The *Syn* Conformers of Several 2,11-Dithia[3.3](1,4)naphthalenometacyclophanes: Novel Preference for a Conformation with Parallel Benzenoid Rings from Direct Confrontation of Two Different Modes of Non-bonding Interaction

Yee-Hing Lai
Department of Chemistry, National University of Singapore, Kent Ridge, Republic of Singapore 0511

2,11-Dithia[3.3](1,4)naphthalenometacyclophane and its 9-bromo- and 9-fluoro-derivative have been synthesized. ^{1}H and ^{19}F n.m.r. studies have indicated that all three dithiacyclophanes prefer the *syn*-conformation with near-parallel stacking of aromatic rings. This conformational preference is supported by results from MMP2 calculations. The angle of tilting of the *meta*-bridged ring is dependent on the 9-substituent. Variable-temperature n.m.r. studies have unexpectedly shown neither a flipping of the *meta*-bridged ring nor a wobbling of the C–S–C bridges. Possible conformational behaviour is the continuous tilting process of the *meta*-bridged ring in the rigid *syn*-conformation. A solvent effect on the chemical shifts of both the reference protons and the fluorine has been observed.

Dithiacyclophanes, which can now be prepared readily by high-dilution techniques,[1] have been used extensively as precursors for novel conjugated aromatic compounds.[2] However, many of these medium-ring and macrocyclic molecules exhibit novel conformational processes[3] and deserve to be independently studied. In the dithia[3.3]cyclophane series, all three symmetrically bridged parent systems, namely the dithia[3.3]paracyclophane (**1**),[4] dithia[3.3]orthocyclophane (**2**),[5] and dithia[3.3]metacyclophane (**3**),[6] are known. From conformational studies of these cyclophanes, two different conformational processes involving the flipping of the benzene rings and the C–S–C bridges, respectively, have been suggested. Among the unsymmetrical parent dithia[3.3]cyclophanes (**4**)–(**6**), both dithia[3.3]metaorthocyclophane (**5**) and dithia[3.3]metaparacyclophane (**6**) have been reported. The former seemed to undergo the pendulum-like interconversion (**5A**) $\rightleftharpoons$ (**5B**) with a conformational energy barrier of <38 kJ mol^{-1}.[7] The metaparacyclophane (**6**)[8] was expected to undergo a different pendulum-like interconversion (**6A**) $\rightleftharpoons$ (**6B**), a novel ring-flipping process involving the impingement of the internal proton H_i of the *meta*-bridged ring onto the π-electron cloud of the *para*-bridged ring. The energy barrier to overcome this non-bonding interaction, however, could not be estimated, possibly due to high conformational mobility of the macroring. Such a conformational process was later studied using the related fluoro-derivative (**7**) with an observed conformational barrier of *ca.* 76 kJ mol^{-1}.[8] The preparation of the related dithia[3.3]anthracenometacyclophane (**9**) was also reported,[9] although no details of the *meta*-ring flipping process (**9A**) $\rightleftharpoons$ (**9B**) were described. Two kinds of non-bonding interaction are clearly encountered in (**9A**) [or (**9B**)]: the π–π repulsion between the *meta*-ring and the adjacent terminal anthracene ring, and the steric interaction due to the H_i proton projecting into the adjacent terminal ring of the anthracene moiety. Either factor would be unfavourable and could destabilize the conformational ground state in (**9**) compared with that in (**6**). In fact the results of having a proton projecting into a benzene cavity or having two parallel-stacked benzene rings have been used frequently to infer the conformational behaviour in cyclophanes.[3] An ideal model to allow studies and direct comparison of both interactions in the same molecule would thus be the naphthalenometacyclophane (**10**). The dithiacyclophane (**10**) was expected to be sufficiently mobile to allow fast *meta*-ring flipping (**10A**) $\rightleftharpoons$ (**10B**) on the n.m.r. timescale and the preferred conformation, if any, found experimentally will then provide direct evidence to indicate which of the two kinds of non-bonding interaction is the over-riding factor in the conformational behaviour in both phanes (**9**) and (**10**).

Table. Chemical shifts of selected protons and fluorines in dithiacyclophanes (**6**)–(**12**).

