Fe(II)-Catalyzed Amination of Aromatic C-H Bonds via Ring Opening of 2*H*-Azirines: Synthesis of 2,3-Disubstituted Indoles

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Experimental Section

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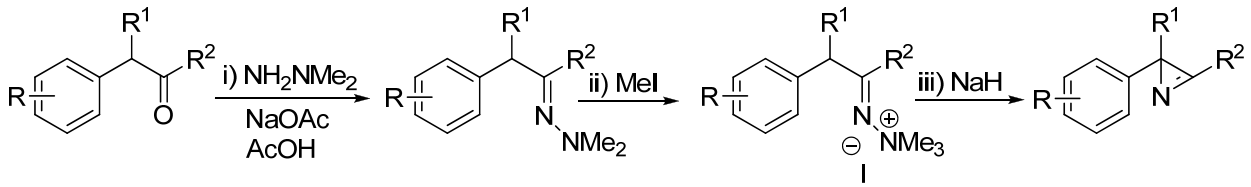
General Considerations

All reactions were carried out under a nitrogen atmosphere unless otherwise stated. Dry solvents were purchased and used as received except THF, CH_2Cl_2, Et_2O, and toluene. They were rigorously purged with argon for 2 h and then further purified by passing through two packed columns of neutral alumina (for THF and Et_2O) or through neutral alumina and copper (II) oxide (for toluene and CH_2Cl_2) under argon from a solvent purification system. Anhydrous DMSO was purchased from Alfa Aesar in a ChemSeal™ bottle. 1,2-Dichloroethane and 1,2-dimethoxyethane were purchased from EMD in spetum–seal bottles (DriSol®). All the chemicals were purchased from Sigma-Aldrich, Alfa Aesar, TCI-America, or Acros. 1,1-Diphenylacetone was purchased from TCI America; 4-bromophenyl acetone was purchased from Acros; 4-nitrophenyl acetone, (4-pyridyl) acetone and cyclopropyl phenyl ketone were purchased from Alfa Aesar. All the reactions from azirines to indoles were carried out under a nitrogen atmosphere in an oven-dried disposable screw-cap test tube (PTFE/Silicone Rubber Septa) with a stir bar.

All new compounds were characterized by ^{1}H NMR, ^{13}C NMR, and IR spectroscopy, in addition to elemental analysis performed by Atlantic Microlabs Inc., Norcross, GA and/or high resolution mass spectroscopy. For starting materials, copies of the ^{1}H and ^{13}C NMR spectra are attached for those new compounds of which a satisfactory elemental analysis was not obtained. Copies of the ^{1}H and ^{13}C NMR spectra are attached for all final products (indoles). Nuclear Magnetic Resonance spectra were recorded on a Bruker 400 instrument. All ^{1}H NMR experiments are reported in δ units, parts per million (ppm) and were measured relative to the signals for residual chloroform (7.26 ppm), acetone (2.05) in the deuterated solvents. All ^{13}C NMR spectra (obtained with ^{1}H decoupling) are reported in ppm relative to deuterochloroform (77.00 ppm) or acetone-d_6 (207.07 ppm). The following abbreviations are used to designate multiplicities of nmr signals: s = singlet, brs = broad singlet, d = doublet, t = triplet, q = quartet, m = multiplet, quint = quintet, and dd (doublet of doublet). Coupling constants (*J* value) are reported as hertz (Hz). Infrared spectra were recorded using a Perkin-Elmer Spectrum 100 FT-IR spectrometer. Melting points (uncorrected) were obtained on a Stuart SMP 10 melting point apparatus. The following compounds have been previously prepared and characterized: **1a**[1], **2a**[1], **1b**[2], **2b**[2], **1d**[3], **2d**[4], **1e**[2], **2e**[2], **1h**[1], **2h**[1], **1i**[2], **2i**[2], **2i′**[2], **1o**[1], **2o**[1], and **2o′**[1].

General Sequence for the Synthesis of Azirines



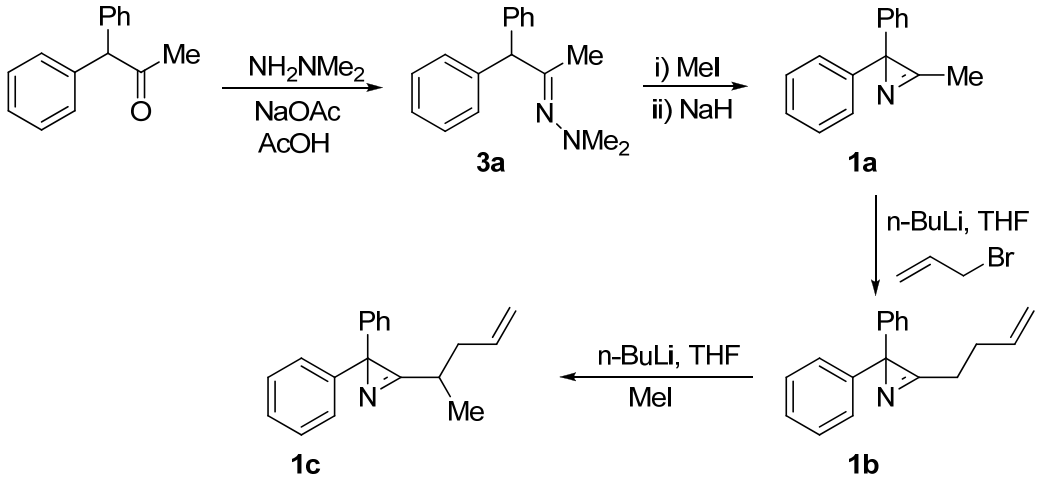
The synthesis of azirines following a published sequence[1,3] is stated as follows:

i) Preparation of Hydrazone: Ketone (1 mmol), sodium acetate (1.2 mmol) and acetic acid (0.15 mmol) were taken in ethanol (1.5 mL) in a microwave tube. Then *N*, *N*-dimethyl hydrazine (3 mmol) was added. The resulting mixture was heated to 150 °C in microwave. After 1 h, it was diluted with water (1.5 mL) and then extracted with EtOAc (3 × 10 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried over Na_2SO_4. Removal of solvent under reduced pressure provided the crude hydrazone that was purified by column chromatography on silica gel.

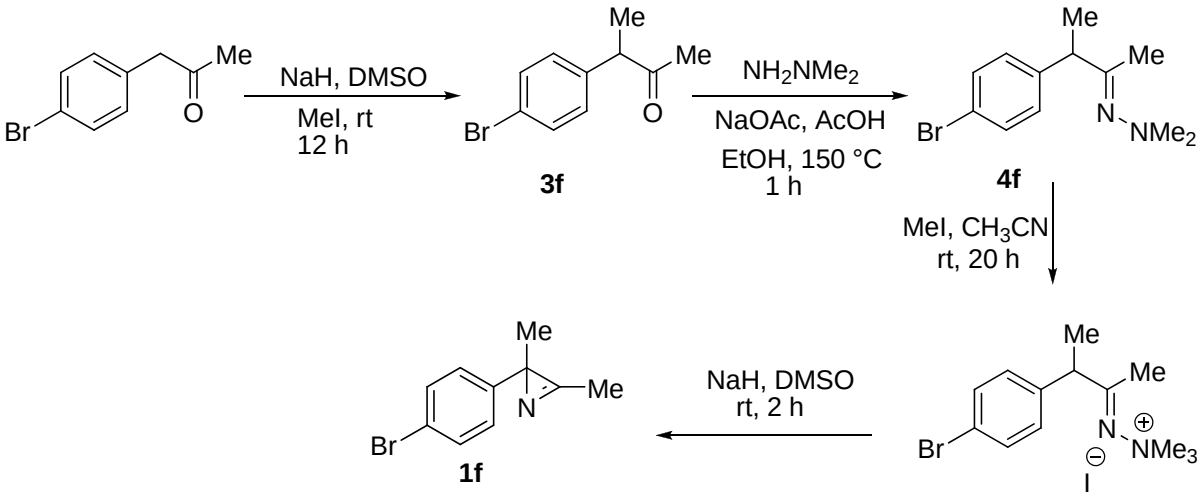
ii) Preparation of Hydrazonium Salt: Hydrazone (1 mmol) was dissolved in CH_3CN (0.5 mL) and MeI (3 mmol) was added at room temperature. After stirring at room temperature for 20 h, the solvent was removed under reduced pressure to provide a salt. The crude salt was triturated with Et_2O to provide the pure hydrazonium iodide salt that was used in next step without further purification.

iii) Preparation of Azirine: Hydrazonium salt (1 mmol) was dissolved in DMSO (2 mL). Then NaH (1.1 mmol) was added in one portion at room temperature. After 2 h, it was poured into ice cold water. The resutling mixture was extracted with hexanes (3 × 20 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried over Na_2SO_4. The solvent was removed under reduced pressure to provide the crude azirine that was purified by column chromatography on silica gel.

Azirines 1a[1,2] **and 1b.**[2] Azirines **1a** and **1b** (both are known compounds) were synthesized according to the general sequence (see the following scheme).



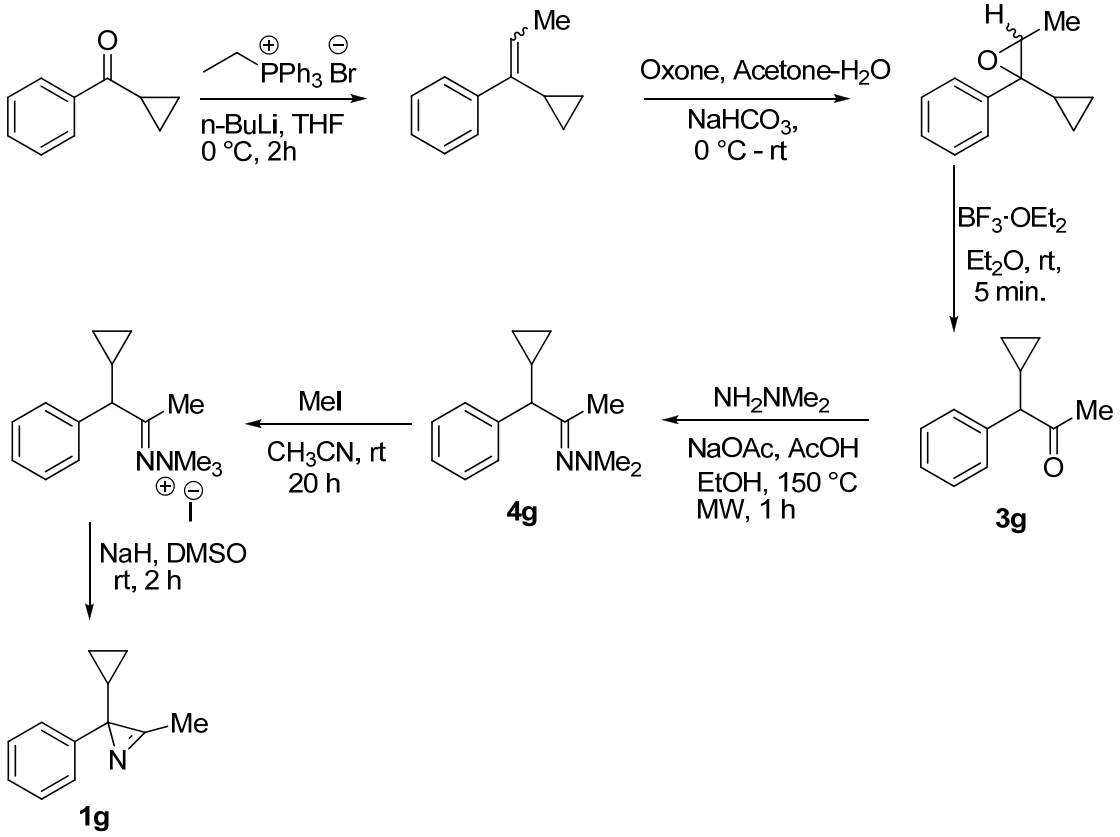
3-(Pent-4-en-2-yl)-2,2-diphenyl-2*H*-azirine (1c). To a stirred solution of azirine **1b** (345 mg, 1.39 mmol) in THF (2.5 mL), *n*-BuLi (1.6 M in hexanes, 0.96 mL, 1.53 mmol) was added slowly at –78 °C. After 1 h, iodomethane (0.09 mL, 1.53 mmol) was added slowly at –78 °C. Then it was allowed to warm to –10 °C over 1 h. After quenching with water (2 mL) at –10 °C, the mixture was extracted with EtOAc (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and dried over Na_2SO_4. The solvent was removed under reduced pressure to obtain a crude mass that was purified by column chromatography on silica gel (20:1 hexanes:EtOAc as eluent) to afford azirine **1c** (337 mg) as oil in 92% yield. IR (neat, cm^{-1}): 3065, 3029, 2976, 2930, 1750, 1601, 1495, 1446, 993, 918, 776. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.34-7.21 (m, 10H), 5.79-5.73 (m, 1H), 5.06-5.00 (m, 2H), 3.20-3.15 (m, 1H), 2.59-2.52 (m, 1H), 2.35-2.28 (m, 1H), 1.34 (d, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 173.2, 142.2, 142.1, 134.5, 128.3, 128.2, 128.0, 127.9, 126.9, 126.8, 117.9, 44.5, 36.9, 33.5, 15.7. Anal. calcd. for $C_{19}H_{19}N$: C, 87.31; H, 7.33; N, 5.36. Found: C, 87.39; H, 7.40; N, 5.48.



3-(4-Bromophenyl)butan-2-one (3f). To a stirred solution of 4-bromophenyl acetone (500 mg, 2.35 mmol) in DMSO (5 mL) was added sodium hydride (60% dispersion in mineral oil, 103 mg, 2.58 mmol) in one portion at room temperature. After 1 h, iodomethane (0.18 mL, 2.82 mmol) was added slowly. The reaction mixture was stirred at room temperature for 12 h and then quenched by pouring into ice cold water (5 mL). The mixture was extracted with diethyl ether (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried over Na_2SO_4. The solvent was removed under reduced pressure to obtain a crude mass that was purified by column chromatography on silica gel (10:1 hexanes:EtOAc) to afford ketone **3f** (380 mg) as oil in 71% yield. IR (neat, cm^{-1}): 2980, 2927, 2861, 1714, 1486, 1354, 1164, 1073, 1010, 829. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.46 (d, J = 8.5 Hz, 2H), 7.10 (d, J = 8.5 Hz, 2H), 3.71 (q, J = 7.0 Hz, 1H), 2.05 (s, 3H), 1.37 (d, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 208.1, 139.5, 132.0, 129.5, 121.1, 53.0, 28.3, 17.2. Anal. calcd. for $C_{10}H_{11}Br$: C, 52.89; H, 4.88. Found: C, 53.12; H, 4.89.

2-(3-(4-Bromophenyl)butan-2-ylidene)-1,1-dimethylhydrazine (4f). Following the general sequence (step i), hydrazone **4f** (275 mg) was obtained as oil in 83% yield from ketone **3f** (280 mg) after silica gel chromatography (15% EtOAc in hexanes as an eluent). IR (neat, cm^{-1}): 2978, 2934, 1714, 1486, 1355, 1164, 1073, 1010, 830. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.43 (d, J = 8.7 Hz, 2H), 7.14 (d, J = 8.6 Hz, 2H), 3.63 (q, J = 7.1 Hz, 1H), 2.48 (s, 6H), 1.73 (s, 3H), 1.42 (d, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 168.5, 141.7, 131.5, 129.2, 120.4, 47.0, 17.6, 14.6.

2-(4-Bromophenyl)-2,3-dimethyl-2*H*-azirine (1f). Following the general sequence (steps ii and iii), azirine **1f** (172 mg) was obtained as white solid in 76% yield from hydrazone **4f** (270 mg) after silica gel chromatography (10% EtOAc in hexanes as an eluent). m.p. 50-51 °C. IR (neat, cm^{-1}): 2958, 2921, 2860, 1764, 1485, 1399, 1313, 1079, 1006, 827, 717. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.42 (d, J = 8.6 Hz, 2H), 6.98 (d, J = 9.1 Hz, 2H), 2.44 (s, 3H), 1.63 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 169.8, 143.3, 131.1, 127.3, 120.2, 35.4, 21.0, 12.3. Anal. calcd. for $C_{10}H_{10}BrN$: C, 53.60; H, 4.50; N, 6.25. Found: C, 53.93; H, 4.55; N, 5.97.



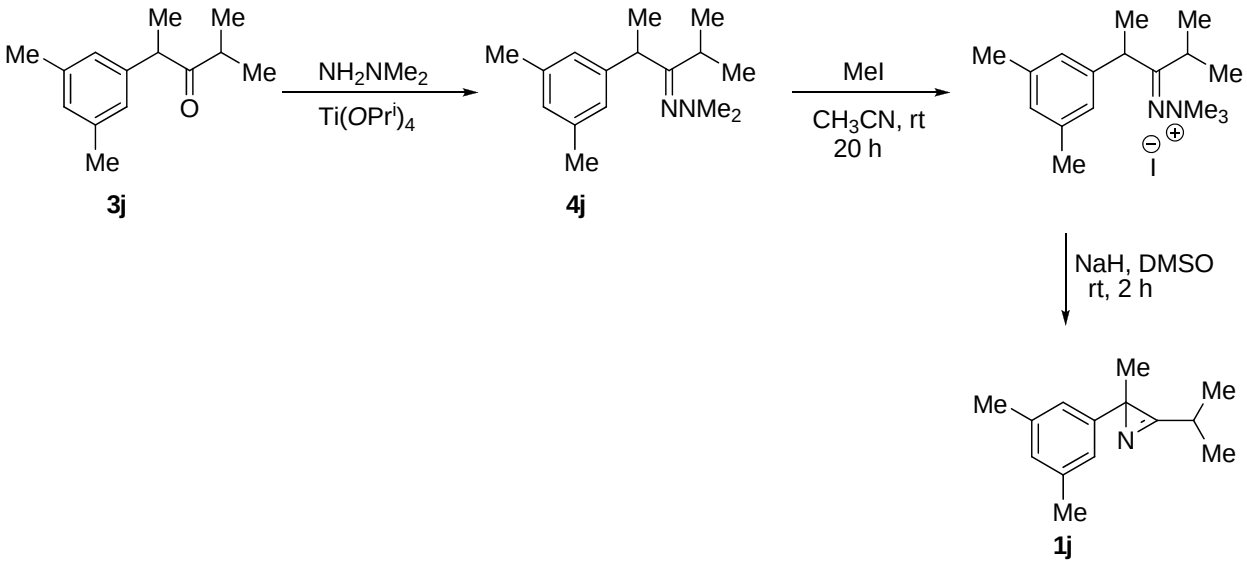
1-Cyclopropyl-1-phenylpropan-2-one (3g). To a stirred solution of ethyl triphenyl phosphonium bromide (6.1 g, 16.4 mmol) in THF (25 mL) was added *n*-BuLi (1.6 M in hexanes, 10.3 mL) dropwise at 0 °C. After 1 h, cyclopropyl phenyl ketone (1.00 g, 6.84 mmol) was added dropwise at the same temperature. Two hours later, the reaction mixture was quenched with AcOH (0.55 mL, 9.6 mmol) and then filtered through a silica pad. Removal of the solvent under reduced pressure provided the crude olefin that was used directly for the next step.

A solution of Oxone® (4.2 g, 13.68 mmol) in H_2O (20 mL) was added dropwise to a mixture of olefin (6.84 mmol) and $NaHCO_3$ (2.76 g, 32.83 mmol) in acetone (20 mL) at 0 °C. After 10 minutes, it was warmed to room temperature and stirred for 6 h at that temperature. Then Et_2O (50 mL) was added and the organic layer was separated. More water (10 mL) was added to the aqueous layer to make it homogeneous. The clear aqueous layer was extracted with diethyl ether (3 × 25 mL). The combined organic layers were washed with water, brine and dried over Na_2SO_4. The solvent was removed under reduced pressure to obtain the crude epoxide that was used directly for the next step.

The crude epoxide (1.0 g, 5.74 mmol) was dissolved in diethyl ether (30 mL) and BF_3•OEt_2 (46.5%, 3.1 mL, 11.5 mmol) was added very quickly at room temperature. After 5 minutes, it was carefully quenched with saturated aqueous $NaHCO_3$ solution and then extracted with Et_2O (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL), and finally dried over Na_2SO_4. The solvent was removed under reduced pressure to get a crude mass that was purified by silica gel chromatography (20:1 hexanes:EtOAc) to afford ketone **3g** (434 mg, 36% overall yield from cyclopropyl phenyl ketone) as oil. IR (neat, cm^{-1}): 3080, 3029, 3003, 2922, 1713, 1599, 1494, 1454, 1353, 1209, 1162, 1021, 750, 700. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.37-7.33 (m, 3H), 7.30-7.28 (m, 2H), 2.85 (d, J = 10.2 Hz, 1H), 2.11 (s, 3H), 1.42-1.34 (m, 1H), 0.74-0.67 (m, 1H), 0.59-0.52 (m, 1H), 0.31-0.25 (m, 1H), 0.18-0.11 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 208.5, 138.7, 128.7, 128.0, 127.2, 64.7, 28.4, 12.8, 5.0, 3.8. Anal. calcd. for $C_{12}H_{14}O$: C, 82.72; H, 8.10. Found: C, 82.58; H, 7.91.

2-(1-Cyclopropyl-1-phenylpropan-2-ylidene)-1,1-dimethylhydrazine (4g). Following the general sequence (step i), hydrazone **4g** (434 mg) was obtained as oil in 92% yield from ketone **3g** (380 mg) after silica gel chromatography (gradient, 10% to 20% EtOAc in hexanes as an eluent). IR (neat, cm^{-1}): 3082, 3004, 2954, 2855, 2817, 2772, 1603, 1499, 1454, 1362, 1022. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.41-7.39 (m, 2H), 7.35-7.30 (m, 2H), 7.27-7.21 (m, 1H), 2.74 (d, J = 10.3 Hz, 1H), 2.49 (s, 6H), 1.82 (s, 3H), 1.32-1.24 (m, 1H), 0.74-0.68 (m, 1H), 0.61-0.55 (m, 1H), 0.37-0.32 (m, 1H), 0.28-0.23 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 169.0, 140.9, 128.3, 127.6, 126.5, 58.3, 47.1, 13.9, 12.2, 5.6, 3.8. Anal. calcd. for $C_{14}H_{20}N_2$: C, 77.73; H, 9.32; N, 12.95. Found: C, 77.67; H, 7.40; N, 12.74.

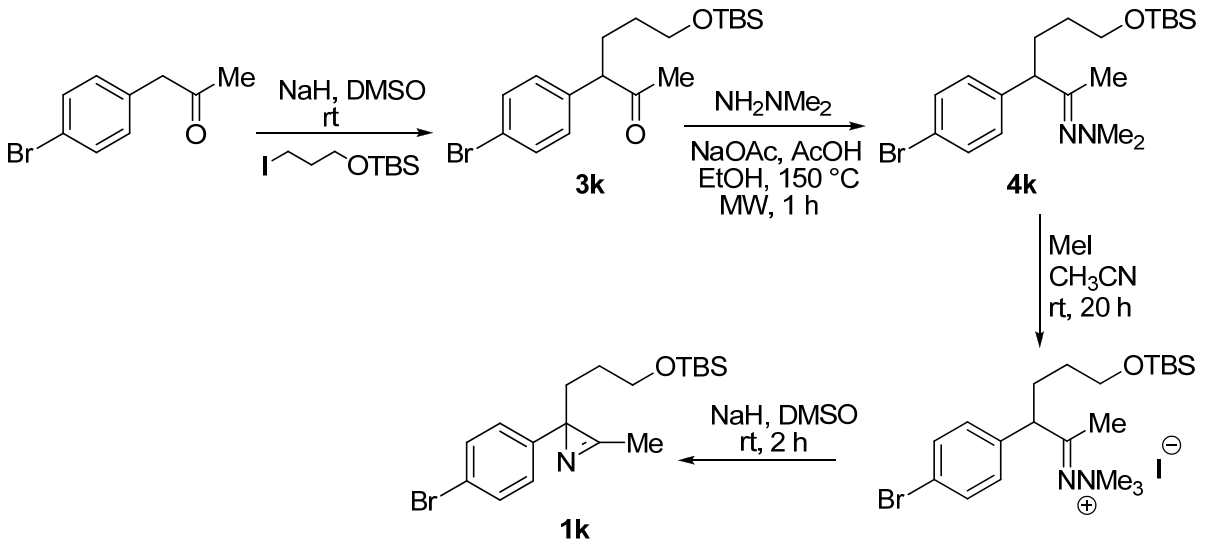
2-Cyclopropyl-3-methyl-2-phenyl-2*H*-azirine (1g). Following the general sequence (steps ii and iii), azirine **1g** (249 mg) was prepared as oil in 57% yield from hydrazone **4g** (550 mg) after silica gel chromatography (20:1 hexanes:EtOAc as an eluent). IR (neat, cm^{-1}): 3085, 3002, 2924, 2854, 1760, 1714, 1601, 1495, 1448, 1029, 769, 698. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.36-7.22 (m, 5H), 2.43 (s, 3H), 1.71-1.64 (m, 1H), 0.70-0.61 (m, 2H), 0.29-0.25 (m, 1H), 0.21-0.17 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 167.1, 143.7, 128.0, 126.3, 126.0, 41.3, 14.1, 12.8, 4.6, 3.5. HRMS (ESI) *m/z* calcd. for $C_{12}H_{13}NNa$ ($M+Na^+$) 194.0946, found 194.0938.



2-(2-(3,5-Dimethylphenyl)-4-methylpentan-3-ylidene)-1,1-dimethylhydrazine (4j). Ketone **3j**[5] (1.81 g, 8.86 mmol) and *N*,*N*-dimethylhydrazine (2.0 mL, 26.3 mmol) were charged to an oven-dried disposable screw-cap test tube (PTFE/Silicone Rubber Septa) with a stir bar. The tube was sealed and a nitrogen balloon was placed over its top. Neat $Ti(O^iPr)_4$ (9.0 mL, 30.2 mmol) was added dropwise to the test tube and then the balloon was removed. The test tube was immersed into a preheated oil bath at 100 °C. After heating at 100 °C for 24 h, the test tube was removed from the oil bath, cooled to room temperature, and then poured into saturated $NaHCO_3$ solution (40 mL). The mixture was filtered through Celite and EtOAc (3 × 10 mL) was used to wash the Celite bed. The filtrate was separated and the aqueous layer was extracted with EtOAc (2 × 20 mL). The combined organic layers were washed with water (20 mL), brine (20 mL), and dried over Na_2SO_4. Removal of the solvent under reduced pressure provided a residual that was

purified by silica gel chromatography (gradient, 16:1 to 15:1 hexanes:EtOAc as eluent) to provide hydrazone (1.80 g, a 1:1 mixture of *E*: *Z* iosmers) as oil in 83% yield. Spectral data are provided for mixture of two isomers. IR (neat, cm^{-1}): 2966, 2853, 2814, 2768, 1601, 1466, 1377, 962, 849. ^1H NMR (400 MHz, $CDCl_3$) δ: 6.98 (s, 1H), 6.84 (s, 0.5H), 6.81 (s, 1.5H), 5.07 (q, J = 7.3 Hz, 0.5H), 3.64 (q, J = 7.1 Hz, 0.5H), 3.47 (septet, J = 7.0 Hz, 0.5H), 2.47 (s, 3H), 2.46 (s, 3H), 2.29 (s, 3H), 2.28 (s, 3H), 2.32-2.28 (m, 0.5H), 1.40 (d, J = 7.3 Hz, 1.5H), 1.36 (d, J = 7.0 Hz, 1.5H), 1.09 (d, J = 6.9 Hz, 1.5H), 1.08 (d, J = 6.8 Hz, 1.5H), 0.78 (d, J = 6.8 Hz, 1.5H), 0.76 (d, J = 7.1 Hz, 1.5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 179.1, 177.1, 144.5, 141.1, 137.45, 137.42, 127.8, 127.7, 125.5, 125.3, 47.9, 47.7, 41.4, 38.4, 29.7, 29.6, 23.2, 22.6, 22.5, 21.34, 21.27, 20.2, 19.8, 15.6. Anal. calcd. for $C_{16}H_{26}N_2$: C, 77.99; H, 10.64; N, 11.37. Found: C, 78.13; H, 10.71; N, 11.29.

2-(3,5-Dimethylphenyl)-3-isopropyl-2-methyl-2*H*-azirine (1j). Following the general sequence (steps ii and iii), azirine **1j** was obtained as oil (550 mg) in 61% yield from hydrazone (1.78 g) after silica gel chromatography (20:1 hexanes:EtOAc as eluent). IR (neat, cm^{-1}): 2977, 2927, 2876, 1751, 1606, 1460, 1380, 1022, 850, 710. ^1H NMR (400 MHz, $CDCl_3$) δ: 6.85 (s, 1H), 6.75 (s, 2H), 3.05 (septet, J = 7.0 Hz, 1H), 2.29 (s, 6H), 1.66 (s, 3H), 1.30 (d, J = 7.0 Hz, 3H), 1.27 (d, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 176.2, 144.5, 137.5, 127.7, 123.4, 37.2, 27.9, 21.8, 21.3, 18.2, 17.9. Anal. calcd. for $C_{14}H_{19}N$: C, 83.53; H, 9.51; N, 6.96. Found: C, 83.37; H, 9.74; N, 6.85.

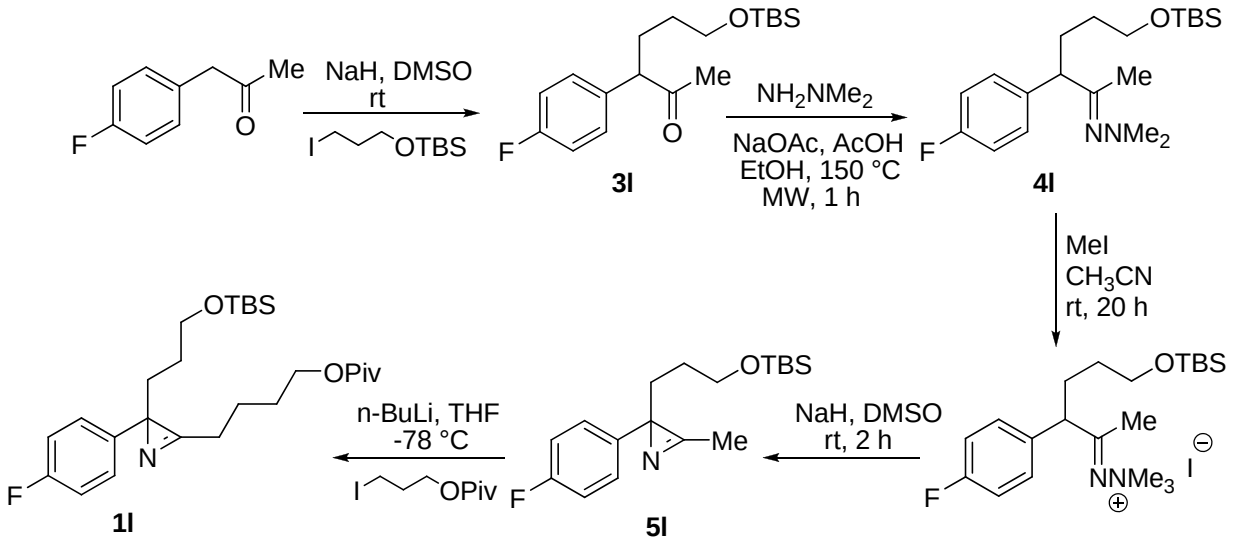


3-(4-Bromophenyl)-6-(tert-butyldimethylsilyloxy)hexan-2-one (3k). To a stirred solution of 4-bromophenyl acetone (500 mg, 2.35 mmol) in DMSO (5 mL) was added sodium hydride (60% dispersion in mineral oil, 113 mg, 2.82 mmol) in one portion at room temperature. One hour later, a solution of 3-(*tert*-butyldimethylsilyloxy)-1-iodopropane (776 mg, 2.58 mmol) in DMSO (2.5 mL) was added slowly. After stirring at room temperature for 12 h, the reaction was quenched with ice cold water (5 mL) and then extracted with diethyl ether (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and dried over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (20:1 hexanes:EtOAc) to provide ketone **3k** (694 mg) as oil in 77% yield. IR (neat, cm^{-1}): 2958, 2929, 2857, 1715, 1486, 1471, 1356, 1254, 1159, 1101, 1011, 836, 776. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.45 (d, J = 8.4 Hz, 2H), 7.10 (d, J = 8.4 Hz, 2H), 3.62 (dd, J = 8.0, 7.1 Hz, 1H), 3.58 (dt, J = 1.6, 6.3 Hz, 2H), 2.10-2.00 (m, 1H), 2.05 (s, 3H), 1.76-1.67 (m, 1H), 1.44-1.30 (m, 2H), 0.87 (s, 9H), 0.02 (s, 3H), 0.015 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 207.8, 137.9, 132.0, 130.0, 121.2, 62.8, 58.7, 30.4, 29.0, 28.3, 25.9, 18.3, -5.3. Anal. calcd. for $C_{18}H_{29}BrO_2Si$: C, 56.09; H, 7.58. Found: C, 56.15; H, 7.67.

