1,2-Dithiins and Precursors, 19[‡]

Oxidation of (*Z*,*Z*)-1,4-Diaminobuta-1,3-diene-1,4-dithiolates and Related Precursors − Alternatives For 1,2-Dithiin Formation

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Dedicated to Professor Rolf Huisgen on the occasion of his 80th birthday

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Oxidation of the title compounds, in contrast to that of "normal" (*Z*,*Z*)-buta-1,3-diene-1,4-dithiolates, does not lead to the formation of 1,2-dithiins. Thus, the aliphatic diaminodithiolates **7** and **8** were converted into the (*E*)-2-butenedithioamides **12** and **15** as a result of resonance stabilization of the thiocarbonyl group. On the other hand, the 3,3′-biindole-2,2′-dithiolate **9**, the aromatic counterpart of **8**, undergoes disulfide formation with preservation of aromaticity in the hetarene rings and yields the 1,2-dithiin dimer **31** with a 12-membered ring structure. In this instance, the formation of the expected (*E*)-3,3′-biindolinylidene-2,2′-dithione **29** (a thioxo analogue of isoindigo) does not take place, paralleling the general problems for the existence of thioxo indigoid compounds **37**. On the other hand, oxidation of the 2,2′-bihetarene-3,3′-dithiolates **34** [formally, (*Z*,*Z*)-buta-1,3-diene-1,4-dithiolates with π-donor substituents X in the 2- and 3-positions] affords either monomeric (**38c**) or dimeric 1,2-dithiins (e.g. **39a**,**b**,**d**) depending on the heteroatom X in the anellated hetarene ring. It was possible to correct some long-standing erroneous structures: such as the 3,6-diamino-1,2-dithiins **20** in favor of the (*E*)-2-butenedithioamides **22**, and the alleged thioxoisoindigo **29** – obtained from 1-methylindoline-2-thione (**23**) and *N*,*N*-dimethyl-4-nitrosoaniline – in favor of the 1,2-dithiin dimer **31**.

Introduction

Oxidation of (*Z*,*Z*)-buta-1,3-diene-1,4-dithiolates **A** smoothly affords the 1,2-dithiin ring **1** when X is H or an organic group such as alkyl, aryl, hetaryl, etc. (Scheme 1).[1] On the other hand, when X is a π-donor substituent such as OR or NR_2, the ring-opened valence isomers **2a**,**b** represent dithiomaleic derivatives, which should be favored because of resonance stabilization.[2] Indeed, an ab initio study by Fabian and Mann[3] predicts that the parent compound **1** (X = H) should be more stable than the valence isomer **2** (X = H) by at least 15 kcal/mol, whereas 3,6-diamino derivative **1** (X = NH_2) should be less stable (by about 11 kcal/mol) than the corresponding alternative **2** (X = NH_2). Nevertheless, the (*Z*)-2-butene-1,4-dithiones **2**, particularly the conformers **2b**, act as short-lived intermediates in the photoinduced conversion of ''normal'' 1,2-dithiins **1** (X = H or organic groups) to episulfides **3**, which immediately undergo aromatization to yield the thiophenes **4** (sulfur extrusion) or **5** (rearrangement).[4] Finally, the formation of diethyl dithiofumarate **6** by oxidation of the dithiolate **A** (X = OEt), even at −50 °C, points to an alternative course of stabilization. According to Hartke and Pfleging,[5] the valence isomer **2** of the initially formed 3,6-diethoxy-1,2-dithiin **1** (X = OEt), should undergo geometric isomerization. It should be noted that 1,2-dithiins **1** with X = *p*-$C_6H_4NMe_2$[2] and *p*-C_6H_4OMe,[6] where the respective donor substituents occupy positions in the phenyl ring, are well-known and unequivocally exist as cyclic disulfides.

As a consequence of these observations, we became interested in the question of whether 3,6-diamino-1,2-dithiins **1** (X = NR_2) might exist. Thus, we investigated the oxidation of *N*,*N*′-tetrasubstituted 1,4-diaminobuta-1,3-diene-1,4-dithiolates of type **A** (X = NR_2), and chose the dithiolates **7**−**9** as test compounds (Scheme 2).

Results and Discussions

All attempts to transform the dithiolates mentioned above into the corresponding 1,2-dithiins failed. In each case alternative reactions occurred, depending on the structure of the thiolate. This is described in the following sections.[7]

[‡] Part 18: Ref.[2]
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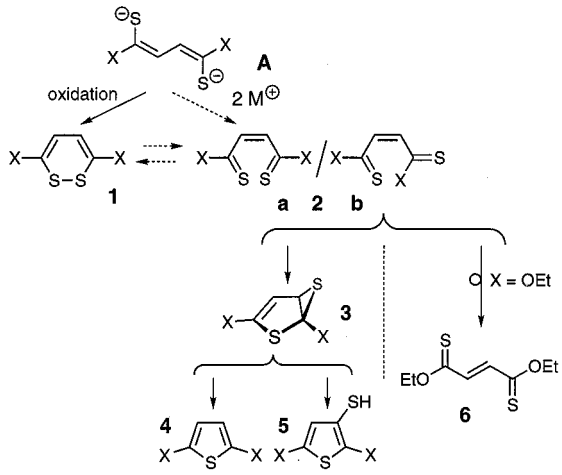
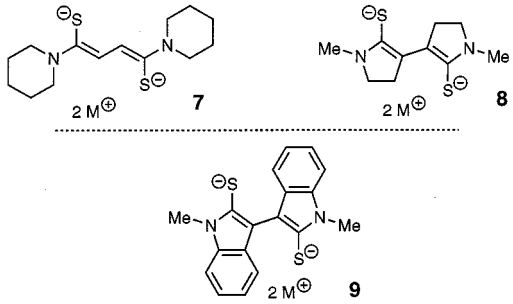
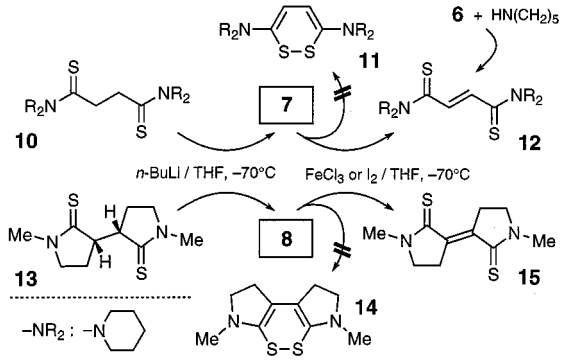


Scheme 1



Scheme 2



Scheme 3

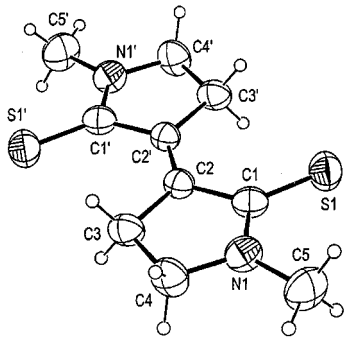


Figure 1. X-ray crystal structure of (*E*)-1,1′-dimethyl-3,3′-bipyrrolidinylidene-2,2′-dithione (**15**) with 30% probability ellipsoids; H atoms are drawn as circles of arbitrary radius; selected bond lengths [A]: C(1)−S(1) 1.674(7), C(2)−C(2′) 1.352(9)

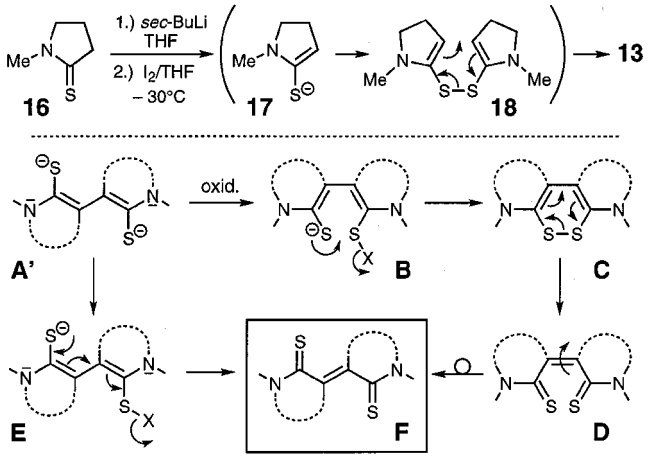
1. Predominance of Thioamide Formation in the Case of the (*Z*,*Z*)-1,4-Diaminobuta-1,3-diene-1,4-dithiolates A/A′ (7 and 8); Revision of an Erroneous Structure Assignment: Thioamide 22 Instead of 1,2-Dithiin 20

Lithium 1,4-dipiperidylbuta-1,3-diene-1,4-dithiolate (**7**), from 1,4-dipiperidylbutane-1,4-dithione (**10**)[8] and *n*-butyllithium, was oxidized with the aid of iodine as well as ferric chloride (improved yield) at −70 °C with exclusion of daylight (Scheme 3). Only (*E*)-1,4-dipiperidylbut-2-ene-1,4-dithione (**12**) could be obtained, paralleling the conversion mentioned above of **A** (X = OEt) into **6**.[5] TLC confirmed the absence of other potential products, particularly of dithiin **11** and the corresponding thiophene. Whereas the dithiin formation might have failed in this case as a result of previous rearrangement of **7** into the (*E*,*Z*)- or (*E*,*E*)-isomeric dithiolates, in dithiolate **8** the required (*Z*,*Z*) configuration is inevitably fixed by anellation and, thus, intramolecular disulfide oxidation clearly must occur. However, oxidation of **8**, obtained from bithiopyrrolidone **13**[9] by deprotonation, also failed to produce the 1,2-dithiin **14** and gave the unsaturated bithiolactam **15**.

