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SYNTHESIS AND PROPERTIES OF NOVEL MEDIUM-SIZED HETEROCYCLIC COMPOUNDS CONTAINING TWO SULFUR ATOMS IN THE RING AND SYNTHETIC APPROACHES TO CONJUGATED CYCLIC DISULFONIUM YLIDES

Hiroshi Shimizu,* Hiroyoshi Watanabe, Masahiro Mizuno, Tadashi Kataoka, and Mikio Hori

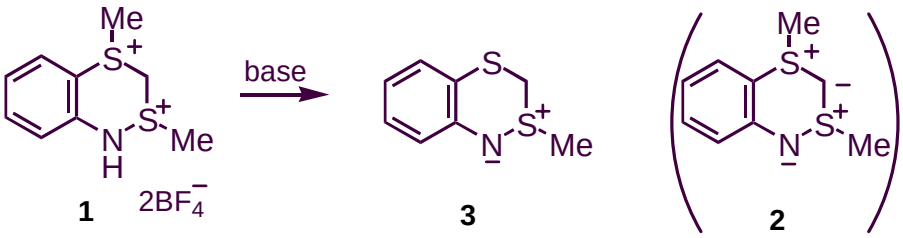
Gifu Pharmaceutical University, 6-1, Mitahora-higashi 5 chome, Gifu 502-8585, Japan

Abstract - Tribenzo[*b,f,h*][1,4]dithiecin (**8**) was prepared by coupling 2,2'-bis(bromomethyl)biphenyl (**10**) with 1,2-benzenedithiol (**11**) in the presence of NaH in acetonitrile. Another novel dithiecin derivative, 1,8-dihydro-2,7-benzodithiecin (**9**) was synthesized by coupling of 1,4-dimercapto-2,3-*O*-isopropylidene-Lg-threitol (**13a**) with α,α'-dibromo-*o*-xylene (**12**), followed by hydrolysis and subsequent dehydration *via* the mesylate derivative (**16**). The benzodithiecin (**9**) was also prepared by treatment of dithiol (**18**) with butadiyne along with α,α'-bis(1-buten-3-ynylthio)-*o*-xylene (**19**) as a byproduct. Compound (**19**) was subjected to an intramolecular coupling reaction using CuCl-pyridine-O_2 in benzene to yield the 12-membered ring compound (**23**). We also describe our effort to prepare the corresponding cyclic diylide compounds from the above new dithiecins (**8**) and (**9**), and known dithiecin (**7**).

In connection with our interest in heterocyclic conjugated (4n+2)π electron system, we have extensively investigated the chemistry of thiabenzenes[1] and azathiabenzenes.[2] In the formers, sulfonium ylide bond forms part of a cyclic conjugated ring system containing six π-electrons. In the latters, sulfilimine bond forms part of a cyclic conjugated ring system.

In continuing our study on the chemistry of cyclic sulfonium ylides, we planned to create a novel cyclic disulfonium ylide in which two sulfonium ylide moieties are incorporated in the (4n+2)π ring system. There is no paper on the synthesis and properties of cyclic diylides, although there have been described a few examples of the preparation of acyclic diylides containing two ylide structures in a given molecule.[3]

In our previous paper we attempted the preparation of cyclic disulfonium ylide having a benzodithiazine skeleton (**2**) from disulfonium salt (**1**) by deprotonation with strong base, but our attempt resulted in vain to afford a demethylated sulfilimine (**3**) shown below.[4] Thus, we planned to start with two sulfur atoms-containing ten-membered ring, dithiecin (**4**), in order to construct disulfonium ylides with 10 π-



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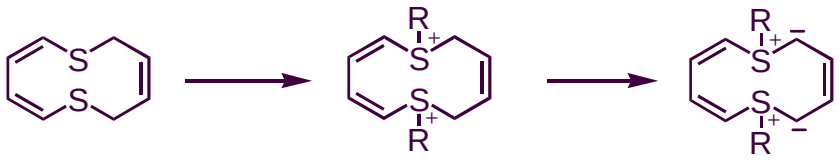
electrons (**6**) *via* the corresponding salt (**5**). In this paper, we describe the synthesis and some chemical properties of new dithiecins (**8**) and (**9**), and some approaches to the preparation of ten-membered disulfonium ylides from these new dithiecins and known dithiecin (**7**).[5]



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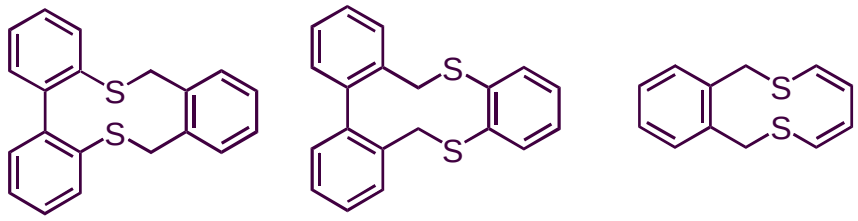
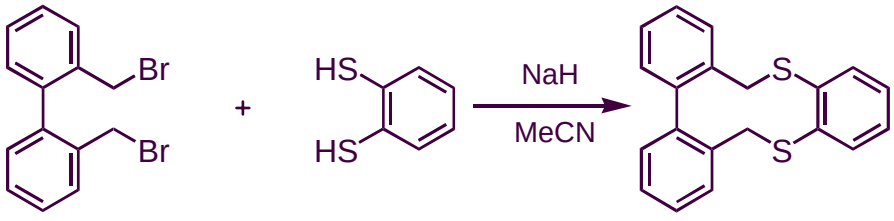


7 8 9

Preparation and Some Properties of Novel Dithiecins (8 and 9).

Tribenzo[*b*,*f*,*h*][1,4]dithiecin (**8**) was prepared in 44% yield by coupling 2,2'-bis(bromomethyl)biphenyl (**10**) with 1,2-benzenedithiol (**11**) in the presence of NaH in acetonitrile (Scheme 1). Another novel

