Synthesis of the ABC- and D- Ring Systems of the Indole Alkaloid Ambiguine G

Aroop Chandra, Rajesh Viswanathan, and Jeffrey N. Johnston*

Department of Chemistry, Vanderbilt University
2301 Vanderbilt Place, Nashville, TN 37235-1822

Experimental Section

Unless otherwise noted, all reactions were carried out under argon or nitrogen using flame or oven dried glassware. Tetrahydrofuran (THF) and dichloromethane (CH_2Cl_2) were dried by passage through a column of activated alumina as described by Grubbs.[1] Molecular sieves (spheres, 4Å) were activated at 400 ºC and then stored at room temperature in an air-tight container.

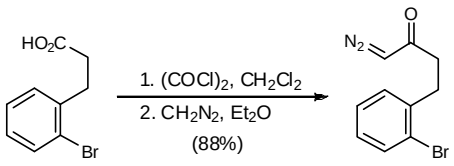
Flash column chromatography was performed using Sorbent Technologies 40-63 mm, pore size 60 Å silica gel with solvent systems indicated. Analytical thin layer column chromatography was performed using Sorbent Technologies 250 mm glass-backed UV254 silica gel plates that were visualized by fluorescence upon 250 nm radiation and/or the by use of ceric ammonium molybdate or potassium permanganate. Solvent removal was effected by rotary evaporation under aspirator vacuum (~ 25-40 mmHg).

IR spectra were recorded on a Nicolet Avatar 360 spectrophotometer and are reported in wavenumbers (cm^{-1}). Liquids and oils were analyzed as neat films on a NaCl plate (transmission), whereas solids were applied to a diamond plate (ATR). Proton nuclear magnetic resonance spectra were recorded on either a Varian INOVA-400 (400 MHz), VXR-400 (400 MHz) or Bruker DRX-500 (500 MHz) spectrometers and are recorded in parts per million from residual undeuterated chloroform and are reported as follows: chemical shift [multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, qu = quintet, m = multiplet), coupling constant(s) in hertz, integration]. ^{13}C NMR data were recorded on a Bruker DRX-500 spectrometer. High resolution mass spectrometry (HRMS) was performed by the Indiana University Mass Spectrometry Facility.

Ratios of diastereomers and isomeric products were measured directly from integration of ^1H NMR absorptions of protons common to the components. Precision was checked by varying

[1] Pangborn, A. B.; Giardello, M.A.; Grubbs, R. H.; Rosen, R. K.; Timmers, F. J. *Organometallics* **1996**, *15*, 1518-1520.

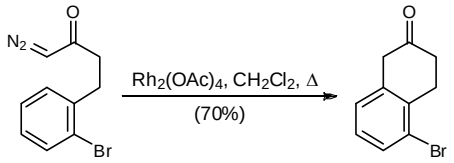
the relaxation delay for measurements on the same compound. Literature procedure was followed for the synthesis of diazomethane,[2] glycine *tert*-butyl ester,[3] β-chloro methacrolein **8**[4] and Cohen's diene **9.**[5]



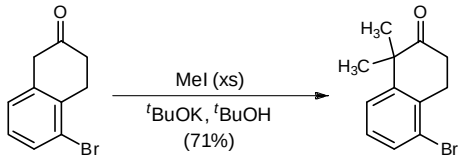
4-(2-Bromophenyl)-1-diazobutan-2-one (3). To a 0 °C solution of 3-(2-bromophenyl)propanoic acid (8.00 g, 34.9 mmol) in dichloromethane (0.5 M), was added oxalyl chloride (5.90 mL, 69.8 mmol) over 5 minutes. The solution was slowly warmed to room temperature and stirred until complete conversion was achieved, as evidenced by ^{1}H NMR. The solvent was removed *in vacuo* to give the title compound, which was used without further purification.

The acid chloride (8.50 g, 34.6 mmol) in diethyl ether (80 mL) was added dropwise over 20 min to an ethereal diazomethane solution [prepared from *N*-methyl-*N*-nitrosourea (14.24 g, 138.2 mmol)], at -40 °C while stirring under nitrogen. The solution was allowed to warm to room temperature, and it was then stirred for an additional 6 h. The ether and residual diazomethane were evaporated under reduced pressure at room temperature, using a rotary evaporator fitted with an acetic acid trap. The resulting yellow residue was purified by flash column chromatography (SiO_2, 15% ethyl acetate in hexanes) to afford the desired product as a yellow oil (7.76 g, 88%). R_f = 0.27 (20% EtOAc/hexanes); IR (film) 3087, 2101, 1641 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.51 (d, J = 8.0 Hz, 1H), 7.22 (m, 2H), 7.06 (m, 1H), 5.27 (s, 1H), 3.05 (t, J = 4.5 Hz, 2H), 2.62 (s, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 193.5, 139.8, 132.8, 130.6, 128.0, 127.61, 124.2, 54.5, 40.5, 31.4; HRMS (EI): Exact mass calcd for $C_{10}H_9BrO$ $[M]^+$ 223.9837. Found 223.9839.

[2] Arndt, F.; Amstutz, E. D.; Myers, R.R. *Org Synth.* **1935**, *2*, 461. Noller, C.R.; Bergsteinsson, I. *Org. Synth.* **1935**, *2*, 165.
[3] Siebum, A.H.G.; Woo, W.S.; Lugtenburg, J. *Eur. J. Org. Chem.* **2003**, *23*, 4664.
[4] Mooradian, A.; Cloke. J. B. *J. Am. Chem. Soc*. **1946**, *68*, 785. Hatch, L. F.; Russ, J. J.; Gordon, L. B. *J. Am. Chem. Soc*. **1947**, *69*, 2614. Williard, P.G.; Grab, L.A.; Delaszlo, S. E. *J. Org. Chem.* **1983**, *48*, 1123.
[5] Cohen, T.; Ruffner, R. J.; Shull, D. W.; Fogel, E. R.; Falck, J. R. *Org. Synth*. **1980**, *59*, 202.

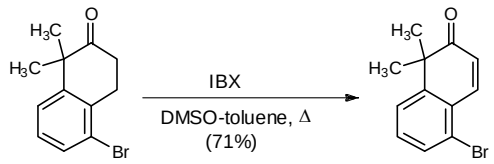


5-Bromo-3,4-dihydronapthalen-2(1*H*)-one (S1). The α-diazo ketone (7.70 g, 30.4 mmol) in CH_2Cl_2 (200 mL) was added dropwise over 1 h to a refluxing solution of rhodium(II) acetate (80 mg, 180 μmol) in CH_2Cl_2 (2 L).The reaction was monitored by TLC and was complete once the diazoketone had been added. The solution was cooled, washed with water and satd aq $NaHCO_3$, dried, and concentrated to 500 mL solution. This solution was treated with trifluoroacetic acid (3 mL) and the solution was stirred for 4 h at room temperature, washed with water and satd aq $NaHCO_3$, and dried. After solvent removal, the red residue was purified by flash column chromatography (SiO_2, 5-10% ethyl acetate in hexanes) to afford the desired product as a viscous oil (4.80 g, 70%). R_f = 0.30 (10% EtOAc/hexanes); IR (film) 2960, 2923, 1705, 1393, 1301 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.45 (dd, *J* = 6.0, 3.0 Hz, 1H), 7.04 (m, 2H), 3.57(s, 2H), 3.20 (t, *J* = 6.5 Hz, 2H), 2.53 (t, *J* = 6.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 211.1, 136.1, 135.3, 130.9, 128.1, 127.5, 123.7, 45.0, 37.6, 28.0; HRMS (EI): Exact mass calcd for $C_{10}H_9BrO$ $[M]^+$ 223.9837. Found 223.9840.

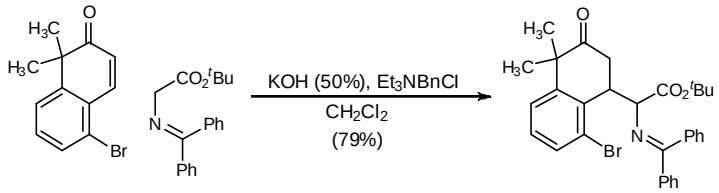


5-Bromo-1,1-dimethyl-3,4-dihydronapthalen-2(1*H*)-one (S2). To a 0 °C solution of β-tetralone (800 mg, 4.36 mmol) in *tert*-butanol (7 mL), was added potassium *tert*-butoxide (480 mg, 4.28 mmol) in small portions over 10 minutes. The reaction was stirred for 10 minutes at 0 °C, and methyl iodide (357 μL, 7.14 mmol) in THF (1 mL) was added to the solution. The reaction was allowed to warm to room temperature and the reaction stirred for 2 h at room temperature. MeI (268 μL, 5.36 mmol) in THF (1mL) was added to the solution and the reaction stirred for another 6 h at room temperature. The reaction was quenched with satd aq NH_4Cl, the layers were separated, and the aqueous layer was extracted with Et_2O. The combined organic

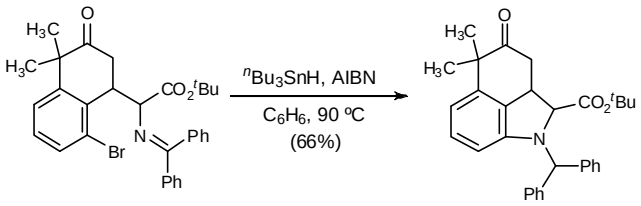
layers were washed with water, dried, filtered, and concentrated. The resulting red residue was purified by flash column chromatography (SiO_2, 5-10% ethyl acetate in hexanes) to afford the dimethylated product as a colorless oil (634 mg, 71% yield). R_f = 0.34 (10% EtOAc/hexanes); IR (film) 2971, 2929, 2867, 1716, 1560, 1461, 1301 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.45 (dd, *J* = 8.0, 0.5 Hz, 1H), 7.31 (d, *J* = 8.0 Hz, 1H), 7.13 (t, *J* = 8.0 Hz, 1H), 3.22 (t, *J* = 7.0 Hz, 2H), 2.70 (t, *J* = 7.0 Hz, 2H), 1.43 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 213.7, 146.1, 134.6, 130.7, 128.3, 125.6, 124.4, 47.7, 36.5, 28.7, 27.2; HRMS (EI): Exact mass calcd for $C_{12}H_{13}BrO$ $[M]^+$ 252.0150. Found 252.0144**.**



5-Bromo-1,1-dimethylnapthalen-2(1*H*)-one (4). To a solution of 5-bromo-1,1-dimethyl-3,4-dihydronapthalen-2(1*H*)-one (2.62 g, 10.3 mmol) in toluene/DMSO (2:1, 140 mL) was added IBX (11.56 g, 41.30 mmol) and the mixture was stirred at 85 °C for 16 h. The reaction mixture was then cooled to room temperature, diluted with Et_2O, and washed with 5% aq $NaHCO_3$, H_2O, and brine, and then dried, filtered, and concentrated. The resulting yellow residue was purified by flash column chromatography (SiO_2, 5-10% ethyl acetate in hexanes) to afford the desired product as a yellow oil (1.92 g, 65%). R_f = 0.32 (10% EtOAc/hexanes); IR (film) 2973, 2928, 2867, 1664, 1613, 1583, 1551, 1458, 1438, 1385, 1291, 1216, 1197 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.91 (d, *J* = 10.0 Hz, 1H), 7.45 (d, *J* = 8.0 Hz, 1H), 7.36 (d, *J* = 8.0 Hz, 1H), 7.19 (t, *J* = 8.0 Hz, 1H), 6.18 (d, *J* = 10.0 Hz, 1H), 1.41 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 203.3, 149.8, 141.9, 131.0, 130.7, 127.6, 125.5 (2C), 124.6, 47.3, 27.6; HRMS (EI): Exact mass calcd for $C_{12}H_{11}BrO$ $[M]^+$ 249.9993. Found 249.9998.



