Científica y Técnica (DGICYT, PB88-0500). L.A.L. thanks the Ministerio de Educación y Ciencia for a predoctoral scholarship.

Registry No. **1a**, 28752-82-1; (*E*)-**1d**, 28809-05-4; (*Z*)-**1d**, 28809-09-8; **1e**, 38002-87-8; **1f**, 135192-15-3; **2a**, 126797-54-4; **2b**, 135192-03-9; **2c**, 135192-04-0; (*E*)-**2d**, 135192-05-1; (*Z*)-**2d**, 135192-14-2; **2e**, 135192-06-2; **2f**, 126797-60-2; **5a**, 126797-57-7; **5b**, 135192-07-3; **5c**, 135192-08-4; **5d**, 135192-09-5; **5e**, 135192-10-8; **5f**, 135192-11-9; **5g**, 126797-58-8; **5h**, 135192-12-0; **5i**, 135269-28-2; **6a**, 126797-59-9; **6b**, 135192-13-1; **7**, 126797-62-4; phenyl isothiocyanate, 103-72-0; 4-chlorophenyl isothiocyanate, 2131-55-7; ethyl isothiocyanate, 542-85-8; cyclohexyl isothiocyanate, 1122-82-3.

Mesoions as Versatile Intermediates in Tetrathiafulvalene Synthesis

M. Jørgensen,* K. A. Lerstrup, and K. Bechgaard

Centre for Interdisciplinary Studies of Molecular Interactions, Chemistry Department, University of Copenhagen, Blegdamsvej 21, DK-2100 Denmark

Received November 26, 1990 (Revised Manuscript Received June 11, 1991)

Fourteen new alkylthio-substituted tetrathiafulvalene (TTF) donors have been prepared via the mesoionic 2-(*N*,*N*-dialkylamino)-5-methyl-1,3-dithiolium-4-thiolates **4**. By S-alkylation with alkyl halogenides and alkyl dihalogenides, **4** was transformed into a variety of mono- and bis-1,3-dithiolium salts **5**. Coupling of **5** with the anion of 4,5-dimethyl-2*H*-1,3-dithiole-2-phosphonate ester **6** yielded a series of bis(tetrathiafulvalenes) **2** and (alkylthio)tetrathiafulvalenes **3**. By conventional methods, **5** was coupled to bis(alkylthio)tetrathiafulvalenes. The synthesis of **4** was improved. An *N*,*N*-dialkyldithiocarbamate salt was allowed to react with a 2-halo carboxylic acid to yield a 1-(carboxyalkyl)-*N*,*N*-dialkyldithiocarbamate ester **10**, which was then transformed into **4**. The electrochemistry of the new TTFs is reported.

Introduction

Tetrathiafulvalenes (TTFs) **1** are widely employed as π-electron donors for the formation of highly conducting charge-transfer salts or binary cation radical salts.[1] The physical properties of these solids depend strongly on the electronic and structural properties of the TTF unit, i.e., on the substituent pattern.

We report the preparation of two series of asymmetrically substituted TTFs, so-called dimeric TTFs **2**, and TTFs carrying long alkylthio or (carboxyalkyl)thio substituents **3**.

In most cases such a series of asymmetrically substituted TTFs has been obtained by statistical cross-coupling of two different 1,3-dithioles. The desired compounds were then isolated from the mixture of TTFs by tedious fractional recrystallization and/or chromatographic methods.[2-4]

Our synthetic strategy was to prepare the desired compounds via the mesoions **4**, which can now be obtained easily (see below). The mesoions are then S-alkylated to form 2-amino-5-(alkylthio)-1,3-dithiolium salts **5**. Compounds **5** serve as substrates in a selective Horner–Emmons-type coupling[5] to yield asymmetrically substituted TTFs **2** and **3**.

Scheme I

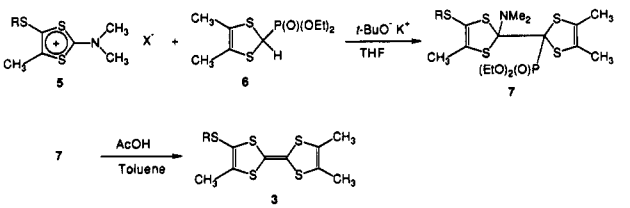
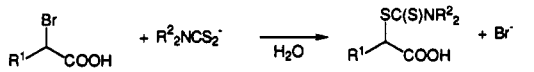


Table I. 1-(Carboxyalkyl)-*N*,*N*-dialkyldithiocarbamate Esters 10a–e



compd no.	R^1	R^2
10a	CH_3	CH_3
10b	$(CH_2)_3CH_3$	CH_3
10c	$(CH_2)_{15}CH_3$	CH_3
10d	Ph	CH_3
10e	CH_3	$-(CH_2)_5-$

We have targeted the dimeric TTFs **2**[6] since the $-S-(CH_2)_nS-$ link presumably gives rise to only a negligible electronic interaction between the two TTF subunits of the total molecule in the solid state, which may lead to interesting electronic properties of the solids due to the spatial degeneracy of the π-system.[6a,7] The interaction may also have interesting electrochemical consequences in solution (see below).

(1) (a) Ferraro, J. R.; Williams, J. M. *Introduction to Synthetic Electrical Conductors*; Academic Press: Orlando, 1987. (b) Jerome, D.; Schultz, H. J. *Adv. Phys.* **1982**, *31*, 299. (c) *The Physics and Chemistry of Organic Superconductors*, ISPP, Int. Symp. Proc. Tokyo; Saito, G., Kagoshima, S., Eds.; Springer Proceedings in Physics: Berlin, Heidelberg, 1990; Vol. 51.

(2) (a) Schukat, G.; Richter, A. M.; Fanghänel, E. *Sulfur Rep.* **1987**, *7*, 155.

(3) Krief, A. *Tetrahedron* **1986**, *42*, 1209.

