Synthesis of Chromeno[4,3-b]quinolines and Spirobenzofuran-3,3'-quinolines through Silver-Mediated Appel Reaction/C-Br Bond Cleavage/Double Selective Rearrangement Sequence

Hong-Ping Zhao[a], Xiao-Pan Ma[a], Shu-Min Nie[a], Yuhong Xiao[b], and Dong-Liang Mo*[,a]

[a]*State Key Laboratory for Chemistry and Molecular Engineering of Medicinal Resources, Ministry of Science and Technology of China; School of Chemistry and Pharmaceutical Sciences, Guangxi Normal University, 15 Yu Cai Road, Guilin 541004, China*

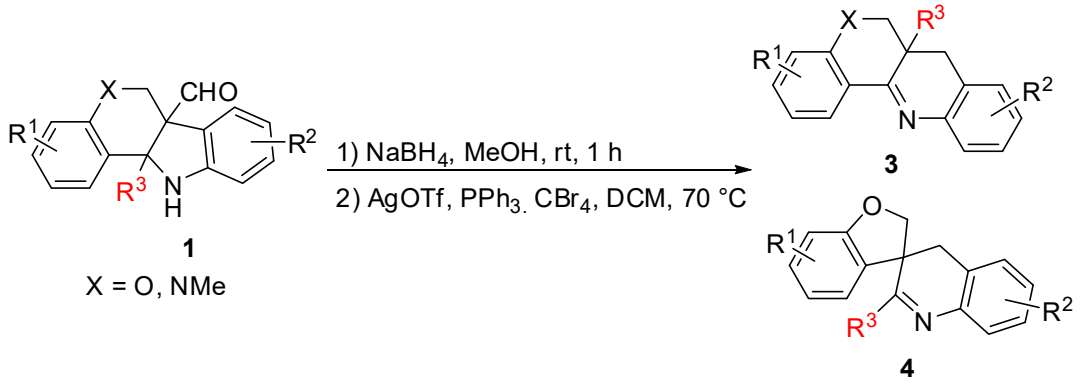
[b] *School of Chemistry and Chemical Engineering, Hunan University of Science and Technology, Xiangtan 411201, P. R. China*

Contents

1. General Experimental Information:

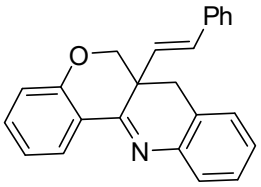
^{1}H NMR and ^{13}C NMR spectra were recorded at ambient temperature using 400 or 500 MHz spectrometers. The data are reported as follows: chemical shift in ppm from internal tetramethylsilane on the δ scale, multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants (Hz), and integration. High resolution mass spectra were acquired on an LTQ FT spectrometer, and were obtained by peak matching. Melting points are reported uncorrected. Analytical thin layer chromatography was performed on 0.25 mm extra hard silica gel plates with UV254 fluorescent indicator. Chromatography was performed using with 300-400 mesh silica gel (SiO_2). Unless otherwise noted, all reactions were performed under air atmosphere. All reagents and solvents were obtained from commercial sources and, where appropriate, purified prior to use. The fused indolines **1a-u** [1], **1x-z**[1] was prepared according to literature method and their spectral data matched literature values.

2. Synthesis of compounds 3, 4, and 5x



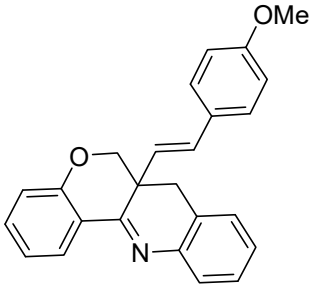
General procedure A: In a Teflon-sealed flask was charged with compound **1** (0.2 mmol) and MeOH (2.0 mL), after stirring for 10 min, $NaBH_4$ (0.8 mmol, 4.0 equiv) was added. The reaction vessel was stirred vigorously at room temperature (about 30 °C) for 1 h until the substrate **1** disappeared (monitored by TLC). At this time, the reaction was quenched by H_2O (5 mL) and extracted with EtOAc (10 mL × 3). The combined organic layers were dried over Na_2SO_4, and filtered. The solvent was removed under reduced pressure. Then, AgOTf (0.3 mmol, 1.5 equiv), PPh_3 (0.3 mmol, 1.5 equiv.) and CBr_4 (0.3 mmol, 1.5 equiv.) were added to the residue under N_2

atmosphere, dissolved in DCM (3.0 mL). The mixture was stirred vigorously at 70 °C for 5-20 h (monitored by TLC). At this time, the reaction was quenched by H_2O (5 mL) and extracted with DCM (10 mL × 3). The combined organic layers were dried over Na_2SO_4, and filtered. the solvent was removed under reduced pressure and the crude product was purified by flash column chromatography (the crude residue was dry loaded with silica gel, 1/50 to 1/30, ethyl acetate/petroleum ether) to provide quinolones **3** or **4**.



3a

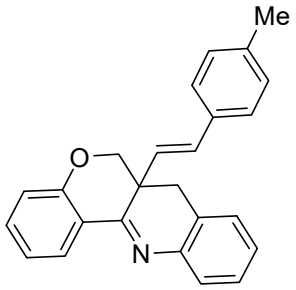
(*E*)-6a-Styryl-6a,7-dihydro-6H-chromeno[4,3-b]quinoline (3a), yellow solid, 0.064 g, 95% yield; Mp: 165−166 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 7.6 Hz, 1H), 7.45 (d, J = 7.2 Hz, 1H), 7.35–7.32 (m, 1H), 7.27–7.23 (m, 1H), 7.16–7.04 (m, 8H), 6.90 (d, J = 8.0 Hz, 1H), 6.35 (d, J = 16.0 Hz, 1H), 6.15 (d, J = 16.4 Hz, 1H), 4.46 (d, J = 10.8 Hz, 1H), 4.30 (d, J = 10.8 Hz, 1H), 2.94 (d, J = 16.0 Hz, 1H), 2.74 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.1, 158.5, 144.2, 136.5, 132.7, 131.7, 128.3, 127.9, 127.8, 127.6, 127.0, 126.9, 126.5, 126.4, 126.3, 124.8, 121.8, 120.4, 117.6, 74.8, 41.7, 32.6; IR (thin film) 2926, 1610, 1466, 1207, 1037, 965, 758, 695 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{20}NO$ $[M + H]^+$: 338.1539, found 338.1542.



3b

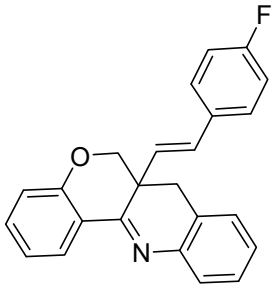
(*E*)-6a-(4-Methoxystyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinoline (3b), yellow solid, 0.072 g, 98% yield. Mp: 160−161 ℃; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (d, J = 7.5 Hz, 1H), 7.44 (d, J = 7.5 Hz, 1H), 7.34–7.31 (m, 1H), 7.26–7.23 (m, 1H), 7.12–7.03 (m, 5H), 6.90 (d, J = 8.0 Hz, 1H), 6.71–6.69 (m, 2H), 6.29 (d, J = 16.0

Hz, 1H), 6.00 (d, J = 16.5 Hz, 1H), 4.45 (d, J = 11.0 Hz, 1H), 4.29 (d, J = 11.0 Hz, 1H), 2.94 (s, 3H), 2.93 (d, J = 15.5 Hz, 1H), 2.73 (d, J = 15.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.3, 159.2, 158.6, 144.3, 132.7, 131.1, 129.4, 128.0, 127.8, 127.6, 127.0, 126.9, 126.5, 124.9, 124.1, 121.8, 120.5, 117.6, 113.7, 74.9, 55.2, 41.7, 32.7; IR (thin film) 3037, 2963, 2920, 1605, 1590, 1465, 1253, 1023, 824 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO_2$ $[M + H]^+$: 368.1645, found 368.1632.



3c

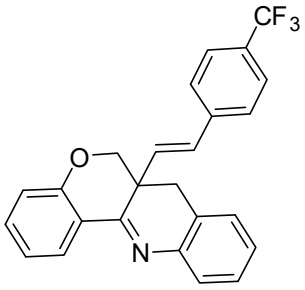
(*E*)-6a-(4-Methylstyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3c), yellow solid, 0.066 g, 94% yield. Mp: 140−141 ℃; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (d, J = 7.5 Hz, 1H), 7.44 (d, J = 7.5 Hz, 1H), 7.34–7.31 (m, 1H), 7.26–7.23 (m, 1H), 7.11–7.05 (m, 5H), 6.98–6.96 (m, 2H), 6.90 (d, J = 8.5 Hz, 1H), 6.31 (d, J = 16.0 Hz, 1H), 6.08 (d, J = 16.5 Hz, 1H), 4.45 (d, J = 11.0 Hz, 1H), 4.29 (d, J = 11.0 Hz, 1H), 2.93 (d, J = 15.5 Hz, 1H), 2.73 (d, J = 15.5 Hz, 1H), 2.23 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 160.2, 158.6, 144.2, 137.4, 133.7, 132.7, 131.6, 129.0, 128.0, 127.8, 127.0, 126.9, 126.5, 126.3, 125.3, 124.9, 121.8, 120.4, 117.6, 74.9, 41.7, 32.6, 21.1; IR (thin film) 2924, 1607, 1588, 1452, 1232, 1043, 824, 764 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO$ $[M + H]^+$: 352.1696, found 352.1684.



3d

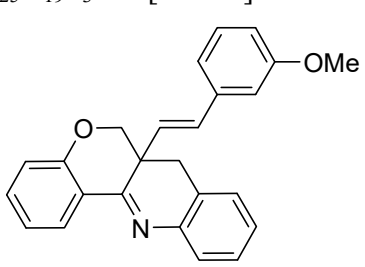
(*E*)-6a-(4-Fluorostyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3d), yellow solid, 0.065 g, 92% yield. Mp: 150−151 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J

= 7.6 Hz, 1H), 7.45 (d, *J* = 7.6 Hz, 1H), 7.36–7.32 (m, 1H), 7.28–7.24 (m, 1H), 7.12–7.04 (m, 5H), 6.91–6.82 (m, 3H), 6.31(d, *J* = 16.4 Hz, 1H), 6.05 (d, *J* = 16.0 Hz, 1H), 4.46 (d, *J* = 10.8 Hz, 1H), 4.31 (d, *J* = 11.2 Hz, 1H), 2.95 (d, *J* = 15.6 Hz, 1H), 2.74 (d, *J* = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.5 (d, *J* = 245.7 Hz), 160.0, 158.5, 144.2, 132.8, 132.7 (d, *J* = 2.9 Hz), 130.6, 128.0, 127.9, 127.8, 127.1, 126.9, 126.5, 126.2, 124.7, 121.9, 120.4, 117.6, 115.3 (d, *J* = 21.9 Hz), 74.8, 41.7, 32.6; IR (thin film) 2921, 1590, 1508, 1450, 1288, 1037, 817, 759 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}FNO$ $[M + H]^+$: 356.1445, found 356.1433.



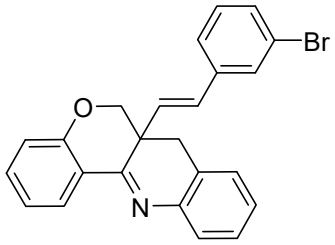
3e

(*E*)-6a-(4-(Trifluoromethyl)styryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3e), yellow solid, 0.071 g, 88% yield. Mp: 153−154 ℃; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.40 (d, *J* = 7.5 Hz, 1H), 7.46 (d, *J* = 7.5 Hz, 1H), 7.39–7.33 (m, 3H), 7.28–7.20 (m, 3H), 7.11–7.07 (m, 3H), 6.91 (d, *J* = 8.5 Hz, 1H), 6.36 (d, *J* = 16.5 Hz, 1H), 6.22 (d, *J* = 16.0 Hz, 1H), 4.47 (d, *J* = 11.0 Hz, 1H), 4.32 (d, *J* = 11.0 Hz, 1H), 2.97 (d, *J* = 16.0 Hz, 1H), 2.75 (d, *J* = 15.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.7, 158.6, 144.2, 139.9, 132.9, 130.6, 129.5(q, *J* = 27.4 Hz), 129.3, 128.0, 127.9, 127.3(q, *J* = 269.6 Hz), 127.2, 127.0, 126.6, 126.5, 125.2(q, *J* = 3.6 Hz), 124.5, 122.0, 120.4, 117.7, 74.7, 41.9, 32.5; IR (thin film) 2925, 1612, 1590, 1450, 1213, 1038, 816, 766 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{19}F_3NO$ $[M + H]^+$: 406.1413, found 406.1399.



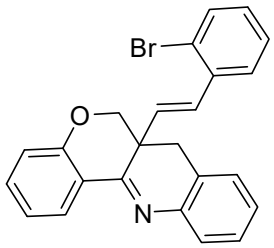
3f

(*E*)-6a-(3-Methoxystyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3f), yellow solid, 0.073 g, 99% yield. Mp: 164−165 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 7.6 Hz, 1H), 7.44 (d, J = 8.0 Hz, 1H), 7.36–7.32 (m, 1H), 7.27–7.24 (m, 1H), 7.13–7.04 (m, 4H), 6.91 (d, J = 8.4 Hz, 1H), 6.78 (d, J = 7.6 Hz, 1H), 6.69–6.68 (m, 2H), 6.32 (d, J = 16.0 Hz, 1H), 6.14 (d, J = 16.4 Hz, 1H), 4.47 (d, J = 10.8 Hz, 1H), 4.32 (d, J = 10.8 Hz, 1H), 3.71 (s, 3H), 2.96 (d, J = 15.6 Hz, 1H), 2.75 (d, J = 15.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.1, 159.6, 158.6, 144.3, 138.0, 132.7, 131.7, 129.3, 128.0, 127.9, 127.1, 126.9, 126.8, 126.5, 124.8, 121.8, 120.4, 119.1, 117.6, 113.3, 111.9, 74.8, 55.2, 41.8, 32.6; IR (thin film) 2963, 2925, 1594, 1466, 1263, 1035, 866, 766, 690 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO_2$ $[M + H]^+$: 368.1645, found 368.1636.



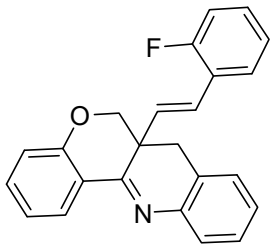
3g

(*E*)-6a-(3-Bromostyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3g), yellow solid, 0.076 g, 91% yield. Mp: 103−104 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 7.6 Hz, 1H), 7.45 (d, J = 7.6 Hz, 1H), 7.36–7.22 (m, 4H), 7.13–6.98 (m, 5H), 6.91 (d, J = 8.0 Hz, 1H), 6.26 (d, J = 16.0 Hz, 1H), 6.14 (d, J = 16.0 Hz, 1H), 4.45 (d, J = 10.8 Hz, 1H), 4.30 (d, J = 11.2 Hz, 1H), 2.95 (d, J = 15.6 Hz, 1H), 2.73 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.7, 158.5, 144.2, 138.6, 132.8, 130.5, 130.4, 129.8, 129.3, 128.1, 128.0, 127.9, 127.2, 127.0, 126.5, 125.1, 124.6, 122.5, 121.9, 120.4, 117.7, 74.8, 41.8, 32.5; IR (thin film) 2921, 1608, 1588, 1451, 1233, 1038, 878, 763, 686 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}BrNO$ $[M + H]^+$: 416.0645, found 416.0631.



3h

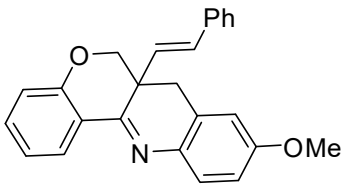
(*E*)-6a-(2-Bromostyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3h), yellow solid, 0.075 g, 90% yield. Mp: 130−131 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 8.0 Hz, 1H), 7.46 (d, J = 8.0 Hz, 1H), 7.37–7.24 (m, 4H), 7.15–7.04 (m, 4H), 6.94–6.91 (m, 2H), 6.76 (d, J = 16.0 Hz, 1H), 6.07 (d, J = 16.4 Hz, 1H), 4.47 (d, J = 10.8 Hz, 1H), 4.32 (d, J = 11.2 Hz, 1H), 2.97 (d, J = 15.6 Hz, 1H), 2.79 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.7, 158.5, 144.2, 136.7, 132.7, 132.6, 131.3, 129.0, 128.8, 128.0, 127.9, 127.2, 127.1, 127.0, 126.9, 126.6, 124.7, 123.7, 121.9, 120.3, 117.5, 74.8, 41.8, 32.2; IR (thin film) 3066, 2963, 2921, 1608, 1589, 1466, 1262, 1022, 756 , 661cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}BrNO$ $[M + H]^+$: 416.0645, found 416.0630.



3i

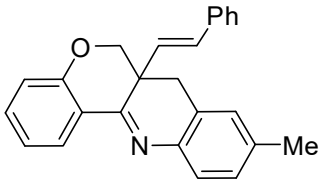
(*E*)-6a-(2-Fluorostyryl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3i), yellow solid, 0.057 g, 80% yield (ran for 30 h). Mp: 158−159 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (d, J = 7.5 Hz, 1H), 7.45 (d, J = 7.5 Hz, 1H), 7.35–7.32 (m, 1H), 7.27–7.19 (m, 2H), 7.13–7.04 (m, 4H), 6.93–6.85 (m, 3H), 6.52 (d, J = 16.0 Hz, 1H), 6.24 (d, J = 16.5 Hz, 1H), 4.47 (d, J = 11.0 Hz, 1H), 4.31 (d, J = 11.0 Hz, 1H), 2.95 (d, J = 16.0 Hz, 1H), 2.76 (d, J = 15.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 161.0 (d, J = 248.8 Hz), 159.8, 158.5, 144.2, 132.8, 129.0, 128.9, 128.8, 128.7, 127.9, 127.5 (d, J = 3.8 Hz), 127.1 (d, J = 20.9 Hz), 126.6, 124.7, 124.4, 124.3, 123.8 (d, J = 3.6 Hz), 121.9, 120.3, 117.6, 115.6 (d, J = 21.8 Hz), 74.8, 42.0, 32.4; IR (thin film) 2960, 2928,

1610, 1590, 1464, 1225, 1038, 744 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}FNO$ [M + H]$^+$: 356.1445, found 356.1431.



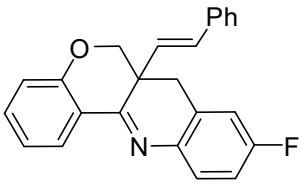
3j

(*E*)-9-Methoxy-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3j), yellow solid, 0.070 g, 95% yield. Mp: 160−161 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.35 (d, *J* = 6.8 Hz, 1H), 7.38 (d, *J* = 8.0 Hz, 1H), 7.32–7.29 (m, 1H), 7.24–7.17 (m, 5H), 7.06–7.03 (m, 1H), 6.89 (d, *J* = 7.6 Hz, 1H), 6.78 (d, *J* = 7.2 Hz, 1H), 6.63 (s, 1H), 6.35 (d, *J* = 16.0 Hz, 1H), 6.15 (d, *J* = 16.4 Hz, 1H), 4.45 (d, *J* = 10.8 Hz, 1H), 4.29 (d, *J* = 10.8 Hz, 1H), 3.78 (s, 3H), 2.94 (d, *J* = 15.6 Hz, 1H), 2.70 (d, *J* = 15.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.5, 158.2, 157.6, 138.2, 136.5, 132.2, 131.7, 128.3, 128.1, 127.6, 126.5, 126.4, 126.3, 126.2, 121.8, 120.6, 117.6, 114.1, 112.1, 74.8, 55.4, 41.7, 33.0; IR (thin film) 2960, 2925, 1613, 1588, 1465, 1261, 1035, 807, 766 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO_2$ [M + H]$^+$: 368.1645, found 368.1635.



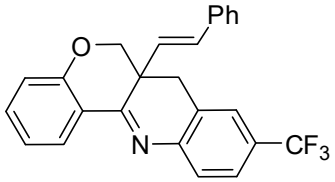
3k

(*E*)-9-Methyl-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3k), yellow solid, 0.070 g, 99% yield. Mp: 142−143 ℃; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.37 (d, *J* = 7.5 Hz, 1H), 7.33–7.31 (m, 2H), 7.17–7.05 (m, 7H), 6.89–6.87 (m, 2H), 6.34 (d, *J* = 16.0 Hz, 1H), 6.14 (d, *J* = 16.0 Hz, 1H), 4.45 (d, *J* = 10.5 Hz, 1H), 4.29 (d, *J* = 11.0 Hz, 1H), 2.91 (d, *J* = 15.5 Hz, 1H), 2.68 (d, *J* = 16.0 Hz, 1H), 2.30 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.1, 158.4, 142.0, 136.9, 136.5, 132.5, 131.7, 128.8, 128.4, 128.3, 127.6, 126.7, 126.6, 126.4, 126.3, 124.5, 121.8, 120.6, 117.6, 74.8, 41.8, 32.7, 21.2; IR (thin film) 2925, 1608, 1587, 1466, 1231, 1037, 743, 694 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO$ [M + H]$^+$: 352.1696, found 352.1683.



3l

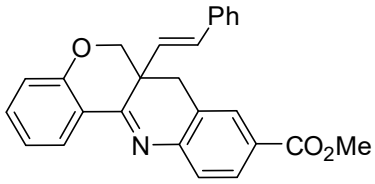
(*E*)-9-Fluoro-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3l), yellow solid, 0.065 g, 91% yield. Mp: 142−143 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.35 (d, J = 8.0 Hz, 1H), 7.42–7.39 (m, 1H), 7.36–7.33 (m, 1H), 7.18–7.14 (m, 5H), 7.07–7.04 (m, 1H), 6.95–6.89 (m, 2H), 6.82 (d, J = 8.0 Hz, 1H), 6.33 (d, J = 16.0 Hz, 1H), 6.13 (d, J = 16.0 Hz, 1H), 4.46 (d, J = 11.0 Hz, 1H), 4.30 (d, J = 11.0 Hz, 1H), 2.94 (d, J = 16.0 Hz, 1H), 2.73 (d, J = 15.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.2 (d, J = 245.0 Hz), 159.5, 158.5, 140.6 (d, J = 2.8 Hz), 136.3, 132.8, 132.0, 128.4, 128.3, 127.7, 126.9 (d, J = 8.3 Hz), 126.4, 126.3, 126.0, 121.9, 120.2, 117.7, 115.1 (d, J = 22.8 Hz), 114.5 (d, J = 21.9 Hz), 74.7, 41.5, 32.8; IR (thin film) 2926, 1615, 1598, 1466, 1261, 1038, 750, 692 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}FNO$ $[M + H]^+$: 356.1445, found 356.1433.



3m

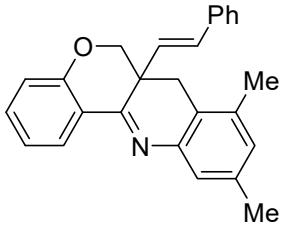
(*E*)-6a-Styryl-9-(trifluoromethyl)-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3m), yellow solid, 0.074 g, 91% yield. Mp: 132−133 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 7.6 Hz, 1H), 7.52 (s, 2H), 7.40–7.34 (m, 2H), 7.21–7.14 (m, 5H), 7.10–7.06 (m, 1H), 6.92 (d, J = 8.4 Hz, 1H), 6.32 (d, J = 16.4 Hz, 1H), 6.12 (d, J = 16.4 Hz, 1H), 4.50 (d, J = 11.2 Hz, 1H), 4.33 (d, J = 10.8 Hz, 1H), 2.98 (d, J = 16.0 Hz, 1H), 2.82 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.7, 159.0, 146.9, 136.2, 133.5, 132.3, 129.0 (q, J = 32.1 Hz), 128.4, 128.2 (q, J = 269.8 Hz), 127.9, 126.9, 126.7, 126.5, 125.8, 125.5, 125.1 (q, J = 3.6 Hz), 125.0 (q, J = 8.0 Hz), 122.0, 120.0, 117.8, 74.7, 41.7, 32.5; IR (thin film) 3034, 2923, 1610, 1587, 1467,

1267, 1037, 743, 689 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{19}F_3NO$ $[M + H]^+$: 406.1413, found 406.1400.



3n

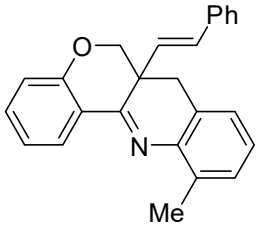
(*E*)-Methyl 6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinoline-9-carboxylate (3n), yellow solid, 0.077 g, 97% yield). Mp: 183−184 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 7.6 Hz, 1H), 7.95 (d, J = 8.0 Hz, 1H), 7.80 (s, 1H), 7.49 (d, J = 8.0 Hz, 1H), 7.39–7.36 (m, 1H), 7.16–7.06 (m, 6H), 6.92 (d, J = 8.0 Hz, 1H), 6.31 (d, J = 16.4 Hz, 1H), 6.12 (d, J = 16.4 Hz, 1H), 4.50 (d, J = 10.8 Hz, 1H), 4.33 (d, J = 11.6 Hz, 1H), 3.89 (s, 3H), 2.97 (d, J = 15.6 Hz, 1H), 2.83 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.7, 162.8, 159.0, 148.0, 136.2, 133.5, 132.1, 129.6, 129.4, 128.3, 128.1, 127.8, 126.7, 126.6, 126.4, 125.8, 124.9, 122.0, 120.0, 117.7, 74.7, 52.1, 41.7, 32.4; IR (thin film) 2960, 2925, 1731, 1615, 1598, 1465, 1261, 1039, 751, 693 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{26}H_{22}NO_3$ $[M + H]^+$: 396.1594, found 396.1580.



3o

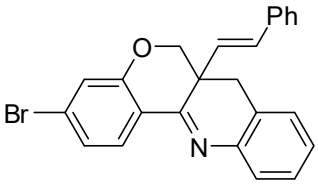
(*E*)-8,10-Dimethyl-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3o), yellow solid, 0.072 g, 98% yield). Mp: 186−187 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 8.37 (d, J = 7.5 Hz, 1H), 7.34–7.31 (m, 1H), 7.17–7.12 (m, 6H), 7.06–7.03 (m, 1H), 6.90 (d, J = 8.5 Hz, 1H), 6.82 (s, 1H), 6.33 (d, J = 16.0 Hz, 1H), 6.15 (d, J = 16.0 Hz, 1H), 4.48 (d, J = 11.0 Hz, 1H), 4.31 (d, J = 11.0 Hz, 1H), 2.85 (d, J = 15.5 Hz, 1H), 2.62 (d, J = 16.0 Hz, 1H), 2.30(s, 3H), 2.23(s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.2, 158.3, 143.8, 136.5, 134.8, 132.4, 131.2, 129.7, 128.2, 127.4, 126.8, 126.4, 126.3, 126.3, 125.7, 121.6, 120.4, 119.8, 117.4, 74.8, 41.4, 28.9, 20.8, 18.6; IR (thin

film) 2925, 2856, 1608, 1584, 1468, 1271, 1039, 742, 693 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{26}H_{24}NO$ $[M + H]^+$: 366.1852, found 366.1839.



3p

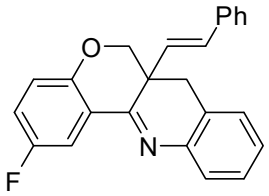
(*E*)-11-Methyl-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3p), yellow solid, 0.068 g, 97% yield. Mp: 116−117 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 8.42 (d, J = 7.5 Hz, 1H), 7.35–7.31 (m, 1H), 7.17–7.16 (m, 4H), 7.13–7.09 (m, 2H), 7.07–7.04 (m, 1H), 7.01–6.98 (m, 1H), 6.91–6.89 (m, 2H), 6.37 (d, J = 16.0 Hz, 1H), 6.16 (d, J = 16.5 Hz, 1H), 4.47 (d, J = 11.0 Hz, 1H), 4.30 (d, J = 11.0 Hz, 1H), 2.91 (d, J = 15.5 Hz, 1H), 2.72 (d, J = 15.5 Hz, 1H), 2.56 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.5, 158.3, 142.2, 136.6, 135.1, 132.4, 131.5, 129.5, 128.3, 127.5, 126.6, 126.5, 126.4, 125.5, 124.6, 121.7, 120.9, 117.6, 75.0, 41.2, 33.0, 17.5; IR (thin film) 2961, 2924, 1600, 1577, 1450, 1262, 1018, 766, 696 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{22}NO$ $[M + H]^+$: 352.1696, found 352.1685.



3q

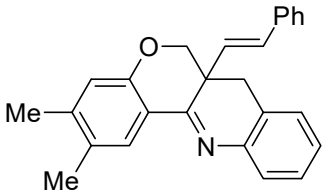
(*E*)-3-Bromo-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3q), yellow solid, 0.062 g, 75% yield. Mp: 156−157 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 8.24 (d, J = 8.5 Hz, 1H), 7.43 (d, J = 7.6 Hz, 1H), 7.28–7.24 (m, 1H), 7.19–7.07 (m, 9H), 6.33 (d, J = 16.0 Hz, 1H), 6.11 (d, J = 16.0 Hz, 1H), 4.48 (d, J = 10.8 Hz, 1H), 4.30 (d, J = 11.2 Hz, 1H), 2.95 (d, J = 15.6 Hz, 1H), 2.75 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.2, 158.8, 144.0, 136.3, 131.9, 128.4, 128.1, 128.0, 127.8, 127.7, 127.3, 127.0, 126.6, 126.4, 126.0, 125.3, 124.7, 120.8, 119.5, 75.0, 41.7, 32.5; IR

(thin film) 3016, 2921, 1600, 1586, 1456, 1261, 1020, 759, 691 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}BrNO$ $[M + H]^+$: 416.0645, found 416.0631.



3r

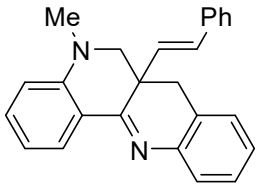
(*E*)-2-Fluoro-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3r), yellow solid, 0.065 g, 92% yield. Mp: 151−152 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 8.06 (dd, J = 8.8 Hz, 2.4 Hz, 1H), 7.44 (d, J = 7.6 Hz, 1H), 7.28–7.24 (m, 1H), 7.17–7.03 (m, 8H), 6.87 (dd, J = 8.8 Hz, 4.4 Hz, 1H), 6.33 (d, J = 16.4 Hz, 1H), 6.12 (d, J = 16.0 Hz, 1H), 4.46 (d, J = 11.2 Hz, 1H), 4.28 (d, J = 10.8 Hz, 1H), 2.95 (d, J = 16.0 Hz, 1H), 2.75 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 159.0 (d, J = 238.5 Hz), 154.7, 144.0, 136.4, 131.9, 128.3, 128.0 (d, J = 2.9 Hz), 127.7, 127.4, 127.1, 126.4, 126.1, 124.7, 121.4 (d, J = 7.3 Hz), 120.1, 119.9, 118.9 (d, J = 7.2 Hz), 111.8 (d, J = 24.0 Hz), 75.0, 41.6, 32.5; IR (thin film) 2962, 2927, 2853, 1592, 1487, 1258, 1031, 750, 696 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{19}FNO$ $[M + H]^+$: 356.1445, found 356.1434.



3s

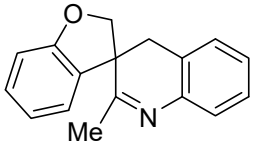
(*E*)-2,3-Dimethyl-6a-styryl-6a,7-dihydro-6*H*-chromeno[4,3-*b*]quinolone (3s), yellow solid, 0.059 g, 81% yield. Mp: 176−177 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.43 (d, J = 7.6 Hz, 1H), 7.26–7.23 (m, 1H), 7.16–7.07 (m, 7H), 6.69 (s, 1H), 6.35 (d, J = 16.4 Hz, 1H), 6.13 (d, J = 16.0 Hz, 1H), 4.42 (d, J = 10.8 Hz, 1H), 4.26 (d, J = 11.2 Hz, 1H), 2.93 (d, J = 15.6 Hz, 1H), 2.72 (d, J = 15.6 Hz, 1H), 2.26 (s, 3H), 2.24 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.5, 156.8, 144.4, 142.7, 136.6, 131.6, 130.3, 128.2, 127.9, 127.8, 127.5, 126.7, 126.6, 126.5, 126.4, 124.8, 118.2, 117.8, 74.9, 41.8, 32.6, 20.1, 18.9; IR (thin film) 2925, 1587, 1451, 1242, 1028, 864,

763, 693 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{26}H_{24}NO$ $[M + H]^+$: 366.1852, found 366.1840.



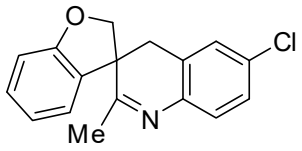
3t

(*E*)-5-methyl-6a-styryl-5,6,6a,7-tetrahydrodibenzo[*b*,*h*][1,6]naphthyridine (3t), yellow solid, 0.057 g, 81% yield. Mp: 156−157 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 8.45 (d, J = 8.0 Hz, 1H), 7.37 (d, J = 7.6 Hz, 1H), 7.32–7.28 (m, 1H), 7.22–7.10 (m, 6H), 7.07–7.03 (m, 2H), 6.84–6.80 (m, 1H), 6.67 (d, J = 8.0 Hz, 1H), 6.31 (d, J = 16.0 Hz, 1H), 6.18 (d, J = 16.0 Hz, 1H), 3.62 (d, J = 11.6 Hz, 1H), 3.31 (d, J = 11.6 Hz, 1H), 3.08 (d, J = 15.6 Hz, 1H), 2.94 (s, 3H), 2.77 (d, J = 15.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.7, 150.2, 144.9, 137.0, 132.5, 130.9, 128.3, 128.1, 127.7, 127.6, 127.4, 127.2, 126.6, 126.4, 126.3, 125.4, 119.6, 118.0, 112.8, 62.9, 42.8, 39.6, 34.8; IR (thin film) 2961, 2925, 1610, 1581, 1448, 1261, 1028, 746, 688 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{25}H_{23}N_2$ $[M + H]^+$: 351.1856, found 351.1843.



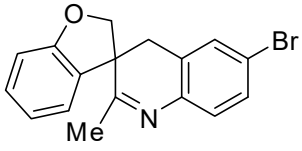
4u

2'-Methyl-2*H*,4'*H*-spiro[benzofuran-3,3'-quinoline] (4u), yellow oil, 0.033 g, 67% yield. ^1H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, J = 7.6 Hz, 1H), 7.33–7.29 (m, 1H), 7.22–7.15 (m, 2H), 7.12 (d, J = 7.2 Hz, 1H), 7.03 (d, J = 7.2 Hz, 1H), 6.90–6.85 (m, 2H), 4.43 (d, J = 9.2 Hz, 1H), 4.35 (d, J = 9.2 Hz, 1H), 3.19 (d, J = 16.0 Hz, 1H), 2.98 (d, J = 16.4 Hz, 1H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.4, 160.0, 143.5, 130.5, 129.4, 128.1, 128.0, 127.0, 126.3, 125.3, 124.1, 121.3, 110.1, 78.9, 50.1, 36.7, 24.1; IR (thin film) 3048, 2922, 2851, 1593, 1458, 1238, 1022, 751 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{16}NO$ $[M + H]^+$: 250.1226, found 250.1219.



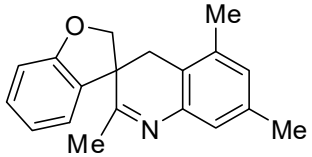
4v

6'-Chloro-2'-methyl-2H,4'H-spiro[benzofuran-3,3'-quinoline] (4v), yellow solid, 0.030 g, 53% yield. Mp: 65−66 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32–7.21 (m, 3H), 7.11 (s, 1H), 7.01 (d, J = 7.5 Hz, 1H), 6.91–6.86 (m, 2H), 4.43 (d, J = 9.5 Hz, 1H), 4.34 (d, J = 9.5 Hz, 1H), 3.16 (d, J = 16.0 Hz, 1H), 2.95 (d, J = 16.0 Hz, 1H), 2.13 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.9, 160.0, 142.0, 132.2, 130.0, 129.6, 128.1, 128.0, 127.5, 127.1, 124.1, 121.4, 110.3, 78.7, 49.8, 36.3, 24.2; IR (thin film) 2960, 2925, 2854, 1595, 1481, 1261, 1097, 752 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{15}ClNO$ $[M + H]^+$: 284.0837, found 284.0829.



4w

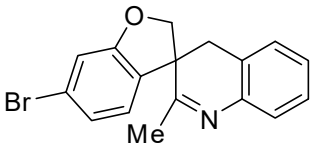
6'-Bromo-2'-methyl-2H,4'H-spiro[benzofuran-3,3'-quinoline] (4w), yellow solid, 0.048 g, 73% yield. Mp: 64−65 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 (d, J = 8.0 Hz, 1H), 7.25–7.21 (m, 3H), 7.01 (d, J = 7.0 Hz, 1H), 6.91–6.86 (m, 2H), 4.43 (d, J = 9.5 Hz, 1H), 4.33 (d, J = 9.5 Hz, 1H), 3.16 (d, J = 16.5 Hz, 1H), 2.95 (d, J = 16.0 Hz, 1H), 2.12 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.1, 160.0, 142.5, 131.1, 130.9, 129.9, 129.6, 127.8, 127.4, 124.0, 121.4, 120.2, 110.3, 78.6, 49.8, 36.2, 24.2; IR (thin film) 2964, 1617, 1480, 1262, 1022, 804, 751 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{15}BrNO$ $[M + H]^+$: 328.0332, found 328.0328.



4x

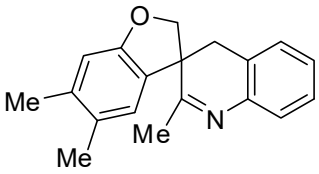
2',5',7'-Trimethyl-2H,4'H-spiro[benzofuran-3,3'-quinoline] (4x), yellow solid, 0.028 g, 50% yield. Mp: 68−69 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.25–7.20 (m, 1H), 7.07–7.06 (m, 2H), 6.92–6.85 (m, 3H), 4.40 (d, J = 9.5 Hz, 1H), 4.31 (d, J = 9.5 Hz,

1H), 2.96 (s, 2H), 2.33 (s, 3H), 2.20 (s, 3H), 2.13 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.6, 160.1, 143.3, 137.0, 135.5, 131.0, 129.7, 129.4, 125.0, 124.3, 121.4, 120.6, 110.2, 79.3, 50.2, 33.6, 24.1, 21.1, 18.7; IR (thin film) 2924, 1617, 1479, 1238, 1102, 977, 801, 750 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{19}H_{20}NO$ $[M + H]^+$: 278.1539, found 278.1533.



4y

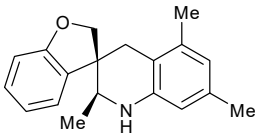
6-Bromo-2'-methyl-2H,4'H-spiro[benzofuran-3,3'-quinoline] (4y), yellow solid, 0.035 g, 54% yield. Mp: 63−64 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, J = 7.6 Hz, 1H), 7.33–7.29 (m, 1H), 7.20–7.16 (m, 1H), 7.12 (d, J = 6.8 Hz, 1H), 7.02–7.00 (m, 2H), 6.85 (d, J = 8.0 Hz, 1H), 4.47 (d, J = 9.6 Hz, 1H), 4.37 (d, J = 9.6 Hz, 1H), 3.15 (d, J = 16.0 Hz, 1H), 2.97 (d, J = 16.0 Hz, 1H), 2.13 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.4, 161.0, 143.4, 129.8, 128.2, 128.0, 127.2, 126.3, 125.1, 124.9, 124.4, 122.6, 113.8, 79.6, 49.7, 36.6, 24.1; IR (thin film) 2926, 1637, 1478, 1262, 1100, 971, 802, 749 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{15}BrNO$ $[M + H]^+$: 328.0332, found 328.0325.



