Thiophene Analogs of Phenanthrene. I. Benzo[1,2-*c*:3,4-*c*′]dithiophene

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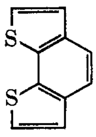
Conversion of 4,4′-dibromo-3,3′-bithienyl(**10**) into 4,4′-diformyl-3,3′-bithienyl (**11**) afforded a useful intermediate from which benzo[1,2-*c*:3,4-*c*′]dithiophene (**6**), a new thiophene analog of phenanthrene, was prepared. The uv and nmr spectra of **6** indicate more formal resemblance to *cis*-1,2-di(3-thienyl)ethylene than to phenanthrene. Compound **6** showed much less stability than phenanthrene. Metalation of **6** with *n*-butyllithium, followed by treatment with N,N-dimethylformamide, afforded a mixture of 1-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (**15**) and 3-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (**16**), separable by tlc in the proportions of 64% **15** and 36% **16**. Reduction of **11** to the bishydroxymethyl compound followed by acid-catalyzed cyclization gave 4,6-dihydrodithieno[3,4-*c*:3′,4′-*e*]oxepin (**14**). The dialdehyde **11** could be transformed into 7,8-epoxy-7,8-dihydrobenzo[1,2-*c*:3,4-*c*′]dithiophene (**12**) by the use of hexamethylphosphorus triamide.

The fusion of two thiophene rings to adjacent positions of a benzene ring can give rise to six possible isomeric benzodithiophenes, **1**–**6**, as shown below.



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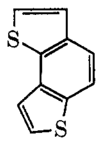

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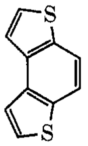

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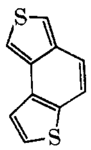

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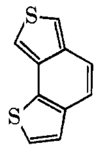

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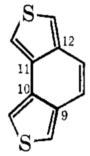

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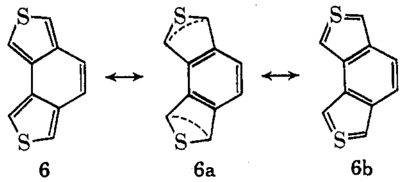
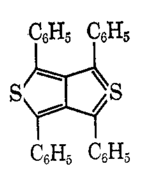
Of these possible isomers, benzo[2,1-*b*:3,4-*b*′]dithiophene (**1**),[1] benzo[1,2-*b*:3,4-*b*′]dithiophene (**2**),[2] and benzo[1,2-*b*:4,3-*b*′]dithiophene (**3**)[3] have been reported in the literature. No derivatives of benzo[1,2-*b*:3,4-*c*′]dithiophene (**4**), benzo[2,1-*b*:3,4-*c*′]dithiophene (**5**), or benzo[1,2-*c*:3,4-*c*′]dithiophene (**6**) appear to have been reported in the literature. Compound **6** shows less formal resemblance to phenanthrene than do any of the compounds **1**–**5**. A comparison of the structure of **6** with that of phenanthrene shows that, while several representations of phenanthrene may be written with the central ring possessing a benzenoid structure, this state of affairs is much less likely to pertain in **6** because of the decreased possibility of electron delocalization across the 9–10 and 11–12 bonds in **6**. However, in the light of recent work by Cava[4] and Schlessinger,[5] who report the synthesis of tetraphenylthieno[3,4-*c*]thiophene (**7**) and 1,3,6,7-tetraphenylacenaphtho[5,6-*cd*]thiopyran (**8**), it is not improbable that structures of the type of **6b** involving do-rbital participation by sulfur may contribute to the overall structure of **6**.