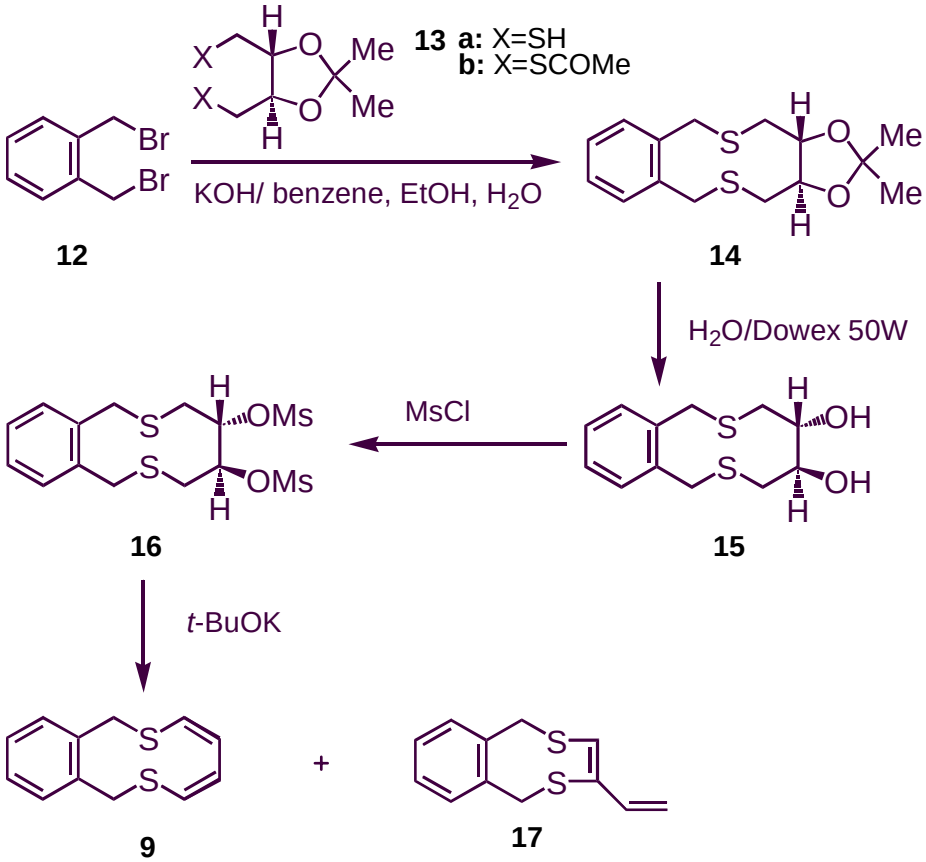


10 11 8

Scheme 1

dithiecin derivative, 1,8-dihydro-2,7-benzodithiecin (**9**) was successfully synthesized by the route depicted in Scheme 2. Coupling of 1,4-dimercapto-2,3-*O*-isopropylidene-Lg-threitol (**13a**) with α,α'-dibromo-*o*-xylene (**12**) in the presence of KOH in benzene-ethanol-water afforded 4,5-*O*-isopropylidene-2,7-benzodithiecin (**14**) in 77% yield. When the reaction was carried out using 1,4-bis(acetylthio) compound (**13b**) instead of dithiol compound (**13a**), the yield of dithiecin (**14**) was lower (67%). Hydrolysis of **14** in refluxing water in the presence of Dowex 50W gave diol compound (**15**) in

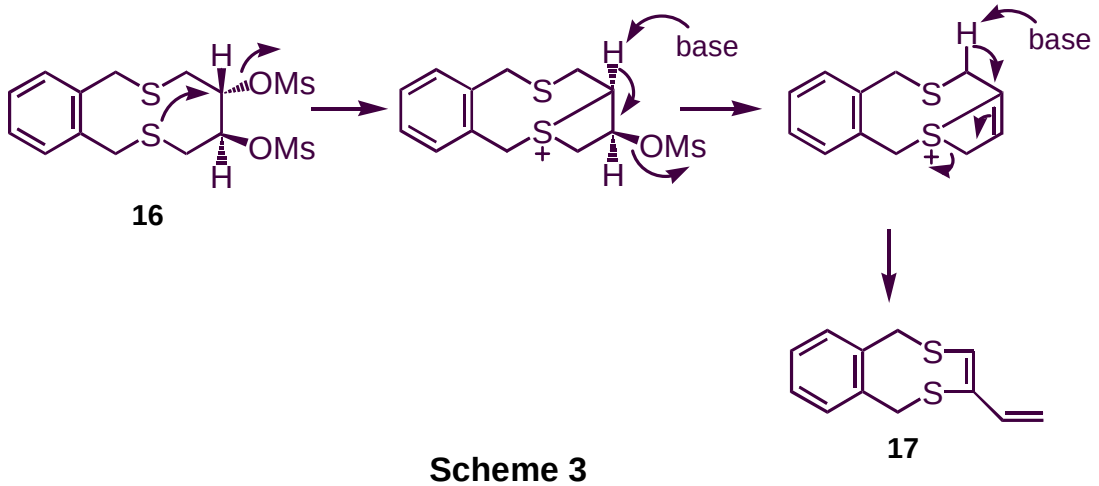
quantitative yield. Direct dehydration of the diol (**15**) with dehydrating agents such as *p*-TsOH, Dowex 50W-X_2, DCC, and PPSE (trimethylsilyl polyphosphate) was unsuccessful and resulted in the formation of complex mixtures. Therefore, the hydroxy functions were converted into better leaving groups which would then give the bisolefin in a base mediated elimination reaction. Mesylate derivative (**16**) prepared from **15** and mesyl chloride was treated with *tert*-BuOK at room temperature to afford the expected product (**9**)**,** but in low yield (10%) as white needles along with a ring-contracted product, dithiocin (**17**, 8%). The structure of compound (**9**) was elucidated on the basis of spectral evidence



Scheme 2

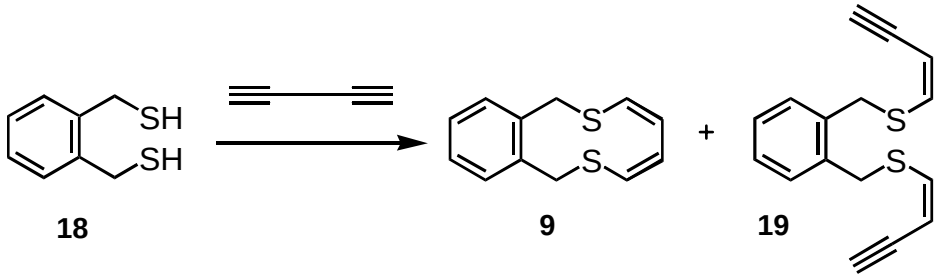
which showed an ^{1}H NMR signal at δ 3.99 (singlet, benzylic protons), and two signals δ 6.14 and 6.50, respectively (doublet, olefinic protons): ^{13}C NMR signals at δ 35.6 (t), 125.0, 127.3, 130.4 and 133.3 (each d) and 137.9 (s); and a mass spectral peak at *m/z* 220 (M^+). That only half of the total carbons are observed signifies the compound (**9**) is symmetrical and conformationally very mobile. The coupling constant (J= 8.3 Hz) between olefinic protons indicates the olefinic geometry takes *cis* configuration. The structure of the compound (**17**) was also determined based on the spectral results. A plausible mechanism for the formation of the compound (**17**), starting with intramolecular attack of sulfur atom on the tosylate carbon is depicted in Scheme 3. Since the above method for the preparation of the dithiecin (**9**) took many steps and the yield was very low, we studied an improved method for it. Stirling et al. reported that addition reaction of phenylmethanethiol to butadiyne afforded the 1,4-dibenzylthio-1,3-butadiene.[6] We now tried to apply this method to the preparation of dithiecin (**9**). Treatment of dithiol (**18**) with butadiyne prepared *in situ* from 1,4- dichloro-2-butyne in the presence of

KOH afforded as expected the dithiecin (**9**) in 16.5% yield in two steps (Scheme 4). In this reaction,



