Supporting Information

Axially Chiral Dicarboxylic Acid Catalyzed Activation of Quinone Imine Ketals: Enantioselective Arylation of Enecarbamates

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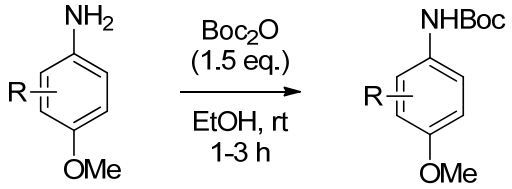
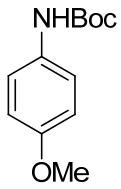
General Information

Infrared (IR) spectra were recorded on a Thermo Fisher Scientific Nicolet iS5 spectrometer. ^{1}H NMR spectra were measured on a JEOL JNM-FX400 (400 MHz) spectrometer. Data were reported as follows: chemical shifts in ppm from tetramethylsilane as an internal standard, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = double-doublet, dq = double quartet, ddd= double double doublet, sept = septet, m = multiplet, br = broad, and appt = apparent), coupling constants (Hz), and assignment. High performance liquid chromatography (HPLC) was performed on Shimadzu 10A instruments at 206 nm using 4.6 nm x 25 cm Daicel chiral columns. For thin layer chromatography (TLC) analysis throughout this work, Merck precoated TLC plates (silica gel 60 GF_{254}, 0.25 mm) were used. The products were purified by flash column chromatography on silica gel (Kanto Chemical silica gel 60 N, neutral, spherical, 40-50 μm), aluminum oxide (Sigma-Aldrich) and/or Merck precoated preparative thin layer chromatography (PLC) plate (silica gel 60 GF_{254}, 0.5 mm). In experiments requiring dry solvent, hexane, dichloromethane, tetrahydrofuran and toluene were purchased from Kanto Chemical Co. Inc. as "Dehydrated" and further purified by passing through neutral alumina under nitrogen atmosphere. (*R*)-**4a**[1] and *N*-(prop-1-en-1-yl)benzamide **2k**[2] were prepared according to the literatures.

Preparation of *N*-*tert*-butoxycarbonyl-4-methoxyanilines

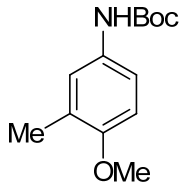


To a solution of 4-methoxyaniline (1.0 eq.) in EtOH (0.5 M) was added Boc_2O (1.5 eq.) at rt. The mixture was stirred at rt until the completion of the reaction. The reaction mixture was directly concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to give *N*-Boc-4-methoxyanilines.



***N*-*tert*-Butoxycarbonyl-4-methoxyaniline**

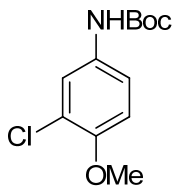
Prepared with 4-methoxyaniline (5.0 mmol, 616 mg) and Boc_2O (7.5 mmol, 1.6 mL) for 2 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a white solid [quant., 1.1 g]. The spectral data were reported in the literature[3].



***N*-*tert*-Butoxycarbonyl-4-methoxy-3-methylaniline**

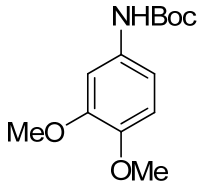
Prepared with 4-methoxy-3-methylaniline (2.2 mmol, 294 mg) and Boc_2O (3.3 mmol, 717 μL) for 3 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 4:1) to give the title compound as a white solid [83%, 422 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15-7.10 (2H, m), 6.74 (1H, d, J = 8.7 Hz), 6.28 (1H, br), 3.79 (3H, s), 2.19 (3H, s), 1.51 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.1, 153.4, 131.1, 127.3, 122.2, 117.6, 110.5, 55.8, 28.5, 16.4; IR (neat) 3330, 2977, 1695, 1507, 1414, 1290, 1224, 1159 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{13}H_{19}N_1O_3$: *m/z* 260.1257 ($[M + Na]^+$), found: *m/z* 260.1250 ($[M + Na]^+$).



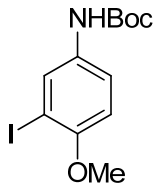
***N*-*tert*-Butoxycarbonyl-3-chloro-4-methoxyaniline**

Prepared with 3-chloro-4-methoxyaniline (2.0 mmol, 375 mg) and Boc_2O (3.0 mmol, 652 μL) for 1 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a white solid [80%, 412 mg]. The spectral data were reported in the literature[4].



***N-tert*-Butoxycarbonyl-3,4-dimethoxyaniline**

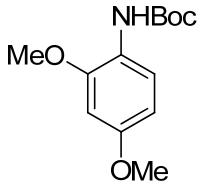
Prepared with 3,4-dimethoxyaniline (2.0 mmol, 306 mg) and Boc_2O (3.0 mmol, 652 μL) for 2 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a colorless oil [84%, 426 mg]. The spectral data were reported in the literature[5].



***N-tert*-Butoxycarbonyl-3-iodo-4-methoxyaniline**

Prepared with 3-iodo-4-methoxyaniline (3.0 mmol, 747 mg) and Boc_2O (4.5 mmol, 978 μL) for 2 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a white solid [89%, 932 mg].

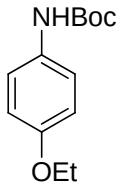
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (1H, d, *J* = 2.4 Hz), 7.30 (1H, d, *J* = 7.0 Hz), 6.74 (1H, d, *J* = 8.9 Hz), 6.35 (1H, br), 3.84 (3H, s), 1.51 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.5, 153.0, 132.8, 130.3, 120.4, 111.1, 85.9, 80.8, 56.8, 28.5; IR (neat) 3325, 2976, 1696, 1492, 1391, 1367, 1238, 1158 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{12}H_{16}I_1N_1O_3$: *m/z* 372.0067 ($[M + Na]^+$), found: *m/z* 372.0084 ($[M + Na]^+$).



***N-tert*-Butoxycarbonyl-2,4-dimethoxyaniline**

Prepared with 2,4-dimethoxyaniline (5.0 mmol, 712 μL) and Boc_2O (7.5 mmol, 1.6 mL) for 3 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a colorless oil [quant., 1.3 g].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (1H, br), 6.82 (1H, br), 6.46-6.44 (2H, m), 3.84 (3H, s), 3.78 (3H, s), 1.51 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.7, 153.2, 149.0, 121.7, 119.2, 103.9, 98.8, 80.1, 55.74, 55.69, 28.5; IR (neat) 3443, 2976, 1720, 1523, 1487, 1414, 1206, 1152 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{13}H_{19}N_1O_4$: *m/z* 276.1206 ($[M + Na]^+$), found: *m/z* 276.1194 ($[M + Na]^+$).



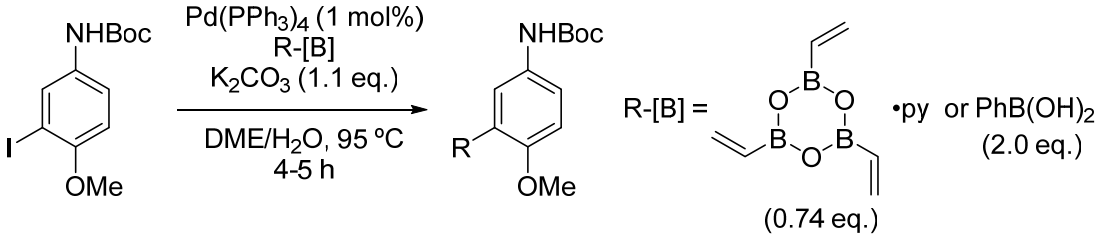
***N-tert*-Butoxycarbonyl-4-ethoxyaniline**

Prepared with 4-ethoxyaniline (3.8 mmol, 514 mg) and Boc_2O (5.6 mmol, 1.2 mL) for 1 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 5:1) to give the title compound as a white solid [73%, 652 mg].

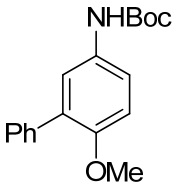
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 (2H, d, *J* = 8.7 Hz), 6.82 (1H, m), 6.33 (1H, br), 3.99 (2H, q, *J* = 6.9 Hz), 1.51 (9H, s), 1.39 (3H, t, *J* = 7.0 Hz); ^{13}C NMR (100 MHz,

$CDCl_3$) δ 155.2, 153.3, 131.5, 120.7, 115.0, 80.3, 63.9, 28.5, 15.0; IR (neat) 3369, 2977, 1693, 1515, 1392, 1226, 1157, 1047 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{13}H_{19}N_1O_3$: *m/z* 260.1257 ($[M + Na]^+$), found: *m/z* 260.1249 ($[M + Na]^+$).

Preparation of *N*-Boc-4-methoxy-3-phenylaniline and *N*-Boc-4-methoxy-3-vinylaniline



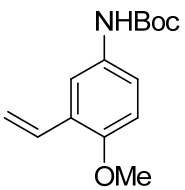
The solution of 3-iodo-4-methoxyaniline (1.0 eq.), $Pd(PPh_3)_4$ (1 mol%), K_2CO_3 (1.1 eq.) and an organoboron reagent in DME (0.1 M) and H_2O (0.4 M) was stirred at 95 °C under Ar atmosphere until the completion of the reaction. The resulting mixture was then cooled to rt, diluted with H_2O and extracted with ethyl acetate. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the title compounds.



***N-tert*-Butoxycarbonyl-4-methoxy-3-phenylaniline**

Prepared with *N*-Boc-3-iodo-4-methoxyaniline (1.5 mmol, 524 mg), phenylboronic acid (3.0 mmol, 366 mg), $Pd(PPh_3)_4$ (15 μmol, 17 mg) and K_2CO_3 (1.7 mmol, 228 mg) for 5 h. The crude material was purified by column chromatography on silica gel (eluting with CH_2Cl_2/EtOAc = 100:1) to give the title compound as a colorless oil [85%, 382 mg].

^1H NMR (400 MHz, $CDCl_3$) δ 7.50 (2H, m), 7.38 (2H, m), 7.32-7.26 (3H, m), 6.90 (1H, d, *J* = 8.7 Hz), 6.42 (1H, br), 3.75 (3H, s), 1.51 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.3, 152.8, 138.2, 131.7, 131.3, 129.6, 128.1, 127.2, 122.3, 119.5, 112.1, 80.4, 56.1, 28.5; IR (neat) 3328, 2977, 1697, 1507, 1409, 1263, 1230, 1159 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{18}H_{21}N_1O_3$: *m/z* 322.1414 ($[M + Na]^+$), found: *m/z* 322.1413 ($[M + Na]^+$).

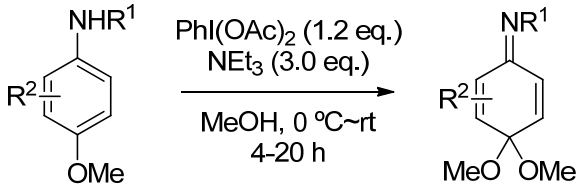


***N-tert*-Butoxycarbonyl-4-methoxy-3-vinylaniline**

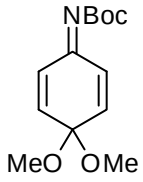
Prepared with *N*-Boc-3-iodo-4-methoxyaniline (0.50 mmol, 175 mg), trivinylboroxine-pyridine complex[6] (0.37 mmol, 89 mg), $Pd(PPh_3)_4$ (5 μmol, 6.0 mg) and K_2CO_3 (0.55 mmol, 76 mg) for 4 h. The crude

material was purified by column chromatography on silica gel (eluting with hexane/EtOAc = 3:1) to give the title compound as a colorless oil [94%, 118 mg].
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (1H, d, *J* = 2.7 Hz), 7.25 (1H, br), 7.00 (1H, dd, *J* = 17.9, 11.1 Hz), 6.80 (1H, d, *J* = 8.9 Hz), 6.34 (1H, br), 5.72 (1H, dd, *J* = 17.9, 1.5 Hz), 5.26 (1H, dd, *J* = 11.1, 1.5 Hz), 3.81 (3H, s), 1.51 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.3, 153.1, 131.6, 131.4, 127.2, 119.9, 117.7, 115.1, 111.7, 80.4, 56.0, 28.5; IR (neat) 3327, 2977, 1697, 1522, 1498, 1425, 1226, 1160 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{19}N_1O_3$: *m/z* 272.1257 ($[M + Na]^+$), found: *m/z* 272.1270 ($[M + Na]^+$).

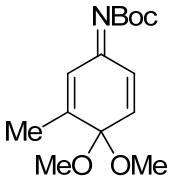
Preparation of *N*-Boc and *N*-Bz quinone imine ketals (1, 5)



To a solution of *N*-protected 4-methoxyaniline (1.0 eq.) and NEt_3 (3.0 eq.) in MeOH (0.34 M), a solution of $PhI(OAc)_2$ (1.2 eq.) in MeOH (0.34 M) was added dropwise at 0 °C under Ar atmosphere. The reaction mixture was stirred at 0 °C for 1 h and gradually warmed to rt. After the consumption of *N*-protected 4-methoxyaniline, the resulting mixture was quenched with saturated aqueous $NaHCO_3$, and extracted with ethyl acetate. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel to give the corresponding quinine imine ketals.



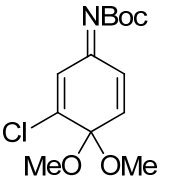
***tert*-Butyl (4,4-dimethoxycyclohexa-2,5-dien-1-ylidene)carbamate (1a)**
Prepared with *N*-Boc-4-methoxyaniline (2.6 mmol, 581 mg), $PhI(OAc)_2$ (3.2 mmol, 1.0 g) and NEt_3 (7.9 mmol, 1.1 mL) for 7 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 5:1:0.06) to give the title compound as a pale yellow oil [94%, 624 mg].
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.53 (2H, br), 6.44 (2H, d, *J* = 10.6 Hz), 3.33 (6H, s), 1.56 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.3, 156.6, 139.3, 131.1, 93.3, 82.9, 50.3, 28.3; IR (neat) 2991, 2936, 1715, 1603, 1369, 1269, 1246, 1152 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{13}H_{19}N_1O_4$: *m/z* 276.1206 ($[M + Na]^+$), found: *m/z* 276.1210 ($[M + Na]^+$).



tert-Butyl (4,4-dimethoxy-3-methylcyclohexa-2,5-dien-1-ylidene)-carbamate (1l)

Prepared with *N*-Boc-4-methoxy-3-methylaniline (1.0 mmol, 237 mg), $PhI(OAc)_2$ (1.2 mmol, 387 mg) and NEt_3 (3.0 mmol, 418 μL) for 7 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow oil [90%, 240 mg].

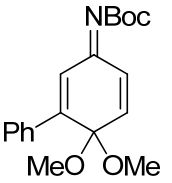
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.56 (1H, d, *J* = 9.7 Hz), 6.45 (1H, d, *J* = 9.4 Hz), 6.34 (1H, m), 3.19 (6H, s), 1.93 (3H, d, *J* = 1.5 Hz), 1.57 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.6, 157.0, 151.2, 139.7, 96.2, 82.7, 51.0, 28.3, 16.8; IR (neat) 2978, 2940, 1713, 1601, 1369, 1248, 1150, 1099 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{21}N_1O_4$: *m/z* 290.1363 ($[M + Na]^+$), found: *m/z* 290.1358 ($[M + Na]^+$).



tert-Butyl (3-chloro-4,4-dimethoxycyclohexa-2,5-dien-1-ylidene)-carbamate (1m)

Prepared with *N*-Boc-3-chloro-4-methoxylaniline (1.6 mmol, 412 mg), $PhI(OAc)_2$ (2.4 mmol, 773 mg) and NEt_3 (4.9 mmol, 683 μL) for 8 h. The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow solid [61%, 281 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.73 (1H, d, *J* = 2.2 Hz), 6.59 (1H, dd, *J* = 10.2, 1.9 Hz), 6.49 (1H, br), 3.27 (6H, s), 1.58 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 160.8, 155.9, 139.6, 132.1, 124.2, 95.5, 83.4, 51.5, 28.3; IR (neat) 2980, 2940, 1717, 1601, 1369, 1267, 1246, 1152 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{13}H_{18}Cl_1N_1O_4$: *m/z* 310.0817 ($[M + Na]^+$), found: *m/z* 310.0815 ($[M + Na]^+$).

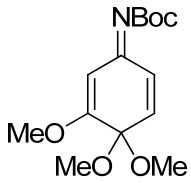


tert-Butyl (4,4-dimethoxy-3-phenylcyclohexa-2,5-dien-1-ylidene)-carbamate (1n)

Prepared with *N*-Boc-4-methoxy-3-phenylaniline (1.3 mmol, 381 mg), $PhI(OAc)_2$ (1.5 mmol, 491 mg) and NEt_3 (3.8 mmol, 531 μL) for 4 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 5:1:0.06) to give the title compound as a pale yellow oil [89%, 373 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (2H, br), 7.42-7.38 (3H, m), 6.83 (1H, br), 6.66 (1H, m), 6.47 (1H, br), 3.20 (6H, s), 1.59 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.5, 157.5, 149.6, 140.5, 135.7, 129.7, 128.6, 128.2, 97.8, 82.9, 51.1, 28.3; IR (neat)

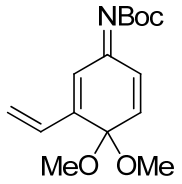
2978, 2936, 1712, 1594, 1393, 1267, 1238, 1148 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{19}H_{23}N_1O_4$: *m/z* 352.1519 ($[M + Na]^+$), found: *m/z* 352.1512 ($[M + Na]^+$).



***tert*-Butyl (3,4,4-trimethoxycyclohexa-2,5-dien-1-ylidene)carbamate (1o)**

Prepared with *N*-Boc-3,4-dimethoxylaniline (1.0 mmol, 283 mg), $PhI(OAc)_2$ (1.2 mmol, 387 mg) and NEt_3 (3.0 mmol, 418 μL) for 7 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow solid [76%, 215 mg].

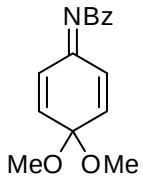
^1H NMR (400 MHz, $CDCl_3$) δ 6.51 (1H, br), 6.39 (1H, br), 5.75 (1H, br), 3.81 (3H, s), 3.29 (6H, s), 1.57 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 165.0, 161.8, 159.2, 137.5, 132.3, 96.6, 94.7, 82.2, 55.7, 51.5, 28.3; IR (neat) 2977, 2938, 1710, 1660, 1596, 1368, 1241, 1148 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{21}N_1O_5$: *m/z* 306.1312 ($[M + Na]^+$), found: *m/z* 306.1304 ($[M + Na]^+$).



***tert*-Butyl (4,4-dimethoxy-3-vinylcyclohexa-2,5-dien-1-ylidene)-carbamate (1p)**

Prepared with *N*-Boc-4-methoxy-3-vinylaniline (0.47 mmol, 118 mg), $PhI(OAc)_2$ (0.71 mmol, 228 mg) and NEt_3 (1.42 mmol, 197 μL) for 20 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow oil [62%, 82.3 mg].

^1H NMR (400 MHz, $CDCl_3$) δ 6.60-6.56 (2H, m), 6.47-6.40 (2H, m), 6.07 (1H, dd, *J* = 17.6, 1.5 Hz), 5.49 (1H, d, *J* = 11.1 Hz), 3.18 (6H, s), 1.58 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.6, 157.5, 148.1, 132.1, 121.8, 96.7, 82.9, 51.2, 28.3; IR (neat) 2978, 2938, 1711, 1595, 1368, 1265, 1246, 1148 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{15}H_{21}N_1O_4$: *m/z* 302.1363 ($[M + Na]^+$), found: *m/z* 302.1353 ($[M + Na]^+$).

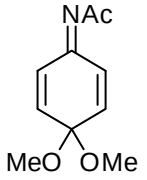


***N*-(4,4-Dimethoxycyclohexa-2,5-dien-1-ylidene)benzamide (1q)**

Prepared with *N*-Bz-4-methoxylaniline (1.0 mmol, 227 mg), $PhI(OAc)_2$ (1.2 mmol, 387 mg) and NEt_3 (3.0 mmol, 418 μL) for 4 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow solid [78%, 201 mg].

^1H NMR (400 MHz, $CDCl_3$) δ 7.92 (2H, m), 7.58 (1H, tt, *J* = 7.5, 1.5 Hz), 7.46 (2H, m),

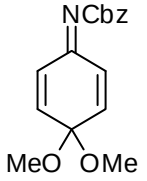
6.57 (2H, d, *J* = 10.4 Hz), 6.46 (2H, d, *J* = 10.4 Hz), 3.35 (6H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.2, 155.3, 139.5, 133.7, 132.9, 129.6, 128.8, 127.0, 93.2, 50.3; IR (neat) 2967, 2941, 1672, 1661, 1601, 1246, 1109, 1059 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{15}H_{15}N_1O_3$: *m/z* 280.0944 ($[M + Na]^+$), found: *m/z* 280.0939 ($[M + Na]^+$).



_N_-(4,4-dimethoxycyclohexa-2,5-dien-1-ylidene)acetamide (1r)

Prepared with *N*-acetoxy-4-methoxyaniline (2.0 mmol, 330 mg), $PhI(OAc)_2$ (2.4 mmol, 797 mg) and NEt_3 (6.0 mmol, 840 μL) for 3 h. The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc/NEt_3 = 2:1:0.03) to give the title compound as a pale yellow oil [47%, 185 mg].

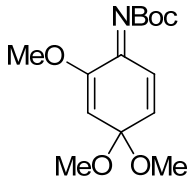
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.55 (2H, d, *J* = 10.3 Hz), 6.36 (2H, d, *J* = 10.3 Hz), 3.34 (6H, s), 2.24 (3H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.9, 151.7, 139.1, 126.4, 92.9, 50.1, 25.4; IR (neat) 2942, 2833, 1693, 1604, 1358, 1214, 1105, 1036 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{10}H_{14}N_1O_3$: *m/z* 196.0968 ($[M + H]^+$), found: *m/z* 196.0970 ($[M + H]^+$).



benzyl (4,4-dimethoxycyclohexa-2,5-dien-1-ylidene)carbamate (1s)

Prepared with *N*-benzyloxycarbonyl-4-methoxyaniline (1.2 mmol, 309 mg), $PhI(OAc)_2$ (1.4 mmol, 478 mg) and NEt_3 (3.6 mmol, 502 μL) for 19 h. The crude material was purified by column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 4:1:0.05) to give the title compound as a pale yellow oil [75%, 259 mg].

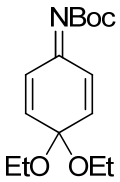
^{1}H NMR (400 MHz, $CDCl_3$, VT50) δ 7.50-7.27 (5H, m), 6.52 (2H, d, *J* = 9.7 Hz), 6.37 (2H, d, *J* = 9.7 Hz), 5.27 (2H, s), 3.30 (6H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 162.0, 157.7, 139.8, 135.5, 128.6, 128.5, 128.4, 93.0, 68.4, 50.1; IR (neat) 2943, 2831, 1717, 1601, 1209, 1104, 1060, 1036 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{16}H_{17}N_1O_4$: *m/z* 310.1050 ($[M + Na]^+$), found: *m/z* 310.1043 ($[M + Na]^+$).



***tert*-Butyl (2,4,4-trimethoxycyclohexa-2,5-dien-1-ylidene)carbamate (5)**

Prepared with *N*-Boc-2,4-dimethoxylaniline (5.3 mmol, 1.3 g), $PhI(OAc)_2$ (6.3 mmol, 2.0 g) and NEt_3 (16 mmol, 2.2 mL) for 11 h. The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give the title compound as a pale yellow oil [81%, 1.2 g].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.48 (1H, dd, *J* = 10.4, 2.4 Hz), 6.35 (1H, d, *J* = 10.2 Hz), 5.50 (1H, br), 3.73 (3H, br), 3.33 (6H, s), 1.55 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.1, 139.0, 134.2, 107.3, 96.8, 82.6, 55.2, 50.4, 28.2; IR (neat) 2978, 2938, 1715, 1622, 1368, 1246, 1152, 1082 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{21}N_1O_5$: *m/z* 306.1312 ([M + Na]$^+$), found: *m/z* 306.1320 ([M + Na]$^+$).

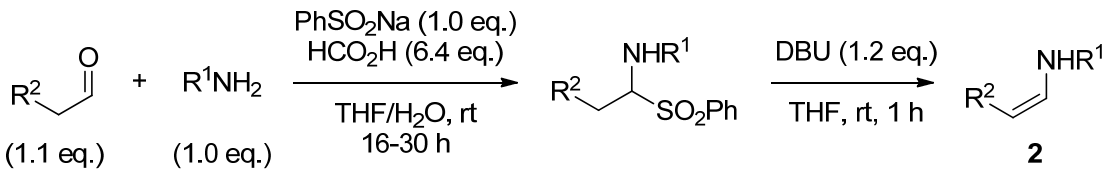


***tert*-Butyl (4,4-diethoxycyclohexa-2,5-dien-1-ylidene)carbamate (14)**

Prepared with *N*-Boc-4-ethoxylaniline (1.5 mmol, 356 mg), $PhI(OAc)_2$ (1.8 mmol, 580 mg) and NEt_3 (4.5 mmol, 627 μL) in EtOH (10 mL) for 4 h. The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc/NEt_3 = 5:1:0.06) to give the title compound as a pale yellow oil [92%, 388 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.54 (2H, br), 6.41 (2H, d, *J* = 10.4 Hz), 3.57 (4H, q, *J* = 7.0 Hz), 1.56 (9H, s), 1.21 (6H, t, *J* = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, VT50) δ 161.4, 156.8, 140.5, 93.1, 82.8, 58.4, 28.3, 15.7; IR (neat) 2977, 2932, 1716, 1602, 1368, 1266, 1244, 1152 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{15}H_{23}N_1O_4$: *m/z* 304.1519 ([M + Na]$^+$), found: *m/z* 304.1515 ([M + Na]$^+$).

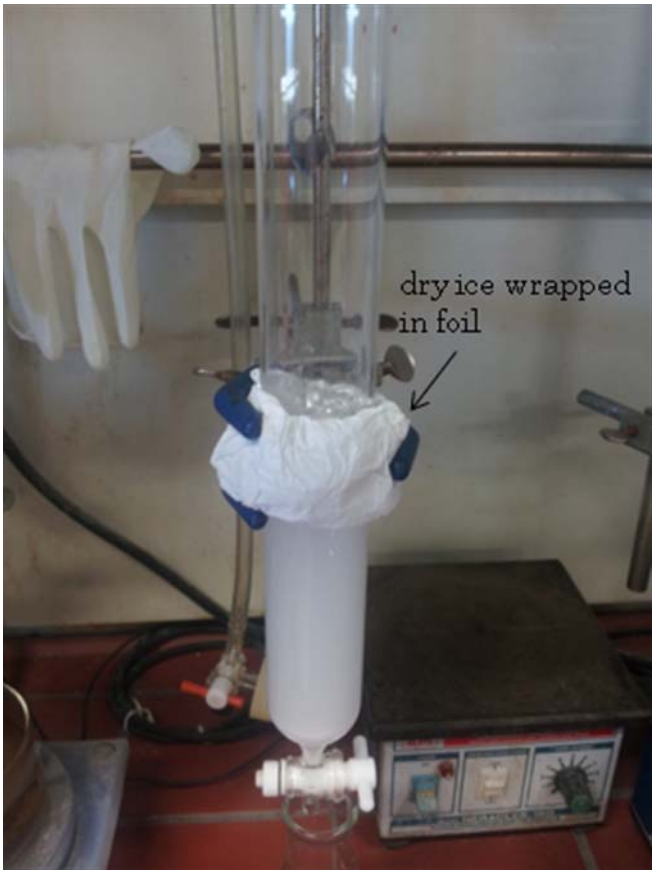
Preparation of *N*-Boc- and *N*-Cbz-enecarbamates[7]

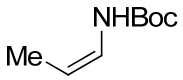


To a solution of aldehyde (1.0 eq.), $PhSO_2Na$ (1.0 eq.) and $BocNH_2$ or $CbzNH_2$ (1.0 eq.) in THF/H_2O (1:2.5, 0.7 M), was added HCO_2H (6.4 eq.) at rt. The mixture was stirred at rt for 16-30 h. The resulting mixture was then diluted with H_2O and extracted with ethyl acetate. The combined organic layers were washed with saturated aqueous $NaHCO_3$, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was washed with hexane to give the corresponding α-phenylsulfonylcarbamate.

To a solution of the α-phenylsulfonylcarbamate (1.0 eq.) in THF (0.2 M), DBU (1.2 eq.) was added at rt under Ar atmosphere. After stirring for 1h at rt, the reaction mixture was poured into water, and extracted with ethyl acetate. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was purified by flash column chromatography on silica gel coated with dry ice jacket (see the picture below) to give the corresponding enecarbamates. In general, the (*Z*)-isomer was less polar than the (*E*)-isomer.

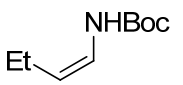
dry ice jacket





***tert*-Butyl (*Z*)-1-propenylcarbamate ((*Z*)-2a) and *tert*-Butyl (*E*)-1-propenylcarbamate ((*E*)-2a)**

The precursor was prepared with propionaldehyde (4.5 mmol, 323 μL), $BocNH_2$ (5.0 mmol, 586 mg), $PhSO_2Na$ (5.0 mmol, 821 mg) and HCO_2H (32.0 mmol, 1.2 mL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (5.0 mmol, 1.7 g) and DBU (6.0 mmol, 897 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 20:1) to give (*Z*)-**2a** (R_f = 0.37, hexane/EtOAc = 10:1) as a white solid [66%, 516 mg] and (*E*)-**2a** (R_f = 0.30, hexane/EtOAc = 10:1) as a white solid [8%, 63 mg]. Their spectral data were reported in the literature[8].

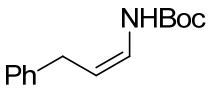


***tert*-Butyl (*Z*)-1-butenylcarbamate ((*Z*)-2b)**

The precursor was prepared with butanal (3.3 mmol, 297 μL), $BocNH_2$

(3.0 mmol, 352 mg), $PhSO_2Na$ (3.0 mmol, 493 mg) and HCO_2H (19.2 mmol, 724 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.6 mmol, 489 mg) and DBU (1.9 mmol, 280 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 20:1) to give the title compound as a white solid [54%, 143 mg].

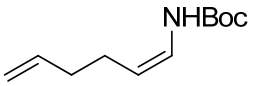
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.37 (1H, appt t, *J* = 10.3 Hz), 6.11 (1H, br), 4.56 (1H, appt q, *J* = 7.7 Hz), 1.96 (2H, m), 1.48 (9H, s), 1.01 (3H, t, *J* = 7.5 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.0, 121.6, 110.0, 80.5, 28.4, 18.9, 14.2; IR (neat) 3282, 2962, 1670, 1519, 1457, 1269, 1251, 1160 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_9H_{17}N_1O_2$: *m/z* 194.1152 ($[M + Na]^+$), found: *m/z* 194.1152 ($[M + Na]^+$).



***tert*-Butyl (*Z*)-1-(3-phenylpropenyl)carbamate ((*Z*)-2c)**

The precursor was prepared with hydrocinnamaldehyde (5.5 mmol, 724 μL), $BocNH_2$ (5.0 mmol, 586 mg), $PhSO_2Na$ (5.0 mmol, 821 mg) and HCO_2H (32 mmol, 1.2 mL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.0 mmol, 723 mg) and DBU (1.2 mmol, 179 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 20:1) to give the title compound as a white solid [65%, 151 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (2H, m), 7.22-7.19 (3H, m), 6.56 (1H, appt t, *J* = 9.7 Hz), 6.23 (1H, d, *J* = 9.9 Hz), 4.80 (1H, appt q, *J* = 7.3 Hz), 3.32 (2H, d, *J* = 7.5 Hz), 1.47 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.0, 140.0, 128.7, 128.3, 126.3, 123.4, 106.1, 80.7, 31.7, 28.4; IR (neat) 3283, 2978, 1698, 1671, 1485, 1381, 1365, 1240 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{19}N_1O_2$: *m/z* 256.1308 ($[M + Na]^+$), found: *m/z* 256.1299 ($[M + Na]^+$).

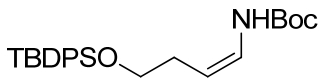


***tert*-Butyl (*Z*)-1-hexa-1,5-dienylcarbamate ((*Z*)-2d)**

The precursor was prepared with 5-hexenal (4.0 mmol, 480 μL), $BocNH_2$ (3.6 mmol, 426 mg), $PhSO_2Na$ (3.6 mmol, 598 mg) and HCO_2H (23 mmol, 879 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.9 mmol, 645 mg) and DBU (2.3 mmol, 338 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 60:1) to give the title compound as a white solid [43%, 158 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.42 (1H, appt t, *J* = 9.8 Hz), 6.14 (1H, br), 5.82 (1H, m),

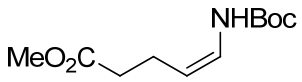
5.05 (1H, dd, *J* = 17.2, 1.7 Hz), 4.99 (1H, dd, *J* = 10.4, 0.7 Hz), 4.57 (1H, appt q, *J* = 7.6 Hz), 2.14 (2H, dd, *J* = 13.8, 7.3 Hz), 2.04 (2H, dd, *J* = 14.7, 7.0 Hz), 1.48 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.9, 138.0, 122.5, 115.3, 107.3, 80.5, 33.5, 28.4, 25.1; IR (neat) 3285, 2977, 1708, 1671, 1512, 1392, 1267, 1247 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{11}H_{19}N_1O_2$: *m/z* 220.1308 ($[M + Na]^+$), found: *m/z* 220.1309 ($[M + Na]^+$).



tert-Butyl (*Z*)-1-(4-((_tert_-butyldiphenylsilyl)oxy)butenyl)-carbamate ((*Z*)-2e)

The precursor was prepared with 4-((*tert*-butyldiphenylsilyl)-oxy)butanal (2.3 mmol, 736 mg), $BocNH_2$ (2.1 mmol, 240 mg), $PhSO_2Na$ (2.1 mmol, 337 mg) and HCO_2H (13 mmol, 494 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.0 mmol, 568 mg) and DBU (1.2 mmol, 179 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 60:1) to give the title compound as a white solid [44%, 185 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (4H, d, *J* = 6.5 Hz), 7.43-7.37 (6H, m), 6.84 (1H, d, *J* = 9.7 Hz), 6.54 (1H, appt t, *J* = 9.7 Hz), 4.66 (1H, appt q, *J* = 8.0 Hz), 3.65 (2H, t, *J* = 5.9 Hz), 2.18 (2H, appt q, *J* = 6.4 Hz), 1.45 (9H, s), 1.05 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.2, 135.8, 133.5, 129.9, 127.8, 124.9, 105.0, 80.3, 64.2, 29.2, 28.4, 27.0, 19.2; IR (neat) 3310, 2930, 1725, 1703, 1486, 1366, 1162, 1110 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{25}H_{35}N_1O_3Si_1$: *m/z* 448.2278 ($[M + Na]^+$), found: *m/z* 448.2300 ($[M + Na]^+$).

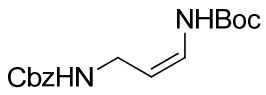


tert-Butyl (*Z*)-1-(4-(methoxycarbonyl)butenyl)carbamate ((*Z*)-2f)

The precursor was prepared with methyl 5-oxopentanoate (0.75 mmol, 98 mg), $BocNH_2$ (0.68 mmol, 80 mg), $PhSO_2Na$ (0.68 mmol, 112 mg) and HCO_2H (4.4 mmol, 164 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (0.68 mmol, 253 mg) and DBU (0.82 mmol, 122 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 10:1) to give the title compound as a white solid [35%, 54 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.62 (1H, br), 6.44 (1H, appt t, *J* = 9.8 Hz), 4.53 (1H, appt q, *J* = 7.8 Hz), 3.69 (3H, s), 2.41 (2H, t, *J* = 6.9 Hz), 2.27 (2H, appt q, *J* = 7.2 Hz), 1.48 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.1, 153.2, 124.0, 106.2, 80.5, 51.9, 33.8, 28.5, 21.0; IR (neat) 3350, 2978, 1721, 1701, 1499, 1366, 1240, 1159 cm^{-1}; HRMS

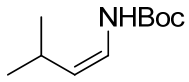
(ESI) exact mass calcd. for $C_{11}H_{19}N_1O_4$: *m/z* 252.1206 ([M + Na]$^+$), found: *m/z* 252.1199 ([M + Na]$^+$).



tert-Butyl (*Z*)-1-(3-(benzyloxycarbamoyl)propenyl)-carbamate ((*Z*)-2g)

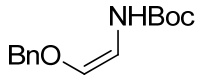
The precursor was prepared with benzyl 3-(oxopropyl)carbamate (1.1 mmol, 228 mg), $BocNH_2$ (1.0 mmol, 117 mg), $PhSO_2Na$ (1.0 mmol, 164 mg) and HCO_2H (6.4 mmol, 241 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.0 mmol, 449 mg) and DBU (1.2 mmol, 179 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 5:1) to give the title compound as a white solid [42%, 130 mg].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 (1H, br), 7.36-7.30 (5H m), 6.59 (1H, appt t, *J* = 9.5 Hz), 5.13 (2H, s), 4.94 (1H, br), 4.66 (1H, appt q, *J* = 7.3 Hz), 3.71 (2H, t, *J* = 7.1 Hz), 1.49 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.3, 136.5, 128.7, 128.4, 128.3, 127.5, 103.4, 80.6, 67.2, 36.3, 28.4; IR (neat) 3324, 2978, 1693, 1505, 1392, 1241, 1156, 1040 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{16}H_{22}N_2O_4$: *m/z* 329.1472 ([M + Na]$^+$), found: *m/z* 329.1469 ([M + Na]$^+$).



tert-Butyl (*Z*)-1-(3-methylbutenyl)carbamate ((*Z*)-2h)

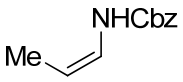
The precursor was prepared with isovaleraldehyde (4.0 mmol, 424 μL), $BocNH_2$ (3.6 mmol, 420 mg), $PhSO_2Na$ (3.6 mmol, 589 mg) and HCO_2H (23 mmol, 868 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (2.0 mmol, 655 mg) and DBU (2.4 mmol, 359 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 20:1) to give the title compound as a white solid [48%, 179 mg]. The spectral data were reported in the literature[9].



tert-Butyl (*Z*)-1-(2-(benzyloxy)vinyl)carbamate ((*Z*)-2i)

The precursor was prepared with 2-(benzyloxy)acetaldehyde (3.3 mmol, 464 μL), $BocNH_2$ (3.0 mmol, 352 mg), $PhSO_2Na$ (3.0 mmol, 493 mg) and HCO_2H (19 mmol, 724 μL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (1.0 mmol, 392 mg) and DBU (1.2 mmol, 180 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with

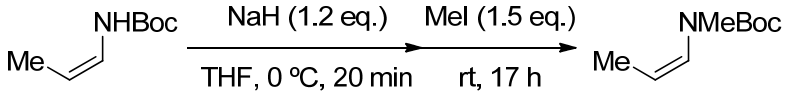
hexane/EtOAc = 15:1) to give the title compound as a colorless oil [65%, 162 mg].
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40-7.31 (5H, m), 6.36 (1H, br), 5.88 (1H, dd, *J* = 10.6, 4.8 Hz), 5.63 (1H, d, *J* = 4.6 Hz), 4.78 (2H, s), 1.46 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.7, 137.1, 129.5, 128.7, 128.3, 127.8, 106.0, 80.3, 74.3, 28.4; IR (neat) 3452, 2977, 1715, 1485, 1454, 1365, 1152, 1078 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{19}N_1O_3$: *m/z* 272.1257 ([M + Na]$^+$), found: *m/z* 272.1257 ([M + Na]$^+$).



Benzyl (*Z*)-propenylcarbamate ((*Z*)-2j)

The precursor was prepared with methyl propionaldehyde (11 mmol, 794 μL), $CbzNH_2$ (10 mmol, 1.5 g), $PhSO_2Na$ (10 mmol, 1.6 g) and HCO_2H (64 mmol, 2.4 mL) to give the corresponding α-phenylsulfonylcarbamate. The title compound was prepared with the precursor (2.0 mmol, 667 mg) and DBU (2.4 mmol, 359 μL). The crude material was purified by column chromatography on silica gel coated with dry ice jacket (eluting with hexane/EtOAc = 20:1) to give the title compound as a colorless oil [60%, 229 mg].
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38-7.31 (5H, m), 6.47 (1H, appt t, *J* = 10.0 Hz), 6.30 (1H, br), 5.16 (2H, s), 4.70 (1H, m), 1.55 (3H, dd, *J* = 7.0, 1.7 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.7, 136.1, 128.7, 128.50, 128.48, 123.1, 103.3, 67.3, 10.6; IR (neat) 3318, 2952, 1701, 1674, 1497, 1268, 1221, 1099 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{11}H_{13}N_1O_2$: *m/z* 214.0839 ([M + Na]$^+$), found: *m/z* 214.0844 ([M + Na]$^+$).

Preparation of *tert*-butyl (*Z*)-*N*-methyl-1-propenylcarbamate (13)

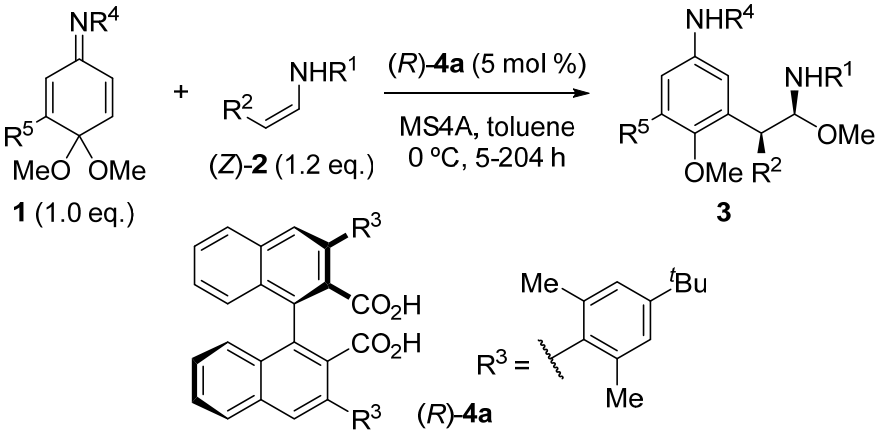


(*Z*)-**2a** **13**

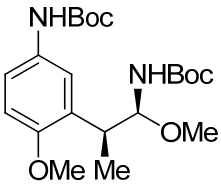
To a suspension of sodium hydride (0.60 mmol, 24 mg) in THF (3 mL), was added a solution of (*Z*)-**2a** (0.50 mmol, 79 mg) in THF (2 mL) at 0 °C. After stirring for 20 min, MeI (0.75 mmol, 47 μL) was added at 0 °C. The reaction mixture was stirred at rt for 17 h. Then the resulting mixture was quenched with saturated aqueous NH_4Cl and extracted with ethyl acetate. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, and evaporated under reduced pressure. The residue was purified by flash column chromatography on silica gel (eluting with hexane/EtOAc = 15:1) to give **13** as a colorless oil [44%, 38 mg].
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.17 (1H, br), 4.98 (1H, m), 3.04 (3H, s), 1.65 (3H, dd, *J* = 7.1, 1.8 Hz), 1.47 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.9, 129.9, 114.8, 80.2,

35.8, 28.5, 12.9; IR (neat) 2977, 1700, 1657, 1366, 1347, 1254, 1147, 1044 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_9H_{17}N_1O_2$: *m/z* 194.1152 ($[M + Na]^+$), found: *m/z* 194.1142 ($[M + Na]^+$);

General procedure for the enantioselective arylation of enecarbamates with quinone imine ketals (Tables 2 and 3)



To a stirred solution of **1** (0.10 mmol), (*R*)-**4a** (5.0 μmol, 3.3 mg) and MS4A (50 mg) in toluene (1.0 mL) was added (*Z*)-**2** (0.12 mmol) at 0 °C. The reaction mixture was stirred at the same temperature until the completion of the reaction. The reaction solution was quenched with aqueous $NaHCO_3$ (2 mL) and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC to give **3** as a mixture of diastereomers.



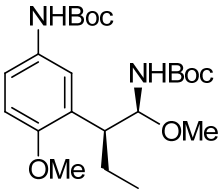
3a

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 10 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1) to give **3a** as a white solid [83%, 33.9 mg, 14:1 dr, 97% ee].

Scale-up reaction: Prepared with **1a** (1.0 mmol, 253 mg) and (*Z*)-**2a** (1.2 mmol, 189 mg) in toluene (4 ml) for 31 h. The crude material was purified by flash column chromatography on silica gel (eluting with hexane/EtOAc/NEt_3 = 3:1:0.04) to give **3a** as a white solid [86%, 352 mg, 14:1 dr, 97% ee].

^{1}H NMR (400 MHz, acetone-D_6) δ 8.11 (1H, br), 7.39 (2H, br), 6.86 (1H, d, *J* = 8.9 Hz), 6.09 (1H, d, *J* = 8.5 Hz), 5.07 (1H, dd, *J* = 10.2, 7.5 Hz), 3.80 (3H, s), 3.38 (1H, m), 3.18 (3H, s), 1.47 (9H, s), 1.41 (9H, s), 1.17 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, acetone-D_6) δ 156.8, 153.9, 153.7, 133.7, 132.8, 119.8, 118.0, 112.0, 86.6, 79.5, 79.0, 56.2, 55.4, 38.6, 28.6, 28.5, 17.0; IR (neat) 3331, 2976, 2932, 1695, 1503, 1366, 1240, 1159 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{21}H_{34}N_2O_6$: *m/z* 433.2309 ([M + Na]$^+$), found: *m/z* 433.2291 ([M + Na]$^+$); $[\alpha]_D^{23}$ –1.3 (*c* = 0.92, $CHCl_3$; 97% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 13.9 min (minor) and 55.5 min (major)).

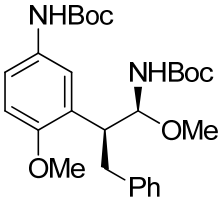


3b

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2b** (0.12 mmol, 20.5 mg) for 10 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1) to give **3b** as a white solid [86%, 36.7 mg, >20:1 dr, 96% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (1H, br), 7.06 (1H, d, *J* = 2.4 Hz), 6.82 (1H, d, *J* = 8.9 Hz), 6.33 (1H, br), 5.04 (1H, dd, *J* = 10.2, 5.3 Hz), 4.76 (1H, d, *J* = 10.4 Hz), 3.78 (3H, s), 3.31 (3H, s), 3.22 (1H, dt, *J* = 10.0, 4.8 Hz), 1.77 (1H, m), 1.64 (1H, m), 1.51 (9H, s), 1.43 (9H, s), 0.80 (3H, t, *J* = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 154.2, 153.2, 131.6, 129.2, 120.8, 118.5, 111.5, 84.8, 80.2, 79.6, 56.13, 56.12, 44.4, 28.54, 28.46, 24.5, 12.0; IR (neat) 3271, 2970, 2934, 1721, 1682, 1526, 1504, 1242 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{22}H_{36}N_2O_6$: *m/z* 447.2466 ([M + Na]$^+$), found: *m/z* 447.2484 ([M + Na]$^+$); $[\alpha]_D^{24}$ +2.7 (*c* = 0.96, $CHCl_3$; 96% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 22.8 min (minor) and 48.8 min (major)).

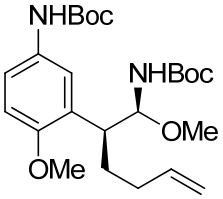


3c

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2c** (0.12 mmol, 28.0 mg) for 100 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1) to give **3c** as a white solid [83%, 40.2 mg, 12:1 dr, 95% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (1H, br), 7.23-7.19 (3H, m), 7.15-7.11 (3H, m), 6.78 (1H, d, *J* = 8.9 Hz), 6.34 (1H, br), 4.94 (1H, dd, *J* = 9.5, 4.7 Hz), 4.73 (1H, d, *J* = 10.2 Hz), 3.68-3.66 (4H, m), 3.31 (3H, s), 3.04 (1H, dd, *J* = 13.5, 8.0 Hz), 2.87 (1H, dd, *J* = 13.5, 7.5 Hz), 1.51 (9H, s), 1.39 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.6, 153.9, 153.2, 140.0, 131.5, 129.2, 128.9, 128.3, 126.1, 120.9, 118.8, 111.7, 83.6, 80.3, 79.6, 56.1, 56.0, 44.1, 38.7, 28.5, 28.4; IR (neat) 3306, 2974, 2940, 1707, 1701, 1503, 1368, 1240 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{27}H_{38}N_2O_6$: *m/z* 509.2622 ([M + Na]$^+$), found: *m/z* 509.2618 ([M + Na]$^+$); $[\alpha]_D^{20}$ +19.3 (*c* = 0.99, $CHCl_3$; 95% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 12.2 min (minor) and 26.5 min (major)).

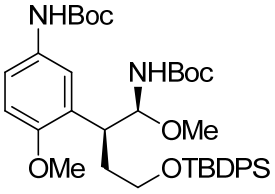


3d

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2d** (0.12 mmol, 29.6 mg) for 101 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 and CH_2Cl_2/EtOAc = 20:1) to give **3d** as a white solid [77%, 34.5 mg, >20:1 dr, 99% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (1H, br), 7.06 (1H, br), 6.82 (1H, d, *J* = 8.9 Hz), 6.33 (1H, br), 5.76 (1H, m), 5.03 (1H, dd, *J* = 10.2, 5.6 Hz), 4.97-4.90 (2H, m), 4.75 (1H, d, *J* = 10.6 Hz), 3.77 (3H, s), 3.36-3.30 (4H, m), 1.91 (2H, appt q, *J* = 7.0 Hz), 1.79 (2H, m), 1.51 (9H, s), 1.42 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 154.1, 153.2, 138.7, 131.6, 128.9, 120.8, 118.6, 114.7, 111.5, 84.9, 80.2, 79.6, 56.11, 56.08, 42.2, 31.5, 30.9, 28.53, 28.45; IR (neat) 3300, 2976, 2936, 1719, 1680, 1526, 1504, 1242 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{24}H_{38}N_2O_6$: *m/z* 473.2622 ([M + Na]$^+$), found: *m/z* 473.2619 ([M + Na]$^+$); $[\alpha]_D^{25}$ +5.4 (*c* = 1.0, $CHCl_3$; 99% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 21.4 min (minor) and 56.1 min (major)).

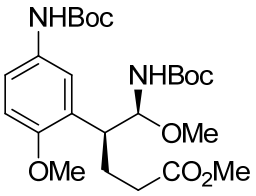


3e

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2e** (0.12 mmol, 51.1 mg) for 81 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3e** as a white solid [71%, 48.4 mg, 19:1 dr, 97% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (2H, dt, *J* = 6.3, 1.6 Hz), 7.55 (2H, dd, *J* = 7.9, 1.3 Hz), 7.42-7.30 (7H, m), 6.87 (1H, br), 6.79 (1H, d, *J* = 8.9 Hz), 6.22 (1H, br), 5.02 (1H, dd, *J* = 9.5, 5.2 Hz), 4.83 (1H, d, *J* = 9.7 Hz), 3.72 (3H, s), 3.59-3.48 (3H, m), 3.28 (3H, s), 2.03 (1H, m), 1.89 (1H, m), 1.51 (9H, s), 1.43 (9H, s), 1.01 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.9, 154.0, 153.1, 135.73, 135.66, 134.1, 131.4, 129.64, 129.59, 128.6, 127.73, 127.69, 120.9, 118.5, 111.3, 85.0, 80.2, 79.6, 61.8, 56.1, 55.8, 34.1, 29.8, 28.55, 28.48, 26.9, 19.3; IR (neat) 3335, 2974, 2932, 1721, 1701, 1503, 1233, 1163 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{38}H_{54}N_2O_7Si_1$: *m/z* 701.3593 ([M + Na]$^+$), found: *m/z* 701.3570 ([M + Na]$^+$); $[\alpha]_D^{25}$ +2.0 (*c* = 0.95, $CHCl_3$; 97% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 9.9 min (minor) and 21.0 min (major)).

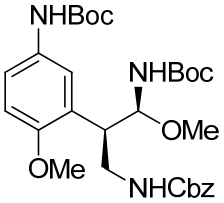


3f

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2f** (0.12 mmol, 27.5 mg) for 61 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 2:1) to give **3f** as a white solid [82%, 39.5 mg, 9.5:1 dr, 98% ee].

^{1}H NMR (400 MHz, acetone-D_6) δ 8.13 (1H, br), 7.43 (1H, d, *J* = 7.5 Hz), 7.37 (1H, d, *J* = 1.9 Hz), 6.89 (1H, d, *J* = 8.9 Hz), 6.08 (1H, d, *J* = 9.9 Hz), 5.11 (1H, dd, *J* = 9.3, 7.9 Hz), 3.79 (3H, s), 3.55 (3H, s), 3.31 (1H, br), 3.18 (3H, s), 2.15-2.04 (3H, m), 1.88 (1H, m), 1.48 (9H, s), 1.42 (9H, s); ^{13}C NMR (100 MHz, acetone-D_6) δ 174.0, 156.7, 154.3, 153.9, 133.7, 130.0, 120.5, 118.4, 112.1, 85.8, 79.5, 79.1, 56.2, 55.4, 51.4, 32.1, 28.6, 28.5, 28.4, 27.2; IR (neat) 3339, 2976, 2934, 1717, 1697, 1503, 1366, 1240 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{24}H_{38}N_2O_8$: *m/z* 505.2520 ([M + Na]$^+$), found: *m/z* 505.2524 ([M + Na]$^+$); $[\alpha]_D^{25}$ +9.5 (*c* = 1.2, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 29.3 min (minor) and 56.2 min (major)).

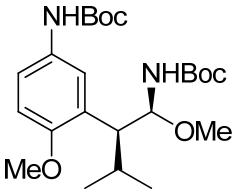


3g

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2g** (0.12 mmol, 36.8 mg) for 59 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 10:1 and hexane/EtOAc = 2:1) to give **3g** as a colorless oil [71%, 39.6 mg, >20:1 dr, >99% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (1H, br), 7.36-7.29 (5H, m), 7.08 (1H, d, *J* = 2.4 Hz), 6.82 (1H, d, *J* = 8.9 Hz), 6.30 (1H, br), 5.15 (1H, dd, *J* = 10.3, 5.2 Hz), 5.07 (1H, d, *J* = 12.1 Hz), 5.02 (1H, d, *J* = 12.6 Hz), 4.90 (1H, d, *J* = 10.6 Hz), 3.76 (3H, s), 3.66 (1H, dd, *J* = 13.1, 6.3 Hz), 3.55 (1H, br), 3.39 (1H, m), 3.30 (3H, s), 1.51 (9H, s), 1.42 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.5, 155.7, 154.0, 153.2, 136.8, 131.7, 128.6, 128.2, 128.1, 126.3, 121.0, 119.3, 111.6, 83.3, 80.3, 79.9, 66.7, 56.00, 55.98, 43.2, 42.6, 28.5, 28.4; IR (neat) 3329, 2976, 2934, 1699, 1504, 1240, 1161, 1024 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{29}H_{41}N_3O_8$: *m/z* 582.2786 ([M + Na]$^+$), found: *m/z* 582.2792 ([M + Na]$^+$); $[\alpha]_D^{24}$ +23.4 (*c* = 1.2, $CHCl_3$; >99.5% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 16.4 min (minor) and 43.7 min (major)).

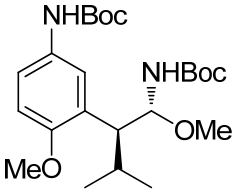


3h (major diastereomer)

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2h** (0.12 mmol, 22.2 mg) for 52 h at rt. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3h** as a white solid [89%, 39.1 mg, 6.7:1 dr, 94% ee]. Analytically pure samples of both diastereomers could be obtained by PLC.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (1H, br), 7.10 (1H, br), 6.84 (1H, d, *J* = 8.9 Hz), 6.33 (1H, br), 5.17 (1H, dd, *J* = 10.5, 3.7 Hz), 4.49 (1H, d, *J* = 10.4 Hz), 3.75 (3H, s), 3.32 (3H, s), 3.09 (1H, dd, *J* = 9.9, 3.9 Hz), 2.02 (1H, m), 1.51 (9H, s), 1.40 (9H, s), 1.07 (3H, d, *J* = 6.5 Hz), 0.65 (3H, d, *J* = 6.5 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.7, 154.7, 153.3, 131.5, 128.7, 121.2, 118.6, 111.5, 82.7, 80.3, 79.5, 56.3, 55.8, 47.8, 30.6, 28.54, 28.48, 21.2, 20.9; IR (neat) 3334, 2973, 2933, 1721, 1701, 1503, 1244, 1163 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{38}N_2O_6$: *m/z* 461.2622 ([M + Na]$^+$), found: *m/z* 461.2626 ([M + Na]$^+$); $[\alpha]_D^{24}$ –17.6 (*c* = 1.0, $CHCl_3$; 96% ee).

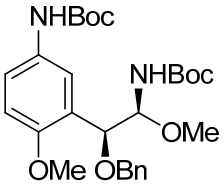
Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 12.6 min (minor) and 18.5 min (major)).



3h (minor diastereomer)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (1H, br), 6.84 (1H, d, *J* = 2.2 Hz), 6.80 (1H, d, *J* = 8.7 Hz), 6.34 (1H, br), 5.16-5.12 (2H, m), 3.77 (3H, s), 3.34 (3H, s), 3.10 (1H, br), 2.20 (1H, td, *J* = 13.8, 6.9 Hz), 1.50 (9H, s), 1.36 (9H, s), 0.94 (3H, d, *J* = 6.8 Hz), 0.75 (3H, d, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.0, 154.0, 153.2, 131.3, 128.6, 121.7, 118.3, 111.6, 84.1, 80.2, 79.4, 56.0, 55.5, 42.1, 29.0, 28.5, 28.4, 21.3, 20.3; IR (neat) 3334, 2975, 2932, 1701, 1504, 1366, 1244, 1162 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{38}N_2O_6$: *m/z* 461.2622 ([M + Na]$^+$), found: *m/z* 461.2625 ([M + Na]$^+$); $[\alpha]_D^{32}$ +31.5 (*c* = 0.51, $CHCl_3$; 99% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 8.9 min (major) and 10.0 min (minor)).

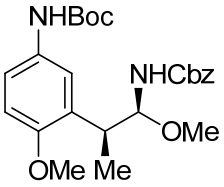


3i

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2i** (0.50 mmol, 124.7 mg) for 85 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 and CH_2Cl_2/EtOAc = 20:1) to give **3i** as a colorless oil [64%, 32.1 mg, 7.2:1 dr, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (1H, br), 7.38-7.27 (5H, m), 7.19 (1H, d, *J* = 2.2 Hz), 6.81 (1H, d, *J* = 8.8 Hz), 6.33 (1H, br), 5.45 (1H, d, *J* = 9.9 Hz), 5.03 (1H, br), 4.91 (1H, d, *J* = 10.1 Hz), 4.60 (1H, d, *J* = 11.7 Hz), 4.52 (1H, d, *J* = 11.7 Hz), 3.80 (3H, s), 3.40 (3H, s), 1.51 (9H, s), 1.35 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.2, 153.0, 138.3, 131.6, 128.4, 128.0, 127.7, 126.4, 119.7, 118.8, 111.0, 84.6, 80.3, 79.7, 76.0, 72.1, 55.8, 28.5, 28.4; IR (neat) 3337, 2977, 2929, 1721, 1500, 1236, 1161, 1079 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{27}H_{38}N_2O_7$: *m/z* 525.2571 ([M + Na]$^+$), found: *m/z* 525.2564 ([M + Na]$^+$); $[\alpha]_D^{23}$ +27.8 (*c* = 1.2, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 11.8 min (minor) and 18.5 min (major)).

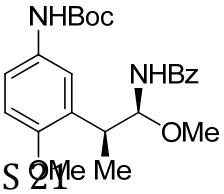


3j

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2j** (0.12 mmol, 22.9 mg) for 43 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3j** as a colorless oil [53%, 23.4 mg, >20:1 dr, 82% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.29 (6H, m), 7.09 (1H, br), 6.79 (1H, d, *J* = 8.7 Hz), 6.32 (1H, br), 5.09-5.08 (4H, m), 3.76 (3H, s), 3.45 (1H, appt d, *J* = 5.8 Hz), 3.33 (3H, s), 1.50 (9H, s), 1.25 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.4, 153.4, 153.2, 136.6, 131.5, 130.4, 128.7, 128.3, 128.1, 120.3, 118.7, 111.3, 86.2, 80.3, 66.8, 56.4, 56.0, 37.2, 28.5, 16.5; IR (neat) 3325, 2975, 2933, 1703, 1505, 1231, 1162, 1026 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{24}H_{32}N_2O_6$: *m/z* 467.2153 ([M + Na]$^+$), found: *m/z* 467.2155 ([M + Na]$^+$); $[\alpha]_D^{23}$ –10.7 (*c* = 0.95, $CHCl_3$; 82% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 19.9 min (minor) and 34.1 min (major)).



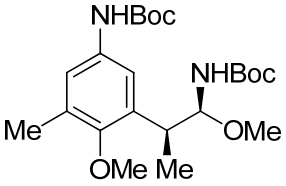
3k

Prepared with **1a** (0.10 mmol, 25.3 mg) and (*Z*)-**2k** (0.12 mmol, 19.3 mg) for 12 h. The crude material was purified by PLC (eluting with

hexane/EtOAc = 3:1 twice) to give **3k** as a white solid [78%, 32.3 mg, >20:1 dr, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (2H, m), 7.50 (1H, t, *J* = 7.3 Hz), 7.45-7.36 (3H, m), 7.19 (1H, d, *J* = 2.7 Hz), 6.82 (1H, d, *J* = 8.7 Hz), 6.48 (1H, d, *J* = 8.9 Hz), 6.39 (1H, br), 5.48 (1H, dd, *J* = 9.4, 4.8 Hz), 3.72 (3H, s), 3.59 (1H, m), 3.39 (3H, s), 1.51 (9H, s), 1.34 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.7, 153.3, 153.2, 134.4, 131.8, 130.1, 128.6, 128.5, 127.1, 120.6, 118.7, 111.2, 84.4, 80.2, 56.8, 56.0, 36.8, 28.5, 16.9; IR (neat) 3307, 2976, 2934, 1699, 1651, 1506, 1488, 1243 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{30}N_2O_5$: *m/z* 437.2047 ([M + Na]$^+$), found: *m/z* 437.2065 ([M + Na]$^+$); $[\alpha]_D^{30}$ –32.3 (*c* = 1.0, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 16.2 min (minor) and 19.3 min (major)).

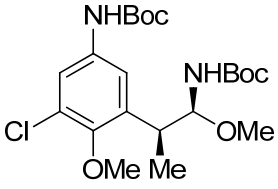


3l

Prepared with **1l** (0.10 mmol, 26.7 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 84 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3l** as a white solid [81%, 34.4 mg, >20:1 dr, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (1H, br), 6.98 (1H, br), 6.37 (1H, br), 4.94 (1H, dd, *J* = 10.0, 5.9 Hz), 4.79 (1H, d, *J* = 9.9 Hz), 3.66 (3H, s), 3.37 (1H, m), 3.29 (3H, s), 2.28 (3H, s), 1.51 (9H, s), 1.43 (9H, s), 1.24 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.1, 152.5, 135.7, 134.2, 131.6, 120.3, 116.6, 86.4, 80.3, 79.7, 60.9, 56.2, 37.1, 28.5, 28.4, 18.3, 16.7; IR (neat) 3327, 2976, 2933, 1698, 1524, 1485, 1366, 1237 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{22}H_{36}N_2O_6$: *m/z* 447.2466 ([M + Na]$^+$), found: *m/z* 447.2465 ([M + Na]$^+$); $[\alpha]_D^{24}$ –0.72 (*c* = 0.92, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 11.0 min (minor) and 19.9 min (major)).



3m

Prepared with **1m** (0.20 mmol, 56.7 mg) and (*Z*)-**2a** (0.24 mmol, 37.1 mg) for 31 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3m** as a white solid [81%, 70.9 mg, >20:1 dr, 97% ee].

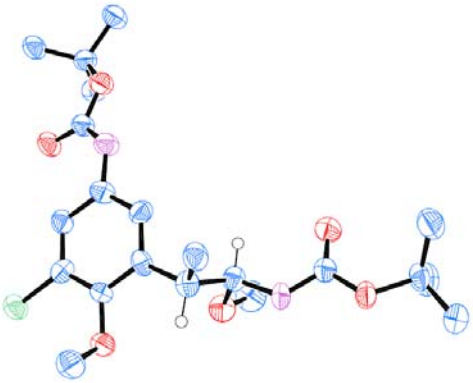
^{1}H NMR (400 MHz, acetone-D_6) δ 8.40 (1H, br), 7.65 (1H, br), 7.37 (1H, d, *J* = 2.2 Hz),

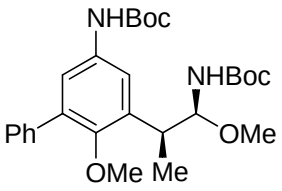
6.36 (1H, d, J = 9.9 Hz), 4.94 (1H, appt t, J = 9.2 Hz), 3.77 (3H, s), 3.45 (1H, m), 3.16 (3H, s), 1.49 (9H, s), 1.43 (9H, s), 1.17 (3H, d, J = 7.3 Hz); ^{13}C NMR (100 MHz, acetone-D_6) δ 156.8, 153.7, 149.8, 140.4, 137.3, 128.0, 118.4, 117.0, 87.5, 80.3, 79.2, 61.4, 55.5, 38.3, 28.53, 28.51, 18.5; IR (neat) 3329, 2976, 2934, 1721, 1695, 1522, 1481, 1368 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{21}H_{33}Cl_1N_2O_6$: *m/z* 467.1919 ([M + Na]$^+$), found: *m/z* 467.1919 ([M + Na]$^+$); $[\alpha]_D^{22}$ +12.9 (*c* = 0.91, $CHCl_3$; 97% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; 9.9 min (minor) and 21.0 min (major)).

The absolute configuration was determined by X-ray crystallographic analysis using **3m** recrystallized from hexane/CH_2Cl_2. The crystal structure has been deposited at the Cambridge Crystallographic Data Centre (CCDC 950393). The data can be obtained free of charge via the Internet at www.ccdc.cam.ac.uk/conts/retrieving.html.

Ortep diagram of 3m (50% probability)





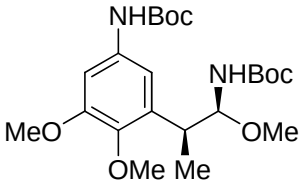
3n

Prepared with **1n** (0.10 mmol, 32.9 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 77 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 and CH_2Cl_2/EtOAc = 20:1) to give **3n** as a white solid [75%, 36.4 mg, >20:1 dr, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 (2H, m), 7.41-7.37 (3H, m), 7.32 (1H, m), 7.16 (1H, d, J = 2.2 Hz), 6.41 (1H, br), 4.99 (1H, dd, J = 10.0, 5.9 Hz), 4.81 (1H, d, J = 10.4 Hz), 3.47 (1H, m), 3.33 (3H, s), 3.26 (3H, s), 1.51 (9H, s), 1.44 (9H, s), 1.30 (3H, d, J = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.0, 151.5, 138.8, 136.3, 135.3, 134.4, 129.2, 128.3, 127.2, 120.3, 118.4, 86.3, 80.5, 79.8, 60.9, 56.1, 37.4, 28.5, 28.4, 18.0; IR (neat) 3327, 2977, 2933, 1698, 1495, 1473, 1366, 1156 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{27}H_{38}N_2O_6$: *m/z* 509.2622 ([M + Na]$^+$), found: *m/z* 509.2601 ([M + Na]$^+$);

$[\alpha]_D^{27}$ +18.4 (*c* = 1.2, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 8.0 min (minor) and 13.6 min (major)).