4z

2',5,6-Trimethyl-2H,4'H-spiro[benzofuran-3,3'-quinoline] (4y), yellow solid, 0.029 g, 53% yield. Mp: 61−62 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, J = 7.6 Hz, 1H), 7.31–7.28 (m, 1H), 7.18–7.14 (m, 1H), 7.11 (d, J = 7.2 Hz, 1H), 6.76 (s, 1H), 6.66 (s, 1H), 4.38 (d, J = 9.2 Hz, 1H), 4.30 (d, J = 9.2 Hz, 1H), 3.17 (d, J = 16.4 Hz, 1H), 2.93 (d, J = 16.0 Hz, 1H), 2.23 (s, 3H), 2.16 (s, 3H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.0, 158.4, 143.5, 138.0, 129.2, 128.0, 127.9, 127.6, 126.9, 126.2, 125.5, 124.8, 111.1, 78.9, 50.1, 36.6, 24.1, 20.2, 19.4; IR (thin film) 2964, 1622, 1481,

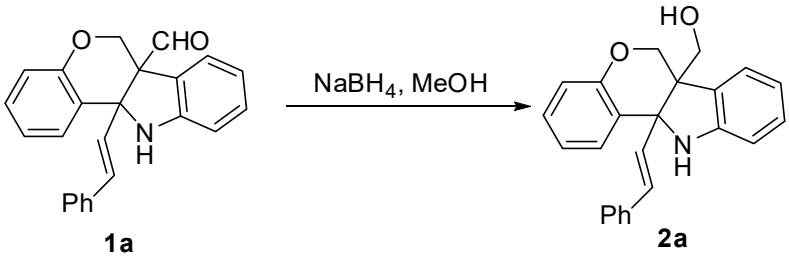
1262, 1096, 802, 751, 657 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{19}H_{20}NO$ $[M + H]^+$: 278.1539, found 278.1531.



5x (*dr* >20:1)

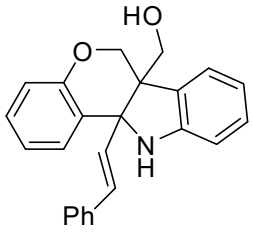
2',5',7'-Trimethyl-2',4'-dihydro-1'*H*,2*H*-spiro[benzofuran-3,3'-quinoline] (5x), which was obtained when compound **1x** was performed at the standard conditions. yellow oil, 0.017 g, 30% yield. ^1H NMR (400 MHz, $CDCl_3$) δ 7.16–7.12 (m, 1H), 6.90 (d, J = 7.2 Hz, 1H), 6.81–6.76 (m, 2H), 6.42 (s, 1H), 6.30 (s, 1H), 4.52 (d, J = 8.8 Hz, 1H), 4.23 (d, J = 9.2 Hz, 1H), 3.37 (q, J = 6.0 Hz, 1H), 2.95 (d, J = 16.8 Hz, 1H), 2.73 (d, J = 16.8 Hz, 1H), 2.24 (s, 3H), 2.13 (s, 3H), 0.99 (d, J = 6.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.6, 143.6, 137.4, 136.4, 130.3, 128.5, 125.7, 120.5, 120.4, 114.9, 112.3, 109.1, 81.1, 52.9, 46.6, 34.5, 21.1, 19.3, 16.6; IR (thin film) 3452, 2925, 2855, 1640, 1461, 1381, 1262, 1022, 802, 749 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{19}H_{22}NO$ $[M + H]^+$: 280.1696, found 280.1687.

3. Synthesis of compound 2a



Procedure B: In a 100 mL round-bottom flask was charged with fused indoline **1a** (2 mmol) and MeOH (20.0 mL), after stirring for 10 minutes, sodium borohydride (8 mmol, 4.0 equiv) was added. The mixture was stirred vigorously at room temperature (about 30 °C) for 1-4 h until the substrate **1a** disappeared (monitored by TLC). At this time, the reaction was quenched by H_2O (50 mL) and extracted with EtOAc (100 mL × 3). The combined organic layers were dried over Na_2SO_4, and filtered. The solvent was removed under reduced pressure and the crude product was purified by flash

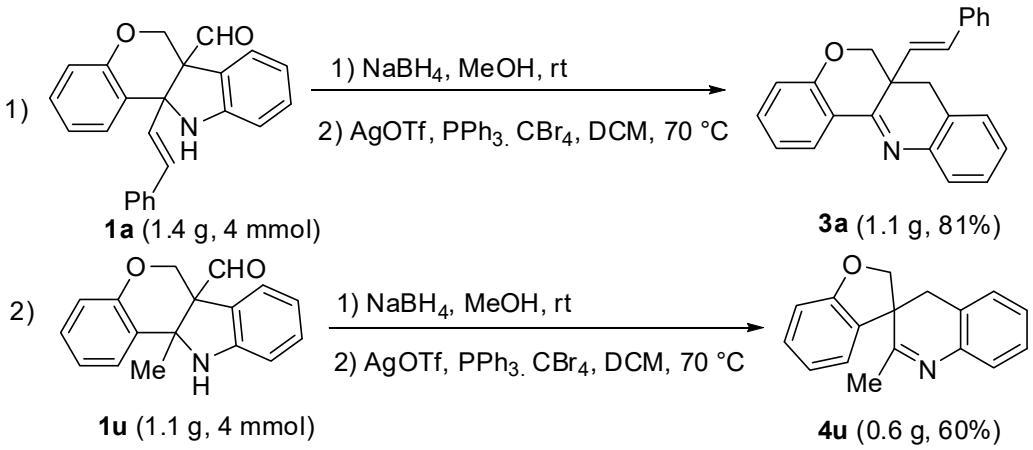
chromatography (the crude residue was dry loaded on silica gel, 1/30 to 1/4, ethyl acetate/petroleum ether) to provide indol methanol **2a**.



2a

(*E*)-(11a-Styryl-6,6a,11,11a-tetrahydrochromeno[4,3-b]indol-6a-yl)methanol (2a), yellow solid, 0.639 g, 90% yield. Mp: 155−156 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.38 (m, 2H), 7.33–7.30 (m, 2H), 7.27–7.24 (m, 2H), 7.17 (d, J = 8.0 Hz, 1H), 7.13–7.06 (m, 2H), 6.93–6.90 (m, 1H), 6.83–6.79 (m, 3H), 6.65 (d, J = 7.5 Hz, 1H), 6.52 (d, J = 16.0 Hz, 1H), 4.62 (d, J = 11.5 Hz, 1H), 4.28 (s, 1H), 4.22 (d, J = 11.5 Hz, 1H), 3.79 (d, J = 15.5 Hz, 1H), 3.66 (d, J = 15.5 Hz, 1H), 1.69 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 154.7, 148.8, 136.3, 131.2, 130.3, 128.8, 128.7, 128.3, 128.2, 127.9, 127.5, 126.6, 124.3, 121.8, 119.6, 117.5, 110.3, 68.9, 66.0, 64.1, 52.9; IR (thin film) 3029, 2928, 2868, 1607, 1486, 1270, 1099, 748 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{22}NO_2$ $[M + H]^+$: 356.1645, found 356.1631.

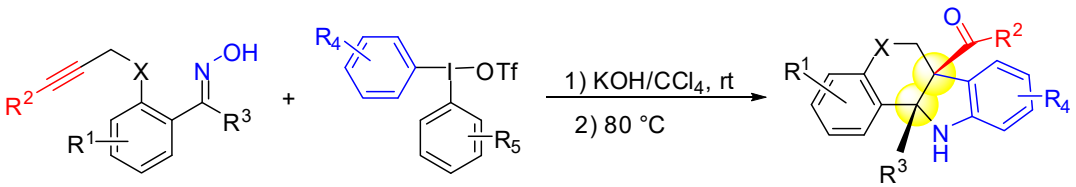
4. Gram scale preparation of 3a and 4u



General procedure C: In a 100 mL round-bottom flask was charged with fused indoline **1a** or **1u** (4 mmol) and MeOH (40.0 mL), after stirring for 10 minutes, sodium borohydride (16 mmol, 4.0 equiv) was added. The mixture was stirred

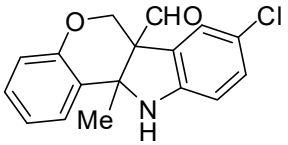
vigorously at room temperature (about 30 °C) for 1-4 h until the substrate **1a** or **1u** disappeared (monitored by TLC). At this time, the reaction was quenched by H_2O (50 mL) and extracted with EtOAc (100 mL × 3). The combined organic layers were dried over Na_2SO_4, and filtered. Then, AgOTf (6 mmol, 1.5 equiv), PPh_3 (6 mmol, 1.5 equiv) and CBr_4 (6 mmol, 1.5 equiv) were added to the residue under N_2 atmosphere, dissolved in DCM (40.0 mL). The mixture was stirred vigorously at 70 °C for 5-20 h (monitored by TLC). At this time, the reaction was quenched by H_2O (50 mL) and extracted with DCM (100 mL × 3). The combined organic layers were dried over Na_2SO_4, and filtered. the solvent was removed under reduced pressure and the crude product was purified by flash column chromatography (the crude residue was dry loaded with silica gel, 1/50 to 1/10, ethyl acetate/petroleum ether) to provide quinolones **3a** or **4u.**

5. Synthesis of starting material 1[1]:



1

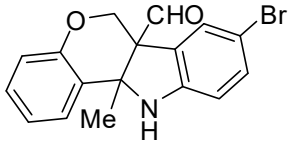
General procedure D: In a Teflon-sealed reaction flask was charged with alkynyl tethered oximes (2 mmol), diaryliodonium salts (4 mmol, 2.0 equiv) and KOH (2.4 mmol, 1.2 equiv) under an air atmosphere, CCl_4 (20 mL) was added. The reaction vessel was sealed with a Teflon cap and stirred vigorously at 25 °C for 3–12 h until the alkynyl tethered oximes disappeared (monitored by TLC). And then, the reaction mixture was stirred vigorously at 80 °C for 3–6 h. At this time, the solvent was removed under reduced pressure and the crude product was purified by flash chromatography (the crude residue was dry loaded with silica gel, 1/50 to 1/10, ethyl acetate/petroleum ether) to provide product **1**.



1v

8-Chloro-11a-methyl-6,6a,11,11a-tetrahydrochromeno[4,3-b]indole-6a-carbaldehyde, yellow solid , 0.191 g, 32%. Mp: 161−162 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ

9.72 (s, 1H), 7.31 (d, J = 7.6 Hz, 1H), 7.16−7.13 (m, 2H), 7.07 (d, J = 8.0 Hz, 1H), 7.01 (t, J = 7.2 Hz, 1H), 6.82 (d, J = 8.0 Hz, 1H), 6.56 (d, J = 8.0 Hz, 1H), 4.52 (d, J = 12.0 Hz, 1H), 4.37 (s, 3H), 4.32 (d, J = 12.0 Hz, 1H), 1.74 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.2, 153.5, 148.4, 129.9, 128.9, 128.2, 125.6, 125.5, 125.2, 124.7, 122.1, 117.6, 111.5, 86.0, 62.8, 61.0, 24.4; IR (thin film) 3574, 1651, 1478, 1383, 1262, 766, 652 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{15}ClNO_2$ $[M + H]^+$: 300.0786, found 300.0779.



1w

8-Bromo-11a-methyl-6,6a,11,11a-tetrahydrochromeno[4,3-b]indole-6a-carbaldehyde, yellow solid, 0.274 g, 40%. Mp: 148−149 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.71 (s, 1H), 7.30 (d, J = 7.5 Hz, 1H), 7.25 (s, 1H), 7.19−7.18 (m, 1H), 7.15−7.12 (m, 1H), 7.00 (t, J = 7.5 Hz, 1H), 6.81 (d, J = 8.0 Hz, 1H), 6.51 (d, J = 8.5 Hz, 1H), 4.49 (d, J = 12.5 Hz, 1H), 4.38 (s, 1H), 4.31 (d, J = 12.5 Hz, 1H), 1.74 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 198.1, 153.5, 148.8, 132.7, 128.9, 128.2, 128.0, 125.9, 125.6, 122.1, 117.6, 112.0, 111.6, 85.9, 62.8, 60.9, 24.4; IR (thin film) 3574, 3355, 1707, 1651, 1475, 1253, 814, 740 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{17}H_{15}BrNO_2$ $[M + H]^+$: 344.0281, found 344.0274.

6. References

[1] X.-P. Ma, K. Li, S.-Y. Wu, C. Liang, G.-F. Su, and D.-L. Mo, *Green. Chem.* 2017, **19**, 5761.

7. X-ray structure for compounds 3a

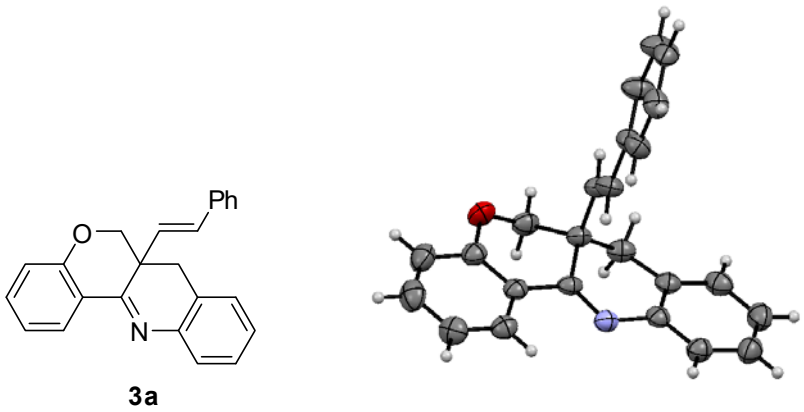
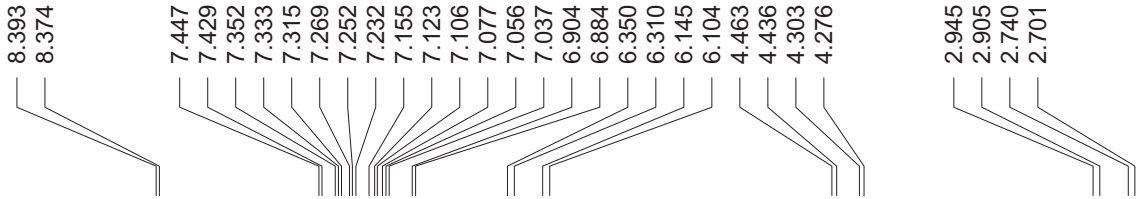
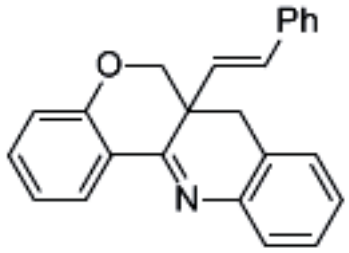


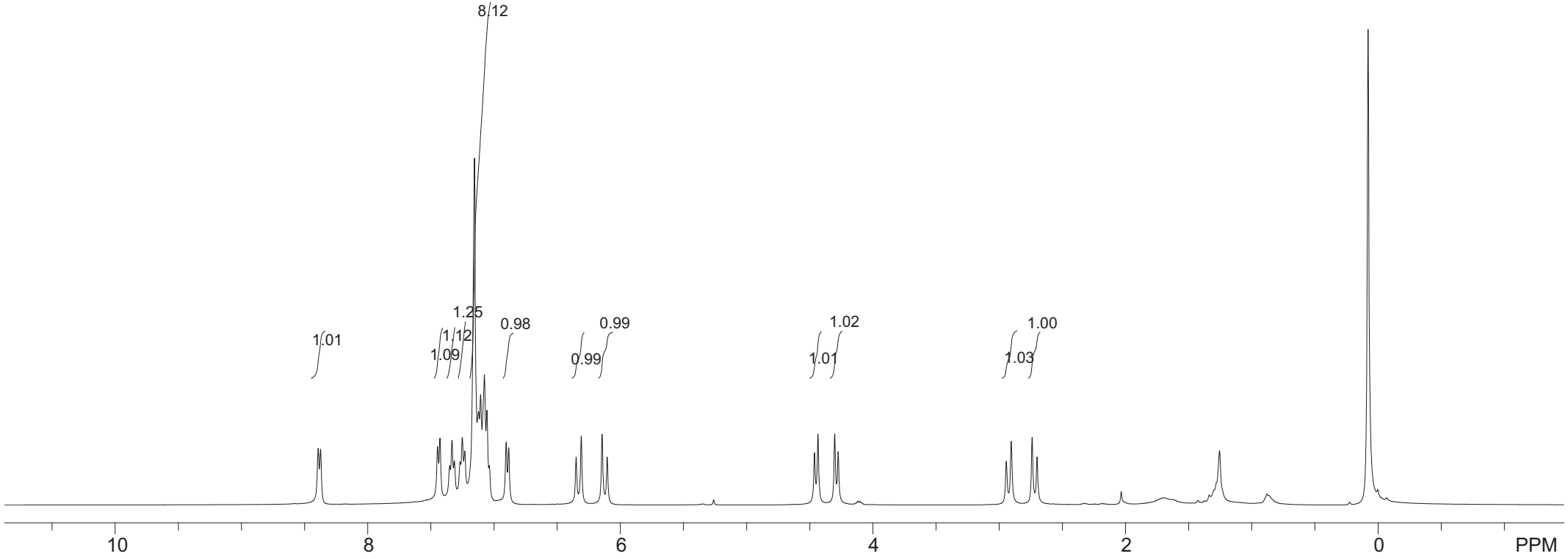
Figure S1: ORTEP diagram of **3a** at 50% ellipsoid probability

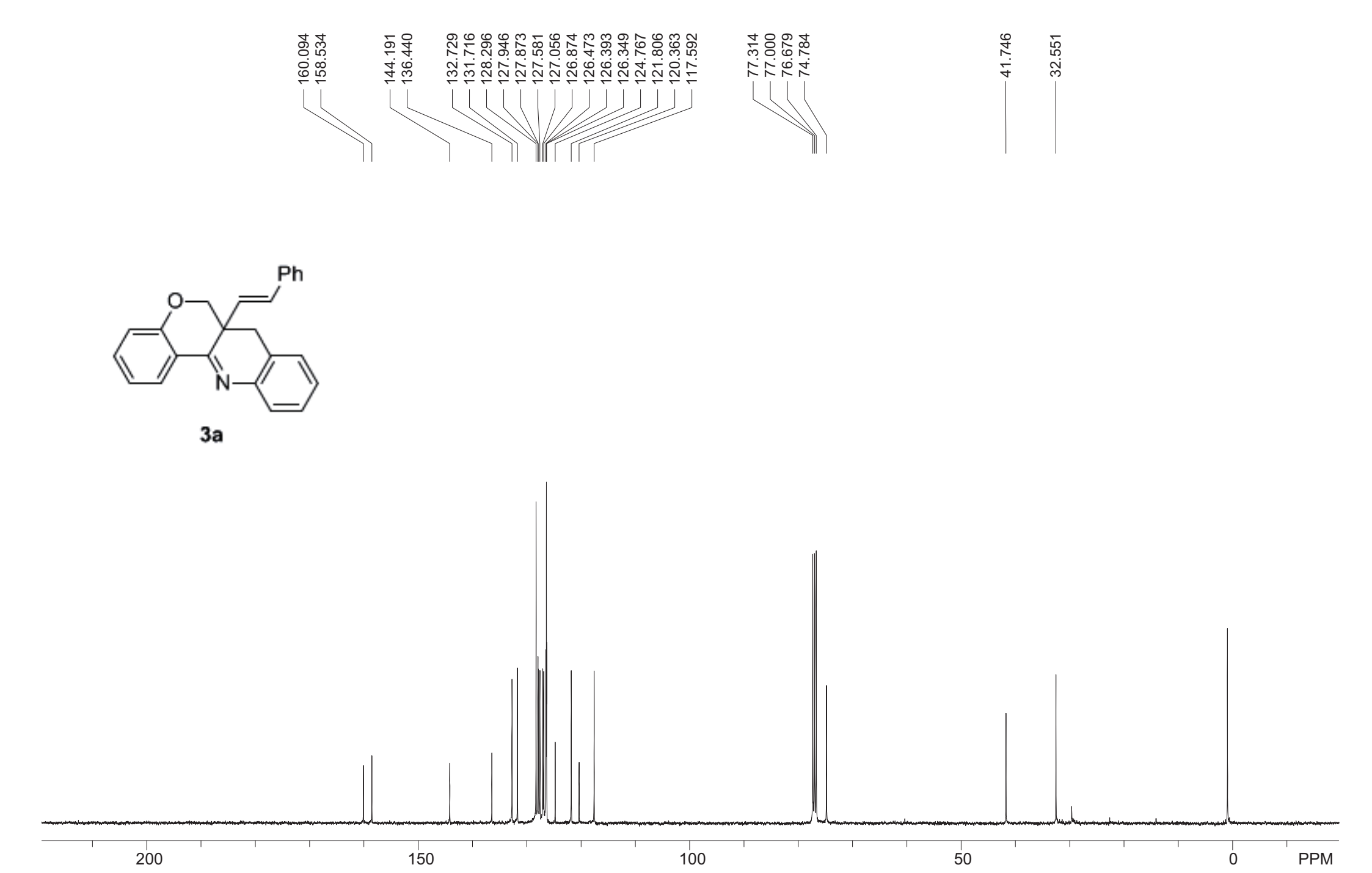
8. NMR spectra for 3, 4, 5x, 2a, 1v, and 1w

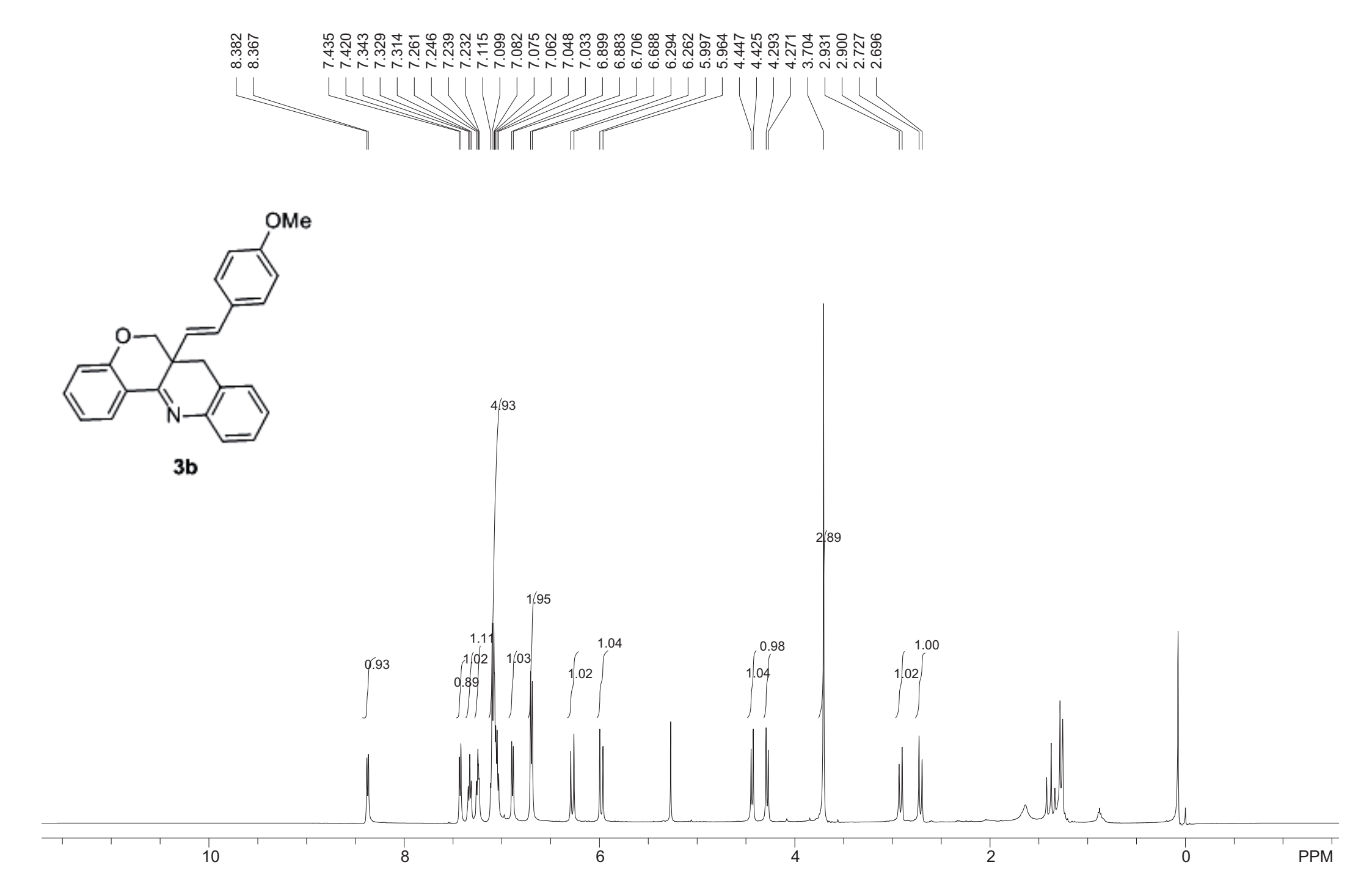

8.393
8.374
7.447
7.429
7.352
7.333
7.315
7.269
7.252
7.232
7.155
7.123
7.106
7.077
7.056
7.037
6.904
6.884
6.350
6.310
6.145
6.104
4.463
4.436
4.303
4.276
2.945
2.905
2.740
2.701

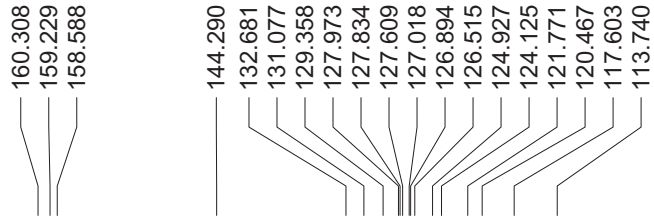

Ph
O
N

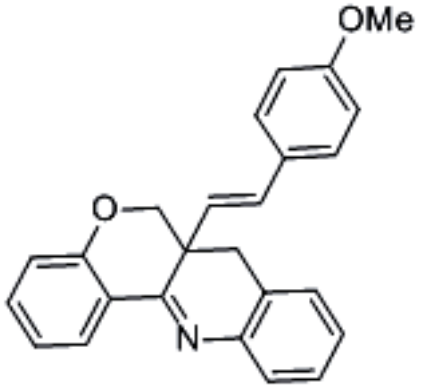
3a


8.12
1.01
1.09
1.12
1.25
0.98
0.99
0.99
1.01
1.02
1.03
1.00
10
8
6
4
2
0
PPM

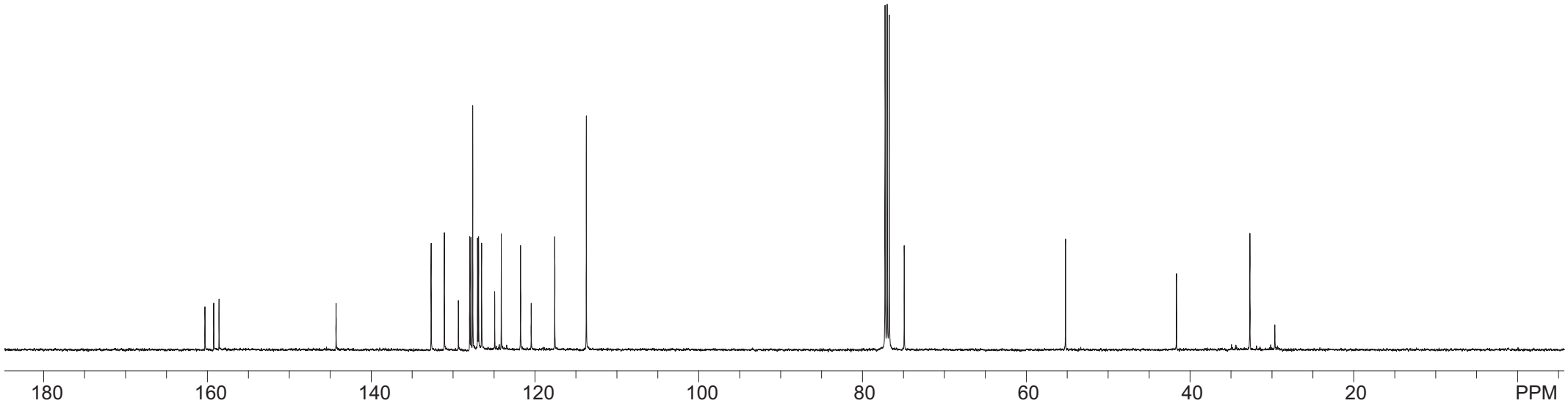

160.094
158.534
144.191
136.440
132.729
131.716
128.296
127.946
127.873
127.581
127.056
126.874
126.473
126.393
126.349
124.767
121.806
120.363
117.592
77.314
77.000
76.679
74.784
41.746
32.551
Ph
O
N
3a
200
150
100
50
0
PPM

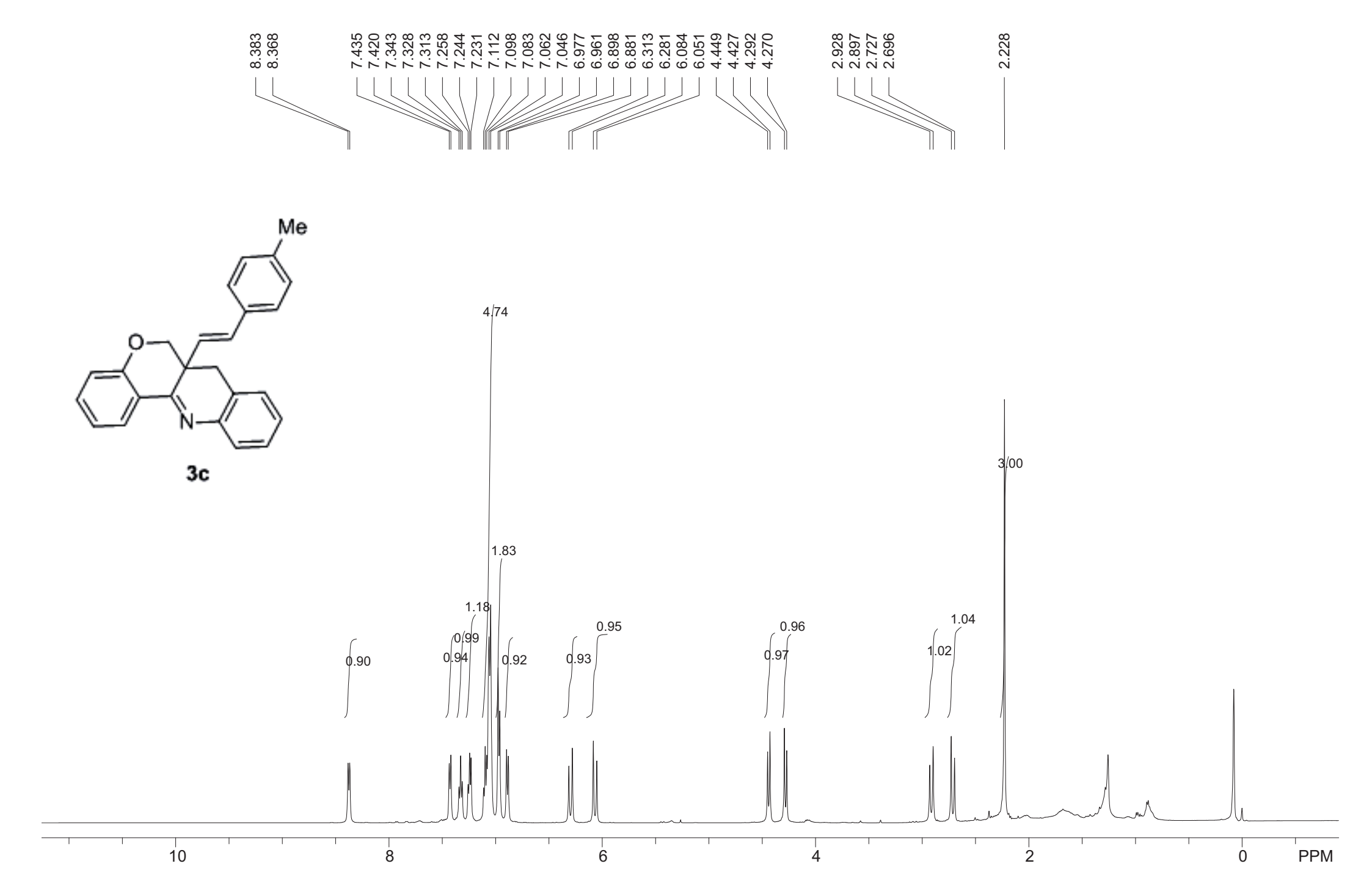

8.382
8.367
7.435
7.420
7.343
7.329
7.314
7.261
7.246
7.239
7.232
7.115
7.099
7.082
7.075
7.062
7.048
7.033
6.899
6.883
6.706
6.688
6.294
6.262
5.997
5.964
4.447
4.425
4.293
4.271
3.704
2.931
2.900
2.727
2.696
OMe
O
N
3b
4.93
2.89
1.95
1.11
1.04
1.03
1.02
0.98
1.00
0.93
0.89
10
8
6
4
2
0
PPM

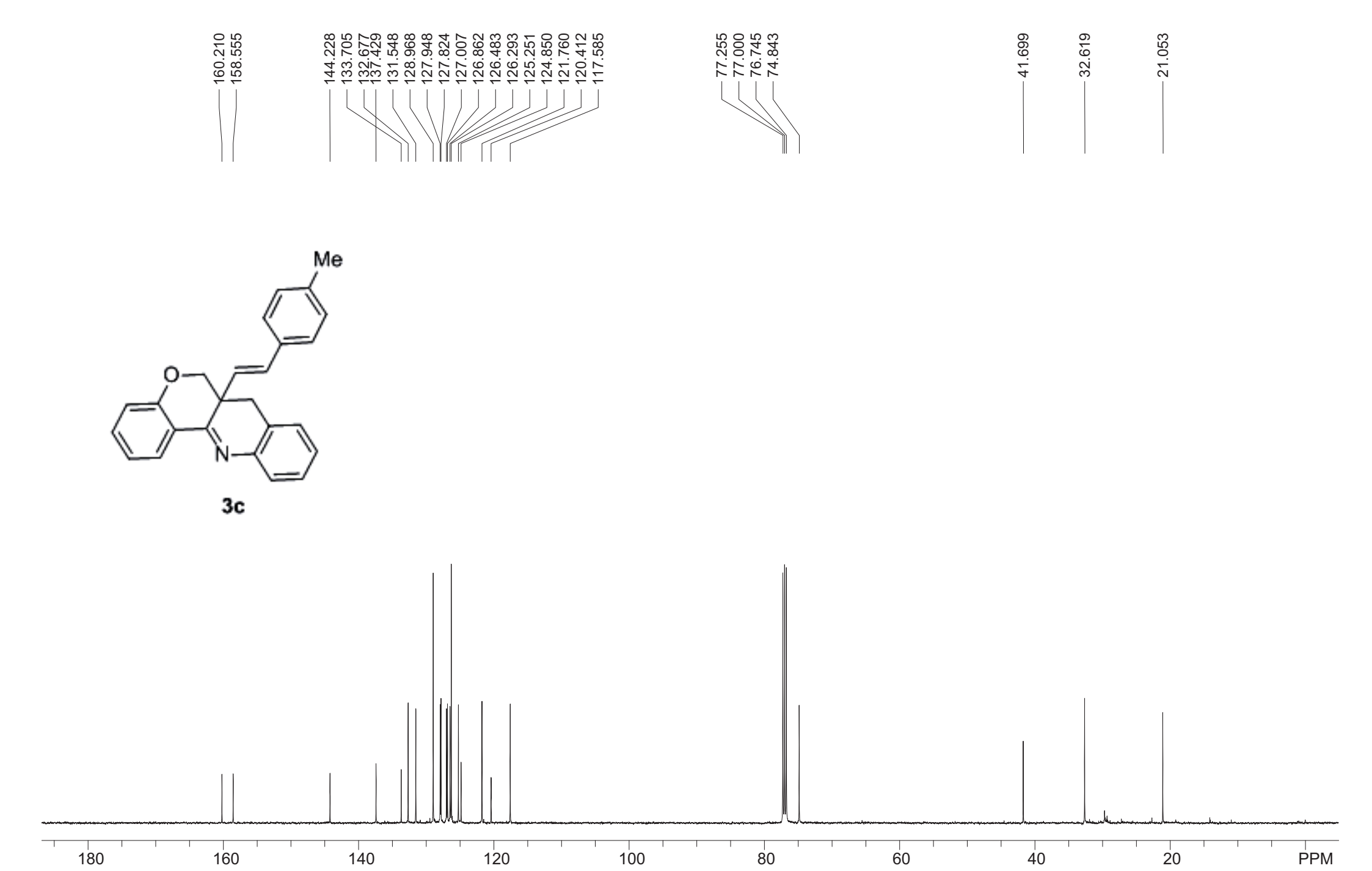

160.308
159.229
158.588
144.290
132.681
131.077
129.358
127.973
127.834
127.609
127.018
126.894
126.515
124.927
124.125
121.771
120.467
117.603
113.740
77.266
77.011
76.756
74.926
55.228
41.673
32.724

