# Condensed Thiophenes and Selenophenes: Thionyl Chloride and Selenium Oxychloride as Sulfur and Selenium Transfer Reagents

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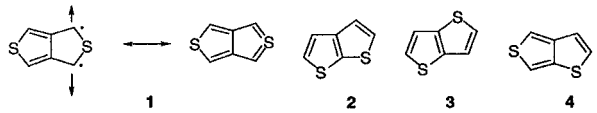
3,4-Cyanomethyl substituted thiophenes reacted with thionyl chloride in the presence of base to give dicyano substituted thieno(3,4-*c*)thiophenes. The use of selenium oxychloride furnished the corresponding cyano substituted seleno(3,4-*c*)thiophene. 1,2-Phenylenediacetonitriles gave the corresponding cyano substituted benzo(*c*)thiophenes and benzo(*c*)selenenophenes, respectively, upon reaction with thionyl chloride and selenium oxychloride in the presence of base.

## Introduction

Thieno[3,4-*c*]thiophene (**1**) is unique among the isomeric thienothiophenes (**2**−**4**) in that it cannot be represented by a classical Kekulè structure without invoking the presence of a tetracovalent sulfur.

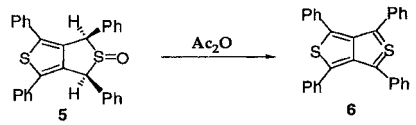


Whereas compounds **2**−**4** have been known for long, only during the last 32 years have a few stable derivatives of **1** been made.[1] The first such derivative was the tetraphenyl derivative **6**, which was obtained by an acid-catalyzed Pummerer dehydration of the corresponding 3,4-dihydrotetraphenylthieno[3,4-*c*]thiophene sulfoxide **5**[2] (Scheme 1).

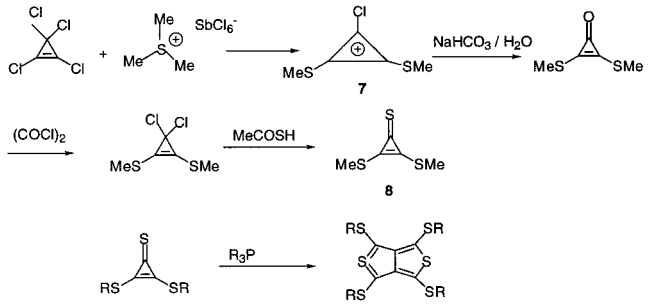
Whereas the tetracovalent sulfur structure is written for convenience, photoelectron spectroscopic studies and theoretical calculations during the 1970s indicated that the structure of **1** is best represented as a stable singlet 1,3-diradical.[3] Using the sulfoxide dehydration approach (both acid and base- catalyzed), various analogues were made or generated.[4] The presence of four bulky groups on the rings appeared to confer stability, and it was generally assumed that bulky substituents were necessary for isolable derivatives.

Reaction of methyl (bismethylthio)sulfonium hexachloroantimonate with tetrachlorocyclopropene yielded the

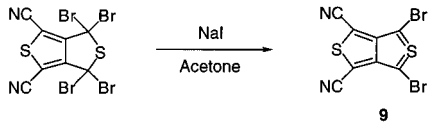
**Scheme 1**



**Scheme 2**



**Scheme 3**



2,3-bis(methylthio)-1-chlorocyclopropenium salt **7**. The latter was converted to the 2,3-bis(methylthio)cyclopropene-1-thione (**8**) via several steps. (Scheme 2).[5] A number of 2,3-di-(*S*)-alkylcyclopropene-1-thiones were made by this method. These underwent a novel dimerization reaction in the presence of tributyl or triphenylphosphine to give an *S*-alkyl-substituted thieno[3,4-*c*]thiophene.[6] Indeed, the mechanism of this reaction has only recently been elucidated.[7]

In 1992, the first example of a purely electronically stabilized derivative **9** was synthesized by a 1,4-Finkelstein elimination (Scheme 3).[8b]

(1) (a) Cava, M. P.; Lakshmikantham, M. V. *Acc. Chem. Res.* **1975**, *8*, 139. (b) Cava, M. P.; Lakshmikantham, M. V. In *Comprehensive Heterocyclic Chemistry*; Katrizky, A. R., Rees, C. W., Eds.; Pergamon Press: Oxford, 1984; Vol.4, Chapter 3−18. (c) Krutosikova, A. In *Comprehensive Heterocyclic Chemistry II;* Katrizky, A. R., Rees, C. W., Scriven E. F. V., Eds.; Elsevier Sci.: Oxford, 1996; Vol. 7, Chapter 7.01.

(2) Cava, M. P.; Husbands, G. E. M. *J. Am. Chem. Soc.* **1968**, *91*, 3952.

(3) Müller, C.; Schweig, A.; Cava, M. P.; Lakshmikantham, M. V. *J. Am. Chem. Soc.* **1976**, *98*, 7187.

(4) (a) Cava, M. P.; Pollack, N. M. *J. Am. Chem. Soc.* **1967**, *89*, 3639. (b) Cava, M. P.; Pollack, N. M.; Dieterle, G. A. *J. Am. Chem. Soc.* **1973**, *95*, 2558. (c) Cava, M. P.; Behforouz, M.; Husbands, G. E. M.; Srinivasan, M. *J. Am. Chem. Soc.* **1973**, *95*, 2651. (d) Ishii, A.; Nakayama, J.; Kazami, J. Ida.; Nakamura, T.; Hoshino, M. *J. Org. Chem.* **1991**, *56*, 78.

(5) Weiss, R.; Schlierf, C.; Schloter. K. *J. Am. Chem. Soc.* **1976**, *98*, 4668.