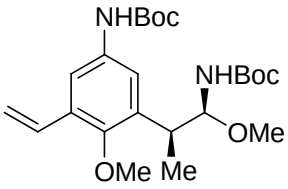


3o

Prepared with **1o** (0.10 mmol, 28.3 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 5 h. The crude material was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **3o** as a white solid [74%, 32.4 mg, 16:1 dr, 97% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (1H, br), 6.60 (1H, d, *J* = 1.7 Hz), 6.40 (1H, br), 4.94 (1H, dd, *J* = 10.2, 5.6 Hz), 4.79 (1H, d, *J* = 10.2 Hz), 3.87 (3H, s), 3.75 (3H, s), 3.39 (1H, m), 3.30 (3H, s), 1.51 (9H, s), 1.43 (9H, s), 1.23 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.0, 152.9, 142.9, 135.9, 134.7, 110.1, 102.4, 86.1, 80.5, 79.7, 61.0, 56.2, 55.9, 37.2, 28.5, 28.4, 18.2; IR (neat) 3333, 2976, 2936, 1699, 1524, 1495, 1366, 1246 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{22}H_{36}N_2O_7$: *m/z* 463.2415 ($[M + Na]^+$), found: *m/z* 463.2431 ($[M + Na]^+$); $[\alpha]_D^{24}$ +3.3 (*c* = 1.0, $CHCl_3$; 97% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 8.3 min (minor) and 17.4 min (major)).



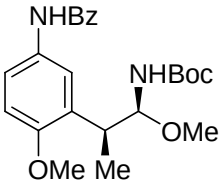
3p

Prepared with **1p** (0.10 mmol, 27.9 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 42 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 and CH_2Cl_2/EtOAc = 20:1) to give **3p** as a white solid [81%, 35.2 mg, >20:1 dr, 99% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (1H, br), 7.11 (1H, d, *J* = 2.2 Hz), 6.96 (1H, dd, *J* = 17.8, 11.0 Hz), 6.39 (1H, br), 5.77 (1H, dd, *J* = 17.6, 1.2 Hz), 5.31 (1H, dd, *J* = 10.9, 1.2 Hz), 4.94 (1H, dd, *J* = 10.2, 6.0 Hz), 4.77 (1H, d, *J* = 10.4 Hz), 3.66 (3H, s), 3.39 (1H, m), 3.30 (3H, s), 1.52 (9H, s), 1.43 (9H, s), 1.25 (3H, d, *J* = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.0, 151.7, 136.3, 134.6, 131.9, 131.5, 118.8, 115.6, 115.3, 86.3, 80.4, 79.8, 62.1, 56.2, 37.0, 28.5, 28.4, 18.3; IR (neat) 3326, 2977, 2933, 1690, 1521, 1471, 1366, 1243 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{36}N_2O_6$: *m/z* 459.2466 ($[M + Na]^+$), found: *m/z* 459.2482 ($[M + Na]^+$); $[\alpha]_D^{26}$ +3.6 (*c* = 1.3, $CHCl_3$;

99% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 8.0 min (minor) and 12.1 min (major)).

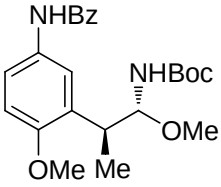


3q (major diastereomer)

Prepared with **1q** (0.10 mmol, 25.7 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 26 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 2:1) to give **3q** as a white solid [81%, 33.4 mg, 3.0:1 dr, 96% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (2H, m), 7.73-7.70 (2H, m), 7.56-7.47 (3H, m), 7.32 (1H, d, *J* = 1.9 Hz), 6.89 (1H, d, *J* = 8.9 Hz), 5.04 (1H, dd, *J* = 9.5, 5.2 Hz), 4.85 (1H, d, *J* = 9.9 Hz), 3.84 (3H, s), 3.46 (1H, m), 3.33 (3H, s), 1.43 (9H, s), 1.27 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.7, 155.9, 154.4, 135.3, 131.8, 131.2, 131.1, 128.9, 127.1, 121.5, 120.2, 111.3, 85.8, 79.7, 56.2, 56.0, 37.5, 28.5, 16.8; IR (neat) 3318, 2976, 2934, 1695, 1651, 1501, 1246, 1169 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{30}N_2O_5$: *m/z* 437.2047 ([M + Na]$^+$), found: *m/z* 437.2056 ([M + Na]$^+$); $[\alpha]_D^{28}$ –20.1 (*c* = 0.92, $CHCl_3$; 96% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak OD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; major diastereomer, 30.8 min (minor) and 52.1 min (major); minor diastereomer, 18.0 min (minor) and 22.5 min (major)).

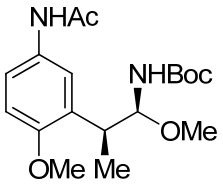


3q (minor diastereomer)

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (2H, m), 7.78-7.73 (2H, m), 7.57-7.46 (3H, m), 7.18 (1H, d, *J* = 1.0 Hz), 6.87 (1H, d, *J* = 8.7 Hz), 5.12 (1H, d, *J* = 9.9 Hz), 4.80 (1H, appt t, *J* = 9.1 Hz), 3.85 (3H, s), 3.41-3.33 (4H, m), 1.33 (3H, d, *J* = 7.0 Hz), 1.30 (9H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.6, 155.8, 154.1, 135.2, 131.8, 131.6, 131.3, 128.9, 127.1, 120.7, 120.2, 111.1, 87.3, 79.5, 55.9, 55.8, 37.6, 28.3, 16.8; IR (neat) 3316, 2976, 2934, 1701, 1649, 1537, 1501, 1244 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{30}N_2O_5$: *m/z* 437.2047 ([M + Na]$^+$), found: *m/z* 437.2045 ([M + Na]$^+$); $[\alpha]_D^{28}$ –7.0 (*c* = 0.84, $CHCl_3$; 96% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak OD-H, hexane/2-propanol = 9:1, flow rate = 0.5 mL/min, retention time; major diastereomer,

30.8 min (minor) and 52.1 min (major); minor diastereomer, 18.0 min (minor) and 22.5 min (major)).

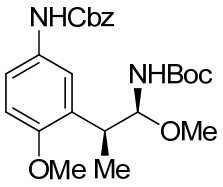


3r

Prepared with **1** (0.10 mmol, 19.5 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 10 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 2:1 and CH_2Cl_2/EtOAc = 10:1) to give **3** as a colorless oil [74%, 26.0 mg, 12:1 dr, 78% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (1H, dd, *J* = 8.7, 2.4 Hz), 7.16 (2H, br), 6.82 (1H, d, *J* = 8.7 Hz), 5.01 (1H, dd, *J* = 9.9, 5.8 Hz), 4.86 (1H, d, *J* = 10.2 Hz), 3.80 (3H, s), 3.43 (1H, m), 3.31 (3H, s), 2.14 (3H, s), 1.43 (9H, s), 1.24 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.4, 155.9, 154.1, 131.2, 130.9, 121.3, 120.1, 111.2, 85.8, 79.7, 56.1, 55.9, 37.5, 28.4, 24.4, 16.8; IR (neat) 3303, 2977, 2934, 1694, 1667, 1498, 1366, 1243 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{18}H_{28}N_2O_5$: *m/z* 375.1890 ([M + Na]$^+$), found: *m/z* 375.1879 ([M + Na]$^+$); $[\alpha]_D^{26}$ +0.36 (*c* = 1.0, $CHCl_3$; 78% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak IC-3, hexane/2-propanol = 85:15, flow rate = 0.5 mL/min, retention time; 36.9 min (minor) and 40.7 min (major))



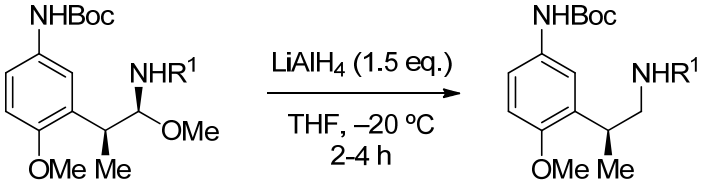
3s

Prepared with **1** (0.10 mmol, 28.7 mg) and (*Z*)-**2a** (0.12 mmol, 18.9 mg) for 28 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 and CH_2Cl_2/EtOAc = 40:1) to give **3** as a white solid [80%, 35.5 mg, 12:1 dr, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.30 (6H, m), 7.14 (1H, *d*, J = 1.7 Hz), 6.80 (1H, d, *J* = 8.7 Hz), 6.61 (1H, br), 5.18 (2H, s), 5.01 (1H, dd, *J* = 10.0, 5.7 Hz), 4.85 (1H, d, *J* = 10.2 Hz), 3.79 (3H, s), 3.42 (1H, m), 3.30 (3H, s), 1.42 (9H, s), 1.22 (3H, d, *J* = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 153.8, 136.4, 131.1, 130.9, 128.7, 128.37, 128.35, 120.4, 118.6, 111.3, 85.7, 79.6, 67.0, 56.1, 56.0, 37.5, 28.4, 16.6; IR (neat) 3318, 2976, 2836, 1698, 1501, 1455, 1366, 1220 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{24}H_{32}N_2O_6$: *m/z* 467.2153 ([M + Na]$^+$), found: *m/z* 467.2135 ([M + Na]$^+$); $[\alpha]_D^{26}$ –7.0 (*c* = 1.2, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak IC, hexane/2-propanol = 85:15, flow rate = 0.5 mL/min, retention time; 20.5 min (major) and 21.7 min (minor))

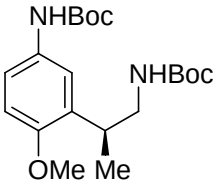
Hydride reduction of 3a and 3k (Scheme 1, a)



R^1 = Boc (**3a**)
97% ee
R^1 = Bz (**3k**)
98% ee

R^1 = Boc
75% (**7a**), 98% ee
R^1 = Bz
90% (**7b**), 98% ee

To a stirred solution of **3** (1.0 eq.) in THF (1.0 mL) was added $LiAlH_4$ (1.5 eq.) at –20 °C. After the completion of the reaction, the reaction mixture was quenched with aqueous HCl (1 mL) and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC to give **7**.

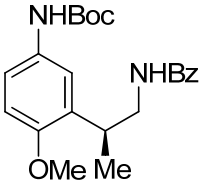


7a

Prepared with **3a** (0.14 mmol, 59.2 mg) and $LiAlH_4$ (0.22 mmol, 8.2 mg) for 4 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1) to give **7a** as a white solid [75%, 41.2 mg, 98 % ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26 (1H, br), 7.04 (1H, br), 6.79 (1H, d, *J* = 8.7 Hz), 6.34 (1H, br), 4.50 (1H, br), 3.78 (3H, s), 3.39-3.22 (3H, m), 1.51 (9H, s), 1.40 (9H, s), 1.21 (3H, d, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.1, 153.5, 153.3, 132.9, 131.7, 118.9, 118.3, 111.3, 80.3, 79.0, 55.8, 46.2, 33.2, 28.5, 28.4, 18.1; IR (neat) 3329, 2974, 2932, 1695, 1504, 1366, 1240, 1161 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{20}H_{32}N_2O_5$: *m/z* 403.2203 ($[M + Na]^+$), found: *m/z* 403.2205 ($[M + Na]^+$); $[\alpha]_D^{24}$ –30.9 (*c* = +1.0, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 11.6 min (minor) and 13.6 min (major)).



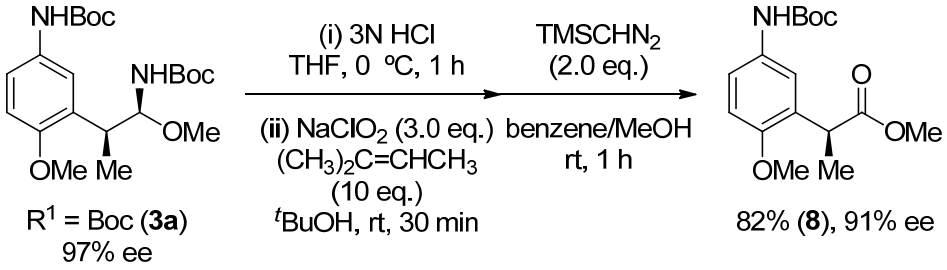
7b

Prepared with **3k** (0.090 mmol, 37.5 mg) and $LiAlH_4$ (0.14 mmol, 5.1 mg) for 2 h. The crude material was purified by PLC (eluting with hexane/EtOAc = 3:1 twice) to give **7b** as a white solid [90%, 31.2 mg, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (2H, m), 7.45 (1H, m), 7.37 (2H, t, *J* = 7.4 Hz), 7.24

(1H, br), 7.18 (1H, d, J = 2.4 Hz), 6.82 (1H, d, J = 8.7 Hz), 6.38-6.32 (2H, m), 3.79 (3H, s), 3.72 (1H, m), 3.52 (2H, m), 1.51 (9H, s), 1.31 (3H, d, J = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.6, 153.36, 153.33, 135.1, 132.9, 132.0, 131.3, 128.6, 127.0, 119.0, 118.6, 111.4, 80.4, 56.0, 46.3, 32.4, 28.5, 18.1; IR (neat) 3301, 2975, 1644, 1535, 1504, 1239, 1160, 1027 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{22}H_{28}N_2O_4$: m/z 407.1941 ($[M + Na]^+$), found: m/z 407.1949 ($[M + Na]^+$); $[\alpha]_D^{26}$ –81.2 (c = 1.3, $CHCl_3$; 98% ee).
Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak OD-H, hexane/2-propanol = 19:1, flow rate = 0.5 mL/min, retention time; 79.1 min (minor) and 93.5 min (major)).

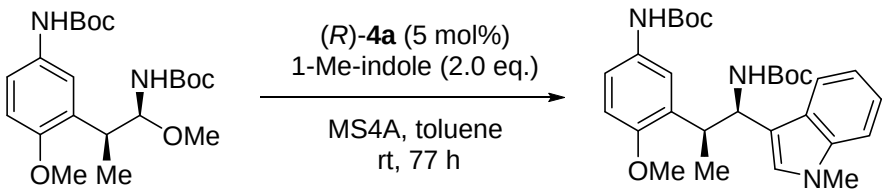
Transformation of 3a into the corresponding methyl ester (Scheme 1, b)



To a stirred solution of **3a** (0.073 mmol, 30.0 mg, 97% ee) in THF (6.0 mL) was added 3N HCl (366 μL) at 0 °C. After stirring for 1 h at 0 °C, $NaClO_2$ (0.22 mmol, 19.8 mg), 2-methyl-2-butene (0.73 mmol, 77 μL) and ^{t}BuOH (3 mL) were added. After stirring for 30 min at rt, the reaction mixture was quenched with aqueous H_2O, and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was then dissolved in toluene/MeOH (500 μL/500 μL). To this solution was added $TMSCHN_2$ 2.0 M solution in diethyl ether (0.15 mmol, 73 μL) at rt. After stirring for 1 h at rt, the reaction mixture was quenched with acetic acid (200 μL), and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with CH_2Cl_2/EtOAc = 30:1) to give **8** as a colorless oil [82%, 18.4 mg, 91% ee].
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (1H, br), 7.11 (1H, d, J = 2.7 Hz), 6.80 (1H, d, J = 8.9 Hz), 6.34 (1H, br), 4.00 (1H, q, J = 7.3 Hz), 3.79 (3H, s), 3.65 (3H, s), 1.50 (9H, s), 1.44 (3H, d, J = 7.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.5, 153.2, 153.0, 131.6, 130.1, 119.7, 119.1, 111.5, 80.4, 56.1, 52.1, 39.4, 28.5, 17.5; IR (neat) 3345, 2978, 1720, 1533, 1506, 1227, 1159, 1027 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{16}H_{23}N_1O_5$: m/z 332.1468 ($[M + Na]^+$), found: m/z 332.1463 ($[M + Na]^+$); $[\alpha]_D^{29}$ +37.2 (c = 0.74, $CHCl_3$; 91% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 11.1 min (major) and 13.1 min (minor)).

Addition of 1-methylindole to 3a (Scheme 1, c)



3a
97% ee

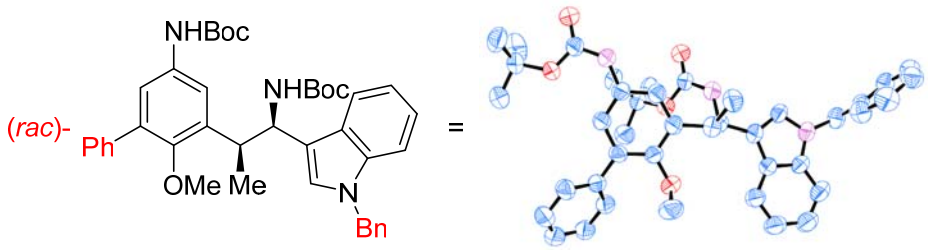
63% (**9**), >20:1 dr
99% ee

To a stirred solution of **3a** (0.10 mmol, 41.1 mg, 97% ee), 1-methylindole (0.20 mmol, 25 μL) and MS4A (50 mg) in toluene (1.0 mL) was added (*R*)-**4a** (5.0 μmol, 3.3 mg) at rt. After stirring for 77 h at rt, the mixture was quenched with aqueous $NaHCO_3$, and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with hexane/EtOAc = 2:1) to give **9** as a white solid [63%, 31.9 mg, >20:1 dr, 99% ee]. The relative configuration was not assigned yet.

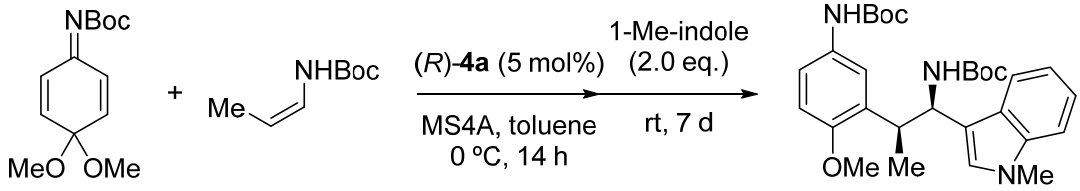
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 (1H, br), 7.22-7.17 (3H, m), 7.09 (1H, m), 6.94 (1H, br), 6.77 (2H, br), 6.22 (1H, br), 5.34 (1H, dd, *J* = 9.4, 6.8 Hz), 4.90 (1H, d, *J* = 9.4 Hz), 3.88 (1H, appt t, *J* = 6.9 Hz), 3.79 (3H, br), 3.66 (3H, br), 1.48 (9H, s), 1.39 (9H, s), 1.23 (3H, br); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.7, 153.2, 153.1, 137.3, 133.5, 131.4, 127.0, 126.6, 121.6, 119.9, 119.4, 119.0, 118.0, 115.6, 111.1, 109.2, 80.1, 79.0, 55.9, 52.1, 36.5, 32.8, 28.5, 16.8; IR (neat) 3327, 2975, 2931, 1694, 1502, 1366, 1240, 1162 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{29}H_{39}N_3O_5$: *m/z* 532.2782 ([M + Na]$^+$), found: *m/z* 532.2774 ([M + Na]$^+$); $[\alpha]_D^{22}$ +4.8 (*c* = 0.62, $CHCl_3$; 99% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 7:3, flow rate = 0.5 mL/min, retention time; 11.1 min (minor) and 39.8 min (major)).

The relative configuration of the product was determined by the X-ray crystallographic analysis of an analog shown below. The crystal structure has been deposited at the Cambridge Crystallographic Data Centre (CCDC 965786). The data can be obtained free of charge via the Internet at www.ccdc.cam.ac.uk/conts/retrieving.html.



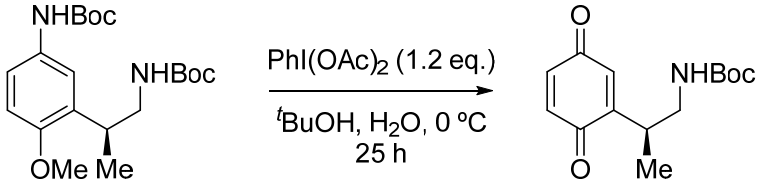
One-pot sequential transformation of 1a to 9



1a (*Z*)-**2a** 44% (**9**), >20:1 dr, >99% ee

To a stirred solution of **1a** (0.10 mmol, 25.3 mg), (*R*)-**4a** (5.0 μmol, 3.3 mg) and MS4A (50 mg) in toluene (1.0 mL) was added (*Z*)-**2a** (0.12 mmol, 18.9 mg) at 0 °C. After stirring for 14 h at 0 °C, 1-methylindole (0.20 mmol, 25 μL) was added to the solution, and the reaction mixture was stirred at rt for 7 d. The solution was quenched with aqueous $NaHCO_3$, and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with hexane/EtOAc = 2:1) to give **9** as a white solid [44%, 22.4 mg, >20:1 dr, >99% ee].

Oxidation of 7a to quinone 10 (Scheme 1, d)



7a, 98% ee 73% (**10**), 96% ee

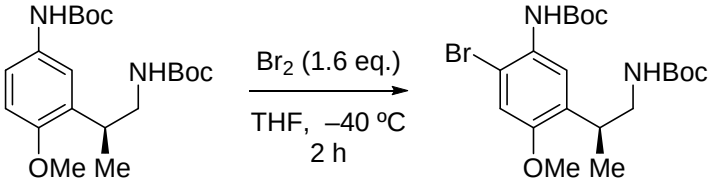
To a stirred solution of **7a** (0.064 mmol, 24.4 mg, 98% ee) in ^{t}BuOH/H_2O (1.0 mL/1.0 mL) was added $PhI(OAc)_2$ (0.13 mmol, 41.3 mg) at 0 °C. After stirring for 25 h at 0 °C, the reaction mixture was quenched with aqueous $NaHCO_3$, and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on aluminum

oxide (eluting with hexane/EtOAc = 3:1) to give **10** as a colorless oil [73%, 12.4 mg, 96% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.79 (1H, dd, *J* = 10.0, 3.0 Hz), 6.70 (1H, dd, *J* = 9.9, 2.4 Hz), 6.52 (1H, br), 4.61 (1H, br), 3.36 (1H, m), 3.14 (2H, m), 1.36 (9H, s), 1.15 (3H, d, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.8, 187.0, 156.1, 151.0, 137.4, 135.9, 132.0, 79.7, 44.9, 33.7, 28.4, 16.2; IR (neat) 3368, 2976, 2934, 1698, 1655, 1519, 1249, 1166 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{14}H_{19}N_1O_4$: *m/z* 288.1206 ([M + Na]$^+$), found: *m/z* 288.1206 ([M + Na]$^+$); $[\alpha]_D^{24}$ –42.1 (*c* = 1.0, $CHCl_3$; 96% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 19:1, flow rate = 0.5 mL/min, retention time; 32.8 min (major) and 35.0 min (minor)).

Bromination of 7a (Scheme 1, e)



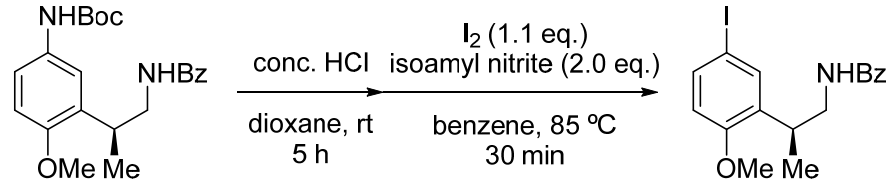
7a, 98% ee — 86% (**11**), 98% ee

To a stirred solution of **7a** (0.054 mmol, 20.6 mg, 98% ee) in THF (1.0 mL) was added Br_2 (0.084 mmol, 4.3 μL) at –40 °C. After stirring for 2 h at the same temperature, the reaction mixture was quenched with aqueous $NaHSO_3$ and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with hexane/EtOAc = 3:1) to give **11** as a white solid [86%, 21.3 mg, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (1H, br), 6.98 (1H, s), 6.68 (1H, br), 4.51 (1H, br), 3.78 (3H, s), 3.40-3.20 (3H, m), 1.53 (9H, s), 1.40 (9H, s), 1.23 (3H, d, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.1, 153.7, 152.9, 133.0, 129.9, 120.4, 114.6, 111.0, 80.9, 79.1, 56.1, 46.1, 33.4, 28.52, 28.49, 17.9; IR (neat) 3419, 2976, 2932, 1702, 1510, 1366, 1232, 1153 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{20}H_{31}Br_1N_2O_5$: *m/z* 481.1309 ([M + Na]$^+$), found: *m/z* 481.1321 ([M + Na]$^+$); $[\alpha]_D^{23}$ –71.9 (*c* = 1.1, $CHCl_3$; 98% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 8.3 min (minor) and 9.7 min (major)).

Transformation of 7b into the iodoarene 12 (Scheme 1, f)



7b, 98% ee

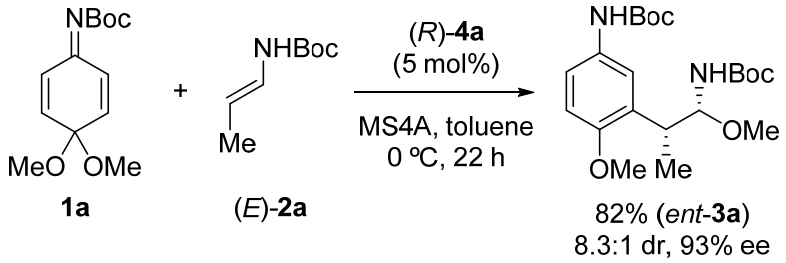
76% (**12**), 98% ee

To a stirred solution of **7b** (0.081 mmol, 31.2 mg, 98% ee) in dioxane (1.0 mL) was added concentrated HCl (210 μL) at rt. After stirring for 5 h at rt, the reaction mixture was quenched with aqueous $NaHCO_3$ and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was then dissolved in benzene. To this solution were added I_2 (0.089 mmol, 22.7 mg) and isoamyl nitrite (0.16 mmol, 22 μL). After stirring for 30 min at 85 °C, the reaction mixture was quenched with aqueous $Na_2S_2O_3$ and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and hexane/EtOAc = 3:1) to give **12** as a colerless oil [76%, 24.5 mg, 98% ee].

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 (2H, m), 7.52-7.49 (2H, m), 7.46 (1H, d, *J* = 7.0 Hz), 7.40 (2H, t, *J* = 7.3 Hz), 6.65 (1H, d, *J* = 9.2 Hz), 6.17 (1H, br), 3.79 (3H, s), 3.70 (1H, m), 3.48 (2H, m), 1.30 (3H, d, *J* = 6.5 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.6, 157.2, 136.6, 136.2, 135.2, 135.0, 131.4, 128.7, 126.9, 113.1, 83.7, 55.7, 46.1, 32.5, 17.9; IR (neat) 3311, 2963, 2932, 1637, 1541, 1486, 1285, 1242 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{17}H_{18}I_1N_1O_2$: *m/z* 418.0274 ($[M + Na]^+$), found: *m/z* 418.0290 ($[M + Na]^+$); $[\alpha]_D^{25}$ –84.2 (*c* = 0.92, $CHCl_3$; 98% ee).

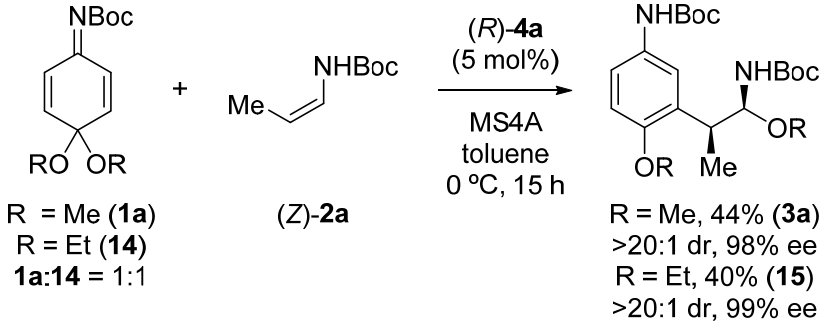
Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 15.4 min (minor) and 18.6 min (major)).

Use of (*E*)-2a (Scheme 2, eq. 1)

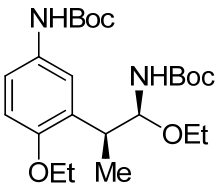


To a stirred solution of **1a** (0.10 mmol, 25.3 mg), (*R*)-**4a** (5.0 μmol, 3.3 mg) and MS4A (50 mg) in toluene (1.0 mL) was added (*E*)-**2a** (0.12 mmol, 18.9 mg) (0.12 mmol, 19.3 mg) at 0 °C. After stirring for 22 h at 0 °C, the reaction mixture was quenched with aqueous $NaHCO_3$ and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with CH_2Cl_2/EtOAc = 20:1 and Hex/EtOAc = 3:1) to give *ent*-**3a** as a white solid [82%, 33.6 mg, 8.3:1 dr, 93% ee/84% ee].

Crossover experiment (Scheme 2, eq. 3)



To a stirred solution of **1a** (0.050 mmol, 12.7 mg), **14** (0.050 mmol, 14.1 mg) and (*R*)-**4a** (5 μmol, 3.3 mg) in toluene (1.0 mL) was added (*Z*)-**2a** (0.12 mmol, 18.9 mg) at 0 °C. After stirring for 15 h at 0 °C, the reaction mixture was quenched with aqueous $NaHCO_3$ and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by PLC (eluting with hexane/EtOAc = 3:1) to give **3a** as a white solid [44%, 18.1 mg, >20:1 dr, 98% ee] and **15** as a white solid [40%, 17.6 mg, >20:1 dr, 99% ee].



15

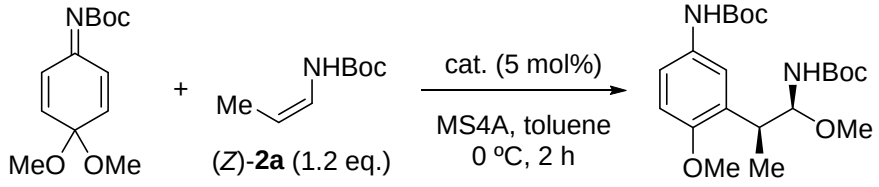
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (1H, br), 7.11 (1H, br), 6.78 (1H, d, *J* = 8.7 Hz), 6.31 (1H, br), 5.10-5.01 (2H, m), 4.00 (1H, m), 3.66 (1H, m), 3.48 (2H, m), 1.51 (9H, s), 1.42-1.38 (12H, m), 1.26 (3H, d, *J* = 7.0 Hz), 1.14 (3H, t, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$)

δ 155.8, 153.3, 152.8, 131.3, 130.9, 120.7, 118.5, 112.2, 83.9, 80.2, 79.4, 64.3, 64.0, 37.1, 28.53, 28.45, 16.5, 15.2, 15.0; IR (neat) 3336, 2976, 2933, 1700, 1505, 1366, 1244, 1164 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{23}H_{38}N_2O_6$: *m/z* 461.2622 ($[M + Na]^+$), found: *m/z* 461.2613 ($[M + Na]^+$); $[\alpha]_D^{25}$ –5.4 (*c* = 1.1, $CHCl_3$; 99% ee).

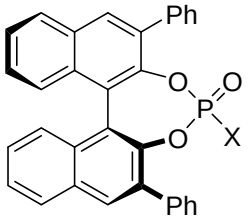
Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 4:1, flow rate = 0.5 mL/min, retention time; 39.4 min (major) and 45.1 min (minor)).

Use of chiral phosphoric acid and phosphoramide as chiral Brønsted acid catalyst (ref 16)

Following our general procedure, the reaction of the quinone imine ketal **1a** and enecarbamate (*Z*)-**2a** was conducted by using representative 3,3'-diphenyl-BINOL derived chiral phosphoric acid and N-triflyl phosphoramide.[10,11] Whereas both reactions gave the products with good enantioselectivity, the diastereoselectivity was found to be low. This is presumably due to the high acidity of these catalysts which promote epimerization of the labile hemiaminal ether moiety.



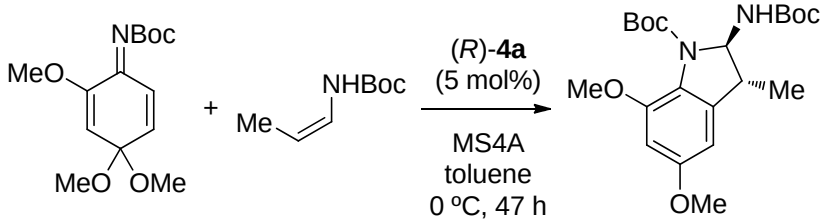
1a (1.0 eq.) **3a**



X = OH
49%, 1:1.4 dr, 83% ee/77% ee

X =NHTf
56%, 1:1.2 dr, 84% ee/84% ee

Use of 2-substituted quinone imine ketal 5 (ref 17)



5 (*Z*)-**2a** (1.2 eq.) **6** 21% yield >20:1 dr 16% ee

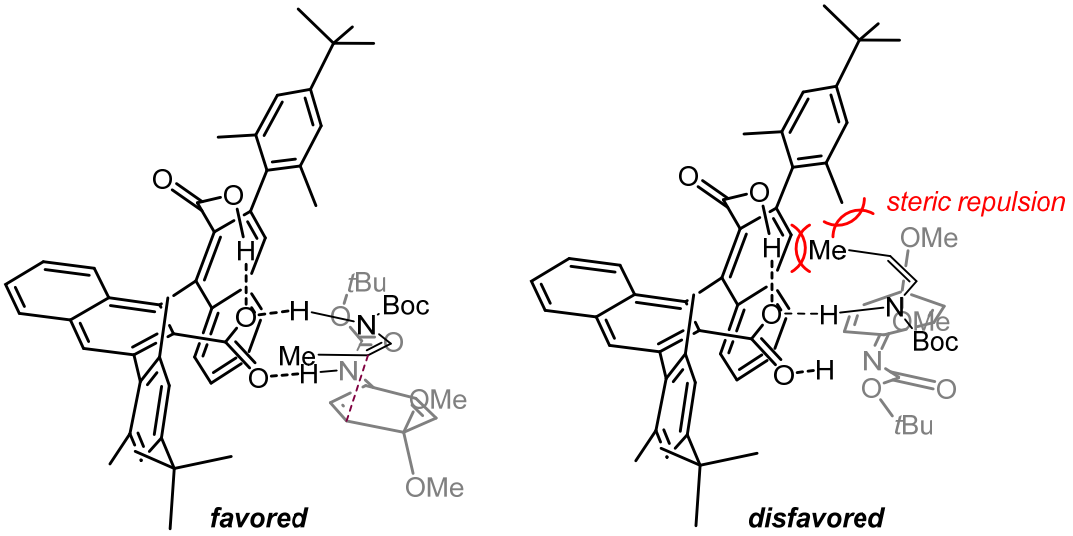
To a stirred solution of **5** (0.20 mmol, 47.7 mg), (*R*)-**4a** (10 μmol, 6.6 mg) and MS4A (50 mg) in toluene (2.0 mL) was added (*Z*)-**2a** (0.24 mmol, 37.7 mg) at rt. After stirring for 47 h at rt, the reaction mixture was quenched with aqueous $NaHCO_3$ (2 mL) and extracted with ethyl acetate. The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated. The residue was purified by column chromatography (eluting with hexane/EtOAc/NEt_3 = 5:1:0.06) to give **6** as a white solid [21%, 16.9 mg, >20:1 dr, 16% ee]. The relative configuration was determined by X-ray analysis.

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.38-6.36 (2H, m), 5.58 (1H, br), 4.99 (1H, br), 3.83 (3H, s), 3.78 (3H, s), 2.96 (1H, q, *J* = 7.2 Hz), 1.50 (9H, s), 1.43 (9H, s), 1.27 (3H, d, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 154.6, 153.7, 150.7, 139.5, 122.9, 101.1, 99.2, 81.0, 79.8, 55.9, 55.8, 46.0, 28.5, 28.3, 19.7; IR (neat) 3342, 2973, 2928, 1704, 1497, 1366, 1290, 1248 cm^{-1}; HRMS (ESI) exact mass calcd. for $C_{21}H_{32}N_2O_6$: *m/z* 431.2153 ([M + Na]$^+$), found: *m/z* 431.2150 ([M + Na]$^+$); $[\alpha]_D^{22}$ –1.3 (*c* = 0.67, $CHCl_3$; 16% ee).

Enantiomeric purity was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane/2-propanol = 19:1, flow rate = 0.5 mL/min, retention time; 41.3 min (major) and 56.1 min (minor)).

Explanation of the enantioselectivity (ref 25)

Based on our previous study revealing the X-ray structure of the catalyst (*R*)-**4a**,[12] we propose the transition state model as below. In the favored transition state, the hydrogen-bonded quinone imine ketal and enecarbamte can be properly positioned in the chiral pocket of the catalyst. On the other hand, the transition state which gives the opposite enantiomer seems not be favorable because of the steric repulsion between the catalyst and the incoming enecarbamate.



References

(1) Hashimoto, T.; Maruoka, K. *Synthesis*, **2008**, *22*, 3703.

(2) Fisher, L. E.; Muchowski, J. M.; Clark, R. D. *J. Org. Chem.* **1992**, *57*, 2700.

(3) Baechler, S. A.; Fehr, M.; Habermeyer, M.; Hofmann, A.; Merz, K.-H.; Fiebig, H-.H.; Marko, D.; Eisenbrand, G. *Bio. Med. Chem.* **2013**, *21*, 814.

(4) Roosen, P. C.; Kallepalli, V. A.; Chattopadhyay, B.; Singleton, D. A.; Maleczka, R. E., Jr; Smith, M. R., III. *J. Am. Chem. Soc.* **2012**, *134*, 11350.

(5) Saá, C.; Guitián, E.; Castedo, L. *J. Org. Chem.* **1986**, *51*, 2781.

(6) Dalili, S.; Yudin, A. K. *Org. Lett.* **2005**, *7*, 1161.

(7) (a) Mecozzi, T.; Petrini, M. *Synlett* **2000**, *1*, 73. (b) Pansare, S. V.; Vederas, J. C. *J. Org. Chem.* **1989**, *54*, 2311.

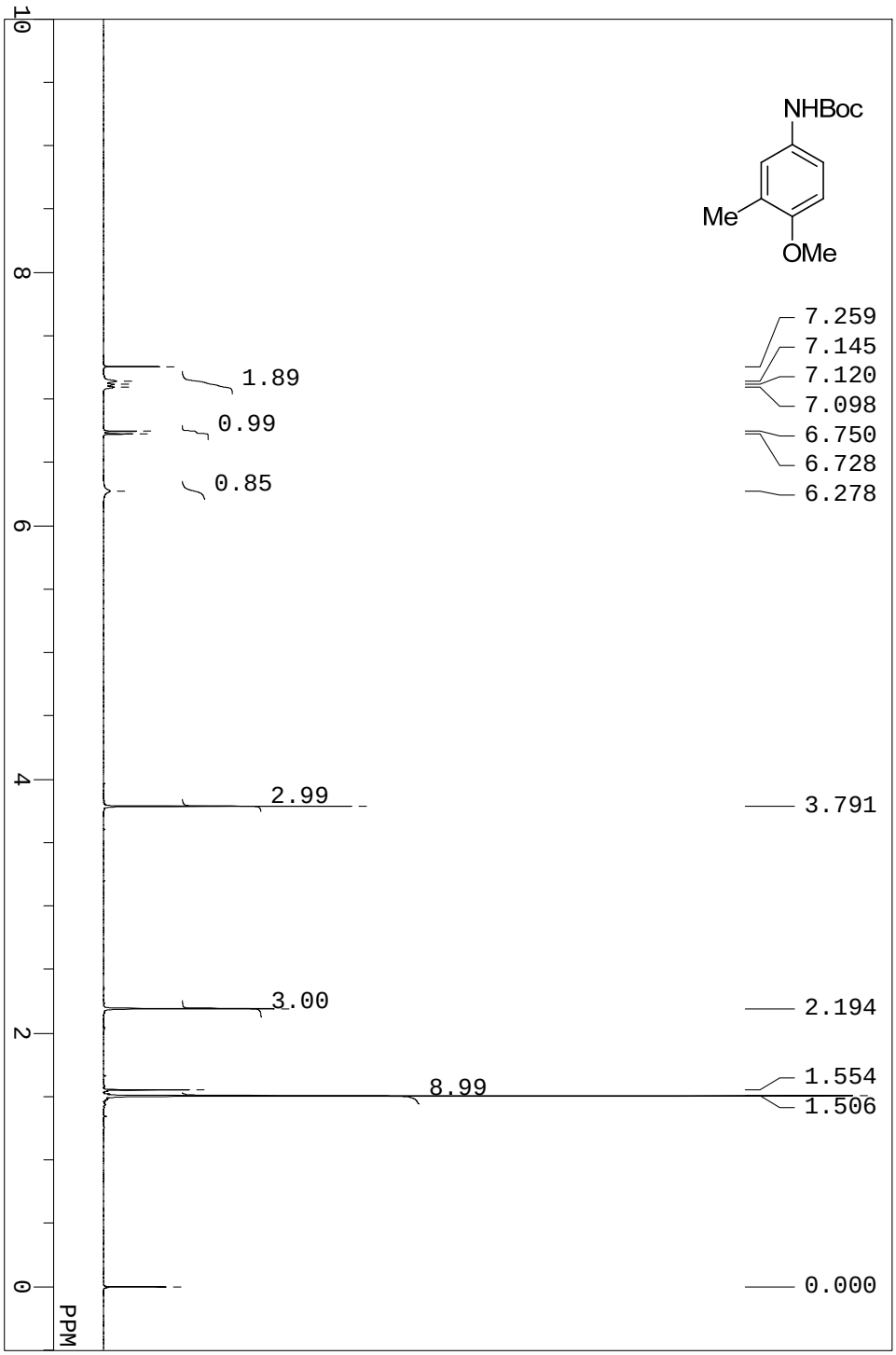
(8) Pansare, S. V., Vederas, J. C. *J.Org. Chem.* **1989**, *54*, 2311.

(9) Min, G. K.; Hernández, D.; Lindhardt, A. T.; Skrydstrup, T. *Org. Lett.* **2010**, *12*, 4716.

(10) (a) Akiyama, T.; Itoh, J.; Yokota, K.; Fuchibe, K. *Angew. Chem., Int. Ed.* **2004**, *43*, 1566. (b) Uraguchi, D.; Terada, M. *J. Am. Chem. Soc.* **2004**, *126*, 5356.

(11) Nakashima, D.; Yamamoto, H. *J. Am. Chem. Soc.* **2006**, *128*, 9626.