The structure and the (*E*) configuration of both oxidation products **12** and **15** are well established. Compound **12** can also be obtained by reaction of the spectroscopically (NMR) confirmed (*E*)-dithioester **6** with piperidine.[10] Unambiguous evidence for the (*E*) configuration of **15** is provided by X-ray crystallography (Figure 1).[11] Because of its nearly planar >N−CS−C=C−CS−N< moiety, the latter compound absorbs at a substantially longer wavelength (λ_{max} = 430 nm, in agreement with an n→π* transition) than **12**, in which the CS group is capable of rotation (λ_{max} = 329 nm).

It should also be noted that bithiopyrrolidone **13** has been generated by deprotonation of thiopyrrolidone **16** to thiolate **17**, with subsequent oxidation[9] (Scheme 4). The (3*R**,3′*R**) isomer was expected on the assumption that a Cope rearrangement of the initially formed disulfide **18** involves a chairlike transition state. The role of thioamide formation as the driving force here is obvious. In view of this, it also seems evident that, in going from dithiolate **A**′ via **B**, a 1,2-dithiin **C** is initially formed, and this undergoes spontaneous electrocyclic ring-opening to give the (*Z*)-bithioamide **D** (X = an initially bound electrophile). The only serious problem would be the conversion of the latter to the (*E*)-isomer **F** under such mild conditions as already assumed for the transformation of **A** into **6** via **1** and **2** (X = OEt).[5] Incidentally, the dianellated 1,2-dithiin **14** should be stable towards subsequent reactions in any case (even exposure to light), in agreement with our observations in the dianellated series.[12]

In ref.[3] (p. 57), it is stated that ''the high barrier of rotation around the essential double bond should prevent thermal isomerization.'' Hence, we are inclined to explain these results in terms of the oxidation course. Instead of the disulfide detour (via **B** → **C** → **D**), electron transfer within the C_4 chain according to **E** should directly afford the unsaturated (*E*)-bithioamides **F**, so that any entry into the 3,6-diam-



Scheme 4

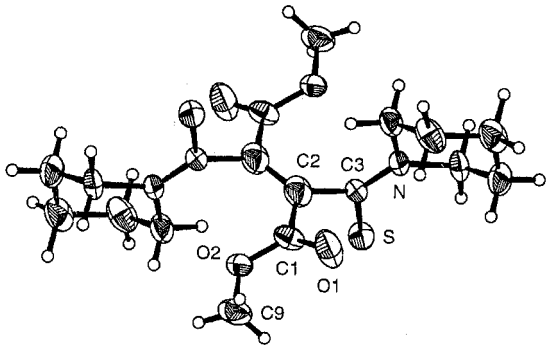
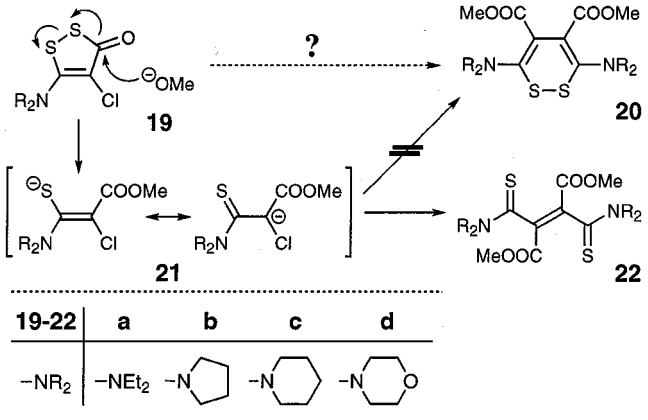


Figure 2. X-ray crystal structure of dimethyl (*E*)-2,3-bis[piperidyl-(thiocarbonyl)]but-2-ene-1,4-dioate (**22c**) with 50% probability ellipsoids; H atoms are drawn as circles of arbitrary radius; selected bond lengths [A] and torsion angles [°]: C(3)−S 1.670(3), C(2)−C(2′) 1.310(9); O(1)−C(1)−C(2)−C(3) 35.0(5), C(1)−C(2)−C(3)−S 88.3(3)

ino-1,2-dithiin series **1** (X = NR_2) appears highly questionable.

Despite this, extremely stable 3,6-bis(dialkylamino)-1,2-dithiins of type **20** have been known for three decades[13,14] (Scheme 5). These compounds (obtained by reaction of 1,2-dithiol-3-ones **19** with sodium methoxide) could owe their existence to a push-pull interaction between the NR_2 and COOMe groups. However, their remarkable stability towards sulfur extrusion casts some doubts on their structure. Indeed, reexamination of these compounds by NMR spectroscopy confirmed an error in structure assignment, and the compounds were shown to be the thioamides **22**. In the ^{1}H NMR spectra, multiplets for NR_2 indicate restricted rotation of this group, and in ^{13}C NMR spectra the signal around δ = 188 suggests a C=S group. Finally, X-ray analysis of the piperidino derivative **22c** (rather than **20c**[13a]) unequivocally shows the (*E*) configuration (Figure 2).[11] Thus, the formation of **22** appears to proceed by nucleophilic ring-opening of the dithiolone ring **19** to give the thioamide anion **21**, which then undergoes self-condensation to afford **22**. The latter step corresponds to the well-known behavior of halomalonic acid derivatives.[15]



Scheme 5

2. Cyclization of Dithiolate 9 to Bis(disulfide) 31 Instead of Bithioamide 29, a Thioxo Analogue of Isoindigo

Any approach to dithiolate **9** requires appropriate functionalized 3,3′-biindole precursors such as **24**, **25b**, and **27** (Scheme 6). Three routes to **9** can be considered.

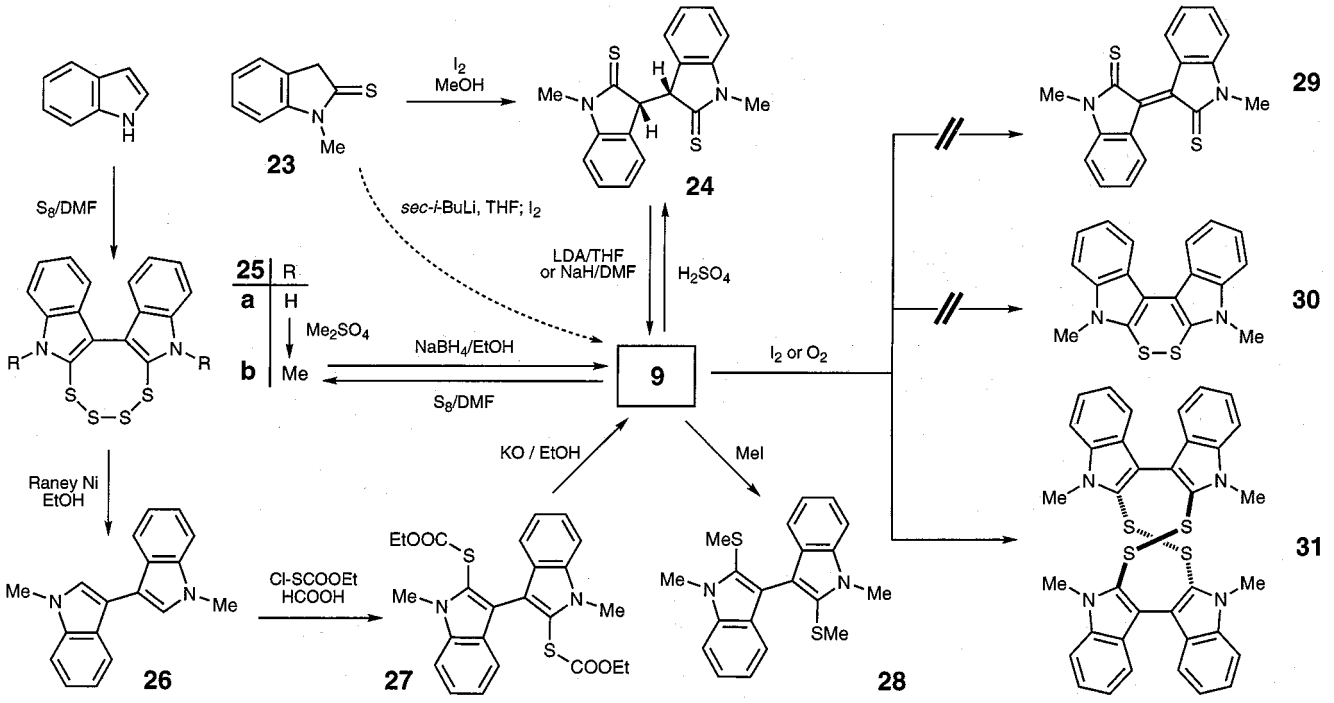
i) The most simple precursor, **24** − the conjugate acid of **9** and the aromatic counterpart of **13** − requires only deprotonation. This compound can be obtained from 1-methylindolethione **23** by oxidative dimerization with iodine in methanol.[16] With the appropriate amounts of *sec*-butyllithium and iodine in tetrahydrofuran, **9** can be prepared directly from **23** in a one-pot operation that avoids precipitation of the initially produced **24**. X-ray crystallography[17] indicates that **24** has the (3*R**,3′*R**) configuration. Thus, it appears likely that the course of the oxidative dimerization is by Cope rearrangement, analogous to the formation of **13** via **18**. The same configuration would also arise, however, from acidification of **9**, so thermodynamic control may also be considered.

ii) Another approach starts by treatment of indole with elemental sulfur to produce the NH-tetrathiocine **25a**,[18] methylation to yield the NMe derivative **25b**, and finally reductive fission with elimination of two sulfur atoms to give the desired dithiolate **9**.

iii) In the third method, the thio functionality is selectively introduced into the 3,3′-biindole parent **26** (derived from the corresponding NH species by methylation),[19] from 1-methylindolone by reaction with elemental sulfur[16] or from **25b** by reductive degradation with Raney nickel. Substitution with ethoxycarbonylsulfenyl chloride provides the 2,2′-bis(ethoxycarbonylthio) derivative **27**, which after saponification affords **9**.