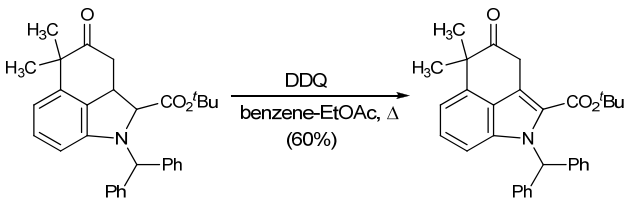
***tert*-Butyl 2-(8-bromo-4,4-dimethyl-3-oxo-1,2,3,4-tetrahydronaphthalen-1-yl)-2-(diphenylmethyleneamino)acetate (6).** The enone (50.0 mg, 199 μmol), Schiff base (88.0 mg, 119 μmol), and benzyl triethyl ammonium chloride (13.6 mg, 59.6 μmol) were dissolved in CH_2Cl_2 (1 mL). 50% KOH (140 μL) was then added and the mixture was stirred vigorously for 8 h. The reaction mixture was diluted with CH_2Cl_2, and the organic layer was separated, washed with water, dried ($NaSO_4$), filtered, and concentrated. Flash column chromatography (SiO_2, 5-15% ether in hexanes) of the resulting oil furnished the desired Michael adduct as a white solid (85.4 mg, 79%) in addition to *ca*. 6.1 mg of the enone (*ca*. 12%). A single diastereomer was detected by ^{1}H NMR. mp 172-174 °C; R_f = 0.20 (20% Et_2O/hexanes); IR (film) 3059, 2976, 2918, 2849, 1719, 1623, 1447, 1368, 1266, 1152 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 (d, *J* = 8.0 Hz, 1H), 7.41 (d, *J* = 7.0 Hz, 2H), 7.32 (m, 2H), 7.28-7.21 (m, 5H), 7.15 (t, *J* = 8.0 Hz, 1H), 6.36 (d, *J* = 5.0 Hz, 2H), 4.50 (d, *J* = 2.0 Hz, 1H), 4.41 (m, 1H), 2.95 (m, 2H), 1.43 (s, 9H), 1.33 (s, 3H), 1.12 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 210.9, 172.5, 169.1, 148.5, 138.8, 136.2, 133.6, 130.9, 130.4, 130.1, 129.5, 128.7, 128.2 (2C), 127.7, 127.1, 126.9, 124.8, 81.7, 67.8, 47.0, 44.1, 38.2, 33.5, 29.7, 28.1, 25.7; HRMS (ESI): Exact mass calcd for $C_{31}H_{32}BrNO_3Na$ $[M+Na]^+$ 568.1463. Found 568.1440.



***tert*-Butyl 1-benzhydryl-5,5-dimethyl-4-oxo-1,2,2a,3,4,5-hexahydrobenzo[*cd*]indole-2-carboxylate (S3)**. To a refluxing (90 °C) benzene (12 mL) solution of the ketimine (65.0 mg, 119 μmol) and ^{n}Bu$_3$SnH (34.1 μL, 125 μmol) was added AIBN (23.6 mg, 143 μmol) and ^{n}Bu$_3$SnH (34.1 μL, 125 μmol) dissolved separately in benzene (1 mL) via a syringe pump over 4 h. The solution was stirred for an additional 6 h at 90 °C and the solvent was removed in *vacuo*. The residue was treated with a 1:1 (v/v) solution of Et_2O (5 mL) and satd aq KF,[6] and the mixture was stirred vigorously until a white solid precipitated. The organic layer was washed with water, dried ($NaSO_4$), filtered, and concentrated. The resulting white residue was purified

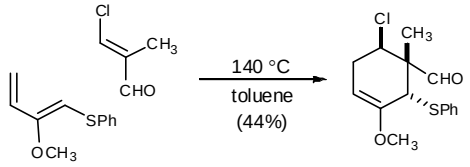
[6] Complete saturation by KF is necessary.

by flash column chromatography (SiO_2, 15% ether in hexanes) to afford the product as a viscous oil (36 mg, 66%) in addition to *ca*. 8.5 mg of the aryl bromide (*ca*. 13%). The indoline was characterized as a 5:3 ratio of diastereomers (^{1}H NMR). R_f = 0.33 (20% Et_2O/hexanes); IR (film) 2975, 2927, 2855, 1730, 1711, 1596, 1454, 1367, 1276, 1238, 1217, 1150 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (d, *J* = 7.5 Hz, 2H), 7.50 (d, *J* = 7.5 Hz, 2H), 7.40-7.36 (m, 4H), 7.32-7.20 (m, 12H), 6.96-6.90 (m, 2H), 6.63 (d, *J* = 7.5 Hz, 1H), 6.59 (d, *J* = 7.5 Hz, 1H), 5.96 (d, *J* = 7.5 Hz, 1H), 5.78 (d, *J* = 7.5 Hz, 1H), 5.59 (s, 1H), 5.55 (s, 1H), 4.20 (d, *J* = 9.5 Hz, 1H), 3.94 (d, *J* = 9.5 Hz, 1H), 3.89 (ddd, *J* = 11.0, 11.0, 5.5 Hz, 1H), 3.61 (ddd, *J* = 11.0, 11.0, 5.5 Hz, 1H), 2.91 (dd, *J* = 15.5, 5.5 Hz, 1H), 2.75 (dd, *J* = 15.5, 5.5 Hz, 1H), 2.52 (dd, *J* = 16.0, 12.0 Hz, 1H), 2.43 (dd, *J* = 16.0, 12.0 Hz, 1H), 1.45 (s, 3H), 1.39 (s, 3H), 1.38 (s, 9H), 1.36 (s, 3H), 1.32 (s, 3H), 1.27 (s, 9H) ; ^{13}C NMR (125 MHz, $CDCl_3$) ppm 214.2, 213.5, 171.6, 169.3, 149.7, 149.6, 142.6, 140.5 (2C), 139.8, 139.5, 139.0, 130.4, 129.5, 129.4, 129.1, 128.8, 128.7, 128.4, 128.3, 127.6 (2C), 127.4, 127.0, 126.7, 126.4, 125.9, 114.8, 114.7, 107.7, 107.6, 81.8, 81.6, 74.3, 70.7, 67.9, 67.1, 46.9, 46.5, 42.9, 40.9, 40.0, 38.5, 28.0 (2C), 27.3, 26.9, 26.3, 24.6; HRMS (ESI): Exact mass calcd for $C_{31}H_{33}NO_3Na$ $[M+Na]^+$ 490.2358. Found 490.2376.

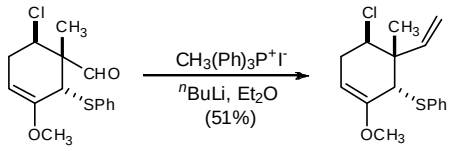


***tert*-Butyl 2-benzhydryl-6,6-dimethyl-7-oxo-2,6,7,8-tetrahydrobenzo[*cd*]indole-1-carboxylate (7).** A solution of indoline (100 mg, 214 μmol) and DDQ (51.0 mg, 225 μmol) in EtOAc-benzene (1:2, 2 mL) was stirred for 8 hours at 60 °C. The reaction mixture was then cooled to room temperature, diluted with EtOAc, and washed with satd aq $NaHCO_3$, dried, filtered, and concentrated. The resulting yellow residue was purified by flash column chromatography (SiO_2, 5-15% ether in hexanes) to afford the desired product as a viscous oil (59.8 mg, 60%) in addition to *ca*. 19.6 mg of the indoline (*ca*. 20%). R_f = 0.44 (20% Et_2O/hexanes); IR (film) 2973, 2925, 1696, 1655, 1604, 1450, 1396, 1368, 1324, 1211, 1171, 1132 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.29 (s, 1H), 7.33-7.28 (m, 6H), 7.23-7.21 (m, 4H), 7.02 (dd, *J* = 12.0, 6.5 Hz, 1H), 6.94 (d, *J* = 6.0 Hz, 1H), 6.50 (d, *J* = 7.0 Hz, 1H), 4.06 (s, 2H), 1.57 (s, 9H), 1.45 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) ppm 211.1, 161.6, 139.9, 139.8, 136.7,

128.4 (2C), 127.4, 126.3, 123.8, 123.6, 118.5, 114.3, 112.2, 81.9, 62.4, 48.1, 38.2, 28.5, 26.3; HRMS (EI): Exact mass calcd for $C_{31}H_{30}BrNO_3$ $[M]^+$ 465.2304. Found 465.2298.



6-Chloro-3-methoxy-1-methyl-2-phenylsulfanyl-cyclohex-3-enecarbaldehyde (10). Cohen's diene[7] (82.3 mg, 428 μmol), β-chloro-α-methyl acrolein[4] (504 μL, 7.14 mmol), *tert*-butyl-4-hydroxy-5-methyl phenylsulfide (12.8 mg, 35.7 μmol), hydroquinone (3.93 mg, 35.7 μmol), Hünig's base (375 μL, 2.14 mmol), and dry toluene (1.40 mL) were added to a silanized sealed tube. The contents were heated to 140 °C for 40 hours. The cooled reaction mixture was then concentrated to a residue that was purified by flash chromatography (3% ethyl acetate in hexanes) to furnish the desired *endo* adduct as a yellow oil (56.0 mg, 44%). About 10% of the regioisomeric adduct was also isolated. R_f = 0.1 (3% EtOAc/hexanes); IR (film) 3062, 1727 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 9.89 (s, 1H), 7.44 (dd, *J* = 8.2, 1.8 Hz, 2H), 7.33-7.27 (m, 3H), 4.39 (dd, *J* = 10.5, 6.2 Hz, 1H), 4.64 (dd, *J* = 4.8, 2.8 Hz, 1H), 3.60 (s, 3H), 3.55 (s, 1H), 2.79 (dt, *J* = 17.2, 5.6 Hz, 1H), 2.42 (ddd, *J* = 16.8, 10.4, 1.6 Hz, 1H), 1.24 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) ppm 202.7, 152.6, 135.0, 132.4, 129.1, 127.9, 93.1, 91.8, 56.4, 56.4, 55.0, 52.5, 30.8, 13.6; HRMS (EI): Exact mass calcd for $C_{15}H_{17}ClO_2S$ $[M]^+$ 296.0638. Found 296.0647.

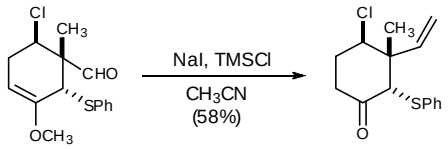


(5-Chloro-2-methoxy-6-methyl-6-vinyl-cyclohex-2-enylsulfanyl)-benzene(S4).

Methyltriphenylphosphonium iodide (549 mg, 1.36 mmol) was dissolved in Et_2O (7 mL) and cooled to –78 °C. *n*-Butyllithium (490 μL, 1.18 mmol) was added, followed by addition of the aldehyde (268 mg, 905 μmol) as a solution in Et_2O (2.0 mL). After stirring for 45 min at –78 °C,

[7] Cohen, T.; Ruffner, R. J.; Shull, D. W.; Fogel, E. R. *Org. Synth.* **1980**, *59*, 202.

