Synthesis of Phenaleno[1,9-*bc*]thiophene

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The cyclization of 2-acetonylthionaphthalene, prepared from 2-mercaptonaphthalene (**1**) and chloroacetone in the presence of sodium hydroxide, with polyphosphoric acid gave 1-methylnaphtho[2,1-*b*]thiophene (**4**) in 64% overall yield from **1**. By bromination with *N*-bromosuccinimide, **4** was converted in 40% yield into 1-bromomethylnaphtho[2,1-*b*]thiophene (**8**). Treatment of **8** with potassium cyanide in a phase-transfer medium gave 1-cyanomethylnaphtho[2,1-*b*]thiophene (**10**) in good yield. Compound **10** was reduced to the corresponding aldehyde **11** and then cyclized with polyphosphoric acid to phenaleno[1,9-*bc*]thiophene (**12**) in 24% overall yield from **10**.

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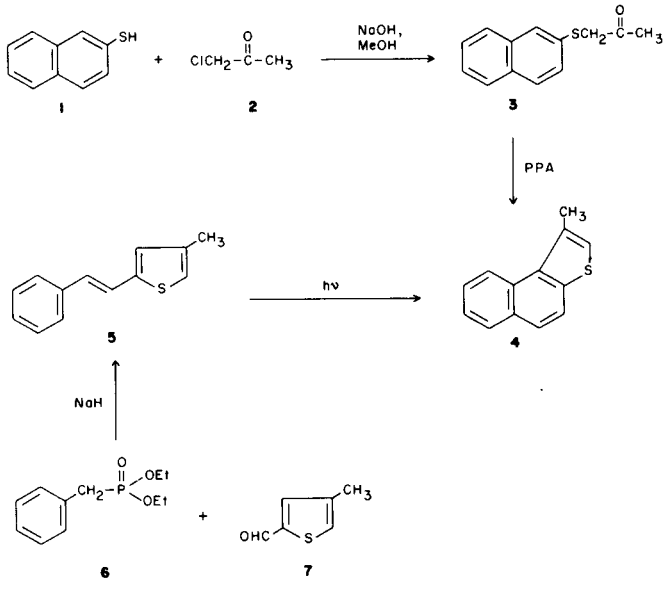
Recently, we prepared all of the isomeric phenathro[*b*]-thiophenes in order to assign the absolute structure of each tetracyclic thiophene in coal derived products (2). These compounds have a molecular formula and weight of either $C_{16}H_{10}S$ = 234, or, in the case of two isomers, of $C_{14}H_8S$ = 208. One of these last mentioned isomers is phenanthro[1,9-*bcd*]thiophene, which has already been isolated, identified (3) and synthesized by Klemm (4). However, the other isomer, phenaleno[1,9-*bc*]thiophene, is a ring system which is unreported in the literature. As a continuation of the work currently in progress in this laboratory, we now report the facile synthesis of phenaleno-[1,9-*bc*]thiophene (**12**) according to a modification of Newman's method for the synthesis of benzo[*a*]pyrene (5). The Newman procedure has also been found to be applicable to the preparation of other polycyclic aromatic hydrocarbons (6).

It has been reported that refluxing a mixture of potassium cyanide and a bromomethyl compound in benzene/water in the presence of methyltricaprylammonium chloride (Aliquat 336) (7) gives the corresponding key intermediate cyanomethyl derivatives, which can be used for the synthesis of polycyclic compounds. 1-Cyanomethylnaphtho[2,1-*b*]thiophene (**10**), which was expected to be prepared by bromination of 1-methylnaphtho[2,1-*b*]thiophene (**4**) with *N*-bromosuccinimide followed by treatment with potassium cyanide, is a key intermediate for the synthesis of the desired phenaleno-[1,9-*bc*]thiophene (**12**).

Dann reported the synthesis of 3-methylnaphtho[2,1-*b*]-thiophene (**4**) from 2-mercaptonaphthalene (**1**) and chloroacetone (**2**) in the presence of sodium hydroxide in methanol followed by cyclization with hydrogen fluoride or concentrated sulfuric acid (8). In this procedure the total yield from **1** is only 40%, and therefore we attempted to improve the yield. Thus, a solution of sodium hydroxide was added portion-wise to a solution of compounds **1** and **2** in methanol with stirring at room temperature to give compound **3**, which was treated with polyphosphoric acid on a steam bath for 30 minutes without purification of **3** to afford **4** in 64% overall yield from **1**.