(6) Yoneda, S.; Ozaki, T.; Inoue, T.; Sugimoto, A.; Yangi, K.; Minobe, M. *J. Am. Chem. Soc.* **1985**, *107*, 5801.

(7) Matsumura, N.; Tanaka, H.; Yagyu, Y.; Mizuno, K.; Inoue, H.; Takada, K.; Yasui, M.; Iwasaki, F. *J. Org. Chem.* **1998**, *63*, 163.

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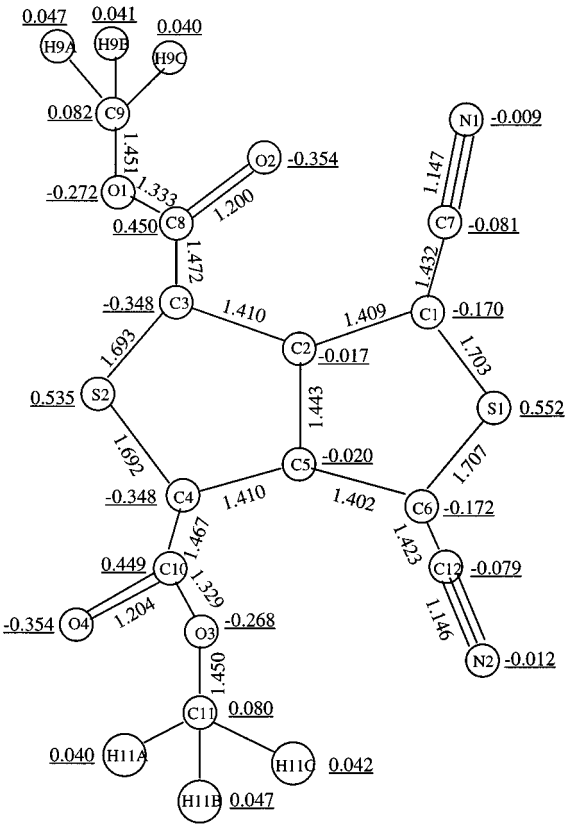


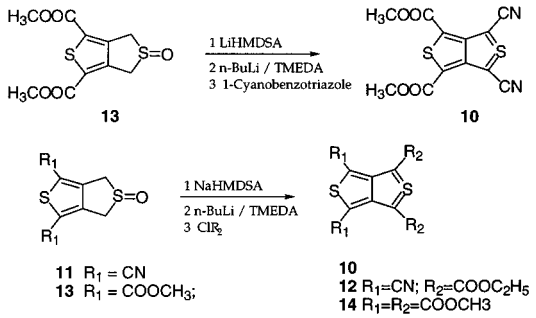

**Figure 1.** Bond lengths (Å) from X-ray diffraction analysis and $PM_3$ calculated partial charges (underlined) on atoms in the molecule.

## Results

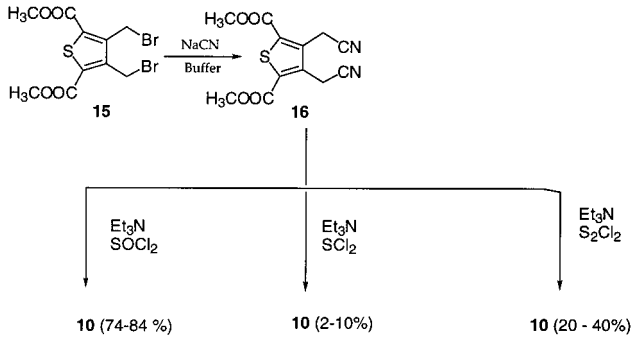
Recently, we have attempted to synthesize derivatives of **1** bearing only electron-withdrawing groups, employing different strategies. One of our target molecules, viz. dicyanodicarbomethoxythieno[3,4-*c*]thiophene[9] (**10**), was first made in miniscule yield via a tandem Pummerer−cyanation route. The structure of **10** was confirmed by single-crystal X-ray diffraction analysis, as shown in the Supporting Information.

The molecule deviates slightly from 2*m* symmetry, probably caused by the inequivalent geometries of the carbomethoxy substituents, presumably dictated by packing considerations. Figure 1 shows the significant interatomic bond distances (in Å; the estimated standard deviations are less than ±0.003 Å). The thieno[3,4-*c*]-thiophene ring is planar: the deviations from the least-squares plane of its atoms are less than 0.008 Å for five out of six carbon atoms, but 0.011 Å for C4, 0.008 Å for S1, and 0.013 Å for S2. This least-squares plane is inclined by 6.85° from the molecular stacking axis, *c*. The C−C bond distances within the thieno[3,4-*c*] rings are typical aromatic bond distances; the C−S bond distances (1.703−1.692 Å) are slightly shorter than in isomeric thienothiophenes (1.72 and 1.74 Å) or in thiophene itself (1.714 Å). The carbomethoxy substituents prevent a dense $\pi$-to-$\pi$ stacking; the least-squares planes of adjacent molecules stacked almost along the *c* axis are 5.25 Å from each other, much larger than van der Waals intermolecular distances in aromatic crystals. A molecular orbital calculation, using a molecular mechanics program followed by the PM3 semiempirical all-valence electron calculation, with geometry optimization (CACHE programming package), yielded a molecular geometry close to that shown by the X-ray structure determination, except that the two carbomethoxy rings have the C=O bond facing the nitrile carbon atoms for both substituents. The calculated enthalpy of formation is 4.548 kcal/mol, the HOMO energy is −9.082 eV, and the LUMO energy is −3.183 eV. The net atomic charges are also shown in Figure 1.

