Synthesis of bis-4H-furo[3,4-b]indoles

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Abstract

We describe the synthesis of two novel bis-4H-furo[3,4-b]indoles from indole. Several alternative pathways to these potential DNA bis-intercalator precursors are discussed, and the synthesis of a novel semi-rigid tether is reported.

Keywords: Indole, furo[3,4-b]indole, furan, acylation, acid chloride
Introduction

We have had a long interest in the synthesis and Diels–Alder cycloaddition reactions of 4H-furo[3,4-b]indoles,1–8 particularly as a novel route to the synthesis of ellipticine alkaloids.3–5 Following our inaugural synthesis of the 4H-furo[3,4-b]indole (2, 3) ring system (Figure 1),1,2 we greatly improved the efficiency and the overall yield of this ring system from indole.7,8 For example, our original synthesis1 of 1,3-dimethyl-4-(phenylsulfonyl)-4H-furo[3,4-b]indole (3) from indole (1) proceeded in 21% yield, whereas our shortened synthesis of 3 from indole gives an overall yield of 45%.8

![Figure 1](image1.png)

Results and Discussion

In connection with our interest in the synthesis and antitumor activity of potential bis-DNA intercalators,2,9,10 we utilized bis-furoindole 4 for the synthesis of 1,10-bis(6-methyl-5H-benzo[b]carbazol-11-yl)decane (Figure 2).2 Although successful, our early synthesis of 4 was less efficient than we desired. We now describe syntheses of bis-furo[3,4-b]indoles 5 and 6 using our improved methodology8 (Scheme 1). Our newer method avoids an extra reduction step featured earlier1,2 and relies on an initial indole acylation protocol.

![Figure 2](image2.png)
Commercially available decanedioic acid (7) and tetradecanedioic acid (8) were converted into the respective diacid chlorides 9 and 10 in high yields (Scheme 1). Friedel–Crafts acylation\textsuperscript{11} of 1-(phenylsulfonyl)indole (11)\textsuperscript{12} with 9 and 10 afforded the respective 3-acylindoles 12 and 13 in good yields. In a one-pot operation, ketones 12 and 13 were transformed into the desired bis-furo[3,4-\(b\)]indoles 5 and 6 by a sequence of carbonyl protection as the bis-enol ethers 14 and 15, C-2 lithiation and quenching with acetaldehyde to generate intermediates 16 and 17, followed by trifluoroacetic acid–induced twin
cyclodehydration to give the desired furoindoles 5 and 6. Although the final yields of these new bis-furoindoles 5 and 6 are low, the method is relatively short and should be amenable to the preparation of analogues and the subsequent synthesis of Diels–Alder cycloadducts.  

We explored an alternative approach to these bis-furo[3,4-b]indoles by removing the carbonyl groups at an early stage as shown in Scheme 2. Thus, bis-acylation of 1-(phenylsulfonyl)indole (11) with dodecanedioic acid chloride (18), prepared from dodecanedioic acid and thionyl chloride, gave diketone 19. Reduction\(^{11}\) of 19 with NaBH\(_4\)/TFA gave 20 in 85\% yield. Unfortunately, attempts to effect bis-lithiation of 20 with sec-BuLi and quenching with acetaldehyde failed to afford a clean mixture of diastereomeric diols 21, and this alternative route was not further pursued.

![Scheme 2](image)

In an approach to the isomeric bis-furo[3,4-b]indole 27, we prepared dodecanedial (23) via the ozonolysis of cyclododecene (22).\(^{13,14}\) Other attempts to prepare 23 via the reduction of 1,10-dodecanedioic acid\(^{15,16}\) were unsatisfactory. Lithiation of 3-ethyl-1-(phenylsulfonyl)indole (25),\(^{11}\) prepared by reduction of 3-acetyl-1-(phenylsulfonyl)indole (24),\(^{11}\) and condensation with dialdehyde 23 gave a mixture of diols 26 in modest yield, along with other products (Scheme 3). Therefore, we deemed that this route was not worth further investigation.
Scheme 3

DNA-bis intercalators possessing semi-rigid tethers typically exhibit improved antitumor activity over those with flexible tethers.\textsuperscript{17–20} In this regard, we targeted the potential semi-rigid tethers embodied in diacid 32 and diacid chloride 33 (Scheme 4) for study. Bis-bromination of diphenyl ether 28 gave dibromide 29, and subsequent alkylation with dimethyl malonate gave the new tetraester 30. Double Krapcho decarbomethoxylation\textsuperscript{21–23} led to the corresponding diester 31. Future work will involve the conversion of 31 into acid 32 and then acid chloride 33, which will serve in an indole acylation protocol.

