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Naphtho[1',2':4,5]thieno[2,3-*c*][1,10]phenanthroline and naphtho[2',1':4,5]thieno[2,3-*c*][1,10]phenanthroline, two novel polycyclic heterocyclic ring systems, have been synthesized in four steps from known starting materials. The total  $^1\text{H}$  nmr spectral assignments were made using a COSY experiment to identify the spin systems.

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### Introduction.

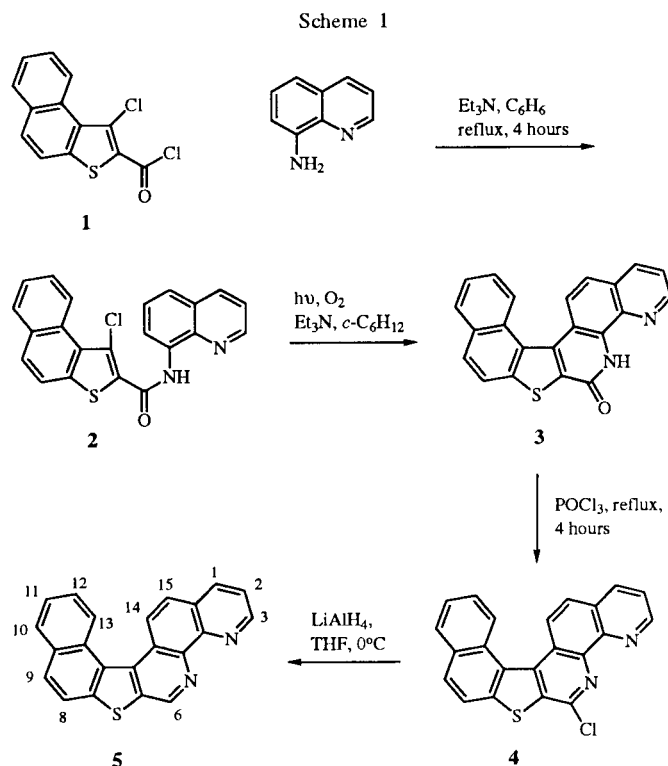
We report here the synthesis of two novel polycyclic ring systems *via* photocyclization, naphtho[1',2':4,5]-thieno[2,3-*c*][1,10]phenanthroline (**5**) and naphtho[2',1':4,5]thieno[2,3-*c*][1,10]phenanthroline (**10**), which we add to the series reported in references [1a-p]. These new ring systems are especially interesting because of the presence of the 1,10-phenanthroline moiety, which can serve as a chelation site.

### Results and Discussion.

#### Synthesis.

1-Chloronaphtho[2,1-*b*]thiophene-2-carbonyl chloride (**1**) [2] served as the starting material for the synthesis of **5** (Scheme 1). When **1** was allowed to react with 8-aminoquinoline, 1-chloro-*N*-(8'-quinoly)naphtho[2,1-*b*]thiophene-2-carboxamide (**2**) was obtained in 68% yield. Photocyclization of **2** afforded naphtho[1',2':4,5]-thieno[2,3-*c*][1,10]phenanthroline-6(5*H*)-one (**3**) in a crude yield of 80%. Chlorination of crude **3** with phosphoryl chloride gave 6-chloronaphtho[1',2':4,5]thieno[2,3-*c*][1,10]phenanthroline (**4**) in 60% yield. Dechlorination of **4** using lithium aluminum hydride in tetrahydrofuran [3] generated naphtho[1',2':4,5]thieno[2,3-*c*][1,10]phenanthroline (**5**) in 25% yield (8% overall yield). Conversion of **4** to **5** could not be accomplished by catalytic dechlorination [1d]. The starting materials for the synthesis of **10** (Scheme 2) were 3-chloronaphtho[1,2-*b*]thiophene-2-carbonyl chloride (**6**) [4] and 8-aminoquinoline, which afforded 3-chloro-*N*-(8'-quinoly)naphtho[1,2-*b*]thiophene-2-carboxamide (**7**) in 85% yield. Photocyclization of **7** afforded naphtho[2',1':4,5]thieno[2,3-*c*][1,10]phenanthroline-6(5*H*)-one (**8**) which was used in the next step without further purification. Chlorination of crude **8** with phosphoryl chloride gave 6-chloronaphtho[2',1':4,5]thieno[2,3-*c*][1,10]phenanthroline (**9**) in 29% yield based

on **7**. Dechlorination of **9** using lithium aluminum hydride in tetrahydrofuran generated naphtho[2',1':4,5]thieno[2,3-*c*][1,10]phenanthroline **10** in 35% yield (9% overall yield). As in the case of **4**, catalytic dechlorination [1d] of **9** was unsuccessful.



