Highly enantioselective Michael reaction of 2-oxindoles to vinyl selenone in RTILs catalyzed by a cinchona alkaloid-based thiourea

Tao Zhang,[a,b] Liang Cheng,[a] Shahid Hameed,[c] Li Liu,*[a] Dong Wang,[a] and Yong-Jun Chen*[a]

[a]Beijing National Laboratory for Molecular Sciences (BNLMS), CAS Key Laboratory of Molecular Recognition and Function, Institute of Chemistry, Chinese Academy of Sciences, Beijing 100190, China; [b]Graduate School of Chinese Academy of Sciences, Beijing 100049, China; [c]Department of Chemistry, Quaid-i-Azam University, Islamabad 45320, Pakistan

Supporting information

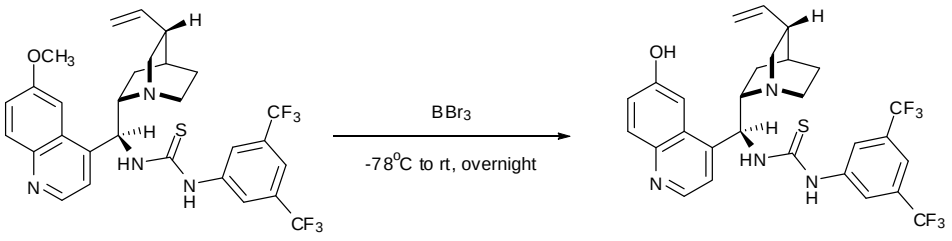
Contents

1. General methods

Unless otherwise noted, all reagents were obtained from commercial suppliers and were used without further purification. Cinchona alkaloid based catalysts **3c-3e** and **3g-3i** and all the substrates were prepared according to original or modified literature procedures. All reactions were carried out directly in air atmosphere, unless otherwise noted. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard. The following abbreviations were used to designate chemical shift multiplicities: s= singlet, d= doublet, t= triplet, q= quartet, h= heptet, m= multiplet, br= broad. All first-order splitting patterns were assigned on the basis of the appearance of the multiplet. Splitting patterns that could not be easily interpreted are designated as multiplet (m) or broad (br). IR spectra were recorded on a Bruker tensor 27 infrared spectrometer. Melting points were measured on Beijing Tech X-4 apparatus without correction. Mass spectra were obtained using electrospray ionization (ESI) mass spectrometer. Optical rotations were measured using a 1 mL cell with a 1 dm path length and are reported as follows: $[\alpha]_D^{rt}$ (c in g per 100 mL of solvent). HPLC analysis was performed using ChiralPak columns purchased. Column chromatography was performed using silica gel (200-300 mesh). TLC was performed on glass-backed silica plates.

2. Experimental section

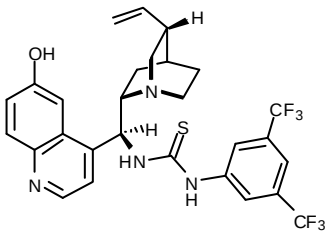
2.1. synthesis of catalyst 3h[1]



3g **3h**

To the solution of **3g**[2] (1.19g, 2mmol) in dry DCM (20mL), BBr_3 (20mL, 1mol/L in dry DCM) was added at -78℃. The reaction was slowly warmed to rt and stirred overnight. Then the mixture was quenched with 40mL H_2O and neutralized with excess aqueous ammonia. The system was extracted with ethyl acetate (3×50mL). The combined organic phase was dried over Na_2SO_4 and concentrated. Flash chromatography (DCM/MeOH/$NH_3{\cdot}H_2O$: 100/5/1) offered the title product (0.7g, 60% yield).