Our planned indole acylation using diacid chloride 33 is modeled with the syntheses of 3-acylindoles 35 and 38 (Scheme 5). Interestingly, whereas 1-(phenylsulfonyl)indole (11) undergoes smooth acylation with phenylacetyl chloride (34) to give ketone 35 in high yield, an acylation attempt of 11 with 3-phenylpropionyl chloride (37) yielded mainly indanone (not shown). However, the desired ketone 38 could be synthesized from 3-bromo-1-(phenylsulfonyl)indole\textsuperscript{24} (36) via the corresponding indolyl bromo cuprate as according to the method of Dieter.\textsuperscript{25}
Scheme 4

Scheme 5

An attractive target for our future work on this project is bis-ellipticine 40 (Figure 3). The diphenyl ether tether imparts significant anticancer activity when tethered to two 9-aminoacridines. Accordingly, tethers such as 31-33 can be envisaged to forge 39 and, subsequently, bis-ellipticine 40.
Conclusions

We have synthesized the novel bis-4H-furo[3,4-b]indoles 5 and 6, which now join the first member, 4, of this family. These bis-dienes are suitable for double Diels–Alder cycloaddition reactions leading to potent DNA bis-intercalators. Furthermore, we prepared the bifunctional tether 31, which can be envisioned as leading to the semi-rigid bis-4H-furo[3,4-b]indole 39 and thence to bis-ellipticine 40.

Experimental Section

General. Thin layer chromatography was performed on precoated (0.2 mm) silica gel 60 F254 plastic sheets with spots visualized using a 254 nm UV lamp. Flash chromatography was performed with 230–400 mesh Silicycle gel 60. Melting points were taken on a Laboratory Devices Mel Temp or a Buchi 510 melting point apparatus in open capillaries and are uncorrected. 1H and 13C NMR spectra were recorded on Varian XL-300 and XL-500 Fourier transform spectrometers as noted. The chemical shifts noted from these spectra are reported in parts per million (ppm, δ) using the signal of chloroform-d1 (δ 7.27) or acetone-d6 (δ 1.94) or Me4Si as an internal standard. In a few cases a Varian EM 360A NMR Spectrometer measuring at 60 MHz was used. Infrared spectra were recorded with a Perkin Elmer 1600 FTIR or on a Perkin-Elmer 599 spectrophotometer and were obtained either neat or using solid potassium bromide pellets. Both low-resolution and high-resolution mass spectra (MS and HRMS) were performed at the Mass Spectrometry Laboratory, School of Chemical Sciences, University of Illinois at Urbana Champaign, or were measured at 35 eV and 70 eV on a Finnigan El-CI 4023 gas chromatograph-mass spectrometer. Elemental analyses were performed by Atlantic Microlab, Inc. (Norcross, GA). Tetrahydrofuran (THF) was distilled from sodium/benzophenone and the alkyl lithium reagents were standardized by titration against diphenylacetic acid.

1,10-Decanedioyl dichloride (9). To a stirred solution of 1,10-decanedioic acid (7) (2.0 g, 10 mmol, 1 eq.) in anhydrous CH2Cl2 (165 mL) under nitrogen was added oxalyl chloride (16.5 mL, 190 mmol, 10 eq.) rapidly via
The reaction was stirred for 24 h, after which the solvent and unreacted oxalyl chloride were distilled off under reduced pressure. The resulting yellow liquid was concentrated via azeotrope with benzene (3 x 50 mL) in vacuo, following which it was redissolved in CH$_2$Cl$_2$ and filtered to remove unreacted 7. The solvent was removed in vacuo and the product dried under a vacuum to yield (9) (2.21 g, 92%) as a yellow liquid; $^1$H NMR (CDCl$_3$): δ 2.89 (t, 4H), 1.78–1.68 (m, 4H), 1.31–1.25 (b, 8H). This was used directly in the next step with 11.