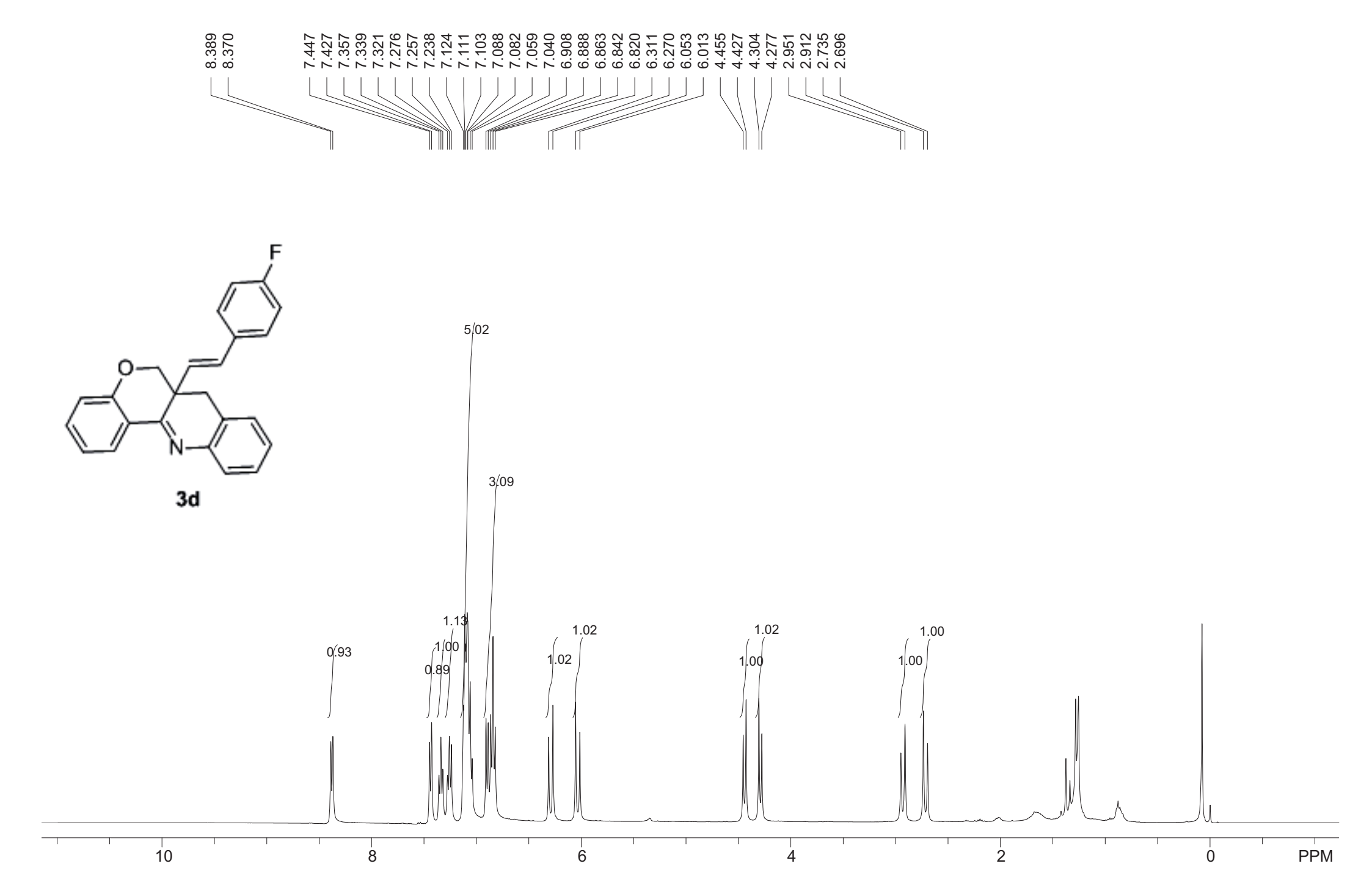

OMe
O
N

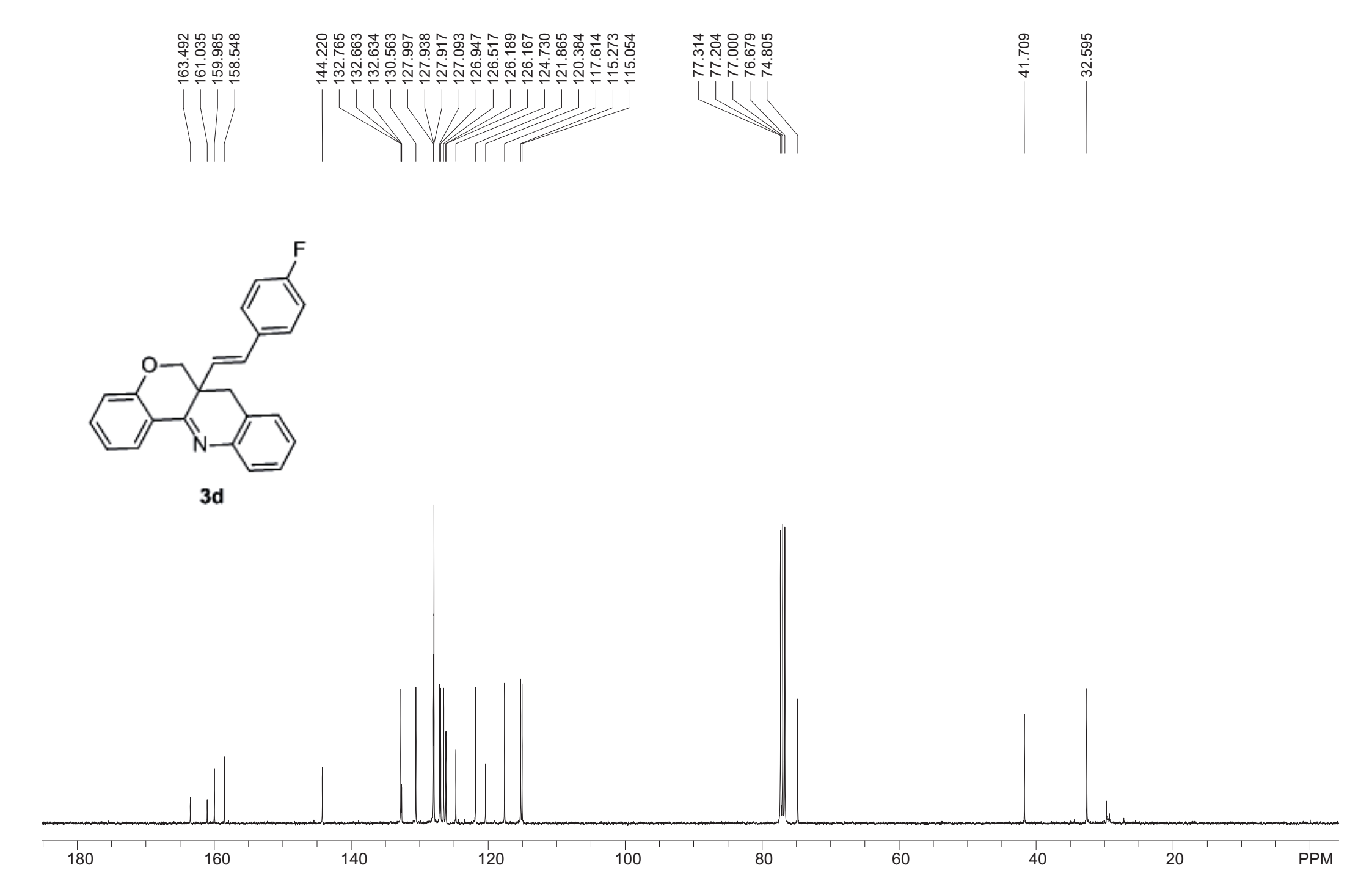
3b

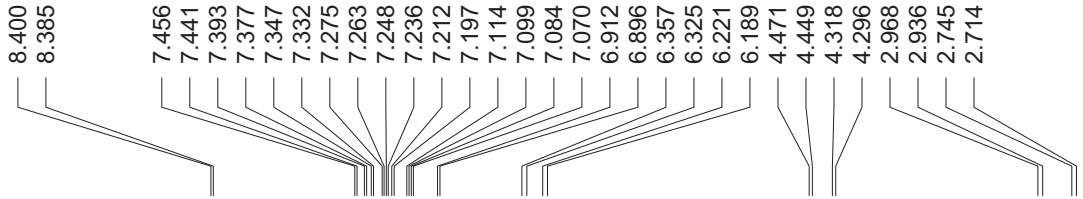

180
160
140
120
100
80
60
40
20
PPM

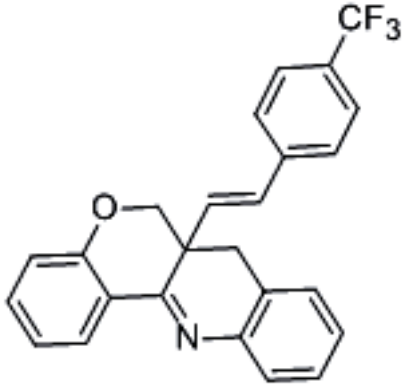

8.383
8.368
7.435
7.420
7.343
7.328
7.313
7.258
7.244
7.231
7.112
7.098
7.083
7.062
7.046
6.977
6.961
6.898
6.881
6.313
6.281
6.084
6.051
4.449
4.427
4.292
4.270
2.928
2.897
2.727
2.696
2.228
Me
O
N
3c
4.74
3.00
1.83
1.18
0.99
0.95
0.96
1.04
0.90
0.94
0.92
0.93
0.97
1.02
10
8
6
4
2
0
PPM


160.210
158.555
144.228
133.705
132.677
137.429
131.548
128.968
127.948
127.824
127.007
126.862
126.483
126.293
125.251
124.850
121.760
120.412
117.585
77.255
77.000
76.745
74.843
41.699
32.619
21.053
Me
O
N
3c
180
160
140
120
100
80
60
40
20
PPM

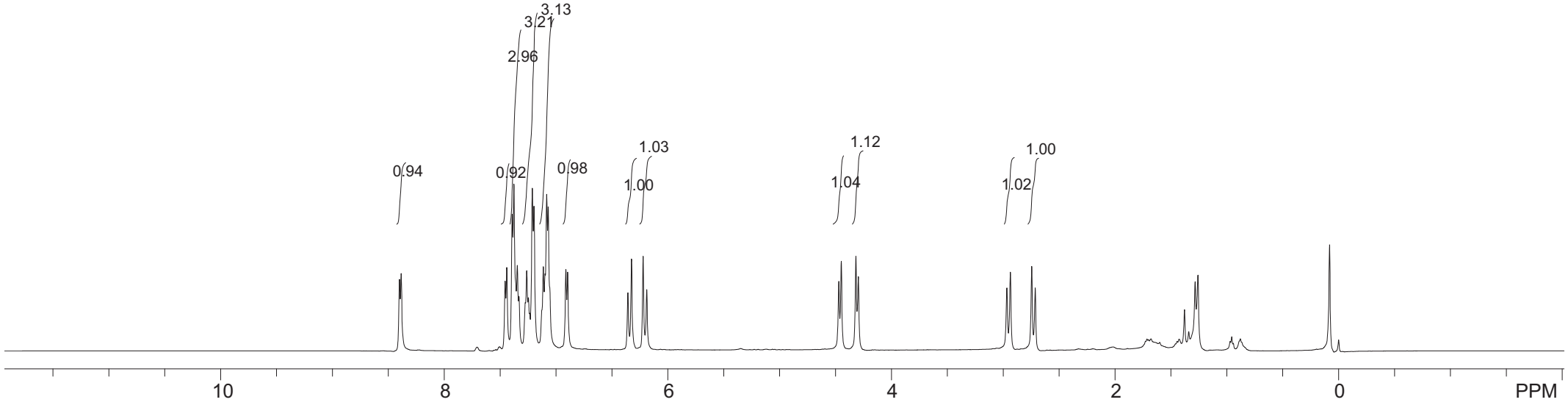

8.389
8.370
7.447
7.427
7.357
7.339
7.321
7.276
7.257
7.238
7.124
7.111
7.103
7.088
7.082
7.059
7.040
6.908
6.888
6.863
6.842
6.820
6.311
6.270
6.053
6.013
4.455
4.427
4.304
4.277
2.951
2.912
2.735
2.696
F
O
N
3d
5.02
3.09
1.13
1.00
0.89
0.93
1.02
1.02
1.02
1.00
1.00
1.00
10
8
6
4
2
0
PPM

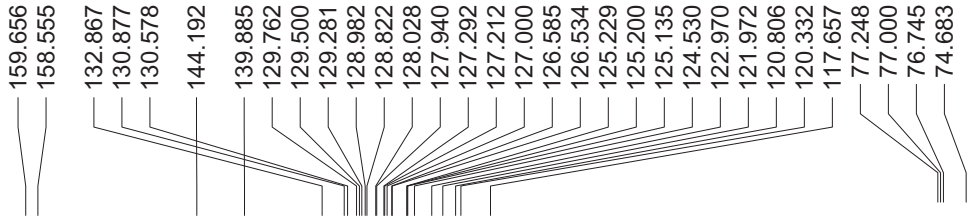

163.492
161.035
159.985
158.548
144.220
132.765
132.663
132.634
130.563
127.997
127.938
127.917
127.093
126.947
126.517
126.189
126.167
124.730
121.865
120.384
117.614
115.273
115.054
77.314
77.204
77.000
76.679
74.805
41.709
32.595
F
O
N
3d
180
160
140
120
100
80
60
40
20
PPM

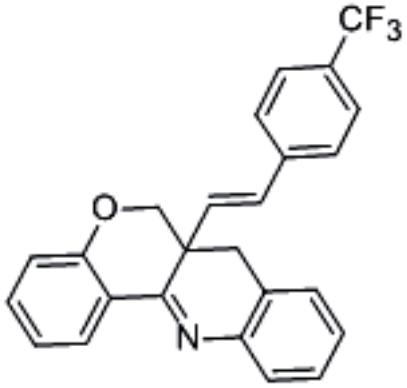

8.400
8.385
7.456
7.441
7.393
7.377
7.347
7.332
7.275
7.263
7.248
7.236
7.212
7.197
7.114
7.099
7.084
7.070
6.912
6.896
6.357
6.325
6.221
6.189
4.471
4.449
4.318
4.296
2.968
2.936
2.745
2.714


CF3
O
N

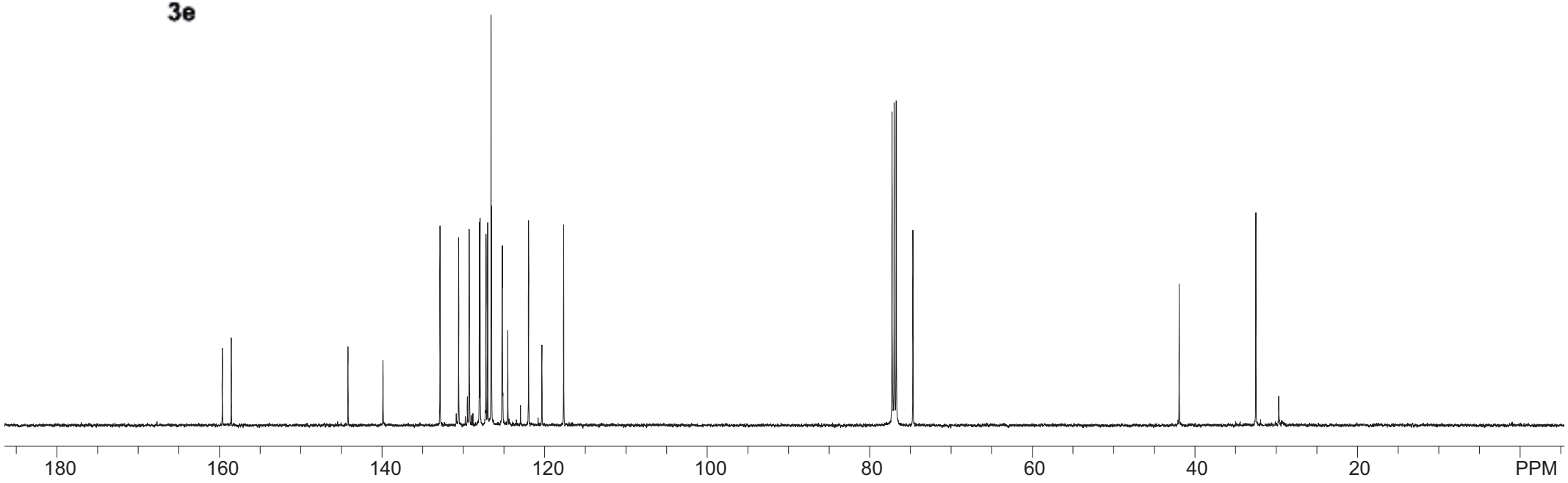
3e

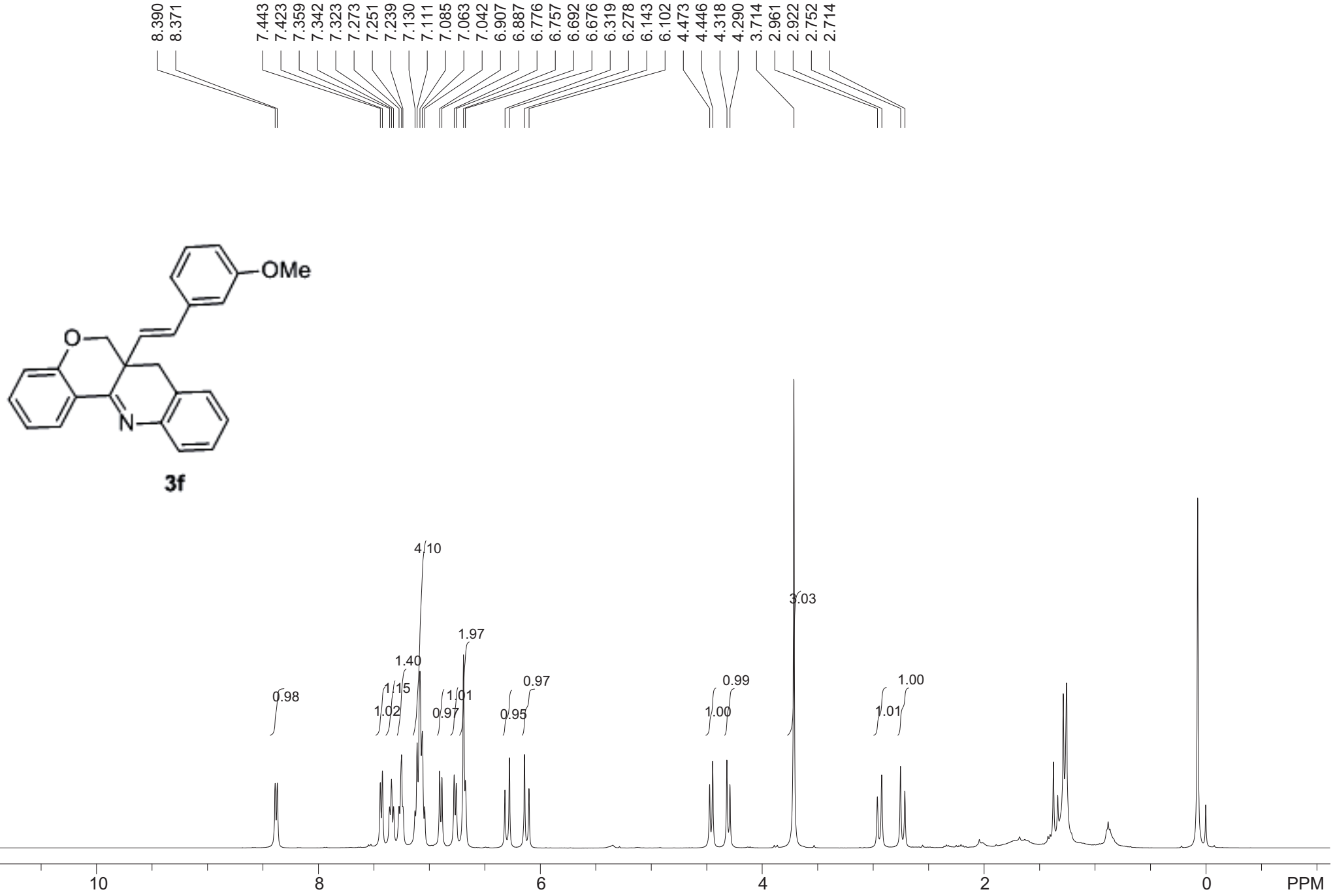

3.13
3.21
2.96
0.94
0.92
0.98
1.03
1.00
1.12
1.04
1.00
1.02
10
8
6
4
2
0
PPM

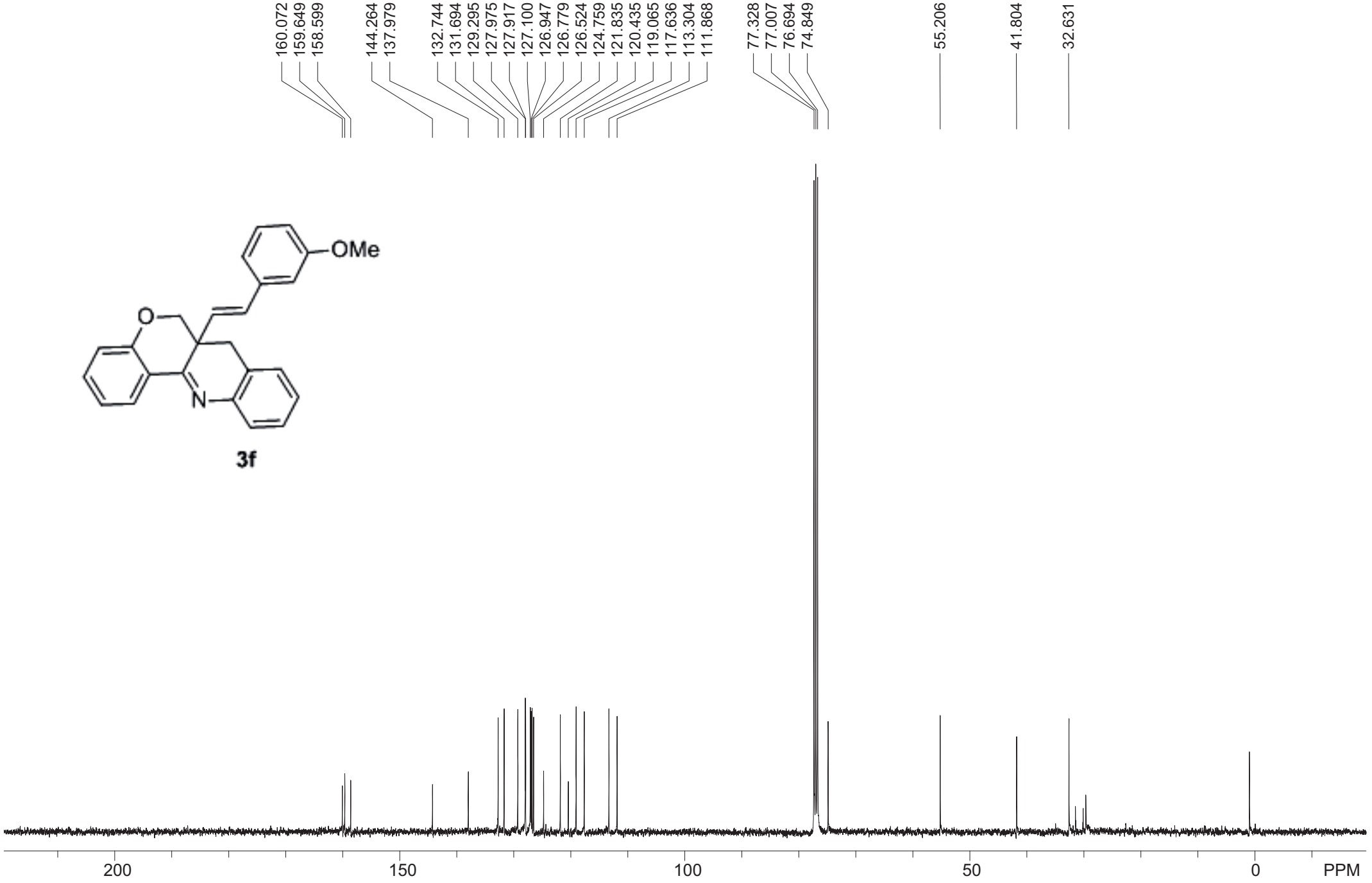

159.656
158.555
132.867
130.877
130.578
144.192
139.885
129.762
129.500
129.281
128.982
128.822
128.028
127.940
127.292
127.212
127.000
126.585
126.534
125.229
125.200
125.135
124.530
122.970
121.972
120.806
120.332
117.657
77.248
77.000
76.745
74.683
41.925
32.487
29.674

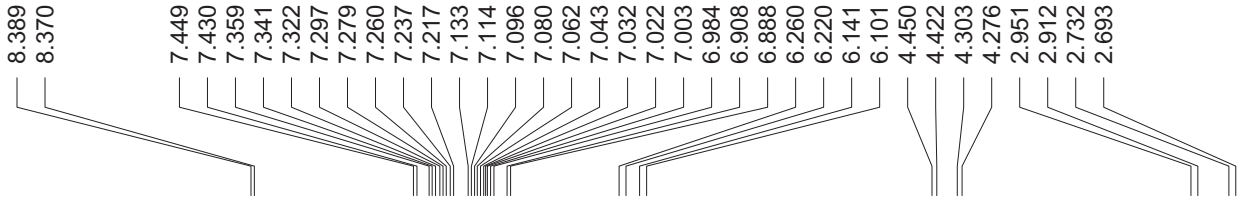

CF3
O
N

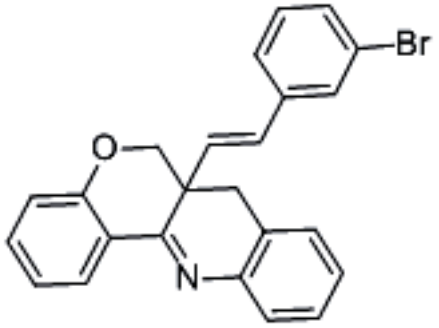
3e


180
160
140
120
100
80
60
40
20
PPM

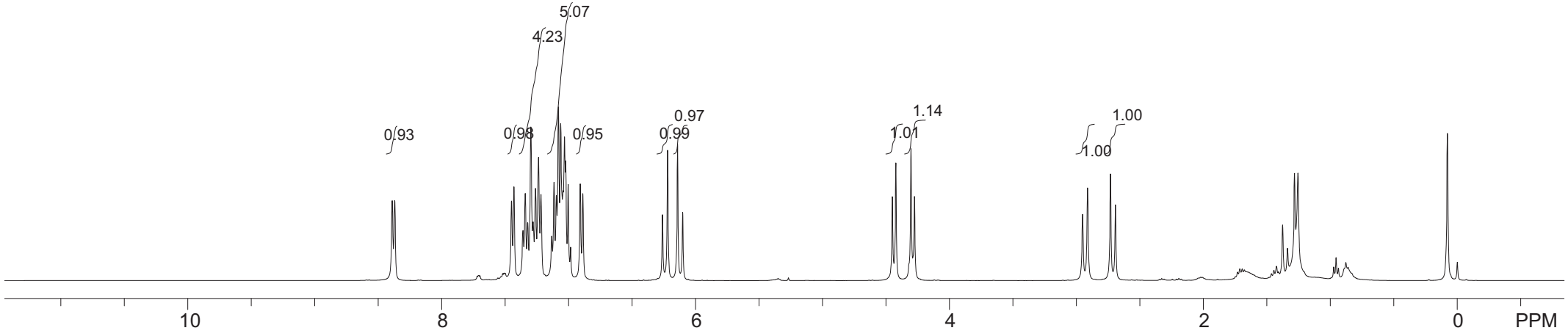

8.390
8.371
7.443
7.423
7.359
7.342
7.323
7.273
7.251
7.239
7.130
7.111
7.085
7.063
7.042
6.907
6.887
6.776
6.757
6.692
6.676
6.319
6.278
6.143
6.102
4.473
4.446
4.318
4.290
3.714
2.961
2.922
2.752
2.714
OMe
O
N
3f
4.10
3.03
1.97
1.40
0.98
1.15
1.02
1.01
0.97
0.97
0.95
0.99
1.00
1.00
1.01
10
8
6
4
2
0
PPM

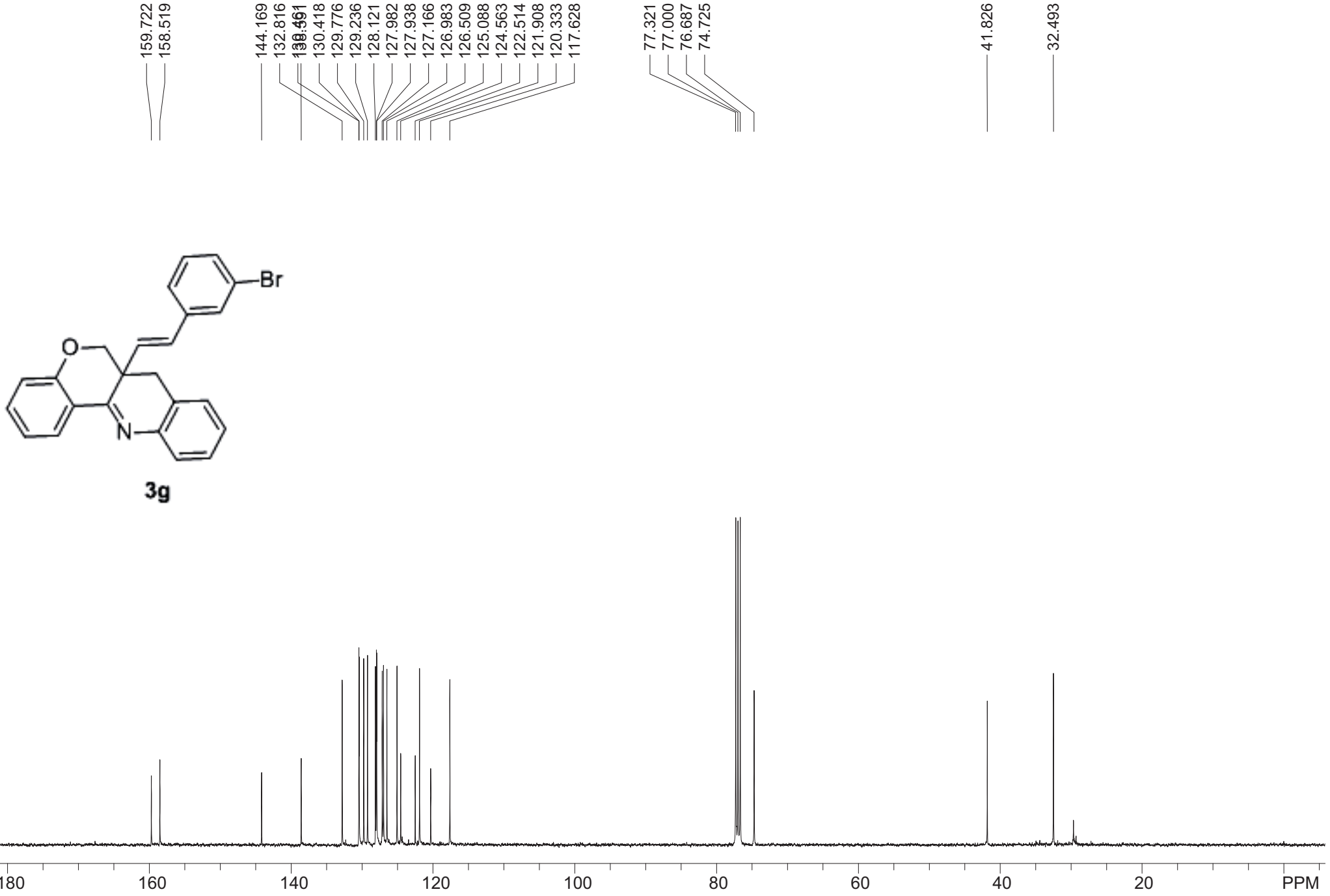

160.072
159.649
158.599
144.264
137.979
132.744
131.694
129.295
127.975
127.917
127.100
126.947
126.779
126.524
124.759
121.835
120.435
119.065
117.636
113.304
111.868
77.328
77.007
76.694
74.849
55.206
41.804
32.631
OMe
O
N
3f
200
150
100
50
0
PPM

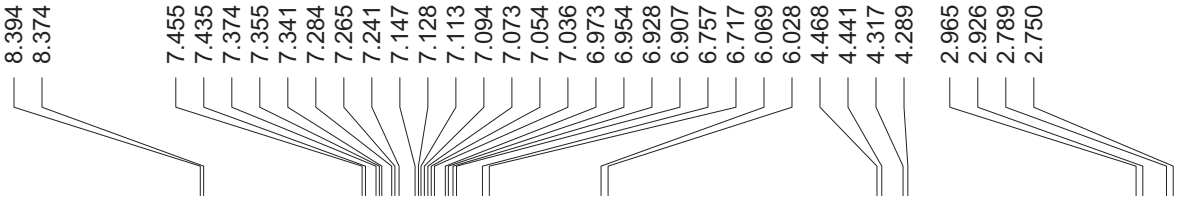

8.389
8.370
7.449
7.430
7.359
7.341
7.322
7.297
7.279
7.260
7.237
7.217
7.133
7.114
7.096
7.080
7.062
7.043
7.032
7.022
7.003
6.984
6.908
6.888
6.260
6.220
6.141
6.101
4.450
4.422
4.303
4.276
2.951
2.912
2.732
2.693

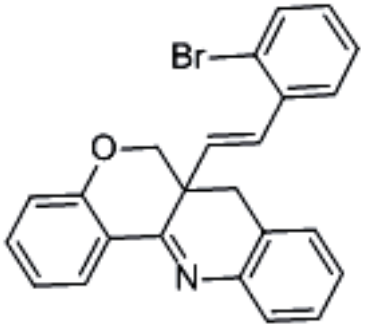

Br
O
N

3g

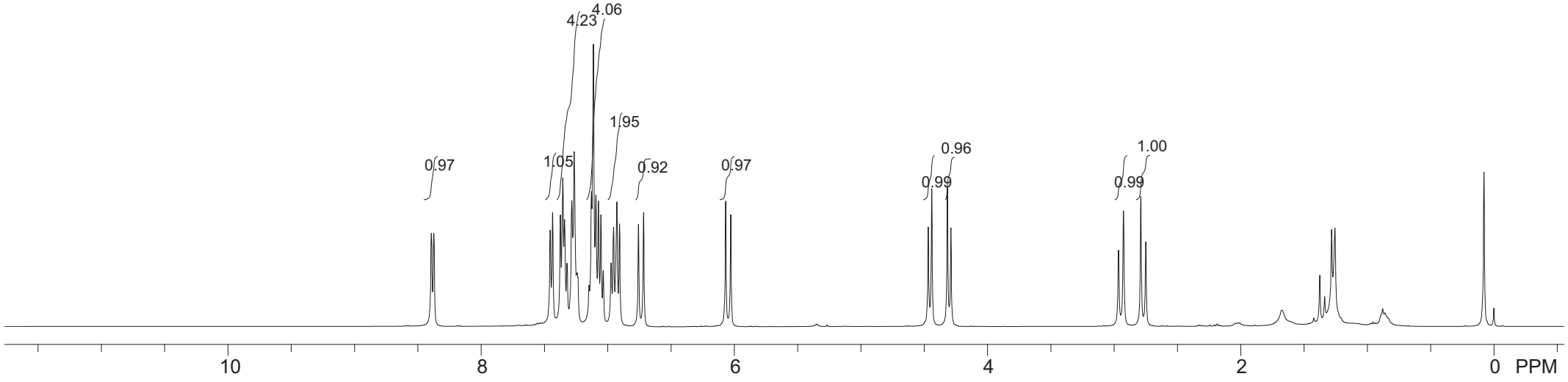

5.07
4.23
0.93
0.98
0.95
0.99
0.97
1.01
1.14
1.00
1.00
10
8
6
4
2
0
PPM

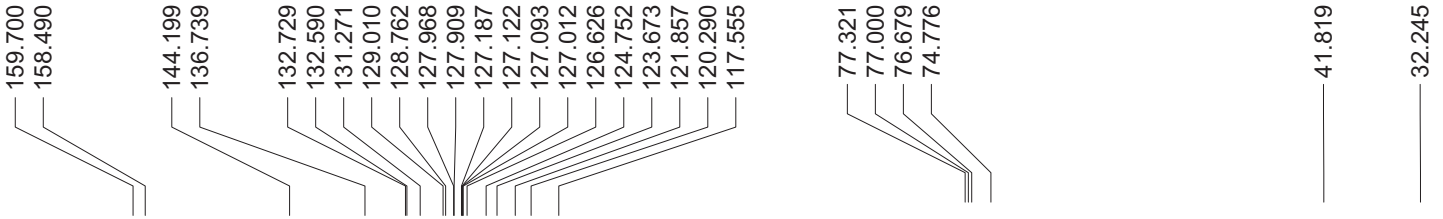

159.722
158.519
144.169
132.816
130.461
130.418
129.776
129.236
128.121
127.982
127.938
127.166
126.983
126.509
125.088
124.563
122.514
121.908
120.333
117.628
77.321
77.000
76.687
74.725
41.826
32.493
Br
O
N
3g
180
160
140
120
100
80
60
40
20
PPM

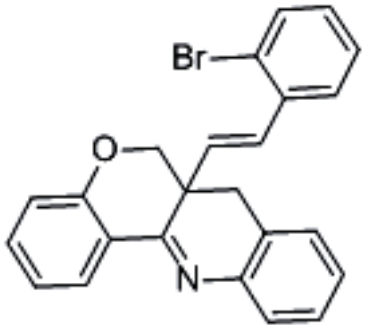

8.394
8.374
7.455
7.435
7.374
7.355
7.341
7.284
7.265
7.241
7.147
7.128
7.113
7.094
7.073
7.054
7.036
6.973
6.954
6.928
6.907
6.757
6.717
6.069
6.028
4.468
4.441
4.317
4.289
2.965
2.926
2.789
2.750


Br
O
N

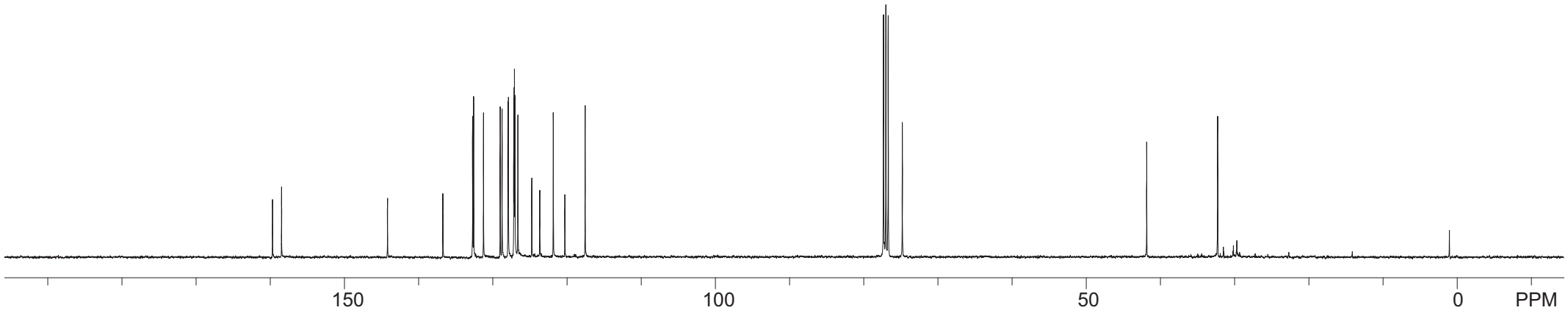
3h

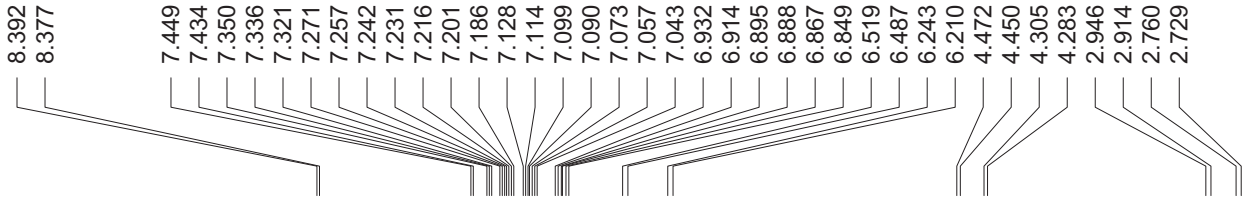

0.97
1.05
4.23
4.06
1.95
0.92
0.97
0.99
0.96
0.99
1.00
10
8
6
4
2
0
PPM

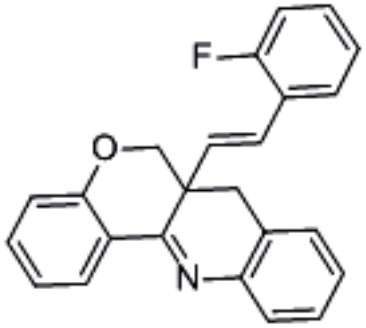

159.700
158.490
144.199
136.739
132.729
132.590
131.271
129.010
128.762
127.968
127.909
127.187
127.122
127.093
127.012
126.626
124.752
123.673
121.857
120.290
117.555
77.321
77.000
76.679
74.776
41.819
32.245