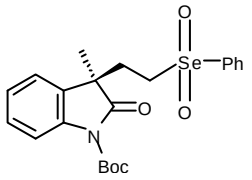
1-(3,5-bis(trifluoromethyl)phenyl)-3-((S)-(6-hydroxyquinolin-4-yl)((2S,4S,8R)-8-vinylquinuclidin-2-yl)methyl)thiourea (3h): yellowish solid. yield 60%. $[\alpha]_D^{20}$ -176.0 (*c* 0.5, MeOH). ^{1}H NMR (300 MHz, MeOH): δ 8.51-8.53 (d, *J* = 4.8 Hz, 1H), δ 8.03 (s, 2H), δ 7.80-7.83 (d, *J* = 9.3 Hz, 2H), δ7.50 (s, 1H), δ 7.41-7.43 (d, *J* = 4.8 Hz, 1H), δ 7.26-7.30 (dd, *J* = 2.4 Hz, *J* = 9.3 Hz, 1H), δ 6.13-6.16 (d, *J* = 10.5 Hz, 1H), δ 5.65-5.77 (m, 1H), δ 4.85-4.95 (m, 2H), δ 3.18-3.40 (m, 4H), δ 2.70-2.83 (m, 2H), δ 2.29 (br, 1H), δ 1.56-1.73 (m, 3H), δ 1.24-1.32 (m, 1H), 0.87-0.94 (m, 1H). ^{13}C NMR (75.0 MHz, MeOH): δ 182.4, 157.8, 147.6, 147.4, 144.3, 140.3, 142.1, 132.7(q, $^2J_{CF}$ = 33.0 Hz), 131.3, 130.5, 124.7 (q, $^1J_{CF}$ = 270.8 Hz), 123.7, 123.5, 120.8 (m), 117.8, 115.3, 107.0, 62.1, 56.4 (2C, overlapping), 42.7, 40.4, 28.6, 28.2, 26.2. IR ν_{max} (KBr, film, cm^{-1}): 3250, 1620, 1511, 1384, 1279, 1182, 1134. HRMS (ESI): calcd for $C_{28}H_{27}F_6N_4OS$ $[M+H]^+$ 581.1804; found: 581.1792.



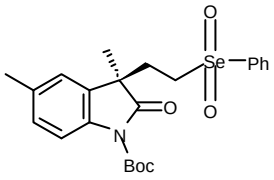
2.2. General procedure for the Michael addition of 2-oxindoles with selenone 2

To the mixture of 2-oxindoles (0.2mmol) and selenone **2** (0.2 mmol, 43 mg) in 0.5 mL [bpy][BF_4], catalyst **3i** (0.02 mmol, 11.3 mg**)** was added. Then, the reaction system was stirred for about 4h at room temperature. The system was extracted with ethyl acetate (3×5mL). The combined organic phase was dried over Na_2SO_4 and concentrated. FC (petroleum ether/ ethyl acetate, 1: 1-1.5) afforded target products.

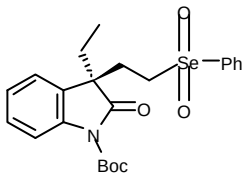
(R)-tert-butyl 3-methyl-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4a): white solid. yield 88%, ee 95%. $[\alpha]_D^{20}$ -8.0 (*c* 0.5, DCM). m.p. 85-87 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.93 (overlapping: s, 1H; d, *J* = 1.2 Hz, 1H), δ 7.81-7.83 (d, *J* = 7.8 Hz, 1H), δ 7.71-7.76 (t, *J* = 7.2 Hz, 1H), δ 7.62-7.67 (t, *J* = 7.2 Hz, 2H), δ 7.31-7.36 (m, 1H), δ 7.19-7.24 (m, 2H), δ 3.29-3.39 (m, 1H), δ 3.14-3.23 (m, 1H), δ 2.33-2.52 (m, 2H), δ 1.64 (s, 9H), δ 1.46 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 177.3, 148.8, 140.9, 138.8, 134.5, 130.4, 129.0, 127.0, 125.2, 122.5, 115.4, 85.0, 54.8, 47.6, 30.4, 28.1, 24.1. IR ν_{max} (KBr, film, cm^{-1}): 1790, 1763, 1728, 1150, 937, 885. HRMS (ESI): calcd for $C_{22}H_{25}NNaO_5Se$ $[M+Na]^+$ 486.0791; found: 486.0786. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 31.9 min (major), 35.8 min (minor)].



