stretching vibrations of the amino group in aminoMCP **4a** appeared at 3432 and 3363 cm^{-1}, respectively. The corre-

sponding vibrations of 2,6-dimethylaniline **7** were observed at 3484 and 3400 cm^{-1}, respectively. Values for MCP **4a** are 52 and 37 cm^{-1} smaller than those for **7**. In contrast, wavenumbers of the amino group in aminoMCP **4b** were observed at 3449 and 3367 cm^{-1}, respectively. The corresponding vibrations of 3,5-dimethylaniline **8** were observed at 3433 and 3366 cm^{-1}, respectively. Values for MCP **4b** are only 16 and 1 cm^{-1} smaller than those for **8**. These results prove the existence of NH–π interaction between the amino protons and the opposite aromatic rings in MCP **4a**. In contrast, such an interaction is not involved in MCP **4b**.

In MCP **6**, vibrational absorption of the hydroxy group appeared at 3399 cm^{-1}. This value is also 10 cm^{-1} smaller than that of 2,6-dimethylphenol **8** (3409 cm^{-1}). These results also support the proposal that some weak interactions exist in MCP **6**.

Interestingly, the conformation of hydroxyMCP **6** is "Cone" form. This can be explained by the intramolecular hydrogen-bonding (*ca.* 1.92 Å) between the hydroxy proton and the oxygen atom of the methoxy group in the opposite aromatic ring restricting the ring inversion of the opposite aromatic ring.

In computer calculations (AM1 level), the lowest conformational energy (heat of formation (H(f))) values for the structures of these MCPs were −30.86 kJ mol^{-1} for **3a**, −40.87 kJ mol^{-1} for **3b**, −40.66 kJ mol^{-1} for **3c** and −38.08 kJ mol^{-1} for **4a**, respectively. The results indicate that the most stable conformations of the MCPs, except for aminoMCP **4a**, are identical to the conformations from the X-ray analyses. For aminoMCP **4a**, the calculation result indicates that the most stable conformation is not the "Folded-Inward" form (−38.08 kJ mol^{-1}) but the "Cone" form (−40.78 kJ mol^{-1}). Generally, the stabilization energy of one NH–π interaction is *ca.* −2.22 kcal mol^{-1} (*ca.* −9.30 kJ mol^{-1}).[1] The most stable conformation of amino MCP **4a** seems to be stabilized by the two NH–π interactions in the structure. This result also indicates the existence of the intramolecular NH–π interaction in aminoMCP **4a**.

Conclusion

We have established the preparation procedure for dithia-[3.3.1]MCPs carrying an electron-releasing or -withdrawing substituent on their inner or outer positions. It can be concluded that the conformations of dithia[3.3.1]MCPs are affected by not only the steric hindrance and the electronic properties of the internal substituent but also by intramolecular weak interactions such as NH–π interactions or hydrogen-bonding.

Experimental

All melting points were recorded on a Yanako hot-stage microscope apparatus and are uncorrected. ^{1}H-NMR spectra were recorded on a Nippon Densi a-500 spectrometer in $CDCl_3$ or CD_3CN with Me_4Si as an internal reference. IR spectra were recorded on a Hitachi 260-30 spectrometer and a Nippon Bunko JASCO IR-700 spectrometer. Mass spectra were obtained on a Nippon Densi JEOL-DX-300 spectrometer at 75 eV using a direct inlet system. Column chromatography was carried out on silica gel (Wako gel, C-300). The amounts of silica gel used were 5–50 g.

Preparation of MCPs 3

Typical procedure. A solution of 2.14 g of 2,6-bis(bromomethyl)arene (**1**) (6.93 mmol) and 3.00 g of 1,1′-bis(3-mercaptomethyl-5-*tert*-butyl-2-methoxyphenyl)methane (**2**) (6.93 mmol) in benzene–ethanol (1 : 2) (300 cm^3) was added dropwise over a period of 8 h from a Henshborg funnel with stirring to a refluxing solution of 6.72 g of Cs_2CO_3 (40.0 mmol) in ethanol (800 cm^3). After the addition, the reaction mixture was concentrated under reduced pressure to leave the residue, which was extracted with dichloromethane. The extract was concentrated and the residue was chromatographed over silica gel, using toluene as an eluent to give nitroMCP **3**.