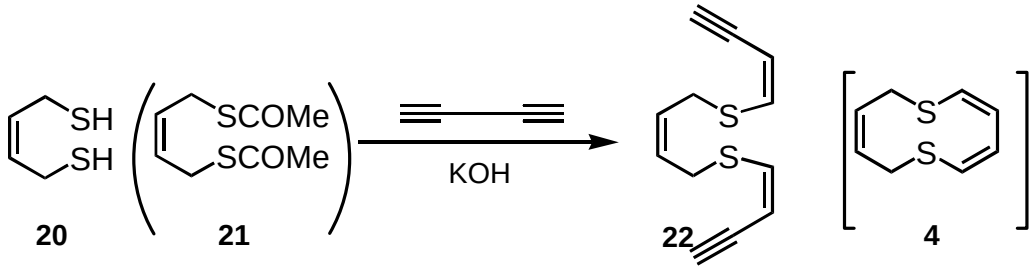
Scheme 3

α,α'-bis(1-buten-3-ynylthio)-*o*-xylene (**19**) was obtained as a byproduct in spite of high dilution conditions (0.18 mole). The above successful result made us couple the dithiol (**20**) or its acetyl



Scheme 4

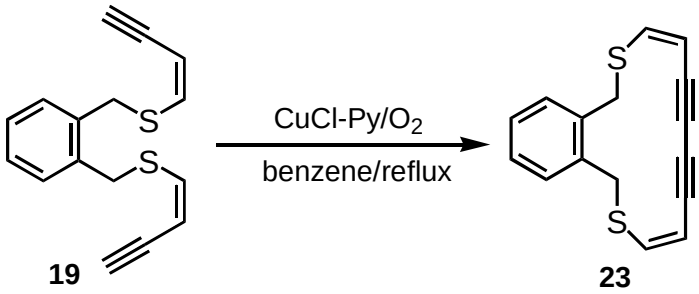
derivative (**21**) with butadiyne for the preparation of dithiecin (**4)** having no fused-benzene ring. However, the attempt resulted only in the formation of **22** which corresponds to the byproduct (**19**) described in the above reaction (Scheme 5).



Scheme 5

We next performed the cyclization of the compound (**19**) to produce dithiacyclotetradecin derivative (**23**), which could be led to the conjugated 14π-electron disulfonium ylide compound after alkylation, followed by deprotonation (Scheme 6). The compound (**19**) was subjected to intramolecular coupling reaction using CuCl-pyridine-O_2 in benzene[7] to yield the expected 12-membered ring compound (**23**) in 40% yield.

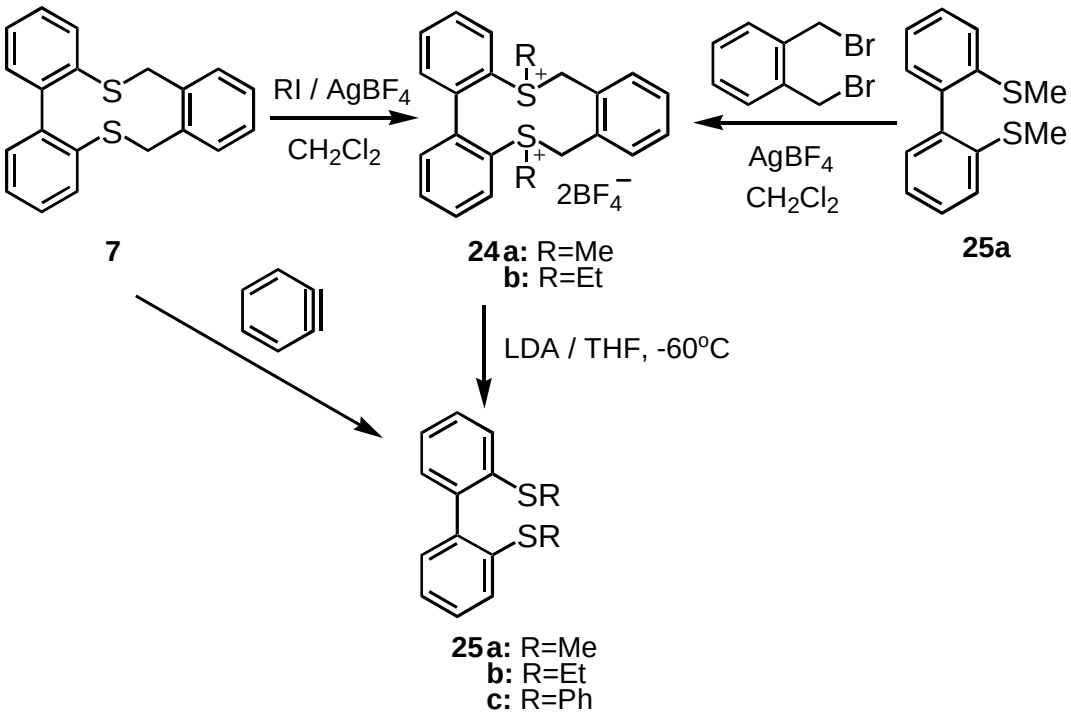
We now succeeded in the preparation of novel dithiacyclophanes (**8**), (**9**), and (**23)**.



Scheme 6

Synthetic Approaches to Disulfonium Ylides---Dialkylation, followed by Deprotonation with Strong Base.

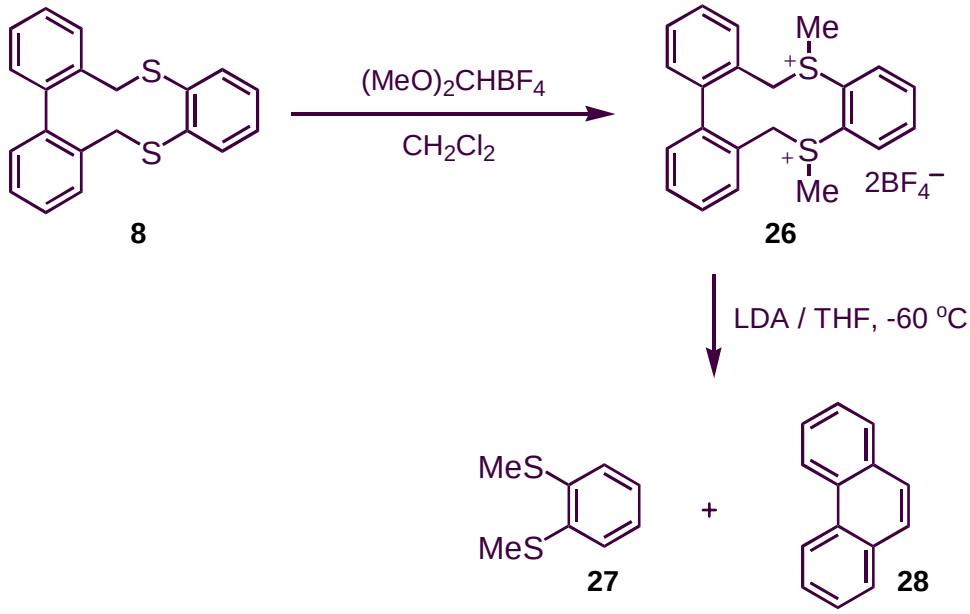
We next prepared the corresponding cyclic disulfonium salts from the above new dithiecins (**8**) and (**9**), known dithiecin (**7**), and dithiacyclophane (**23**), and examined the reactivity of the disulfonium salts with strong base. Dithiecin (**7**) was treated with alkyl iodide in the presence of silver tetrafluoroborate to give the disulfonium salts (**24a**) and (**24b**) in high yields, respectively (Scheme 7). The salt (**24a**) was also prepared from **25a** and α,α'-dibromo-*o*-xylene in the presence of silver tetrafluoroborate. The salts (**24a**) and (**24b**) were deprotonated with 2.2 eq. of LDA in THF at –60 °C to result in the formation of **25a** and **25b** in the yields of 87 and 47%, respectively. It is well-known that *S*-phenyl substituted



Scheme 7

sulfonium ylides are prepared from the reaction of sulfides with benzyne.[8] Therefore, benzyne generated from *o*-bromofluorobenzene and Mg was allowed to react with the dithecin (**7**) as asulfide to afford only the product (**25c**) in 27% yield.