2-(3-(4-Bromophenyl)-6-(*tert*-butyldimethylsilyloxy)hexan-2-ylidene)-1,1-dimethyl hydrazine (4k). Following the general sequence (step i), hydrazone **4k** (598 mg) was obtained as oil in 78% yield from ketone **3k** (694 mg) after silica gel chromatography (10% EtOAc in hexanes as an eluent). IR (neat, cm^{-1}): 2953, 2934, 2857, 1487, 1470, 1359, 1254, 1102, 1011, 836, 775. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.41 (d, J = 8.3 Hz, 2H),7.14 (d, J = 8.3 Hz, 2H), 3.61 (t, J = 6.4 Hz, 2H), 3.44 (t, J = 7.8 Hz, 1H), 2.45 (s, 6H), 2.00-1.92 (m, 1H), 1.85-1.81 (m, 1H), 1.73 (s, 3H), 1.50-1.42 (m, 2H), 0.88 (s, 9H), 0.33 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 167.8, 140.4, 131.5, 129.6, 120.5, 62.9, 52.9, 47.0, 30.6, 27.8, 25.9, 18.3, 14.7, -5.3.

2-(4-Bromophenyl)-2-(3-(*tert*-butyldimethylsilyloxy)propyl)-3-methyl-2*H*-azirine (1k). Following the general sequence (steps ii and iii), azirine **1k** (300 mg) was obtained as oil in 63% yield from hydrazone **4k** (534 mg) after silica gel chromatography (20:1 hexanes:EtOAc as eluent). IR (neat, cm^{-1}): 2957, 2933, 2861, 1490, 1255, 1106, 1011, 838, 778. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.41 (d, J = 8.5 Hz, 2H), 7.02 (d, J = 8.9 Hz, 2H), 3.61 (dd, J = 6.2, 6.0 Hz,

2H), 2.45 (s, 3H), 2.15-2.04 (m, 2H), 1.50-1.42 (m, 2H), 0.89 (s, 9H), 0.04 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 169.6, 142.5, 131.2, 127.7, 120.2, 62.6, 39.3, 29.8, 29.2, 26.0, 18.3, 13.0, -5.3. Anal. calcd. for $C_{18}H_{28}BrNOSi$: C, 56.53; H, 7.38; N, 3.66. Found: C, 56.78; H, 7.55; N, 3.56.



6-(*tert*-Butyldimethylsilyloxy)-3-(4-fluorophenyl)hexan-2-one (3l). To a stirred solution of 4-fluorophenyl acetone[6] (600 mg, 3.94 mmol) in DMSO (4 mL) was added sodium hydride (60% dispersion in mineral oil, 189 mg, 4.73 mmol) in one portion at room temperature. One hour later, a solution of 3-(*tert*-butyldimethylsilyloxy)-1-iodopropane (1.30 g, 4.33 mmol) in DMSO (3 mL) was added slowly. After stirring at room temperature for 12 h, the reaction was quenched with ice cold water (5 mL) and then extracted with diethyl ether (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (5% EtOAc in hexanes) to afford ketone **3l** (1.02 g) as oil in 80% yield. IR (neat, cm^{-1}): 2954, 2933, 2861, 1716, 1508, 1359, 1258, 1228, 1156, 1099, 836, 775. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.19 (dd, J = 8.7, 5.3 Hz, 2H), 7.03 (t, J = 8.7 Hz, 2H), 3.63 (dd, J = 7.9, 6.9 Hz, 1H), 3.57 (td, J = 6.3, 2.0 Hz, 2H), 2.08-2.00 (m, 1H), 2.05 (s, 3H), 1.76-1.67 (m, 1H), 1.46-1.31 (m, 2H), 0.87 (s, 9H), 0.02 (s, 3H), 0.01(s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 208.2, 162.0 (d, J = 245.8 Hz), 134.6 (d, J = 3.4 Hz), 129.7 (d, J = 8.1 Hz), 115.7 (d, J = 21.5

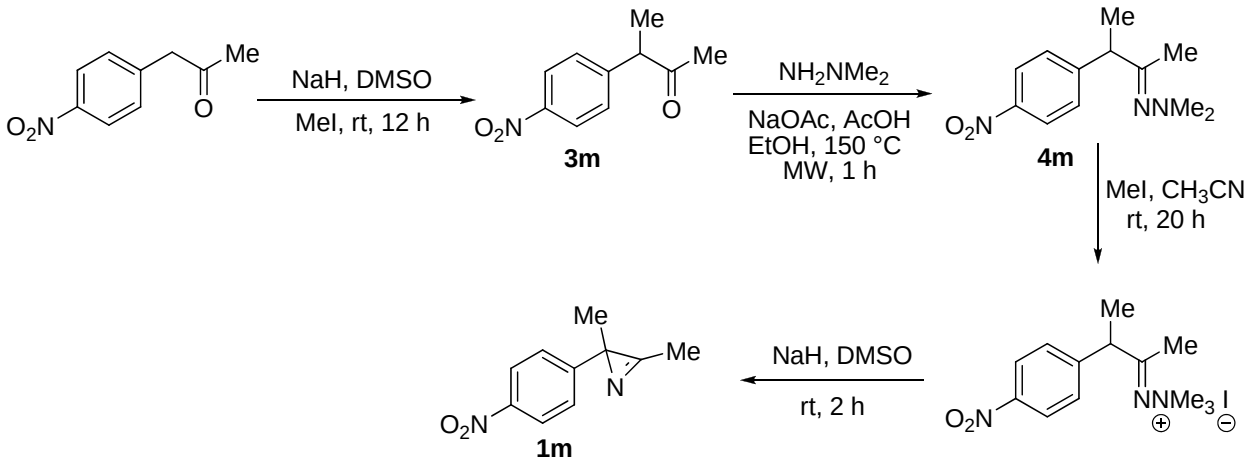
Hz), 62.8, 58.5, 30.4, 28.9, 28.3, 25.9, 18.3, -5.4. Anal. calcd. for $C_{18}H_{29}FO_2Si$: C, 66.62; H, 9.01. Found: C, 66.47; H, 9.07.

2-(6-(*tert*-Butyldimethylsilyloxy)-3-(4-fluorophenyl)hexan-2-ylidene)-1,1-dimethylhydrazine (4l). Following the general sequence (step i), hydrazone **4l** (535 mg) was obtained as oil in 95% yield from ketone **3l** (500 mg) after silica gel chromatography (gradient, 9:1 hexanes:EtOAc to 4:1 hexanes:EtOAc as an eluent). IR (neat, cm^{-1}): 2953, 2930, 2857, 2817, 2772, 1508, 1470, 1359, 1154, 1224, 1100, 835, 775. ^1H NMR (400 MHz, $CDCl_3$) δ: 7.22 (dd, J = 8.7, 5.6 Hz, 2H), 6.98 (dd, J = 9.0, 8.6 Hz, 2H), 3.61 (t, J = 6.4 Hz, 2H), 3.46 (t, J = 7.8 Hz, 1H), 2.45 (s, 6H), 2.01-1.83 (m, 2H), 1.72 (s, 3H), 1.51-1.43 (m, 2H), 0.88 (s, 9H), 0.03 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 168.1, 161.7 (d, J = 244.6 Hz), 137.1, 129.3 (d, J = 7.9 Hz), 115.2 (d, J = 21.2 Hz), 63.0, 52.7, 47.0, 30.7, 28.0, 25.9, 18.3, 14.5, -5.3. Anal. calcd. for $C_{20}H_{35}FN_2OSi$: C, 65.53; H, 9.62; N, 7.64. Found: C, 65.77; H, 9.71; N, 7.53.

2-(3-(*tert*-Butyldimethylsilyloxy)propyl)-2-(4-fluorophenyl)-3-methyl-2*H*-azirine (5l). Following the general sequence (steps ii and iii), azirine **5l** (224 mg) was obtained as oil in 57% yield from hydrazone **4l** (450 mg) after silica gel chromatography (20:1 hexanes:EtOAc as eluent). IR (neat, cm^{-1}): 2954, 2929, 2857, 1511, 1472, 1256, 1232, 1103, 836, 776. ^1H NMR (400 MHz, $CDCl_3$) δ: 7.10 (dd, J = 9.0, 5.3 Hz, 2H), 6.97 (dd, J = 9.0, 8.6 Hz, 2H), 3.62 (t, J = 6.3 Hz, 2H), 2.46 (s, 3H), 2.18-2.04 (m, 2H), 1.51-1.42 (m, 2H), 0.89 (s, 9H), 0.04 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 170.1, 161.5 (d, J = 244.8 Hz), 139.1 (d, J = 3.0 Hz), 127.4 (d, J = 7.8 Hz), 114.9 (d, J = 21.3 Hz), 62.6, 39.2, 30.1, 29.2, 25.9, 18.3, 13.0, -5.3. Anal. calcd. for $C_{18}H_{28}FNOSi$: C, 67.24; H, 8.78; N, 4.36. Found: C, 67.53; H, 9.04; N, 4.29.

4-(2-(3-(*tert*-Butyldimethylsilyloxy)propyl)-2-(4-fluorophenyl)-2*H*-azirin-3-yl)butyl pivalate (1l). To a stirred solution of azirine **5l** (195 mg, 0.61 mmol) in THF (1.0 mL) was added *n*-BuLi (1.6 M in hexanes, 0.42 mL, 0.67 mmol) slowly at –78 °C. One hour later, a solution of 3-iodopropyl pivalate[7] (214 mg, 0.79 mmol) in THF (1.0 mL) was added slowly at –78 °C. Upon the completion of the addition, the mixture was allowed to warm to –10 °C over 1 h. The reaction mixture was quenched with water (2 mL) and then extracted with EtOAc (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried

over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (gradient, 20:1 hexanes:EtOAc to 9:1 hexanes:EtOAc) to afford azirine **1l** (71 mg) as oil in 25% yield. IR (neat, cm^{-1}): 2955, 2937, 2857, 1729, 1607, 1510, 1287, 1254, 1233, 1157, 1103, 837, 780. ^1H NMR (400 MHz, $CDCl_3$) δ: 7.10 (dd, J = 8.9, 5.2 Hz, 2H), 6.97 (t, J = 8.7 Hz, 2H), 4.07 (t, J = 6.0 Hz, 2H), 3.61 (t, J = 6.2 Hz, 2H), 2.80 (dd, J = 7.0, 6.6 Hz, 2H), 2.23-2.16 (m, 1H), 2.02-1.95 (m, 1H), 1.85-1.72 (m, 4H), 1.51-1.44 (m, 2H), 1.18 (s, 9H), 0.89 (s, 9H), 0.04 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 178.5, 173.2, 161.4 (d, J = 245.3 Hz), 139.1 (d, J = 2.82 Hz), 127.3 (d, J = 8.0 Hz), 114.9 (d, J = 21.0 Hz), 63.5, 62.6, 39.6, 38.7, 30.4, 29.1, 28.2, 27.1, 27.0, 25.9, 21.1, 18.3, -5.3. Anal. calcd. for $C_{26}H_{42}FNO_3Si$: C, 67.34; H, 9.13; N, 3.02. Found: C, 67.44; H, 9.24; N, 2.99.

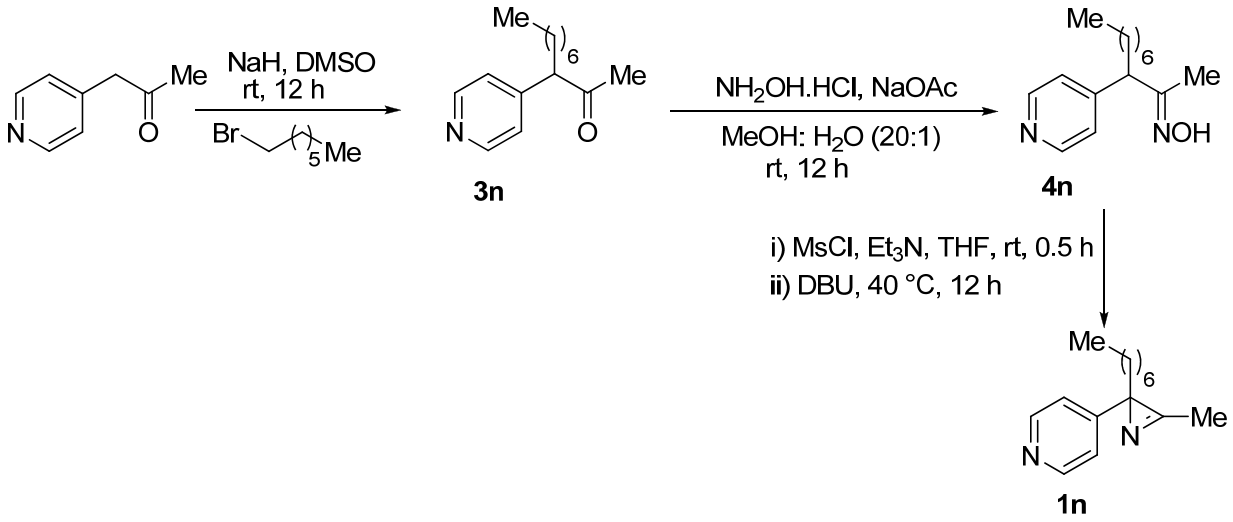


3-(4-Nitrophenyl)butan-2-one (3m). To a stirred solution of 4-nitrophenyl acetone (1.00 g, 5.58 mmol) in DMSO (6 mL) was added NaH (60% dispersion in mineral oil, 246 mg, 6.14 mmol) in one portion at room temperature. One hour later, iodomethane (0.38 mL, 6.14 mmol) was added slowly. After stirring at room temperature for 12 h, the reaction mixture was quenched with ice cold water (5 mL) and then extracted with diethyl ether (3 × 25 mL). The combined organic layers were washed with water (2 × 5 mL), brine (5 mL) and finally dried over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (10% EtOAc in hexanes) to afford ketone **3m** (870 mg) as white solid in 81% yield. m.p. 50-52 °C. IR (neat, cm^{-1}): 2980, 2917, 2849, 1715, 1604, 1519, 1346, 1163, 1110, 857. ^1H NMR (400 MHz, $CDCl_3$) δ: 8.21 (d, J = 8.7 Hz, 2H), 7.40 (d, J = 8.7 Hz, 2H), 3.89 (q, J = 7.0 Hz, 1H), 2.11 (s, 3H), 1.45 (d, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ:

207.0, 147.7, 147.1, 128.8, 124.1, 53.3, 28.7, 17.3. Anal. calcd. for $C_{10}H_{11}NO_3$: C, 62.17; H, 5.74; N, 7.25. Found: C, 62.39; H, 5.69; N, 7.21.

1,1-dimethyl-2-(3-(4-nitrophenyl)butan-2-ylidene)hydrazine (4m). Following the general sequence (step i), hydrazone **4m** (550 mg) was obtained as oil in 90% yield from ketone **3m** (503 mg) after silica gel chromatography (30% EtOAc in hexanes as eluent). IR (neat, cm^{-1}): 2954, 2858, 2818, 1598, 1520, 1347, 856, 702. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.17 (d, J = 8.9 Hz, 2H), 7.43 (d, J = 8.9 Hz, 2H), 3.76 (q, J = 7.1 Hz, 1H), 2.48 (s, 6H), 1.75 (s, 3H), 1.47 (d, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 167.2, 150.4, 146.8, 128.3, 123.7, 47.8, 47.0, 17.7, 15.0. HRMS (ESI) *m/z* calcd. for $C_{12}H_{18}N_3O_2$ ($M+H^+$) 236.1339, found 236.1390.

2,3-Dimethyl-2-(4-nitrophenyl)-2*H*-azirine (1m). Following the general sequence (steps ii and iii), azirine **1m** (168 mg) was synthesized as white solid in 35% yield from hydrazone **4m** (596 mg) after silica gel chromatography (15% EtOAc in hexanes as eluent). m.p. 90-92 °C. IR (neat, cm^{-1}): 2918, 2852, 1775, 1599, 1514, 1344, 853. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.16 (d, J = 8.8 Hz, 2H), 7.25 (d, J = 8.8 Hz, 2H), 2.48 (s, 3H), 1.70 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 168.6, 152.0, 146.2, 126.2, 123.3, 35.7, 20.7, 12.2. Anal. calcd. for $C_{10}H_{10}N_2O_2$: C, 63.15; H, 5.30; N, 14.73. Found: C, 63.27; H, 5.28; N, 14.54.



3-(Pyridin-4-yl)pentan-2-one (3n). To a stirred solution of (4-pyridyl) acetone (500 mg, 3.70 mmol) in DMSO (4 mL) was added NaH (60% dispersion in mineral oil, 163 mg, 4.07 mmol) in

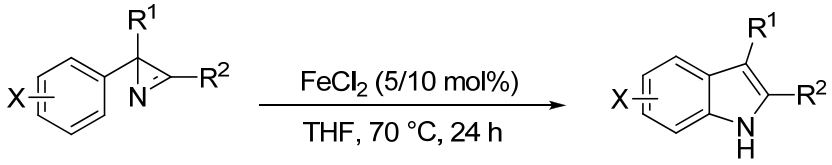
one portion at room temperature. Half an hour later, 1-bromoheptane (0.70 mL, 4.44 mmol) was added dropwise. After stirring at room temperature for 12 h, the reaction mixture was quenched with ice cold water (5 mL) and then extracted with 10:1 EtOAc: hexanes (3 × 25 mL). The combined organic layers were dried over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (50% EtOAc in hexanes) to afford ketone **3n** (557 mg) as oil in 65% yield. IR (neat, cm^{-1}): 2959, 2926, 2859, 1717, 1598, 1561, 1463, 1417, 1357, 1161. ^1H NMR (400 MHz, $CDCl_3$) δ: 8.56 (dd, J = 4.5, 1.7 Hz, 2H), 7.15 (dd, J = 4.5, 1.7 Hz, 2H), 3.61 (t, J = 7.4 Hz, 1H), 2.09 (s, 3H), 2.07-1.98 (m, 1H), 1.73-1.64 (m, 1H), 1.27-1.13 (m, 10H), 0.86 (dd, J = 7.1, 6.9 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 206.9, 150.2, 147.8, 123.4, 59.0, 31.7, 31.6, 29.3, 28.9, 27.3, 22.5, 14.0. GCMS (CI) *m/z* calcd. for $C_{15}H_{24}NO$ ($M+H^+$) 234, found 234.

3-(Pyridin-4-yl)pentan-2-one oxime (4n). Ketone **3n** (527 mg, 2.26 mmol) was dissolved in MeOH:H_2O (20:1, 21 mL). Then $NH_2OH{\cdot}HCl$ salt (236 mg, 3.39 mmol) was added at room temperature followed by sodium acetate (278 mg, 3.39 mmol). It was stirred for 12 h at that temperature. After the solvent was removed, the residual was partitioned between CH_2Cl_2 (4 mL) and water (4 mL). The aqueous layer was separated and extracted with CH_2Cl_2 (2 × 4 mL). The combined organic layers were dried over Na_2SO_4 before they were concentrated under reduced pressure. The residual was purified by silica gel chromatography (50% EtOAc in hexanes) to afford oxime **4n** (529 mg) as oil in 94% yield. IR (neat, cm^{-1}): 3198, 2934, 2859, 1601, 1561, 1469, 1417, 1371. ^1H NMR (400 MHz, $CDCl_3$) δ: 8.54 (dd, J = 4.5, 1.6 Hz, 2H), 7.18 (d, J = 5.0 Hz, 2H), 3.45 (t, J = 7.6 Hz, 1H), 1.98-1.89 (m 1H), 1.82-1.77 (m, 1H), 1.72 (s, 3H), 1.30-1.24 (m, 10H), 0.86 (dd, J = 7.1, 6.8 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 157.6, 151.1, 149.4, 123.4, 50.6, 31.7, 30.8, 29.4, 29.0, 27.3, 22.5, 14.0, 11.8. GCMS (CI) *m/z* calcd. for $C_{15}H_{25}N_2O$ ($M+H^+$) 249, found 249.

4-(2-Ethyl-3-methyl-*2H*-azirin-2-yl)pyridine (1n). To a stirred solution of oxime **4n** (80 mg, 0.32 mmol) in THF (1.5 mL) was added Et_3N (34 μL, 0.45 mmol) followed by methane sulfonyl chloride (62 μL, 0.45 mmol) at room temperature. After 0.5 h, DBU (0.13 mL, 0.89 mmol) was added at room temperature and then it was heated to 40 °C for 12 h. After that, it was filtered through a silica pad and washed with EtOAc. Solvent was evaporated to obtain a crude mass

that was purified by silica gel chromatography (EtOAc) to afford pure azirine **1n** (62 mg) as an oil in 84% yield. IR (neat, cm^{-1}): 2959, 2928, 2862, 1596, 1463, 1411. ^1H NMR (400 MHz, $CDCl_3$) δ: 8.50 (dd, J = 4.6, 1.7 Hz, 2H), 7.02 (dd, J = 4.6, 1.7 Hz, 2H), 2.46 (s, 3H), 2.15-1.97 (m, 2H), 1.29-1.21 (m, 10H), 0.87 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 167.7, 152.6, 149.4, 120.7, 38.9, 32.3, 31.7, 29.4, 29.1, 25.8, 22.6, 14.0, 12.8. GCMS (CI) *m/z* calcd. for $C_{15}H_{23}N_2$ ($M+H^+$) 231, found 231.

General procedure for Fe(II) Chloride Catalyzed Rearrangement of Azirines to Indoles:



R^1 = Aryl, Alkyl; R^2 = Alkyl, Aryl; X = Me, OMe, CF_3, Br, F

Azirine (1 mmol) was transferred to a disposable test tube with a stir bar and carefully dried under high vacuum for ca. 10 min (until no air bubble was seen escaping from the azirine). The test tube was refilled with nitrogen and then taken into a nitrogen-filled glove box where $FeCl_2$ (0.1 or 0.2 mmol) was added. After removing from the glove box, a nitrogen balloon was placed on the top of the test tube and THF (1 mL) was added. The nitrogen balloon was detached from the test tube and the nitrogen filled test tube was then placed into a preheated oil bath (70 °C) for 24 h. After removing from the oil bath, it was diluted with CH_2Cl_2 or EtOAc. The diluted reaction mixture was washed with water (2 mL) and brine (2 mL) and then dried over Na_2SO_4. The solvent was evaporated under reduced pressure to obtain a crude mass that was purified by column chromatography on silica gel.

Optimization of Catalytic Conditions

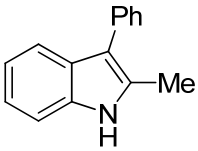
Following the general procedure, a mixture of azirine **1a** (1 mmol), catalyst (5-100 mol%) in THF (1 mL, 1 M) was stirred at room temperature to 70 °C for 1-24 h. A crude mass was obtained after aqueous workup. Hexamethylbenzene (5-10 mg) was added as an internal standard. Then the crude mass was analyzed by ^1H NMR. For some of the runs, the crude mass was purified by silica gel chromatography. Twelve entries from the following table are selected for Table 1 in the manuscript.

Complete Optimization Table

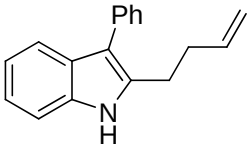
1a 2a

Entry	Catalyst (mol%)	Reaction Conditions	**2a**,Yield(%)
1	$FeCl_2$ (5)	THF, 70 °C, 24 h	77[a]
2	None	THF, 70 °C, 24 h	0
3	$FeCl_2$ (5)	THF, rt, 24 h	75[a]
4	$FeCl_2$ (5)	CH_2Cl_2, rt, 12 h	0
5	$FeCl_2$ (5)	Toluene, rt, 12 h	0
6	$FeCl_2$ (5)	DME, rt, 12 h	0
7	$FeCl_2$ (5)	1,2-Dichloroethane,rt,12 h	0
8	$FeBr_2$ (5)	THF, rt, 12 h	69[a]
9	FeI_2 (5)	THF, rt, 12 h	60[a]
10	$Fe(OAc)_2$ (5)	THF, rt, 12 h	0
11	$FeCl_3$ (5)	THF, rt, 12 h	0
12	$FeCl_2$ (5)	THF, 70 °C, MW, 1 h	74[a]
13	$FeCl_2$ (10)	THF, 70 °C, MW, 1 h	74[b]
14	$FeCl_2$ (10)	THF, 70 °C, 24 h	58[a]
15	$FeCl_2$ (5)	THF,TMEDA,70 °C,24 h	76[b]
16	$FeCl_2$ (5)	Toluene, 70 °C, 24 h	0
17	$FeCl_2$ (5)	DME,70 °C, 24 h	trace
18	$FeCl_2$ (5)	1,2-DCE, 70 °C, 24 h	40[b]
19	CuCl (5)	THF, rt, 12 h	27[b,c]
20	$CuCl_2$ (5)	THF, rt, 12 h	trace[b,d]
21	$AlCl_3$ (100)	THF, 70 °C, 24 h	0[d]
22	BF_3•Et_2O (100)	THF, 70 °C, 24 h	0[d]
23	HCl/Et_2O (100)	THF, 70 °C, 24 h	0[d]

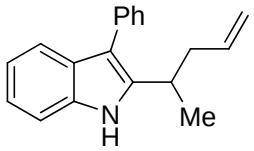
[a]Yield after chromatography; [b]NMR yield using hexamethyl benzene as internal standard. [c]**1a** (40%) was recovered.
[d]None of **1a** was recovered.



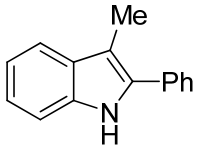
2-Methyl-3-phenyl-1*H*-indole (2a).[1] Following the general procedure, indole **2a** (61 mg) was obtained as oil in 77% yield from azirine **1a** (80 mg) after silica gel chromatography (20:1 hexanes: EtOAc as eluent). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.96 (brs, 1H), 7.67 (d, J = 7.8 Hz, 1H), 7.54-7.45 (m, 4H), 7.35-7.29 (m, 2H), 7.19-7.10 (m, 2H), 2.52 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 135.4, 135.1, 131.4, 129.4, 128.5, 127.7, 125.7, 121.4, 119.9, 118.7, 114.3, 110.3, 12.4.



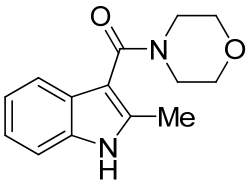
2-(But-3-enyl)-3-phenyl-1*H*-indole (2b).[2] Following the general procedure, indole **2b** (72 mg) was obtained as oil in 79% yield starting from the azirine **1b** (91 mg) after silica gel chromatography (10:1 hexanes: EtOAc as eluent). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.08 (brs, 1H), 7.64 (d, J = 7.4 Hz, 1H), 7.51-7.44 (m, 4H), 7.37-7.30 (m, 2H), 7.20-7.16 (m, 1H), 7.13-7.09 (m, 1H), 5.96-5.86 (m, 1H), 5.14-5.04 (m, 2H), 2.98 (dd, J = 7.7, 7.4 Hz, 2H), 2.49-2.44 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 137.6, 135.25, 135.23, 135.15, 129.6, 128.5, 127.7, 125.9, 121.6, 119.9, 118.9, 115.9, 114.6, 110.4, 33.7, 25.7.



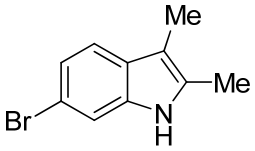
2-(Pent-4-en-2-yl)-3-phenyl-1H-indole (2c). Following the general procedure, indole **2c** (93 mg) was obtained as oil in 93% yield starting from the azirine **1c** (100 mg) after silica gel chromatography (20:1 hexanes: EtOAc as eluent). IR (neat, cm^{-1}): 3415, 3060, 2974, 2924, 1641, 1603, 1496, 1463, 1308, 921, 755. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.02 (brs, 1H), 7.60 (d, J = 7.6 Hz, 1H), 7.50-7.44 (m, 4H), 7.38 (d, J = 8.1 Hz, 1H), 7.35-7.31 (m, 1H), 7.21-7.17 (m, 1H), 7.13-7.09 (m, 1H), 5.80-5.70 (m, 1H), 5.07-4.98 (m, 2H), 3.36 (sextet, J = 7.1 Hz, 1H), 2.51-2.35 (m, 2H), 1.35 (d, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 139.6, 136.0, 135.3, 135.1, 129.9, 128.4, 127.9, 126.0, 121.6, 119.8, 119.0, 116.9, 114.0, 110.5, 41.3, 30.5, 20.6. HRMS (ESI) *m/z* calcd. for $C_{19}H_{19}N$ (M^+) 261.1517, found 261.1520.



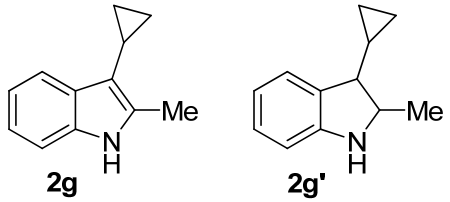
3-Methyl-2-phenyl-1*H*-indole (2d).[4] Following the general procedure, indole **2d** (35 mg) was obtained as oil in 52% yield starting from azirine **1d** (67 mg) after silica gel chromatography (20:1 hexanes: EtOAc as eluent). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.02 (brs, 1H), 7.62-7.58 (m, 3H), 7.51-7.46 (m, 2H), 7.39-7.34 (m, 2H), 7.23-7.19 (m, 1H), 7.17-7.13 (m, 1H) 2.49 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 135.8, 134.0, 133.3, 130.0, 128.8, 127.7, 127.3, 122.3, 119.5, 119.0, 110.6, 108.7, 9.6.



(2-Methyl-1*H*-indol-3-yl)(morpholino)methanone (2e).[2] Following the general procedure, indole **2e** (44 mg) was obtained as oil in 46% yield starting from the azirine **1e** (95 mg) after silica gel chromatography (3% MeOH in CH_2Cl_2 as eluent). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.47 (brs, 1H), 7.50-7.48 (m, 1H), 7.29-7.26 (m, 1H), 7.17-7.14 (m, 2H), 3.73 (br, 8H), 2.48 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 168.1, 138.2, 134.8, 125.9, 121.5, 120.4, 118.4, 111.1, 107.1, 67.2, 12.2.

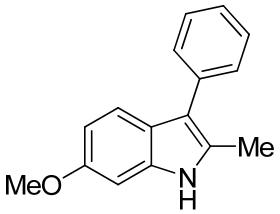


6-Bromo-2,3-dimethyl-1*H*-indole (2f). Following the general procedure, indole **2f** (111 mg) was obtained as light yellow solid in 66% yield starting from the azirine **1f** (169 mg) after silica gel chromatography (9:1 hexanes:EtOAc as eluent). m.p. 151-152 °C. IR (neat, cm^{-1}): 3399, 2919, 2857, 1417, 1322, 1239, 851, 807, 638. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.67 (brs, 1H), 7.39 (d, J = 1.7 Hz, 1H), 7.30 (d, J = 8.4 Hz, 1H), 7.16 (dd, J = 8.4, 1.7 Hz, 1H), 2.34 (s, 3H), 2.19 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 135.9, 131.4, 128.3, 122.1, 119.1, 114.2, 112.9, 107.3, 11.5, 8.3. HRMS (ESI) *m/z* calcd. for $C_{10}H_9BrN$ (M-H$^+$) 221.9918, found 221.9924.