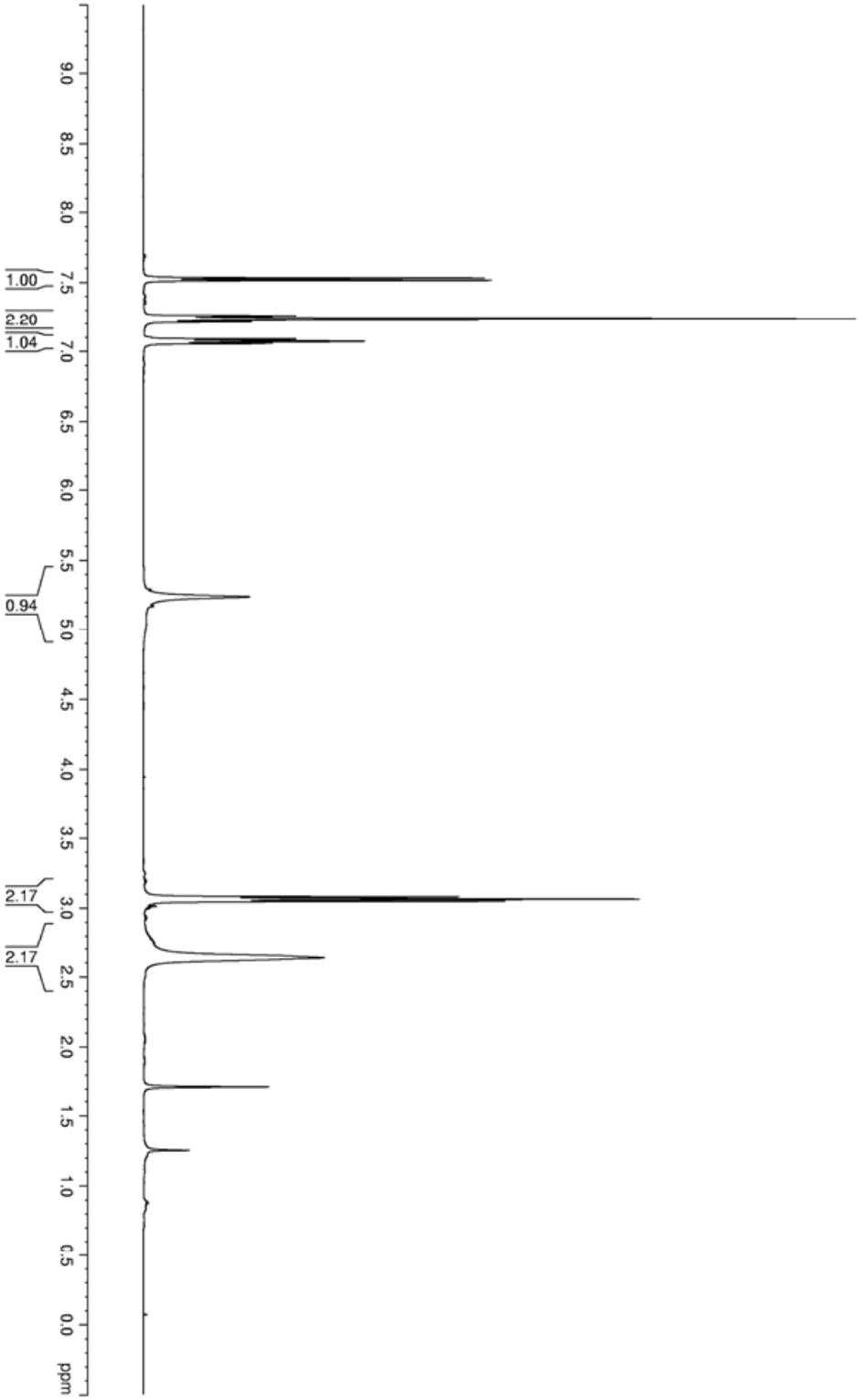
the reaction mixture was allowed to warm to room temperature and was stirred overnight. The solution was diluted with ether, washed with water, dried, and concentrated to a residue that was purified by flash chromatography (1% ethyl acetate in hexanes) to furnish the product as a yellow oil (136 mg, 51% yield). R_f = 0.5 (2% EtOAc/hexanes); IR (film) 3076, 1716 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.48 (dd, *J* = 8.4, 1.6 Hz, 2H), 7.30-7.22 (m, 3H), 6.23 (dd, *J* = 14.0, 10.4 Hz, 1H), 5.14 (dd, *J* = 14.4, 2.8 Hz, 2H), 4.59 (t, *J* = 7.6 Hz, 1H), 4.35 (dd, *J* = 9.2, 6.0 Hz, 1H), 3.55 (s, 3H), 3.52 (s, 1H), 2.76 (dt, *J* = 17.6, 4.8 Hz, 1H), 2.42 (ddd, *J* = 13.2, 9.2, 0.8 Hz, 1H), 1.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) ppm 153.7, 142.4, 137.1, 131.9, 128.6, 126.9, 115.4, 92.5, 61.7, 59.5, 54.8, 45.8, 31.6, 17.1; HRMS (EI): Exact mass calcd for $C_{16}H_{19}ClOS$ $[M]^+$ 294.0845. Found 294.0846.

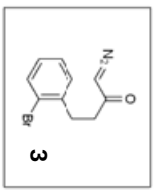


4-Chloro-3-methyl-2-phenylsulfanyl-3-vinyl-cyclohexanone (11). Using the procedure described by Cohen,[8] the enol ether (58.7 mg, 199 μmol) and NaI (29.8 mg, 199 μmol) were combined in CH_3CN (4 ml). Trimethylsilyl chloride (25.2 μL, 199 μmol) was added dropwise to this mixture at room temperature causing the solution to turn orange. After stirring for 15 min, the mixture was diluted with CH_2Cl_2 (5 mL) and was purified by filtration through a plug of silica gel-alumina to furnish the product as a yellow oil (32.3 mg, 58% yield). R_f = 0.1 (10% EtOAc/hexanes); IR (film) 3059, 1719 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, *J* = 6.8 Hz, 2H), 7.31-7.27 (m, 3H), 6.00 (dd, *J* = 17.6, 10.8 Hz, 1H), 5.33 (dd, *J* = 10.8, 5.6 Hz, 1H), 5.26 (dd, *J* = 17.6, 5.2 Hz, 1H), 4.48 (dd, *J* = 8.4, 4.0 Hz, 1H), 3.80 (s, 1H), 3.07-2.99 (m 1H), 2.59-2.52 (m, 1H), 2.50-2.43 (m, 1H), 2.26-2.17 (m, 1H), 1.40 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) ppm 204.2, 140.3, 134.3, 131.8, 129.1, 127.7, 116.8, 65.7, 63.5, 49.6, 35.7, 31.0, 20.6; HRMS (EI): Exact mass calcd for $C_{15}H_{17}ClOS$ $[M]^+$ 280.0689. Found 280.0674.

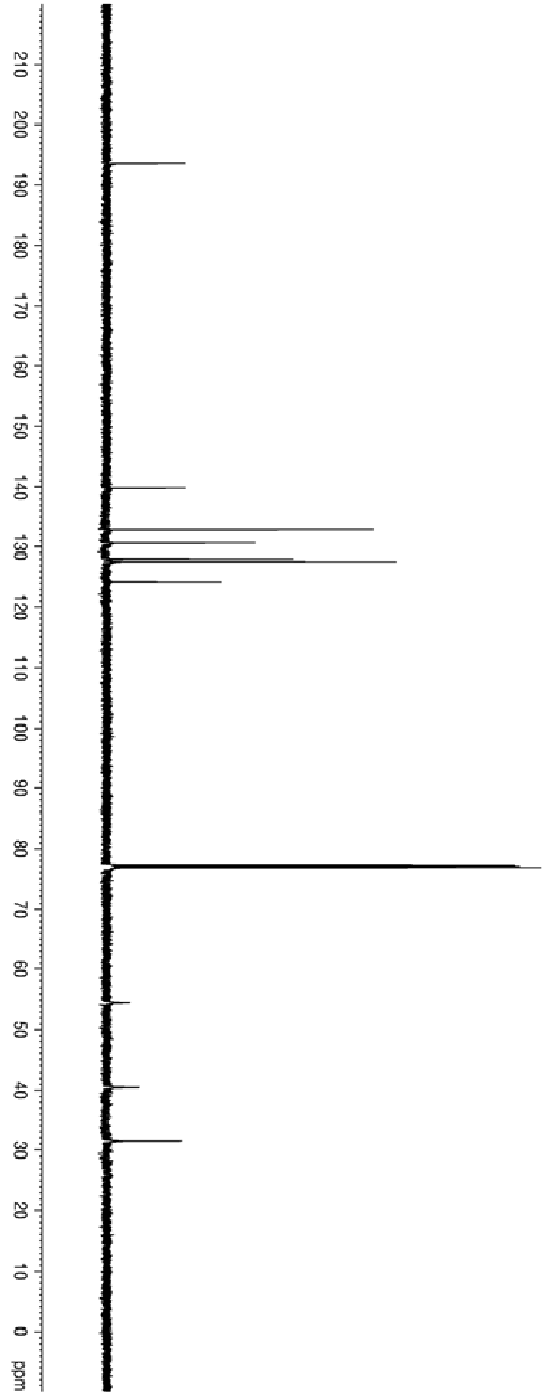
[8] Kosarych, Z.; Cohen, T. *Tetrahedron Lett.* **1980**, *21*, 3959-3962.

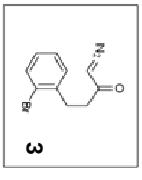
^{1}H NMR


1.00
2.20
1.04
0.94
2.17
2.17
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