6 **6a** **6b**



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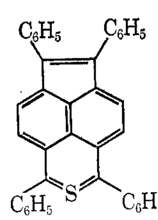

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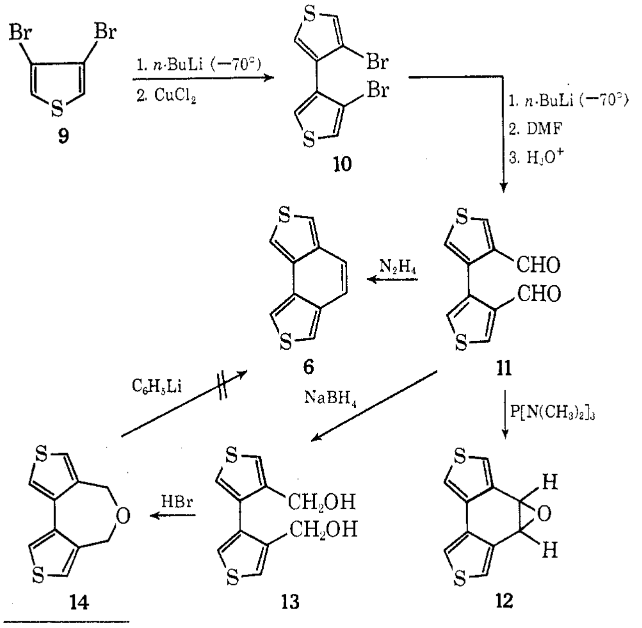
The synthesis of **6** was undertaken with a view to comparing its properties with those of phenanthrene. 3,4-Dibromothiophene[6] (**9**) was transformed into 3-bromo-4-lithiothiophene at −70° and coupled in the presence of copper(II) chloride to give 4,4′-dibromo-3,3′-bithienyl (**10**).[7] The dibromide **10**, upon halogen–metal interchange with *n*-butyllithium followed by formylation with N,N-dimethylformamide, afforded 4,4′-diformyl-3,3′-bithienyl (**11**) in 50% yield. Subjection of the dialdehyde **11** to treatment with Mark reagent,[8] hexamethylphosphorous triamide, resulted in a low yield of the epoxide **12**, the ir and nmr spectra of



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[1] D. S. Rao and B. D. Tilak, *J. Sci. Ind. Res.* (India), **17B**, 260 (1958); *Chem. Abstr.*, **55**, 22282*e* (1960).

[2] D. S. Rao and B. D. Tilak, *J. Sci. Ind. Res.* (India), **13B**, 829 (1954); *Chem. Abstr.*, **50**, 934b (1956); R. M. Kellogg, M. B. Groen, and H. Wynberg, *J. Org. Chem.*, **32**, 3093 (1967).

[3] D. S. Rao and B. D. Tilak, *J. Sci. Ind. Res.* (India), **16B**, 65 (1957); *Chem. Abstr.*, **51**, 13841*i* (1957); C. E. Loader and C. J. Timmons, *J. Chem. Soc., C*, 1677 (1967).

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[6] S. Gronowitz, P. Moses, and R. Hakansson, *Ark. Kemi*, **16**, 267 (1960).

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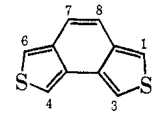
[8] V. Mark, *Org. Syn.*, **46**, 42 (1966).

which showed the characteristics of an epoxide. Attempts to transform this epoxide into hydroxy derivatives of **6** were unfruitful. A second synthetic approach to **6** proceeded as follows. Reduction of the dialdehyde **11** with sodium borohydride in ethanol solution provided the corresponding dialcohol, **13**, in 90% yield. Treatment of the dialcohol with 16% hydrobromic acid solution caused cyclization to occur, resulting in the formation of 4,6-dihydrodithieno[3,4-*c*:3′,4′-*e*]oxepin (**14**). Attempts to apply a Wittig rearrangement[9] to **14** to produce an alcohol which could be dehydrated to form **6** proved ineffective, the only product isolable from quenching the Wittig reaction being starting material.