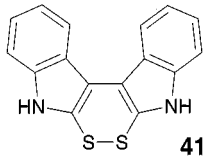
In every case, the dithiolate **9** was not isolated but immediately subjected to in situ oxidation. Independent evidence for the presence of **9** was shown by the smooth regeneration of the tetrasulfide **25b** by reaction with elemental sulfur, and by transformation into the methylthio derivative **28**.

However, oxidation of **9** afforded neither the bithioamide **29**, as might be expected from the transformation of **8** into



Scheme 6

15, nor the dianellated 1,2-dithiin **30**; only the dimer [i.e. the 12-membered cyclic bis(disulfide) **31**] could be isolated, in the form of orange-red crystals. In ref.[18] the bisindolo[2,3-*c*:3′,2′-*e*][1,2]dithiin **41**, the NH analogue of **30**, has been claimed.



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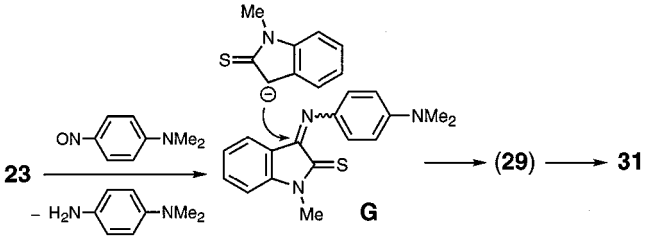
The compound was obtained by reductive fission of **25a** with $NaBH_4$ and subsequent aerial oxidation (comparable with **25b** → **9** → **31**). In our experience, the NH analogue of **31**, or even a higher oligo(disulfide), are more likely. Investigations to clarify this situation are in progress. Reduction of the latter with, for example, $NaBH_4$ regenerated **9**.

The generation of a disulfide instead of a thioamide corresponds to the preservation of aromaticity in the hetarene part. The formation of the cyclic bis(disulfide) **31** instead of the dianellated 1,2-dithiin **30** is probably a result of the lower strain of the disulfide group, which concurs with a more detailed structure analysis. The structure of **31** is strongly distorted, as shown unambiguously by X-ray crystallography.[7] Two indole rings face each other, and are twisted relative to one other by nearly 180°, while the planes of the other two are tilted outwards. The planes of the 3,3′-biindole units are twisted by nearly 127°. The S−S bond length of 204 pm is in the expected range, while the C−S−S−C dihedral angles of about 87° deviate significantly from that of the 1,2-dithiin ring, which is around 50−55°. From the ^1H and ^{13}C NMR spectra (see Experimental Section), **31** suffers a rapid, reversible conformational change in solution, obviously favored by rotation around the $C^3-C^{3'}$ axis of both biindole moieties.[20] The electron impact mass spectrum indicates easy fission to the monomeric unit (corresponding to **29**/**30**) as the base peak and, therefore, as the more stable component in the gas phase. In contrast to this, the molecular peak of **31** is scarcely detectable. Moreover, the mass-spectrometric fragmentation of the tetrasulfide **25b** also shows **29**/**30** as the base peak.

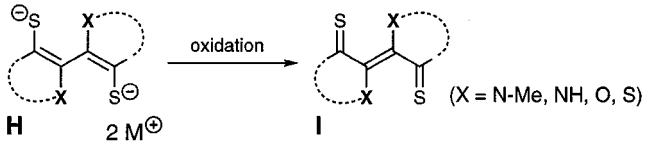
Contrary to our results, the bithioamide **29** was described 25 years ago as a stable compound, obtained by reaction of 1-methylindolethione **23** with both *N*,*N*-dimethyl-*p*-nitrosoaniline and arenesulfonyl azides [21] (Scheme 7). The formation, by condensation at the methylene group, illustrated by **G**, seems quite plausible; a comparable case is provided by the reaction of *N*-methylindolone affording *N*,*N*′-dimethylisoindigo.[22] However, the structure assignment of **29** is incorrect and this product again proved to be the dimer **31**. Thus, we must assume that **29**, if initially formed, immediately undergoes dimerization to give **31**.



Scheme 7

3. Extension: Oxidation of (*Z*,*Z*)-Buta-1,3-diene-1,4-dithiolates H/34 Containing Donor Substituents in the 2- and 3-Positions; the Problematic Existence of Thioxo Indigoid Compounds

In addition to the different behavior of the (*Z*,*Z*)-1,4-diaminobuta-1,3-diene-1,4-dithiolates **A**/**A**′ (**7**−**9**) reported above, the oxidation of the corresponding buta-1,3-diene-1,4-dithiolates of the general type **H** with donor substituents X in the 2- and 3-positions is also of great interest (Scheme 8). Here, the most important question to be answered is to what extent the donor substituents X could favor the stability of buta-1,3-diene-1,4-dithiones **I** as potential oxidation products; in this case by *vinylogous* resonance with the thiocarbonyl group. Moreover, it should be emphasized that the buta-1,3-diene-1,4-dithiones **I** represent thioxo analogs of indigoid compounds; for example the hypothetical bithioamide **29** can be considered as a thioxo analogue of isoindigo. The reduced stability of the latter is in direct contrast to that in the classic oxygen series. Indeed, all our attempts to prepare thioxo indigoid compounds of type **I** by oxidation of the dithiolates **H** failed.[23] Some of our observations should be mentioned at this juncture.



Scheme 8

The 2,2′-bihetarene-3,3′-dithiolates of type **34** − formally leuko indigoid analogues − adopt the role of the central intermediates **I** (Scheme 9). Their synthesis parallels the sequence **26** → **27** → **9**. Thus, reaction of the 2,2′-bihetarenes **32**[24] with ethoxycarbonylsulfenyl chloride to yield the 3,3′-bis(ethoxycarbonylthio) derivatives **33**, and subsequent treatment of the latter with alcoholic potassium hydroxide to deblock the thio function, gave **34**. The presence of **34** in solution was independently proved by the smooth formation of the crystalline 3,3′-dithiols, e.g. **35a**, and by transformation to 3,3′-bis(benzylthio) derivatives, such as **36a** and **36d**.

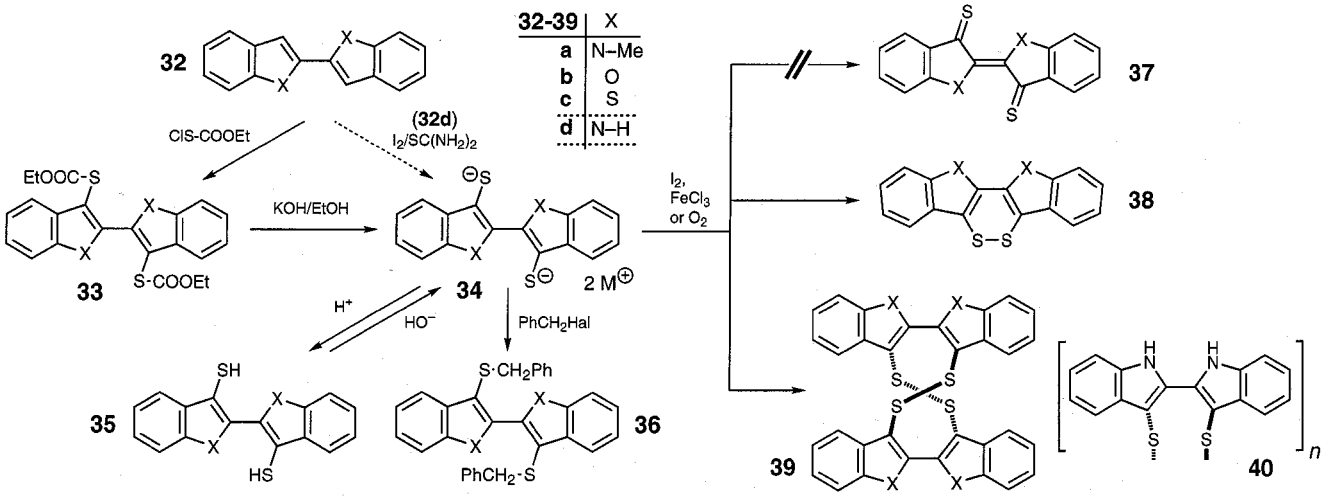
In all cases, in situ oxidation of **34** again gave rise to disulfide formation, with the production of the 1,2-dithiin monomers and dimers **38** and **39**, respectively. Generation of the thioxo indigoid compounds **37** was not observed. The preference for **38** and **39** surprisingly depends on the nature of the heteroatom X as a consequence of some (as yet) unexplained thermodynamic differentiation when X = N−Me, N−H and O on the one hand and with X = S on the other.

Thus, dithiolate **34a** (isomeric with **9**) was transformed exclusively into the 12-membered cyclic 1,2-dithiin dimer **39a** (isomeric with **31**).[12d,23] Likewise, the corresponding dimer **39b** resulted from the precursor **34b**, although a small quantity of the monomeric 1,2-dithiin **38b** could be detected in solution as a component of the equilibrium.[25] In contrast, the 1,2-dithiin **38c** was the sole product from **34c**.[12d,12e] A comparable differentiation between 6- and 12-ring disulfide formation has been found in the dithieno anellated series, depending on the mode of anellation.[12c]

Finally, it should be noted that, in the case of X = NH, a quite different reaction course was observed (cf. also ref.[12d]). Oxidation of **34d** afforded a mixture of the cyclic bis(disulfide) **39d**, together with oligomeric cyclic disulfides **40**.[26] The latter is amorphous, extremely insoluble, melts over a wide range above 360 °C and is separable only with difficulty. The same result was obtained from the stepwise reaction of **32d** with iodine and thiourea, followed by alkaline hydrolysis and aerial oxidation analogous to the procedure in ref.[27] The mass spectrum up to *m*/*z* = 600 contains a peak consistent with **39d** (*m*/*z* = 588), together with a base peak corresponding to **37d**/**38d**. The latter again confirms the preferred existence of the monomeric unit in the gas phase. Reduction of the product with sodium tetrahydroborate regenerated the dithiolate **34d** (proved by in situ benzylation to yield **36d**). Strong IR bands at 2700 ± 50 and 3340 cm^{-1} point to association by intermolecular NH hydrogen bonds.