Br
O
N

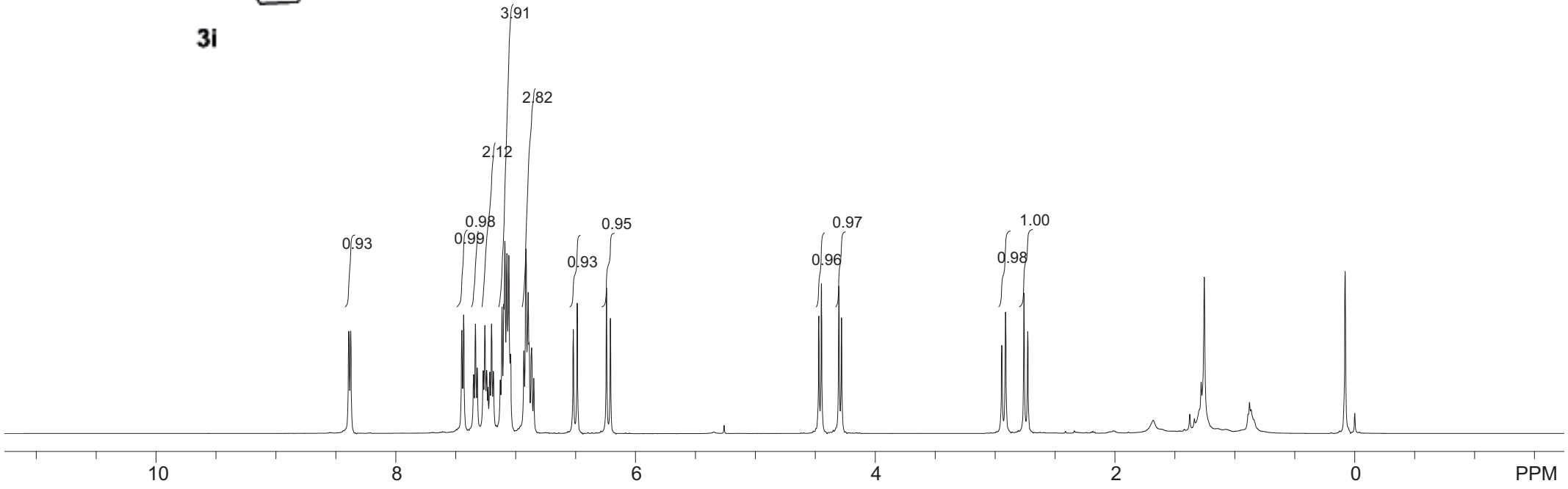
3h

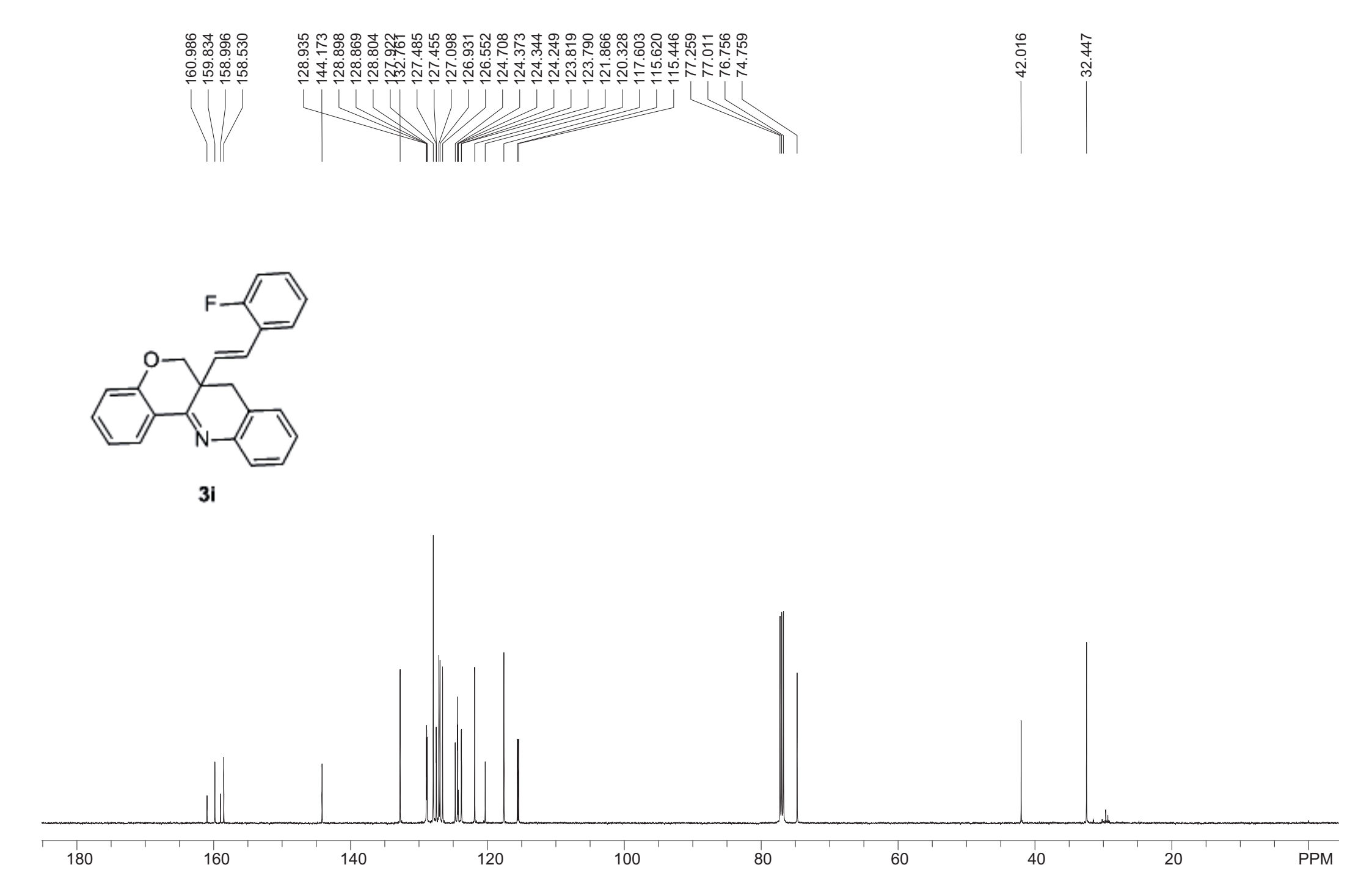

150
100
50
0
PPM

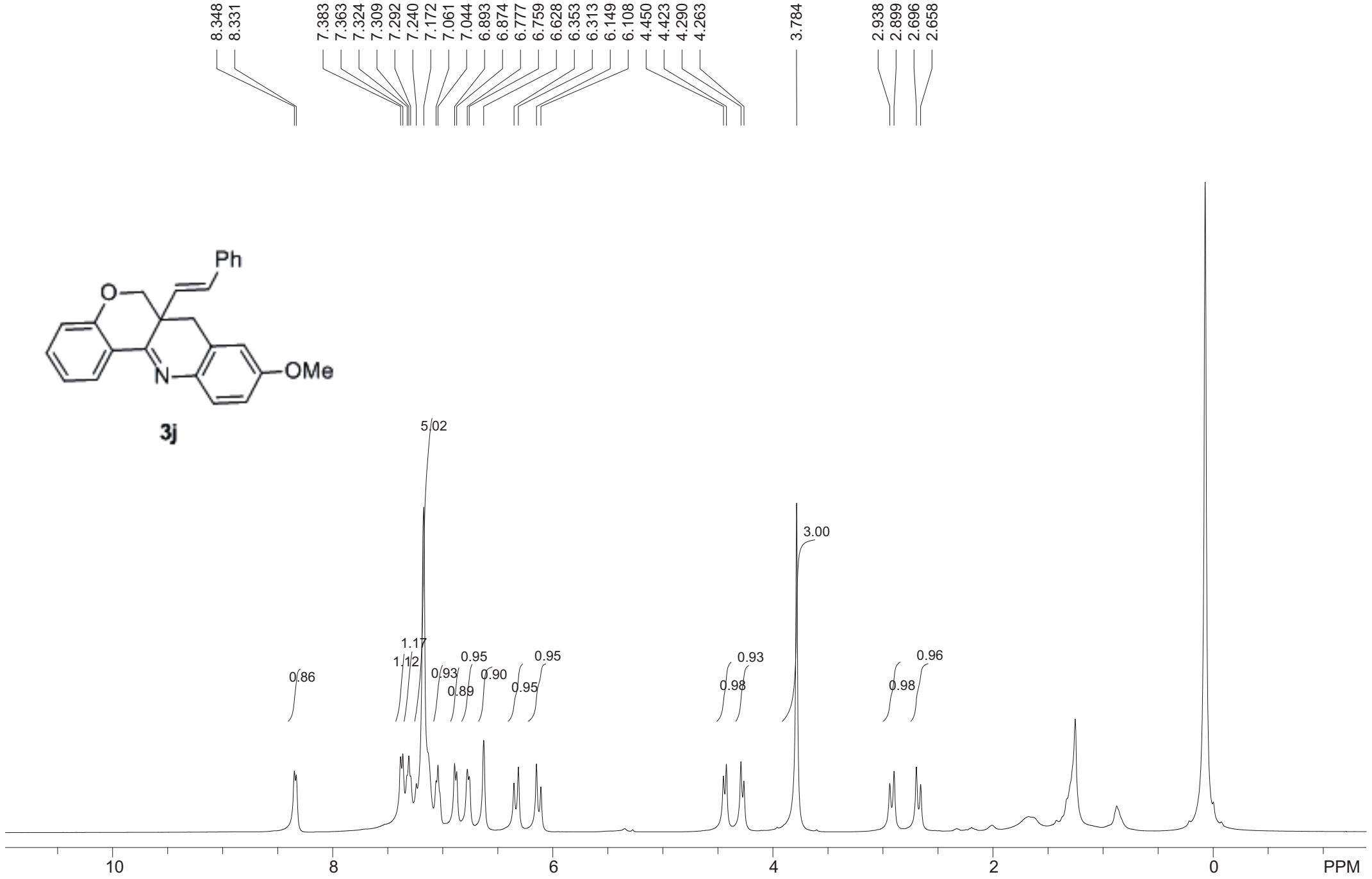

8.392
8.377
7.449
7.434
7.350
7.336
7.321
7.271
7.257
7.242
7.231
7.216
7.201
7.186
7.128
7.114
7.099
7.090
7.073
7.057
7.043
6.932
6.914
6.895
6.888
6.867
6.849
6.519
6.487
6.243
6.210
4.472
4.450
4.305
4.283
2.946
2.914
2.760
2.729

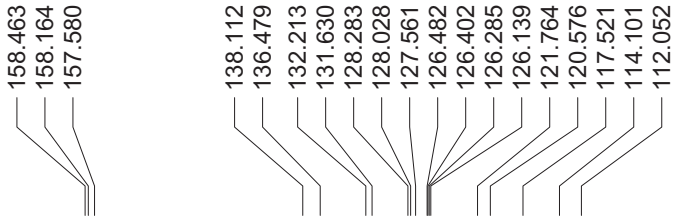

F
O
N

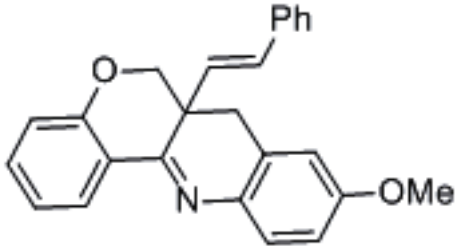
3i


3.91
2.82
2.12
0.98
0.99
0.93
0.93
0.95
0.96
0.97
0.98
1.00
10
8
6
4
2
0
PPM

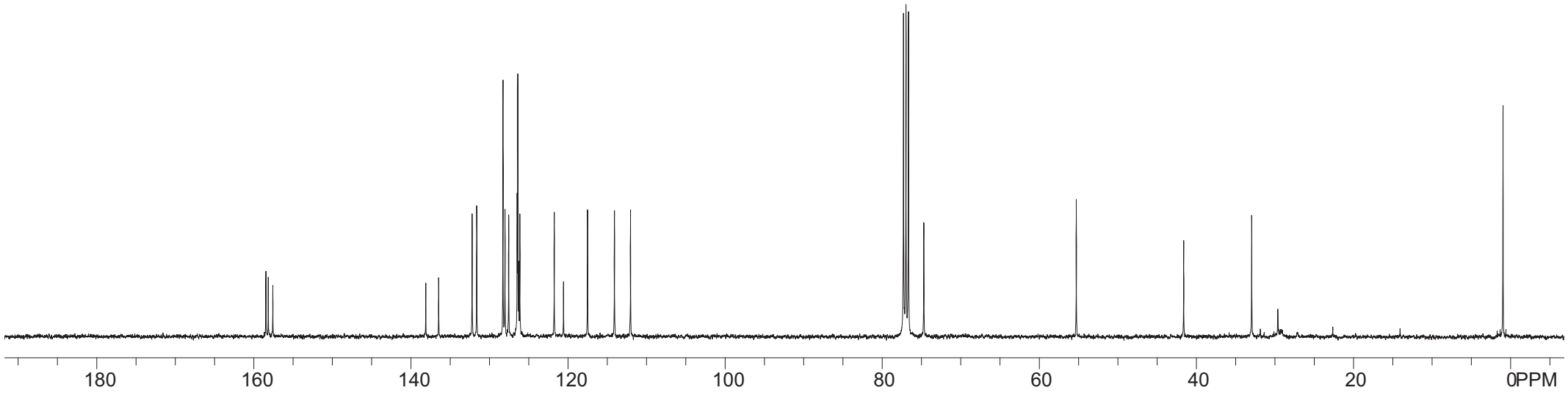

160.986
159.834
158.996
158.530
128.935
144.173
128.898
128.869
128.804
127.922
132.761
127.485
127.455
127.098
126.931
126.552
124.708
124.373
124.344
124.249
123.819
123.790
121.866
120.328
117.603
115.620
115.446
77.259
77.011
76.756
74.759
42.016
32.447
F
O
N
3i
180
160
140
120
100
80
60
40
20
PPM

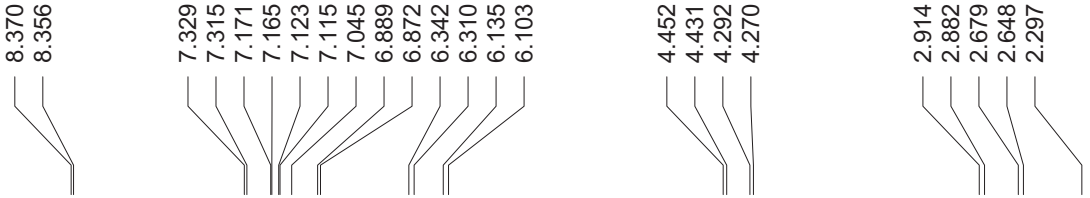

8.348
8.331
7.383
7.363
7.324
7.309
7.292
7.240
7.172
7.061
7.044
6.893
6.874
6.777
6.759
6.628
6.353
6.313
6.149
6.108
4.450
4.423
4.290
4.263
3.784
2.938
2.899
2.696
2.658
Ph
O
N
OMe
3j
5.02
3.00
1.17
1.12
0.86
0.93
0.89
0.95
0.90
0.95
0.95
0.93
0.98
0.98
0.96
10
8
6
4
2
0
PPM

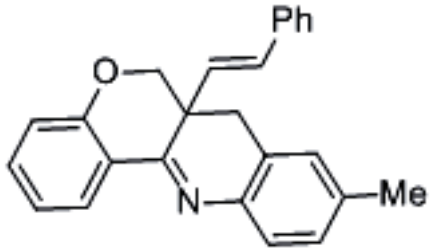

158.463
158.164
157.580
138.112
136.479
132.213
131.630
128.283
128.028
127.561
126.482
126.402
126.285
126.139
121.764
120.576
117.521
114.101
112.052
77.301
76.987
76.666
74.712
55.302
41.631
32.976


Ph
O
N
OMe

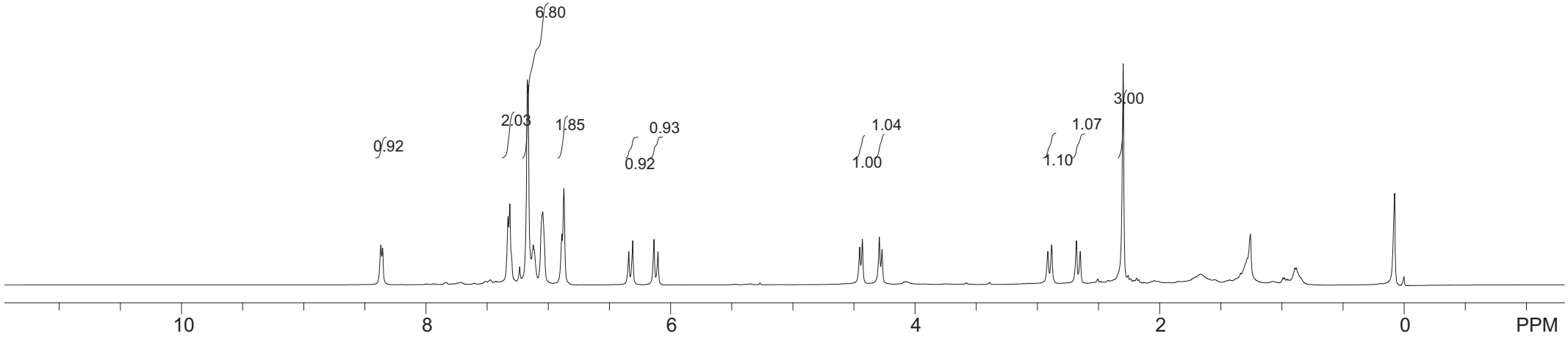
3j

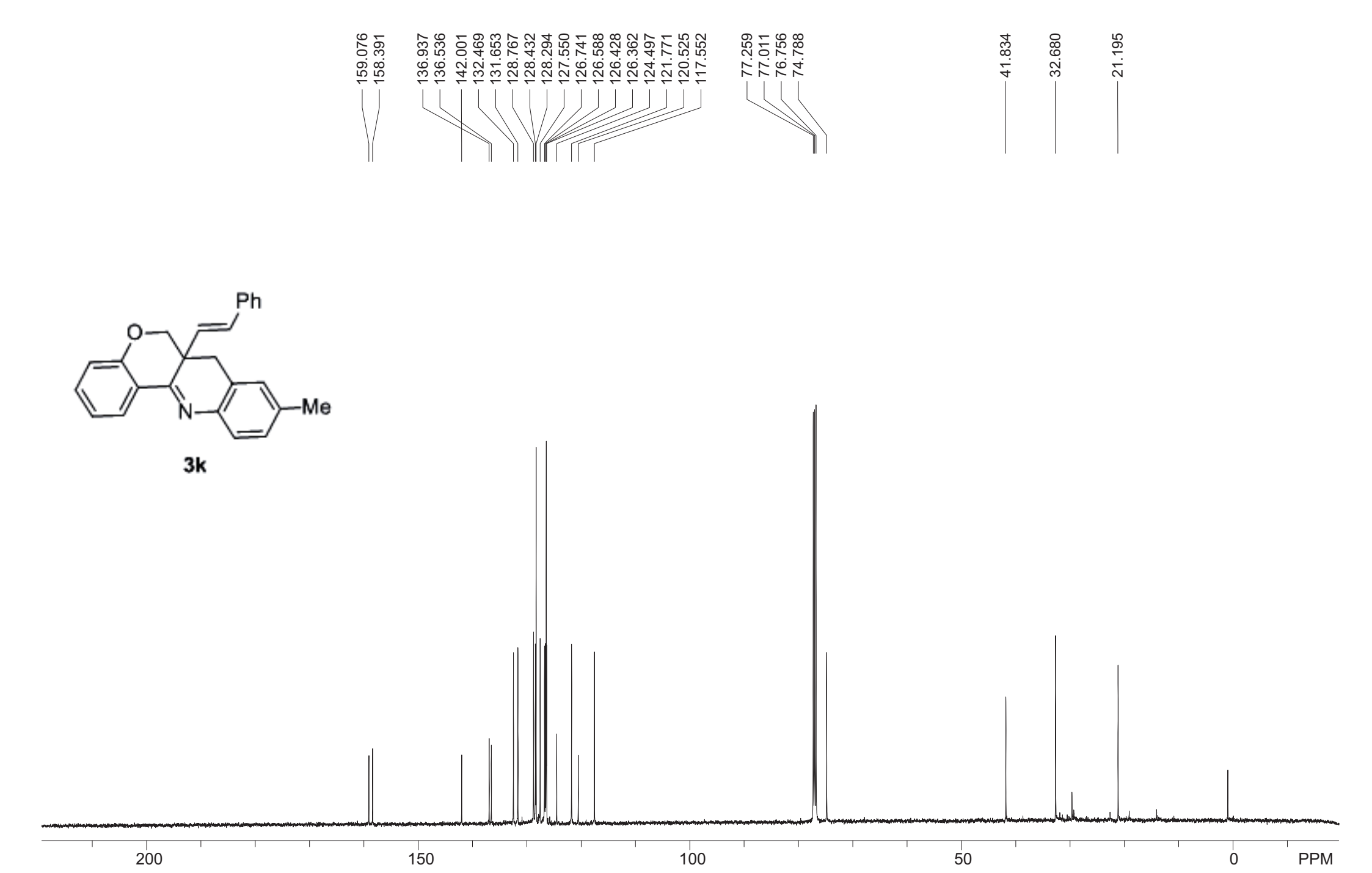

180
160
140
120
100
80
60
40
20
0PPM

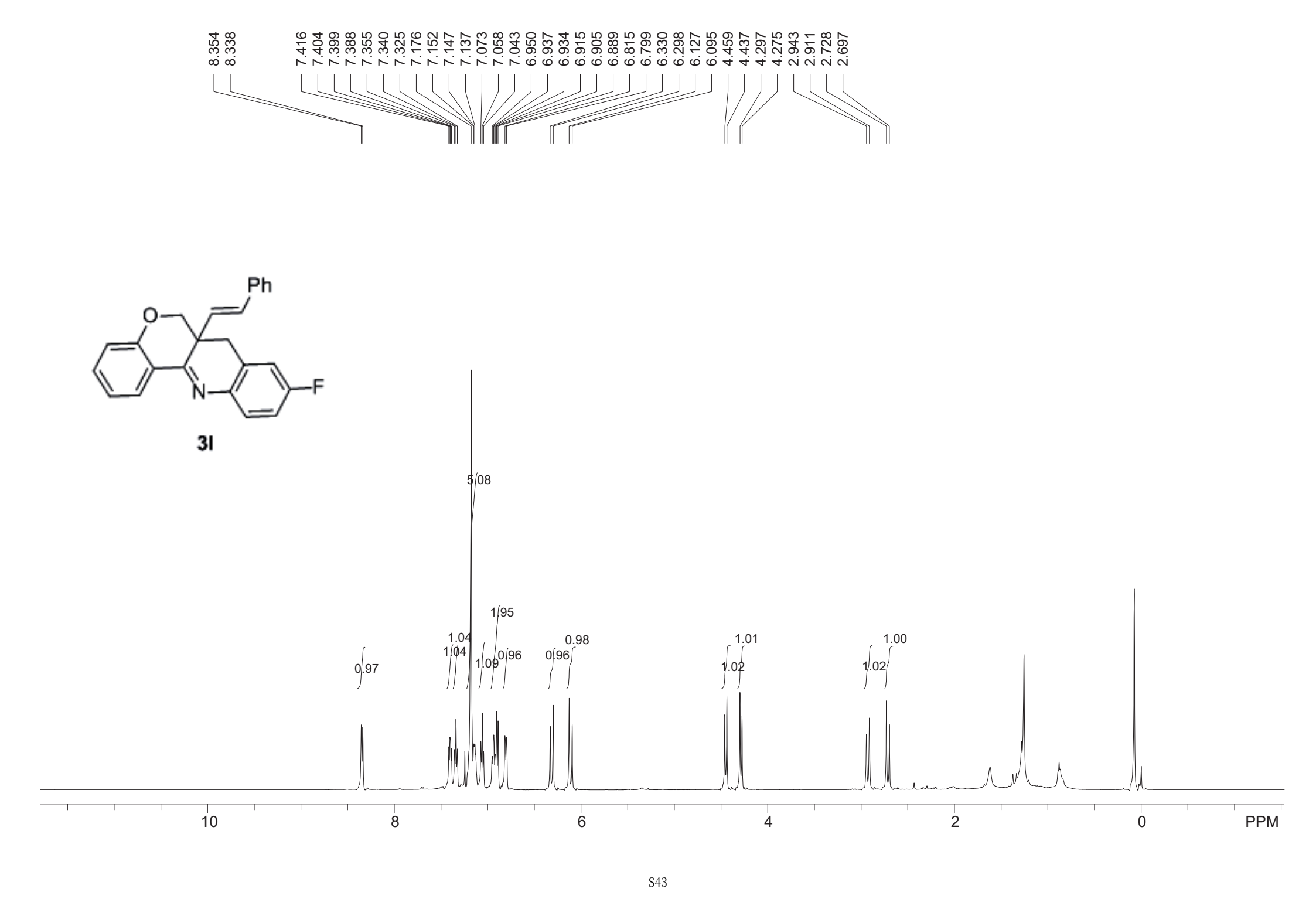

8.370
8.356
7.329
7.315
7.171
7.165
7.123
7.115
7.045
6.889
6.872
6.342
6.310
6.135
6.103
4.452
4.431
4.292
4.270
2.914
2.882
2.679
2.648
2.297

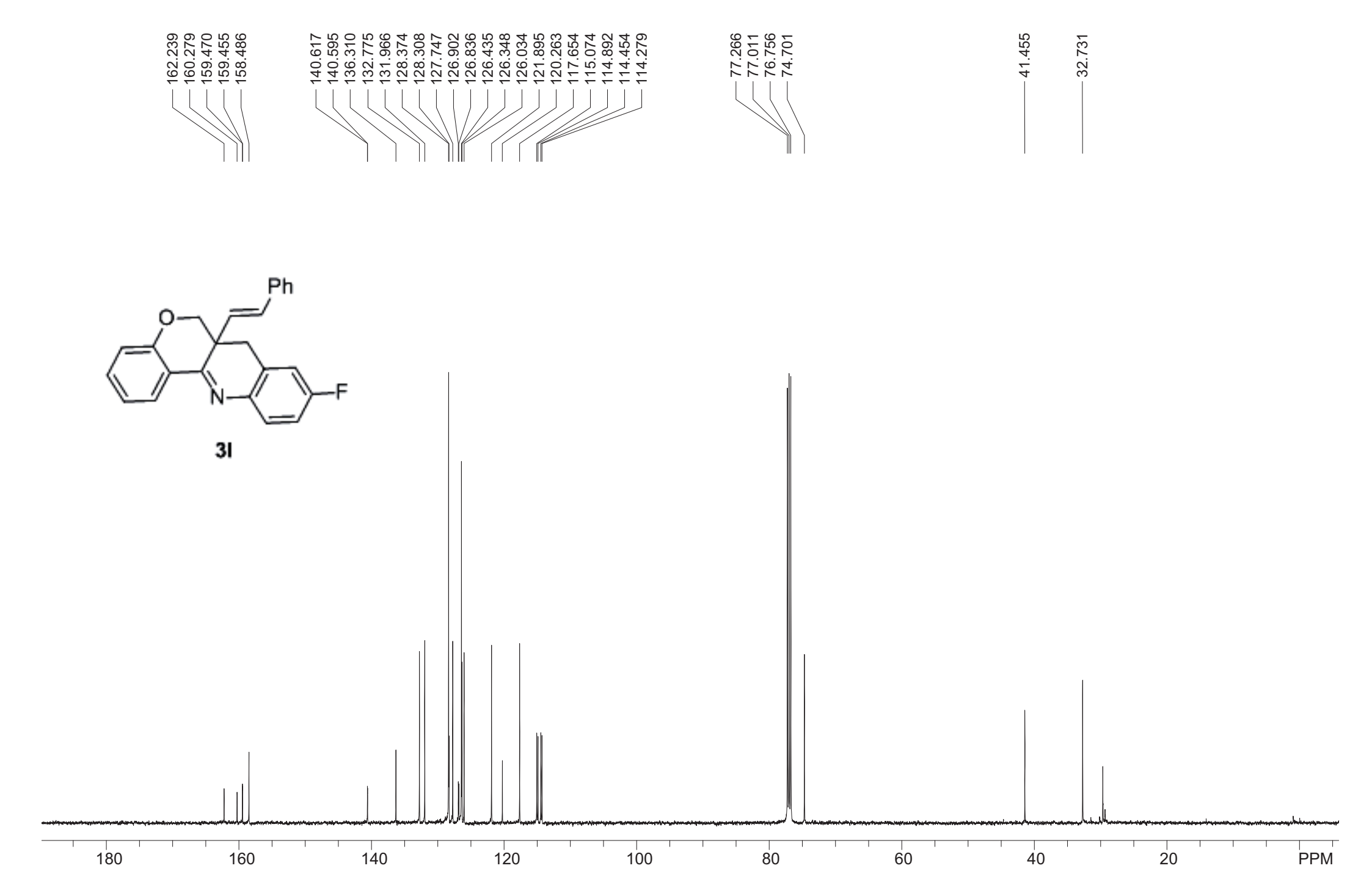

Ph
O
N
Me

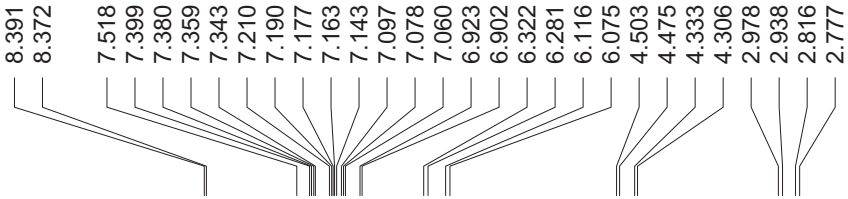
3k

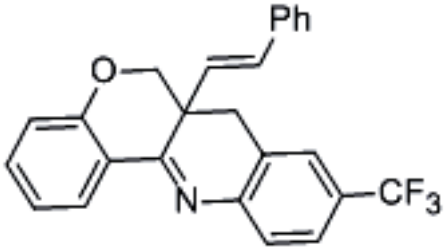

6.80
2.03
1.85
0.93
0.92
1.04
1.00
1.07
1.10
3.00
10
8
6
4
2
0
PPM


159.076
158.391
136.937
136.536
142.001
132.469
131.653
128.767
128.432
128.294
127.550
126.741
126.588
126.428
126.362
124.497
121.771
120.525
117.552
77.259
77.011
76.756
74.788
41.834
32.680
21.195
Ph
O
N
Me
3k
200
150
100
50
0
PPM

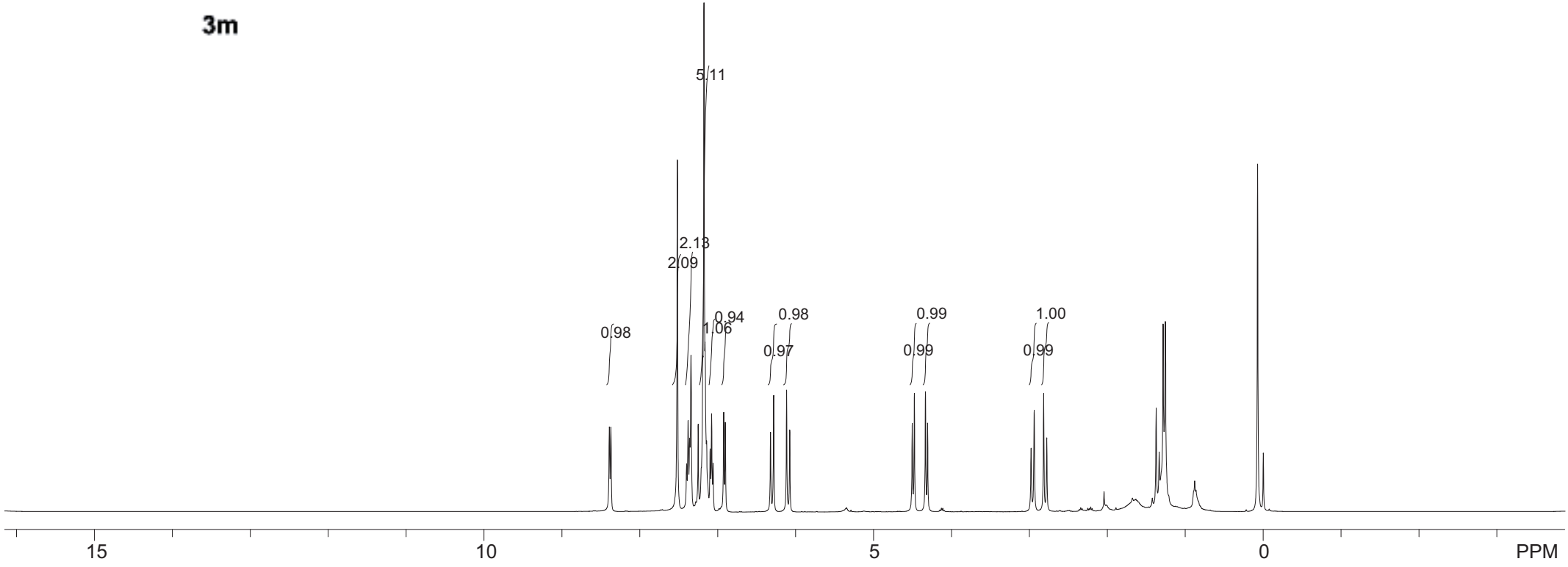

8.354
8.338
7.416
7.404
7.399
7.388
7.355
7.340
7.325
7.176
7.152
7.147
7.137
7.073
7.058
7.043
6.950
6.937
6.934
6.915
6.905
6.889
6.815
6.799
6.330
6.298
6.127
6.095
4.459
4.437
4.297
4.275
2.943
2.911
2.728
2.697
Ph
O
N
F
3l
5.08
1.95
1.04
1.04
0.98
1.01
1.00
0.97
1.09
0.96
0.96
1.02
1.02
10
8
6
4
2
0
PPM

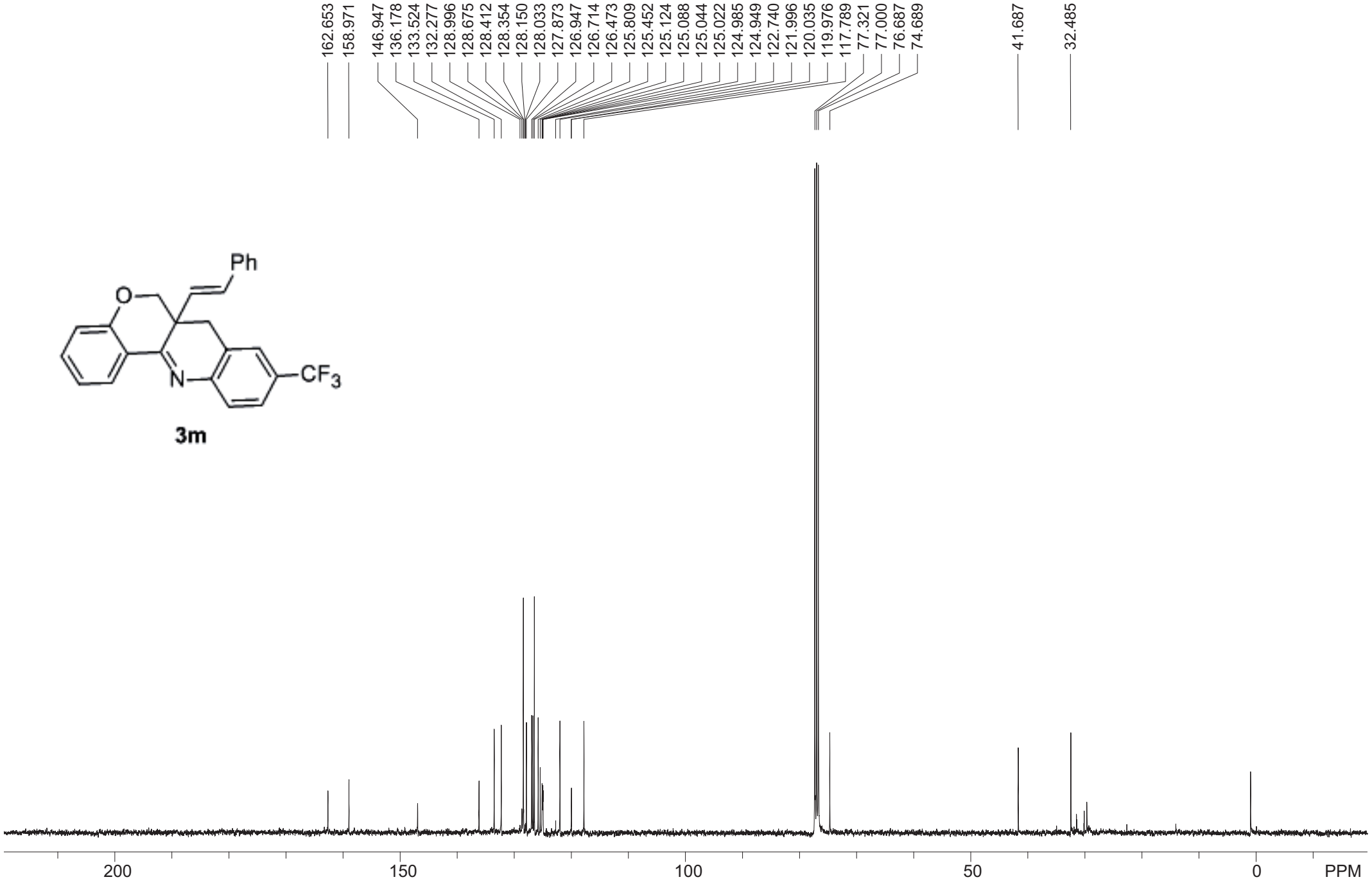

162.239
160.279
159.470
159.455
158.486
140.617
140.595
136.310
132.775
131.966
128.374
128.308
127.747
126.902
126.836
126.435
126.348
126.034
121.895
120.263
117.654
115.074
114.892
114.454
114.279
77.266
77.011
76.756
74.701
41.455
32.731
Ph
O
N
F
3l
180
160
140
120
100
80
60
40
20
PPM