(4) See for example: Papavassiliou, G. C.; Kakoussis, V. C.; Lagouvardos, D. J.; Mousdis, G. A. *Mol. Cryst. Liq. Cryst.* **1990**, *181*, 171.

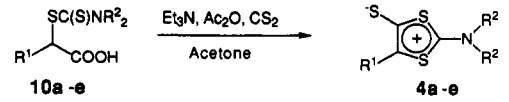
(5) (a) Lerstrup, K.; Johannsen, I.; Jørgensen, M. *Synth. Met.* **1988**, *27*, B9. (b) Gonnella, N. C.; Cava, M. P. *J. Org. Chem.* **1978**, *43*, 369.

(6) (a) Lerstrup, K.; Jørgensen, M.; Johannsen, I.; Bechgaard, K. In ref 1c, p 383. (b) Kaplan, M. L.; Haddon, R. C.; Wudl, F. *J. Chem. Soc., Chem. Commun.* **1977**, 388. (c) Schumaker, R. R.; Engler, E. M. *J. Am. Chem. Soc.* **1977**, *99*, 5519. (d) Lee, V. Y. Private communication.

(7) Bechgaard, K.; Lerstrup, K.; Jørgensen, M.; Johannsen, I. In ref 1c, p 349.

0022-3263/91/1956-5684$02.50/0

Table II. 2-(Dialkylamino)-1,3-dithiolium-4-thiolate Mesoions 4a–e



compd no.	R^1	R^2
4a	CH_3	CH_3
4b	$(CH_2)_3CH_3$	CH_3
4c	$(CH_2)_{15}CH_3$	CH_3
4d	Ph	CH_3
4e	CH_3	$-(CH_2)_5-$

Previously, fused[6b] TTFs and dimeric TTFs connected by conjugated links[6c,d] have been prepared in order to investigate the solid-state effects of the extended π-systems, expected to give rise to more two-dimensional electronic interactions.

Compounds **3** were prepared in order to make it possible to investigate TTFs incorporated in Langmuir–Blodgett layers.[8]

Results and Discussion

The preparation of the mesoion **4d** has been described previously[9] together with the preparation of symmetrically substituted TTFs based on this molecule.[10] We have improved the synthesis of **4**. The mesoions can now easily be prepared on a large scale as described below. Compound **4** was alkylated with a variety of alkyl halogenides to yield 2-(dialkylamino)-4-(alkylthio)-1,3-dithiolium salts **5**, which were allowed to react with the deprotonated 2*H*-1,3-dithiole-2-phosphonate ester **6**[5] to provide the intermediate **7** (see Scheme I). Compound **7** was treated with glacial acetic acid in toluene to yield the (alkylthio)trimethyl-TTFs **2** and **3**.

Similarly, we prepared the 4-(alkylthio)-4′,5,5′-trimethyl-TTFs **3a–c** and also the TTF-containing fatty acids **3d** and **3e**.

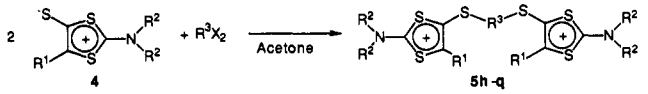
Compound **5** could also be reduced and deaminated to 4-(alkylthio)-1,3-dithiolium salts,[11] which could be coupled by treatment with base in a widely employed coupling reaction[12] to provide the symmetric bis(alkylthio)-TTFs **8** and **9**.

Preparation of the Mesoions 4. Five mesoions (**4a–d**) differing by the substituent in the 5-position were prepared according to the procedure outlined in Tables I and II. A 2-halo carboxylic acid was treated with an excess of *N,N*-dialkyldithiocarbamate in ethanol to yield the 1-(carboxyalkyl)-*N,N*-dialkyldithiocarbamates **10**.[13] The crude product was isolated and dried and, without further purification, dissolved in acetone and treated with acetic acid anhydride and triethylamine. The yellow solution, presumably now containing the 4-olate mesoion, was treated with an excess of carbon disulfide at ambient temperature, whereupon **4** was formed with liberation of carbonyl sulfide.

1,3-Dithiolium Salts 5. Compound **4** was alkylated on the thiolate function with a variety of alkyl mono- and dihalides as well as with benzyl halides and α,α'-dihaloxylenes to provide the mono- and bifunctional 5-alkyl(or -aryl)-2-(dialkylamino)-4-(alkylthio)-1,3-dithiolium salts **5a–q** listed in Table III.

Table III

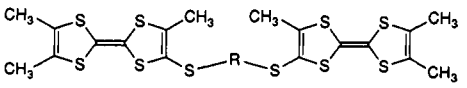
compd no.	R^1	R^2	R^3	X^-
5a	CH_3	CH_3	CH_3	I^-
5b	CH_3	CH_3	$(CH_2)_{17}CH_3$	Br^-
5c	CH_3	CH_3	$(CH_2)_{10}COOEt$	Br^-
5d	CH_3	CH_3	$(CH_2)_{15}COOEt$	I^-
5e	CH_3	CH_3	CH_2Ph	Br^-
5f	$(CH_2)_3CH_3$	CH_3	CH_2Ph	Br^-
5g	$(CH_2)_{15}CH_3$	CH_3	CH_2Ph	Br^-



compd no.	R^1	R^2	R^3	X^-
5h	CH_3	CH_3	α,α'-*o*-xylene	Br^-
5i	CH_3	CH_3	α,α'-*m*-xylene	Br^-
5j	CH_3	CH_3	α,α'-*p*-xylene	Br^-
5k	CH_3	CH_3	$-(CH_2)_3-$	Br^-
5l	CH_3	CH_3	$-(CH_2)_{10}-$	Br^-
5m	CH_3	$-(CH_2)_5-$	α,α'-*o*-xylene	Br^-
5n	CH_3	$-(CH_2)_5-$	α,α'-*m*-xylene	Br^-
5o	CH_3	$-(CH_2)_5-$	α,α'-*p*-xylene	Br^-
5p	CH_3	$-(CH_2)_5-$	$-CH_2-$	Br^-
5q	CH_3	$-(Ch_{25}-$	$-(CH_2)_2-$	Br^-