#### NMR.

The  $^1\text{H}$  nmr chemical shift assignments for **5** and **10** were straightforward. In each of the COSY spectra (Figures 1 and 2, respectively) the expected one three-spin, one four-spin and two two-spin systems were observed.

Scheme 2

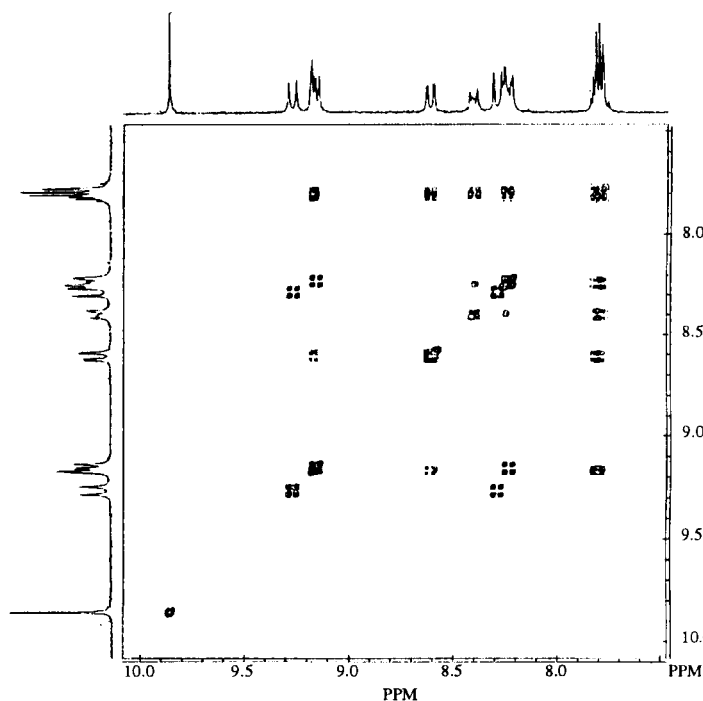
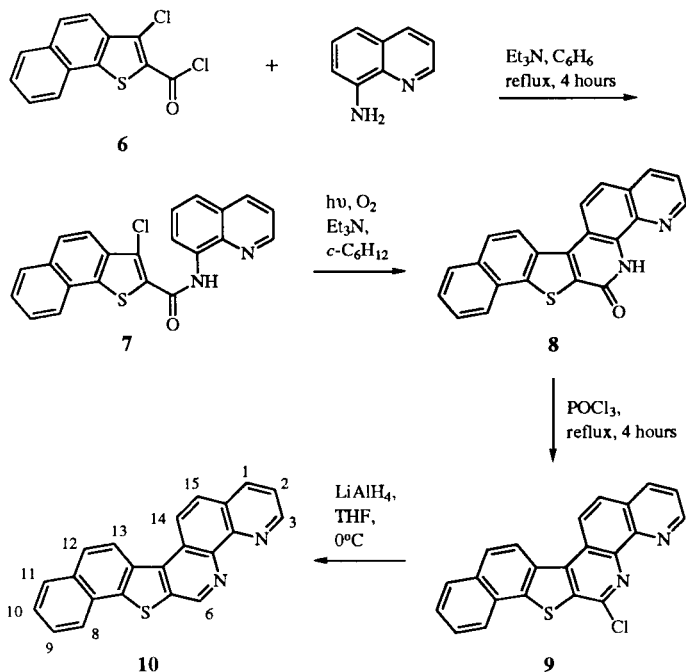


Figure 2. COSY spectrum of 5.

Table 1.