We also attempted an alternative synthesis of **4** by photocyclization of styrylthiophene. Recently, Iwao, *et al.*, have reported that phenanthro[*b*]thiophene derivatives are conveniently prepared by the oxidative photocyclization of naphthylethenylthiophene (2). The synthesis of the parent naphtho[2,1-*b*]thiophene from 2-styrylthiophene in a similar photocyclization has also been reported (9). We applied this procedure for the synthesis of **4**. Compound **5** was readily prepared by the Wadsworth-Emmons reaction (10-12) between diethyl benzylphosphonate (**6**) and 4-methylthiophene-2-carboxaldehyde (**7**) in 87% yield. The photocyclization of **5** was carried out in cyclohexane in the presence of iodine and air. However, the yield using this procedure proved to be poor (40% yield). In general, the photocyclization of the methyl compounds does not proceed as well as that of the corresponding unsubstituted derivatives (**13-14**).



Bromination of aromatic methyl compounds with *N*-bromosuccinimide is most often reported to occur in nonpolar solvents, such as carbon tetrachloride. However,

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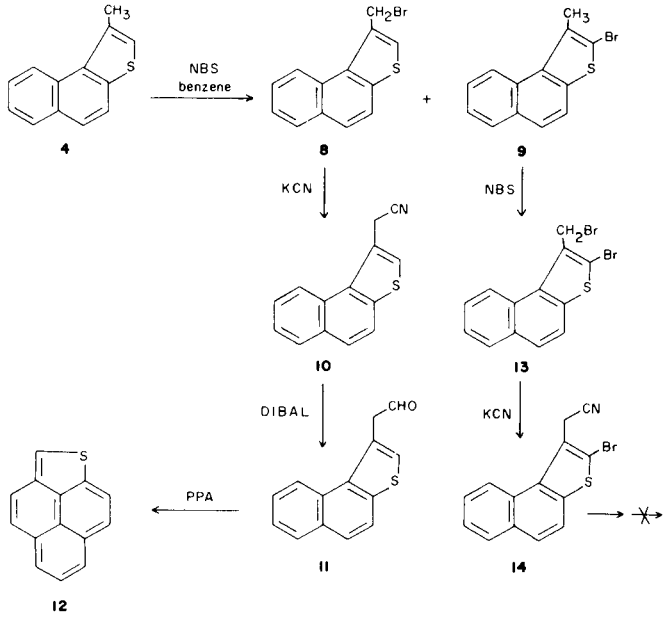
bromination of **4** with *N*-bromosuccinimide in carbon tetrachloride gave only 2-bromo-1-methylnaphtho-[2,1-*b*]thiophene (**9**) in 79% yield. However, Campaigne reported the bromination of 3-methylbenzo[*b*]thiophene with *N*-bromosuccinimide in dry benzene to give only the corresponding bromomethyl compound in good yield (15). Thus, we attempted the bromination of **4** with *N*-bromosuccinimide in dry benzene. Compound **4** was allowed to react with *N*-bromosuccinimide in dry benzene in the presence of benzoyl peroxide under reflux for 2 hours giving two products, **9** and 1-bromomethylnaphtho[2,1-*b*]-thiophene (**8**) in 25% and 40% yield, respectively.

Treatment of **8** with potassium cyanide in benzene/water in the presence of methyltricaprylammonium chloride (Aliquat 336) gave 1-cyanomethylnaphtho[2,1-*b*]thiophene (**10**) in 68% yield. This compound was reduced to the corresponding aldehyde (not isolated) and then cyclized with polyphosphoric acid to give the desired phenaleno[1,9-*bc*]thiophene (**12**) in 24% overall yield from **10**. However, cyclization of **14** under similar conditions did not give the desired product. Compound **14** was successfully prepared by the bromination of **9** with *N*-bromosuccinimide in dry benzene followed by cyanation with potassium cyanide in good yield.