Conclusions

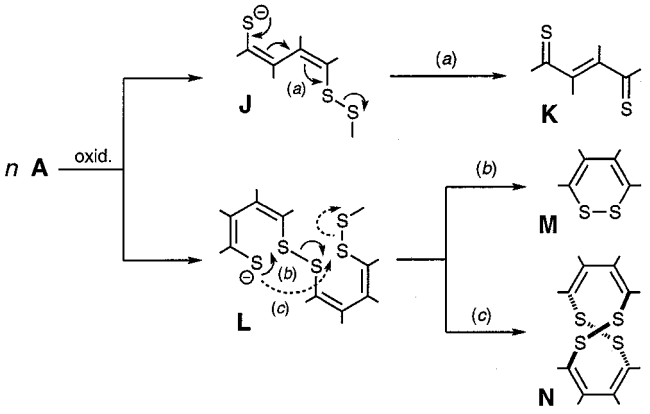
The oxidation of (*Z*,*Z*)-buta-1,3-diene-1,4-dithiolates (**A**/**A**′) can lead, in principle, to two different types of product:



Scheme 9

namely 2-butene-1,4-dithiones and cyclic disulfides. The first case is favored when π-donor substituents, amino groups in this investigation, give rise to suitable resonance stabilization of the thioxo group (e.g. **12**, **15**; corresponding to the revision of **20** to **22**). In all other instances, the formation of cyclic disulfides predominates, with the formation of 1,2-dithiins (e.g. **38c**) or their dimers as 12-membered cyclic bis(disulfides) (**31**, **39**), depending on structural factors. For this reason, thioxo indigoid compounds (e.g. **29**, **37**) are also disadvantaged in favor of the cyclic disulfides.

Even if intermolecular disulfide formation is a common initial step, product control is nevertheless determined by different subsequent paths dependent upon the structure (Scheme 10). According to **J** (cf. **E** in Scheme 4), electronic transfer (a) along the buta-1,3-diene chain, originating from the sulfur anion and completed by disulfide fission, leads to the (*E*)-butene-1,4-dithione **K** (model for **12** and **15**). According to **L**, intramolecular ''thiol−disulfide interchange''[28] would enable ring formation combined with S−S bond fission. Thus, arrow sequence (b) leads to the 1,2-dithiin **M** (model for **38c**), and (c) directly to its dimer (model for **31**, **39**).



Scheme 10

Experimental Section

Solvents and reagents were purified and dried according to standard procedures. − For TLC, Merck silica gel plates were used; detection was carried out with iodine vapor. − CC was performed with silica gel 60 A, 32−63 μm (ICN Biomedicals). − Melting points were taken with a Boetius M hot-stage microscope and are uncorrected. − Elemental analyses (C, H, N, S) were obtained with an automatic microanalyzer (Carlo Erba). − NMR: Varian Unity 500 and Varian Gemini 200 and 2000 spectrometers, using TMS as internal standard and broad-band decoupling of ^{13}C NMR. − EI-MS: Varian MAT CH6 and AMD Intectra 402 (70 eV, in special cases 20 eV). − IR: Perkin−Elmer FT-IR spectrometer 100. − UV/Vis: Perkin−Elmer Lambda 14 spectrophotometer.

1,1′-(Dithiofumaroyl)dipiperidine (12): A solution of *n*BuLi in hexanes (2.25 mL/1.6 M; 3.6 mmol) was added dropwise with stirring under argon to a suspension of freshly pulverized 1,4-dipiperidylbutane-1,4-dithione (**10**)[8] (430 mg, 1.5 mmol) in abs. THF (40 mL) at −70 °C. The mixture was stirred at this temperature for 4 h until a clear solution of **7** resulted. Subsequently, a solution of anhydrous $FeCl_3$ (580 mg, 3.6 mmol) in abs. THF (10 mL) was added under the same conditions and with exclusion of daylight, and the deep red solution was stirred for 90 min. After the addition of water (20 mL) and benzene (30 mL) at about 0 °C, the aqueous phase was extracted with benzene (2 × 10 mL). The combined organic layers were dried (Na_2SO_4) and concentrated, and the residue was purified by CC with benzene/acetone (20:1; R_f = 0.41). Recrystallization from MeOH gave 250 mg (59%) of orange-red prisms, m.p. 180−181 °C (decomp.); identical with the compound obtained from **6** and piperidine according to ref.[10] (m.p. 180 °C). − A similar result was obtained with a solution of I_2 (400 mg, 1.58 mmol) in THF (20 mL) and an analogous isolation procedure. − UV/Vis (CH_2Cl_2): λ_{max} (lg ε) = 247 nm (4.27), 267 (4.19, sh), 315 (3.81), 329 (3.81). − ^{13}C NMR ($CDCl_3$): δ = 24.1/26.8 (N−CH_2−CH_2−), 25.4 (N−CH_2−CH_2−CH_2−), 51.4/52.1 (N−CH_2−), 137.8 (−CH=), 192.5 (C=S). − MS (70 eV); *m/z* (%): 282 (32) [M^+], 249 (18) [M^+ − SH], 199 (100) [M^+ − C_5H_9N], 166 (60) [M^+ − C_5H_9N − SH], 84 (50) [$C_5H_{10}N^+$].

(*E*)-1,1′-Dimethyl-3,3′-bipyrrolidinylidene-2,2′-dithione (15): A solution of *s*BuLi in cyclohexane (2 mL/1.6 M, 3.2 mmol) was added dropwise under argon with stirring to a solution of **13**[9] (300 mg, 1.32 mmol) in abs. THF (30 mL) at −70 °C. The resulting yellow solution of **8** was stirred at −70 °C for a further 3 h. A solution of anhydrous $FeCl_3$ (584 mg, 3.6 mmol) in abs. THF (6 mL) under the above conditions in diffuse light was then added, and the mixture was stirred for 90 min. The mixture was treated with water (20 mL), and the aqueous layer extracted with benzene (2 × 10 mL). The combined organic phases were dried (Na_2SO_4) and concentrated. Recrystallization of the brown residue from ethyl acetate afforded 250 mg (84%) of orange-red rods, m.p. 256−257 °C (decomp. with color change to brown). Oxidation with I_2 (400 mg, 1.6 mmol) in THF (20 mL) and isolation by CC (benzene/*n*-hexane, 5:1) yielded **15** in 54% yield. − IR ($CHCl_3$): ν = 1299 cm^{-1} [w, C=S (symm. stretch. vibr.)], 1311 [s, C=S (antisymm. stretch. vibr.)] (Raman spectrum: reversed relation), no band at 1625 [C=C (stretch. vibr.)] but in Raman spectrum (rule of mutual exclusion): indication of (*E*) configuration. − UV/Vis (CH_2Cl_2): λ_{max} (lg ε) = 232 nm (4.28), 296 (4.27, sh), 308 (4.32), 320 (4.21, sh), 341 (3.99, sh), 4.30 (2.57, sh). − ^1H NMR ($CDCl_3$): δ = 3.34 (s, 6 H, NCH_3), 3.72 (m_c, 4 H, N−CH_2−), 3.89 (m_c, 4 H, =C−CH_2). − ^{13}C NMR ($CDCl_3$): δ = 28.1 (=C−CH_2−), 36.1 (N−CH_3), 54.1 (N−CH_2−), 141.7 (=C−), 193.8 (C=S). − MS (70 eV); *m/z* (%): 226 (100) [M^+], 193 (38) [M^+ − SH], 160 (34) [M^+ − 2 SH], 150 (10) [M^+ − SH − CH_3NCH_2], 112 (7) [$M^+/2$ − H]. − $C_{10}H_{14}N_2S_2$ (226.4): calcd. C 53.06, H 6.23, N 12.38, S 28.33; found C 53.28, H 6.29, N 12.36, S 28.36.

Dimethyl (*E*)-2,3-Bis[piperidyl(thiocarbonyl)]but-2-ene-1,4-dioate (22c): Prepared according to ref.[13a] for ''**20c**'' from **19c**. − Yellow compact prisms (ethyl acetate), m.p. 223−224 °C [decomp., above 180 °C sublimation and new growth of crystals; 198 °C[13a] (decomposition temp.)]; homogenous by TLC [benzene/acetone (20:1), R_f = 0.42]; stable to daylight. − IR (KBr): ν = 1723 cm^{-1} (s, C=O). − UV/Vis (CH_2Cl_2): λ_{max} (lg ε) = 282 nm (4.51), 332 (3.59), 389 (3.47). − ^1H NMR ($CDCl_3$): δ = 1.75 [m_c (broad), 12 H, piperid. (β-, γ-H)], 3.74 (s, 6 H, OCH_3), 3.61−3.94 [m (broad), 6 H, piperid. (α-H)], 4.45 [m_c, 2 H, piperid. (α-H)]. − ^{13}C NMR ($CDCl_3$): δ = 23.9, 24.8, 25.3 [CH_2, piperid. (hindrance of rotation)], 48.8, 52.92, 52.99 (N−CH_2, OCH_3), 133.4 (C^q, olefin. C), 162.9 (C=O), 188.9 (C=S). − MS (70 eV); *m/z* (%): 398 (14) [M^+], 365 (16) [M^+ − SH], 333 (20) [M^+ − SH − S] or [M^+ − SH − CH_3OH], 315 (53) [M^+ − NC_5H_9], 301 (24) [M^+ − NC_5H_9 − CH_2] or [M^+ − SH − S − CH_3OH], 283 (100) [M^+ − NC_5H_9 − S] or [M^+ − NC_5H_9 − CH_3OH], 251 (26) [M^+ − NC_5H_9 − 2 S], 84 (60) [$NC_5H_{10}^+$].