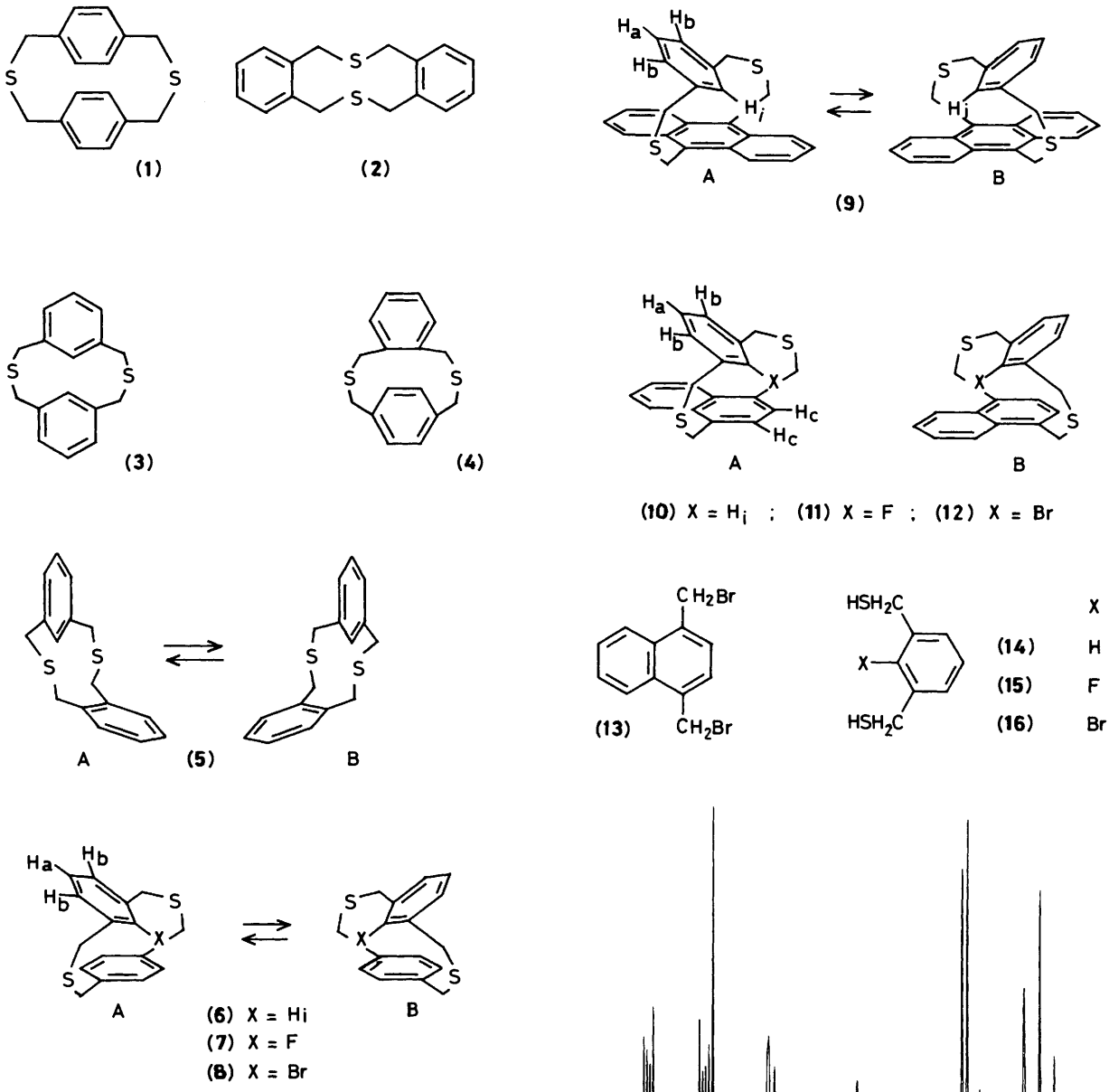
Cyclophane	δ_{H_i}	δ_{H_a}	δ_{H_b}	δ_F	δ_{CH_2} [a]	δ_{CH_2} [b]	Ref.
(**6**)	5.52	6.8—7.2			3.38, 3.76		8
(**7**)		*ca.* 7.1		−117 [d]	3.49, 3.71		8
(**8**)		7.0—7.3			3.72, 3.78		9
(**9**)	3.92	6.3—6.6			3.24	4.87	9
(**10A**)	5.51	6.3—6.6			3.46	4.25	*c*
(**11A**)		6.03	6.61	−118 [e]	3.50	4.19	*c*
(**12A**)		6.07	6.72		3.71	4.17	*c*

[a] Adjacent to (1,3)-bridged ring. [b] Adjacent to (1,4)-bridged ring. [c] This paper. [d] Relative to $CFCl_3$. [e] Relative to CF_3CO_2H and correlated to $CFCl_3$.

Results and Discussion

Syntheses.—All three dithiacyclophanes (**10**)–(**12**) were prepared *via* the thiol–bromide coupling reaction under high-dilution conditions.[1] The cyclization reactions were carried out with 1,4-bis(bromomethyl)naphthalene (**13**)[10] and 1,3-bis(mercaptomethyl)benzenes (**14**),[8,11] (**15**),[12] and (**16**) respectively. The respective dithiacyclophanes (**10**)–(**12**) were isolated in 56, 31, and 38% yield. All t.l.c. studies on silica gel using various solvent systems indicated only one component for each of the isolated dithiacyclophanes. These results gave the first indication that a single conformer is preferred in each of these dithiacyclophanes.

The Preferred Conformation.—The ^{1}H n.m.r. spectrum (90 MHz) of dithiacyclophane (**10**) is shown in Figure 1. With the available ^{1}H n.m.r. data reported for both planes (**6**)[8] and (**9**),[9] a direct comparison (Table) of the chemical shifts of the respective H_i, H_a, and H_b protons will clearly lead to the assignment of the preferred conformation in compound (**10**). In structure (**6**), the *meta*-bridged ring is expected to be at an angle to the *para*-