MCP **3a**: pale yellow prisms (hexane) (860 mg, 22%); mp 146–149 °C (Found: C, 68.2; H, 7.2; N, 2.4. $C_{33}H_{41}NO_4S_2$ requires C, 68.4; H, 7.1; N, 2.4%); δ_H(500 MHz; $CDCl_3$) 1.35 (18H, s, *tert*-butyl), 3.19 (1H, d, CH_2, J = 11.6 Hz), 3.53 (2H, d, bridged CH_2S, J = 13.7 Hz), 3.56 (2H, d, bridged CH_2S, J = 13.7 Hz), 3.63 (1H, d, CH_2, J = 11.6 Hz), 3.70 (6H, s, OMe), 4.03 (2H, d, bridged SCH_2, J = 14.1 Hz), 4.10 (2H, d, bridged SCH_2, J = 14.1 Hz), 6.12 (1H, t, aromatic, J = 7.9 Hz), 6.48 (2H, d, aromatic, J = 7.9 Hz), 7.20 (2H, d, aromatic, J = 2.3 Hz), 7.30 (2H, d, aromatic, J = 2.3 Hz); m/z 579(M^+).

Compound **3b**: pale yellow needles (hexane–dichloromethane) (163 mg, 20%); mp 214–216 °C (Found: C, 68.3; H, 7.2; N, 2.4. $C_{33}H_{41}NO_4S_2$ requires C, 68.4; H, 7.1; N, 2.4%); δ_H(500 MHz; $CDCl_3$) 1.23 (18H, s, *tert*-butyl), 3.16 (1H, d, CH_2, J = 11.2 Hz), 3.17 (2H, d, bridged CH_2S, J = 13.6 Hz), 3.29 (2H, d, bridged CH_2S, J = 13.6 Hz), 3.45 (2H, d, bridged SCH_2, J = 14.0 Hz), 3.59 (6H, s, OMe), 3.87 (2H, d, bridged SCH_2, J = 14.0 Hz), 4.49 (1H, d, CH_2, J = 11.2 Hz), 5.74 (1H, s, aromatic), 7.05 (1H, s, aromatic), 7.07 (1H, s, aromatic), 7.25 (2H, d, aromatic, J = 7.3 Hz), 7.93 (2H, d, aromatic, J = 7.3 Hz); m/z 579(M^+).

Compound **3c**: colourless prisms (butan-1-ol) (2.93 g, 80%); mp 133–136 °C (Found: C, 74.4; H, 8.0. $C_{33}H_{42}O_2S_2$ requires C, 74.1; H, 7.9%); δ_H(500 MHz; $CDCl_3$) 1.23 (18H, s, *tert*-butyl), 3.14 (2H, d, bridged CH_2S, J = 14.0 Hz), 3.26 (2H, d, bridged SCH_2, J = 13.7 Hz), 3.39 (2H, d, bridged CH_2S, J = 14.0 Hz), 3.55 (1H, d, CH_2, J = 13.4 Hz), 3.62 (6H, s, OMe), 3.90 (2H, d, bridged SCH_2, J = 13.7 Hz), 4.50 (1H, d, CH_2, J = 13.4 Hz), 5.52 (1H, s, aromatic), 7.03–7.11 (3H, m, aromatic), 7.25–7.28 (4H, m, aromatic); m/z 534(M^+).

Compound **3d**: colourless needles (hexane–dichloromethane) (920 mg, 24%); mp 110–112 °C (Found: C, 81.9; H, 7.3. $C_{33}H_{41}O_2S_2F$ requires C, 71.7; H, 7.5%); δ_H(500 MHz; $CDCl_3$) 1.28 (18H, s, *tert*-butyl), 3.32 (1H, d, CH_2, J = 14.0 Hz), 3.42 (2H, d, bridged CH_2S, J = 14.0 Hz), 3.50 (2H, d, bridged SCH_2, J = 13.7 Hz), 3.55 (6H, s, OMe), 3.56 (1H, d, bridged CH_2, J = 13.1 Hz), 3.81 (2H, d, bridged SCH_2, J = 13.7 Hz), 4.39 (1H, d, CH_2, J = 13.1 Hz), 6.89 (1H, t, aromatic, J = 7.5 Hz), 7.11 (2H, d, aromatic, J = 7.5 Hz), 7.14 (2H, d, aromatic, J = 2.4 Hz), 7.25 (2H, d, aromatic, J = 2.4 Hz); m/z 552(M^+).

Preparation of aminoMCPs 4

Typical procedure. 100 mg of 10% Pd/C was added to a solution of nitroMCP **3** (0.15 mmol) in benzene (50 cm^3). After hydrogen gas was introduced into the mixture with stirring for 2 h at RT, the Pd/C was filtered off. The filtrate was evaporated under reduced pressure to leave the residue, which was recrystallized from benzene to give product **4**.