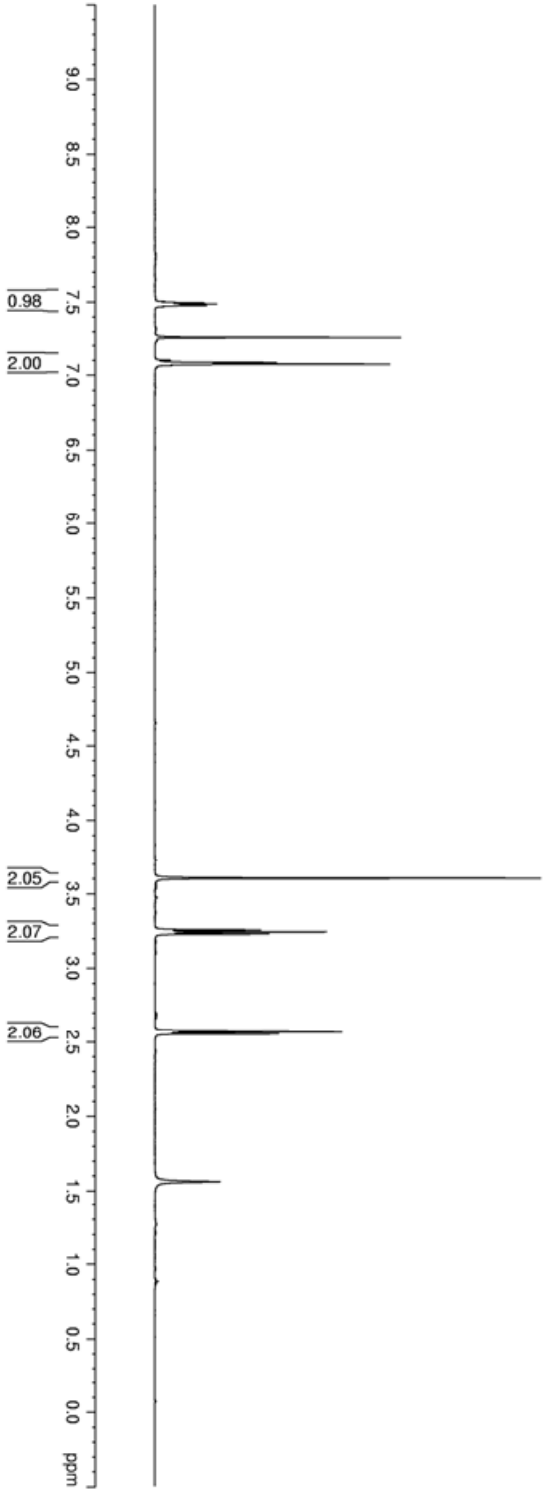

N2
O
Br

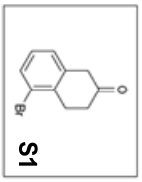
3


^{13}C NMR
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


N2
O
Br
3

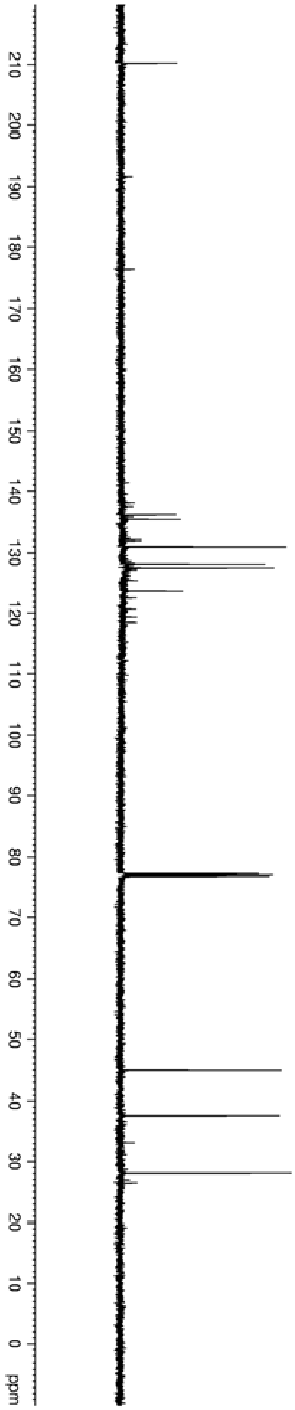
^{1}H NMR

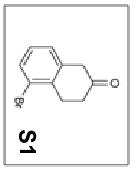

9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
0.98
2.00
2.05
2.07
2.06


O
Br

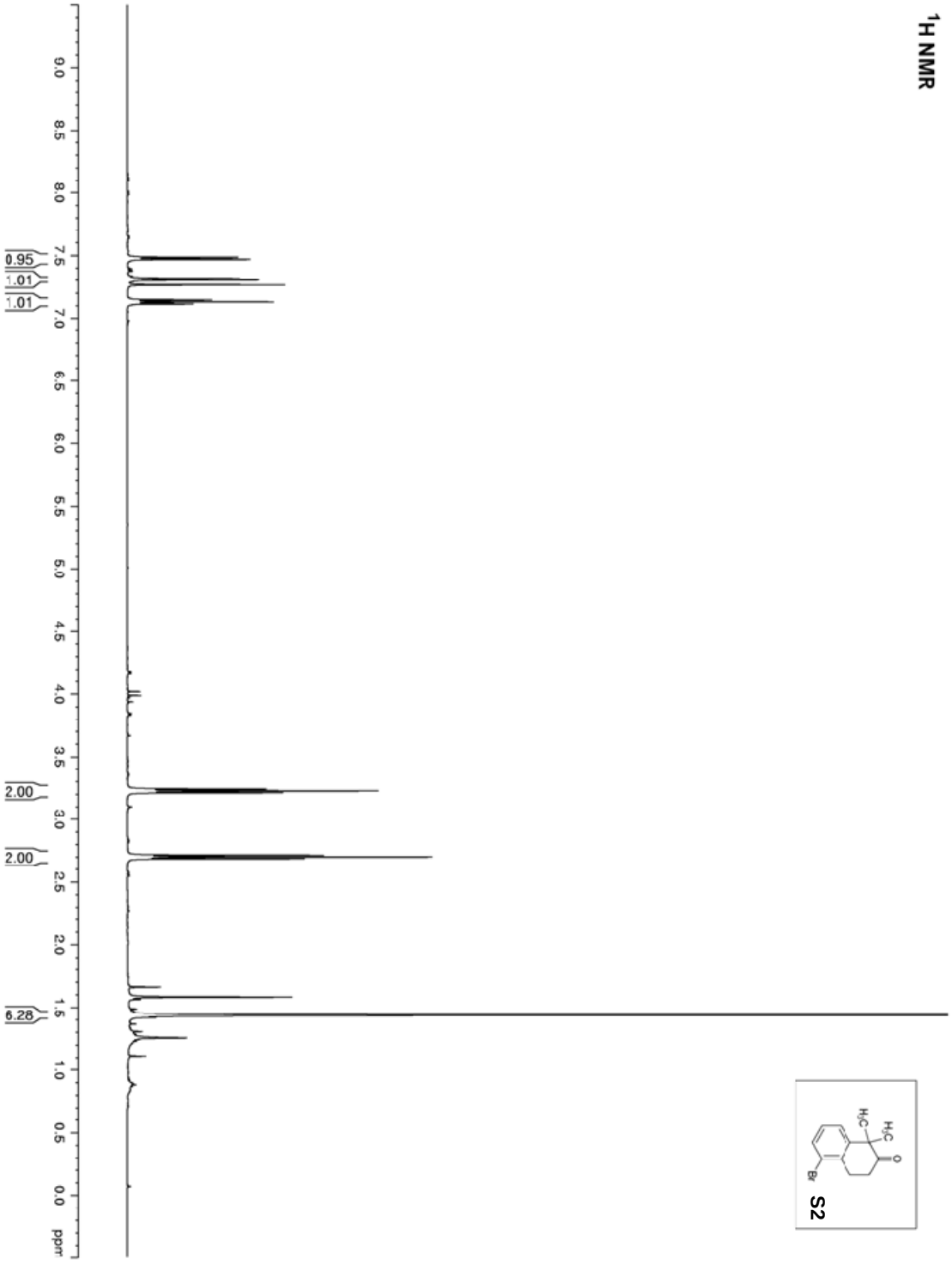
S1