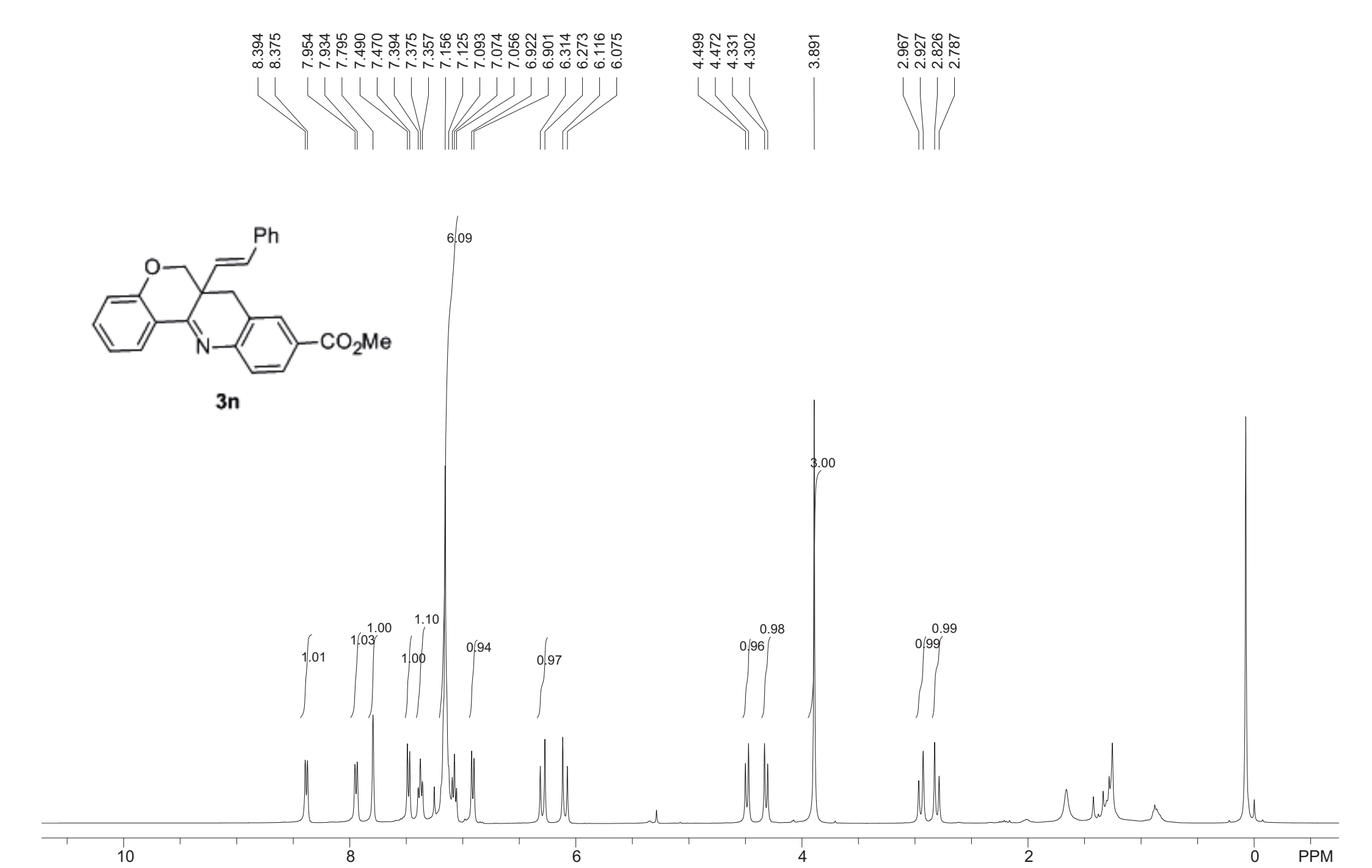

8.391
8.372
7.518
7.399
7.380
7.359
7.343
7.210
7.190
7.177
7.163
7.143
7.097
7.078
7.060
6.923
6.902
6.322
6.281
6.116
6.075
4.503
4.475
4.333
4.306
2.978
2.938
2.816
2.777

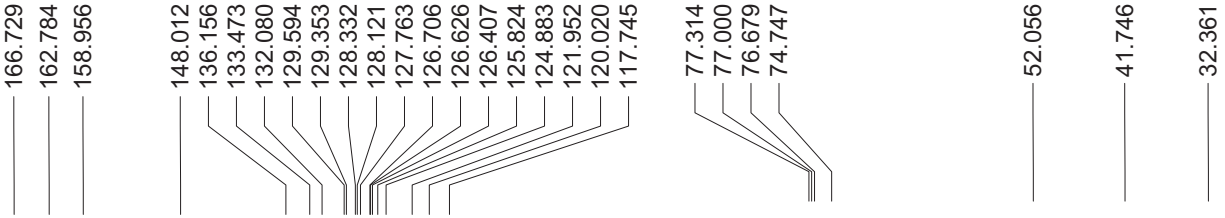

Ph
O
N
CF3

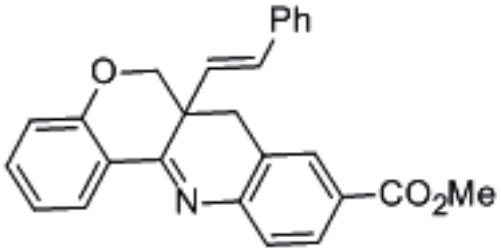
3m


5.11
2.13
2.09
0.98
0.94
1.06
0.98
0.97
0.99
0.99
1.00
0.99
15
10
5
0
PPM

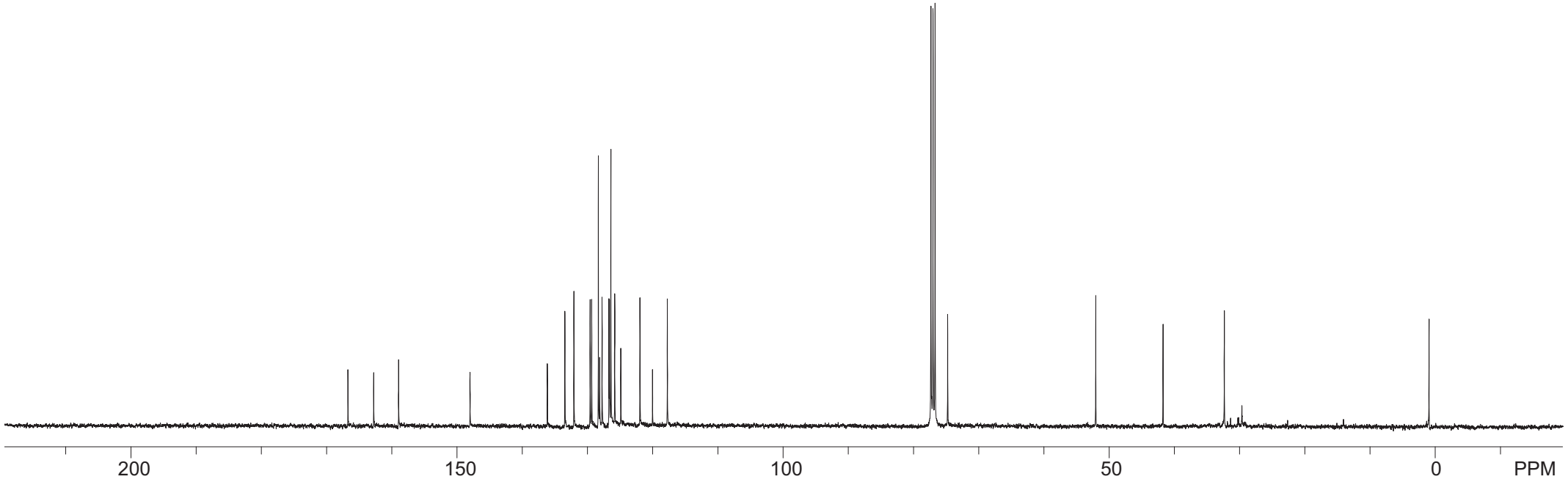

162.653
158.971
146.947
136.178
133.524
132.277
128.996
128.675
128.412
128.354
128.150
128.033
127.873
126.947
126.714
126.473
125.809
125.452
125.124
125.088
125.044
125.022
124.985
124.949
122.740
121.996
120.035
119.976
117.789
77.321
77.000
76.687
74.689
41.687
32.485
Ph
O
N
CF3
3m
200
150
100
50
0
PPM

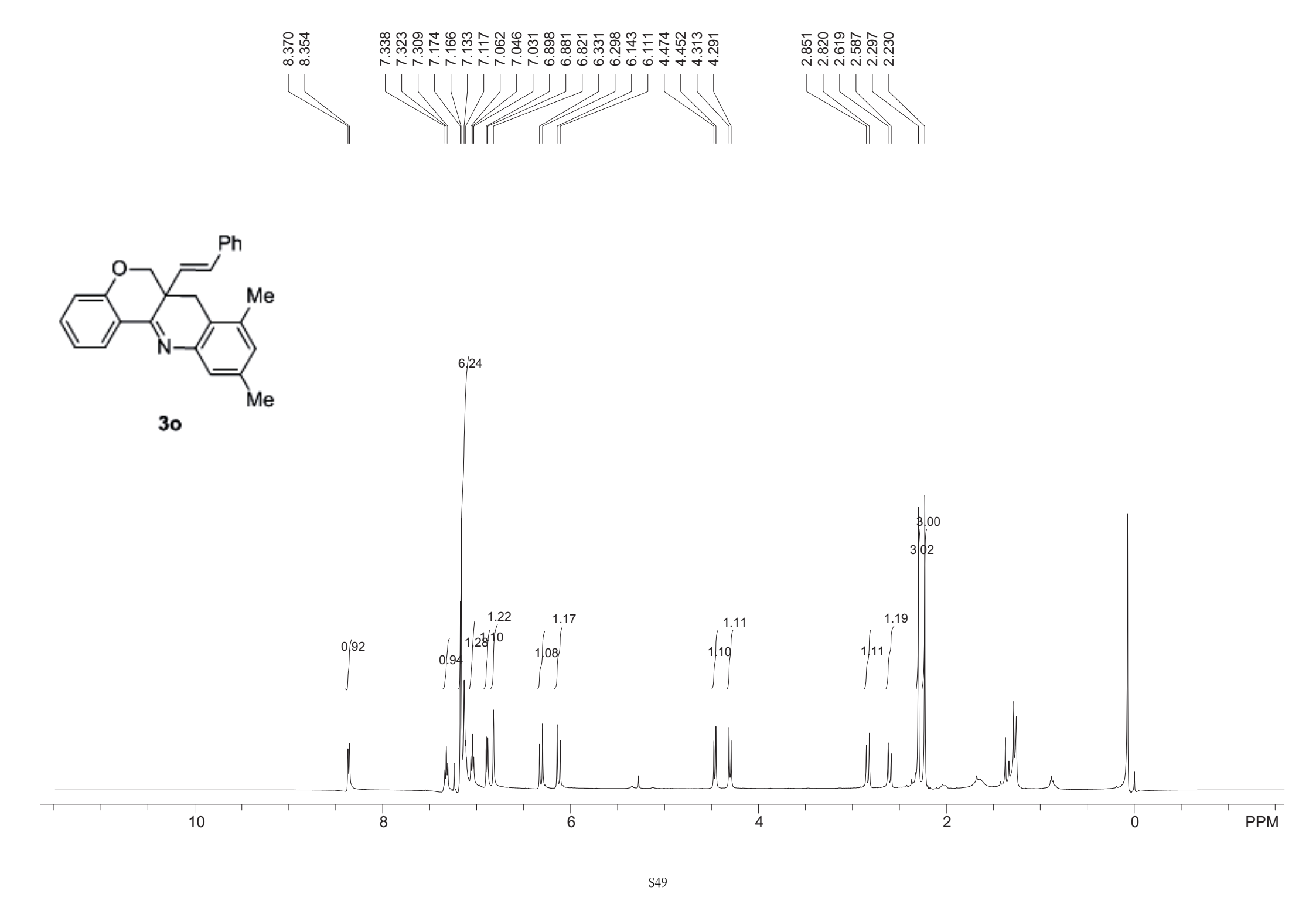

8.394
8.375
7.954
7.934
7.795
7.490
7.470
7.394
7.375
7.357
7.156
7.125
7.093
7.074
7.056
6.922
6.901
6.314
6.273
6.116
6.075
4.499
4.472
4.331
4.302
3.891
2.967
2.927
2.826
2.787
Ph
O
N
CO2Me
3n
6.09
3.00
1.01
1.03
1.00
1.00
1.10
0.94
0.97
0.96
0.98
0.99
0.99
10
8
6
4
2
0
PPM

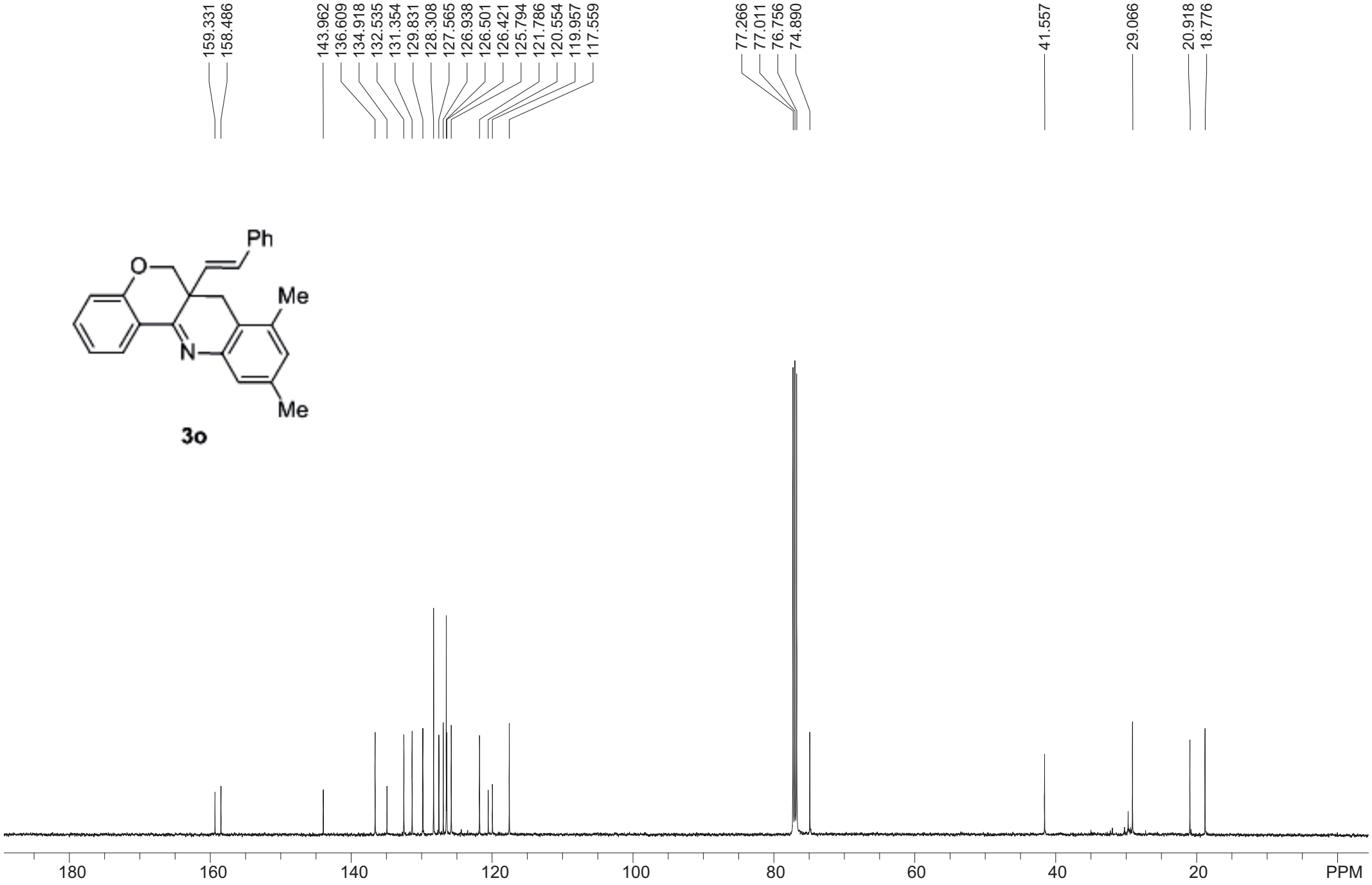

166.729
162.784
158.956
148.012
136.156
133.473
132.080
129.594
129.353
128.332
128.121
127.763
126.706
126.626
126.407
125.824
124.883
121.952
120.020
117.745
77.314
77.000
76.679
74.747
52.056
41.746
32.361

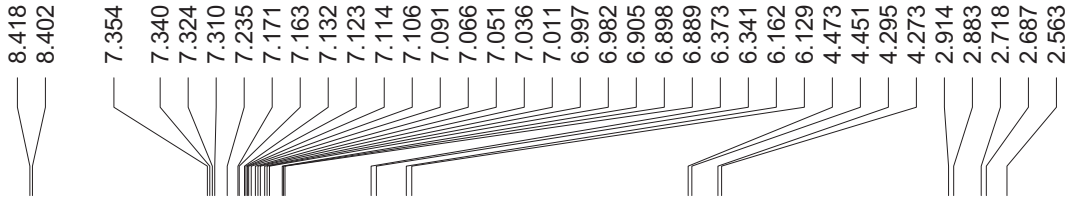

Ph
O
N
CO2Me

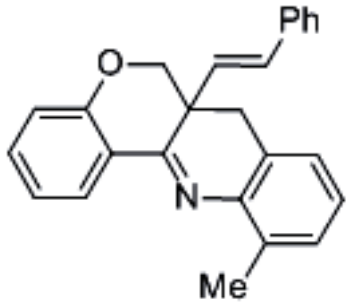
3n


200
150
100
50
0
PPM

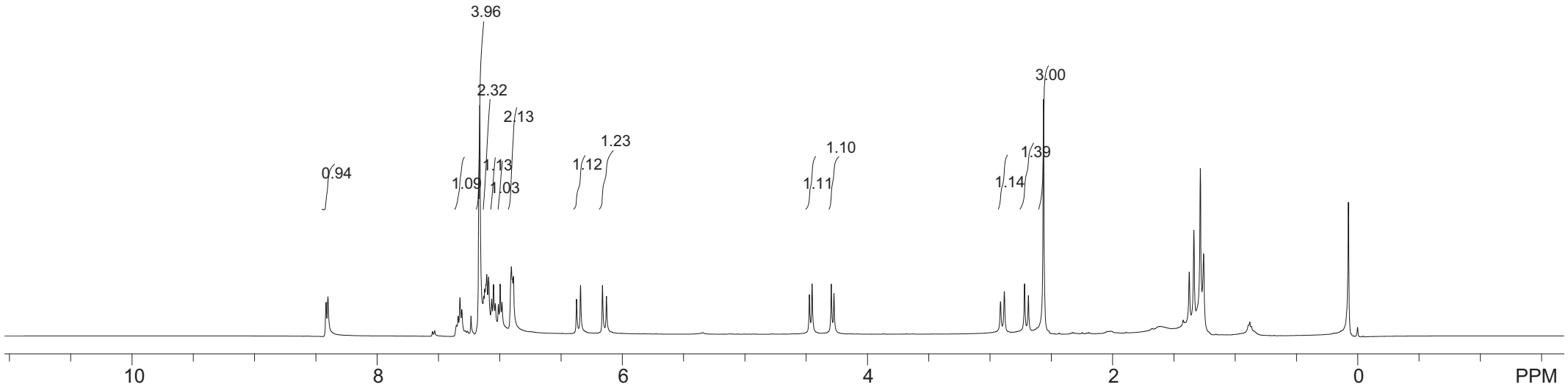

8.370
8.354
7.338
7.323
7.309
7.174
7.166
7.133
7.117
7.062
7.046
7.031
6.898
6.881
6.821
6.331
6.298
6.143
6.111
4.474
4.452
4.313
4.291
2.851
2.820
2.619
2.587
2.297
2.230
Ph
O
Me
N
Me
3o
6.24
0.92
0.94
1.28
1.10
1.22
1.08
1.17
1.10
1.11
1.11
1.19
3.00
3.02
10
8
6
4
2
0
PPM

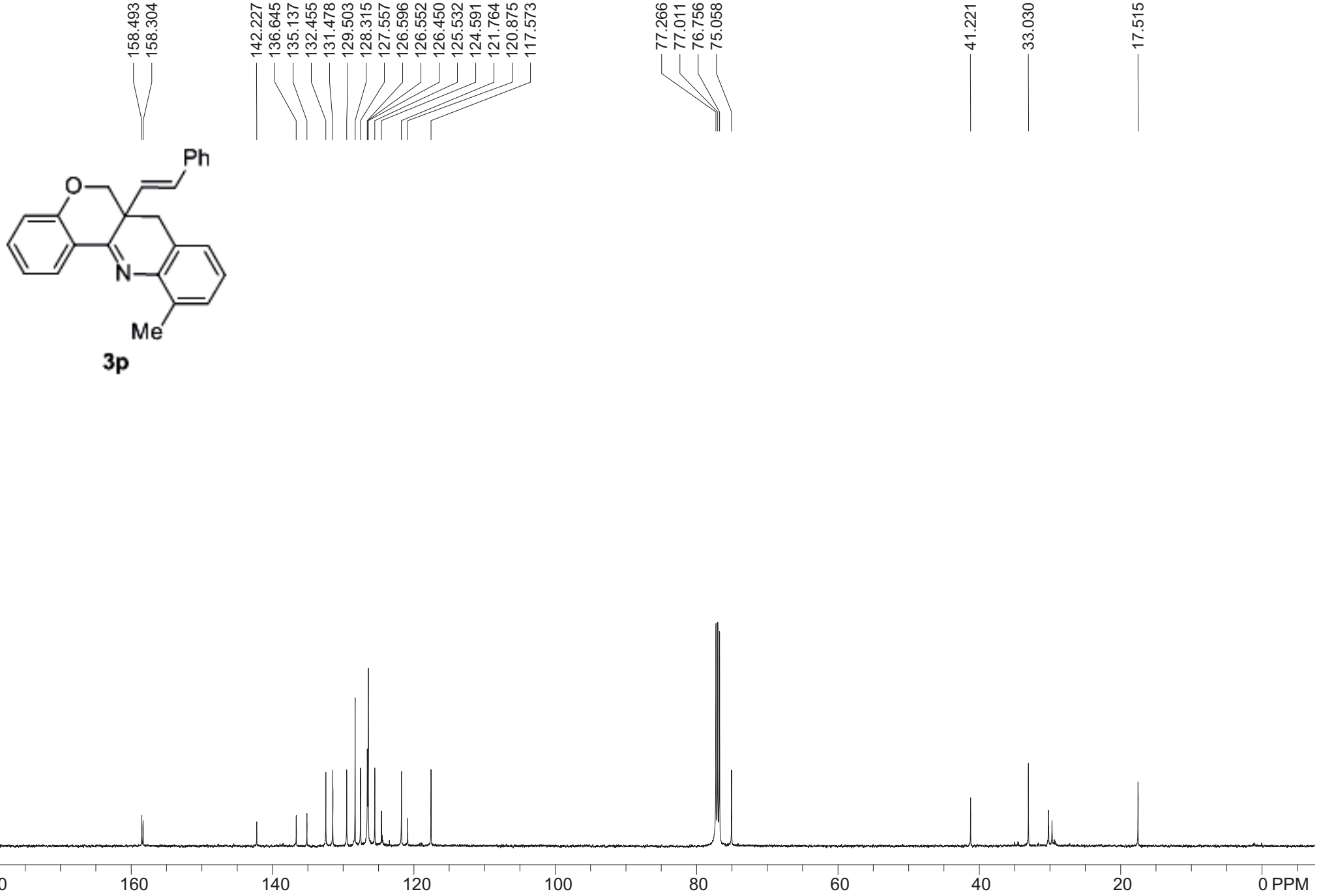

159.331
158.486
143.962
136.609
134.918
132.535
131.354
129.831
128.308
127.565
126.938
126.501
126.421
125.794
121.786
120.554
119.957
117.559
77.266
77.011
76.756
74.890
41.557
29.066
20.918
18.776
Ph
O
Me
N
Me
3o
180
160
140
120
100
80
60
40
20
PPM

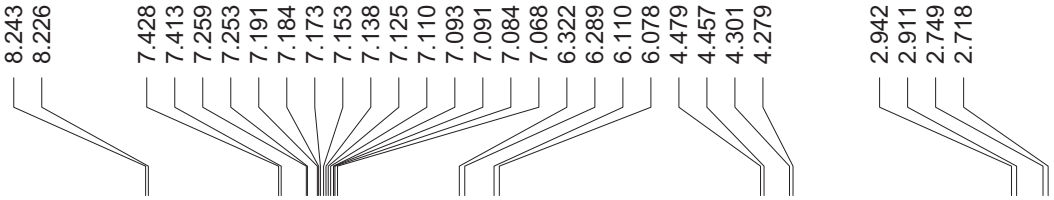

8.418
8.402
7.354
7.340
7.324
7.310
7.235
7.171
7.163
7.132
7.123
7.114
7.106
7.091
7.066
7.051
7.036
7.011
6.997
6.982
6.905
6.898
6.889
6.373
6.341
6.162
6.129
4.473
4.451
4.295
4.273
2.914
2.883
2.718
2.687
2.563

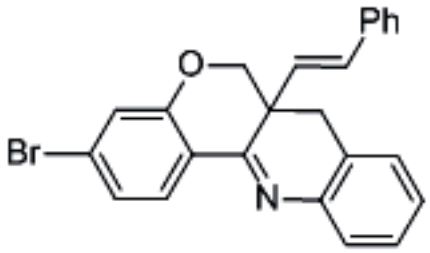

Ph
O
N
Me

3p

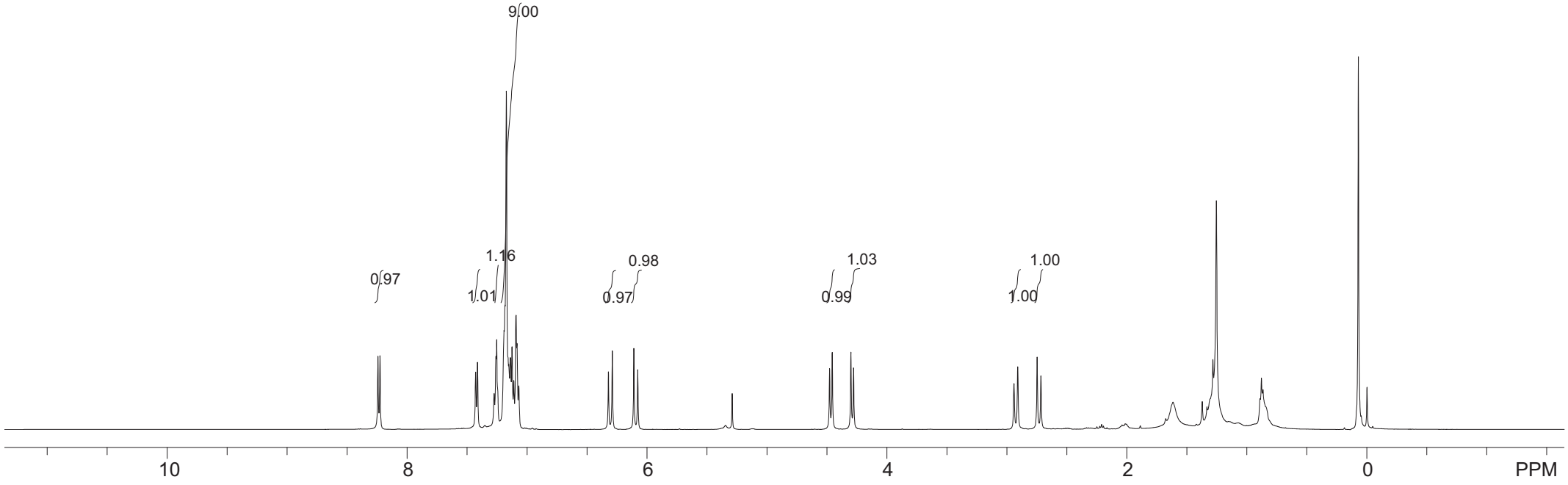

3.96
2.32
2.13
1.23
1.10
3.00
1.39
0.94
1.13
1.12
1.09
1.03
1.11
1.14
10
8
6
4
2
0
PPM

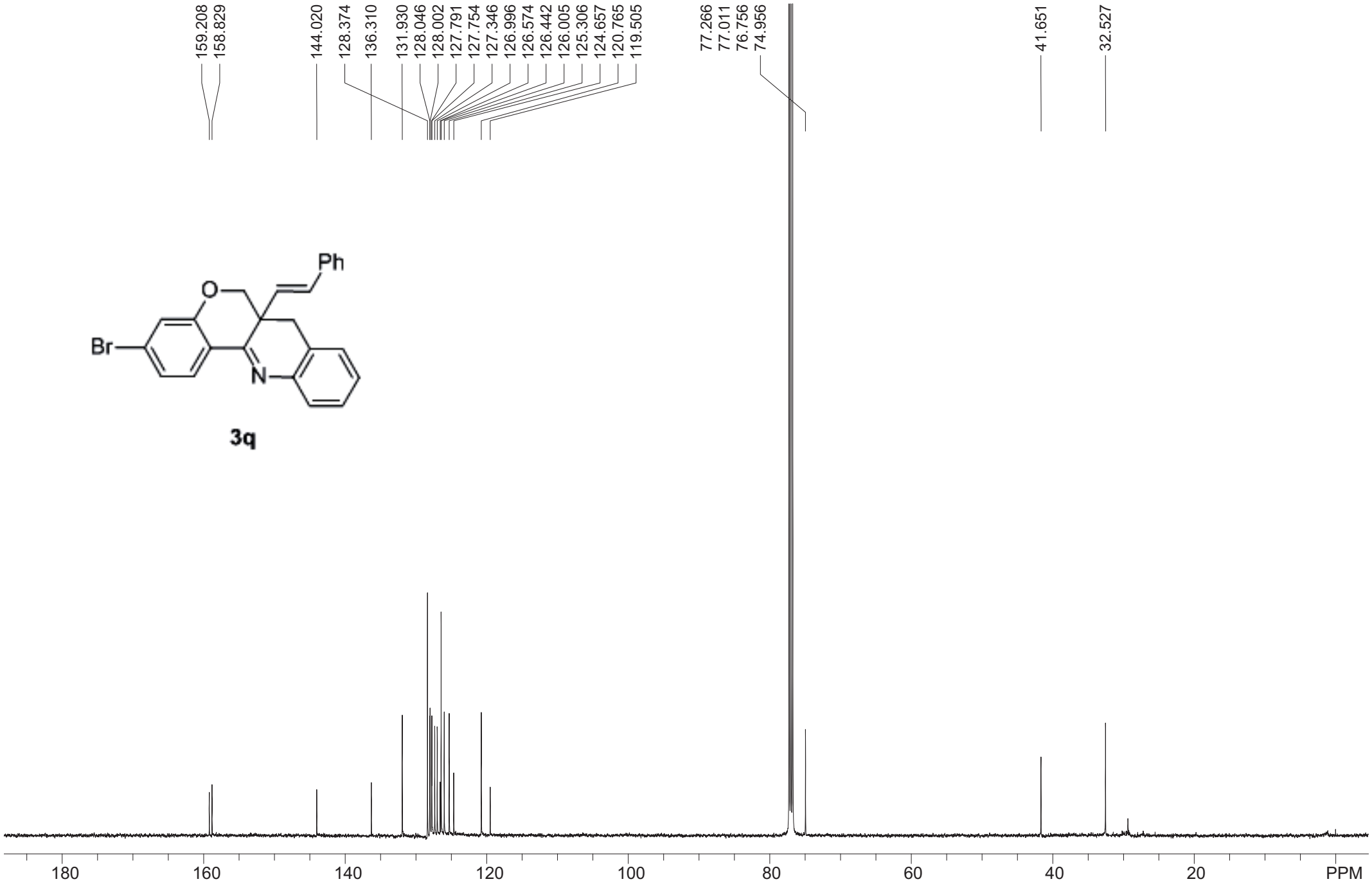

158.493
158.304
142.227
136.645
135.137
132.455
131.478
129.503
128.315
127.557
126.596
126.552
126.450
125.532
124.591
121.764
120.875
117.573
77.266
77.011
76.756
75.058
41.221
33.030
17.515
Ph
O
N
Me
3p
180
160
140
120
100
80
60
40
20
0 PPM


8.243
8.226
7.428
7.413
7.259
7.253
7.191
7.184
7.173
7.153
7.138
7.125
7.110
7.093
7.091
7.084
7.068
6.322
6.289
6.110
6.078
4.479
4.457
4.301
4.279
2.942
2.911
2.749
2.718