(R)-tert-butyl 3,5-dimethyl-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4b): white solid. yield 84%, ee 91%. $[\alpha]_D^{20}$ +17.4 (*c* 0.5, DCM). m.p. 68-69 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.93 (d, *J* = 7.5 Hz, 2H), δ 7.63-7.76 (m, 4H), δ 7.11-7.14 (d, *J* = 8.4 Hz, 1H), δ 7.00 (s, 1H), δ 3.28-3.38 (m, 1H), δ 3.14-3.28 (m, 1H), δ 2.30-2.51 (m, 5H), δ 1.63 (s, 9H), δ 1.44 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 177.5, 148.8, 140.8, 136.3, 135.6, 134.5, 130.4, 130.3, 129.5, 127.1, 123.1, 115.2, 84.8, 54.8, 47.7, 30.5, 28.1, 24.2, 21.1. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1763, 1730, 1155, 939, 886. HRMS (ESI): calcd for $C_{23}H_{27}NNaO_5Se$ $[M+Na]^+$ 500.0948; found: 500.0945. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 23.2 min (major), 44.1 min (minor)].



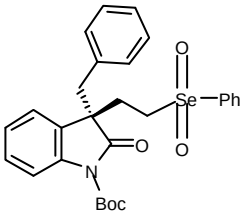
(R)-tert-butyl 3-ethyl-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4c): white solid. yield 86%, ee 94%. $[\alpha]_D^{20}$ +2.0 (*c* 0.5, DCM). m.p. 150-151 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.89-7.92 (d, *J* = 7.2 Hz, 2H), δ 7.80-7.83 (d, *J* = 7.8 Hz, 1H), δ 7.64-7.71 (m, 3H), δ 7.32-7.37 (t, *J* = 7.5 Hz, 1H), δ 7.15-7.24 (m, 2H), δ 3.26-3.36 (m, 1H), δ 3.07-3.15 (m, 1H), δ 2.35-2.51 (m, 2H), δ 1.96-2.03 (m, 1H), δ 1.78-1.85 (m, 1H),δ 1.64 (s, 9H), δ 0.61-0.66 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 177.0, 148.7, 140.8, 139.8, 134.5, 130.4, 129.0, 128.4, 127.0, 125.2, 122.8, 115.2, 85.0, 54.7, 52.7, 31.5, 29.6, 28.1, 8.4. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1753, 1737, 1154, 927, 885. HRMS (ESI): calcd for $C_{23}H_{27}NNaO_5Se$ $[M+Na]^+$ 500.0948; found: 500.0948. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (94:6), 20℃, 1 mL·min^{-1}, t_R = 49.1 min (major), 57.8 min (minor)].



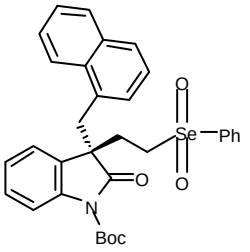
(R)-tert-butyl 2-oxo-3-(2-(phenylselenonyl)ethyl)-3-propylindoline-1-carboxylate (4d): white solid. yield 86%, ee 88%. $[\alpha]_D^{20}$ +2.0 (*c* 0.5, DCM). m.p. 137-138 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.89-7.92 (d, *J* = 7.2 Hz, 2H), δ 7.79-7.82 (d, *J* = 8.1 Hz, 1H), δ 7.71-7.75 (t, *J* = 7.2 Hz, 1H), δ 7.62-7.67 (t, *J* = 7.5 Hz, 2H), δ 7.31-7.36 (t, *J* = 7.5 Hz, 1H), δ 7.15-7.24 (m, 2H), δ 3.26-3.32 (m, 1H), δ 3.07-3.17 (m, 1H), δ 2.37-2.47 (m, 2H), δ 1.87-1.95 (m, 1H), δ 1.68-1.78

(m, 1H), δ 1.64 (s, 9H), δ 0.83-1.07 (m, 2H), δ 0.75-0.80 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 177.1, 148.7, 140.8, 139.6, 134.5, 130.4, 129.0, 128.7, 127.0, 125.2, 122.7, 115.2, 85.0, 54.6, 52.2, 40.5, 29.9, 28.1, 17.4, 13.9. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1758, 1737, 1151, 928, 885. HRMS (ESI): calcd for $C_{24}H_{29}NNaO_5Se$ $[M+Na]^+$ 514.1105; found: 514.1105. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (94:6), 20℃, 1 mL·min^{-1}, t_R = 32.2 min (major), 56.2 min (minor)].