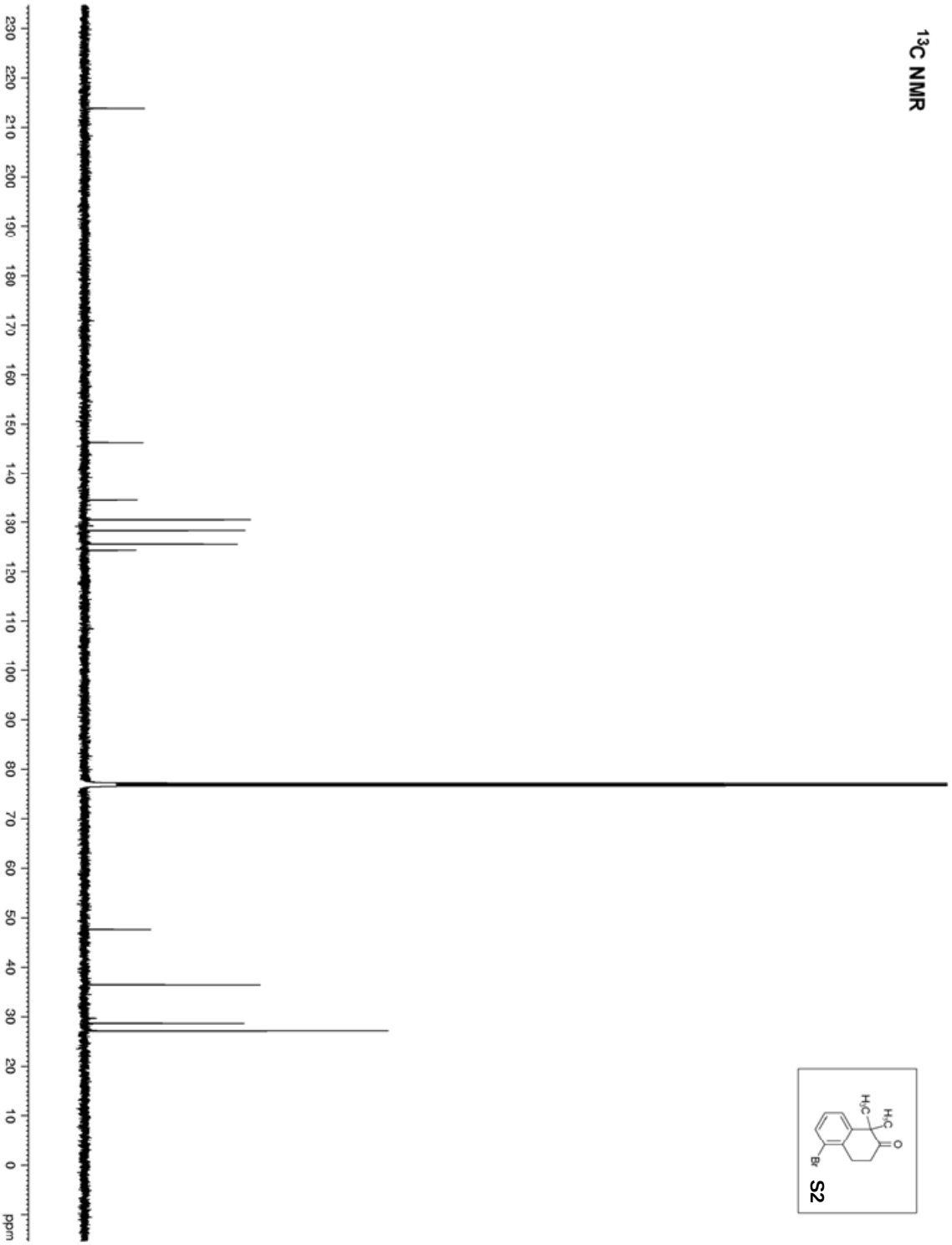
^{13}C NMR

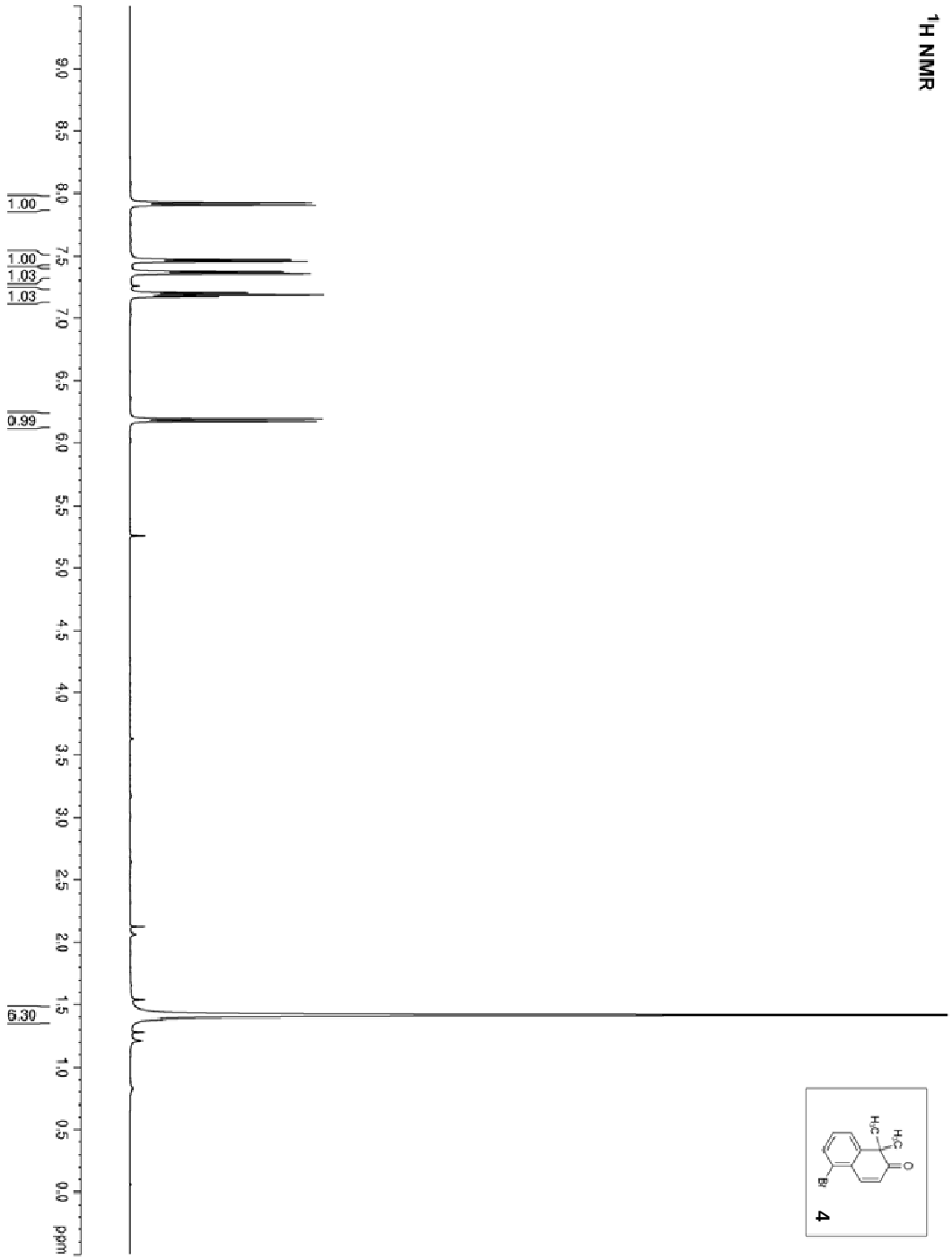

210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

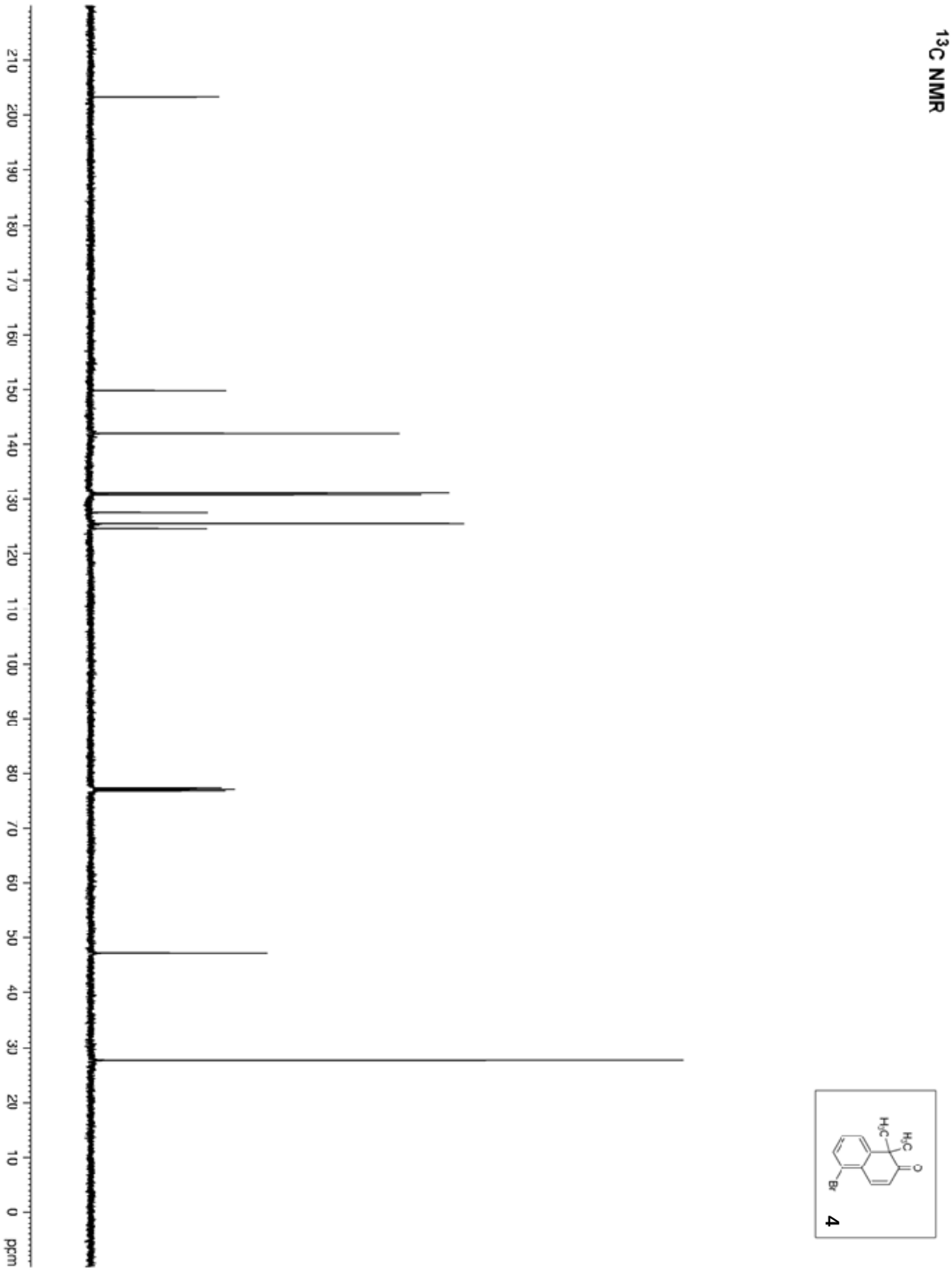

Br
O

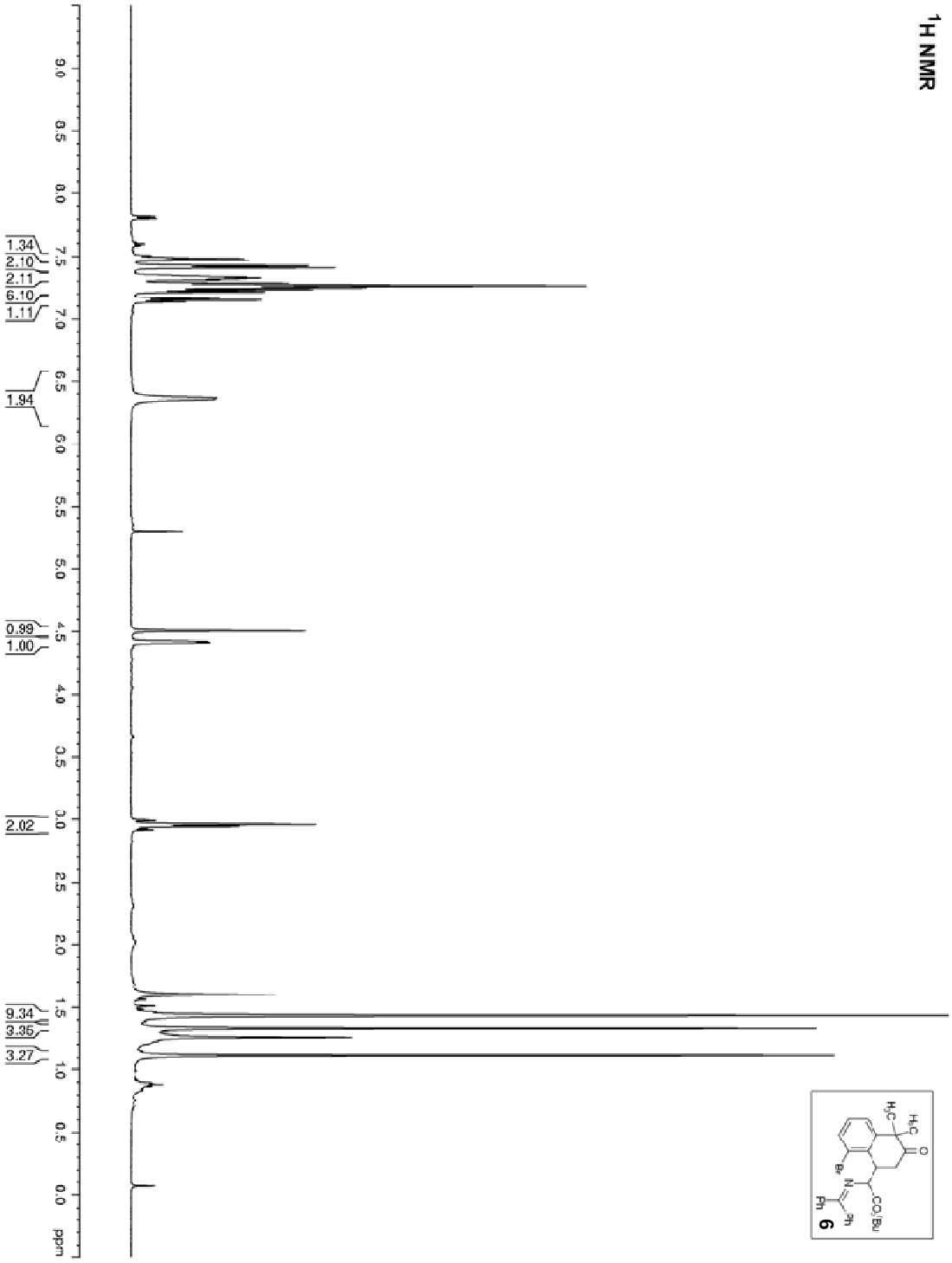
S1

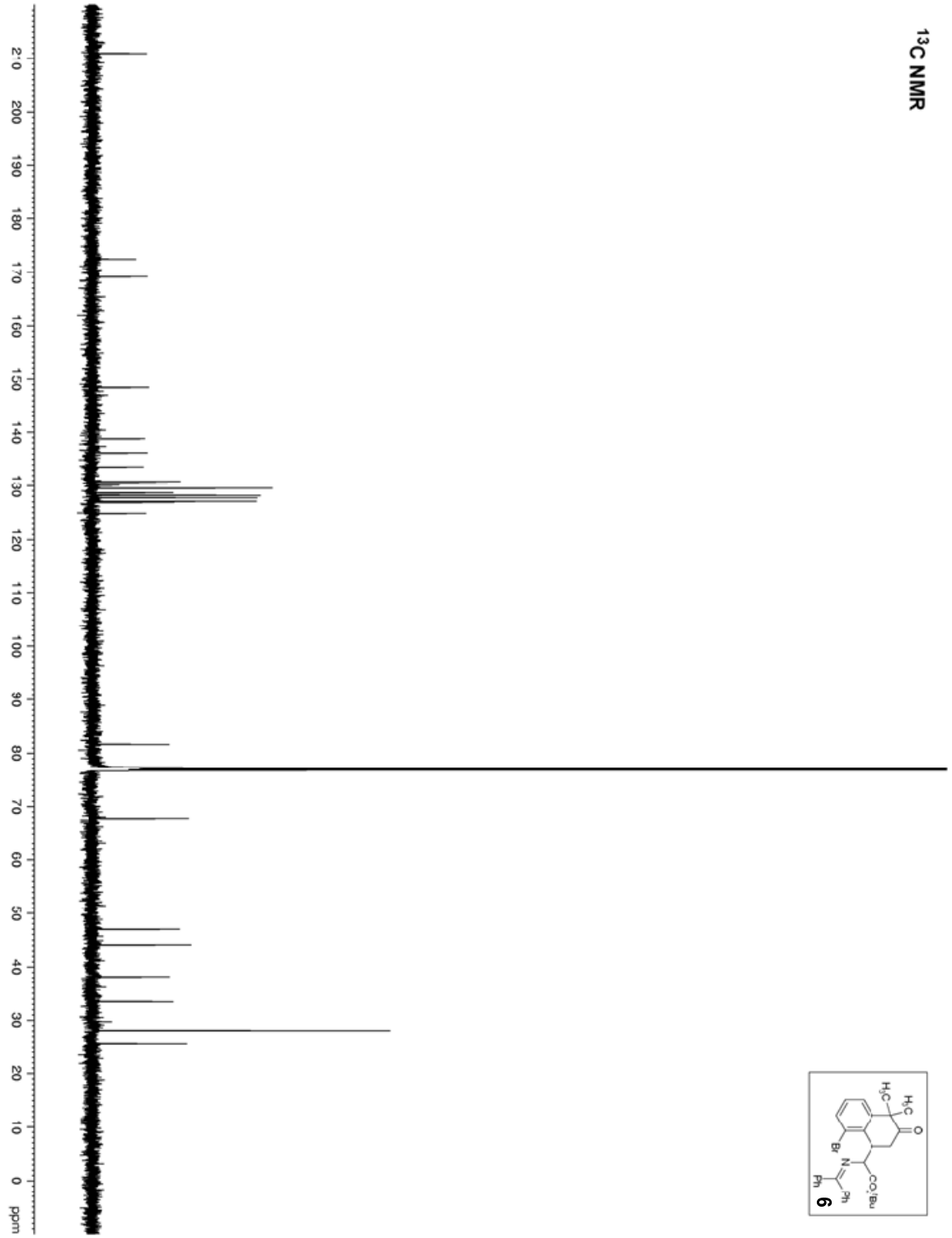

^{1}H NMR
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
0.95
1.01
1.01
2.00
2.00
6.28
H3C
H3C
O
Br
S2