(3*R,3′*R**)-1,1′-Dimethyl-3,3′-biindoline-2,2′-dithione (24). – a) From 23 by Reaction with I_2 in MeOH (71% Yield) According to Ref.**[16] **– b) From 25b (via 9) by Reaction with $NaBH_4$:** A solution of **25b** (see below; 500 mg, 1.3 mmol) in THF (20 mL) was treated with $NaBH_4$ (150 mg, 4 mmol) with stirring and exclusion of air at ambient temperature to produce **9**. After stirring for 12 h, water (25 mL) and AcOH (5 mL) were added to the reaction mixture. After extraction with diethyl ether and concentration of the organic extracts, the residue was purified by CC. Elution with benzene/*n*-hexane (2:1) gave unchanged **25b** (R_f = 0.64; 150 mg, 30%), followed by a product (R_f = 0.15) which was recrystallized from benzene to yield 200 mg of colorless prisms, 68% with respect to the reacted portion of **25b**; m.p. 182 °C, 182–184 °C;[16] identical with the compound obtained under (a) by NMR and mixed m.p. – ^{1}H NMR ($CDCl_3$): δ = 3.67 (s, 6 H, N–CH_3), 4.99 (s, 2 H, CH–C=S), 6.78–7.32 (m, 8 H, aromat. H). – ^{13}C NMR ($CDCl_3$): δ = 31.5 (N–CH_3), 61.2 (CH–C=S), 109.3, 123.4, 124.2, 128.5 (aromat. C), 129.5 (=*C*–C), 145.7 (=C–N), 203.0 (C=S). – $C_{18}H_{16}N_2S_2$ (324.5): calcd. C 66.63, H 4.97, N 8.63, S 19.77; found C 66.38, H 4.98, N 8.58, S 19.87. – **Regeneration from 9:** A suspension of NaH (50 mg, 2 mmol) and **24** (160 mg, 0.5 mmol) in abs. DMF (10 mL) was stirred under argon for 1 h. Degassed water (20 mL) was then added to the solution (of **9**), followed by acidification with 2 N H_2SO_4. The solid, which precipitated immediately, was filtered by suction, washed until neutral and dried (140 mg). ^{1}H NMR showed no signal in the range of δ = 4–6 other than that of H_{tert} (at δ = 4.99) of the compound **24**.

5,10-Dimethyl-5,10-dihydro[1,2,3,4]tetrathiocino[5,6-*b*:8,7-*b*′]-diindole (25b). – a) From 25a by Methylation: A suspension of **25a** [18] (7.2 g, 20 mmol), benzene (200 mL), 50% aqueous NaOH (100 mL), [N(*n*Bu)$_4$]HSO_4 (340 mg, 1 mmol) and Me_2SO_4 (7.57 g, 60 mmol) was vigorously stirred for 3 h at 33 °C. A solid separated from the yellowish-brown solution after some time. Water (40 mL) was added and the solid was filtered off by suction. The organic layer was concentrated and the residue, together with the above solid, was recrystallized from DMF/EtOH (10:1) to yield 4.5 g (58%) of yellow leaflets, m.p. 259–260 °C (decomp.), 252–254 °C[18] (from **25a** by successive treatment with sodium and MeI, yield 19%). – ^{1}H NMR ($CDCl_3$): δ = 3.96 (s, 6 H, N–CH_3), 7.01–7.43 (m, 8 H, aromat. H). – ^{13}C NMR ($CDCl_3$): δ = 30.8 (CH_3), 110.3 (N–C=*C*–*C*=C–N), 120.5, 121.1, 121.4, 124.9 ($CH_{aromat.}$), 126.8 (N–C–S), 128.2 (N–C=$C^q_{aromat.}$), 137.6 (N–$C_{aromat.}$). – MS (70 eV); *m/z* (%): 386 (23) [M^+], 322 (100) [M^+ – 2 S], 290 (36) [M^+ – 3 S], 275 (18) [M^+ – 3 S – CH_3]. – **b) From 24 via 9 by Thiation:** A solution of **24** (200 mg, 0.62 mmol) in abs. DMF (6 mL) was added dropwise to NaH (50 mg, 2.1 mmol) and stirred for 60 min at 0 °C and then 30 min at room temperature. Finely ground sulfur (256 mg, 1 mmol) was added and the dark mixture stirred for 30 min. After the addition of water (10 mL), the separated solid was isolated and recrystallized from DMF/EtOH to afford **25b** (130 mg, 54%).

1,1′-Dimethyl-3,3′-biindole (26): A mixture of **25b** (4.1 g, 10.6 mmol), Raney nickel (130 g) and EtOH (200 mL) was refluxed for 6 h, filtered hot, and the sludge cake washed several times with hot DMF. Concentration of the filtrate and washings gave a solid, which was recrystallized from benzene/EtOH (5:1) to give 1.68 g (61%) of fine colorless needles; m.p. 180 °C; 181–183 °C[16] (see also ref.[19]). – ^{1}H NMR ($CDCl_3$): δ = 3.95 (s, 6 H, CH_3), 7.0–7.5 (m, 8 H, aromat. H), 7.8–8.0 (m, 2 H, N–CH=). – ^{13}C NMR ($CDCl_3$): δ = 32.8 (CH_3), 109.4 (N–C=*C*–*C*=C–N), 109.7, 119.3, 120.4, 121.9 ($CH_{aromat.}$), 126.2 (N–CH=), 127.4 (N–C=$C^q_{aromat.}$), 137.3 (N–$C_{aromat.}$).

2,2′-Bis(ethoxycarbonylthio)-1,1′-dimethyl-3,3′-biindole (27): A mixture of ethoxycarbonylsulfenyl chloride (430 mg, 3.1 mmol) and abs. dichloromethane (5 mL) was slowly added, with stirring under argon, at 0 °C to a solution of **26** (400 mg, 1.54 mmol) in abs. dichloromethane (20 mL) and 98% formic acid (10 mL). The mixture was then stirred at 0 °C for 2 h. After concentration, the residue was dissolved in a little water and filtered by suction. Recrystallization from EtOH furnished 560 mg (78%) of colorless needles, m.p. 155–156 °C. – IR (nujol): ν = 1715 cm^{-1} (s), 1690 (s, C=O). – ^{1}H NMR ($CDCl_3$): δ = 1.22 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 3.88 (s, 6 H, NCH_3), 4.20 (q, *J* = 7.1 Hz, OCH_2CH_3), 7.01–7.44 (m, 8 H, aromat. H). – ^{13}C NMR ($CDCl_3$): δ = 14.3 (OCH_2CH_3), 30.6 (NCH_3), 64.3 (OCH_2CH_3), 109.9, 117.2, 119.9, 121.2, 122.3, 123.6, 127.7, 138.6 (C_{indole}), 168.2 (C=O). – MS (70 eV); *m/z* (%): 468 (22) [M^+], 322 (4) [M^+ – 2 COOEt], 290 (100) [M^+ – 2 COOEt – S], 275 (23) [M^+ – 2 COOEt – S – CH_3], 260 (4) [M^+ – 2 COOEt – S – 2 CH_3]. – $C_{24}H_{24}N_2O_4S_2$ (468.6): calcd. C 61.52, H 5.16, N 5.98, S 13.69; found C 61.83, H 5.18, N 5.35, S 13.89.

1,1′-Dimethyl-2,2′-bis(methylthio)-3,3′-biindole (28): A mixture of **25b** (800 mg, 2.1 mmol), $NaBH_4$ (230 mg, 6 mmol) and EtOH (30 mL) was stirred at ambient temperature for 1 h and then heated under reflux for a further 1 h to generate **9** [according to the preparation of **24**, part (b)]. After the addition of methyl iodide (1.49 g, 10.5 mmol), the mixture was stirred for a further 3 h, treated with water (5 mL) and filtered. The isolated solid was recrystallized from *n*-hexane/benzene (3:1) to give 400 mg (55%) of short white needles; m.p. 182–183 °C; 183–184 °C[16] (by treatment of **24** with K_2CO_3 and MeI). – ^{1}H NMR ($CDCl_3$): δ = 2.15 (s, 6 H, SCH_3), 3.97 (s, 6 H, NCH_3), 6.99–7.07 (m, 6 H, CH_{indole}), 7.22–7.40 (m, 2 H, CH_{indole}). – ^{13}C NMR ($CDCl_3$): δ = 20.0 (SCH_3), 30.4 (NCH_3), 109.5 (S–C=*C*–), 114.8, 119.6, 120.6, 122.7 (CH_{indole}), 128.3 (S–*C*=C–), 131.6 (N–C^q=*C*^{q}–), 138.0 ((N–*C*^{q}=C^q–). – MS (70 eV); *m/z* (%): 352 (76) [M^+], 290 (100) [M^+ – SCH_3 – CH_3], 275 (31) [M^+ – SCH_3 – 2 CH_3], 260 (5) [M^+ – SCH_3 – 3 CH_3], 145 (14) [M^+ – SCH_3 – CH_3 (*z* = 2)]. – $C_{20}H_{20}N_2S_2$ (352.5): calcd. C 68.14, H 5.72, N 7.95, S 18.19; found C 67.85, H 5.78, N 7.63, S 18.54.