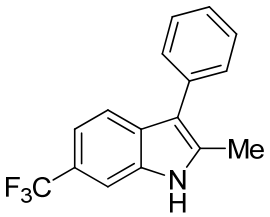


3-Cyclopropyl-2-methyl-indoline (2g′). Following the general procedure, azirine **1g** (50 mg) was converted to indole **2g**. Because of its instability upon exposure to air, the crude indole obtained after workup was immediately treated with $NaBH_3(CN)$ (54.7 mg) in AcOH (0.5 mL) at 15 °C for 2 h. Then it was diluted with water and extracted with Et_2O. The combined organic layers were washed with 10% $NaHCO_3$ solution, water and dried over Na_2SO_4. The solvent was

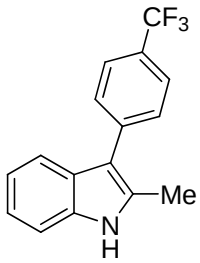
removed under reduced pressure to provide the crude product containing a mixture of two diastereomers in 2:1 ratio based on ^{1}H NMR. After silica gel chromatography (5% EtOAc in hexanes), indoline **2g′** (32 mg, 63%) was obtained as oil containing a 2:1 mixture of two diastereomers. IR (neat, cm^{-1}): 3370, 3077, 3005, 2961, 2922, 2849, 1608, 1482, 1464, 1376, 1246, 1017, 747. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.28-7.23 (m, 1H), 7.06-7.01 (m, 1H), 6.72 (dt, J = 1.0, 7.3 Hz, 1H), 6.61 (d, J = 7.8 Hz, 1H), 6.62 (d, J = 7.7 Hz, 1H for minor isomer), 3.99-3.92 (m, 1H, minor isomer), 3.81 (brs, NH), 3.80-3.73 (m, 1H), 2.43 (t, J = 9.2 Hz, 1H), 2.51 (dd, J = 9.1, 8.9 Hz, 1H), 1.33 (d, J = 6.2 Hz, 3H, major isomer), 1.29 (d, J = 6.5 Hz, 3H), 0.94-0.86 (m, 2 × 1H, major and minor isomer), 0.69-0.62 (m, 1H, major isomer), 0.53-0.46 9m, 1H, major isomer), 0.41-0.34 (m, 1H, major isomer), 0.33-0.26 (m, 1H, major isomer), 0.24-0.18 (m, 1H, minor isomer). ^{13}C NMR (100 MHz, $CDCl_3$) of mixture of isomers δ: 150.3, 132.9, 132.5, 128.8, 127.53, 127.50, 124.4, 124.0, 118.5, 109.4, 109.2, 62.4, 58.6, 54.7, 50.7, 21.6, 17.2, 14.2, 10.3, 3.5, 3.1, 2.7, 1.9. HRMS (ESI) *m/z* calcd. for $C_{12}H_{15}N$ (M^+) 173.1204, found 173.1203.



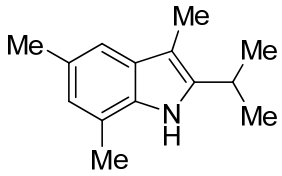
6-Methoxy-2-methyl-3-phenyl-1*H*-indole (2h).[1] Following the general procedure, indole **2h** (12 mg) was obtained as white solid in 60% yield starting from azirine **1h** (20 mg) after silica gel chromatography (9:1 hexanes:EtOAc as eluent). m.p. 145-146 °C (Lit. 155-156 °C[1a]). ^{1}H NMR (400 MHz, Acetone-d_6) δ: 9.98 (brs, 1H), 7.48-7.40 (m, 5H), 7.25-7.20 (m, 1H), 6.87 (d, J = 2.4 Hz, 1H), 6.67 (dd, J = 8.6, 2.3 Hz, 1H), 3.76 (s, 3H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, Acetone-d_6) δ: 157.5, 138.1, 137.7, 131.9, 130.5, 129.9, 126.8, 123.5, 120.1, 114.7, 110.4, 95.8, 56.3, 13.1.



2-Methyl-3-phenyl-6-(trifluoromethyl)-1*H*-indole (2i).[2] Following the general procedure, indoles **2i** and **2i′** (56 mg total) were obtained as a mixture of two regioisomers (**2i**:**2i′** = 1:1.8, as determined by GC) in 80% yield starting from azirine **1i** (70 mg) after silica gel chromatography (20:1 hexanes:EtOAc as eluent). The two isomers were separated by preparative TLC (20% EtOAc in hexanes). Spectral data of **2i**: ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.16 (brs, 1H), 7.70 (d, J = 8.4 Hz, 1H), 7.61-7.60 (m, 1H), 7.49-7.48 (m, 4H), 7.36-7.33 (m, 2H), 2.55 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 134.5, 134.3, 134.1, 130.2, 129.4, 128.7, 126.3, 123.6 (q, J = 31.6 Hz), 119.0, 116.7 (q, J = 3.6 Hz), 115.0, 107.7 (q, J = 4.2 Hz), 12.6. (The quaternary carbon of the CF_3 group was not obtained).

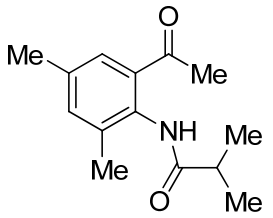


2-Methyl-3-(4-(trifluoromethyl)phenyl)-1*H*-indole (2i′).[2] ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.04 (brs, 1H), 7.71 (d, J = 8.0 Hz, 1H), 7.65 (d, J = 8.8 Hz, 2H), 7.62 (d, J = 8.1 Hz, 2H), 7.35 (dt, J = 7.9, 1.0 Hz, 1H), 7.22-7.18 (m, 1H), 7.16-7.12 (m, 1H), 2.53 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 139.3, 135.2, 132.1, 129.4, 127.7 (q, J = 32.0 Hz), 127.4, 125.4 (q, J = 4.0 Hz), 124.5 (q, J = 271.0 Hz), 121.9, 120.4, 118.5, 113.4, 110.5, 12.6.

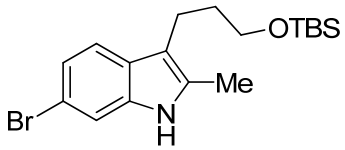


2-Isopropyl-3,5,7-trimethyl-1*H*-indole (2j). Following the general procedure, azirine **1j** (153 mg) was converted to indole **2j**. Because of its instability upon exposure to air, the crude indole obtained after workup was immediately converted to amide **2j′** upon treatment with oxygen for 1 h. The ^{1}H and ^{13}C spectra of compound **2j** are given below. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.49 (brs, 1H), 7.13 (s, 1H), 6.77 (s, 1H), 3.25 (septet, J = 7.0 Hz, 1H), 2.44 (s, 3H), 2.41 (s, 3H), 2.22

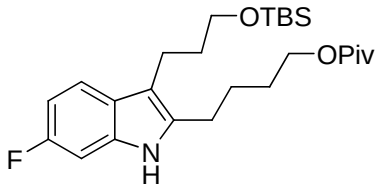
(s, 3H), 1.33 (d, J = 7.0 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 140.0, 132.5, 129.2, 128.4, 123.2, 119.0, 115.4, 105.3, 25.7, 22.3, 21.4, 16.5, 8.5.



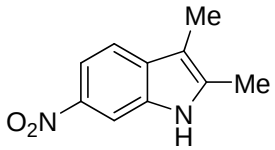
***N*-(2-Acetyl-4,6-dimethylphenyl)isobutyramide (2j′).** Amide **2j′** (85 mg) was obtained in 48% yield as a white solid from azirine **1j** after trituration with Et_2O and hexanes. m.p. 110-112 °C. IR (neat, cm^{-1}): 3288, 2967, 2918, 2849, 1682, 1661, 1505, 1354, 1307, 1257, 1191. ^{1}H NMR (400 MHz, Acetone-d_6) δ: 9.00 (brs, 1H), 7.41 (s, 1H), 7.21 (s, 1H), 2.63 (septate, J = 6.8 Hz, 1H), 2.49 (s, 3H), 2.32 (s, 3H), 2.20 (s, 3H), 1.17 (d, J = 6.8 Hz, 6H). ^{13}C NMR (100 MHz, Acetone-d_6) δ: 200.7, 174.7, 135.3, 134.9, 134.8, 134.3, 132.1, 126.9, 35.3, 28.3, 19.9, 18.9, 17.7. HRMS (ESI) *m/z* calcd. for $C_{14}H_{19}NNaO_2$ ($M+Na^+$) 256.1313, found 256.1305.



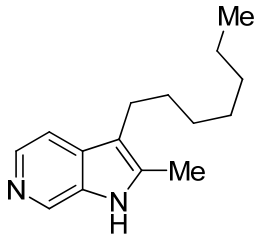
6-Bromo-3-(3-(*tert*-butyldimethylsilyloxy)propyl)-2-methyl-1*H*-indole (2k). Following the general procedure, indole **2k** (56 mg) was obtained as oil in 70% yield starting from azirine **1k** (80 mg) after silica gel chromatography (9:1 hexanes:EtOAc as eluent). IR (neat, cm^{-1}): 3413, 2955, 2928, 2856, 1463, 1254, 1099, 835, 776. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.68 (brs, 1H), 7.39 (d, J = 1.7 Hz, 1H), 7.35 (d, J = 8.5 Hz, 1H), 7.15 (dd, J = 8.5, 1.7 Hz, 1H), 3.61 (t, J = 6.2 Hz, 2H), 2.72 (dd, J = 7.6, 7.4 Hz, 2H), 2.35 (s, 3H), 1.82-1.75 (m, 2H), 0.92 (s, 9H), 0.05 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 136.0, 131.6, 127.7, 122.1, 119.3, 114.1, 113.0, 111.9, 62.3, 33.5, 25.9, 19.9, 18.3, 11.5, -5.3. HRMS (EI) *m/z* calcd. for $C_{18}H_{29}BrNOSi$ ($M+H^+$) 382.1202, found 382.1191.



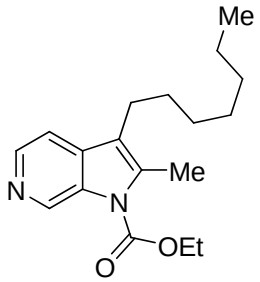
4-(3-(3-(*tert*-Butyldimethylsilyloxy)propyl)-6-fluoro-1*H*-indol-2-yl)butyl pivalate (2l). Following the general procedure, indole **2l** (53 mg) was obtained as oil in 75% yield starting from azirine **1l** (71 mg) after silica gel chromatography (9:1 hexanes:EtOAc as eluent). IR (neat, cm^{-1}): 3385, 2955, 2928, 2860, 1728, 1713, 1464, 1286, 1254, 1158, 1098, 835, 775. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.86 (brs, 1H), 7.41 (dd, J = 8.6, 5.3 Hz, 1H), 6.96 (dd, J = 9.7, 2.3 Hz, 1H), 6.85-6.79 (m, 1H), 4.11 (t, J = 6.2 Hz, 2H), 3.64 (t, J = 6.2 Hz, 2H), 2.77-2.71 (m, 4H), 1.83-1.76 (m, 2H), 1.71-1.68 (m, 4H), 1.20 (s, 9H), 0.92 (s, 9H), 0.06 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 178.9, 159.4 (d, J = 241.6 Hz), 135.2 (d, J = 12.3 Hz), 134.9 (d, J = 3.4 Hz), 125.2, 118.8 (d, J = 10.0 Hz), 111.7, 107.3 (d, J = 24.6 Hz), 96.7 (d, J = 25.9 Hz), 63.8, 62.4, 38.8, 34.0, 28.3, 27.2, 26.0, 25.9, 25.4, 20.1, 18.3, -5.3. HRMS (EI) *m/z* calcd. for $C_{26}H_{42}FNO_3Si$ (M^+) 463.2918, found 463.2937.



2,3-Dimethyl-6-nitro-1*H*-indole (2m). Following the general procedure, indole **2m** (45 mg) was obtained in 94% yield as orange solid from azirine **1m** (48 mg) after silica gel chromatography (9:1 hexanes:EtOAc as eluent). m.p. 144-145 °C. IR (neat, cm^{-1}): 3367, 2924, 2861, 1503, 1338, 1314, 1077, 1055. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.22 (d, J = 2.2 Hz, 1H), 8.17 (brs, 1H), 8.00 (dd, J = 8.7, 2.1 Hz, 1H), 7.47 (d, J = 8.7 Hz, 1H), 2.44 (s, 3H), 2.25 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 142.0, 138.3, 134.2, 133.4, 117.4, 114.8, 108.8, 107.1, 12.0, 8.3. Anal. calcd. for $C_{10}H_{10}N_2O_2$: C, 63.15; H, 5.30; N, 14.73. Found: C, 63.05; H, 5.17; N, 14.59.

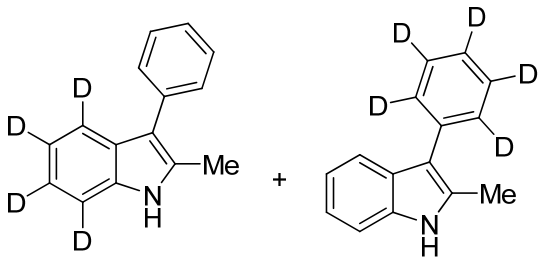


3-Heptyl-2-methyl-1H-pyrrolo[2,3-c]pyridine (2n). Azirine **1n** (33 mg, 0.14 mmol) was transferred to a disposable test tube with a stir bar and carefully dried under high vacuum for ca. 10 min (until no air bubble was seen escaping from the azirine). The test tube was refilled with nitrogen and then taken into a nitrogen-filled glove box where $FeCl_2$ (9.1 mg, 0.07 mmol) was added. After removing from the glove box, a nitrogen balloon was placed on the top of the test tube and THF (0.5 mL) was added. The nitrogen balloon was detached from the test tube and the nitrogen filled test tube was then placed into a preheated oil bath (70 °C) for 24 h. After removing from the oil bath, it was diluted with CH_2Cl_2 and 1N NaOH solution was added to make the pH around 10. The mixture was extracted with EtOAc (3 × 25 mL). The combined organic layers were washed with brine (5 mL) and then dried over Na_2SO_4. The solvent was evaporated under reduced pressure to obtain a crude mass that was purified by column chromatography on silica gel (10% MeOH in CH_2Cl_2 as eluent) to afford indole **2n** (18 mg) in 55% yield as oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 11.99 (brs, 1H), 9.08 (s, 1H), 7.99 (d, J = 4.4 Hz, 1H), 7.58 (d, J = 5.2 Hz, 1H), 2.70 (dd, J = 7.6, 7.4 Hz, 2H), 2.58 (s, 3H), 1.60-1.56 (m, 2H), 1.31-1.25 (m, 8H), 0.86 (t, J = 7.0 Hz, 3H). The purified compound **2n** was contaminated with trace amount of impurities so it was converted to **2n′** in order to get rid of the impurities.



Ethyl 3-heptyl-2-methyl-1H-pyrrolo[2,3-c]pyridine-1-carboxylate (2n′). A solution of NaHMDS (42 mg, 0.23 mmol) in THF (0.4 mL) was slowly added to compound **2n** (44 mg, 0.19 mmol) in THF (0.2 mL) at -78 °C. After 0.5 h, ethylchloroformate (22 μL) was added and the resulting mixture was left at -78 °C for 0.5 h. The reaction mixture was warmed to room

temperature, stirred for 12 h, and then quenched with water. The mixture was extracted with EtOAc (3 × 25 mL). The combined organic layers were washed with water (5 mL), brine (5 mL) and finally dried over Na_2SO_4. The solvent was removed under reduced pressure to obtain a crude mass that was purified by column chromatography on silica gel (30% EtOAc in hexanes) to afford pure compound **2n′** (33 mg) as oil in 57% yield. IR (neat, cm^{-1}): 2954, 2904, 2859, 1745, 1590, 1472, 1440, 1377, 1342, 1224, 1144. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 9.31 (s, 1H), 8.38 (d, J = 5.0 Hz, 1H), 7.36 (d, J = 5.2 Hz, 1H), 4.52 (q, J = 7.1 Hz, 2H), 2.63 (t, J = 7.5 Hz, 2H), 2.59 (s, 3H), 1.57-1.53 (m, 2H), 1.51 (t, J = 7.1 Hz, 3H), 1.35-1.25 (m, 8H), 0.87 (t, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 151.6, 142.0, 137.2, 137.0, 135.9, 132.6, 118.7, 112.7, 63.4, 31.8, 29.9, 29.4, 29.1, 23.7, 22.6, 14.3, 14.1, 13.6. HRMS (EI) *m/z* calcd. for $C_{18}H_{27}N_2O_2$ ($M+H^+$) 303.2067, found 303.2070.

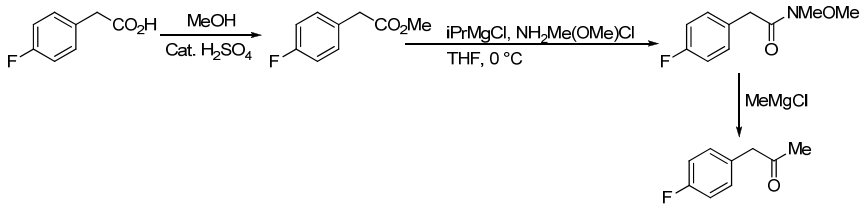


2o **2o'**

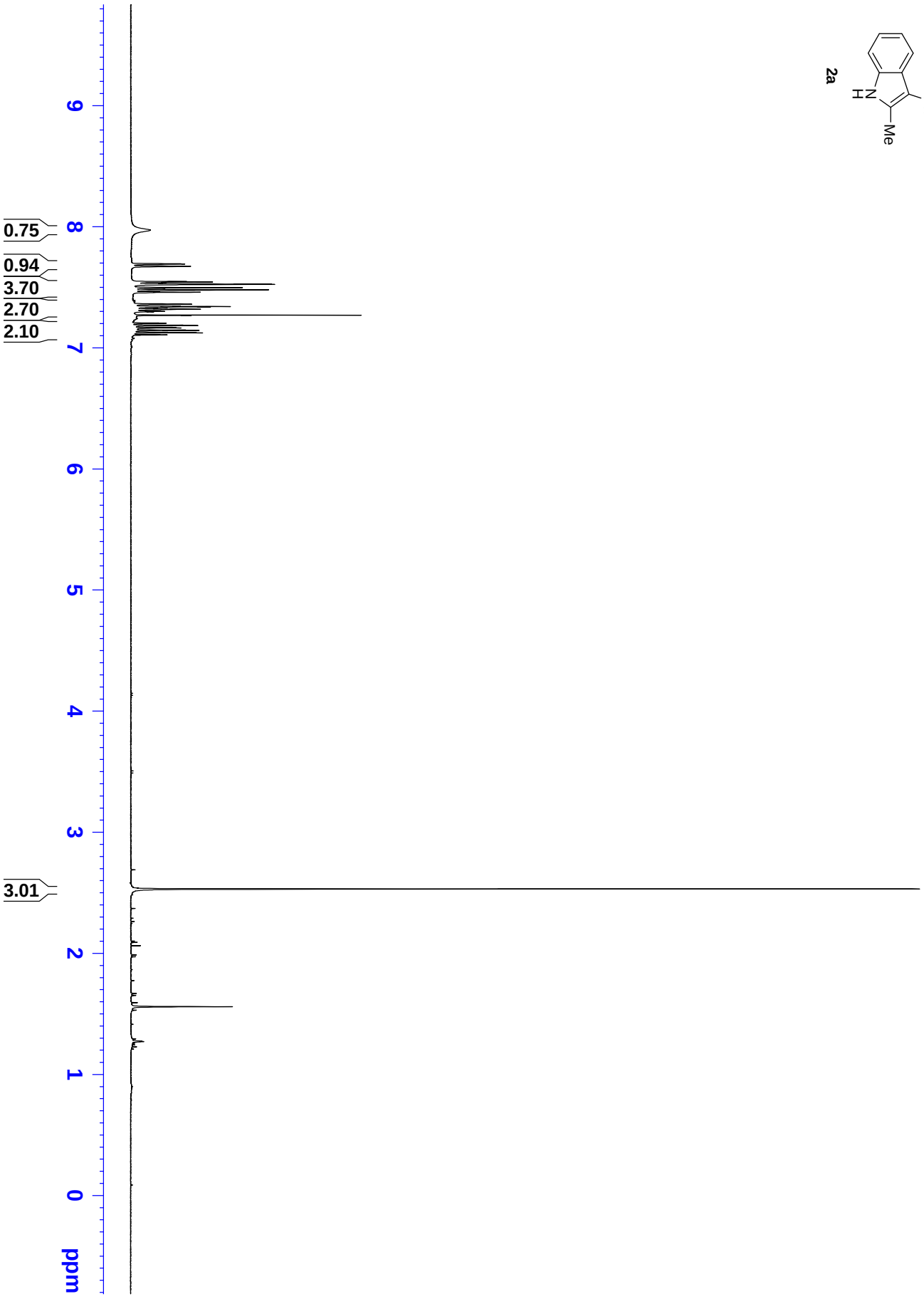
2-Methyl-3-phenyl-1*H*-indole-4,5,6,7-d$_4$ (2o) and **2-methyl-3-(phenyl-d$_5$)-1*H*-indole (2o′).**[1] Following the general procedure, indoles **2o** and **2o′** (47 mg) were obtained as oil and an inseparable mixture of two indoles (**2o**:**2o′** = 1:1.3, as determined by ^{1}H NMR) in 63% yield from azirine **1o** (75 mg) after silica gel column chromatography (10:1 hexanes:EtOAc as eluent). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.97 (brs, 2H), 7.67 (d, J = 7.6 Hz, 1H), 7.53-7.45 (m, 4H), 7.35-7.29 (m, 2H), 7.19-7.09 (m, 2H), 2.52 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 135.4, 135.2, 131.4, 129.3, 128.5, 127.7, 125.7, 121.4, 119.9, 118.7, 114.3, 110.3, 12.4.

References:

1) a) Taber, D. F.; Tian, W. *J. Am. Chem. Soc*. **2005**, *128*, 1058. b) Alper, H.; Prickett, J. E. *J. Chem. Soc., Chem. Commun.* **1976**, 483.
2) Chiba, S.; Hattoti, G.; Narasaka, K. *Chem. Lett.* **2007**, *36*, 52.
3) Padwa, A.; Rosenthal, R. J.; Dent, W.; Filho, P. *J. Org. Chem*. **1984**, *49*, 3174.
4) a) Kraus, G. A.; Guo, H. *J. Org. Chem.* **2009**, *74*, 5337. b) Cui, X.; Li, J.; Fu, Y.; Liu, L.; Guo, Q.-X. *Tetrahedron Lett.* **2008**, *49*, 3458. c) Fang, Y. Q.; Lautens , M. *J. Org. Chem*. **2008**, *73*, 538.
5) Old, D. W.; Wolfe, J. P.; Buchwald, S. L. *J. Am. Chem. Soc*. **1998**, *120*, 9722.
6) 4-fluorophenyl acetone is commercially available. But we have made it using the following sequence.



7) Ostwald, R.; Chavant, P.-Y.; Stadtmüller, H.; Knochel, P. *J. Org. Chem*. **1994**, *59*, 4143.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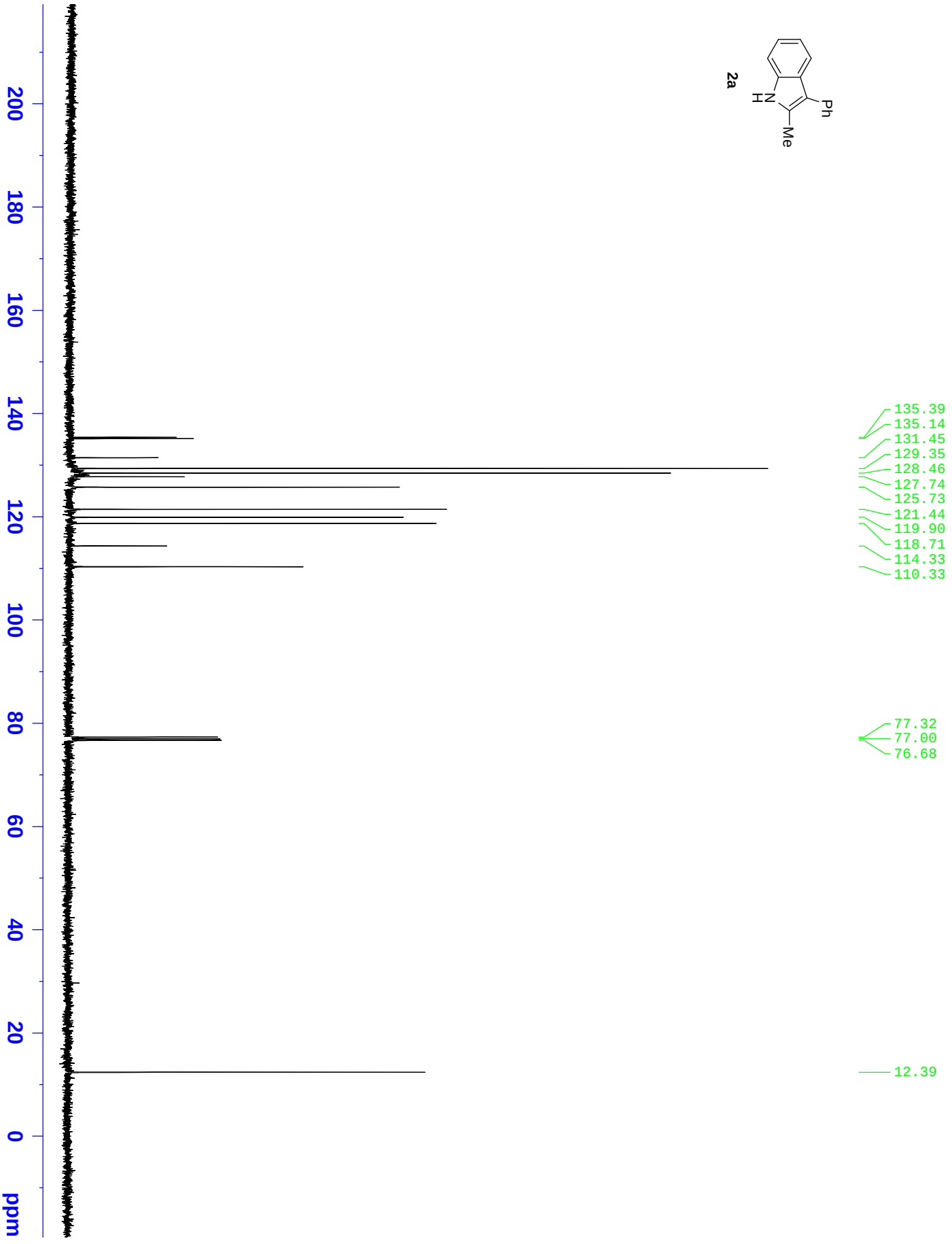
0.94
3.70
2.70
2.10
3.01
9
8
7
6
5
4
3
2
1
0
ppm
2a
N
H
Me
Ph


2a
N
H
Ph
Me
135.39
135.14
131.45
129.35
128.46
127.74
125.73
121.44
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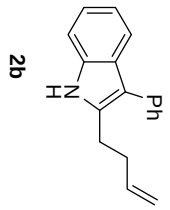
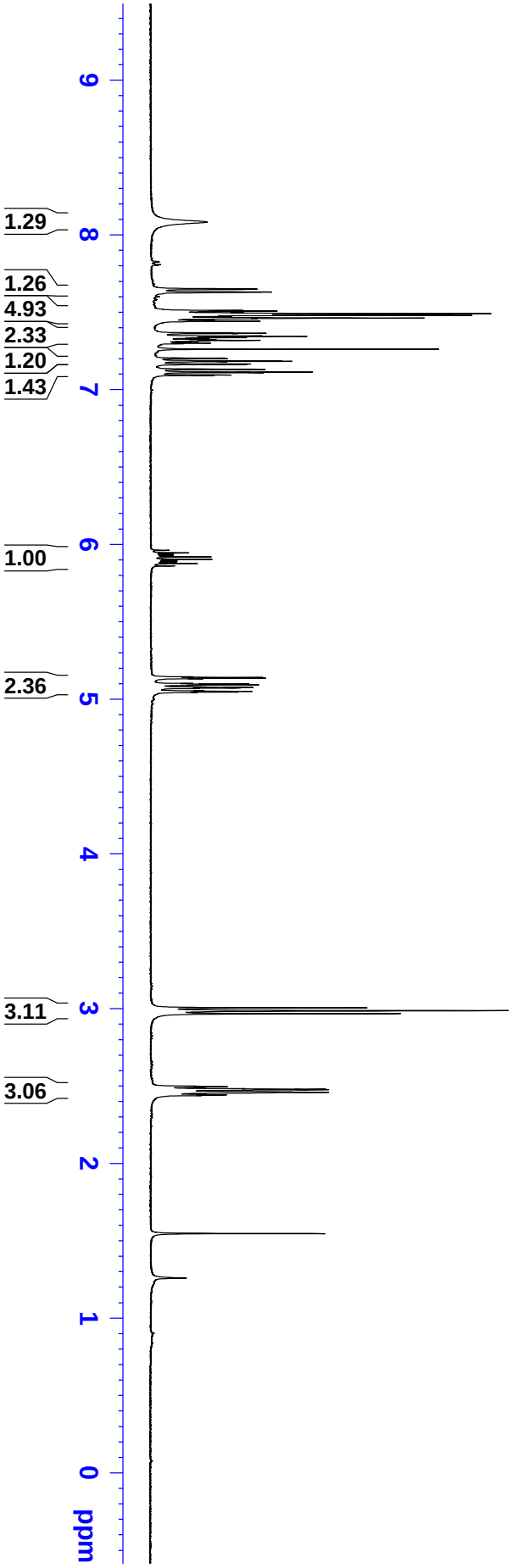
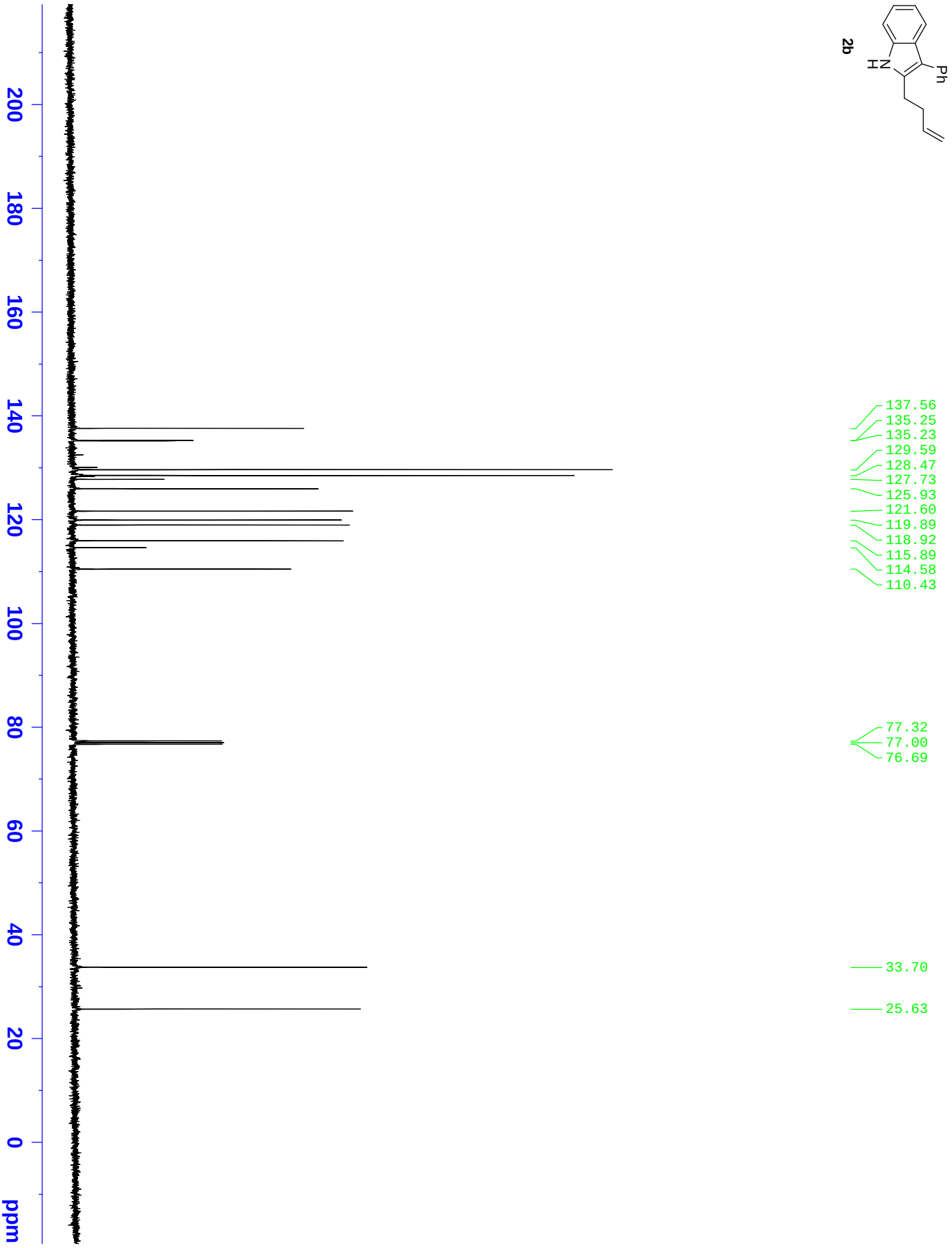
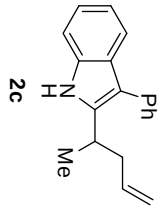
118.71
114.33
110.33
77.32
77.00
76.68
12.39
200
180
160
140
120
100
80
60
40
20
0
ppm