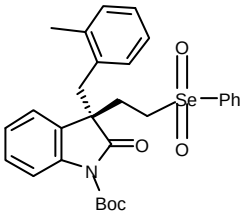
(R)-tert-butyl 3-benzyl-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4e): white solid. yield 91%, ee 88%. $[\alpha]_D^{20}$ +12.2 (*c* 0.5, DCM). m.p. 149-150 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.93 (overlapping: s, 1H; d, *J* = 1.5 Hz, 1H), δ 7.71-7.76 (t, *J* = 7.5 Hz, 1H), δ 7.62-7.67 (t, *J* = 7.5 Hz, 2H), δ 7.53-7.56 (d, *J* = 7.8 Hz, 1H), δ 7.13-7.28 (m, 3H), δ 7.00-7.09 (m, 3H), δ 6.72-6.74 (d, *J* = 6.9 Hz, 2H), δ 3.26-3.34 (m, 1H), δ 3.16-3.20 (d, *J* = 12.9 Hz, 1H), δ 3.00-3.10 (m, 2H), δ 2.55-2.67 (m, 2H), δ 1.54 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.4, 148.2, 140.9, 139.7, 134.5, 133.8, 130.4, 129.7, 129.2, 127.8, 127.3, 127.1, 127.1, 124.8, 123.3, 115.1, 84.6, 54.8, 53.9, 45.3, 28.7, 28.0, 22.3, 14.4. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1738, 1150, 932, 885. HRMS (ESI): calcd for $C_{28}H_{29}NNaO_5Se$ $[M+Na]^+$ 562.1105; found: 562.1101. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 30.7 min (major), 39.7 min (minor)].



(R)-tert-butyl 3-(naphthalen-1-ylmethyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4f): white solid. yield 86%, ee 88%. $[\alpha]_D^{20}$ -9.0 (*c* 0.5, DCM). m.p. 153-155 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.86-7.89 (d, *J* = 7.5 Hz, 2H), δ 7.60-7.72 (m, 6H), δ 7.53-7.56 (d, *J* = 8.1 Hz, 1H), δ 7.30-7.40 (m, 2H), δ 7.14-7.26 (m, 2H), δ 6.98-7.03 (t, *J* = 7.5 Hz, 1H), δ 6.91-6.93 (d, *J* = 7.8 Hz, 2H), δ 3.67-3.71 (d, *J* = 13.8 Hz, 1H), δ 3.48-3.53 (d, *J* = 13.8 Hz, 1H), δ 3.24-3.29 (m, 1H), δ 2.93-3.01 (m, 1H), δ 2.75-2.82 (m, 1H), δ 2.60-2.66 (m, 1H), δ 1.45 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.7, 148.3, 140.8, 139.6, 134.5, 133.6, 132.1, 130.4, 130.2, 129.1, 128.7, 128.5, 128.1, 127.2, 127.1, 125.6, 125.4, 124.6, 124.6, 124.0, 123.9, 115.0, 84.5, 55.0, 53.8, 40.8, 28.4, 27.8. IR ν_{max} (KBr, film, cm^{-1}): 1766, 1727, 1150, 939, 887. HRMS (ESI): calcd for $C_{32}H_{31}NNaO_5Se$ $[M+Na]^+$ 612.1262; found: 612.1250. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 35.1 min (major), 48.5 min (minor)].