EXPERIMENTAL

Melting points were determined on a Thomas-Hoover melting point apparatus and are uncorrected. Ir spectra were obtained on a Perkin Elmer model 457 spectrophotometer and a Beckman Acculab 2 spectrophotometer. ^{1}H nmr spectra were obtained on a Varian EM 390 spectrometer and on a JEOL FX 90 Q spectrometer in the solvents indicated. Chemical shifts are reported in ppm from TMS as an internal standard and are given in δ units. Mass spectra were obtained on a Hewlett-Packard model 5980A mass spectrometer. Uv spectra were recorded for solutions in cyclohexane with a Perkin Elmer 320 spectrometer. Elemental analyses were performed by MHW Laboratories, Phoenix, Arizona.

1-Methylnaphtho[2,1-*b*]thiophene (**4**).

a) A solution of sodium hydroxide (2 g of sodium hydroxide + 4 ml of water) was added dropwise to a stirred solution of 4.8 g (30 mmoles) of 2-naphthalenethiol and 2.8 g (30 mmoles) of chloroacetone in 30 ml of methanol. The mixture was stirred for 1 hour at room temperature and then heated to reflux for 30 minutes. The reaction mixture was chilled, poured into 300 ml of water and acidified with 10% hydrochloric acid. The resulting precipitate was collected by filtration.

Polyphosphoric acid (15 g) was pre-warmed on a steam bath and the above product was thoroughly mixed into the polyphosphoric acid. The mixture was heated for 30 minutes on a steam bath and was then poured into 300 ml of ice water. An oily product appeared, from which the aqueous layer was decanted, and the crude product was dissolved in 200 ml of benzene. The solution was dried with sodium sulfate and evaporated to give a dark oil. The residue was mixed with 5 g of silica gel (60-200 mesh) and this mixture was placed on a silica gel column. Using hexane as the eluent, colorless crystals were obtained which were recrystallized from methanol yielding 3.3 g (64%) of colorless prisms, mp 60° [lit. (8) mp 58-60°].

b) A solution of 1 g (5 mmoles) of 4-methyl-2-styrylthiophene and 0.05 g of iodine in 500 ml of cyclohexane was irradiated for 6 hours with a 450 Watt Hanovia medium pressure mercury lamp, through a corex filter. During the course of the reaction, a slow stream of air was passed through the solution. The solvent was evaporated *in vacuo* and the residue was effectively purified by silica gel chromatography using hexane as the eluent giving 0.41 g (41%) of 1-methylnaphtho[2,1-*b*]thiophene; nmr (deuteriochloroform): 2.89 (s, CH_3, 3H), 7.49-7.99 (m, H-2, H-4, H-5, H-6, H-7, H-8, 6H), 8.69 (dd, J = 1, 7 Hz, H-9, 1H); ms: m/e 198 (M^+, 100).

4-Methyl-2-styrylthiophene (**5**).

Sodium hydride (50%, 1 g, 22 mmoles) was placed in 50 ml of dry 1,2-dimethoxyethane. The slurry was cooled to 20° and 2.28 g (10 mmoles) of dimethyl benzylphosphonate was added dropwise with stirring. After the addition, the solution was stirred at room temperature for 30 minutes. To the pale yellow solution, maintained below 25°, was added dropwise 1.26 g (10 mmoles) of 4-methyl-2-thiophenecarboxaldehyde (16). During the addition, a gummy precipitate appeared. The solution was stirred at room temperature for 1 hour and then heated at 50° for 30 minutes. After cooling, a large excess of water was added and the resulting precipitate was collected by filtration. The product was recrystallized from hexane giving 0.87 g (87%) of pale yellow leaflets, mp 67°; nmr (deuteriochloroform): 2.23 (s, CH_3, 3H), 6.78 (s, H-5 or H-3, 1H), 6.89 (s, H-3 or H-5, 1H), 6.96 (d, J = 16 Hz, ethylene proton, 1H), 7.19 (d, J = 16 Hz, ethylene proton, 1H), 7.28-7.46 (m, phenyl protons, 5H).

Anal. Calcd. for $C_{13}H_{12}S$: C, 77.95; H, 6.04; S, 16.01. Found: C, 78.02; H, 6.15; S, 16.19.

2-Bromo-1-methylnaphtho[2,1-*b*]thiophene (**9**).