**1,14-Tetradecanediol dichloride (10).** To a stirred solution of 1,14-tetradecanediol acid (8) (2.6 g, 10 mmol, 1 eq.) in anhydrous CH$_2$Cl$_2$ (165 mL) under nitrogen was added oxalyl chloride (16.5 mL, 190 mmol, 10 eq.) rapidly via syringe. The reaction was stirred for 24 h, after which the solvent and unreacted oxalyl chloride were removed by distillation under reduced pressure. The resulting yellow liquid was concentrated via azeotrope with benzene (3 x 50 mL) in vacuo, following which it was redissolved in CH$_2$Cl$_2$ and filtered to remove unreacted 8. The solvent was removed in vacuo and the product was dried under a vacuum to yield (10) (2.68 g, 91%) as a yellow liquid, which was used directly in the next step with 11.

**1,10-Bis(1-(phenylsulfonyl)-1H-indol-3-yl)decane-1,10-dione (12).** To a stirred solution of AlCl$_3$ (2.24 g, 16.8 mmol, 4 eq.) in CH$_2$Cl$_2$ (90 mL) at 0 °C was added after 15 min a solution of 1,10-decanediol dichloride (9) (1.01 g, 4.2 mmol, 1 eq.) in CH$_2$Cl$_2$ (3 mL) dropwise via an addition funnel. The solution was stirred 30 min, after which a solution of 1-(phenylsulfonyl)indole (11) (2.15 g, 8.41 mmol, 2 eq.) in CH$_2$Cl$_2$ (20 mL) was added over 30 min via addition funnel. During this time the solution turned from light yellow to dark orange. The solution was allowed to come to rt and stirred for 2.5 h, during which the solution appeared dark red. The reaction was quenched with ice (150 g) in a 400 mL beaker and covered with a watch glass until the ice melted. The aqueous layer was then extracted with CH$_2$Cl$_2$ (4 x 75 mL) and the combined organic extracts were washed with brine (2 x 50 mL), aqueous sodium carbonate (50 mL), and brine (2 x 50 mL). The organic layer was then dried (MgSO$_4$), filtered, and concentrated in vacuo to yield (12) as a white solid (2.54 g, 89%). The solid was washed with 4:1 hexane:EtOAc and recrystallized in CH$_2$Cl$_2$/hexane to yield white solid product (12): mp 194–197 °C; $^1$H NMR (CDCl$_3$): δ 8.37–8.34 (m, 2H), 8.23 (s, 2H), 7.98–7.93 (m, 6H), 7.64–7.58 (m, 2H), 7.53–7.40 (m, 4H), 7.39–7.35 (m, 4H), 2.91 (t, 4H), 1.78–1.68 (m, 4H), 1.31–1.25 (b, 8H). This was used directly in the next step with 13.