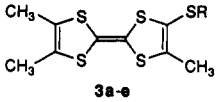
a. 1,3-Dithiolium Salts **5a–g** b. Bis-1,3-dithiolium Salts **5h–q**

Table IV. Bis-TTFs 2a–g Synthesized



compd no.	R	compd no.	R
2a	$-CH_2-$	**2e**	α,α'-*o*-xylene
2b	$-(CH_2)_2-$	**2f**	α,α'-*m*-xylene
2c	$-(CH_2)_3-$	**2g**	α,α'-*p*-xylene
2d	$-(CH_2)_{10}-$		

Table V. (Alkylthio)trimethyl-TTFs 3a–e Synthesized



compd no.	R	compd no.	R
3a	CH_3	**3d**	$(CH_2)_{10}COOEt$
3b	$(CH_2)_{17}CH_3$	**3e**	$(CH_2)_{15}COOEt$
3c	CH_2Ph		

Unsymmetrically Substituted TTFs. The salts **5** are the key intermediates in the synthesis of a large number of TTFs. We have focused on the Horner–Emmons-type coupling[5a] and further explored the scope and limitations of this reaction. We found that **5a–q** are good substrates for "attack" by **6**. Thus, the diethyl 4,5-dimethyl-2*H*-1,3-dithiole 2-phosphonate (**6**) was deprotonated in THF at low temperature and treated with 1 equiv of **5** to give the intermediate **7**. The compound was without purification dissolved in toluene and treated with glacial acetic acid to yield the desired TTFs **2** and **3** (Tables IV and V).

In order to investigate the mutual effect of the close proximity of the two TTF moieties on the redox potentials we have prepared the bis-TTFs listed in Table IV.

(8) (a) Lerstrup, K.; Jørgensen, M.; Rosenkilde, S. Submitted for publication. (b) Dhindsa, A. S.; Bryce, M. R.; Petty, M. In ref 1c, p 420.
(9) Souizi, A.; Robert, A. *Synthesis* **1972**, 1059.
(10) Souizi, A.; Robert, A. *Tetrahedron* **1984**, *40*(10), 1817.
(11) Takamizawa, A.; Hirai, K. *Chem. Pharm. Bull.* **1969**, *17*, 1924. See also refs 2 and 3.
(12) Klingsberg, E. *J. Am. Chem. Soc.* **1964**, *86*, 5290. Prinzbach, H.; Berger, A.; Lüttringhaus, A. *Angew. Chem.* **1965**, *77*, 453. Wudl, F.; Smith, G. M.; Hufnagel, E. J. *J. Chem. Soc., Chem. Commun.* **1970**, 1453. For recent results see also refs 2 and 3.
(13) Nachmias, G. *Ann. Chim. (Paris)* **1957**, *7*, 617.

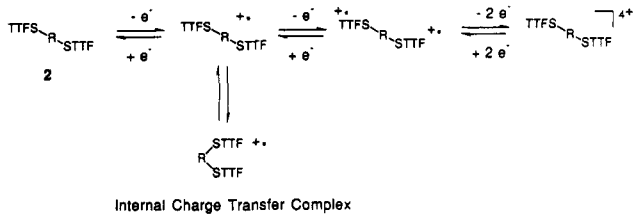


Figure 1. Proposed oxidation and reduction reactions of the TTFs **2** in cyclic voltammetry.

Coupling of 5 to Symmetrically Substituted TTFs. 4-(Alkylthio)-1,3-dithiolium salts similar to **5** have been coupled to symmetrically substituted TTFs via reduction to 2-ethoxy-4-(alkylthio)-2*H*-1,3-dithioles and heating these with trichloroacetic acid in benzene to yield 4,4′-bis(alkylthio)-TTFs.[10] Since this reaction does not in all cases give high and reliable yields we have used **5** to prepare symmetrically substituted TTFs via the traditional route, namely by reduction[11] of **5a** and **5b** to the corresponding amines **11** and **12** followed by deamination by treatment with strong acid yielding **13** and **14**. Coupling to the symmetrically substituted TTFs **8** and **9** was facilitated by reaction with triethylamine[12] in dry acetonitrile.

Electrochemistry. Cyclic voltammetry was preformed on all the new donors to determine the half-wave oxidation potentials. The results are collected in Table VI together with the oxidation potentials for tetramethyl-TTF (TMTTF) and bis(ethylenedithio)-TTF (BEDT-TTF) for comparison. As can be seen, the series **2a–g** and **3a–e** are fairly strong donors with oxidation potentials lying between those of TMTTF and BEDT-TTF.

Exchanging a methyl group for a methylthio (alkylthio) group raises the first potential by 80–100 mV, and there is an almost linear correlation between the number of alkylthio groups and the first oxidation potential. The second potential is raised by only 10–50 mV per thioalkyl group, but the same trend is observed.

The oxidation and reduction reactions of dimeric TTFs can be illustrated as shown in Figure 1. For the bis-TTF series **2a–g** some interesting effects are observed. In most cases (**c–g**) both TTF moieties are oxidized at the same potential and only two two-electron oxidation waves are seen. However, a broadening of the first oxidation wave is observed for compounds **2c** and **2e** in which the spacer groups are propylene or α,α'-*o*-xylene. In compounds **2a** and **2b**, where the two TTF-thio moieties are separated by a methylene or an ethylene group, respectively, three oxidation steps are seen.

This effect may be explained in terms of Coulombic repulsion between the two positively charged TTF moieties formed in the second step. This model is however not entirely satisfactory since no splitting is observed in $E^2_{1/2}$, where Coulombic repulsion should also play a role. Also, the first oxidation potentials of compounds **2a** and **2b** are *lower* than those of **2c–g**, i.e., the proximity of the second TTF somehow makes the removal of the first electron *easier*.

