Electronic Supplementary Material (ESI) for Photochemical & Photobiological Science

Supporting Information

Bichromophoric Fluorescent Photolabile Protecting Group for Alcohols and Carboxylic Acids

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General Information. All organic solvents were dried and freshly distilled before use. Flash chromatography was performed using 40-63 μm silica gel. All NMR spectra were recorded on 400 MHz instruments in $CDCl_3$ and referenced to TMS unless otherwise noted. Solutions were prepared using HPLC grade water, and acetonitrile. Substrates concentrations were kept at ca $2.5*10^{-4}$ M in acetonitrile – water (1 : 4) unless otherwise noticed. Solutions of compounds **1a-c** were irradiated using mini-Rayonet photochemical reactor equipped with 8 fluorescent UV lamps (4W, 300, 350, or 419 nm) or using immersion type reactor equipped with 450W medium-pressure Hg lamp. Reaction mixtures after photolysis were analyzed by HPLC and deprotection yields were calculated using calibration plots. Quantum efficiencies of photochemical reactions were measured by ferrioxalate actinometry.

Materials: 6-(Hydroxymethyl)naphthalene-1,7-diol (NQMP **3**) and NQMP-caged thymidine derivative **8c** were prepared according to procedure reported previously.[1] Dansyl chloride, γ-aminobutyric acid and N-Boc phenylalanine were purchased from Sigma-Aldrich.

2,2-Dimethyl-4H-naphtho[2,3-d][1,3]dioxin-9-ol (**4**): 2,2-Dimethoxypropane (1.3 mL, 11 mmol) and catalytic amount of TsOH were added to a solution of **3** (0.7 g, 3.68 mmol) in acetone (15 mL). The reaction mixture was stirred at r.t. overnight. The solvent was removed under reduced pressure and the residue was taken in DCM. The DCM solution was washed with brine, dried over anhydrous magnesium sulfate and the solvent was removed under reduced pressure. The product was purified by column chromatography using 50% ethyl acetate in hexane to yield 0.745 g of **4** (88%) as yellow oil. ^{1}H NMR: 7.58 (s, 1H), 7.39 (s, 1H), 7.27 (d, J = 8.4 Hz, 1H), 7.10 (t, J = 8.0 Hz, 1H), 6.71 (d, J = 7.2 Hz, 1H), 6.00 (s, 1H), 5.05 (s, 2H), 1.60 (s, 6H). ^{13}C NMR: 150.87, 149.56, 130.06, 125.26, 124.07, 123.62, 121.76, 120.16, 108.63, 106.83, 100.25, 61.48, 25.19. EI-MS m/z: 231(5), 230(30), 187(1), 173(14), 172(93), 145(12), 131(1), 114(3), 144(100), 102(1), 89(8), 77(3), 63(4), 51(4), 43(11).

FW calc ($C_{14}H_{14}O_3$):230.0938; EI-HRMS: 230.0943.

9-Dansyl-2,2-dimethyl-4H-naphtho[2,3-d][1,3]dioxin-9-ol (**5**): A solution of dansyl chloride (0.67 g, 2.5 mmol) and Et_3N (1.4 ml, 10 mmol) in DCM (10 ml) was added to solution of **4** (0.23 g, 1mmol) in DCM (10 ml). The reaction mixture was stirred at r.t. for 20 h and the solvent was evaporated. The crude product was purified by column chromatography using dichloromethane–ethyl acetate–n-hexane (1:1:1, v/v) mixture as eluent to give the compound **5** (0.37 g, 80%) as yellow oil. ^{1}H NMR: 8.61 (t, J = 7.2 Hz, 1H), 8.16 (d, 8.4 Hz, 1H), 7.65 (t, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 1H), 7.45 (t, 7.6 Hz, 1H), 7.43 (s, 1H), 7.38 (s, 1H), 7.23 (d, 7.2 Hz, 1H), 7.02 (t, 8.0 Hz, 1H), 6.79 (d, 7.6 Hz, 1H), 4.98 (s, 2H), 2.89 (s, 6H), 1.54 (s, 6H). ^{13}C NMR: 152.14, 150.88, 145.28, 132.22, 132.09, 131.07, 130.43,

[1] S. Arumugam, and V. V. Popik, Light-Induced Hetero Diels-Alder Cycloaddition: A Facile and Selective Photo-Click Reaction, *J. Am. Chem. Soc.,* 2011, **133,** 5573-5579.

130.11, 129.95, 129.30, 128.25, 126.67, 123.68, 123.20, 122.91, 122.47, 119.83, 117.93, 115.87, 107.06, 100.23, 61.20, 45.67, 25.18. FW calc ($C_{26}H_{25}NO_5S$):463.1453; EI-HRMS: 463.1445.

7-Hydroxy-6-(hydroxymethyl)naphthalen-1-yl 5-(dimethylamino)naphthalene-1-sulfonate (**2**): Catalytic amount of conc. HCl was added to a solution of acetal **5** (150 mg, 0.32 mmol) in 10 mL of acetonitrile and stirred for 2 h at r.t. Excess of solid sodium bicarbonate was added and stirred for 5 more minutes. The reaction mixture was filtered and the solvent was removed under reduced pressure. The crude product was purified by chromatography using methanol in dichloromethane as eluent to yield 110 mg of **2** (85%) as yellow oil. ^{1}H NMR: 8.58 (t, J = 8.4 Hz, 1H), 8.11 (d, 7.6 Hz, 1H), 7.76 (s, 1H), 7.64 (t, J = 8.0 Hz, 1H), 7.40-7.47 (m, 1H), 7.45 (s, 1H), 7.37 (s, 1H), 7.22 (d, 7.2 Hz, 1H), 6.95 (t, 8.0 Hz, 1H), 6.69 (d, 7.2 Hz, 1H), 4.81 (s, 2H), 2.89 (s, 6H). ^{13}C NMR: 154.57, 152.09, 144.90, 132.26, 131.73, 131.21, 130.37, 130.06, 130.04, 129.35, 129.29, 128.75, 127.40, 127.08, 123.29, 122.69, 119.79, 118.39, 115.95, 105.21, 63.58, 45.67. EI-MS *m/z*: 424(11), 423(42), 342(7), 324(6), 236 (15), 235(100), 189(6), 172(10), 171(74), 170(57), 169(10), 168(20), 155(15) 154 (17), 131(7), 129(7), 128(13), 127(15), 126(5), 115(23), 77(5). FW calc ($C_{23}H_{21}NO_5S$):423.1140; EI-HRMS: 423.1134.