9,12,21,24-Tetramethyl-9,12,21,24-tetrahydro[1,2,7,8]tetrathiacyclododecino[3,4-*b*:6,5-*b*′:9,10-*b*′′:12,11-*b*′′′]tetraindole (31). – a) From 23 and *s*BuLi/I_2: A solution of *s*BuLi in cyclohexane (2.9 mL/1.6 M; 3.7 mmol) was added dropwise at –70 °C with stirring to a solution of **23** (300 mg, 1.84 mmol) in THF (30 mL). The solution was stirred for a further 2 h, warmed to room temperature for a short time and again cooled to –45 °C. At this temperature, a solution of I_2 (470 mg, 1.85 mmol) in THF (25 mL) was added dropwise over 2 h with stirring and admittance of air (color change to red). The mixture was treated at 0 °C with water (40 mL), the organic layer was concentrated and the residue was recrystallized from DMF to afford 207 mg (70%) of orange-red prisms of **31**, m.p. 231–232 °C (decomp.); R_f [benzene/*n*-hexane (1:1)] = 0.34. – UV/Vis (CH_2Cl_2): λ_{max} (lg ε) = 251 nm (5.24), 307 (4.81), 333 (4.61, sh), 441 (3.21, sh). – ^{1}H NMR ($CDCl_3$): δ = 3.50 (s, 12 H, NCH_3), 7.04–7.27 (m, 16 H, CH_{indole}). – ^{13}C NMR ([D_6]DMSO): δ = 31.0, 30.0 (N–CH_3), 124.3, 130.0 (C^2), 115.5, 114.5 (C^3), 123.8, 125.7 (C^{3a}), 118.9, 119.6 (C^4), 120.28, 120.30 (C^5), 122.40, 123.29 (C^6), 110.31, 110.34 (C^7), 137.64, 137.71 (C^{7a}) [two sets of signals (relative intensities A > B); assignments based on attached proton test (APT); H/C correlations: δ = 7.78 (H^4)/118.85 (C^4), 7.19 (H^5)/120.30 (C^5), 7.26 (H^6)/122.39 (C^6), 7.54 (H^7)/110.31 (C^7)]. – ^{13}C NMR (C_6D_5Br): δ = 29.8, 30.6 (N–CH_3); 109.51, 109.97, 119.64; 119.92, 120.42, 121.13; 122.27, 123.36, 124.09; 124.96, 126.22, 126.50; 127.45, 128.17, 129.41; 129.71, 130.62, 130.98; 131.29,

131.84, 132.25; 132.82, 138.11, 138.29 [three (temperature-depending) sets of signals; at 139 °C for CH_3 only one signal δ = 30.5]. − MS (70 eV); *m/z* (%): 644 (0.07) [M^+], 612 (0.06) [M^+ − S], 550 (1) [M^+ − 2 S − 2 CH_3], 386 (2) [$M^+/2$ + 2 S], 322 (100) [$M^+/2$], 290 (44) [$M^+/2$ − S], 275 (34) [$M^+/2$ − S − CH_3]; (20 eV); *m/z* (%): 644 (3) [M^+], 322 (100) [$M^+/2$], 290 (36) [$M^+/2$ − S]. − $C_{36}H_{28}N_4S_4$ (644.9): calcd. C 67.05, H 4.38, N 8.69, S 19.89; found C 66.88, H 4.42, N 8.99, S 19.58. − **b) From 23 and *p*-Nitroso-*N*,*N*-dimethylaniline According to Ref.[21]:** Carried out with **23** (250 mg, 1.53 mmol) and *p*-nitroso-*N*,*N*-dimethylaniline (125 mg, 0.83 mmol) in AcOH (25 mL) to yield orange-red prisms, 77%, m.p. 228 °C with decomposition (in ref.[21] described as red-brown amorphous solid or dark red solid, 79%, m.p. 210−213 °C and 213−215 °C, respectively); identical with a sample of **31** obtained above (UV/Vis, NMR, and MS). − **c) From 24. − c_1):** A solution of LDA in hexane (4.1 mL/1.1 M; 8.2 mmol) was added with stirring to a solution of **24** (1.2 g, 3.7 mmol) in THF (25 mL) under argon at −78 °C. The mixture was stirred for a further 3 h at the above temperature. A solution of I_2 (1 g, 3.9 mmol) in THF (15 mL) was then added with stirring over 4 h at −70 °C. After concentration, the residue was washed with water and recrystallized from DMF to give 650 mg (54%) of **31**. − **c_2):** A solution of **24** (200 mg, 0.62 mmol) in DMF (5 mL) was added dropwise with stirring at 0 °C to a suspension of NaH (50 mg, 2.1 mmol; from an 80% suspension in paraffin oil after washing with *n*-hexane) in DMF (15 mL). Stirring was continued at room temperature for 1 h and then for a further 5 h in air. After dilution with water (30 mL), the resulting precipitate was treated as before to give 116 mg (58%) of **31**. − **d) From 25b:** Sodium tetrahydroborate (250 mg, 6.6 mmol) was added in portions under argon to a solution of **25b** (500 mg, 1.3 mmol) in EtOH (50 mL). Stirring was continued for 3 h at ambient temperature, heated under reflux for 2 h and then for a further 3 h with the admittance of air. The precipitate was treated as described above to give 250 mg (60%) of **31**. − **e) From 27:** A solution of **27** (300 mg, 0.64 mmol) and KOH (100 mg, 1.8 mmol) in EtOH (30 mL) was heated under argon at reflux for 1 h. Stirring was continued with admittance of air for a further 2 h. The precipitated solid was purified by recrystallization from DMF/EtOH (9:1) to afford 156 mg (75%) of **31**.

3,3′-Bis(ethoxycarbonylthio)-1,1′-dimethyl-2,2′-biindole (33a): A solution of ethoxycarbonylsulfenyl chloride (550 mg, 3.91 mmol) in dichloromethane (25 mL) was added dropwise over 30 min at 0 °C with stirring to a solution of **32a**[24a] (500 mg, 1.92 mmol) in dichloromethane (25 mL) and 98% formic acid (12.5 mL). After stirring for a further 30 min at the above temp., the mixture was concentrated, the residual solid washed with water and then recrystallized from ethanol/water (4:1) to yield 750 mg (83%) of colorless needles, m.p. 139−140 °C; R_f (benzene/AcOEt, 2:1) = 0.14. − IR (nujol): ν = 1720 cm^{-1} (s, C=O). − ^{1}H NMR ($CDCl_3$): δ = 1.20 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 3.80 (s, 6 H, NCH_3), 4.16 (q, *J* = 7.1 Hz, 4 H, OCH_2CH_3), 7.24−7.42 (m, 6 H, CH_{indole}), 7.70−7.74 (m, 2 H, CH_{indole}). − ^{13}C NMR ($CDCl_3$): δ = 14.3 (OCH_2CH_3), 31.3 (NCH_3), 63.6 (OCH_2CH_3), 101.9, 110.3, 119.9, 121.4, 123.7, 129.5, 134.6, 138.0 (C_{indole}), 169.4 (C=O). − MS (70 eV); *m/z* (%): 468 (50) [M^+], 322 (21) [M^+ − 2 COOEt], 290 (100) [M^+ − 2 COOEt − S], 258 (6) [M^+ − 2 COOEt − 2 S]. − $C_{24}H_{24}N_2O_4S_2$ (468.6): calcd. C 61.52, H 5.16, N 5.98, S 13.68; found C 61.06, H 5.21, N 5.86, S 13.94.

3,3′-Bis(ethoxycarbonylthio)-2,2′-bibenzo[*b*]furan (33b): A solution of ethoxycarbonylsulfenyl chloride (480 mg, 3.4 mmol) in chloroform (10 mL) was added dropwise with stirring under argon at ambient temp. to a solution of **32b**[24c] (400 mg, 1.7 mmol) and $BF_3{\cdot}Et_2O$ (0.5 mL) in abs. chloroform (25 mL). The mixture was stirred for 1 h and then heated for 6 h under reflux. After concentration, the residue (700 mg) was recrystallized several times from 2-propanol to give 440 mg (58%) of small crystals, m.p. 139−140 °C; R_f (benzene/*n*-hexane, 2:1) = 0.38. By CC [benzene/*n*-hexane (2:1)] of the mother liquors 60 mg (15%) of unchanged **32b** was obtained, followed by 50 mg (9%) of the monosubstitution product [colorless needles (EtOH), m.p. 150−151 °C] as second fraction. − IR (nujol): ν = 1714 cm^{-1} (s, C=O). − ^{1}H NMR ($CDCl_3$): δ = 1.28 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 4.28 (q, *J* = 7.1 Hz, 4 H, OCH_2CH_3), 7.24−7.66 (m, 6 H, $CH_{benzo[b]furan}$), 7.93−7.95 (m, 2 H, $CH_{benzo[b]furan}$). − ^{13}C NMR ($CDCl_3$): δ = 14.3 (OCH_2CH_3), 64.6 (OCH_2CH_3), 107.6, 111.9, 120.8, 121.6, 124.1, 126.6, 129.3, 155.0 ($C_{benzo[b]furan}$), 167.3 (C=O). − MS (70 eV); *m/z* (%): 442 (8) [M^+], 296 (100) [M^+ − 2 COOEt], 264 (44) [M^+ − 2 COOEt − S]. − $C_{22}H_{18}O_6S_2$ (442.5): calcd. C 59.71, H 4.10, S 14.49; found C 59.53, H 4.22, S 14.65.