**Scheme 4**




**Scheme 5**




In contrast to the minute yields from the tandem Pummerer−cyanation reaction, the in situ Pummerer−carbomethoxylation of dicyanodihydrothieno[3,4-*c*]thiophene sulfoxide **11** using NaHMDSA/methyl chloroformate afforded **10** in 10% yield. The use of ethyl chloroformate led to the dicarbethoxydicyano derivatives **12** in 15% yield (Scheme 4). The tetraester **14** was made by this procedure in 10% yield, starting from the corresponding diester sulfoxide **13**. (Scheme 4)

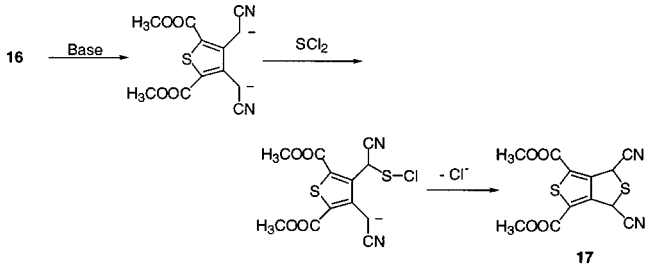
In view of the extremely poor yields of **10**, it was decided that the nitrile functionality should be introduced first, followed by sulfur transfer. The known dibromide[8a] **15** was converted in good yield to the dinitrile **16** by reaction with buffered potassium or sodium cyanide at pH 9−10. Reaction of the 2,5-dicarbomethoxy-3,4-dicyanomethylthiophene **16** with sulfur dichloride in the presence of base gave **10** in varying low yields (2−10%). In contrast, the use of sulfur monochloride under the same conditions gave 20−40% yields of **10** reproducibly. However, when thionyl chloride was used, the yields of product **10** increased dramatically to 74−84% (Scheme 5). To our knowledge, this is the first example of the reaction of thionyl chloride with a carbanion acting as a S-transfer agent.

**Mechanism of the Reaction.** A comparison of the reactions of $SCl_2$, $S_2Cl_2$, and $SOCl_2$ as S-transfer agents

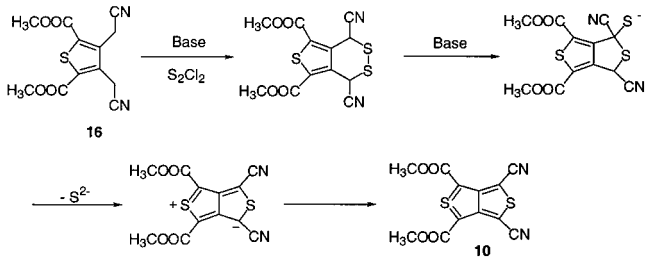
(8) (a) Wynberg, H.; Zwanenburg, B. *J. Org. Chem.* **1964**, *29*, 1919. (b) Beye, N.; Cava, M. P. *J. Org. Chem.* **1994**, *59*, 2223.

(9) A preliminary account of this work was published: Amaresh, R. R.; Lakshmikantham, M. V.; Geng, R.; Cava, M. P. *Tetrahedron Lett.* **2000**, *41*, 8843.

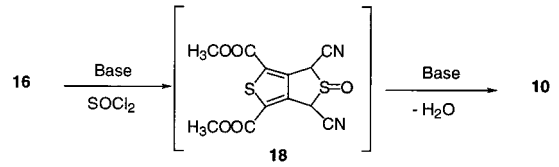
**Scheme 6**



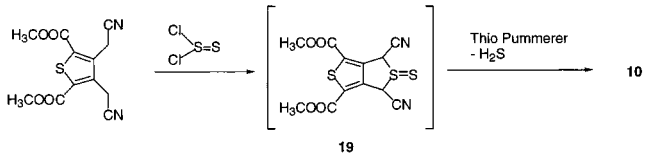
**Scheme 7**



**Scheme 8**



**Scheme 9**



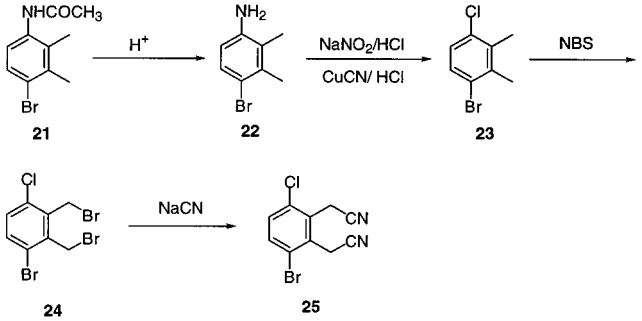
is in order. It is interesting to note that the product **10** could be isolated in the reaction of the bisnitrile **16** with $SCl_2$ in the presence of base, since the expected product would be the dihydro compound **17.** (Scheme 6).

Since **17** must be more acidic than **16** and could readily form an anion/dianion, it is conceivable that oxidation of **16** may have produced **10**. However, since we were unable to improve the yield and most of the starting material was recovered, we were led to conclude that **10** was really forming from the sulfur monochloride contaminant in the $SCl_2$. Indeed, the reaction was carried out with $S_2Cl_2$ in higher yield and the product formation was rationalized as follows (Scheme 7).

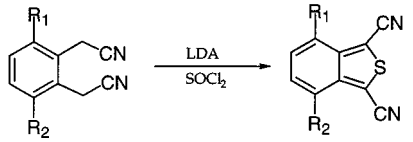
In the case of thionyl chloride as the sulfur transfer reagent, an intermediate sulfoxide**18** must be involved, which then suffers a spontaneous base-catalyzed Pummerer reaction to give **10** in high yield (Scheme 8).