7-(TBDMSoxy)-6-((TBDMSoxy)methyl)naphthalen-1-yl 5-(dimethylamino)naphthalene-1-sulfonate (**6**): Imidazole (482 mg, 7.10 mmol), catalytic amount of DMAP, and *tert*-butyldimethylsilyl chloride (531 mg, 3.54 mmol) were added to a solution of **2** (500 mg, 1.18 mmol) in 10 ml of dry DMF and stirred overnight at r.t. The reaction mixture was poured into 100 mL of saturated solution of sodium bicarbonate and the product **6** was extracted with ethyl acetate (3X50 mL). Extracts were combined, washed with brine, and dried over sodium sulfate. Solvent was removed under reduced pressure and the product **6** was purified by silica gel column using 25% of ether in dichloromethane to yield 0.62 g of **6** (80 %) as yellow oil. ^{1}H NMR: 8.67 (d, J=8.8Hz, 1H), 8.63 (d, J=8.8Hz, 1H), 8.33 (d, J=7.2 Hz, 1H), 7.94 (s, 1H), 7.66-7.70 (m, 2H), 7.50-7.60 (m, 2H), 7.27 (d, J=8Hz, 1H), 7.05 (t, J=8Hz, 1H), 6.66 (d, J=7.2 Hz), 4.94 (s, 2H), 2.93 (s, 6H),1.09 (s, 9H), 1.05 (s, 9H), 0.35 (s, 6H), 0.20 (s, 6H). ^{13}C NMR: 152.21, 145.19, 135.32, 132.31, 132.21, 131.04, 130.95, 130.45, 130.26, 129.34, 128.04, 127.04, 125.60, 123.34, 122.84, 119.99, 117.53, 115.99, 107.63, 61.36, 45.72, 26.09, 26.04, 18.86, 18.58, -4.05, -5.0. FW calc ($[C_{35}H_{49}NO_5SSi_2 + H]^+$):652.2943, ESI-HRMS: 652.2948.

7-(TBDMSoxy)-6-(hydroxymethyl)naphthalen-1-yl 5-(dimethylamino)naphthalene-1-sulfonate (**7**): $CeCl_3.7H_2O$ (570 mg. 1.54 mmol) was added to a solution of **6** (500 mg, 0.77 mmol) in 20 ml of dry acetonitrile, reaction mixture was refluxed for 4 h, stirred overnight, and poured into 100 mL of saturated solution of sodium bicarbonate. The product was extracted with ethyl acetate (3X25 mL). Extracts were combined, washed with brine, and dried over sodium sulfate. Solvent was removed under reduced pressure and the residue was purified on silica gel column using 40% of ether in

dichloromethane to yield 0.34g of **7** (82 %) as yellow oil. ^{1}H NMR: 8.52 (d, J=8.8Hz, 1H), 8.43 (d, J=8.8Hz, 1H), 8.03 (d, J=7.2 Hz, 1H), 7.64 (s, 1H), 7.53 (t, J=8Hz, 1H), 7.47 (d, J=8.4Hz, 2H), 7.35-7.40 (m, 2H), 7.12-7.14 (m, 1H), 6.88 (t, J=7.6 Hz, 1H), 6.46 (d, J=7.6 Hz, 1H), 4.69 (d, J=4.8Hz, 2H), 2.79 (s, 6H), 0.91 (s, 9H), 0.20 (s, 6H). ^{13}C NMR: 153.12, 152.31, 145.22, 134.39,132.30, 131.10, 130.83, 130.49, 130.33, 128.41, 127.66, 127.33, 127.04, 123.38, 123.26, 120.02, 118.09, 116.07, 108.31, 62.40, 45.80, 26.15, 18.57, -4.0. FW calc ($[C_{29}H_{35}NO_5SSi + H]^+$):538.2078, ESI-HRMS: 652.2084.

6-(Bromomethyl)-7-(TBDMSoxy)naphthalen-1-yl 5-(dimethylamino)naphthalene-1-sulfonate **9**: PBr_3 (38 mg, 13μL, 0.14 mmol) was added dropwise to a solution of **7** (150 mg, 0.28 mmol) in 10 ml of anhydrous THF, the resultant solution was stirred for 3 h at r.t., poured in to 20 mL of saturated sodium bicarbonate solution, extracted with ethyl ether (3X10 mL), dried over sodium sulfate, and the solvent was removed under reduced pressure. The residue was purified on silica gel column using 10% ethyl acetate in hexane to yield 131 mg of **9** (80%) as yellowish oil. ^{1}H NMR: 8.48 (d, J=8.8Hz, 1H), 8.39 (d, J=8.8Hz, 1H), 7.00 (d, J=6.8 Hz, 1H), 7.63 (s, 1H), 7.49 (t, J=8Hz, 1H),), 7.39-7.41 (m, 2H), 7.33 (t, J=7.6Hz, 1H) 7.08 (d, J=7.2Hz, 1H), 6.84 (t, J=8 Hz, 1H), 6.45 (d, J=7.6 Hz, 1H), 4.47 (s, 2H), 2.75 (s, 6H), 0.92 (s, 9H), 0.20 (s, 6H). ^{13}C NMR: 153.09, 152.29, 145.06, 132.35, 132.12, 131.44, 131.09, 130.65, 130.46, 130.42, 130.28, 129.43, 127.05, 123.36, 123.35, 119.91, 118.65, 116.06, 108.51, 45.77, 29.25, 26.21, 18.65, -4.0. FW calc ($[C_{29}H_{34}NO_4SSi + H]^+$): 600.1239, 602.1219, ESI-HRMS: 600.1224, 602.1227.

DNS-NQMP-caged Z-GABA **1a:** DMAP (2 mg, 0.016 mmol) and EDC (40 mg, 0.216 mmol) were added to a solution of *4*-(benzyloxycarbonylamino)butanoic acid **8a** (33 mg, 0.140 mmol) and **7** (90 mg, 0.170 mmol) in dichloromethane (5 mL), and the reaction mixture was stirred overnight at r.t. Solids were removed by filtration, the organic layer was washed with brine, dried over sodium sulfate, and solvent was removed in vacuum. The crude **10a** was taken in 5mL of dry THF and TBAF (1 mL of 1 M THF solution, 1 mmol) was added dropwise. The reaction mixture was stirred at r.t. for 10 min, poured into saturated NH_4Cl solution, and extracted with ethyl acetate (3X10 mL). Combined extracts were washed with brine and dried over sodium sulfate. The solvent was removed in vacuum, and the residue was purified by chromatography (25% ethyl acetate in dichloromethane) to afford 63 mg (70% over 2steps) of **1a** as yellow oil. ^{1}H NMR: 8.61 (d, J=8.8Hz, 1H), 8.57 (d, J=8.8Hz, 1H), 8.12 (d, J=7.6 Hz, 1H), 7.70 (s, 1H), 7.65 (t, J=8Hz, 1H),), 7.55-7.57 (m, 2H), 7.42-7.47 (m, 2H) 7.28-7.34 (m, 3H), 7.24 (t, J=7.6Hz, 1H), 6.98 (t, J=7.6Hz, 1H), 6.69 (d, J=7.6 Hz, 1H), 5.26 (s, 2H), 5.10 (s, 2H), 5.05 (t, J=4Hz, 1H), 3.23-3.26 (m, 2H), 2.90 (s, 6H), 2.43 (t, 7.2Hz, 2H), 1.85 (t, 7.2Hz, 2H). ^{13}C NMR: 174.19, 156.97, 153.86, 152.13, 144.88, 136.10, 132.20, 131.80, 131.17, 130.50, 130.35, 130.05, 129.99, 129.36, 129.29, 128.70, 128.29, 127.14, 125.80, 123.21, 122.74, 119.77, 118.69, 115.88, 105.71, 67.11, 62.94, 45.65, 40.51, 31.66, 25.39. FW calc ($[C_{35}H_{34}N_2O_8S + H]^+$):643.2109; ESI-HRMS: 643.2117.