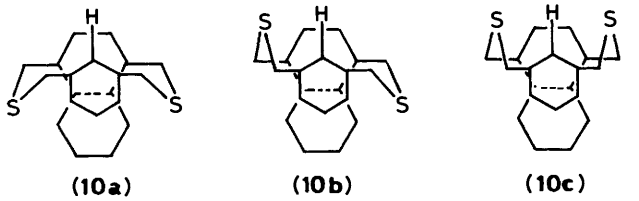


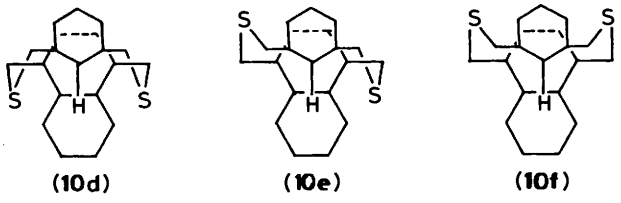
bridged ring with the internal H_i proton located slightly over the latter thus resulting in the apparent upfield shift of the H_i proton (δ 5.52). In dithiacyclophane (**9**), however, the corresponding H_i proton is directly over the cavity of a terminal ring in the anthracene moiety, resulting in a much stronger shielding effect on the H_i proton (δ 3.92). The internal H_i proton of the isolated isomer of compound (**10**) was observed as a broad singlet at δ 5.51, almost identical with that of (**6**), which is consistent with the *syn*-conformer (**10A**). The *anti*-conformation (**10B**) would be expected to have the H_i proton appear at a chemical shift similar to that of compound (**9**). In addition, the *meta*-bridged ring in (**10A**) is now tilted toward the non-bridged ring of the naphthalene moiety; the H_a and H_b protons were thus observed deshielded at δ 6.4–6.6, similar to the range reported for compound (**9**) (δ 6.3–6.6) thus further supporting the above assignment. The H_a and H_b protons of compound (**6**), similar in environment to those in conformer (**10B**), were observed in the normal aryl region at δ 6.8–7.2.

^{19}F N.m.r. spectroscopy has not yet been used extensively in the conformational studies of cyclophanes.[3a] However, with the fluorine atom in *anti*-isomer (**11B**) located much closer to the π-electron cloud of the naphthalene moiety compared with that in *syn*-isomer (**11A**), a marked shielding effect on the fluorine atom in the former would be expected. The ^{19}F chemical shift (room temperature) of the isolated isomer of (**11**) was observed at −117 p.p.m. (relative to CF_3CO_2H and correlated to $CFCl_3$), almost identical with that of (**7**) (Table) which is known to be conformationally rigid at room temperature.[8] This result is again consistent with the *syn*-conformation (**11A**). This preference is also evident from a comparison of the ^1H n.m.r. chemical shifts of H_a and H_b protons in (**11A**) and (**12A**) which are significantly deshielded (Table) compared with those observed for phanes (**7**) and (**8**) (which are both conformationally rigid at room temperature) respectively.

Figure 1. ^1H N.m.r. spectrum (90 MHz; $CDCl_3$; 35 °C) of 2,11-dithia[3.3](1,4)naphthalenometacyclophane (**10**).

The above n.m.r. data have provided the experimental





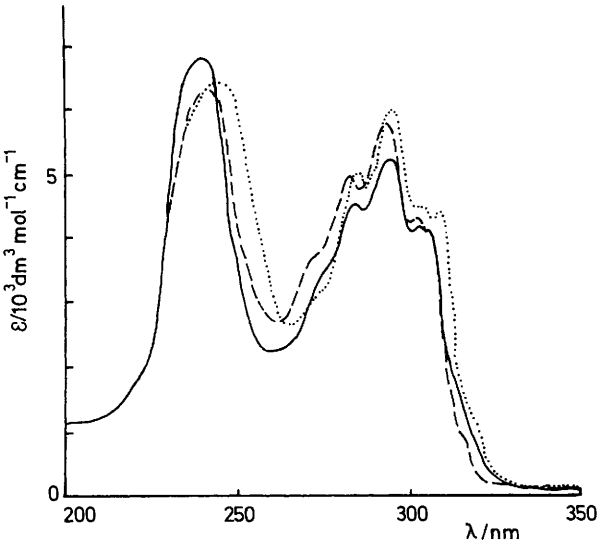


Figure 2. U.v. absorption spectra of phanes (**10**) (——), (**11**) (– – – –), and (**12**) (· · · ·) taken in cyclohexane.

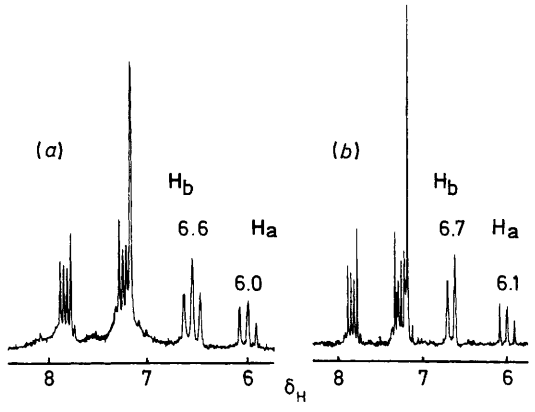


Figure 3. ^{1}H N.m.r. spectra (90 MHz; $CDCl_3$; 35 °C) of the aromatic protons of (*a*) fluorodithiacyclophane (**11**) and (*b*) bromodithiacyclophane (**12**).

evidence to show that in 2,11-dithia[3.3](1,4)naphthalenometacyclophanes (**10**)–(**12**), the preferred conformation has the *meta*-bridged ring stacking over the non-bridged naphthalene ring (*syn*-conformation), independent of the 'internal' substituent in the former. This conformation is presumably thermo-

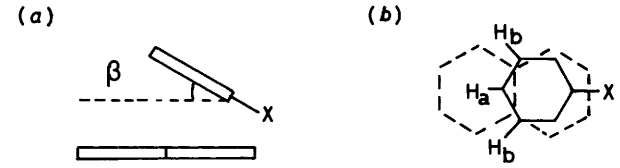


Figure 4. (*a*) Side view showing tilting of *meta*-bridged ring and (*b*) top view showing stacking of aromatic rings in dithiacyclophane (**10**).

dynamically more stable. In order to support this conformational preference, MMP2[13] calculations were performed to determine the energy difference between the various conformers of phane (**10**). All the three *syn*-conformers, (**10a–c**), and the three *anti*-conformers, (**10d–f**), were considered. Results from MMP2 calculations indicate that *syn*-conformer (**10a**) is the most stable. Energies of the other conformers relative to (**10a**) are as follows: *syn*-(**10b**), 11.2 kJ mol^{-1}; *syn*-(**10c**), 27.2 kJ mol^{-1}; *anti*-(**10d**), 34.4 kJ mol^{-1}; *anti*-(**10e**), 20.0 kJ mol^{-1} and *anti*-(**10f**), 14.4 kJ mol^{-1}. These data clearly show that energies of all the *anti*-conformers of phane (**10**) are much higher than those of the *syn*-conformers, suggesting that the population of the former conformers would be negligibly small.