**1,14-Tetradecanediol dichloride (10).** To a stirred solution of 1,14-tetradecanediol acid (8) (2.67 g, 9.1 mmol, 2 eq.) in CH$_2$Cl$_2$ (180 mL) at 0 °C was added after 15 min a solution of 1,14-tetradecanediol dichloride (9) (4.85 g, 16.8 mmol, 10 eq.) in CH$_2$Cl$_2$ (40 mL) was added over 30 min via addition funnel. During this time the solution turned from light yellow to dark orange-red. The solution was allowed to come to rt and stirred for 2.5 h, during which the solution appeared dark red. The reaction was quenched with ice (300 g) in a 600 mL beaker and allowed to stand overnight covered with a watch glass. The aqueous layer was extracted with CH$_2$Cl$_2$ (4 x 125 mL) and the combined organic extracts were washed with brine (2 x 100 mL), aqueous sodium carbonate (100 mL), and brine (2 x 100 mL). The organic layer was then dried (MgSO$_4$), filtered, and concentrated in vacuo to yield (13) as a beige solid (4.81 g, 72%). The solid was washed with 4:1 hexane:EtOAc and recrystallized from EtOAc/hexane to yield the 13 as a light beige solid: mp 155–156 °C. $^1$H NMR (CDCl$_3$): δ 8.40–8.36 (m, 2H), 8.25 (s, 2H), 8.02–7.92 (m, 6H), 7.64–7.60 (t, 2H), 7.57–7.45 (m, 4H), 7.42–7.32 (m, 4H), 2.95 (t, 4H), 1.82–1.75 (m, 4H), 1.63–1.55 (b, 2H), 1.45–1.24 (m, 12H). $^{13}$C NMR (CDCl$_3$): δ 196.7, 141.7, 134.8, 131.7, 129.8, 127.3, 126.0, 125.1, 123.4, 113.2, 40.4, 29.8, 29.7, 29.6, 24.8. IR (KBr): 3111, 3067, 3049, 2920, 2850, 1661 (C=O), 1540, 1444, 1381, 1287, 1180, 1134, 980, 934, 754, 594. MS (EI): 680.4 (M$^+$), 539.2, 446.2, 399.2, 327.1, 297.1, 257.1, 144.0, 116.1, 77.0 (100%).

$^*$H NMR (CDCl$_3$): δ 196.7, 141.7, 134.8, 131.7, 129.8, 127.3, 126.0, 125.1, 123.4, 113.2, 40.4, 29.8, 29.7, 29.6, 24.8.
2924, 2847, 1669 (C=O), 1541, 1444, 1386, 1290, 1172, 1134, 1097, 990, 755, 683 cm$^{-1}$; MS (EI): 736.3 (M$^+$), 595.3, 539.0, 446.2, 398.2, 327.1 (100%), 267.1, 141.0, 88.1. Anal. Calcd for C$_{42}$H$_{44}$N$_2$O$_5$S$_2$: C, 68.45; H, 6.02; N, 3.80; S, 8.70. Found: C, 67.04; H, 5.93; N, 3.79; S, 8.49.

1,8-Bis(3-methyl-4-(phenylsulfonyl)-4H-furo[3,4-b]indol-1-yl)octane (5). To a $-78$ °C stirred solution of 1,10-bis(1-(phenylsulfonyl)-1H-indol-3-yl)decane-1,10-dione (12) (680 mg, 1 mmol, 1 eq.) in dry THF (50 mL) under nitrogen was added lithium diisopropylamide (LDA) (1 mL of 2.0 M in THF/heptane, 2 mmol, 2 eq.) dropwise via syringe. The reaction was stirred for 15 min, after which tert-butylimethylsilyl triflate (TBSOTf) (0.46 mL, 2 mmol, 2 eq.) was added dropwise via syringe. The reaction was stirred 1 h at $-78$ °C, after which lithium diisopropylamide (1 mL of 2.0 M in THF/heptane, 2 mmol, 2 eq.) was added dropwise. The reaction turned from yellow to orange. The mixture was stirred for 10 min, after which freshly distilled acetaldehyde (0.24 mL, 4 mmol, 4 eq.) was quickly added in one portion, after which the solution turned rapidly from orange to yellow. The mixture was stirred for 1 h before it was quenched in aqueous ammonium chloride (50 mL). The THF was removed under reduced pressure and the mixture was extracted with CH$_2$Cl$_2$ (3 x 25 mL). The combined organic layers were treated with TFA (0.25 mL, 3.4 mmol, 3.4 eq.) and the mixture was stirred for 2 h under nitrogen. The reaction was then neutralized with saturated sodium bicarbonate (50 mL) and the aqueous layer was extracted with CH$_2$Cl$_2$ (3 x 25 mL). The combined organic layers were dried over sodium sulfate and the solvent was removed in vacuo to yield a dark yellow oil. Purification by flash chromatography (20% EtOAc in hexane) afforded 5 as a light yellow oil (66 mg, 9%). Further purification on activity III neutral alumina (20% EtOAc in hexane) afforded the analytical sample of 5 as a colorless oil; $^1$H NMR (acetone-$d_6$): δ 8.07–7.78 (m, 6H), 7.68–7.11 (m, 12H), 2.71 (s, 6H), 2.68 (t, 4H), 1.69–1.57 (m, 4H), 1.39–1.05 (m, 8H); HRMS (ESI): 732.2 (M + H)$^+$, 722.3, 721.3, 708.2, 707.2. Calcd for C$_{42}$H$_{44}$N$_2$O$_5$S$_2$: 732.2328 (M), C$_{42}$H$_{44}$N$_2$O$_5$S$_2$: 733.2406 (M + H). Found: 733.2410 (M + H)$^+$.