DNS-NQMP-caged N-Boc-phenylalanine **1b:** DMAP (2 mg, 0.016 mmol) and EDC (40 mg, 0.216 mmol) were added to a solution of N-Boc-phenylalanine **8b** (37 mg, 0.140 mmol) and **7** (90 mg, 0.170 mmol) in 5 mL of dichloromethane, and the reaction mixture was stirred overnight at r.t. Solids were removed by filtration, the organic layer was washed with brine, dried over sodium sulfate, and solvent was removed under vacuum. The crude **10b** was taken in 5mL of dry THF and TBAF (1 mL of 1 M THF solution, 1 mmol) was added dropwise. The reaction mixture was stirred at room temperature for 10 min, poured into saturated NH_4Cl solution, and extracted with ethyl acetate. Combined extracts were washed with brine and dried over sodium sulfate. The solvent was removed in vacuum, and the residue was purified by chromatography (25% ethyl acetate in dichloromethane) to afford 66 mg (73% over 2steps) of **1c** as yellow oil.^{1}H NMR: 8.63-8.65 (m,2H), 8.16 (d, J=7 Hz, 1H), 7.71 (t, J=8.5 Hz, 1H), 7.67 (s, 1H),), 7.59 (d, J=8.5 Hz, 1H), 7.48 (t, J=8.0Hz, 1H) 7.42(s, 1H), 7.25-7.29 (m 2H), 7.06-7.14(m, 3H), 6.98-7.00 (m, 2H), 6.334 (d, J=8 Hz, 1H), 5.29 (dd, J= 41.5Hz, J= 13.5Hz, 2H), 5.02-5.04 (m, 1H), 4.64-4.67 (m, 1H), 3.85 (d, J=5.5 Hz,2H), 2.94 (s, 6H), 1.45 (s, 9H). ^{13}C NMR: 173.11, 153.45, 152.24, 144.96, 135.67, 132.26, 132.87, 131.22, 130.46, 130.11, 130.09, 129.42, 129.31, 128.74, 127.26, 127.18, 125.04, 123.26, 123.04, 119.83, 119.07, 115.89, 106.15, 63.41, 45.66, 28.52. FW calc ($[C_{37}H_{38}N_2O_8S + H]^+$):671.2422; ESI-HRMS: 643.2442.

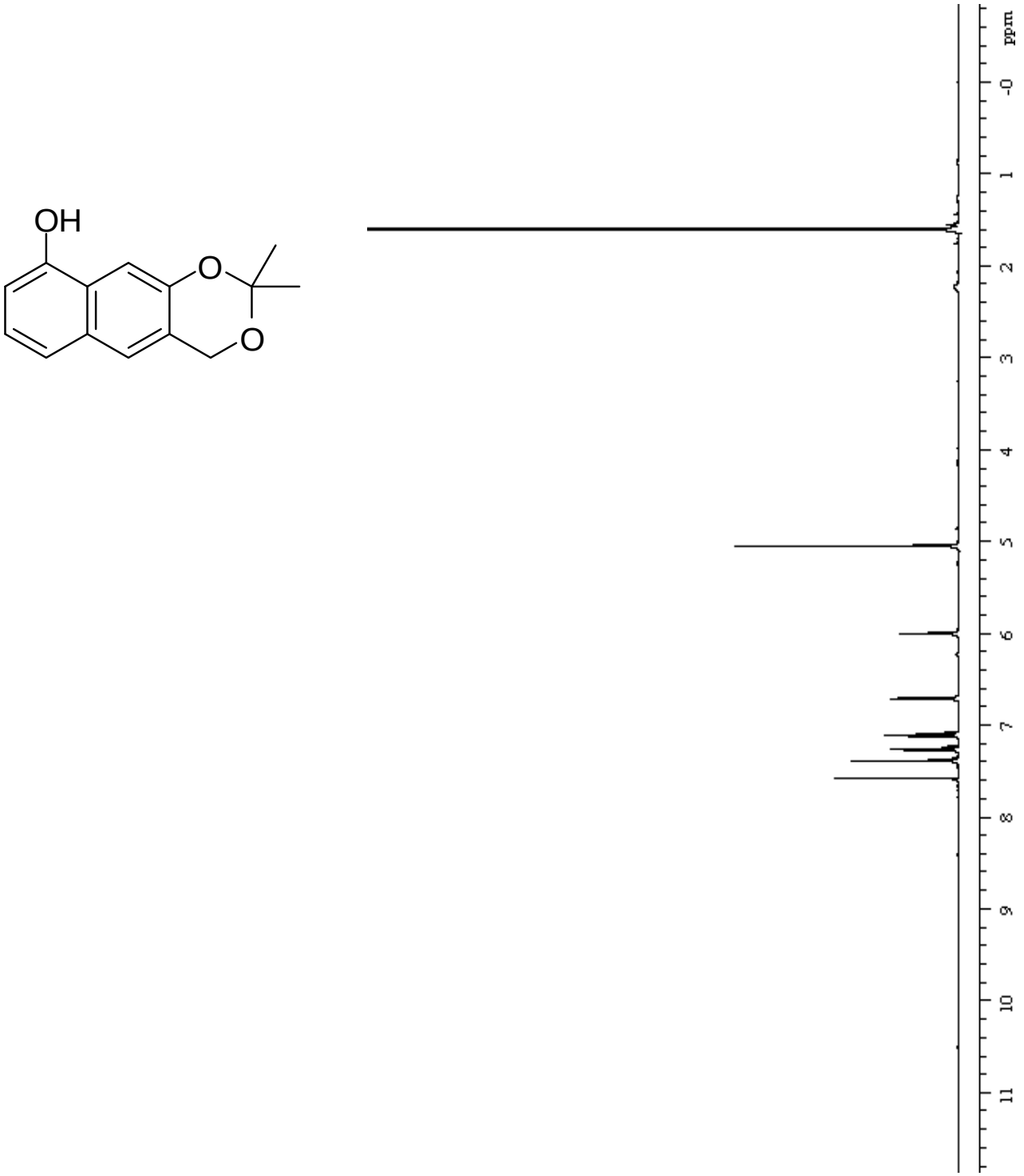
DNS-NQMP-caged thymidine **1c**: 2,6-Di-tert-butylpyridine (45 μL, 37 mg, 0.21 mmol) and silver triflate (47 mg, 0.19 mmol) were added to a solution of **9** (55 mg, 0.19 mmol) in 2 mL of dichloromethane, the resulting suspension was cooled to 0^{o}C, and a solution of thymidine derivative **8c** (100 mg, 0.17 mmol) in 1 ml of dichloromethane was added at once. Reaction mixture was stirred at r.t. for 2 h, 10 mL of dichloromethane was added, and solid residue was removed by filtration. The filtrate was evaporated under reduced pressure and the residue was filtered through short silica gel column. Crude **10c** was dissolved in 2 mL of THF, 0.35 mL of 1M solution of TBAF in THF was added to it at 0^{o}C, reaction mixture stirred for 10 min, poured into 30 mL of brine, and extracted with ethyl acetate (3X10 mL). Extracts were combined, washed with brine, and dried over sodium sulfate. Solvent was removed under reduced pressure and the residue was purified by column chromatography using 50% ethyl acetate in hexane to yield 87 mg of **1c** (69% over 2 steps) as colorless oil. ^{1}H NMR: 8.56-8.64 (m, 2H), 8.13 (d, J=8.5Hz, 1H), 7.66-7.70 (m, 1H), 7.61 (s, 1H),), 7.54 (m, 1H), 7.46-7.50 (m, 2H) 7.42(s, 1H), 7.24-7.27(m 1H), 7.01(t, J=10Hz, 1H), 6.70 (d, J=9.5 Hz, 1H), 6.31 (t, J=8 Hz, 1H), 4.84 (dd, J= 24Hz, J= , 12.5Hz, 2H), 4.15-4.17 (m, 1H), 4.02-4.04 (m, 1H), 3.87-3.90 (m, 1H), 3.75-3.79 (m, 1H), 3.34 (s, 3H), 3.33 (s, 3H), 2.92 (s, 6H), 2.41-2.45 (m, 1H), 2.05-2.13 (m, 1H),1.67 (s, 3H). ^{13}C NMR: 163.95, 154.16, 152.19, 151.24, 145.06, 133.77, 132.25, 131.91, 131.12, 130.38, 130.11, 129.98, 129.31, 129.11, 128.06, 126.87, 126.51, 123.25, 123.00, 119.80, 118.66, 115.91, 110.41, 105.63, 86.11, 83.35, 80.94, 71.33, 70.98, 57.33, 45.66, 37.47, 28.11, 13.28. FW calc ($[C_{35}H_{37}N_3O_9S + H]^+$):676.2323; ESI-HRMS: 676.2320.