The Inclining meta-*Bridged Ring*.—U.v. absorption spectral studies of a series of paracyclophanes[14] have revealed that closely stacked parallel benzene rings would result in a bathochromic shift and broadening of peaks. From the electronic spectra of dithiacyclophanes (**10A**), (**11A**), and (**12A**) (Figure 2), a more distinctive feature is in fact the gradually broadened and bathochromic shifts absorption at *ca.* 240 nm going from (**10A**) ⟶ (**11A**) ⟶ (**12A**). This indicates a possible increase in π-interaction between the benzene and naphthalene moieties in the series resulting from the various degrees of tilting of the *meta*-bridged benzene rings. The ^{1}H n.m.r. data could, however, lead to a more conclusive comparison (see below).

The H_a and H_b protons of (**10A**) appear as a multiplet shifted upfield to *ca.* δ 6.5 (Figure 1). Such a shielding effect by the non-bridged naphthalene ring is still evident in conformers (**11A**) and (**12A**) and in addition their respective H_a and H_b protons are clearly resolved (Figure 3). The H_a protons of conformers (**11A**) and (**12A**), which appear as triplets due to coupling with the *ortho*-H_b protons, are in fact shifted further upfield to *ca.* δ 6.0. From steric considerations, the much larger spatial requirement of the bromine atom in (**12A**) compared with that of hydrogen in (**10A**) would result in a decrease in the angle of inclination β [Figure 4(a)], making the benzene ring more closely parallel to the non-bridge naphthalene ring. This would increase the π,π-interaction and lead to a bathochromic shift and peak broadening in the electronic spectrum as mentioned above. In addition, the H_a proton in (**12A**) would be forced closer to the central cavity of the non-bridged naphthalene ring [Figure 4(b)] and thus experience a larger shielding effect, as observed in the ^{1}H n.m.r. spectrum. Unexpectedly, the H_a proton in (**11A**) is also shifted similarly (Figure 3) although fluorine is a much smaller atom. It is believed that the dipole interaction between the more polarized C–F bond and the π-electron cloud of the bridged naphthalene ring [Figure 4(a)] further decreases the angle β in addition to the spatial requirement of the fluorine atom.

Two other interesting features of the dithiacyclophane (**11A**) are worth mentioning. The H_b protons of (**11A**) clearly appear as a triplet (*J ca.* 7.5 Hz; Figure 3) resulting from the couplings with the *ortho*-H_a proton and the *meta*-fluorine atom. The H_b–F coupling in (**11A**) is evident when the H_b protons of (**12A**) were in fact observed as a doublet (*J ca.* 7.3 Hz; Figure 3). Secondly,

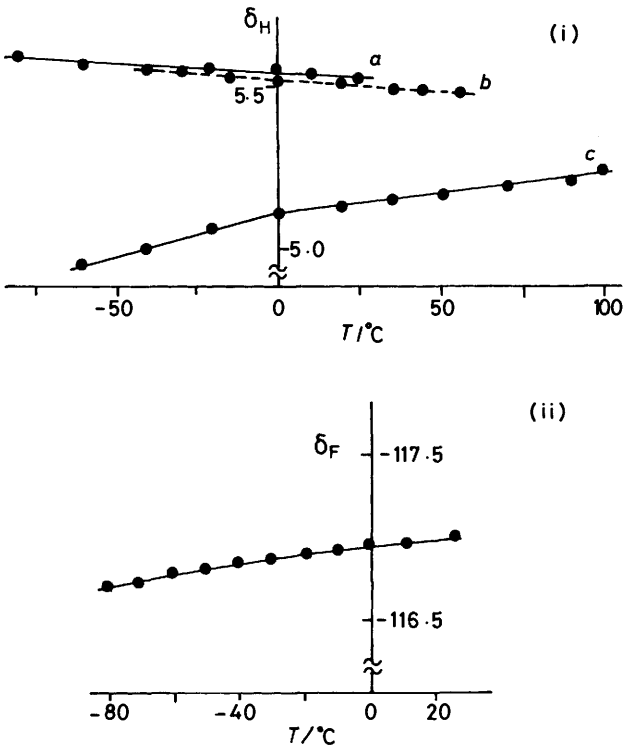
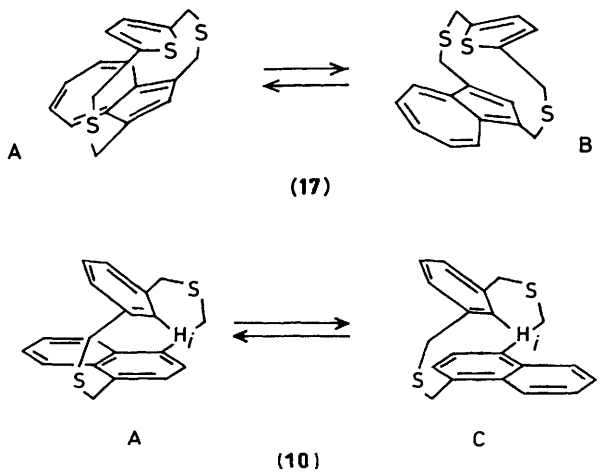


Figure 5. A plot of (i) δ_{H_i} of compound (**10**) {(*a*) in CD_2Cl_2; (*b*) in $CDCl_3$; (*c*) in [$^2H_8$]toluene} and (ii) δ_F of compound (**11**) *vs.* temperature.