1,12-Bis(3-methyl-4-(phenylsulfonyl)-4H-furo[3,4-b]indol-1-yl)dodecane (6). To a $-78$ °C stirred solution of 1,14-bis(1-(phenylsulfonyl)-1H-indol-3-yl)tetradecane-1,14-dione (13) (740 mg, 1 mmol, 1 eq.) in dry THF (50 mL) under nitrogen was added lithium diisopropylamide (LDA) (1 mL of 2.0 M in THF/heptane, 2 mmol, 2 eq.) dropwise via syringe. The reaction was stirred for 15 min, after which tert-butylimethylsilyl triflate (TBSOTf) (0.46 mL, 2 mmol, 2 eq.) was added dropwise via syringe. The reaction was stirred for 1 h at $-78$ °C, after which lithium diisopropylamide (1 mL of 2.0 M in THF/heptane, 2 mmol, 2 eq.) was added dropwise. The mixture was stirred for 10 min, after which freshly distilled acetaldehyde (0.24 mL, 4 mmol, 4 eq.) was quickly added in one portion. The mixture was stirred for 1 h before it was quenched in aqueous ammonium chloride (50 mL). The THF was removed under reduced pressure and the mixture was extracted with CH$_2$Cl$_2$ (3 x 25 mL). The combined organic layers were treated with TFA (0.25 mL, 3.4 mmol, 3.4 eq.) and the mixture was stirred for 2 h under nitrogen. The reaction was then neutralized with saturated sodium bicarbonate (50 mL) and the aqueous layer was extracted with CH$_2$Cl$_2$ (3 x 25 mL). The combined organic layers were dried over sodium sulfate and the solvent was removed in vacuo to yield a dark yellow oil. Purification by flash chromatography (20% EtOAc in hexane) afforded 6 as a light yellow oil (66 mg, 9%). Further purification on activity III neutral alumina (20% EtOAc in hexane) afforded the analytical sample of 6 as a colorless oil; $^1$H NMR (acetone-$d_6$): δ 8.03 (m, 2H), 7.63 (m, 4H), 7.45–7.18 (m, 12H), 2.75 (t, 4H), 2.69 (s, 6H), 1.71–1.60 (m, 4H), 1.28–1.19 (m, 16H). MS (ESI): 789.3 (M$^+$ + H$^+$), 787.3, 777.4, 773.3, 761.2. Calcd for C$_{46}$H$_{48}$N$_2$O$_8$S$_2$: 789.3032 (M + H). Found: 789.3015 (M + H)$^+$.
1,12-Di-(1-(phenylsulfonyl)-3-indolyl)-1,12-dioxododecane (19). To a magnetically stirred suspension of AlCl₃ (13.9 g, 0.104 mol) in CH₂Cl₂ (180 mL) at 0 °C was added dropwise the crude 1,12-dodecanedioyl dichloride (18) (2.21 g, 8.27 mmol) in CH₂Cl₂ (5 mL). The mixture was stirred for 30 min, at which time a solution of (11) (4.52 g, 0.018 mol) in CH₂Cl₂ (40 mL) was added dropwise. The mixture was allowed to reach rt and stirred an additional 2 h. The resulting dark red-brown reaction mixture was poured over crushed ice (300 mL) and extracted with CH₂Cl₂ (3 x 75 mL). The organic layer was washed with brine (2 x 75 mL), NaHCO₃ (75 mL), made basic with dilute NaOH and washed with brine (2 x 75 mL). The product was then dried over K₂CO₃ and concentrated in vacuo. The crude powder (5.34 g) was purified by flash chromatography over silica gel with gradient elution of EtOAc/hexane (0:1, 1:1, 0:1). The purest fractions were combined, filtered, and concentrated in vacuo to give a crude light brown powder 1.22 g (85%). The sample was purified by flash chromatography over silica gel with gradient elution of Et₂O/hexane (1:1, 1:9, 1:1, 1:0) and finally ether/CH₂Cl₂ (9:1, 1:1, 0:1). The purest fractions were combined, filtered, and concentrated in vacuo to give 20 as a fine off-white powder: mp 121 °C; IR (CHCl₃) 2930, 2870, 1660, 1600, 1530, 1450, 1380, 1170 cm⁻¹; ¹H NMR (CDCl₃) δ 8.4–7.25 (m, 10H), 1.8 (t, 2H), 1.4 (m, 16H); ¹³C NMR (CDCl₃) δ 138.3, 135.4, 133.5, 131.2, 129.1, 126.7, 124.6, 123.9, 123.0, 119.5, 113.8, 77.0, 76.9, 76.6, 29.3, 29.4, 28.8, 24.9; Mass spectrum, m/e 680 (M⁺), 271, 270, 170, 156, 141, 131, 130, 77 (100).

