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 Received February 28, 1991

The synthesis of two novel polycyclic heterocyclic ring systems *via* photocyclization are reported. These are benzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline and benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline. The total assignment of their ¹H- and ¹³C-nmr spectra was determined by utilizing two-dimensional nmr spectroscopic methods.

J. Heterocyclic Chem., **28**, 737 (1991).

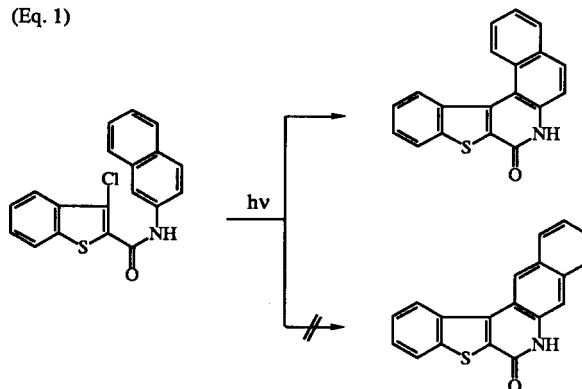
We have been interested in the synthesis of novel polycyclic heterocyclic ring systems *via* photocyclization of the appropriate amides [1a] and the study of their spectroscopic properties [1b,3,4]. In a recent paper [5] we reported that the photocyclization of 3-chloro-*N*-(2-naphthyl)-benzo[*b*]thiophene-2-carboxamide in benzene afforded only benzo[*f*][1]benzothieno[2,3-*c*]quinolin-8(*7H*)-one with no benzo[*g*][1]benzothieno[2,3-*c*]quinolin-7(*6H*)-one being detected (Equation 1). The structural confirmation was supported by a 1D-HOHAHA spectra [3]. In contrast, photocyclization of 3-chloro-*N*-(3-phenanthryl)benzo[*b*]thiophene-2-carboxamide led to an isomeric mixture of [1]benzothieno[2,3-*c*]naphtho[1,2-*f*]quinolin-6(*5H*)-one and [1]benzothieno[2,3-*c*]naphtho[2,1-*g*]quinolin-6(*7H*)-one [1b] (Equation 2). As a continuation of our studies of novel heterocyclic ring systems we now report the extension of a photo-induced cyclization leading to two previously unknown heterocyclic ring systems, namely benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (6) and benzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (11).

Synthesis.

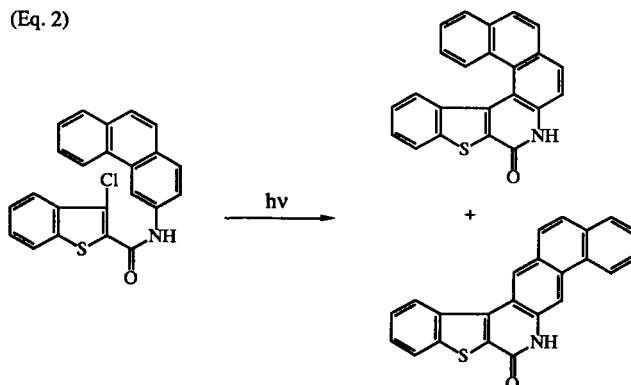
The requisite key intermediate, 3-chlorothieno[3,2-*b*]thiophene-2-carbonyl chloride (1), has been described by Wright, Jr. [6] and Gronowitz and Maltesson [7] by refluxing 3-(2-thienyl)acrylic acid and thionyl chloride in the presence of pyridine. Thus when carbonyl chloride 1 was allowed to react with 1-naphthylamine (2) in benzene solution, 3-chloro-*N*-(1-naphthyl)thieno[3,2-*b*]thiophene-2-carboxamide (3) was obtained in 87% yield. Irradiation of the amide 3 in benzene solution containing triethylamine with a 450 watt medium pressure mercury vapor lamp gave the only possible cyclization product, *i.e.* benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinolin-6(*5H*)-one (4) in 69% yield. Chlorination of 4 was performed by refluxing in phosphorus oxychloride to yield 6-chlorobenzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (5) in 47% yield. Catalytic dechlorination of 5 with 10% Pd-C in 2:1 benzene-methanol solution in the presence of potassium hydroxide provided the novel parent ring system benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (6) in 49% yield after column chromatography (Scheme I).