3,3′-Bis(ethoxycarbonylthio)-2,2′-biindole (33d): According to the procedure for **33a** from ClSCOOEt (1.42 g, 10 mmol)/CH_2Cl_2 (25 mL), **32d**[24b] (1.16 g, 5 mmol)/CH_2Cl_2 (50 mL)/98% HCOOH (25 mL) at −10 °C. Yellow needles (2.16 g, 98%) were obtained (MeCN/DMF, 4:1), m.p. (decomp.) > 215 °C (change of color to yellowish-brown). − IR (nujol): ν = 1693 cm^{-1}, 1703 (s, C=O), 3350 (s, N−H). − ^{1}H NMR ([D_6]DMSO): δ = 1.15 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 4.13 (q, *J* = 7.1 Hz, 4 H, OCH_2CH_3), 7.25 (m_c, 4 H, CH_{indole}), 7.52 (m_c, 4 H, CH_{indole}), 12.21 (s, 2 H, NH). − MS (70 eV); *m/z* (%): 440 (68) [M^+], 367 (27) [M^+ − COOEt], 294 (100) [M^+ − 2 COOEt], 262 (56) [M^+ − 2 COOEt − S]. − $C_{22}H_{20}N_2O_4S_2$ (440.5): calcd. C 59.98, H 4.58, N 6.36, S 14.56; found C 60.15, H 4.59, N 6.20, S 14.72.

1,1′-Dimethyl-2,2′-biindole-3,3′-dithiol (35a): A solution of **33a** (100 mg, 0.21 mmol) and KOH (100 mg, 1.8 mmol) in ethanol (30 mL) was heated at reflux under argon for 1 h. The solution was then slightly acidified with 2 N hydrochloric acid, filtered to remove the precipitated NaCl, concentrated, and the resulting (unstable) solid isolated under oxygen-free conditions to afford 60 mg (88%) of small colorless crystals, m.p. 185−187 °C (above 240 °C resolidification, above 290 °C decomp.). − ^{1}H NMR ($CDCl_3$): δ = 2.89 (s, 2 H, SH), 3.59 (s, 6 H, NCH_3), 7.19−7.43 (m, 6 H, CH_{indole}), 7.76−7.81 (m, 2 H, CH_{indole}); ca. 5% impurities. − MS (70 eV); *m/z* (%): 324 (86) [M^+], 322 (82) [M^+ − 2 H], 307 (15) [M^+ − 2 H − CH_3], 290 (79) [M^+ − H_2S], 258 (100) [M^+ − 2 SH], 161 (12) [$M^+/2-1$]. − $C_{18}H_{16}N_2S_2$ (324.5): calcd. C 66.63, H 4.97, N 8.63, S 19.77; found C 67.03, H 4.68, N 8.52, S 19.43.

3,3′-Bis(benzylthio)-1,1′-dimethyl-2,2′-biindole (36a). − a) From 33a by Saponification and Benzylation: A solution of **33a** (300 mg, 0.64 mmol) and KOH (100 mg, 1.8 mmol) in ethanol (25 mL) was heated under argon at reflux for 1 h. Benzyl chloride (165 mg, 1.3 mmol) was added at room temperature and the mixture was stirred for a further hour. The separated solid was recrystallized from EtOH to give 240 mg (74%) of white short needles, m.p. 138−139 °C. − ^{1}H NMR ($CDCl_3$): δ = 3.24 (s, 6 H, NCH_3), 3.76 (d, *J* = 12.7 Hz, 2 H, CH_2), 3.97 (d, *J* = 12.7 Hz, 2 H, CH_2), 7.06 (m_c, 10 H, C_6H_5), 7.18 (m_c, 6 H, CH_{indole}), 7.73 (m_c, 2 H, CH_{indole}). − ^{13}C NMR ($CDCl_3$): δ = 30.8 (NCH_3), 40.8 (CH_2), 108.2 (C^3_{indole}), 109.9 (C^7_{indole}), 120.0 (C^6_{indole}), 120.5 (C^4_{indole}), 123.0 (C^5_{indole}), 126.7 (C^p_{phenyl}), 128.2 (C^m_{phenyl}), 128.9 (C^o_{phenyl}), 129.7 (C^2_{indole}), 133.9 (C^{3a}_{indole}), 137.7 (C^q_{phenyl}), 138.6 (C^{7a}_{indole}). − MS (70 eV); *m/z* (%): 504 (100) [M^+], 413 (8) [M^+ − $CH_2C_6H_5$], 322 (52) [M^+ − 2 $CH_2C_6H_5$], 290 (33) [M^+ − 2 $CH_2C_6H_5$ − S], 289 (13) [M^+ − 2 $CH_2C_6H_5$ − SH], 275 (11) [M^+ − 2 $CH_2C_6H_5$ − S − CH_3], 274 (16) [M^+ − 2 $CH_2C_6H_5$ − SH − CH_3]. − $C_{32}H_{28}N_2S_2$

(504.7): calcd. C 76.15, H 5.59, N 5.55, S 12.71; found C 75.94, H 5.71, N 5.38, S 12.81. – **b) From 39a by Reductive Fission and Benzylation:** A mixture of **39a** (500 mg, 0.78 mmol) and $NaBH_4$ (120 mg, 3.2 mmol) in ethanol (30 mL) was heated under reflux for 2 h. After the addition of benzyl chloride (444 mg, 3.5 mmol), the mixture was stirred for 40 min and treated with water (5 mL). The precipitated solid was treated as described above to yield 669 mg (85%) of the product.

3,3′-Bis(benzylthio)-2,2′-biindole (36d). – a) From 33d by Saponification and Benzylation: A mixture of **33d** (440 mg, 1 mmol) and KOH (200 mg, 3.6 mmol) in EtOH (20 mL) was heated at reflux under argon for 1 h. After the addition of benzyl choride (278 mg, 2.2 mmol), the mixture was stirred for a further 3 h. The separated solid was recrystallized from MeCN/DMF (3:1) to afford 420 mg (88%) of yellow cubic crystals, m.p. 188–189 °C. – ^{1}H NMR ($CDCl_3$): δ = 3.89 (s, 4 H, CH_2), 7.03 (m_c, 10 H, C_6H_5), 7.23 (m_c, 6 H, CH_{indole}), 7.63 (d, 2 H, C^7H_{indole}), 10.39 (s, 2 H, NH). – ^{13}C NMR ($CDCl_3$): δ = 41.6 (S–CH_2), 101.5 (C^3_{indole}), 111.5, 118.9, 120.8, 123.7 (CH_{indole}), 127.4 (C^p_{phenyl}), 128.5, 128.6 ($C^{o,m}_{phenyl}$), 130.1 (C^2_{indole}), 132.9, 135.6, 138.3 [C^q (C^{3a}_{indole}, C^q_{phenyl}, C^{7a}_{indole})]. – MS (70 eV); *m/z* (%): 476 (32) [M^+], 385 (15) [$M^+ - C_6H_5CH_2$], 352 (27) [$M^+ - C_6H_5CH_2 - SH$], 320 (43) [$M^+ - C_6H_5CH_2 - SH - S$], 294 (100) [$M^+ - 2\ C_6H_5CH_2$], 261 (32) [$M^+ - 2\ C_6H_5CH_2 - SH$]. – $C_{30}H_{24}N_2S_2$ (476.7): calcd. C 75.59, H 5.08, N 5.88, S 13.45; found C 75.37, H 5.06, N 5.91, S 13.87.

b) From 39d/40 ($n \geq 2$) by Reductive Fission and Benzylation: A suspension of the oligo(disulfide) **39d**/**40** (150 mg, 0.5 mmol relative to the 3,3′-dithio-2,2′-biindole unit) and $NaBH_4$ (100 mg, 2.6 mmol) in ethanol (10 mL) was heated for 30 min under reflux. Benzyl chloride (316 mg, 2.5 mmol) was added at room temperature to the orange-red solution, and the mixture was stirred for a further 30 min. The precipitated solid was isolated and recrystallized (see above) to give 160 mg (67%) of the product.

5,6,17,18-Tetramethyl-5,6,17,18-tetrahydro[1,2,7,8]tetrathiacyclododecino[4,3-*b*:5,6-*b*′:10,9-*b*′′:11,12-*b*′′′]tetraindole (39a), cf. also Information in Ref.[12d] – a) From 33a by Saponification and Oxidation: A suspension of **33a** (230 mg, 0.5 mmol) in ethanolic KOH (100 mg, 1.8 mmol/10 mL EtOH) was heated at reflux under argon for 1 h. The mixture was then concentrated under reduced pressure, diluted with water, neutralized with 2 N hydrochloric acid and a current of air passed through the solution. The precipitated yellow solid was filtered by suction and recrystallized from DMF to produce 140 mg (87%) of yellow plates, difficult to dissolve, m.p. 319–320 °C (decomp.). – UV ($CHCl_3$): λ_{max} (lg ε) = 235 nm (4.54), 300 (4.27). – ^{1}H NMR (D_{18}HMPT): δ = 3.45 (s, 12 H, CH_3), 7.09–7.30 (m, 12 H, CH_{indole}), 7.74–7.81 (m, 4 H, CH_{indole}). – ^{13}C NMR (D_{18}HMPT): δ = 31.8, 31.5, 31.2 (CH_3), 133.9, 132.0, 132.1 (C^2), 112.0, 106.9, 110.4 (C^3), 128.5, 126.5, 127.9 (C^{3a}), 123.6, 123.4, 123.2/121.5, 120.6, 120.5/118.9, 119.4, 118.4 (C^4, C^5, C^6), 111.4, 111.2, 109.5 (C^7), 139.3, 137.9, 138.5 (C^{7a}) [three sets of signals (relative intensities A ≈ B > C), reversible increase of C at increased temperature (e.g. 80 °C); assignments based on attached proton test (APT); H/C correlations: δ = 7.74 (H^4)/118.9 (C^4), 7.20 (H^5)/120.4 (C^5), 7.10 (H^6)/123.6 (C^6), 7.24 (H^7)/111.4 (C^7)]. – MS (70 eV); *m/z* (%): 644 (8) [M^+], 322 (100) [$M^+/2$ or M^{2+}], 289 (14) [$M^+/2 - SH$], 274 (11) [$M^+/2 - SH - CH_3$]; (20 eV); *m/z* (%): 644 (32) [M^+], 322 (46) [$M^+/2$], 289 (100) [$M^+/2 - SH$]. MIKE spectrum; *m/z* (%): 644 (100) [M^+], 580 (28) [$M^+ - 2$ S], 322 (37) [$M^+/2$]. – $C_{36}H_{28}N_4S_4$ (644.9): calcd. C 67.05, H 4.38, N 8.69, S 19.89; found C 67.53, H 4.50, N 8.65, S 19.77. – **b) From 39d/40 by Methylation:** A mixture of **39d**/**40** (500 mg, 1.7 mmol relative to the 3,3′-dithio-2,2′-biindole unit), tetra(*n*-butyl)ammonium hydrogen sulfate (500 mg, 1.47 mmol), dimethyl sulfate (1.26 g, 10 mmol), 50% aqueous NaOH (20 mL) and benzene (20 mL) was stirred for 48 h at 33 °C. The organic layer was dried (Na_2SO_4) and concentrated. The residue was recrystallized from DMF to give 150 mg (27%) of **39a**.