(12) Hashimoto, T.; Kimura, H.; Nakatsu, H.; Maruoka, K. *J. Org. Chem.* **2011**, *76*, 6030.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2.99
3.00
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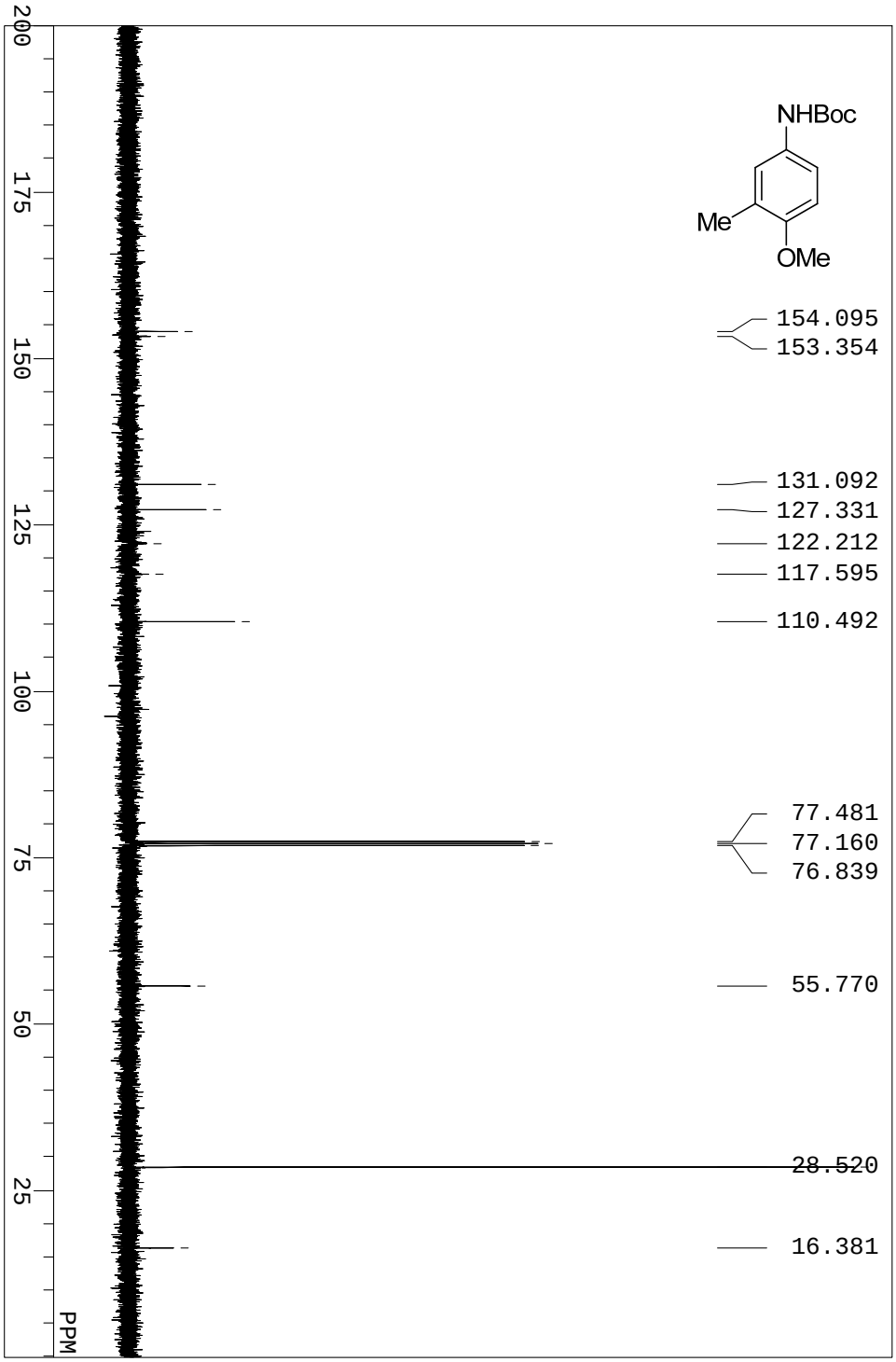
1.554
1.506
0.000
PPM
10
8
6
4
2
0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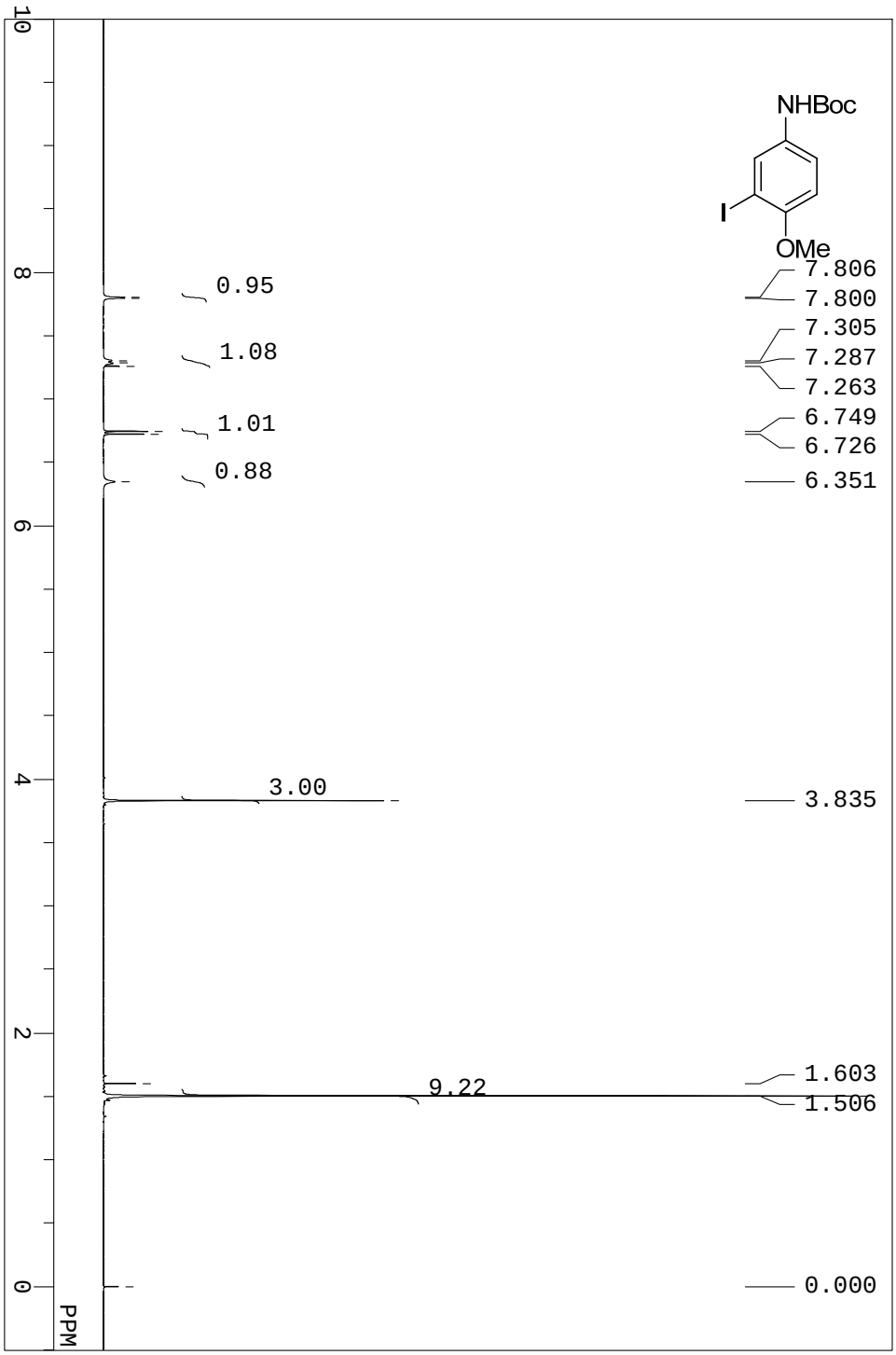
28.520
16.381
200
175
150
125
100
75
50
25
PPM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OMe
10
8
6
4
2
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9.22
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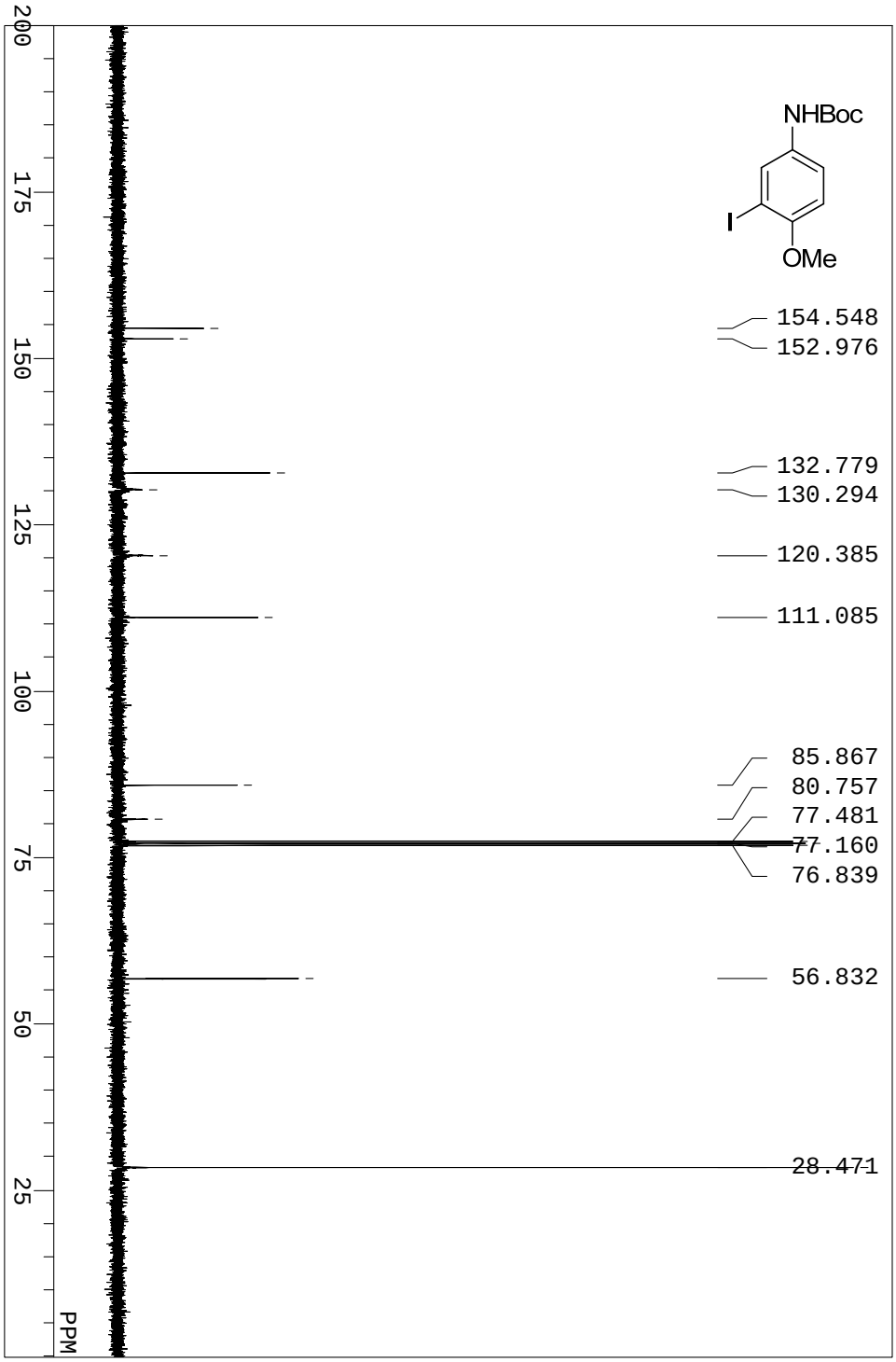
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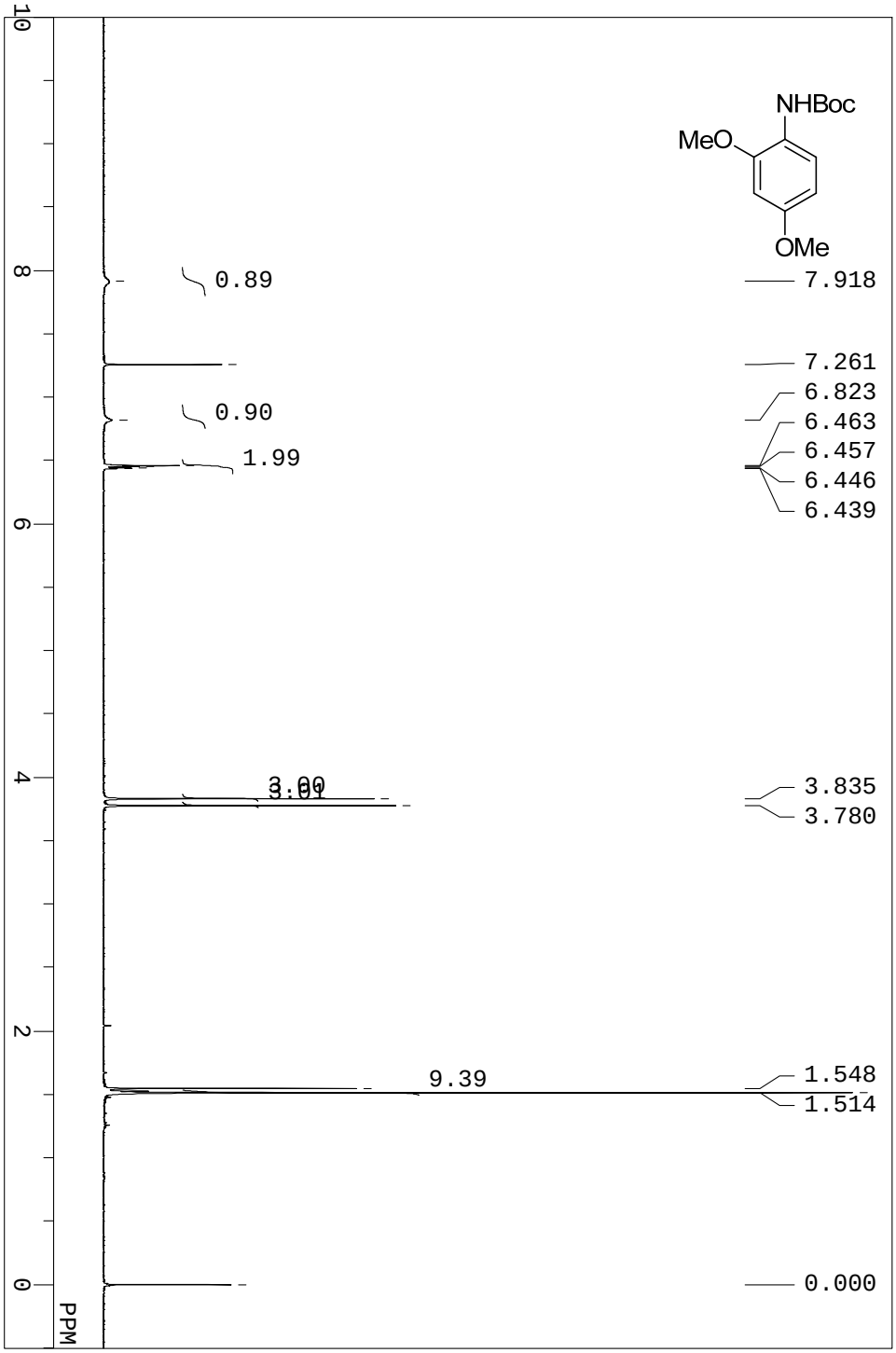
50
25
PPM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6
4
2
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PPM
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3.00
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6.446
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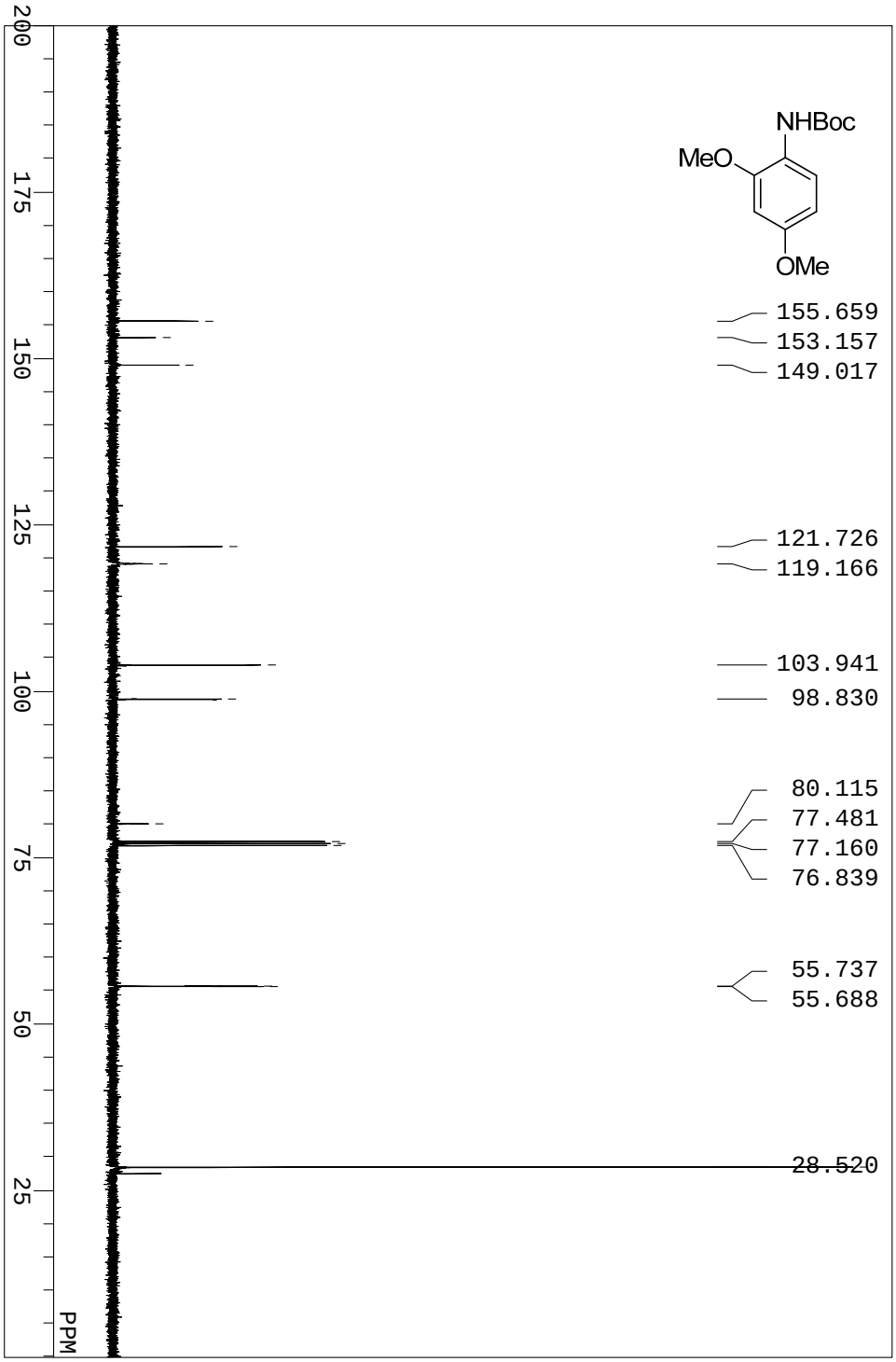
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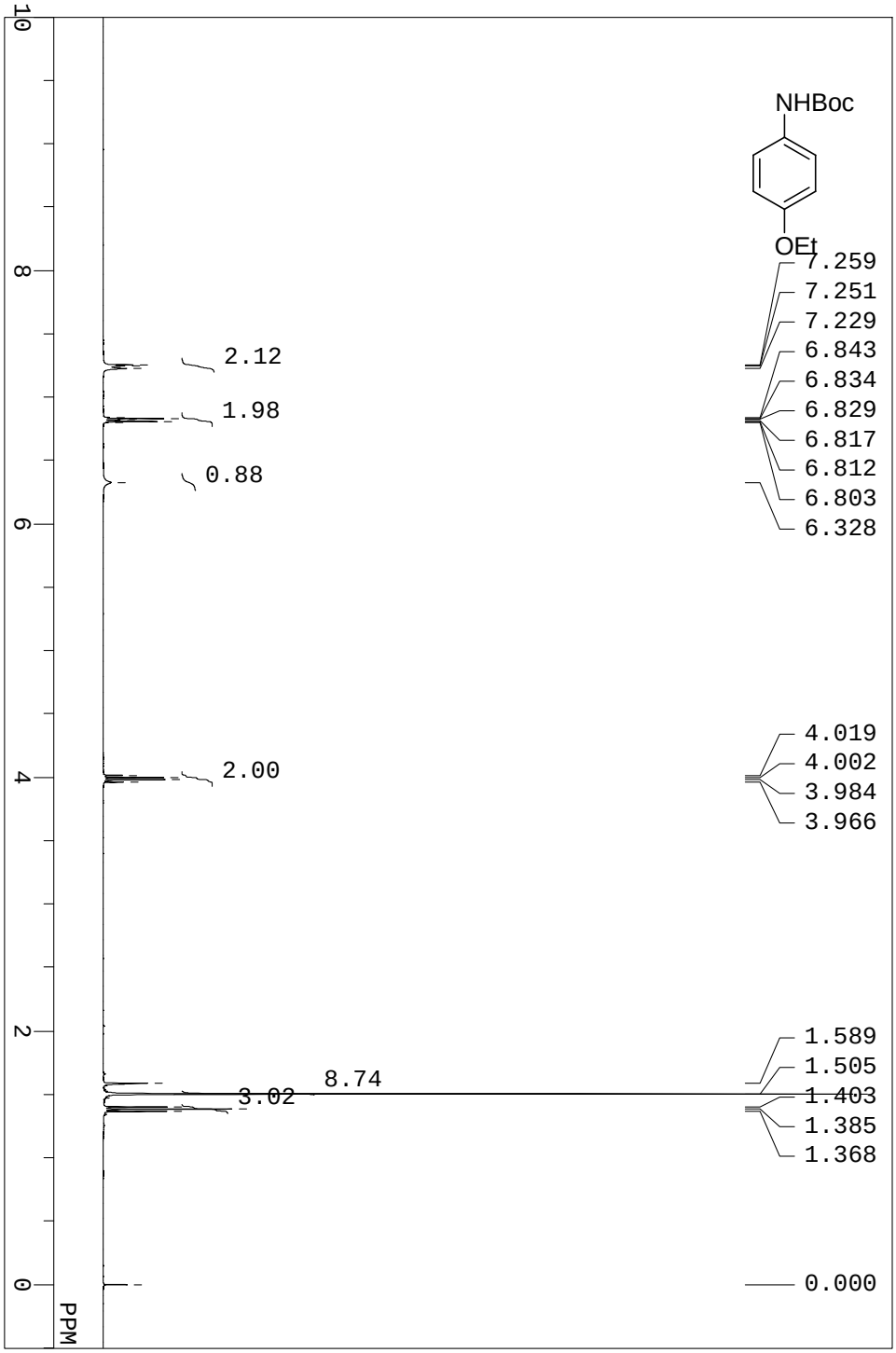
100
75
50
25
PPM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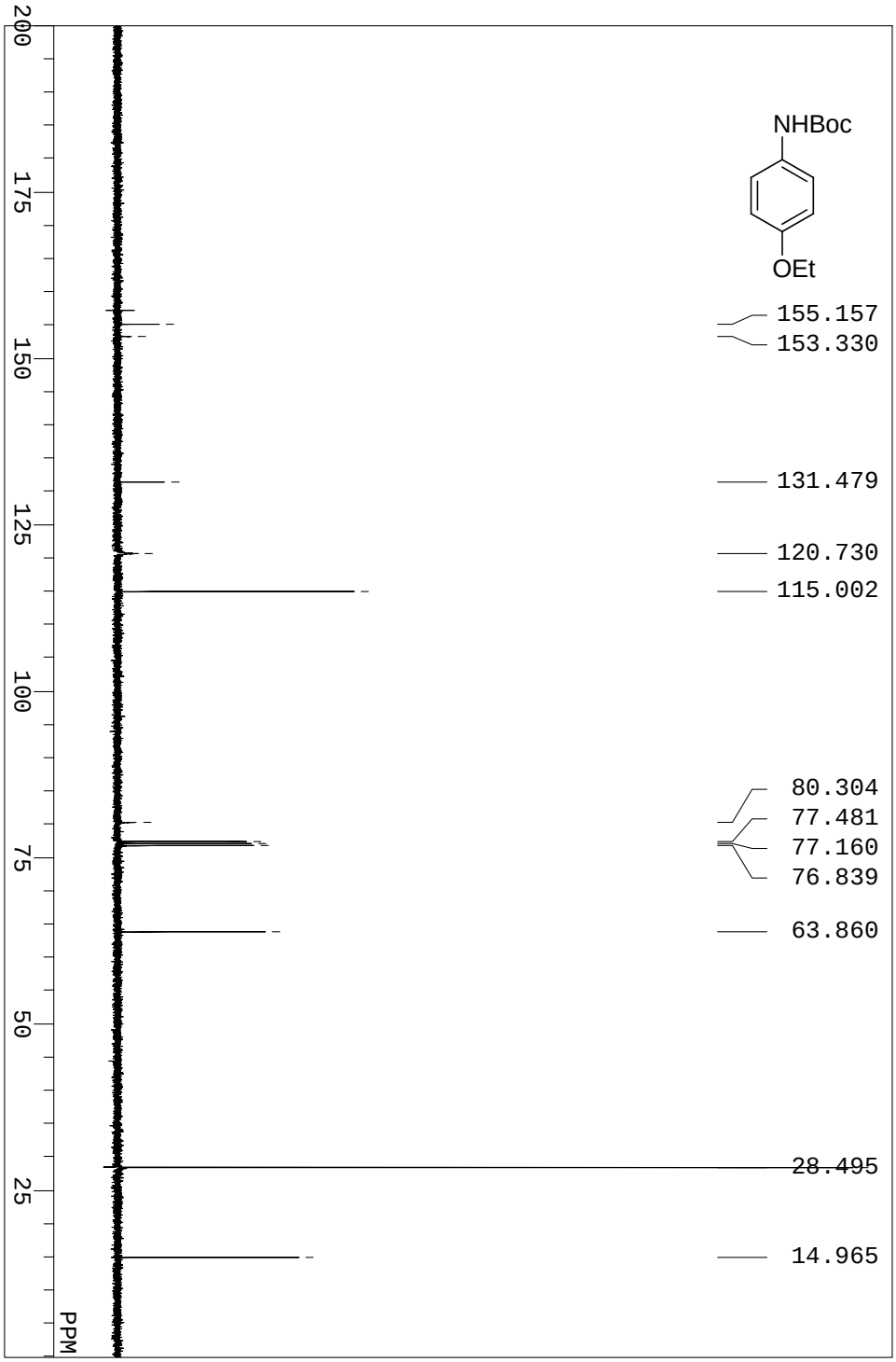
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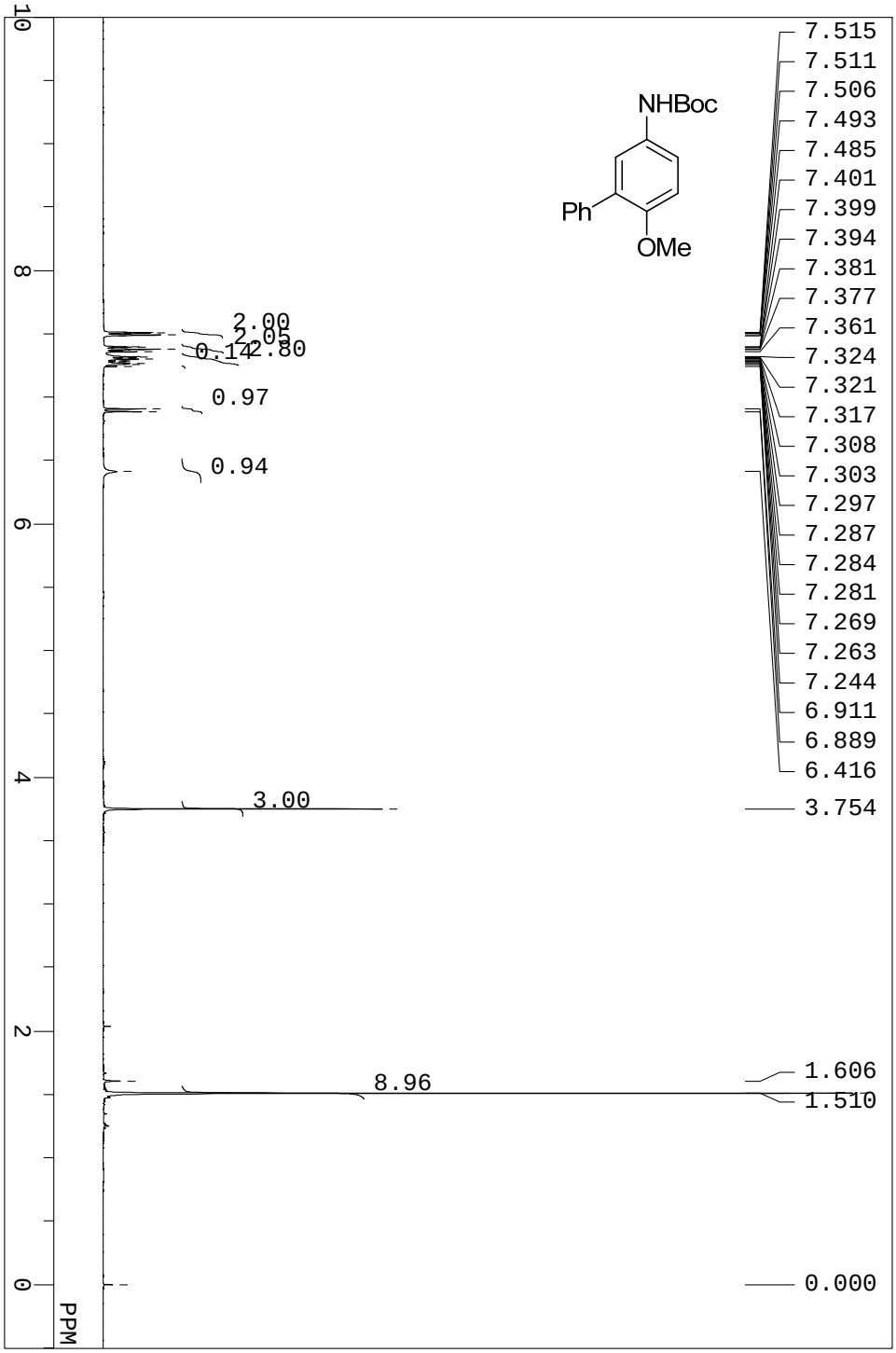
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7.324
7.321
7.317
7.308
7.303
7.297
7.287
7.284
7.281
7.269
7.263
7.244
6.911
6.889
6.416
3.754
1.606
1.510
0.000
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0.94
3.00
8.96
10
8
6
4
2
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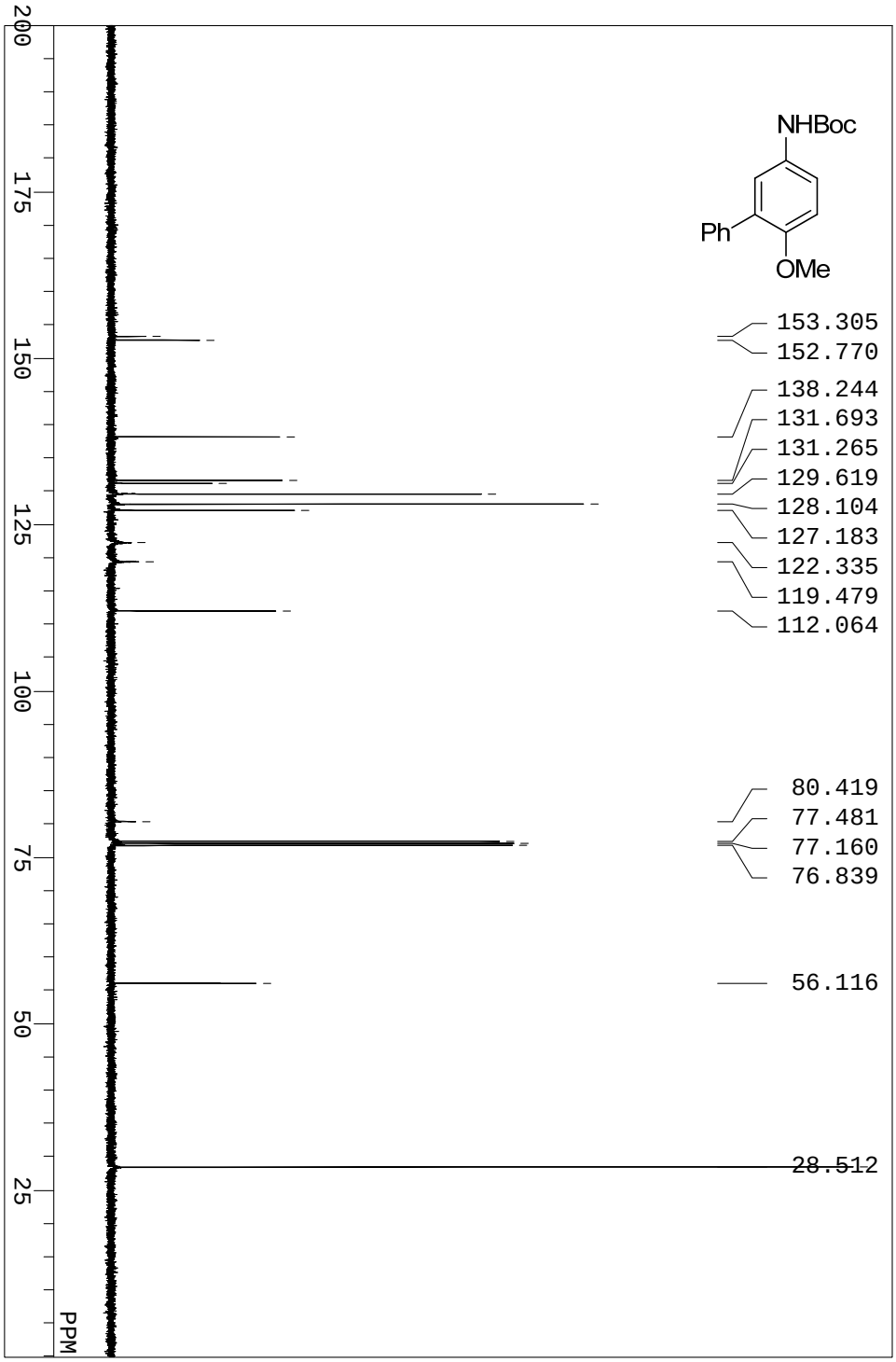
PPM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75
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25
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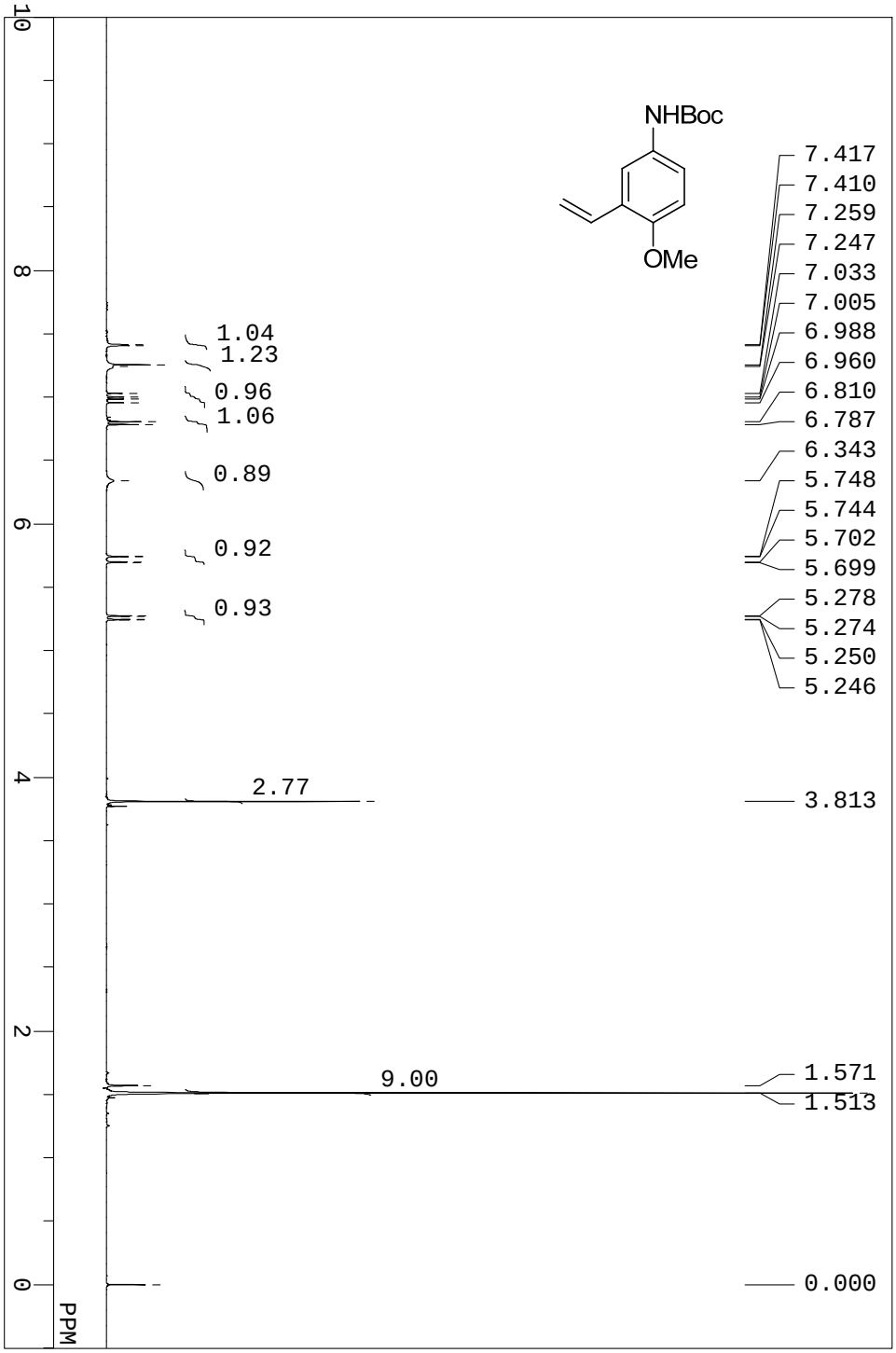
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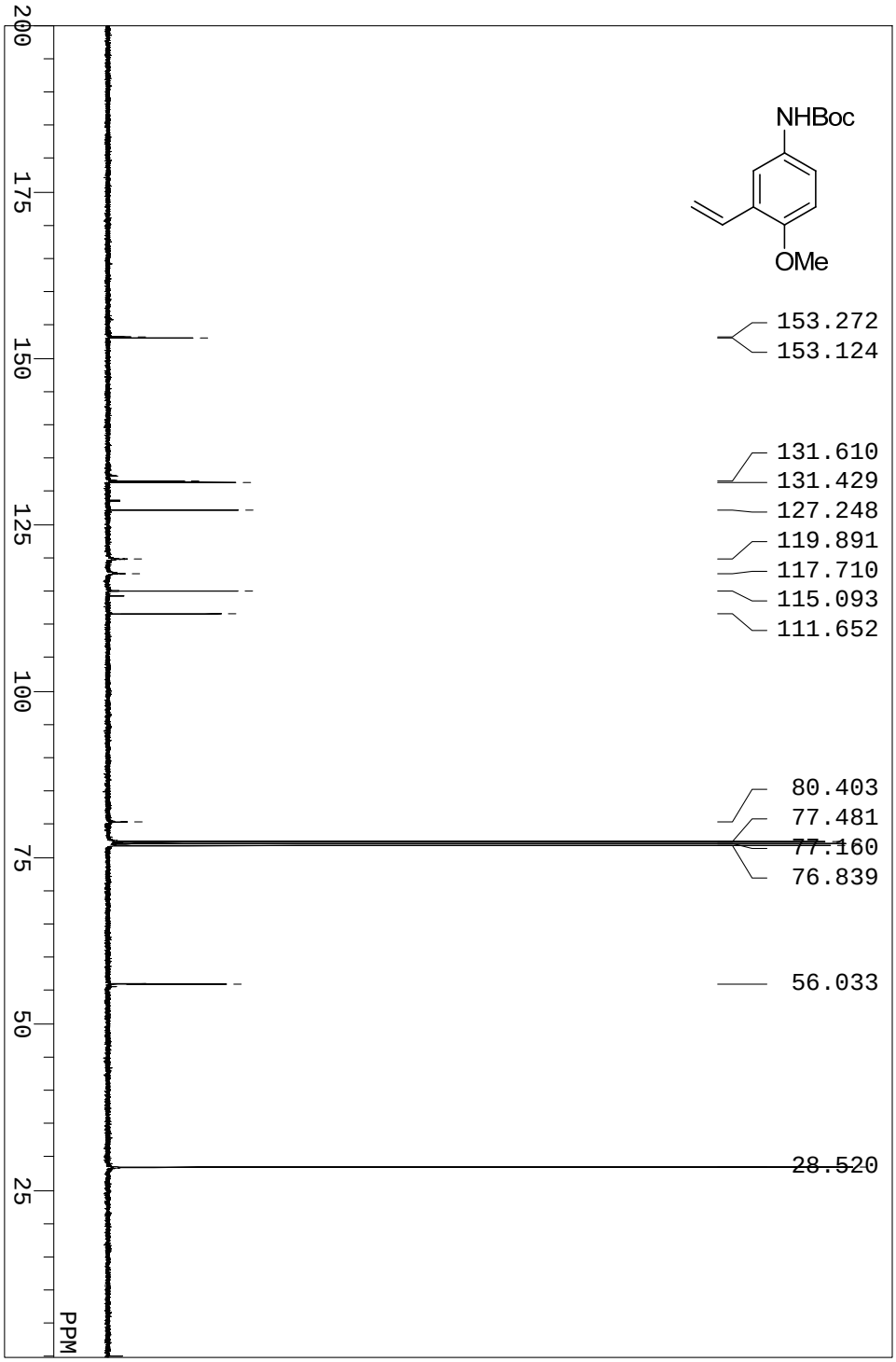
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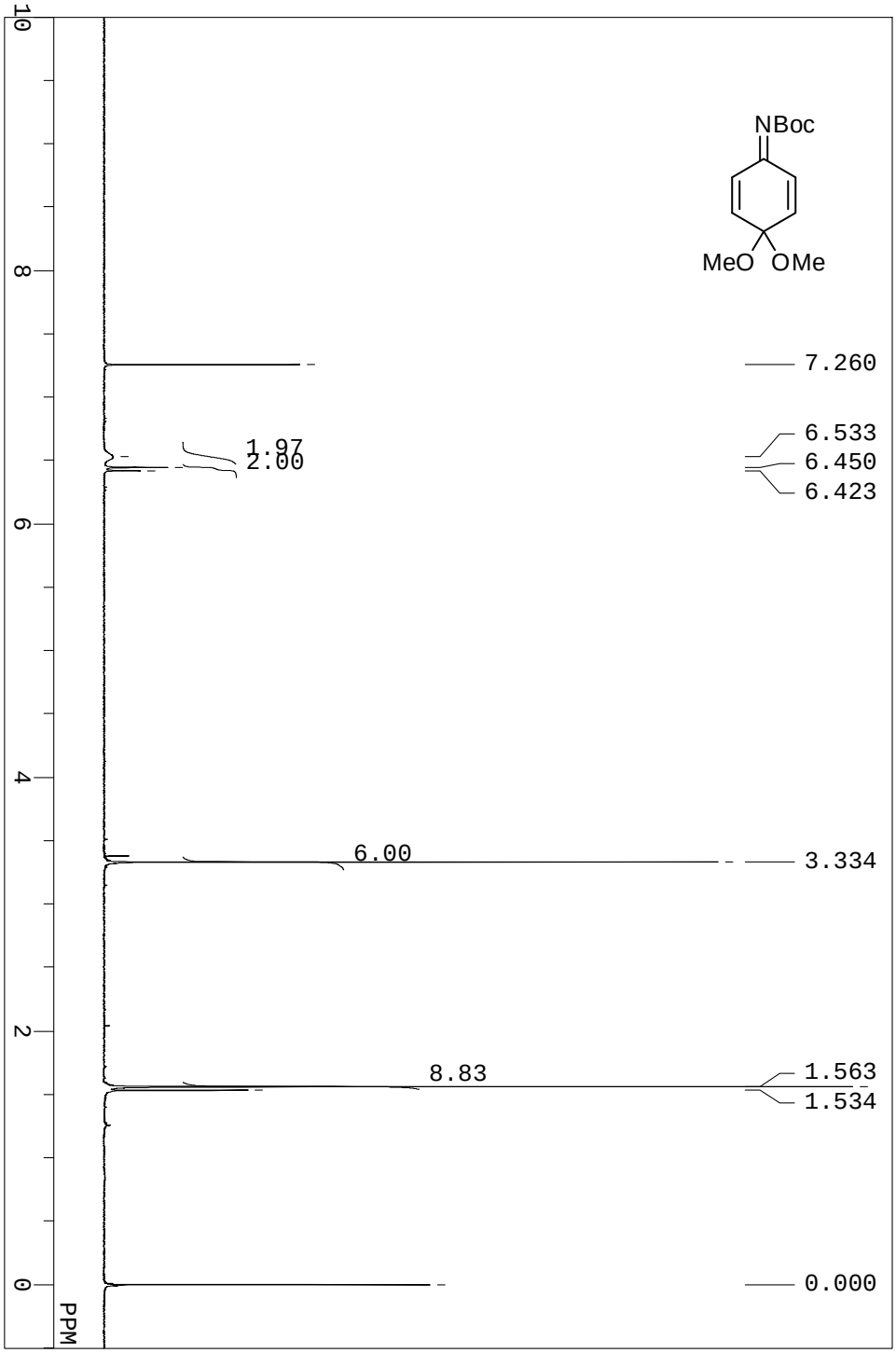
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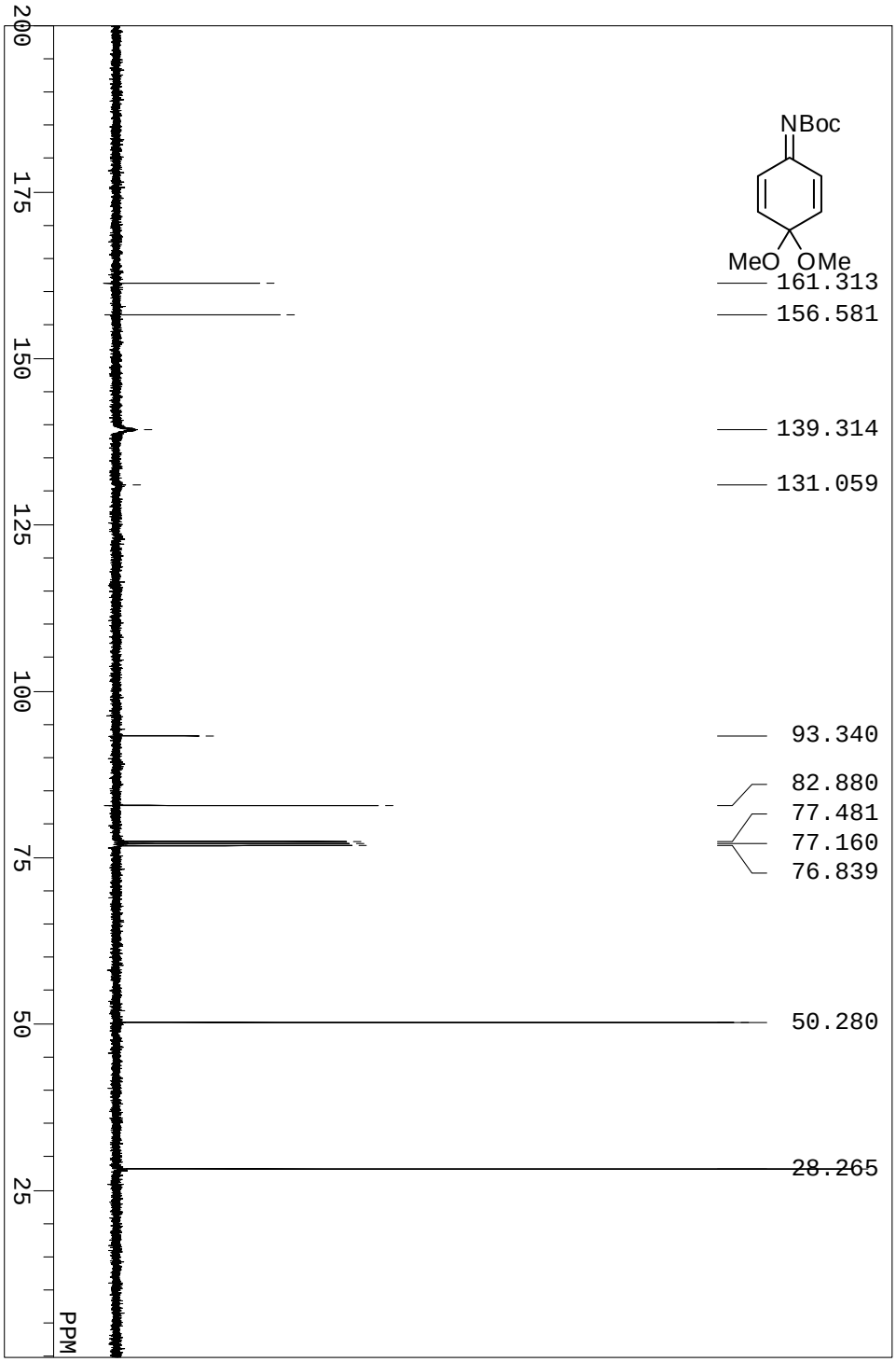
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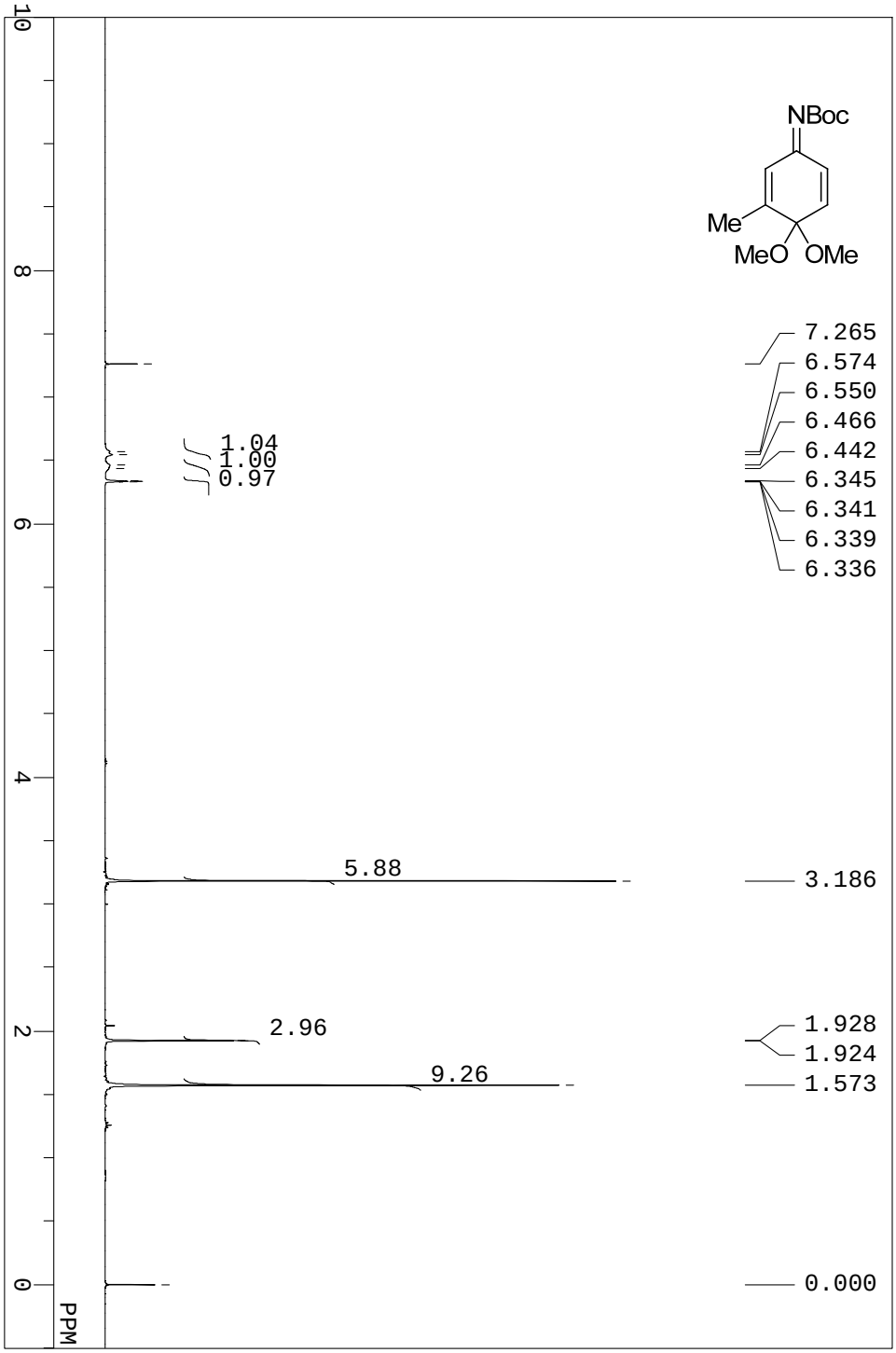
75
50
25
PPM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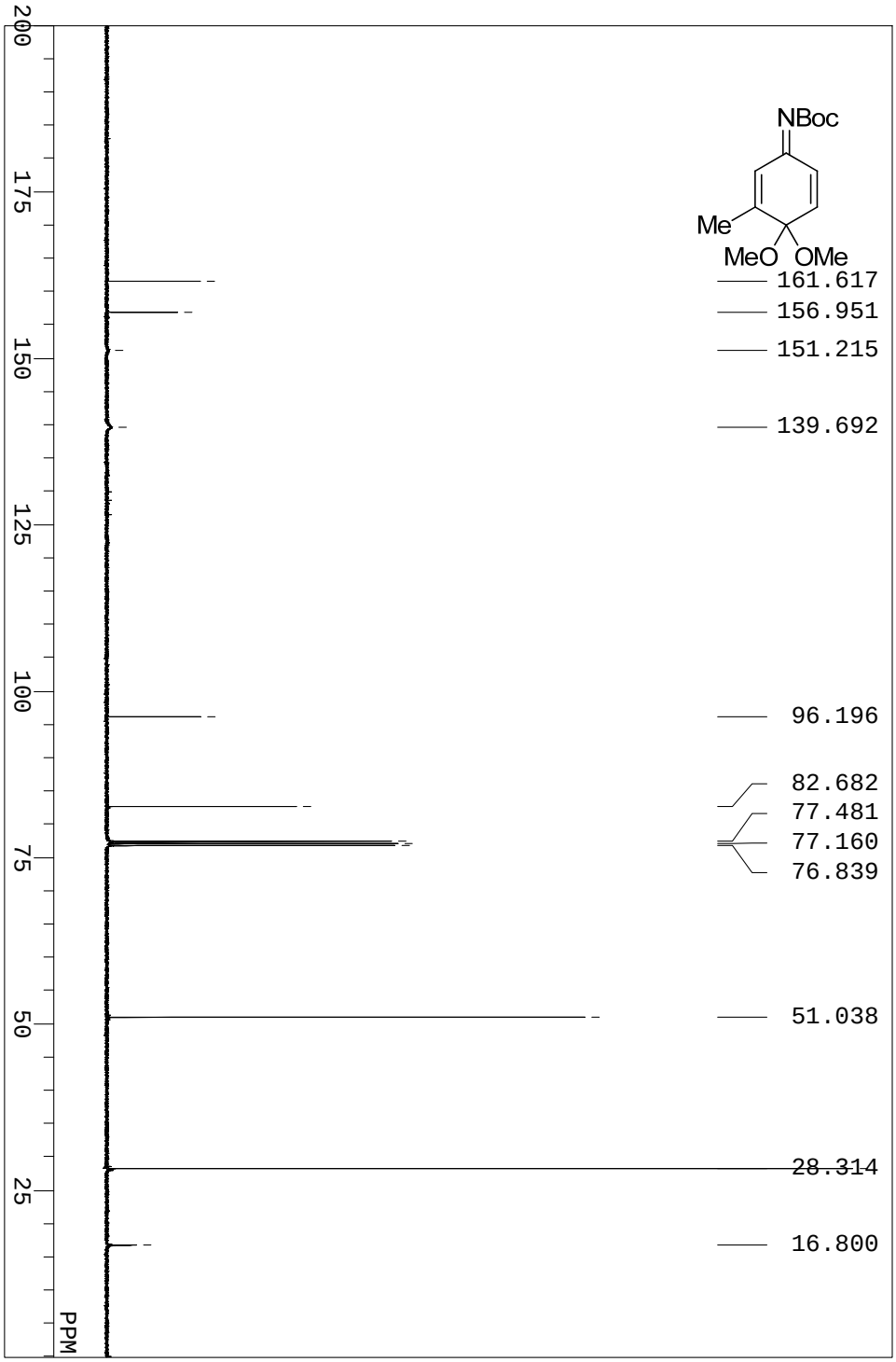
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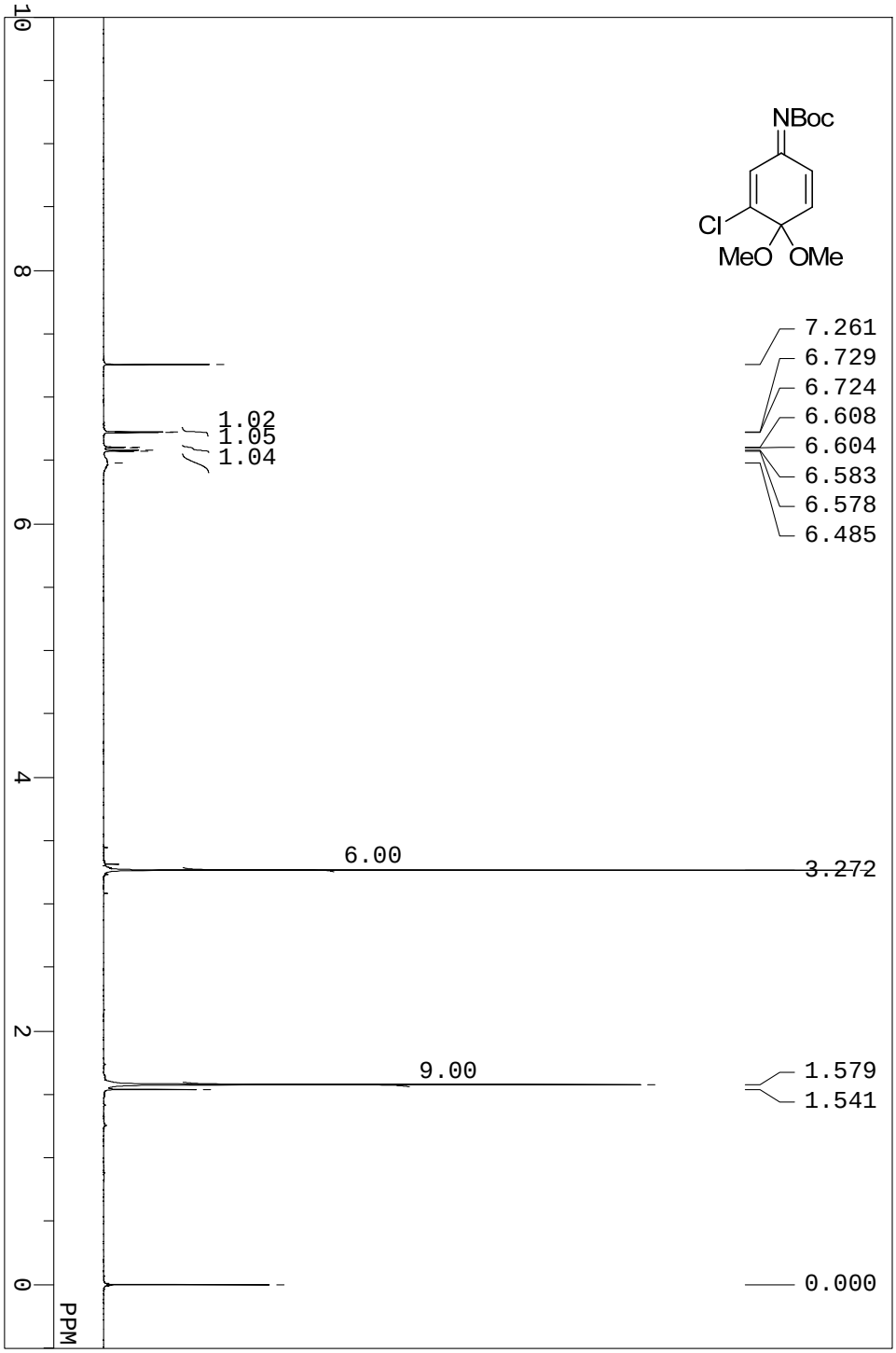
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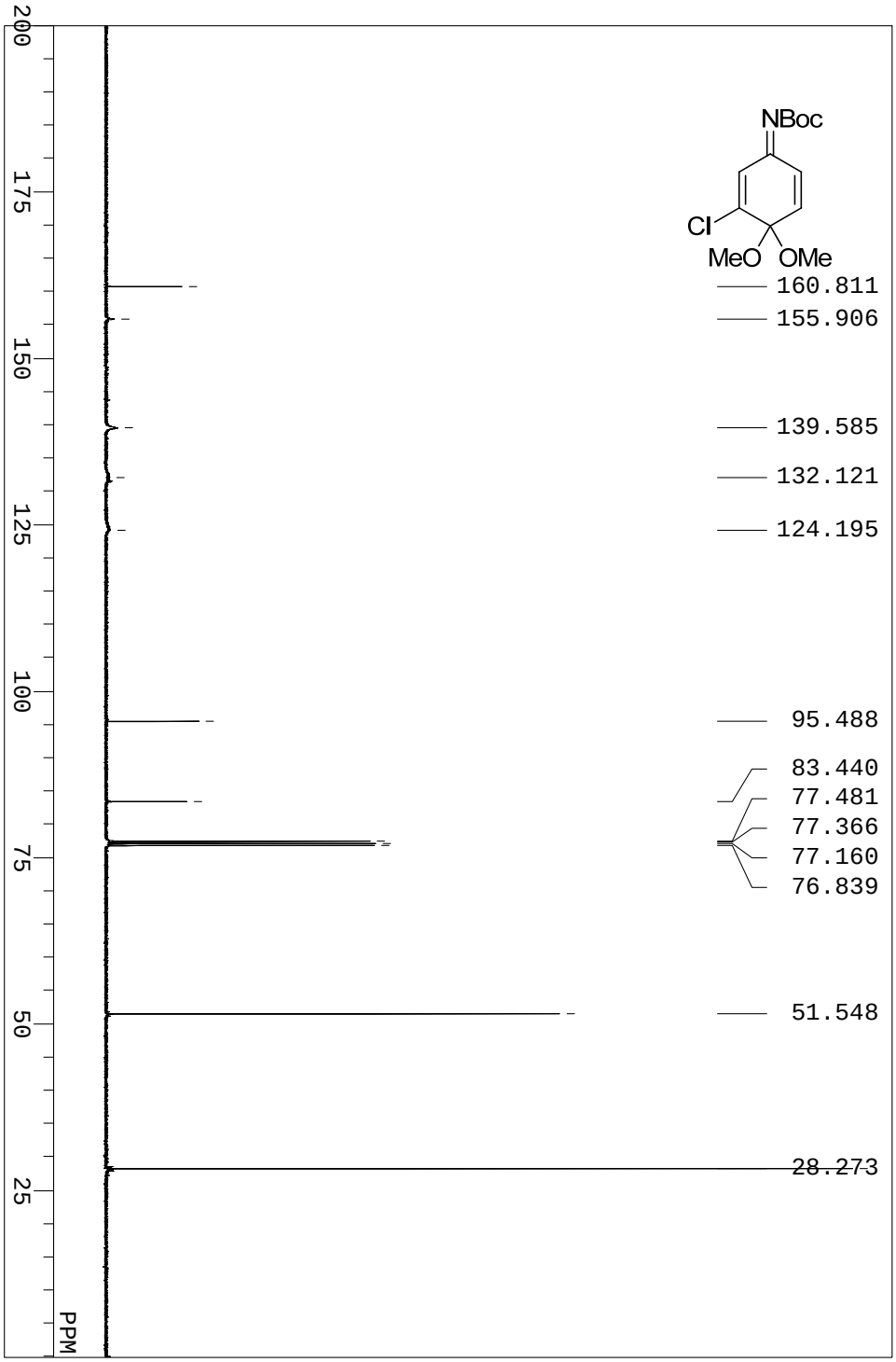
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51.548
28.273
200
175
150
125
100
75
50
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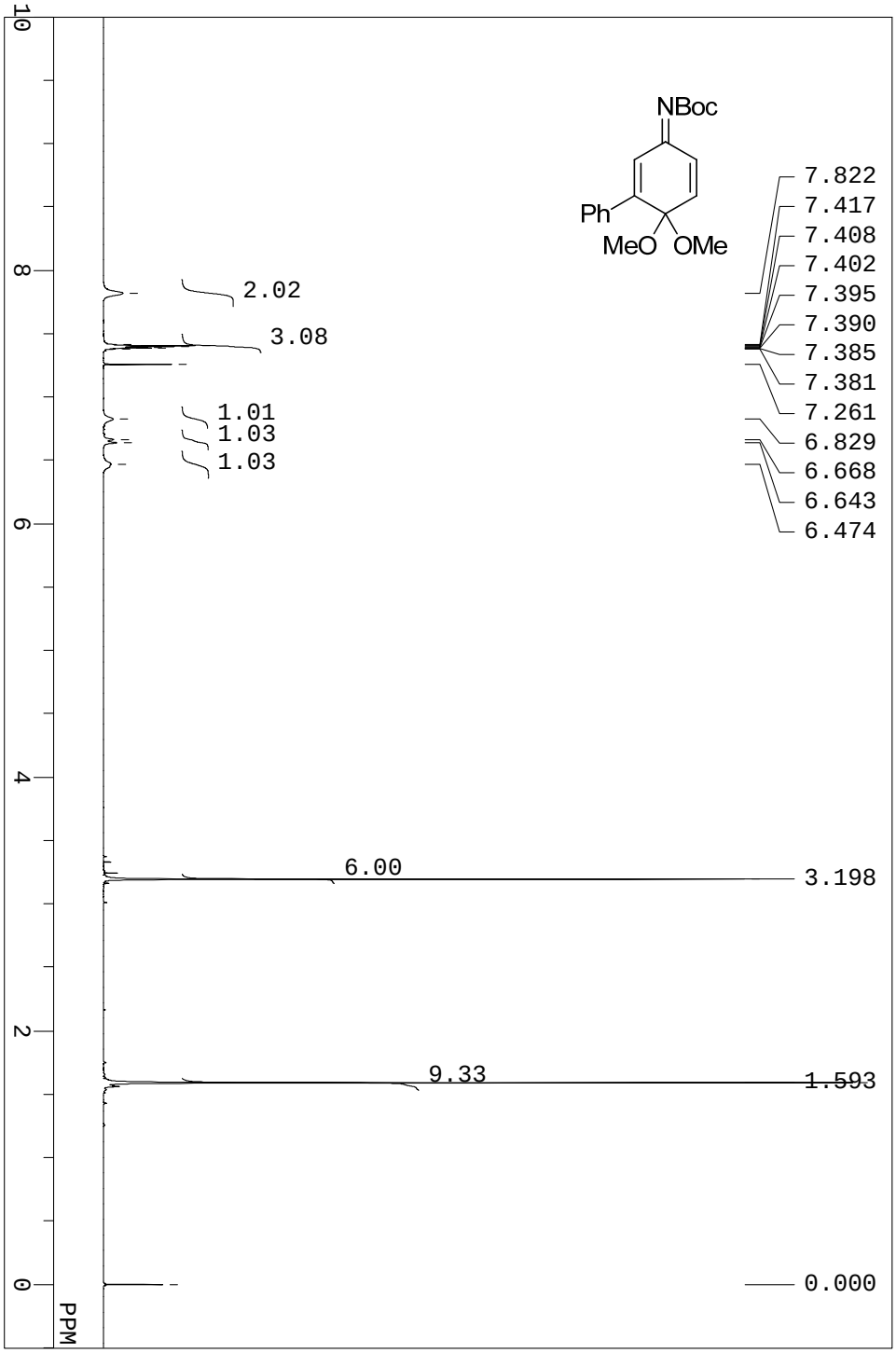
PPM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6.668
6.643
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1.03
1.03
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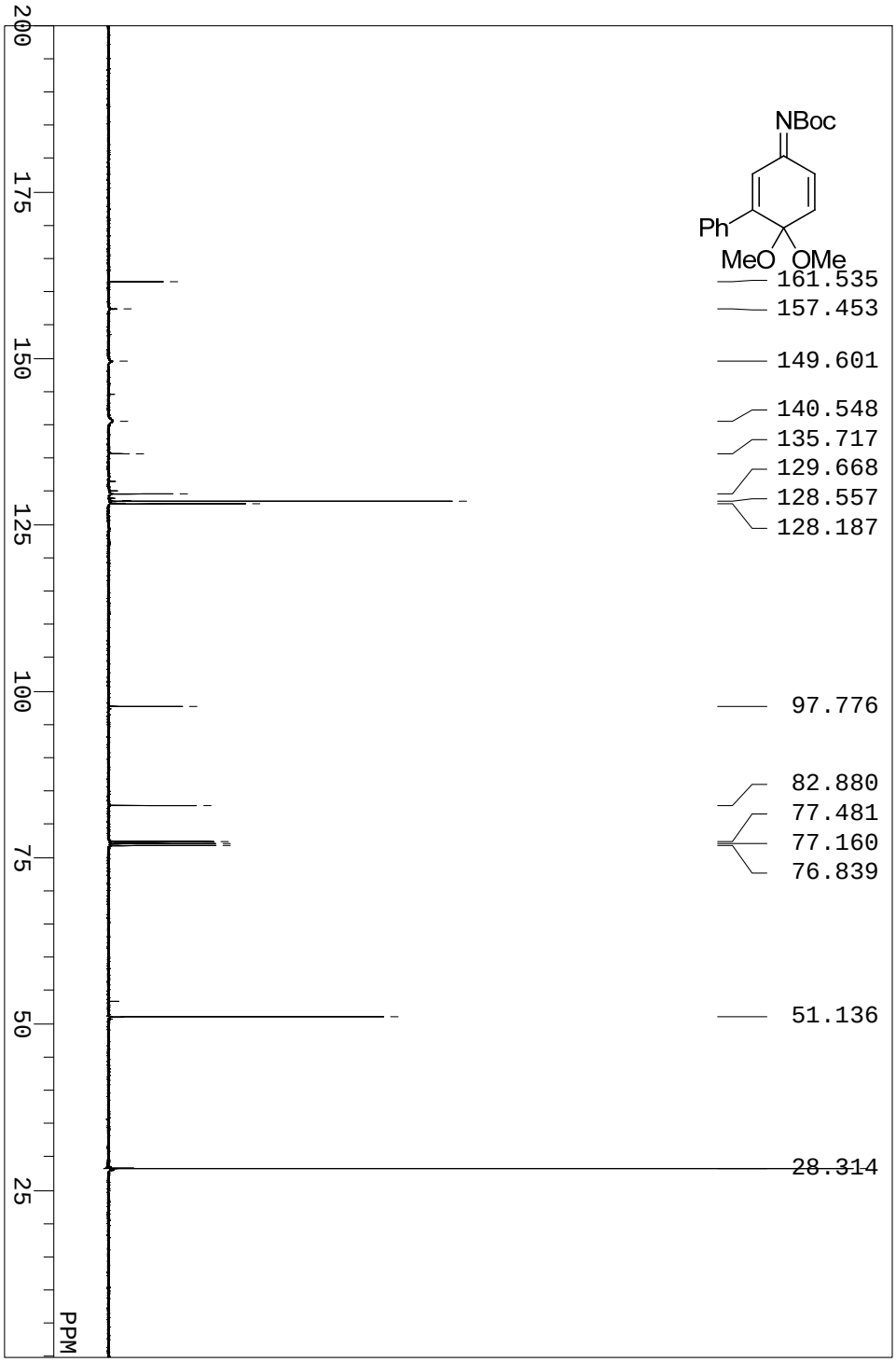
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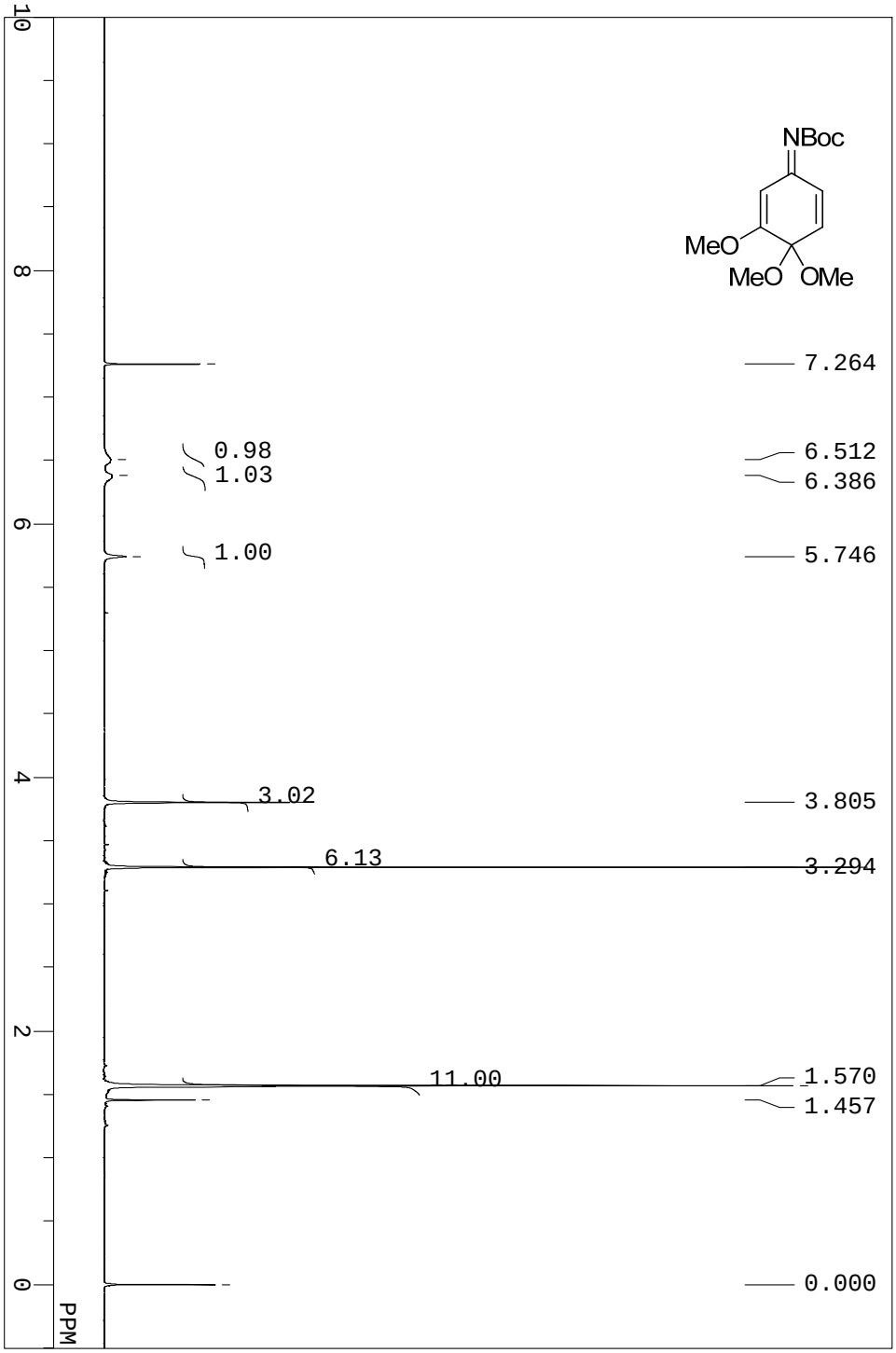
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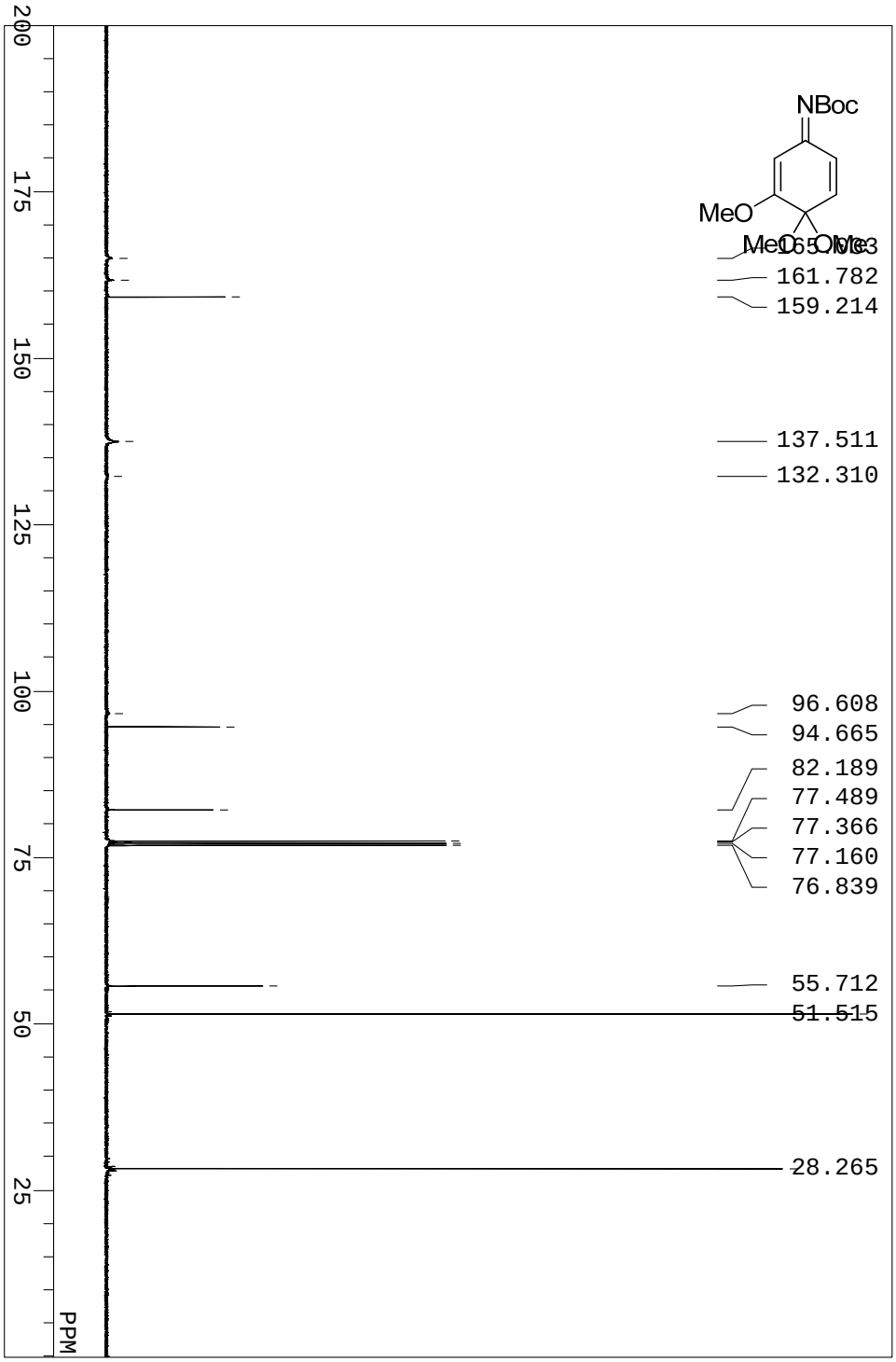
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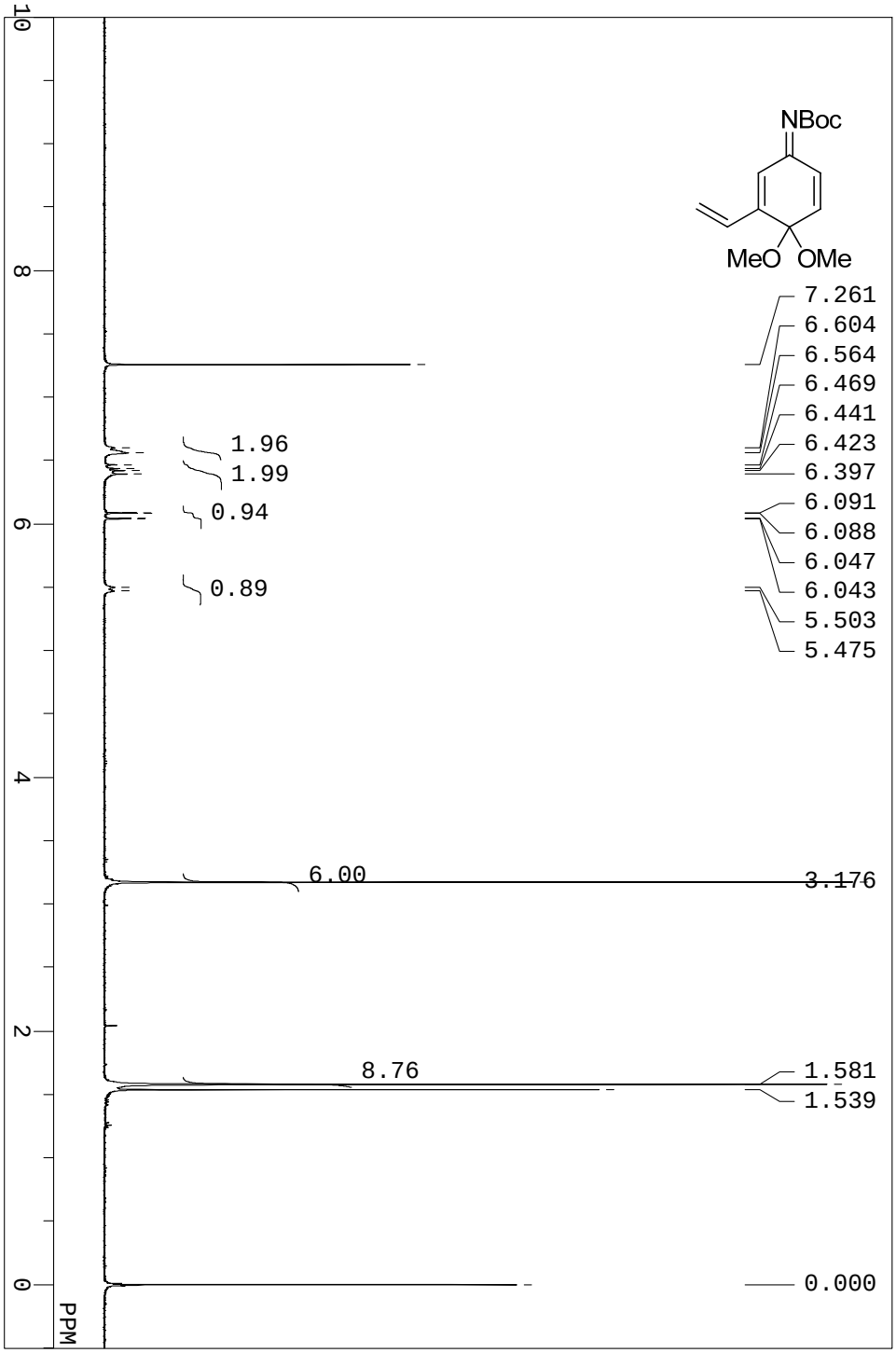
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6.423
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6.088
6.047
6.043
5.503
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8.76
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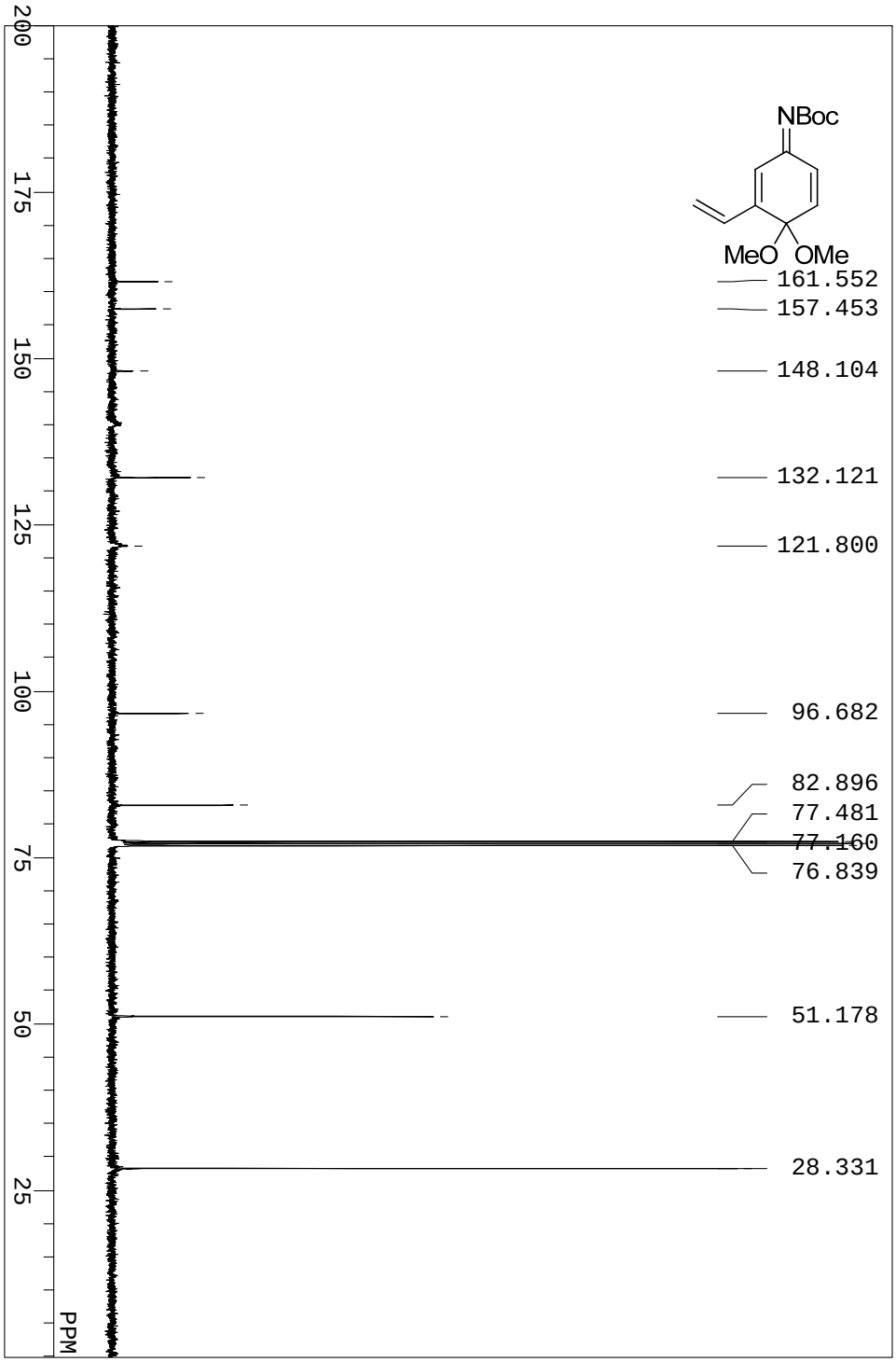
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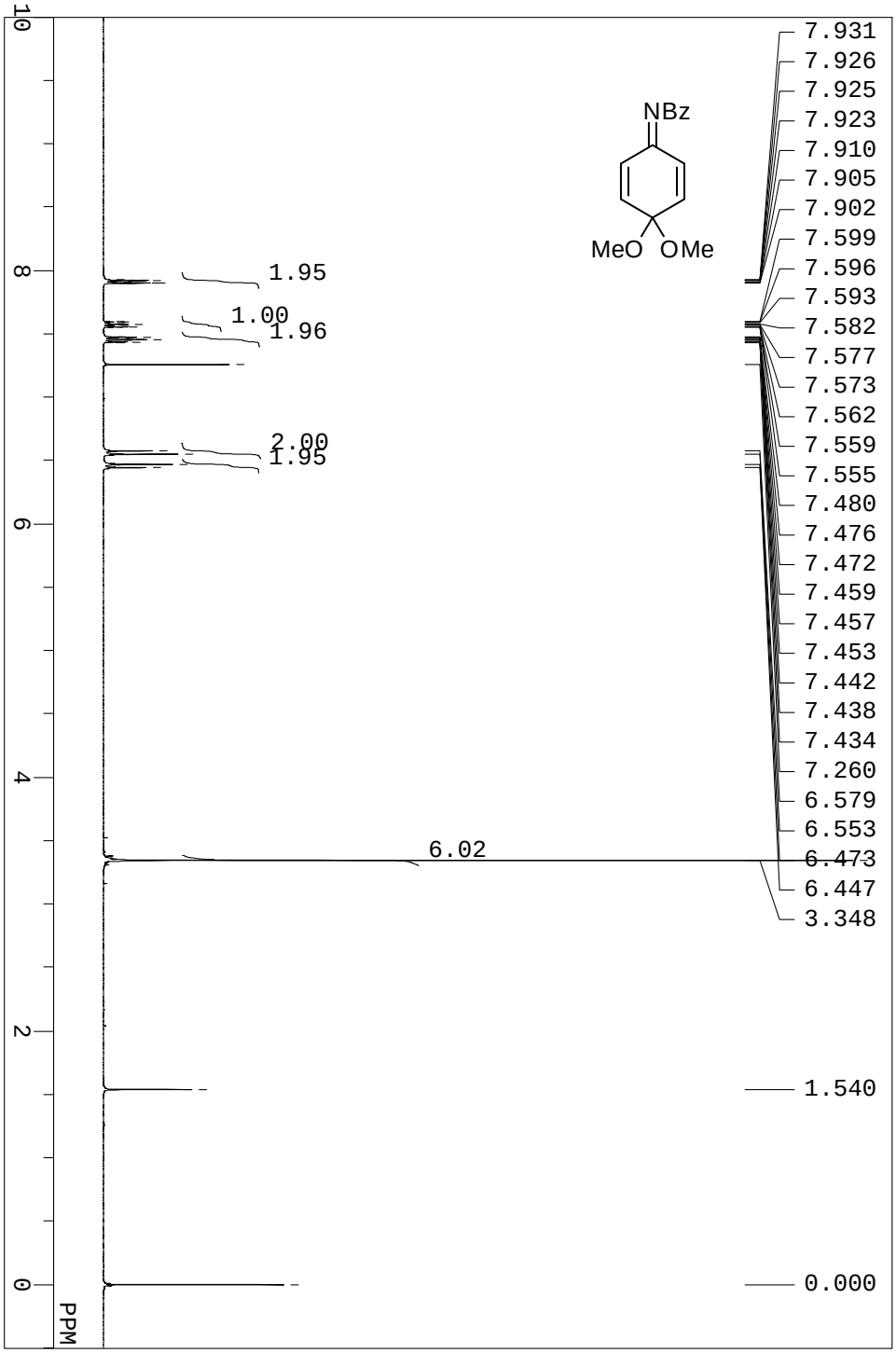
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7.923
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7.905
7.902
7.599
7.596
7.593
7.582
7.577
7.573
7.562
7.559
7.555
7.480
7.476
7.472
7.459
7.457
7.453
7.442
7.438
7.434
7.260
6.579
6.553
6.473
6.447
3.348
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1.00
1.96
2.00
1.95
6.02
10
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6
4
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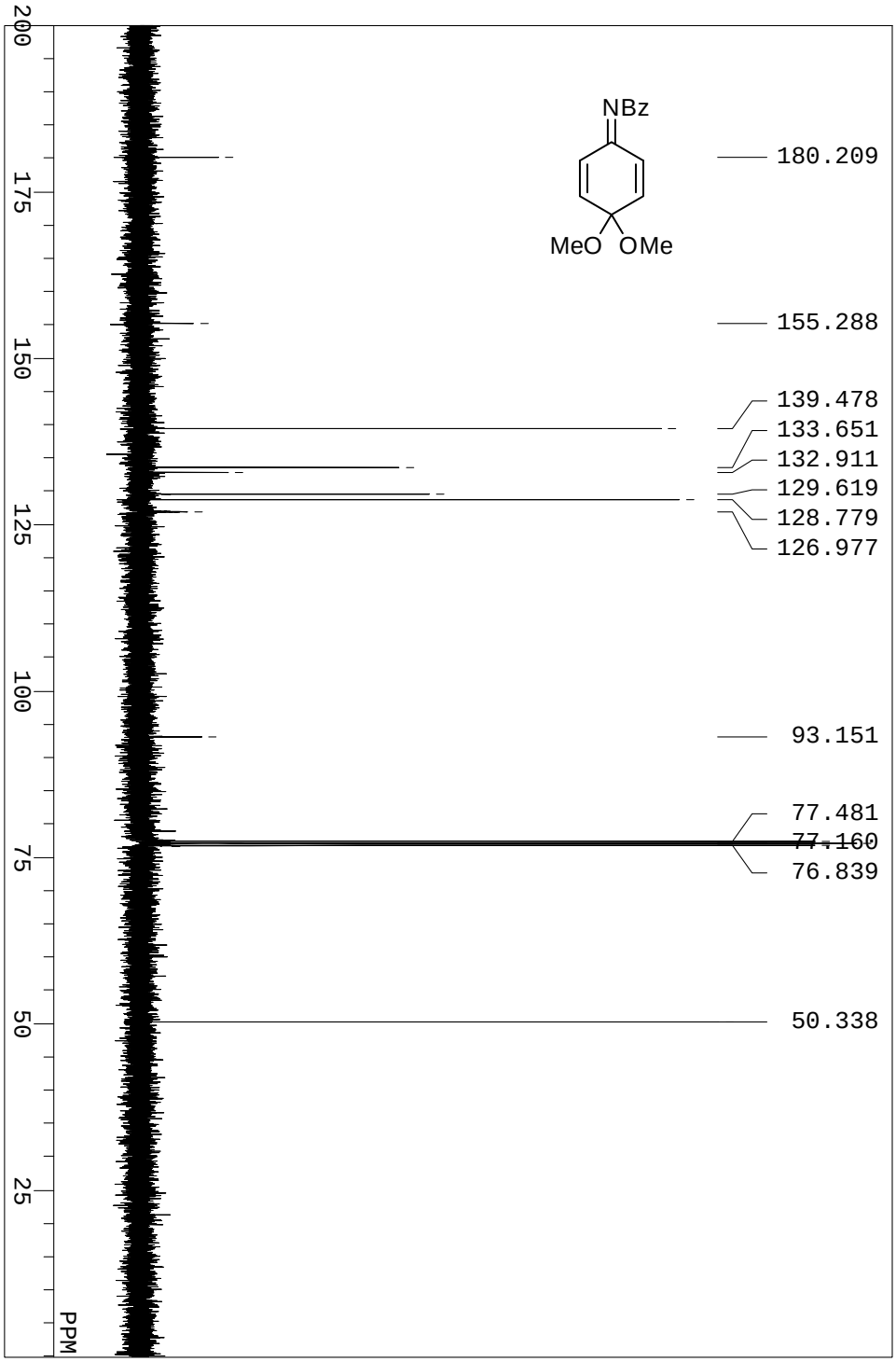
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77.160
76.839
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175
150
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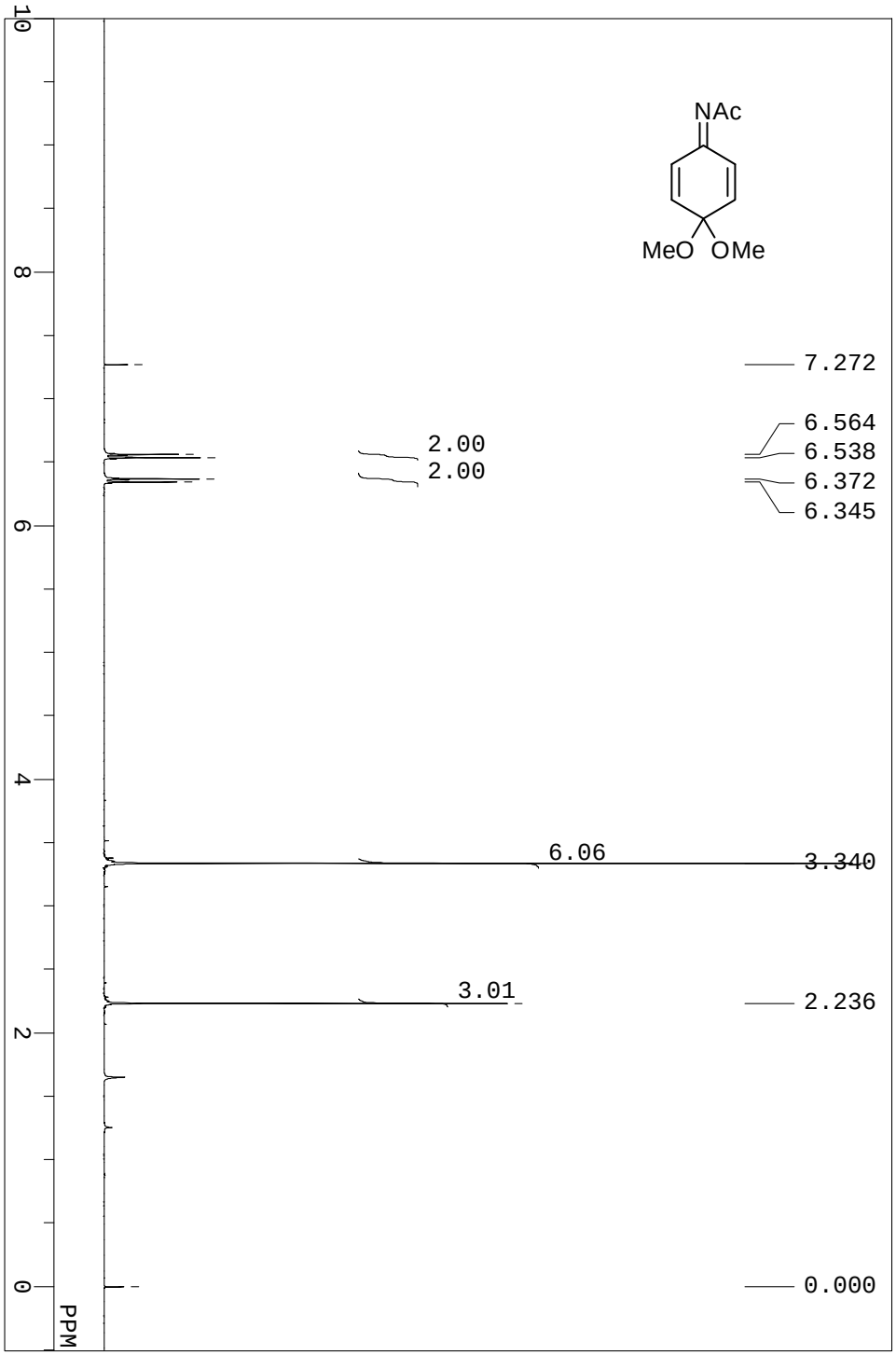
75
50
25
PPM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6.372
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6.06
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2.236
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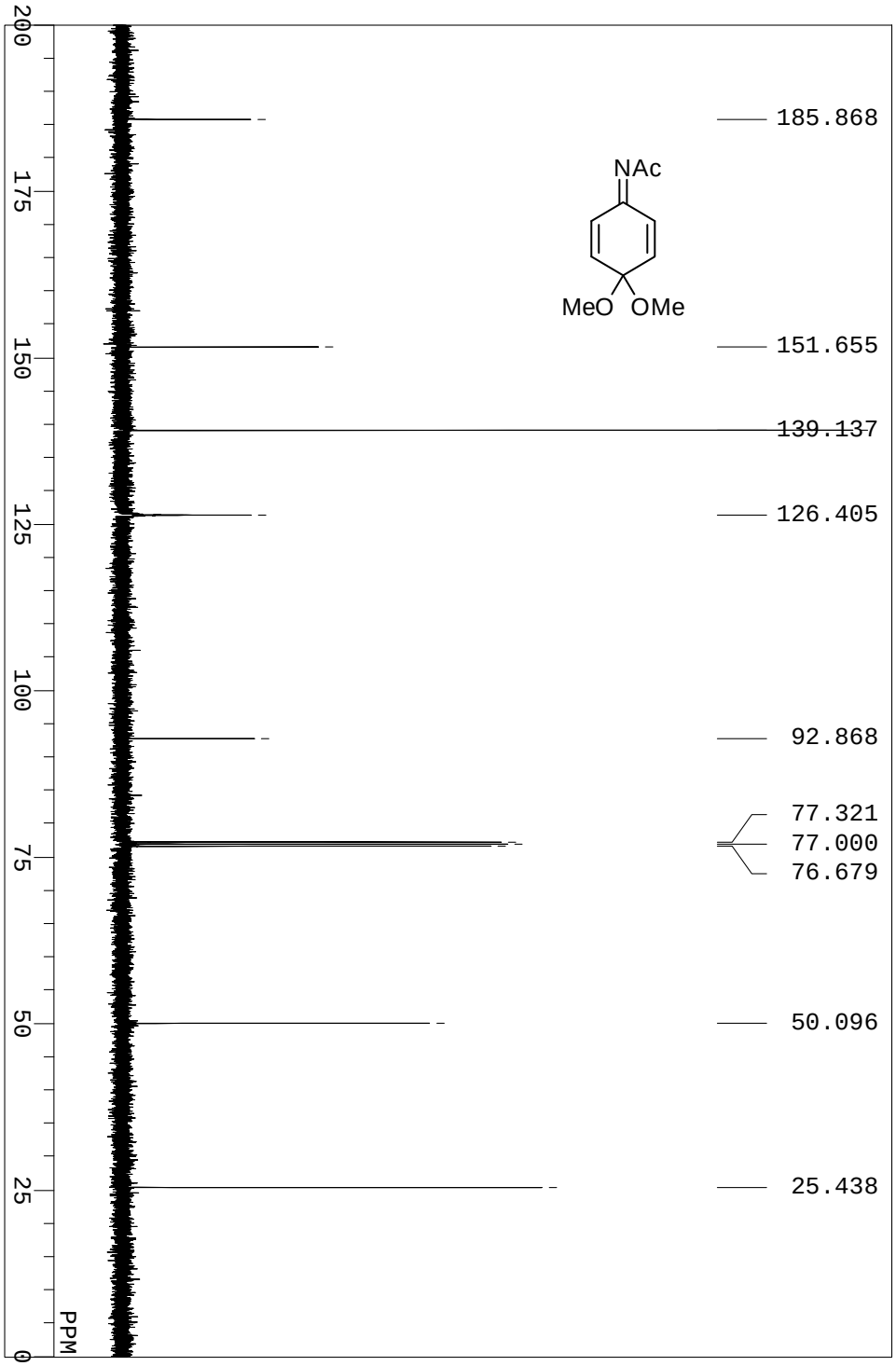
8
6
4
2
0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175
150
125
100
75
50
25
0
PPM
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OMe
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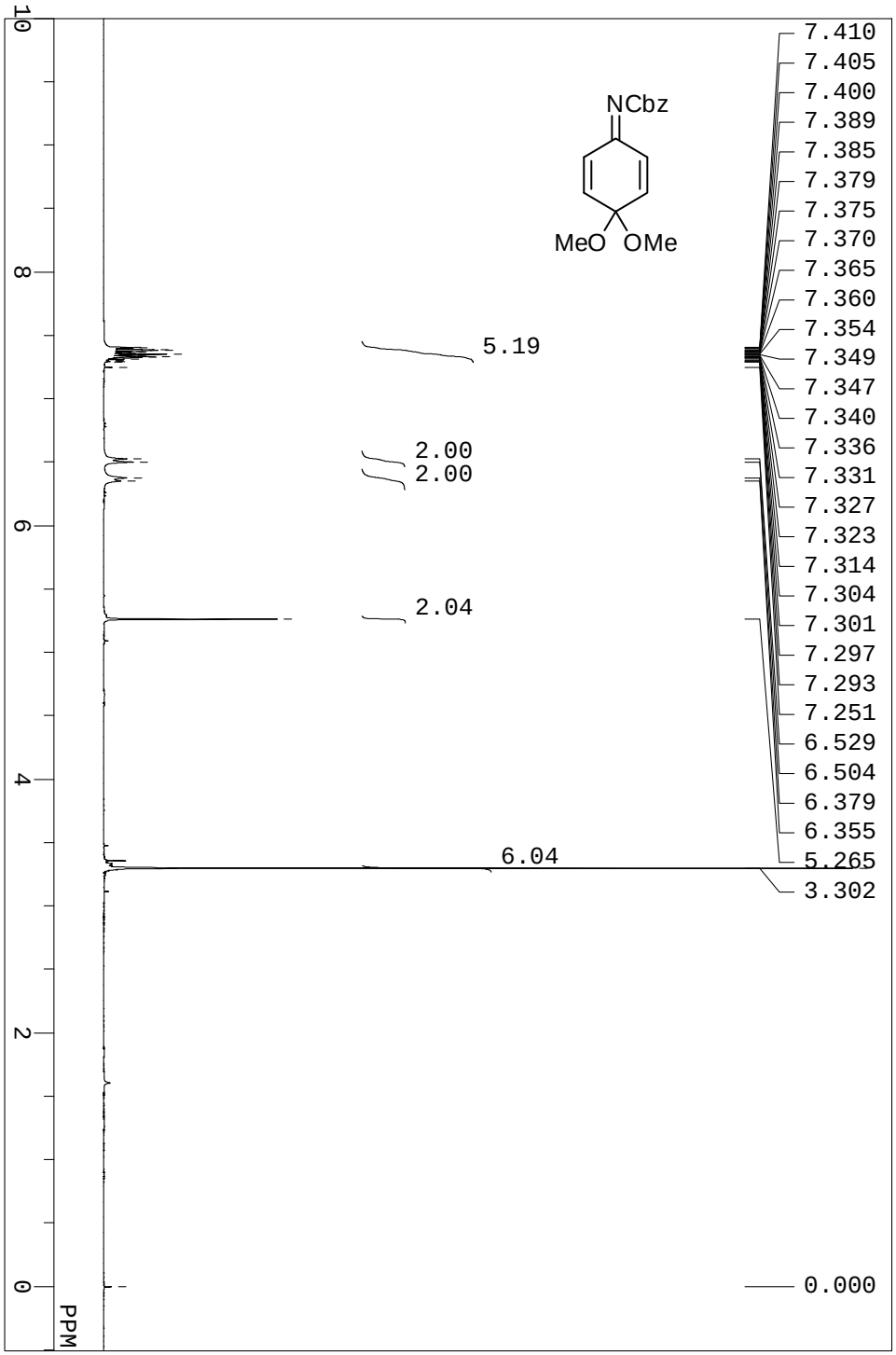
77.000
76.679
50.096
25.438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6.04
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7.405
7.400
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7.385
7.379
7.375
7.370
7.365
7.360
7.354
7.349
7.347
7.340
7.336
7.331
7.327
7.323
7.314
7.304
7.301
7.297
7.293
7.251
6.529
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6.379
6.355
5.265
3.302
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10
8
6
4
2
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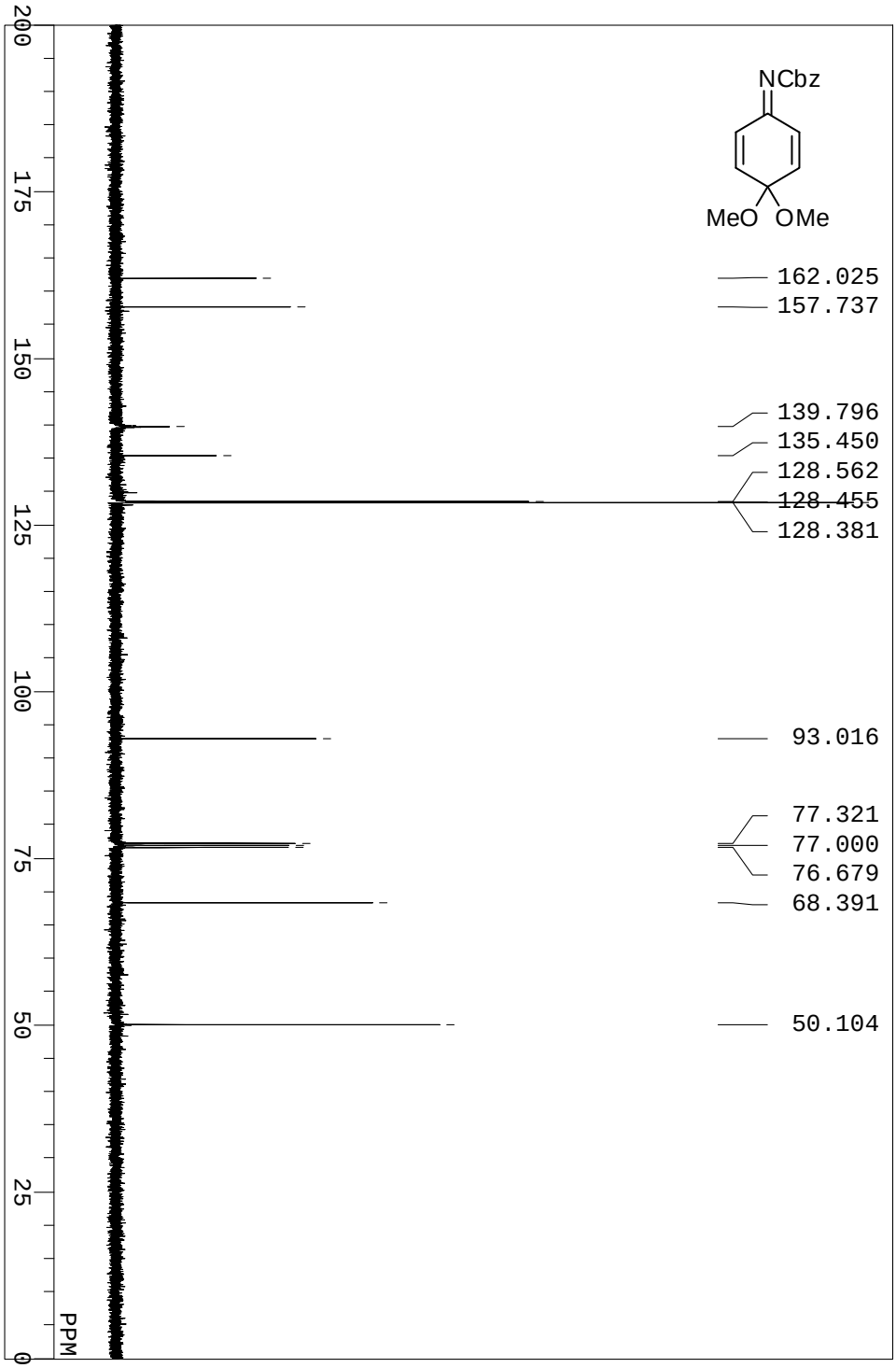
PPM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150
125
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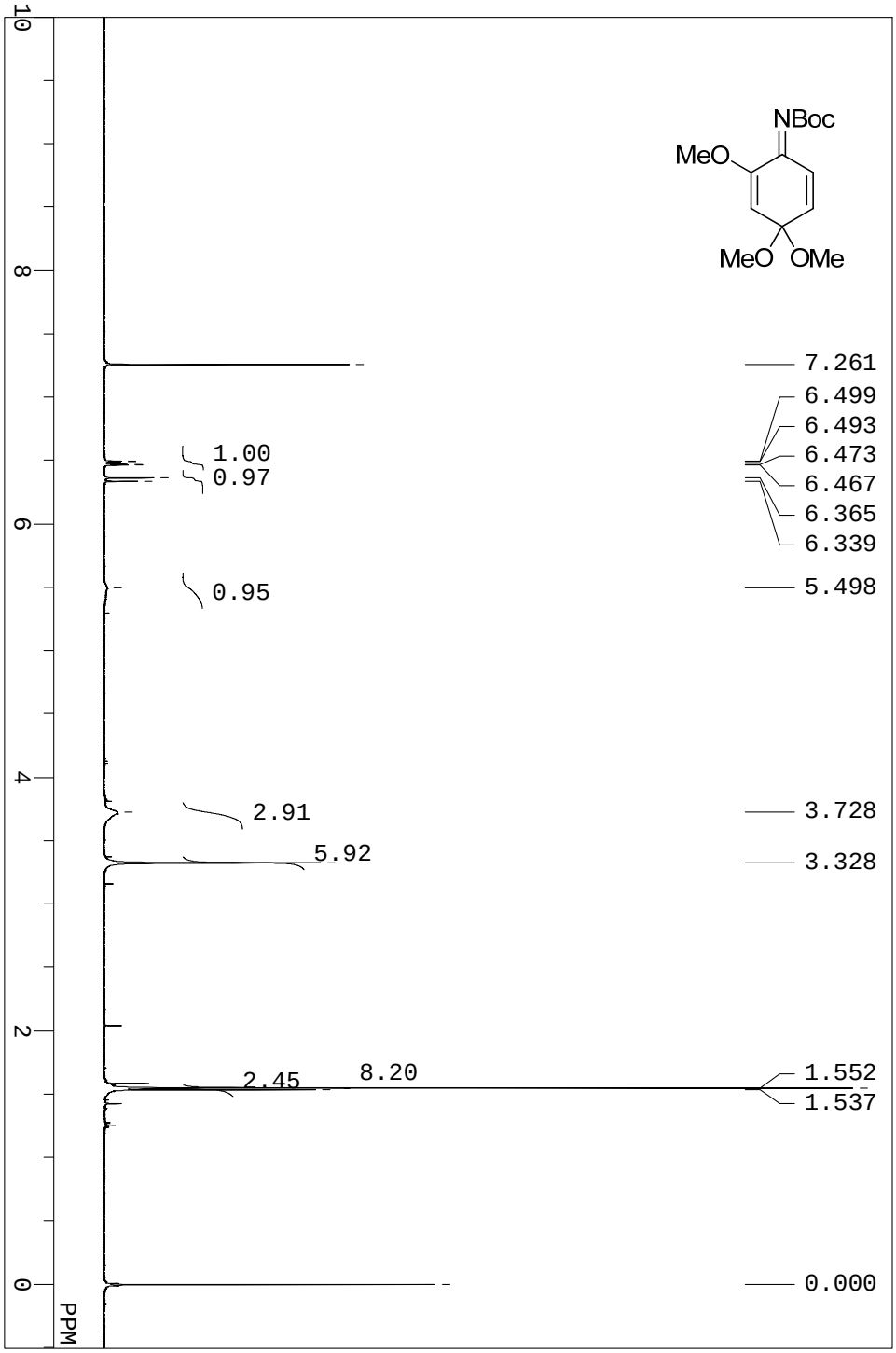
50
25
0
PPM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6.473
6.467
6.365
6.339
5.498
3.728
3.328
1.552
1.537
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0.95
2.91
5.92
2.45
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4
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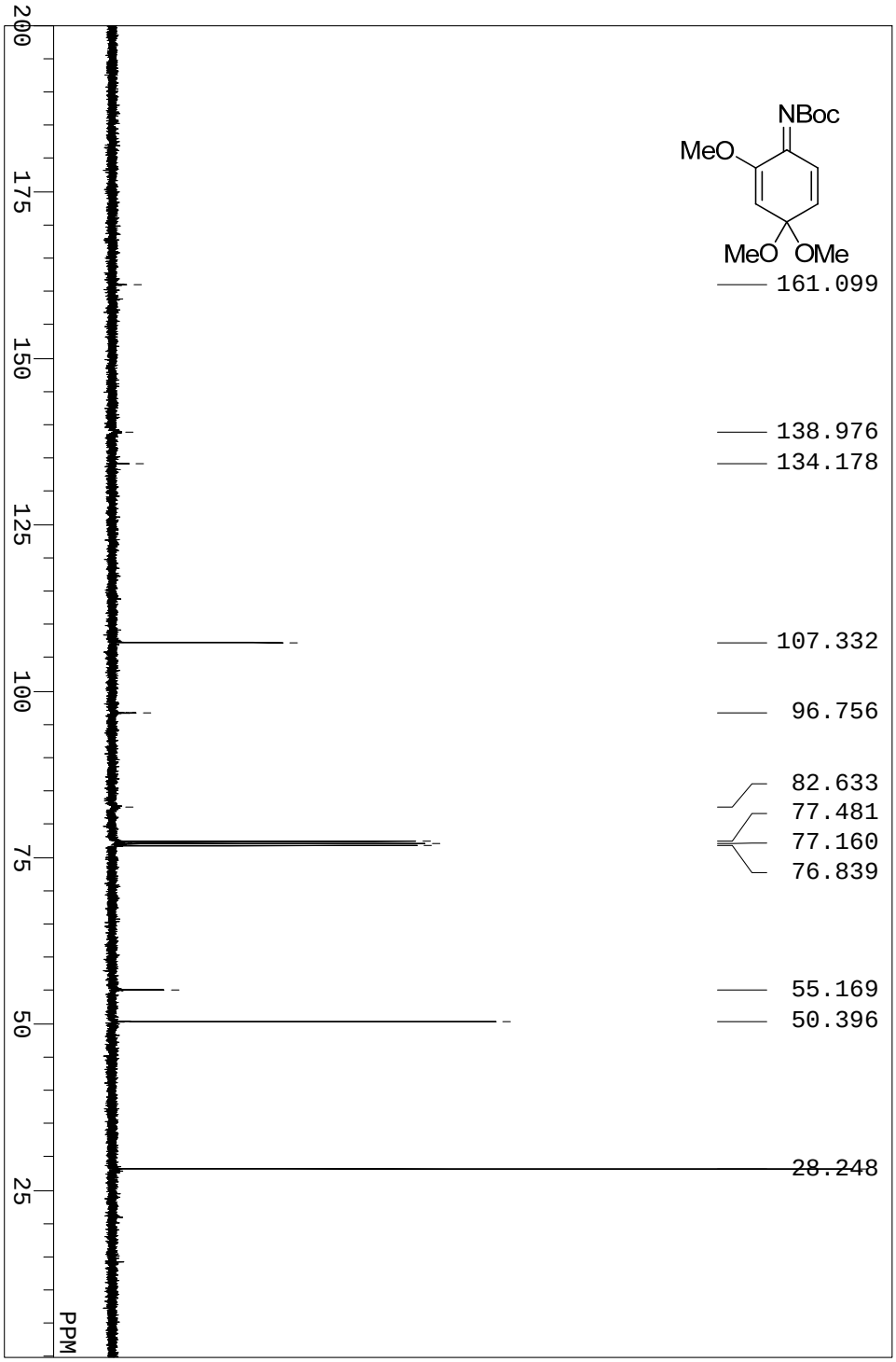