Likewise, 3-chloro-*N*-(2-naphthyl)thieno[3,2-*b*]thiophene-2-carboxamide (8) was obtained in 79% yield upon treatment of 1 with 2-naphthylamine (7). Photocyclization of 8 provided only one of the two possible isomers, benzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinolin-8(*7H*)-one (9) in quantitative yield with no trace of benzo[*g*]thieno[2',3':4,5]thieno[2,3-*c*]quinolin-7(*6H*)-one (12) being formed. These results are consistent with our previous work [5]. The ¹H nmr shows no singlets beyond $\delta = 9.0$ which is anticipated for H-12 of 12 and its structurally analogous polycyclic aromatic hydrocarbons [8] and heterocycles [1b]. Chlorination of 9 was accomplished by refluxing in phosphorus oxychloride to afford 8-chloroben-

(Eq. 1)



(Eq. 2)



bond epi-zig-zag coupling was well documented [10], the anticipated long-range coupling between H-4 and H-12 of **6** is not observable.

The connectivity of the protons with their respective carbon signals was established using heteronuclear chemical shift correlation with broadband homonuclear proton decoupling as described by Bax [11]. With all protons and protonated carbon atoms accounted for, the unequivocal

protonated and quaternary carbon signals were analyzed and assigned in a manner identical with that just described as above.

The assignment of the protons and carbon atoms of the terminal thiophene moiety was rather ambiguous. The signals at $\delta = 7.50$ and 7.82 are correlated with both of the signals at $\delta = 133.24$ and 142.13 (Figure 1). However, a close examination of the spectrum (Figure 2) revealed a response correlating the proton resonating at $\delta = 9.39$ with the carbon at $\delta = 133.24$, which was barely visible at the threshold of the contour plot. Differentiation from noise was provided by examination of the slice corresponding to this correlation, from the long-range heteronuclear experiment. This particular response may result from the four-bond coupling between H-6 and C-10a of **6**. Although four-bond couplings are usually small and difficult to observe, a positive coupling across W path has been observed in pyrene [13], thienopyridines [13], and 7-hydroxyfrullanolide [14,15]. Coupled with the knowledge that the chemical shift and that the three-bond heteronuclear couplings are generally substantially larger than their two-bond counterparts, the carbon atom resonating at $\delta = 133.24$ may be assigned as C-10a and $\delta = 142.13$ as C-7a. Accordingly, responses occurring at $\delta = 7.50$ and 7.82 may be immediately identified as H-8 and H-9, respectively. Thus it was possible to totally assign the proton and carbon spectra of **6** as collected in Table 1.

The spectral assignment of benzo[f]thieno[2',3':4,5]-thieno[2,3-c]quinoline (**11**) was analyzed and achieved in a fashion identical to that employed in the assignment of

Table 1

¹H- and ¹³C-NMR Chemical Shift Assignments and Observed Proton-Carbon Multiple-Bond Correlations for Compound **6** in Deuteriochloroform at 298°K at Observation Frequencies of 360.13 and 90.56 MHz, Respectively

Position	δ_H	δ_C	Two-Bond Correlation	Three-Bond Correlation
1	7.98	127.90		H-3, H-12
2	7.73	127.60		H-4
3	7.78	127.29		H-1
4	9.37	124.67		H-2
4a		131.79		H-1, H-3, H-12
4b		142.31		H-4, H-6, H-11
6	9.39	144.03		
6a		136.86	H-6	
7a		142.13		H-8, H-9
8	7.50	120.32	H-9	
9	7.82	132.31	H-8	
10a		133.24		H-8, H-9
10b		134.88		H-6, H-11
10c		120.17	H-11	H-12
11	8.27	121.24		
12	8.02	128.33		H-1
12a		132.81	H-12	H-2, H-4, H-11

assignment of the quaternary carbons was made *via* a long-range heteronuclear chemical shift correlation, experiment [12] (Figure 1) to complete the total assignment of the ¹H- and ¹³C-nmr spectra of **6**.