2b
N
H
Ph


1.29
1.26
4.93
2.33
1.20
1.43
1.00
2.36
3.11
3.06
9
8
7
6
5
4
3
2
1
0
ppm


2b
Ph
137.56
135.25
135.23
129.59
128.47
127.73
125.93
121.60
119.89
118.92
115.89
114.58
110.43
77.32
77.00
76.69
33.70
25.63
200
180
160
140
120
100
80
60
40
20
0
ppm


2c
N
H
Ph
Me

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0.83
2.82
1.58
0.95
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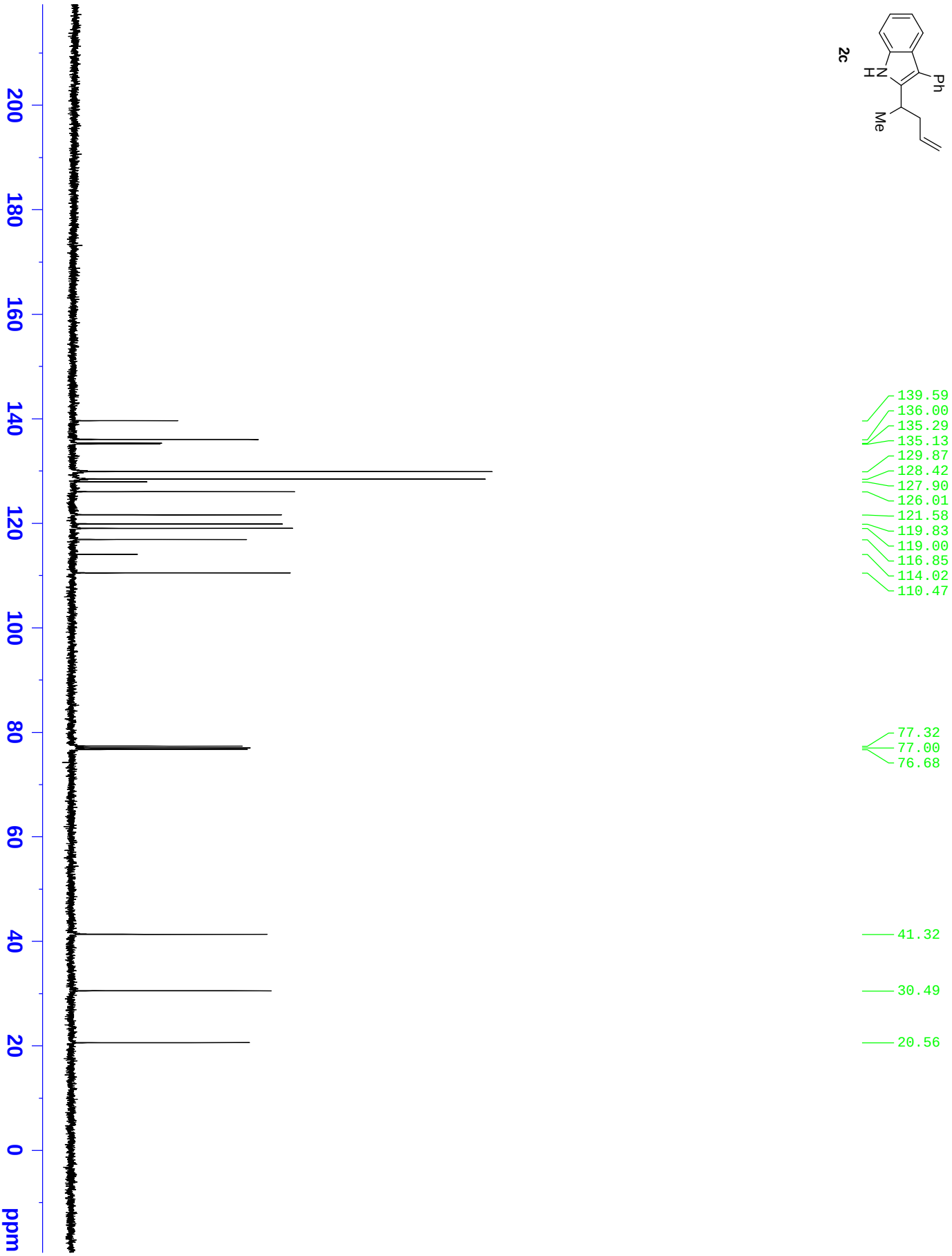
0.95
2.01
2.40
9
8
7
6
5
4
3
2
1
ppm


2c
N
H
Ph
Me
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135.13
129.87
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127.90
126.01
121.58
119.83
119.00
116.85
114.02
110.47
77.32
77.00
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41.32
30.49
20.56
200
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120
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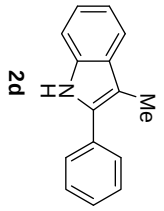
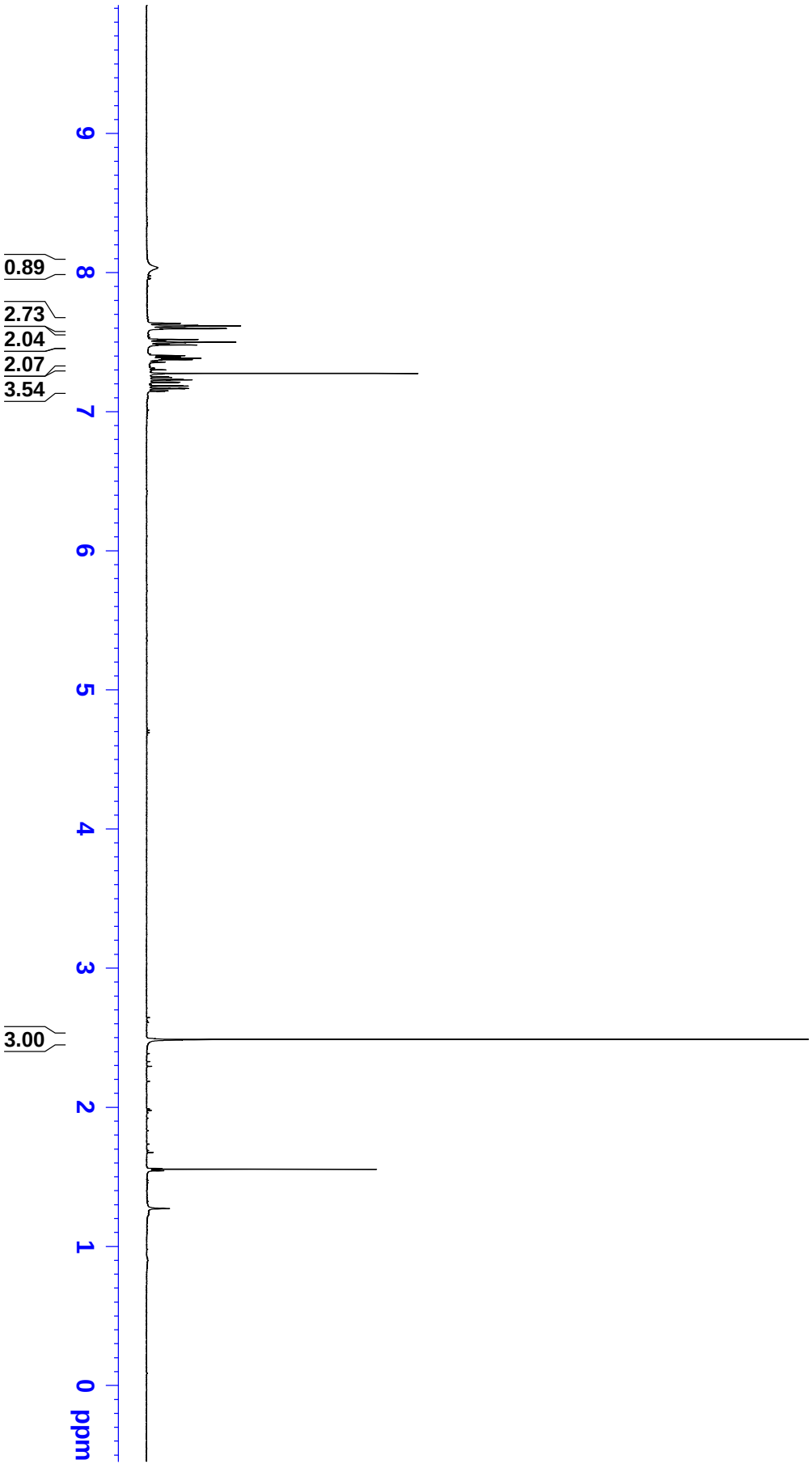
80
60
40
20
0
ppm


2d
H
N
Me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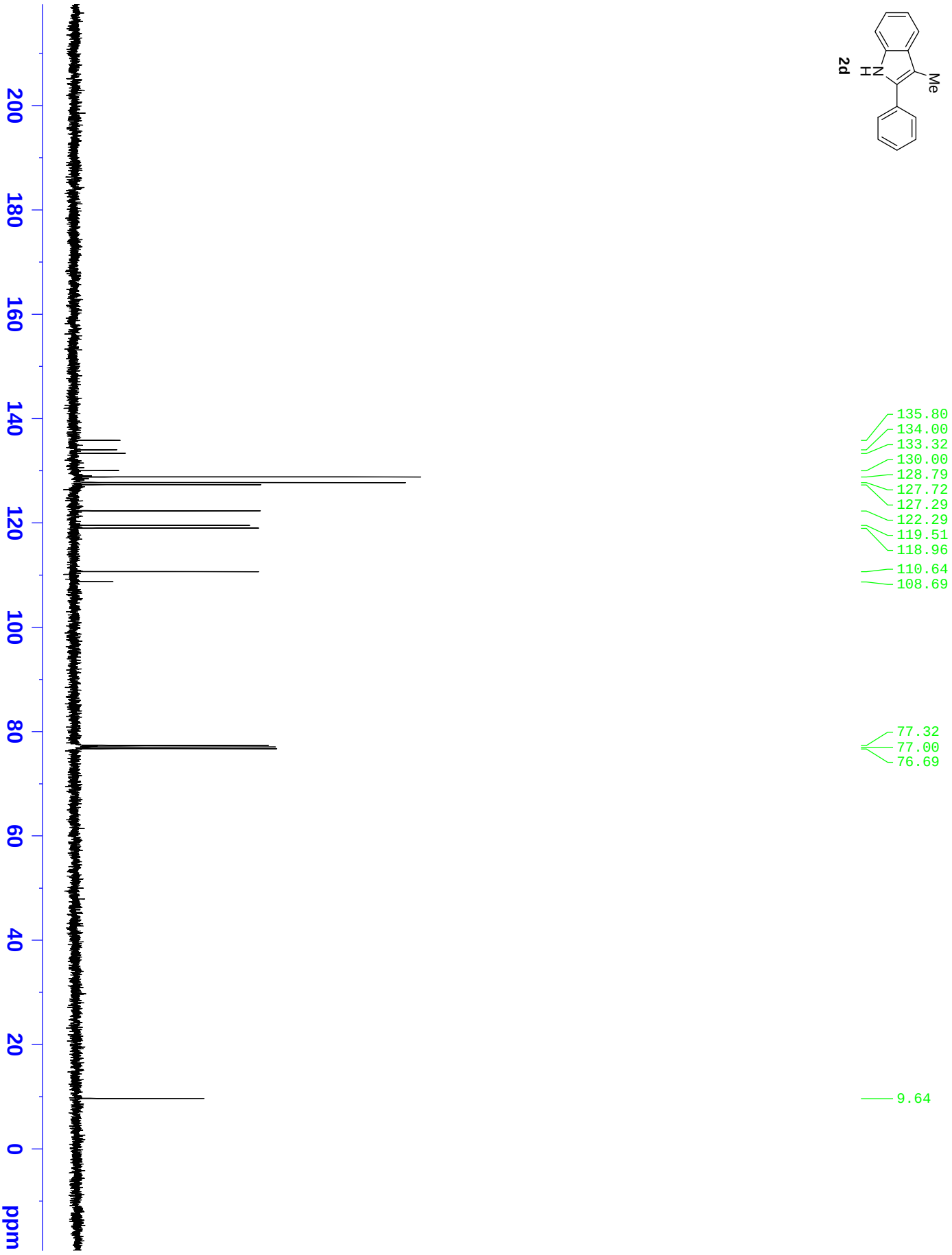
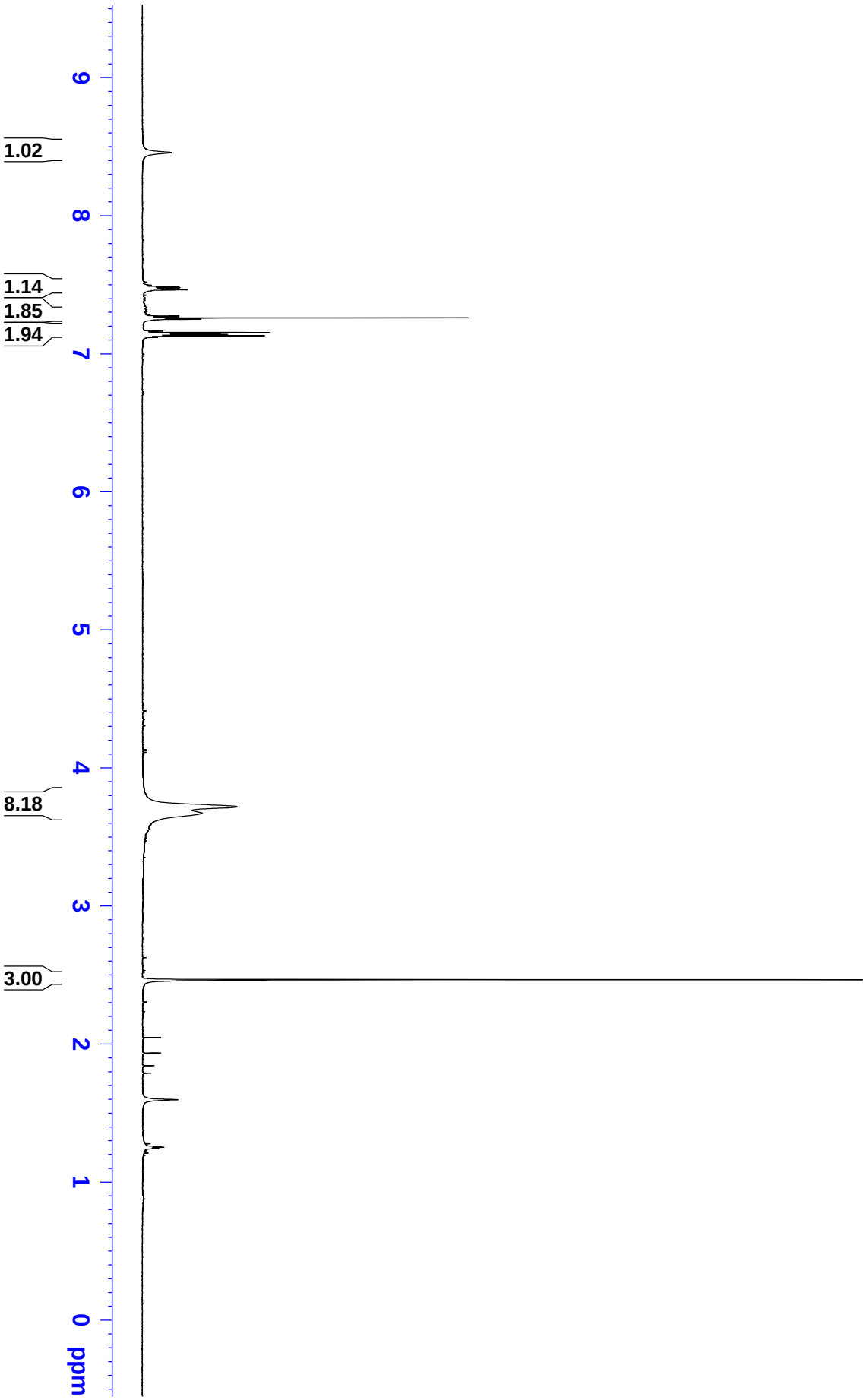
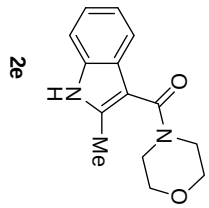
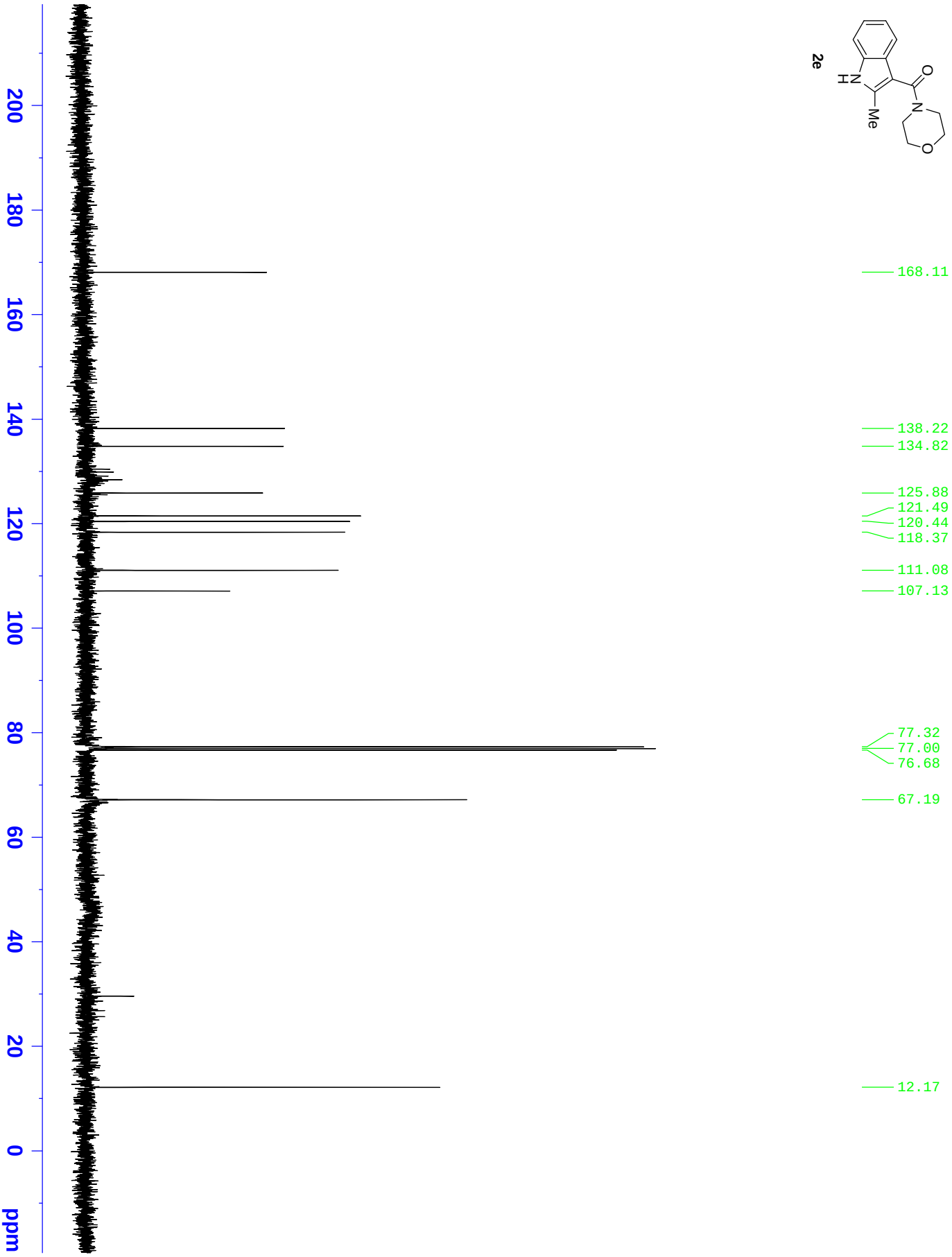
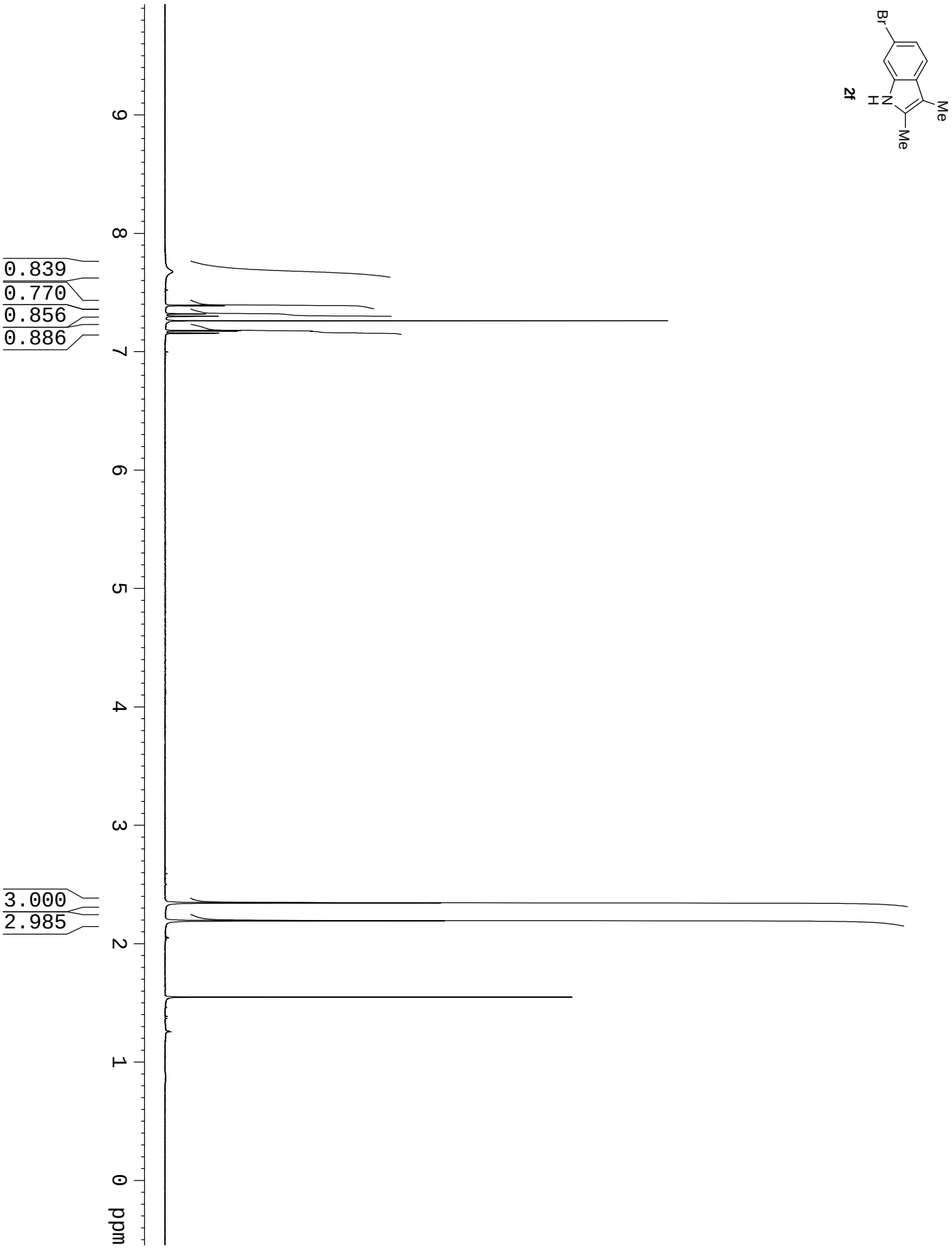
3.54
3.00
9
8
7
6
5
4
3
2
1
0
ppm

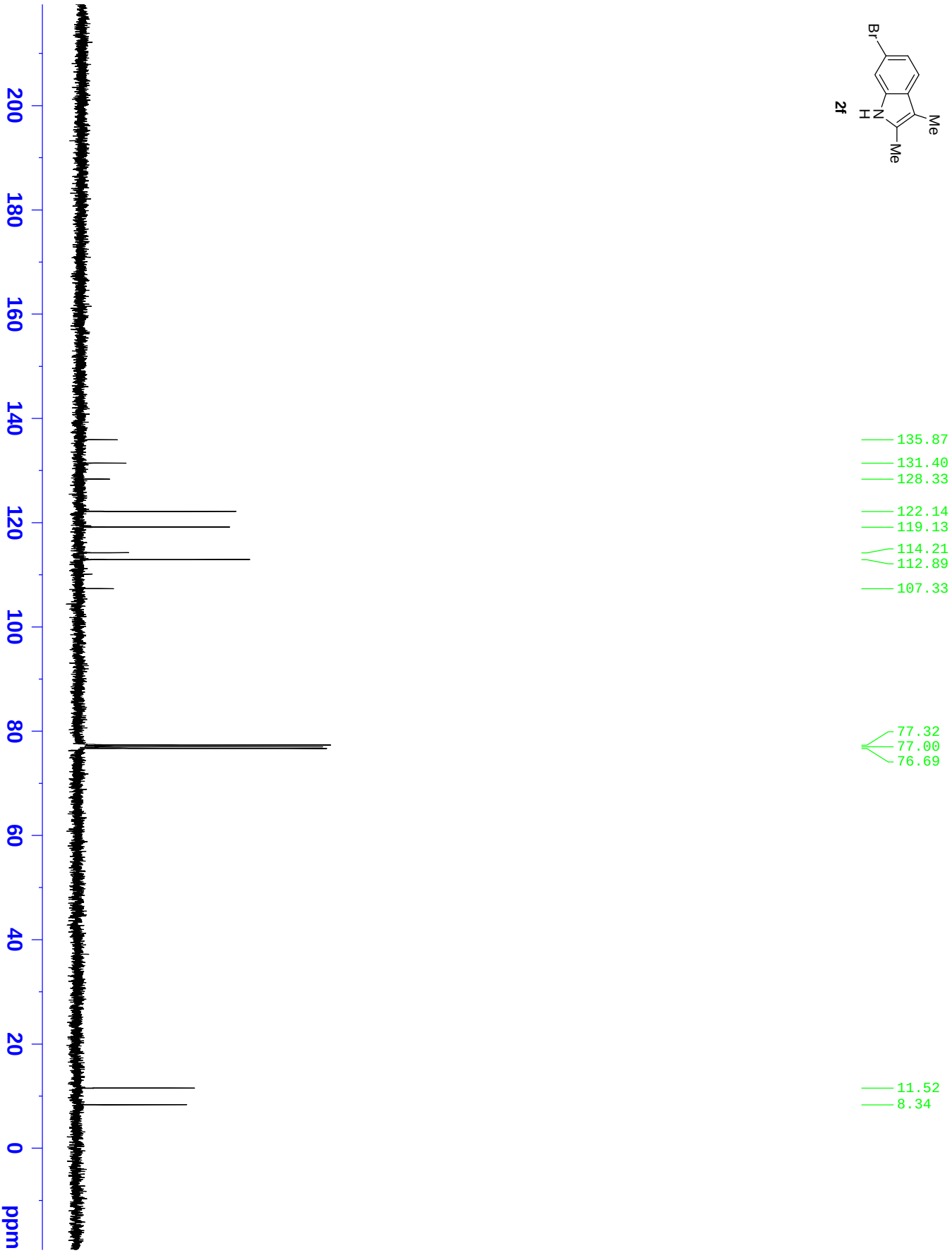

2d
N
H
Me
135.80
134.00
133.32
130.00
128.79
127.72
127.29
122.29
119.51
118.96
110.64
108.69
77.32
77.00
76.69
9.64
200
180
160
140
120
100
80
60
40
20
0
ppm