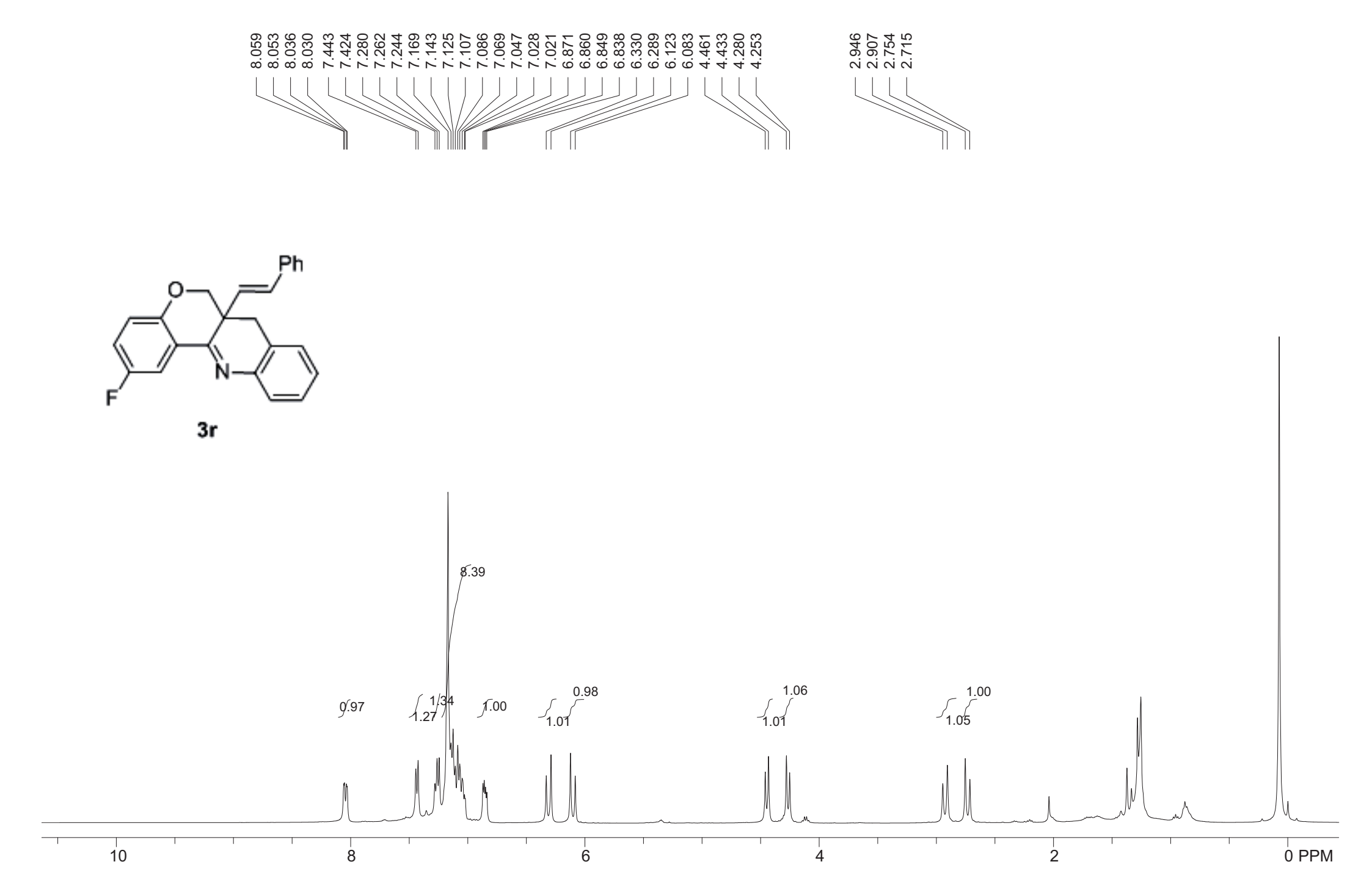

Ph
O
Br
N

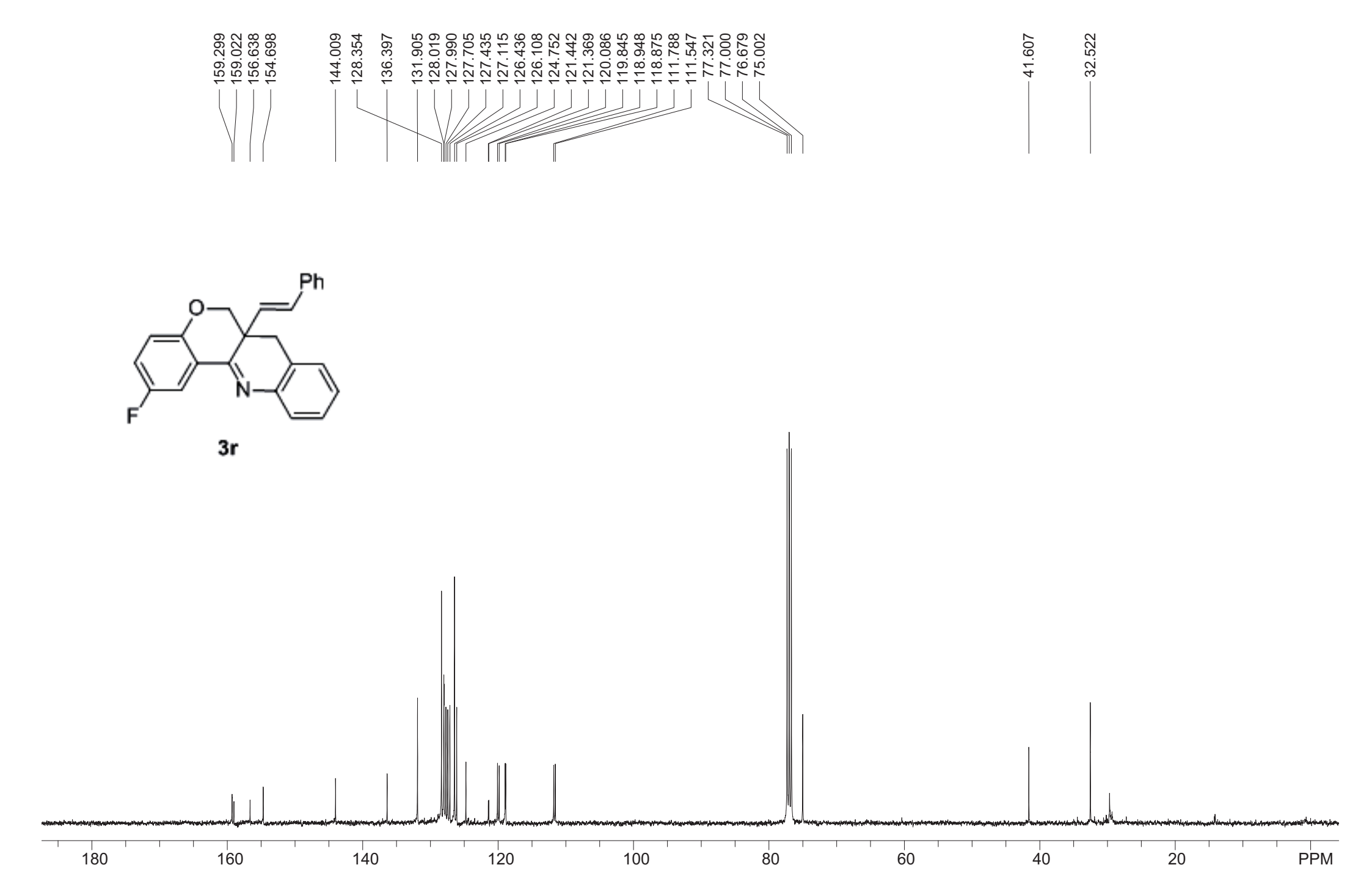
3q

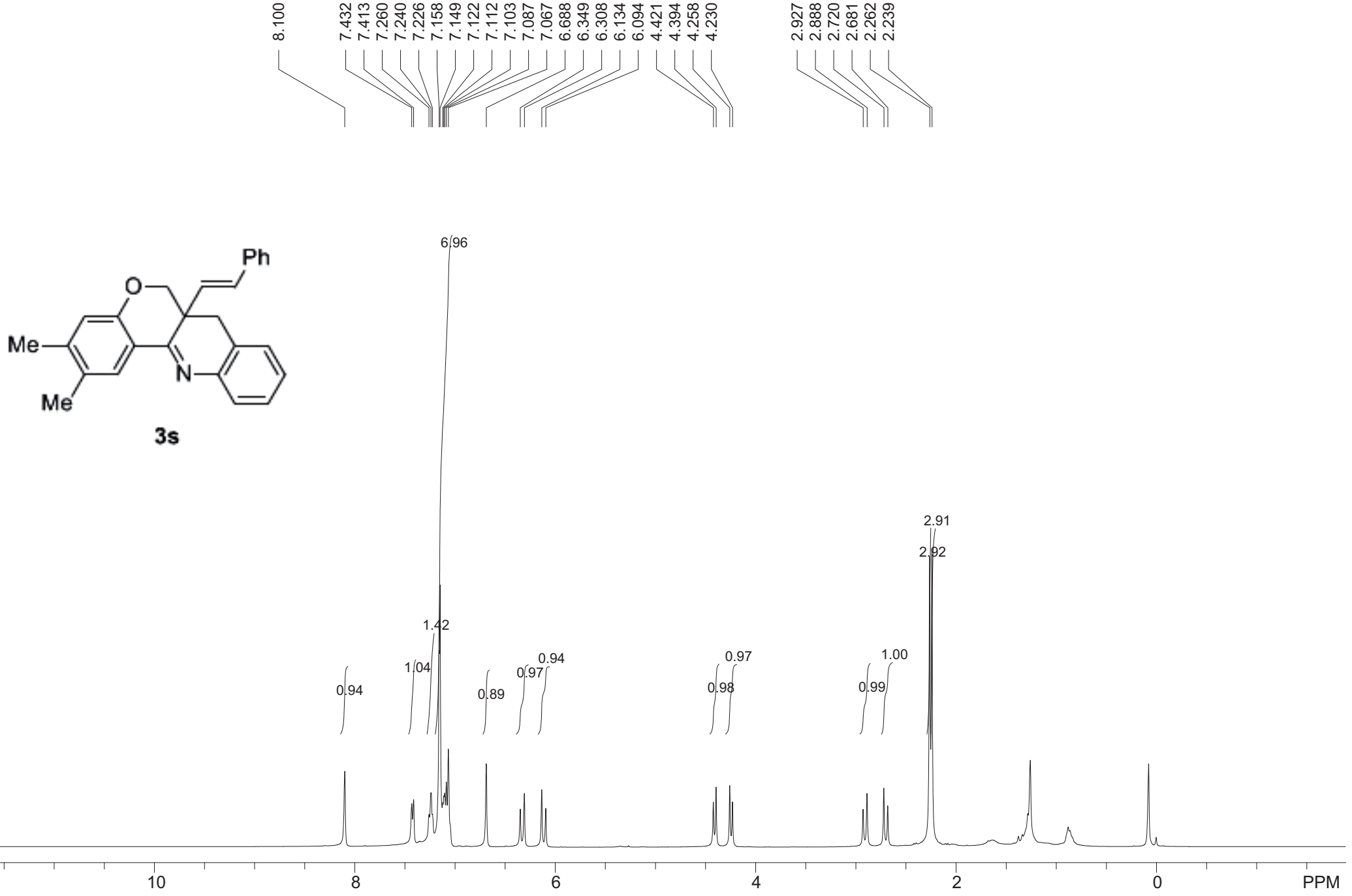

9.00
0.97
1.01
1.16
0.97
0.98
0.99
1.03
1.00
1.00
10
8
6
4
2
0
PPM

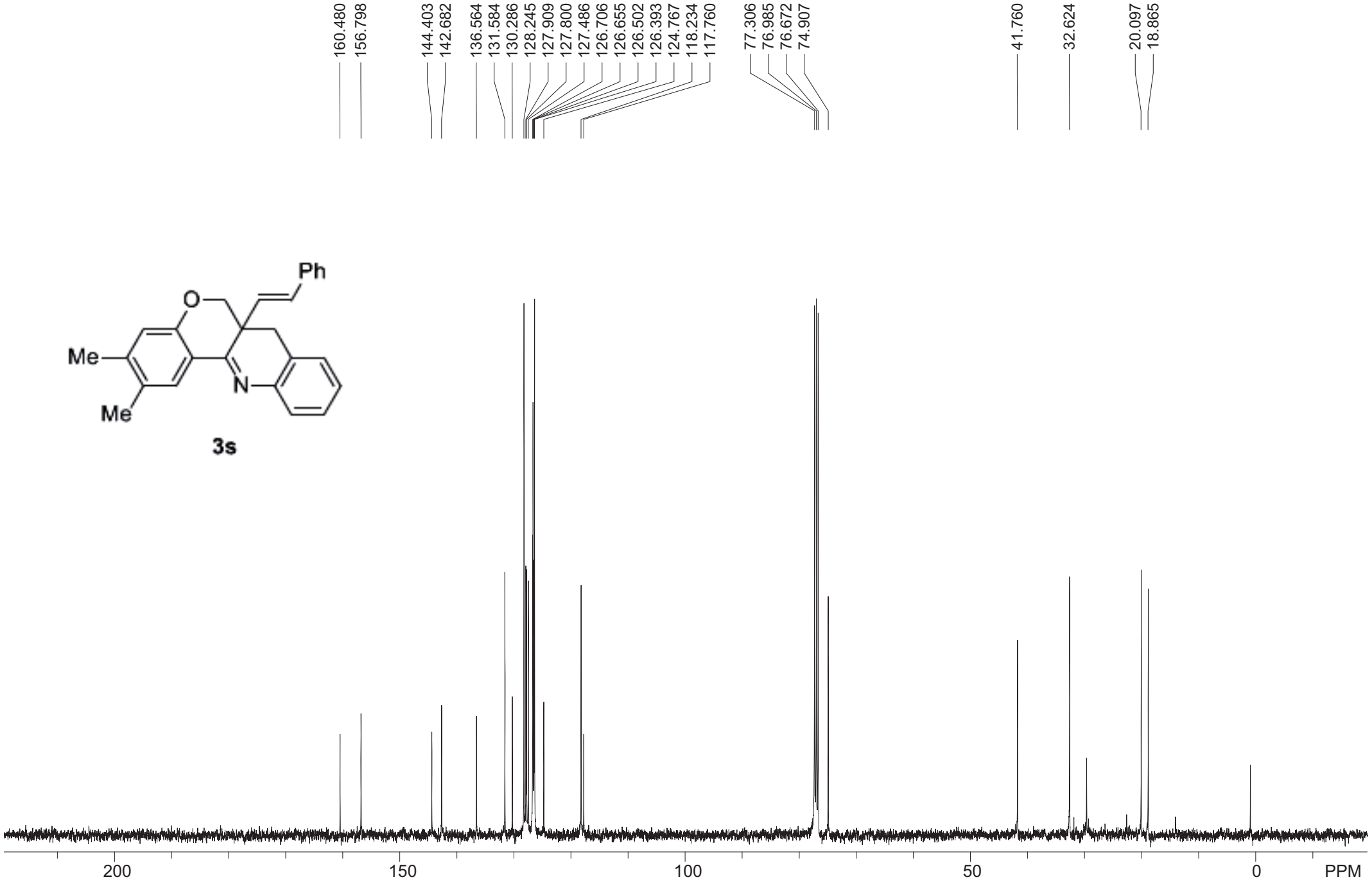

159.208
158.829
144.020
128.374
136.310
131.930
128.046
128.002
127.791
127.754
127.346
126.996
126.574
126.442
126.005
125.306
124.657
120.765
119.505
77.266
77.011
76.756
74.956
41.651
32.527
Ph
O
Br
N
180
160
140
120
100
80
60
40
20
PPM

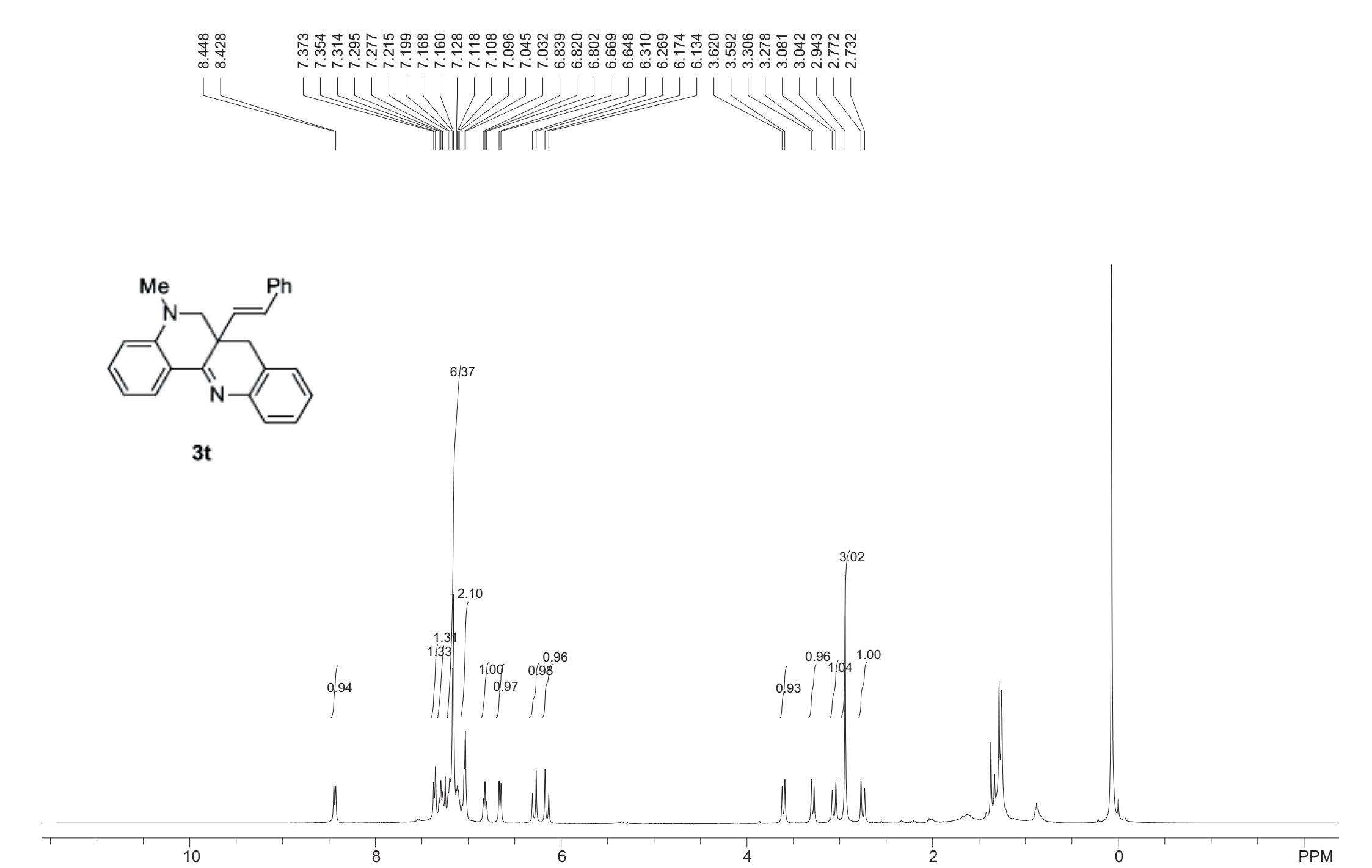
3q

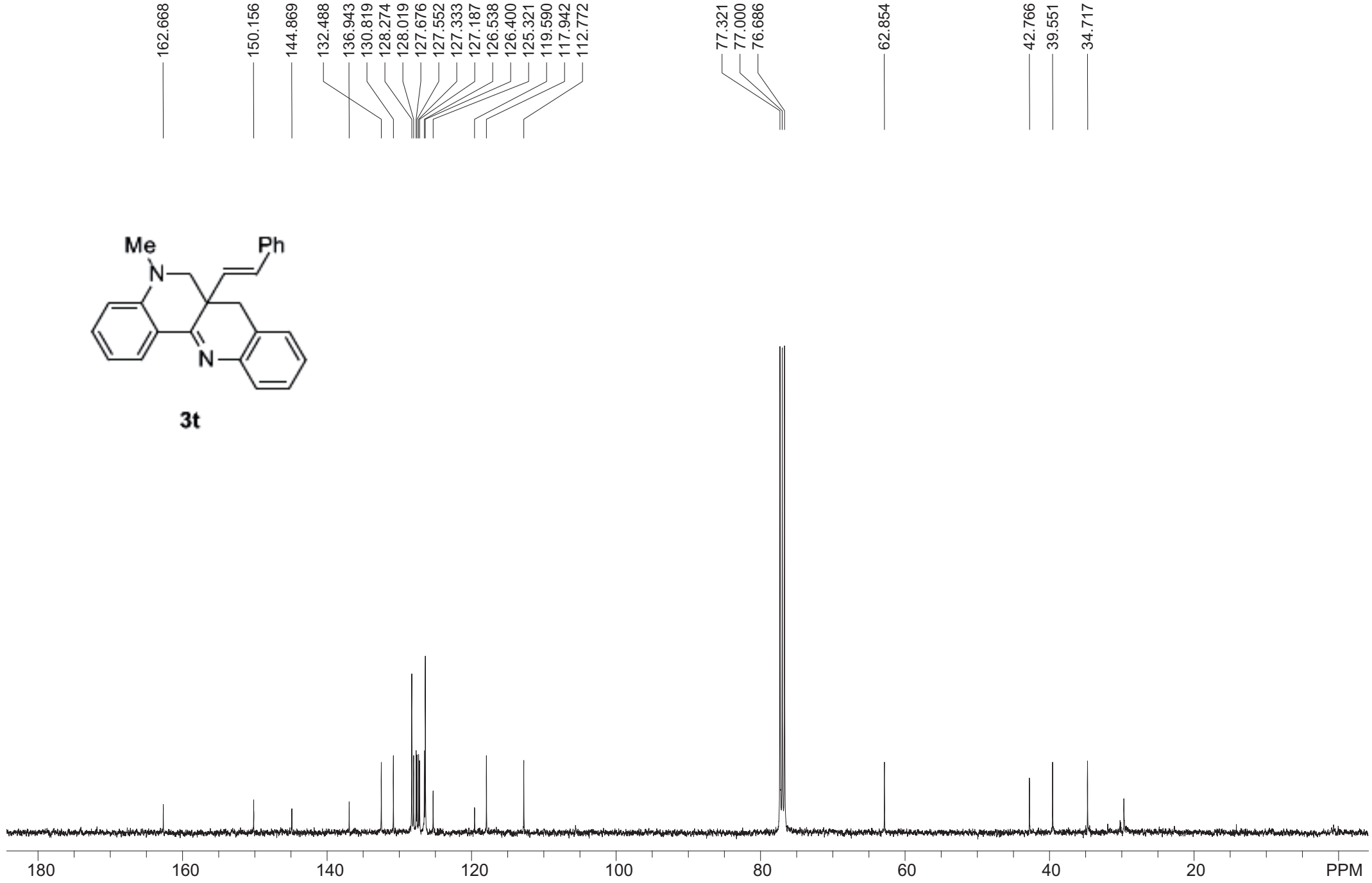

8.059
8.053
8.036
8.030
7.443
7.424
7.280
7.262
7.244
7.169
7.143
7.125
7.107
7.086
7.069
7.047
7.028
7.021
6.871
6.860
6.849
6.838
6.330
6.289
6.123
6.083
4.461
4.433
4.280
4.253
2.946
2.907
2.754
2.715
Ph
O
N
F
3r
8.39
0.97
1.27
1.34
1.00
1.01
0.98
1.01
1.06
1.05
1.00
10
8
6
4
2
0 PPM

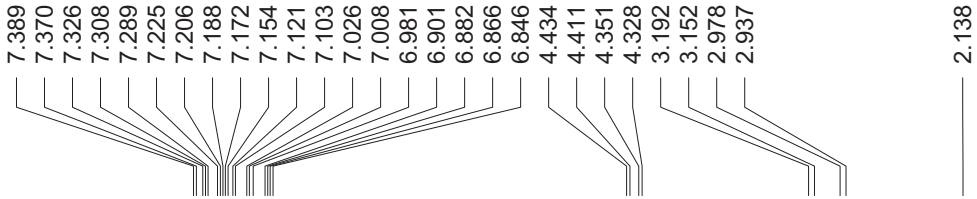

159.299
159.022
156.638
154.698
144.009
128.354
136.397
131.905
128.019
127.990
127.705
127.435
127.115
126.436
126.108
124.752
121.442
121.369
120.086
119.845
118.948
118.875
111.788
111.547
77.321
77.000
76.679
75.002
41.607
32.522
Ph
O
N
F
3r
180
160
140
120
100
80
60
40
20
PPM

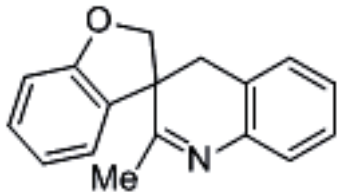

8.100
7.432
7.413
7.260
7.240
7.226
7.158
7.149
7.122
7.112
7.103
7.087
7.067
6.688
6.349
6.308
6.134
6.094
4.421
4.394
4.258
4.230
2.927
2.888
2.720
2.681
2.262
2.239
Ph
O
Me
N
Me
3s
6.96
1.42
1.04
0.94
0.89
0.97
0.94
0.98
0.97
0.99
1.00
2.91
2.92
10
8
6
4
2
0
PPM


160.480
156.798
144.403
142.682
136.564
131.584
130.286
128.245
127.909
127.800
127.486
126.706
126.655
126.502
126.393
124.767
118.234
117.760
77.306
76.985
76.672
74.907
41.760
32.624
20.097
18.865
Ph
O
Me
N
Me
3s
200
150
100
50
0
PPM

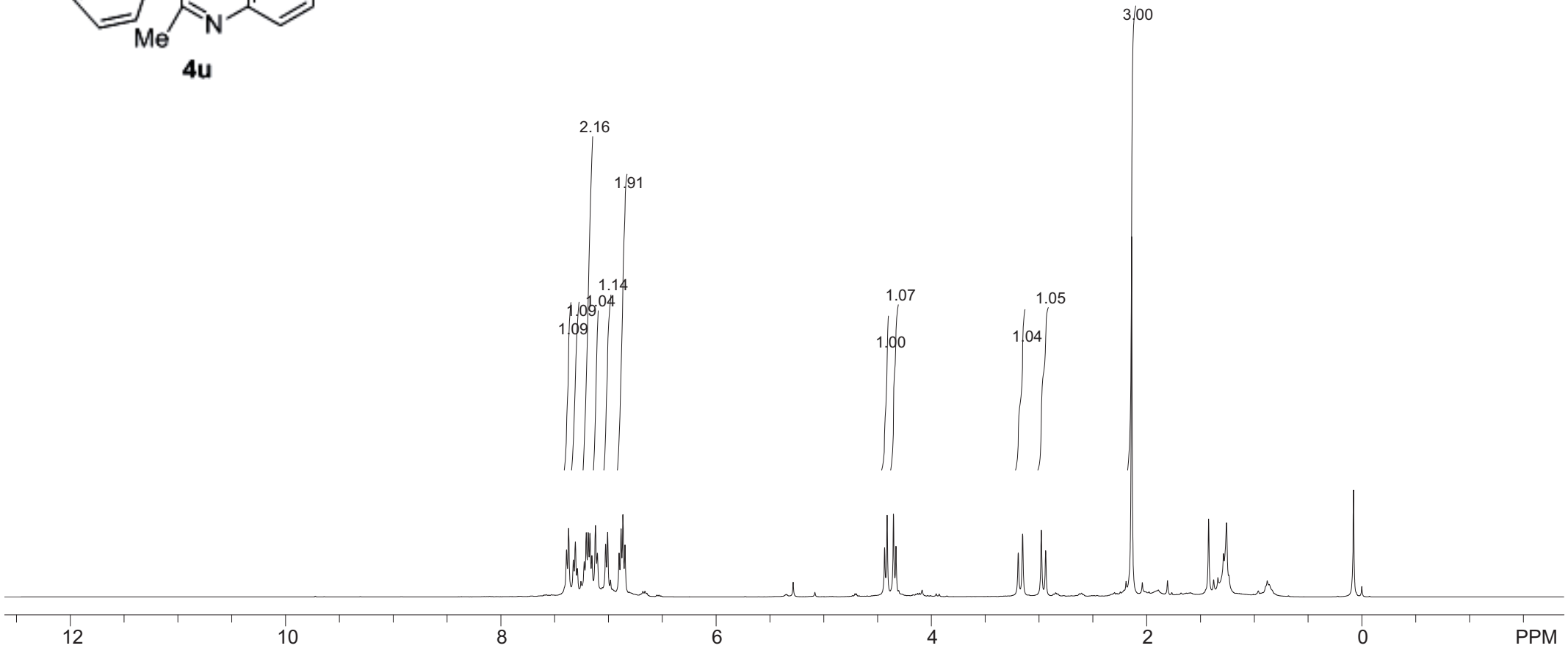

8.448
8.428
7.373
7.354
7.314
7.295
7.277
7.215
7.199
7.168
7.160
7.128
7.118
7.108
7.096
7.045
7.032
6.839
6.820
6.802
6.669
6.648
6.310
6.269
6.174
6.134
3.620
3.592
3.306
3.278
3.081
3.042
2.943
2.772
2.732
Me
Ph
N
N
3t
6.37
2.10
1.31
1.33
1.00
0.97
0.98
0.96
0.94
3.02
0.96
1.04
1.00
0.93
10
8
6
4
2
0
PPM

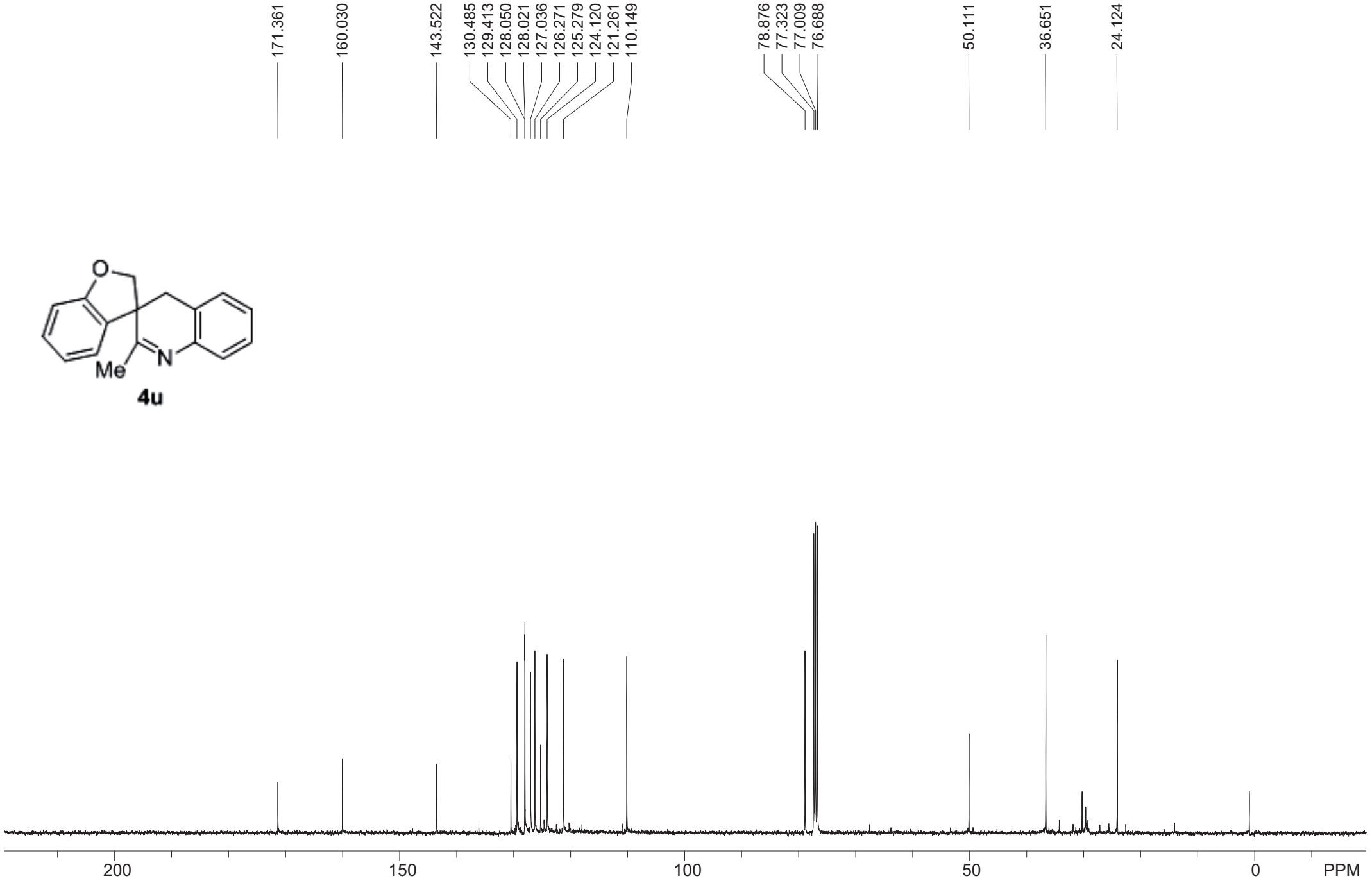

162.668
150.156
144.869
132.488
136.943
130.819
128.274
128.019
127.676
127.552
127.333
127.187
126.538
126.400
125.321
119.590
117.942
112.772
77.321
77.000
76.686
62.854
42.766
39.551
34.717
Me
N
Ph
N
3t
180
160
140
120
100
80
60
40
20
PPM

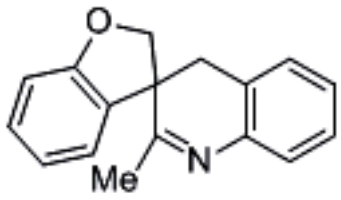

7.389
7.370
7.326
7.308
7.289
7.225
7.206
7.188
7.172
7.154
7.121
7.103
7.026
7.008
6.981
6.901
6.882
6.866
6.846
4.434
4.411
4.351
4.328
3.192
3.152
2.978
2.937
2.138


O
Me
N

4u


3.00
2.16
1.91
1.14
1.04
1.09
1.09
1.07
1.00
1.05
1.04
12
10
8
6
4
2
0
PPM

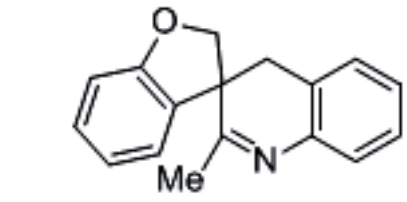

171.361
160.030
143.522
130.485
129.413
128.050
128.021
127.036
126.271
125.279
124.120
121.261
110.149
78.876
77.323
77.009
76.688
50.111
36.651
24.124
O
N
Me
4u
200
150
100
50
0
PPM


O
N
Me

4u

H-H COSY

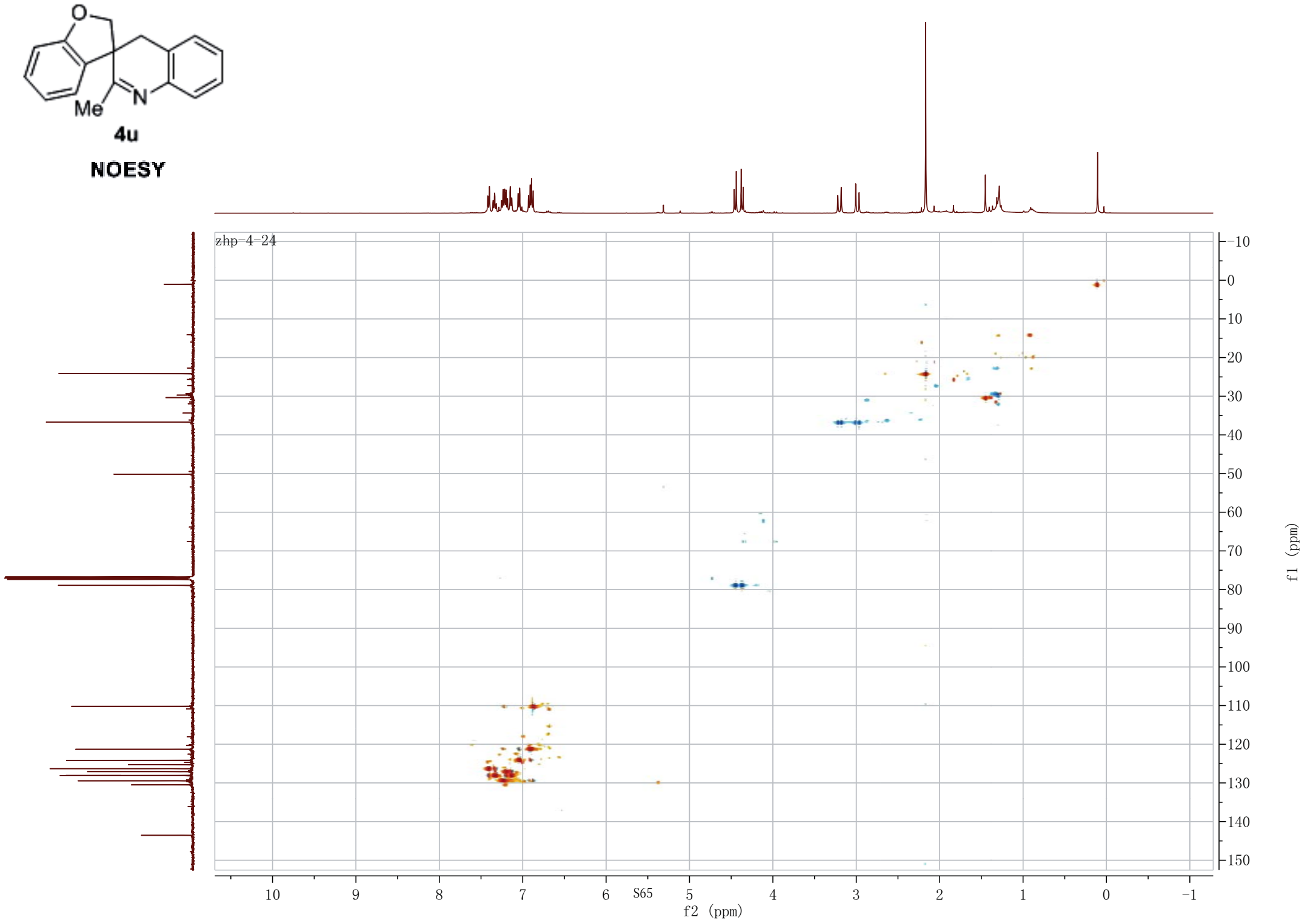
zhp-4-24
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
f2 (ppm)
0
1
2
3
4
5
6
7
8
f1 (ppm)

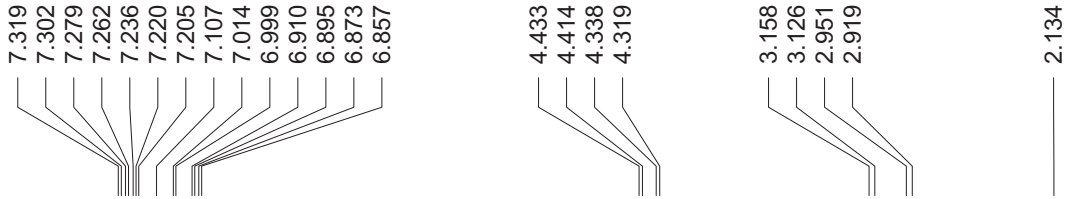

O
N
Me

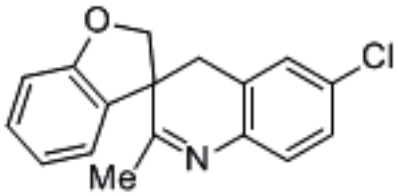
4u

HMBC

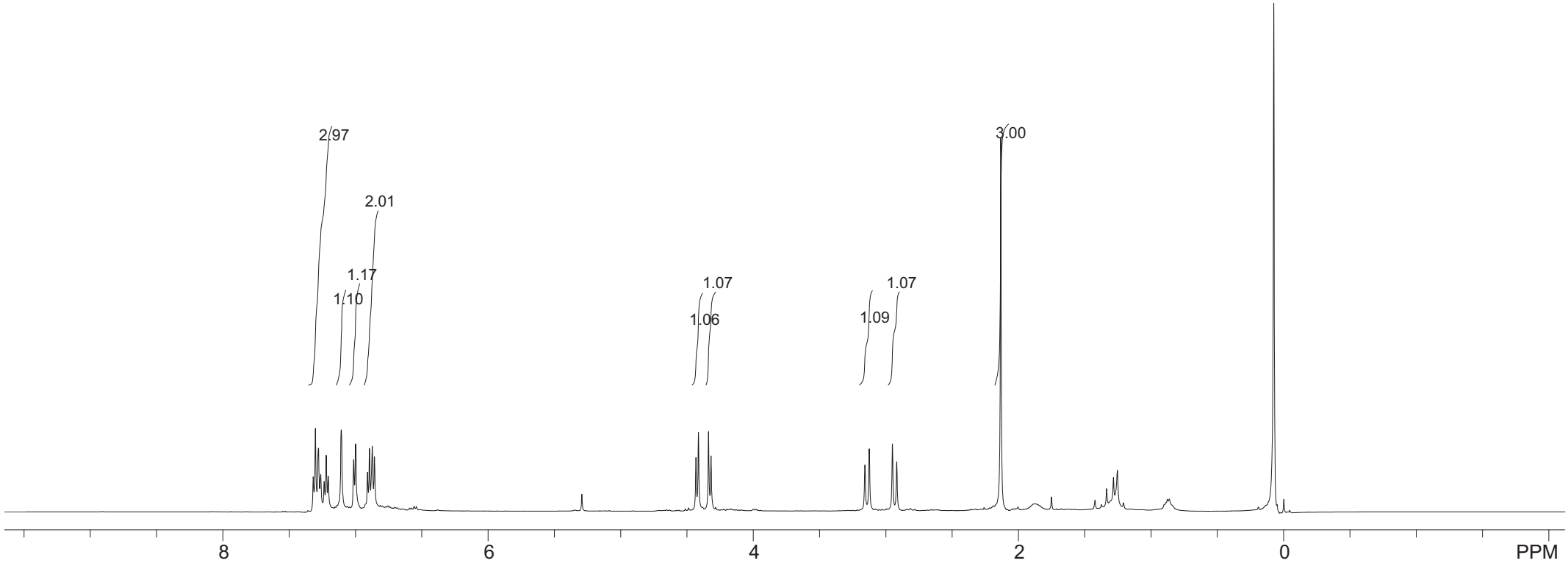
zhp-4-24
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f2 (ppm)
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
f1 (ppm)

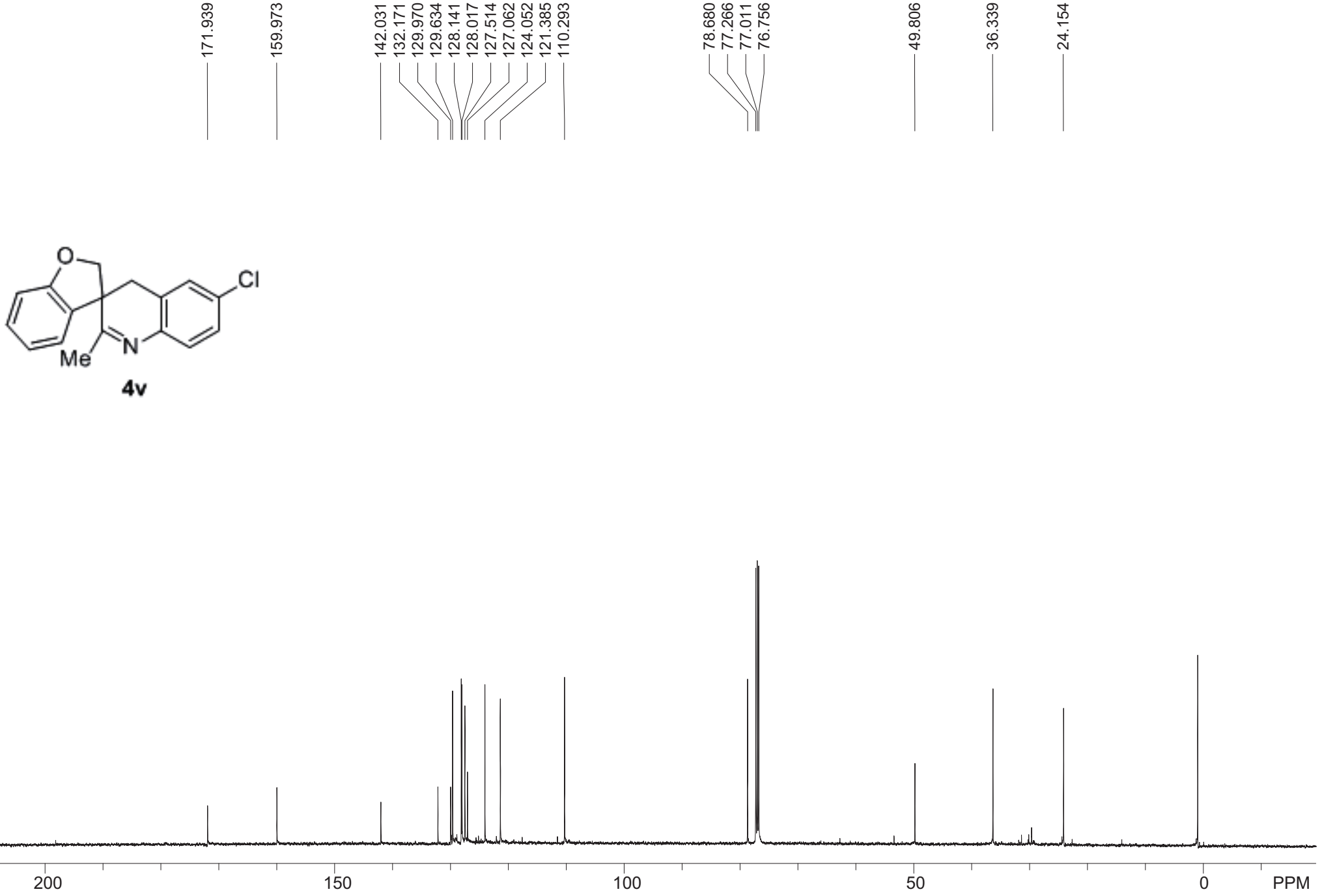

O
N
Me
4u
NOESY
zhp-4-24
10
9
8
7
6
S65
5
4
3
2
1
0
−1
f2 (ppm)
−10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
f1 (ppm)