Compound **4a**: colourless prisms (hexane) (170 mg, 90%); mp 191–193 °C (Found: C, 72.0; H, 7.9; N, 2.5. $C_{33}H_{43}NO_2S_2$ requires C, 72.1; H, 7.9; N, 2.6%); ν_{max}(KBr)/cm^{-1} 3432, 3363 (NH_2); δ_H(500 MHz; $CDCl_3$) 1.26 (9H, s, *tert*-butyl), 1.31 (9H, s, *tert*-butyl), 3.05 (2H, broad s, NH_2), 3.48 (2H, d, bridged CH_2S, J = 13.7 Hz), 3.42 (2H, d, bridged SCH_2, J = 14.4 Hz), 3.50 (2H, d, bridged CH_2S, J = 13.7 Hz), 3.55 (1H, d, CH_2, J = 13.4 Hz), 3.62 (6H, s, OMe), 3.81 (2H, d, bridged SCH_2, J = 14.4 Hz), 4.50 (1H, d, CH_2, J = 12.8 Hz), 6.47 (1H, t, aromatic, J = 7.6 Hz), 6.88 (1H, d, aromatic, J = 7.6 Hz), 6.93 (1H, d, aromatic, J = 7.6 Hz), 7.13 (2H, d, aromatic, J = 2.1 Hz), 7.47 (2H, d, aromatic, J = 2.1 Hz); m/z 549(M^+).

Compound **4b**: colourless oil (38 mg, 85%) (Found: C, 72.4; H, 7.9; N, 2.3. $C_{33}H_{43}NO_2S_2$ requires C, 72.1; H, 7.9; N, 2.6%); ν_{max}(KBr)/cm^{-1} 3449, 3367 (NH_2); δ_H(500 MHz; $CDCl_3$) 1.23

(18H, s, *tert*-butyl), 5.04 (2H, broad s, NH_2), 3.04 (2H, d, bridged CH_2S, J = 13.9 Hz), 3.27 (2H, d, bridged SCH_2, J = 13.9 Hz), 3.27 (2H, d, bridged CH_2S, J = 14.2 Hz), 3.41 (1H, d, CH_2, J = 13.7 Hz), 3.62 (6H, s, OMe), 3.92 (2H, d, bridged SCH_2, J = 14.2 Hz), 4.49 (1H, d, CH_2, J = 13.7 Hz), 4.98 (1H, s, aromatic), 6.39 (2H, s, aromatic), 7.05 (2H, d, aromatic, J = 2.2 Hz), 7.31 (2H, d, aromatic, J = 2.2 Hz); *m*/*z* 549(M^+).

Diazoniation of aminoMCP 4a

To a stirred suspension of aminoMCP **4a** (41 mg, 0.074 mmol) in water (5.0 cm^3) was added 1.0 cm^3 of 35% hydrochloric acid at room temperature, and the mixture was stirred for 10 min. After the addition of sodium nitrite (69 mg, 1.0 mmol) at 0 °C, the reaction mixture was stirred for 10 min, then 42% tetrafluoroboric acid (1.0 cm^3) was added. After stirring for 10 min, 50 cm^3 of absolute ether was added to the reaction mixture. The resulting precipitates were collected by filtration and washed with ether to give moderately unstable diazonium salt **5**. Pale yellow powder (39 mg, 80%); mp 90–95 °C (decomp.); ν_{max}(KBr)/cm^{-1} 2345 (N_2^+).

Preparation of hydroxyMCP 6 from aminoMCP 4a

To a stirred suspension of aminoMCP **4a** (0.17 g, 0.31 mmol) in acetic acid (5 cm^3) was added 0.5 cm^3 of 98% sulfuric acid at 70 °C, and the mixture was stirred for 10 min. After the addition of sodium nitrite (28 mg, 0.40 mmol) at 0 °C, the reaction mixture was stirred for 10 min, then urea (10 mg) was added. After stirring for 10 min, 10 cm^3 of 20% sulfuric acid were added to the reaction mixture and the mixture was stirred for a further 30 min. The resulting precipitates were collected by filtration and chromatographed over silica gel using ethyl acetate–hexane mixed solvent (0.2 vol/vol) as an eluent to give product **6**.

Colorless needles (hexane–dichloromethane) (83 mg, 49%); mp 86–88 °C; ν_{max}(KBr)/cm^{-1} 3399 (OH); δ_H(500 MHz; $CDCl_3$) 1.19 (18H, s, *tert*-butyl), 3.44 (2H, d, bridged CH_2S, J = 13.7 Hz), 3.48 (2H, d, bridged SCH_2, J = 13.7 Hz), 3.57 (6H, s, OMe), 3.65 (2H, d, bridged CH_2S, J = 14.0 Hz), 3.90 (1H, d, CH_2, J = 13.7 Hz), 3.96 (2H, d, bridged SCH_2, J = 14.0 Hz), 4.70 (1H, d, CH_2, J = 13.7 Hz), 4.98 (1H, s, aromatic), 5.42 (1H, s, OH), 6.65 (1H, t, aromatic, J = 7.4 Hz), 6.95 (2H, d, aromatic, J = 7.4 Hz), 7.05 (2H, d, aromatic, J = 2.0 Hz), 7.19 (2H, d, aromatic, J = 2.0 Hz) (Found: C, 71.8; H, 8.0. $C_{33}H_{42}O_3S_2$ requires C, 72.0; H, 7.7%); *m*/*z* 550(M^+).