It is intriguing to consider an alternate mechanism for the $S_2Cl_2$ reaction. One can invoke the formation of a transient thiosulfoxide **19**, which could arise by the reaction of the anion/dianion of **16** with the branched chain tautomer of $S_2Cl_2$, viz $Cl_2S{=}S$: thiosulfoxide **19** could then undergo an unprecedented base-catalyzed thio-Pummerer reaction. (Scheme 9) While $Cl_2S{=}S$ is not known, $F_2S{=}S$ is a well-characterized compound.[10] Although some calculations on the two forms of $S_2Cl_2$ support its existence, photoelectron spectroscopic studies

**Scheme 10**



**Scheme 11**



**20** $R_1{=}R_2{=}H$
**25** $R_1{=}Cl$; $R_2{=}Br$

**26** $R_1{=}R_2{=}H$
**27** $R_1{=}Cl$; $R_2{=}Br$

have not detected the $Cl_2S{=}S$ structure.[11,12] On the other hand, the intermediacy of thiosulfoxides has been invoked to explain some reactions.[13]

The possible extension of the use of thionyl chloride as a S-transfer agent for the synthesis of benzo[*c*]-thiophene derivatives was then investigated. The starting materials for our studies were 1,2-phenylendiacetonitrile (**20**) and 1-chloro-4-bromo-2,3-bis(cyanomethyl)benzene (**25**). Diacetonitrile **25** was synthesized from the known 4-bromo-2,3-dimethylacetanlide[14] as shown in Scheme 10.

Thus acetanilide **21** was converted to the amino derivative **22** by acid hydrolysis. Amine **22** was converted into the chloro derivative **23** by diazotization followed by the Sandmeyer reaction to give 64% yield of 1-chloro-4-bromo-2,3-dimethylbenzene. The dimethyl derivative **23** was brominated with NBS to give a 64% yield of dibromide **24**. Reaction of dibromide **24** with buffered NaCN gave dinitrile **25**.

Indeed, both 1,2-phenylenediacetonitrile **20** and 4-bromo-1-chloro-2,3-bis(cyanomethyl)benzene **25** yielded the corresponding 1,3-dicyanobenzo[*c*]thiophenes **26** and **27** in 37% and 50% yields, respectively (Scheme 11), upon generation of their respective anions and reaction with thionyl chloride.

The investigation was then extended to selenium oxychloride as a selenium transfer reagent. Dinitriles **16**, **20**, and **25** reacted with $SeOCl_2$ in the presence of base to give the corresponding selenium analogues **28**−**30** (Scheme 12). Apparently the reactions follow an analogous pathway via selenoxide intermediates.

**Reactions of Dicarbomethoxydicyanothieno[3,4-*c*]thiophene (10).** In contrast to other known derivatives of thieno[3,4-*c*]thiophene, **10** does not undergo Diels−Alder reactions with electron-poor or electron-rich olefins.

(10) (a) Seel, F. Adv. *Inorg. Chem. Radiochem.* **1974**, *86*, 297. (b) Kuczkowski, R. L. *J. Am. Chem. Soc.* **1963**, *85*, 3047. For PES studies see (c) Wagner, G.; Bock, H.; Budenz, R.; Seel, F. *Chem. Ber.* **1973**, *106*, 1285.

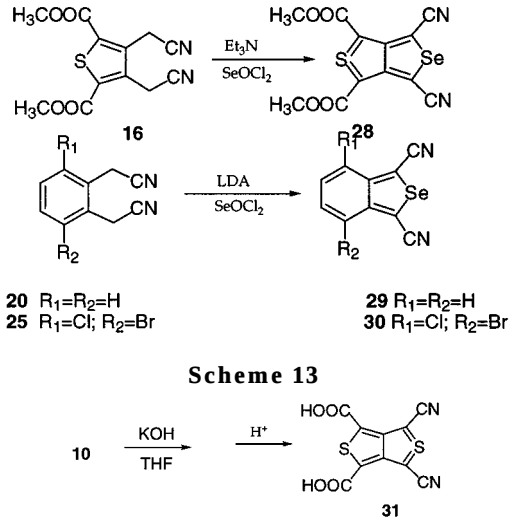
(11) Harpp, D. N. In *Perspectives in the Organic Chemistry of Sulfur;* Zwanenburg, B., Klunder, A. J. H., Eds.; Elsevier: Amsterdam, 1987; pp 1−22.

(12) Solouki, R.; Bock, H. *Inorg. Chem.* **1977**, *16*, 665.

(13) Höfle, G.; Baldwin, J. E. *J. Am. Chem. Soc.* **1971**, *93*, 6307.

(14) Kleinschmidt, E. G.; Braeuiger, H. *Pharmazie* **1969**, *24(2)*, 87.

**Scheme 12**




**Scheme 13**




While the lack of reaction with electron-poor double bonds was not unexpected, absence of reaction with electron-rich olefins such as norbornene was a surprise. Indeed, a highly fluorescent solution of **10** is not quickly decolorized under ambient laboratory conditions. The decomposition was extremely slow, as indicated by changes in the UV−visible spectrum over a period of weeks.

The diester can be hydrolyzed readily at room temperature by aqueous alkali in THF. The resulting aqueous solution of the dianion of the diacid is highly fluorescent. Acidification produced the diacid dinitrile **31** as a stable deep red insoluble solid (Scheme 13).