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OMe
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76.839
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150
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75
50
25
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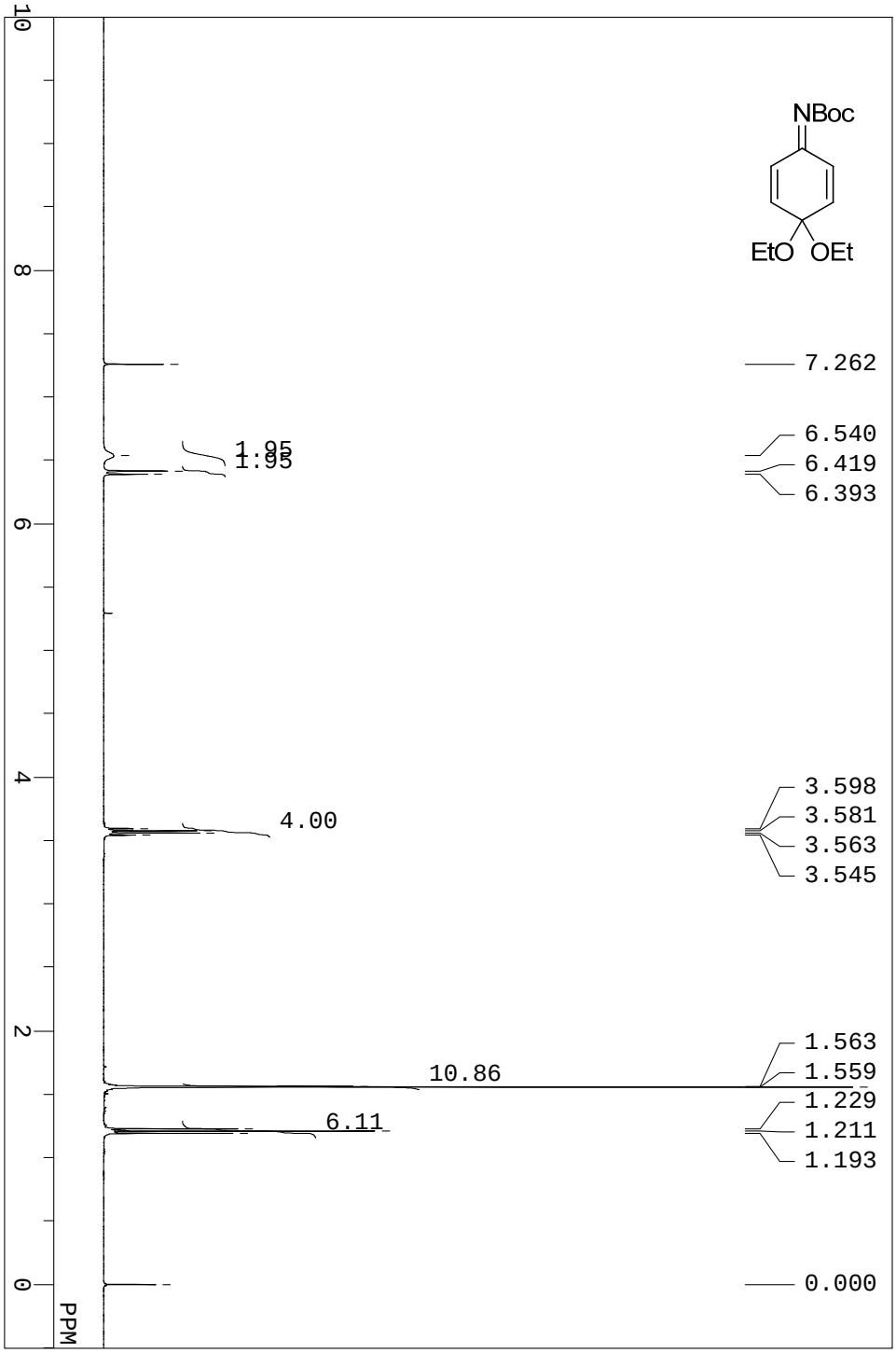
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3.581
3.563
3.545
1.563
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1.229
1.211
1.193
6.11
0.000
PPM
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8
6
4
2
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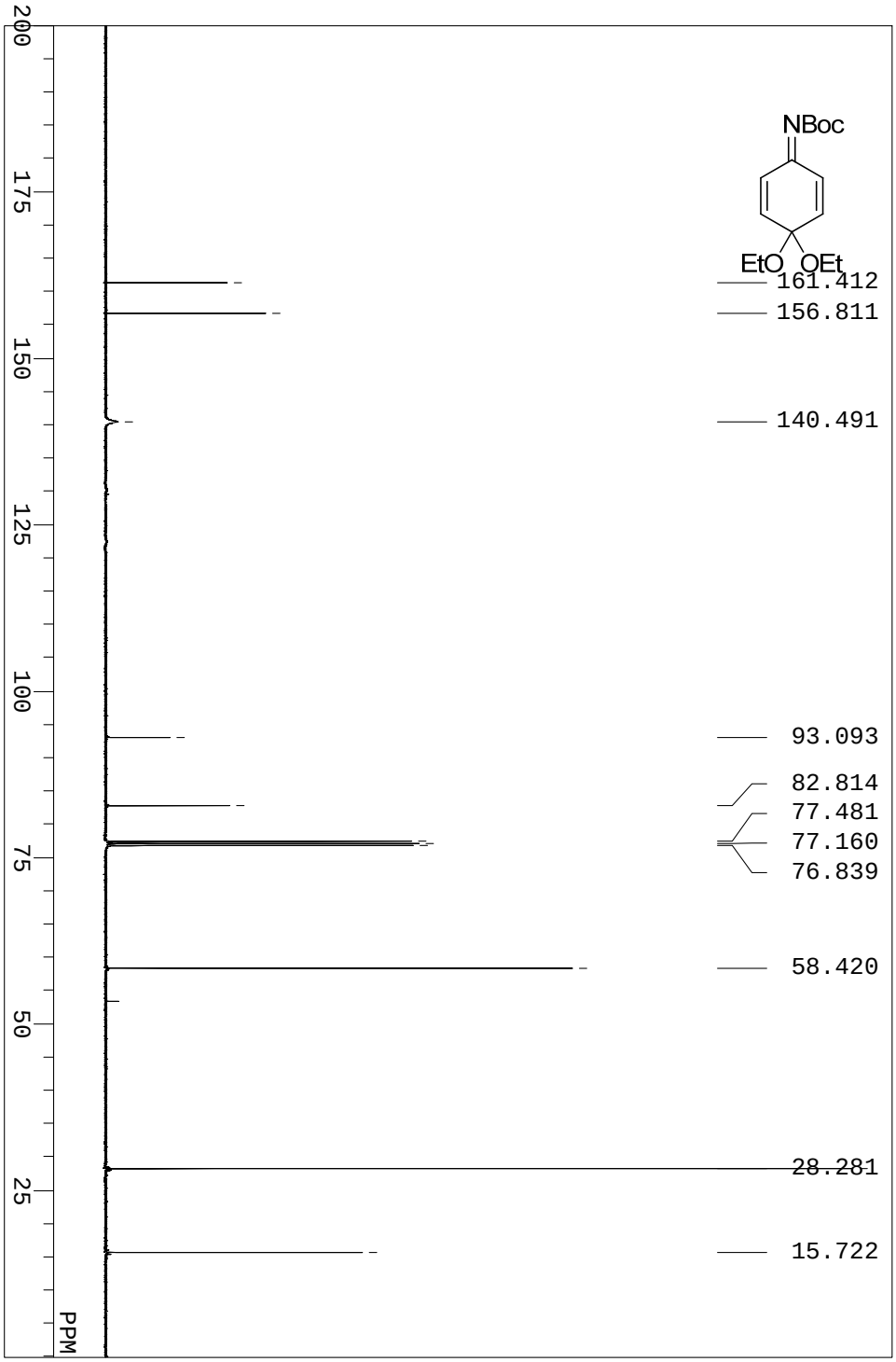
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75
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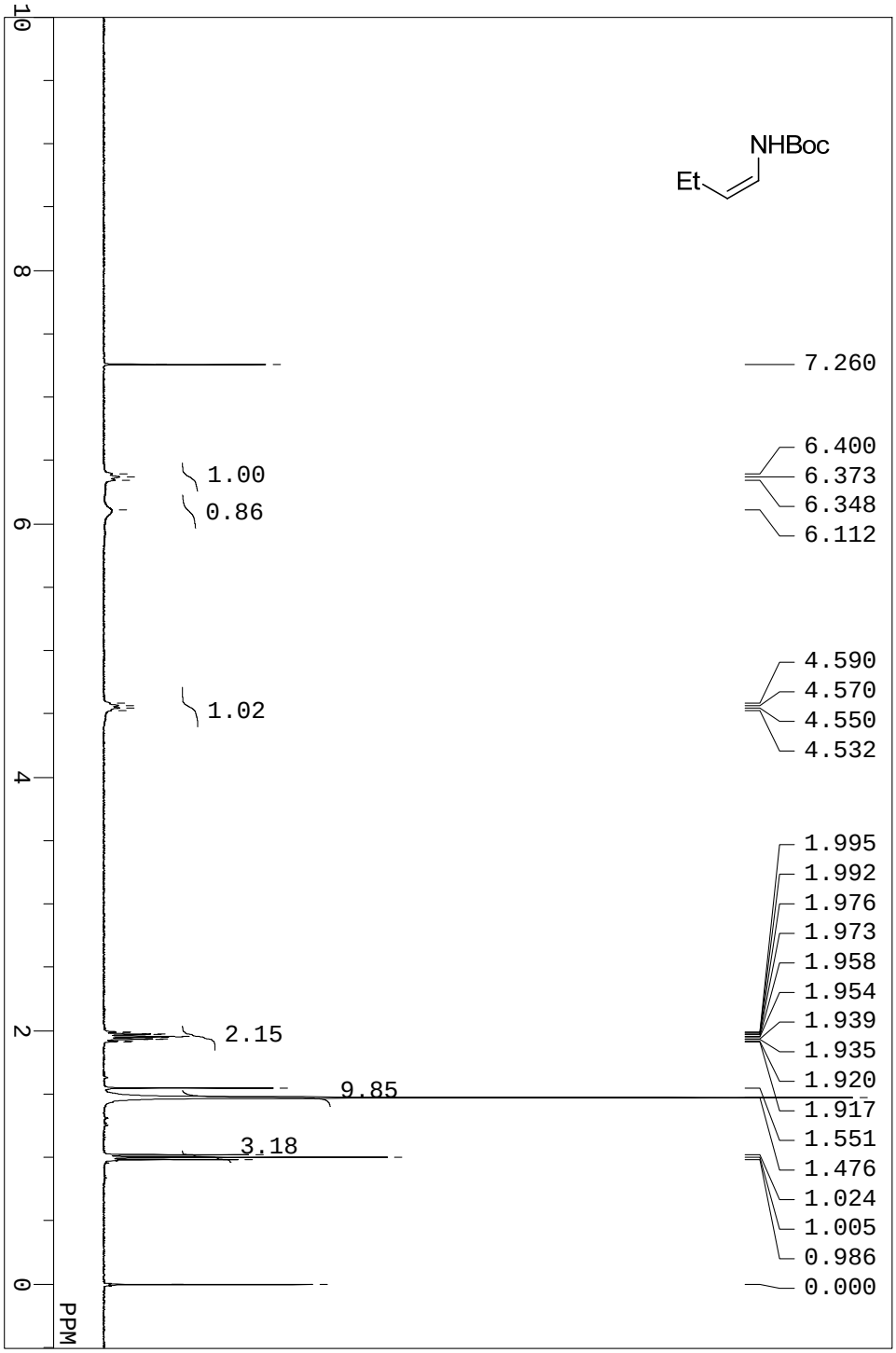
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6.373
6.348
6.112
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4.570
4.550
4.532
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1.992
1.976
1.973
1.958
1.954
1.939
1.935
1.920
1.917
1.551
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1.005
0.986
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1.00
0.86
1.02
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9.85
3.18
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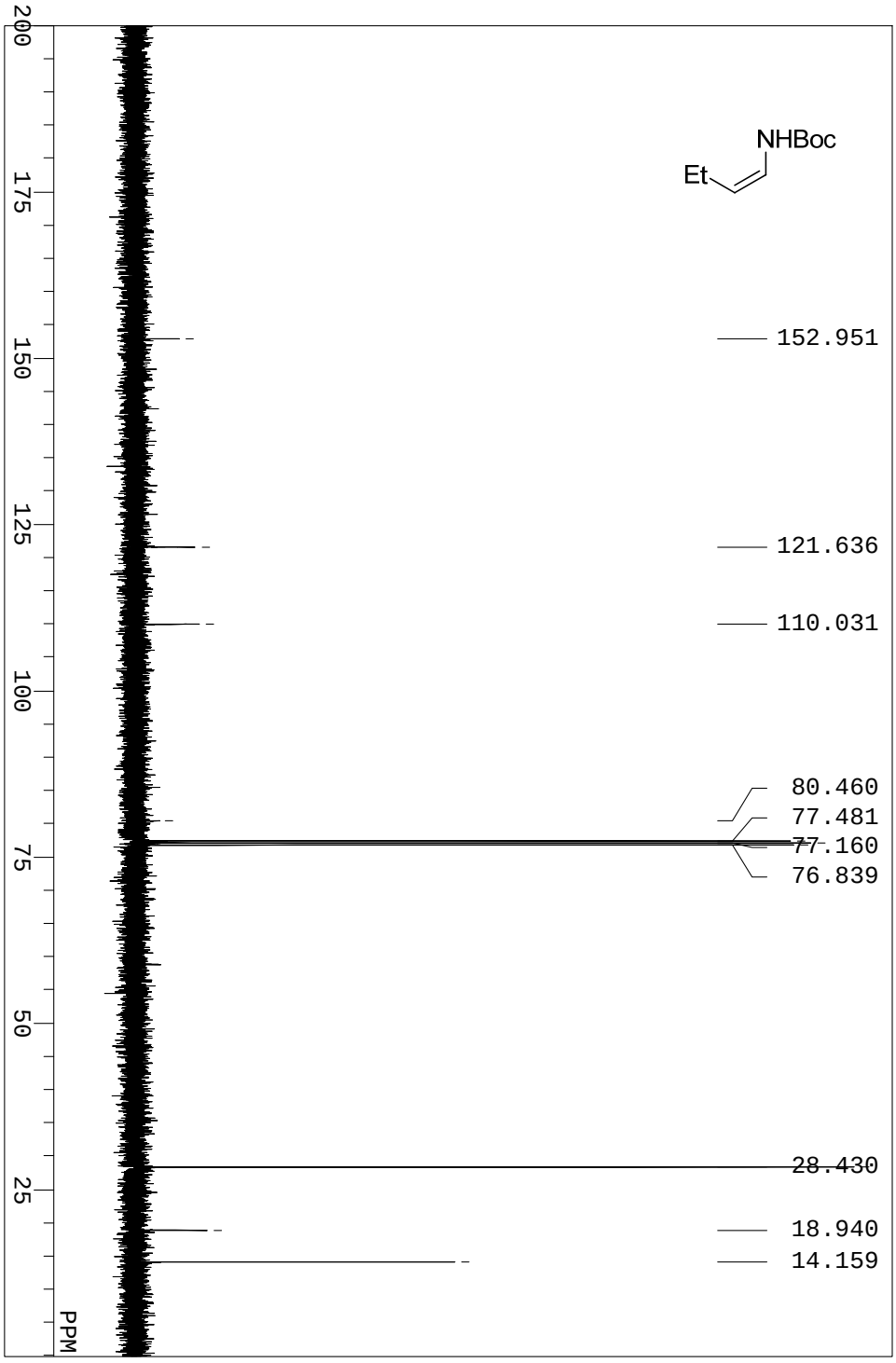
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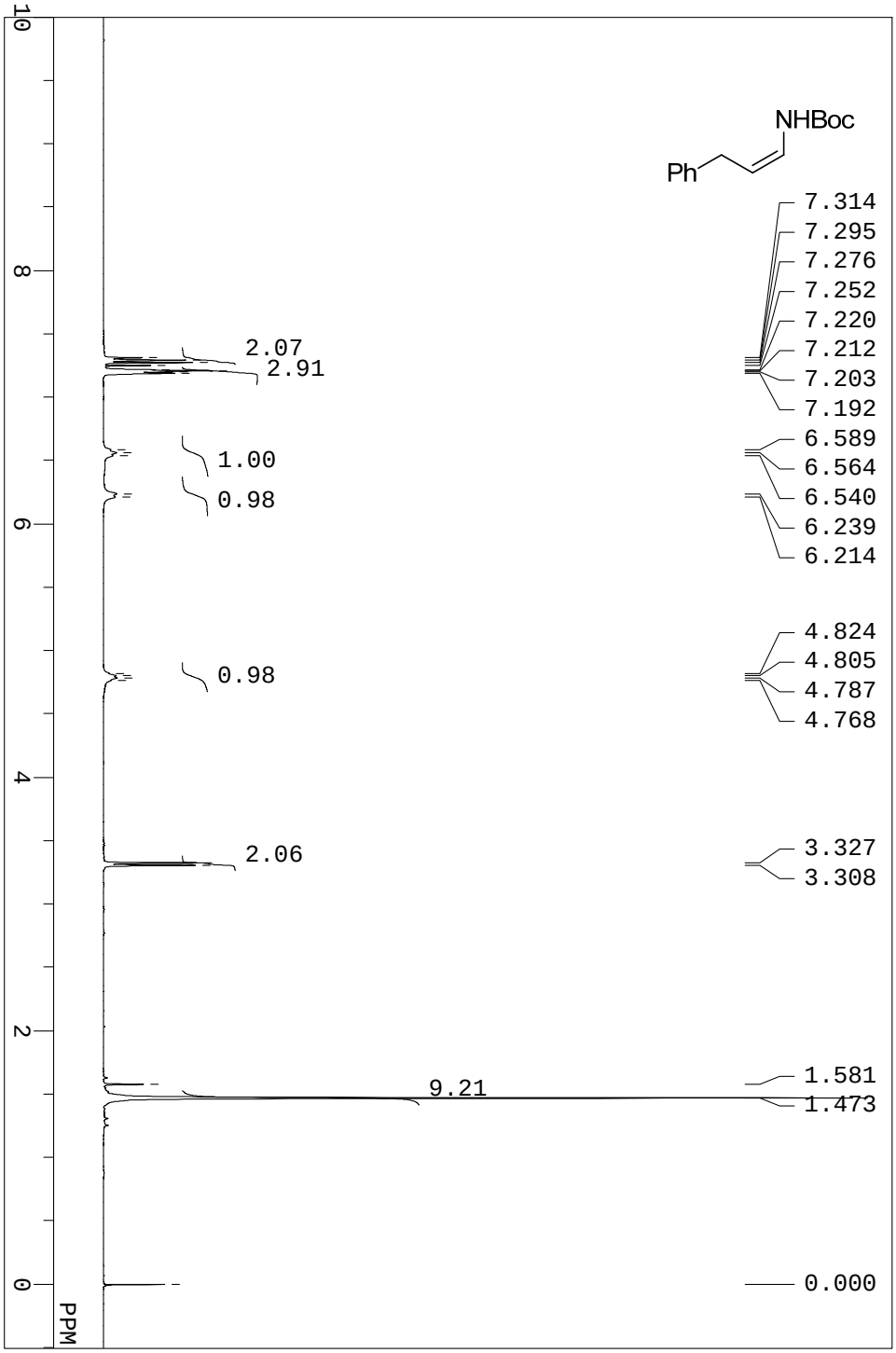
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7.203
7.192
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6.564
6.540
6.239
6.214
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4.805
4.787
4.768
3.327
3.308
1.581
1.473
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0.98
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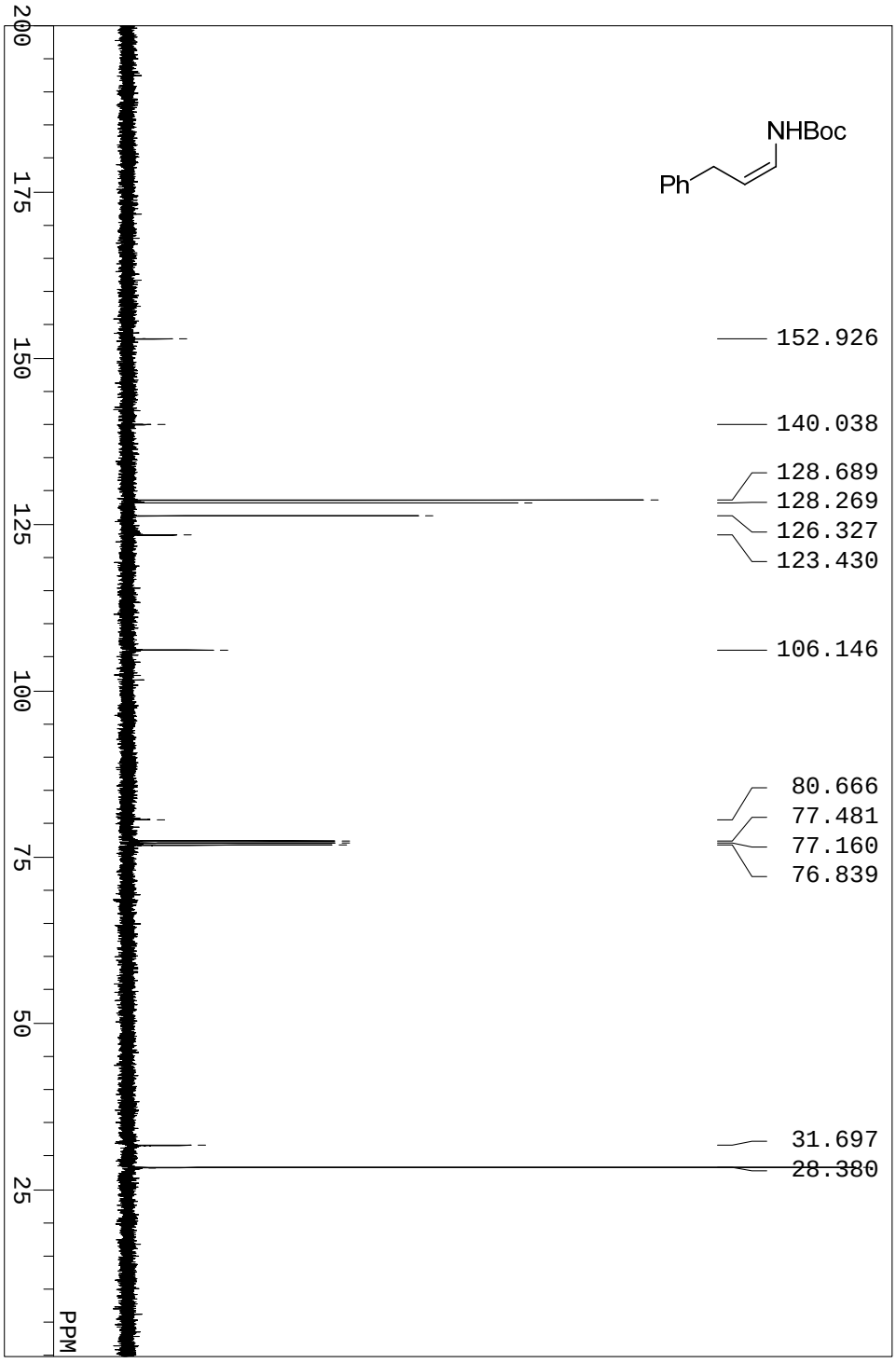
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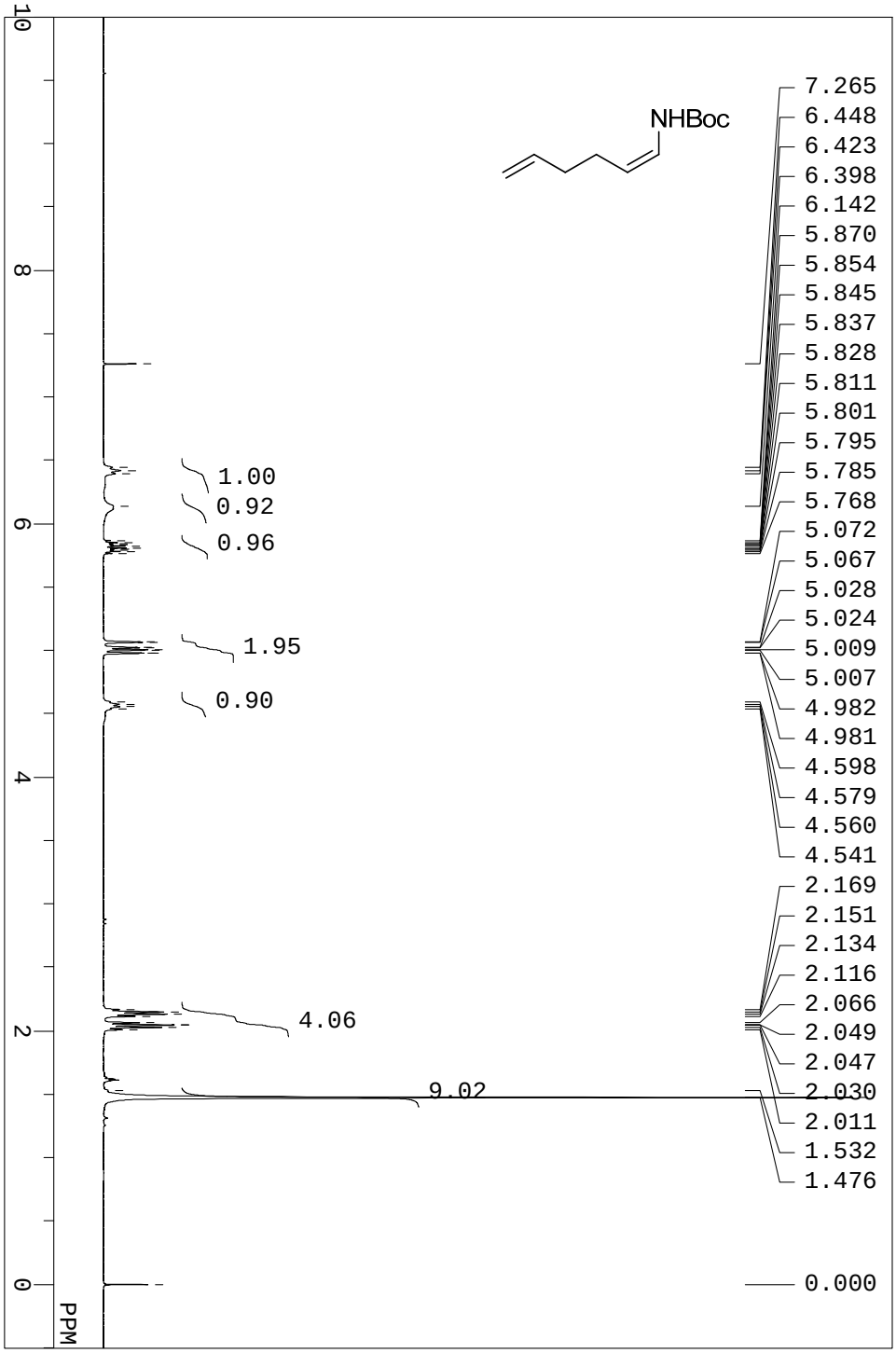
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5.795
5.785
5.768
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5.009
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2.047
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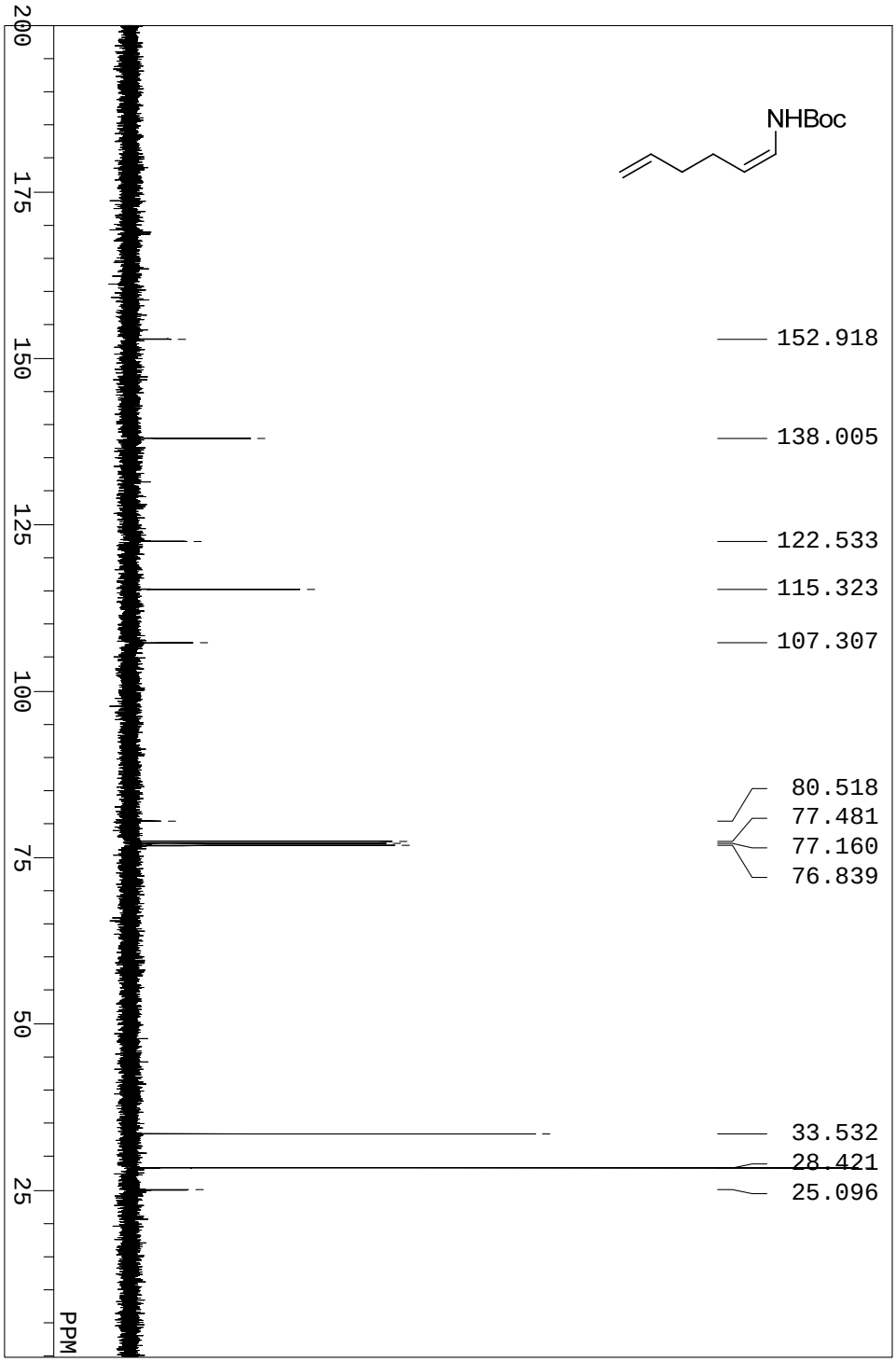
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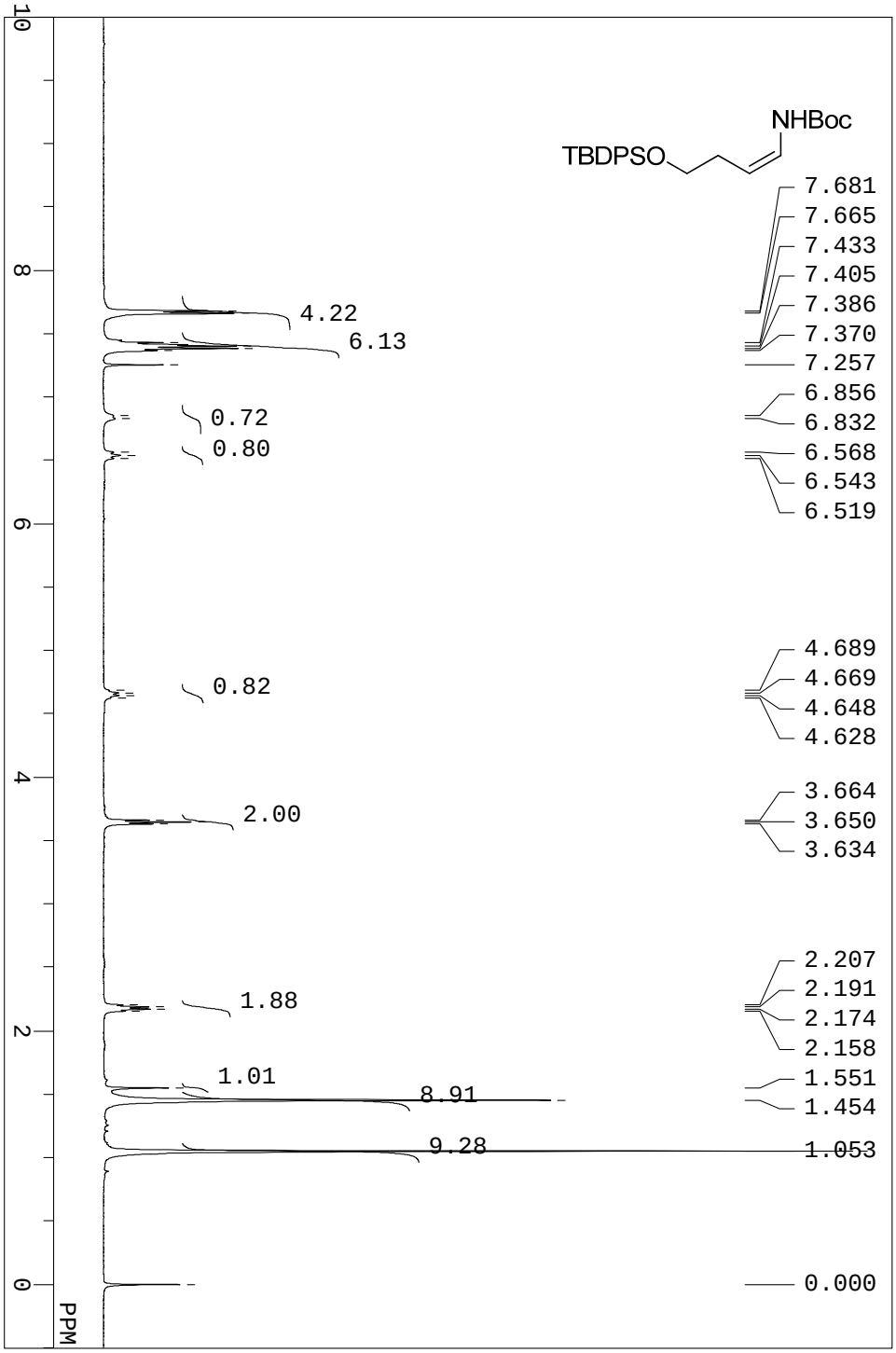
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6.568
6.543
6.519
4.689
4.669
4.648
4.628
3.664
3.650
3.634
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2.191
2.174
2.158
1.551
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1.053
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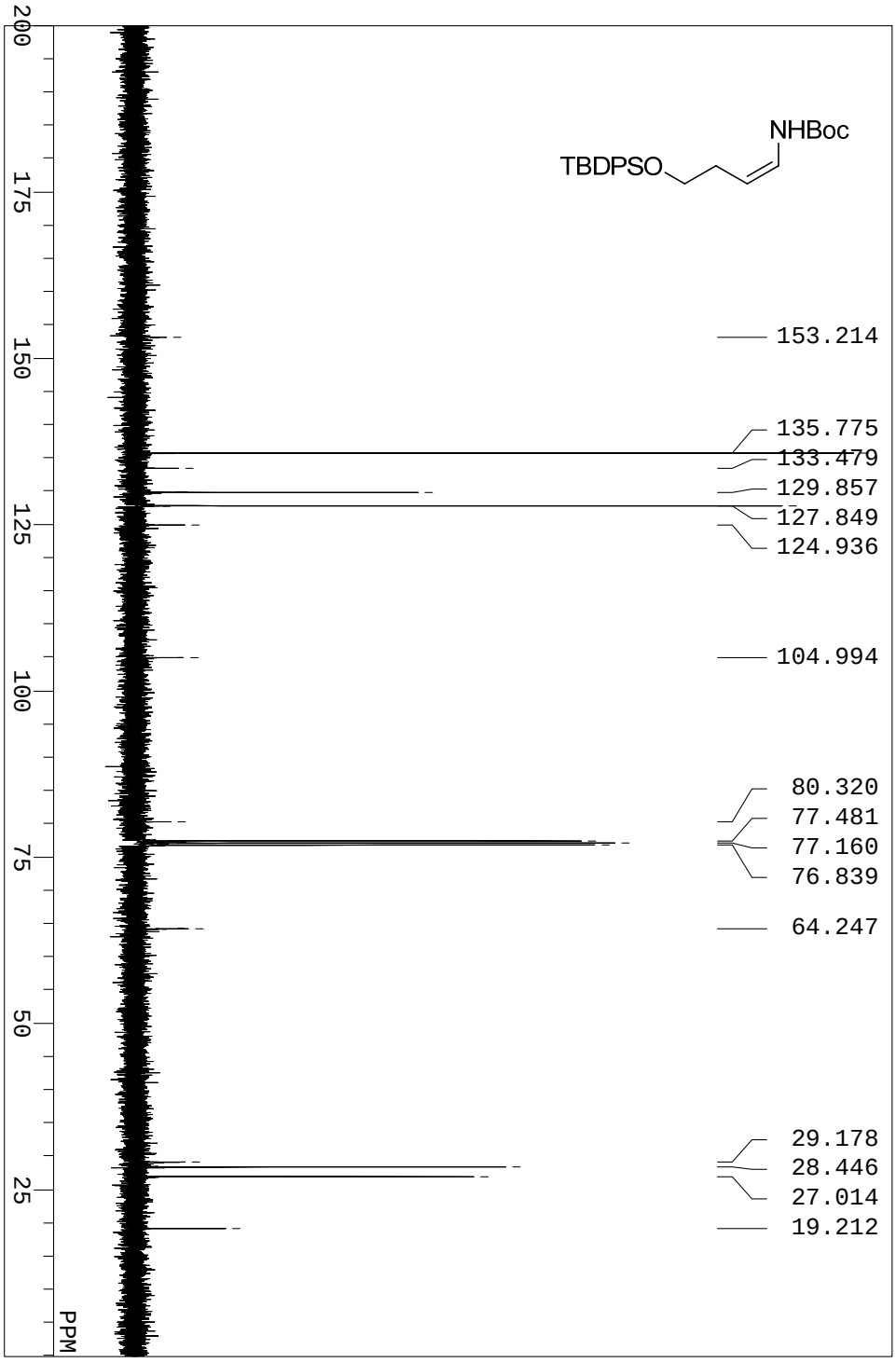
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77.160
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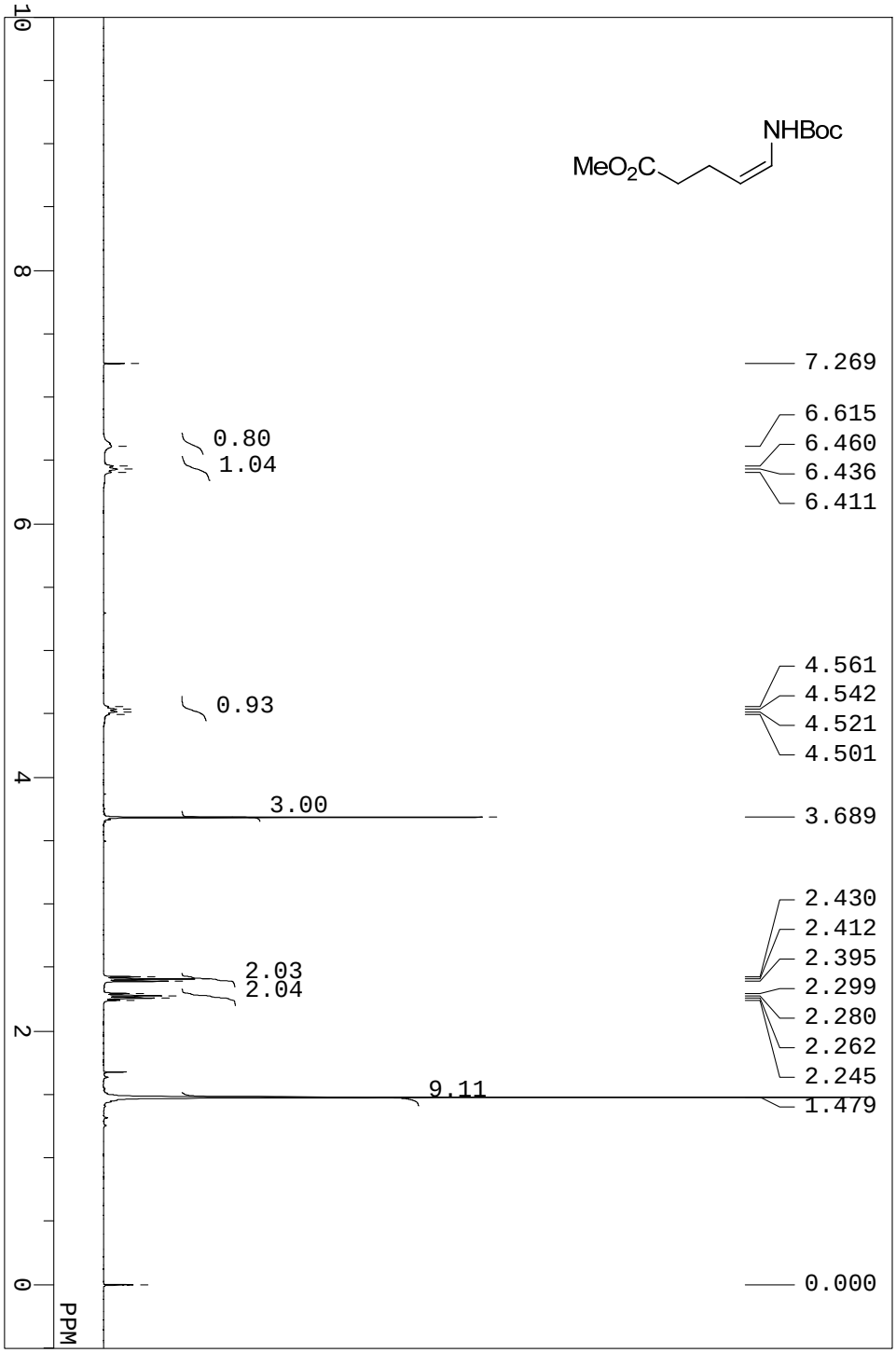
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4.501
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2.412
2.395
2.299
2.280
2.262
2.245
1.479
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0.93
3.00
2.03
2.04
9.11
10
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4
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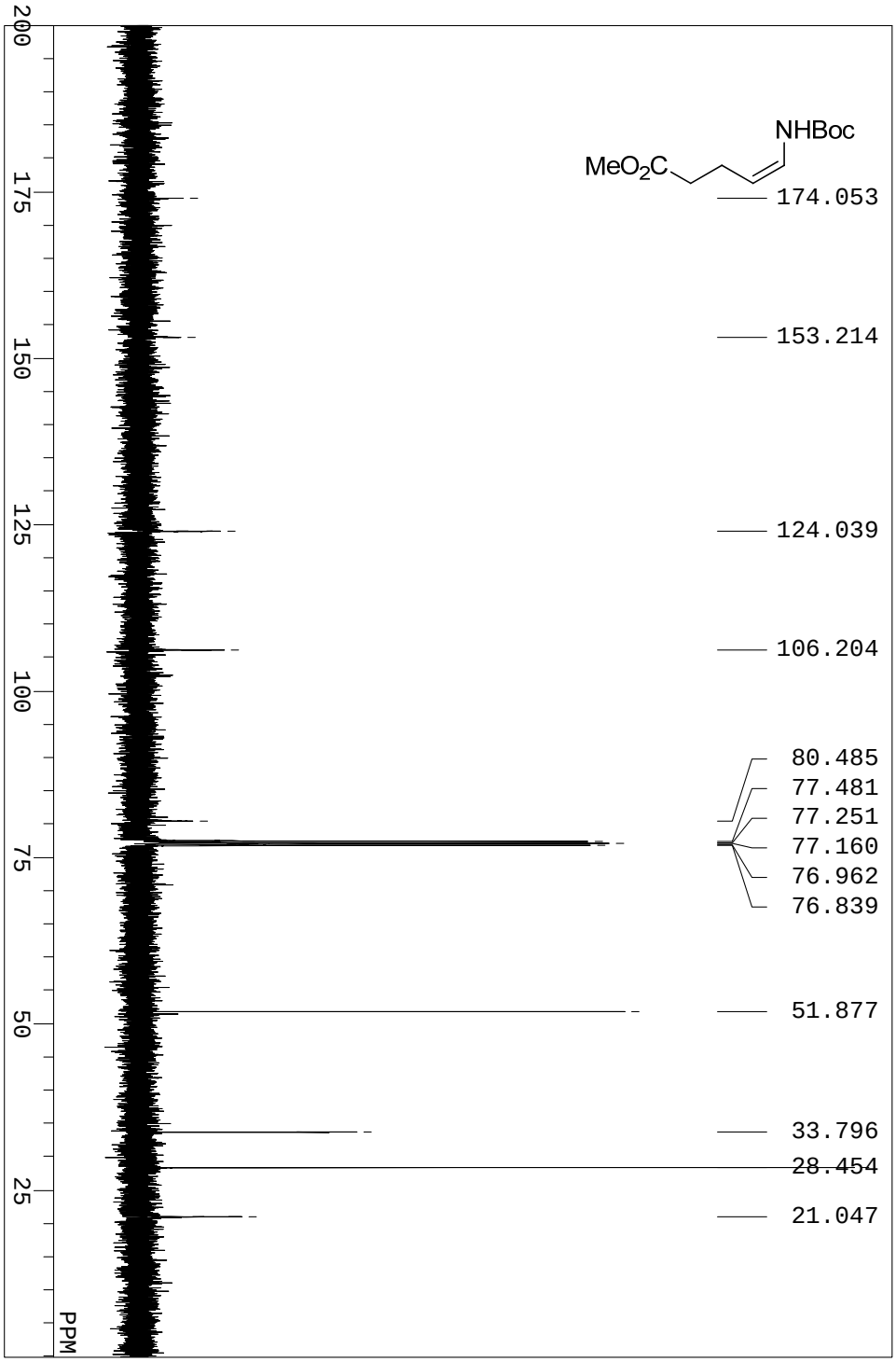
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77.160
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33.796
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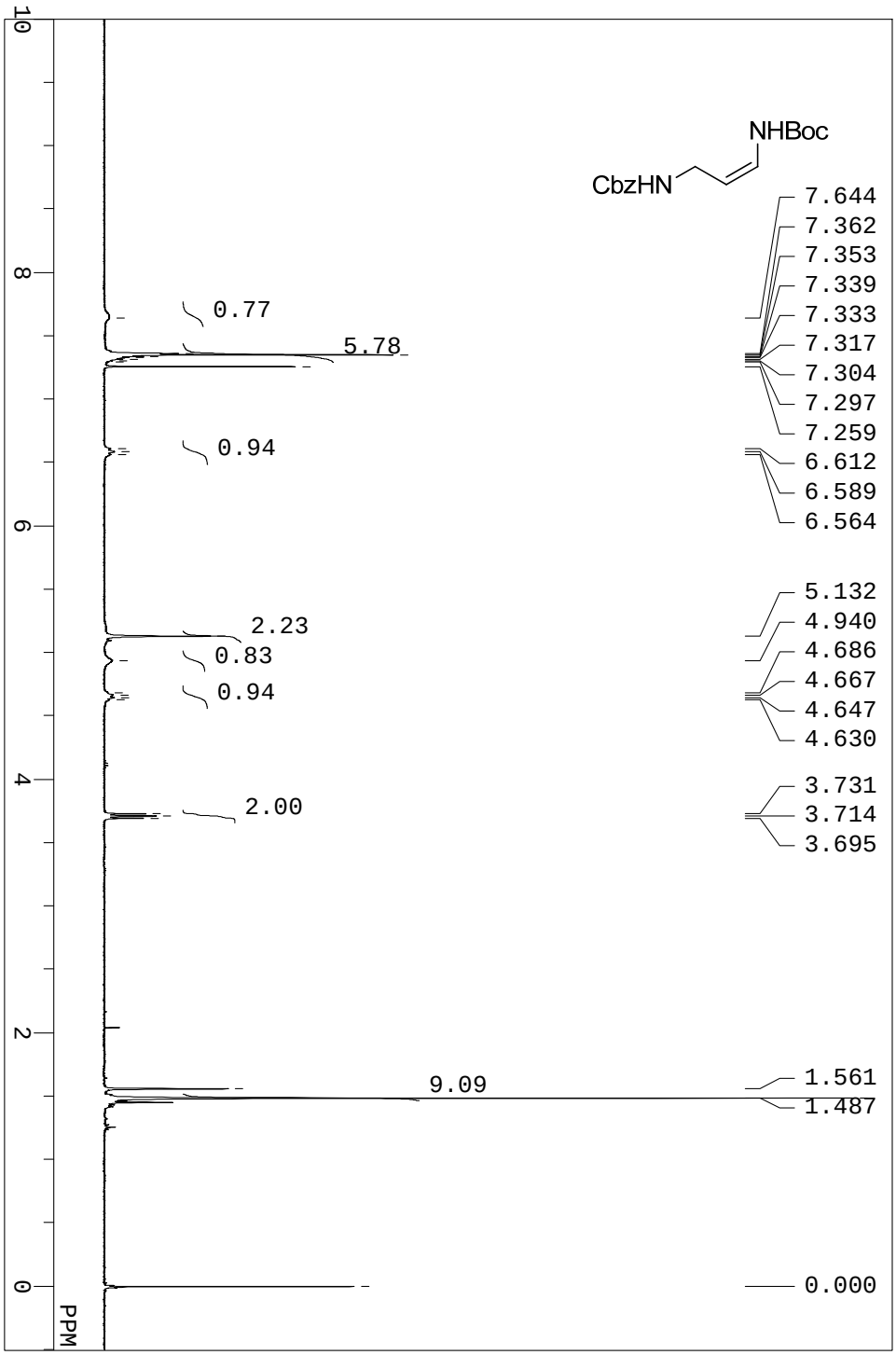
175
150
125
100
75
50
25
PPM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7.297
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6.564
5.132
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4.686
4.667
4.647
4.630
3.731
3.714
3.695
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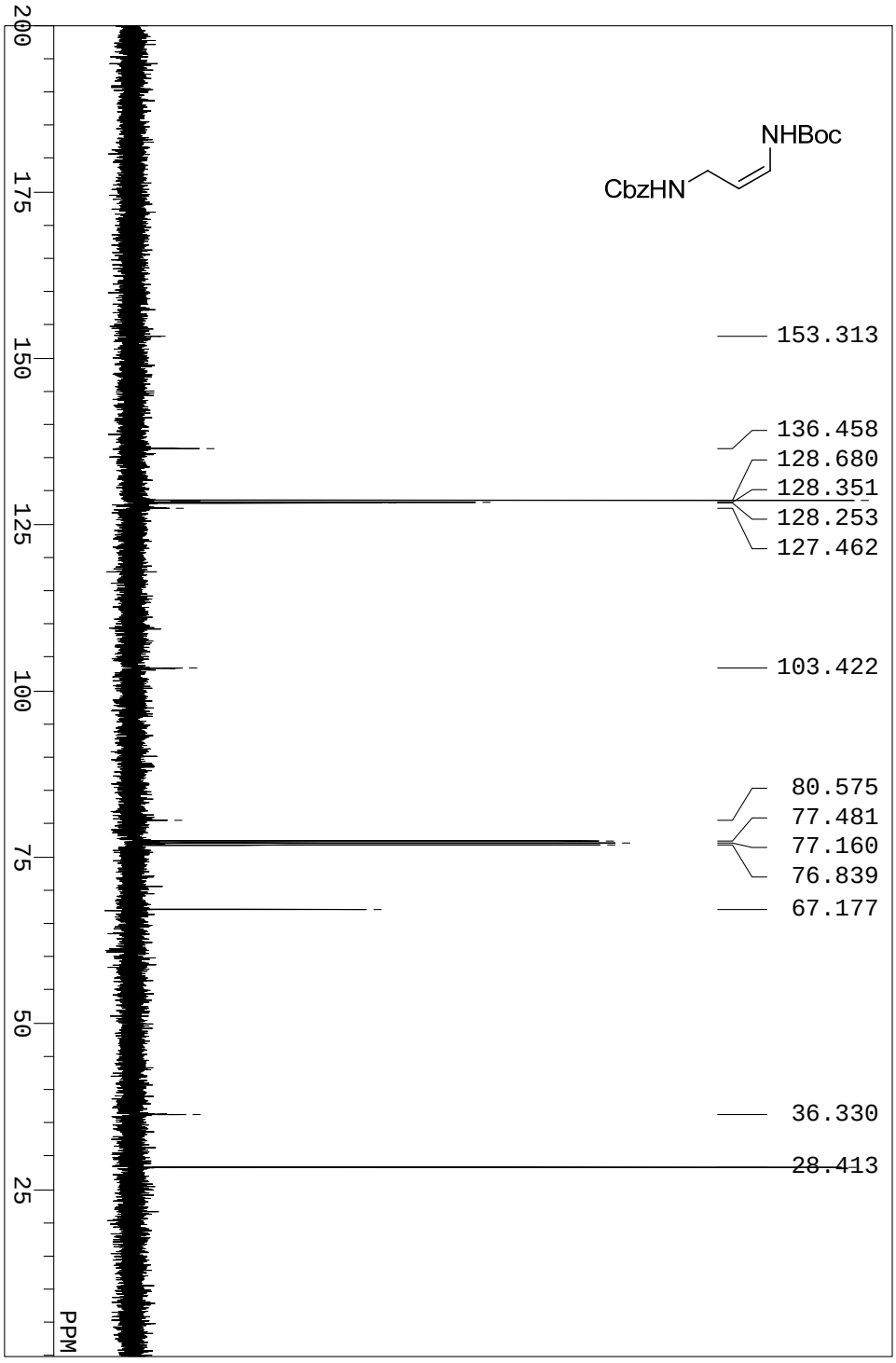
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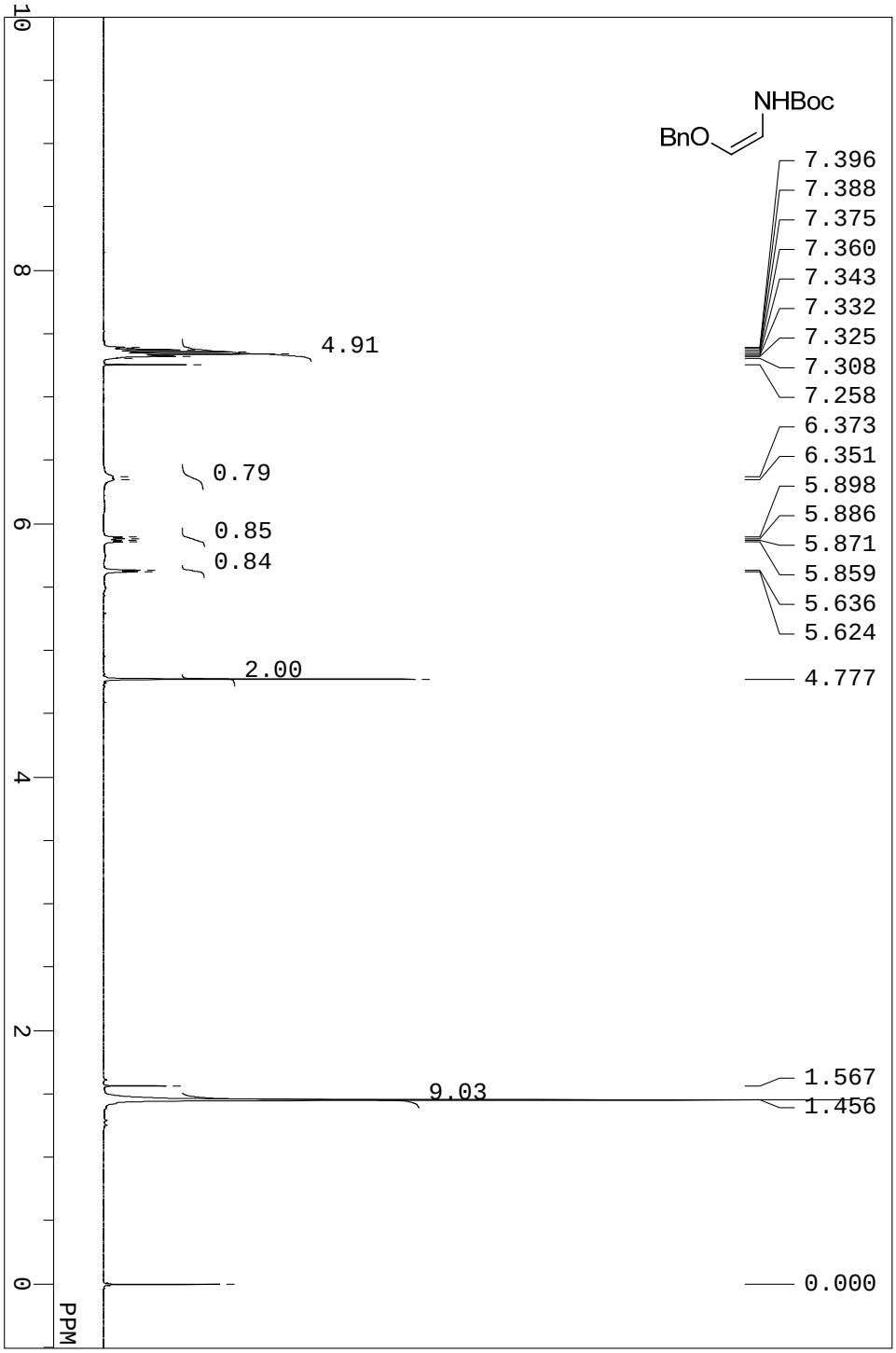
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5.886
5.871
5.859
5.636
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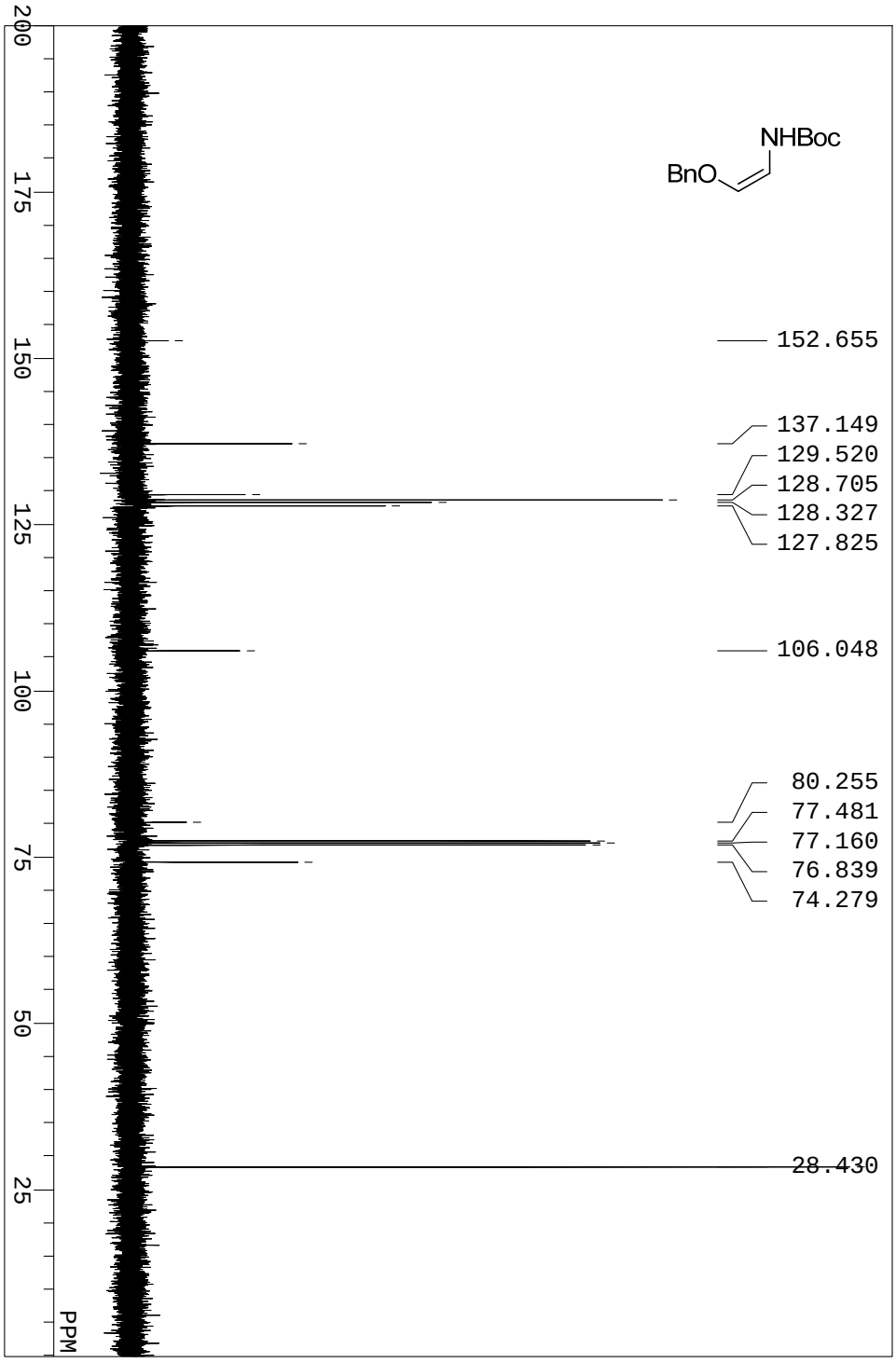
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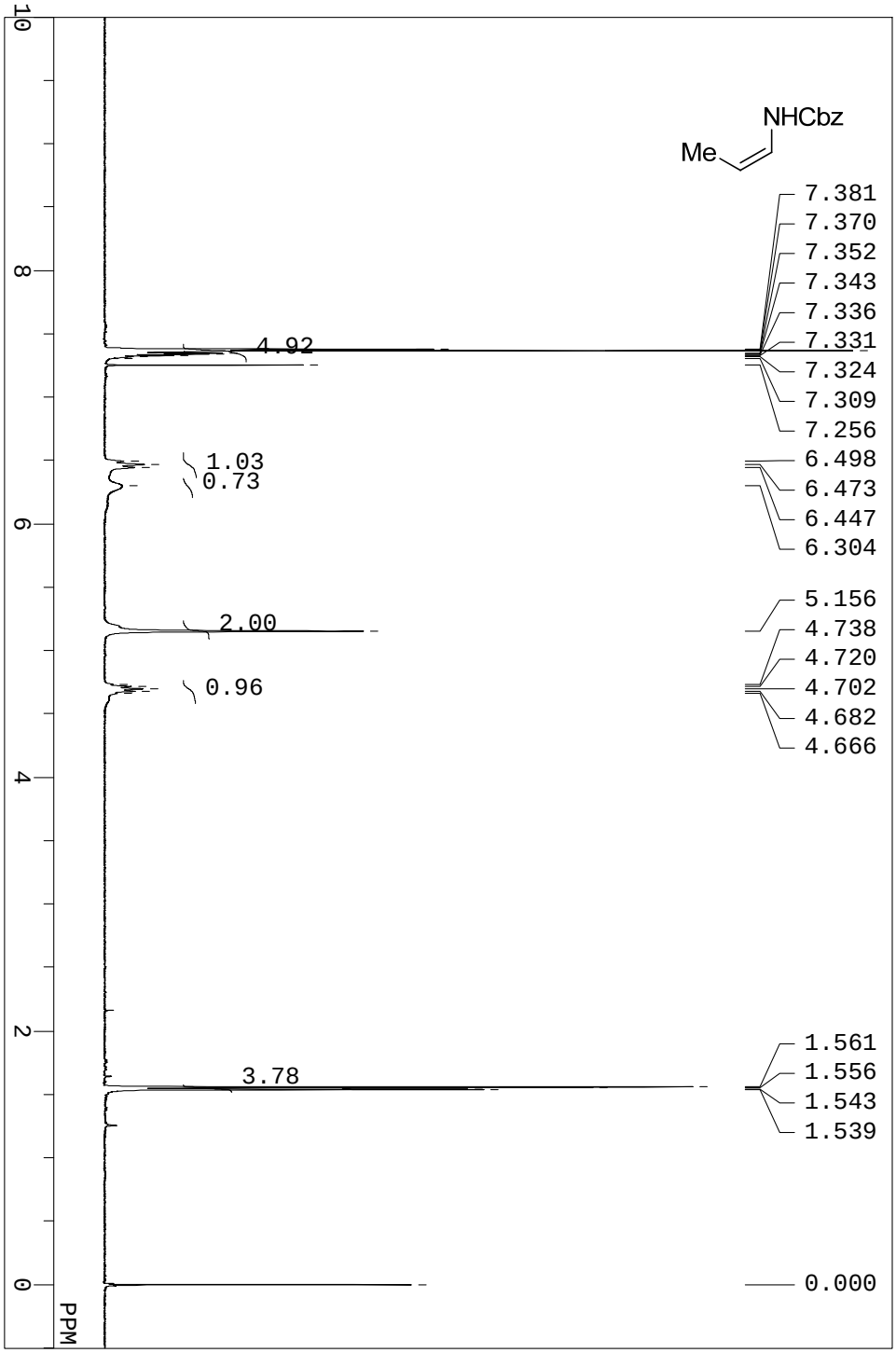
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7.309
7.256
6.498
6.473
6.447
6.304
5.156
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4.720
4.702
4.682
4.666
1.561
1.556
1.543
1.539
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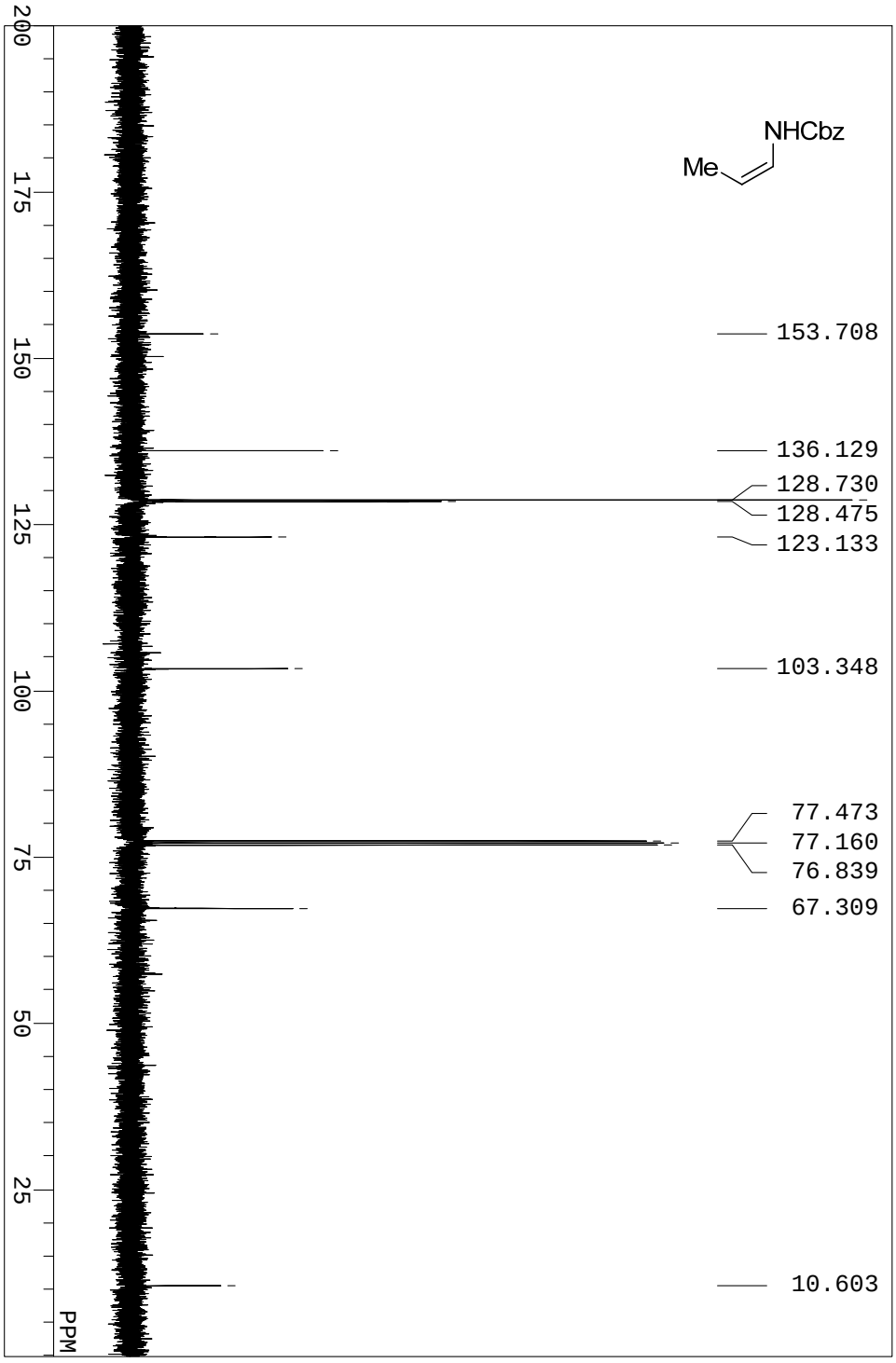
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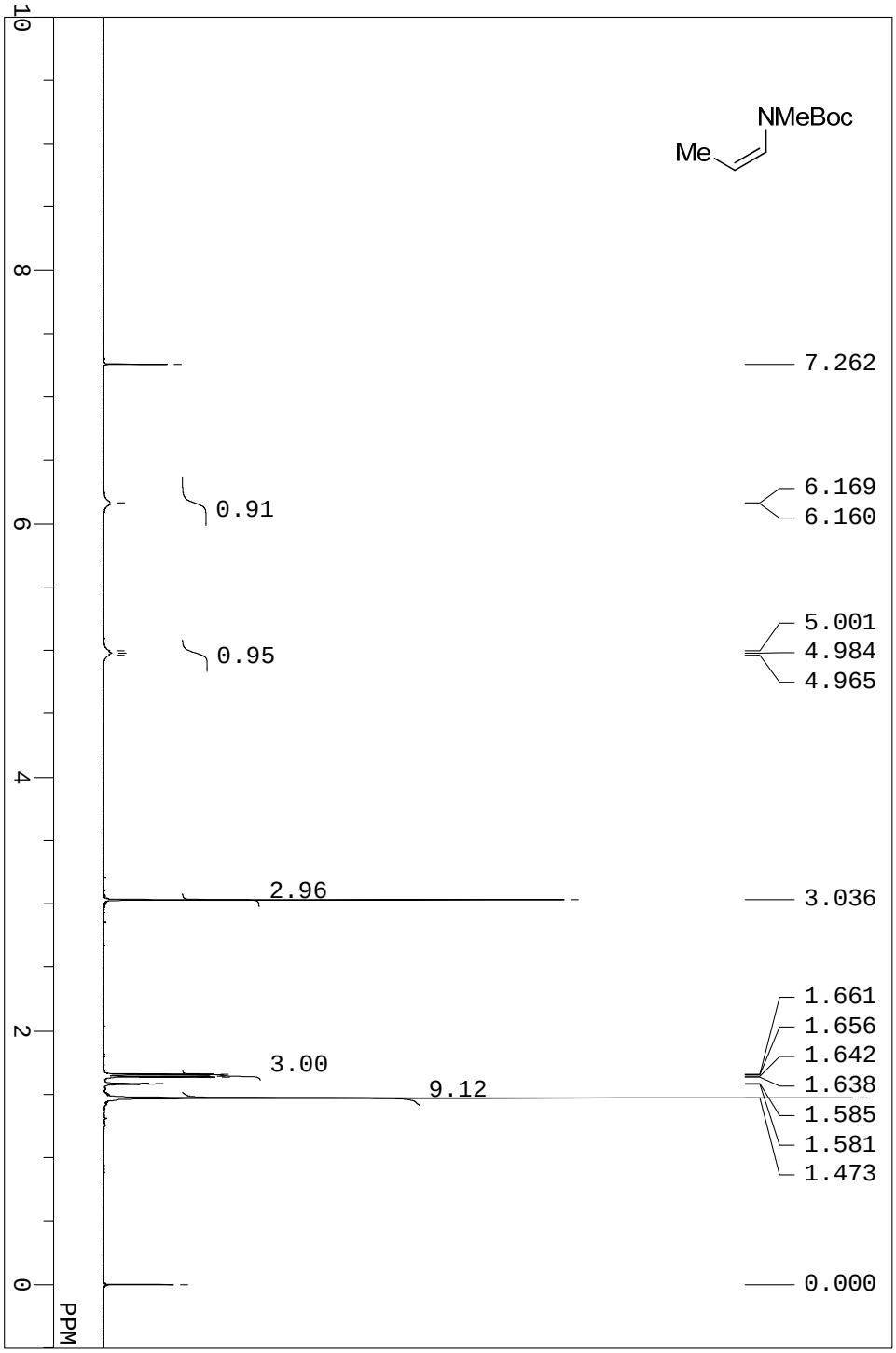
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1.638
1.585
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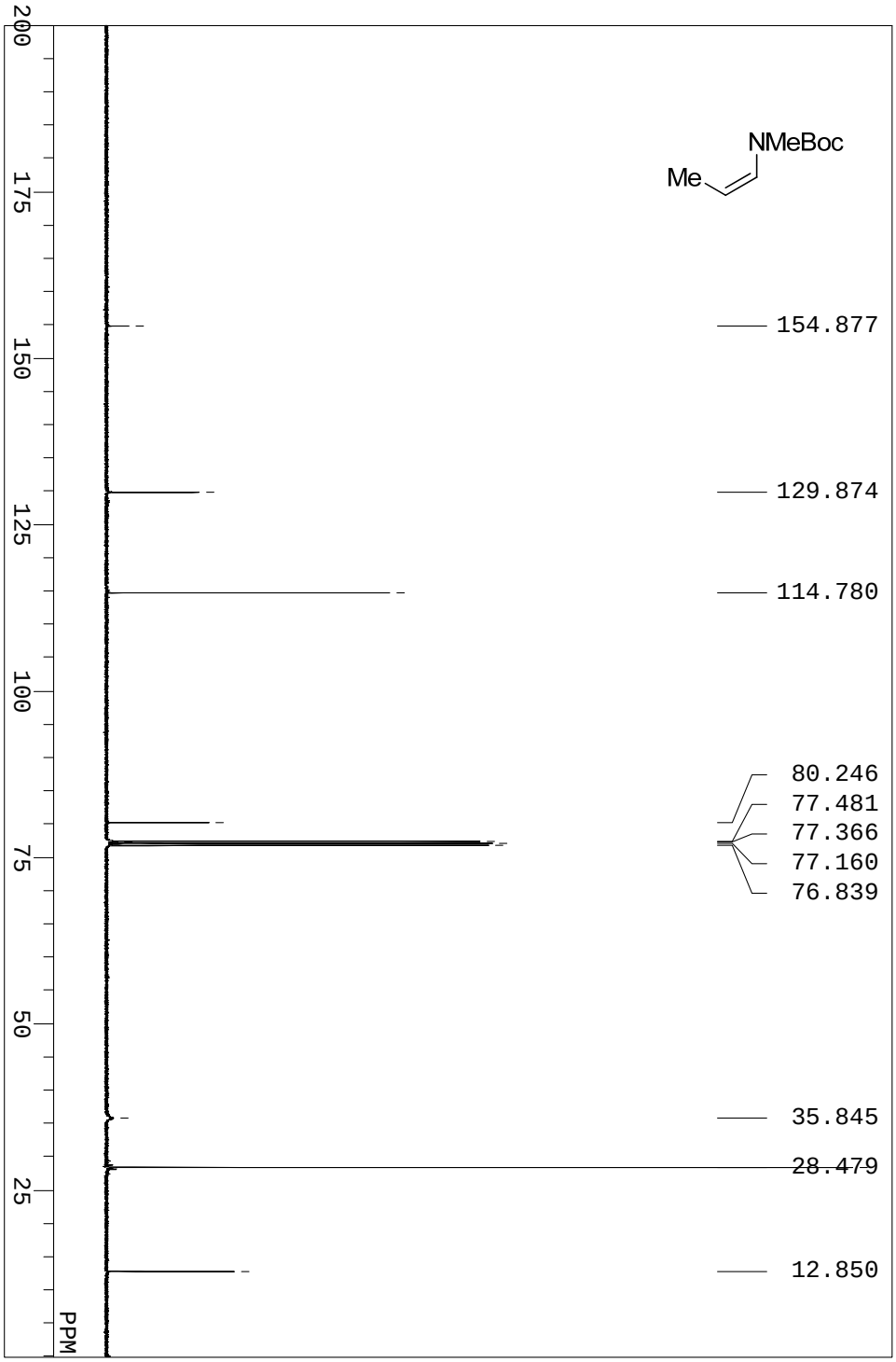
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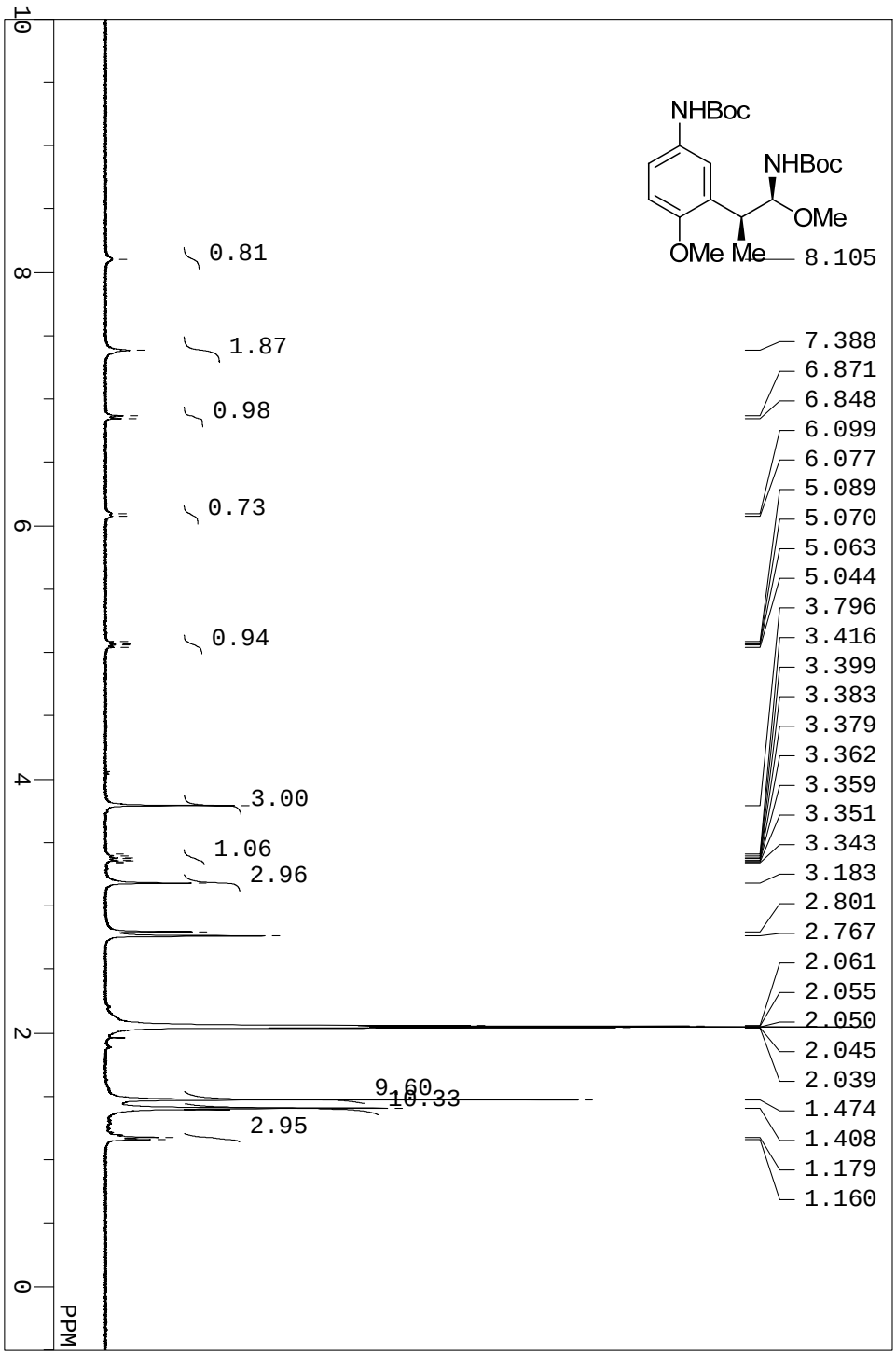
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OMe
Me
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6.077
5.089
5.070
5.063
5.044
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3.399
3.383
3.379
3.362
3.359
3.351
3.343
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2.801
2.767
2.061
2.055
2.050
2.045
2.039
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1.408
1.179
1.160
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1.87
0.98
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10
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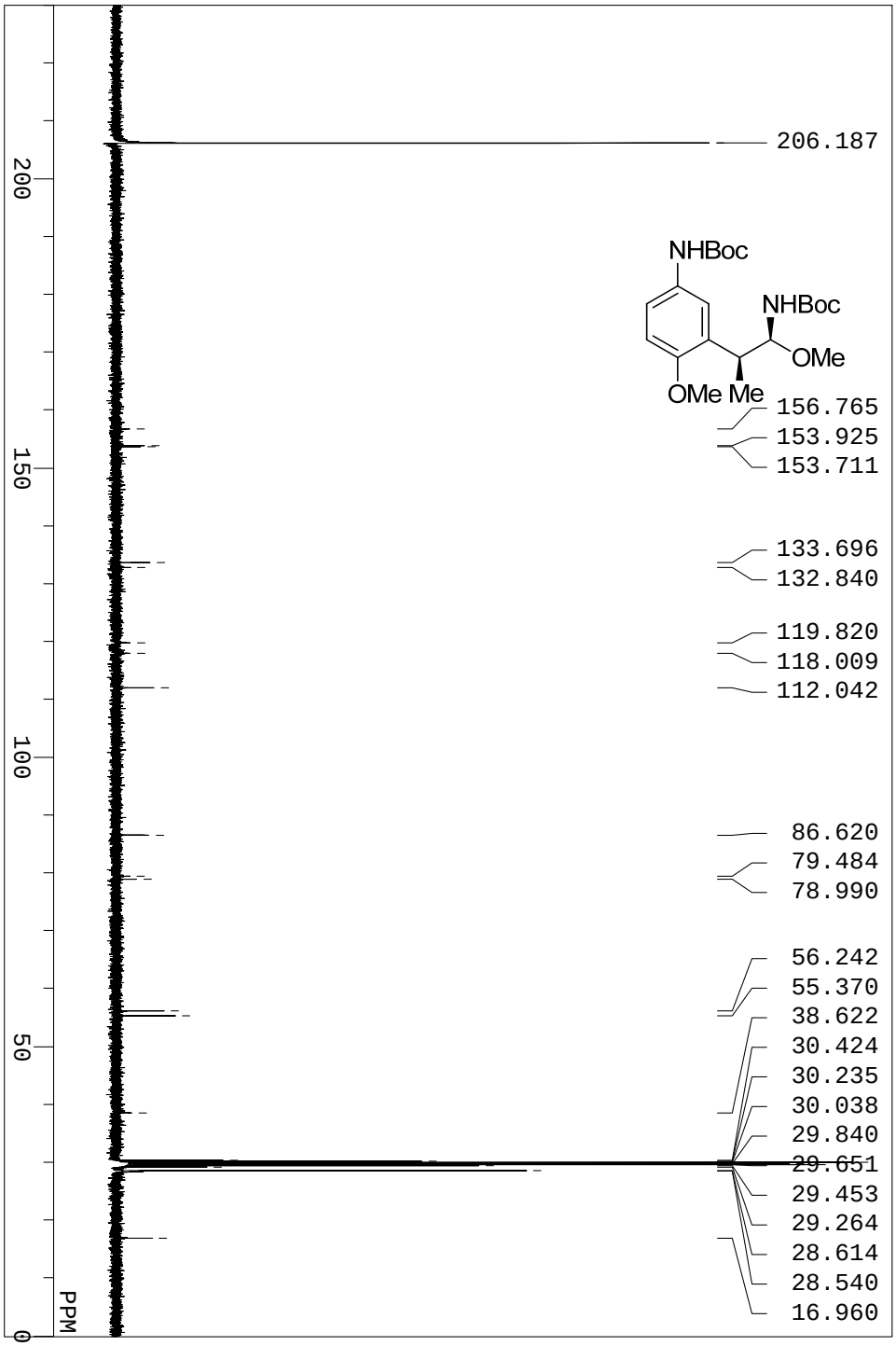
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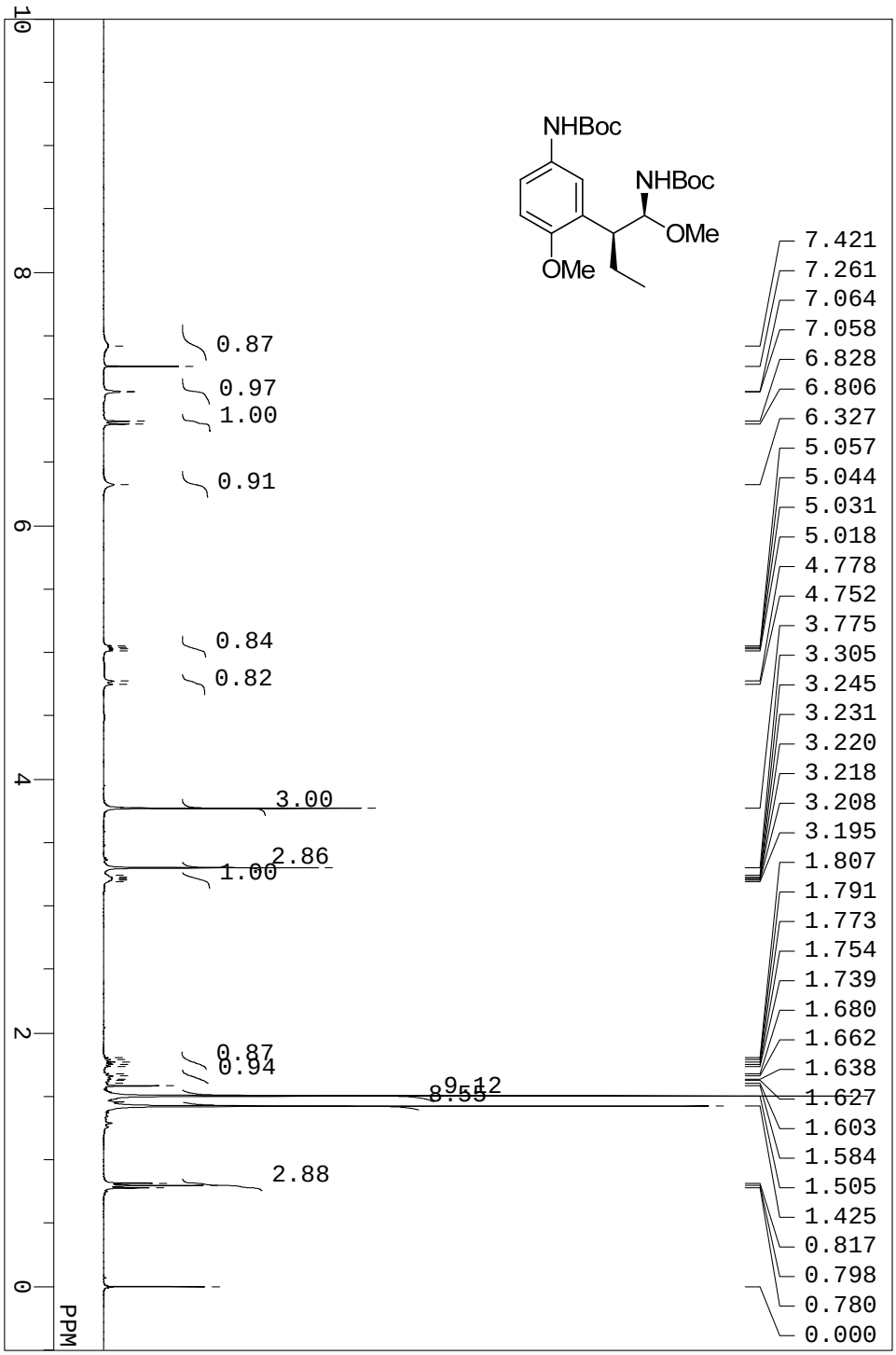
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0.84
0.82
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1.00
0.87
0.94
9.12
8.55
2.88
7.421
7.261
7.064
7.058
6.828
6.806
6.327
5.057
5.044
5.031
5.018
4.778
4.752
3.775
3.305
3.245
3.231
3.220
3.218
3.208
3.195
1.807
1.791
1.773
1.754
1.739
1.680
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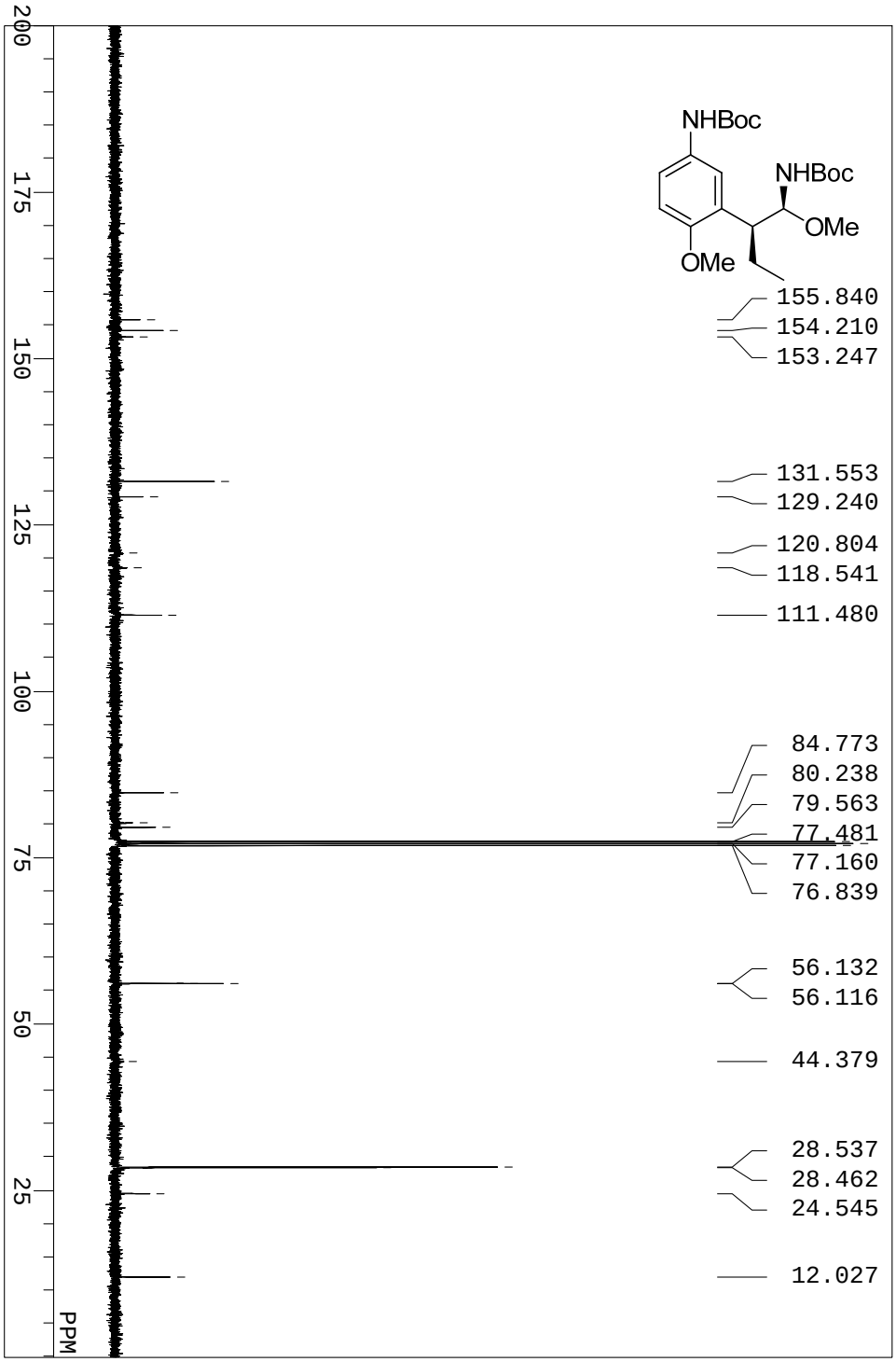
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OMe