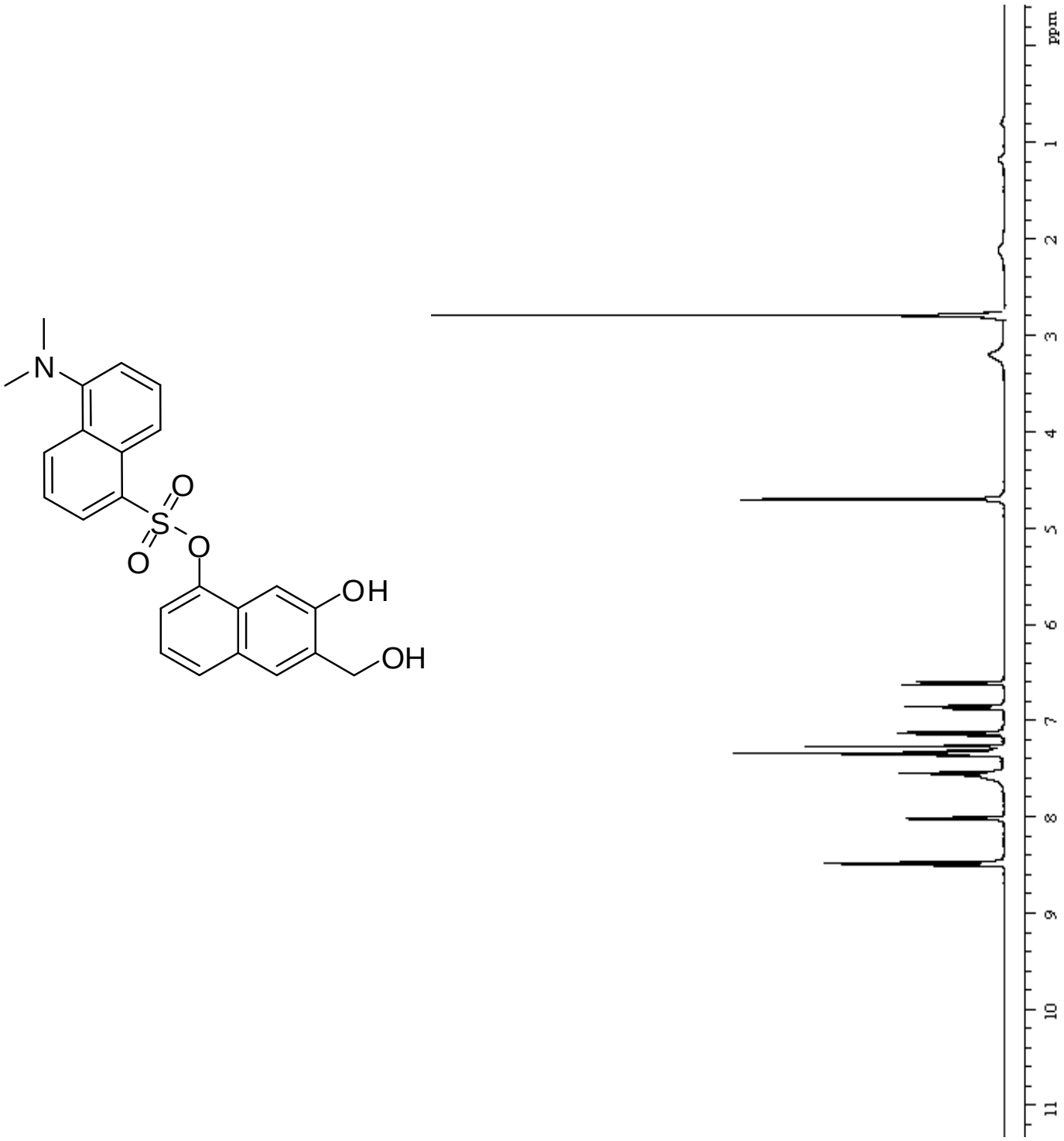
*Benzochroman **11c***: Solution of **1c** (195 mg, 0.29 mmol) and ethyl vinyl ether (2.8 mL, 29 mmol) in acetonitrile – water (1:1, 290 mL) was irradiated using mini-Rayonet photochemical reactor equipped with 8 fluorescent UV lamps (4W, RPR-3000A^{o}) for 15 min. Photolysate was extraxted with ethyl acetate (3X60), dried over sodium sulfate, and solvents were removed in vacuum. The residue was separated by chromathography (20% EtOAc in hexane) to give 57 mg (87%) of **11c** as colorless oil. ^{1}H NMR: 8.54 (t, J = 8.0 Hz, 1H), 8.09 (d, J = 6.8 Hz, 1H), 7.60 (t, J = 8.0 Hz, 1H), 7.42 (s, 1H), 7.38-7.46 (m, 2H), 7.36 (s, 1H), 7.17 (d, J =7.2 Hz, 1H), 6.92 (t, J = 8.0 Hz, 1H), 6.64 (d, J = 7.6 Hz, 1H), 5.22 (t, J = 2.8 Hz, 1H), 3.74-3.80 (m, 1H), 3.53-3.60 (m, 1H), 3.02-3.11 (m, 1H), 2.84 (s, 6H), 2.80-2.82 (m, 1H), 2.70-2.77 (m, 1H), 1.88-2.03 (m, 2H), 1.11 (t, J = 7.2 Hz, 3H).^{13}C NMR: 152.17, 152.08, 145.27, 132.19, 132.06, 131.09, 130.50, 130.43, 130.12, 129.22, 127.90, 127.76, 127.40, 126.35, 126.05, 123.22, 122.59, 119.99, 117.35, 115.84, 106.83, 97.28, 63.95, 45.68, 26.75, 21.17, 15.33. FW calc. for $C_{27}H_{27}NO_5S$: 477.1610, EI-HRMS found 477.1594.