The dithiecin (**8**) was easily dimethylated with a slight excess of dimethoxycarbenium tetrafluoroborate to give the dimethylsulfonium salt (**26**) in 73% yield (Scheme 8).

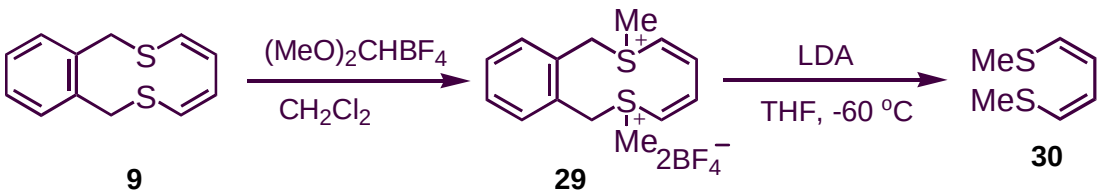


8 **26** **27** **28**

Scheme 8

Treatment of the salt (**26**) with 2.2 eq. of LDA in THF at –60 °C resulted in the similar degradation to that for the salt (**29**) to afford 1,2-bis(methylthio)benzene (**27**) in 68% yield together with 11% yield of phenanthrene (**28**).

Finally, we attempted leading the dithecin (**9**) to the dimethylsulfonium salts (**29**) with dimethoxycarbenium tetrafluoroborate, followed by treatment with 2.2 eq. of LDA in THF at –60 °C to afford degrated product (**30**) in 68% yield (Scheme 9).

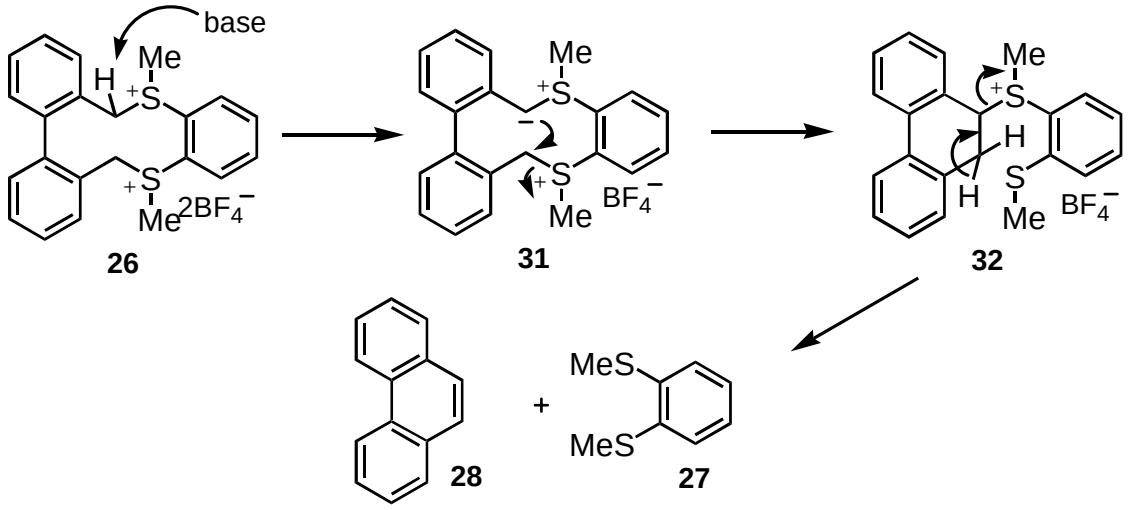


9 **29** **30**

Scheme 9

The transformation of dithiacyclotetradecin derivative (**23**) to a 14π-diylide compound was also conducted under similar conditions *via* the corresponding disulfonium salt, but only inseparable complex mixtures were obtained.

The mechanism for the above degradation reaction is depicted in Scheme 10 by using benzodithiecinium salt (**26**) as a representative. The salt (**26**) is deprotonated with base to generate monoylide intermediate (**31**) which immediately undergoes transannular S_N2 attack of the ylide carbanion to benzylic carbon attached to sulfonio group, before deprotonation of another benzylic proton by base. The formed intermediate (**32**) decomposes with an assist of a base to give bis(methylthio)benzene (**27**) and



Scheme 10

phenanthrene (**28**). The other dithiecinium salts (**24**) and (**29**) would be also decomposed in a similar way to the above.

In conclusion, we have succeeded in the first preparation of novel dithiecin derivatives (**8**) and (**9**), and new 14-membered dithiacyclophane (**23**), and we have also found the reaction of disulfonium salts, prepared from these dithiecins, with strong base afforded the corresponding bissulfides *via* intramolecular decomposition of initially formed monoylide intermediates in preference to the formation of disulfonium ylides.

EXPERIMENTAL

General Notes. IR spectra were determined with a JASCO IR A-1 infrared spectrophotometer and are expressed in reciprocal centimeters. The ^{1}H and ^{13}C NMR spectra were determined with JEOL FX-100 spectrometer and are referenced to tetramethylsilane as an internal standard. The MS were obtained on a JEOL JMS-D 300 spectrometer with a direct-insertion probe at an ionization voltage of 70 eV. Exact mass determination was conducted on the JMA 2000 on-line system. Melting points were taken on a Yanagimoto micromelting point apparatus and are uncorrected. Elemental analyses were performed by the Microanalytical Laboratory of Gifu Pharmaceutical University. Analytical and preparative thin-layer chromatography were carried out with E. Merck silica gel 60PF-254.

Tribenzo[*b,f,h*][1,4]dithiecin (8). Sodium hydride (55% dispersion in mineral oil, 614 mg, 14.1 mmol) was added portionwise with stirring to an ice-cooled solution of 1,2-benzenedithiol[9] (**11**, 1g, 7 mmol) in dry acetonitrile (5 mL) under nitrogen, and the mixture was stirred for 80 min. A solution of 2,2'-bis(bromomethyl)biphenyl[10] (**10**. 2.4 g, 7 mmol) in dry acetonitrile (10 mL) was added dropwise over a period of 20 min to the stirred above mixture. After being stirred for 29 h, the reaction mixture was poured onto ice-water and extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and concentrated to dryness. The residual oil was chromatographed on silica gel with hexane-dichloromethane (8:1) to afford the dithiecin (**8**, 0.99 g, 43.9%). Recrystallization from hexane-dichloromethane afforded pure colorless prisms; mp 105-106 ^{o}C, ^{1}H-NMR ($CDCl_3$) δ: 3.76 and 4.14 (each 2H, d, *J*= 13.8 Hz, 2 x $ArCH_2$), and 6.99-7.53(12H, m, ArH); MS *m/z*: 320 (M^+) and 179(base). *Anal.* Calcd for $C_{20}H_{16}S_2$: C, 74.96; H, 5.03. Found: C, 74.96; H, 5.17.