the H_c protons on the bridged naphthalene ring of both (**10A**) and (**12A**) appear as sharp singlets while those of (**11A**) were clearly observed as a doublet (*J ca.* 1.0 Hz). The latter is believed to result from a small coupling with the fluorine atom in close proximity. Similar transannular long-range fluorine–proton coupling has also been reported for other closely stacked fluorine-substituted cyclophanes.[7b,15]

Variable-temperature N.M.R. Studies.—Conformational interconversions (**6A**) $\rightleftharpoons$ (**6B**) and (**9A**) $\rightleftharpoons$ (**9B**) were evident at room temperature. In their ^1H n.m.r. spectra, only one signal was observed for each of the respective sets of aromatic protons of the *para*-bridged ring in the former[8] and those of the anthracene ring in the latter.[9] Variable-temperature n.m.r. studies of phanes (**10**) and (**11**) have, however, revealed some surprising results. The chemical shift of H_i proton in (**10**) in [^2H]chloroform and dichloro[$^2H_2$]methane changed only slightly with no significant peak broadening in the temperature range −80 to 55 °C [Figure 5(i)]. A larger shift was observed when the spectra were taken in [$^2H_8$]toluene within the temperature range −60 to 100 °C [Figure 5(i)]. This behaviour of a larger solvent effect causing the H_i proton to appear at higher field in toluene is believed to be due to stronger π–π interactions between the solute and solvent, consistent with earlier results.[6,16] The above observation, however, only indicates a normal solvent shift effect[6,17] and does not suggest a change from one conformer to the other. It is in fact consistent with a rigid *syn*-conformation (**10A**) with no ring flipping, although the same observation could also be explained by a less likely assumption that the ratio of (**10A**) to (**10B**) stayed constant over the considerable temperature range used. The H_i proton in conformers (**10A**) and (**10B**) would be in very different magnetic environments and should be expected to result in a significant continuous shift going from a single frozen conformation to a free ring-flipping process involving the equilibrium (**10A**) $\rightleftharpoons$ (**10B**). Such a phenomenon was in fact observed when the H_i proton in dithiacyclophane (**17**) was used as a probe to study its fluxional behaviour.[18] Our results seemed to rule out this possibility in compound (**10**). Dithiacyclophane (**7**) is known to be conformationally rigid[8] at room temperature and thus (**11A**) is expected to behave similarly. When a sample of compound (**11**) was warmed from −80 to 25 °C, an expected small solvent shift was observed for the ^{19}F chemical shift [Figure 5(ii)]. In the higher temperature ^1H n.m.r. studies ([$^2H_8$]toluene, nitro[$^2H_5$]benzene; −60 to 150 °C), only a similar solvent effect comparable to that mentioned for H_i proton in (**10A**) was observed for the chemical shifts of the H_a and H_b protons in (**11A**). These data would again suggest that (**11A**) also exists rigidly without flipping of the *meta*-bridged ring within the temperature range studied.

The two sets of methylene protons of compound (**6**) appeared as two singlets with rather similar chemical shifts of δ 3.38 and 3.76.[8] Those of (**9**), however, were observed as two singlets 1.63 ppm apart at δ 3.24 and 4.87.[9] The ^1H n.m.r. spectrum of compound (**10**) (Figure 1) shows two clearly resolved AB systems at δ_a 3.30, δ_b 3.61; and δ_a 4.18, δ_b 4.32 respectively. These could then be assigned to the two sets of methylene protons of the *meta*-bridged ring and the naphthalene ring of (**10A**) respectively (Table). The interconversion between (**10A**) $\rightleftharpoons$ (**10B**) involving the *meta*-ring flipping alone would not make the methylene protons equivalent. These AB systems could in principle correspond to a naphthalene flip (**10A**) $\rightleftharpoons$ (**10C**) fast on the n.m.r. timescale with a *meta*-ring flip slow on the n.m.r. timescale. This process is, however, considered unlikely as it would be expected to result in a continuous shift or broadening of the H_i proton peak at low temperatures, unless it is assumed that there is no substantial barrier to this process. Conformational studies of the related dithiacyclophane (**17**) have shown that at higher temperatures the two methylene AB systems observed at room temperature coalesced at *ca.* 70 °C and became two sharp singlets at 90 °C, resulting from rapid flippings of both azulene and thiophene rings.[18] Similar variable-temperature ^1H n.m.r. studies of compound (**10**) in dichloro[$^2H_2$]methane, [^2H]chloroform, [$^2H_8$]toluene, and nitro[$^2H_5$]benzene, however, showed no such coalescence of the AB systems from −80 to 170 °C. This result thus further supports the absence of concurrent flipping processes of both naphthalene and benzene rings in conformer (**10A**). An unexpected observation was, however, the change in chemical shifts, δ_a and δ_b, of each AB system with temperature. The Δδ ($\delta_a - \delta_b$)-value in fact seems to change linearly with temperature (Figure 6) although Δδ of the lower field AB increased while that of the higher field AB decreased when the temperature was raised. Similar dependence of Δδ on temperature was also observed for compound (**11**) but the