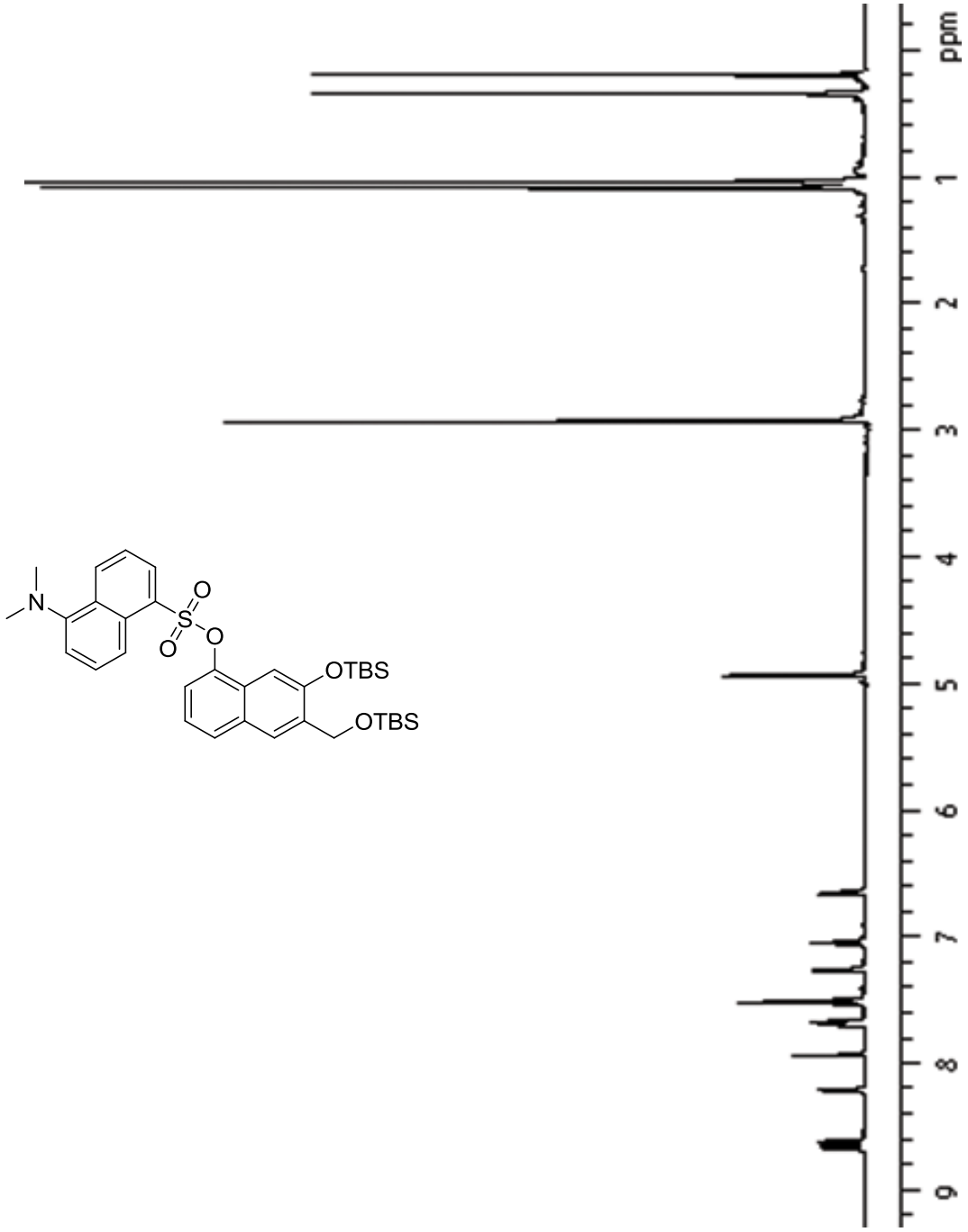
Fluorescent measurements: Fluorescent spectra of **1a-c, 2**, and irradiated solution of **1c** were recorded at λ_{ex} = 400 nm in 20% acetonitrile in water solution with the substrate concentration ca. 1 x 10^{-5} M. The excitation source slits and the detector slits were set to 2 nm and 4 nm respectively. The fluorescence quantum yields were determined using 5-(dimethylamino)-N-propylnaphthalene-1-sulfonamide as the standard reference.[2]

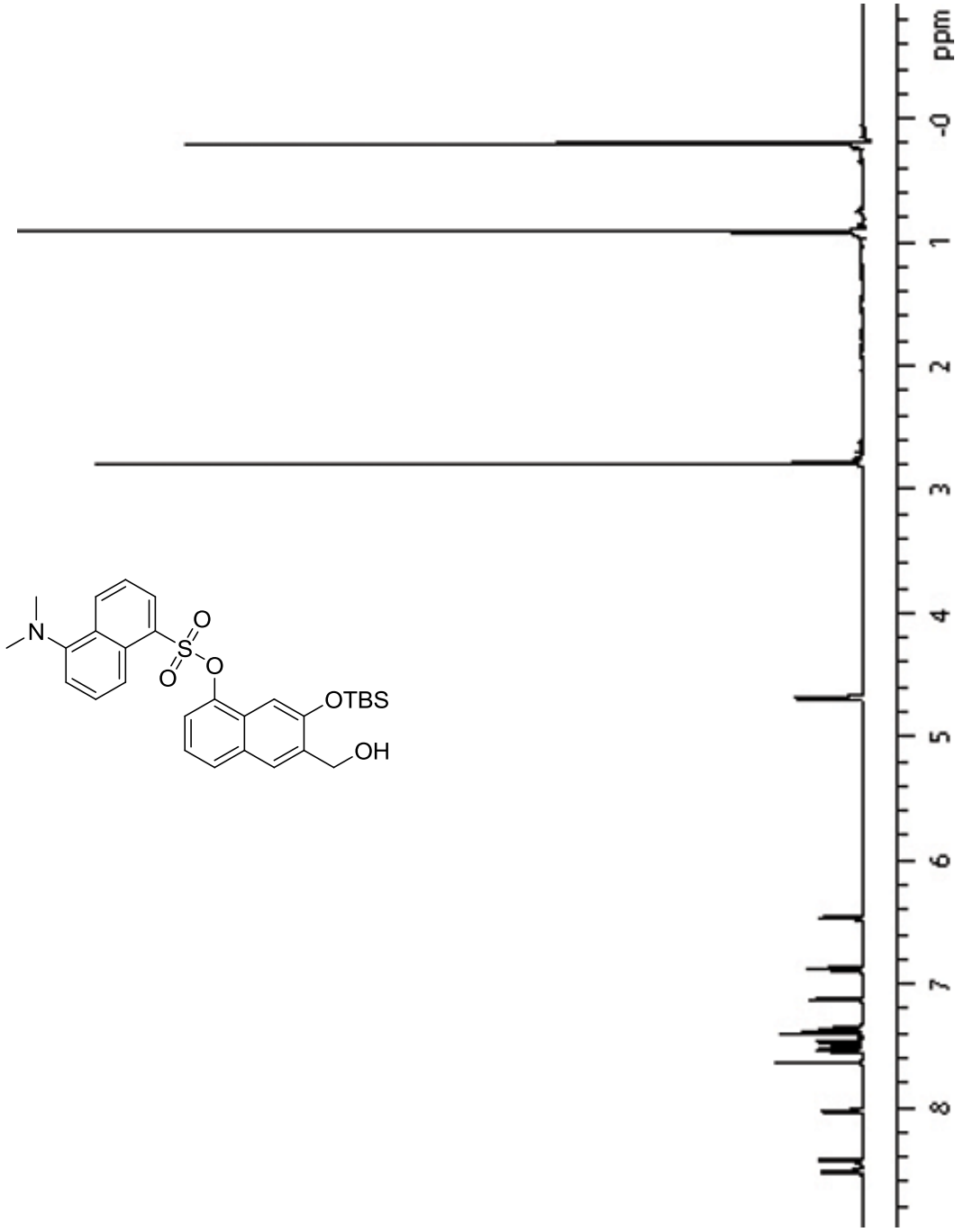
[2] 2. Berlman, I. B. (1971) Handbook of Fluorescence Spectra of Aromatic Molecules. Academic Press, New York.