1,12-Di-(1-(phenylsulfonyl)-3-indolyl)dodecane (20). To magnetically stirred trifluoroacetic acid (80 mL) at 0 °C under argon, equipped with a reflux condenser and drying tube, was added sodium borohydride (30 pellets, 0.214 mol) as a buffer. The flask was cooled to –78 °C (isopropanol/dry ice) and ozone was allowed to bubble through for 0.5 h more. Ozone addition was stopped, and nitrogen was passed through to discharge the blue color. The cold bath was then removed, and dimethyl sulfide (5.07 g, 0.075 mol) was added via syringe. The reaction mixture was stirred overnight at rt, then filtered to remove the NaHCO₃, and concentrated to a white slurry by rotary evaporation. CH₂Cl₂ (50 mL) was added and the mixture was washed with H₂O (40 mL). The aqueous layer was extracted with CH₂Cl₂ (2 x 50 mL), and the combined organic extract was washed with H₂O (50 mL). The aqueous layer was extracted again with CH₂Cl₂ (50 mL). The combined organic layers were dried over anhydrous MgSO₄, filtered, and concentrated in vacuo to yield the crude product. Short path distillation yielded 4.58 g (62%) of 1,12-dodecanedial (23) as a white solid. mp 28–38 °C; (lit.¹⁶ mp 65-66 °C); bp 123–131 °C at 0.4 Torr; IR (CHCl₃) 3510, 3430, 2940, 2740, 1725, 1465, 1400, 1230, 1100 cm⁻¹; ¹H NMR (CDCl₃) δ 9.7 (t, 2H, J 1.8 Hz), 2.4 (m, 4H), 1.4 (m, 16H) (lit.²⁷ ¹H NMR (CDCl₃) δ 9.78 (t, J 1.65...
was removed on a sintered glass filter funnel. The solvent was removed (10 mL), dried (MgSO$_4$) to yield desired product as white crystals: mp 85–86 °C (lit. $^{29}$ mp 93–95 °C). $^1$H NMR (CDCl$_3$): δ 7.38 (d, 4H), 6.98 (d, 4H), 4.52 (s, 4H). MS (EI): 458.2 (M +), 427.2, 398.2, 357.2, 327.2 (100%), 267.1, 227.1, 197.1, 181.8, 151.1, 131.1, 101.1, 91.1. HRMS (EI): Calcd for C$_{34}$H$_{26}$O$_5$: 458.1577 (M). Found: 458.1585 (M$^+$).