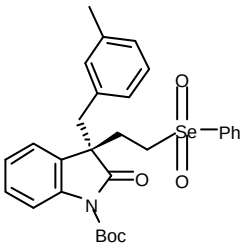


(R)-tert-butyl 3-(2-methylbenzyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4g): white solid. yield 86%, ee 91%. $[\alpha]_D^{20}$ +7.6 (*c* 0.5, DCM). m.p. 64-66 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.93 (overlapping: s, 1H; d, *J* = 1.2 Hz, 1H), δ 7.62-7.73 (m, 4H), δ 7.25-7.31 (m, 2H), δ 6.92-7.14 (m, 5H), δ 6.70-6.72 (d, *J* = 7.5 Hz, 1H), δ 3.18-3.28 (m, 2H), δ 2.97-3.10 (m, 2H), δ 2.58-2.70 (m, 2H), δ 1.93 (s, 3H), δ 1.56 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.7, 148.4, 140.9, 139.7, 137.1, 134.5, 132.3, 130.5, 130.4, 130.3, 129.2, 127.3, 127.3, 127.0, 125.4, 124.7, 123.6, 115.1, 84.6, 54.8, 53.4, 41.2, 28.2, 28.0, 19.7. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1762, 1732, 1150, 940, 886. HRMS (ESI): calcd for $C_{29}H_{31}NNaO_5Se$ $[M+Na]^+$ 576.1262; found: 576.1254. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 25.6 min (major), 38.1 min (minor)].

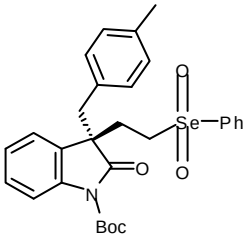


(R)-tert-butyl 3-(3-methylbenzyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4h): white solid. yield 90%, ee 91%. $[\alpha]_D^{20}$ +12.0 (*c* 0.5, DCM). m.p. 148-149 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.88-7.93 (t, *J* = 7.2 Hz, 2H), δ 7.71-7.76 (t, *J* = 7.5Hz, 1H), δ 7.62-7.67 (t, *J* = 7.5 Hz, 2H),

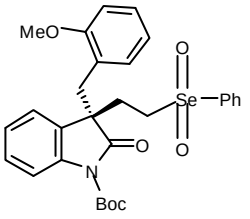
δ 7.55-7.57 (d, *J* = 7.8 Hz, 1H), δ 7.12-7.25 (m, 3H), δ 6.90-6.94 (t, *J* = 7.5 Hz, 2H), δ 6.50-6.55 (d, *J* = 7.5 Hz, 2H), δ 3.25-3.35 (m, 1H), δ 2.96-3.15 (m, 3H), δ 2.49-2.70 (m, 2H), δ 2.13 (s, 3H), δ 1.45 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.5, 148.3, 140.9, 139.7, 137.4, 134.5, 133.7, 130.5, 130.4, 129.1, 127.8, 127.7, 127.4, 127.1, 126.8, 124.7, 123.4, 115.1, 84.5, 54.8, 53.9, 45.2, 28.6, 28.0, 21.1. IR ν_{max} (KBr, film, cm^{-1}): 1766, 1727, 1149, 938, 886. HRMS (ESI): calcd for $C_{29}H_{31}NNaO_5Se$ $[M+Na]^+$ 576.1262; found: 576.1256. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 24.9 min (major), 33.8 min (minor)].



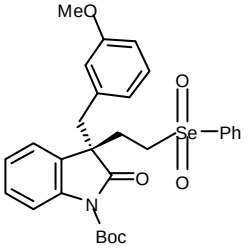
(R)-tert-butyl 3-(4-methylbenzyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4i): white solid. yield 86%, ee 85%. $[\alpha]_D^{20}$ +10.2 (*c* 0.5, DCM). m.p. 147-148 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.92 (d, *J* = 7.2 Hz, 2H), δ 7.56-7.73 (m, 4H), δ 7.12-7.26 (m, 3H), δ 6.83-6.86 (d, *J* = 7.2 Hz, 2H), δ 6.61-6.63 (d, *J* = 7.5 Hz, 2H), δ 3.25-3.35 (m, 1H), δ 2.97-3.14 (m, 3H), δ 2.49-2.69 (m, 2H), δ 2.20 (s, 3H), δ 1.54 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.5, 148.3, 140.9, 139.7, 136.6, 134.5, 130.7, 130.4, 129.6, 129.1, 128.5, 127.4, 127.0, 124.8, 123.4, 115.1, 84.5, 54.8, 53.9, 44.8, 28.6, 27.9, 21.0. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1739, 1153, 929, 885. HRMS (ESI): calcd for $C_{29}H_{31}NNaO_5Se$ $[M+Na]^+$ 576.1262; found: 576.1252. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 29.3 min (major), 37.1 min (minor)].