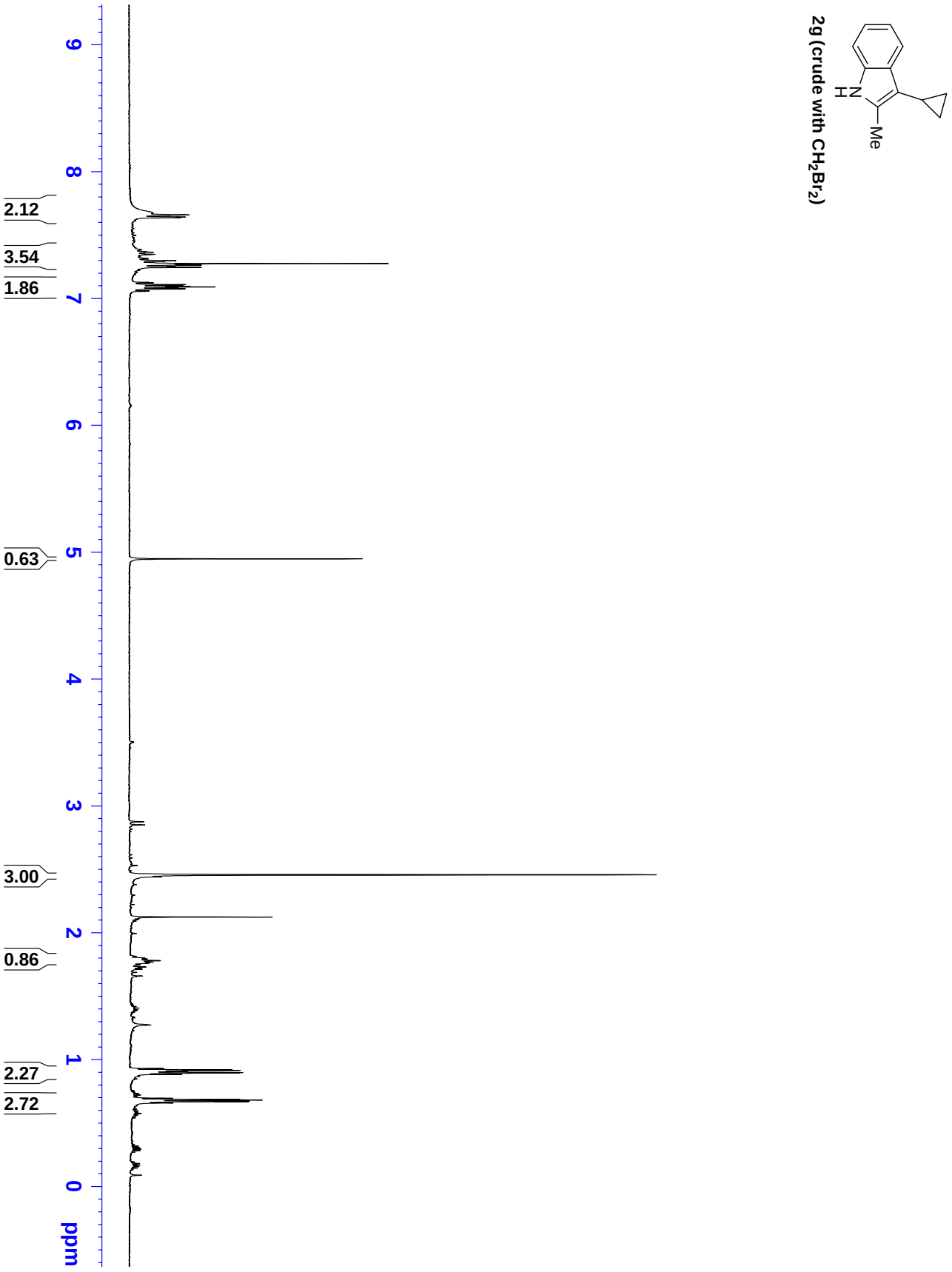

1.02
1.14
1.85
1.94
8.18
3.00
9
8
7
6
5
4
3
2
1
0
ppm

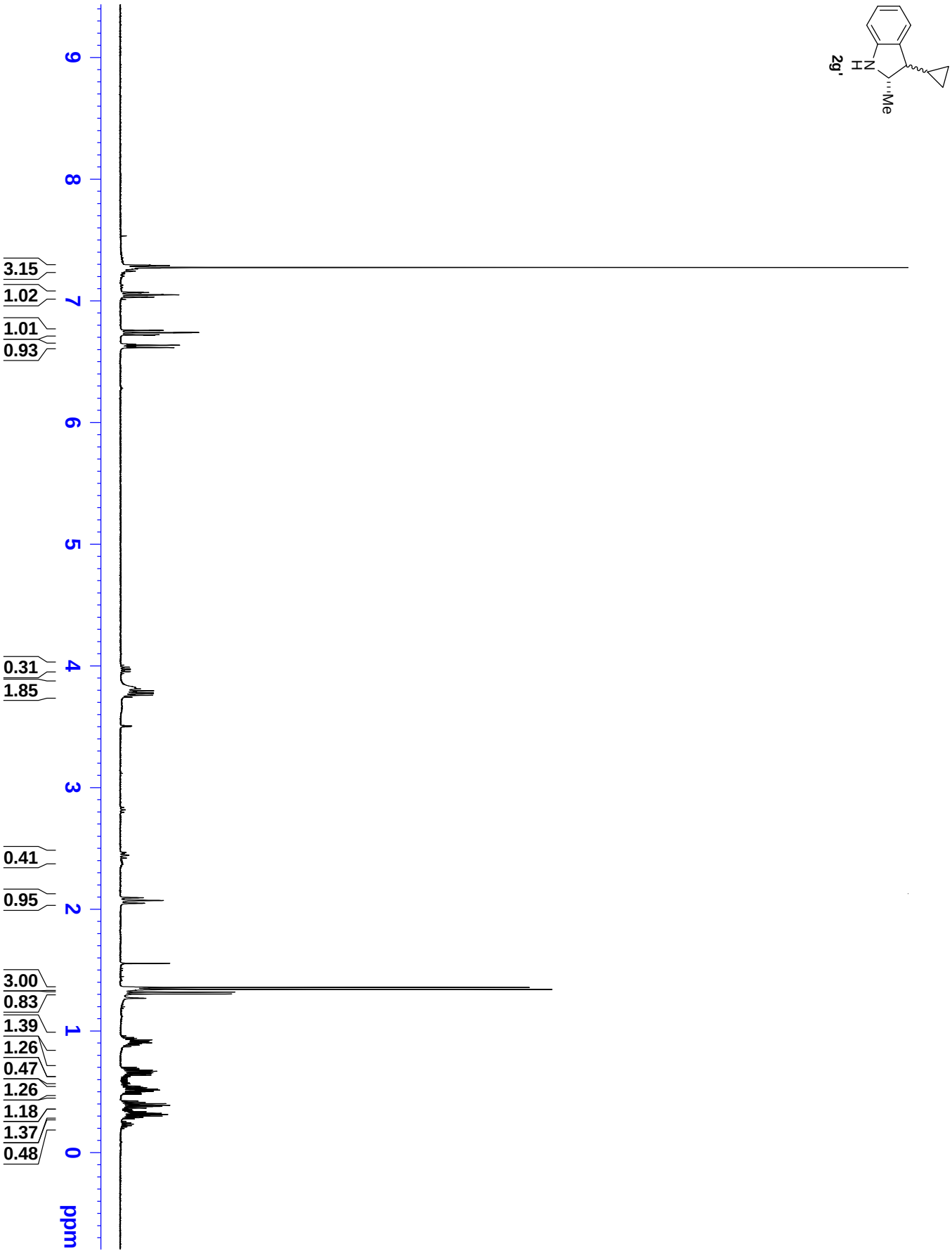

2e
H
N
Me
O
N
O

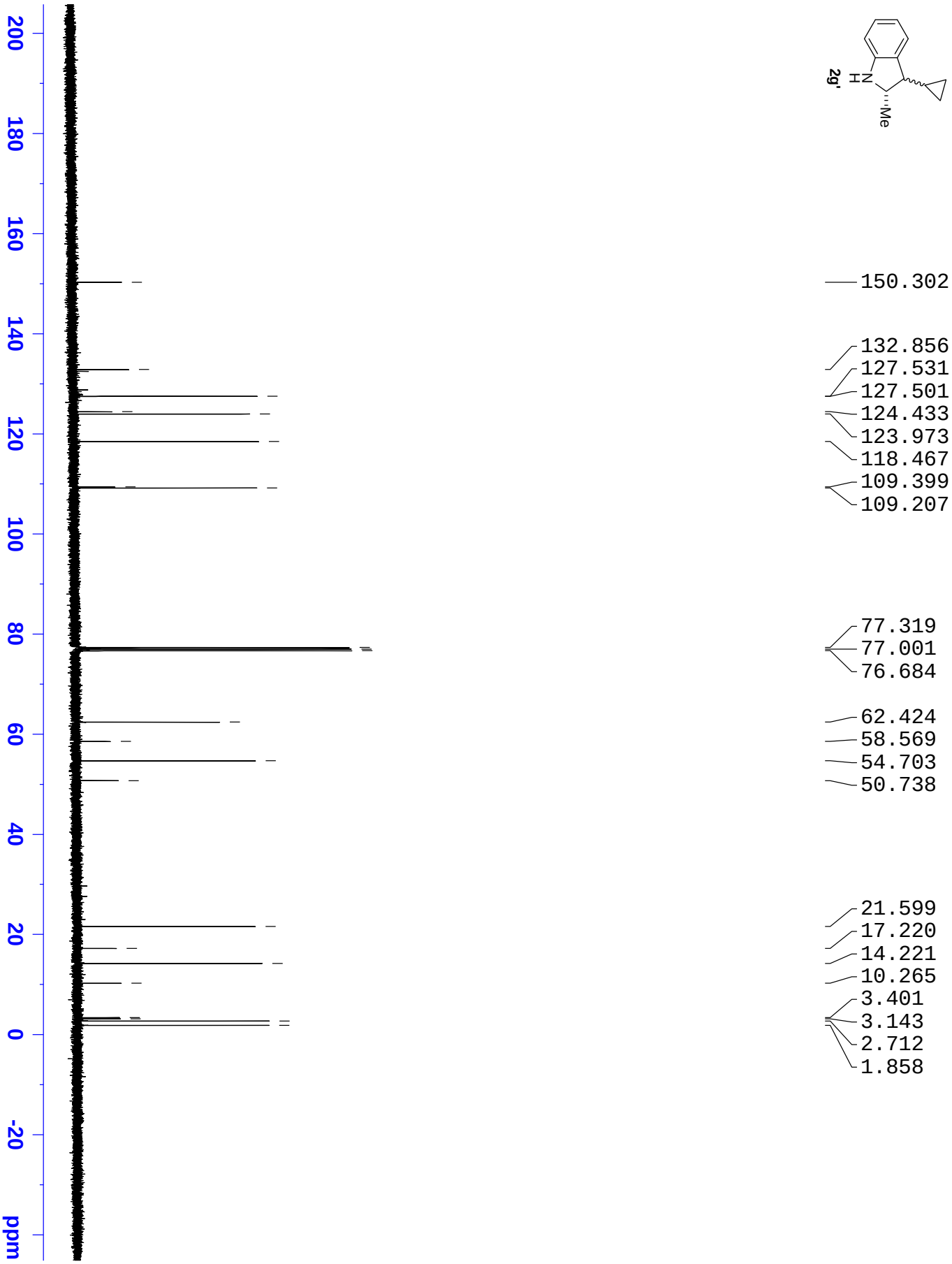

2e
H
N
Me
O
N
O
200
180
160
140
120
100
80
60
40
20
0
ppm
168.11
138.22
134.82
125.88
121.49
120.44
118.37
111.08
107.13
77.32
77.00
76.68
67.19
12.17

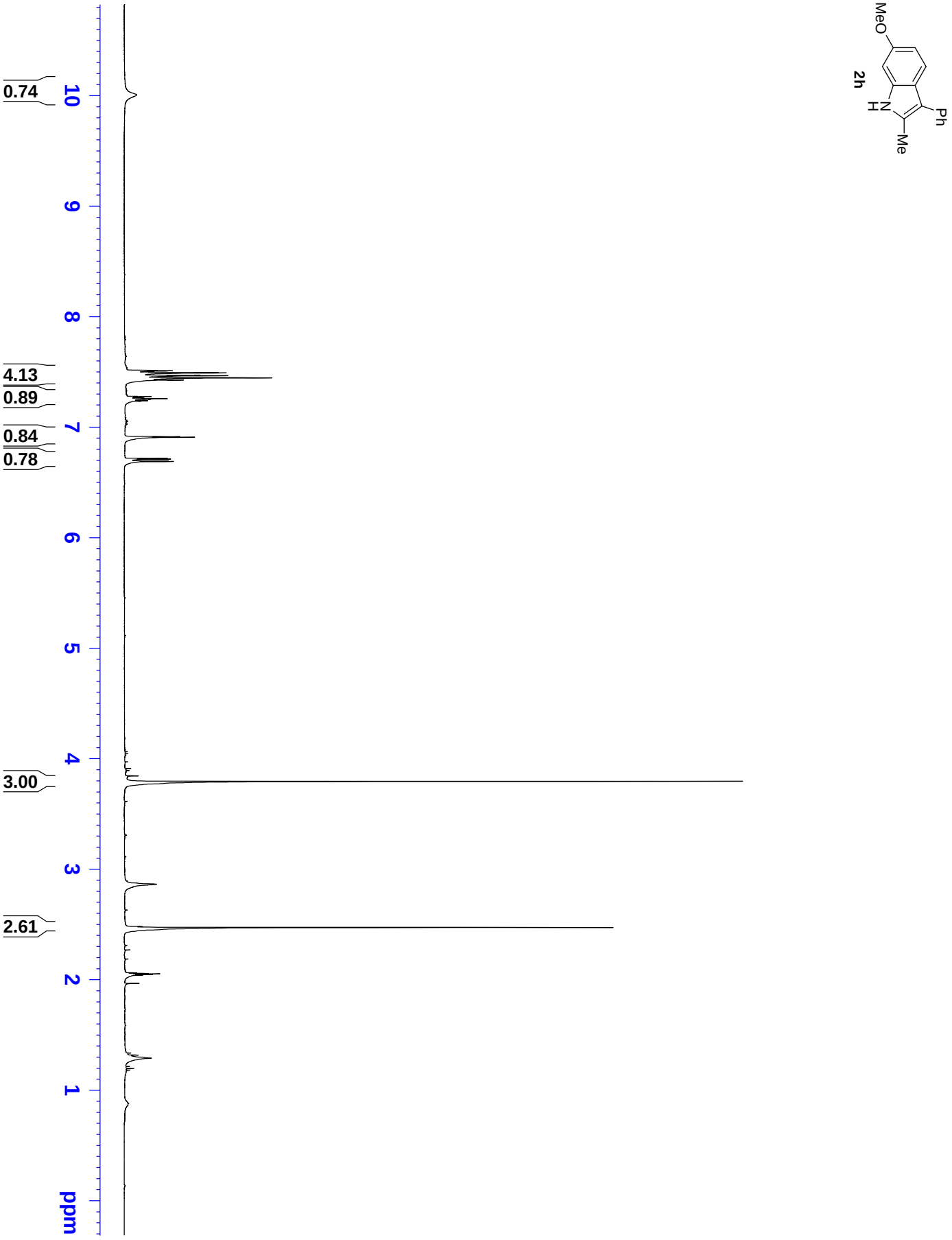

Br
N
H
Me
Me
2f
0.839
0.770
0.856
0.886
3.000
2.985
9
8
7
6
5
4
3
2
1
0
ppm


Br
N
H
Me
Me
2f
135.87
131.40
128.33
122.14
119.13
114.21
112.89
107.33
77.32
77.00
76.69
11.52
8.34
200
180
160
140
120
100
80
60
40
20
0
ppm

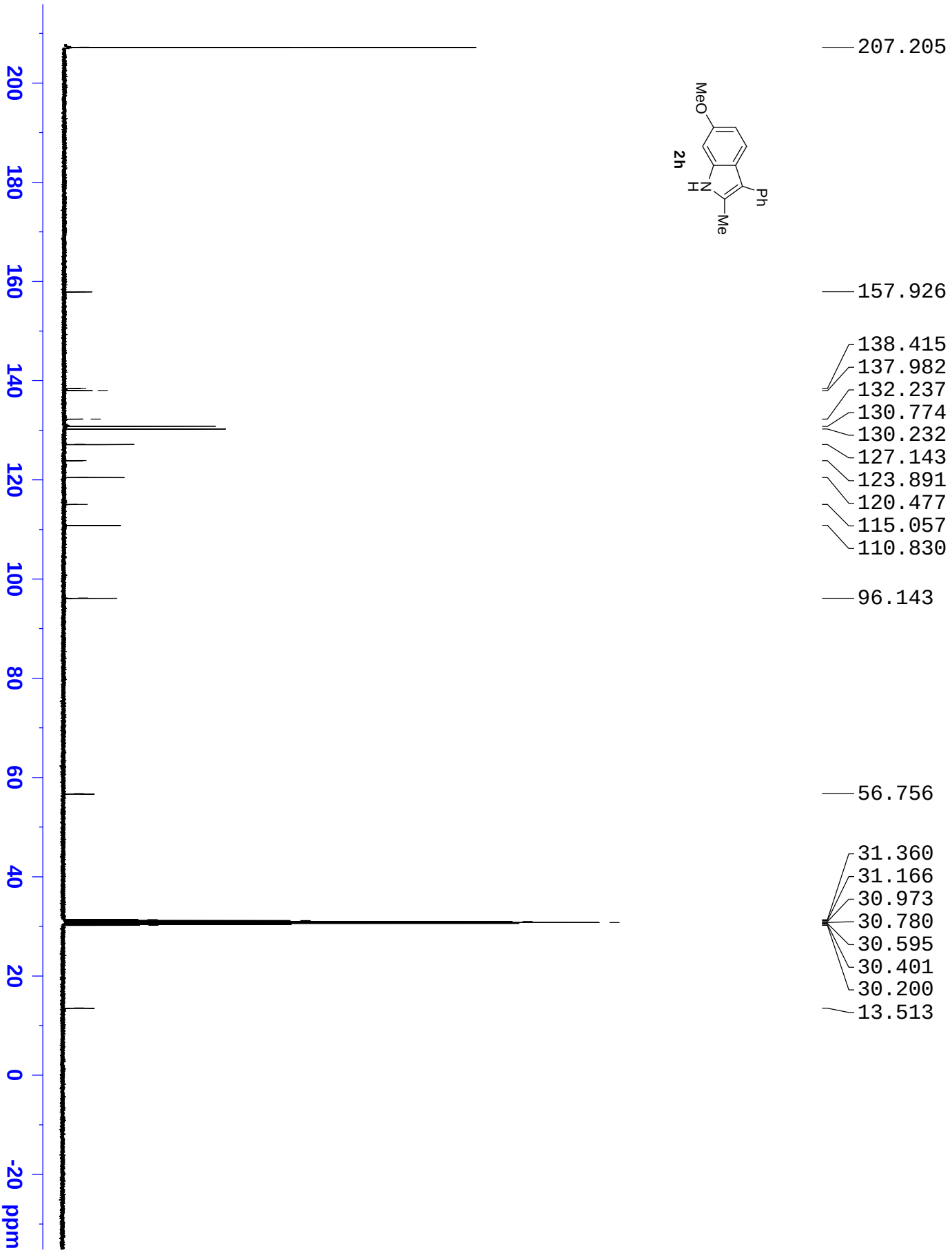

2g (crude with CH2Br2)
N
H
Me
2.12
3.54
1.86
0.63
3.00
0.86
2.27
2.72
9
8
7
6
5
4
3
2
1
0
ppm

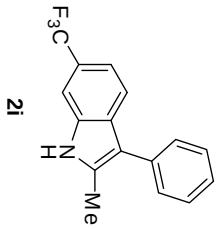

2g'
N
H
Me
9
8
7
6
5
4
3
2
1
0
ppm
3.15
1.02
1.01
0.93
0.31
1.85
0.41
0.95
3.00
0.83
1.39
1.26
0.47
1.26
1.18
1.37
0.48


200
180
160
140
120
100
80
60
40
20
0
-20
ppm
2g'
H
N
Me
150.302
132.856
127.531
127.501
124.433
123.973
118.467
109.399
109.207
77.319
77.001
76.684
62.424
58.569
54.703
50.738
21.599
17.220
14.221
10.265
3.401
3.143
2.712
1.858

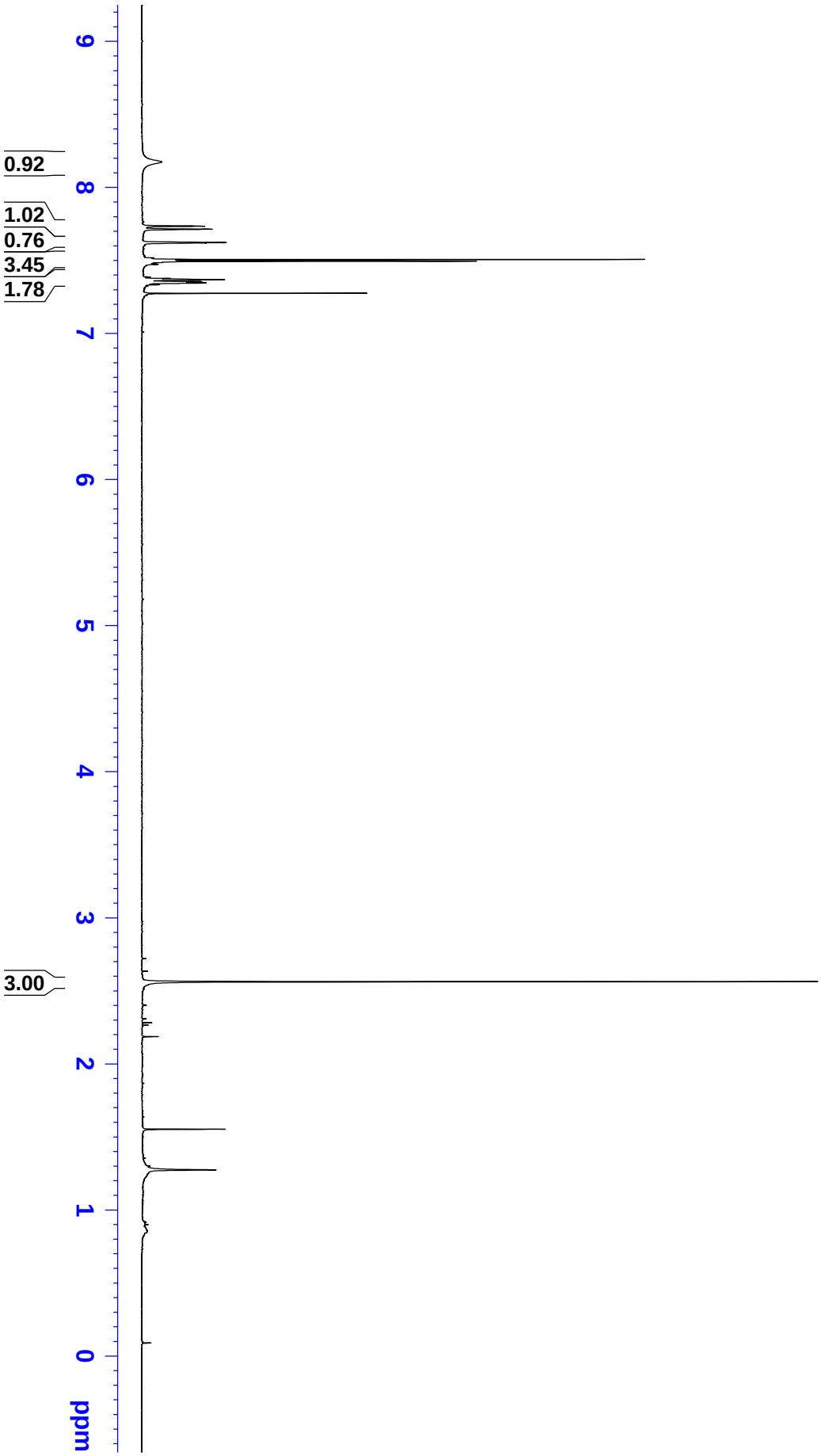

0.74
4.13
0.89
0.84
0.78
3.00
2.61
10
9
8
7
6
5
4
3
2
1
ppm

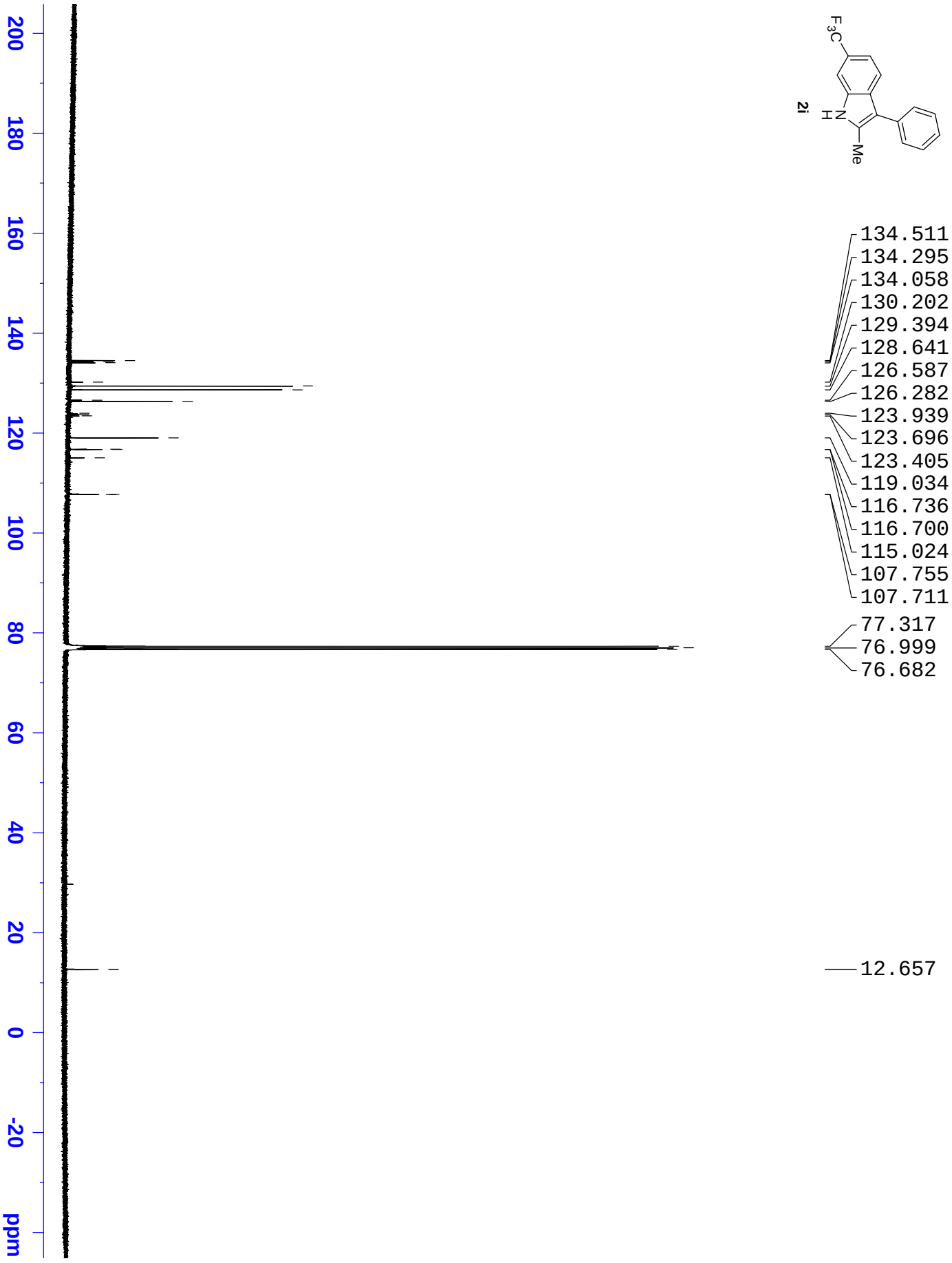
MeO
2h
N
H
Ph
Me

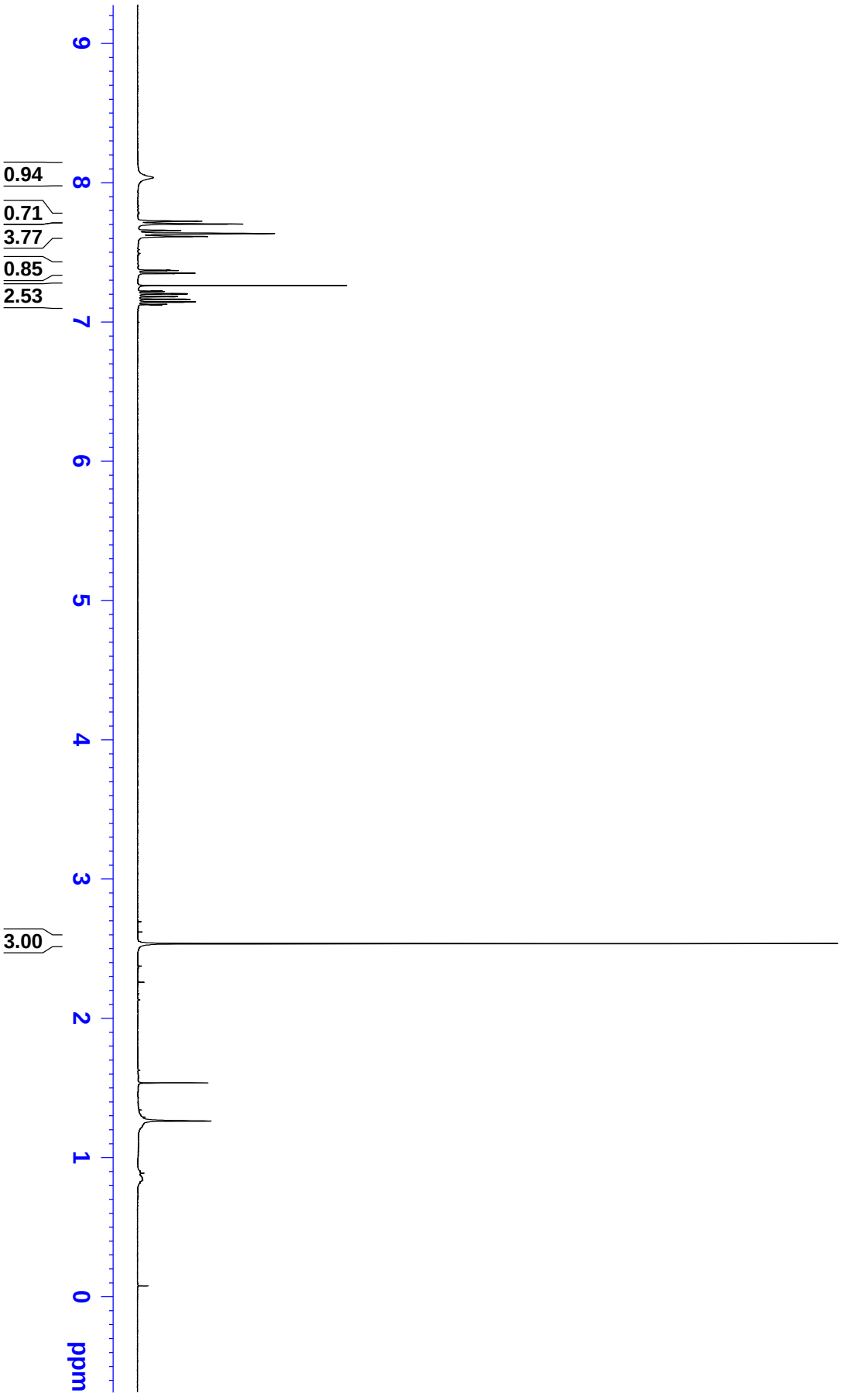

207.205
157.926
138.415
137.982
132.237
130.774
130.232
127.143
123.891
120.477
115.057
110.830
96.143
56.756
31.360
31.166
30.973
30.780
30.595
30.401
30.200
13.513
200
180
160
140
120
100
80
60
40
20
0
-20
ppm
MeO
2h
N
H
Ph
Me



2i




200
180
160
140
120
100
80
60
40
20
0
-20
ppm
F3C
N
H
Me
2i
134.511
134.295
134.058
130.202
129.394
128.641
126.587
126.282
123.939
123.696
123.405
119.034
116.736
116.700
115.024
107.755
107.711
77.317
76.999
76.682
12.657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0.71
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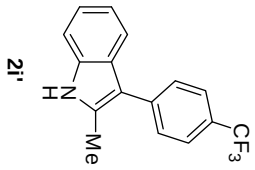
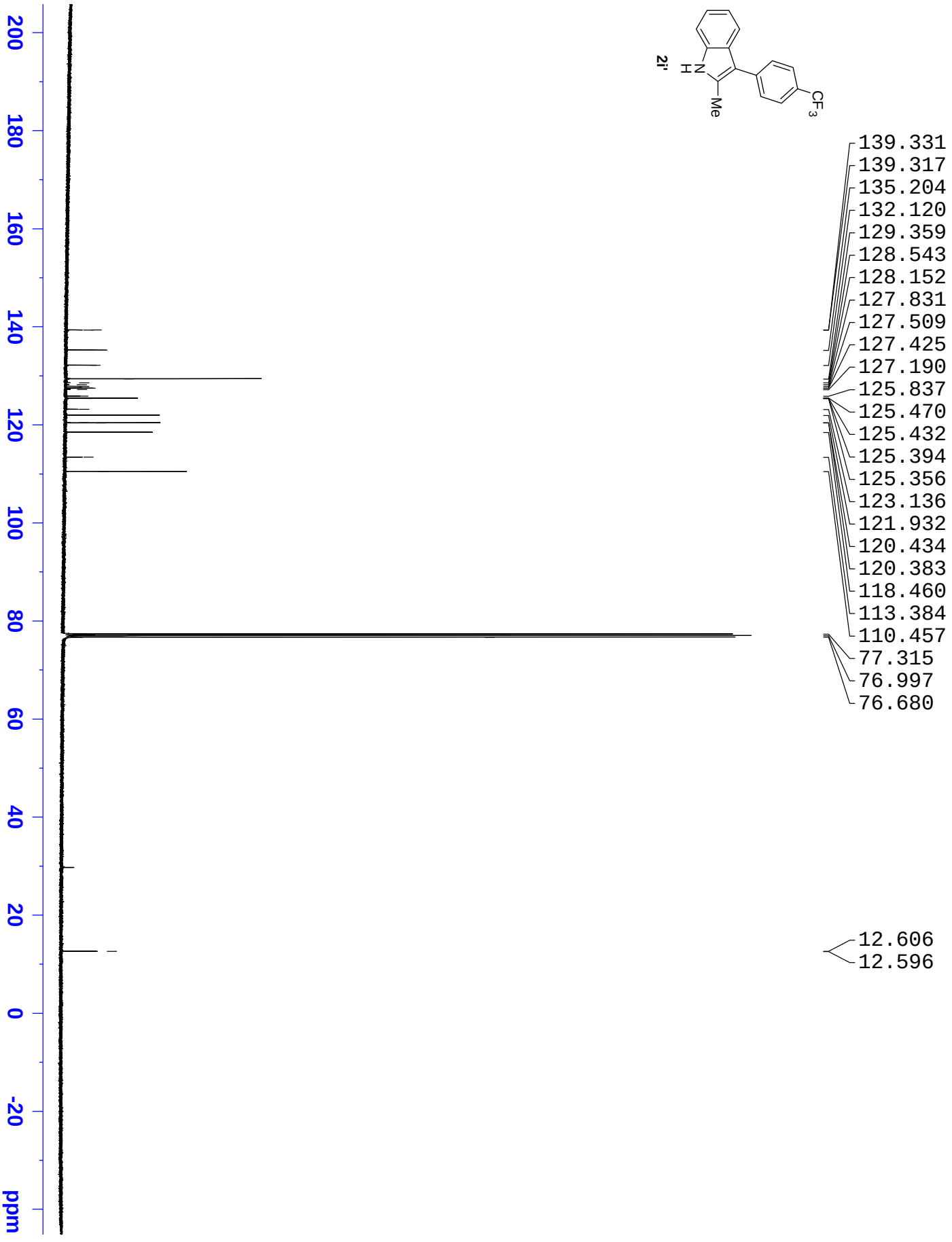
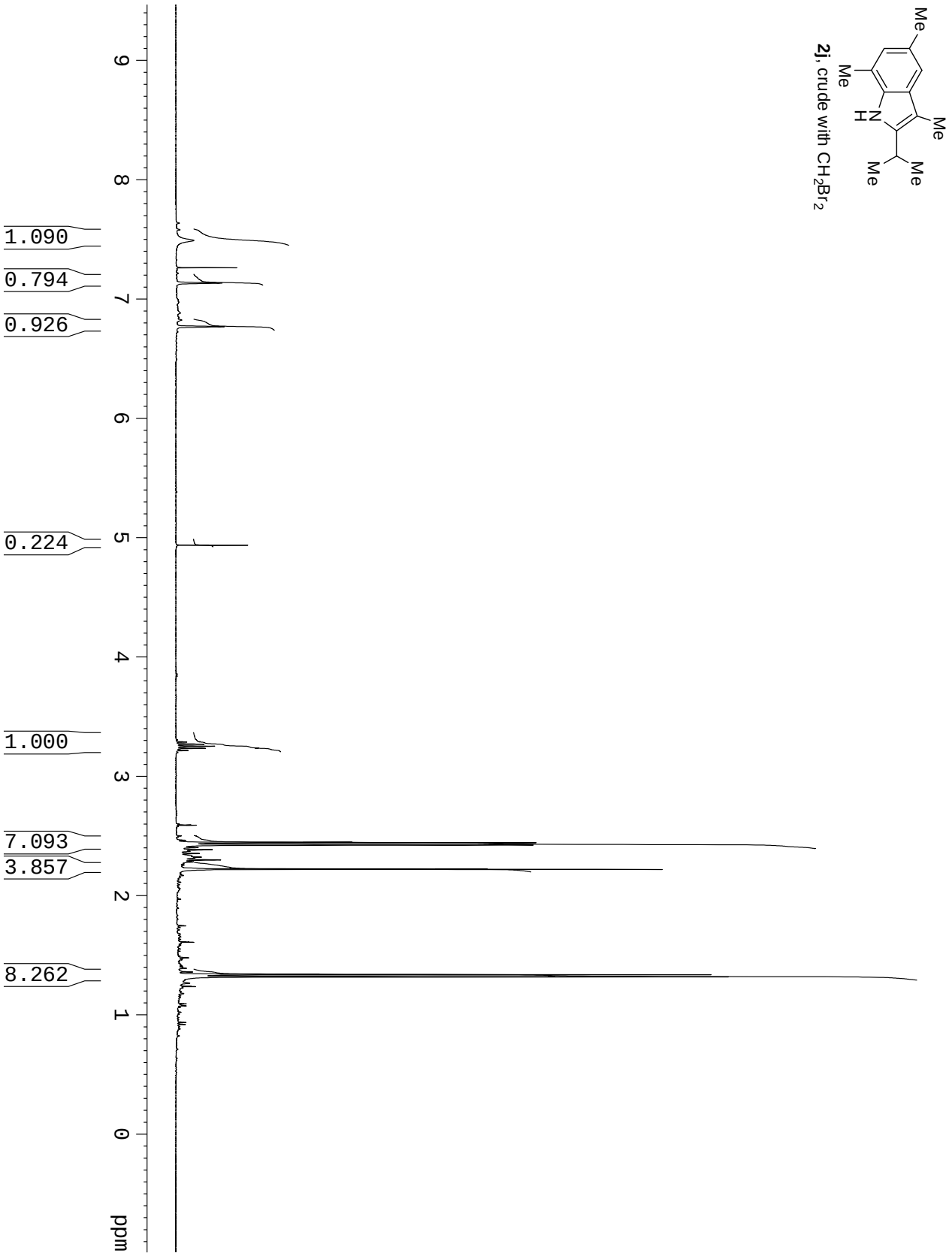
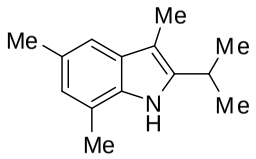
3.00
9
8
7
6
5
4
3
2
1
0
ppm