**Conclusion.** The utility of thionyl chloride as a superior S-transfer agent for the synthesis of nonclassical thienothiophenes and benzo[*c*]thiophenes has been demonstrated. The use of selenium oxychloride produces the analogous annelated selenophene derivatives, albeit in lesser yield than in the case of thionyl chloride giving thiophenes. The tandem Pummerer−alkoxycarbonylation is superior to the tandem Pummerer−cyanation reaction for the synthesis of **10** and its analogues.

## Experimental Section

**General Comments.** Melting points are uncorrected. THF was freshly distilled from sodium−benzophenone.

**2,5-Dicarbomethoxy-3,4-dicyanomethylthiophene 16.** To a stirred solution of dibromide **15** [8a] (6.0 g, 15.4 mmol) in acetonitrile (135 mL) was added a solution of buffered sodium cyanide (9.09 g, 185.5 mmol) in water (30 mL) (the pH of this was adjusted to 9−10 by the slow addition of glacial acetic acid). After adding more acetonitrile (150 mL), the heterogeneous solution was refluxed for about 15−20 min. The solvent was evaporated and ice water was added. The resulting brown solid was filtered and washed with water to give the crude dicyanide in 84% yield. Crystallization from methylene chloride gave the pure product: mp 167.8−168.2 °C; $^1$H NMR ($CDCl_3$, 360 MHz) $\delta$ 4.36 (s, 4H), 3.96 (s, 6H); $^{13}$C NMR ($CDCl_3$, 90 MHz) $\delta$ 161.17, 135.58, 133.90, 115.40, 53.07, 15.38; MS *m*/*z* (relative intensity, %) 278 ($M^+$, 37), 263 (35), 246 (99), 236 (31), 220 (26), 181 (39), 136 (100); IR (KBr) $\nu$ 2260, 1715 $cm^{-1}$. Anal. Calcd for $C_{12}H_{10}N_2O_4S$: C, 51.79; H, 3.62; N, 10.07; S, 11.52. Found: C, 51.95; H, 3.54; N, 9.93; S, 11.40.

**CAUTION:** sodium cyanide is extremely toxic and reaction mixtures should be properly disposed according to safety guidelines

**4,6-Dicyano-1*H*,3*H*-thieno[3,4-*c*]thiophene Sulfoxide (11).** To a stirred solution of 1,3-dihydro-4,6-dicyanothieno-[3,4-*c*]thiophene[8b] (2.3 g, 11.7 mmol) in methanol (65 mL) and benzene (65 mL) was added a solution of sodium periodate (3.84 g, 17.9 mmol) in a water (14 mL). After refluxing for 3 h, the solution was concentrated and extracted with methylene chloride to give **11** in 82% yield. This crude product was used for the next step without further purification: mp 185 °C (dec); $^1$H NMR ($CDCl_3$, 360 MHz) $\delta$ 4.26 (d, 2H, $J$ = 16.92 Hz), 4.07 (d, 2H, $J$ = 16.92 Hz).

**1,3-Dicarbomethoxy-4,6-dicyanothieno[3,4-*c*]thiophene (10). Method I.** To a stirred, ice-cold solution of dicyanide **16** (0.15 g, 0.53 mmol) in dichloromethane (3 mL) was added slowly a solution of sulfur monochloride (0.14 g, 1.07 mmol) in dichloromethane (3 mL). After a few minutes, triethylamine (0.16 g, 1.61 mmol) was added to the above solution. The mixture was stirred overnight. Evaporation of the solvent and column chromatography (50:50, hexane: dichloromethane) gave **10** as a red solid in 44% yield.

**Method II.** To a stirred, ice cold solution of dicyanide **16** (0.15 g, 0.53 mmol) in THF (3 mL) was added slowly a solution of sulfur dichloride (0.11 g, 1.07 mmol) in THF (3 mL). Triethylamine (0.16 g, 1.61 mmol) was added to the above solution. The mixture was stirred overnight. Evaporation of the solvent and column chromatography of the residue gave **10** as a red solid in 10% yield (best yield).

**Method III.** To a stirred, ice-cold solution of dicyanide **16** (1.0 g, 3.59 mmol) in dichloromethane (25 mL) was added slowly a solution of thionyl chloride (0.85 g, 7.19 mmol) in dichloromethane (15 mL). After a few minutes, triethylamine (1.08 g, 10.7 mmol) was added to the above solution. Standard workup gave **10** as a red solid in 74−84% yield.

**Method IV.** To a stirred solution of sulfoxide **11** (0.33 g, 1.5 mmol) in THF (25 mL) at −78 °C was added slowly sodium bis(trimethylsilylamide) (2.4 mL, 6.0 mmol). After 1 h the mixture was warmed to room temperature for 30 min. The reaction mixture was recooled to −78 °C, and TMEDA (0.87 g, 7.5 mmol) and *n*-butyllithium (2.4 mL, 6.0 mmol) were added. After 45 min, a solution of methyl chloroformate (0.56 g, 6.0 mmol) in THF (5 mL) was added. After 4 h, the mixture was quenched with saturated ammonium chloride solution, extracted with dichloromethane, washed with water and sodium chloride solution, and dried. Chromatotron separation of the residue gave **10** in 10% yield: mp 226.4−226.6 °C; $^1$H NMR ($CDCl_3$, 360 MHz) $\delta$ 4.06 (s, 6H); $^{13}$C NMR ($CDCl_3$, 90 MHz) $\delta$ 160.37, 144.88, 122.29, 118.82, 100.40, 52.82; MS *m*/*z* (relative intensity, %) 306 ($M^+$, 97), 275 (100), 248 (39), 217 (21), 205 (119), 190 (21), 118 (31); IR (KBr) $\nu$ 2213, 1715 $cm^{-1}$; UV−vis ($CH_2Cl_2$) $\lambda_{max}$ nm (log $\epsilon$) 476 (3.86), 317 (3.70), 250 (3.81), 222 (3.88); fluorescence $\lambda_{excitation}$ 476 nm, $\lambda_{emision}$ 525 nm. Anal. Calcd for $C_{12}H_6N_2O_4S_2$: C, 47.05; H, 1.97; N, 9.15; S, 20.94. Found: C, 46.64; H, 2.13; N, 9.03; S, 20.82.