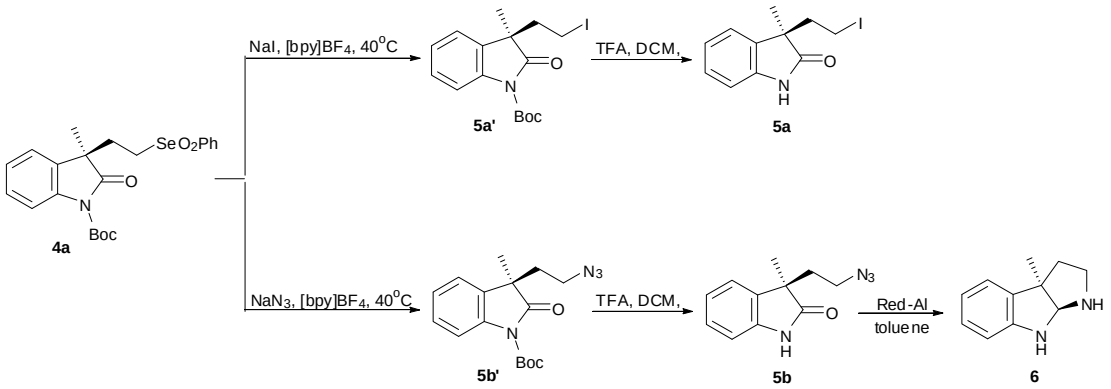
(R)-tert-butyl 3-(2-methoxybenzyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4j): white solid. yield 80%, ee 90%. $[\alpha]_D^{20}$ +32.8 (*c* 0.5, DCM). m.p. 138-139 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.89-7.92 (d, *J* = 7.5 Hz, 2H), δ 7.60-7.75 (m, 4H), δ 7.18-7.23 (t, *J* = 7.8 Hz, 1H), δ 7.04-7.13 (m, 2H), δ 6.96-6.98 (d, *J* = 7.2 Hz, 1H), δ 6.82-6.84 (d, *J* = 6.3 Hz, 1H), δ 6.69-6.74 (t, *J* = 7.5 Hz, 1H), δ 6.61-6.64 (d, *J* = 8.4 Hz, 1H), δ 3.54 (s, 3H), δ 3.30-3.39 (m, 2H), δ 3.00-3.12 (m, 2H), δ 2.59-2.70 (m, 1H), δ 2.44-2.53 (m, 1H), δ 1.60 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.9, 157.4, 148.6, 140.9, 139.3, 134.4, 131.5, 130.3, 128.7, 128.7, 127.7, 127.0, 124.2, 124.0, 122.8, 119.9, 114.7, 110.1, 84.5, 55.1, 54.7, 53.2, 38.0, 28.6, 28.1. IR ν_{max} (KBr, film, cm^{-1}): 1789, 1760, 1731, 1150, 939, 995. HRMS (ESI): calcd for $C_{29}H_{31}NNaO_6Se$ $[M+Na]^+$ 592.1211; found: 592.1206. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (92:8), 20℃, 1 mL·min^{-1}, t_R = 36.2 min (major), 45.9 min (minor)].



(R)-tert-butyl 3-(3-methoxybenzyl)-2-oxo-3-(2-(phenylselenonyl)ethyl)indoline-1-carboxylate (4k): white solid. yield 80%, ee 90%. $[\alpha]_D^{20}$ +13.0 (*c* 0.5, DCM). m.p. 149-150 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90-7.93 (d, *J* = 7.5 Hz, 2H), δ 7.56-7.75 (m, 4H), δ 7.18-7.28 (m, 3H), δ 6.92-6.97 (t, *J* = 7.8 Hz, 1H), δ 6.62-6.64 (d, *J* = 7.2 Hz, 1H), δ 6.33-6.35 (d, *J* = 7.5 Hz, 1H), δ 6.23 (s, 1H), δ 3.57 (s, 3H), δ 3.26-3.36 (m, 1H), δ 2.98-3.18 (m, 3H), δ 2.51-2.71 (m, 2H), δ 1.54 (s, 9H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 176.4, 159.0, 148.3, 140.9, 139.8, 135.2, 134.5, 130.4, 129.2, 128.8, 127.4, 127.1, 124.8, 123.3, 122.1, 115.2, 114.6, 113.4, 84.6, 55.0, 54.7, 53.9, 45.3, 28.8, 27.9. IR ν_{max} (KBr, film, cm^{-1}): 1788, 1737, 1154, 929, 883. HRMS (ESI): calcd for $C_{29}H_{31}NNaO_6Se$ $[M+Na]^+$ 592.1211; found: 592.1204. HPLC analysis [Chiralcel AD-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 38.5 min (major), 47.9 min (minor)].