The following explanation could serve as a model for these findings. For compounds **2a** and **2b** the two TTFs form a sandwich with some degree of sharing of the π-electrons, which may lower the first oxidation potential by stabilizing the mono radical cation. Removal of the second electron from the molecule causes the dimer to "unfold" because the Coulombic repulsion between the two TTF moieties. The TTFs now behave like individual molecules and the third and the fourth electrons are removed at the same potential. When the spacer becomes longer, the distance between the TTFs will increase together with the number of degrees of freedom for the molecule and hence the effect becomes less pronounced. The implication from the results is that the interaction does not, to a large extent, occur through bonds. Further investigation into these interesting effects will be pursued.

Table VI. Cyclic Voltammetry of the New Donor Molecules and Two Reference Compounds (TMTTF and BEDT-TTF) vs SEC in CH_2Cl_2 with 0.10 M n-Bu_4NPF_6 (Scanspeed: 100 mV/s)

compd no.	R	$E_{1/2}{}^1$	$E_{1/2}{}^2$
2a	$-CH_2-$	0.22, 0.36	0.80
2b	$-(CH_2)_2-$	0.23, 0.36	0.74
2c	$-(CH_2)_3-$	0.28	0.75
2d	$-(CH_2)_{10}-$	0.27	0.77
2e	α,α'-*o*-xylene	0.29	0.79
2f	α,α'-*m*-xylene	0.26	0.75
2g	α,α'-*p*-xylene	0.28	0.76
3a	CH_3	0.28	0.73
3b	$(CH_2)_{17}CH_3$	0.27	0.78
3c	CH_2Ph	0.27	0.81
3d	$(CH_2)_{10}COOEt$	0.27	0.77
3e	$(CH_2)_{15}COOEt$	0.27	0.78
8	CH_3	0.36	0.72
9	$(CH_2)_{17}CH_3$	0.35	0.73
TMTTF		0.16	0.72
BEDT-TTF		0.43	0.85

Experimental Section

1-(Carboxyalkyl)-*N*,*N*-dialkyldithiocarbamates (10), General Procedure. Compound **10a** was prepared as described in ref 13. The higher homologues **10b–e** were synthesized according to the following general procedure.

The appropriate 2-halo carboxylic acid (100 mmol) was dissolved in 100 mL of ethanol and 120 mmol of *N*,*N*-dialkyldithiocarbamate as the sodium or potassium salt was added portionwise while the reaction temperature was kept below 10 °C with an ice bath. After addition, the reaction mixture was allowed to come to room temperature. The mixture was then poured into 200 mL of ice–water and acidified to pH 1 with concentrated hydrochloric acid. The free acid was filtered, dissolved in dichloromethane (200 mL), and extracted once with water (200 mL). The organic phase was dried over $MgSO_4$, filtered, and evaporated to provide product sufficiently pure for further reaction.

10a: yield 73%; mp 144–5 °C; ^{1}H NMR ($CDCl_3$) δ 1.63 (d, 3 H, J = 7.3 Hz), 3.40 (s, 3 H), 3.55 (s, 3 H), 4.76 (q, 1 H, J = 7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 16.65, 41.88, 45.72, 48.71, 176.10, 195.09.

10b: yield 74%; mp 76–7 °C; ^{1}H NMR ($CDCl_3$) δ 0.85 (t, 3 H, J = 1.5 Hz), 1.35 (m, 4 H), 1.93 (m, 2 H), 3.37 (s, 3 H), 3.47 (s, 3 H), 4.69 (t, 2 H, J = 7.0 Hz), 10.89 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.79, 22.31, 29.20, 30.69, 41.75, 45.65, 54.30, 176.43, 195.09.

10c: yield 72%; mp 98 °C; ^{1}H NMR ($CDCl_3$) δ 0.88 (t, unresolved, 3 H), 1.26 (s, 26 H), 1.98 (m, 2 H), 3.40 (s, 3 H), 4.73 (t, 1 H, J = 7.2 Hz), 11.26 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.99, 22.57, 24.52, 27.06, 29.20, 29.53, 30.89, 31.80, 41.56, 45.53, 54.30, 176.37, 195.16.

10d: yield 71%; mp 191 °C; ^{1}H NMR ($CDCl_3$) δ 3.35 (s, 3 H), 3.52 (s, 3 H), 5.83 (s, 1 H), 7.42 (m, 5 H). Anal. Calcd for $C_{11}H_{13}NO_2S_2$: C, 51.74; H, 5.13; N, 5.49. Found: C, 51.87, H, 5.20; N, 5.30.

10e: yield 63%; mp 136 °C; ^{1}H NMR ($CDCl_3$) δ 1.67 (t, 3 H, J = 7.3 Hz), 1.72 (b, 6 H), 4.04 (q, 1 H, J = 7.3 Hz), 9.72 (s, 1 H).

2-(Dimethylamino)-1,3-dithiolium-4-thiolate Mesoions (4). General Procedure. The synthesis of **4a–e** was based on the procedure in ref 9 modified in the following manner.

The dithiocarbamate ester **10** (10 mmol) was dissolved in acetone (25 mL) and treated successively with acetic acid anhydride (3 mL), triethylamine (3 mL), and carbon disulfide (3 mL) at ambient temperature. As the carbon disulfide was added a dark color developed, and after a few minutes liberation of carbonyl sulfide (warning! toxic!) started while the product precipitated from the solution as yellow or orange crystals. After 6 h

the product was filtered, washed with acetone and ether, and vacuum dried. Further purification of the products did not prove necessary for the following step, but samples for elemental analysis were recrystallized from DMSO (**4a**) or *n*-heptane (**4c**). In general, recrystallization of **4** is not recommended due to thermal decomposition.

4a: yield 71%; mp >260 dec; ^{1}H NMR (DMSO-d_6) δ 2.28 (s, 3 H), 3.35 (s, 6 H). Anal. Calcd for $C_6H_9NS_3$: C, 37.68; H, 4.71; N, 7.32. Found: C, 37.64; H, 4.78; N, 7.23.