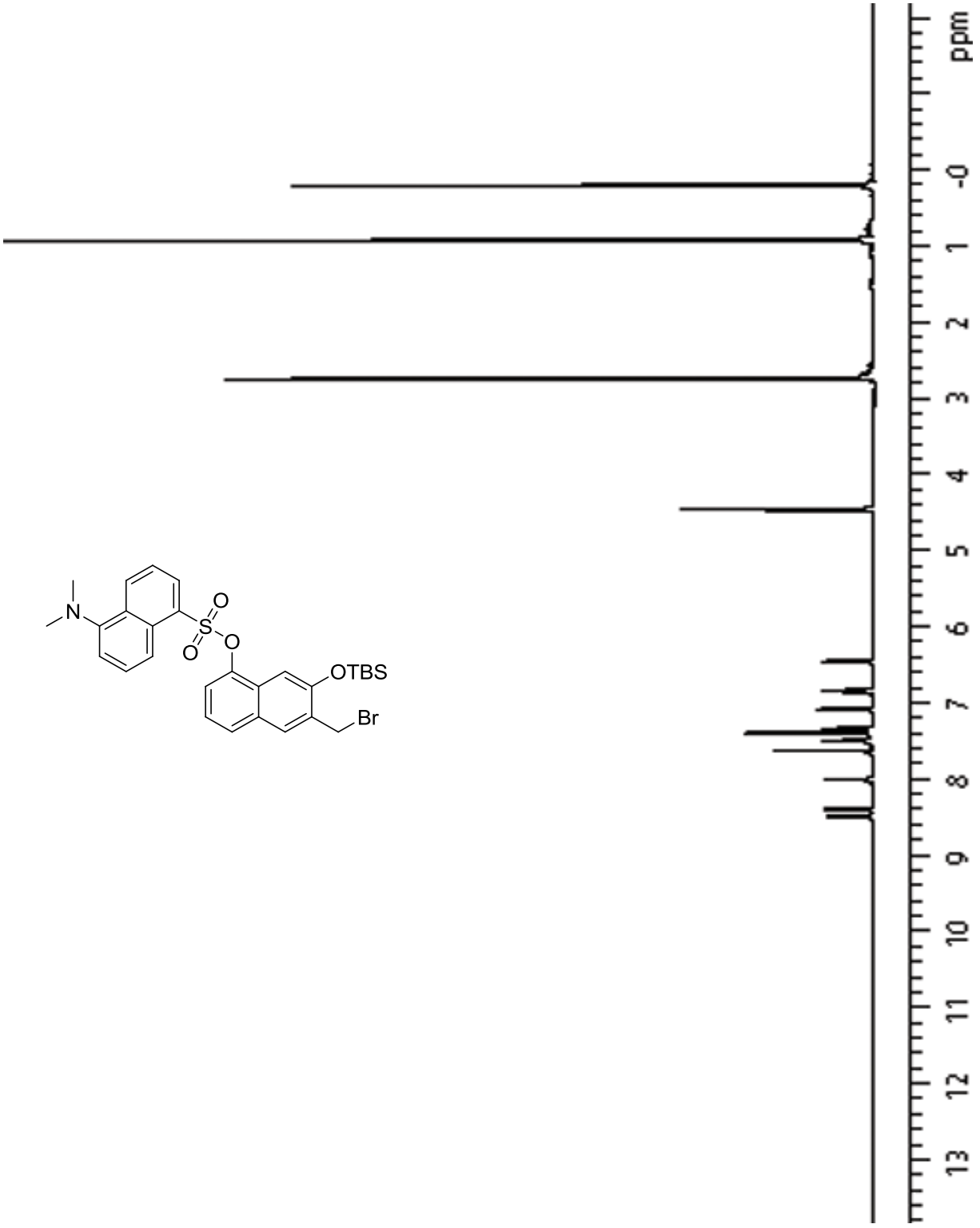
^{1}H NMR Spectra

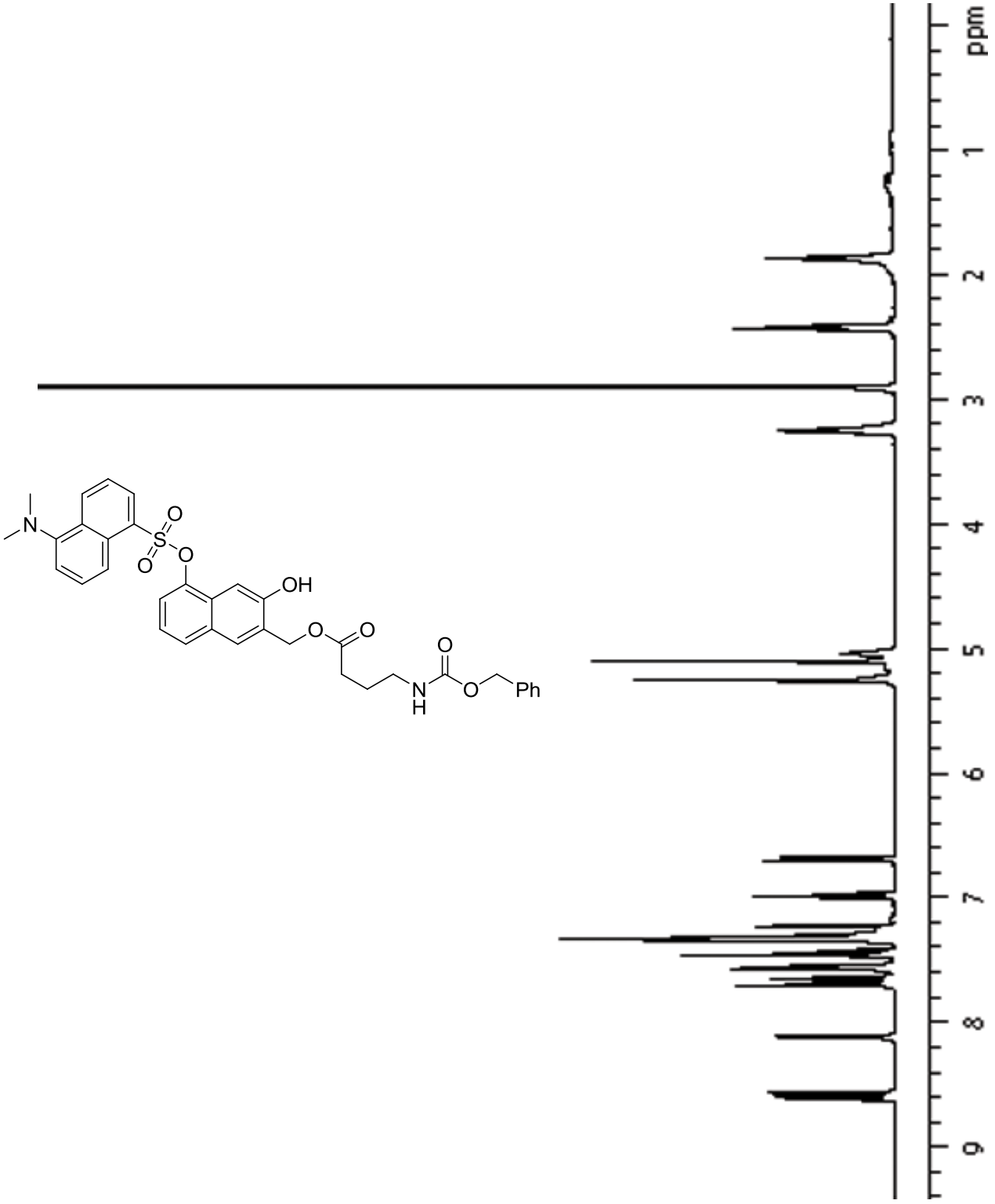


