# Synthesis of Phenanthro[*b*]thiophenes



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All isomers of the parent phenanthro[*b*]thiophenes, namely, phenanthro[1,2-*b*]thiophene, phenanthro[2,1-*b*]thiophene, phenanthro[2,3-*b*]thiophene, phenanthro[3,2-*b*]thiophene, phenanthro[3,4-*b*]thiophene, phenanthro[4,3-*b*]thiophene and phenanthro[9,10-*b*]thiophene have been synthesized.

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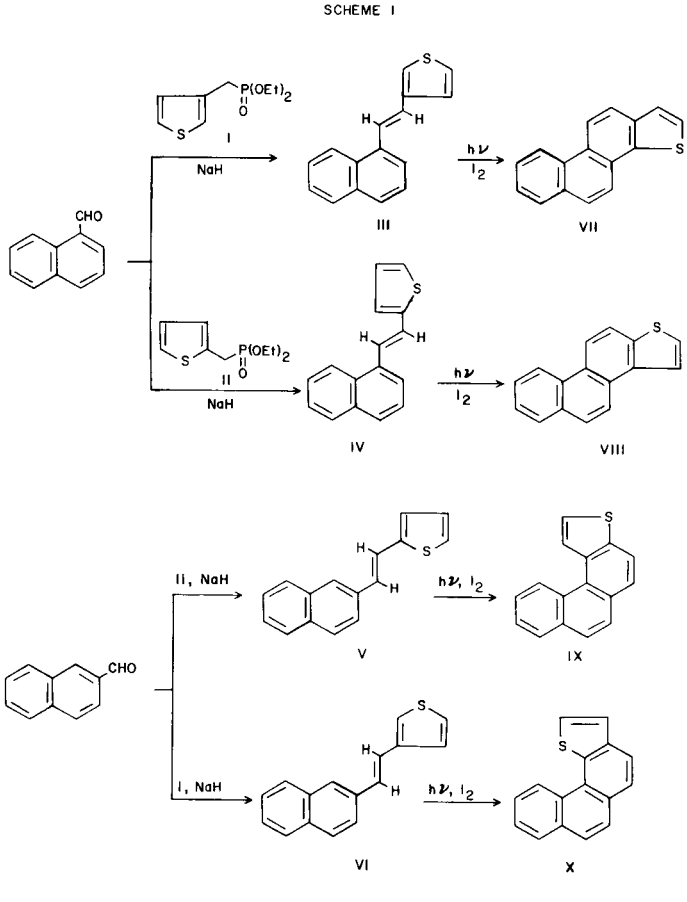
Polycyclic aromatic hydrocarbons have been studied extensively because of their carcinogenic activity and their character as major environmental pollutants (1a,b). Recently, we have separated various polycyclic thiophenes (thiophene isosters of polycyclic hydrocarbons) from coal derived products by glass capillary-column gas chromatography and have postulated their structures by mass spectrometry (2). However, because of the many isomeric structures possible, it was difficult to assign the absolute structure of each polycyclic thiophene based only on mass spectrometry. Therefore, we have decided to synthesize a series of authentic compounds for positive identification of the proposed structures. Furthermore, determination of the carcinogenic and mutagenic activities of the synthetic compounds is also of interest. In this paper, the synthesis of all isomers of the parent phenanthro[*b*]thiophenes will be described.

SCHEME I




It is well known that chrysene and benzo[*c*]phenanthrene derivatives are conveniently available by the oxidative photocyclization of 1-styryl- and 2-styrylnaphthalenes, respectively (3a-d, 4a-c). By analogy with the above reactions, it was expected that phenanthro[1,2-*b*]thiophene (VII), phenanthro[2,1-*b*]thiophene (VIII), phenanthro[3,4-*b*]thiophene (IX) and phenanthro[4,3-*b*]thiophene (X) should be available from the corresponding naphthylvinylthiophenes by photolysis (Scheme I).

The starting olefins III, IV, V and VI were readily prepared by the Wadsworth-Emmons reaction (5) between diethyl 2- (or 3)-thenylphosphonate (II or I) and 1- (or 2)-naphthaldehyde in good yields (72-90%). The photocyclization of these olefins was carried out in cyclohexane or benzene in the presence of iodine. As expected, the photocyclization of 2-naphthylvinylthiophenes IV and V proceeded smoothly and gave the desired phenanthro[2,1-*b*]thiophene (VIII) and phenanthro[3,4-*b*]thiophene (IX) in 88% and 75% yield, respectively. However, in the photolysis of 3-naphthylvinylthiophenes III and VI, a large amount of tarry material was formed and the yields of the phenanthro[*b*]thiophenes were poor (VII, 32%; X, 17%). A similar tendency of the reaction was observed in the photolysis of a series of thienylvinylthiophenes and the poor results obtained in the photolysis of 3-substituted thiophenes were attributed to the expulsion of the thienyl radicals during the oxidative process of the dihydro intermediates (6).

In these reactions, it is possible that 3-naphthylvinylthiophenes cyclize at the 4-position of the thiophene ring and give phenanthro[*c*]thiophenes. However, this orientation for the cyclization seems to be unlikely, because 3-styrylthiophenes and 3-thienylvinylthiophene are known to cyclize exclusively at the 2-position (6,7).