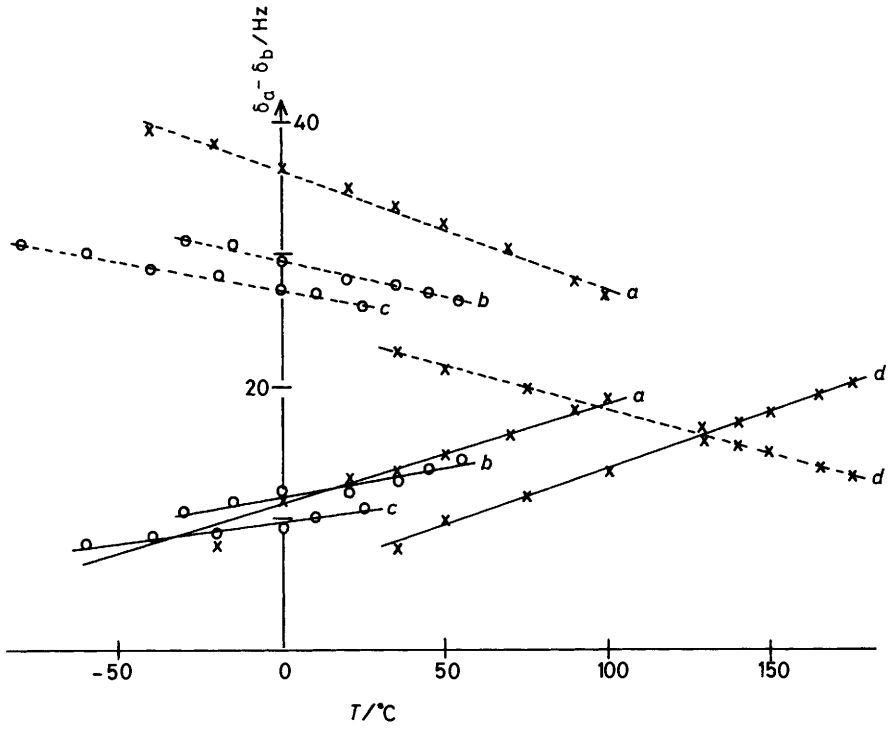
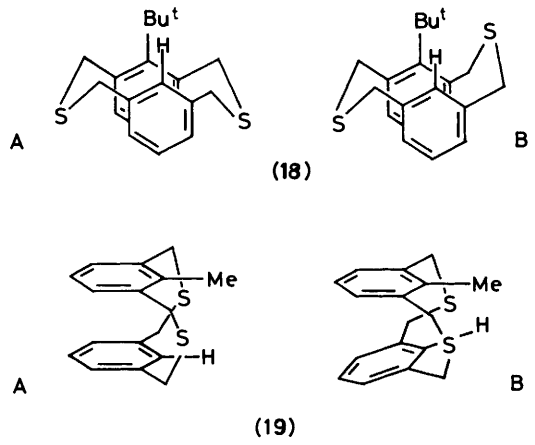


Figure 6. A plot of $\delta_a - \delta_b$ *vs.* temperature for dithiacyclophane (**10**) {lower-field AB (——), higher-field AB (– – – –); (*a*) in [$^2H_8$]toluene, (*b*) in $CDCl_3$, (*c*) in CD_2Cl_2, (d) in nitro[$^2H_5$]benzene}.



results were more varied.[19] The above observation may or may not correspond solely to solvent shifts. A possible conformational interconversion would be the bridge-wobbling process (**10a**) ⇄ (**10b**). From the energy difference between (**10a**) and (**10b**) obtained from MMP2 calculations mentioned earlier, the latter might be an observable minor isomer. This is, however, considered unlikely based on a similar process reported for (**18A**) ⇄ (**18B**).[20] The AB multiplet for the methylene protons adjacent to the t-butyl group in compound (**18**) collapsed and reappeared as a new AB system at lower temperatures. Our results (Figure 6) do not show such a phenomenon. A more plausible alternative is a slight tilting process [varying β in Figure 4(*a*)] of the *meta*-bridged ring in (**10A**) similar to that reported for (**19A**) ⇄ (**19B**).[20] The small change in geometry in compound (**19**) during the fluxional process resulted in a slight change of chemical shifts when the AB system for one set of the bridge methylene protons became a singlet on cooling. At lower temperatures, the Δδ-value of the lower field AB in conformer (**10A**) decreased gradually until the inner lines were unresolved, with the outer lines hardly visible (a 'broad singlet').

Conclusions.—Our studies have clearly shown that 2,11-dithia[3.3](1,4)naphthalenometacyclophane (**10**) exists exclusively in the *syn*-conformation (**10A**) [as do its derivatives (**11A**) and (**12A**)], presumably as the *syn*-conformer (**10a**). This unexpectedly rigid conformation shows no ring flipping interconversion (**10A**) ⇄ (**10B**) and also absence of a bridge-wobbling process (**10a**) ⇄ (**10b**), two conformational changes commonly observed in cyclophane chemistry.[3] The conformational preference for the *syn*-conformation (**10A**) to *anti*-conformation (**10B**) indicates that the non-bonded interaction between the H_i proton and the π-electron cloud of the non-bridged ring in (**10B**) is in this case the unfavourable and most important factor. The π–π interaction between the stacking aromatic rings in conformer (**10A**) is presumably minimized by the longer and rather flexible C–S–C bridges with the *meta*-bridged ring tilted at an appropriate angle with respect to the naphthalene moiety.

Experimental

All m.p.s were determined using a Sybron/Thermolyne MP12615 melting point apparatus and are uncorrected. ^1H N.m.r. spectra were determined in $CDCl_3$, unless otherwise stated, on a JEOL FX90Q (90 MHz) Fourier Transform spectrometer. All chemical shifts are reported in ppm downfield from tetramethylsilane as the internal standard. ^{19}F N.m.r. spectra were recorded on a JEOL FX90Q Fourier Transform spectrometer at a field strength of 84.25 MHz. The chemical shifts are reported in ppm with respect to $CFCl_3$ (correlated from CF_3CO_2H). I.r. spectra were recorded on a Perkin-Elmer 1310 spectrometer. U.v.–visible spectra were determined in cyclohexane on a Shimadzu UV240 Graphicord spectrometer. Mass spectra were determined on a VG Micromass 7035 mass spectrometer at 70 eV using electron

impact. Relative intensities are given in parentheses. Only the molecular ion containing ^{79}Br is given for compounds (**12**) and (**16**); the correct isotope pattern was obtained. Microanalyses were performed by the Microanalytical Laboratory of the Department of Chemistry, National University of Singapore. All evaporations were carried out under reduced pressure on a rotary evaporator at *ca.* 40 °C, and all organic layers were washed with water and dried with anhydrous magnesium sulphate.