Benzo[1,2-*c*:3,4-*c*′]dithiophene (**6**) was obtained from **11** by the use of hydrazine following a modification of the method of Bacon and coworkers.[10] The modification consisted of slowly distilling a mixture of the dialdehyde **11**, hydrazine, water, and sulfuric acid. The azine formation takes place *in situ* followed by decomposition to **6** accompanied by evolution of nitrogen. The product **6** distils with the aqueous distillate and is obtained in a pure state after recrystallization in a yield of 20% from **11**. The benzo[1,2-*c*:3,4-*c*′]dithiophene (**6**) is a white solid melting at 112–113° and darkens slightly upon an overnight exposure to air. It could, however, be stored unchanged for several months in a refrigerator. The nmr spectrum of **6** indicates that the 7,8 bond exhibits considerably more olefinic character than the analogous 9,10 bond of phenanthrene, the 7- and 8-hydrogen resonance appearing as a singlet at τ 3.08, whereas the 9 and 10 hydrogens of phenanthrene absorb at τ 2.44[11] (Table I).

Table I



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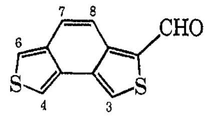

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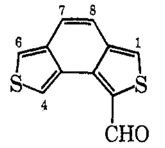

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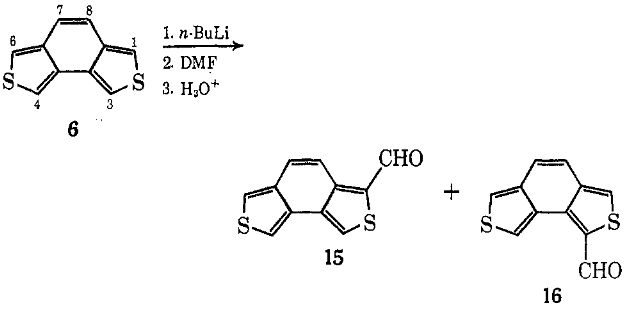
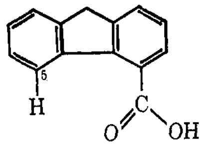
Proton	τ	Proton	τ	Proton	τ
1,6	2.75 (m, 2H)	CHO	−0.37 (s, 1H)	1	1.57 (s, 1H)
	$J_{1,3}$ = 3 Hz	3	1.28 (s, 1 H)	CHO	−0.52 (s, 1 H)
	$J_{1,8}$ = 0.5 Hz	4	1.70 (d, 1 H)	4	1.05 (d, 1 H)
3,4	2.48 (d, 2 H)		$J_{4,6}$ = 3 Hz		$J_{4,6}$ = 3 Hz
	$J_{1,3}$ = 3 Hz	6	2.07 (d, 1 H)	6	2.07 (d, 1 H)
7,8	3.08 (s, 2 H)		$J_{4,6}$ = 3 Hz		$J_{4,6}$ = 3 Hz
		7	2.50 (d, 1 H)	7,8	2.73 (s, 2 H)
			$J_{7,8}$ = 10 Hz		
		8	2.12 (d, 1 H)		
			$J_{7,8}$ = 10 Hz		

The ultraviolet spectrum of **6** showed a maximum at 273.5 mμ (ϵ 38,400). In the light of the shorter wavelength of absorption of *cis*-stilbene, compared with that of *trans*-stilbene, and the recently reported value for *trans*-1,2-di(3-thienyl)ethylene by Wynberg and coworkers[2] [291 mμ (ϵ 31,600)], the reported value for **6** would seem to indicate that the 7,8 bond in benzo[1,2-*c*:3,4-*c*′]dithiophene is more like the double bond in *cis*-stilbene than the 9,10 bond in phenanthrene.