In fact, the phenanthro[3,4-*c*]thiophene structure for compound X was easily excluded by the agreement of the melting point of X with the reported melting points of phenanthro[4,3-*b*]thiophene (8,9). In addition, the nmr data also supported this exlusion. Namely, in compound IX, two protons at the 1- and 11-positions absorb in the very low aromatic region, apart from the complex multiplet of the other aromatic protons, due to the deshielding effect of the opposite aromatic ring [$H_1$: ($\delta$

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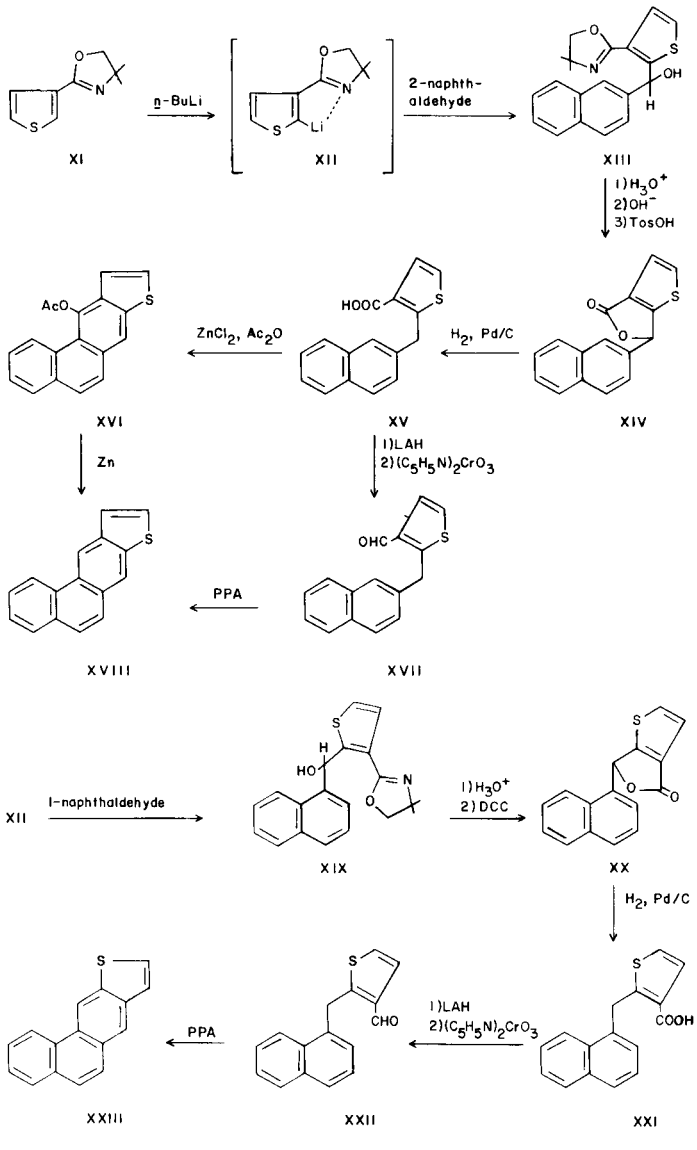
8.62, d), $H_{11}$: (δ 9.12, near dd)]. However, in compound X, only one proton at the 11-position appeared at low field (δ 9.20), because the 1-position of the ring is sulfur. If X were phenanthro[3,4-*c*]thiophene, a proton at the 1-position should also absorb at low field.

In the case of the photolysis of III, however, it is difficult to exclude a phenanthro[1,2-*c*]thiophene structure for the product VII based only on nmr data, because the peaks of the protons around the thiophene ring overlap with other aromatic protons and it is almost impossible to assign these complex multiplets. However, since benzo[*c*]-thiophene and its higher benzologs are known to react with dienophiles at the *ortho*-quinodimethane part of the molecule (10-12), it is possible to exclude a phenanthro-[1,2-*c*]thiophene structure if VII does not react with a dienophile. In fact, when VII was reacted with maleic anhydride in refluxing xylene for 24 hours, the starting material was quantitatively recovered. This is support for the phenanthro[1,2-*b*]thiophene structure of VII.

SCHEME II




Next, our attention was turned to the synthesis of phenanthro[2,3-*b*]thiophene (XVIII) and phenanthro[3,2-*b*]-thiophene (XXIII). The synthesis of the 7,11-dimethyl derivatives of these ring systems has been reported by Sandin, *et al.* (13,14). The parent compounds could be available by a modification of their synthesis. However, the key step of this synthesis, condensation of thienyl-magnesium iodide and 1,2-naphthoic anhydride, requires the tedious separation of two isomeric products by fractional crystallization and the yields are poor.

Recently, Newman and Kannan reported the regio-selective synthesis of some fluorobenzo[*a*]pyrenes and fluorobenz[*a*]anthracenes (15). The crucial step in these syntheses is the *ortho*-directed lithiation of fluorophenyl-oxazoline followed by condensation with 1- or 2-naphth-aldehyde. We applied this procedure for the synthesis of XIV and XX (Scheme II).