2-*Bromo*-1,3-*bis*(*mercaptomethyl*)*benzene* (**16**).—A solution of 2-bromo-1,3-bis(bromomethyl)benzene[21] (1.04 g, 3 mmol) and thiourea (0.46 g, 6 mmol) in 95% ethanol (100 cm^3) was heated at reflux for 3 h. The bulk of the solvent was removed under reduced pressure and crystals of the corresponding bis(thiouronium) salt were filtered off. The salt was added to an aqueous solution (100 cm^3) of KOH (5.0 g) and the mixture was heated at reflux for 3.5 h. The mixture was cooled and made just acidic with conc. H_2SO_4. The product was extracted into benzene, and the solution was washed, dried, and evaporated. The *thiol* (**16**) was obtained as a thick oil (0.62 g, 83%) (Found: M^+, 247.9330. $C_8H_9{}^{79}BrS_2$ requires M, 247.9329); $\nu_{max.}$ 1 440, 1 415, 1 300, 1 248m, 1 150, 1 010, 850, 790, 746, and 719 cm^{-1}; δ_H 1.65 (2 H, t, J 8 Hz, SH), 3.78 (4 H, d, J 8 Hz, CH_2), and 6.9–7.4 (3 H, m, ArH); m/z 248 (M^+, 68%), 215 (100), and 135 (73).

2,11-*Dithia*[3.3](1,4)*naphthalenometacyclophane* (**10**).—The coupling reaction was carried out under nitrogen. A solution of the dibromide (**13**)[10] (690 mg, 2.2 mmol) and 1,3-bis(mercaptomethyl)benzene (**14**)[8,11] (375 mg, 2.2 mmol) in benzene (250 cm^3) was added dropwise using a rotaflow dropping funnel into a well stirred solution of KOH (370 mg, 6.5 mmol) in degassed 95% ethanol (1.2 dm^3). After the addition, the reaction mixture was stirred for another 15 h. The bulk of the solvent was evaporated off under reduced pressure and water and CH_2Cl_2 (1:1; 400 cm^3) were added. The organic layer was separated, washed, and dried. The crude product was filtered through a column of silica gel with CH_2Cl_2–hexane (1:1) as eluant to yield the *dithiacyclophane* (**10**) (517 mg, 56%). Recrystallization from cyclohexane gave crystals of compound (**10**), m.p. 194–196 °C (Found: C, 74.2; H, 5.5. $C_{20}H_{18}S_2$ requires C, 74.5; H, 5.6%); $\lambda_{max.}$(cyclohexane) 240 (ε 7 460 dm^3 mol^{-1} cm^{-1}), 274sh (3 700), 285 (5 490), 296 (6 610), 304 (4 930), 309 (4 840), and 318sh (1 500); $\nu_{max.}$ 1 590, 1 430, 1 375, 1 310, 1 150, 1 060, 952, 900, 832, 754, and 700 cm^{-1}; δ_H 3.30 and 3.61 (4 H, AB, J 15.3 and 27.7 Hz, 3- and 10-H_2), 4.18 and 4.32 (4 H, AB, J 13.3 and 13.1 Hz, 1- and 12-H_2), 5.51 (1 H, br s, 9-H), 6.3–6.6 (3 H, m, 5-, 6-, and 7-H), 7.19 (2 H, s, 21- and 22-H), and 7.24–7.39, 7.84–7.99 (4 H, AA′BB′, 15-, 16-, 17-, and 18-H); m/z 322 (M^+, 88%), 185 (65), 184 (32), 155 (100), and 135 (25).

9-*Fluoro*-2,11-*dithia*[3.3](1,4)*naphthalenometacyclophane* (**11**).— This was prepared by a similar high-dilution coupling reaction as described for compound (**10**). A solution of the dibromide (**13**) (0.58 g, 2.06 mmol) and the thiol (**15**) (0.39 g, 2.06 mmol) in benzene (400 cm^3) was employed. Purification by column chromatography gave the desired *dithiacyclophane* (**11**) (0.20 g, 31%). Recrystallization from cyclohexane gave crystals of compound (**11**), m.p. 206–208 °C (Found: C, 70.2; H, 4.9. $C_{20}H_{17}FS_2$ requires C, 70.55; H, 5.0%); $\lambda_{max.}$(cyclohexane) 242 (ε 7 030 dm^3 mol^{-1} cm^{-1}), 273sh (4 380), 283 (5 650), 294 (6 470), 302 (4 880), 307 (4 800), and 317sh (1 130); $\nu_{max.}$ 1 578, 1 507, 1 457, 1 405, 1 250, 1 230, 1 159, 1 062, 1 050, 905, 846, 830, 820, 760, and 743 cm^{-1}; δ_H 3.26, 3.73 (4 H, AB, J 15.8 and 41.9 Hz, 3- and 10-H_2), 4.15 and 4.22 (4 H, AB, J 13.2 and 6.9 Hz, 1- and 12-H_2), 6.03 (1 H, t, J 7.6 Hz, 6-H), 6.61 (2 H, t, J 7.5 Hz, 5- and 7-H), 7.19 (2 H, d, J 1.0 Hz, 21- and 22-H), and 7.22–7.33 and 7.83–7.94 (4 H, AA′BB′, 15-, 16-, 17-, and 18-H); m/z 340 (M^+, 86%), 185 (72), 184 (37), and 155 (100).