Several key long-range connectivities are critical to the assignment of the proton and carbon nmr spectra of **6**. Once H-6 has been tentatively identified, it would in turn be expected to be long-range coupled to C-10b resonating at $\delta = 134.88$ as well as C-4b at 142.31 on the basis of their chemical shifts. The verification of the C-4b assignment was provided by two additional three-bond correlations both to H-11, a two spin system, and H-4 in the adjacent four spin system. For C-10b, the assignment was confirmed by coupling to only one of the protons, H-11, from the two spin system. Confirmation of the assignment of C-6a was derived from the two-bond coupling between H-6 and C-6a at $\delta = 136.86$, which would show no other possibility for a long-range response.

Here, H-12 would also be utilized as a key focal point in addition to H-6. Possible three-bond coupling pathways for H-12 would include coupling to C-10c, C-1, and C-4a, respectively. Long-range coupling responses to the other

Table 2

¹H- and ¹³C-NMR Chemical Shift Assignments and Observed Proton-Carbon Multiple-Bond Correlations for Compound **11** in Deuteriochloroform at 298°K at Observation Frequencies of 360.13 and 90.56 MHz, Respectively

Position	δ_H	δ_C	Two-Bond Correlation	Three-Bond Correlation
1	9.28	126.48		H-3
2	7.70	125.48		H-4
3	7.70	127.26		H-1
4	7.98	128.30		H-2, H-5
4a		132.20	H-4, H-5	H-1, H-3, H-6
5	7.98	129.30		H-4
6	8.08	128.24		
6a		145.18		H-5, H-8
8	9.31	145.26		
8a		137.72	H-8	
9a		143.25	H-10	H-11
10	7.42	119.97	H-11	
11	7.60	130.01	H-10	
12a		135.19		H-10, H-11
12b		134.40		H-8
12c		120.97		H-1, H-6
12d		128.83		H-2, H-4, H-5