<sup>1</sup>H NMR Assignments for 5 and 10

Compound 5			Compound 10		
Position	$\delta$	Correlated <sup>1</sup> H's	Position	$\delta$	Correlated <sup>1</sup> H's
H <sub>1</sub>	8.33	H <sub>2</sub> , H <sub>3</sub>	H <sub>1</sub>	8.60	H <sub>2</sub> , H <sub>3</sub>
H <sub>2</sub>	7.67	H <sub>1</sub> , H <sub>3</sub>	H <sub>2</sub>	7.80	H <sub>1</sub> , H <sub>3</sub>
H <sub>3</sub>	9.27	H <sub>2</sub> , H <sub>1</sub>	H <sub>3</sub>	9.17	H <sub>2</sub> , H <sub>1</sub>
H <sub>6</sub>	9.71		H <sub>6</sub>	9.85	
H <sub>8</sub>	8.03	H <sub>9</sub>	H <sub>8</sub>	8.40	H <sub>9</sub> , H <sub>12</sub>
H <sub>9</sub>	8.10	H <sub>8</sub> , H <sub>13</sub>	H <sub>9</sub>	7.79	H <sub>8</sub> , H <sub>10</sub>
H <sub>10</sub>	8.03	H <sub>11</sub>	H <sub>10</sub>	7.81	H <sub>9</sub> , H <sub>11</sub>
H <sub>11</sub>	7.68	H <sub>12</sub>	H <sub>11</sub>	8.23	H <sub>10</sub>
H <sub>12</sub>	7.66	H <sub>13</sub> , H <sub>11</sub>	H <sub>12</sub>	8.25	H <sub>13</sub> , H <sub>8</sub>
H <sub>13</sub>	8.84	H <sub>12</sub> , H <sub>9</sub>	H <sub>13</sub>	9.04	H <sub>12</sub>
H <sub>14</sub>	8.85	H <sub>15</sub>	H <sub>14</sub>	9.26	H <sub>15</sub>
H <sub>15</sub>	7.91	H <sub>14</sub>	H <sub>15</sub>	8.29	H <sub>14</sub>

was observed in the COSY spectrum of 10 between H<sub>8</sub> and H<sub>12</sub>. This correlation allowed for the differentiation of the two two-spin systems and therefore the assignments of H<sub>12</sub>, H<sub>13</sub>, H<sub>14</sub> and H<sub>15</sub>. The H<sub>6</sub> proton corresponds to the farthest downfield singlet in both 5 and 10.

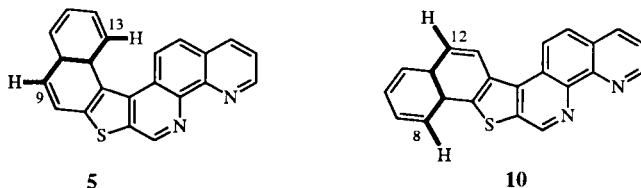


Figure 3. Structures of 5 and 10 showing the epi-zig-zag correlation.

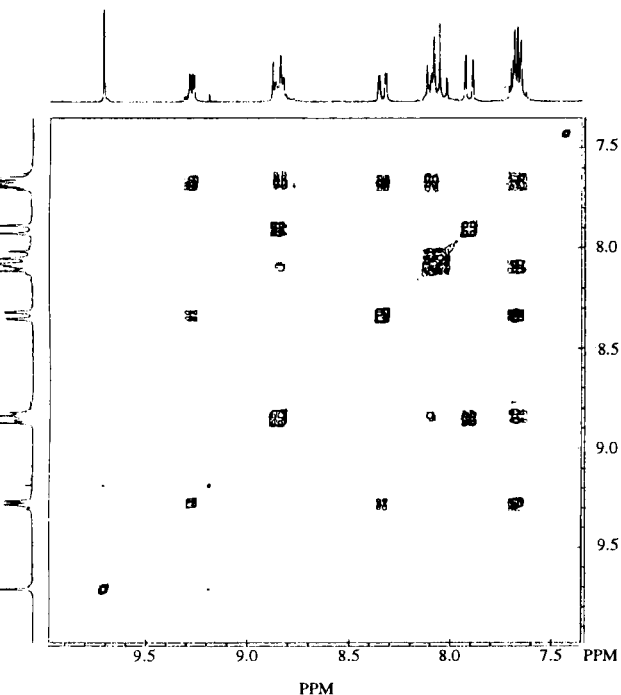


Figure 1. COSY spectrum of 5.