4b: yield 77%; mp 189 dec; ^{1}H NMR ($CDCl_3$) δ 0.94 (t, 3 H, J = 6.4 Hz), 1.48 (m, 4 H), 2.73 (t, 2 H, J = 7.9 Hz), 3.40 (s, 6 H). Anal. Calcd for $C_9H_{15}NS_3$: C, 46.31; H, 6.48; N, 6.00. Found: C, 46.51; H, 6.52; N, 5.99.

4c: yield 53%; mp 154–6 °C; ^{1}H NMR ($CDCl_3$) δ 0.88 (t, unresolved, 2 H), 1.25 (s, 28 H), 2.75 (t, 2 H, J = 7.1 Hz), 3.36 (s, 6 H). Anal. Calcd for $C_{21}H_{39}NS_3$: C, 62.78; H, 9.79; N, 3.49. Found: C, 62.58; H, 9.87; N, 3.52.

4d: yield 61%; mp 258 °C dec; ^{1}H NMR ($CDCl_3$) δ 3.30 (s, 6 H), 7.2–7.4 (m, 3 H), 8.1–8.3 (m, 2 H). Anal. Calcd for $C_{11}H_{11}NS_3$: C, 52.14; H, 4.38; N, 5.53. Found: C, 52.08; H, 4.27; N, 5.54.

43:[9] yield 78%; mp 223 °C; ^{1}H NMR ($CDCl_3$) δ 1.81 (br, 6 H), 2.24 (s, 3 H), 3.7 (br, 4 H).

2-(Dimethylamino)-4-(alkylthio)-1,3-dithiolium Salts (5). General Procedure. The appropriate mesoion **4** (10 mmol) was mixed in acetone (100 mL) with 1 equiv of alkyl halogenide and refluxed for 2 to 6 h until the mixture turned colorless. After being cooled to room temperature, the salt **5** was filtered and washed with acetone and ether. Compound **5** was used in the following reaction without further purification. Yields were 95% or better.

5a: mp 121 °C; ^{1}H NMR (DMSO-d_6) δ 2.50 (d, 3 H, J = 2.0 Hz), 2.53 (d, 3 H, J = 2.0 Hz), 3.53 (s, 6 H). Anal. Calcd for $C_7H_{12}NS_3I$: C, 25.23; H, 3.63; N, 4.20. Found: C, 25.10; H, 3.72; N, 4.13.

5b: mp 111 °C; ^{1}H NMR (DMSO-d_6) δ 0.85 (t, unresolved, 3 H, J = 7.8 Hz), 1.24 (s, 3 H), 2.93 (t, unresolved, 2 H), 3.50 (s, 6 H), 2.48 (s, 3 H).

5c: mp 68 °C; ^{1}H NMR (DMSO-d_6) δ 1.18 (t, 3 H, J = 7.0 Hz), 1.26 (br, 16 H), 2.26 (t, 2 H, J = 6.7 Hz), 2.52 (s, 3 H), 2.96 (t, 2 H, J = 6.4 Hz), 3.58 (s, 6 H), 4.05 (q, 2 H, J = 7.0 Hz).

5d: mp 91 °C; ^{1}H NMR (DMSO-d_6) δ 1.16 (t, 3 H, J = 7.0 Hz), 1.22 (br, 26 H), 2.24 (t, 2 H, J = 6.7 Hz), 2.47 (s, 3 H), 2.92 (t, 2 H, J = 6.4 Hz), 3.50 (s, 6 H), 4.03 (q, 2 H). Anal. Calcd for $C_{24}H_{44}O_2S_2NI$: C, 47.91; H, 7.37; N, 2.33. Found: C, 47.75; H, 7.36; N, 2.37.

5e: mp 163 °C; ^{1}H NMR (DMSO-d_6) δ 2.00 (s, 3 H), 3.53 (s, 6 H), 4.19 (s, 2 H), 7.35 (s, 5 H); ^{13}C NMR ($CDCl_3$) δ 13.73, 40.06, 46.11, 46.63, 123.17, 125.71, 126.68, 127.07, 127.31, 134.23, 141.32, 182.20. Anal. Calcd for $C_{13}H_{16}NS_3Br$: C, 43.07; H, 4.45; N, 3.87. Found: C, 43.22; H, 4.62; N, 3.79.

5f: mp 91 °C; ^{1}H NMR (DMSO-d_6) δ 0.79 (m, 3 H), 1.16 (m, 4 H), 2.46 (m, 2 H), 3.56 (s, 6 H), 4.18 (s, 2 H), 7.31 (s, 5 H); ^{13}C NMR (DMSO-d_6) δ 13.29, 21.35, 28.64, 31.50, 46.91, 47.30, 123.32, 127.61, 128.59, 129.04, 136.65, 147.12, 183.86. Anal. Calcd for $C_{16}H_{22}NS_3Br$: C, 47.52; H, 5.48; N, 3.46. Found: C. 47.57; H, 5.78; N, 3.23.

5g: mp 107 °C; ^{1}H NMR (DMSO-d_6) δ 0.85 (t, 3 H, J = 5.2 Hz), 1.24 (28 H), 2.46 (t, 2 H, J = 5.2 Hz), 3.49 (s, 6 H), 4.17 (s, 2 H0, 7.32 (s, 5 H).

5h: mp 247 °C dec; ^{1}H NMR (DMSO-d_6) δ 2.01 (s, 6 H), 3.47 (s, 12 H), 4.29 (s, 4 H), 7.18 (m, 4 H); ^{13}C NMR (DMSO-d_6) δ 14.89, 37.90, 46.84, 47.23, 123.61, 128.33, 131.13, 135.02, 143.19, 183.74.

5i: mp 191 °C; ^{1}H NMR (DMSO-d_6) δ 2.11 (s, 6 H), 3.51 (s, 6 H), 4.20 (s, 4 H), 7.25 (m, 4 H); ^{13}C NMR (DMSO-d_6) δ 15.03, 40.40, 46.84, 47.27, 123.64, 129.07, 129.92, 137.21, 142.32, 183.77.