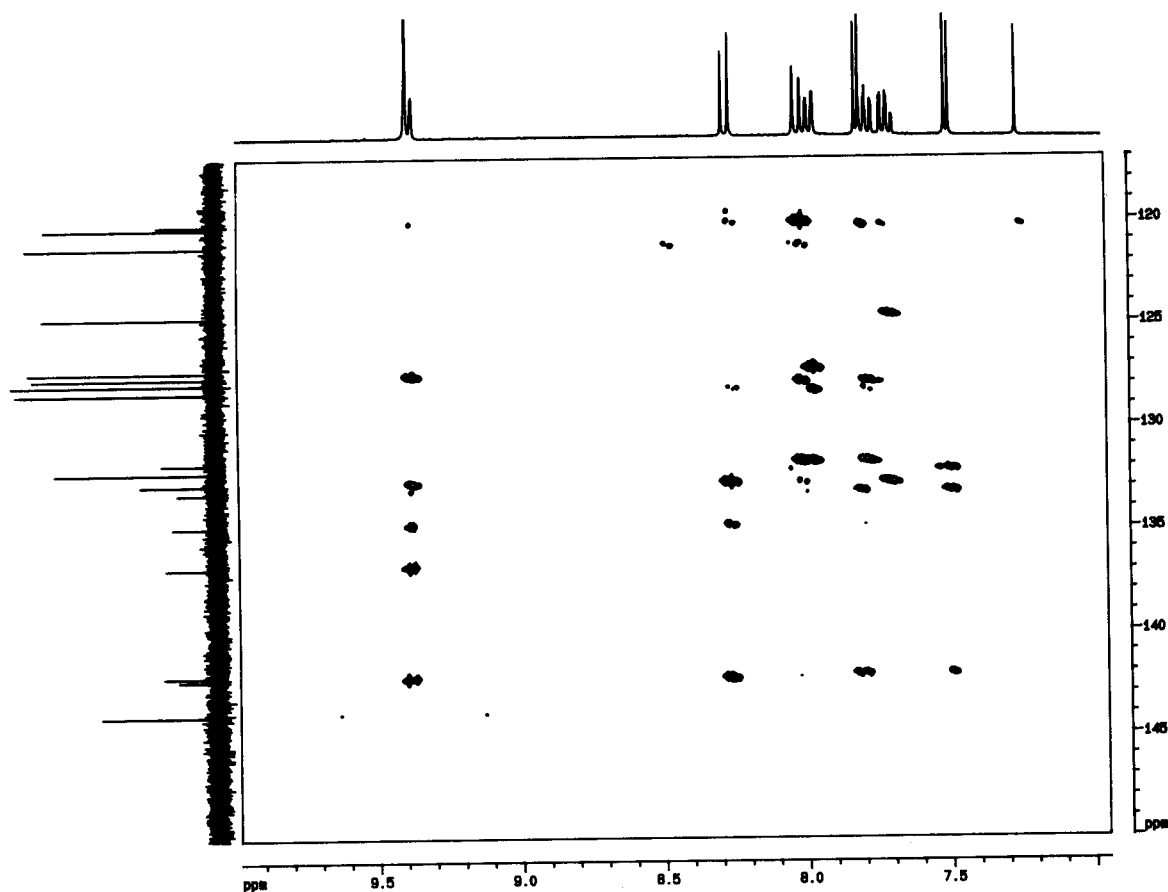


Figure 1. Long-range heteronuclear chemical shift correlation spectrum of **6** recorded in deuteriochloroform at observation frequencies of 360.13/90.56 MHz for ^1H and ^{13}C , respectively.

the spectra of **6**. Interestingly, in contrast to **6** the COSY spectrum (not shown) of **11** clearly demonstrated the anticipated five-bond epi-zig-zag coupling [10] between H-1 and H-5 (*vide supra*), linking the four spin system to the adjacent two spin system, and facilitated the assignment of benzo[*f*]quinoline moiety of **11**. The assignment of the remaining resonances of the terminal thiophene moiety is rather ambiguous due to the lack of a four-bond coupling across a *W* path between H-8 and C-12a [16] (*vide supra*). Based upon the prior assignment of **6** (*vide supra*) there is little doubt that the unequivocal total assignment of **11** can be achieved (Table 2).

EXPERIMENTAL

Melting points were determined on a Thomas-Hoover melting point apparatus and are uncorrected. The ir spectra were recorded on a Beckman FT 1100 spectrometer as potassium

bromide pellets and frequencies are expressed in cm^{-1} . The ^1H nmr spectra were obtained on a JEOL FX-90Q spectrometer in the solvent indicated with TMS as the internal standard and chemical shifts are reported in ppm (δ) and *J* values in Hz. Column chromatography was performed utilizing Aldrich silica gel, 70-230 mesh. Elemental analyses were performed by M-H-W Laboratories, Phoenix, Arizona.

Proton and carbon nmr spectra of final products were acquired using a Bruker AMX360 spectrometer operating at a proton frequency of 360.13 MHz and a carbon frequency of 90.56 MHz. The proton spectra were obtained using a $5\ \mu\text{s}$ (48.6°) pulse and 5 seconds between transients to insure accurate integrals. All two-dimensional experiments were acquired using a Bruker inverse geometry probe. Spectral width for all proton and proton correlation experiments was 992.06 Hz. A one-dimensional carbon spectrum was obtained with a sweep width of 15001.5 Hz with 2 seconds between transients. A phase