1,3,4,5,6,8-Hexahydro-4,5-*O*-isopropylidene-2,7-benzodithiecin (14). a) A solution of *S,S*-diacetyl-2,3-*O*-isopropylidene-1,4-dithio-Lg-threitol[11] (**13b**, 1.06 g, 3.8 mmol) in a mixture of ethanol (9 mL) and

water (6 mL) containing potassium hydroxide (531 mg, 9.5 mmol) and a separate solution of α,α'-dibromo-*o*-xylene (**12**, 1 g, 3.8 mmol) in benzene (15 mL) were added simultaneously and slowly under nitrogen to a stirred solution of ethanol (15 mL) and benzene (7.5 mL) over a period of 30 min, and the mixture was then stirred for 36 h. The reaction mixture was concentrated *in vacuo*, and the residue was extracted with dichloromethane. The organic layer was washed with water, dried over $MgSO_4$, and evaporated to dryness. The residue was subjected to column chromatography on silica gel using hexane-ethyl acetate (10:1) to give the benzothiecin (**14**, 752 mg, 67%) as a white powder. Recrystallization from hexane-dichloromethane afforded colorless prisms; mp 140-142 °C. ^{1}H-NMR ($CDCl_3$) δ: 1.34 (6H, s, 2 x Me), 2.81 and 2.97 (each 2H, dd, *J*= 15.1 and 4.4 Hz, 2 x CH_2), 3.75 and 3.97 (each 2H, d, *J*= 13.7 Hz, $ArCH_2$), 3.72-3.77 (2H, m, 2 x CH), and 7.23-7.31 (4H, m, ArH); ^{13}C -NMR ($CDCl_3$) δ: 27.0 (q), 32.6 (t), 33.6 (t), 79.1 (d), 108.3 (s), 127.9 (d), 130.7 (d), and 136.7 (s). MS *m/z*: 296 (M^+) and 135 (base). *Anal*. Calcd for $C_{15}H_{20}O_2S_2$: C, 60.78; H, 6.80. Found: C, 60.49; H, 6.75.

b) A solution of 2,3-*O*-isopropylidene-1,4-dithiol-Lg-threitol[11](**13a**, 300 mg, 1.5 mmol) in a mixture of ethanol (4 mL) and water (2 mL) containing potassium hydroxide (215 mg, 3.8 mmol) and a separate solution of α,α'-dibromo-*o*-xylene (**12**, 408 mg, 1.54 mmol) in benzene (6 mL) were added simultaneously and slowly under nitrogen to a stirred solution of ethanol (6 mL) and benzene (3 mL) over a period of 20 min, and the mixture was worked up as above to afford (**14**, 353 mg, 77%).

1,3,4,5,6,8-Hexahydro-2,7-benzodithiecin-4,5-diol (15). A mixture of compound (**14**, 1.77 g, 5.97 mmol) and Dowex 50w-x2 (1.95 g) in water (100 mL) was refluxed for 5 h. Dichloromethane was added to the reaction mixture, and the mixture was stirred well. The mixture was filtered to separate from solid materials and washed with water. The organic layer was dried over $MgSO_4$ and evaporated to dryness *in vacuo* to leave the compound (**15**, 1.53 g, 100%) as a white powder. Recrystallization from hexane-dichloromethane afforded colorless needles; mp 100-101 °C, IR (KBr) cm^{-1}: 3390-3350 (OH) and 1055. ^{1}H-NMR ($CDCl_3$) δ: 2.37 (4H, brs, 2 x CH_2), 3.55 (2H, brs, 2 x OH), 3.64 (2H, brs, 2 x CH), 3.80 and 3.89 (each 2H, d, J= 14.1 Hz, 2 x $ArCH_2$), and 7.26-7.29 and 7.51-7.54 (each 2H, m, ArH). ^{13}C-NMR ($CDCl_3$) δ: 30.4 (t), 31.4 (t), 72.6 (d), 127.9 (d), 130.1 (d), and 135.6 (s). MS *m/z*: 256 (M^+) and 135 (base). *Anal*. Calcd for $C_{12}H_{16}O_2S_2$: C, 56.22; H, 6.29. Found: C, 55.94; H, 6.32.

1,3,4,5,6,8-Hexahydro-4,5-dimesyloxy-2,7-benzodithiecin (16). Mesyl chloride (1.33 mL, 17.2 mmol) was added to a solution of the diol (**15**, 2 g, 7.8mmol) and dry triethylamine (3.3 mL, 23.4 mmol) in dry dichloromethane (50 mL) at -10 °C, and the mixture was then stirred for 12 h during which time the temperature was gradually raised up to 0 °C. The reaction mixture was washed successively with water, 10% HCl, aq $NaHCO_3$ and aq NaCl, dried over $MgSO_4$, and evaporated under reduced pressure. The residue was recrystallized from hexane-dichloromethane to give the compound (**16**, 3.22 g, 100%) as colorless needles; mp 145-146.5 °C, IR (KBr) cm^{-1} :1345 and 1165 (SO_2); ^{1}H-NMR ($CDCl_3$) δ: 2.51 and 2.65 (each 2H, brd, *J*= 15.6 Hz, 2 x CH_2), 3.20 (6H, s, 2 x Me), 3.85 and 3.98 (each 2H, d, *J*= 14.1 Hz, 2 x $ArCH_2$), 4.83 (2H, brs, 2 x CH), and 7.29-7.34 and 7.48-7.53 (each 2H, m, ArH). ^{13}C-NMR ($CDCl_3$) δ: 30.4 (t), 30.8 (t), 39.3 (q), 78.5 (d), 128.4 (d), 130.5 (d), and 135.2 (s). MS *m/z* : 412 (M^+) and 135 (base). *Anal*. Calcd for $C_{14}H_{20}O_6S_4$: C, 40.76; H, 4.89. Found: C, 40.50; H, 4.81.