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84.773
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79.563
77.481
77.160
76.839
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24.545
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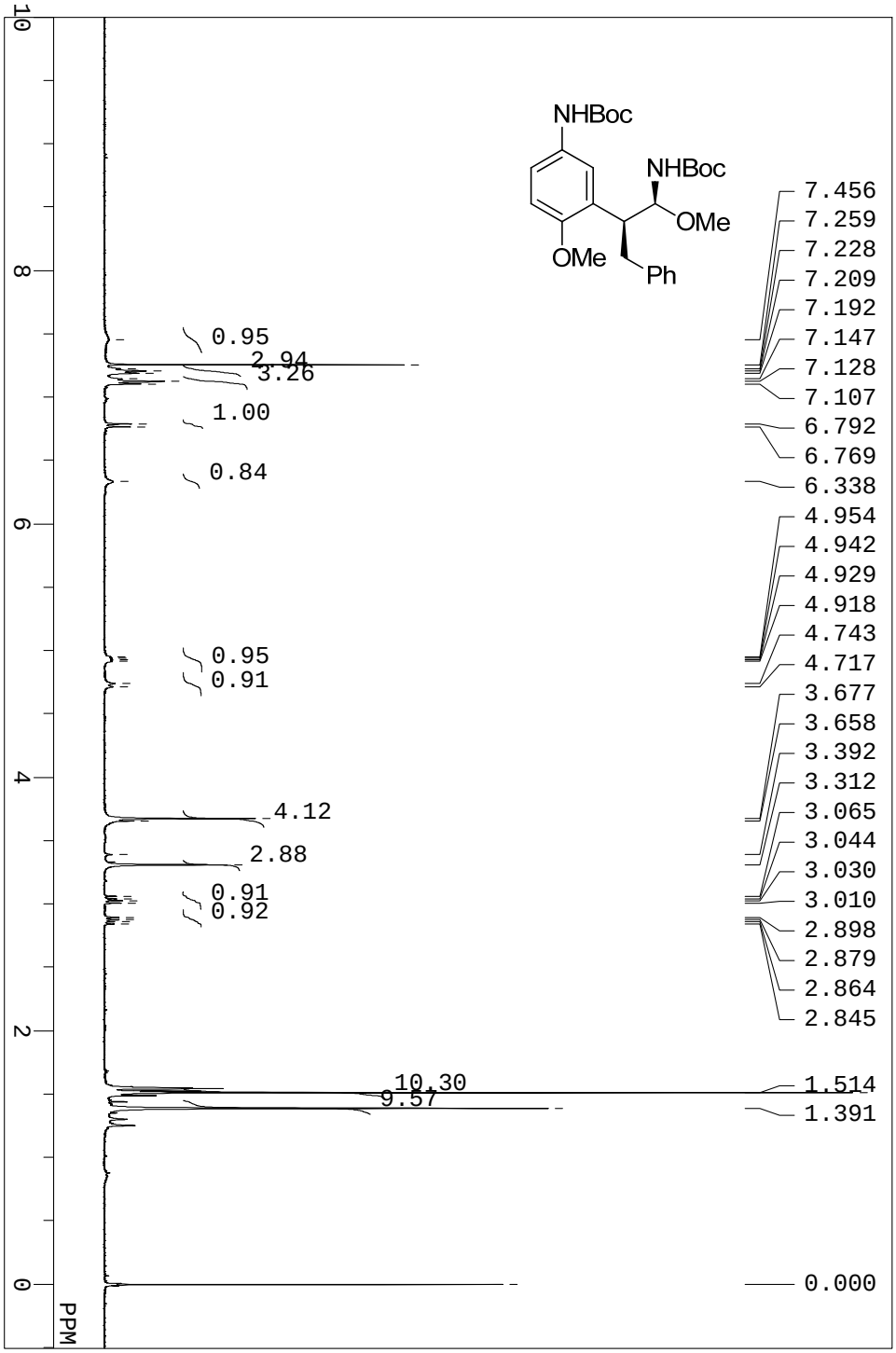
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NHBoc
OMe
OMe
Ph
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7.228
7.209
7.192
7.147
7.128
7.107
6.792
6.769
6.338
4.954
4.942
4.929
4.918
4.743
4.717
3.677
3.658
3.392
3.312
3.065
3.044
3.030
3.010
2.898
2.879
2.864
2.845
1.514
1.391
0.000
0.95
2.94
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0.84
0.95
0.91
4.12
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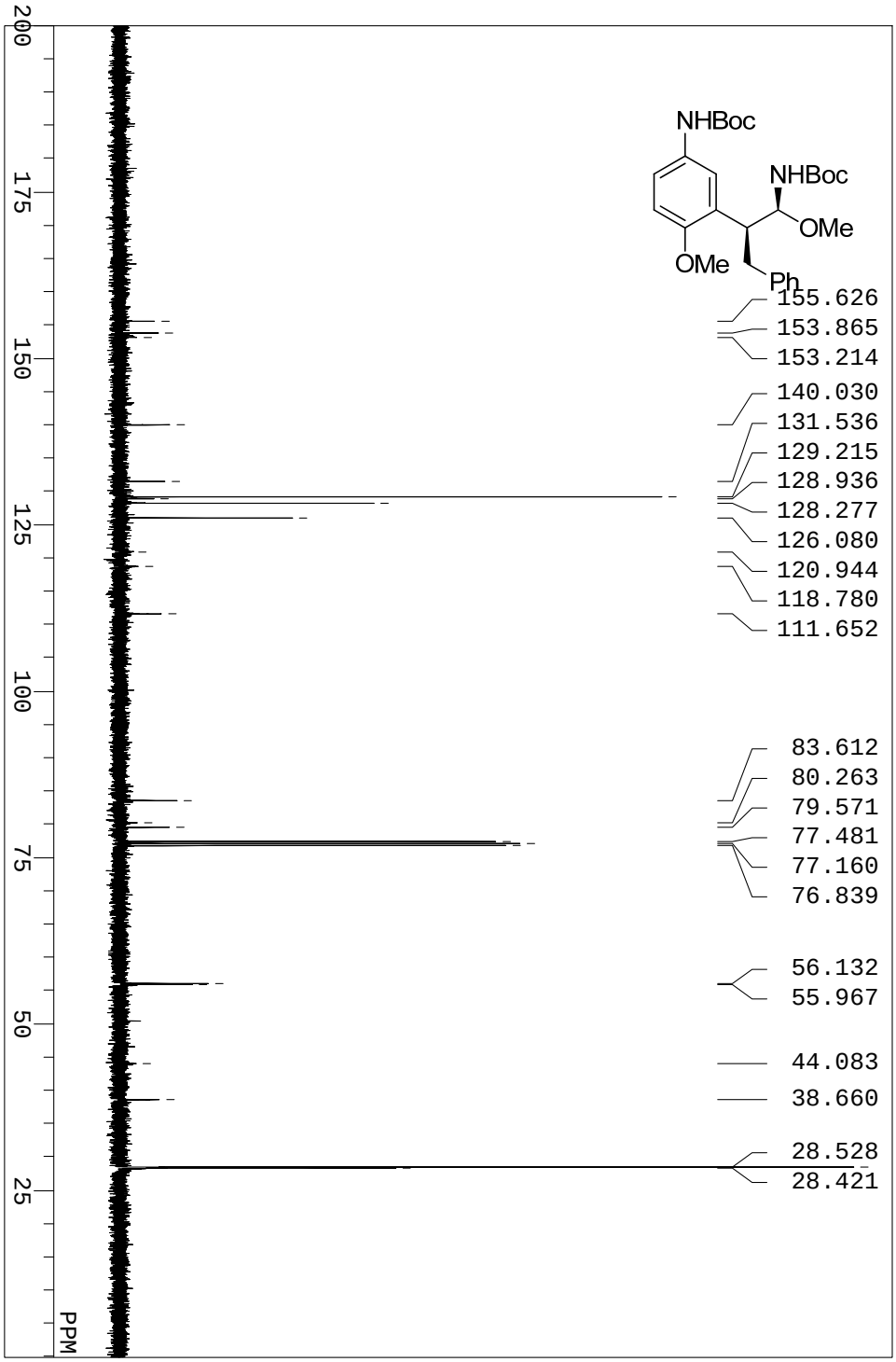
0.91
0.92
10.30
9.57
PPM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NHBoc
OMe
OMe
Ph
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153.214
140.030
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129.215
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128.277
126.080
120.944
118.780
111.652
83.612
80.263
79.571
77.481
77.160
76.839
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44.083
38.660
28.528
28.421
200
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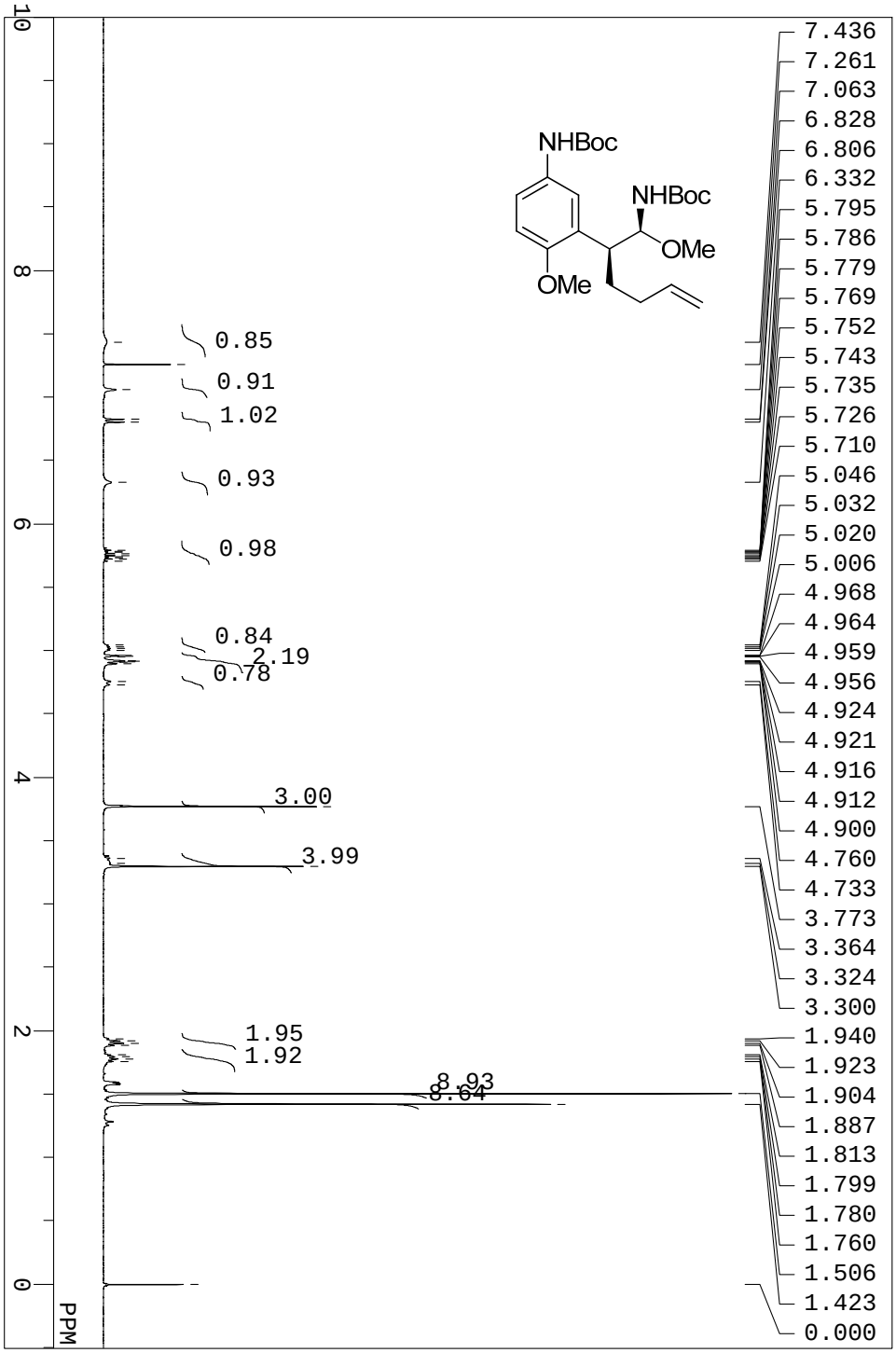
150
125
100
75
50
25
PPM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1.02
0.93
0.98
0.84
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0.78
3.00
3.99
1.95
1.92
8.93
8.64
7.436
7.261
7.063
6.828
6.806
6.332
5.795
5.786
5.779
5.769
5.752
5.743
5.735
5.726
5.710
5.046
5.032
5.020
5.006
4.968
4.964
4.959
4.956
4.924
4.921
4.916
4.912
4.900
4.760
4.733
3.773
3.364
3.324
3.300
1.940
1.923
1.904
1.887
1.813
1.799
1.780
1.760
1.506
1.423
0.000
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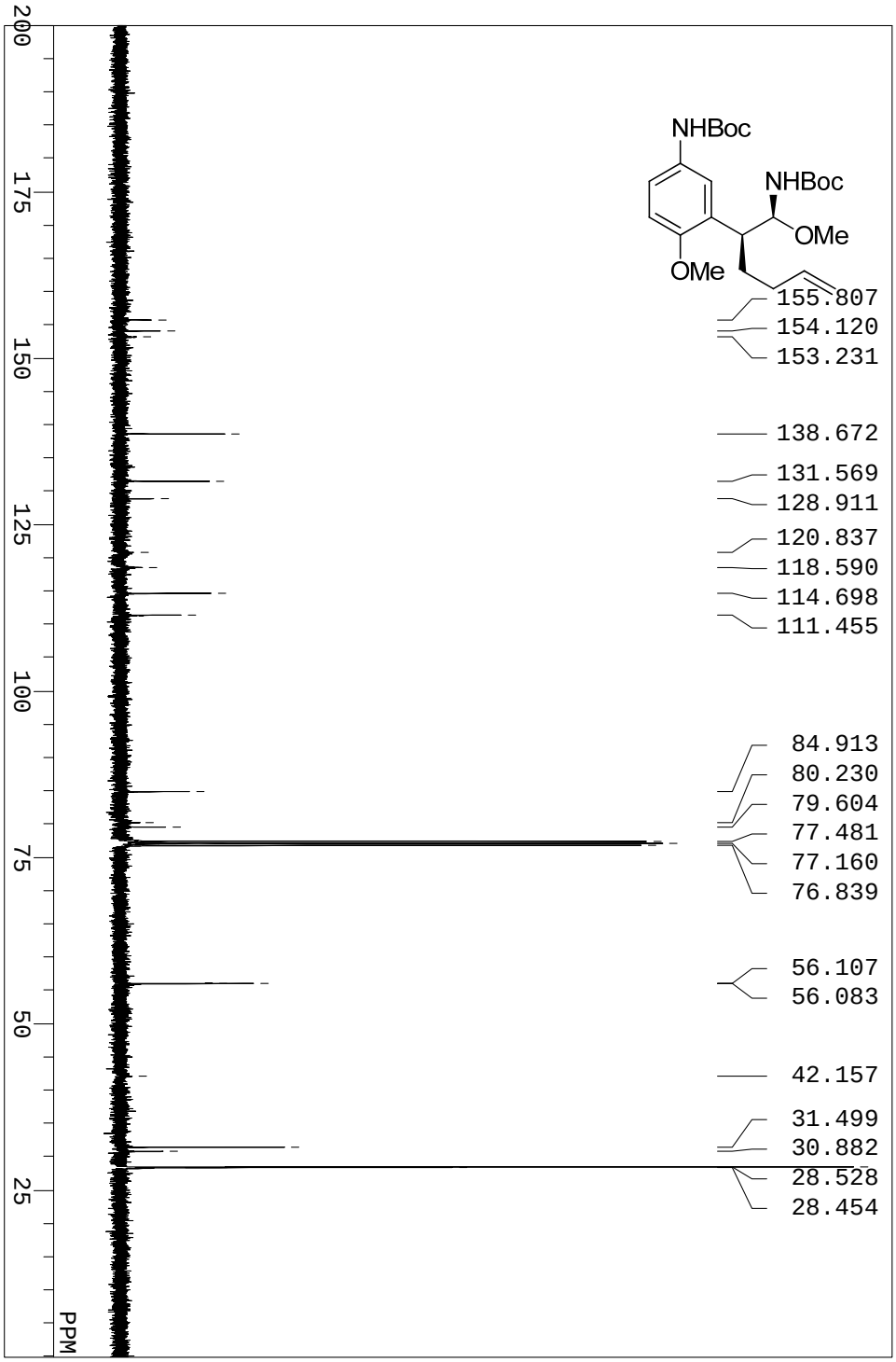
6
4
2
0
PPM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OMe
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111.455
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80.230
79.604
77.481
77.160
76.839
56.107
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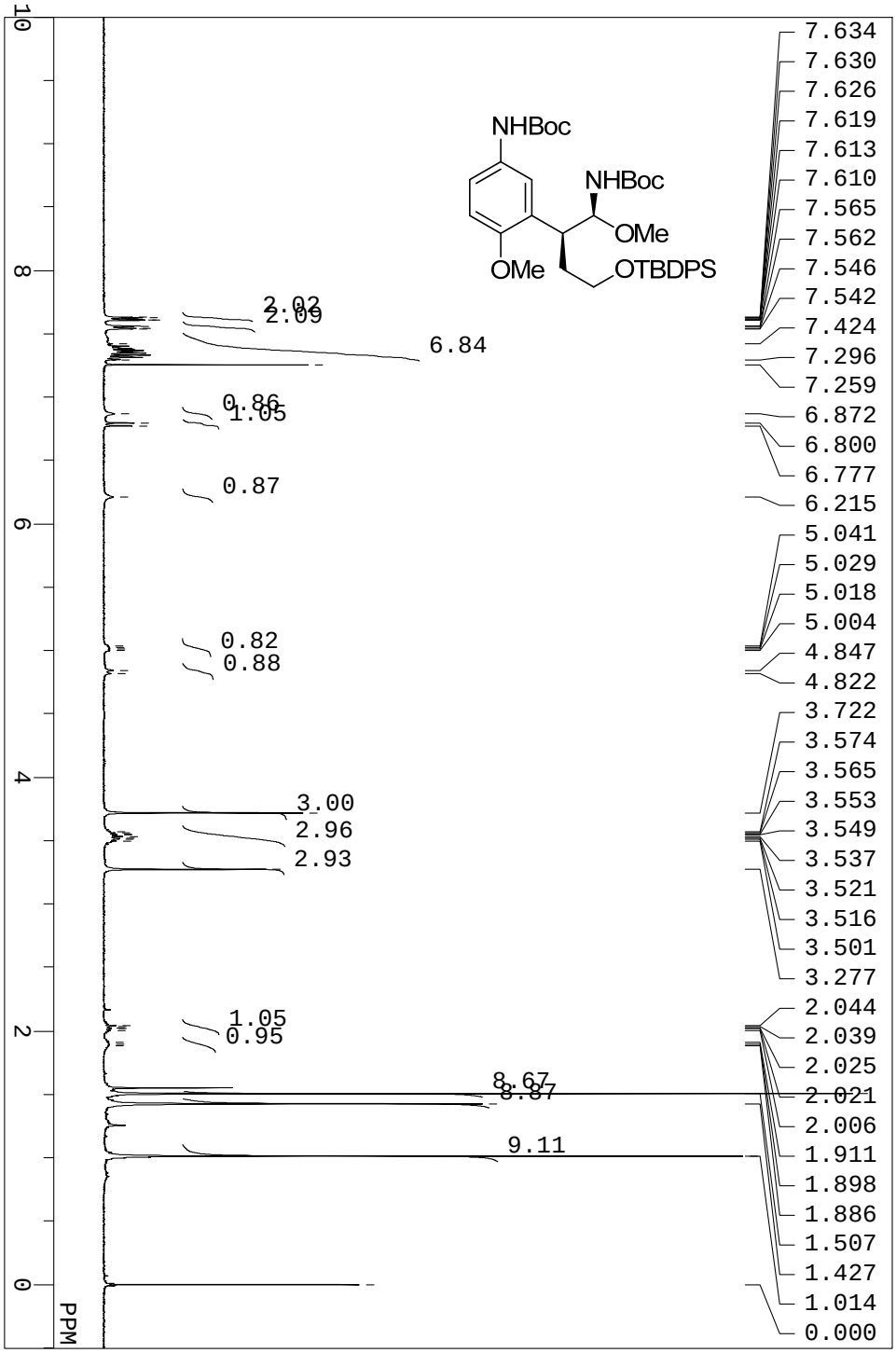
42.157
31.499
30.882
28.528
28.454
200
175
150
125
100
75
50
25
PPM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OMe
OMe
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0.86
1.05
0.87
0.82
0.88
3.00
2.96
2.93
1.05
0.95
8.67
8.87
9.11
7.634
7.630
7.626
7.619
7.613
7.610
7.565
7.562
7.546
7.542
7.424
7.296
7.259
6.872
6.800
6.777
6.215
5.041
5.029
5.018
5.004
4.847
4.822
3.722
3.574
3.565
3.553
3.549
3.537
3.521
3.516
3.501
3.277
2.044
2.039
2.025
2.021
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1.886
1.507
1.427
1.014
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6
4
2
0
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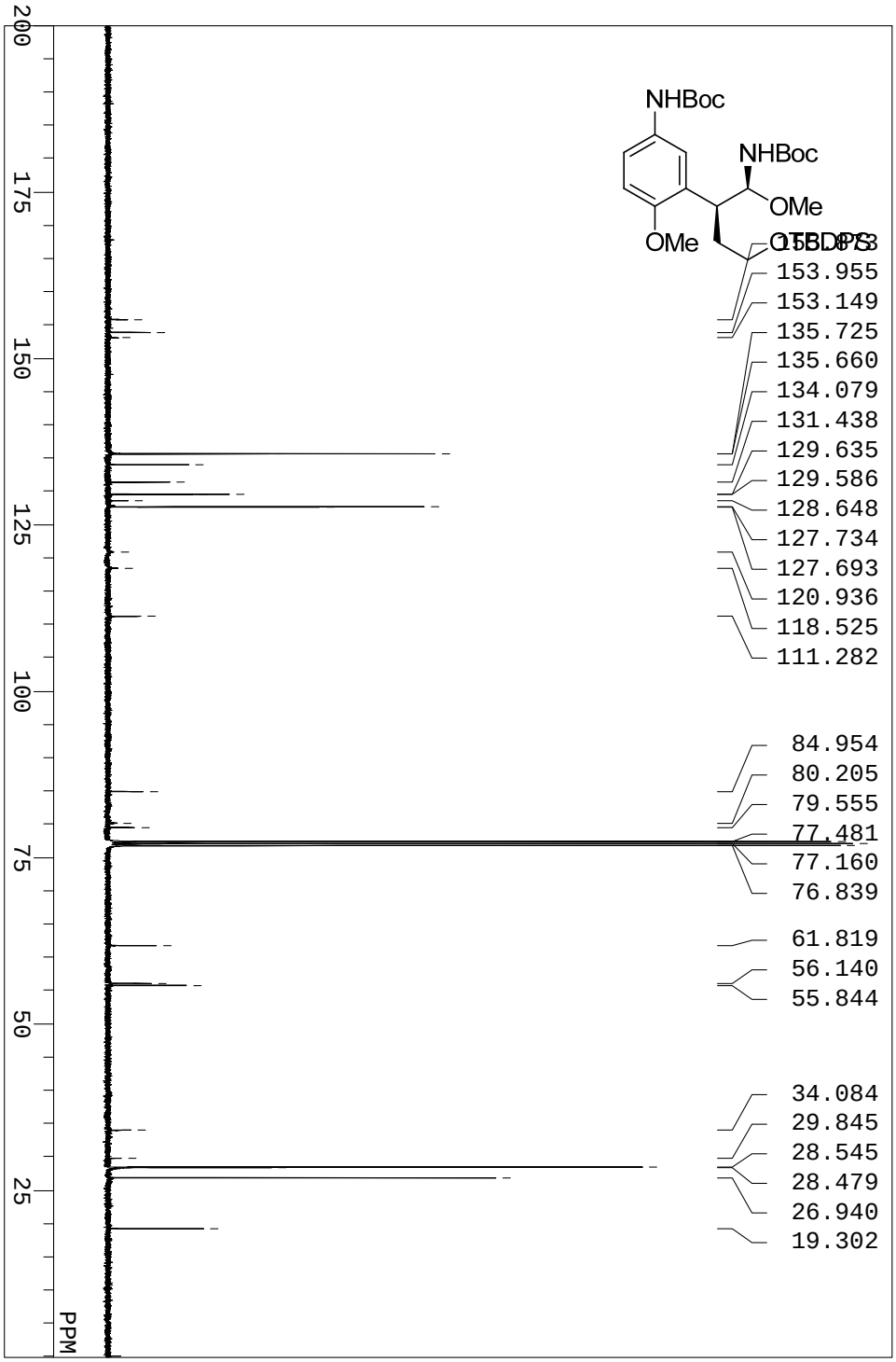
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OMe
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134.079
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129.635
129.586
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127.693
120.936
118.525
111.282
84.954
80.205
79.555
77.481
77.160
76.839
61.819
56.140
55.844
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28.545
28.479
26.940
19.302
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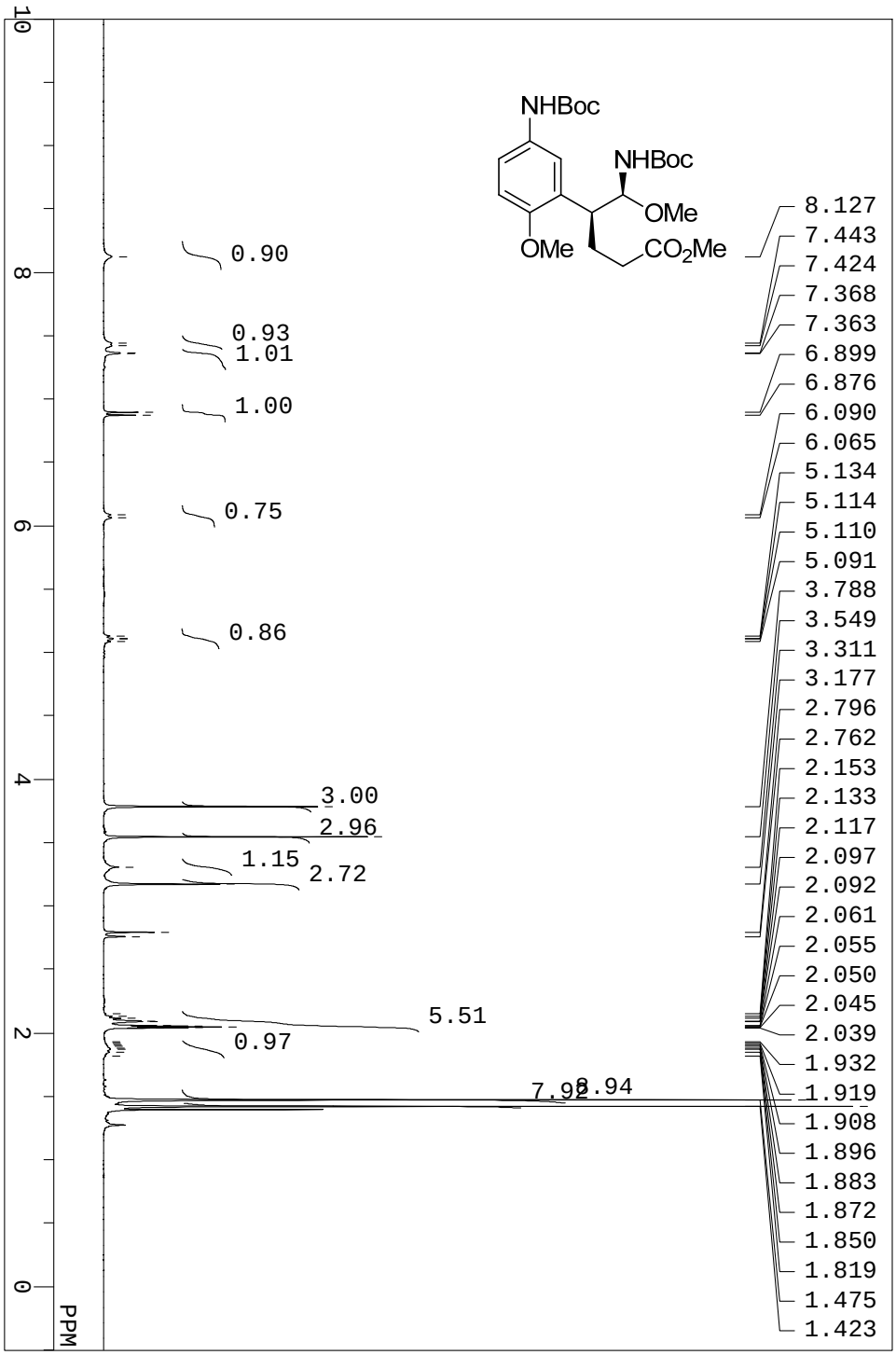
175
150
125
100
75
50
25
PPM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OMe
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1.00
0.75
0.86
3.00
2.96
1.15
2.72
5.51
0.97
7.92
2.94
8.127
7.443
7.424
7.368
7.363
6.899
6.876
6.090
6.065
5.134
5.114
5.110
5.091
3.788
3.549
3.311
3.177
2.796
2.762
2.153
2.133
2.117
2.097
2.092
2.061
2.055
2.050
2.045
2.039
1.932
1.919
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1.872
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1.819
1.475
1.423
10
8
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4
2
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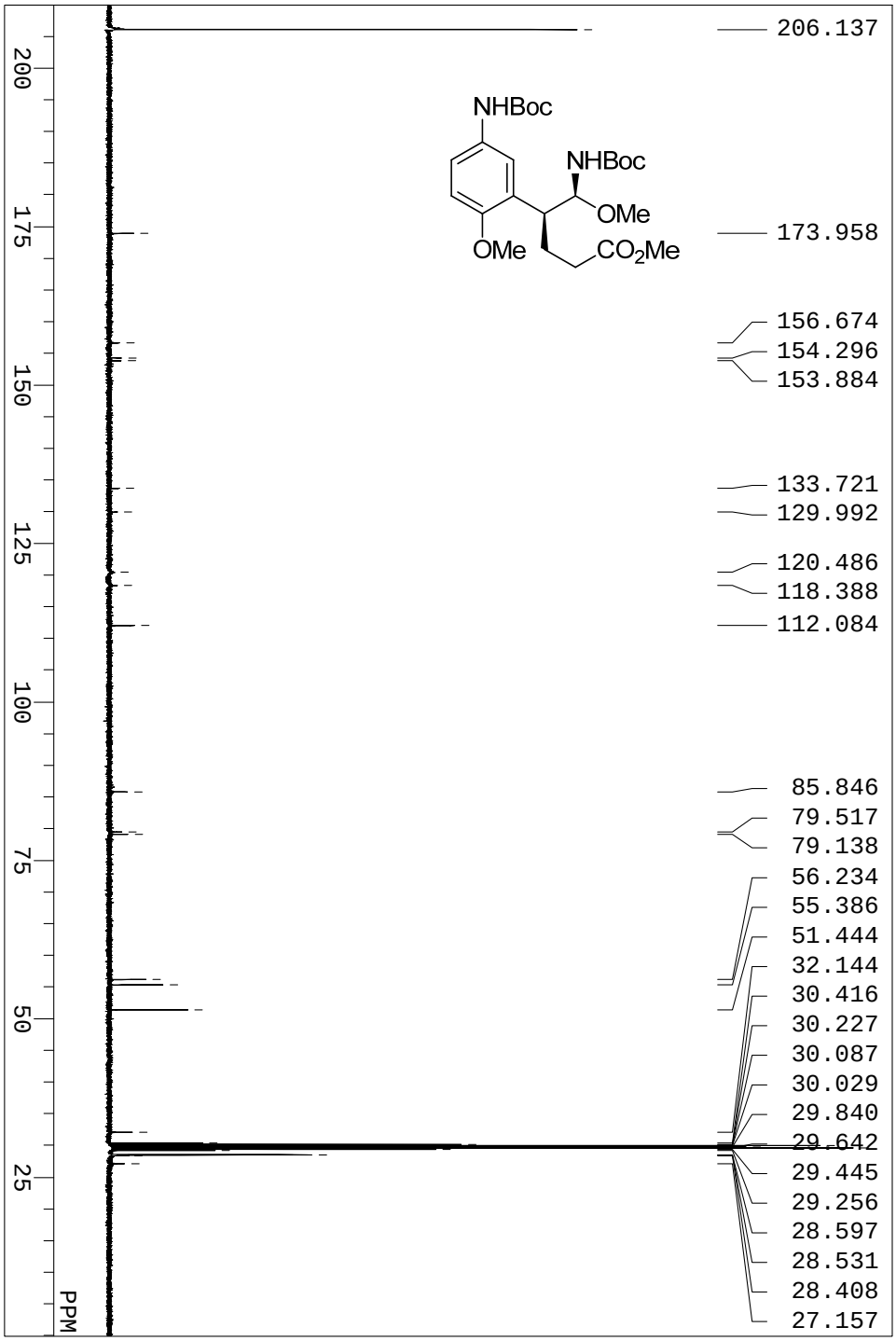
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OMe
CO2Me
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85.846
79.517
79.138
56.234
55.386
51.444
32.144
30.416
30.227
30.087
30.029
29.840
29.642
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28.531
28.408
27.157
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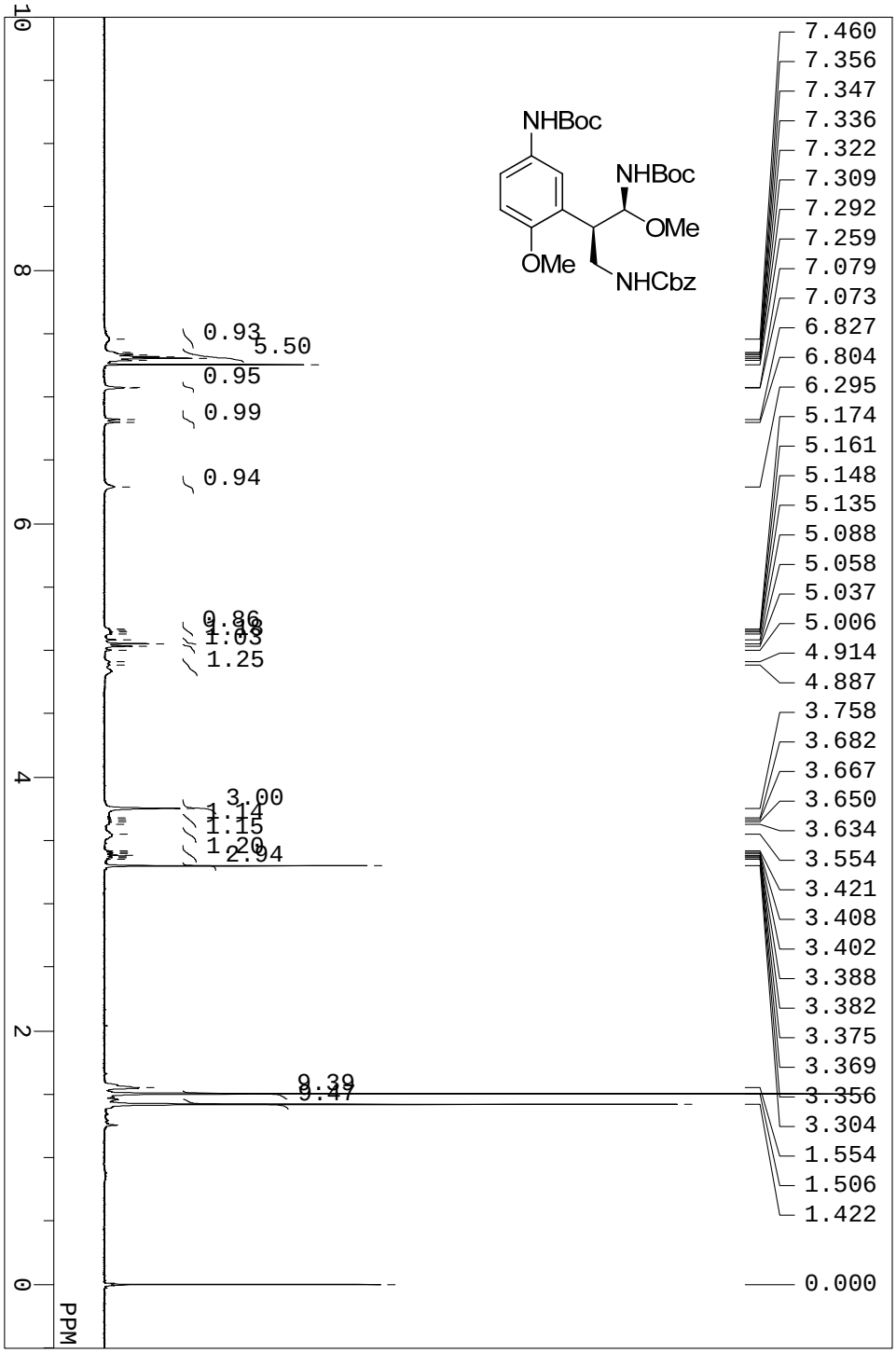
175
150
125
100
75
50
25
PPM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NHBoc
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OMe
NHCbz
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7.292
7.259
7.079
7.073
6.827
6.804
6.295
5.174
5.161
5.148
5.135
5.088
5.058
5.037
5.006
4.914
4.887
3.758
3.682
3.667
3.650
3.634
3.554
3.421
3.408
3.402
3.388
3.382
3.375
3.369
3.356
3.304
1.554
1.506
1.422
0.000
0.93
5.50
0.95
0.99
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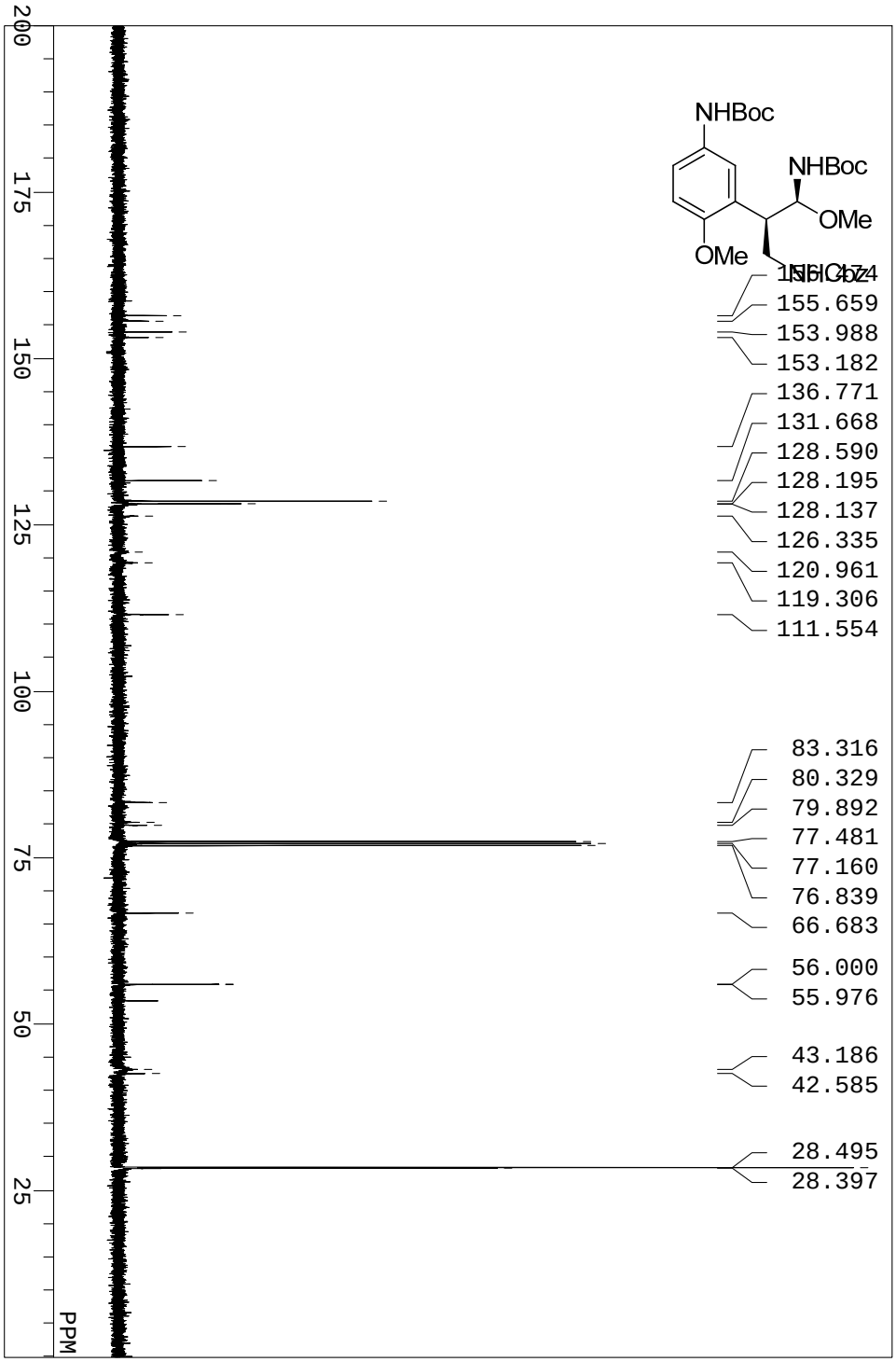
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120.961
119.306
111.554
83.316
80.329
79.892
77.481
77.160
76.839
66.683
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28.495
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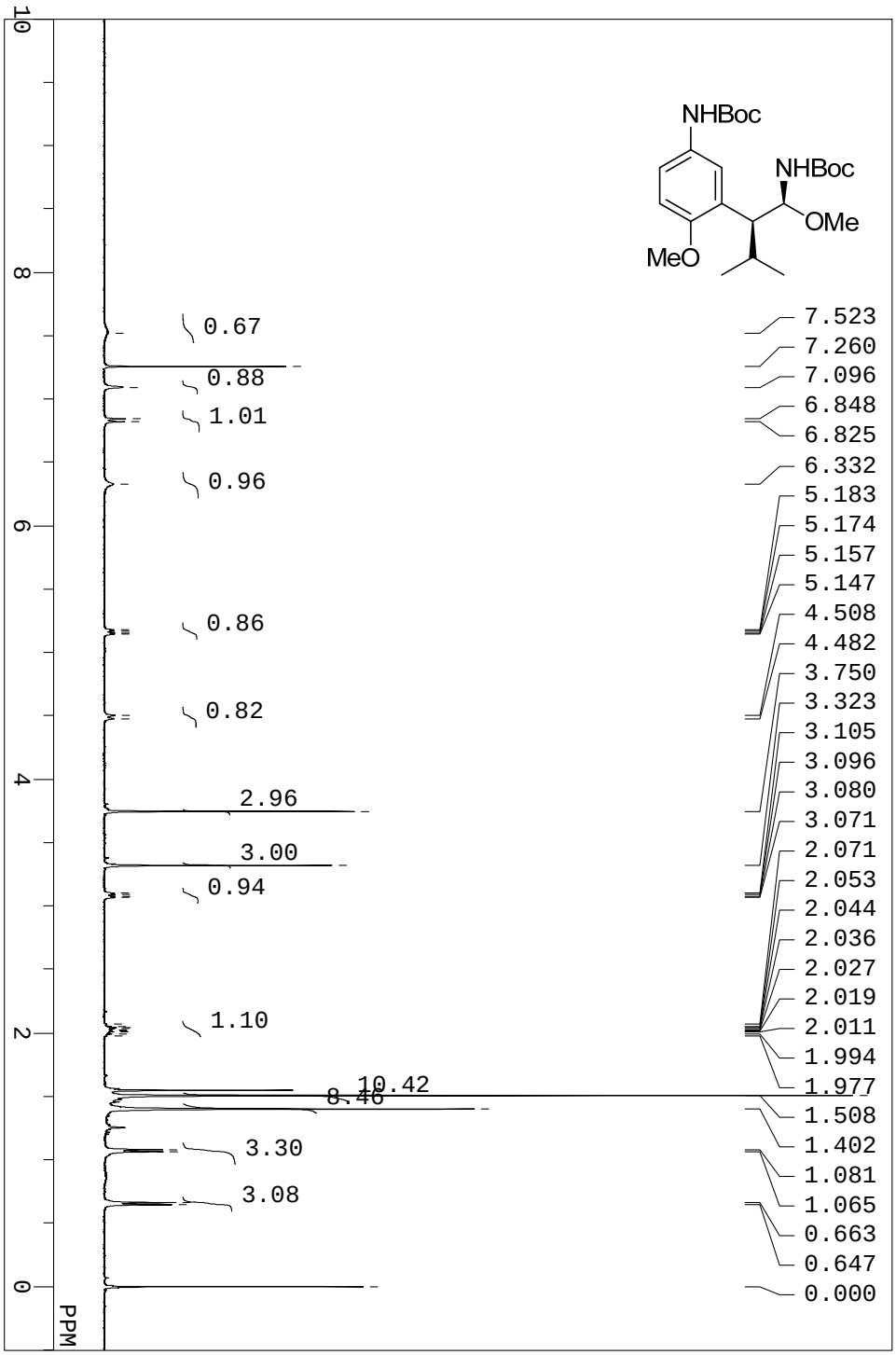
150
125
100
75
50
25
PPM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0.86
0.82
2.96
3.00
0.94
1.10
10.42
8.46
3.30
3.08
7.523
7.260
7.096
6.848
6.825
6.332
5.183
5.174
5.157
5.147
4.508
4.482
3.750
3.323
3.105
3.096
3.080
3.071
2.071
2.053
2.044
2.036
2.027
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1.081
1.065
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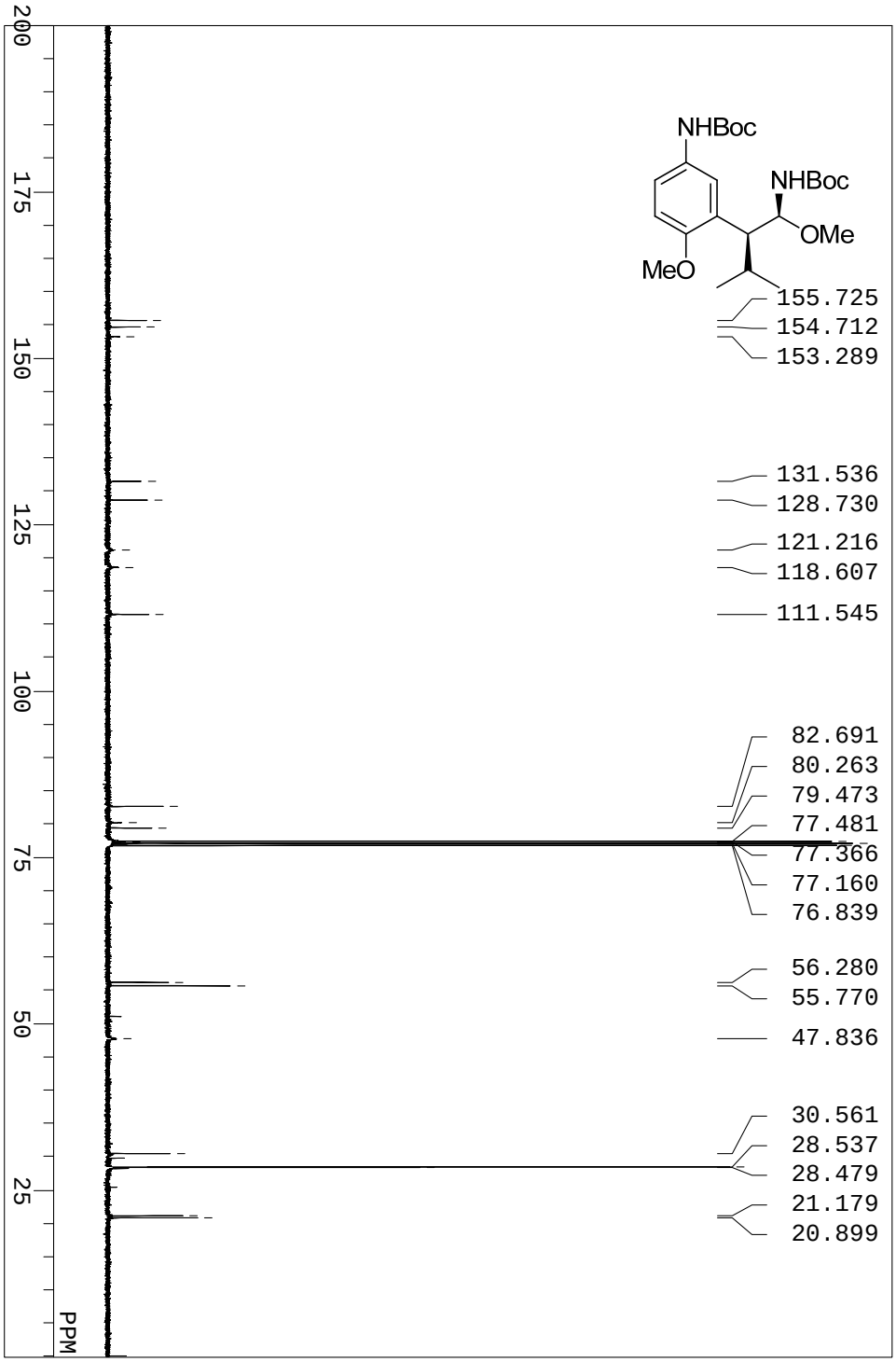
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82.691
80.263
79.473
77.481
77.366
77.160
76.839
56.280
55.770
47.836
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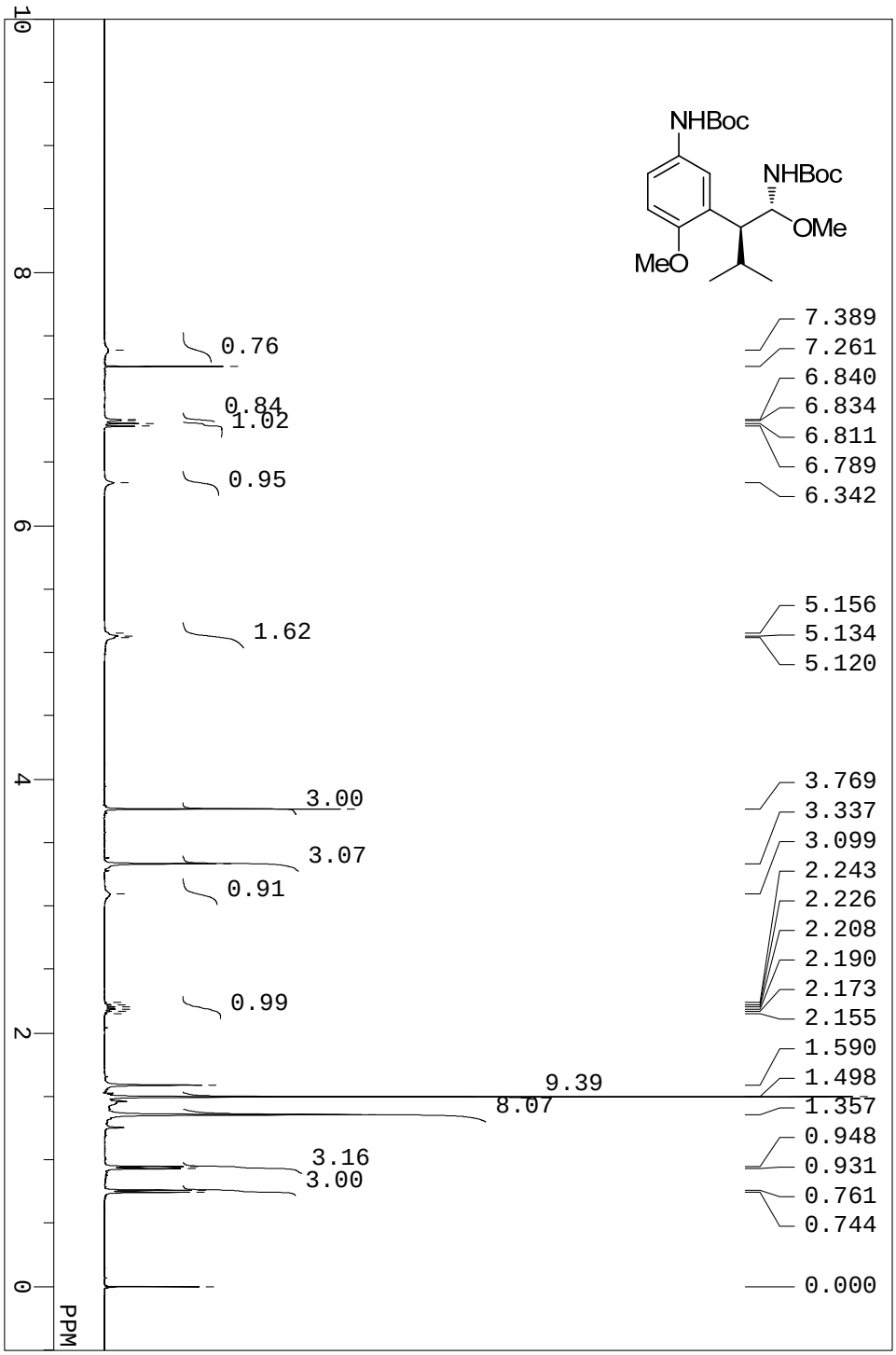
28.537
28.479
21.179
20.899
200
175
150
125
100
75
50
25