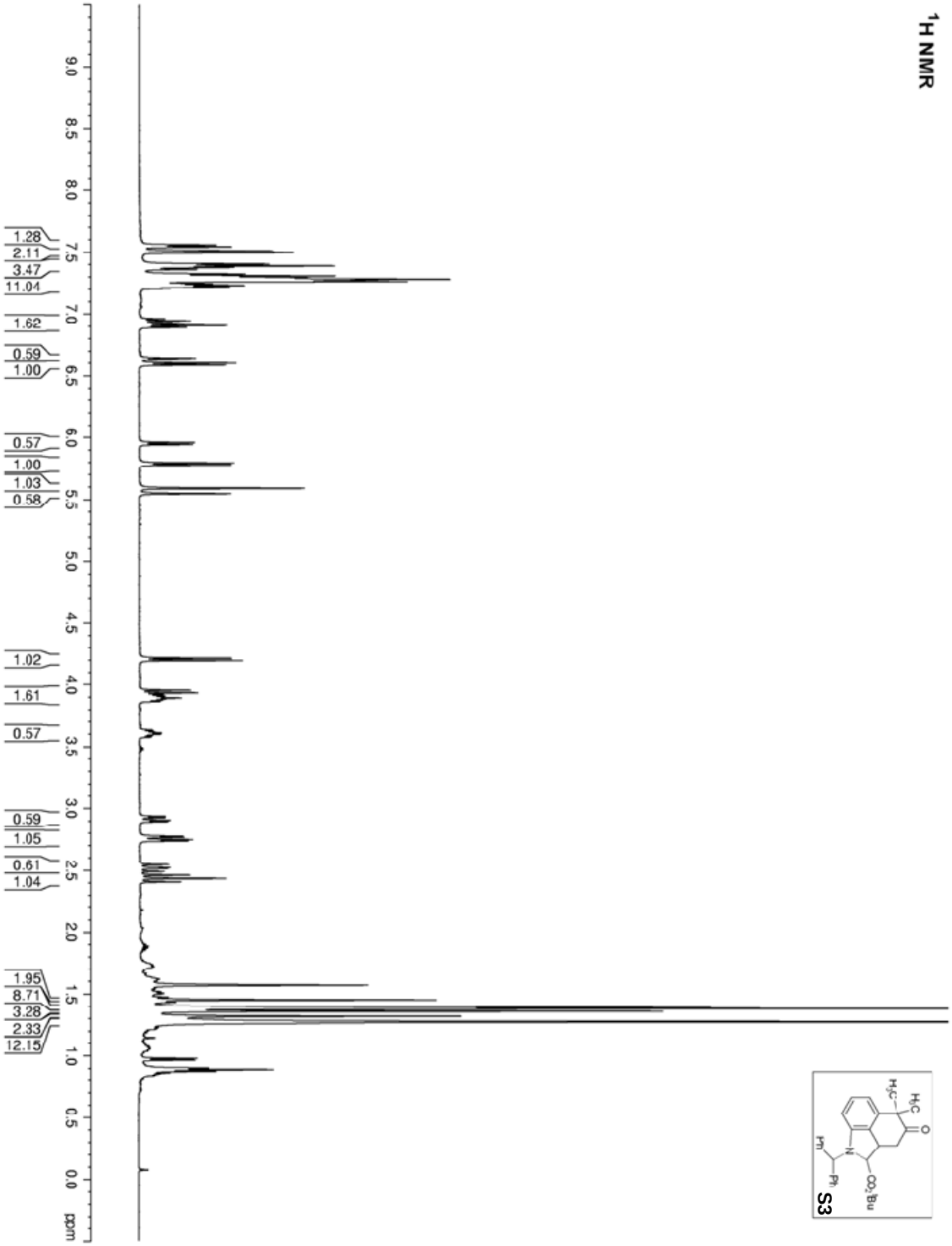

^{13}C NMR
S2
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

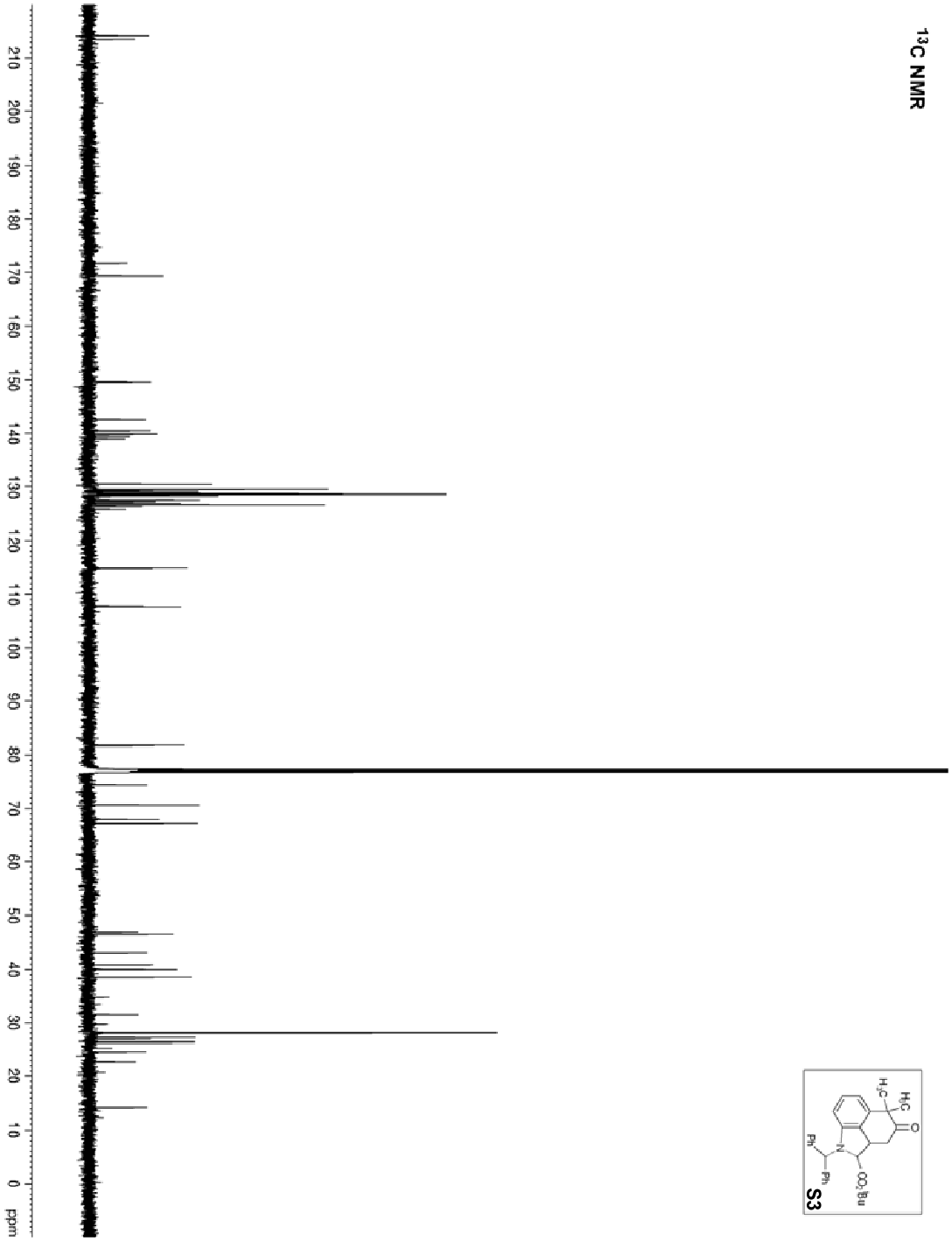

^{1}H NMR
1.00
1.00
1.03
1.03
0.99
6.30
ppm
4

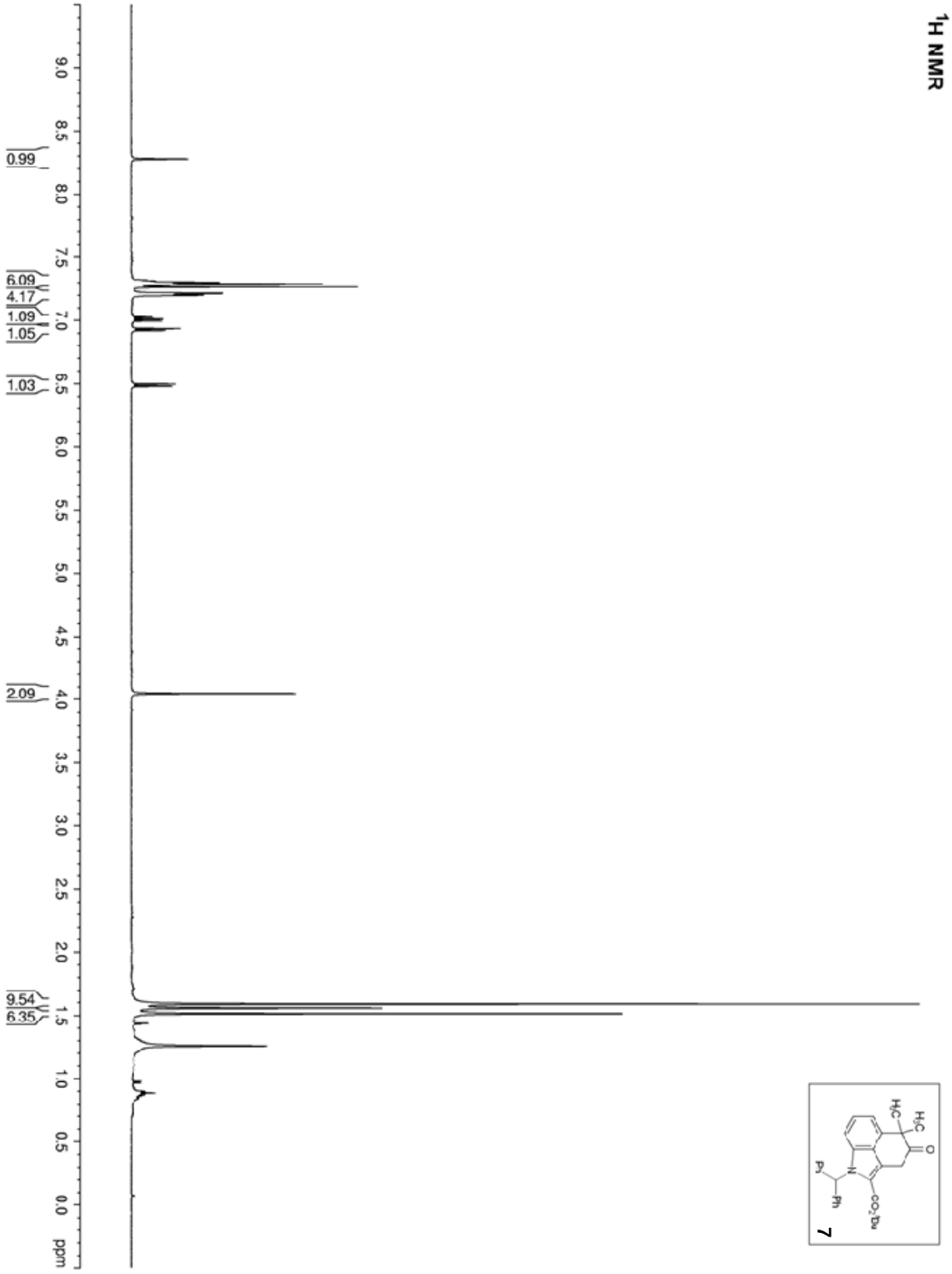

^{13}C NMR
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm
H3C
H3C
O
Br
4

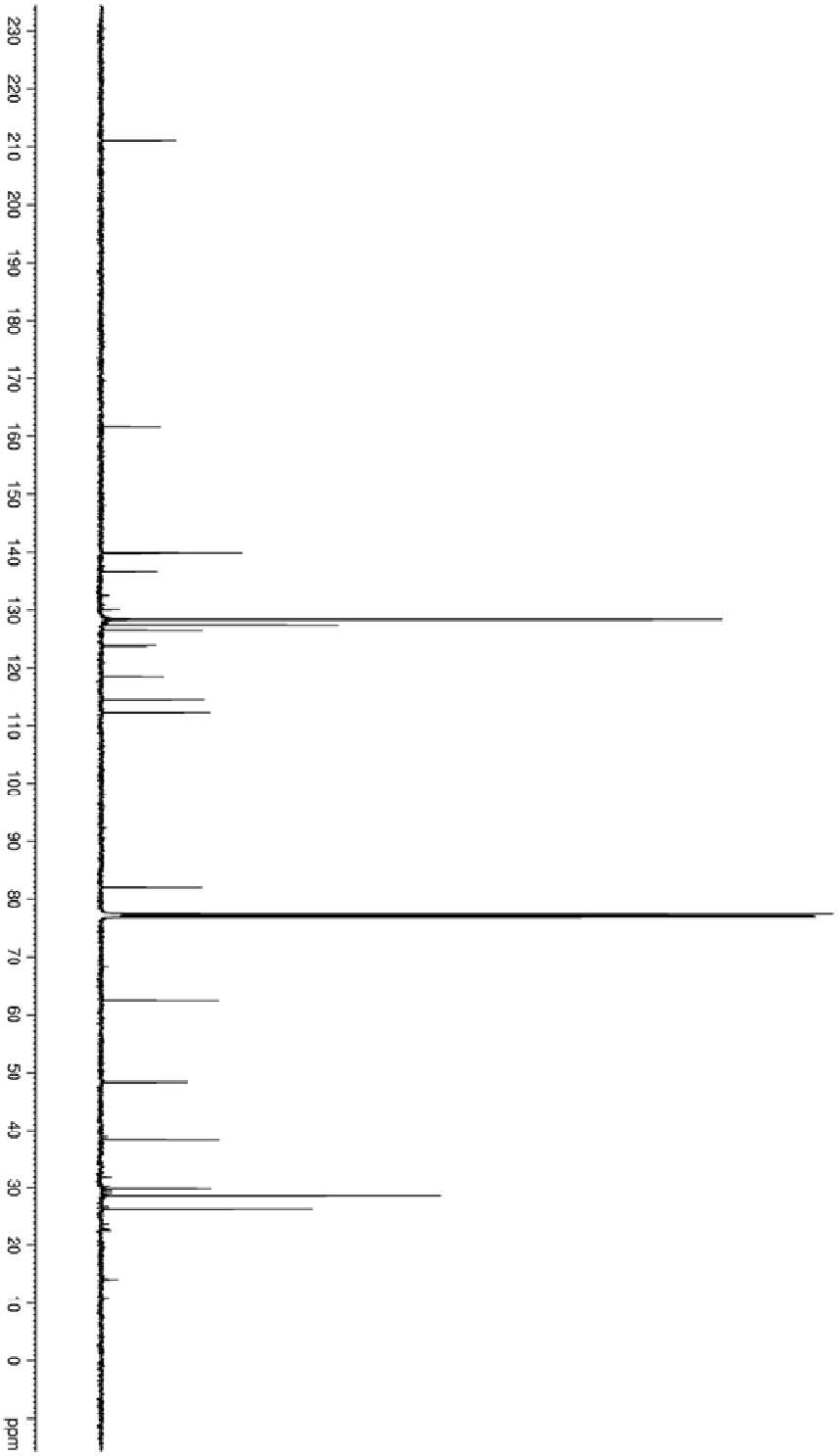

^{1}H NMR
1.34
2.10
2.11
6.10
1.11
1.94
0.99
1.00
2.02
9.34
3.35
3.27
ppm
6

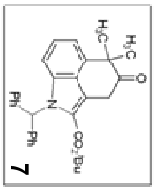

^{13}C NMR
220