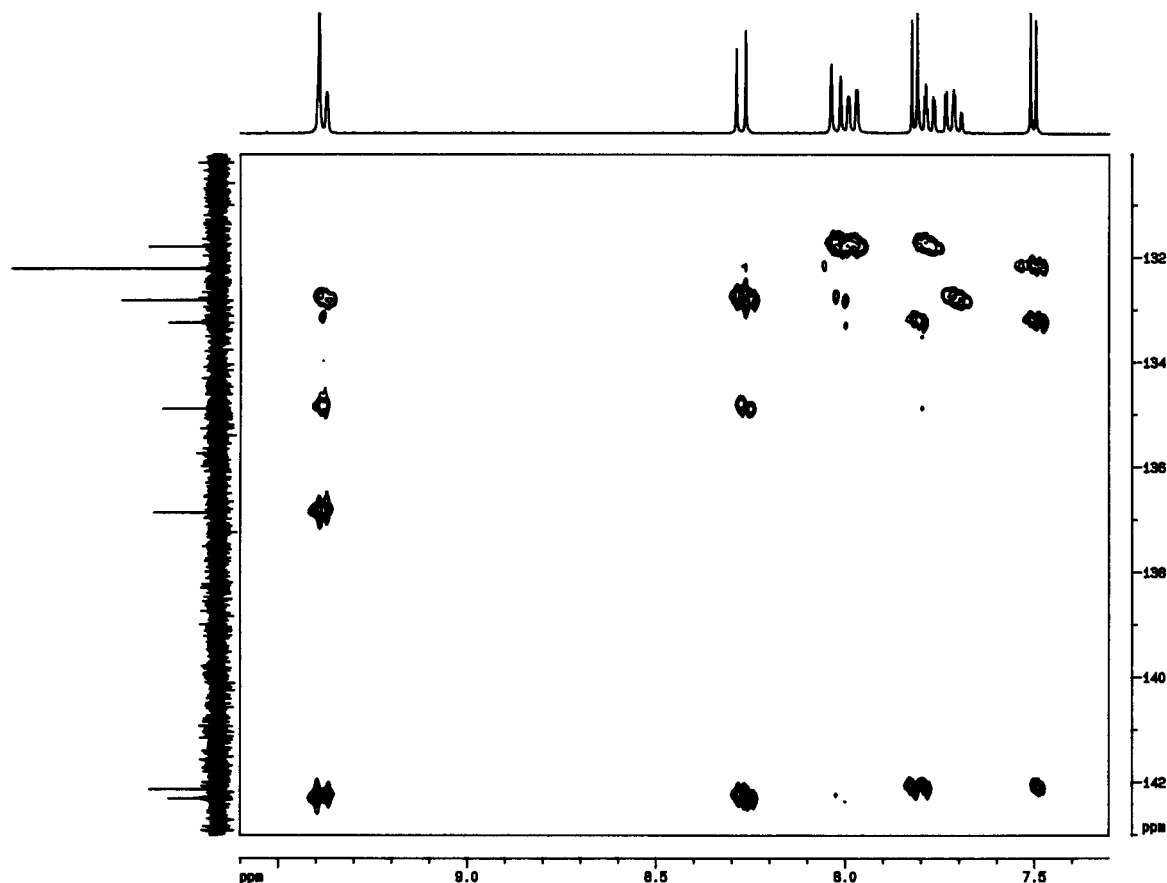


Figure 2. Expansion of the region from 131-143 ppm on F₂ in Figure 1.

sensitive double quantum filtered COSY experiment was acquired [17] with 512 t_1 increments of 504 μs used to encode a second dimension of 992.06 Hz. Proton-carbon correlation experiments were acquired using the proton-detected techniques of Bax [11,12]. Mixing times of 3.0 ms and 47.0 ms were used for direct and long-range methods, respectively. For the phase sensitive direct correlation technique, 256 t_1 increments of 156 μs were used to encode a sweep width of 3205.13 Hz. For the long-range correlation experiment 256 t_1 increments of 312 μs were used to encode a sweep width of 3205.13 Hz.

3-Chloro-*N*-(1-naphthyl)thieno[3,2-*b*]thiophene-2-carboxamide (3).