The thienyloxazoline XI was prepared from thiophene-3-carboxoyl chloride and 2-amino-2-methyl-1-propanol. Slocum and Gierer studied the directed metalation of 3-substituted thiophenes and reported that selective metalation occurred at the 2-position (16). On the basis of this report, it was expected that the metalation of XI should occur exclusively at the 2-position.

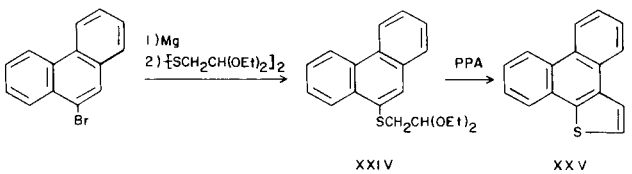
Compound XI was lithiated with *n*-butyllithium in dry ether at −45° and the resulting lithium compound XII was condensed with 2-naphthaldehyde giving XIII as an oil. The oxazoline ring of XIII was hydrolysed with a combination of acid and alkali. The resulting acid was cyclized to the lactone XIV by heating in toluene with a catalytic amount of *p*-toluenesulfonic acid. The overall yield of XIV from XI is 58%. The lactone XIV was hydrogenolysed to the acid XV over palladium on charcoal in warm acetic acid in 72% yield. Cyclization of XV with zinc chloride in a mixture of acetic acid and acetic anhydride gave 11-acetoxyphenanthro[2,3-*b*]thiophene (XVI) in 81% yield. Although the yield is quite poor (3%), the parent phenanthro[2,3-*b*]thiophene (XVIII) was obtained by the reductive cleavage of the acetoxy group in XVI with zinc in alkali. A much better yield of XVIII was obtained by using an alternative route *via* the aldehyde XVII (17,18). Namely, the acid XV was converted to the aldehyde XVII by reduction with lithium aluminum hydride to give the primary alcohol followed by oxidation with the chromium trioxide-pyridine complex. Cyclization of the crude aldehyde XVII by heating with polyphosphoric acid gave XVIII in 56% overall yield from XV.

Using the same rational, phenanthro[3,2-*b*]thiophene (XXIII) was prepared. Condensation of lithiothiophene X with 1-naphthaldehyde gave XIX as colorless crystals in 84% yield. This compound was converted to the lactone

XX in 38% yield by hydrolysis of the oxazoline ring by heating in a mixture of hydrochloric acid and dioxane followed by lactonization with dicyclohexylcarbodiimide. Although the yield was poor, this proved to be the most satisfactory way to carry out this transformation. The same conditions used for the conversion of XIII to XIV gave poorer yields. The lactone XX was hydrogenolysed to the acid XXI over palladium on charcoal in 62% yield. This acid was converted to the aldehyde XXII and cyclized with polyphosphoric acid to the desired compound XXIII in 57% overall yield.

Finally, phenanthro[9,10-*b*]thiophene XXV was prepared. Although methods for the synthesis of this compound have been reported (19), we synthesized XXV more conveniently by using Tilak's benzo[*b*]thiophene synthesis (20). The Grignard reagent derived from 9-bromophenanthrene was allowed to react with β,β-diethoxyethyldisulfide to give the sulfide XXIV. After removal of unreacted bromophenanthrene by column chromatography the crude XXIV, obtained as an oil, was heated with polyphosphoric acid to give XXV in 25% overall yield.

SCHEME III




XXIV XXV

Some of phenanthro[*b*]thiophenes (VII, VIII, IX, X and XXV) have already been assayed for mutagenic activity in the histidine reversion (Ames assay) system. Phenanthro[3,4-*b*]thiophene (IX) showed potent mutagenic activity on test strains TA98, TA100 and TA1535. Phenanthro[2,1-*b*]thiophene (VIII) and phenanthro[4,3-*b*]thiophene (X) were weakly mutagenic against the same strains (21). Mutagenic assays of the remaining phenanthro[*b*]thiophenes XVIII and XXIII are in progress. Carcinogenesis studies of these compounds are also in progress.

## EXPERIMENTAL

All melting points are uncorrected. Ir spectra were obtained on a Beckman Acculab-2 spectrometer. Nmr spectra were obtained on a Varian EM 390 spectrometer or a JEOL FX 90 Q spectrometer. 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.

Diethyl 2-Thenylphosphonate (II) and Diethyl 3-Thenylphosphonate (I).

A mixture of 2-chloromethyl thiophene (22) (21 g., 0.16 mole) and triethyl phosphite (27 g., 0.16 mole) was heated at 150° for 5 hours giving, upon distillation, 32 g. (82%) of II as a colorless liquid, b.p. 84-89°/0.03 mm (lit. (6) b.p. 152-154°/10 mm); nmr (deuteriochloroform): δ 1.26 (t, 6H, $CH_3CH_2O$-), 3.35 (d, 2H, $-CH_2\overset{\uparrow}{P}=O$), 4.04 (near quintet, 4H, $CH_3CH_2O$-), 6.92 (m, 2H, ArH), 7.10 (m, 1H, ArH).