4,4′-Oxybis((bromomethyl)benzene) (29). Prior to use, NBS was recrystallized from water and the carbon tetrachloride was bubbled with nitrogen, stirred for 45 min with sodium sulfate, and checked by $^1$H-NMR spectroscopy. To a stirred solution of 4,4′-oxybis(methylbenzene) (28) (5.0 g, 25.2 mmol, 1 eq.) and NBS (8.98 g, 50.4 mmol, 2 eq.) in carbon tetrachloride (125 mL) under nitrogen was added a catalytic amount of AIBN. The reaction mixture was heated to 80–90 °C (reflux) and stirred for 6.5 h. The solution was then cooled and the succinimide was removed on a sintered glass filter funnel. The solvent was removed in vacuo to yield the desired product 29 as beige crystals (8.3 g, 93%). A portion (1.82 g) was purified by flash chromatography (10:1 hexane:EtOAc) to yield 29 as white crystals: mp 85–86 °C (lit. $^{29}$ mp 93–95 °C). $^1$H NMR (CDCl$_3$): δ 7.38 (d, 4H), 6.98 (d, 4H), 4.52 (s, 4H).

Tetramethyl 2,2′-((oxybis(4,1-phenylene))bis(methylene))dimalonate (30). To a freshly prepared 5% weight solution of NaOMe in anhydrous MeOH (2 mL) was added dimethyl malonate (0.12 mL, 1.13 mmol, 2 eq.) dropwise via syringe. The solution was cooled to 0 °C and a solution of 4,4′-oxybis((bromomethyl)benzene) (29) (crude, 0.2 g, 0.56 mmol, 1 eq.) in anhydrous benzene (0.6 mL) was added dropwise via syringe. The solution was stirred for 0.5 h before allowing it to warm to rt, after which it was stirred for 15 h. The solvent was removed in vacuo, and the resulting oil was resuspended in water (5 mL) and extracted with chloroform (3 x 3 mL). The combined organic extracts were washed with brine (5 mL), dried (MgSO$_4$), and filtered. The solvent was removed in vacuo to yield crude 30 as a yellow oil (100 mg, 39%). Preparative TLC was used to purify 20 mg of the oil to confirm product identification by NMR spectroscopy. Column chromatography (3:2 hexane:EtOAc) gave 30 (30 mg, 12%) as a colorless oil.

Dimethyl 3,3′-(oxybis(4,1-phenylene))dipropionate (31). To a stirred solution of LiCl (5.14 mg, 0.12 mmol, 2 eq.) in DMF (4.5 mL) and water (1 drop) was added tetramethyl 2,2′-((oxybis(4,1-phenylene))bis(methylene))dimalonate (30) (27 mg, 0.06 mmol, 1 eq.). The reaction mixture was heated in an oil bath to reflux (140 °C) for 1 h. The reaction mixture was then cooled to rt and poured into H$_2$O (10 mL). The aqueous layer was extracted with Et$_2$O (4 x 8 mL), and the combined organic extracts were washed with brine (10 mL), dried (MgSO$_4$), and concentrated in vacuo to yield the crude product as a colorless oil. To remove any residual DMF the oil was then rewash with H$_2$O (10 mL), extracted with Et$_2$O (4 x 8 mL), and the combined organic layers were washed again with brine (10 mL), dried (MgSO$_4$), and concentrated in vacuo to yield 31 as a colorless oil (15 mg, 73%); $^1$H NMR (CDCl$_3$): δ 7.15 (d, 4H), 6.92 (d, 4H), 3.73 (s, 6H), 2.95 (t, 4H), 2.62 (t, 4H). MS (EI): 458.2 (M +), 427.2, 398.2, 357.2, 327.2 (100%), 267.1, 227.1, 197.1, 181.8, 151.1, 131.1, 101.1, 91.1. HRMS (EI): Calcd for C$_{24}$H$_{22}$O$_5$: 458.1577 (M). Found: 458.1585 (M$^+$).