When benzo[1,2-*c*:3,4-*c*′]dithiophene was treated with slightly more than 1 molar equiv of *n*-butyllithium in ether at −30°, metalation took place. The site of metalation was determined by adding N,N-dimethylformamide to the lithiated compound at −30°, quenching the reaction mixture, and isolating and identifying the solid product. The resulting mixture consisted of 1-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (**15**) and 3-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (**16**). Separation of the mixture was effected by preparative thin layer chromatography and the components **15** and **16** were shown to constitute *ca.* 64 and 36% of the mixture, respectively. The nmr absorptions of **6**, **15**, and **16** are summarized in Table I. In the case of the 3-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (**16**), the assignment of the carboxaldehyde group to the 3 position is based upon the shift of H_4 to lower fields in **16** owing to the proximate anisotropic effect of the aldehyde carbonyl group in the 3 position. Precedent for this exists in the cases of fluorene-4-carboxylic acid (**17**), where H_5 absorbs at τ 1.50, and 8H-indeno[1,2-*c*]thiophene-3-carboxylic acid[12] (**18**), where H_4 absorbs at τ 1.25.[12] The assignment of the aldehyde group to the 1 position in **15** is in agreement with the chemical shifts of the ring protons and the dissimilarity of the 7 and 8 protons, resulting in splitting of one another.





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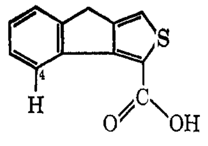

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Experimental Section[13]

4,4′-Diformyl-3,3′-bithienyl (II).—Into a 1-l. three-necked flask under an atmosphere of dry nitrogen was placed 1.05 *M* *n*-butyllithium solution (300 ml, 0.32 mol). The solution was cooled to −70° and a solution of 4,4′-dibromo-3,3′-bithienyl (**10**, 48.3 g, 0.15 mol) in anhydrous tetrahydrofuran (350 ml) was added. The mixture was stirred at −70° for 30 min and then (70 ml, 66.5 g, 0.91 mol) N,N-dimethylformamide in anhydrous ether (50 ml) was added. After a further 1-hr period of stirring, the mixture was allowed to warm to room temperature and was hydrolyzed by the addition of water (100 ml). The aqueous layer was separated and extracted with methylene chloride. The organic extracts were combined, washed with dilute hydro-

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(10) R. G. R. Bacon and W. S. Lindsay, *J. Chem. Soc.*, 1382 (1958); R. G. R. Bacon and R. Bankhead, *ibid.*, 839 (1963).

(11) K. D. Bartle and S. A. S. Smith, *Spectrochim. Acta*, **23A**, 1689 (1967).

(12) D. W. H. MacDowell and A. T. Jeffries, *J. Org. Chem.*, in press.

(13) All temperatures are uncorrected. Elemental analyses were performed by Galbraith Laboratories, Knoxville, Tenn. Nuclear magnetic resonance spectra were recorded on a Varian HA-60 spectrometer using tetramethylsilane as an internal standard (τ 10) and solvents as specified. The ultraviolet spectra were determined in 95% ethanol on a Bausch and Lomb spectronic 505. Infrared spectra were recorded on a Perkin-Elmer Model 137B and on a Beckman IR-8 spectrophotometer.

chloric acid and water, and dried (Na_2SO_4). Removal of the solvents yielded a yellow solid (22 g). Three recrystallizations from chloroform gave **11**: yield 17 g (50%); mp 167–168°; ir (KBr) 1675 cm^{-1} (C=O); nmr (DMSO-d_6) τ 0.15 (2, s H, CHO), 1.44 (d, 2 H, J = 3 Hz, thiophene), and 2.40 (d, 2 H, J = 3 Hz, thiophene).

Anal. Calcd for $C_{10}H_6O_2S_2$: C, 54.03; H, 2.72; S, 28.25. Found: C, 53.86; H, 2.79; S, 28.73.