A similar reaction between 3-bromomethylthiophene (23) and triethyl phosphite gave I, b.p. 123-133°/0.7mm; nmr (deuteriochloroform): δ 1.22 (t, 6H, $CH_3CH_2O$-), 3.22 (d, 2H, $-CH_2\overset{\uparrow}{P}=O$), 4.06 (near quintet, 4H, $CH_3CH_2O$-), 7.0-7.4 (m, 3H, ArH).

3-[β-(1-Naphthyl)vinyl]thiophene (III). Typical Procedure for the Preparation of Naphthylvinyl Thiophenes.

Under a nitrogen atmosphere, 5.28 g. (0.11 mole) of a 50% dispersion of sodium hydride in mineral oil, after washing with dry dimethoxyethane, was added to a stirred solution of 15.62 g. (0.10 mole) of 1-naphthaldehyde and 23.43 g. (0.10 mole) of phosphonate I in 200 ml. of dry dimethoxyethane. After allowing to stand for two hours at room temperature, the reaction mixture was poured into water. The precipitate was collected and recrystallized from ethanol to give 18.04 g. (76%) of III, m.p. 98.5-99°.

*Anal.* Calcd. for $C_{16}H_{12}S$: C, 81.32; H, 5.12; S, 13.57. Found: C, 81.25; H, 5.09; S, 13.35.

2-[β-(1-Naphthyl)vinyl]thiophene (IV).

This compound was prepared from 1-naphthaldehyde and phosphonate II and recrystallized from ethanol, yield 85%, m.p. 100.5-101°.

*Anal.* Calcd. for $C_{16}H_{12}S$: C, 81.32; H, 5.12; S, 13.57. Found: C, 81.54; H, 5.24; S, 13.34.

2-[β-(2-Naphthyl)vinyl]thiophene (V).

This compound was prepared from 2-naphthaldehyde and phosphonate II and recrystallized from acetone, yield 90%, m.p. 166-167°.

*Anal.* Calcd. for $C_{16}H_{12}S$: C, 81.32; H, 5.12; S, 13.57. Found: C, 81.47; H, 5.22; S, 13.28.

3-[β-(2-Naphthyl)vinyl]thiophene (VI).

This compound was prepared from 2-naphthaldehyde and phosphonate I and recrystallized from benzene, yield 72%, m.p. 172.5-173°.

*Anal.* Calcd. for $C_{16}H_{12}S$: C, 81.32; H, 5.12; S, 13.57. Found: C, 81.53; H, 5.00, S, 13.33.

Photocyclization of Naphthylvinylthiophenes. General Method.

A solution of 1.77 g. (7.5 mmoles) of the appropriate naphthylvinylthiophene and 0.10 g. of iodine in 750 ml. of cyclohexane (for III, IV, V) or benzene (for VI) was irradiated for four 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 each crude product was purified as described below.

Phenanthro[1,2-*b*]thiophene (VII).

The crude product obtained from III was passed through a column of alumina using benzene as the eluent. The eluate was evaporated and the residue was recrystallized from cyclohexane giving 0.57 g. (32%) of VII as colorless fine plates, m.p. 160-169°. Further recrystallization from cyclohexane raised and sharpened the melting point to 168-170°; ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.3-7.7 (m, 4H, $H_1$, $H_2$, $H_7$ and $H_8$), 7.7-8.1 (m, 4H, $H_4$, $H_5$, $H_6$ and $H_{11}$), 8.55 (d, 1H, $H_{10}$), 8.63 (near dd, 1H, $H_9$), $J_{10,11}$ = 9 Hz; uv: λ max (log ε) 211 (4.53), 270.5 (4.89), 288 (sh) (4.37), 300 (4.30) and 311 nm (3.99).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.29; H, 4.22; S, 13.44.

Phenanthro[2,1-*b*]thiophene (VIII).

The crude product obtained from IV was recrystallized from benzene (charcoal) to give 1.18 g. of VIII as slightly colored fine plates, m.p. 236.5-237.5°. The mother liquor was passed through a column of alumina using benzene as the eluent. The residue obtained by the evaporation of the eluate was washed with petroleum ether and filtered to give 0.37 g. of additional VIII, m.p. 235-236°. Total yield was 1.55 g. (88%). An analytical sample, colorless fine plates, had m.p. 237-238°;

ms: m/e 234 ($M^+$); FT nmr (deuteriochloroform): δ 7.5-7.7 (m, 3H, $H_2$, $H_7$ and $H_8$), 7.8-8.1 (m, 4H, $H_3$, $H_5$, $H_6$ and $H_{11}$), 8.32 (d, 1H, $H_4$), 8.65 (d, 1H, $H_{10}$), 8.73 (near dd, 1H, $H_9$), $J_{4,5}$ = 9, $J_{10,11}$ = 9 Hz; uv: λ max (log ε) 207 (4.48), 232.5 (4.53) 254 (sh) (4.72), 261 (4.82), 289.5 (4.34), 302 (4.22) and 315.5 nm (4.27).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.19; H, 4.25; S, 13.67.

Phenanthro[3,4-*b*]thiophene (IX).