A mixture of 0.95 g (5.3 mmoles) of *N*-bromosuccinimide, 1 g (5 mmoles) of 1-methylnaphtho[2,1-*b*]thiophene, 0.005 g of benzoyl peroxide and 50 ml of dry carbon tetrachloride was refluxed. Boiling was continued for 2 hours, the mixture was cooled in an ice bath, and the crystals of succinimide were removed by filtration. The filtrate was washed with 10% sodium hydroxide solution and then with water. The benzene layer was dried with sodium sulfate and evaporated to give brown crystals. The crude product was purified by chromatography on a silica gel column using hexane as the eluent giving 1.1 g (79%) of the product as colorless needles, mp 89°. An analytical sample was recrystallized from methanol; nmr (deuteriochloroform): 2.83 (s, CH_3, 3H), 7.50-7.68 (m, H-7, H-8, 2H), 7.69 (s, H-4, H-5, 2H). 7.89-7.92 (m, H-6, 1H), 8.60 (dd, J = 2, 6 Hz, H-9, 1H); ms: m/e 278 (M + 2, 100), 276 (M^+, 99), 197 (M - HBr).

Anal. Calcd. for $C_{13}H_9BrS$: C, 56.33; H, 3.27; S, 11.57. Found: C, 56.56; H, 3.52; S, 11.38.

1-Bromomethylnaphtho[2,1-*b*]thiophene (**8**).

A mixture of 3.8 g (21.5 mmoles) of *N*-bromosuccinimide, 3.96 g (20

mmoles) of 1-methylnaphtho[2,1-*b*]thiophene, 0.01 g of benzoyl peroxide and 100 ml of dry benzene was gently refluxed. Boiling was continued for 2.5 hours, the mixture was cooled in an ice water bath and the crystals of succinimide were removed by filtration. The filtrate was washed with 10% sodium hydroxide solution and water. The benzene layer was dried with sodium sulfate and evaporated to give crystals. After washing with hexane, the colorless crystals were recrystallized from hexane giving 2.20 g (40%) of **8** as colorless needles, mp 142°; nmr (deuteriochloroform): 5.04 (s, CH_2, 2H), 7.45-7.94 (m, H-2, H-4, H-5, H-6, H-7, H-8, 6H), 8.54 (dd, J = 2, 7 Hz, 9-H, 1H); ms: m/e 278 (M^+ + 2, 38), 276 (M^+, 37), 197 (M - Br, 100).

Anal. Calcd. for $C_{13}H_9BrS$: C, 56.33; H, 3.27; S, 11.57. Found: C, 56.38; H, 3.40; S, 11.60.

The hexane layer wash was evaporated and the residual brown oil was chromatographed over a silica gel column using hexane as the eluent to give 1.37 g (25%) of 2-bromo-1-methylnaphtho[2,1-*b*]thiophene (**9**).

1-Cyanomethylnaphtho[2,1-*b*]thiophene (**10**).

A mixture of 2 g (7.2 mmoles) of 1-bromomethylnaphtho[2,1-*b*]thiophene, 2.5 g of potassium cyanide, 100 ml of benzene, 15 ml of water and 10 drops of Aliquat 336 was refluxed for 2.5 hours. After the addition of 100 ml of benzene, the benzene layer was washed successively with water, 10% hydrochloric acid and water. After drying over sodium sulfate, the benzene was evaporated. The residue was recrystallized from benzene/hexane (1:1) giving 1.1 g (68.3%) of pale brown needles, mp 102°; ir (potassium bromide): 2245 (CN); nmr (deuteriochloroform): 4.17 (s, CH_2, 2H), 7.47-8.16 (m, H-2, H-4, H-5, H-6, H-7, H-8, H-9, 7H); ms: m/e 223 (M^+, 100), 195 (M-28, 14).

Anal. Calcd. for $C_{14}H_9NS$: C, 75.31; H, 4.06; N, 6.27; S, 14.36. Found: C, 75.20; H, 4.33; N, 6.23; S, 14.08.

Phenaleno[1,9-*bc*]thiophene (**12**).

Diisobutylaluminum hydride (25% solution in toluene, 2 ml, 3 mmoles) was added with a syringe to a solution of 0.5 g (2.24 mmoles) of 1-cyanomethylnaphtho[2,1-*b*]thiophene in 15 ml of dry benzene. The reaction mixture was stirred at room temperature for 2 hours. Dilute hydrochloric acid was added and the product was extracted with chloroform. Evaporation of the dried extract gave the aldehyde as an oil which slowly crystallized; ir (neat): 1710 (C=O).