A mixture of 2.25 g (10 mmoles) of carbonyl chloride 1 [6,7], 1.43 g (10 mmoles) of 1-naphthylamine (2), and 40 ml of benzene was heated under reflux for 4 hours. After cooling the solid was collected by filtration and recrystallized from cyclohexane to give 2.99 g (8.70 mmoles, 87%) of 3 as colorless crystals, mp 160-162°; ir (potassium bromide): 3237 (NH stretching), 3091, 3073, 3050 (aromatic CH stretching), 1617

(C=O stretching); ¹H nmr (deuteriochloroform): δ 7.32 (d, 1H, $J_{5,6} = 5.4$ Hz, H-6), 7.43-8.27 (m, 8H, ArH including a doublet at δ 7.61 with $J_{5,6} = 5.4$ Hz assigned to H-5), 9.13 (br s, 1H, NH).

Anal. Calcd. for C₁₇H₁₀ClNOS₂: C, 59.38; H, 2.93; N, 4.07; S, 18.65. Found: C, 59.18; H, 3.07; N, 3.98; S, 18.49.

Benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinolin-6(5*H*)-one (4).

A mixture of 0.5 g (1.45 mmoles) of 3, 0.159 g (1.45 mmoles) of triethylamine, and 500 ml of benzene was irradiated with a 450 watt Hanovia medium pressure mercury vapor lamp for 4 hours. A slow stream of air was passed through the solution during the course of the reaction. The solid was collected by filtration and washed with water to give 0.31 g (1.01 mmoles, 69%) of 4, mp >280°; ir (potassium bromide): 3160 (NH stretching), 3055 (aromatic CH stretching), 1653 (C=O stretching); ¹H nmr (DMSO-*d*₆): 140° δ 7.55-8.11 (m, 7H, ArH), 8.92 (m, 1H, H-4). The compound was used for the next step without further purification because of low solubility.

6-Chlorobenzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (5).

A mixture of 1.00 g (3.25 mmoles) of 4 and 25 ml of phosphorus oxychloride was heated at 110-120° for 4 hours. After cooling the mixture was poured into 350 ml of ice-water with caution. The solid was collected by filtration and recrystallized from benzene to afford 0.50 g (1.53 mmoles, 47%) of 5 as colorless crystals, mp 229-231°; ir (potassium bromide): 3065 (aromatic CH stretching); ¹H nmr (deuteriochloroform): 5.0 δ 7.49 (d, J_{8,9} = 5.1 Hz, 1H, H-8), 7.60-8.04 (m, 5H, ArH), 8.22 (d, J_{11,12} = 8.8 Hz, 1H, H-11), 9.21-9.36 (m, 1H, H-4).

Anal. Calcd. for C₁₇H₈ClNS₂: C, 62.66; H, 2.48; N, 4.30; S, 19.68. Found: C, 62.71; H, 2.50; N, 4.15; S, 19.47.

Benzo[*h*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (6).

A mixture of 0.43 g (1.32 mmoles) of 5, 74 mg (1.32 mmoles) of potassium hydroxide, 100 ml of methanol, 200 ml of benzene, and 0.1 g of 10% Pd-C was hydrogenated at atmospheric pressure and room temperature until the uptake of hydrogen ceased. The catalyst was removed by filtration and the filtrate was evaporated to dryness *in vacuo*. The solid was dissolved in 20 ml of chloroform and subjected to column chromatography, eluting with cyclohexane-benzene (2:1) mixture to recover 0.20 g of starting material 5 and to yield 0.10 g (0.34 mmole, 49%) of 6 as yellow prisms after recrystallization from cyclohexane, mp 212-213°; ir (potassium bromide): 3106, 3042 (aromatic CH stretching).

Anal. Calcd. for C₁₇H₉NS₂: C, 70.07; H, 3.11; N, 4.81. Found: C, 69.96; H, 3.25; N, 4.78.

3-Chloro-*N*-(2-naphthyl)thieno[3,2-*b*]thiophene-2-carboxamide (8).