4,4′-Bis(hydroxymethyl)-3,3′-bithienyl (13).—To a stirred mixture of sodium borohydride (3 g, 0.08 mol) and ethanol (200 ml) cooled to 0° was slowly added 4,4′-diformyl-3,3′-bithienyl (5 g, 0.0223 mol). After the addition was complete, the mixture was allowed to warm up to room temperature and was stirred for a further 3 hr. The solvent was removed under reduced pressure and the gray, solid residue was cautiously treated with cold 5 M hydrochloric acid (12 ml). The resulting supension was made slightly basic with aqueous sodium hydroxide solution and then extracted with ether. The organic extract was washed with water and dried (Na_2SO_4). Removal of the solvent left a white, crystalline solid (4.7 g) which was recrystallized from benzene to afford **13**: yield 4.5 g (90%); mp 136–137°; ir (KBr) 3500–3350 cm^{-1} (typical OH absorption); nmr (DMSO-d_6) τ 2.70 (m, 4 H, thiophene), 5.03 (t, 2 H, J = 5.0 Hz, OH), and 5.75 (d, 4 H, J = 5.0 Hz, methylene).

Anal. Calcd for $C_{10}H_{10}O_2S_2$: C, 53.07; H, 4.45; S, 28.34. Found: C, 53.24; H, 4.39; S, 28.21.

4,6-Dihydrodithieno[3,4-*c*:3,4-*e*]oxepin (14).—A mixture of 4,4′-bis(hydroxymethyl)-3,3′-bithienyl (2 g, 0.0089 mol) and 16% hydrobromic acid solution (75 ml) was heated with stirring on a steam bath for 45 min. The reaction mixture was cooled and the yellow, solid material was extracted with ether. The ethereal extract was washed with aqueous sodium bicarbonate solution, sodium chloride solution, and finally with water and dried (Na_2SO_4). Removal of the ether left a slightly yellow solid (1.5 g). Recrystallization from aqueous ethanol afforded **14** as white cubes: yield 1.2 g (65%); mp 108–109°; ir (KBr) 1065 cm^{-1} (s, ether); nmr (CS_2) τ 2.70 (d, 2 H, J = 3 Hz, thiophene), 3.00 (m, 2 H, thiophene), and 5.36 (s, 4 H, CH_2).

Anal. Calcd for $C_{10}H_8OS_2$: C, 57.66; H, 3.87; S, 30.79. Found: C, 57.96; H, 3.89; S, 31.08.

7,8-Dihydro-7,8-epoxybenzo[1,2-*c*:3,4-*c*′]dithiophene (12).—A solution of 4,4′-diformyl-3,3′-bithienyl (2.22 g, 0.01 mol) in anhydrous benzene (45 ml) was heated under reflux. To the refluxing solution was added, over a 5-min interval, hexamethylphosphorous triamide.[8] The mixture was heated under reflux for an additional 1 hr. The solvent was then removed under reduced pressure at room temperature, leaving a yellow, oily solid. Trituration with cold hexane left 1.4 g of solid material. Four recrystallizations from cyclohexane gave 7,8-dihydro-7,8-epoxybenzo[1,2-*c*:3,4-*c*′]dithiophene: yield 0.5 g (24%); mp 143–144°; ir (KBr) 875 cm^{-1} (oxirane); nmr ($CDCl_3$) τ 2.27 (d, 2 H, J = 3 Hz, thiophene), 2.38 (d, 2 H, J = 3 Hz, thiophene), and 5.47 (s, 2 H, epoxide).

Anal. Calcd for $C_{10}H_6OS_2$: C, 58.23; H, 2.93; S, 31.09. Found: C, 58.43; H, 2.85; S, 31.22.