PPM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NHBoc
OMe
MeO
10
8
6
4
2
0
PPM
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0.84
1.02
0.95
1.62
3.00
3.07
0.91
0.99
9.39
8.07
3.16
3.00
7.389
7.261
6.840
6.834
6.811
6.789
6.342
5.156
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2.243
2.226
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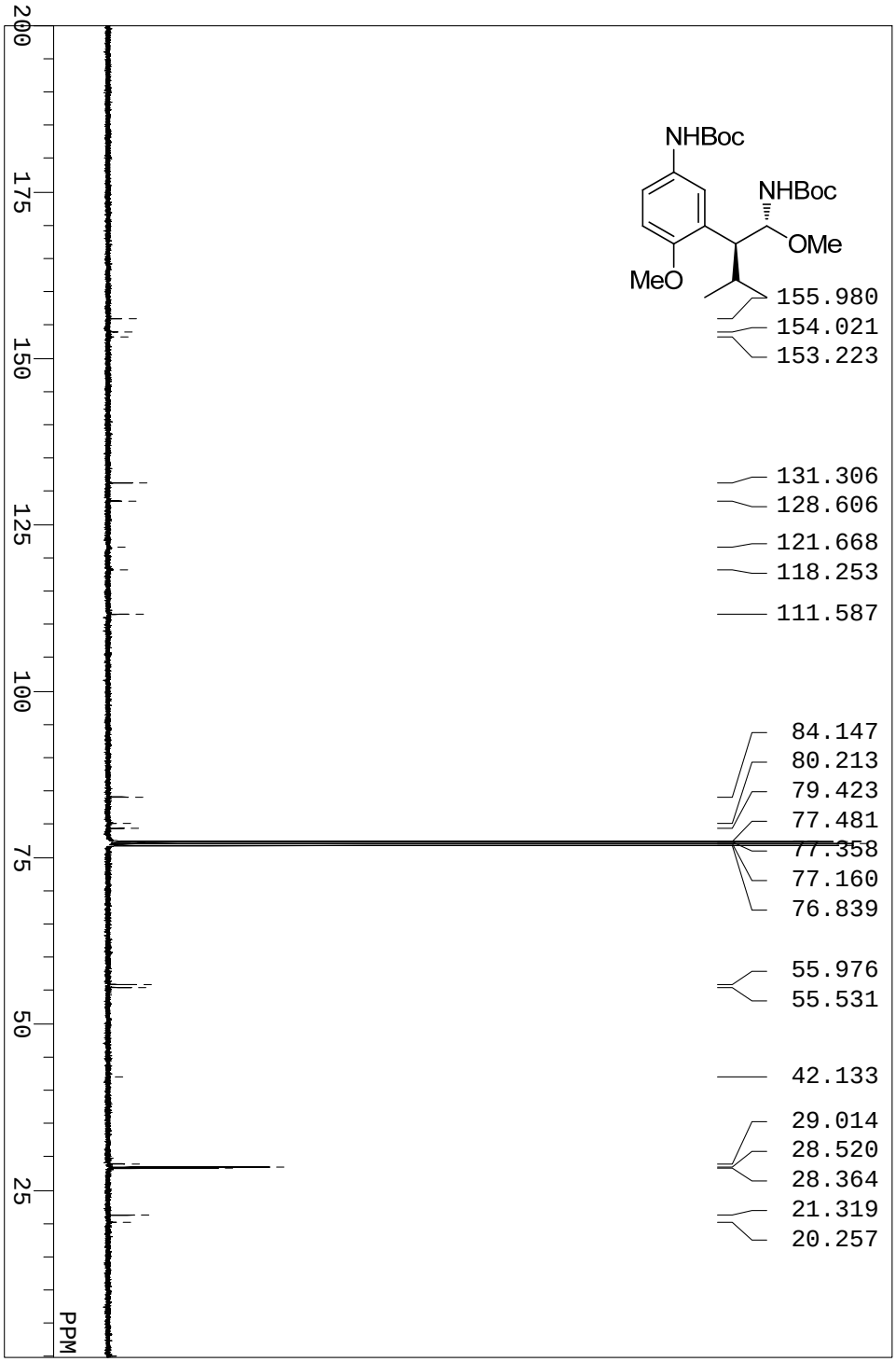
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76.839
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150
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100
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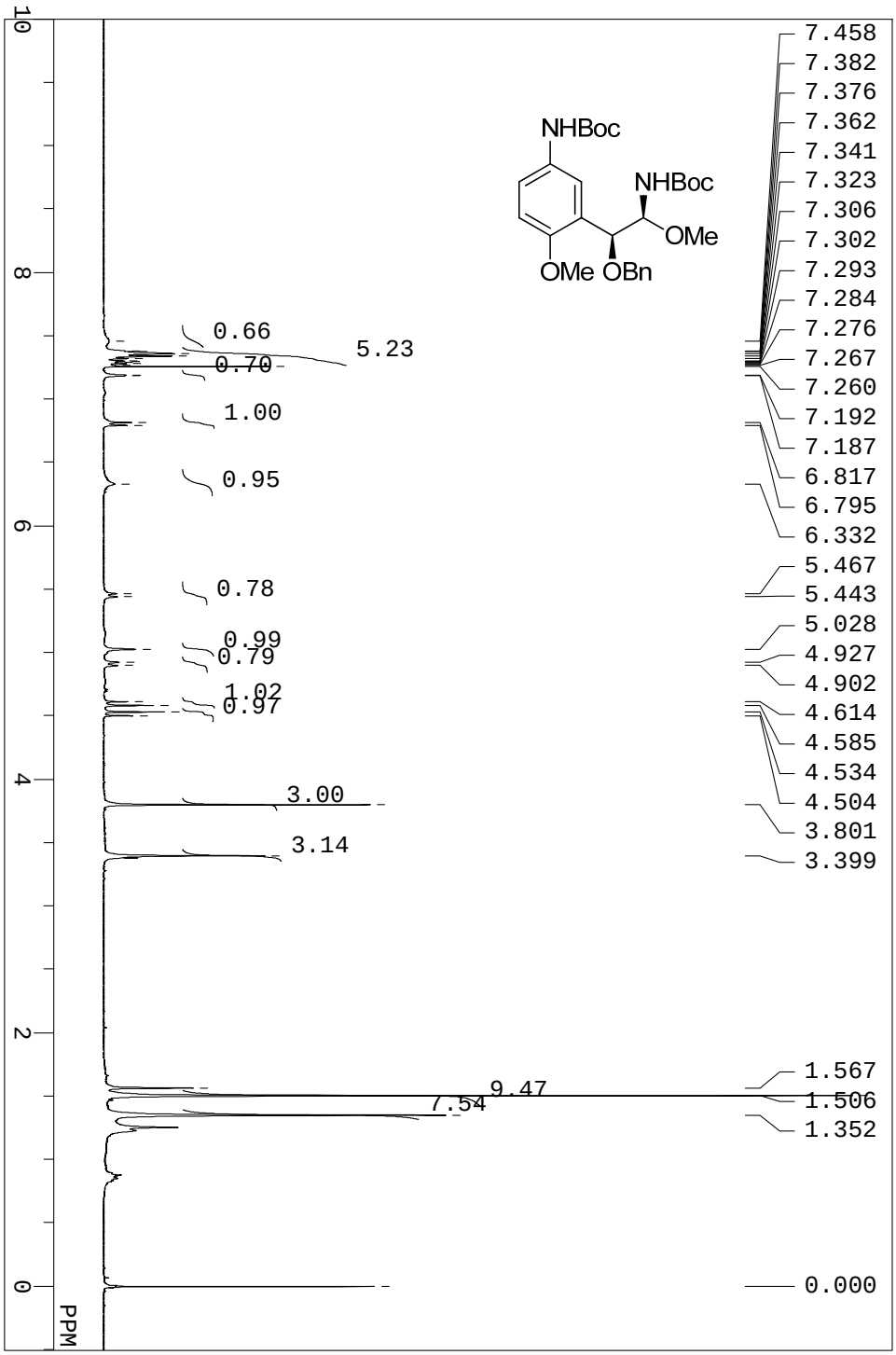
25
PPM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NHBoc
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OMe OBn
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7.293
7.284
7.276
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4.927
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1.567
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0.78
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3.00
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10
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2
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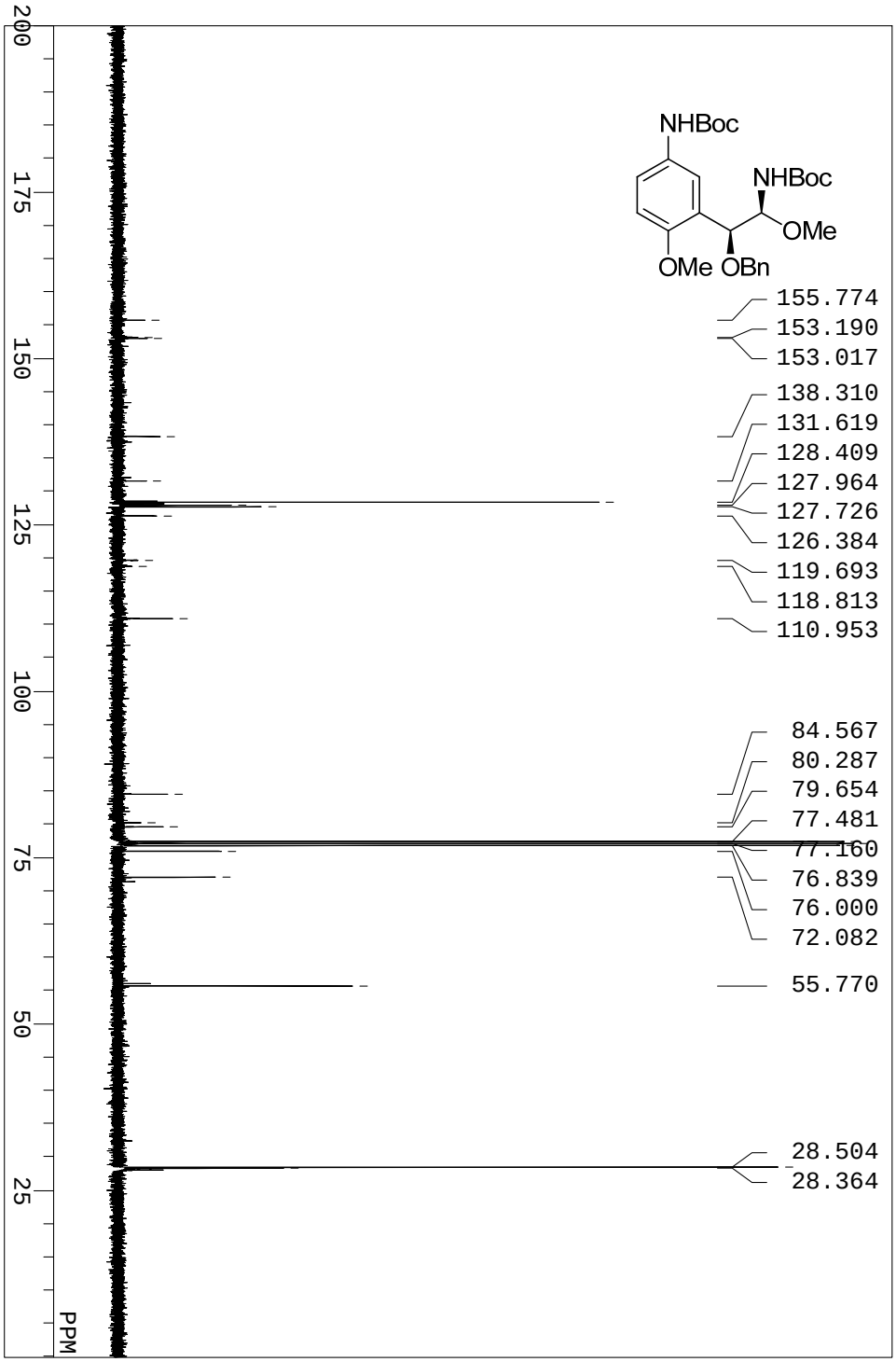
PPM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NHBoc
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OMe OBn
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127.726
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119.693
118.813
110.953
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79.654
77.481
77.160
76.839
76.000
72.082
55.770
28.504
28.364
200
175
150
125
100
75
50
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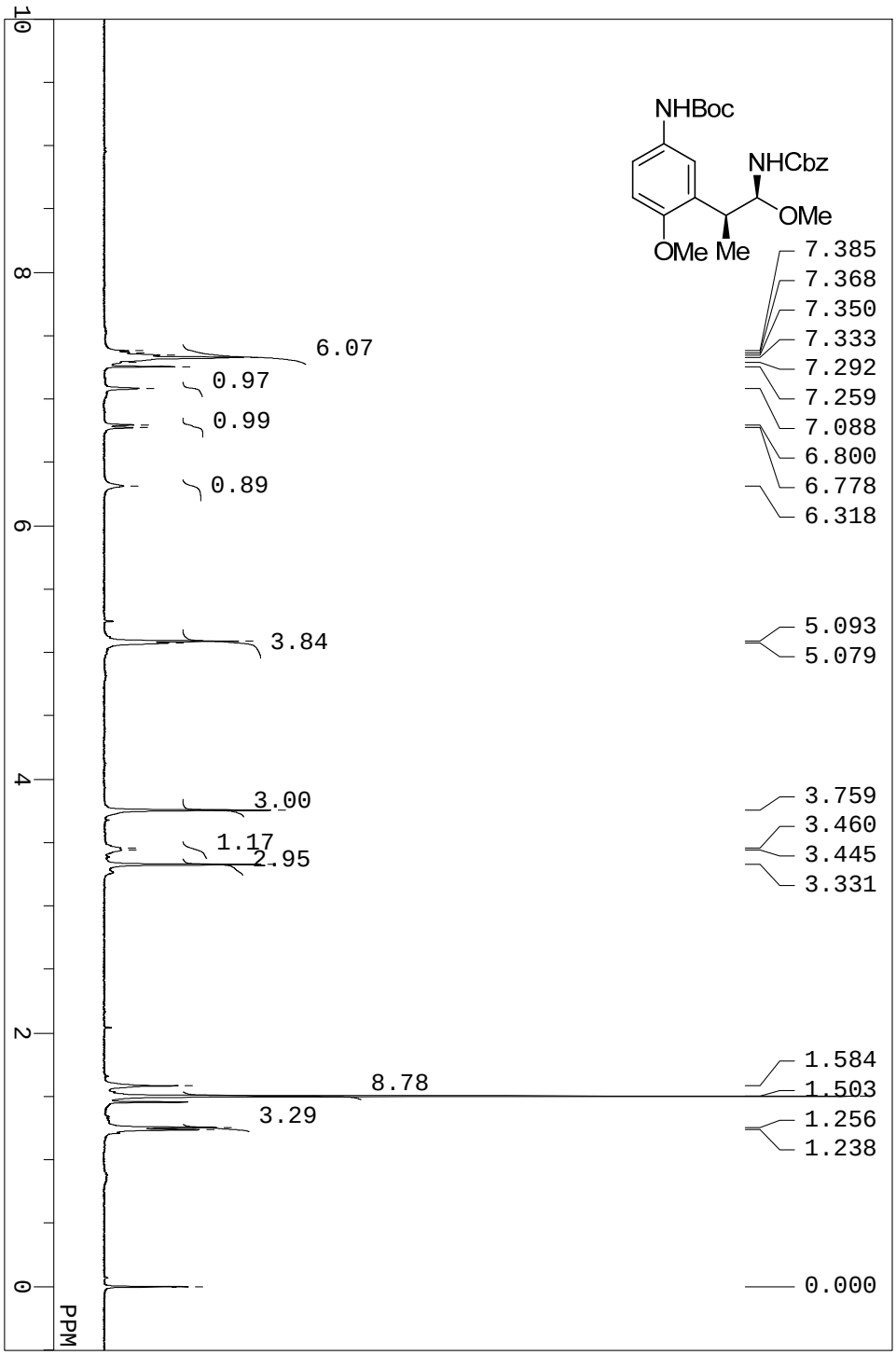
PPM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OMe
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6.778
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5.079
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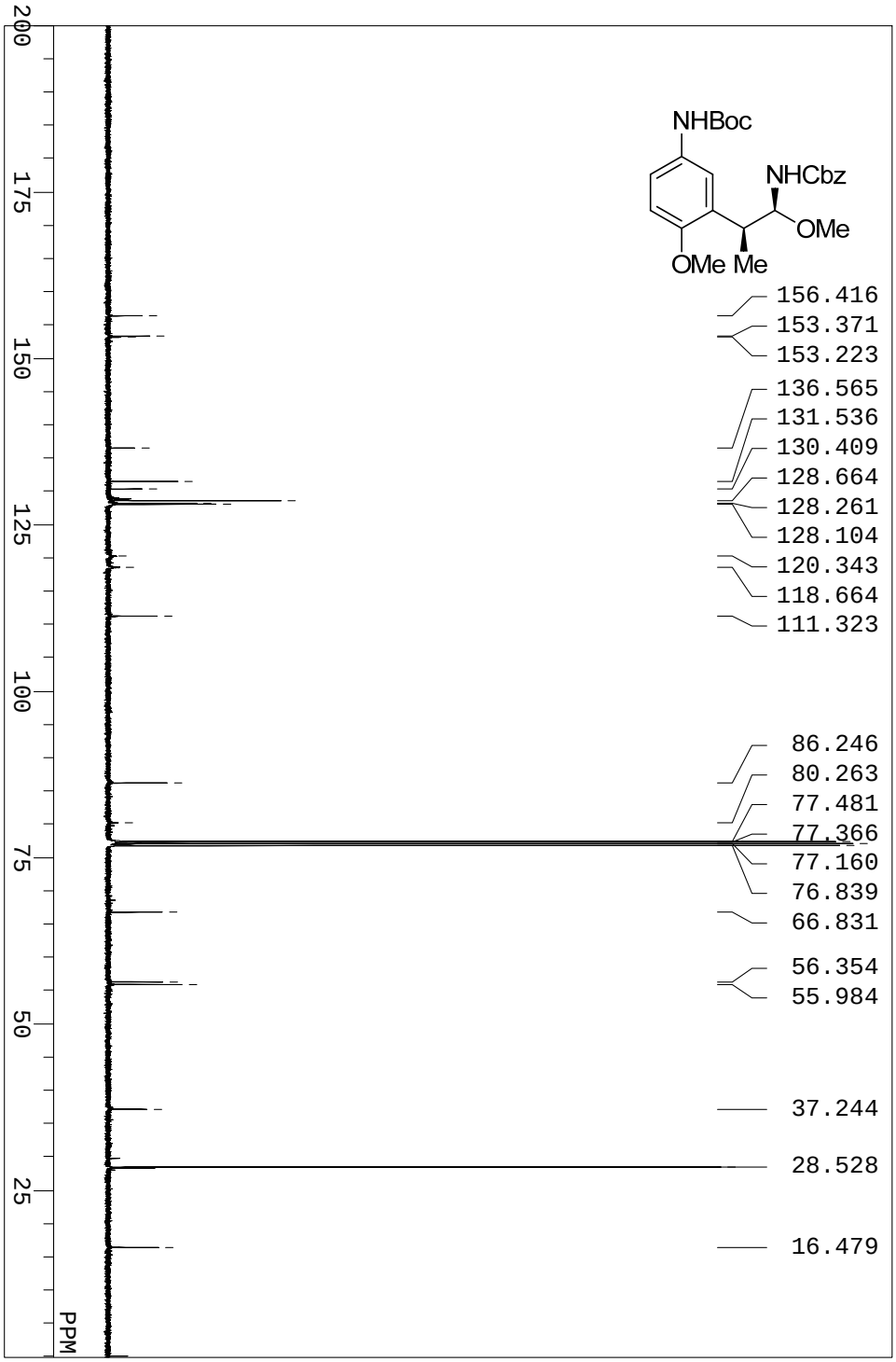
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128.104
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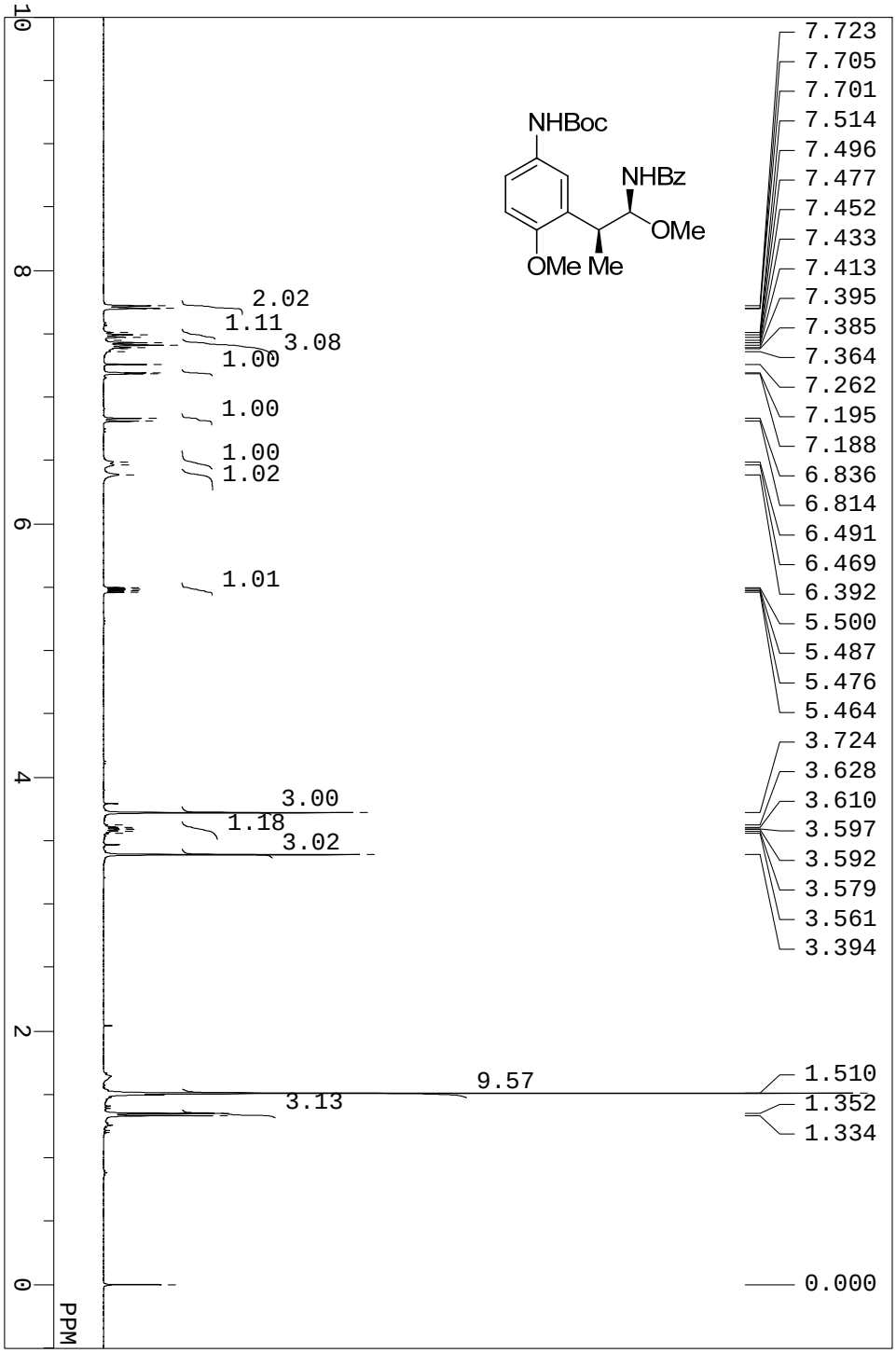
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1.334
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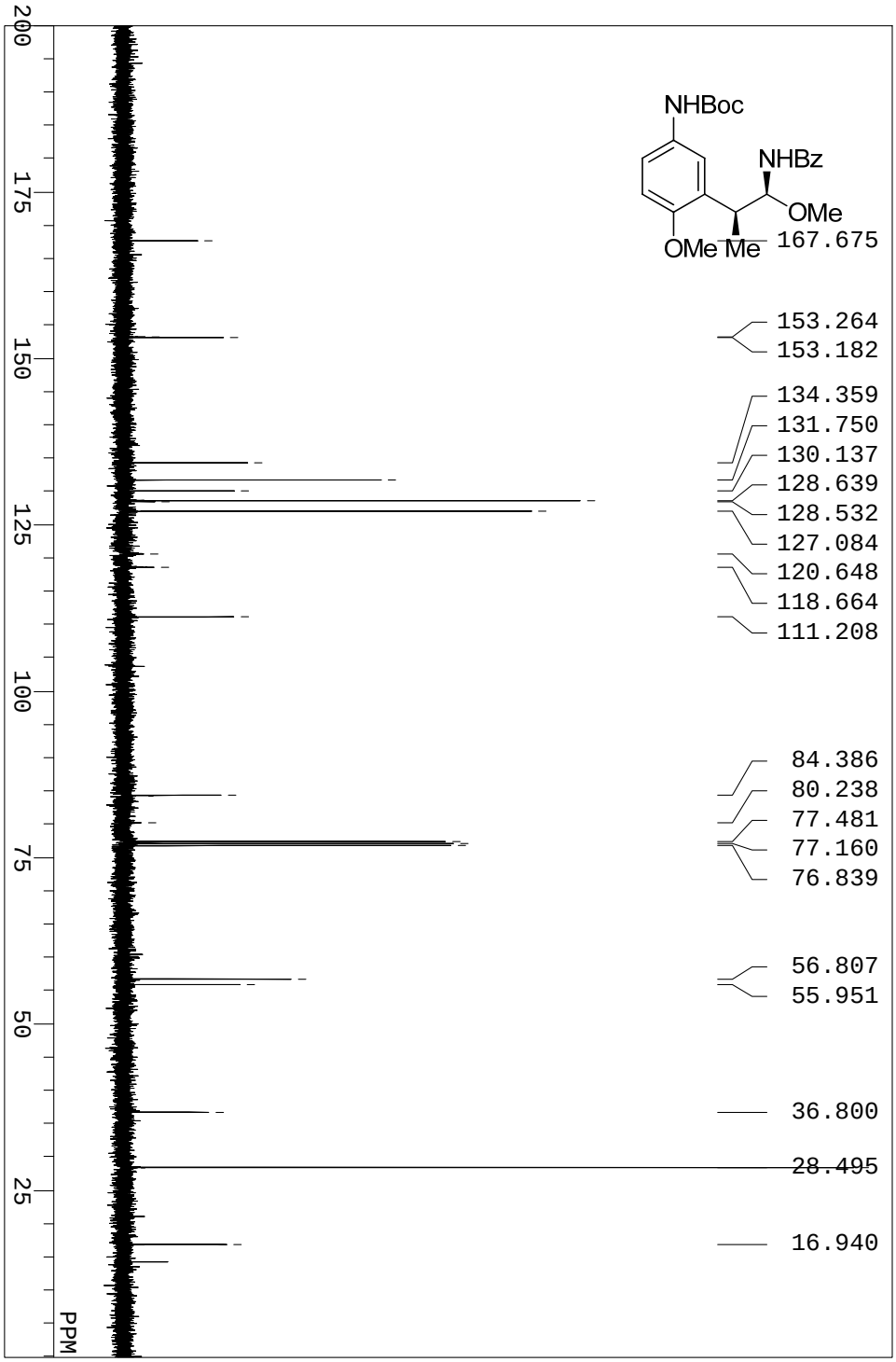
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127.084
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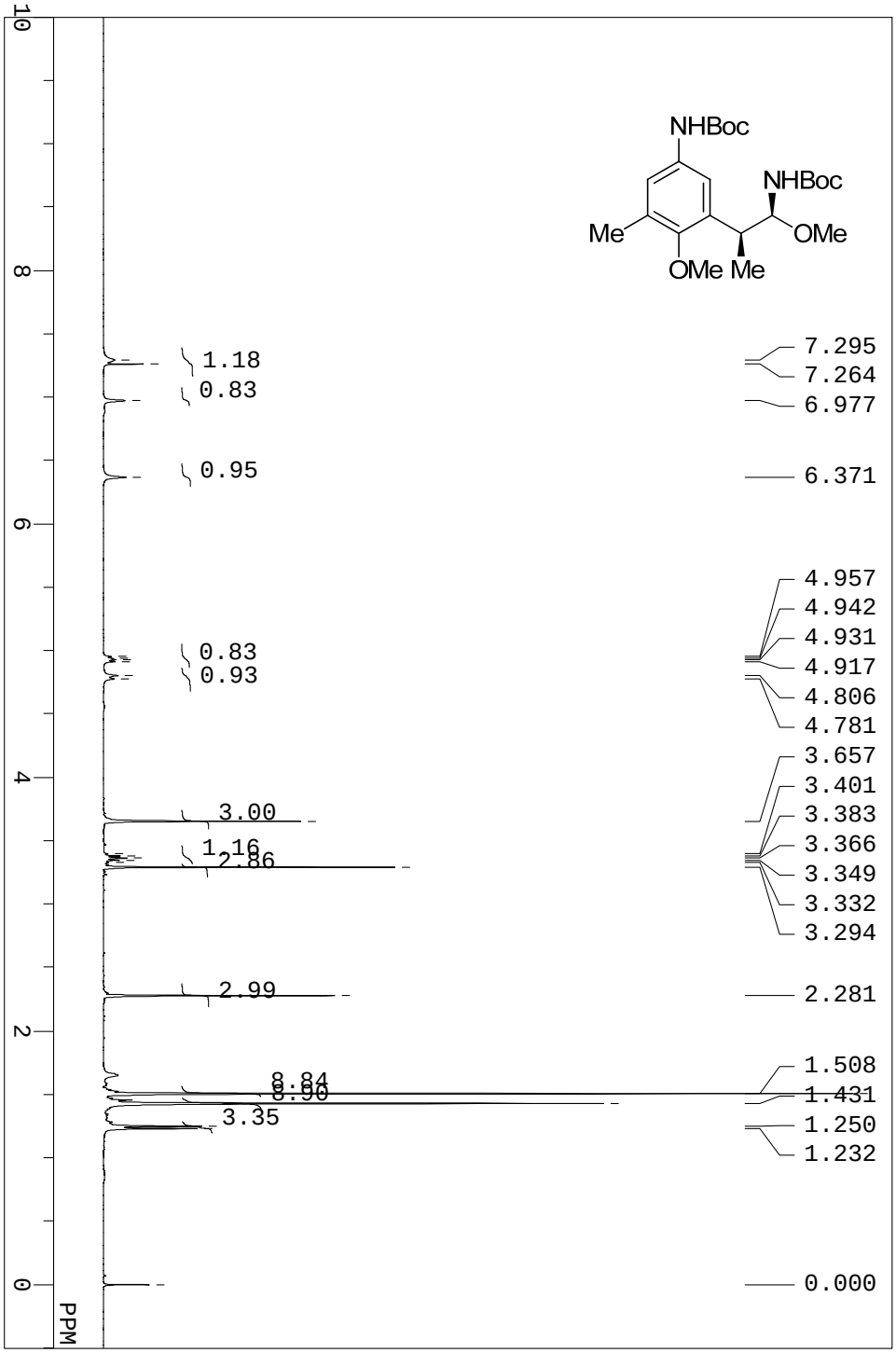
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OMe Me
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2.99
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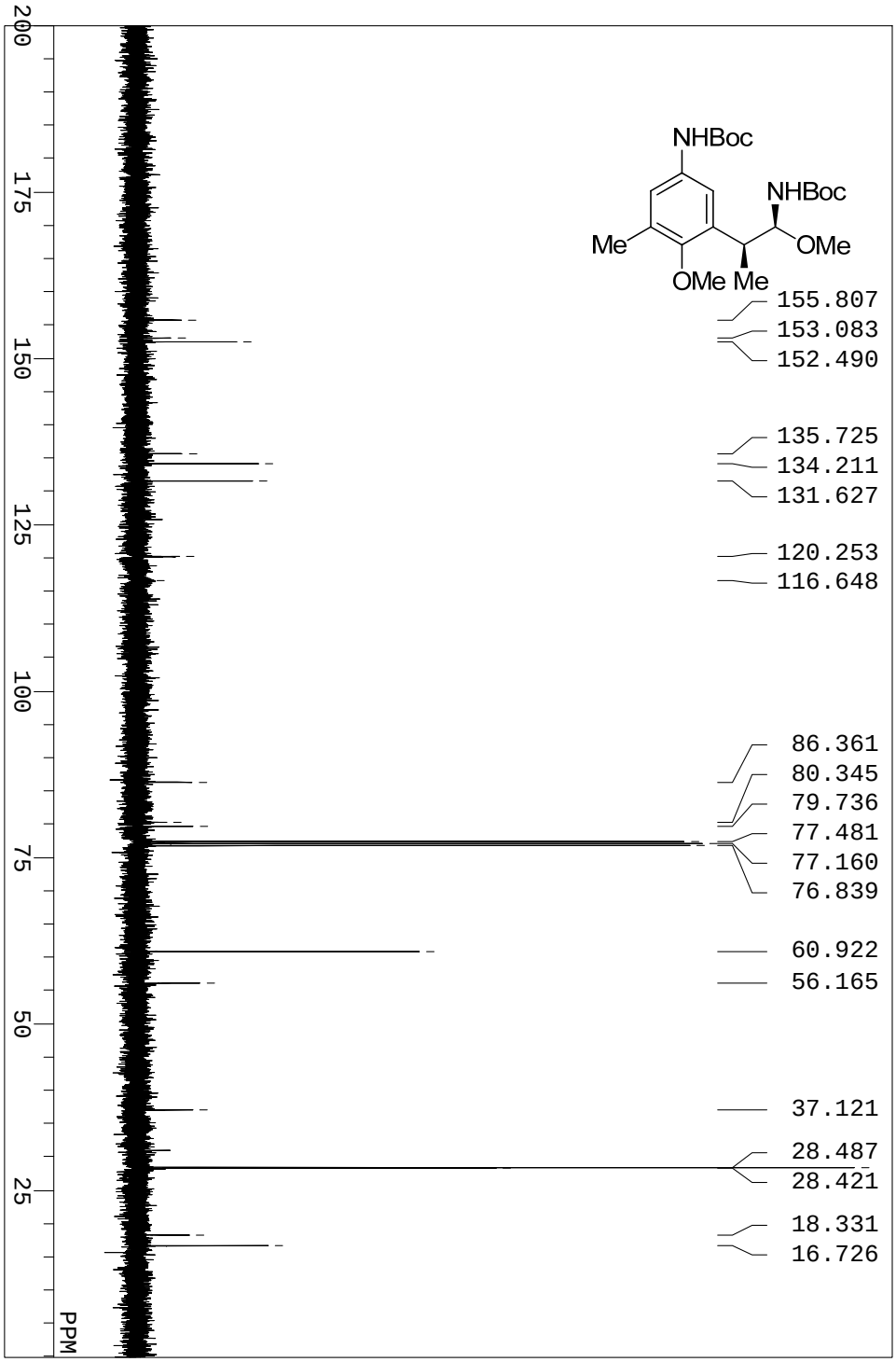
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OMe
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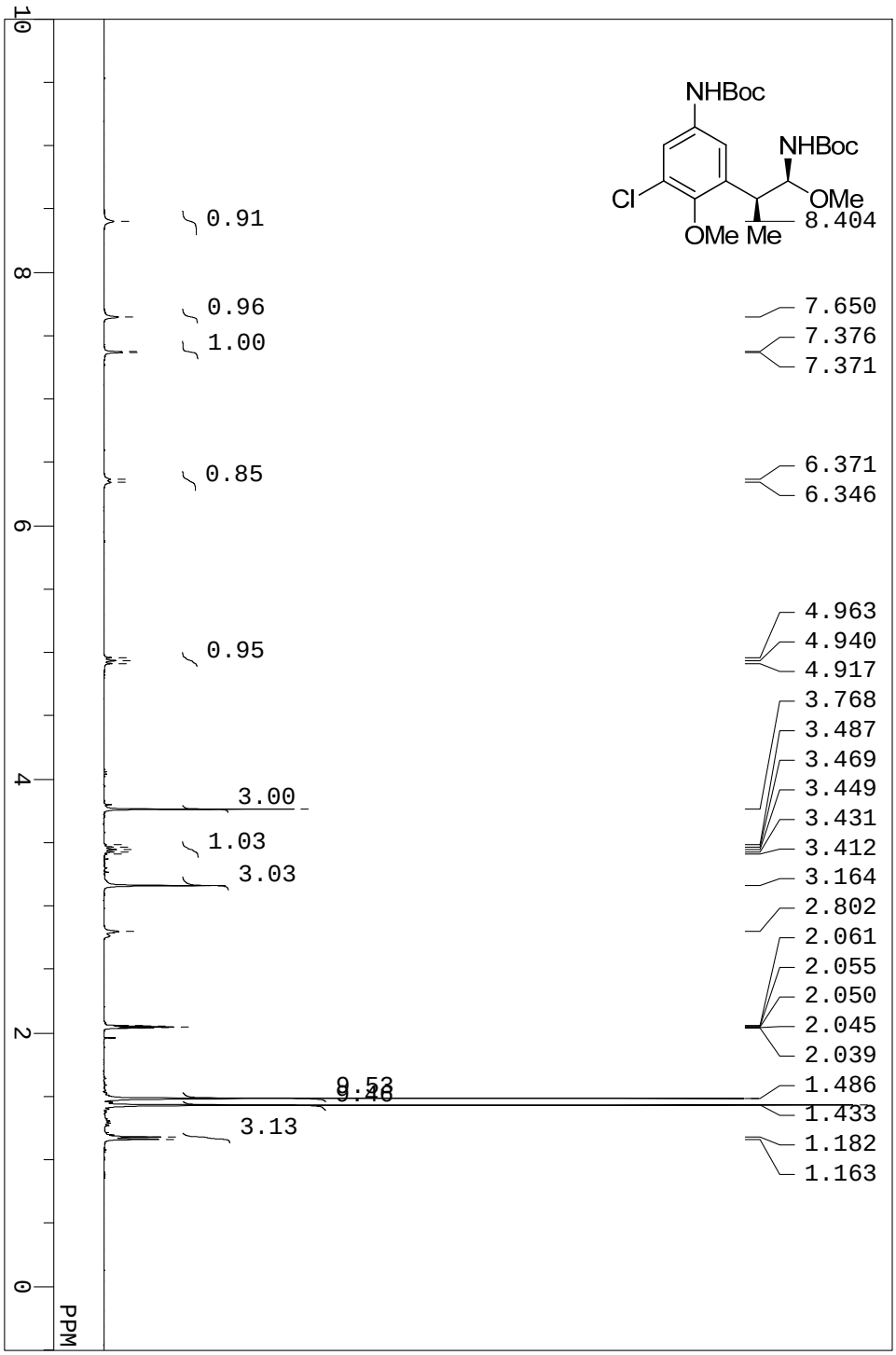
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OMe
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0.95
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6.346
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4.940
4.917
3.768
3.487
3.469
3.449
3.431
3.412
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2.055
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2.045
2.039
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1.163
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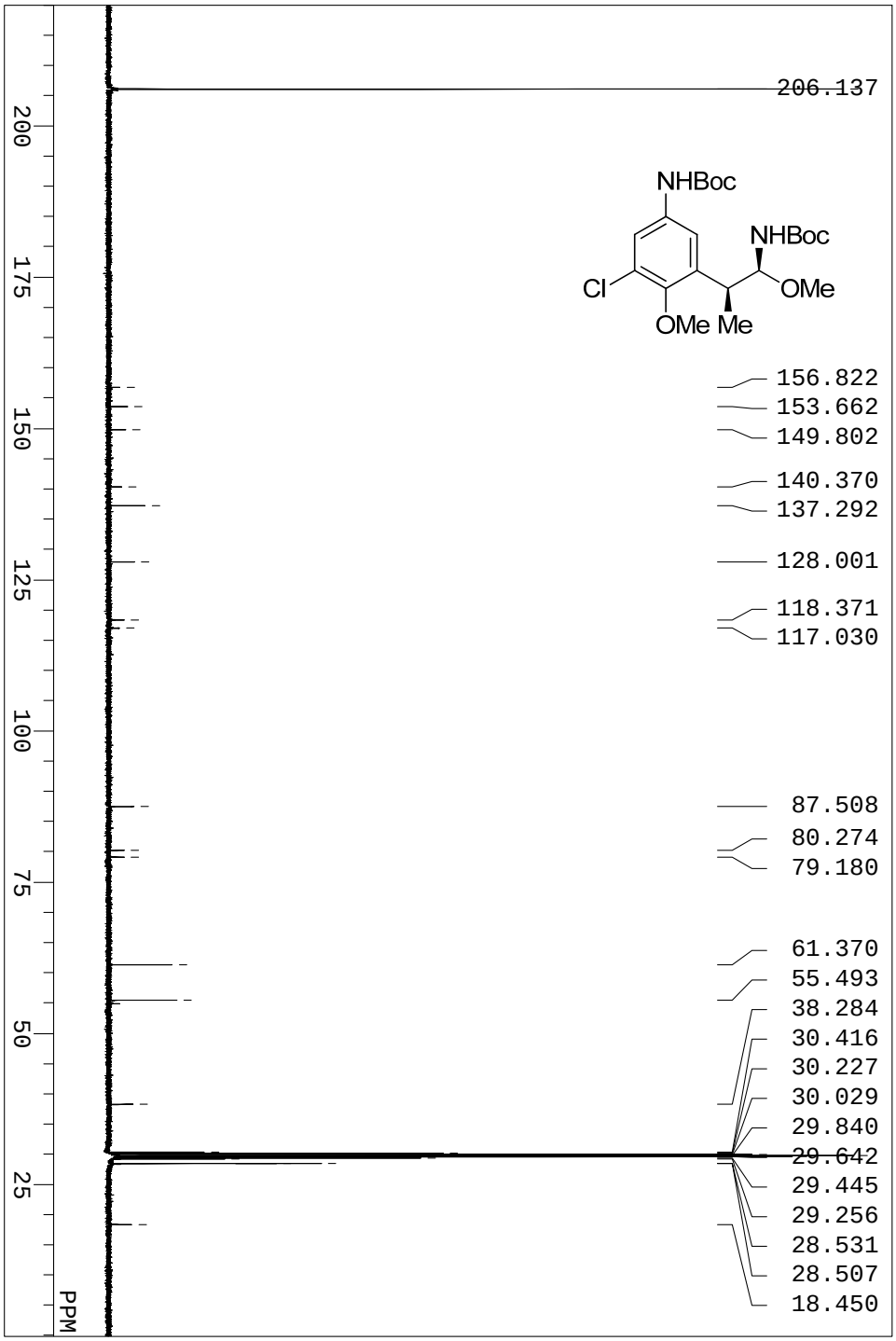
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30.227
30.029
29.840
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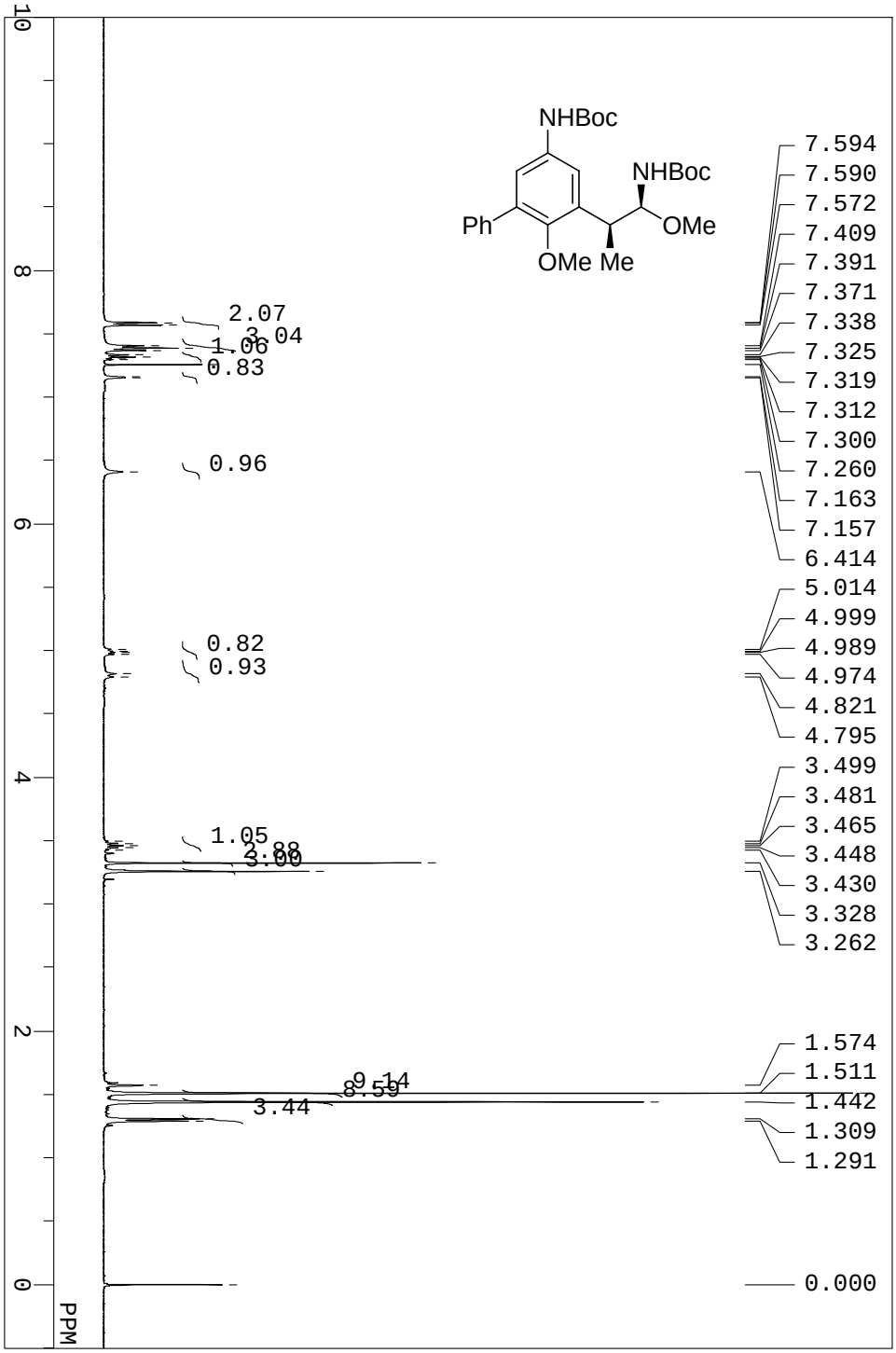
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7.319
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7.260
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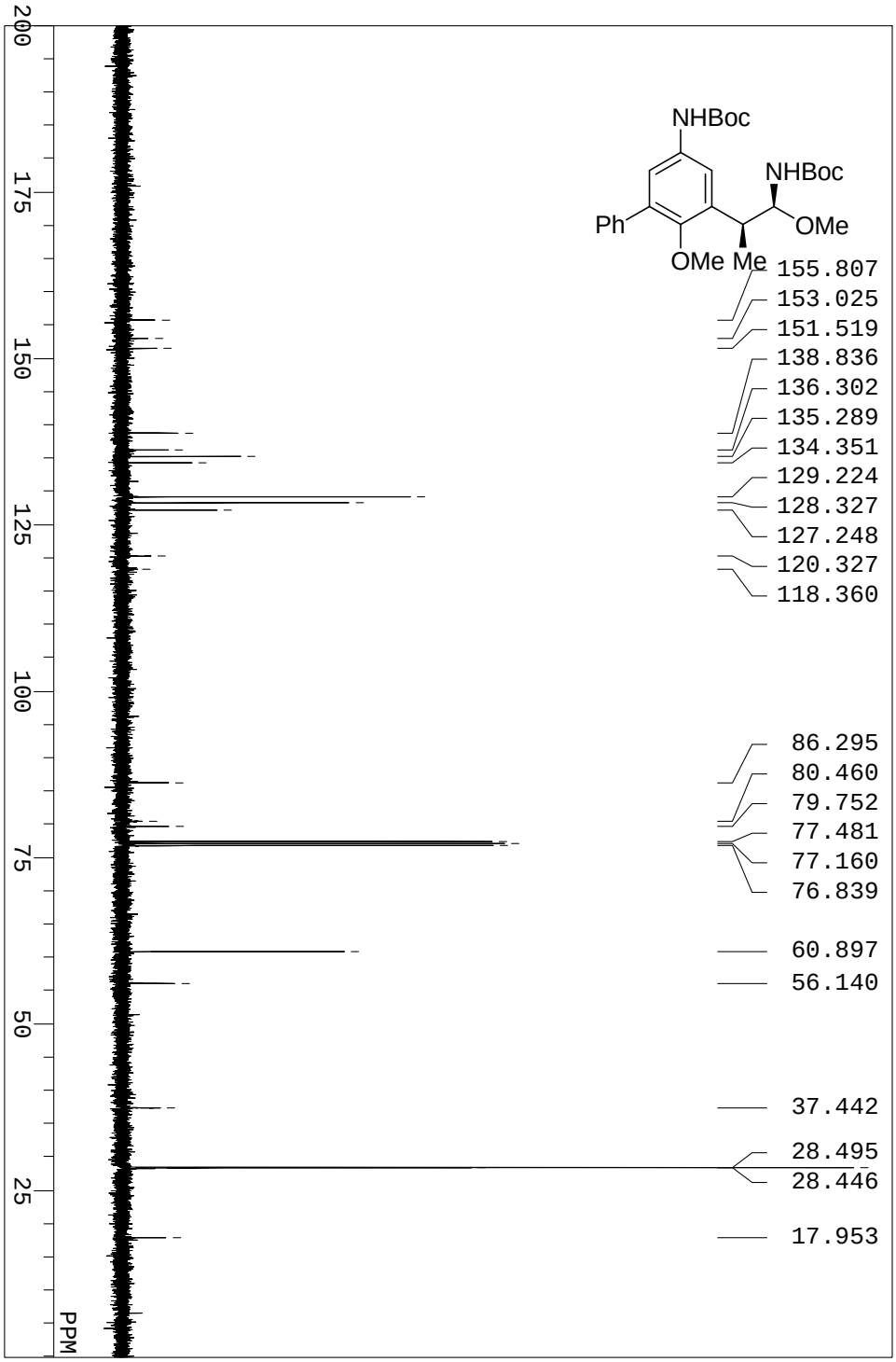
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50
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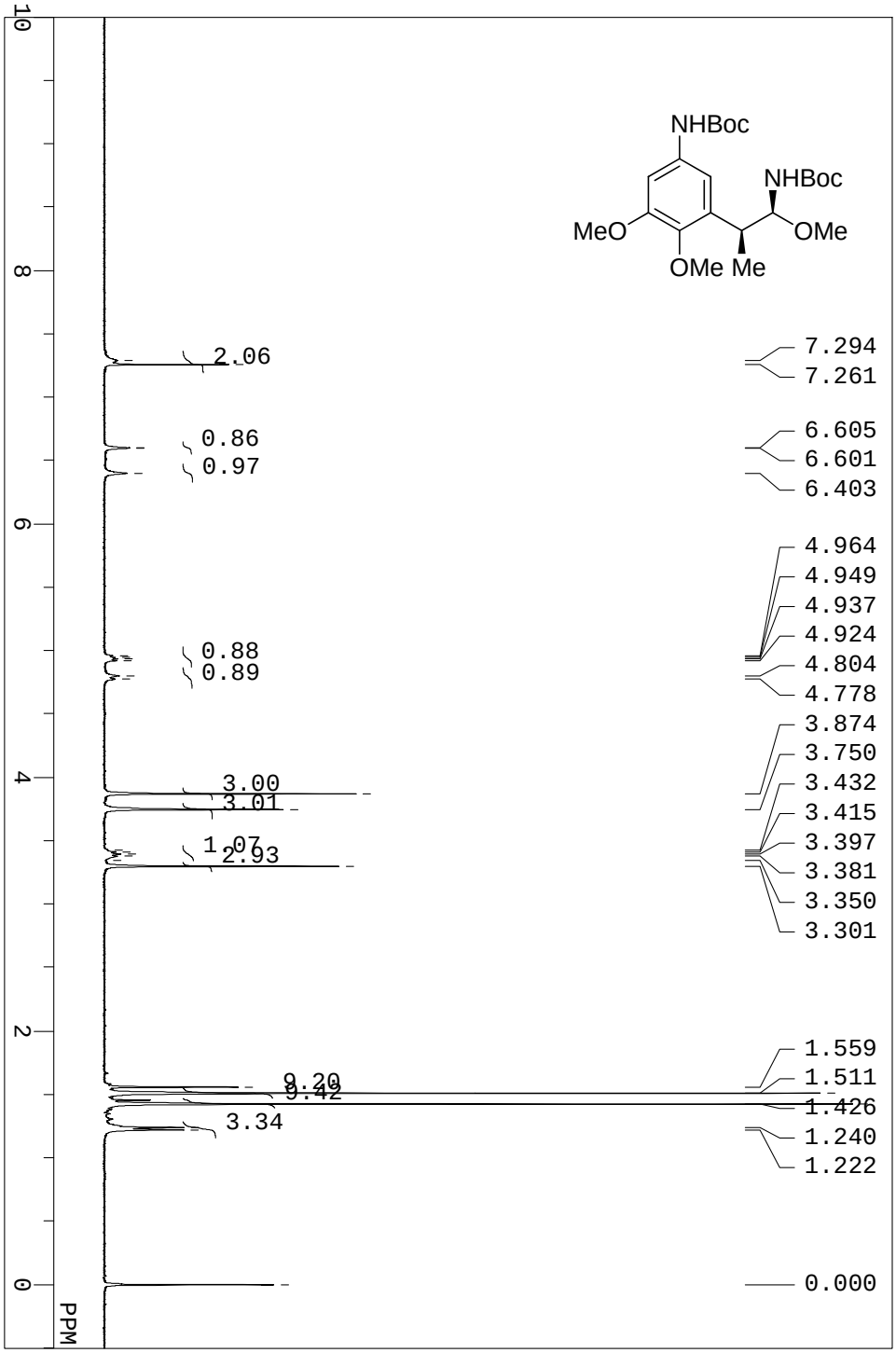
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OMe
Me
10
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6
4
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PPM
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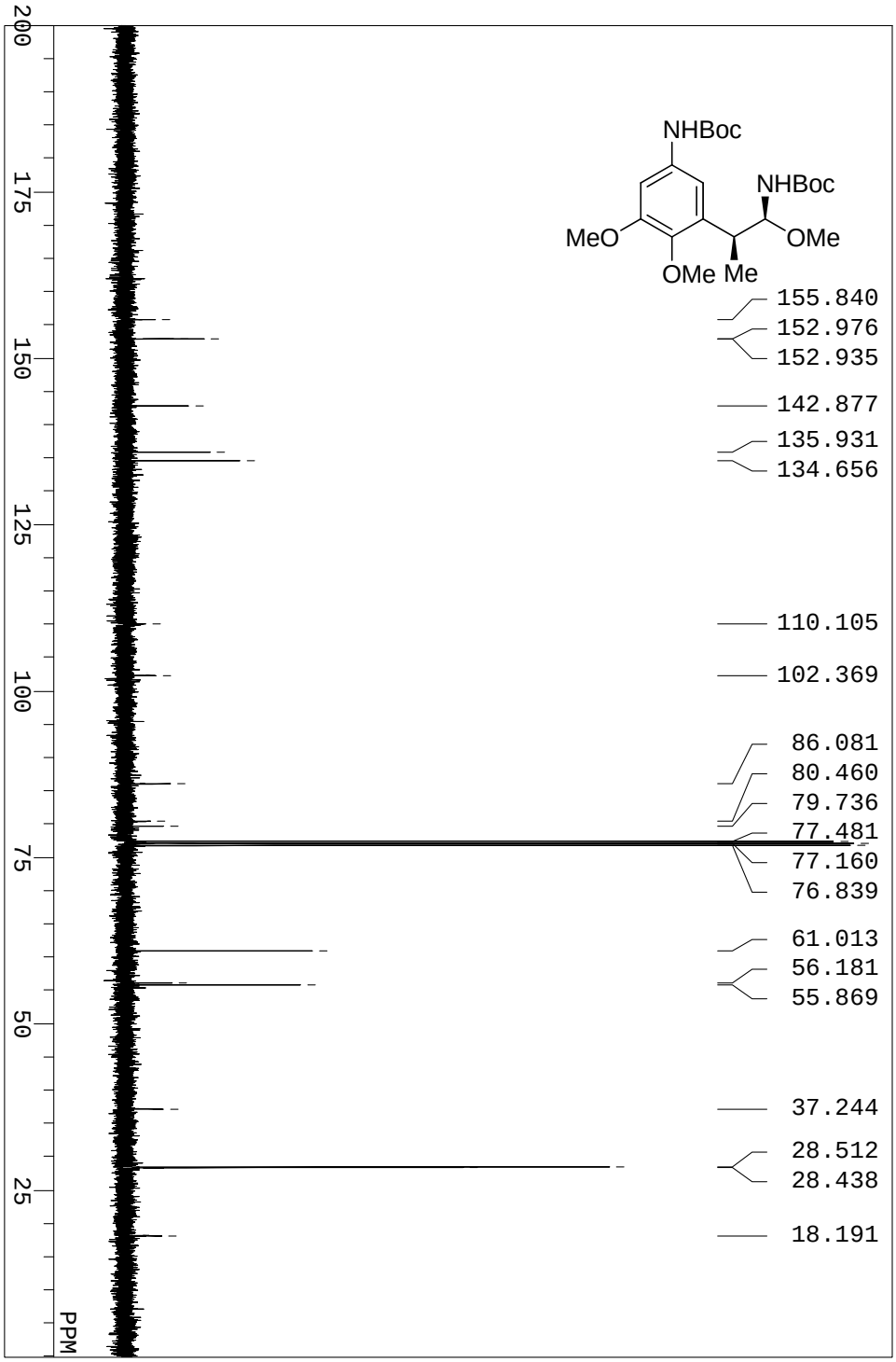
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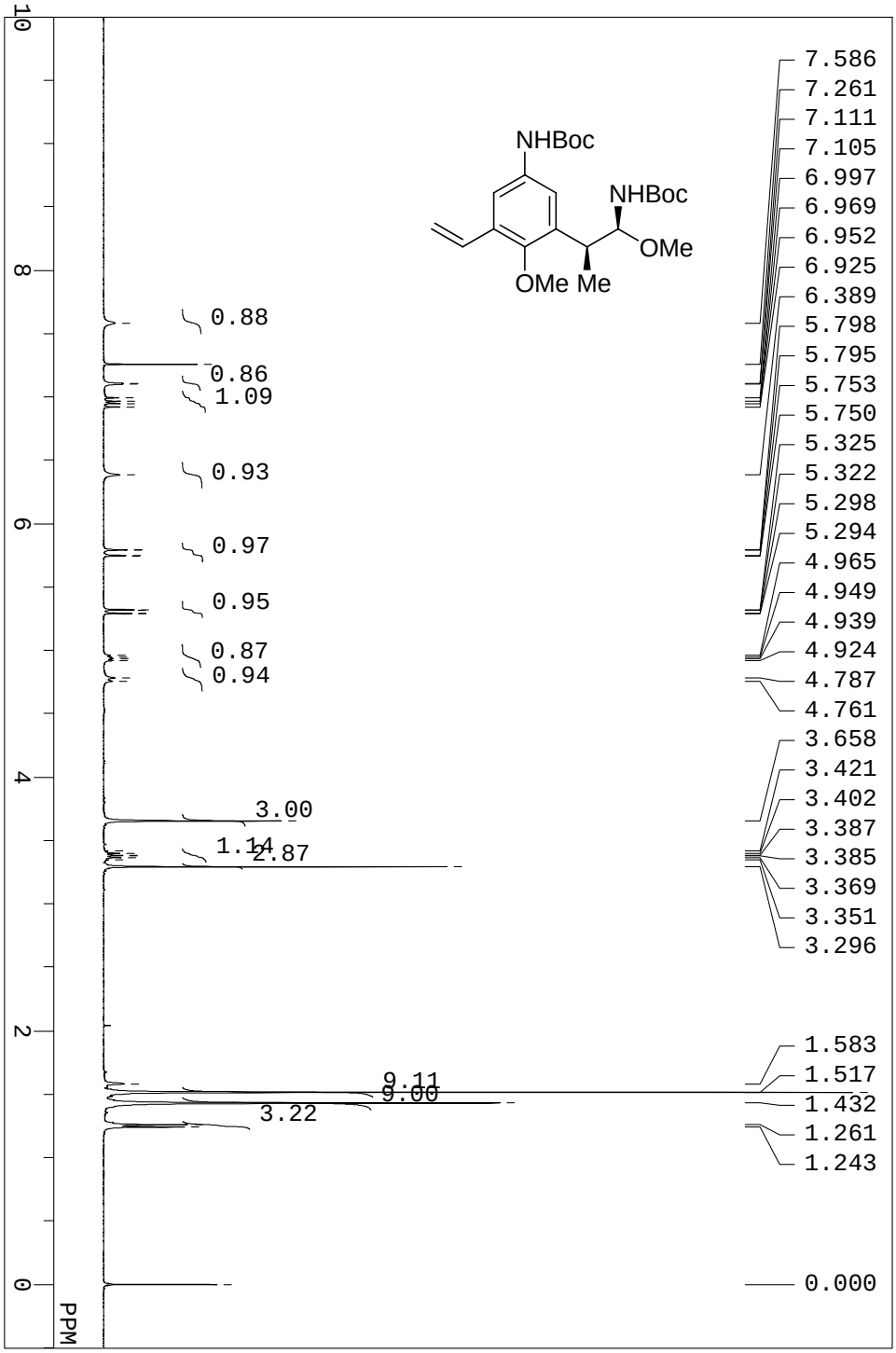
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0.95
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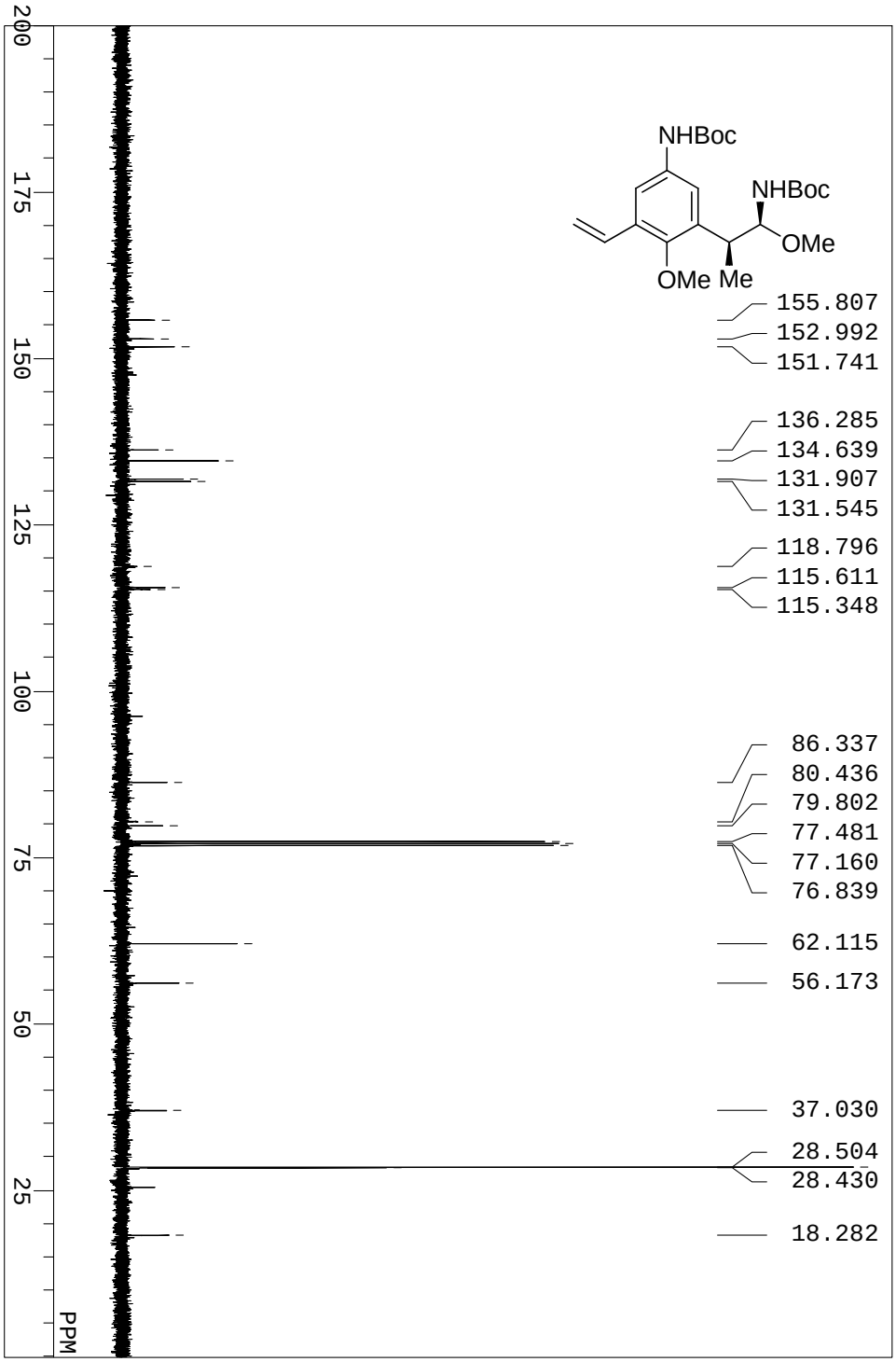
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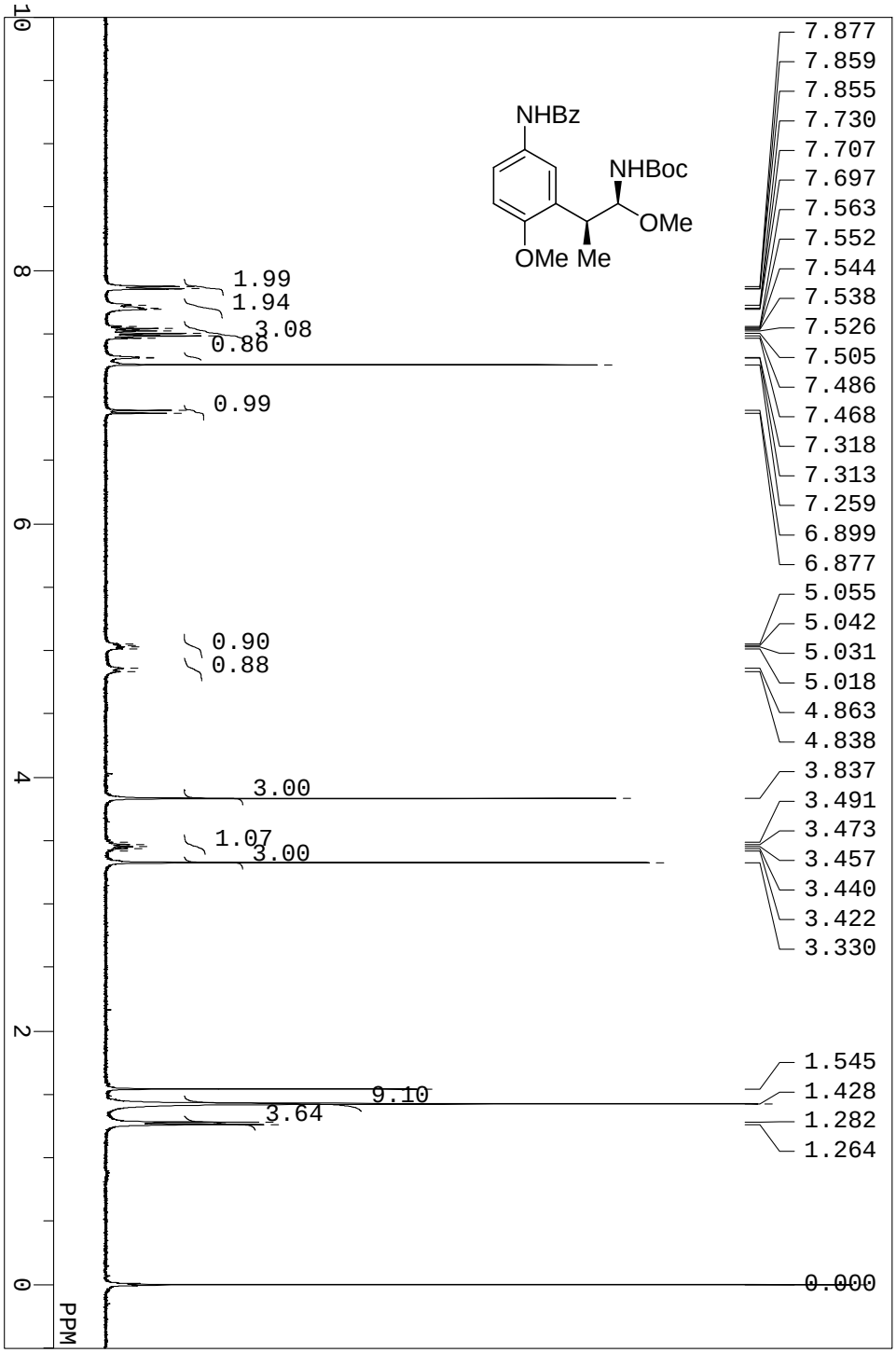
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OMe
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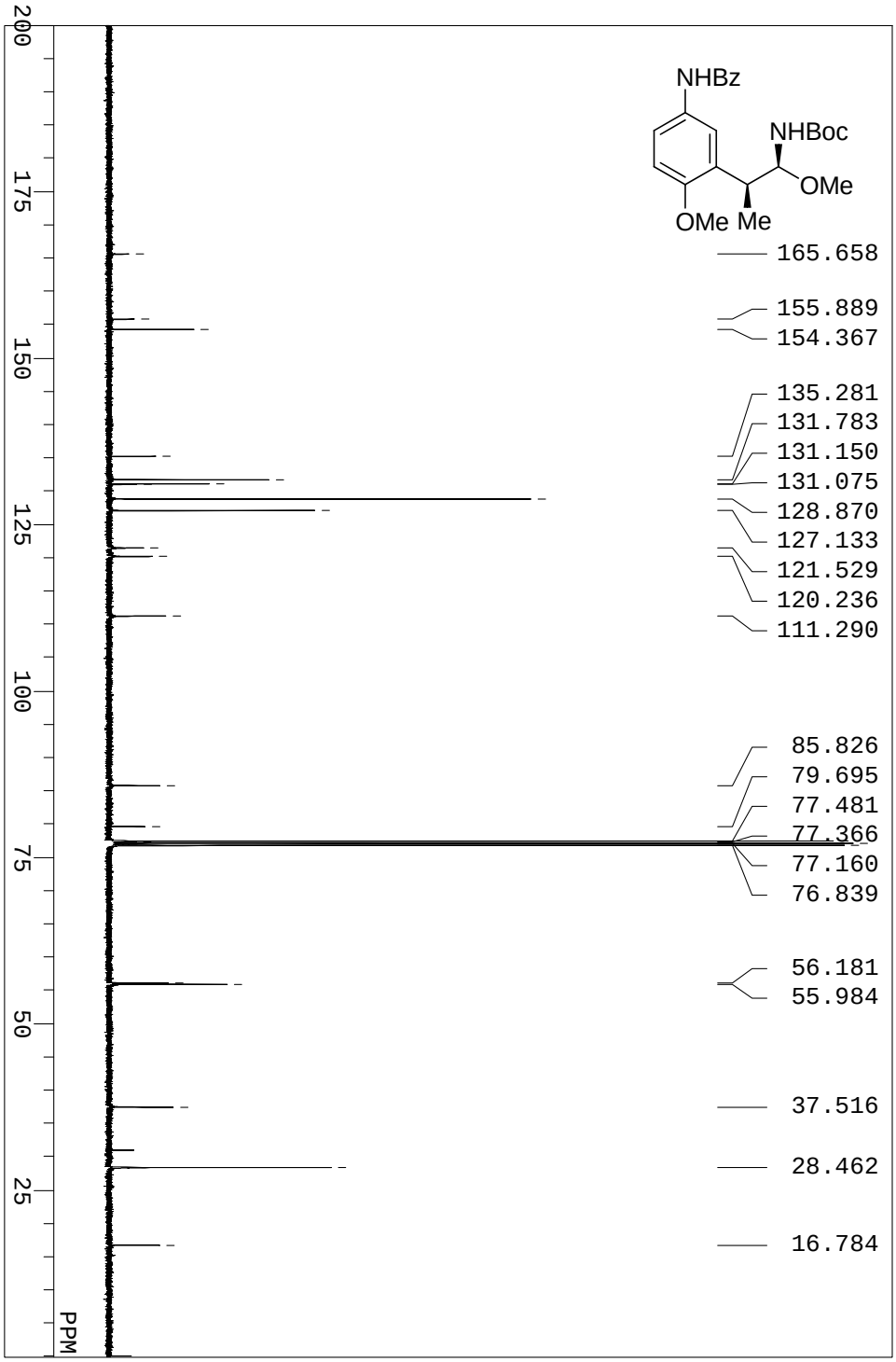
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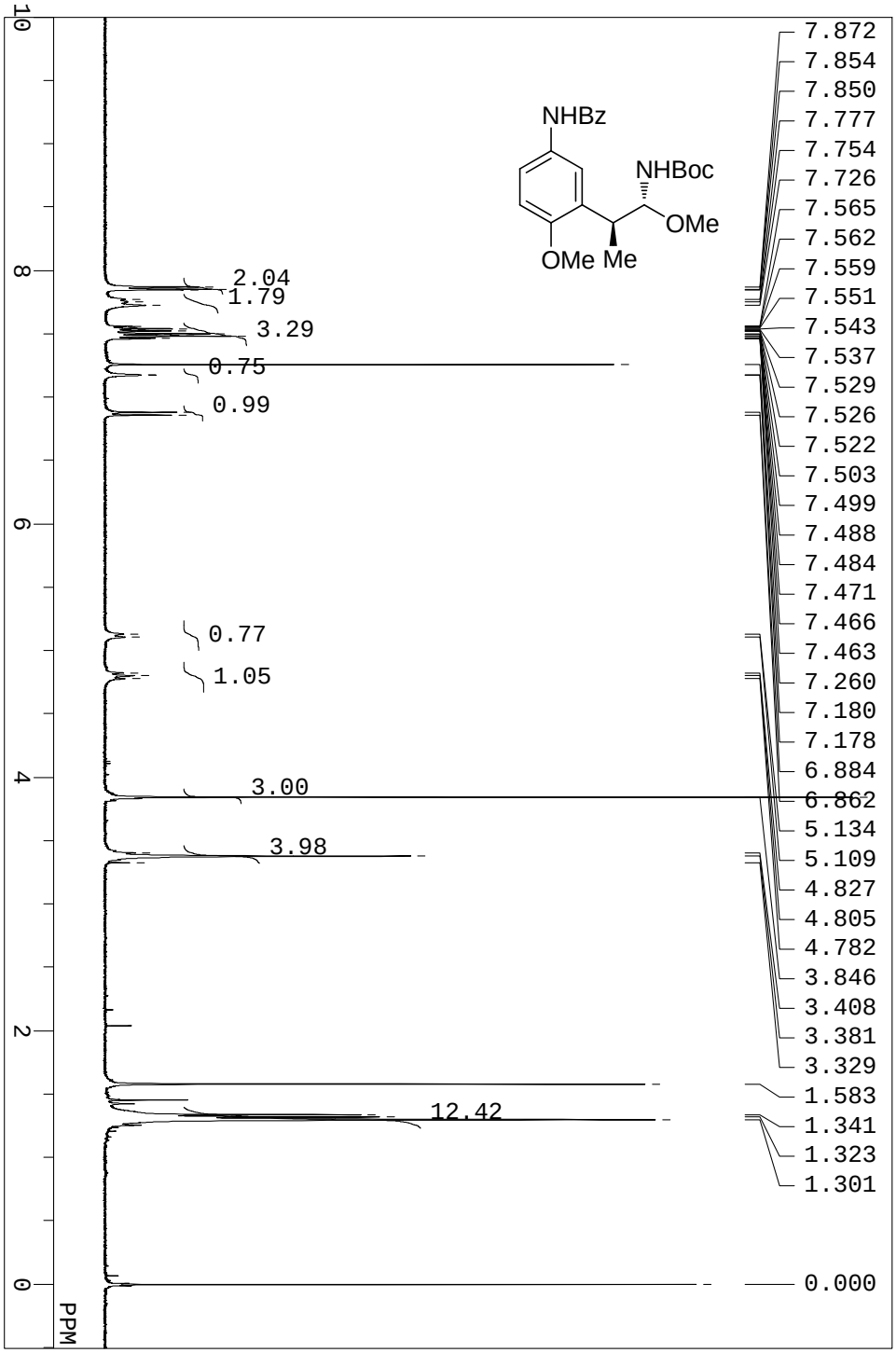
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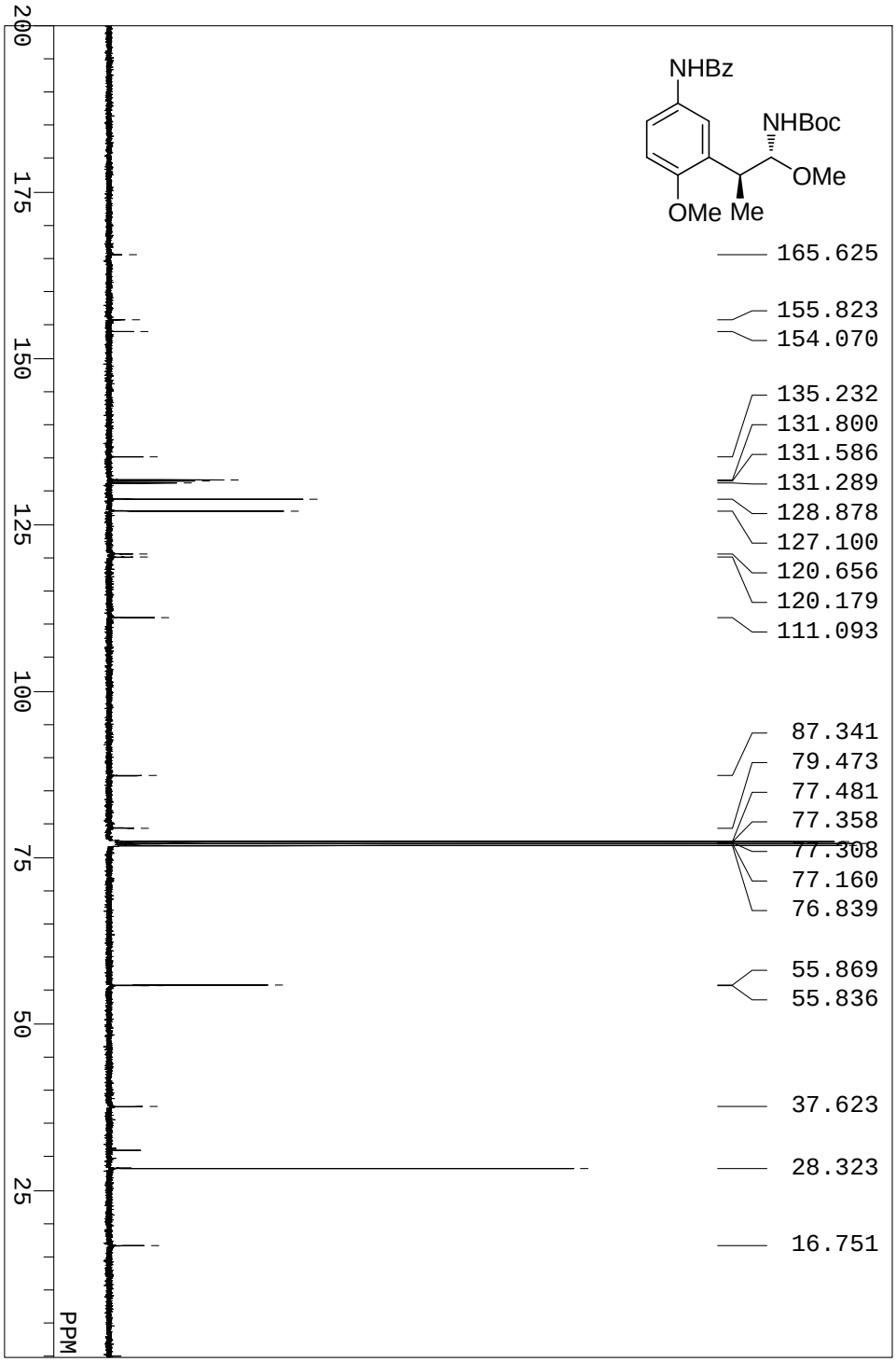
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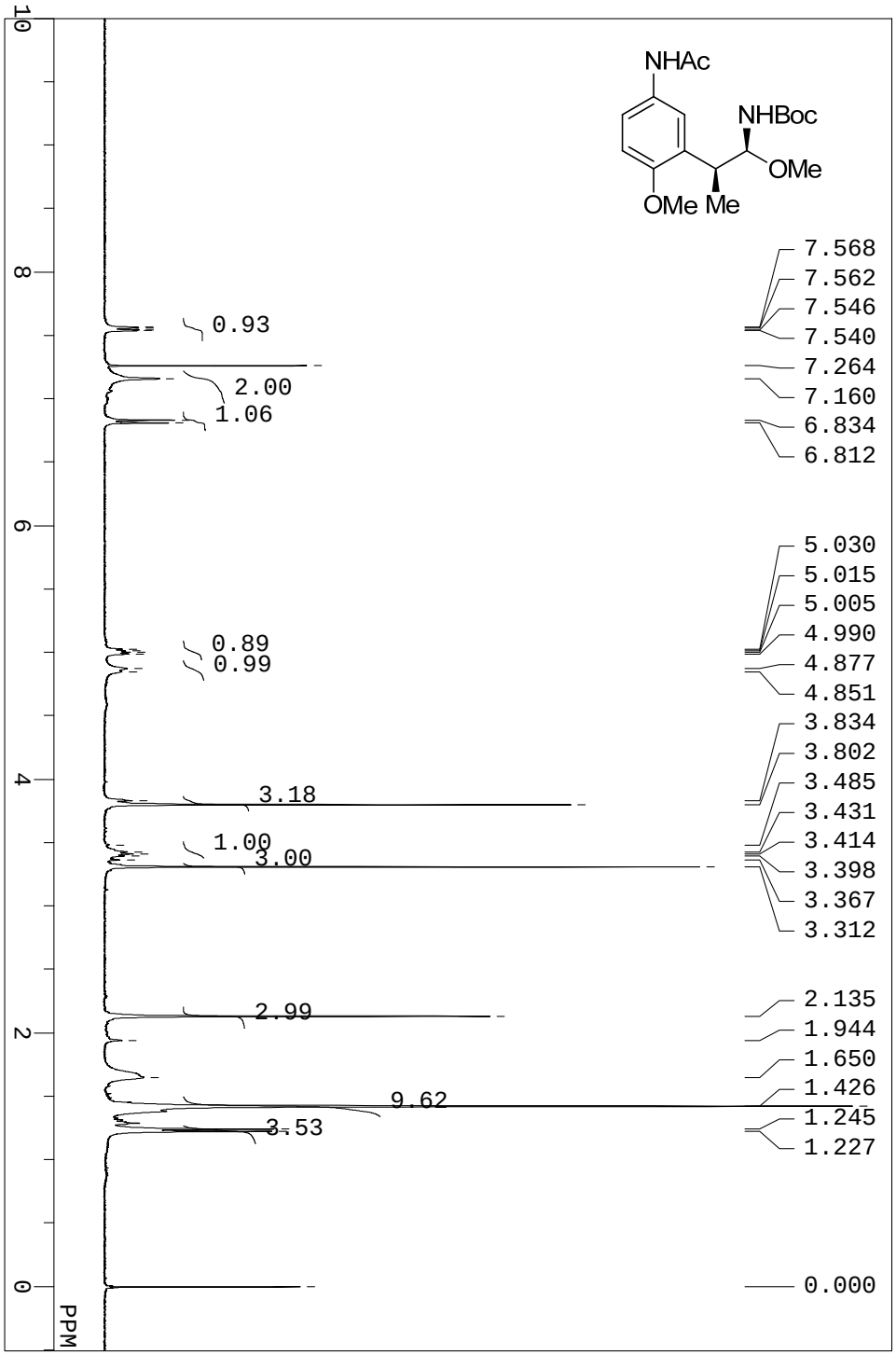
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PPM
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5.005
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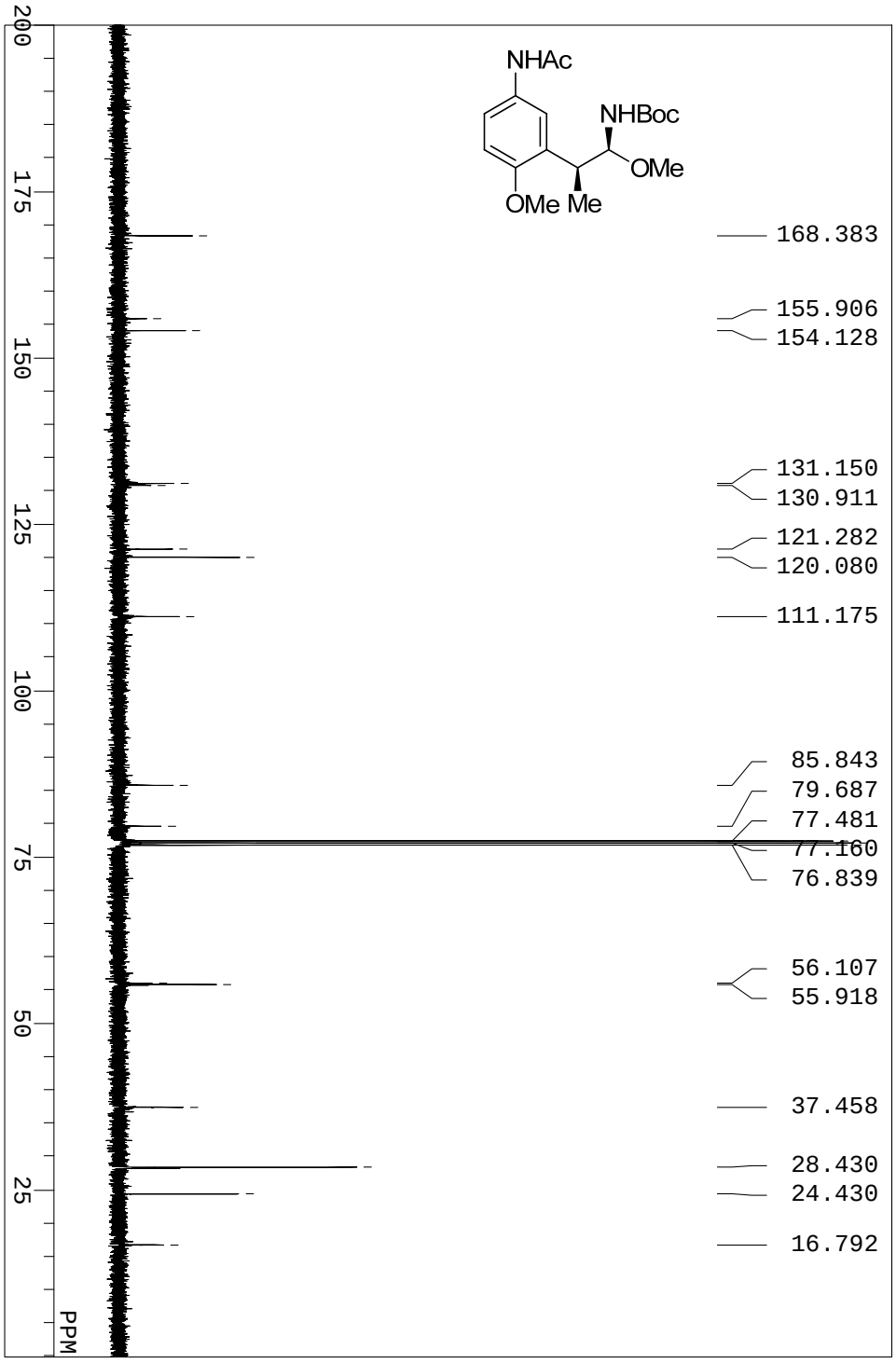
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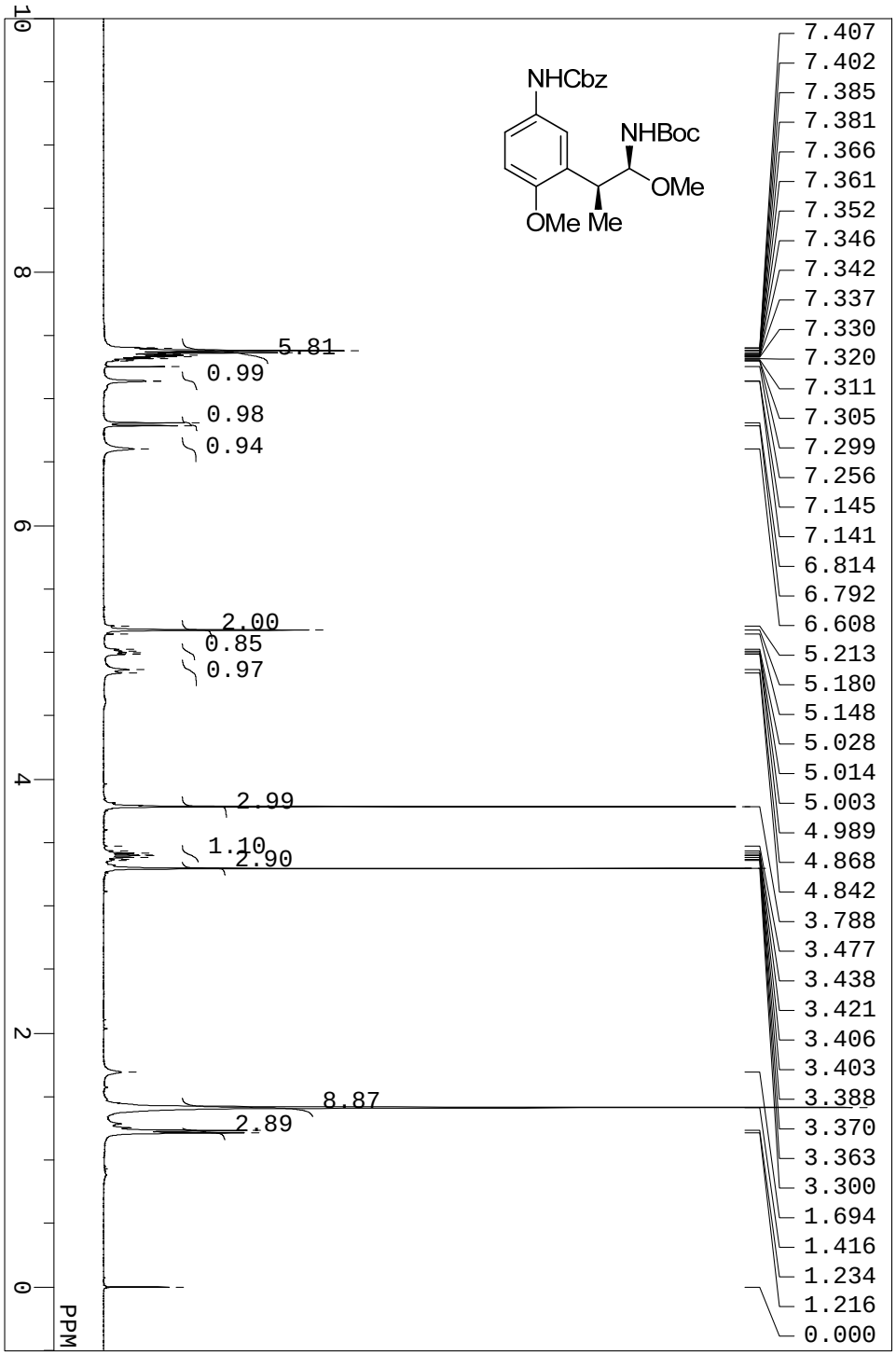
PPM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PPM
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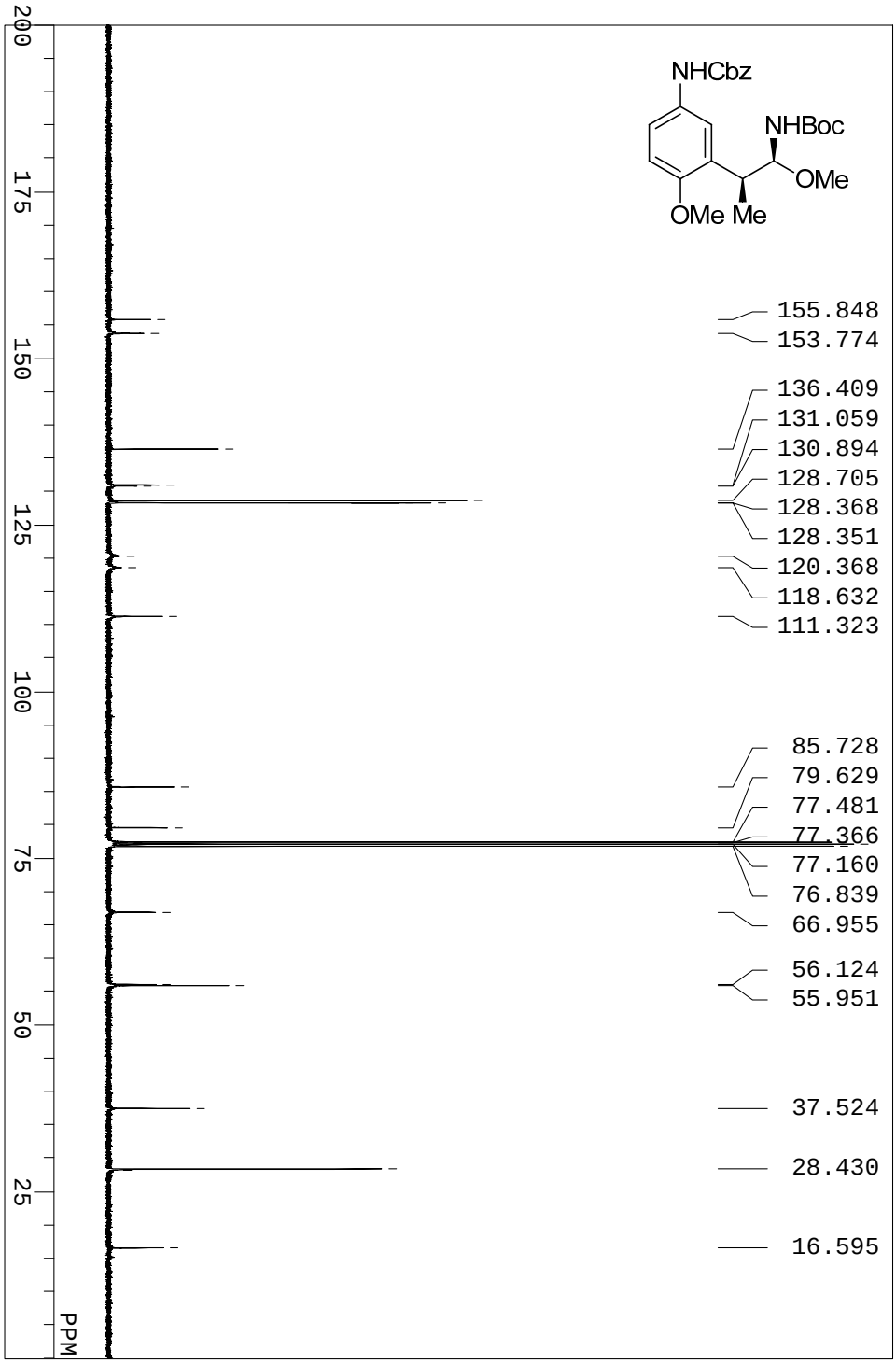
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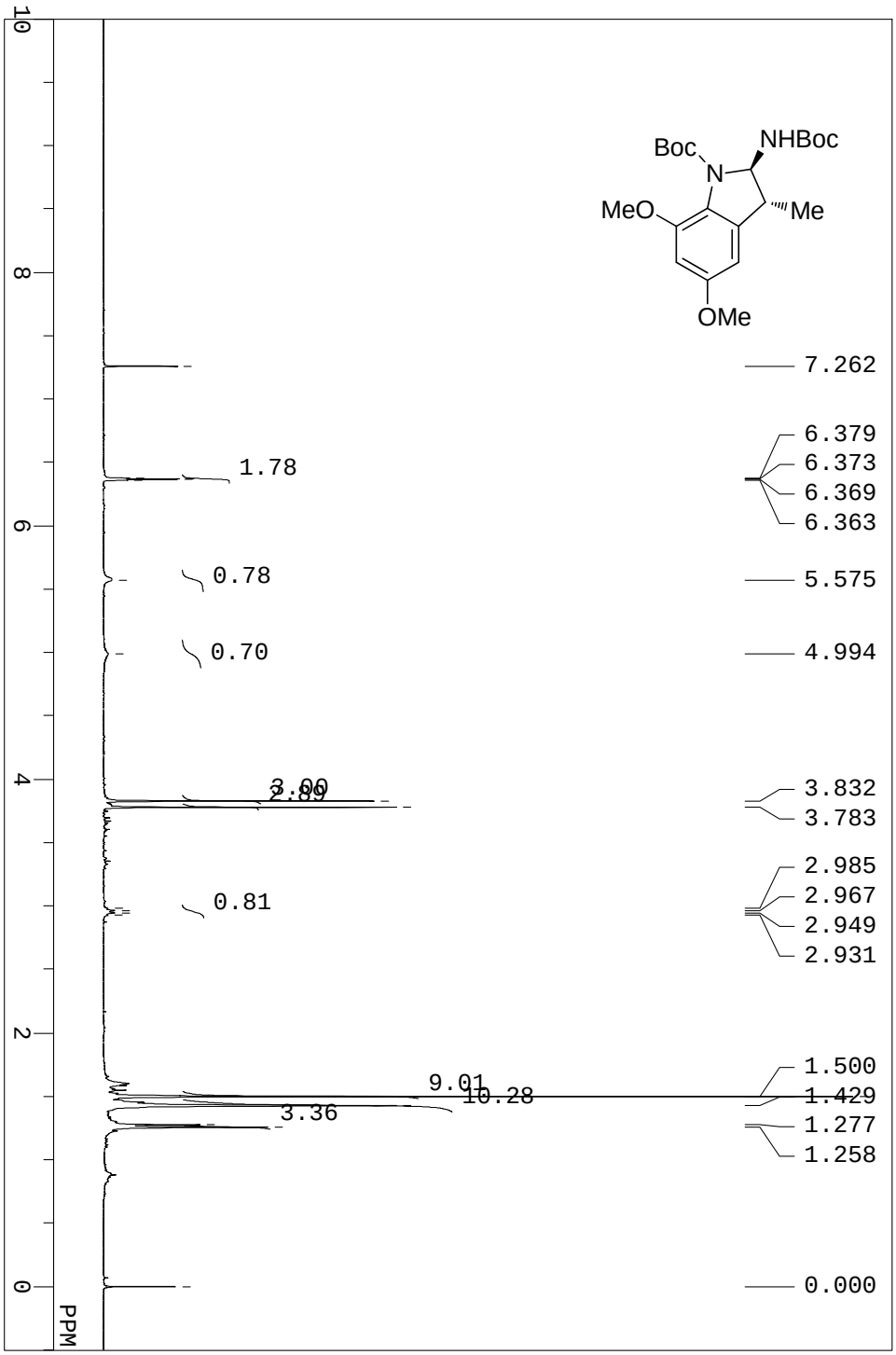
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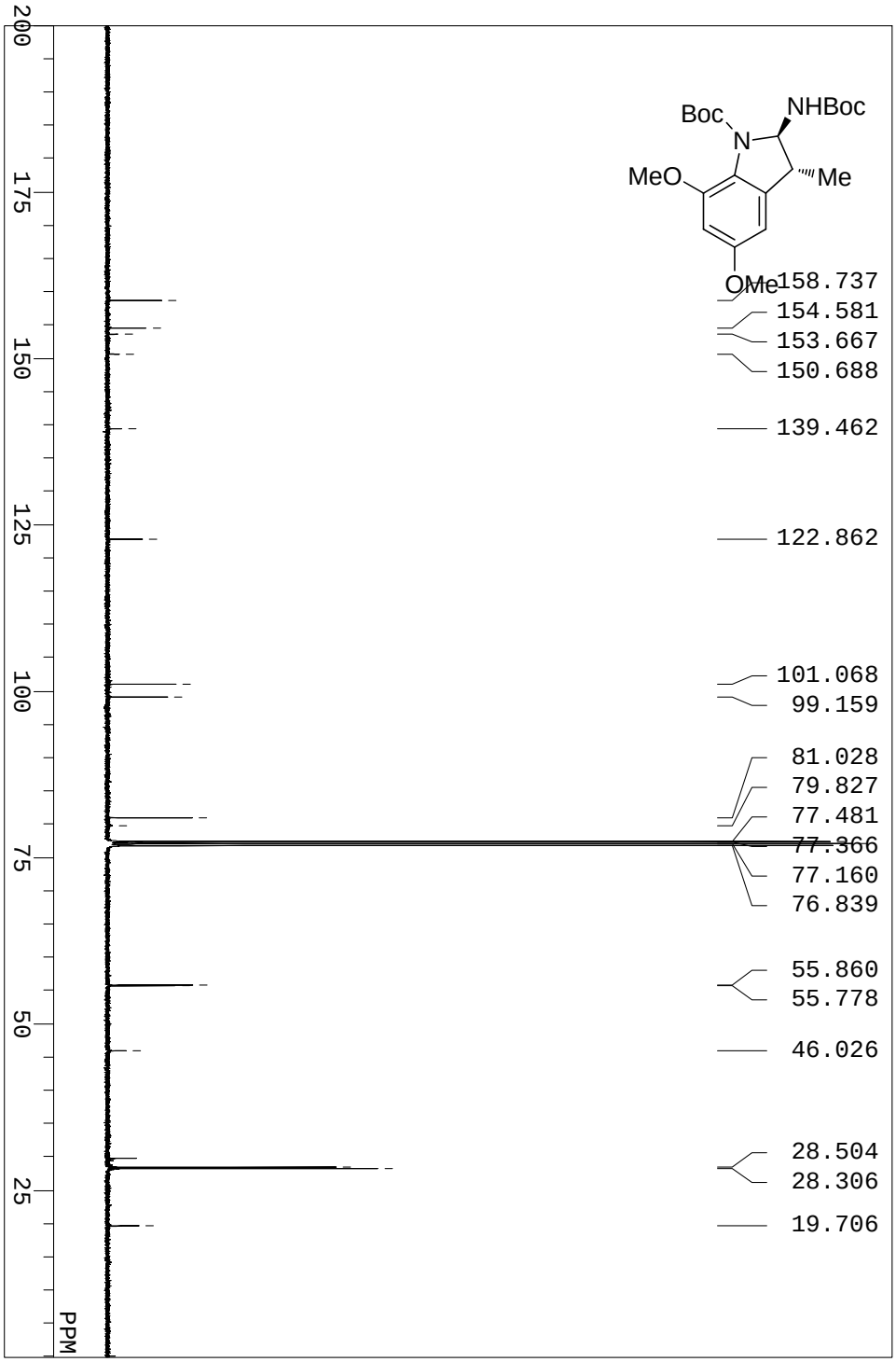
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175
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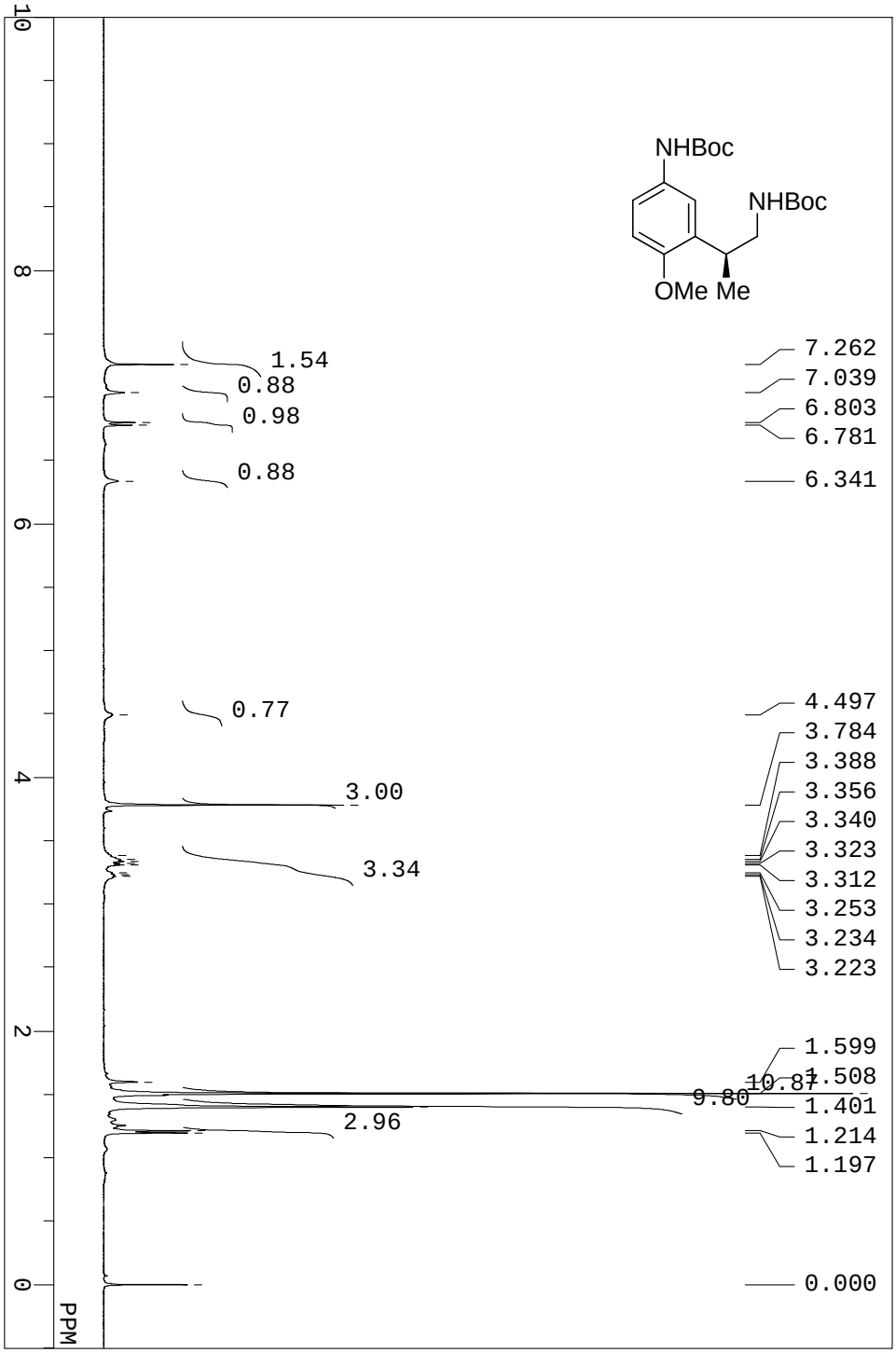
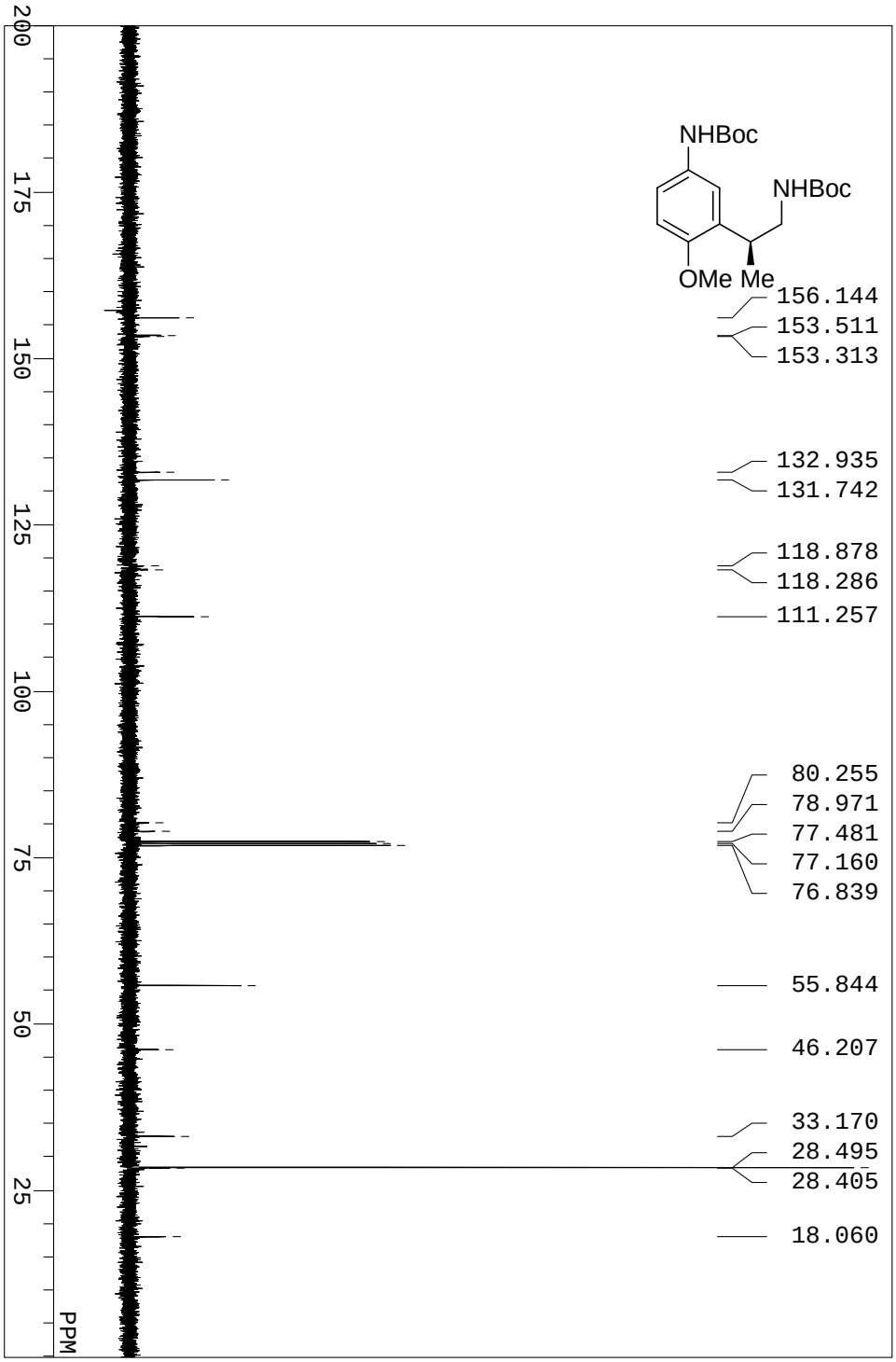
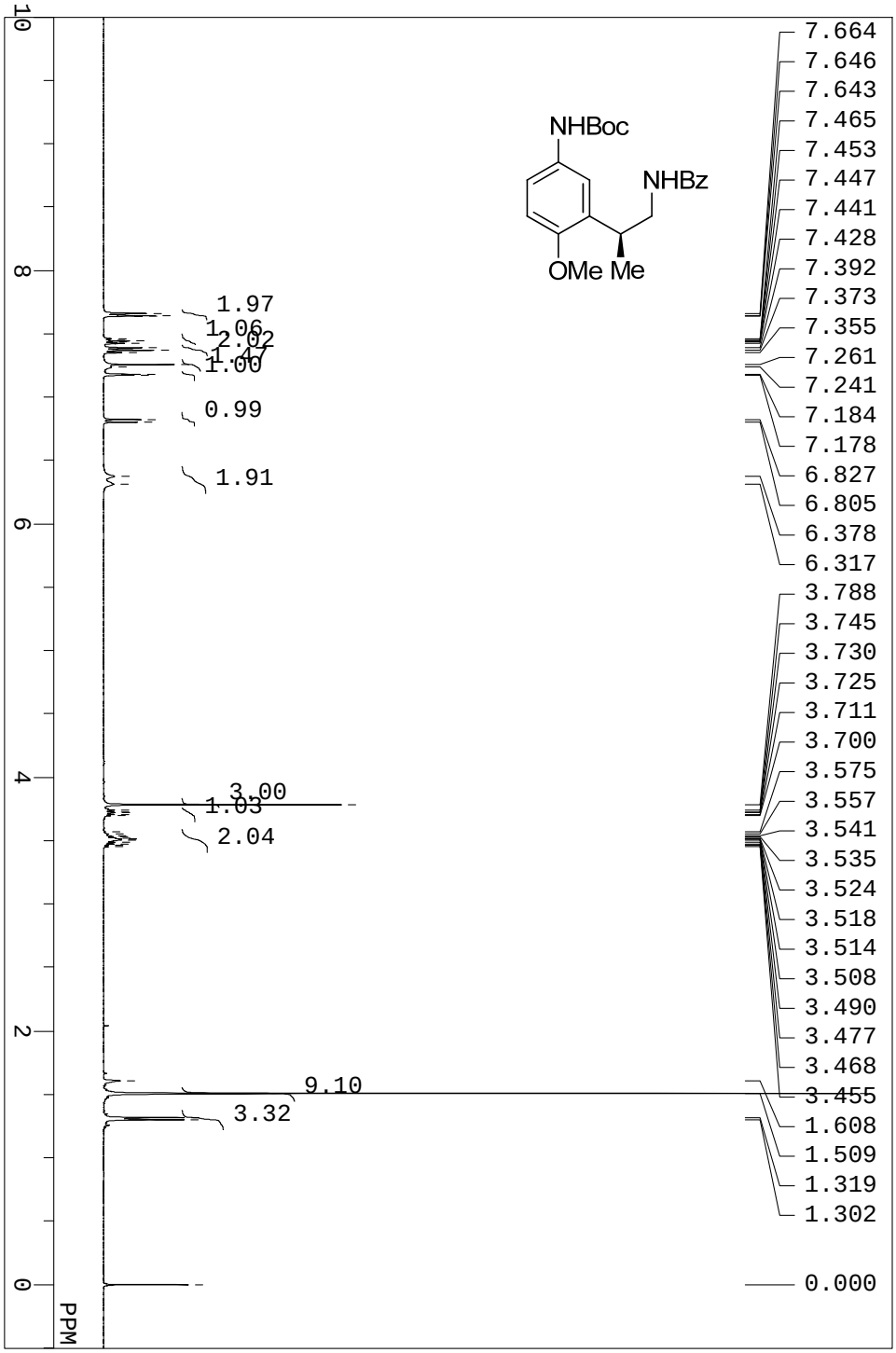
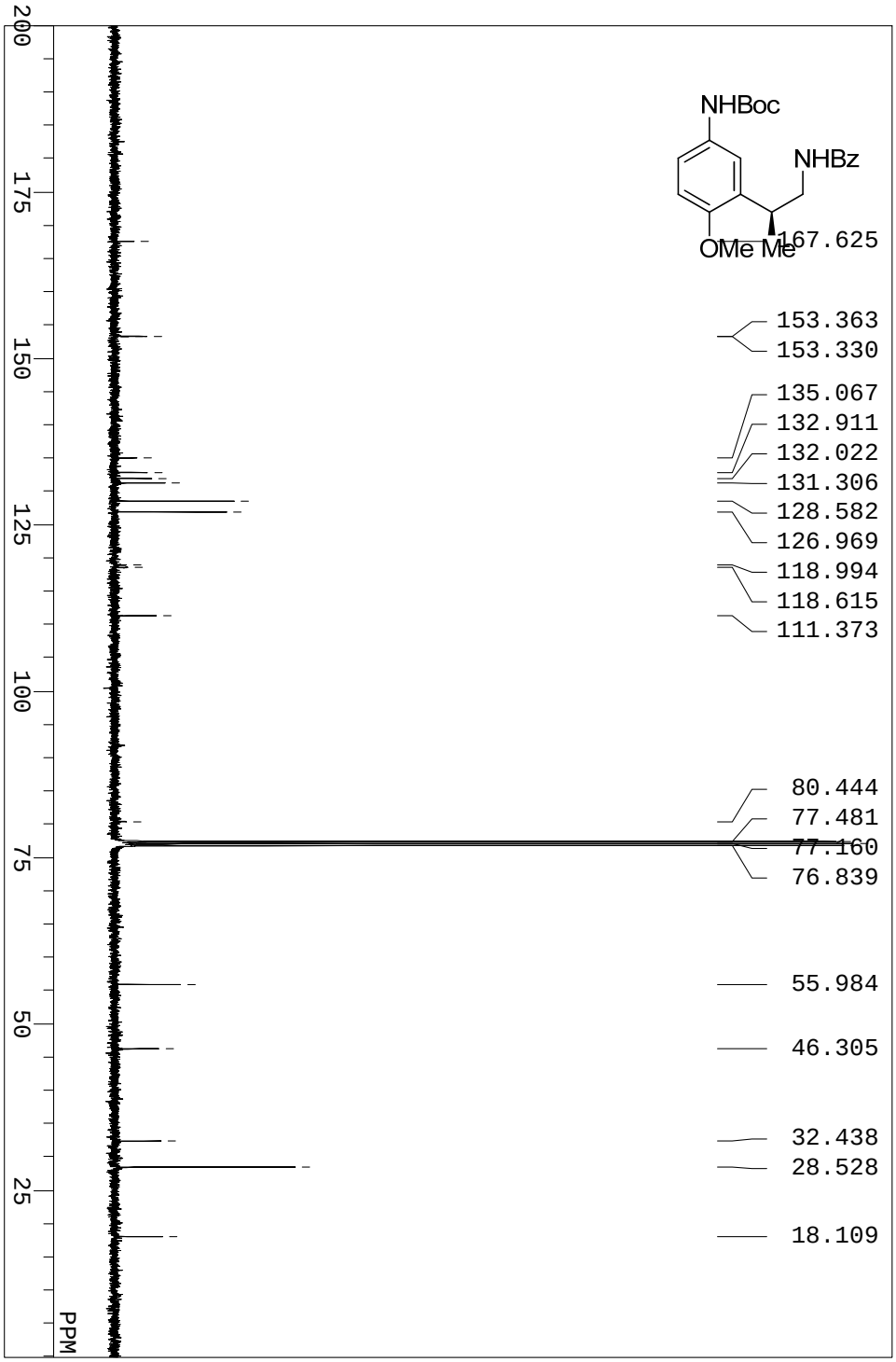
100
75
50
25
PPM