1,2,7,8-Tetrathiacyclododecino[4,3-*b*:5,6-*b*′:10,9-*b*′′:11,12-*b*′′′]-tetrakis(1-benzofuran) (39b): Cf. also the information in refs.[12d,25]. A suspension of **33b** (200 mg, 0.45 mmol) in KOH (100 mg, 1.8 mmol)/ethanol (25 mL) was stirred at reflux and under argon for 1 h. Air was bubbled into the mixture. The solid which rapidly separated was isolated and recrystallized from EtOH/DMF (1:1) to give 120 mg (90%) of brick-red needles, m.p. 244 °C (decomp.). – R_f (benzene/*n*-hexane, 1:1) = 0.61. – UV/Vis (CH_2Cl_2): λ_{max} (lg ε) = 243 nm (4.14), 334 (4.13), 473 (3.26). – ^{1}H NMR (D_{18}HMPT): δ = 6.73–6.74 (m, 4 H, C^4H), 7.29–7.30 (m, 4 H, C^6H), 7.57–7.60 (m, 4 H, C^5H), 7.88–7.90 (m, 4 H, C^7H). – ^{13}C NMR (D_{18}HMPT): δ = 148.8, 145.6 (C^2), 115.6, 109.7 (C^3), 128.6, 125.2 (C^{3a}), 120.2, 120.9 (C^4), 125.0, 125.3 (C^5), 128.3, 127.6 (C^6), 112.7, 111.2 (C^7), 154.1, 155.1 (C^{7a}) [two sets of signals (A > B); cf. also detailed spectral analysis, especially regarding the equilibrium with **38b**, in ref.[25]]. – MS (70 eV); *m/z* (%): 592 (8) [M^+], 560 (0.3) [$M^+ - S$], 328 (3) [$M^+/2 + S$], 296 (100) [$M^+/2$], 264 (9) [$M^+/S - S$]; (20 eV): 592 (21) [M^+], 296 (100) [$M^+/2$], 264 (71) [$M^+/2 - S$]. – $C_{32}H_{16}O_4S_4$ (592.7): calcd. C 64.84, H 2.72, S 21.64; found C 64.51, H 2.68, S 21.75.

"Oligo(disulfide)" 39d/40; cf. also the Information in Ref.[12d] – a) From 33d by Saponification and Oxidation: The mixture of **33d** (1 g, 2.3 mmol), KOH (4 g, 71 mmol) and ethanol (40 mL) was stirred under argon at reflux for 90 min. The resulting solution was then treated as described above [**33a**, procedure (a)] to give 620 mg [92%, calculated as **39d** (dimer, $n = 2$)] of yellow microcrystalline material, difficult to dissolve, which did not melt below 360 °C (above 360 °C decomp., partial sublimation at ca. 340 °C with the formation of an orange solid). – IR (nujol): ν = 3340 cm^{-1}, 2700 ± 50 (s, NH). – UV (MeCN): λ_{max} (lg ε, calcd. for **39d**) = 285 nm (4.40), 310 (4.54), 359 (4.23). – ^{1}H NMR ([D_6]DMSO): δ = 6.80 (d, aromat. H), 6.94 (t, aromat. H′), 7.10–7.14 (m, aromat. H/H′), 7.17 (t, aromat. H′), 7.45 (d, aromat. H′), 7.49 (d, aromat. H′), 7.70 (d, aromat. H), 11.02 (s, NH), 11.67 (s, NH′). – ^{13}C NMR ([D_6]DMSO): δ = 133.3, 131.0 (C^2), 106.9, 101.5 (C^3), 129.7, 125.8 (C^{3a}), 118.6, 119.1, 120.5, 121.1, 123.5, 123.2 (C^4, C^5, C^6), 112.3, 112.7 (C^7), 136.2, 136.4 (C^{7a}) [two sets of signals (A > B, in ^{1}H NMR the B set signed by H′). – MS (70 eV); *m/z* (%): 588 (3) [M^+], 556 (0.3) [$M^+ - S$], 524 (0.4) [$M^+ - 2$ S], 492 (0.2) [$M^+ - 3$ S], 460 (0.2) [$M^+ - 4$ S], 294 (100) [$M^+/2$], 261 (29) [$M^+/2 - SH$]. – $C_{32}H_{20}N_4S_4$ (588.8): calcd. C 65.28, H 3.42, N 9.52, S 21.78; found C 64.80, H 3.40, N 9.62, S 21.80. – **b) From 32d by Reaction with Iodine and Thiourea:** According to ref.[27] I_2 (3 g, 11.8 mmol) was added with vigorous stirring to a mixture of **32d** (1.16 g, 5 mmol), thiourea (2.3 g, 30.2 mmol), ethanol (20 mL), and water (10 mL). The mixture was stirred for 15 min, and caustic potash (K_2CO_3) added to the almost clear solution until alkaline. A yellow solid separated and was purified by Soxhlet extraction using $CHCl_3$ (24 h), to afford a yellow powder, 1.1 g, 75%, relative to **40**, $n = 2$.

Crystal Data of 15: $C_{10}H_{14}N_2S_2$, M = 226.35 g·mol^{-1}, monoclinic, space group $P2_1/c$ (no. 14), $Z = 8$, a = 7.638(2), b = 13.701(3), c = 10.610(4) A, β = 101.66(4)°, V = 1087.5(6) A^3 (by least-square refinement of 2000 reflections), μ = 0.451 mm^{-1}, $\rho_{calcd.}$ = 1.383 g.cm^{-3}. Data collection: STOE IPDS diffractometer with area detector, graphite-monochromatized Mo-K_α radiation, λ = 0.71073 A, 5083 reflections measured (2.46° ≤ θ ≤ 22.50°) at 223(2) K, 1372 independent reflections (R_{int} = 0.1201). Structure analysis

and refinement: Direct methods with the program SHELXS, full-matrix, least-squares refinement with the program SHELXL-93, all nonhydrogen atoms refined with anisotropic displacement parameters, H atoms refined with free isotropic displacement ellipsoids; final R values [$I > 2\sigma(I)$]: $R1 = 0.0768$, $wR2 = 0.1473$. The asymmetric unit contains two identical molecules of **15**, both of which exhibit the same bond lengths and angles within the tolerances (2σ).[11]

Crystal Data of 22c: $C_{18}H_{26}N_2O_4S_2$, $M = 398.54$ g.m^{-1}, trigonal, space group $R\bar{3}$ (No. 148), $Z = 9$, $a = 23.505(5)$, $c = 9.4998(16)$ A, $V = 4545.3(14)$ A^3 (by least-squares refinement of 5000 reflections), $\mu = 0.288$ mm^{-1}, $\rho_{calcd.} = 1.31$ g.cm^{-3}. Data collection: STOE IPDS diffractometer with area detector, graphite-monochromatized Mo-K_α radiation, $\lambda = 0.71069$ A, 9997 reflections measured ($2.37° \leq \theta \leq 25.00°$) at 220 K, 1778 independent reflections ($R_{int} = 0.094$). Structure analysis and refinement: Direct methods with SHELXS, full-matrix, least-squares refinement with SHELXL-93, all nonhydrogen atoms anisotropic; [$I > 2\sigma(I)$]: $R1 = 0.0639$, $wR2 = 0.1610$.[11]

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[25] W. Schroth, D. Ströhl, I. Thondorf, W. Brandt, M. Felicetti, T. Gelbrich, *Tetrahedron* **1995**, *51*, 8853−8862.

[26] Cf.: J. Bergman, C. Stalhandske, *Tetrahedron Lett.* **1994**, *29*, 5279−5282. − Here, a so-called "red compound" was obtained from reaction of **32d** with sulfur and described as the bisindolo[3,2-*c*:2′,3′-*e*][1,2]dithiin **38d**. Its structure elucidation was based, however, only on IR and MS data. Moreover, the appearance of **38d** (as molecular peak) in the mass spectrum is not convincing, because of the easy fragmentation of the dimeric and oligomeric molecules **39d**/**40** to the monomeric 1,2-dithiin, and the extremely weak molecular peak of **39d**/**40**. A reexamination would appear to be recommended.

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