With the spin systems identified it was relatively easy to make the assignments which are listed in Table 1. One key correlation observed in the COSY spectrum of 5 (Figure 3) is between H<sub>9</sub> and H<sub>13</sub> via an epi-zig-zag pattern through five bonds. This allowed for the differentiation of the resonances corresponding to H<sub>8</sub> and H<sub>9</sub>. A similar correlation

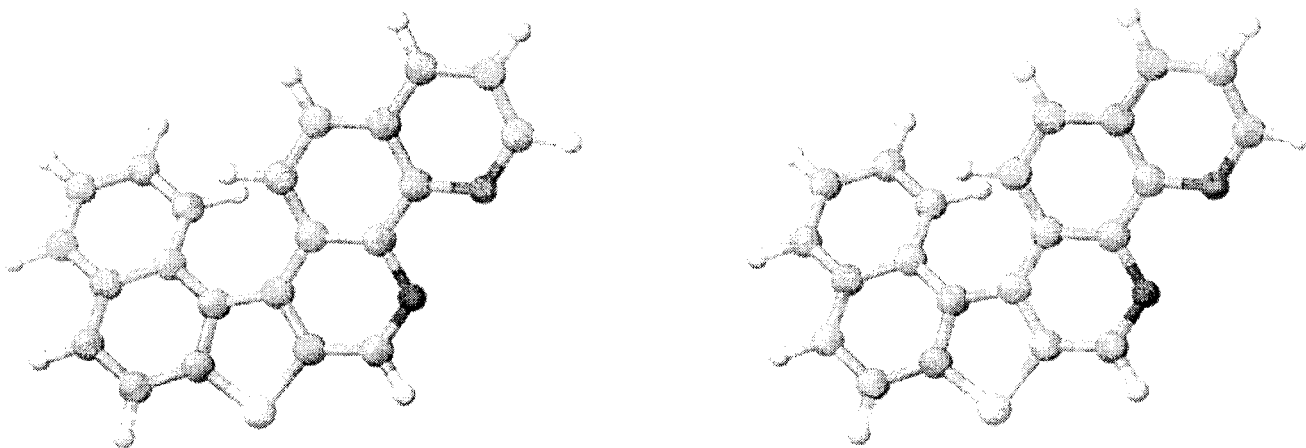


Figure 4. Stereoview of **5**, showing the MM2-minimized structure.

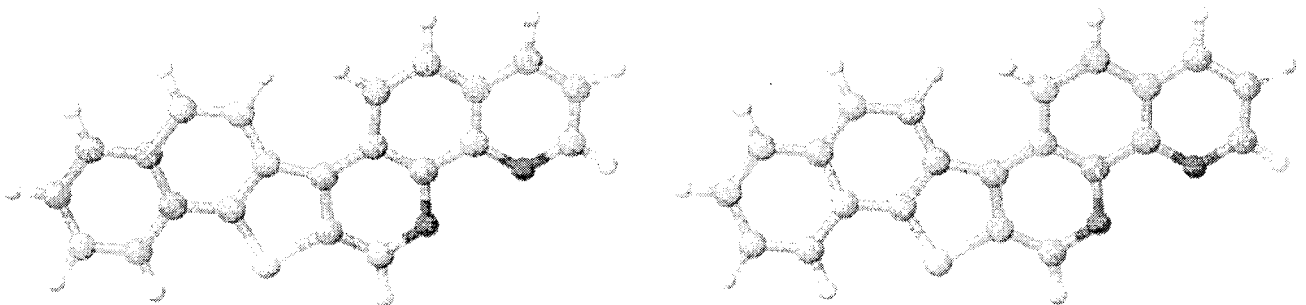


Figure 5. Stereoview of **10**, showing the MM2-minimized structure.

It is interesting to note that while **10** is nearly flat, **5** assumes a helically distorted conformation. MM2 [5] and MOPAC (using PM3 parameters [6]) calculations indicate that this distortion pushes H<sub>13</sub> and H<sub>14</sub> farther apart in **5** (MM2: 2.3 Å; MOPAC: 2.2 Å) than in **10** (MM2: 1.9 Å; MOPAC: 1.8 Å). Stereoviews of **5** and **10** are given in Figures 4 and 5, respectively.