Crystal structure determinations of MCPs 3, 4a and 6†

Crystal data for MCP 3a. Recrystallized from hexane. $C_{33}H_{41}NO_4S_2$, M_r = 579.81, monoclinic, a = 15.169(4), b = 12.719(7), c = 17.684(3) Å, β = 114.97(1)°, V = 3092.6599 Å^3, $P2_1/c$ (#14), Z = 4, D_{calc} = 1.245 g cm^{-3}, T = 103.2 K, R = 0.058, R_w = 0.069; 6686 unique reflections with $2\theta \leq 55.6°$. Of these, 6076 $I > 2.00\ \sigma(I)$.

Crystal data for MCP 3b. Recrystallized from hexane. $C_{33}H_{41}NO_4S_2$, M_r = 579.81, monoclinic, a = 12.9636(5), b = 12.7351(4), c = 19.3901(7) Å, β = 104.0528(8)°, V = 3105.4(2) Å^3, $P2_1/c$ (#14), Z = 4, D_{calc} = 1.240 g cm^{-3}, T = 93 K, R = 0.0314, R_w = 0.0401; 7112 unique reflections with $2\theta \leq 55.6°$. Of these, 4629 $I > 3.00\ \sigma(I)$.

Crystal data for MCP 3c. Recrystallized from hexane. $C_{33}H_{42}O_2S_2$, M_r = 534.81, triclinic, a = 9.7609(6), b = 18.671(2), c = 9.1231(5) Å, α = 90.878(4), β = 116.678(2), γ = 83.190(3)°, V = 1473.8(2) Å^3, $P\bar{1}$ (#2), Z = 2, D_{calc} = 1.205 g cm^{-3}, T = 93 K, R = 0.0379, R_w = 0.0491; 6256 unique reflections with $2\theta \leq 55.6°$. Of these, 3397 $I > 3.00\ \sigma(I)$.

Crystal data for MCP 3d. Recrystallized from hexane. $C_{33}H_{41}FO_2S_2$, M_r = 552.80, monoclinic, a = 18.3159(6), b = 8.4338(2), c = 20.4494(5) Å, β = 104.829(1)°, V = 3053.7(1) Å^3, $P2_1/a$ (#14), Z = 4, D_{calc} = 1.202 g cm^{-3}, T = 93 K, R = 0.0301, R_w = 0.0417; 6994 unique reflections with $2\theta \leq 55.6°$. Of these, 5320 $I > 3.00\ \sigma(I)$.

Crystal data for MCP 4a. Recrystallized from hexane. $C_{33}H_{43}NO_2S_2$, M_r = 549.83, monoclinic, a = 13.415(2), b = 14.115(4), c = 16.489(6) Å, β = 95.63(2)°, V = 5933.9(6) Å^3, $P2_1/n$ (#14), Z = 4, D_{calc} = 1.175 g cm^{-3}, T = 293.2 K, R = 0.063, R_w = 0.114; 4620 unique reflections with $2\theta \leq 60.1°$. Of these, 3433 $I > 3.00\ \sigma(I)$.

Crystal data for MCP 6. Recrystallized from hexane. $C_{33}H_{42}O_3S_2$, M_r = 550.81, monoclinic, a = 11.497(2), b = 16.640(3), c = 15.500(2) Å, β = 94.727(4)°, V = 2955.2(7) Å^3, $P2_1/n$ (#14), Z = 4, D_{calc} = 1.238 g cm^{-3}, T = 93.2 K, R = 0.074, R_w = 0.236; 6093 unique reflections with $2\theta \leq 55.6°$. Of these, 1914 $I > 2.00\ \sigma(I)$.

Intensity data for MCPs **3a**–**d** and **6** were collected on a Rigaku RAXIS-4 Imaging Plate with graphite-monochromatized Mo-Kα radiation. Intensity data for polymorph **4a** were collected on a Rigaku AFC-7R diffractometer with graphite-monochromatized Mo-Kα radiation. These structures were solved with the teXsan crystallographic software package of Molecular Structure Corporation. In the data, all hydrogen atoms were found from differential Fourier maps. *xyz* and isotropic *B* factors of amino protons in MCP **4a** were refined.

† CCDC reference numbers 116636, 165145, 165153, 163830, 119382 and 163959. See http://www.rsc.org/suppdata/p2/b1/b106154m/ for crystallographic files in .cif or other electronic format.

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