Benzo[1,2-*c*:3,4-*c*′]dithiophene (6).—In a 500-ml round-bottomed flask fitted with a Claisen head and condenser arranged for removal of solvent by distillation was placed 4,4′-diformyl-3,3′-bithienyl (1.11 g, 0.005 mol) and water (200 ml). To this mixture was added slowly over a 30-min period a solution of 95% hydrazine (0.5 ml) in water (30 ml). After the brown precipitate of azine had formed, concentrated sulfuric acid (2 ml) was added and the mixture was heated to boiling. Water was removed by distillation and crude benzo[1,2-*c*:3,4-*c*′]dithiophene was passed over in the distillate. The aqueous distillate was extracted at periodic intervals with ether, and the aqueous portion of the distillate was returned to the reaction flask. After 7 hr, a total of 0.22 g (23%) of product had been collected. Sublimation of this product, followed by recrystallization from methanol, afforded pure product, yield 0.17 g (16%), mp 112–113°. Yields in several runs varied from 16 to 22%. The ultraviolet spectrum (95% EtOH) showed maxima at 216 mμ (ϵ 16,650), 273.5 (38,400), and 322 (11,910). For the nmr spectrum (CS_2) see Table I.

Anal. Calcd for $C_{10}H_6S_2$: C, 63.12; H, 3.18; S, 33.70. Found: C, 63.12; H, 3.30; S, 33.65.

The Reaction of Benzo[1,2-*c*:3,4-*c*′]dithiophene with *n*-Butyllithium and N,N-Dimethylformamide.—A solution of benzo[1,2-*c*:3,4-*c*′]dithiophene (0.855 g, 0.0045 mol) in anhydrous ether (30 ml) was stirred magnetically in a nitrogen atmosphere at −30°. To the stirred mixture was added 0.46 M *n*-butyllithium (13 ml, 0.006 mol). The stirring was continued for 1 hr while the temperature was maintained at −30 to −20°, during which time the solution acquired a yellow color. A solution of N,N-dimethylformamide (3 ml) in anhydrous ether (10 ml) was then added at once and the resulting mixture was stirred at the same temperature for a further 30 min. The solution was allowed to warm up to room temperature and was quenched by the addition of 20 ml of cold water. The aqueous layer was thoroughly extracted with ether and the ether extracts were washed with dilute hydrochloric acid. The organic extract was dried (Na_2SO_4) and the solvent was removed under reduced pressure to leave a brown, oily solid (1.05 g). The nmr spectrum of this oil indicated the presence of two aldehydes.

A small portion of this mixture of aldehydes (150 mg) was dissolved in acetone and placed on three preparative thin layer chromatographic plates (20 × 20 × 0.1 cm) using silica gel as adsorbent and benzene as eluent. Three fractions were obtained: fraction 1, yellow solid, R_f *ca.* 0.48, 34 mg; fraction 2, yellow solid, R_f *ca.* 0.44, 60 mg; and fraction 3, brown, oily material, R_f *ca.* 0.20, 36 mg.

Purification of Fraction 1.—The yellow solid was sublimed at 80° (0.05 mm) and then recrystallized from methanol to yield yellow plates (28 mg), mp 98–99.5°. The infrared spectrum (KBr) showed a band at 1635 cm^{-1} (CHO). For the nmr spectrum (DMSO-d_6), see Table I.

Anal. Calcd for $C_{11}H_6OS_2$: C, 60.52; H, 2.77; S, 29.38. Found: C, 60.36; H, 2.68; S, 29.53.

These data are consistent with the assignment of the structure of fraction 1 as 3-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (16).

Purification of Fraction 2.—This fraction was also purified by sublimation and recrystallization from methanol to yield yellow plates (53 mg), mp 151.5–153°. The infrared spectrum (KBr) showed the expected aldehyde band at 1650 cm^{-1}. For the nmr spectrum (DMSO-d_6), see Table I.

Anal. Calcd for $C_{11}H_6OS_2$: C, 60.52; H, 2.77; S, 29.38. Found: C, 60.73; H, 2.98; S, 29.60.

These data are in agreement with the assignment of 1-formylbenzo[1,2-*c*:3,4-*c*′]dithiophene (15) structure as that of fraction 2.

Registry No.—**6**, 23062-31-9; **11**, 23062-32-0; **12**, 23102-68-3; **13**, 23062-33-1; **14**, 23062-34-2; **15**, 23062-35-3; **16**, 23062-36-4.

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