The crude product obtained from V was passed through a column of alumina using benzene as eluent to give 1.72 g. of slightly brown solid. Refiltration of this solid through a short column of alumina (cyclohexane) gave 1.31 g. (75%) of colorless crystals of IX, m.p. 82-83°. An analytical sample was recrystallized from methanol, colorless plates, m.p. 82.5-83.5°; ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.5-8.1 (m, 8H, ArH except $H_1$ and $H_{11}$), 8.62 (d, 1H, $H_1$), 9.12 (near dd, 1H, $H_{11}$) $J_{1,2}$ = 5, $J_{10,11}$ = 9 Hz; uv: λ max (log ε) 229 (4.35), 268.5 (4.65), 278 (4.78), 298 (sh) (4.15) and 310 nm (sh) (3.88).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.10; H, 4.22; S, 13.48.

Phenanthro[4,3-*b*]thiophene (X).

Crude material obtained from VI was passed through a column of alumina using benzene as the eluent. The eluate was evaporated giving a colorless oil which was passed again through a short column of alumina using initially cyclohexane and then a mixture of cyclohexane and benzene (5:1) as eluents to give 0.30 g. (17%) of colorless crystals of X, m.p. 87-93°. An analytical sample was prepared by recrystallization from methanol/water, colorless prisms or plates, m.p. 94-95° (lit. (8) gives m.p. 91.5-92°; lit (9) gives m.p. 95°); ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.3-8.1 (m, 9H, ArH except $H_{11}$), 9.20 (d, 1H, $H_{11}$), $J_{10,11}$ = 8 Hz; uv: λ max (log ε) 211 (4.56), 234 (sh) (4.26), 272 (4.76) 291 (sh) (4.13), 304 (4.02) and 317 nm (4.06).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.29; H, 4.14; S, 13.58.

Reaction of the VII with Maleic Anhydride.

The mixture of 100 mg. (0.43 mmole) in VII, 42 mg. (0.43 mmole) of maleic anhydride and 10 ml. of *m*-xylene was refluxed for 24 hours. Xylene was evaporated and the residue was passed through a column of silica gel using cyclohexane as the eluent to recover VII in quantitative yield, m.p. 162-165°. Recrystallization from cyclohexane raised the melting point to 165-167.5°, which was not depressed by admixing with an authentic sample of VII.

4,4-Dimethyl-2-(3-thienyl)-2-oxazoline (XI).

A solution of 52 g. (0.355 mole) of thiophene-3-carboxoyl chloride in 200 ml. of dry dichloromethane was added dropwise to an ice-cooled, stirred solution of 63.2 g. (0.71 mole) of 2-amino-2-methyl-1-propanol in 200 ml. of dry dichloromethane keeping the temperature below 10°. After stirring at room temperature for 2 hours, the reaction mixture was washed with water, dried over sodium sulfate and evaporated. The residual solid of the intermediate amide was dried and finely powdered. To a suspension of this powder in 300 ml. of dry benzene, thionyl chloride (92 ml., 1.17 moles) was added dropwise with mechanical stirring. The suspension became pasty and then clear. After allowing the reaction mixture to stand overnight, excess thionyl chloride and benzene was removed under reduced pressure. The residue was poured into ice water and made basic with sodium hydroxide. The product was extracted with benzene, washed with water and dried over sodium sulfate. Benzene was evaporated and the residue was distilled *in vacuo* to give 54.7 g. (85%) of XI as a colorless solid, b.p. 68-70°/0.4 mm. An analytical sample was recrystallized from petroleum ether, colorless prisms, m.p. 59.5-60.5°; ir (potassium bromide): 1640 $cm^{-1}$ (C=N); nmr (carbon tetrachloride): δ 1.27 (s, 6H, $CH_3$), 3.86 (s, 2H, $CH_2$), 7.12 (dd, 1H, $H_5$), 7.35 (dd, 1H, $H_4$), 7.65 (dd, 1H, $H_2$). $J_{2,4}$ = 1.2, $J_{2,5}$ = 3, $J_{4,5}$ = 5.5 Hz.

*Anal.* Calcd. for $C_9H_{11}NOS$: C, 59.64; H, 6.12; N, 7.73; S, 17.69. Found: C, 59.42; H, 6.12; N, 7.69; S, 17.81.

6-(2-Naphthyl)thieno[2,3-*c*]furan-4-(6*H*)one (XIV).

Under a nitrogen atmosphere, 34 ml. (0.05 mole) of 1.5 *M* *n*-butyllithium solution in hexane was added dropwise to a solution of 9.06 g. (0.05 mole) of XI in 100 ml. of dry ether keeping the temperature between −35 and −45° (dry ice-chlorobenzene bath). After stirring for one hour, a solution of 7.81 g. (0.05 mole) of 2-naphthaldehyde in 50 ml. of dry ether was added. The reaction mixture was then allowed to warm gradually to room temperature and to stand overnight. Water was added to the mixture, the ether layer was separated and the aqueous layer was extracted with ether. The combined extracts were washed with water, dried over sodium sulfate and evaporated. The residual oil of crude XIII was heated with stirring under reflux in 300 ml. of 10% hydrochloric acid for 5 hours. After cooling, the orange solid was collected and heated again under reflux in a mixture of 200 ml. of methanol and 100 ml. of 30% sodium hydroxide. The reaction mixture was poured into *ca.* 1.5 l. of water and acidified with hydrochloric acid. The precipitated pink solid was collected, washed with water and dried. A solution of this solid and 0.5 g. of *p*-toluenesulfonic acid in 300 ml. of toluene was refluxed for 2 hours with removal of the water formed. The mixture was evaporated to about half amount and passed through a column of silica gel (benzene) to give 7.50 g. (56%) of XIV as colorless solid, m.p. 173-175°. Recrystallization from ethanol gave colorless needles, m.p. 176.5-177.5°; ir (potassium bromide): 1750 $cm^{-1}$ (C=O); nmr (deuteriochloroform): δ 6.60 (s, 1H, methyne H), 7.2-7.7 (m, 5H, ArH), 7.7-8.0 (m, 4H, ArH).