A mixture of 2.25 g (10 mmoles) of 1 [6,7], 1.43 g (10 mmoles) of 2-naphthylamine (7), and 40 ml of benzene was heated under reflux for 4 hours. After cooling the solid was collected by filtration and recrystallized from benzene to give 2.73 g (7.94 mmoles, 79%) of 8 as colorless crystals, mp 199-201°; ir (potassium bromide): 3384 (NH stretching), 3096 (aromatic CH stretching), 1643 (C=O stretching); ¹H nmr (DMSO-*d*₆): δ 7.36-7.70 (m, 3H, ArH, including a doublet at δ 7.62 with J_{5,6} = 5.4 Hz attributed to H-6), 7.78-8.02 (m, 5H, ArH, including a doublet at δ 7.99 with J_{5,6} = 5.4 Hz assigned to H-5), 8.37 (d, J_{1',3'} = 1.8 Hz, 1H, H-1'), 10.47 (br s, 1H, NH).

Anal. Calcd. for C₁₇H₁₀ClNOS₂: C, 59.38; H, 2.93; N, 4.07; S, 18.65. Found: C, 59.56; H, 3.10; N, 3.95; S, 18.43.

Benzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinolin-8(7*H*)-one (9).

A mixture of 0.2 g (0.58 mmole) of 8, 0.06 g of triethylamine in 500 ml of benzene was irradiated with a 450 watt Hanovia medium pressure mercury vapor lamp for 4 hours. A slow stream of air was passed through the solution during the course of the reaction. The solid was collected by filtration and washed with water to afford 0.18 g (0.58 mmole, 100%) of 9, mp, >280°; (ir potassium bromide): 3124 (NH stretching), 3088, 3068 (aromatic CH stretching), 1653 (C=O stretching); ¹H nmr (DMSO-*d*₆): 140° δ 7.46-7.80 (m, 4H, ArH, including a doublet at δ 7.65 with J_{10,11} = 5.4 Hz assigned to H-10), 7.91-8.10 (m, 3H, ArH, including a doublet at δ 7.94 with J_{10,11} = 5.4 Hz, for H-11), 8.96-9.07 (m, 1H, H-1). This compound was used in the next step without further purification because of low solubility.

8-Chlorobenzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (10).

A mixture of 1.85 g (6.05 mmoles) of 9 and 45 ml of phosphorus oxychloride was heated at 110-120° for 4 hours. After cooling the mixture was poured into 450 ml of ice-water with caution. The solid was collected by filtration and recrystallized from a benzene-cyclohexane mixture (1:1) to give 1.20 g (3.68 mmoles, 61%) of 10 as colorless crystals, mp 214-216°; ir (potassium bromide): 3098, 3080, 3044 (aromatic CH stretching); ¹H nmr (deuteriochloroform): δ 7.48 (d, J_{10,11} = 5.4 Hz, 1H, H-10), 7.64-7.80 (m, 3H, ArH), 7.96-8.08 (m 3H, ArH), 9.25-9.35 (m, 1H, H-1).

Anal. Calcd. for C₁₇H₈ClNS₂: C, 62.66; H, 2.48; N, 4.30; S, 19.68. Found: 62.77; H, 2.72; N, 4.23; S, 19.49.

Benzo[*f*]thieno[2',3':4,5]thieno[2,3-*c*]quinoline (11).

A mixture of 0.58 g (1.78 mmoles) of 10, 0.1 g of potassium hydroxide, 100 ml of methanol, 200 ml of benzene, and 0.1 g of 10% Pd-C was hydrogenated at atmospheric pressure and room temperature until the uptake of hydrogen ceased. The catalyst was removed by filtration and the filtrate was evaporated to dryness *in vacuo*. The residual solid was dissolved in 20 ml of chloroform and the solution was chromatographed on silica gel eluting with dichloromethane to recover 0.20 g of the starting material 10 and also to yield 0.20 g (0.69 mmole, 59%) of 11 as colorless crystals after recrystallization from cyclohexane, mp 170-172°; ir (potassium bromide): 3093, 3073, 3044 (aromatic CH stretching)

Anal. Calcd. for C₁₇H₉NS₂: C, 70.07; H, 3.11; N, 4.81. Found: C, 69.96; H, 3.14; N, 4.76

Acknowledgement.

The authors wish to thank National Science Foundation (CHE-8813620) for providing fund for the acquisition and operation of the Bruker AMX360 spectrometer used in this work.

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