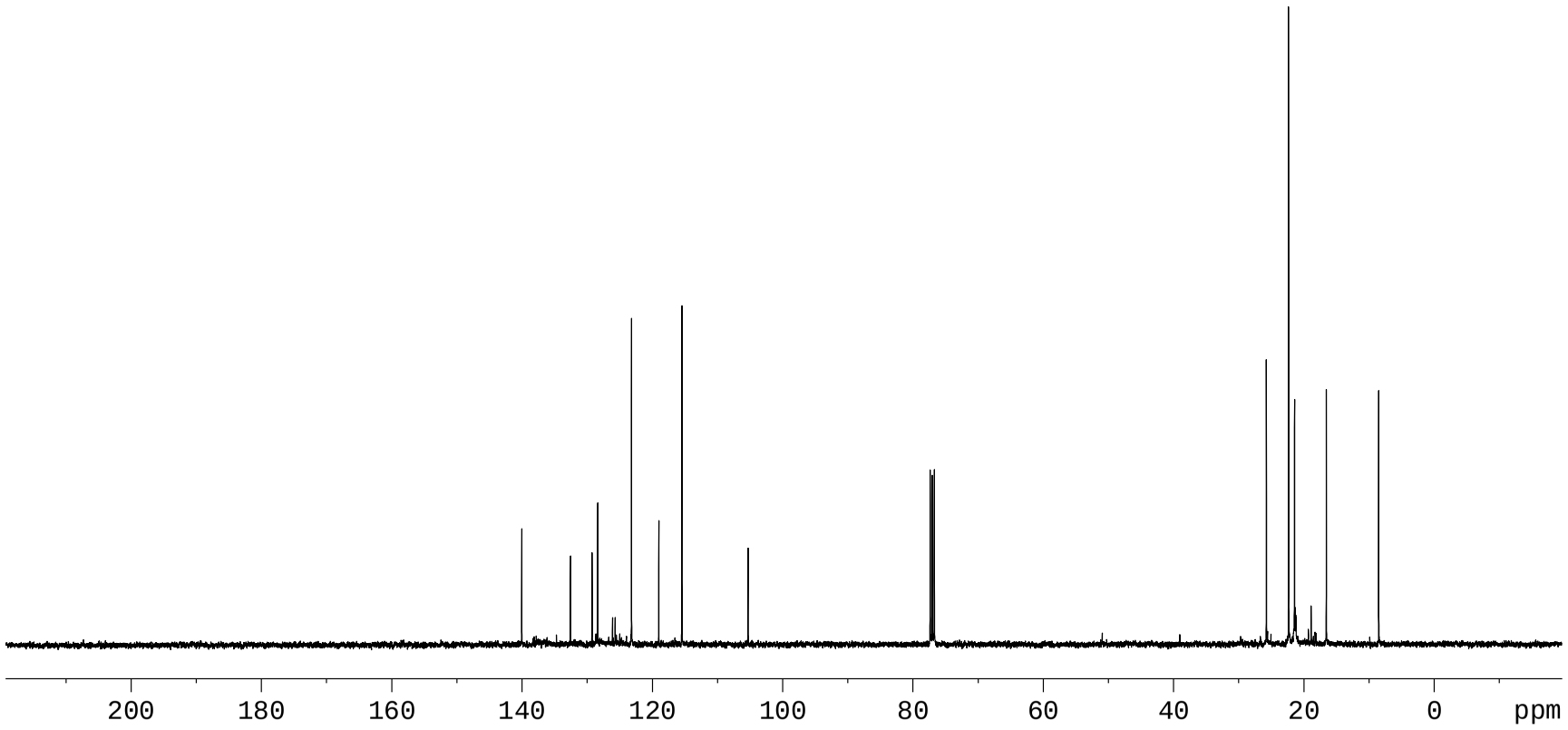

2i'
N
H
Me
CF3

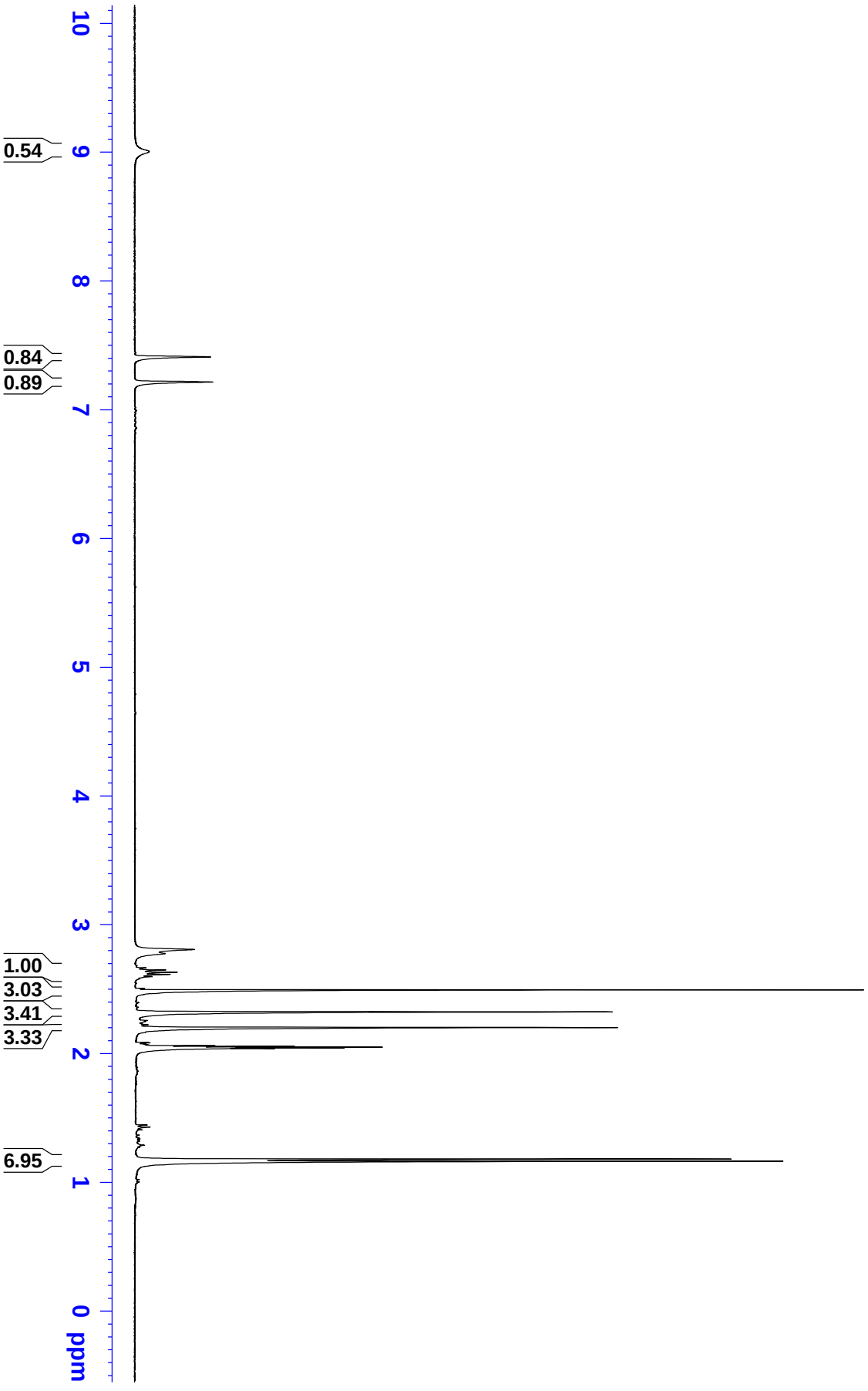

2i'
N
H
Me
CF3
139.331
139.317
135.204
132.120
129.359
128.543
128.152
127.831
127.509
127.425
127.190
125.837
125.470
125.432
125.394
125.356
123.136
121.932
120.434
120.383
118.460
113.384
110.457
77.315
76.997
76.680
12.606
12.596
200
180
160
140
120
100
80
60
40
20
0
-20
ppm

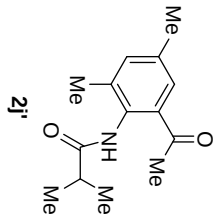

Me
Me
N
H
Me
Me
Me
2j, crude with CH2Br2
1.090
0.794
0.926
0.224
1.000
7.093
3.857
8.262
9
8
7
6
5
4
3
2
1
0
ppm

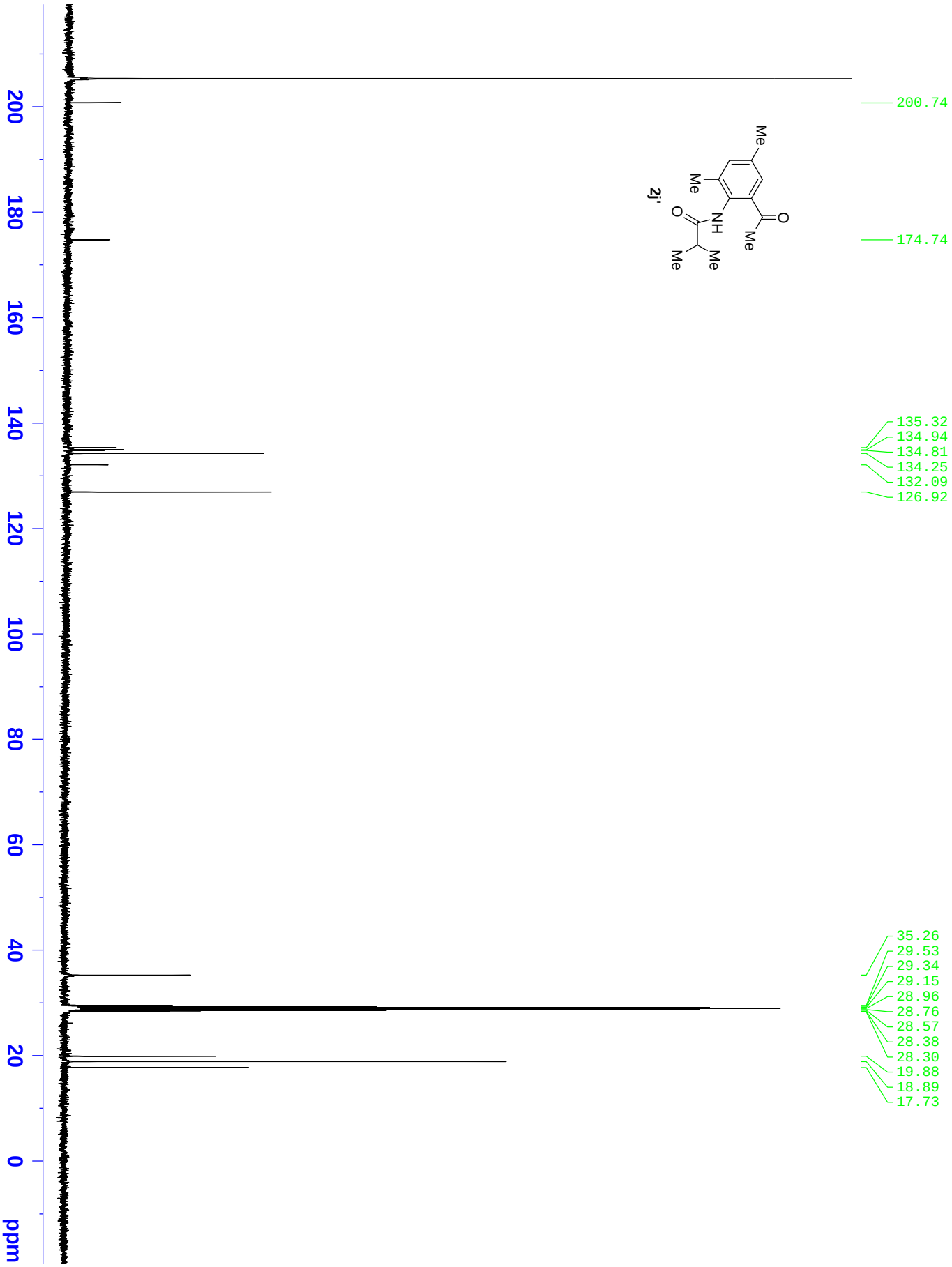


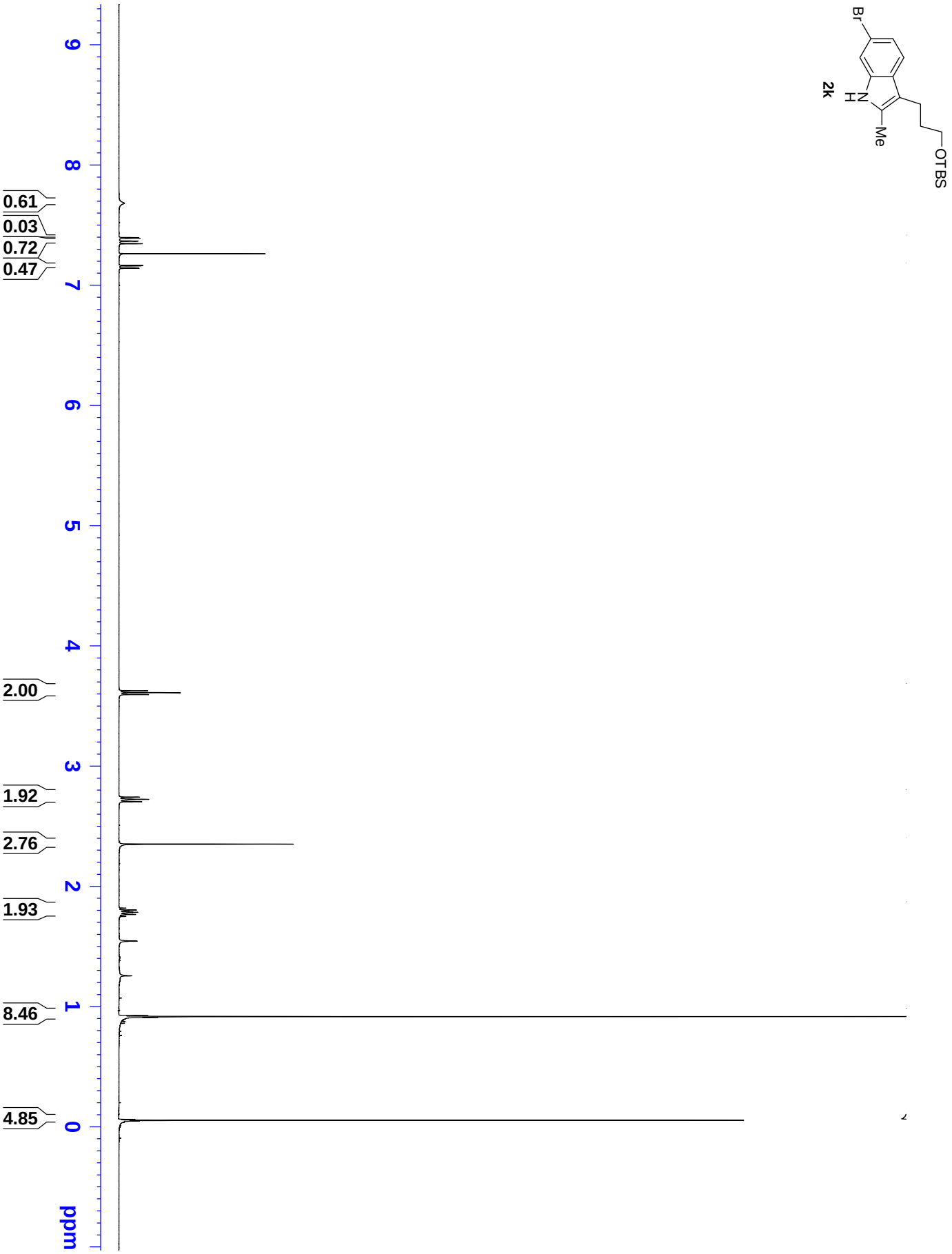
2j, crude with CH_2Br_2

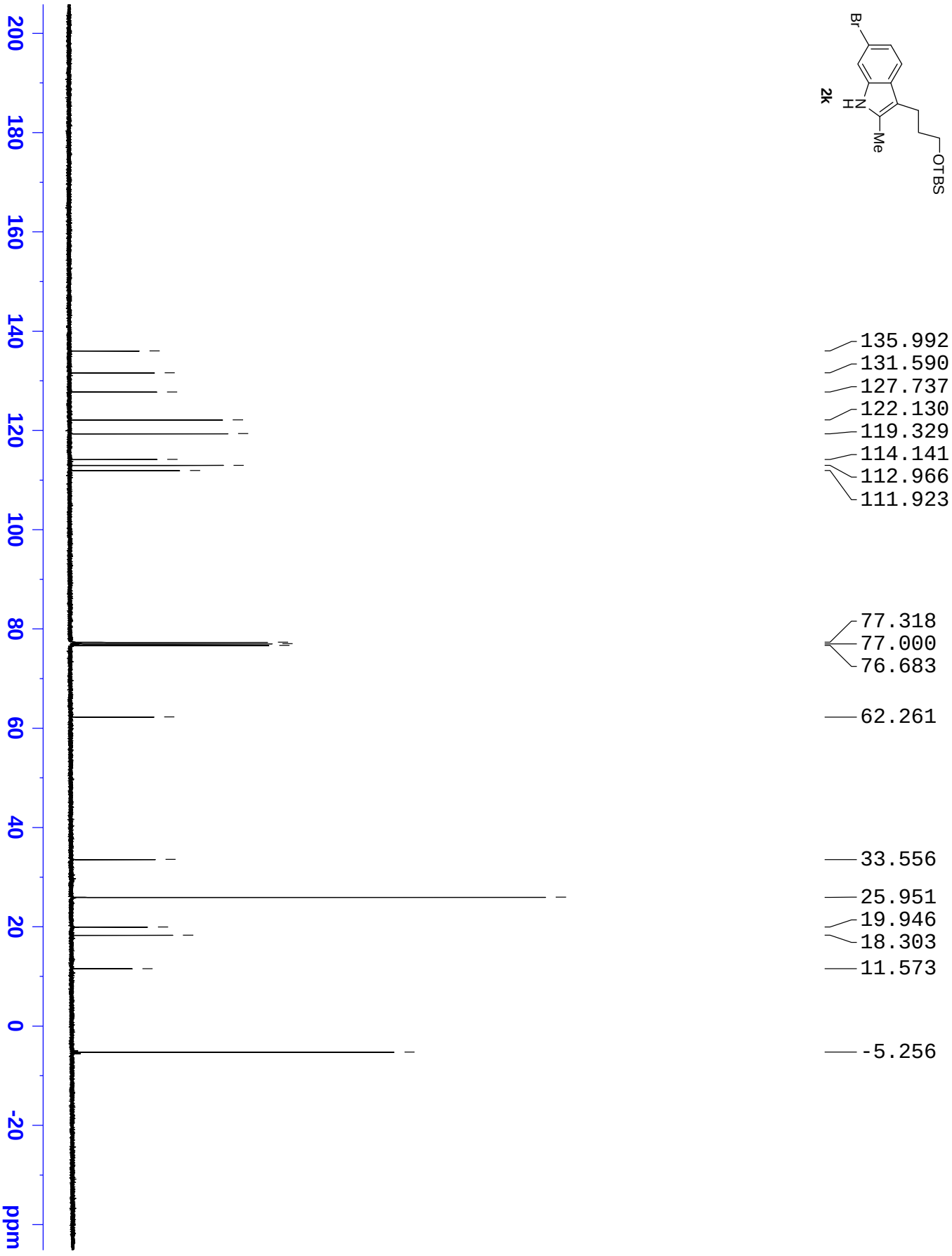


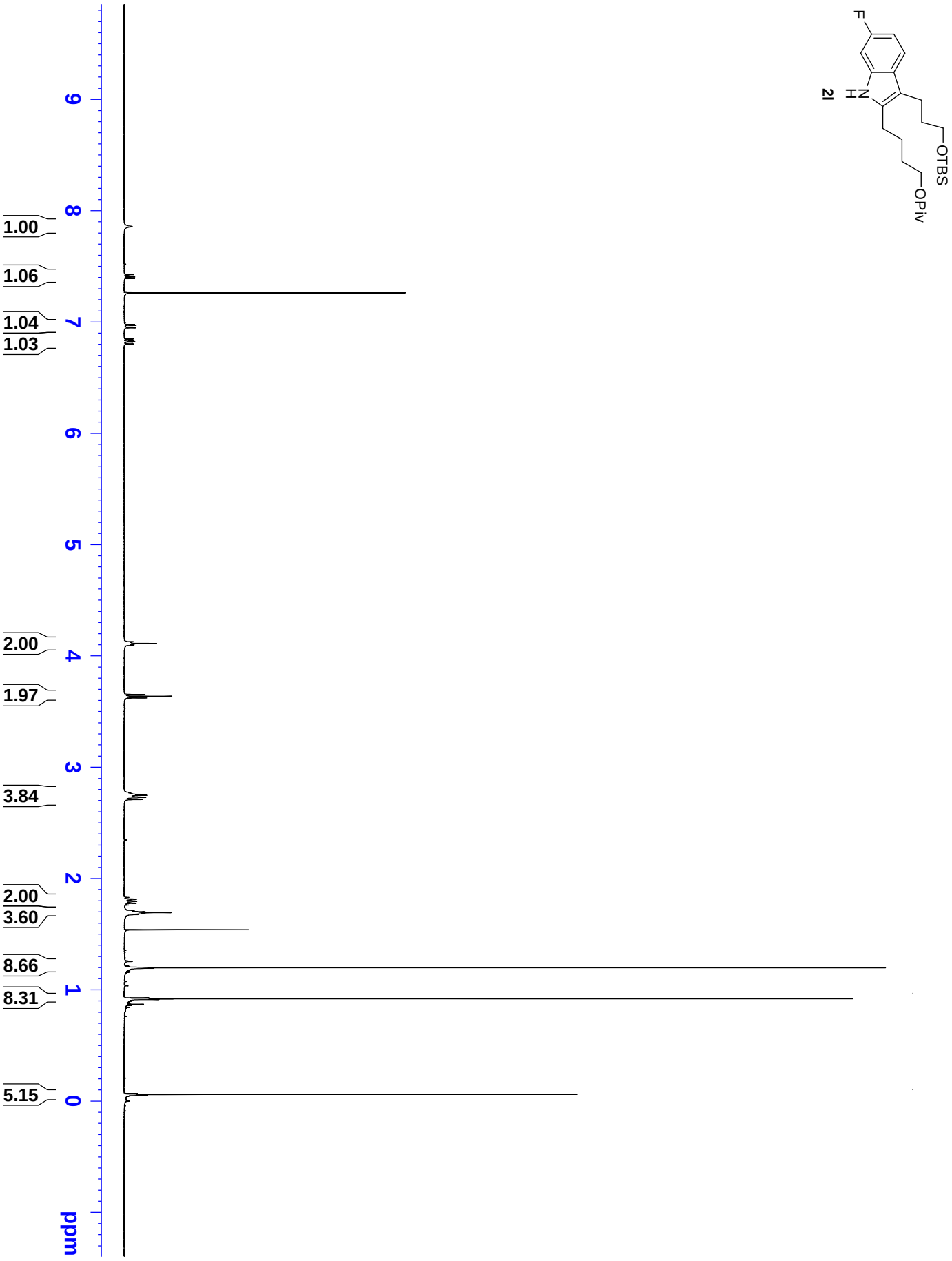

10
9
8
7
6
5
4
3
2
1
0
ppm
0.54
0.84
0.89
1.00
3.03
3.41
3.33
6.95

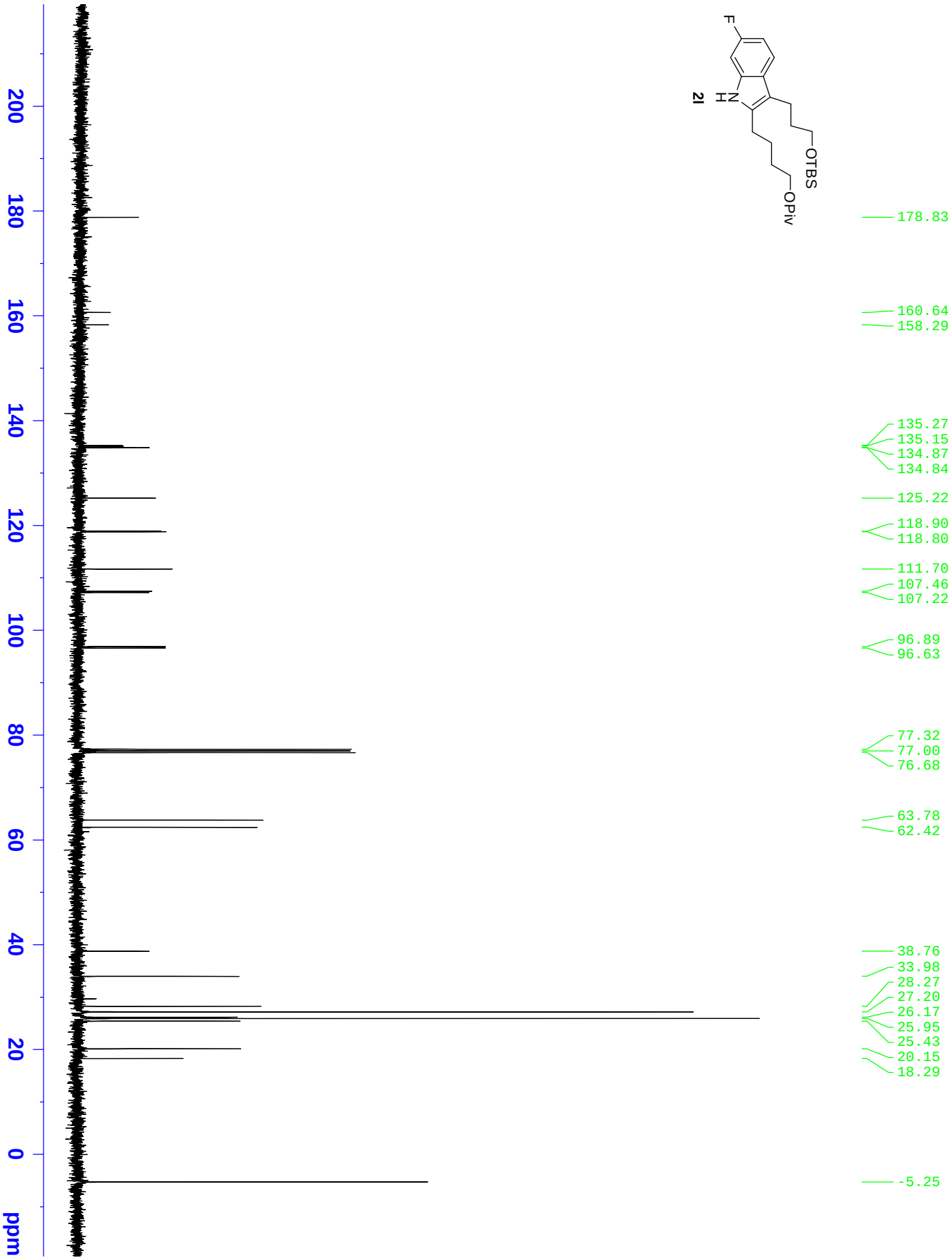

Me
Me
NH
O
O
Me
Me
Me
2j'

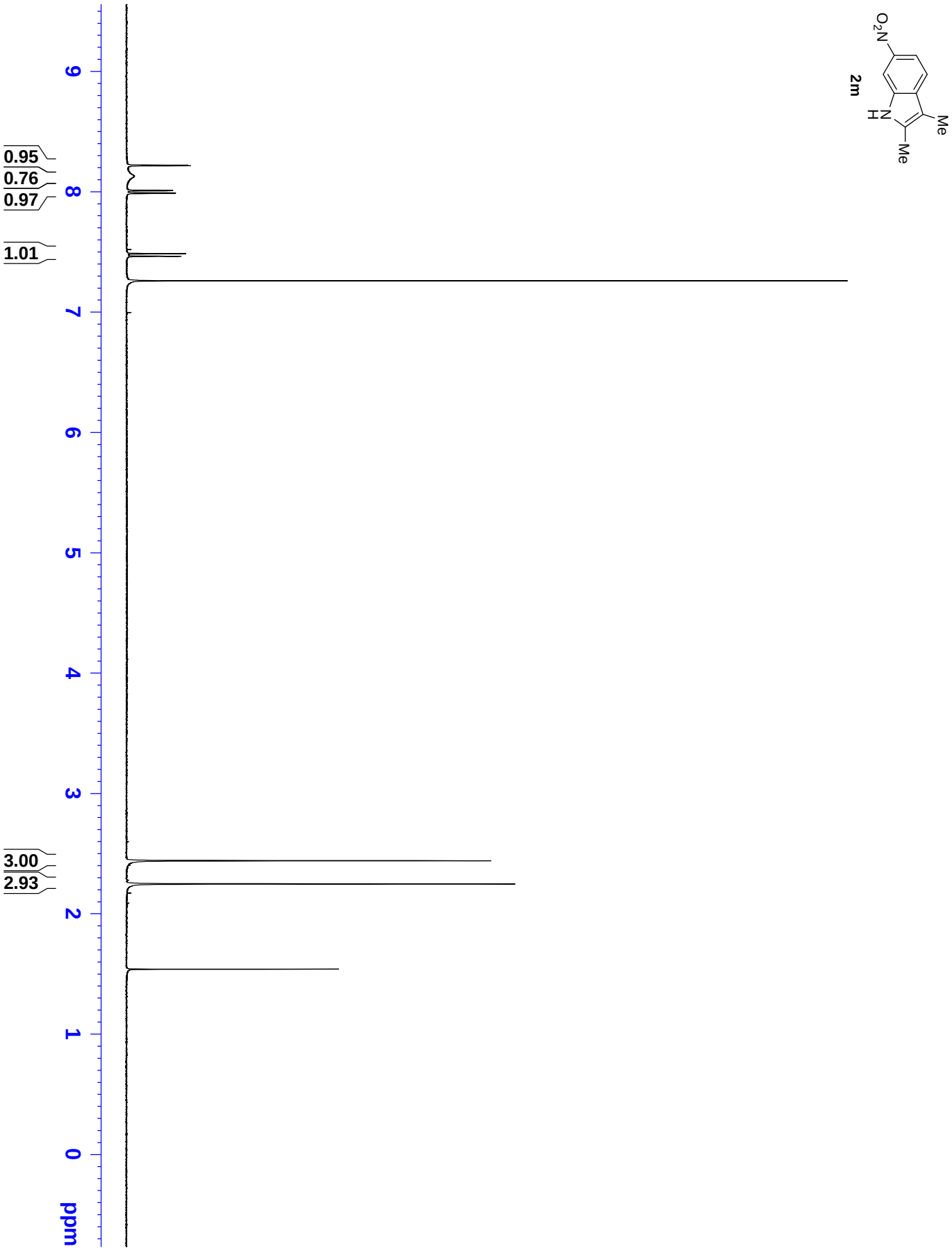

200.74
174.74
135.32
134.94
134.81
134.25
132.09
126.92
35.26
29.53
29.34
29.15
28.96
28.76
28.57
28.38
28.30
19.88
18.89
17.73
2j'
Me
Me
NH
O
O
Me
Me
Me
Me
200
180
160
140
120
100
80
60
40
20
0
ppm