*Anal.* Calcd. for $C_{16}H_{10}O_2S$: C, 72.16; H, 3.78; S, 12.04. Found: C, 72.34; H, 3.86; S, 11.87.

2-(2-Naphthylmethyl)-3-thiophenecarboxylic Acid (XV).

A mixture of 5.00 g. of XIV and 1.0 g. of 5% palladium on charcoal in 300 ml. of acetic acid was stirred under an hydrogen atmosphere at 75° overnight. The mixture was filtered and the filtrate was evaporated to dryness. The residue was recrystallized from methanol (charcoal) to give 3.67 g. (72%) of XV as colorless needles, m.p. 168-170°. An analytical sample had m.p. 171-172°; ir (potassium bromide): 2500-3300 (OH) and 1665 $cm^{-1}$ (C=O); nmr (DMSO-$d_6$): δ 4.70 (s, 2H, $CH_2$), 7.3-7.6 (m, 5H, ArH), 7.7-8.0 (m, 4H, ArH), 12.8 (br s, 1H, COOH).

*Anal.* Calcd. for $C_{16}H_{12}SO_2$: C, 71.62; H, 4.51; S, 11.95. Found: C, 71.61; H, 4.49; S, 12.00.

11-Acetoxyphenanthro[2,3-*b*]thiophene (XVI).

A mixture of 2.00 g. of XV, 0.10 g. of fused zinc chloride, 10 ml. of acetic anhydride and 15 ml. of acetic acid was refluxed for 1 hour. Water (8.5 ml.) was added to the hot solution. After cooling, the precipitated yellow needles were collected by filtration giving 1.76 g. (81%) of XVI, m.p. 156-158°. An analytical sample was recrystallized from ethanol, m.p. 159-160°; ir (potassium bromide): 1760 $cm^{-1}$ (C=O); nmr (deuteriochloroform); 2.53 (s, 3H, $CH_3$), 7.25 (d, 1H, $H_9$), 7.4-7.9 (m, 6H, ArH except $H_1$, $H_7$ and $H_9$), 8.16 (s, 1H, $H_7$), 9.08 (m, 1H, $H_1$), $J_{9,10}$ = 5.5 Hz.

*Anal.* Calcd. for $C_{18}H_{12}SO_2$: C, 73.95; H, 4.14. S, 10.97. Found: C, 74.07; H, 4.17; S, 10.93.

Phenanthro[2,3-*b*]thiophene (XVIII).

Method A.

A solution of 1.46 g. (5.4 mmoles) of XV in 20 ml. of dry tetrahydrofuran was added dropwise to a suspension of 0.23 g. (6.1 mmoles) of lithium aluminum hydride in 50 ml. of dry ether. After reflux for 3 hours, 10% sodium hydroxide was added dropwise and the precipitated aluminum hydroxide was filtered off. The dried filtrate (sodium sulfate) was evaporated to give the crude alcohol as a pale yellow oil which on standing solidified; ir (neat): 3330 and 3230 $cm^{-1}$ (OH).

The solution of this crude alcohol in 11 ml. of dry pyridine was added slowly to a suspension of chromium trioxide-pyridine complex made from 1.1 g. of chromium trioxide and 11 ml. of dry pyridine. After stirring for 2 hours at room temperature, the reaction mixture was filtered through celite and washed with chloroform. The filtrate was washed with 10% hydrochloric acid and then 10% sodium carbonate. After drying over sodium sulfate, chloroform was evaporated to leave the crude

aldehyde XVII as a dark oil; ir (neat): 1670 $cm^{-1}$ (C=O).

A mixture of the crude XVII and 10 ml. of polyphosphoric acid was heated over a steam bath for 15 minutes. After cooling, ice water was added to the mixture and the precipitated gray solid was collected by filtration. After drying, this solid was passed through a column of alumina using benzene as the eluent giving 0.72 g. (56%) of XVIII, m.p. 160-161°. An analytical sample was recrystallized from cyclohexane, colorless fine plates, m.p. 161-161.5° (lit. (24) gives m.p. 81-82° (25)); ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.4-8.0 (m, 7H, ArH except $H_1$, $H_7$ and $H_{11}$), 8.30 (s, 1H, $H_7$), 8.71 (m, 1H, $H_1$), 9.10 (s, 1H, $H_{11}$); uv: λ max (log ε) 222 (4.50), 254 (sh) (4.43), 275 (4.86), 283.5 (4.74), 309 (sh) (3.93), 319.5 (4.06) 334 (4.10), 347 (3.15) and 366 nm (2.65).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.29; H, 4.34; S, 13.29.