## EXPERIMENTAL

Melting points were determined on a Mel-Temp apparatus and are uncorrected. The nmr spectra were obtained on a Bruker AC 250 spectrometer operating at 250.13 MHz for <sup>1</sup>H and 62.90 MHz for <sup>13</sup>C. All nmr experiments were performed using a 5-mm broad band probe. Chemical shifts are reported in ppm (δ) relative to tetramethylsilane as the internal standard. Both the <sup>1</sup>H and <sup>13</sup>C 90° pulses were calibrated and the values obtained were 8.3 and 5.1 μsec, respectively. The COSY spectra were acquired using the standard Bruker microprogram COSY.AU [7]. Column chromatography was performed using Merck silica gel, grade 9385, 230-400 mesh. Starting materials and reagents were purchased from Aldrich; solvents were obtained from Fisher. Elemental analyses were performed by M-H-W Laboratories, Phoenix, AZ. The structures of **5** and **10** were computed using

Computer Aided Chemistry (CACHe) software on a Power Macintosh 6100/60. The structures were first minimized using the forcefield provided by the MM2 [5] program set at the default settings, and the structure generated was then used as a starting point for a MOPAC geometry minimization. The MOPAC calculation was set to PM3 parameters [6] for a singlet state molecule.

1-Chloro-*N*-(8'-quinolyl)naphtho[2,1-*b*]thiophene-2-carboxamide (**2**).

3-Chloronaphtho[2,1-*b*]thiophene-2-carbonyl chloride (**1**) (1.5 g) and 1.0 g of 8-aminoquinoline were dissolved in 80 ml of benzene and allowed to reflux for two and one-half hours. At this time the solvent was removed under reduced pressure and the resulting solid was recrystallized from an acetone/ethanol mixture. The resulting off-white crystals were collected by vacuum filtration and allowed to dry overnight giving 1.9 g of **2** (69% yield), mp 217-218°; <sup>1</sup>H-nmr (deuteriochloroform): δ 7.52 (1H, dd), 7.55-7.78 (4H, m), 7.88 (2H, m), 8.00 (1H, d), 8.25 (1H, d), 8.90-9.00 (2H, m), 9.55 (1H, d), 11.75 (1H, br s).

*Anal.* Calcd. for C<sub>22</sub>H<sub>13</sub>ClN<sub>2</sub>OS: C, 67.95; H, 2.59; N, 7.20; S, 8.25. Found: C, 68.05; H, 2.64; N, 7.15; S, 8.41.

Naphtho[1',2':4,5]thieno[2,3-*c*][1,10]phenanthroline-6(*5H*)-one (**3**).

A stirred solution of 0.305 g (0.852 mmole) of 3-chloro-*N*-(8'-quinolyl)naphtho[2,1-*b*]thiophene-2-carboxamide (**2**) was dissolved in 40 ml of chloroform and placed in the photocyclization

reaction vessel. To this solution was added 850 ml of cyclohexane and 0.2 ml of triethylamine. The resulting solution was irradiated for five and one-half hours with a 450 watt Hanovia medium pressure mercury lamp while a slow stream of air was bubbled through the solution. The precipitate was collected by vacuum filtration, washed with acetone, then water, and then dried to yield **3** as a pale yellow powder (0.240 g, 80% yield), dec 220-230°. The material was used without further purification because of poor solubility in recrystallization solvents; <sup>1</sup>H-nmr (dimethyl sulfoxide-d<sub>6</sub>): δ 7.50 (2H, m), 7.76 (1H, dd), 7.84 (1H, d), 8.23 and 8.18 (1H, dd), 8.18 and 8.23 (2H, AB quartet), 8.52 (1H, dd), 8.58 (1H, d) 8.79 (1H, m), 9.05 (1H, dd), 11.69 (1H, N-H).