NHBoc
NHBoc
OMe Me
1.54
0.88
0.98
0.88
0.77
3.00
3.34
2.96
10.87
9.80
7.262
7.039
6.803
6.781
6.341
4.497
3.784
3.388
3.356
3.340
3.323
3.312
3.253
3.234
3.223
1.599
1.508
1.401
1.214
1.197
0.000
PPM


NHBoc
NHBoc
OMe Me
156.144
153.511
153.313
132.935
131.742
118.878
118.286
111.257
80.255
78.971
77.481
77.160
76.839
55.844
46.207
33.170
28.495
28.405
18.060
200
175
150
125
100
75
50
25
PPM


NHBoc
NHBz
OMe Me
7.664
7.646
7.643
7.465
7.453
7.447
7.441
7.428
7.392
7.373
7.355
7.261
7.241
7.184
7.178
6.827
6.805
6.378
6.317
3.788
3.745
3.730
3.725
3.711
3.700
3.575
3.557
3.541
3.535
3.524
3.518
3.514
3.508
3.490
3.477
3.468
3.455
1.608
1.509
1.319
1.302
0.000
1.97
1.06
2.02
1.47
1.00
0.99
1.91
3.00
1.03
2.04
9.10
3.32
10
8
6
4
2
0
PPM


NHBoc
NHBz
OMe Me
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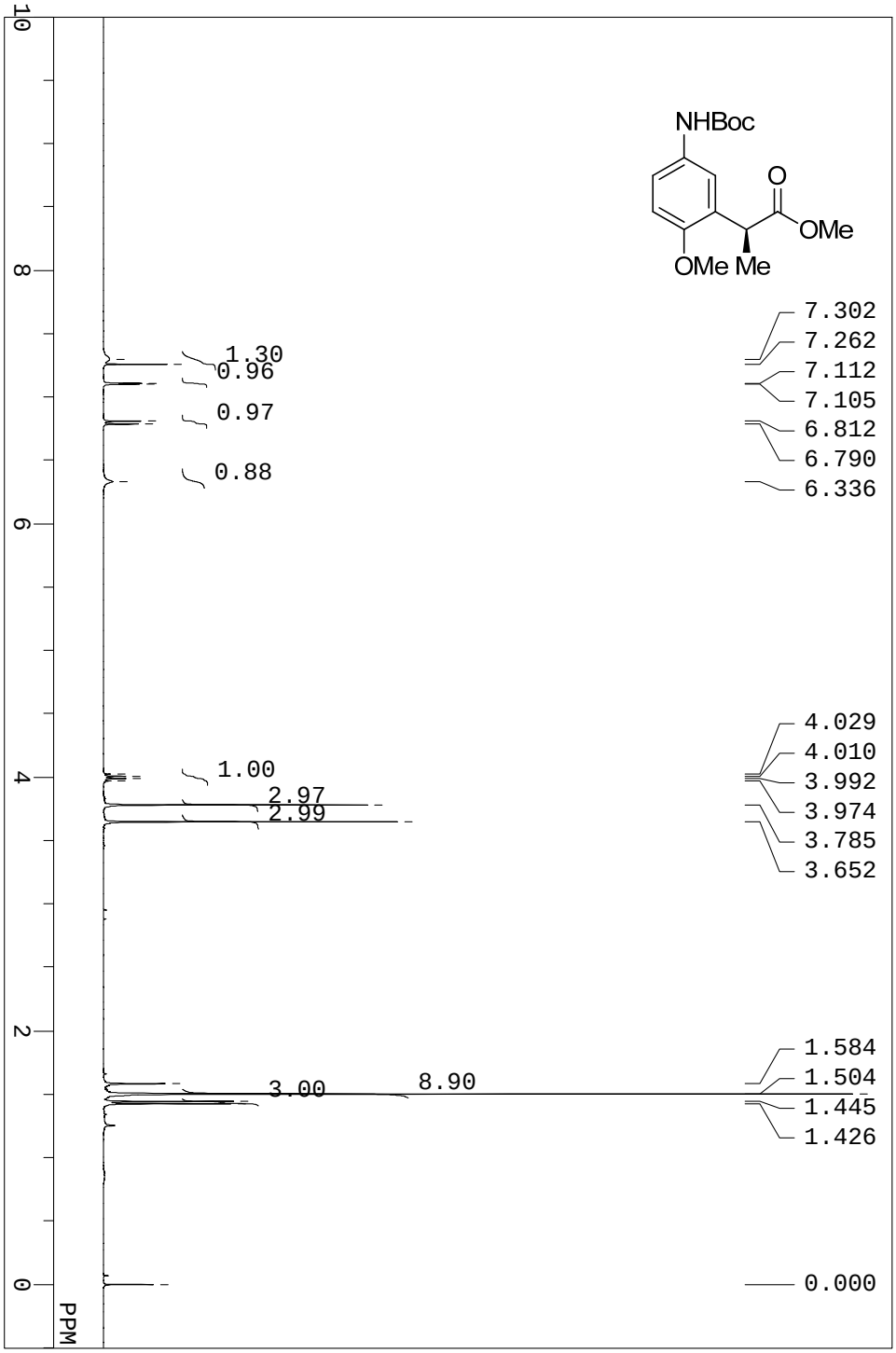
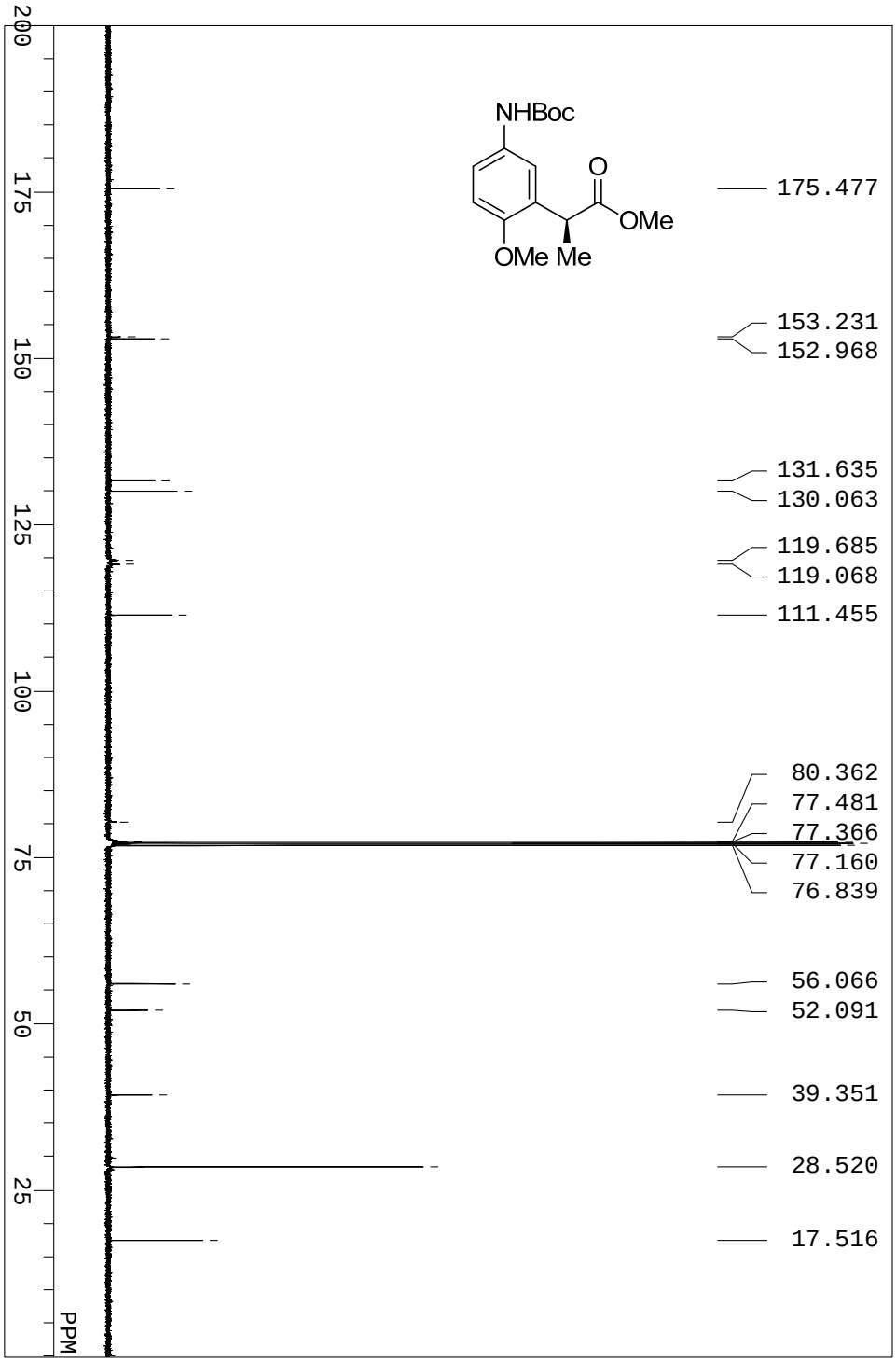
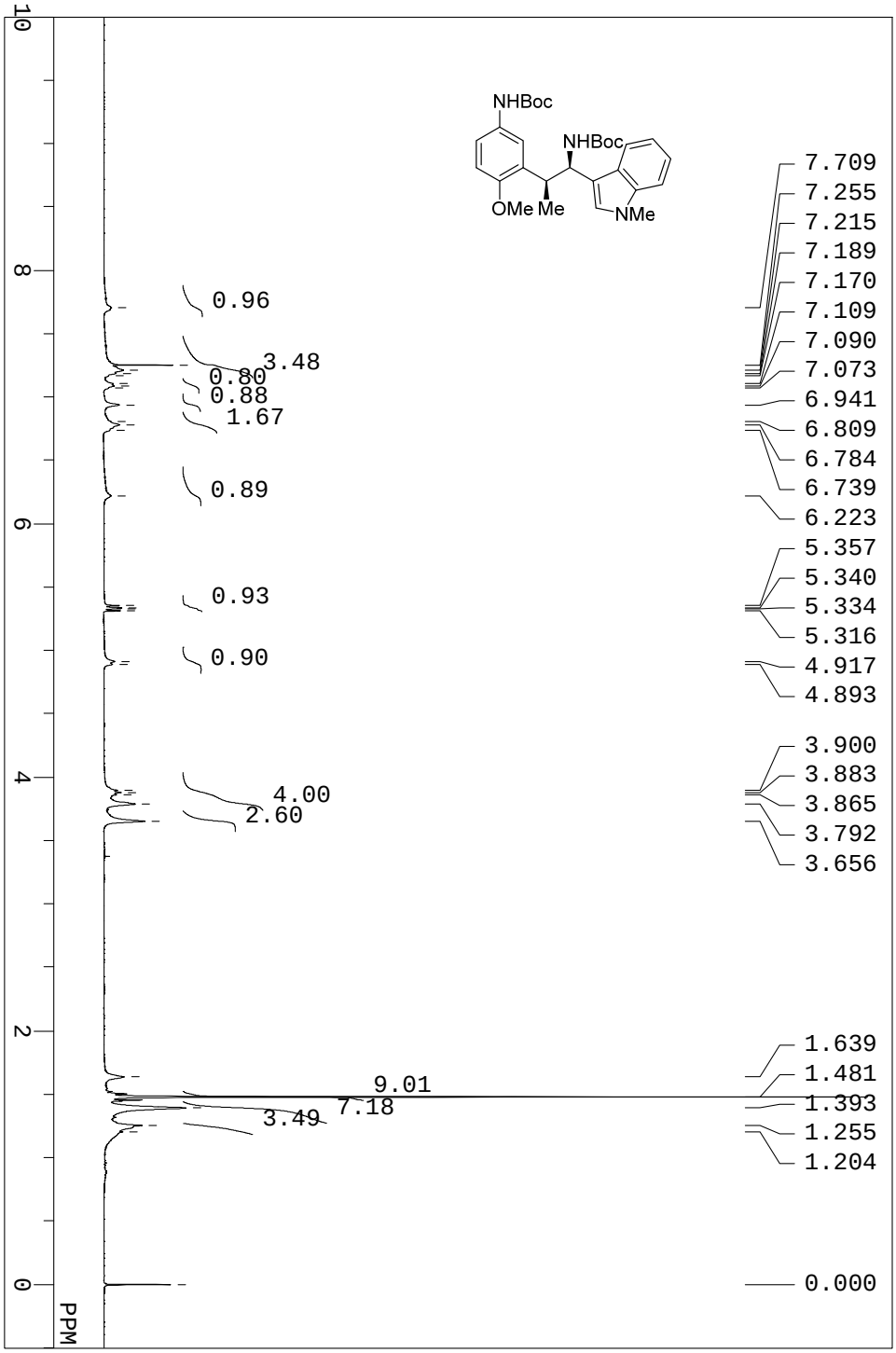
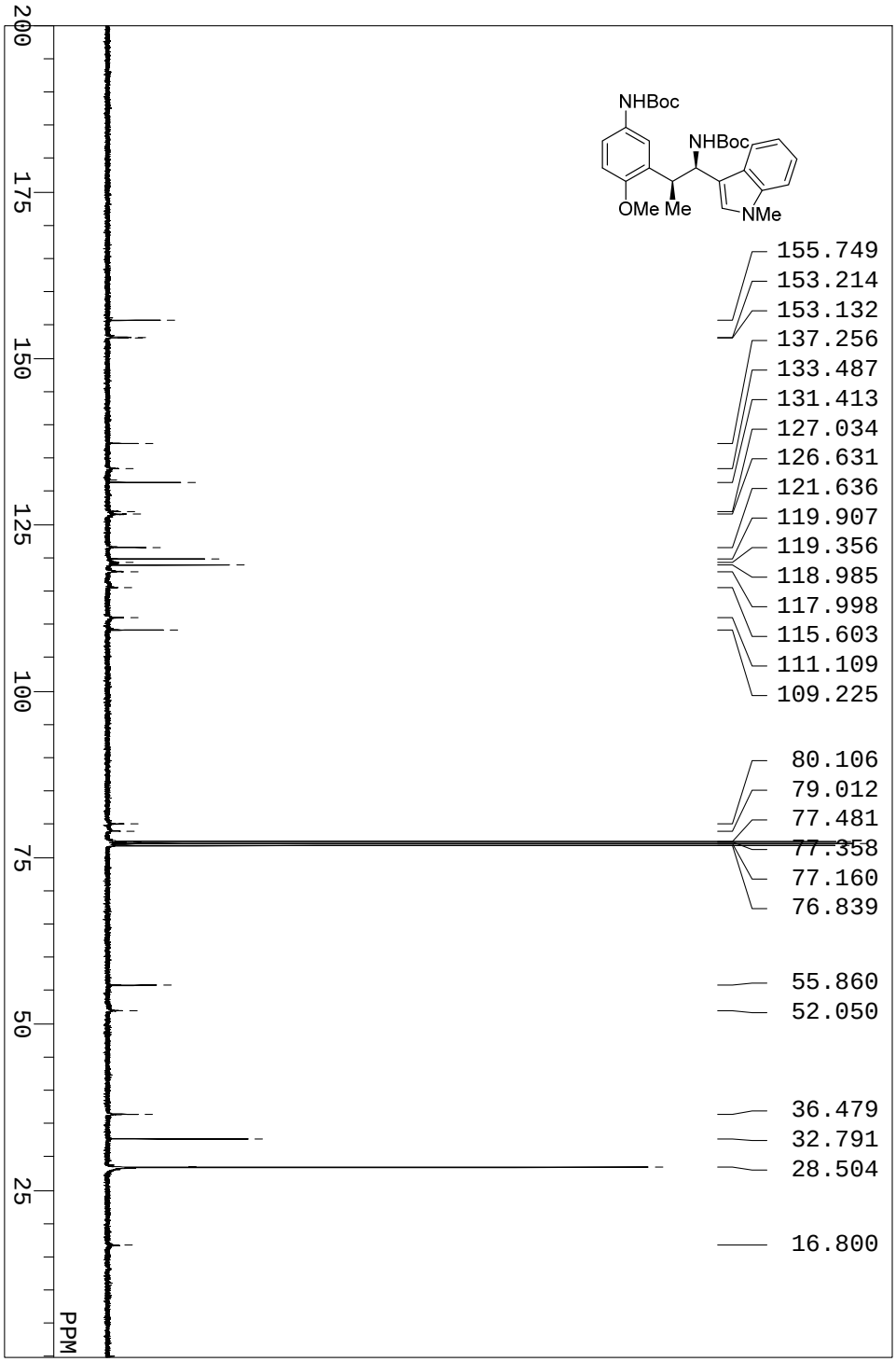
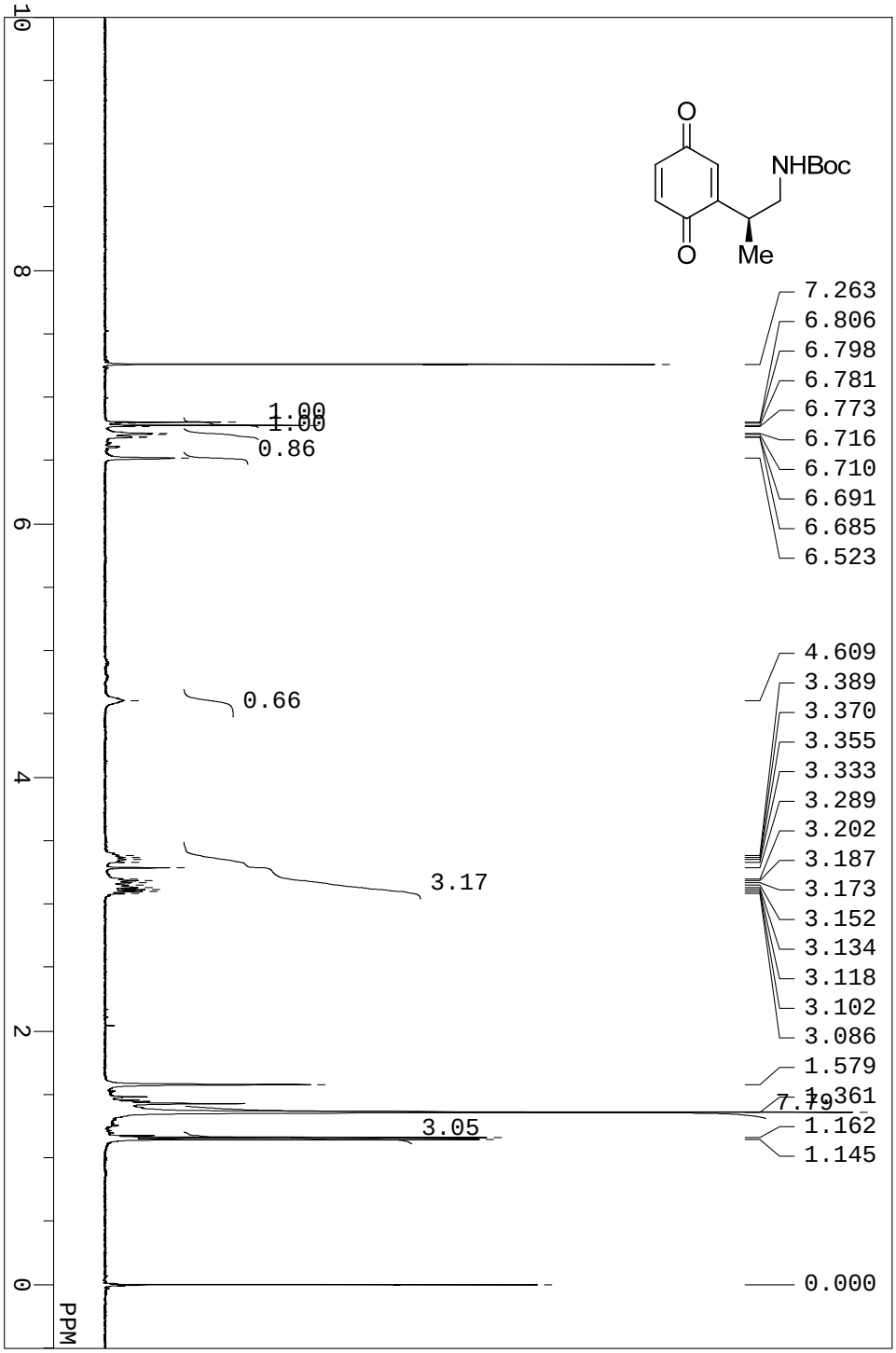
153.363
153.330
135.067
132.911
132.022
131.306
128.582
126.969
118.994
118.615
111.373
80.444
77.481
77.160
76.839
55.984
46.305
32.438
28.528
18.109
200
175
150
125
100
75
50
25
PPM