Method B.

A mixture of 0.50 g. of acetate XVI, 2.5 g. of zinc dust which was activated by washing with an aqueous solution of copper sulfate, 5 ml. of toluene and 25 ml. of 10% sodium hydroxide was refluxed for 24 hours. After cooling, the organic layer was separated and the aqueous layer was extracted with benzene. The combined extracts were washed with water, dried and evaporated. The residue was chromatographed on a column of silica gel using a mixture of cyclohexane and benzene (2:1) as the eluent. From the first fraction, 13 mg. (3%) of XVIII was obtained. The FT nmr spectrum of this compound was identical with that of XVIII obtained by method A. From the next fraction, 0.32 g. of the starting material was recovered.

4,4-Dimethyl-2-[2-(1-naphthylhydroxymethyl)-3-thienyl]-2-oxazoline (XIX).

To a suspension of the lithio derivative of XI (0.05 mole) in dry ether, prepared in the same manner as described above, a solution of 7.81 g. (0.05 mole) of 1-naphthaldehyde in 15 ml. of dry ether was added. After stirring at room temperature for 3 hours, water was added to the mixture. The ether layer was separated and the aqueous layer was extracted with dichloromethane. The combined extracts were dried over sodium sulfate and evaporated. The residual colorless solid was washed with ether and filtered giving 14.16 g. (84%) of XIX, m.p. 131.5-133°. An analytical sample was recrystallized from dichloromethane/ether, colorless prisms, m.p. 133.5-134.5°; ir (potassium bromide): 3100 (OH) and 1640 $cm^{-1}$ (C=N); nmr (deuteriochloroform): δ 1.39 (s, 3H, $CH_3$), 1.41 (s, 3H, $CH_3$), 4.15 (s, 2H, $CH_2$), 6.86 (s, 1H, methyne H) 6.94 (d, 1H, $H_5$ of thiophene ring), 7.2-7.6 (m, 4H, ArH), 7.75-8.1 (m, 4H, ArH), $J_{4,5}$ = 6 Hz.

*Anal.* Calcd. for $C_{20}H_{19}NO_2S$: C, 71.19; H, 5.68; N, 4.15; S, 9.50. Found: C, 71.09; H, 5.45; N, 3.96; S, 9.39.

6-(1-Naphthyl)thieno[2,3-*c*]furan-4-(6*H*)one (XX).

A solution of 9.00 g. (0.027 mole) of XIX in a mixture of 180 ml. of dioxane and 180 ml. of 10% hydrochloric acid was refluxed for 21 hours. After evaporation of the solvent, water was added to the residue and the product was extracted with chloroform. The residue obtained by the evaporation of chloroform was dissolved in 100 ml. of benzene and 5.6 g. (0.027 mole) of dicyclohexylcarbodiimide was added to this solution. After allowing it to stand at room temperature for 3 hours, the mixture was concentrated and passed through a column of silica gel using benzene as the eluent. The colorless solid obtained by the evaporation of the eluate was washed with ether and filtered to give 2.72 g. (38%) of XX, m.p. 135.5-137°. An analytical sample was prepared by recrystallization from dichloromethane/ether, colorless prisms, m.p. 137-137.5°; ir (potassium bromide): 1750 $cm^{-1}$ (C=O); nmr (deuteriochloroform): 7.2-8.2 (m, methyne H and ArH).

*Anal.* Calcd. for $C_{16}H_{10}O_2S$: C, 72.16; H, 3.78; S, 12.04. Found: C, 72.29; H, 3.87; S, 11.87.

2-(1-Naphthylmethyl)-3-thiophenecarboxylic Acid (XXI).

A mixture of 3.00 g. of XX and 0.6 g. of 5% palladium on charcoal in 150 ml. of acetic acid was stirred under an hydrogen atmosphere at 70° overnight. The mixture was filtered and the filtrate was evaporated. The residue was recrystallized from benzene/hexane to give 1.86 g. (62%) of colorless needles of XXI, 157-157.5°; ir (potassium bromide): 2500-3300 (OH) and 1675 $cm^{-1}$ (C=O); nmr (DMSO-$d_6$): δ 5.00 (s, 2H, $CH_2$), 7.2-7.7 (m, 6H, ArH), 7.7-8.2 (m, 3H, ArH), 11.8 (br s, 1H, COOH).

*Anal.* Calcd. for $C_{16}H_{12}O_2S$: C, 71.62; H, 4.51; S, 11.95. Found: C, 71.35; H, 4.48; S, 12.14.

Phenanthro[3,2-*b*]thiophene (XXIII).