5j: mp 232 °C dec; ^{1}H NMR (DMSO-d_6) δ 2.07 (s, 6 H), 3.50 (s, 12 H), 4.17 (s, 4 H), 7.25 (m, 4 H).

5k: mp 164–5 °C; ^{1}H NMR (DMSO-d_6) δ 1.91 (m, 2 H, J = 7.3 Hz), 2.52 (s, 6 H), 3.08 (t, 4 H, J = 7.3 Hz), 3.56 (s, 12 H); ^{13}C NMR (DMSO-d_6) δ 15.48, 28.87, 34.92, 46.82, 47.28, 123.69, 140.79, 183.58.

5l: mp 160 °C; ^{1}H NMR (DMSO-d_6) δ 150 (br, 16 H), 2.50 (s, 6 H), 2.95 (t, 4 H, J = 6.4 Hz), 3.55 (s, 12 H).

5m: >260 °C; ^{1}H NMR (DMSO-d_6) δ 1.88 (br, 12 H), 2.19 (s, 6 H), 3.96 (br 8 H), 4.56 (s, 4 H), 7.52 (m, 4 H).

5n: mp 191–2 °C; ^{1}H NMR (DMSO-d_6) δ 1.73 (br, 12 H), 2.13 (s, 6 H), 3.76 (br, 8 H), 4.14 (s, 4 H0, 7.25 (m, 4 H); ^{13}C NMR (DMSO-d_6) δ 14.70, 21.01, 24.32, 54.76, 55.93, 56.38, 122.45, 128.50, 129.02, 129.74, 137.02, 141.05, 182.61.

5o: mp 159–60 °C; ^{1}H NMR ($CDCl_3$) δ 1.83 (br, 12 H), 2.52 (s, 6 H), 3.9 (br, 8 H+s, 4 H), 7.31 (s, 4 H).

5p: mp 201 °C; ^{1}H NMR ($CDCl_3$) δ 1.9 (br, 12 H0, 2.61 (s, 6 H), 4.1 (br, 8 H), 4.83 (s, 2 H).

5q: mp 263 °C dec; ^{1}H NMR (DMSO-d_6) δ 1.74 (br, 12 H), 2.49 (s, 6 H), 3.31 (s, 2 H), 3.79 (br, 8 H), 5.73 (s, 4 H).

Unsymmetric Coupling of 5 with Phosphonate Ester 6 to Bis-TTF 2 and (Alkylthio)trimethyl-TTF (3). General Procedure. 4,5-Dimethyl-2*H*-1,3-dithiole-2-diethylphosphonate ester[14,15] (10 mmol, 2.4 g) was dissolved in dry THF (20 mL), cooled to −70 °C and, under an argon atmosphere, deprotonated by dropwise addition of a solution of potassium *tert*-butoxide (1.2 g, 11 mmol) in dry THF (10 mL). After 5 min the appropriate 1,3-dithiolium salt **5** (10 mmol) was added in one portion and the mixture stirred for 2 while the temperature was allowed to reach −10 °C. To the mixture was added one volume of cold ether, and the precipitate was removed by filtration or centrifugation. After evaporation of the solvent an amber oil was obtained that was dissolved in dry toluene (10 mL). Glacial acetic acid was added dropwise (1–5 mL) until a permanent red color developed. After standing for 1–2 h the product was filtered and purified by recrystallization from hexane or the solvent was evaporated and the product isolated by column chromatography (silica gel/toluene) followed by recrystallization from hexane.

2a: yield 24%; mp 250 °C dec; ^{1}H NMR ($CDCl_3$) δ 1.61 (s, 6 H), 1.96 (s, 12 H), 4.67 (s, 2 H). Anal. Calcd for $C_{19}H_{20}S_{10}$: C, 40.11; H, 3.54. Found: C, 40.37; H, 3.57.

2b: yield 15%; mp 239 °C; ^{1}H NMR ($CDCl_3$) δ 1.57 (s, 12 H), 1.95 (br, 6 H), 2.90 (s, 4 H). Anal. Calcd for $C_{20}H_{22}S_{10}$: C, 41.21; H, 3.80. Found: C, 41.15; H. 3.81.

2c: yield 33%; mp 196 °C; ^{1}H NMR ($CDCl_3$) δ 1.90 (m 2 H), 1.93 (br, 12 H), 2.11 (s, 6 H), 2.78 (t, 4 H, J = 7.0 Hz); ^{13}C NMR ($CDCl_3$) δ 13.59, 15.28, 29.33, 34.21, 118.59, 122.61, 122.76, 135.62. Anal. Calcd for $C_{21}H_{24}S_{10}$: C, 42.25; H, 4.05. Found: C, 42.35; H, 4.20.

2d: yield 50%; mp 110 °C; ^{1}H NMR ($CDCl_3$) δ 1.28 (m, 12 H), 1.61 (s, 6 H). Anal. Calcd for $C_{28}H_{38}S_{10}$: C, 48.38; H, 5.51. Found: C, 48.57; H, 5.44.

2e: yield 23%; mp 229 °C; ^{1}H NMR ($CDCl_3$) δ 1.62 (s, 6 H), 1.94 (s, 12 H), 4.00 (s, 4 H), 7.15 (m, 4 H). Anal. Calcd for $C_{26}H_{26}H_{10}$: C, 47.38; H, 3.98. Found: C, 47.10; H, 4.02.

2f: yield 31%; mp 181 °C; ^{1}H NMR ($CDCl_3$) δ 1.67 (s, 6 H), 1.93 (s, 12 H), 3.79 (s, 4 H), 7.15 (m, 4 H). Anal. Calcd for $C_{26}H_{26}S_{10}$: 47.38; H, 3.98. Found: C, 47.51; H, 3.89.