**1,3-Dicarbethoxy-4,5-dicyanothieno[3,4-*c*]thiophene (12).** The dicarbethoxy analogue **12** was prepared in 15% yield in an analogous fashion using sulfoxide **11** and ethyl chloroformate: mp 161.8−162.2 °C; $^1$H NMR ($CDCl_3$, 360 MHz) $\delta$ 4.55 (q, 4H), 1.47 (t, 6H); $^{13}$C NMR ($CDCl_3$, 90 MHz) $\delta$ 160.06, 144.94, 122.54, 111.98, 100.29, 62.83, 14.33; MS *m*/*z* (relative intensity, %) 334 ($M^+$, 50), 306 (16), 234 (100), 190 (36), 145 (11); IR (KBr) $\nu$ 2210, 1719 $cm^{-1}$; UV−vis ($CH_2Cl_2$) $\lambda_{max}$ nm (log $\epsilon$) 281 (3.97), 481 (3.53); fluorescence $\lambda_{excitation}$481 nm, $\lambda_{emission}$ 541 nm. Anal. Calcd for $C_{14}H_{10}N_2O_4S_2$. C, 50.29; H, 3.01; N, 8.38; S, 19.18. Found: C, 50.13; H, 3.14; N, 8.14; S, 18.97.

**1,3,4,6-Tetracarbomethoxythieno[3,4-*c*]thiophene (14).** To a stirred solution of sulfoxide **13**[4b] (0.41 g, 1.5 mmol) in THF (20 mL) at −78 °C was added slowly sodium bis-(trimethylsilylamide) (2.4 mL, 6.0 mmol). After 1 h the mixture was warmed to room temperature for 30 min. The reaction mixture was recooled to −78 °C, and TMEDA (0.87 g, 7.5 mmol) and *n*-butyllithium (2.4 mL, 6.0 mmol) were added. After 45 min, a solution of methyl chloroformate (0.56 g, 6.0 mmol) in THF (5 mL) was added. After 4 h, the mixture was quenched with saturated ammonium chloride solution, extracted with dichlormethane, washed with water and sodium chloride solution, and dried. Chromatotron separation gave **14** in 10% yield: mp 171.1−172.6 °C; $^1$H NMR ($CDCl_3$, 360 MHz) $\delta$ 3.96 (s, 6H), 3.86 (s, 3H), 3.76 (s, 3H); $^{13}$C NMR ($CDCl_3$, 90

MHz) δ 172.40, 166.14, 149.95, 144.06, 128.53, 120.60, 48.19, 52.68, 52.80, 53.01; MS *m/z* (relative intensity, %) 372 ($M^+$, 100), 341 (97), 314 (69), 283 (72), 256 (32), 225 (25), 184 (28), 154 (32), 126 (21); IR (KBr) 1729, 1715 ν $cm^{-1}$; UV−vis ($CH_2Cl_2$) $\lambda_{max}$ nm (log ε) 482 (3.98), 319 (4.07); fluorescence $\lambda_{excitation}$ 481 nm, $\lambda_{emission}$ 541 nm; HRMS for $C_{14}H_{12}O_8S_2$ 371.9973, found 371.9965.

**4-Bromo-2,3-dimethylaniline (22).** A mixture of acetanilide **21**[14] (29.6 g, 122 mmol) in ethanol (125 mL) containing 51 mL of concentrated HCl was refluxed till the disappearance of starting material. The reaction mixture was poured into ice water and was neutralized with a 2 M solution of sodium hydroxide. The light brown solid that separated was filtered and washed with water to give **22** in 90% yield: mp 214 °C (dec); $^1$H NMR ($CDCl_3$, 360 MHz) δ 7.16 (d, 1H, *J* = 8.64 Hz), 6.39 (d, 1H, *J* = 8.64 Hz), 3.47 (brs, 2H), 2.08 (s, 3H); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 143.70, 136.02, 129.89, 122.60, 114.33, 114.22, 20.0, 14.11; MS *m/z* (relative intensity, %) 334 ($M^+$, 50), 306 (16), 234 (100), 190 (36), 145 (11).

**1-Chloro-4-bromo-2,3-dimethylbenzene (23).** A solution of aniline **22** (19.0 g, 95 mmol) dissolved in concentrated HCl (21.8 mL), concentrated $H_2SO_4$ (11 mL), and glacial HOAc (33 mL) was cooled to −5 °C. A solution of sodium nitrite (6.55 g, 95 mmol) in water (28.5 mL) was added slowly, so that the temperature of the reaction mixture did not exceed −3 °C. After 15 min of stirring and filtration, and the filtrate was added to a mixture of CuCN (8.50 g, 95 mmol) in concentrated HCl (19 mL) and refluxed for 1 h. The reaction mixture was poured into ice water containing ammonia, extracted with methylene chloride, and washed with 10% HCl solution, water, and brine. The extract was dried over sodium sulfate, and column chromatography of the residue with hexane as eluent gave **23** in 65% yield: $^1$H NMR ($CDCl_3$, 360 MHz) δ 7.30 (d, 1H, *J* = 8.64 Hz), 7.05 (d, 1H, *J* = 8.64 Hz), 2.38 (s, 3H), 2.35 (s, 3H); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 137.85, 136.19, 133.69, 130.50, 127.65, 123.34, 20.66, 17.77; MS *m/z* (relative intensity, %) 219 ($M^+$, 75), 221 ($M^+ + 2$, 99.0), 223 ($M^+ + 4$, 26.1), 183 (39.5), 139 (100), 102 (71.1).