In a similar manner as described for the synthesis of XVIII (Method A), 1.80 g. (6.7 mmoles) of the acid XXI was reduced to the alcohol with 0.30 g. of lithium aluminum hydride and then the alcohol was oxidized to the aldehyde XXII with chromium trioxide-pyridine complex (1.3 g. of chromium trioxide and 13 ml. of pyridine). A mixture of the crude aldehyde and 15 ml. of polyphosphoric acid was heated on a steam bath for 20 minutes. After cooling, ice water was added to the mixture and the precipitated solid was collected by filtration. The crude compound was first purified by passing through a column of alumina (benzene) and then by passing again through a column of silica gel using warmed cyclohexane as the eluent to give 0.90 g. (57%) of XXIII as colorless crystals, m.p. 119-121.5°. An analytical sample was recrystallized from hexane, colorless fine plates, m.p. 121-122°; ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.3-7.9 (m, 7H, ArH except $H_1$, $H_7$ and $H_{11}$), 8.28 (s, 1H, $H_7$), 8.69 (m, 1H, $H_1$), 9.18 (s, 1H, $H_{11}$); uv: λ max (log ε) 210 (4.47), 242.5 (4.45), 272 (4.78), 282 (4.88), 302 (4.03), 314 (4.04), 328 (sh) (3.98), 352 (3.17) and 370 nm (3.17).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 81.79; H, 4.18; S, 13.88.

Phenanthro[9,10-*b*]thiophene (XXV).

Under a nitrogen atmosphere, a solution of 25.71 g. (0.1 mole) of 9-bromophenanthrene (26) in 20 ml. of dry benzene was added slowly to a mixture of 2.43 g. (0.1 g.-atom) of magnesium turnings and 50 ml. of dry ether. The reaction was initiated by the addition of a small amount of iodine and ethyl bromide. After completion of the addition, the reaction mixture was refluxed for one hour. Dry benzene (50 ml.) was added and the reaction mixture was refluxed for an additional 3 hours. After cooling, 29.85 g. of β,β-diethoxyethyldisulfide (27) was added. After refluxing for one hour, an aqueous solution of ammonium chloride was added. The product was extracted with ether, washed with aqueous sodium hydroxide and then with water and dried over sodium sulfate. The crude oily product obtained by the evaporation of ether was applied to a column of silica gel. Elution with cyclohexane gave unreacted 9-bromophenanthrene. Further elution with benzene gave 20 g. of the sulfide XXIV as a yellow oil; nmr (deuteriochloroform): δ 1.15 (t, 6H, $CH_3CH_2O$-), 3.21 (d, 2H, $-CH_2S$-), 3.55 (m, 4H, $CH_3CH_2O$-), 4.68 (t, 1H, methyne H), 7.4-8.0 (m, 5H, ArH), 7.82 (s, 1H, $H_{10}$), 8.4-8.7 (m, 3H, ArH).

A mixture of the crude sulfide and 200 g. of polyphosphoric acid was stirred at 150-160° (external temperature) for 10 minutes. After cooling, the mixture was poured into *ca.* 1 l. of water and the precipitated brown solid was collected. The dried crude product was dissolved in benzene and applied on a column of silica gel. The solid obtained by the elution with a mixture of cyclohexane and benzene (3:1) was passed again through a column of silica gel using hot cyclohexane as the eluent. The orange needles which precipitated from the eluate were collected by filtration to give 2.95 g. of XXV, m.p. 150-151°. Condensation of the filtrate gave 3.00 g. of additional XXV as orange needles, m.p. 150-151°.

The total yield was 5.95 g. (25% from 9-bromophenanthrene). An analytical sample was prepared by recrystallization from cyclohexane, as colorless needles, m.p. 151-152° (lit. (19) gives m.p. 151-153° and m.p. 153-154°); ms: m/e 234 ($M^+$); nmr (deuteriochloroform): δ 7.3-7.7 (m, 5H, $H_2$, $H_3$, $H_6$, $H_9$ and $H_{10}$), 7.88 (near d, 1H, $H_3$), 8.0-8.3 (m, 2H, $H_4$ and $H_{11}$), 8.4-8-8 (m, 2H, $H_7$ and $H_8$), uv: λ max (log ε) 253.5 (4.76), 258.5 (sh) (4.71), 279 (sh) (4.12), 289 (4.21) and 309 nm (3.92).

*Anal.* Calcd. for $C_{16}H_{10}S$: C, 82.02; H, 4.30; S, 13.68. Found: C, 82.19; H, 4.25; S, 13.81.

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(25) Tilak reported he obtained phenanthro[2,3-*b*]thiophene, m.p. 81-82°, by the cyclization of $\beta,\beta$-dimethoxyethyl 3-phenanthryl sulfide with polyphosphoric acid. However, in the cyclization of this sulfide, two ways of cyclization on the phenanthrene ring are possible. One of them is cyclization at the 2-position giving phenanthro[2,3-*b*]thiophene and the other is cyclization at the 4-position giving phenanthro[3,4-*b*]thiophene. We synthesized phenanthro[2,3-*b*]thiophene (XVIII) and found that the m.p. was in disagreement with that reported by Tilak (23). We suggest that his compound was phenanthro[3,4-*b*]thiophene and not phenanthro[2,3-*b*]thiophene. In fact, the melting points of phenanthro[3,4-*b*]thiophene (IX) (m.p. 82.5-83.5°) and its picrate derivative (m.p. 158-159°) almost agreed with those Tilak reported for his compounds (picrate, m.p. 154-155°).

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