#### 6-Chloronaphtho[1',2':4,5]thieno[2,3-c][1,10]phenanthroline (4).

A stirred mixture of 0.102 g (0.284 mmole) of naphtho[1',2':5,4]thieno[2,3-c][1,10]phenanthroline-6(5H)-one (**3**) and 5 ml of phosphorus oxychloride was refluxed for six hours. The reaction was allowed to cool to room temperature and then poured slowly into 200 ml of ice. The resulting liquid slurry was then stirred for one-half hour and left to stand overnight. Vacuum filtration yielded a green solid. The green solid was allowed to dry overnight and then recrystallized from acetone to afford 0.063 g (60% yield) of fine yellow crystals, dec 210-230°; <sup>1</sup>H-nmr (deuteriochloroform): δ 7.71-7.75 (2H, m), 7.93 (1H, dd), 8.11-8.24 (4H, m), 8.70 (1H, dd), 8.78 (1H, m), 8.98 (1H, d), 9.29 (1H, dd).

*Anal.* Calcd. for C<sub>22</sub>H<sub>11</sub>ClN<sub>2</sub>S: C, 71.25; H, 2.99; N, 7.55; S, 8.65. Found: C, 71.05; H, 2.84; N, 7.25; S, 8.77.

#### Naphtho[1',2':4,5]thieno[2,3-c][1,10]phenanthroline (5).

A suspension of **4** (0.04 g, 0.11 mmole) in 15 ml of anhydrous tetrahydrofuran was cooled in an ice bath, under a nitrogen atmosphere. Lithium aluminum hydride (0.75 ml of 1.0 M stock solution in tetrahydrofuran, diluted with 5 ml of tetrahydrofuran, 6.5 molar equivalents) was added dropwise over 4 to 5 minutes, during which time **4** dissolved gradually and the color of the solution slowly changed from light yellow to dark green. The mixture was stirred for 10 minutes at 0 to 5°, then at room temperature for one-half hour. Excess lithium aluminum hydride was quenched by the successive addition of one ml of water, one pellet of potassium hydroxide and one ml of water. The resultant mixture was allowed to stir at room temperature for one hour, during which time the solution gradually changed color to orange and a white gelatinous precipitate formed. The solution was dried over magnesium sulfate, then all insoluble solids were removed by filtration and the solvent was evaporated *in vacuo*. A yellow oil was obtained, which was purified by flash chromatography using 2.5% methanol in chloroform as the eluent. Although some impurities were removed by chromatography, the compound was not yet pure. The resulting orange oil was dissolved in methanol and acetone then precipitated with water yielding 9 mg (25% yield) of the pure compound as an orange solid; <sup>1</sup>H-nmr: see Table 1; <sup>13</sup>C nmr (deuteriochloroform): δ 121.0, 122.6, 124.6, 124.8, 125.9, 126.0, 126.1, 127.7, 129.0, 129.8, 130.2(5), 130.3(4), 130.8, 132.2, 135.3, 135.9, 138.0, 141.8, 143.0, 145.0, 146.6, 150.6.

*Anal.* Calcd. for C<sub>22</sub>H<sub>12</sub>N<sub>2</sub>S·CH<sub>3</sub>OH·1/3H<sub>2</sub>O: C, 73.77; H, 4.49; N, 7.48; S, 8.56. Found: C, 73.98; H, 4.29; N, 7.41; S, 8.71.

#### 3-Chloro-N-(8'-quinolyl)naphtho[1,2-b]thiophene-2-carboxamide (7).

A mixture of **6** (5.4 g, 13.9 mmoles) and 8-aminoquinoline (2.0 g, 13.9 mmoles) in 80 ml of benzene was heated under reflux for 4 hours. The solvent was removed from the mixture under reduced pressure. The solid that remained was recrystallized from ethanol to give yellow crystals (4.55 g, 85% yield), mp 228-231°; <sup>1</sup>H nmr (deuteriochloroform): 7.52 (1H, dd), 7.60-7.70 (4H, m), 7.84-8.01 (3H, m), 8.19-8.24 (2H, m), 8.92 (1H, dd), 8.98 (1H, dd), 11.65 (1H, br s).

*Anal.* Calcd. for C<sub>22</sub>H<sub>13</sub>ClN<sub>2</sub>OS: C, 67.95; H, 3.37; N, 7.20; S, 8.24. Found: C, 68.18; H, 3.44; N, 6.96; S, 8.12.