**1-Chloro-4-bromo-2,3-bis(bromomethyl)benzene (24).** The dibromide **24** was obtained by the treatment of dimethyl derivative **23** with NBS in a standard procedure and used directly in the next step: mp 101.9−102.3 °C;$^1$H NMR ($CDCl_3$, 360 MHz) δ 7.58 (d, 1H, *J* = 8.28 Hz), 7.51 (d, 1H, *J* = 8.28 Hz), 4.78 (s, 2H),4.76 (s, 2H); $^{13}$C NMR ($CDCl_3$, 90 MHz) 141.88, 140.60, 136.39, 133.53, 130.86, 115.85, 25.48, 24.50; MS *m/z* (relative intensity, %) 377 ($M^+$, 24.1), 379 (M + 2, 19.4), 381 (M + 4, 18.1), 297 (71.8), 218 (100), 183 (12.0), 137 (41.0), 109 (15.4).

**1-Chloro-4-bromo-2,3-bis(cyanomethyl)benzene (25).** The above dibromide **24** was converted into dicyanide **25** in 95% yield as described for **16**: mp 191.6 °C (recrystallized from ethanol);$^1$H NMR ($CDCl_3$, 360 MHz) δ 7.63 (d, 1H, *J* = 8.64 Hz), 7.38 (d, 1H, *J* = 8.64 Hz), 4.08 (s, 2H), 4.05 (s, 2H); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 134.99, 134.49, 131.41, 131.16, 129.55, 124.29, 115.02, 114.96; MS *m/z* (relative intensity, %) 269 ($M^+$, 46.3), 271 (M + 2, 14.07), 273 (M + 4, 3.3), 243 (100), 216 (8.0), 206 (8.7), 189 (14.0), 162 (28.8), 127 (29.5). Anal. Calcd for $C_{10}H_6BrClN_2$: C, 44.58; H, 2.24; N, 10.39. Found: C, 44.45; H, 2.23; N, 10.39.

**1,3-Dicarbomethoxy-4,6-dicyanothieno[3,4-*c*]selenophene (28).** To a stirred, ice-cold solution of dicyanide **16** (0.15 g, 0.53 mmol) in dichloromethane (3 mL) was added slowly a solution of selenium oxychloride (0.17 g, 1.07 mmol) in dichloromethane (3 mL). Triethylamine (0.16 g, 1.61 mmol) was added to the above solution. The mixture was stirred overnight. Evaporation of the solvent and column chromatography (12:88, ethyl acetate:hexane) gave **28** as a rose-red solid in 10% yield: mp 181.1−182.8 °C; $^1$H NMR ($CDCl_3$, 360 MHz) δ 4.05 (s, 6H); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 160.53, 148.01, 114.0, 107.52, 52.79; MS *m/z* (relative intensity, %) 353 ($M^+$, 20), 352 (76), 334 (25), 333 (100), 303 (51), 282 (33), 268 (49), 251 (48), 236 (51), 171 (35), 118 (36); IR (KBr) ν 2212, 1716 $cm^{-1}$; HRMS for $C_{12}H_6N_2O_4Se$ 353.921, found 353.921.

**General Procedure for the Synthesis of Dicyanobenzo[*c*]thiophene Derivatives. 1,3-Dicyanobenzo[*c*]thiophene (26).** LDA solution was prepared at −78 °C by slow addition of *n*-butyllithium (1.75 mL, 4.5 mmol) to a stirred solution of diisopropylamine (0.45 g, 4.5 mmol) in THF (5 mL). After 15 min, a solution of dicyanide **20** (0.23 g, 1.5 mmol) in THF (5 mL) was added slowly, with continued stirring for 15 min. To this mixture, a solution of thionyl chloride (0.35 g, 3.0 mmol) in THF (3 mL) was added. The reaction mixture was warmed to room temperature and stirred for 7−8 h. After quenching with 10% HCl solution, standard workup and column chromatography (80:20, hexane: dichloromethane) gave **26** as a yellow solid in 37% yield. The analytical sample was obtained by recrystallization from benzene: mp 183.1−183.4 °C; $^1$H NMR ($CDCl_3$, 360 MHz) δ 7.88 (2H, dd, *J* = 2.88 Hz), 7.53 (2H, dd, *J* = 3.24 Hz); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 142.21, 129.04, 120.89, 112.25, 106.31; MS *m/z* (relative intensity, %) 184 ($M^+$, 100), 157 (16), 140 (10); IR (KBr) ν 2211 $cm^{-1}$. Anal. Calcd for $C_{10}H_4N_2S_2$: C, 65.20; H, 2.19; N, 15.20; S, 17.40. Found: C, 64.92; H, 2.20; N, 14.98; S, 17.35.

**1,3-Dicyanobenzo[*c*]selenophene (29).** The foregoing general procedure was followed, using **20** (0.23 g, 1.5 mmol) and selenium oxychloride (0.49 g, 3.0 mmol). Column chromatography (80:20, hexane:dichlormethane) gave **29** as a yellow solid in 10% yield: mp 231.0−232.1 °C; $^1$H NMR ($CDCl_3$, 360 MHz) δ 7.78 (2H, dd, *J* = 2.88 Hz), 7.53 (2H, dd, *J* = 3.24 Hz); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 145.30, 128.69, 121.73, 114.36, 112.62; MS *m/z* (relative intensity, %) 232 ($M^+$, 100), 152 (43); IR (KBr) ν 2203 $cm^{-1}$. Anal. Calcd for $C_{10}H_4N_2SSe$: C, 51.96; H, 1.74; N, 12.12. Found: C, 52.63; H, 1.83; N, 11.85.