1,8-Dihydro-2,7-benzodithiecin (9). **a)** A suspension of potassium *tert*-butoxide (490 mg, 4.36 mmol) in dry THF (1.4 mL) was added at 0 °C under nitrogen to a solution of dimesylate (**16**, 300 mg, 0.73 mmol) in dry THF (10 mL), and the mixture was stirred for 2 h at rt. Water was added to the reaction mixture, which was then extracted with pentane. A pentane solution was washed with water, then aq. $NaHCO_3$ solution, dried over $MgSO_4$, and evaporated under reduced pressure. The residual oil was submitted to preparative TLC on silica gel using hexane-dichloromethane (3:1) to give the compound (**9**, 16 mg, 10%) and 3-vinyl-1,6-dihydro-2,5-benzodithiocin (**17,** 13 mg, 8.1%). **Dithiecin (9):** colorless needles (from acetone-hexane), mp 71-73 °C, ^{1}H-NMR ($CDCl_3$) δ: 3.99 (4H, s, 2 x CH_2), 6.14 and 6.50 (each 2H, d, *J*= 8.3 Hz, 2 x CH=CH), and 7.14-7.19 and 7.21-7.26 (each 2H, m, ArH). ^{13}C-NMR ($CDCl_3$)

δ: 35.6 (t), 125.0 (d), 127.3 (d), 130.4 (d), 133.3 (d), and 137.9 (s). MS *m/z*: 220 (M^+) and 135 (base). *Anal.* Calcd for $C_{12}H_{12}S_2$: C, 65.41; H, 5.49. Found: C, 65.46; H, 5.53. **Dithiocin (17)**: a pale yellow oil, ^{1}H-NMR ($CDCl_3$) δ: 4.36 and 4.61 (each 2H, s, 2 x CH_2), 5.05 (1H, d, *J*= 10.3 Hz, =C*H*H), 5.62 (1H, d, *J*= 16.5 Hz, =CH*H*), 6.29 (1H, dd, *J*= 16.5 and 10.3 Hz, =CH), 6.44 (1H, s, =CH), 7.06-7.23 (4H, m, ArH); ^{13}C -NMR ($CDCl_3$) δ: 35.3 (t), 35.4 (t), 114.0 (t), 127.4 (d), 127.8 (d), 128.7 (d), 129.7 (d), 130.1 (d), 135.8 (s), 136.6 (s), 136.8 (s), 137.8 (d). MS *m/z*: 220 (M^+) and 104 (base). HRMS: Calcd for $C_{12}H_{12}S_2$: 220.0381. Found: 220.0383.

b) Butadiyne gas [generated by refluxing a mixture of 1,4-dichloro-2-butyne (3.55 mL, 35.2 mmol), potassium hydroxide (5.93 g, 105.7 mmol), water (40 mL), and 1,4-dioxane (6 mL)] was introduced in 4 h into a stirred solution of dithiol[12] (**18**, 4 g, 23.5 mmol) and potassium hydroxide (3.95 g, 70.5 mmol) in methanol (130 mL) at -10 °C under nitrogen , and the mixture was refluxed for 8 h. Potassium hydroxide (1 g) was added to the reaction mixture and the mixture was then refluxed for 8 h. The mixture was concentrated and the residue was extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and evaporated. The residual oil was purified by column chromatography on silica gel using hexane-dichloromethane (10:1) to give dithiecin (**9**, 856 mg, 16.5 %) and α, α'-bis(1-buten-3-ynylthio)-o-xylene (**19,** 230 mg, 3.62 %). The latter compound was determined by the comparison of spectral data with those of the authentic sample (**19**) prepared below.

α, α'-Bis(1-buten-3-ynylthio)-*o*-xylene (19). Butadiyne gas [generated by refluxing a mixture of 1,4-dichloro-2-butyne (7.1 mL, 70.47 mmol), potassium hydroxide (11.86 g, 0.21 mol), water (80 mL), and 1,4-dioxane (12 mL)] was introduced in 3 h into a stirred solution of dithiol (**18**, 4 g, 23.5 mmol) and potassium hydroxide (3.95 g, 70.5 mmol) in methanol (130 mL) under nitrogen , and the mixture was refluxed for 2 h. The mixture was concentrated and the residue was extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and evaporated. The residual oil was purified by column chromatography on silica gel using hexane-dichloromethane (2:1) to give the compound (**19**, 4.36 g, 68.7 %) as an orange oil, IR (neat) cm^{-1}: 3280 and 2080 (C≡CH). ^{1}H-NMR ($CDCl_3$) δ: 3.39 (2H, d, *J* = 1.9 Hz, 2 x C≡CH), 4.13 (4H, s, 2 x CH_2), 5.46 (2H, dd, *J* = 9.7 and 1.9 Hz, 2 x =CHC≡C), 6.57 (2H, d, *J* = 9.7 Hz, 2 x =CH-S), 7.22-7.31 (4H, m, ArH). ^{13}C-NMR ($CDCl_3$) δ: 34.8 (t), 79.8 (s), 85.5 (d), 104.2 (d), 128.0 (d), 130.7 (d), 135.1 (s), 140.2 (d). MS *m/z*: 270 (M^+), 269, and 134 (base). *Anal*. Calcd for $C_{16}H_{14}S_2$: C, 71.07; H, 5.22. Found: C, 70.40; H, 5.22.

***cis*-2-Butene-1,4-dithiol (20)**. Potassium hydroxide (343 mg, 6.12 mmol) was added to a solution of 2-butene (**21**, 500 mg, 2.45 mmol) in methanol (13 mL) and the mixture was stirred for 1 h under nitrogen. After the reaction mixture was acidified by addition of 10% HCl, the mixture was extracted with dichloromethane, and the dichloromethane layer was washed, dried over $MgSO_4$, and evaporated to leave the compound[13] (**20,** 254 mg, 86.4%) as a yellow oil; IR (neat) cm^{-1}: 2550 (SH): ^{1}H-NMR ($CDCl_3$) δ: 1.59 (2H, t, *J* = 7.3 Hz, 2 x SH), 3.20 (4H, dd, *J* = 7.3 and 5.4 Hz, 2 x CH_2), and 5.60 (2H, t, *J* = 5.4 Hz, 2 x CH). ^{13}C-NMR ($CDCl_3$) δ: 20.4 (t), and 129.1 (d). MS *m/z*: 120 (M^+) and 87 (base). *Anal*. Calcd for $C_4H_8S_2$: C, 39.96; H, 6.71. Found: C, 40.25; H, 6.44.

***cis*-1,4-Diacetylthio-2-butene (21).** Potassium thioacetate (5.7 g, 50.2 mmol) was added to a solution of 1,4-dichloro-2-butene (3 g, 22.8 mmol) in absolute ethanol (60 mL), and the mixture was refluxed for 2 h under nitrogen. The reaction mixture was extracted thoroughly with ether, and the ether extracts were concentrated to dryness to yield the compound[13] (**21**, 0.75 g, quant.) as an orange oil; IR (neat) cm^{-1}: 1695 (CO), ^{1}H-NMR ($CDCl_3$) δ: 2.34 (6H, s, 2 x Me), 3.62 (4H, d, *J* = 4.9 Hz, 2 x CH_2), and 5.54 (2H, t, *J* = 4.9 Hz, 2 x CH); ^{13}C-NMR ($CDCl_3$) δ: 25.8 (t), 30,3 (q), 127.4 (d), and 195.1 (s). Ms *m/z*: 129 (M^+-SCOMe) and 43 (base). *Anal.* Calcd for $C_8H_{12}S_2$: C, 55.77; H, 7.02. Found: C, 55.99; H, 6.78.