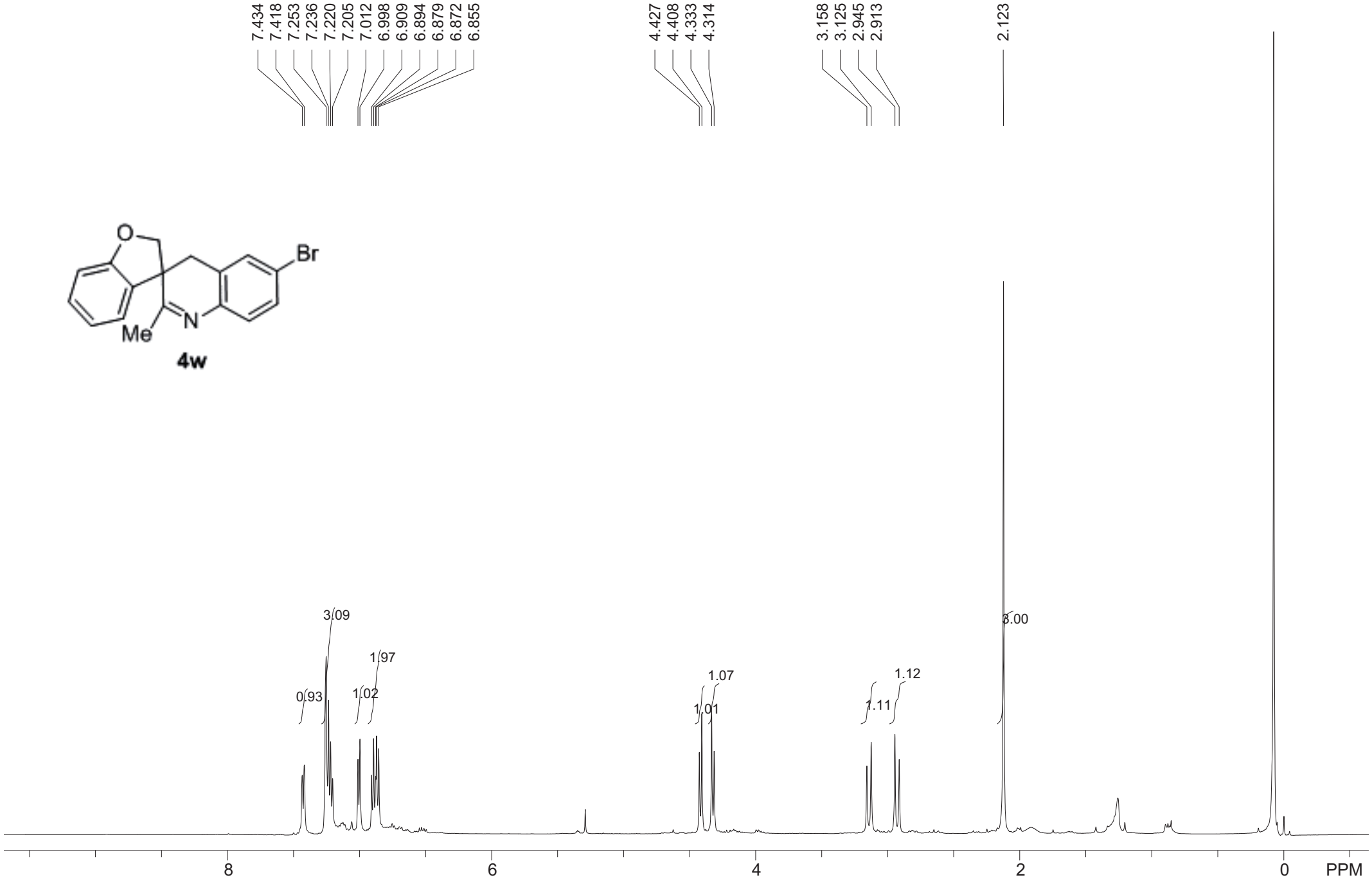

7.319
7.302
7.279
7.262
7.236
7.220
7.205
7.107
7.014
6.999
6.910
6.895
6.873
6.857
4.433
4.414
4.338
4.319
3.158
3.126
2.951
2.919
2.134

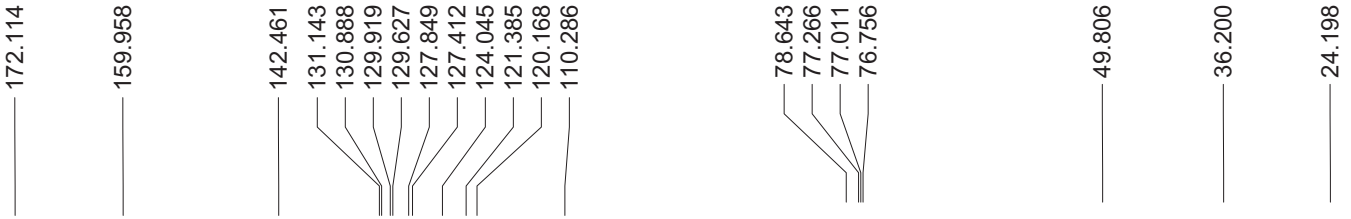

O
Cl
Me
N

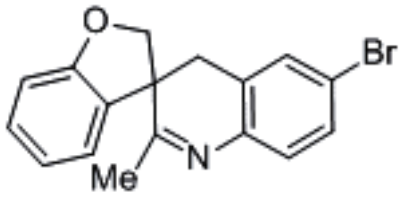
4v


2.97
2.01
1.17
1.10
1.07
1.06
1.07
1.09
3.00
8
6
4
2
0
PPM

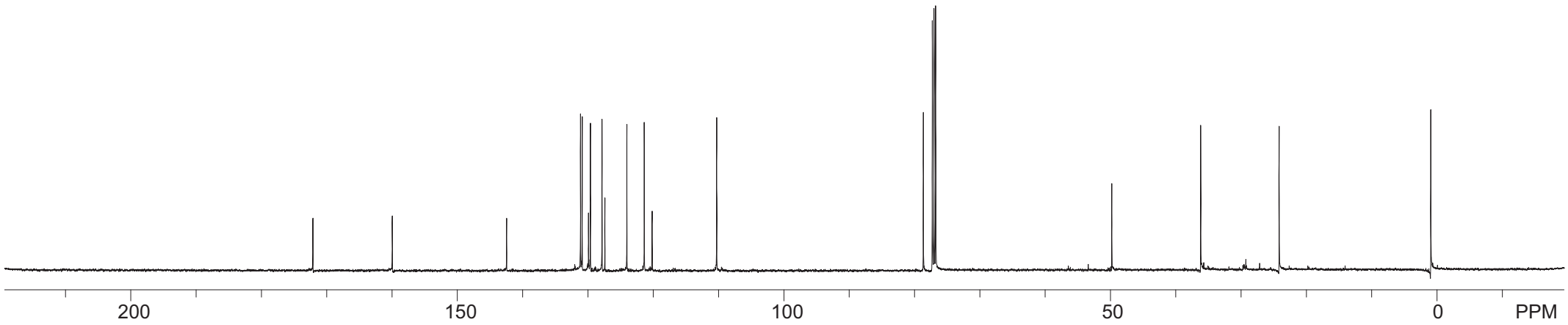

171.939
159.973
142.031
132.171
129.970
129.634
128.141
128.017
127.514
127.062
124.052
121.385
110.293
78.680
77.266
77.011
76.756
49.806
36.339
24.154
O
Cl
Me
N
4v
200
150
100
50
0
PPM

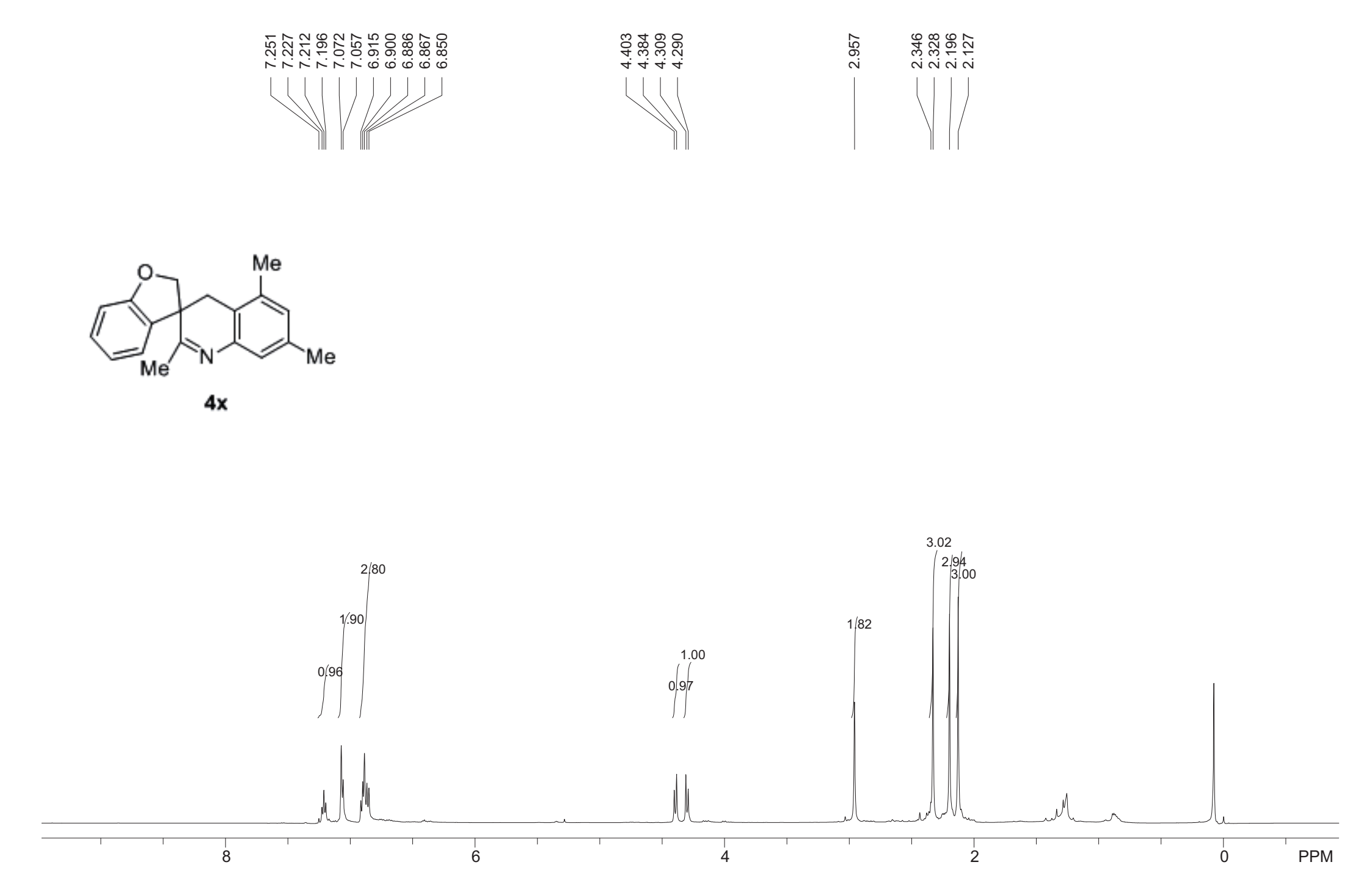

7.434
7.418
7.253
7.236
7.220
7.205
7.012
6.998
6.909
6.894
6.879
6.872
6.855
4.427
4.408
4.333
4.314
3.158
3.125
2.945
2.913
2.123
O
Br
Me
N
4w
3.09
1.97
0.93
1.02
1.07
1.01
1.12
1.11
3.00
8
6
4
2
0
PPM

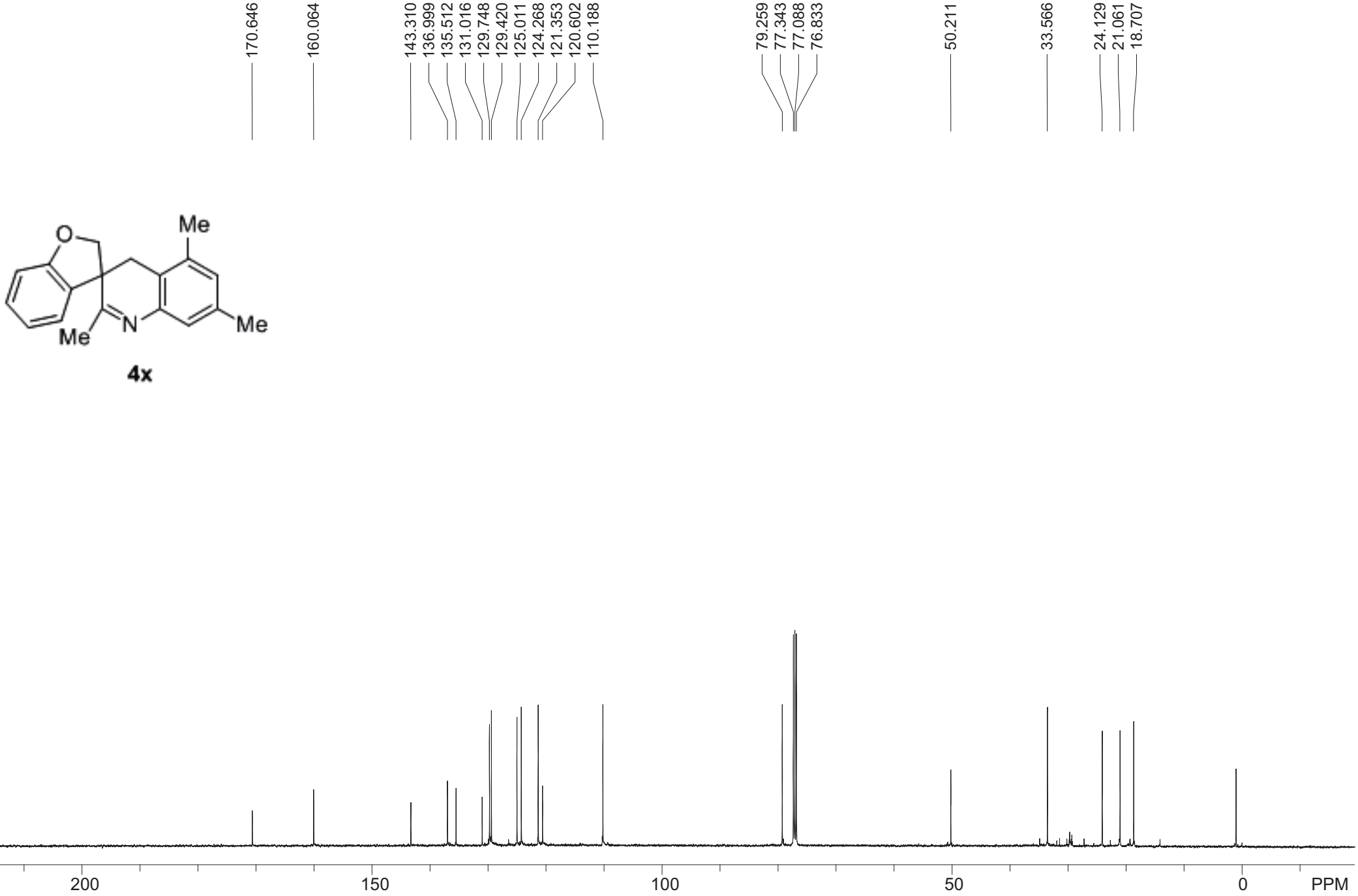

172.114
159.958
142.461
131.143
130.888
129.919
129.627
127.849
127.412
124.045
121.385
120.168
110.286
78.643
77.266
77.011
76.756
49.806
36.200
24.198


O
Br
N
Me

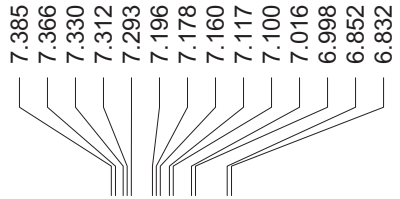
4w

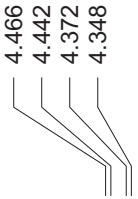

200
150
100
50
0
PPM

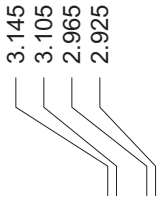

7.251
7.227
7.212
7.196
7.072
7.057
6.915
6.900
6.886
6.867
6.850
4.403
4.384
4.309
4.290
2.957
2.346
2.328
2.196
2.127
O
Me
N
Me
Me
4x
0.96
1.90
2.80
1.00
0.97
1.82
3.02
2.94
3.00
8
6
4
2
0
PPM


170.646
160.064
143.310
136.999
135.512
131.016
129.748
129.420
125.011
124.268
121.353
120.602
110.188
79.259
77.343
77.088
76.833
50.211
33.566
24.129
21.061
18.707
O
Me
N
Me
Me
200
150
100
50
0
PPM

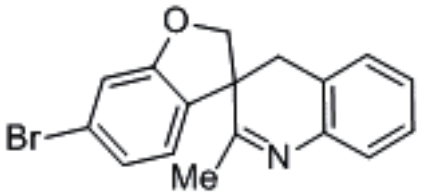
4x


7.385
7.366
7.330
7.312
7.293
7.196
7.178
7.160
7.117
7.100
7.016
6.998
6.852
6.832

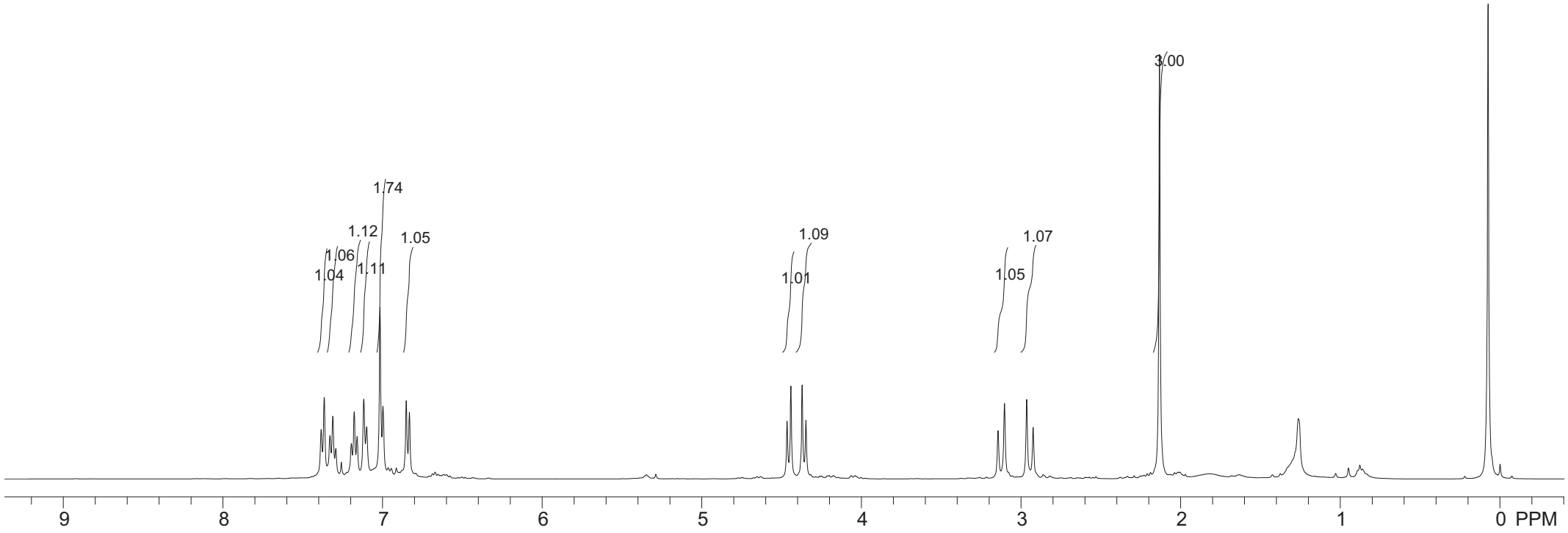

4.466
4.442
4.372
4.348

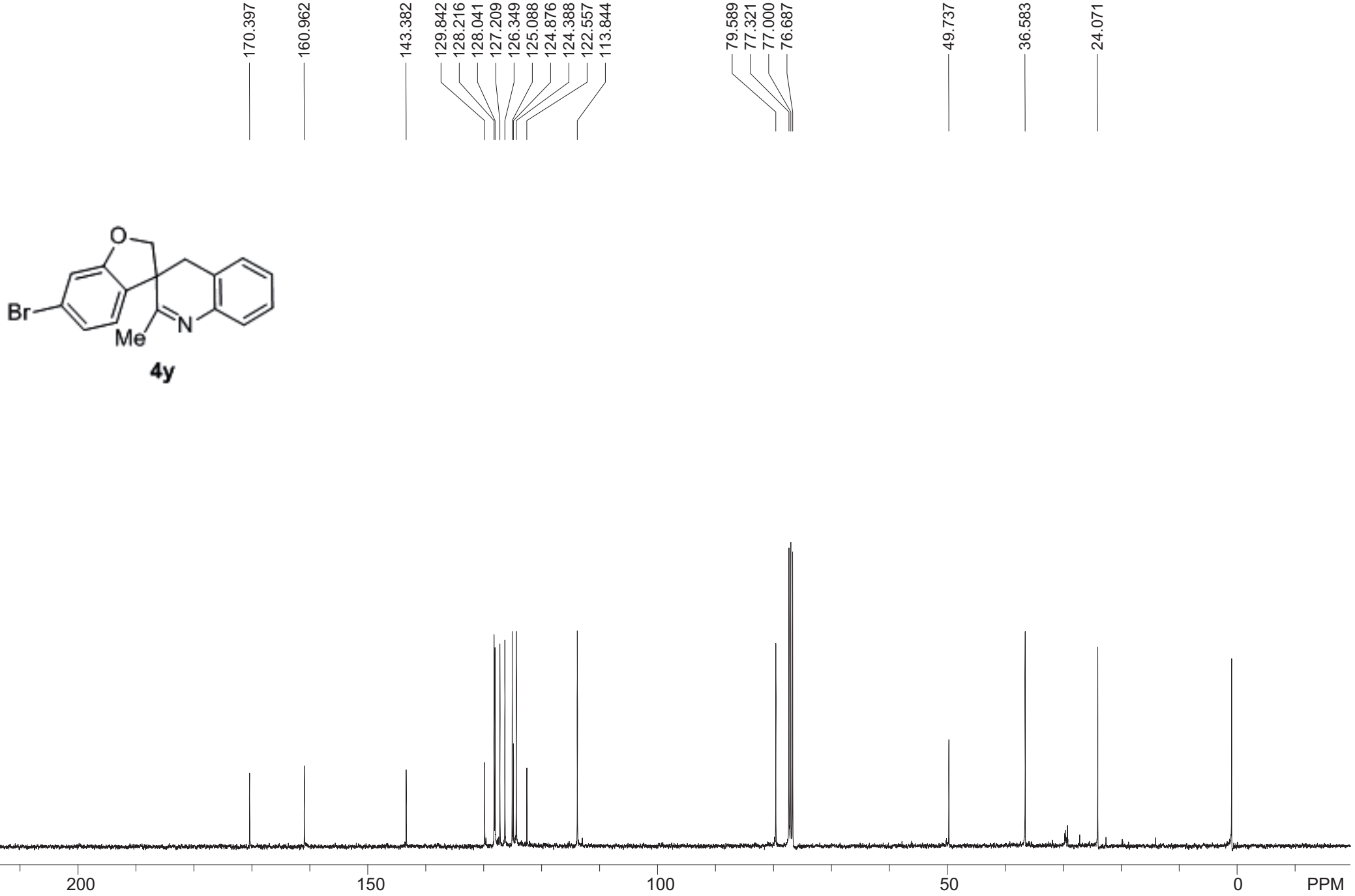

3.145
3.105
2.965
2.925

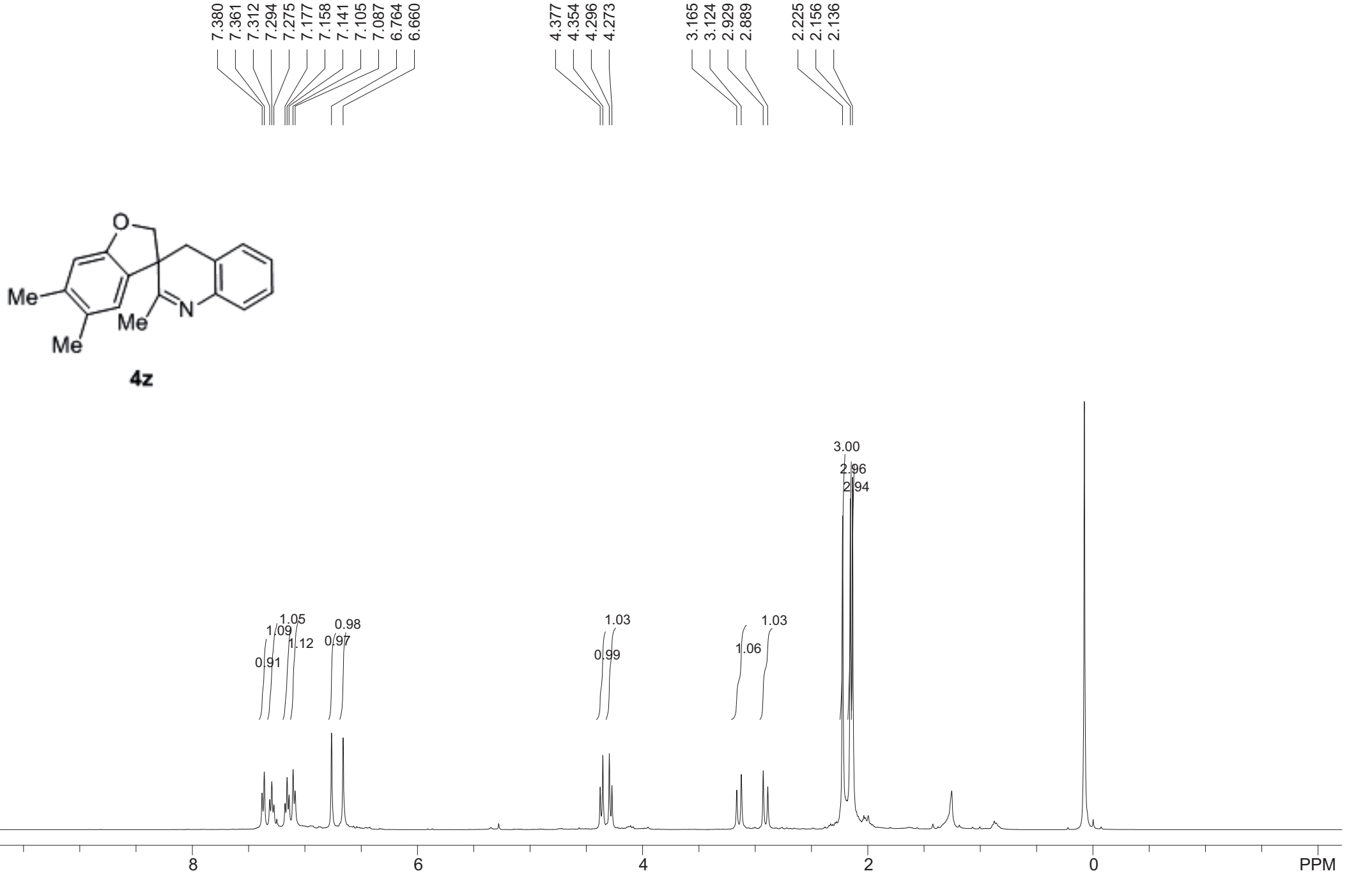
2.134

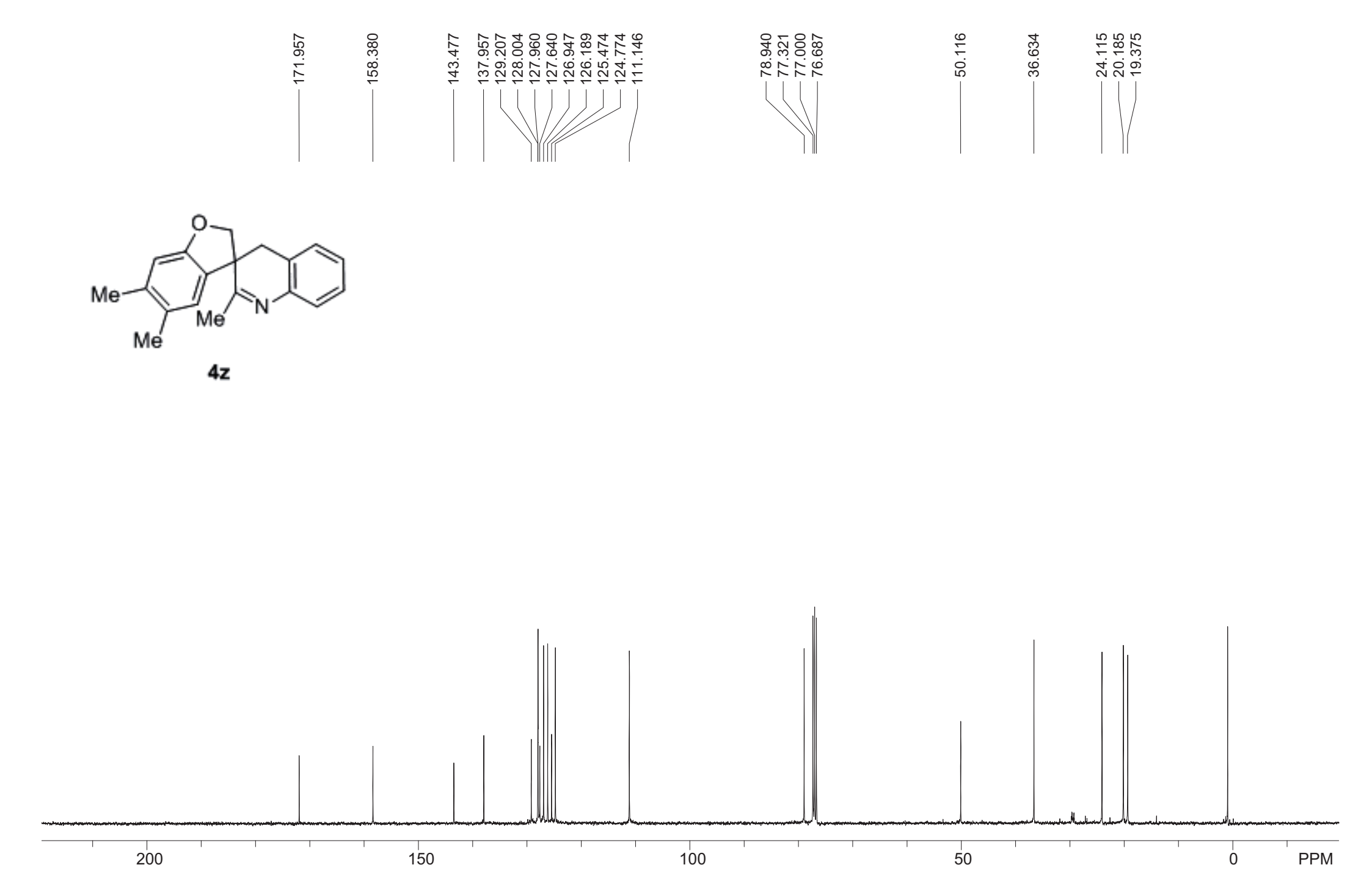

O
Br
N
Me

4y

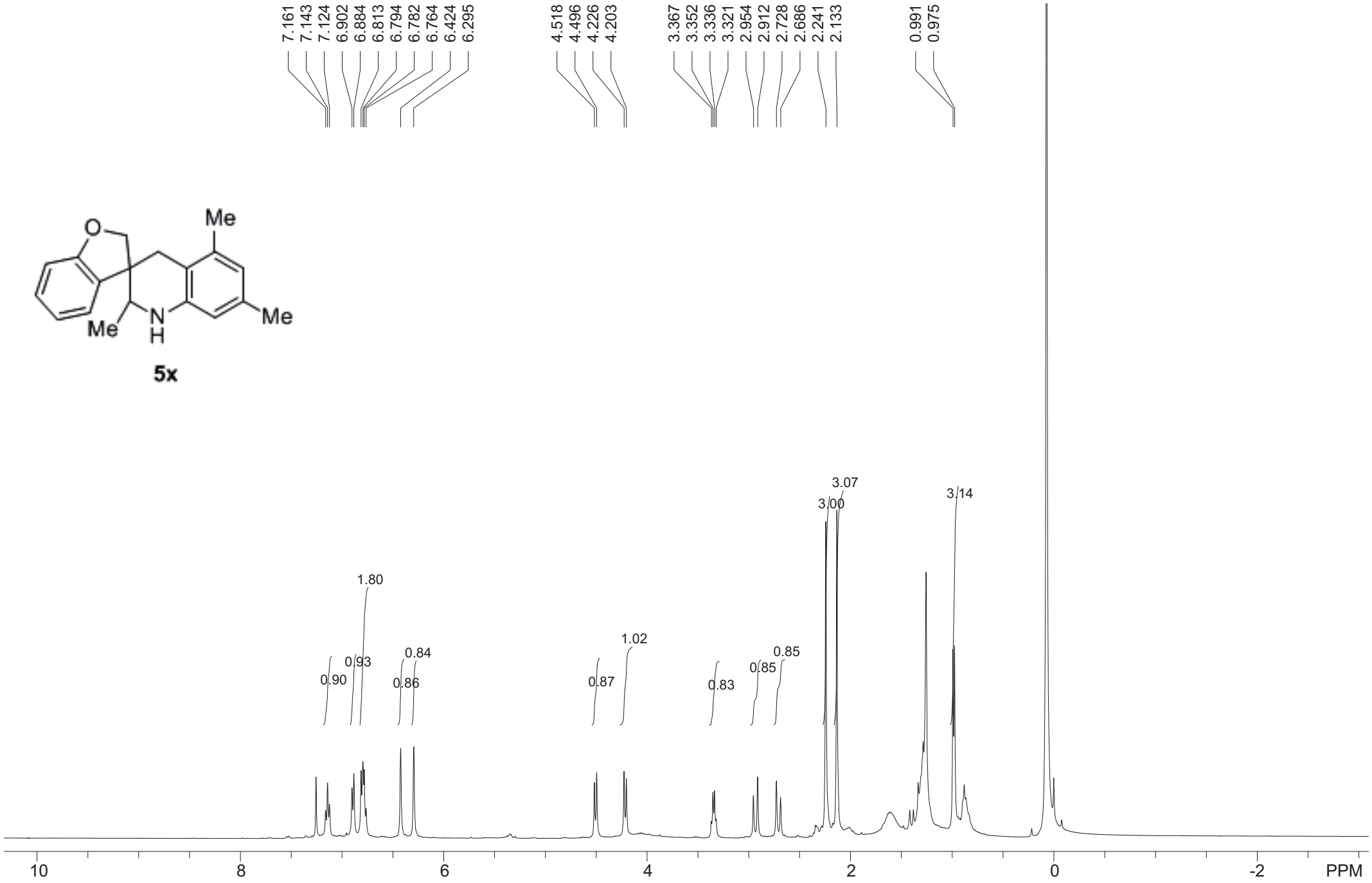

1.74
1.12
1.06
1.04
1.11
1.05
1.09
1.01
1.07
1.05
3.00
9
8
7
6
5
4
3
2
1
0 PPM

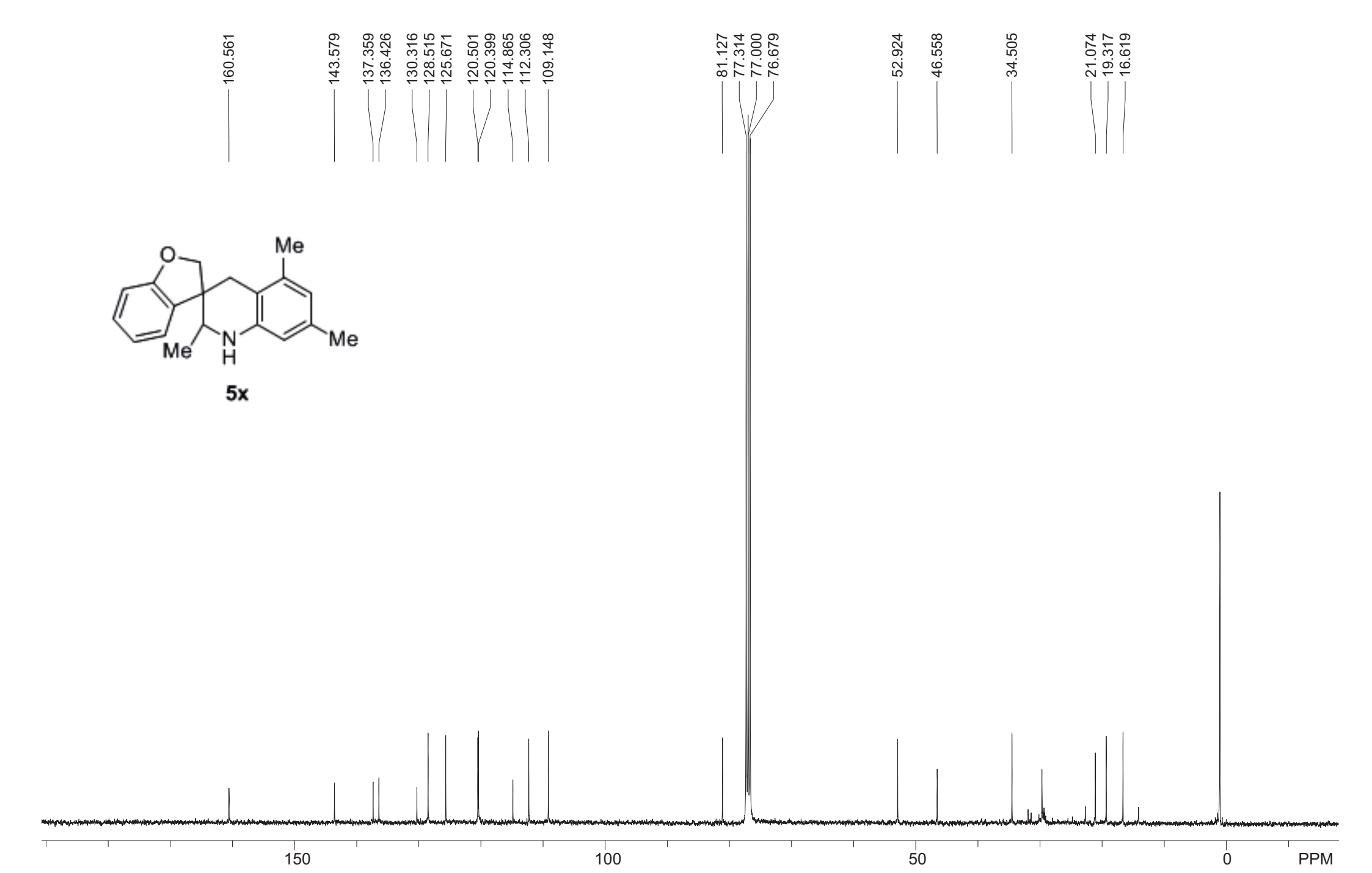

170.397
160.962
143.382
129.842
128.216
128.041
127.209
126.349
125.088
124.876
124.388
122.557
113.844
79.589
77.321
77.000
76.687
49.737
36.583
24.071
Br
O
N
Me
4y
200
150
100
50
0
PPM