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm
6

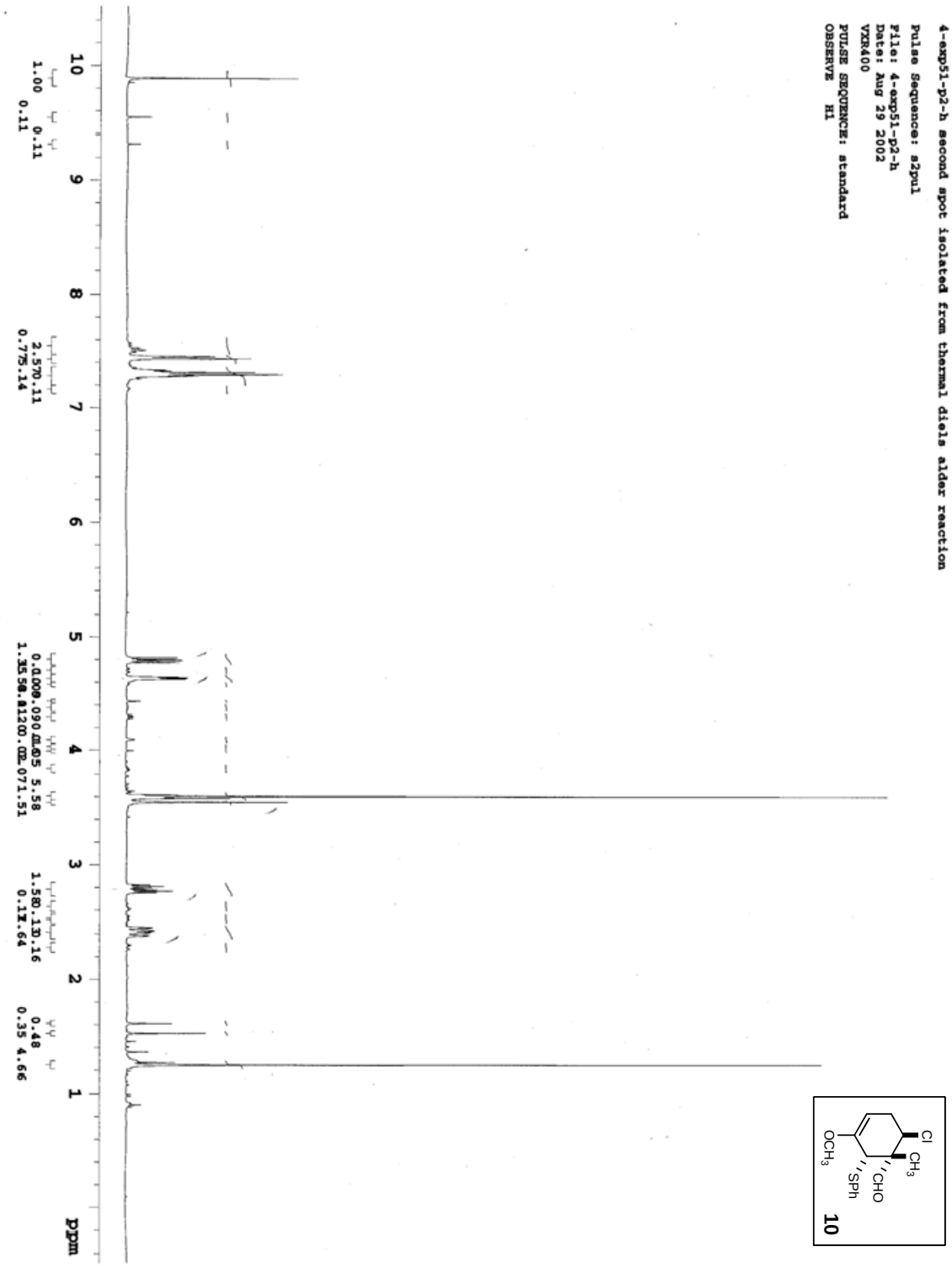

^{1}H NMR
1.28
2.11
3.47
11.04
1.62
0.59
1.00
0.57
1.00
1.03
0.58
1.02
1.61
0.57
0.59
1.05
0.61
1.04
1.95
8.71
3.28
2.33
12.15
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
S3

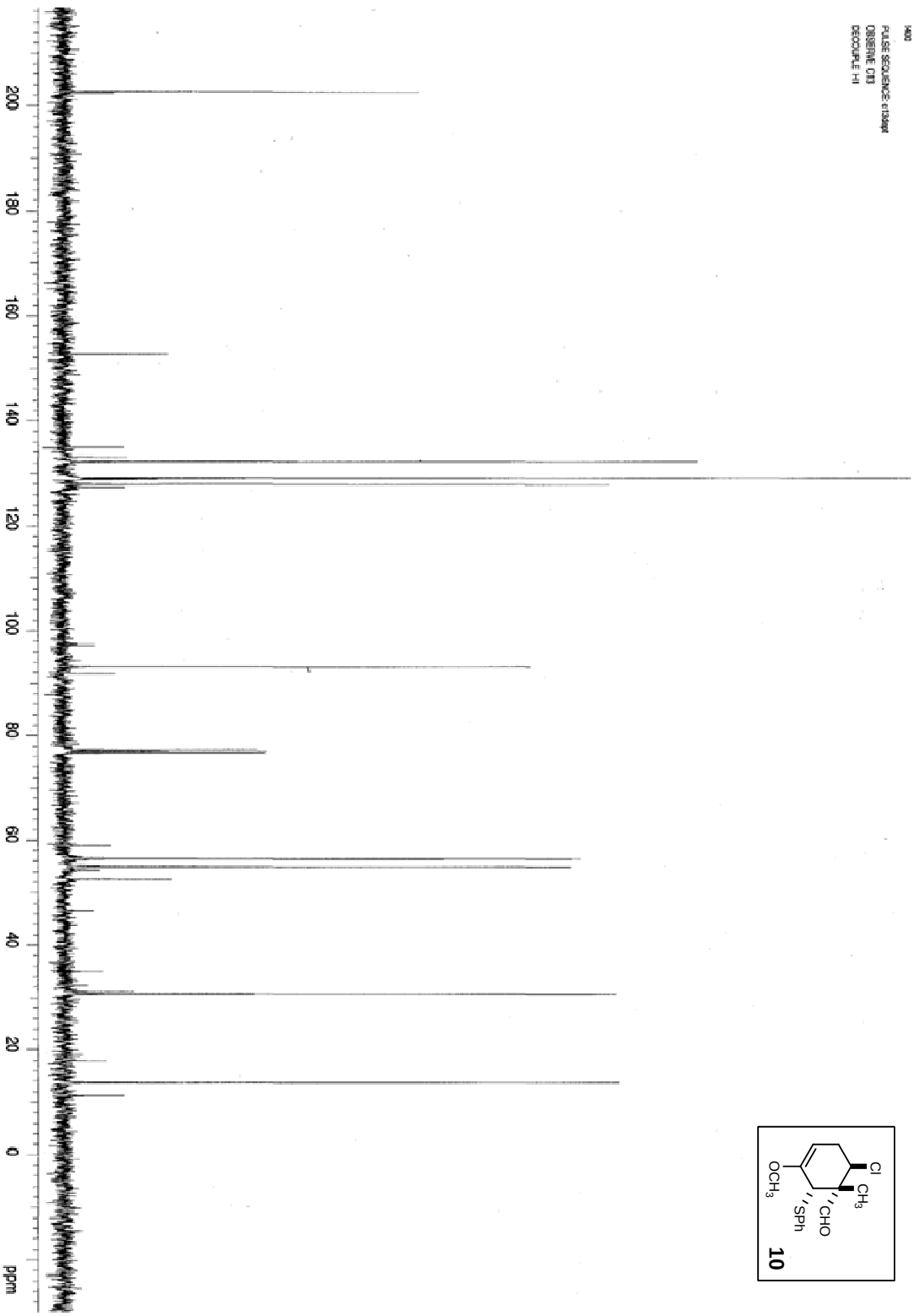

^{13}C NMR
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm
S3

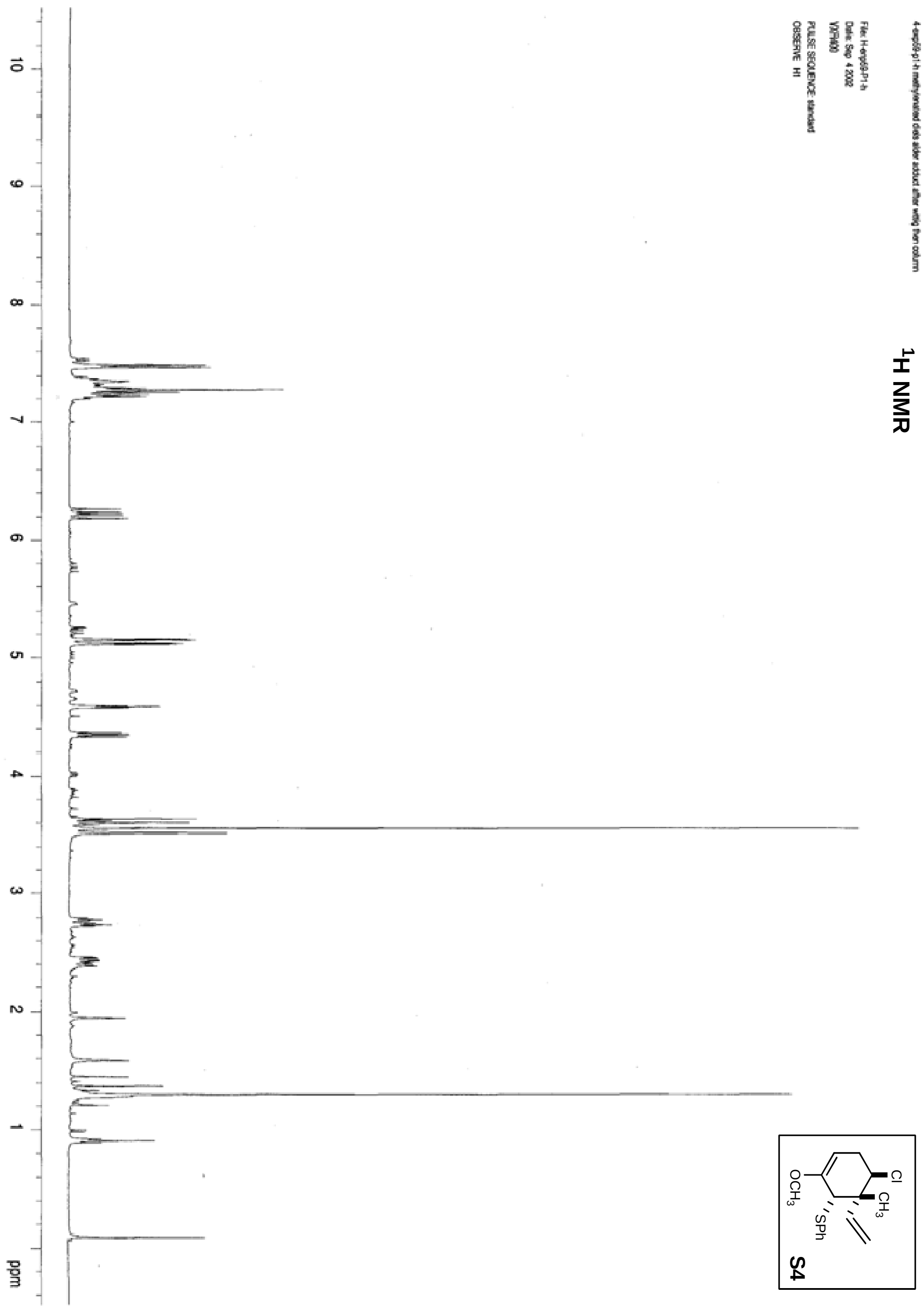

^{1}H NMR
0.99
6.09
4.17
1.09
1.05
1.03
2.09
9.54
6.35
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
7