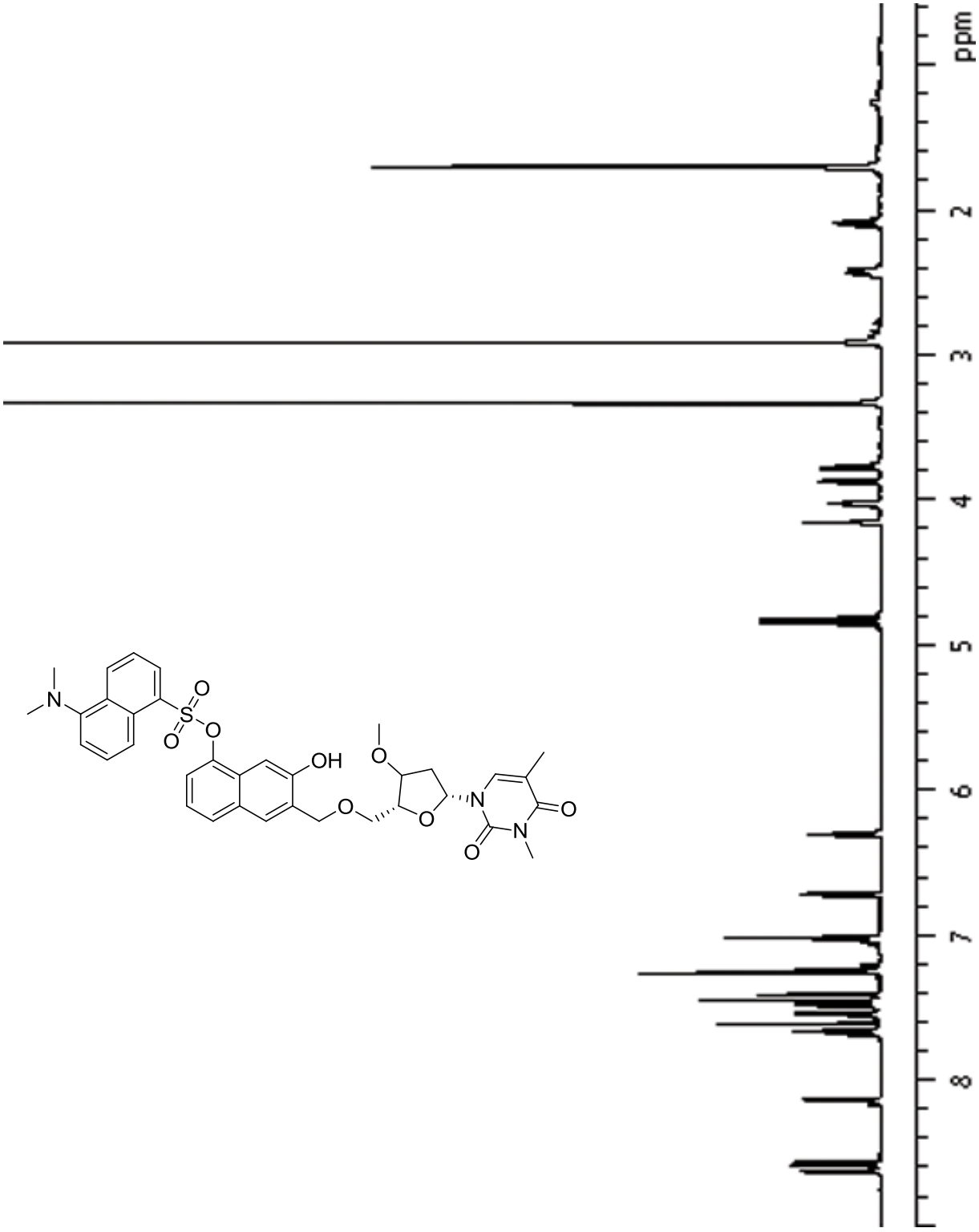


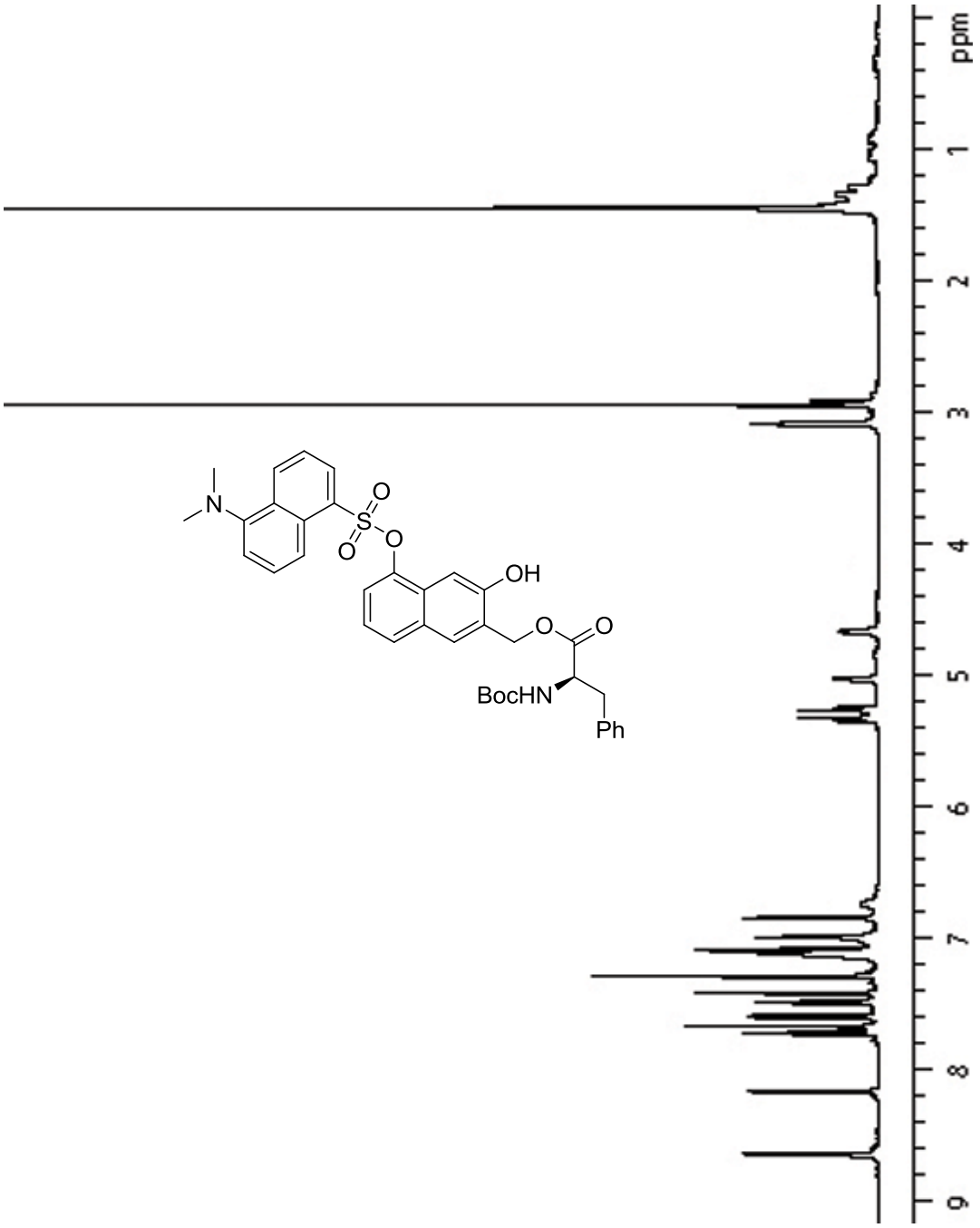