2g: yield 35%; mp 253 °C; ^{1}H NMR ($CDCl_3$) δ 1.65 (s, 6 H), 1.94 (s, 12 H), 3.81 (s, 4 H), 7.17 (m, 4 H). Anal. Calcd for $C_{26}H_{26}S_{10}$: C, 47.38; H, 3.98. Found: C, 47.58; H, 3.88.

3a: yield 51%; mp 119 °C; ^{1}H NMR ($CDCl_3$) δ 1.93 (s, 6 H), 2.11 (s, 3 H), 2.30 (s, 3 H); ^{13}C NMR ($CDCl_3$) δ 13.58, 15.02, 19.15, 122.61, 122.68, 133.58. Anal. Calcd for $C_{10}H_{12}S_5$: C, 41.06; H, 4.14. Found: C, 41.41; H, 4.10.

3b: yield 31%; mp 68 °C; ^{1}H NMR ($CDCl_3$) δ 0.87 (t, 3 H, J = 7.0 Hz), 1.26 (br, 32 H), 1.93 (s, 6 H), 2.31 (s, 3 H), 2.69 (t, 2 H, J = 7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 13.72, 14.17, 15.34, 22.76, 28.48, 29.20, 29.39, 29.72, 32.00, 36.09, 119.65, 122.84, 234.54. Anal. Calcd for $C_{27}H_{46}S_5$: C, 61.08; H, 8.73. Found: C, 60.85; H, 8.50.

3c: yield 57%; mp 127 °C; ^{1}H NMR ($CDCl_3$) δ 1.62 (s, 3 H), 1.94 (s, 6 H), 3.85 (s, 2 H), 7.24 (s, 5 H); ^{13}C NMR ($CDCl_3$) δ 13.72, 14.76, 40.25, 118.03, 122.71, 122.84, 127.33, 128.44, 128.96, 137.48, 138.00.

3d: yield 41%; mp 59 °C; ^{1}H NMR ($CDCl_3$) δ 1.23 (t, 3 H, J = 7.3 Hz), 1.28 (br, 12 H), 1.57 (m, 4 H), 1.95 (s, 6 H), 2.10 (s, 3 H), 2.27 (t, 2 H, J = 8.4 Hz), 2.68 (t, 2 H, J = 7.0 Hz), 4.12 (q, 2 H, J = 7.3 Hz); ^{13}C NMR ($CDCl_3$) δ 13.54, 14.12, 15.18, 24.83, 28.28, 28.96, 29.07, 29.20, 29.26, 34.24, 35.87, 59.98, 119.46, 122.56, 122.69, 134.34, 173.72. Anal. Calcd for $C_{22}H_{34}O_2S_5$: C, 53.84; H, 6.98. Found: C, 53.79; H, 6.98.

3e: yield 32%; mp 71 °C; ^{1}H NMR ($CDCl_3$) δ 1.24 (br, 27 H), 1.95 (s, 6 H), 2.12 (s, 3 H), 2.27 (t, 2 H, J = 7.5 Hz), 2.79 (t, 2 H,

(14) Auban, P.; Jerome, D.; Lerstrup, K.; Johannsen, I.; Jørgensen, M.; Bechgaard, K. *J. Phys. (France)* **1989**, *50*, 2727.
(15) Ishikawa, K.; Akiba, K.; Inamoto, N. *Tetrahedron Lett.* **1976**, *41*, 3695.

J = 7.2 Hz), 4.12 (q, 2 H, J = 7.1 Hz); ^{13}C NMR ($CDCl_3$) δ 13.58, 14.15, 24.87, 28.33, 29.15, 29.39, 29.52, 34.29, 35.92, 60.02, 119.49, 122.59, 122.72, 134.47, 173.82.

4-(Methylthio)-5-methyl-1,3-dithiolium Hexafluorophosphate (13) via 2-(Dimethylamino)-4-(methylthio)-5-methyl-2*H*-1,3-dithiole (11), from 5a. Compound **5a** (6.6 g, 20 mmol) was dissolved in 200 mL of absolute ethanol and cooled to 0 °C. Sodium borohydride (1 g) was added portionwise over 5 min and the mixture was stirred at 0 °C for 1 h. Petroleum ether (200 mL), ether (200 mL), and water (200 mL) were added. The organic phase was washed once with 100 mL of ice water, dried over $MgSO_4$, and filtered and the solvent evaporated to provide **11** as a yellow oil in 79% yield (3.28 g). Without purification the oil was added dropwise to ice-cold concentrated sulfuric acid (50 mL) under vigorous stirring. After 0.5 h the mixture was poured onto 150 g of crushed ice containing 10 mL of 60% hexafluorophosphoric acid whereupon **13** precipitated as white crystals. The product was filtered, the filtrate was extracted once with 100 mL of CH_2Cl_2, and the solid product was dissolved in the CH_2Cl_2 phase. After drying over $MgSO_4$, the filtered solution was concentrated to ca. 50 mL and the product was precipitated by addition of one volume of ether to yield 2.53 g of **13** as white crystals (41%): mp 130 °C; ^{1}H NMR (DMSO-d_6) δ 2.74 (s, 3 H), 2.82 (s, 3 H), 11.34 (s, 1 H). Anal. Calcd for $C_5H_7S_3PF_6$: C, 19.48; H, 2.29. Found: C, 19.51; H, 2.28.

4-Methyl-5-(octadecylthio)-1,3-dithiolium Hexafluorophosphate (14). Compound **14** was prepared via **12** from **5b** by a procedure identical with the one given above for **13**.

4,5-Dimethyl-4′,5′-bis(methylthio)-TTF (8), from 13. Compound **13** (1.0 g, 32 mmol) was dissolved in 10 mL of dry acetonitrile, and 0.5 mL of triethylamine was added dropwise. At first a maroon color was observed that rapidly faded while crystals of the orange-red product precipitated. After 5 min the product was filtered, washed with ethanol and petroleum ether, and dried in vacuo. After recrystallization from heptane, the yield of **8** was 0.252 g (49%): mp 141 °C; ^{1}H NMR ($CDCl_3$) δ 2.14 (s, 6 H), 2.31 (s, 6 H); ^{13}C NMR ($CDCl_3$) δ 15.03, 19.19, 108.63, 120.60, 133.58. Anal. Calcd for $C_{10}H_{12}S_6$: C, 37.00; H, 3.73. Found: C, 36.72; H, 3.67.