9-*Bromo*-2,11-*dithia*[3.3](1,4)*naphthalenometacyclophane* (**12**).—This was prepared by a similar high-dilution coupling reaction with a solution of the dibromide (**13**) (0.44 g, 1.4 mmol) and the dimercaptan (**16**) (0.35 g, 1.4 mmol) in benzene (350 cm^3). Purification by column chromatography gave the desired *dithiacyclophane* (**12**) (0.25 g, 38%). Recrystallization from cyclohexane gave crystals of compound (**12**), m.p. 244–246 °C (Found: C, 59.8; H, 4.1. $C_{20}H_{17}BrS_2$ requires C, 59.85; H, 4.3%); $\lambda_{max.}$(cyclohexane) 245 (ε 7 060 dm^3 mol^{-1} cm^{-1}), 273sh (3 780), 283 (5 190), 294 (5 880), 303infl (4 860), 307infl (4 760), and 317sh (1 860); $\nu_{max.}$ 1 410, 1 210, 1 096, 1 012, 900, 842, 756, 728, and 706 cm^{-1}; δ_H 3.45 and 3.98 (4 H, AB, J 15.8 and 47.4 Hz, 3- and 10-H_2), 4.17 (4 H, AB, outer line unresolved, 1- and 12-H_2), 6.07 (1 H, t, J 7.3, 6-H), 6.72 (2 H, br d, J 7.3 Hz, 5- and 7-H), 7.23 (2 H, s, 21- and 22-H), and 7.27–7.38 and 7.82–7.93 (4 H, AA′BB′, 15-, 16-, 17-, and 18-H); m/z 400 (M^+, 44%), 185 (69), 184 (41), 155 (100), and 135 (16).

Acknowledgements

This work was supported by the National University of Singapore (RP860606). I thank the technical staff of the Department of Chemistry, National University of Singapore for their assistance. The MMP2 calculations were performed with assistance from Dr. G. Yamamoto, Department of Chemistry, Faculty of Science, University of Tokyo and Dr. M. Nakamura, Department of Chemistry, School of Medicine, Toho University.

References

1 L. Rossa and F. Vögtle, *Top. Curr. Chem.*, 1983, **113**, 1.
2 'Cyclophanes,' eds. P. M. Keehn and S. M. Rosenfeld, Academic Press, New York, 1983, vols. I and II; R. H. Mitchell, *Heterocycles*, 1978, **11**, 563.
3 (*a*) R. H. Mitchell, 'Nuclear Magnetic Resonance Properties and Conformational Behaviour of Cyclophanes,' in 'Cyclophanes,' eds. P. M. Keehn and S. M. Rosenfeld, Academic Press, New York, 1983, vol. I, p. 239; (*b*) Y.-H. Lai, *Heterocycles*, 1981, **16**, 1739.
4 F. Vögtle, *Chem. Ztg.*, 1970, **94**, 313.
5 Y-H. Lai and M. Nakamura, *J. Org. Chem.*, 1988, **53**, 2360.
6 W. Anker, G. W. Bushnell, and R. H. Mitchell, *Can. J. Chem.*, 1979, **57**, 3080.
7 (*a*) F. Vögtle, *Tetrahedron*, 1969, **25**, 3231; (*b*) F. Vögtle and M. von P. Neumann, *ibid.*, 1970, **26**, 5299.
8 V. Boekelheide, P. H. Anderson, and T. A. Hylton, *J. Am. Chem. Soc.*, 1974, **96**, 1558.
9 S. A. Sherrod, R. L. da Costa, R. A. Barnes, and V. Boekelheide, *J. Am. Chem. Soc.*, 1974, **96**, 1565.
10 G. Lock and R. Schneider, *Chem. Ber.*, 1958, **91**, 1770.
11 A. J. Speziale, *Org. Synth.*, 1963, Coll. Vol. IV, 40.
12 F. Vögtle, *Chem. Ber.*, 1969, **102**, 3077.
13 N. L. Allinger and H. L. Flanagan, *J. Comput. Chem.*, 1983, **4**, 399.
14 D. J. Cram and H. Steinberg, *J. Am. Chem. Soc.*, 1951, **73**, 5691.
15 Y.-H. Lai and T.-G. Peck, *Heterocycles*, 1987, **26**, 2043.
16 D. J. Bertelli and C. Golino, *J. Org. Chem.*, 1965, **30**, 368; D. H. Williams and D. A. Wilson, *J. Chem. Soc. B*, 1966, 144.
17 J. R. Hanson, *J. Chem. Soc.*, 1965, 5036; A. A. Bothner-By and R. E. Glick, *J. Chem. Phys.*, 1957, **26**, 1651.
18 Y. Fukazawa, M. Kodama, J. Tsuchiya, Y. Fujise, and S. Itô, *Tetrahedron Lett.*, 1986, **27**, 1929.
19 For a preliminary report, see Y.-H. Lai and T.-G. Peck, *Heterocycles*, 1987, **26**, 2037.
20 R. H. Mitchell, T. K. Vinod, G. J. Bodwell, K. S. Weerawarna, W. Anker, R. V. Williams, and G. W. Bushnell, *Pure Appl. Chem.*, 1986, **58**, 15.
21 F. Vögtle, *Chem. Ber.*, 1969, **102**, 1784.

Received 23*rd May* 1988; *Paper* 8/02061B