**4-Bromo-7-chloro-1,3-dicyanobenzo[*c*]thiophene (27).** The general procedure was followed, using dicyanide **25** (0.25 g, 1.0 mmol) and thionyl chloride (0.49 g, 3.0 mmol). After 5 h, workup and column chromatography (65:35, hexane:dichlormethane) gave **27** as a yellow solid in 50% yield. An analytical sample was obtained by recrystallization from benzene: mp 270.5−271.0 °C; $^1$H NMR ($CDCl_3$, 360 MHz) δ 7.60 (1H, d, *J* = 7.92 Hz), 7.31 (1H, d, *J* = 7.92 Hz); $^{13}$C NMR ($CDCl_3$, 90 MHz) δ 139.46, 133.11, 129.22, 127.14, 114.11, 111.99, 111.89; MS *m/z* (relative intensity, %) 297 ($M^+$, 100), 217 (69), 182 (76), 149 (15); IR (KBr) ν 2211 $cm^{-1}$. Anal. Calcd for $C_{10}H_2BrClN_2S$: C, 40.36; H, 0.68; N, 9.41; S, 10.78. Found: C, 40.23; H, 0.75; N, 9.24; S, 10.62.

**4-Bromo-7-chloro-1,3-dicyanobenzo[*c*]selenophene (30).** The general procedure was followed, using dicyanide **25** (0.25 g, 1.0 mmol) and selenium oxychloride (0.33 g, 2.0 mmol). After 10 h, workup and column chromatography (50:50, hexane: dichloromethane) yielded **30** as a reddish brown solid in 30% yield. An analytical sample was obtained by recrystallization from benzene: mp 324.0−325.0 °C; $^1$H NMR ($C_6D_6$, 360 MHz) δ 6.48 (1H, d, *J* = 7.92 Hz), 6.51 (1H, d, *J* = 7.92 Hz); MS *m/z* (relative intensity, %) 345 ($M^+$, 16), 344 (100), 298 (64), 282 (25), 265 (38), 230 (40), 182 (25), 149 (32), 113 (56); IR (KBr) ν 2208 $cm^{-1}$. Anal. Calcd for $C_{10}H_2BrClN_2Se$: C, 34.87; H, 0.59; N, 8.13. Found: C, 34.70; H, 0.70; N, 8.04.

**Diels−Alder Reaction of 1,3-Dicarbomethoxy-4,6-dicyanothieno[3,4-c]thiophene.** The starting material (**10**) was recovered from all attempted Diels−Alder reactions with *N*-phenylmaleimide or norbornene, even after refluxing benzene solutions for 3−4 days.

**1,3-Dicarboxy-4,6-dicyanothieno[3,4-*c*]thiophene (31).** To a stirred solution of thieno[3,4-*c*]thiophene **10** (0.1 g, 0.32 mmol) in THF (14 mL) was added potassium hydroxide (0.065 g, 1.1 mmol) in water (5 mL) After 4 h, the red potassium salt of the carboxylic acid was filtered. The mother liquor was evaporated. The total crude salt was dissolved in 10 mL of water and neutralized to pH 3−4 with 10% HCl solution, to give the diacid as a red solid in quantitative yield.

Potassium salt of carboxylic acid **31**: $^{13}$C NMR ($D_2O$, 360 MHz) δ 170.33, 147.59, 130.21, 116.47, 101.32; IR (KBr) ν 3268, 2214, 1690 $cm^{-1}$. Acid **31**: mp 226.4−226.0 °C (dec); MS *m/z* (relative intensity, %) 234 ($M^+ - CO_2$, 13), 217 (10), 190 (100), 146 (9), 118 (10); IR (KBr) ν 3447, 2212, 1687 $cm^{-1}$.

**X-ray Crystal Structure of 10.** The crystal structure was determined by mounting an orange-red single crystal of **10**

under a stream of cold nitrogen gas (173 K) on a Siemens SMART diffractometer equipped with a CCD area detector and Mo Kα X-radiation ($\lambda = 0.71073$ Å). The compound crystallizes in the monoclinic space group $P2_1/c$ with latttice constants $a$ = 8.2844(5) Å, $b$ = 11.4189(7) Å, $c$ = 13.2859(8) Å, $\beta$ = 101.300(2)°, $V$ = 1232.46 (13) Å$^3$, $D_{calc}$ = 1.651 g cm$^{-3}$ for $Z$ = −4. A total of 2842 reflections were collected, corrected for Lorentz and polarization effects, and empirically corrected for absorption using simulated Ψ-scans from area detector data. The crystal structure solution (by direct methods) and refinement were carried out using the SHELXTL package of computer programs. The final refinement, using data for which $F^2 > 2\sigma(F^2)$, had $R$ (based on $F_{obs}$) = 4.04%.

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**Supporting Information Available:** $^1$H NMR spectra of **10**−**12**, **14**, **16**, and **22**−**30**; $^{13}$C NMR spectra of **10**, **12**, **14**, **16**, **22**−**29**, and **31**; ORTEP drawings of **10**; and tables of crystal structure and refinement data for **10**, including observed and calculated structure factors. This material is available free of charge via the Internet at http://pubs.acs.org.

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