^{13}C NMR
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

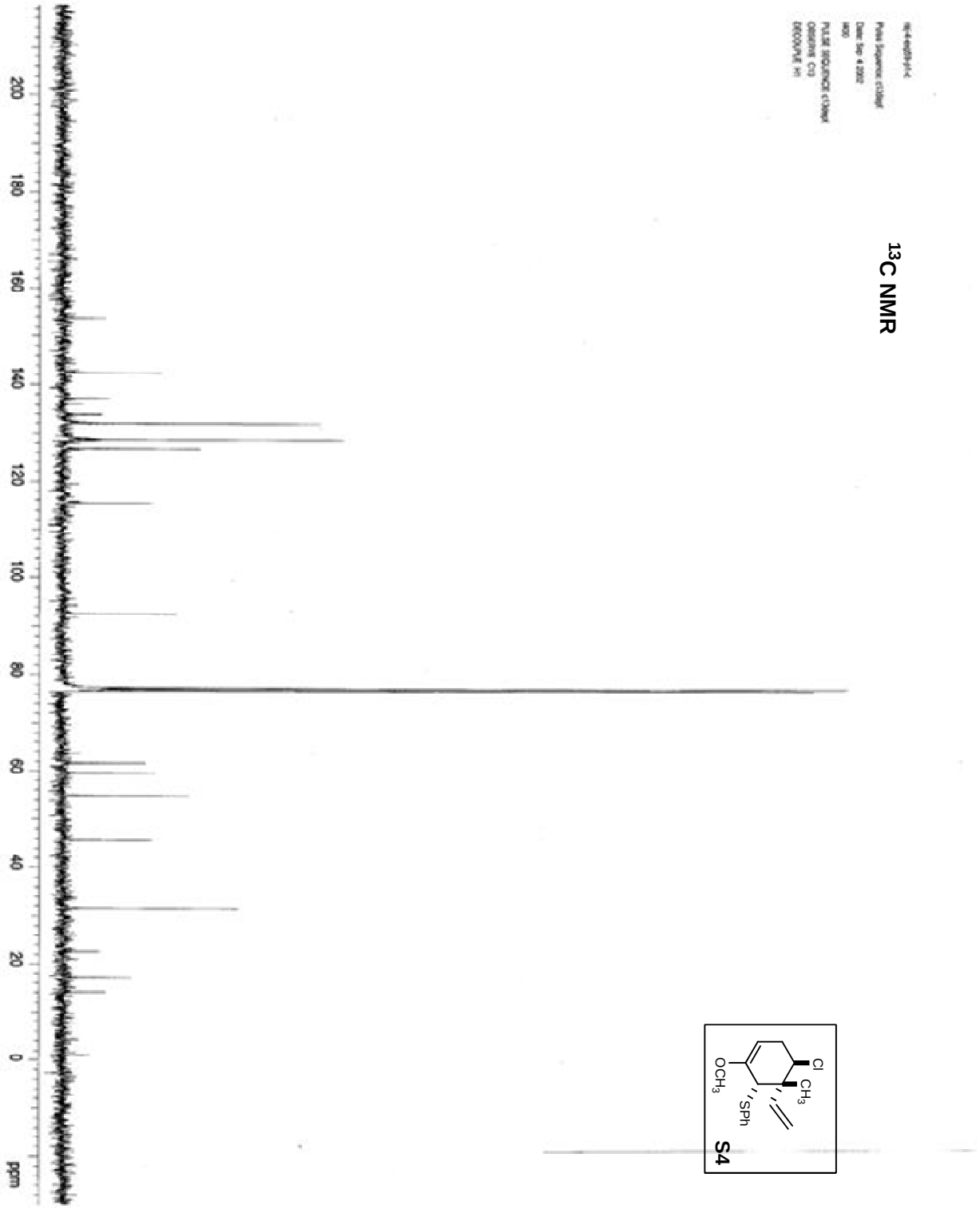

7

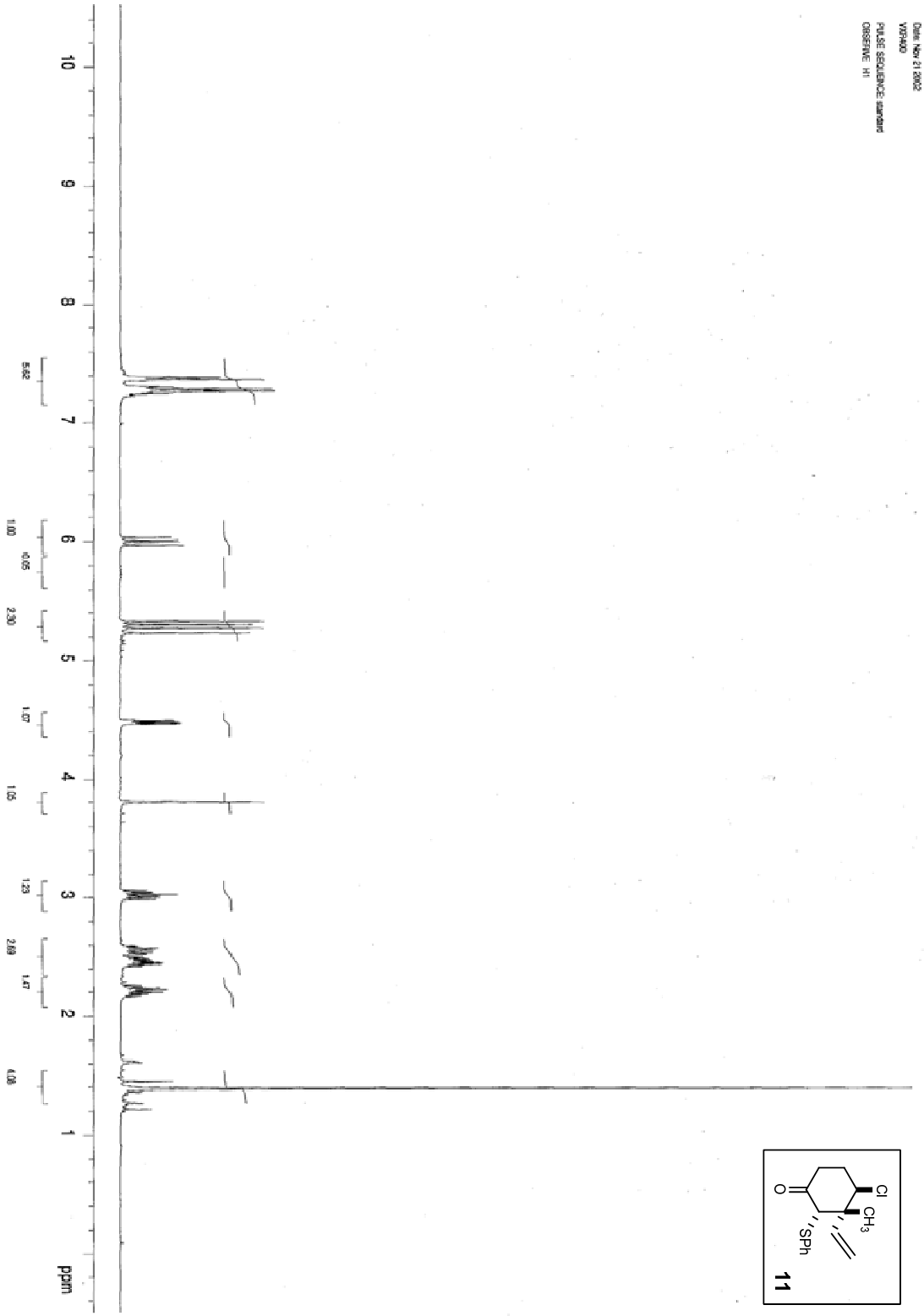

4-exp51-p2-h second spot isolated from thermal diels alder reaction
Pulse Sequence: s2pul
File: 4-exp51-p2-h
Date: Aug 29 2002
VXR400
PULSE SEQUENCE: standard
OBSERVE H1
Cl
CH3
CHO
SPh
OCH3
10
ppm

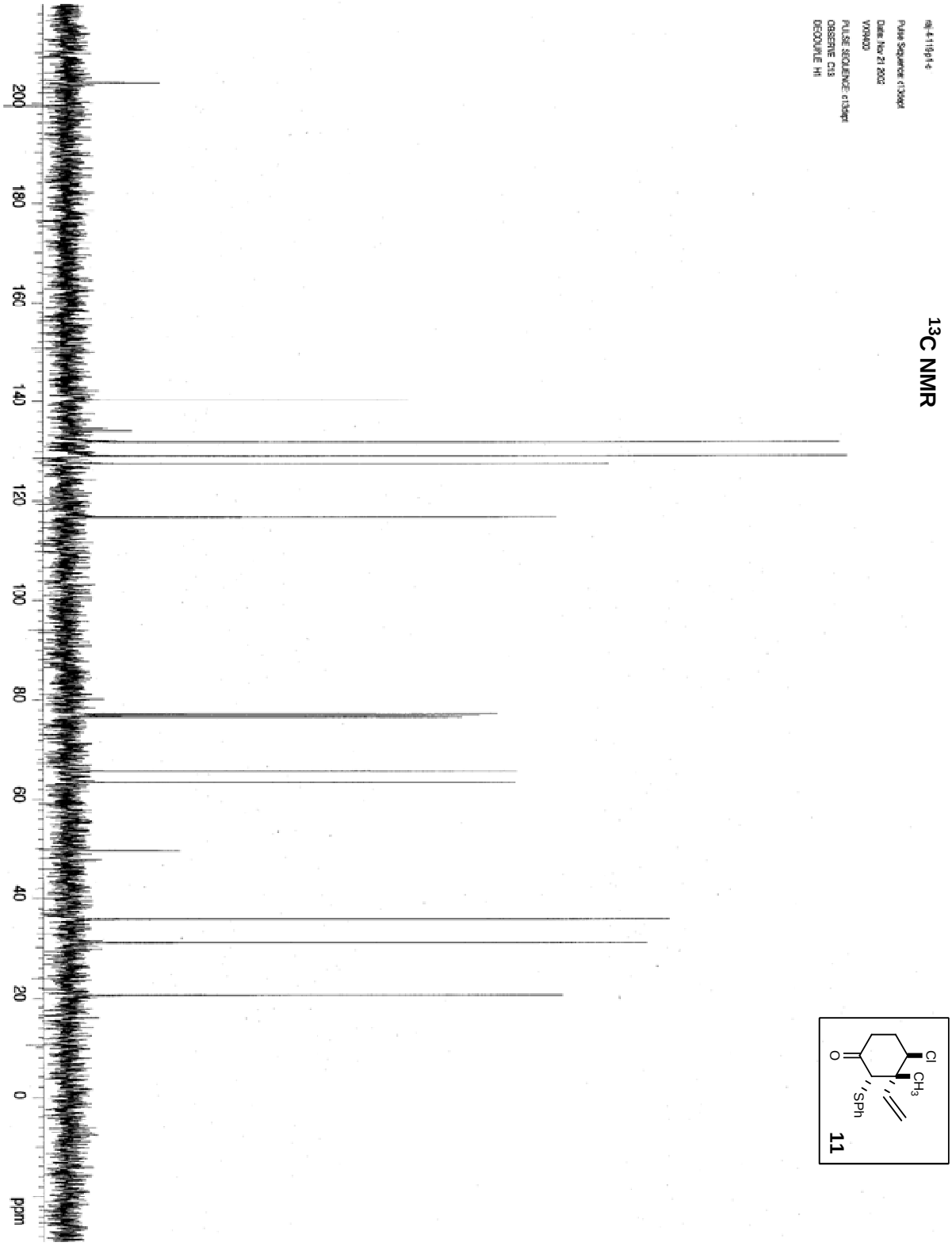

^{13}C NMR
200
180
160
140
120
100
80
60
40
20
0
ppm
Cl
CH3
CHO
SPh
OCH3
10



¹H NMR
S4


^{13}C NMR
200
180
160
140
120
100
80
60
40
20
0
ppm
Cl
CH3
OCH3
SPh
S4


1H NMR
ppm
Cl
CH3
SPh
O
11


^{13}C NMR
Cl
CH3
SPh
O
11
200
180
160
140
120
100
80
60
40
20
0
ppm