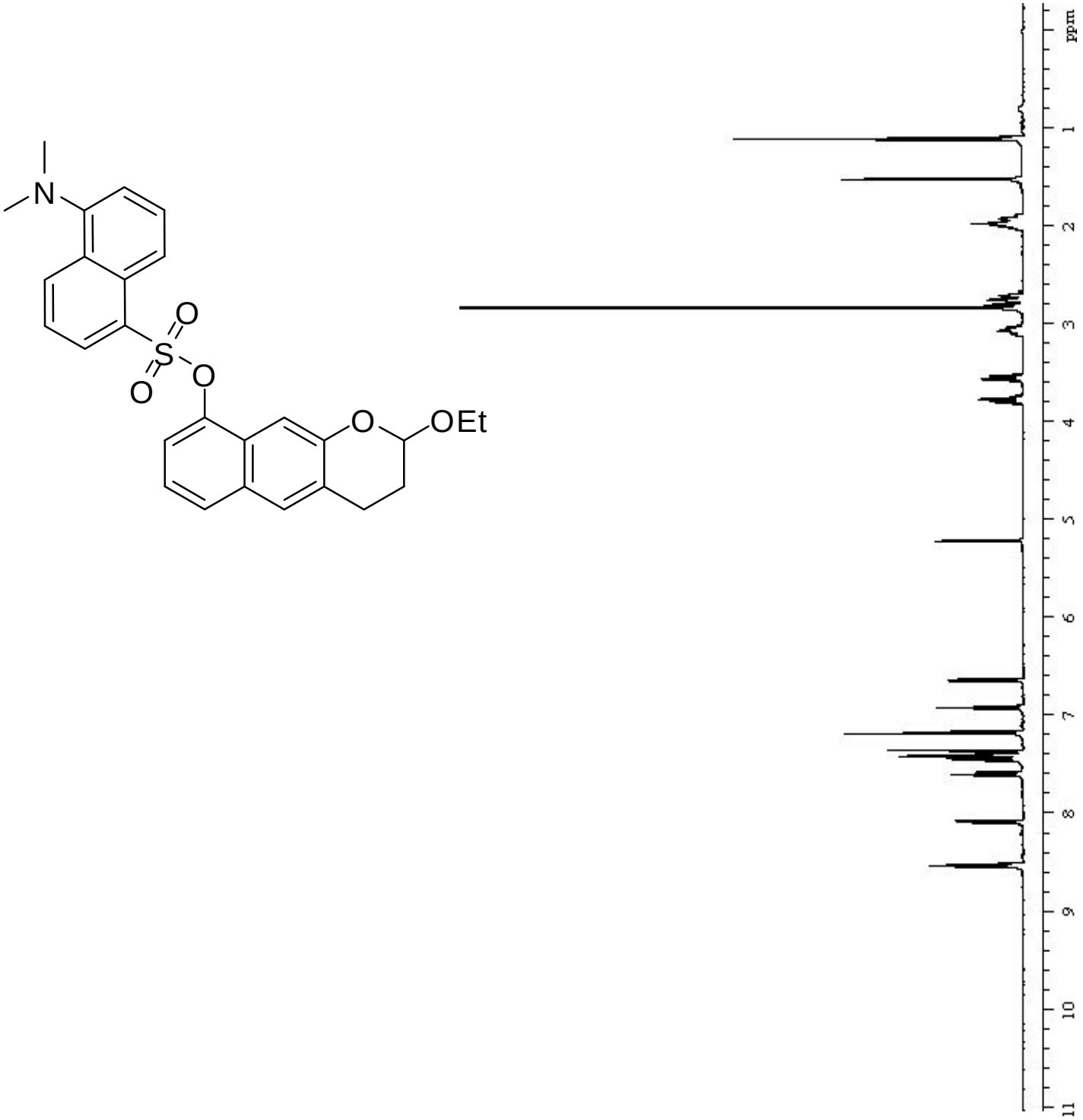












^{13}C NMR Spectra