2-Phenyl-1-(1-phenylsulfonyl)-1H-indol-3-yl)ethan-1-one [35]. To a stirred solution of phenylacetyl chloride (34) (1.11 mL, 8.43 mmol, 1 eq.) in dichloromethane (50 mL) at 0 °C was added AlCl$_3$ (1.30 g, 16.9 mmol, 2 eq.). After the solution was stirred for 15 min a solution of 1-(phenylsulfonyl)indole (11) (2.17 g, 8.43 mmol, 1 eq.) in CH$_2$Cl$_2$ (17.5 mL) was added over 20 min via an addition funnel. During this time the solution turned from light yellow to dark orange-yellow. The solution was allowed to come to rt and stirred for 2.5 h, during which the solution appeared dark orange-red. The reaction was quenched with ice in a 300 mL beaker and allowed to stand overnight covered with a watch glass, during which the solution turned yellow-green. The solution was extracted with CH$_2$Cl$_2$ (6 x 30 mL) and the combined organic extracts were washed with brine (50 mL), aqueous sodium carbonate (50 mL), and brine (50 mL). The organic layer was then dried (MgSO$_4$), filtered, and...
concentrated in vacuo to yield (35) as light peach crystals (2.76 g, 87%). The product was recrystallized from Et₂O to give 35 with mp 121–123 °C; ¹H NMR (CDCl₃): δ 8.25 (s, 1H), 7.94–7.85 (m, 2H), 7.63–7.56 (m, 1H), 7.50–7.26 (m, 6H), 4.21 (s, 2H). ¹³C NMR (CDCl₃): δ 193.62, 137.70, 135.15, 134.99, 134.82, 132.66, 129.88, 129.66, 129.08, 127.30, 126.21, 127.29, 123.53, 113.31, 47.61. IR (KBr): 3313, 3140, 2911, 1678 (C=O), 1602, 1529, 1475, 1451, 1232 cm⁻¹. MS (EI): 375.1 (M⁺), 284.1 (100%), 264.1, 237.0, 223.0, 185.1, 157.1, 143.1, 129.1, 115.1, 91.1, 77.0. Anal. Calcd for C₂₂H₁₇NO₃S: C, 70.38; H, 4.56; N, 3.73; S, 8.54. Found: C, 70.36; H, 4.58; N, 3.62; S, 8.54.

3-Phenylpropanoyl chloride (37). To a stirred solution of 3-phenylpropanoic acid (3.0 g, 20 mmol, 1 eq.) in anhydrous CH₂Cl₂ (165 mL) under nitrogen was added oxalyl chloride (16.5 mL 190 mmol, 10 eq.) rapidly via syringe. The reaction mixture was stirred for 24 h, after which the solvent and unreacted oxalyl chloride were removed by distillation under reduced pressure. The resulting yellow liquid was concentrated via azeotrope with benzene (3 x 50 mL) in vacuo and dried under a vacuum to yield 37 (3.4 g, ~100%) as a yellow liquid, which was used directly in the next step.

3-Phenyl-1-(1-(phenylsulfonyl)-1H-indol-3-yl)propan-1-one (38). To a dark, stirred solution of CuCl (50 mg, 0.5 mmol, 1 eq.), LiCl (42 mg, 1 mmol, 2 eq.), and 3-bromo-1-(phenylsulfonyl)indole (36) (162 mg, 0.5 mmol, 1 eq.) in THF (4 mL) at –100 °C (Et₂O and dry ice) after 15 min was added n-BuLi (0.19 mL, 0.5 mmol, 1 eq.) slowly via syringe. The reaction mixture was stirred 15 min, after which 3-phenylpropanoyl chloride (37) (80 µL, 0.53 mmol, 1.1 eq.) was added rapidly via syringe. The reaction mixture was stirred for an additional 15 min at –100 °C, after which it was warmed rapidly to rt and quenched in aqueous NaHCO₃ (5 mL). The green aqueous layer was extracted with Et₂O (3 x 15 mL), after which the peach-colored organic extracts were combined, dried (MgSO₄), and concentrated in vacuo to yield a pink oil (210 mg). The crude product was further purified by preparative TLC (3:1 hexane:EtOAc) to yield the desired product (38) as a yellow oil (88 mg, 47%). ¹H NMR (acetone-d₆): δ 8.56 (s, 1H), 8.20 (d, 1H), 8.02 (d, 2H), 7.92 (d, 1H), 7.60 (t, 2H), 7.53 (t, 2H), 7.35–7.05 (m, 6H), 3.28 (t, 2H), 2.94 (t, 2H). MS (EI): 389.2 (M⁺), 284.1, 262.2, 248.1, 220.1, 206.1, 191.2, 173.1, 144.1, 115.1, 84.0 (100%).

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