5,10-Dithiatetradeca-3,7,11-trien-1,13-diyne (22). Butadiyne gas [generated from 1,4-dichloro-2-

butyne (1.26 mL, 12.5 mmol), potassium hydroxide (2.1 g, 37.4 mmol), water (15 mL), and 1,4-dioxane (2 mL) as above] was passed into a stirred solution of dithiol (**20**, 1 g, 8.3 mmol) and potassium hydroxide (1.4 g, 25 mmol) in methanol (100 mL) in 2 h at -10 °C under nitrogen. The mixture was continued to stir for 18 h during which time the temperature was raised up to rt. After concentrated to dryness, the reaction mixture was extracted with dichloromethane and the extract was washed with water and dried over $MgSO_4$. Evaporation of the solvent left a yellow oil, which was purified by column chromatography on silica gel with dichloromethane-hexane (1:5) to yield the compound (**22**, 304 mg, 22.1%) as a pale yellow oil, IR (neat) cm^{-1}: 3300 and 2100. ^{1}H-NMR ($CDCl_3$) δ: 3.43 (2H, d, *J* = 2 .9 Hz, 2 x =CH), 3.50 (4H, d, *J* = 6.8 Hz, 2 x CH_2), 5.53 (2H, dd, *J* = 10.7 and 2.9 Hz, 2 x =CH-C=), 5.71 (2H, t, *J* = 6.8 Hz, 2 x =CH), and 6.57 (2H, d, *J* = 10.7 Hz, 2 x =CH-S). ^{13}C-NMR ($CDCl_3$) δ: 29.4 (t), 79.7 (s), 85.4 (d), 104.5 (d), 128.1 (d), and 140.2 (d). MS *m/z*: 220 (M^+) and 134 (base). *Anal.* Calcd for $C_{12}H_{12}S_2$: C, 65.41; H, 5.49. Found: C, 65.32; H, 5.65.

5,6,7,8-Tetrahydro-1,12-dihydro-2,11-benzodithiacyclotetradecin (23). A solution of compound (**19**, 3.5 g, 12.9mmol) in benzene (100 mL) was slowly added to a refluxing mixture of CuCl (5.1 g, 51.8 mmol), pyridine (4.2 mL) and benzene (260 mL) in 4 h, during which time air was bubbled into the reaction mixture, and then the mixture was stirred for 16 h. After concentrated to one third, the reaction mixture was extracted with dichloromethane. The organic layer was washed with water, dried over $MgSO_4$, and evaporated under reduced pressure to yield gray powder, which was subjected to column chromatography on silica gel using hexane-dichloromethane to afford the compound (**23**, 1.39 g, 39.9%) as colorless needles after recrystallization from dichloromethane-hexane (1:10); mp 159-161 °C, IR (KBr) cm^{-1}: 2185 (C≡C), 1545, 870 and 705. ^{1}H-NMR ($CDCl_3$) δ: 4.63 (4H, s, 2 x CH_2), 5.63 (2H, d, *J* = 10.7 Hz, 2 x CH), 6.53 (2H, d, *J* = 10.7 Hz, 2 x CH), 7.35-7.40 and 7.65-7.70 (each 2H, m, ArH). ^{13}C-NMR ($CDCl_3$) δ: 33.0 (t), 80.1 (s), 84.8 (s), 105.4 (d), 127.3 (d), 127.8 (d), 133.8 (s), and 138.1 (d). MS *m/z*: 268 (M^+, base). *Anal*. Calcd for $C_{16}H_{12}S_2$: C, 71.60; H, 4.51. Found: C, 71.58; H, 4.52.

9,16-Dimethyl-10,15-dihydrotribenzo[*b,d,h*][1,6]dithiecin-9,16-diium bis(tetrafluoroborate) (24a). Silver tetrafluoroborate (759 mg, 3.94 mmol) was added to a stirred mixture of compound (**7**, 500 mg, 1.56 mmol) and iodomethane (6.84 g, 48.2 mmol) in dry dichloromethane (10 mL), and the mixture was stirred for 12 h at rt. The precipitates were filtered and washed with acetonitrile. The filtrate and washings were combined and evaporated under reduced pressure followed by addition of dry ether to afford the compound (**24a**, 791 mg, 96.7%) as colorless needles after recrystallization from dichloromethane-ether , mp 187-193 °C(decomp), IR (KBr) cm^{-1}: 1080-1035 (BF_4^-). ^{1}H-NMR (CF_3CO_2D) δ: 3.62 (6H, s, 2 x Me), 4.81 (4H, s, 2 x CH_2), and 7.58-7.93 (12H, m, ArH). ^{13}C-NMR (CF_3CO_2D) δ: 26.7 (q), 52.1 (t), 125.1 (s), 130.3 (s), 130.7 (s), 134.2 (d), 134.5 (d), 134.9 (d), 135.1 (d), 137.1 (d), 141.3 (s). *Anal*. Calcd for $C_{22}H_{22}B_2F_8S_2$: C, 50.41; H, 4.23. Found: C, 50.78; H, 4.01.

9,16-Diethyl-10,15-dihydrotribenzo[*b,d,h*][1,6]dithiecin-9,16-diium bis(tetrafluoroborate) (24b). Silver tetrafluoroborate (670 mg, 3.44 mmol) was added to a stirred mixture of compound (**7**, 500 mg, 1.56 mmol) and iodoethane (7.41 g, 46.6 mmol) in dry dichloromethane (10 mL), and the mixture was stirred for 17 h at rt. The reaction mixture was worked up as above to yield the compound (**24b**, 833 mg, 96.6%) as colorless needles after recrystallization from dichloromethane-ether, mp 153-160 °C (decomp), IR (KBr) cm^{-1}: 1090-1040 (BF_4^-). ^{1}H-NMR (CF_3CO_2D) δ: 1.62 (6H, t, *J* = 10 Hz, 2 x CH_2Me), 4.19 (4H, q, *J* = 10 Hz, 2 x CH_2Me), 4.82 and 5.12 (each 2H, d, *J* = 14.7 Hz, 2 x CH_2), and 7.58-8.04 (12H, m, ArH). ^{13}C-NMR (CF_3CO_2D) δ: 10.7 (q), 41.4 (t), 123.3 (s), 130.2 (s), 133.5 (d), 134.1 (d), 134.2 (d), 135.0 (d), 135.1 (d), 137.3 (d), 143.8 (s). *Anal*. Calcd for $C_{24}H_{26}B_2F_8S_2$: C, 52.20; H, 4.75. Found: C, 52.43; H, 4.51.

Treatment of 24a with lithium diisopropylamide (LDA). A THF solution of LDA (1.68 mmol) was added at -60 °C to a stirred suspension of compound (**24a**, 400 mg, 0.76 mmol) in dry THF (5 mL) in a stream of nitrogen, and the mixture was stirred for 2 h at the same temperature, and further for 13 h at -30

°C. Saturated aq. NH_4Cl was added to the reaction mixture, which was then extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and evaporated to afford a residue, which was subjected to preparative TLC on silica gel using dichloromethane-hexane (1:3) to afford 2,2'-bis(methylthio)biphenyl (**25a**, 164 mg, 87.2%) as colorless crystals , mp 158-159.5 °C (lit.,[5] mp. 155-157 °C), ^{1}H-NMR ($CDCl_3$) δ: 2.32 (6H, s, 2 x Me) and 7.15-7.45 (8H, m, ArH). MS *m/z*: 246 (M^+) and 179 (base).