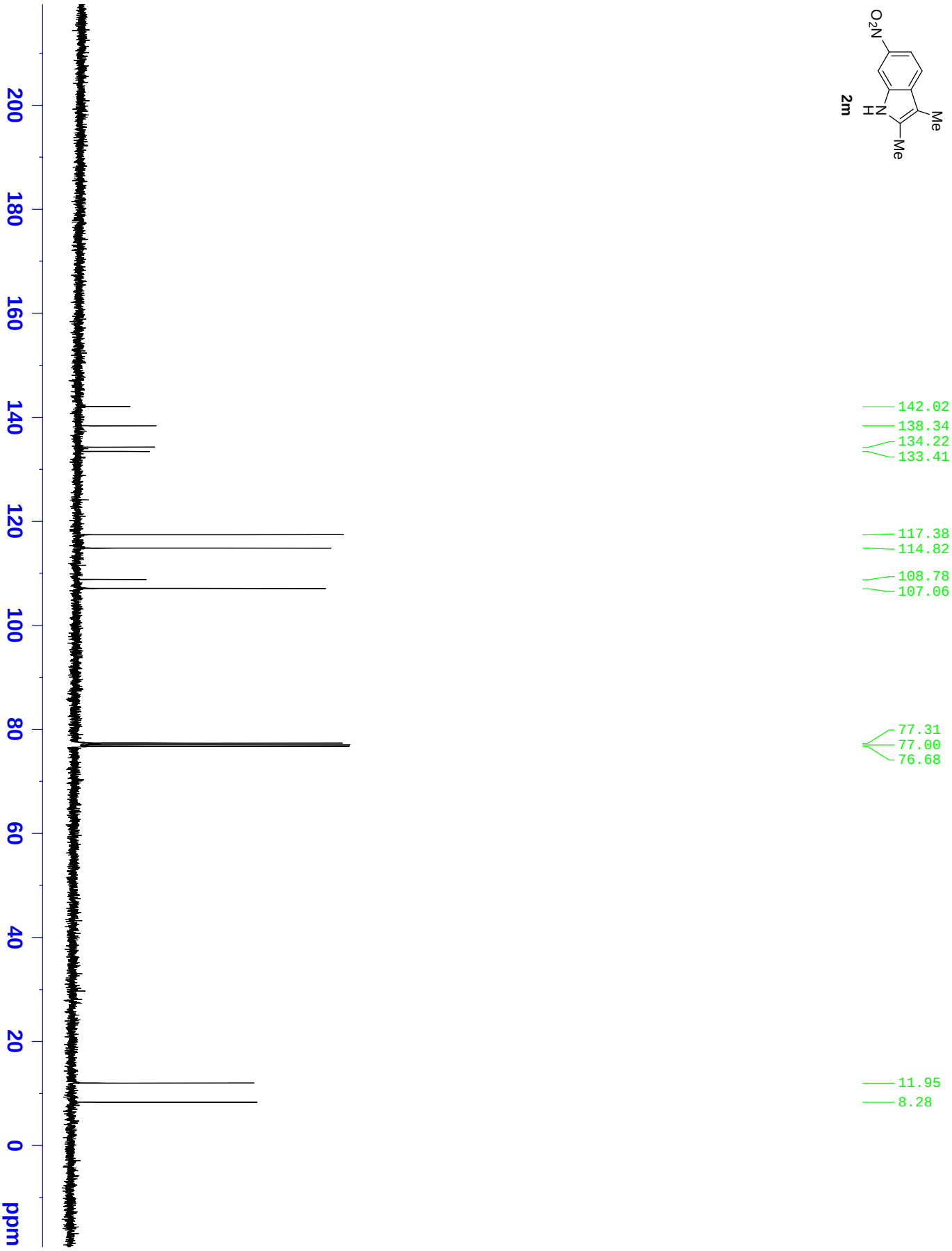

Br
N
H
Me
OTBS
2k
0.61
0.03
0.72
0.47
2.00
1.92
2.76
1.93
8.46
4.85
ppm

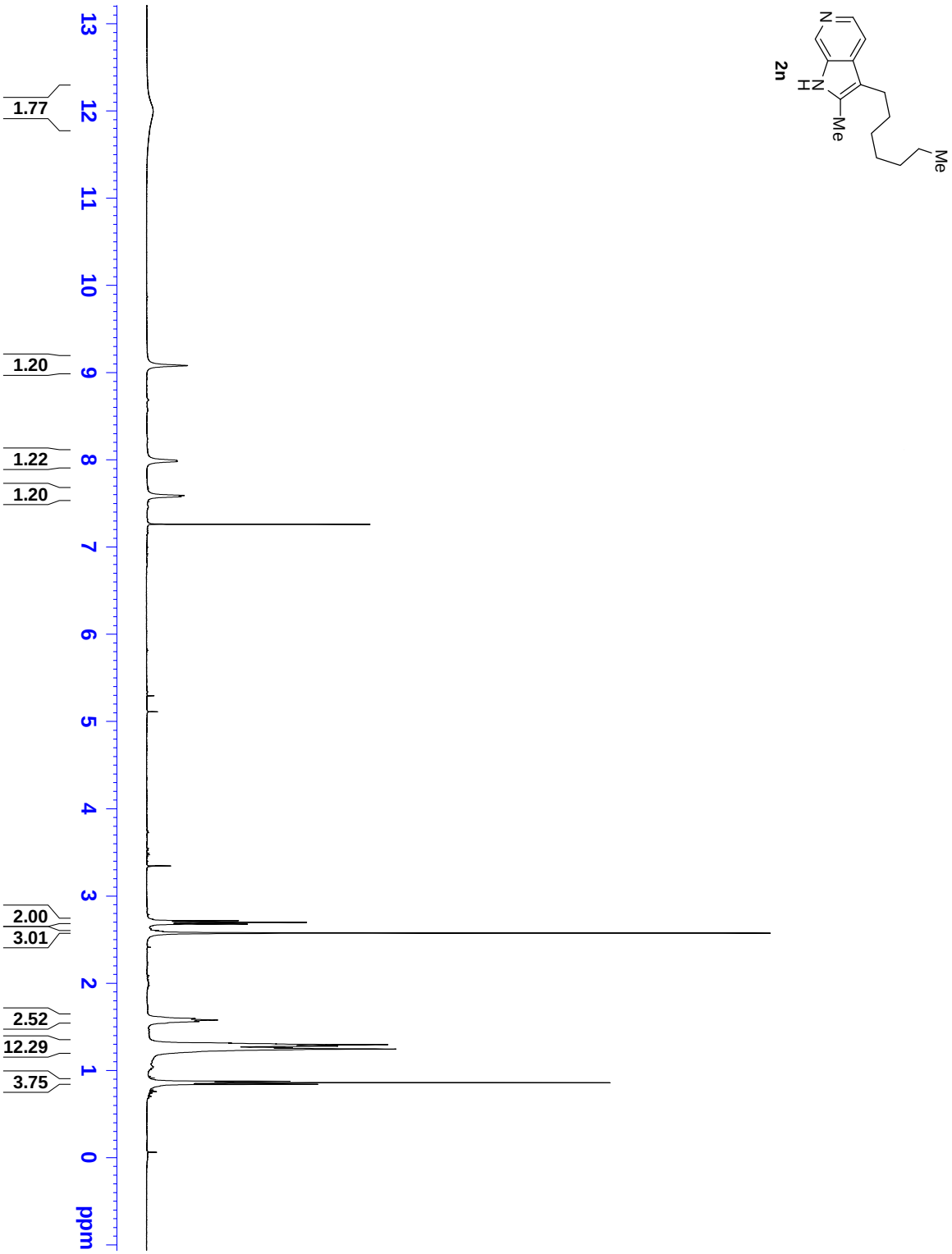

Br
N
H
Me
OTBS
2k
135.992
131.590
127.737
122.130
119.329
114.141
112.966
111.923
77.318
77.000
76.683
62.261
33.556
25.951
19.946
18.303
11.573
-5.256
200
180
160
140
120
100
80
60
40
20
0
-20
ppm

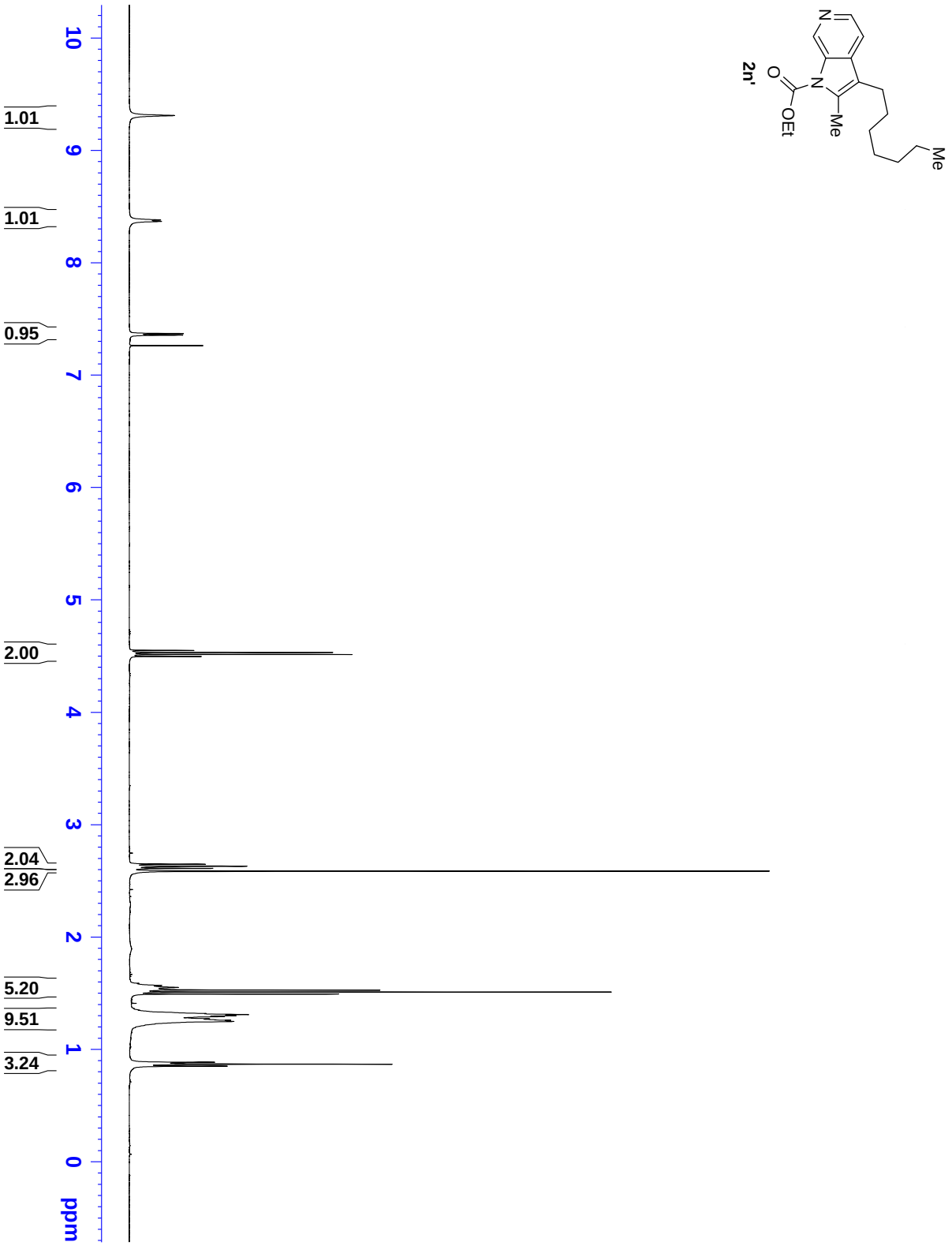

F
N
H
2l
OTBS
OPiv
1.00
1.06
1.04
1.03
2.00
1.97
3.84
2.00
3.60
8.66
8.31
5.15
ppm

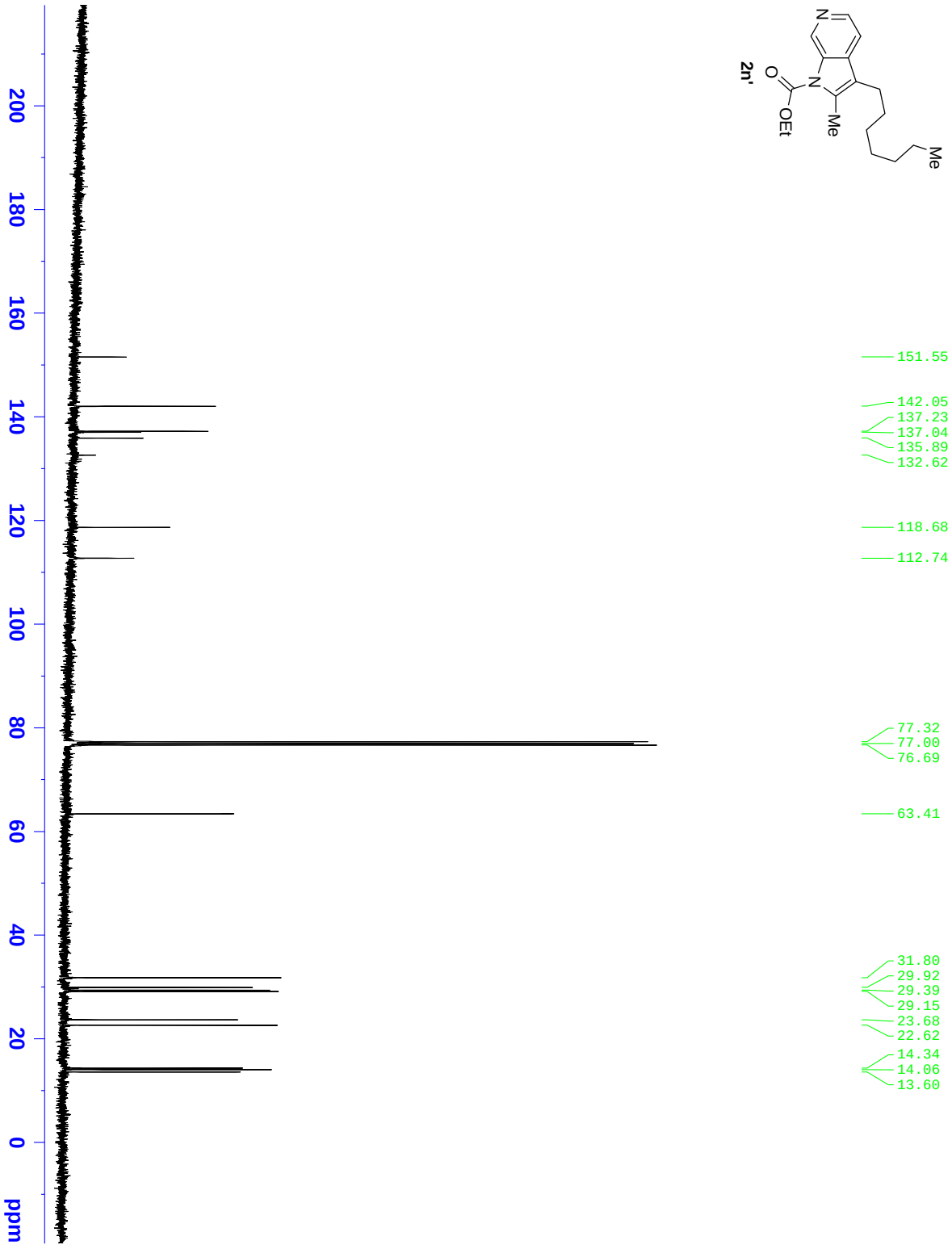

F
N
H
21
OTBS
OPiv
178.83
160.64
158.29
135.27
135.15
134.87
134.84
125.22
118.90
118.80
111.70
107.46
107.22
96.89
96.63
77.32
77.00
76.68
63.78
62.42
38.76
33.98
28.27
27.20
26.17
25.95
25.43
20.15
18.29
-5.25
200
180
160
140
120
100
80
60
40
20
0
ppm

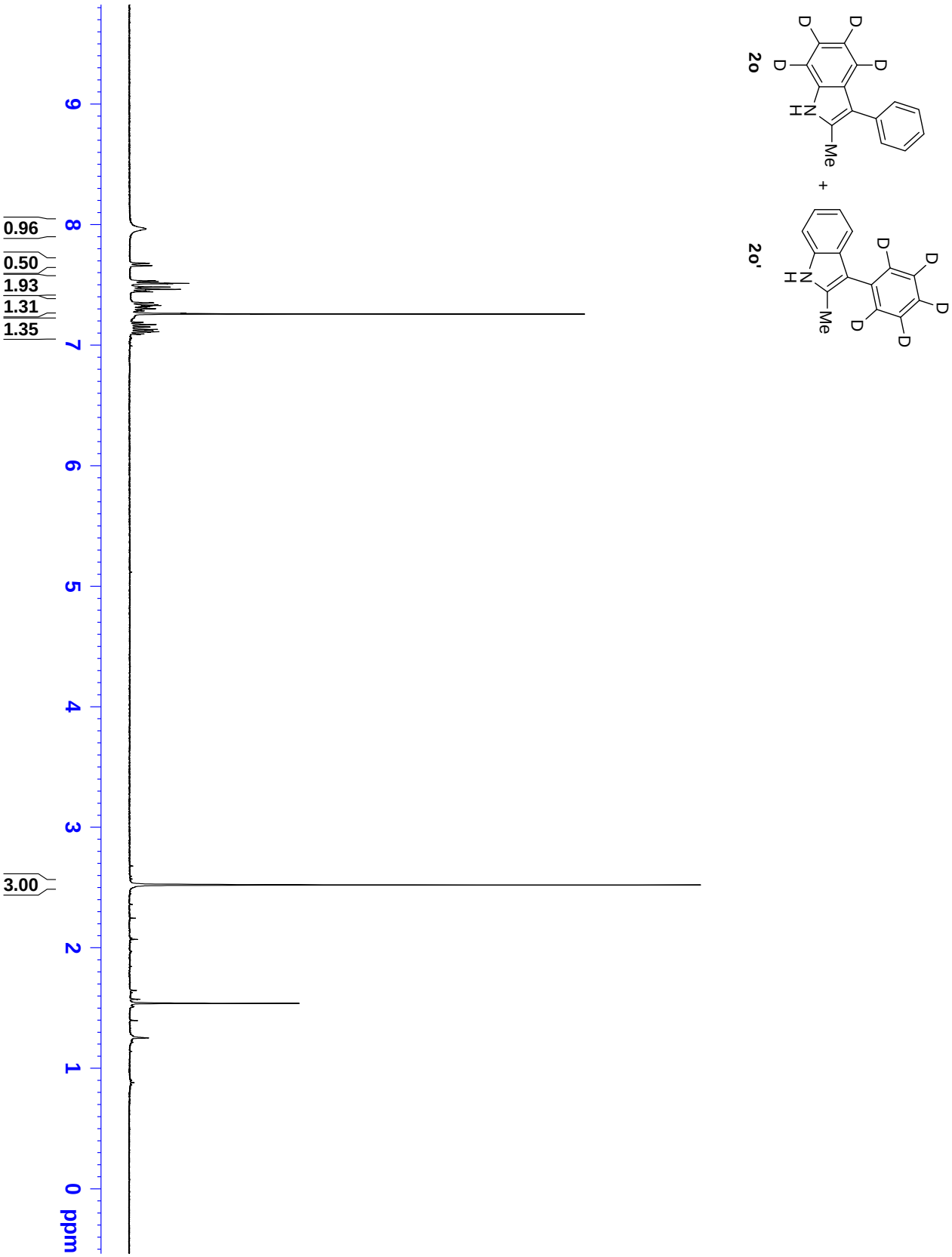

O2N
2m
N
H
Me
Me
0.95
0.76
0.97
1.01
3.00
2.93
9
8
7
6
5
4
3
2
1
0
ppm

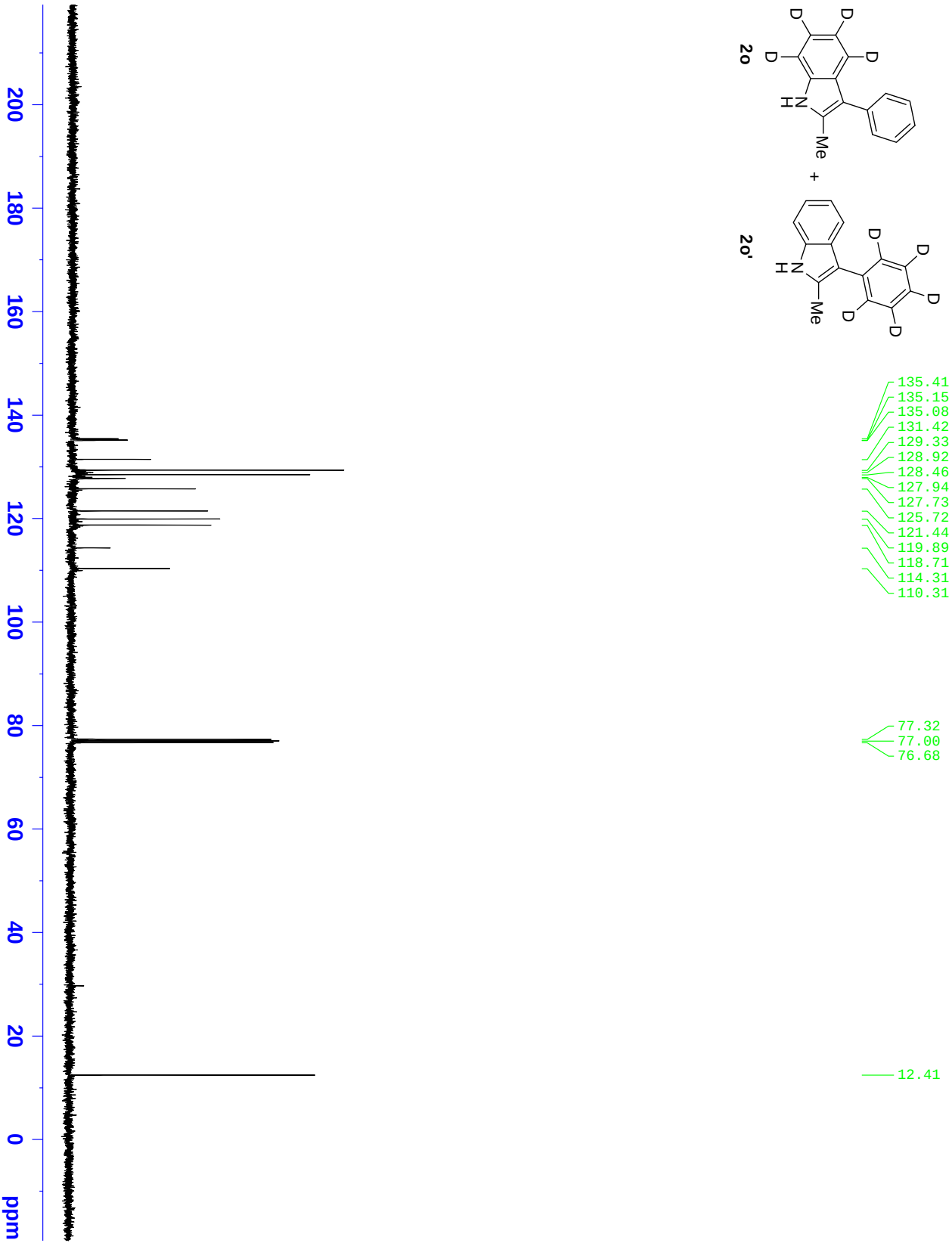

O2N
N
H
Me
Me
2m
142.02
138.34
134.22
133.41
117.38
114.82
108.78
107.06
77.31
77.00
76.68
11.95
8.28
200
180
160
140
120
100
80
60
40
20
0
ppm

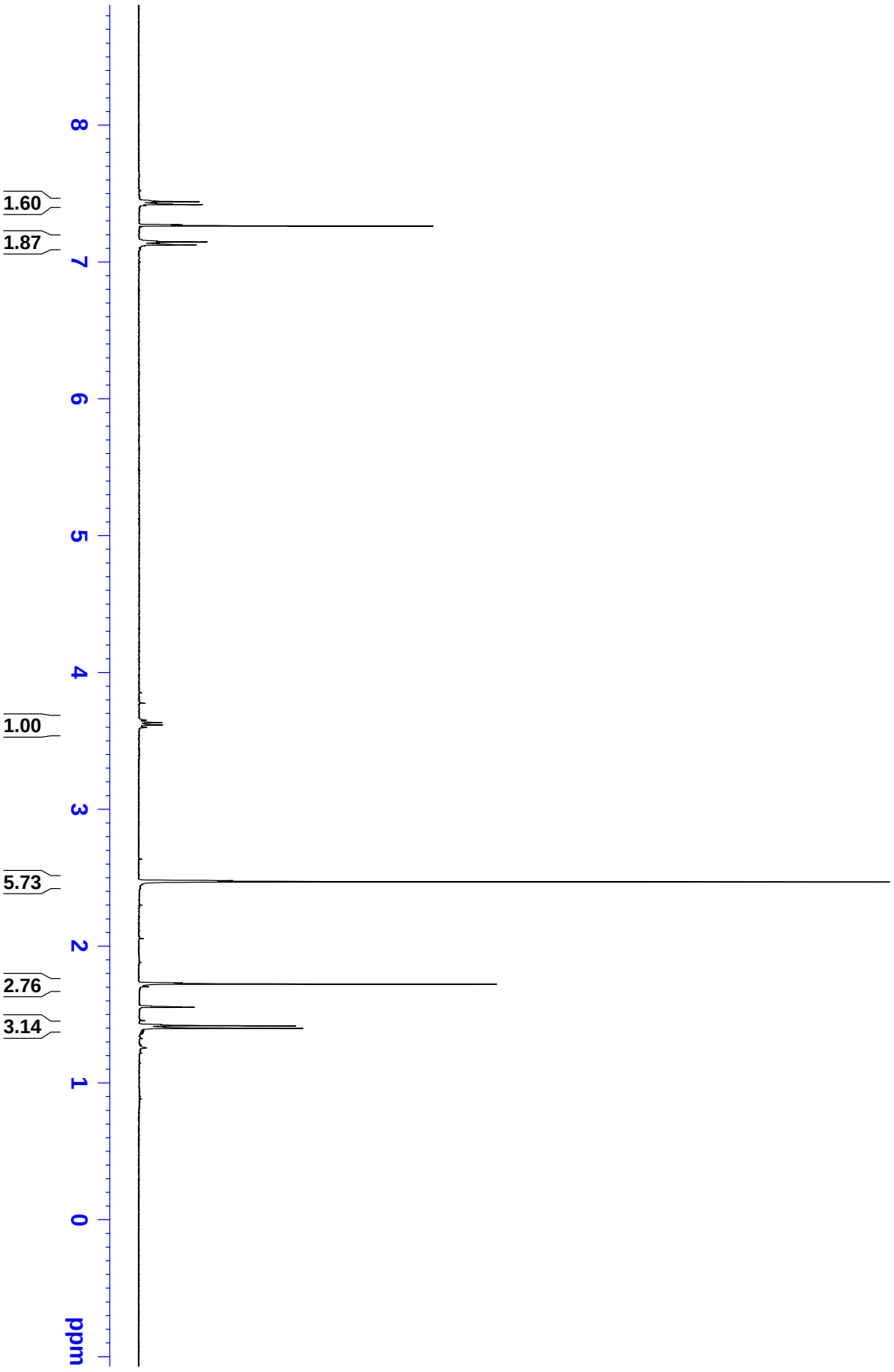

2n
N
H
N
Me
Me
1.77
1.20
1.22
1.20
2.00
3.01
2.52
12.29
3.75
13
12
11
10
9
8
7
6
5
4
3
2
1
0
ppm

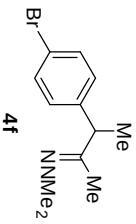

10
9
8
7
6
5
4
3
2
1
0
ppm
1.01
1.01
0.95
2.00
2.04
2.96
5.20
9.51
3.24
2n'
N
O
OEt
N
Me
Me


2n'
N
N
O
OEt
Me
Me
151.55
142.05
137.23
137.04
135.89
132.62
118.68
112.74
77.32
77.00
76.69
63.41
31.80
29.92
29.39
29.15
23.68
22.62
14.34
14.06
13.60
200
180
160
140
120
100
80
60
40
20
0
ppm

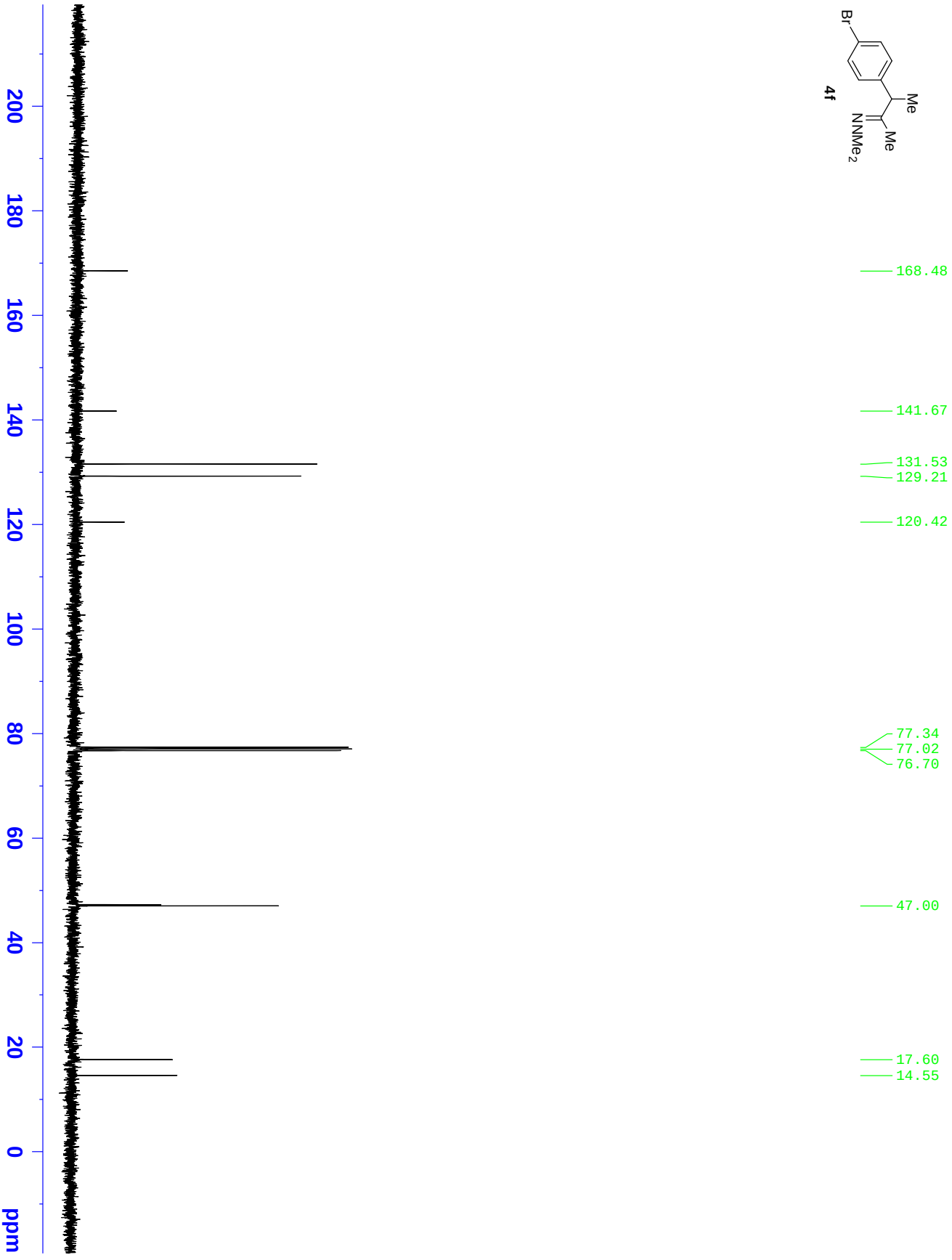

0.96
0.50
1.93
1.31
1.35
3.00
9
8
7
6
5
4
3
2
1
0
ppm
2o
D
D
D
D
N
H
Me
+
2o'
D
D
D
D
N
H
Me