A mixture of the above crude aldehyde and 10 g of polyphosphoric acid was heated on a steam bath for 1 hour. The reaction mixture was poured into ice water and extracted with benzene. The extract was washed with water, dried and evaporated. The residue was chromatographed on a column of silica gel using cyclohexane as the eluent giving 0.13 g of red crystals. This product was purified by sublimation at 130-140°/1.5 mm giving colorless crystals which were recrystallized from methanol yielding 0.11 g (24%) of colorless prisms, mp 156°. The picrate of this compound gave red violet needles from ethanol mp 195° dec; ir (potassium bromide): 3100, 3050 (w), 2930 (w), 1730 (w), 1485 (w), 830, 800, 675; uv: λ max nm (log ϵ) 230 (4.24), 252 (4.13), 263 (4.30), 269 (4.25), 337 (4.08), 344 (4.22), 350 (4.21), 364 (4.21); nmr (deuteriochloroform): 7.66 (s, H-2, 1H), 7.61-8.17 (m, aromatic protons, 7H); ms: m/e 208 (M^+, 100), 163 (M - 45, 29).

Anal. Calcd. for $C_{14}H_8S$: C, 80.73; H, 3.87; S, 15.39. Found: C, 80.49; H, 4.09; S, 15.13.

2-Bromo-1-bromomethylnaphtho[2,1-*b*]thiophene (**13**).

A mixture of 1.13 g (4.08 mmoles) of 2-bromo-1-methylnaphtho[2,1-*b*]-thiophene, 0.6 g (2.1 mmoles) of 1,3-dibromo-5,5-dimethylhydantoin, 0.005 g of benzoyl peroxide and 50 ml of dry benzene was refluxed for 2 hours. The reaction mixture was cooled in an ice bath and the precipitate was removed by filtration. The filtrate was washed with 10% sodium hydroxide solution and water. The benzene layer was dried with sodium sulfate and evaporated giving 1.3 g (90%) of colorless crystals. An analytical sample was recrystallized from hexane/benzene (1:1). In a similar manner, the reaction of 2-bromo-1-methylnaphtho[2,1-*b*]thiophene with *N*-bromosuccinimide gave the dibromo compound in 79% yield; nmr (deuteriochloroform): 5.09 (s, CH_2, 3H), 7.51-7.84 (m, H-4, H-5, H-7, H-8, 4H), 7.99 (dd, J = 1, 7 Hz, H-6, 1H), 8.68 (dd, J = 2, 6 Hz, H-9, 1H); ms: m/e (M^+ + 2, 46), 275 (M^+, 42), 196 (M - Br, 100).

Anal. Calcd. for $C_{13}H_8BrS$: C, 43.85; H, 2.26; Br, 4.49; S, 9.00. Found: C, 43.69; H, 2.46; Br, 4.26; S, 8.79.

2-Bromo-1-cyanomethylnaphtho[2,1-*b*]thiophene (**14**).

A mixture of 1.15 g (3.23 mmoles) of 2-bromo-1-bromomethylnaphtho-[2,1-*b*]thiophene, 2 g of potassium cyanide, 4 drops of Aliquat 336, 50 ml of benzene and 10 ml of water was refluxed for 2 hours. After the addition of 50 ml of benzene, the benzene layer was washed successively with water, 10% hydrochloric acid and water. After drying, the benzene was evaporated. The residue was recrystallized from benzene/hexane giving 0.53 g (53%) of colorless needles, mp 172-173°; ir (potassium bromide): 2260 (CN); nmr (deuteriochloroform): 4.28 (s, CH_2, 2H), 7.57-7.80 (m, H-4, H-5, H-7, H-8, 4H), 7.98 (dd, J = 2, 7 Hz, H-6, 1H), 8.45 (dd, J = 1, 6 Hz, H-9, 1H); ms: m/e 303 (M^+ + 2, 100), 301 (M^+, 100).

Anal. Calcd. for $C_{14}H_8BrNS$: C, 55.64; H, 2.67; N, 4.64; S, 10.61. Found: C, 55.46; H, 2.81; N, 4.57; S, 10.55.

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