4,5-Dimethyl-4′,5′-bis(octadecylthio)-TTF (9), from 14. Compound **14** (1.1 g, 1.9 mmol) was treated as above yielding 0.61 g **9** (40%): mp 85 °C; ^{1}H NMR ($CDCl_3$) δ 0.88 (t, 6 H, J = 7.6 Hz), 1.26 (s, 64 H), 2.11 (s, 6 H), 2.69 (t, 4 H, J = 7.9 Hz). Anal. Calcd for $C_{44}H_{80}S_6$: C, 65.94; H, 10.06. Found: C, 66.38; H, 10.16.

Acknowledgment. This work has been supported by the EEC ESPRIT BRA Programme through grant number 3314 and by the Danish Materials Technological Development Program.

Registry No. **2a**, 135146-89-3; **2b**, 135146-90-6; **2c**, 135146-91-7; **2d**, 135146-92-8; **2e**, 135146-93-9; **2f**, 135146-94-0; **2g**, 135146-95-1; **3a**, 135146-96-2; **3b**, 135146-97-3; **3c**, 135146-98-4; **3d**, 135146-99-5; **3e**, 135147-00-1; **4a**, 129119-29-5; **4b**, 135147-01-2; **4c**, 135147-02-3; **4d**, 135147-03-4; **4e**, 85102-68-7; **5a**, 135147-04-5; **5b**, 135147-05-6; **5c**, 135147-06-7; **5d**, 135147-07-8; **5e**, 135147-08-9; **5f**, 135147-09-0; **5g**, 135147-10-3; **5h**, 135147-11-4; **5i**, 135147-12-5; **5j**, 135147-13-6; **5k**, 135147-14-7; **5l**, 135147-15-8; **5m**, 135147-16-9; **5n**, 135147-17-0; **5o**, 135189-73-0; **5p**, 135147-18-1; **5q**, 135189-74-1; **6**, 122301-24-0; **8**, 107817-01-6; **9**, 135147-19-2; **10a**, 53278-41-4; **10b**, 135147-20-5; **10c**, 135147-21-6; **10d**, 58007-81-1; **10e**, 53278-47-0; **11**, 135147-22-7; **13**, 135147-24-9; **14**, 135147-26-1; $CH_3(CH_2)_3CH(Br)COOH$, 616-05-7; $CH_3(CH_2)_{15}CH(Br)COOH$, 142-94-9; PhCH(Br)COOH, 4870-65-9; $CH_3CH(Br)COOH$, 598-72-1.

A Direct Synthesis of Racemic Demethoxyaflatoxin B_2

George A. Kraus,* Beth E. Johnston, and Jacqueline M. Applegate

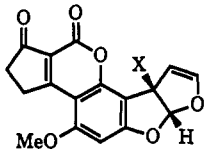
Department of Chemistry and Program in Toxicology, Iowa State University, Ames, Iowa 50011

Received February 28, 1991

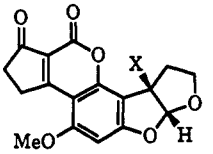
Aflatoxin analogue **19** was prepared by a direct sequence involving a novel silver-mediated cyclization to **12**, the Michael addition of **16** with **17**, and the oxidation of the Michael addition adduct. The overall yield of this six-step route is approximately 11%. The pathway is a flexible one that will permit the synthesis of analogues for toxicological analysis.

The aflatoxins 1–4 comprise a class of naturally occuring mycotoxins that are significant health hazards. Many reports of the potent carcinogenicity of aflatoxins and the fact that aflatoxins have been detected in several foods have stimulated intense interest from toxicologists, chemists, and government regulators.[1] Consequently, several methods have emerged for the detection and control of aflatoxins. There have also been a considerable number of synthetic approaches to the aflatoxin skeleton; however, only a few of the approaches have culminated in total syntheses.[2] A review by Schuda nicely summarizes the synthetic efforts of the Buchi research group.[3]

Recently, we described an approach to the aflatoxin M_2 skeleton using a type II photocyclization reaction to pre-



1: X = H
2: X = OH



3: X = H
4: X = OH

pare the 3-hydroxy-2,3-dihydrobenzofuran ring system.[4] In the context of securing a flexible route to the aflatoxin B_2 system, we examined the cyclization depicted below. Saegusa had reported that β-keto esters and β-diketones reacted with silver oxide in DMSO to form dimers.[5] We reasoned that the radical intermediate involved in the dimerization reaction might be employed to generate a furo[2,3-*b*]furan system if the reaction was conducted in the presence of an excess of 2,3-dihydrofuran. With ethyl

(1) *Mycotoxins-Economic and Health Risks* (Council for Agricultural Science and Technology, Ames, 1989).
(2) Buchi, G.; Francisco, M. A.; Lusch, J. M.; Schuda, P. F. *J. Am. Chem. Soc.* **1981**, *103*, 3497. Horne, S.; Weeratunga, G.; Rodrigo, R. *J. Chem. Soc., Chem. Commun.* **1990**, *39*, and references therein. Castellina, A. J.; Rapoport, H. *J. Org. Chem.* **1986**, *51*, 1006.
(3) Schuda, P. *Top. Curr. Chem.* **1980**, *91*, 75.
(4) Kraus, G. A., Thomas, P. J., Schwinden, M. D. *Tetrahedron Lett.* **1990**, *31*, 1819.
(5) Ito, Y.; Fujii, S.; Konoike, T.; Saegusa, T. *Synth. Commun.* **1976**, *6*, 429.

0022-3263/91/1956-5688$02.50/0