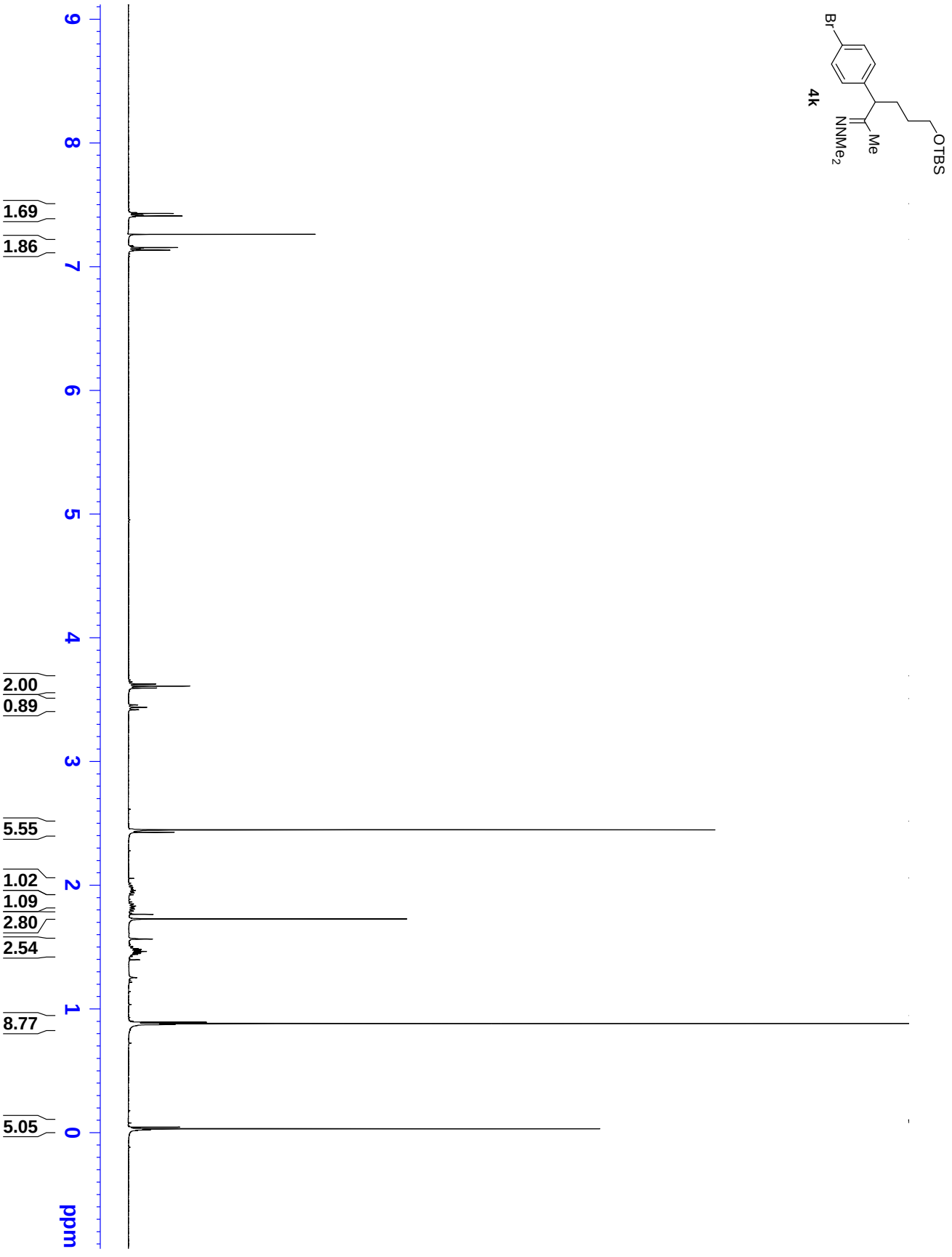

2o
Me
+
2o'
Me
135.41
135.15
135.08
131.42
129.33
128.92
128.46
127.94
127.73
125.72
121.44
119.89
118.71
114.31
110.31
77.32
77.00
76.68
12.41
200
180
160
140
120
100
80
60
40
20
0
ppm

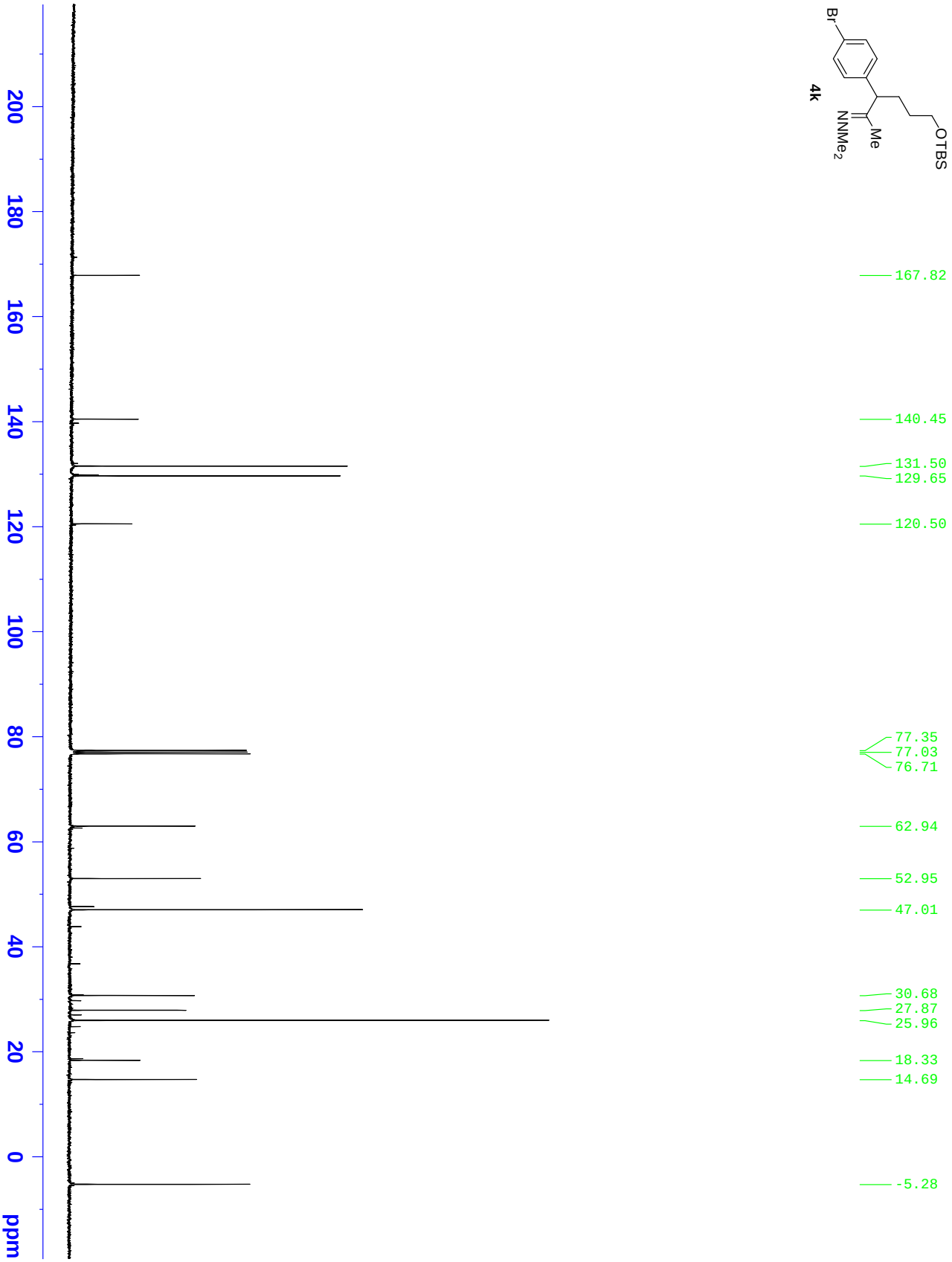


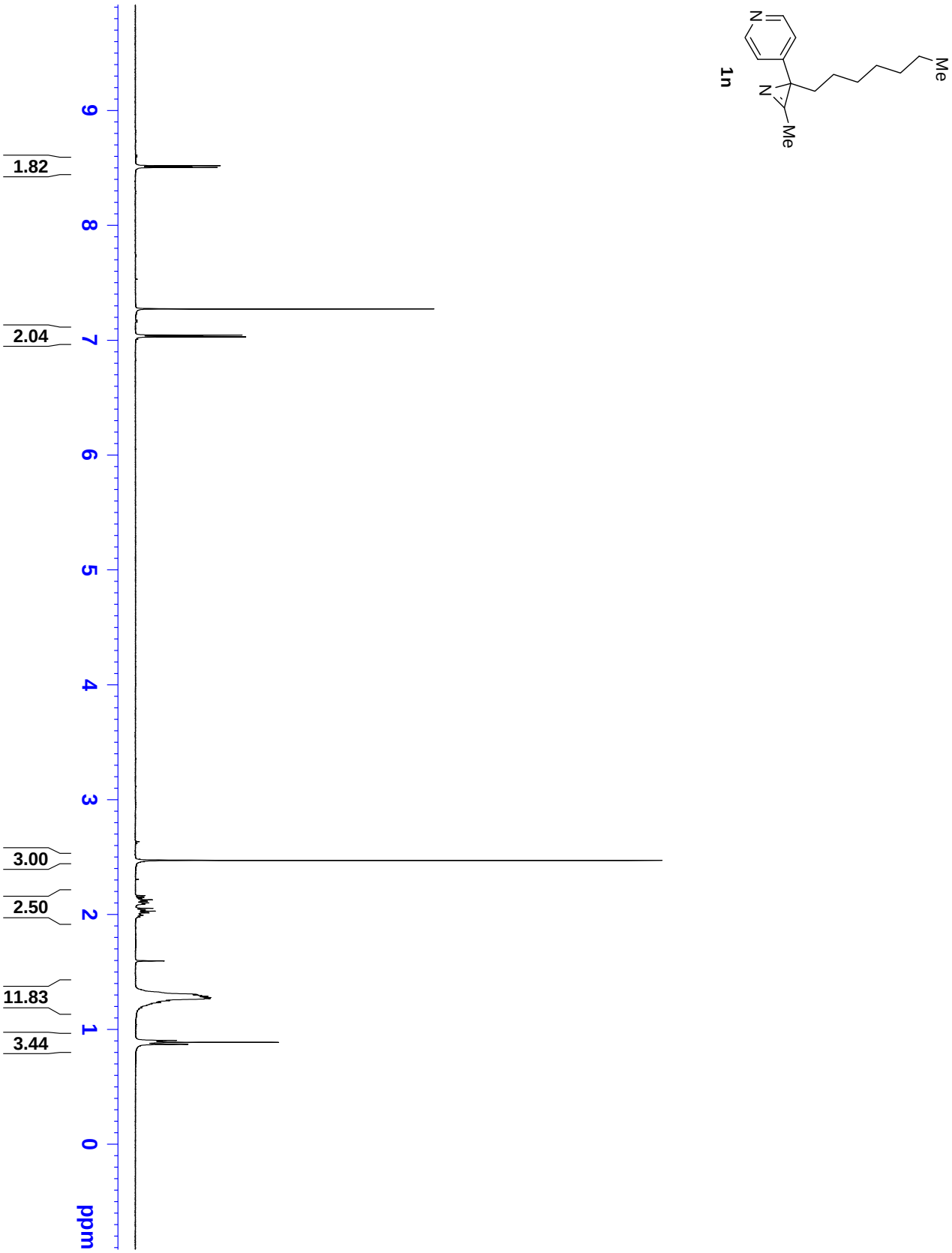


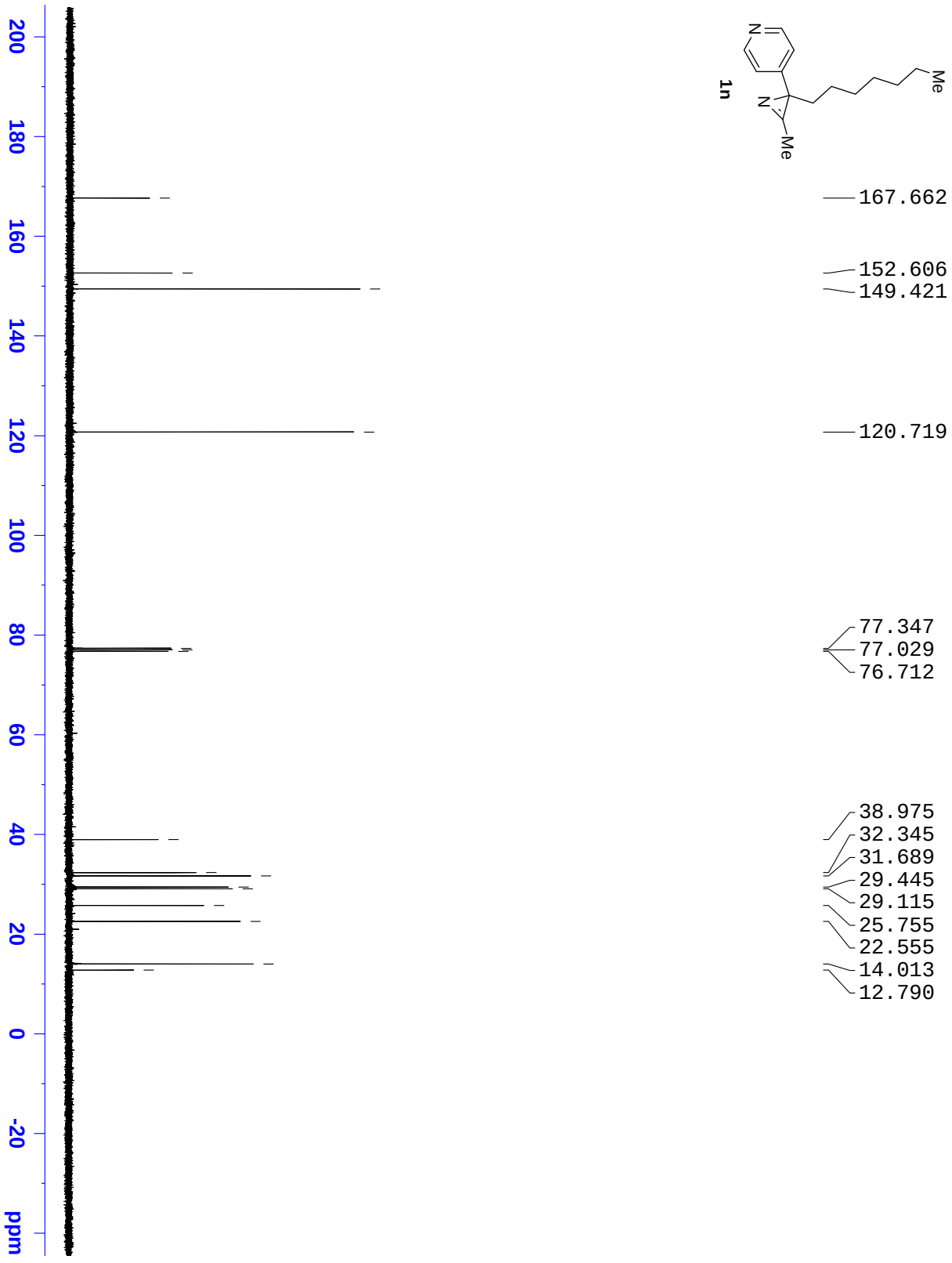
4f

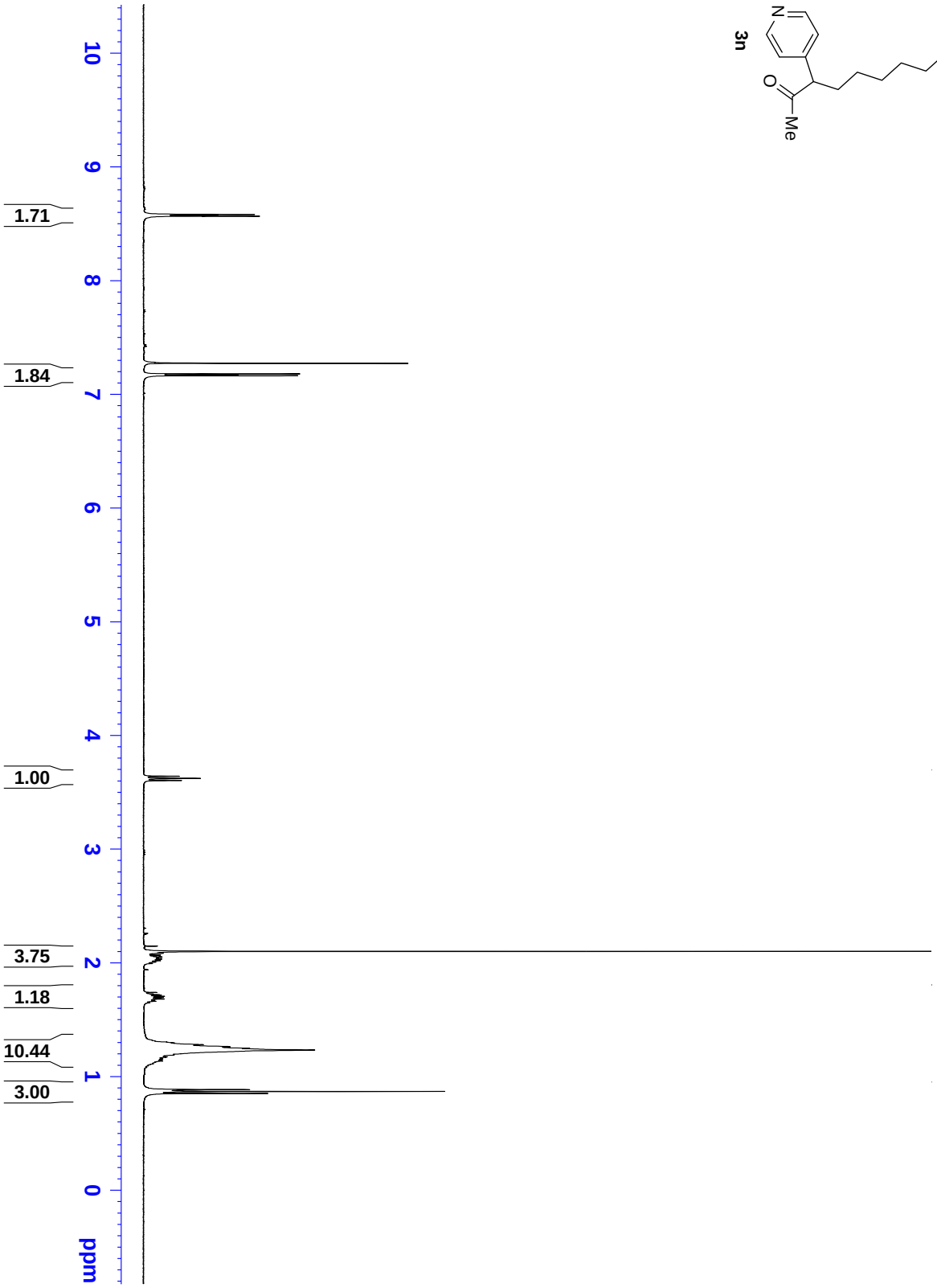

Br
Me
Me
NNMe2
4f
168.48
141.67
131.53
129.21
120.42
77.34
77.02
76.70
47.00
17.60
14.55
200
180
160
140
120
100
80
60
40
20
0
ppm

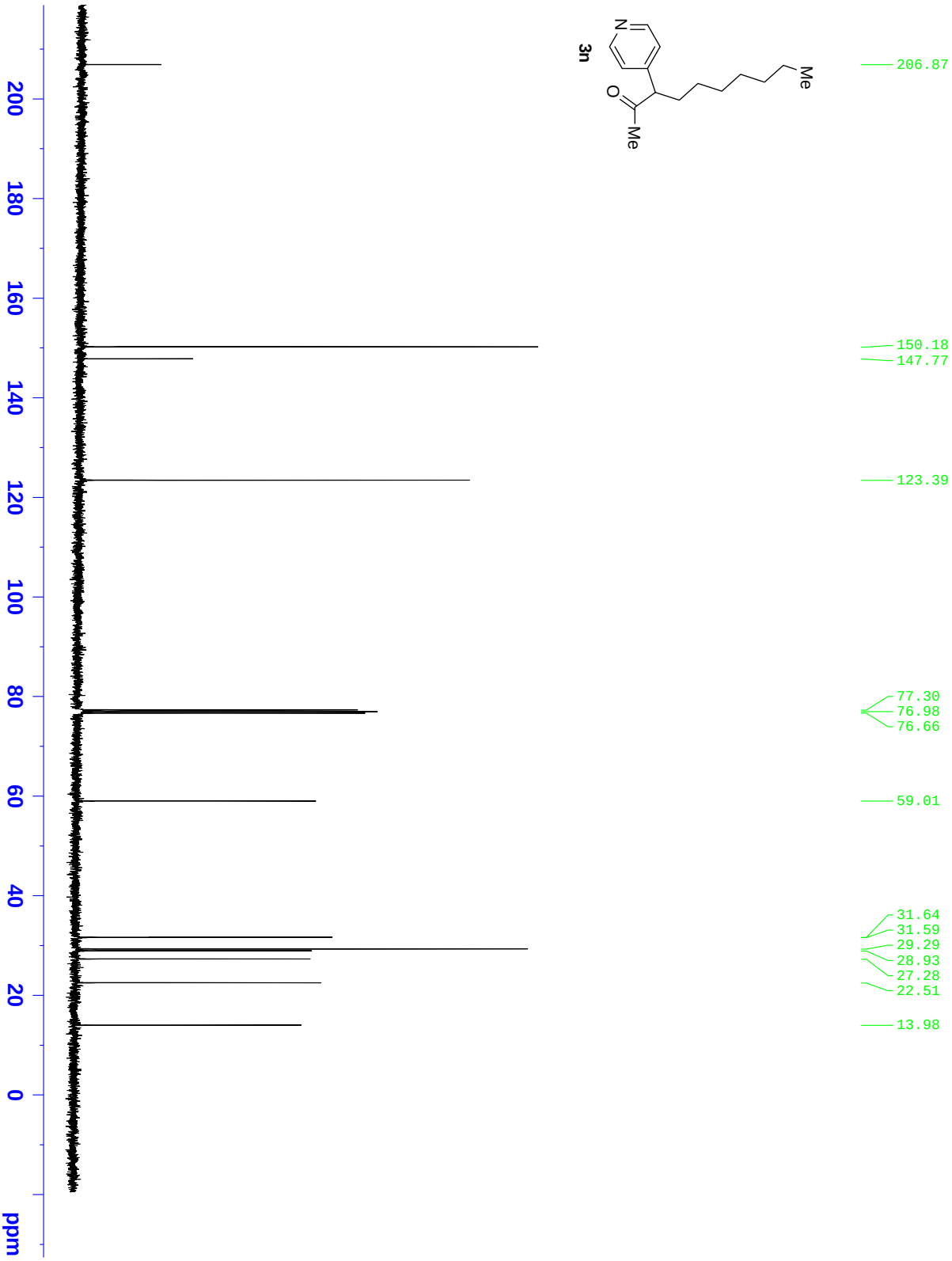

Br
NNMe2
Me
OTBS
4k
1.69
1.86
2.00
0.89
5.55
1.02
1.09
2.80
2.54
8.77
5.05
ppm

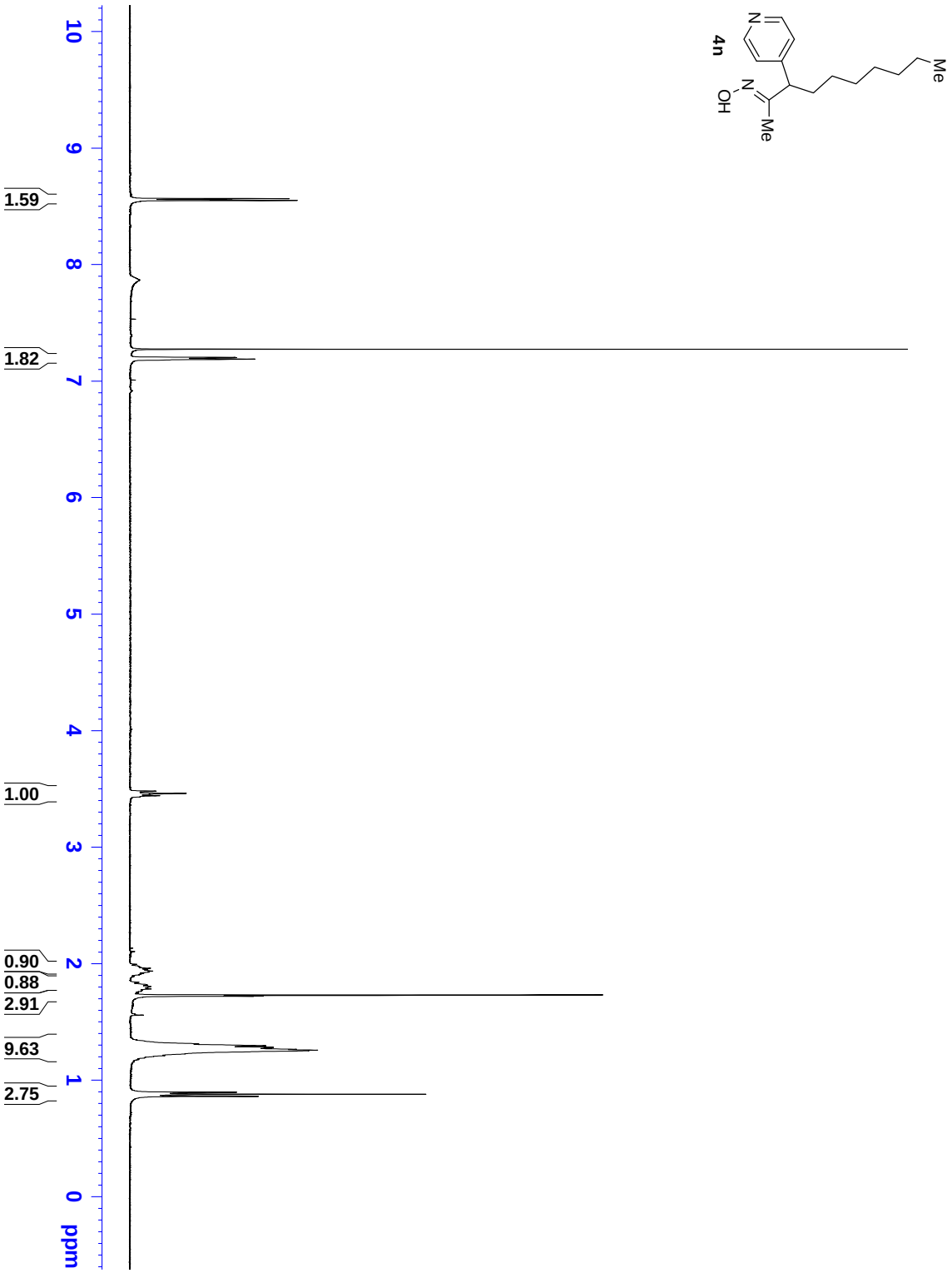

Br
4k
NNMe2
Me
OTBS
167.82
140.45
131.50
129.65
120.50
77.35
77.03
76.71
62.94
52.95
47.01
30.68
27.87
25.96
18.33
14.69
-5.28
200
180
160
140
120
100
80
60
40
20
0
ppm

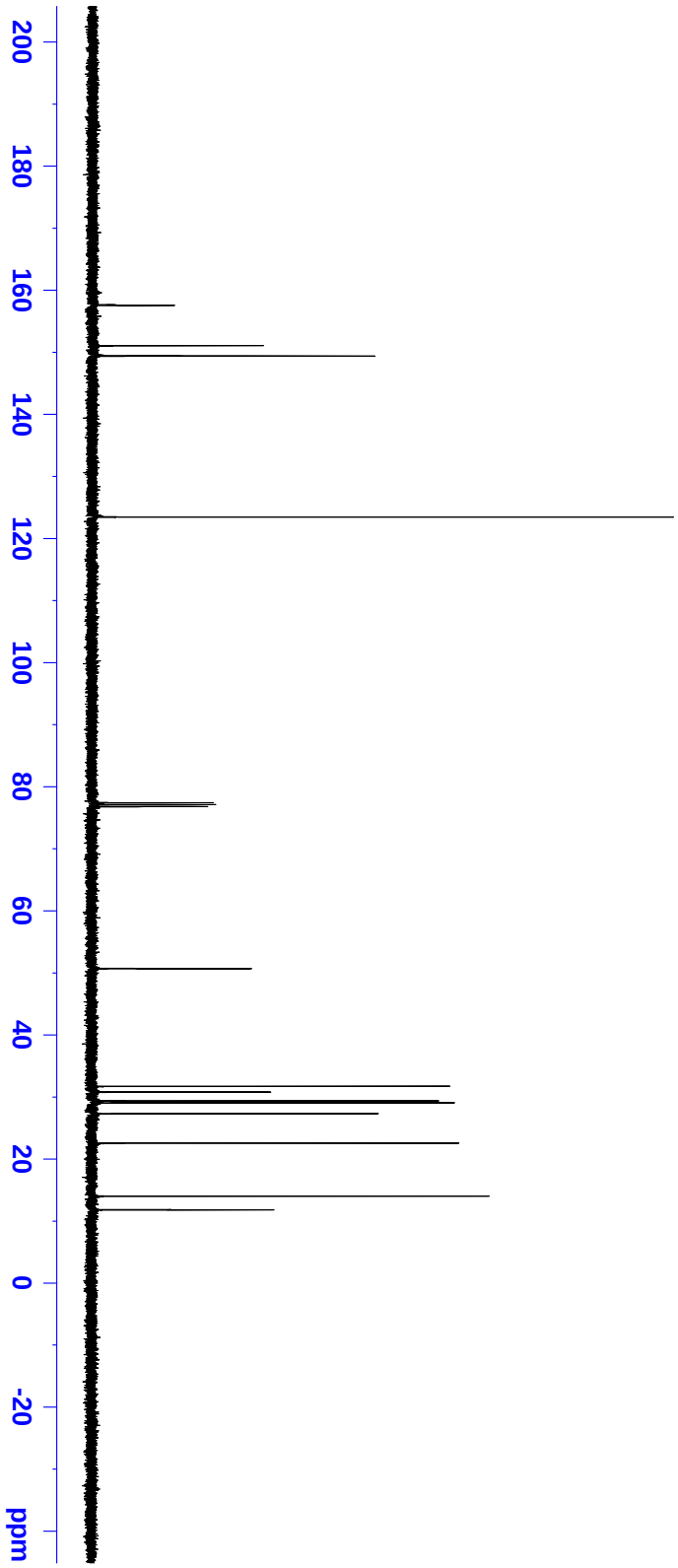

1.82
2.04
3.00
2.50
11.83
3.44
9
8
7
6
5
4
3
2
1
0
ppm
1n
N
N
Me
Me

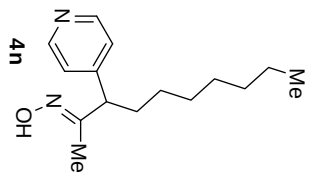

1n
N
N
Me
Me
167.662
152.606
149.421
120.719
77.347
77.029
76.712
38.975
32.345
31.689
29.445
29.115
25.755
22.555
14.013
12.790
200
180
160
140
120
100
80
60
40
20
0
-20
ppm


3n
N
O
Me
Me
1.71
1.84
1.00
3.75
1.18
10.44
3.00
10
9
8
7
6
5
4
3
2
1
0
ppm


3n
N
O
Me
Me
206.87
150.18
147.77
123.39
77.30
76.98
76.66
59.01
31.64
31.59
29.29
28.93
27.28
22.51
13.98
200
180
160
140
120
100
80
60
40
20
0
ppm


4n
N
N
OH
Me
Me
10
9
8
7
6
5
4
3
2
1
0
ppm
1.59
1.82
1.00
0.90
0.88
2.91
9.63
2.75


200
180
160
140
120
100
80
60
40
20
0
-20
ppm


4n
N
N
OH
Me
Me