Treatment of 24b with lithium diisopropylamide. A THF solution of LDA (1.60 mmol) was added at -60 °C to a stirred suspension of compound (**24b**, 400 mg, 0.72 mmol) in dry THF (5 mL) in a stream of nitrogen, and the mixture was stirred for 1 h at the same temperature, and further for 17 h at -30 °C. The reaction mixture was worked up as above to give an oily product, which was subjected to preparative TLC on silica gel using ether-hexane (1:7) to afford 2,2'-bis(ethylthio)biphenyl) (**25b**, 94 mg, 47.3%) as colorless prisms; mp 51.5-52 °C (lit.,[5] mp. 54-55 °C), ^{1}H-NMR ($CDCl_3$) δ: 1.15 (6H, t, *J* = 6.8 Hz, 2 x CH_2CH_3), 2.78 (4H, q, *J* = 6.8 Hz, 2 x CH_2Me), and 7.05-7.40 (8H, m, ArH). MS *m/z*: 274 (M^+) and 195 (base).

Reaction of 7 with benzyne. A mixture of compound (**7**, 250 mg, 0.78 mmol), *o*-bromofluorobenzene (300 mg, 1.17 mmol) and Mg (46 mg, 1.85 mmol), and a small amount of iodine in dry THF (5 mL) was refluxed for 2 h under nitrogen. Saturated aq. NH_4Cl was added to the reaction mixture, which was then extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and evaporated to dryness to afford an oily residue, which was separated by preparative TLC on silica gel using dichloromethane-hexane (1:10) to afford 2,2'-bis(phenylthio)biphenyl (**25c**, 52 mg, 27%) as colorless plates after recrystallization from dichloromethane-hexane along with a recovered (**7**, 81 mg, 32.4%). **25c**: mp 95-96 °C; ^{1}H-NMR ($CDCl_3$) δ: 7.14 (brs, ArH). MS *m/z*: 370 (M^+) and 261 (base). *Anal.* Calcd for $C_{24}H_{18}S_2$: C, 77.80; H, 4.90. Found: C, 77.85; H, 4.97.

10,15-Dimethyl-9,16-dihydrotribenzo[*b,f,h*][1,4]dithiecin-10,15-diium bis(tetrafluoroborate) (26). A solution of dithiecin (**8**, 400 mg, 1.25 mmol) in dry dichloromethane (9 mL) was added at -30 °C through a dropping funnel in about 30 min to a stirred solution of dimethoxycarbenium tetrafluoroborate (4.98 mmol) in dry dichloromethane (6 mL), and the mixture was stirred for 1 h at the same temperature, and further for 20 h at rt. The reaction mixture was concentrated under reduced pressure, and then ether was added to give the compound (**26**, 477 mg, 72.9%) as colorless crystals after recrystallization from ethyl acetate-ether, mp 156-162 °C(decomp), IR (KBr) cm^{-1}: 1150-1030 (BF_4^-). ^{1}H-NMR (CF_3CO_2D) δ: 3.58 (3H, s, Me), 3.68 (3H, s, Me), 4.95 (1H, d, *J* = 12.4 Hz, ArC*H*H), 5.02 (2H, s, $ArCH_2$), 5.53 (1H, d, *J* = 12.4 Hz, ArCH*H*), and 7.23-8.53 (12H, m, ArH); ^{13}C-NMR (CF_3CO_2D) δ: 27.6 (q), 30.2 (q), 55.1 (t), 55.8 (t), 126.3 (s), 127.2 (s), 128.9 (s), 131.7 (d), 132.0 (d), 132.6 (d), 132.8 (d), 133.2 (d), 136.2 (d), 138.6 (d), 140.0 (d), 141.2 (s). *Anal.* Calcd for $C_{22}H_{22}B_2F_8S_2$: C, 50.41; H, 4.23. Found: C, 50.13; H, 4.21.

Reaction of sulfonium salt (26) with LDA. A solution of LDA (0.76 mmol) in THF (4 mL) was added slowly at -60 °C to a stirred suspension of sulfonium salt (**26**, 182 mg) in dry THF (4 mL) under nitrogen, and the mixture was stirred for 1 h at the same temperature, and for 10 h at -30 °C. Saturated aq. NH_4Cl was added at -0 °C to the reaction mixture, which was then extracted with dichloromethane. The extract was washed with water, dried over $MgSO_4$, and evaporated to give a residue, which was submitted to preparative TLC on silica gel using dichloromethane-hexane (1:3) to afford phenanthrene (**28**, 7 mg, 11%) and 1,2-bis(methylthio)benzene[14] (**27**, 40 mg, 67.6%) as a pale yellow oil. **27**: ^{1}H-NMR ($CDCl_3$) δ: 2.43 (6H, s, 2 x Me) and 7.21 (4H, br s, ArH). MS *m/z*: 170 (M^+) and 91 (base). HRMS: Calcd for $C_8H_{10}S_2$: 170.0224. Found: 170.0208.

2,7-Dimethyl-1,8-dihydro-2,7-benzodithiecin-2,7-diium bis(tetrafluoroborate) (29). A solution of dithiecin (**9**, 100 mg, 0.45 mmol) in dry dichloromethane (3 mL) was added at -30 °C through a dropping funnel in about 30 min to a stirred solution of dimethoxycarbenium tetrafluoroborate (1.82 mmol) in dry

dichloromethane (2 mL), and the mixture was stirred for 1 h at the same temperature, and further for 17 h at rt. The reaction mixture was concentrated under reduced pressure, then ether was added to give the compound (**29**, 165 mg, 85.9%) as highly hygroscopic crystals. Therefore, the compound was used without further purification. IR (KBr) cm^{-1}: 1060-1030 (BF_4^-).

Treatment of sulfonium salt (29) with LDA. A powdered sulfonium salt (**29**, 1 g, 2.36 mmol) was added portionwise at -60 °C under nitrogen to a solution of LDA (9.43 mmol) in THF (20 mL), and the mixture was stirred for 4 h at the same temperature and for 14 h at -30 °C. Saturated aq. NH_4Cl was added to the reaction mixture , which was then worked up as above to leave an oil. The obtained oil was purified by preparative TLC on silica gel with dichloromethane-hexane (1:1) to afford 1,4-bis(methylthio)-1,3-butadiene (**30**, 234 mg, 67.8 %), bp 97-100 °C/2 mmHg (lit.,[6] bp 97-98 °C/2 mmHg), ^{1}H-NMR ($CDCl_3$) δ: 2.30 (6H, s, 2 x CH_3), 6.00 and 6.27 (each 4H, dd, J = 6.3, 1.9 Hz, 2 x CH=CH). ^{13}C-NMR ($CDCl_3$) δ: 16.9 (q), 121.6 (d), 129.2 (d). MS *m/z*: 146 (M^+), 133 (base).

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