#### Naphtho[2',1':4,5]thieno[2,3-c][1,10]phenanthroline-6(5H)-one (8).

A mixture of **7** (0.500 g, 1.29 mmoles), triethylamine (0.2 ml) and 500 ml of cyclohexane was irradiated with a 450 watt Hanovia medium pressure mercury lamp for four hours. Oxygen was bubbled through the solution during the course of the reaction. A yellow precipitate was collected by filtration, washed with water, air-dried (0.497 g) and was used in the next step without further purification; <sup>1</sup>H nmr (deuteriochloroform): δ 7.57 (1H, dd), 7.63-7.71 (2H, m), 7.76 (1H, d), 7.95-8.05 (2H, m), 8.27-8.35 (2H, m), 8.71 (1H, d), 8.81 (1H, d), 8.93 (1H, dd), 11.05 (1H, br s).

#### 6-Chloronaphtho[2',1':4,5]thieno[2,3-c][1,10]phenanthroline (9).

A mixture of **8** (1.1 g, 3.12 mmoles) and 40 ml of phosphorus oxychloride was heated to 110-115° for four hours. After cooling, the mixture was slowly poured over ice then basified (to pH 9) with concentrated ammonium hydroxide. The precipitate was filtered, allowed to air-dry, and then recrystallized from benzene to give tan needles (0.39 g, 29% yield), mp >300°; <sup>1</sup>H nmr (deuteriochloroform): δ 7.62-7.74 (3H, m), 8.01-8.11 (3H, m), 8.25-8.38 (2H, m), 8.82 (1H, d), 9.02 (1H, d), 9.29 (1H, dd).

*Anal.* Calcd. for C<sub>22</sub>H<sub>11</sub>N<sub>2</sub>SCl: C, 71.25; H, 2.99; N, 7.55. Found: C, 71.37; H, 2.89; N, 7.42.

#### Naphtho[2',1':4,5]thieno[2,3-c][1,10]phenanthroline (10).

A suspension of **9** (0.04 g, 0.11 mmole) in 15 ml of anhydrous tetrahydrofuran was cooled in an ice bath, under a nitrogen atmosphere. Lithium aluminum hydride (0.6 ml of 1.0 M stock solution in tetrahydrofuran, diluted with 5 ml of tetrahydrofuran, 5.5 molar equivalents) was added dropwise over 4 to 5 minutes, during which time **9** dissolved gradually and the color of the solution slowly changed from light yellow to dark green. The mixture was stirred for 10 minutes at 0 to 5°, then at room temperature for one-half hour. Excess lithium aluminum hydride was quenched by the successive addition of one ml of water, one pellet of potassium hydroxide and one ml of water. The mixture was allowed to stir at room temperature for 1 hour, during which time the solution gradually changed color to orange and a white gelatinous precipitate formed. The solution was dried over magnesium sulfate, then all insoluble solids were removed by filtration and the solvent was evaporated *in vacuo*. An orange oil was obtained, which was purified by flash chromatography on silica gel with gradient elution: chloroform, 1% methanol in chloroform and 2.5% methanol in chloroform. Fractions were combined which gave R<sub>f</sub> 0.25 on tlc (silica gel, 2.5% methanol in chloroform); <sup>1</sup>H-nmr (dimethyl sulfoxide-d<sub>6</sub>): see Table 1. Because of poor solubility, not all of the carbon atoms could be observed in the <sup>13</sup>C nmr spectrum. However, a DEPT90 experiment allowed the identification of the protonated carbon atoms (dimethyl sulfoxide-d<sub>6</sub>): δ 145.9, 146.6, 147.0, 148.0, 150.6, 151.5, 151.6, 151.8, 152.5, 159.7, 168.8, 174.1. Compound **10**

crystallized in the nmr tube after several days. It was separated by filtration, washed with water and air-dried to give a brown solid (0.013 g, 35% yield), decomposes above 245°.

*Anal.* Calcd. for C<sub>22</sub>H<sub>12</sub>N<sub>2</sub>S: C, 78.55; H, 3.60; N, 8.33; S, 9.53. Found: C, 78.56; H, 3.70; N, 8.26; S, 9.44.

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