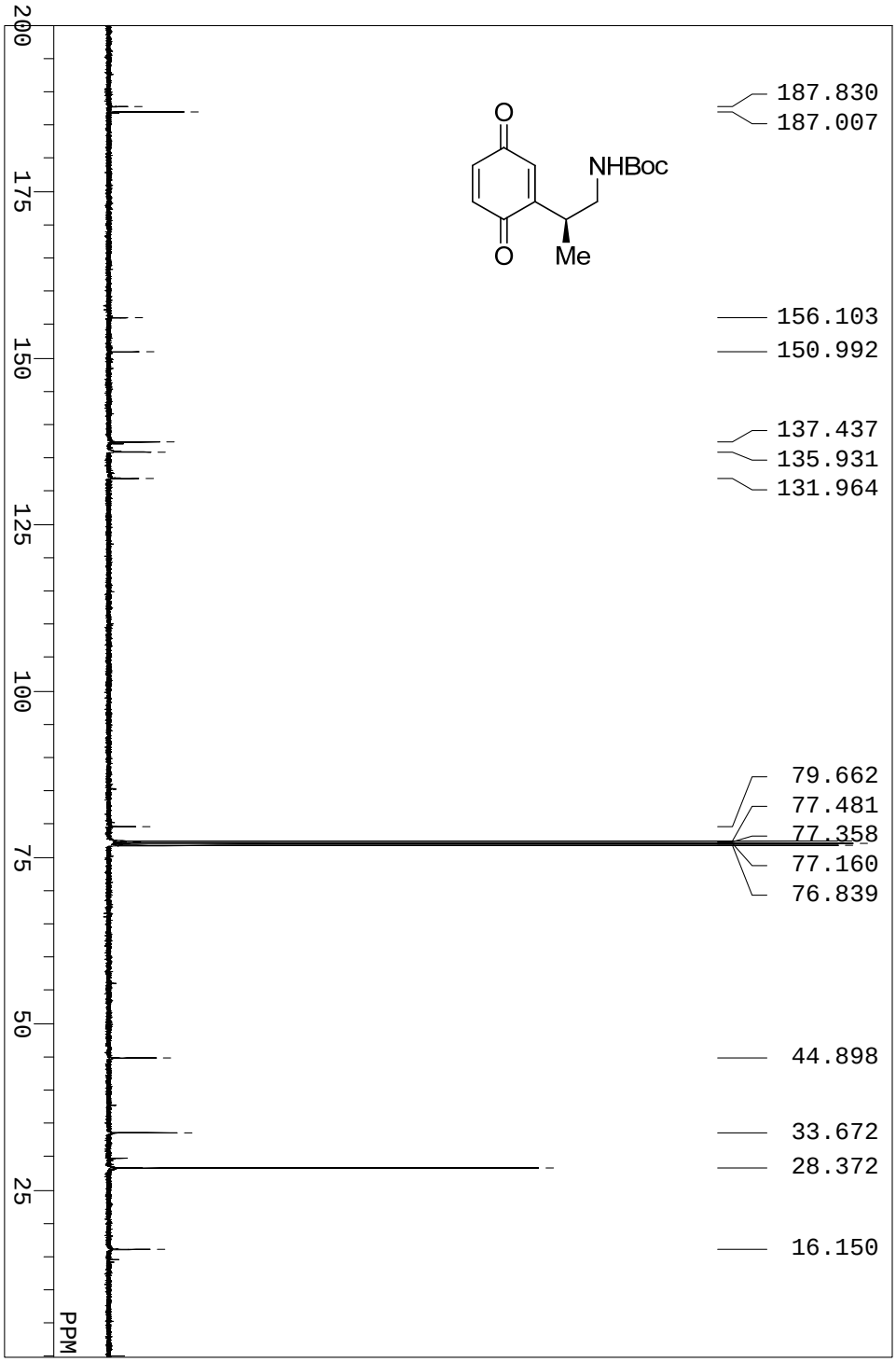

NHBoc
O
OMe
OMe Me
7.302
7.262
7.112
7.105
6.812
6.790
6.336
1.30
0.96
0.97
0.88
4.029
4.010
3.992
3.974
3.785
3.652
1.00
2.97
2.99
1.584
1.504
1.445
1.426
3.00
8.90
0.000
PPM


NHBoc
O
OMe
OMe Me
175.477
153.231
152.968
131.635
130.063
119.685
119.068
111.455
80.362
77.481
77.366
77.160
76.839
56.066
52.091
39.351
28.520
17.516
200
175
150
125
100
75
50
25
PPM


NHBoc
NHBoc
OMe Me
NMe
0.96
3.48
0.80
0.88
1.67
0.89
0.93
0.90
4.00
2.60
9.01
7.18
3.49
7.709
7.255
7.215
7.189
7.170
7.109
7.090
7.073
6.941
6.809
6.784
6.739
6.223
5.357
5.340
5.334
5.316
4.917
4.893
3.900
3.883
3.865
3.792
3.656
1.639
1.481
1.393
1.255
1.204
0.000
PPM


NHBoc
NHBoc
OMe Me
NMe
155.749
153.214
153.132
137.256
133.487
131.413
127.034
126.631
121.636
119.907
119.356
118.985
117.998
115.603
111.109
109.225
80.106
79.012
77.481
77.358
77.160
76.839
55.860
52.050
36.479
32.791
28.504
16.800
200
175
150
125
100
75
50
25
PPM


O
NHBoc
O
Me
7.263
6.806
6.798
6.781
6.773
6.716
6.710
6.691
6.685
6.523
4.609
3.389
3.370
3.355
3.333
3.289
3.202
3.187
3.173
3.152
3.134
3.118
3.102
3.086
1.579
1.361
1.162
1.145
0.000
1.00
1.00
0.86
0.66
3.17
7.79
3.05
10
8
6
4
2
0
PPM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187.007
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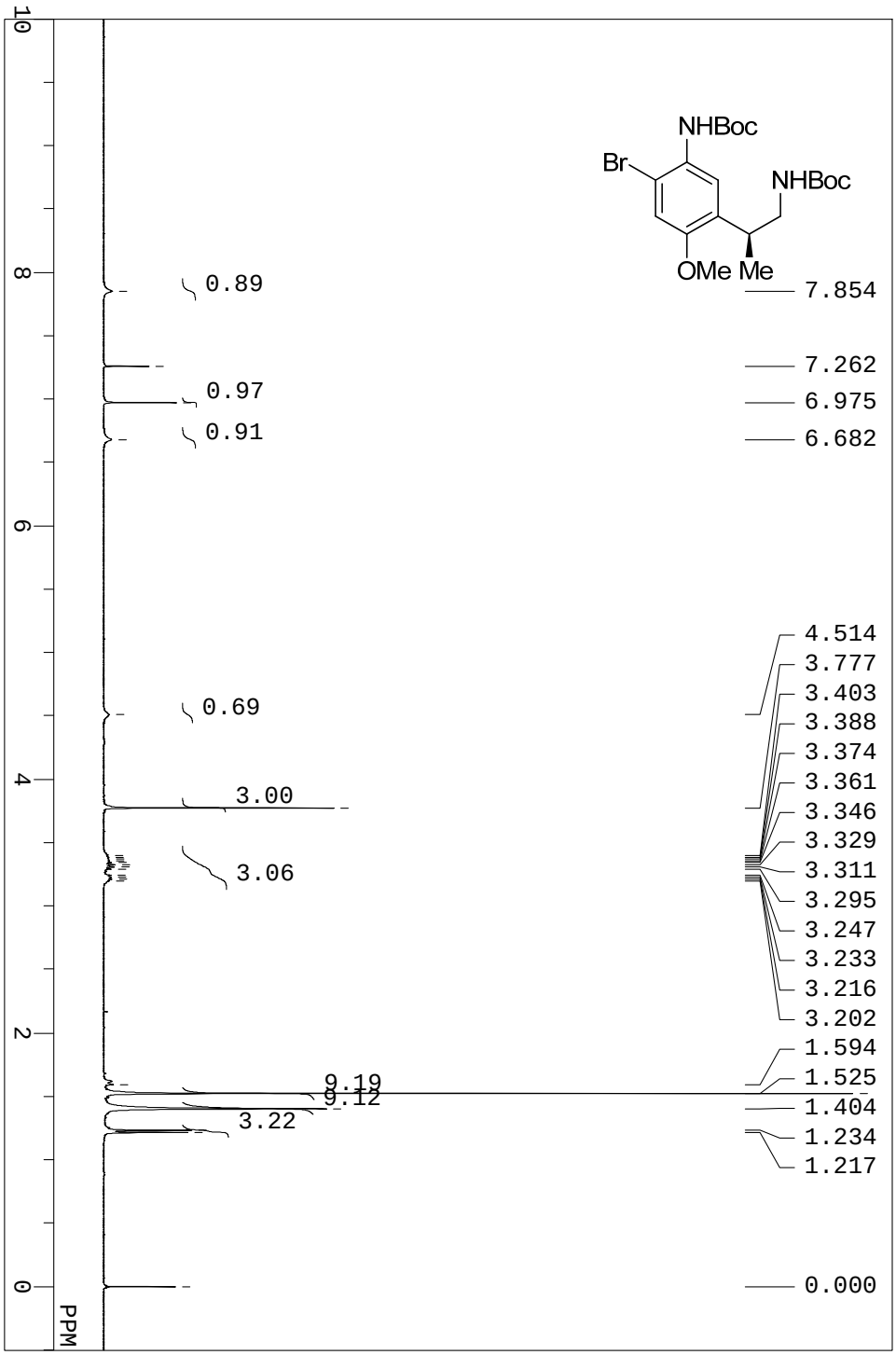
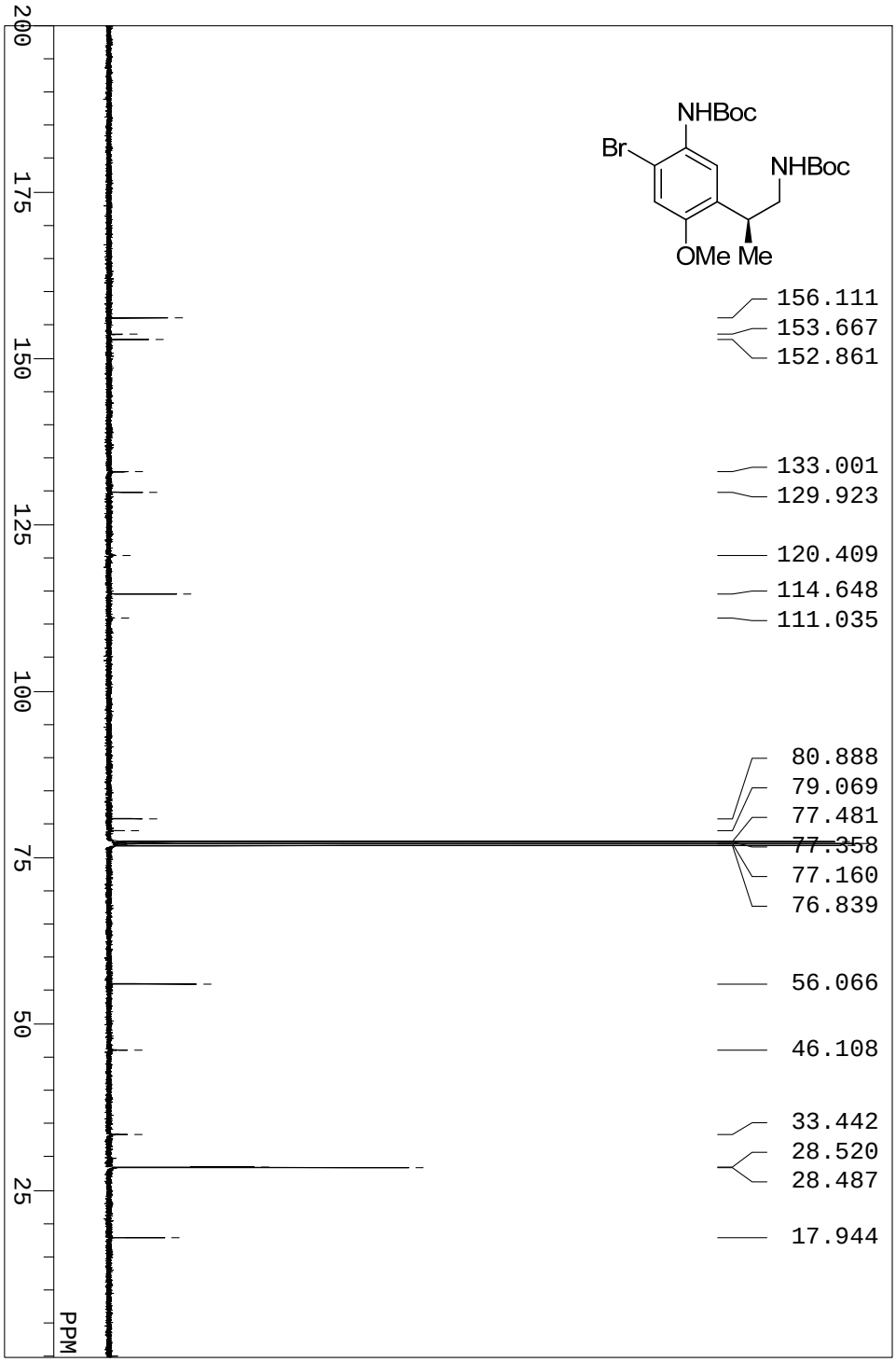
137.437
135.931
131.964
79.662
77.481
77.358
77.160
76.839
44.898
33.672
28.372
16.150
NHBoc
Me
O
O
PPM
200
175
150
125
100
75
50
25


NHBoc
Br
NHBoc
OMe Me
10
8
6
4
2
0
PPM
0.89
0.97
0.91
0.69
3.00
3.06
9.19
9.12
3.22
7.854
7.262
6.975
6.682
4.514
3.777
3.403
3.388
3.374
3.361
3.346
3.329
3.311
3.295
3.247
3.233
3.216
3.202
1.594
1.525
1.404
1.234
1.217
0.000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Br
NHBoc
OMe Me
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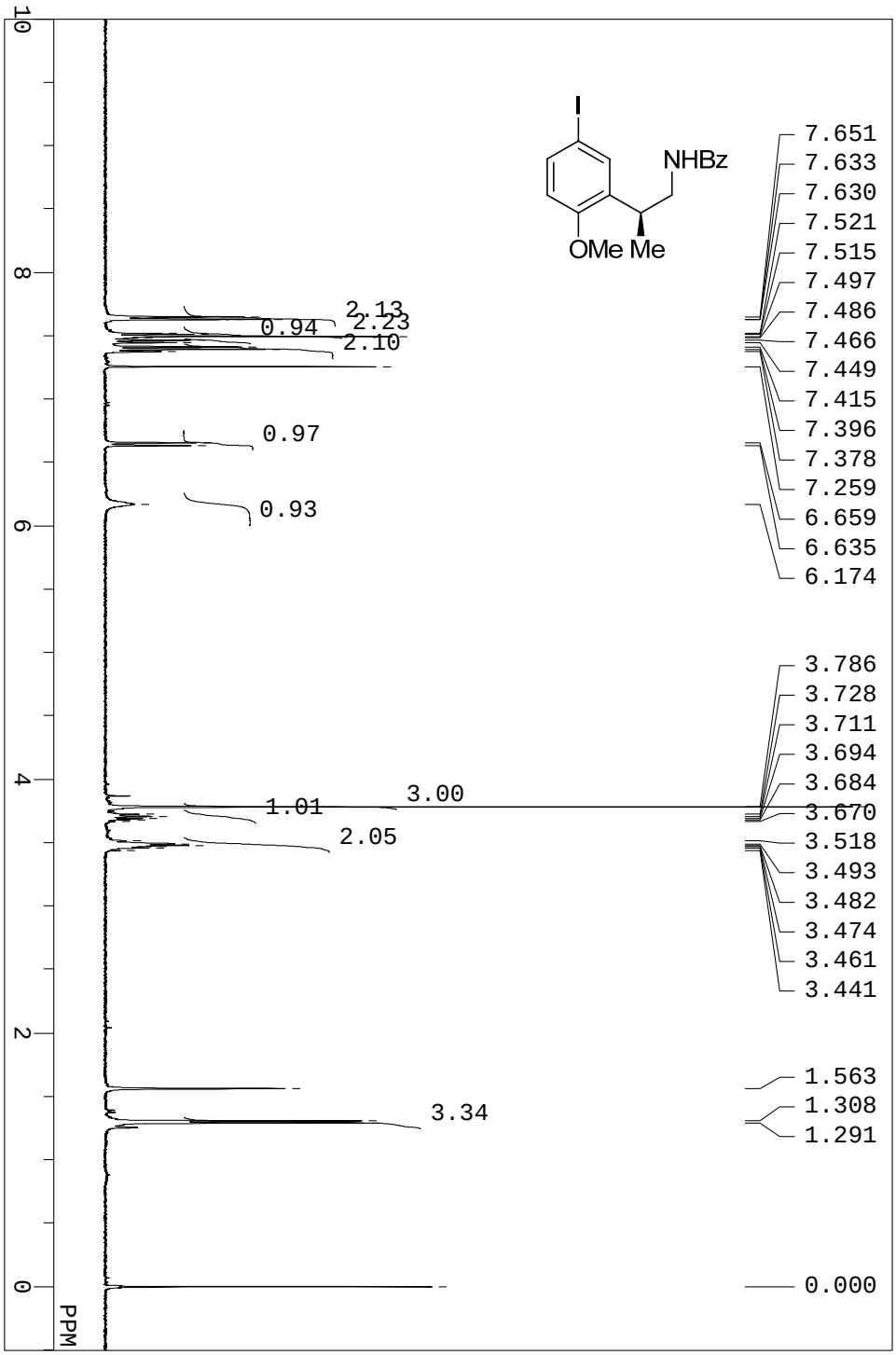
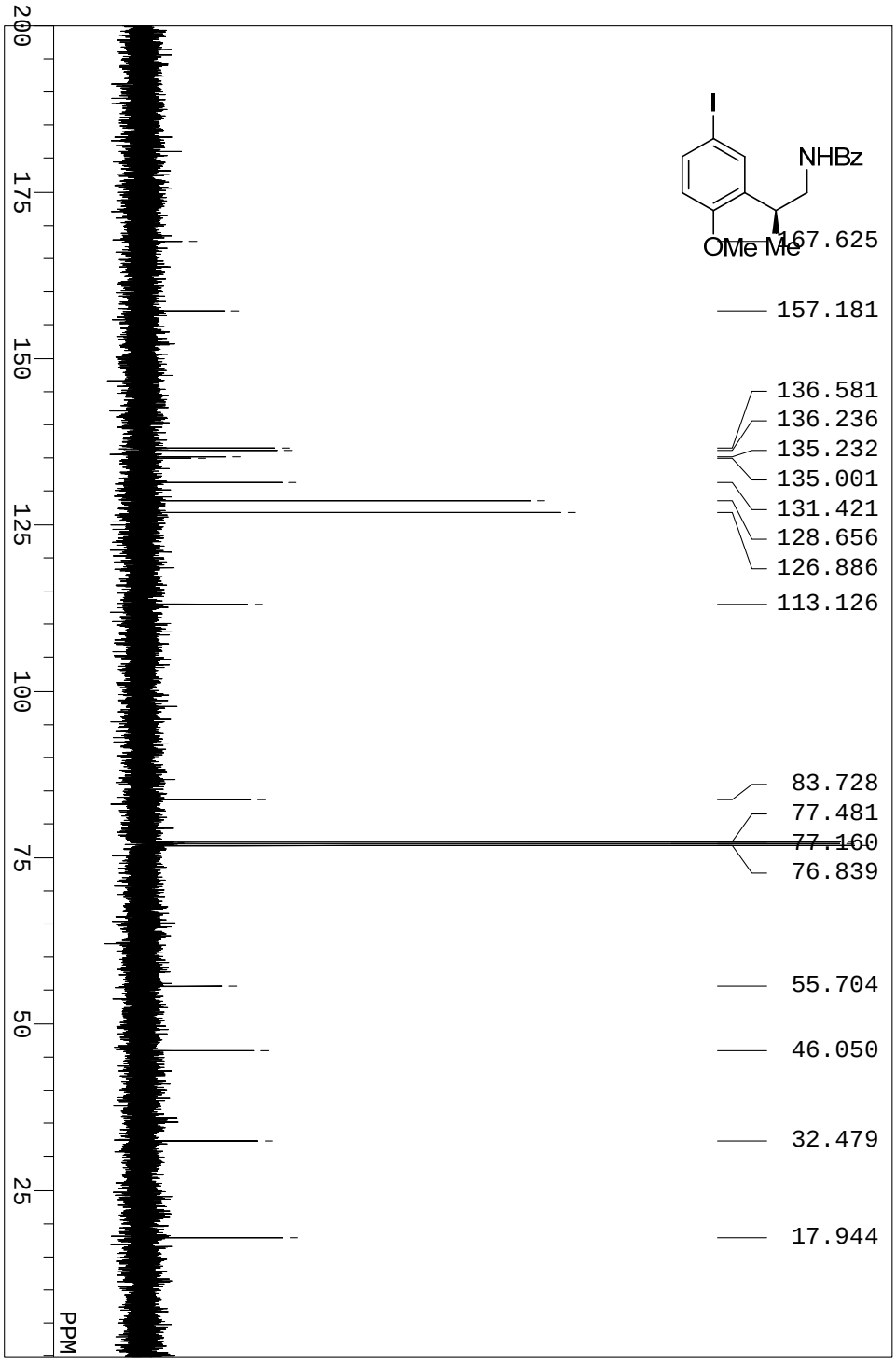
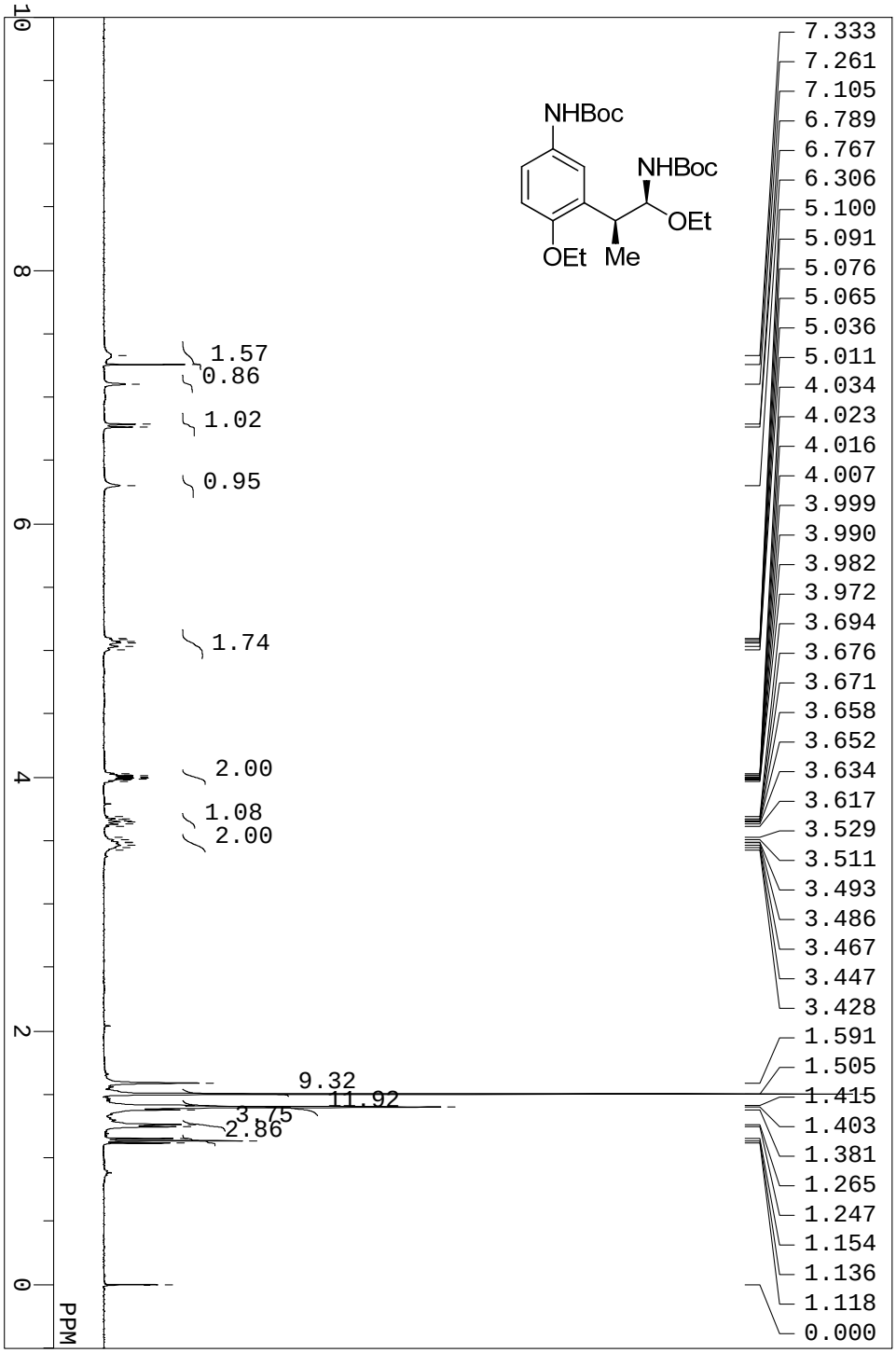
153.667
152.861
133.001
129.923
120.409
114.648
111.035
80.888
79.069
77.481
77.358
77.160
76.839
56.066
46.108
33.442
28.520
28.487
17.944
200
175
150
125
100
75
50
25
PPM


I
NHBz
OMe Me
7.651
7.633
7.630
7.521
7.515
7.497
7.486
7.466
7.449
7.415
7.396
7.378
7.259
6.659
6.635
6.174
3.786
3.728
3.711
3.694
3.684
3.670
3.518
3.493
3.482
3.474
3.461
3.441
1.563
1.308
1.291
0.000
2.13
2.23
0.94
2.10
0.97
0.93
3.00
1.01
2.05
3.34
10
8
6
4
2
0
PPM


I
NHBz
OMe Me
167.625
157.181
136.581
136.236
135.232
135.001
131.421
128.656
126.886
113.126
83.728
77.481
77.160
76.839
55.704
46.050
32.479
17.944
200
175
150
125
100
75
50
25
PPM


NHBoc
NHBoc
OEt
OEt
Me
1.57
0.86
1.02
0.95
1.74
2.00
1.08
2.00
9.32
11.92
3.75
2.86
7.333
7.261
7.105
6.789
6.767
6.306
5.100
5.091
5.076
5.065
5.036
5.011
4.034
4.023
4.016
4.007
3.999
3.990
3.982
3.972
3.694
3.676
3.671
3.658
3.652
3.634
3.617
3.529
3.511
3.493
3.486
3.467
3.447
3.428
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1.415
1.403
1.381
1.265
1.247
1.154
1.136
1.118
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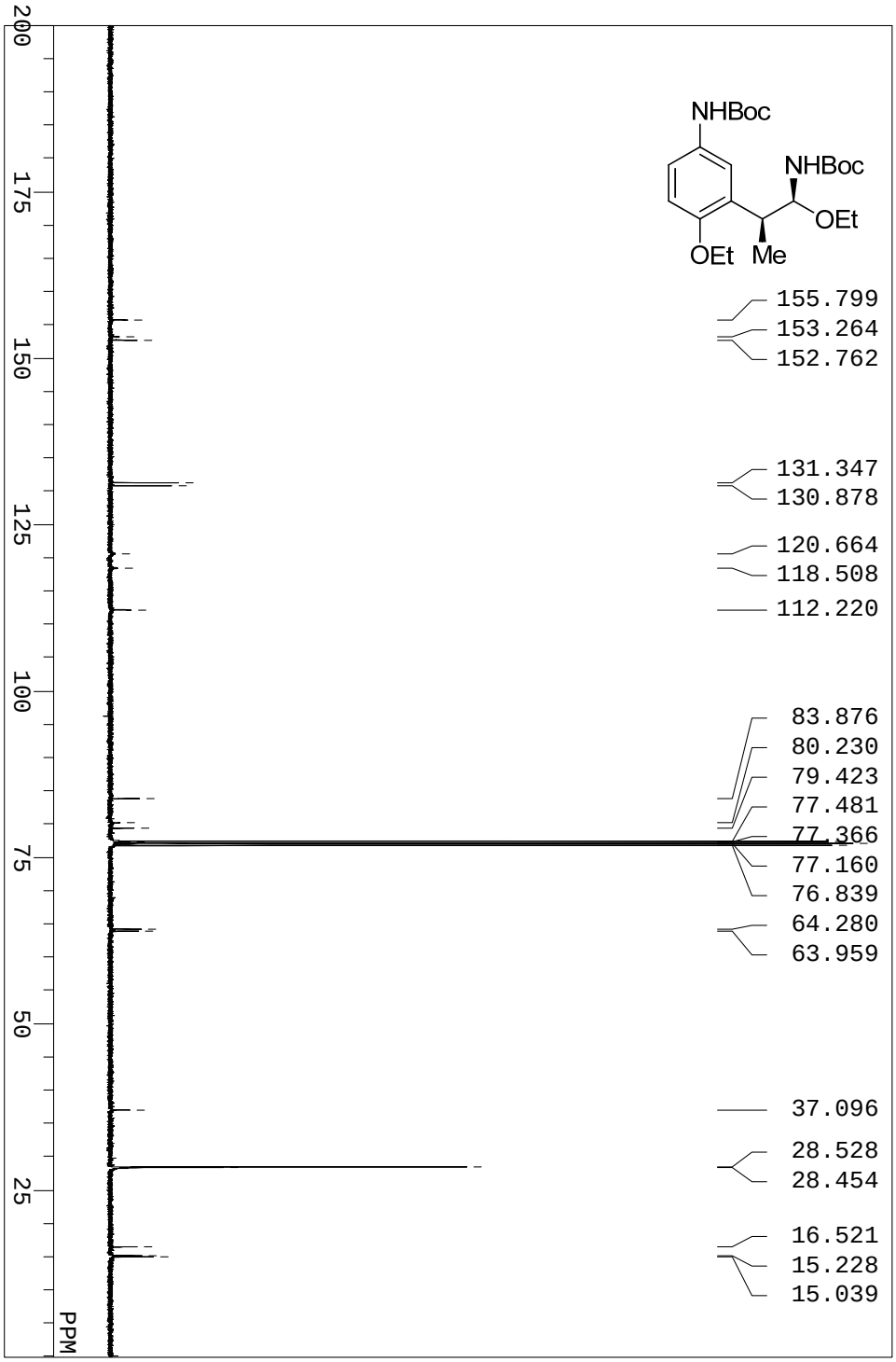
PPM


NHBoc
NHBoc
OEt
OEt
Me
155.799
153.264
152.762
131.347
130.878
120.664
118.508
112.220
83.876
80.230
79.423
77.481
77.366
77.160
76.839
64.280
63.959
37.096
28.528
28.454
16.521
15.228
15.039
200
175
150
125
100
75
50
25
PPM