7.380
7.361
7.312
7.294
7.275
7.177
7.158
7.141
7.105
7.087
6.764
6.660
4.377
4.354
4.296
4.273
3.165
3.124
2.929
2.889
2.225
2.156
2.136
O
Me
Me
Me
N
4z
0.91
1.09
1.05
1.12
0.98
0.97
1.03
0.99
1.06
1.03
3.00
2.96
2.94
8
6
4
2
0
PPM

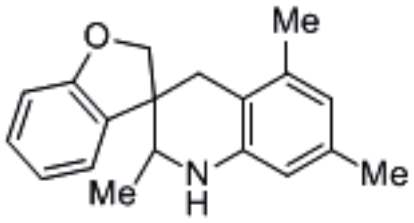

171.957
158.380
143.477
137.957
129.207
128.004
127.960
127.640
126.947
126.189
125.474
124.774
111.146
78.940
77.321
77.000
76.687
50.116
36.634
24.115
20.185
19.375
O
Me
Me
Me
N
200
150
100
50
0
PPM

4z


7.161
7.143
7.124
6.902
6.884
6.813
6.794
6.782
6.764
6.424
6.295
4.518
4.496
4.226
4.203
3.367
3.352
3.336
3.321
2.954
2.912
2.728
2.686
2.241
2.133
0.991
0.975
O
Me
Me
N
H
Me
5x
1.80
0.93
0.90
0.84
0.86
1.02
0.87
0.83
0.85
0.85
3.07
3.00
3.14
10
8
6
4
2
0
-2
PPM


160.561
143.579
137.359
136.426
130.316
128.515
125.671
120.501
120.399
114.865
112.306
109.148
81.127
77.314
77.000
76.679
52.924
46.558
34.505
21.074
19.317
16.619
O
Me
Me
N
H
Me
150
100
50
0
PPM

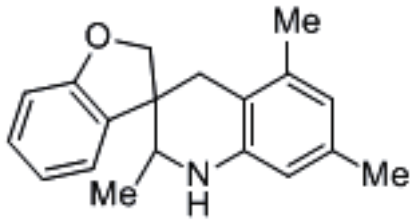
5x


O
Me
N
H
Me
Me

5x

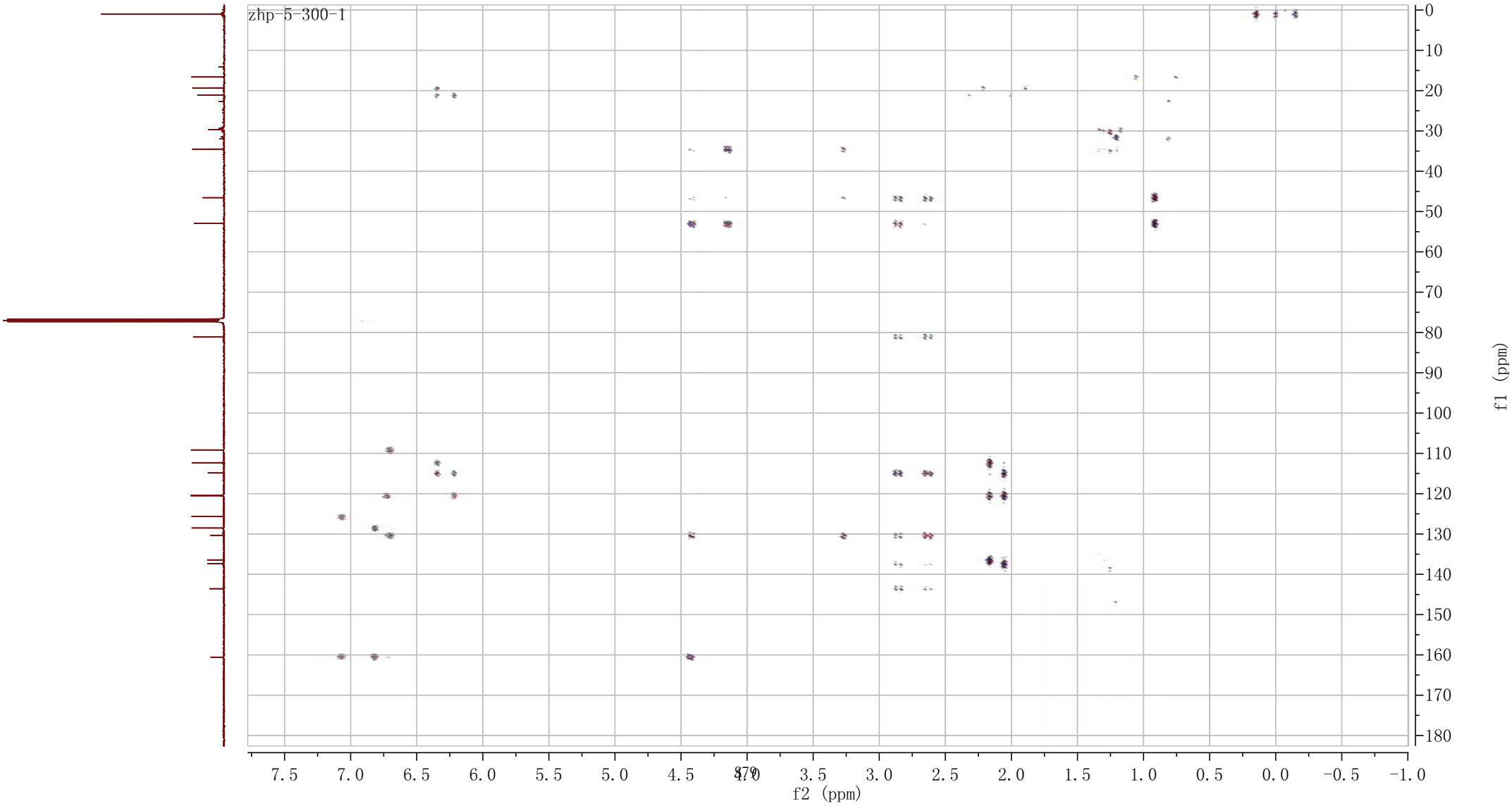
H-H COSY

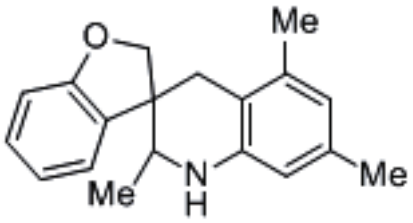
zhp-5-300-1
f2 (ppm)
f1 (ppm)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.5
-2
-1
0
1
2
3
4
5
6
7
8


O
Me
N
H
Me
Me

5x

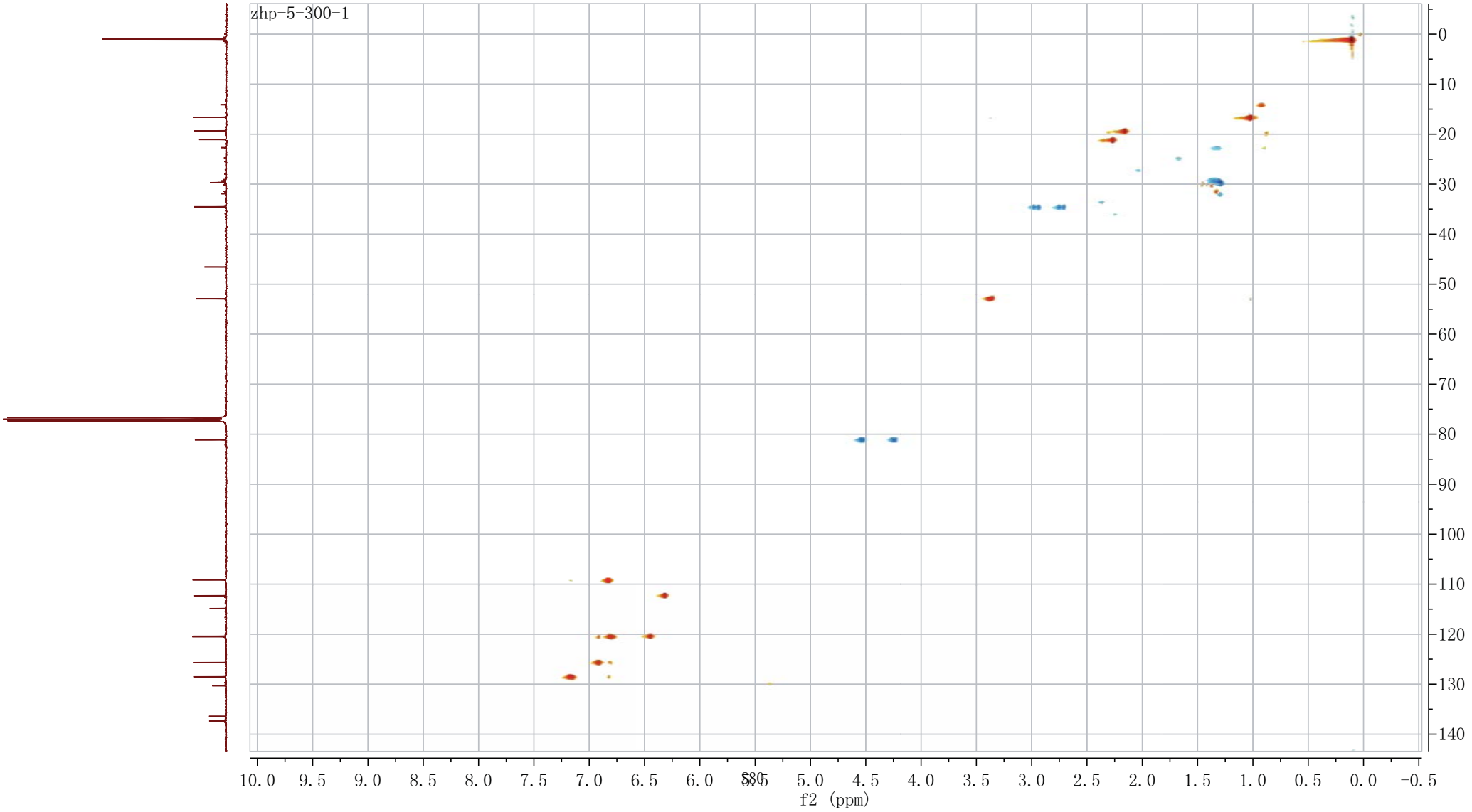
HMBC

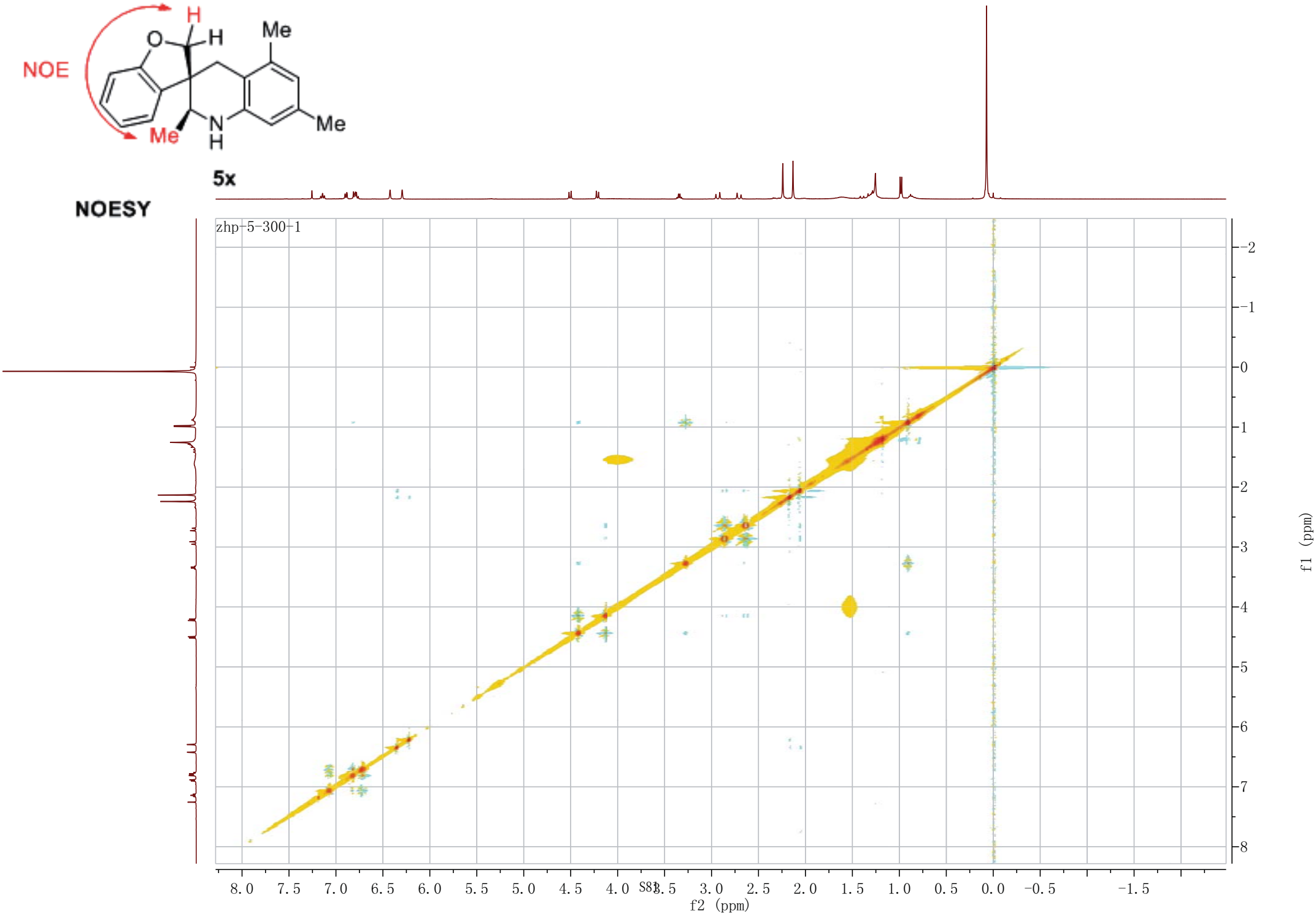

zhp-5-300-1
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
f2 (ppm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
f1 (ppm)

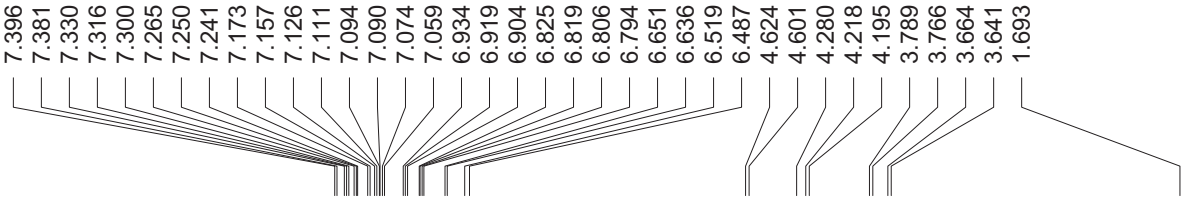

O
Me
N
H
Me
Me

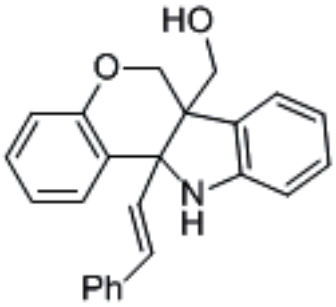
5x

HMQC

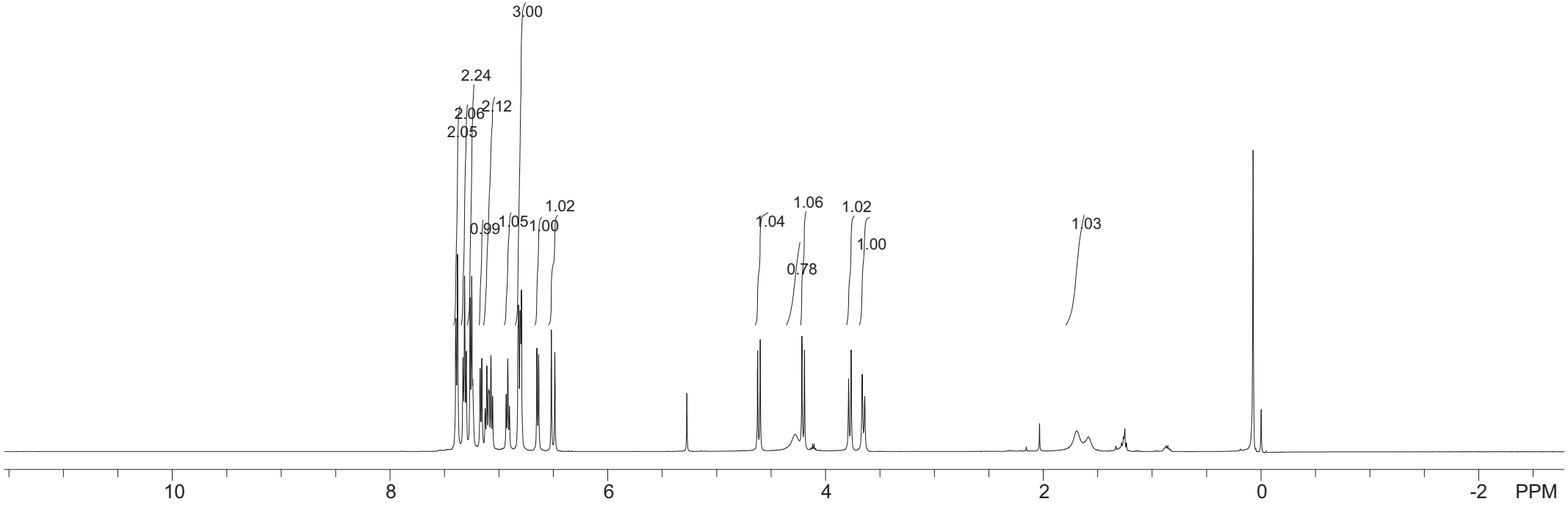

zhp-5-300-1
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f2 (ppm)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
f1 (ppm)

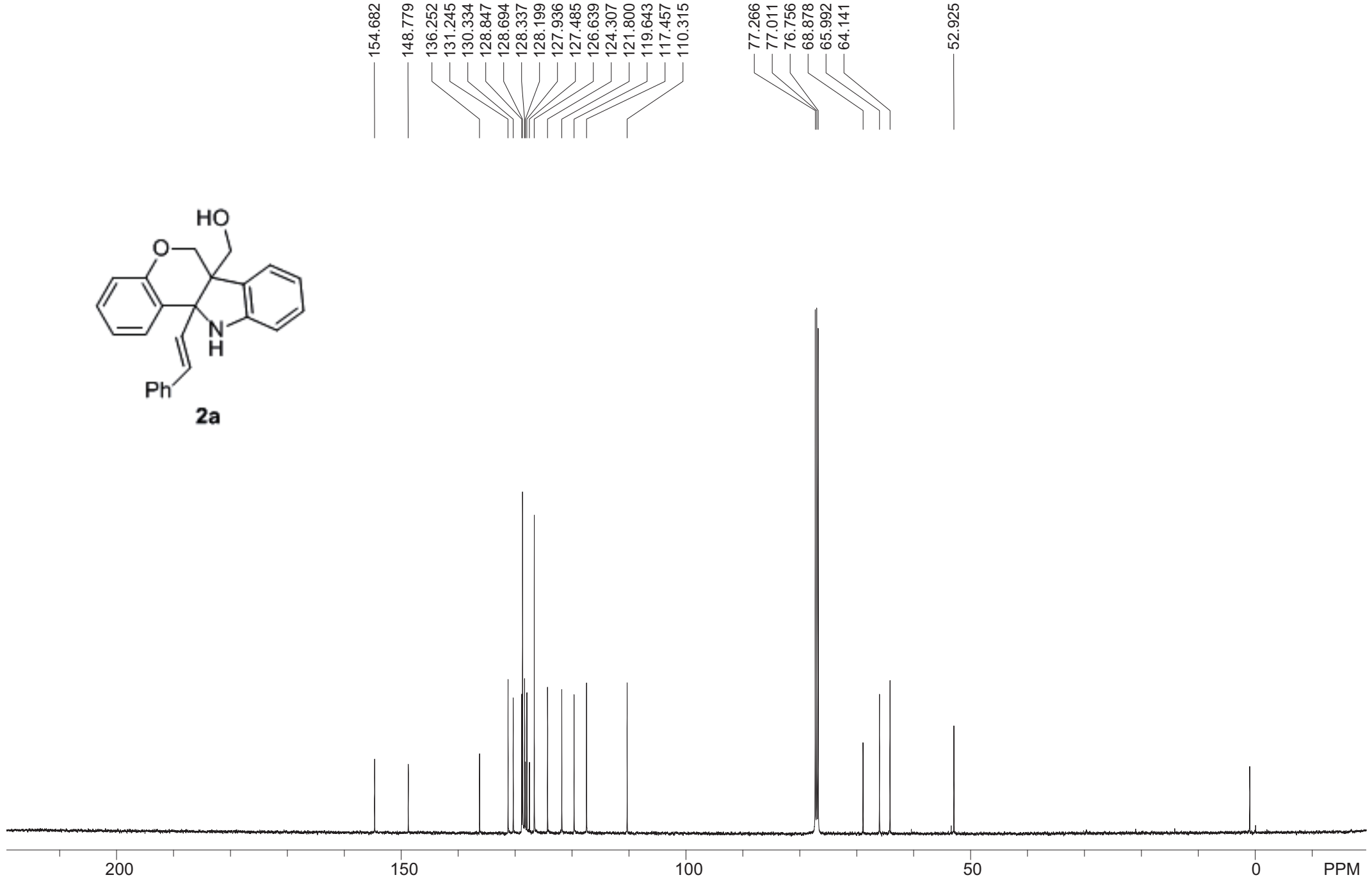

NOE
H
O
H
Me
N
H
Me
Me
5x
NOESY
zhp-5-300-1
f1 (ppm)
f2 (ppm)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.5
-2
-1
0
1
2
3
4
5
6
7
8

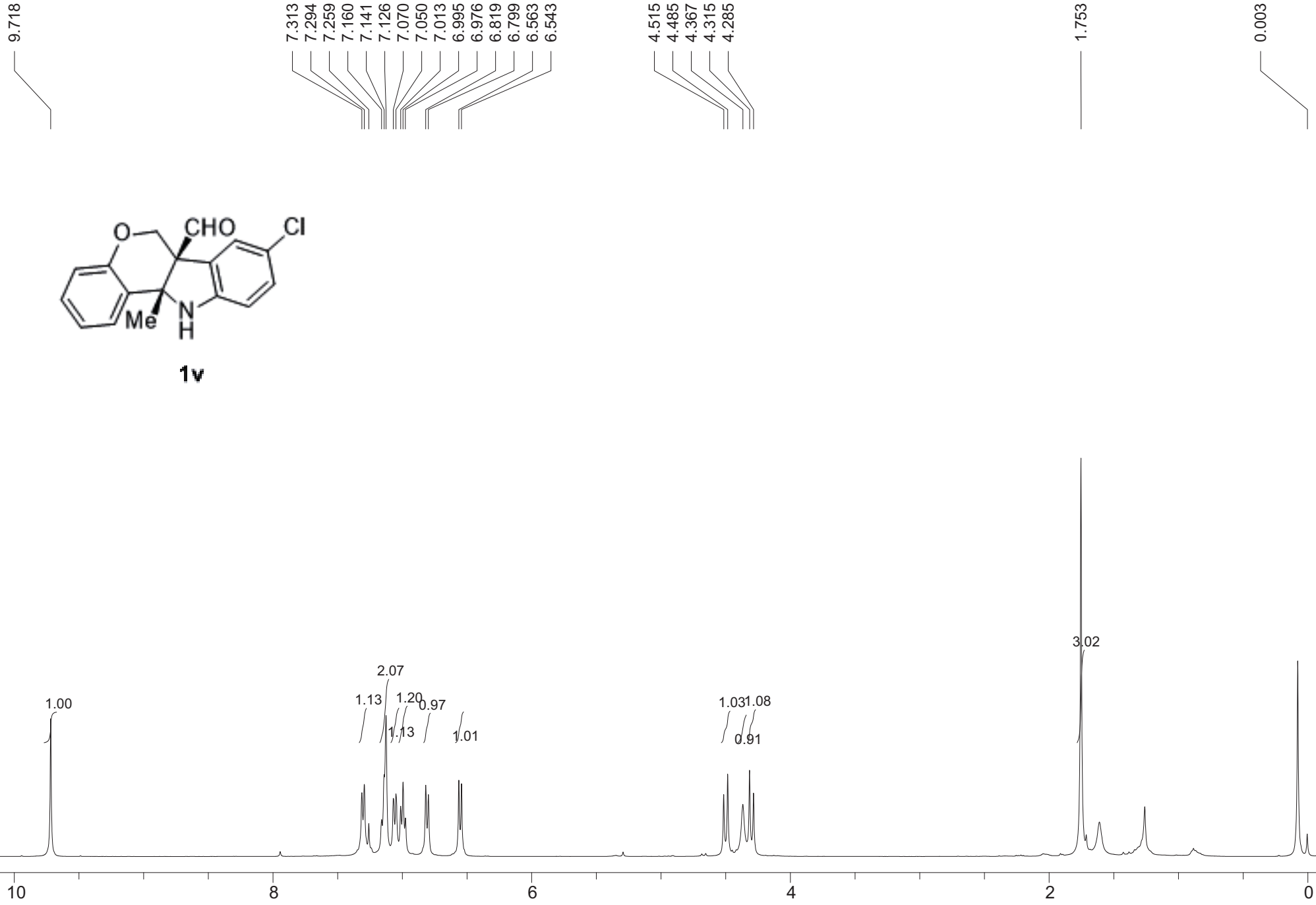

7.396
7.381
7.330
7.316
7.300
7.265
7.250
7.241
7.173
7.157
7.126
7.111
7.094
7.090
7.074
7.059
6.934
6.919
6.904
6.825
6.819
6.806
6.794
6.651
6.636
6.519
6.487
4.624
4.601
4.280
4.218
4.195
3.789
3.766
3.664
3.641
1.693

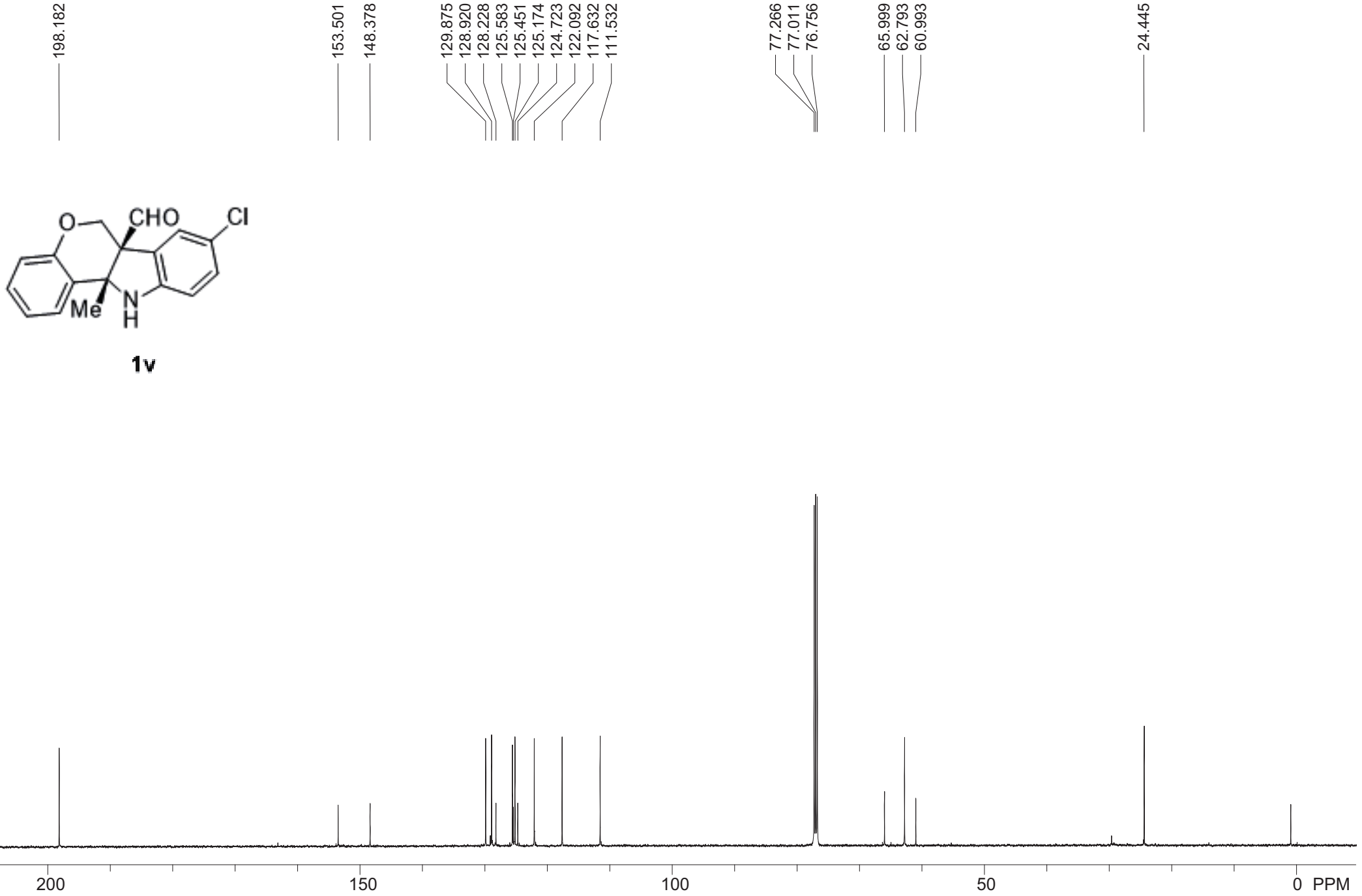

HO
O
N
H
Ph

2a

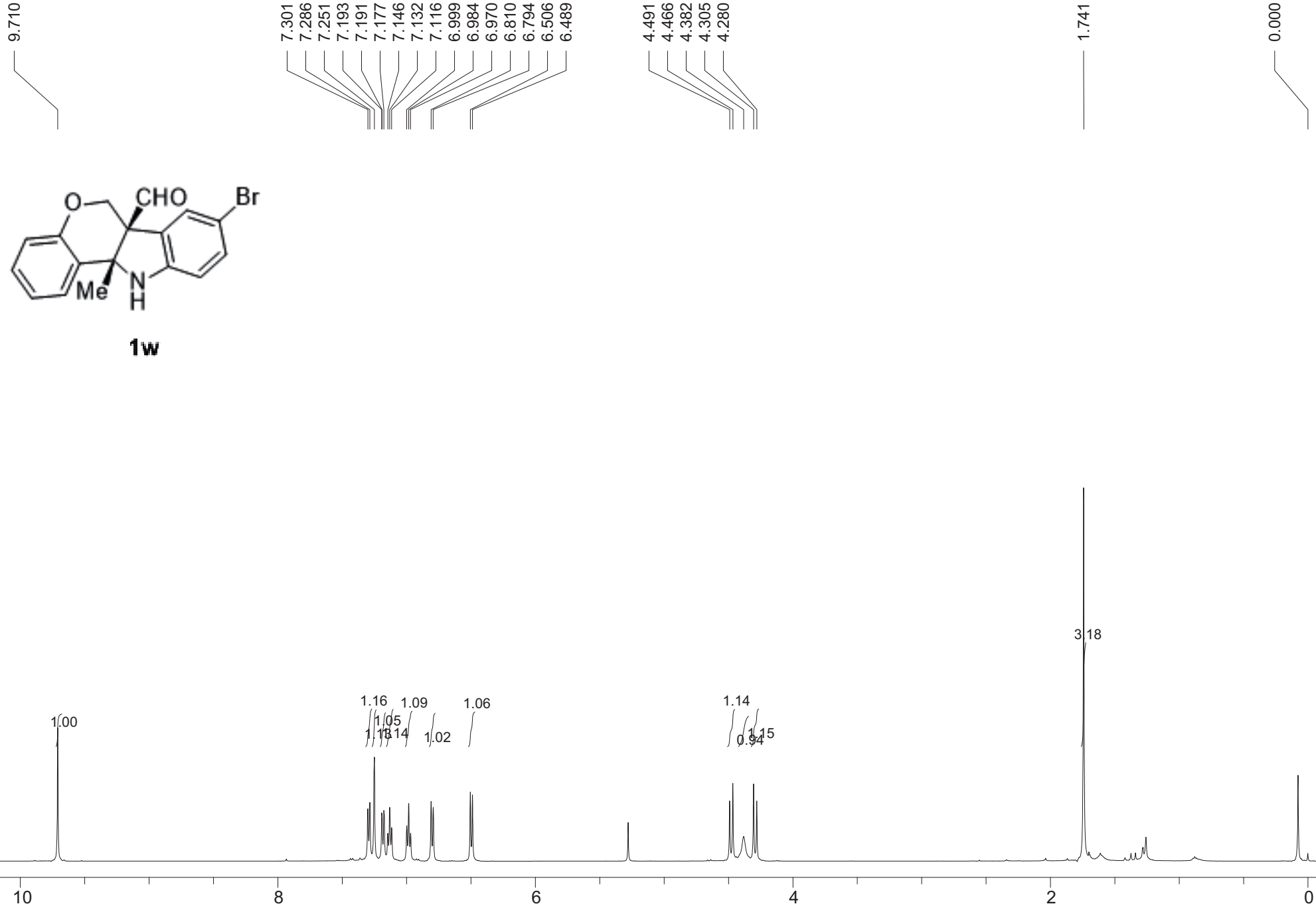

3.00
2.24
2.06
2.05
2.12
1.02
0.99
1.05
1.00
1.04
1.06
1.02
1.00
0.78
1.03
10
8
6
4
2
0
-2
PPM

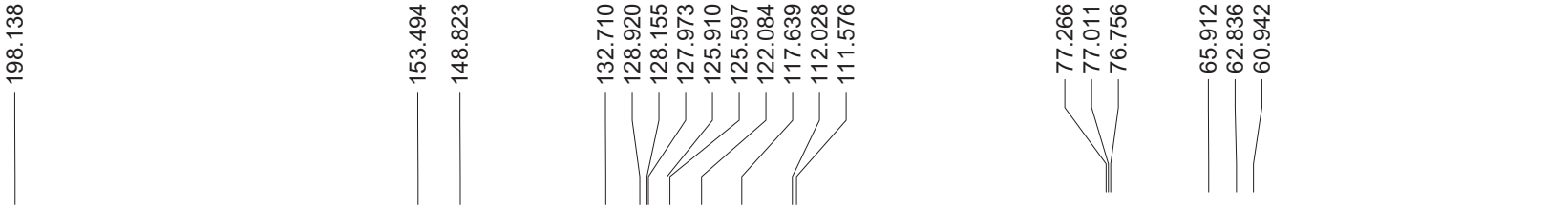

154.682
148.779
136.252
131.245
130.334
128.847
128.694
128.337
128.199
127.936
127.485
126.639
124.307
121.800
119.643
117.457
110.315
77.266
77.011
76.756
68.878
65.992
64.141
52.925
HO
O
N
H
Ph
2a
200
150
100
50
0
PPM

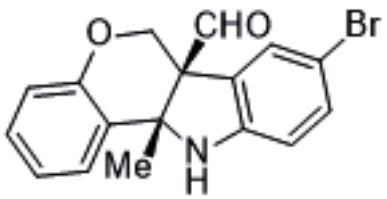

9.718
7.313
7.294
7.259
7.160
7.141
7.126
7.070
7.050
7.013
6.995
6.976
6.819
6.799
6.563
6.543
4.515
4.485
4.367
4.315
4.285
1.753
0.003
O
CHO
Cl
Me
N
H
1v
1.00
2.07
1.13
1.20
0.97
1.13
1.01
1.03
1.08
0.91
3.02
10
8
6
4
2
0
PPM


198.182
153.501
148.378
129.875
128.920
128.228
125.583
125.451
125.174
124.723
122.092
117.632
111.532
77.266
77.011
76.756
65.999
62.793
60.993
24.445
O
CHO
Cl
Me
N
H
200
150
100
50
0 PPM

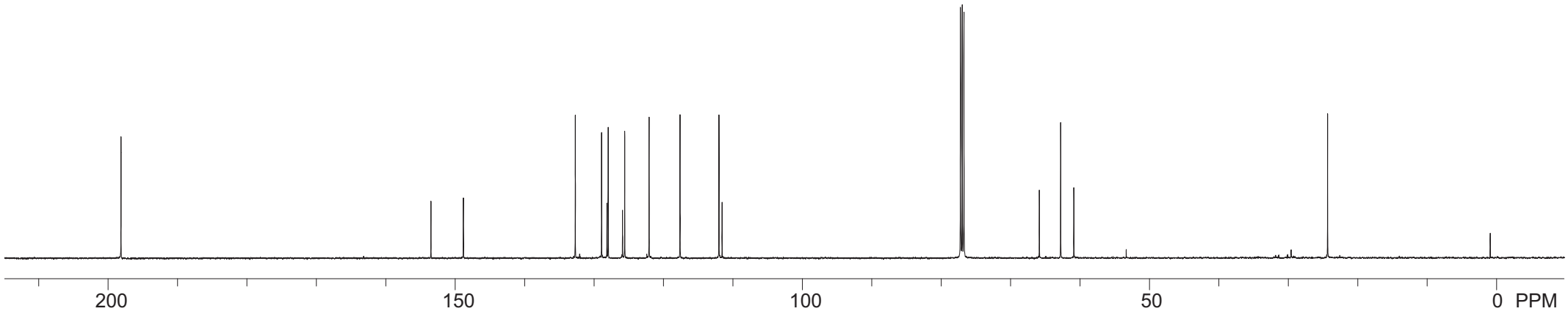
1v


9.710
7.301
7.286
7.251
7.193
7.191
7.177
7.146
7.132
7.116
6.999
6.984
6.970
6.810
6.794
6.506
6.489
4.491
4.466
4.382
4.305
4.280
1.741
0.000
O
CHO
Br
Me
N
H
1w
1.00
1.16
1.05
1.13
1.14
1.09
1.02
1.06
1.14
0.94
1.15
3.18
10
8
6
4
2
0
PPM


198.138
153.494
148.823
132.710
128.920
128.155
127.973
125.910
125.597
122.084
117.639
112.028
111.576
77.266
77.011
76.756
65.912
62.836
60.942
24.409


O
CHO
Br
Me
N
H

1w


200
150
100
50
0 PPM