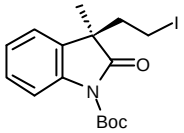
2.3. Derivation of 4a



2.3.1. synthesis of 5a

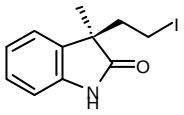
To the mixture of **4a** (0.2 mmol, 92.6 mg) and NaI (0.6mmol, 90mg), [bpy][BF_4] (0.5 mL) was added. The reaction system was stirred for about 8h at 40℃. The reaction was then extracted with ethyl acetate, and organic phase collected was concentrated. FC (petroleum ether/ ethyl acetate, 20: 1) offered **5a'**.

(R)-tert-butyl 3-(2-iodoethyl)-3-methyl-2-oxoindoline-1-carboxylate (5a'): colorless liquid. yield 90%. $[\alpha]_D^{20}$ -33.9 (*c* 1.25, DCM). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.85-7.87 (d, *J* = 8.1 Hz, 1H), δ 7.28-7.36 (m, 1H), δ 7.19-7.21 (d, *J* = 4.2 Hz, 2H), δ 2.85-2.94 (m, 1H), δ 2.71-2.80 (m, 1H), δ 2.54-2.64 (m, 1H), δ 2.31-2.41 (m, 1H), δ 1.66 (s, 9H), δ 1.43 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 177.8, 149.1, 139.1, 131.1, 128.5, 124.8, 122.4, 115.3, 84.6, 50.5, 43.4, 28.1, 24.4, -2.5. IR ν_{max} (KBr, film, cm^{-1}): 1792, 1764, 1731, 1350, 1294, 1150. HRMS (ESI): calcd for $C_{16}H_{20}INNaO_3$ $[M+Na]^+$ 424.0380; found: 424.0376.



To the solution of **5a'** in DCM (2ml), TFA (0.2ml) was added. The reaction system was stirred for 0.5h at rt. After remove solvent, FC (petroleum ether/ ethyl acetate, 4: 1) offered **5a**.

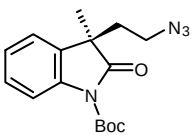
(R)-3-(2-iodoethyl)-3-methylindolin-2-one (5a): white solid. yield 95%, ee 93%. $[\alpha]_D^{20}$ -18.0 (*c* 0.4, DCM). m.p. 132-133 ℃. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.94 (s, 1H) , δ 7.17-7.26 (m, 2H), δ 7.05-7.10 (t, *J* = 7.5 Hz, 1H), δ 6.95-6.98 (d, *J* = 7.8 Hz, 1H), δ 2.88-2.97 (m, 1H), δ 2.71-2.79 (m, 1H), δ 2.51-2.61 (m, 1H), δ 2.33-2.43 (m, 1H), δ 1.42 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 182.0, 140.4, 132.7, 128.3, 122.9 (2C, overlapping), 110.2, 50.8, 42.7, 23.5, -2.1. IR ν_{max} (KBr, film, cm^{-1}): 3196, 1709, 1670, 1623, 1472, 1210. HRMS (ESI): calcd for $C_{11}H_{12}INNaO$ $[M+Na]^+$ 323.9856; found: 323.9853. HPLC analysis [Chiralcel AS-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 20.6 min (minor), 32.5 min (major)].



2.3.2. synthesis of 6

To the mixture of **4b** (0.2 mmol, 92.6 mg) and NaN_3 (0.6mmol, 39mg), [bpy][BF_4] (0.5 mL) was added. The reaction system was stirred for about 8h at 40℃. The reaction was then extracted with ethyl acetate, and organic phase collected was concentrated. FC (petroleum ether/ ethyl acetate, 10: 1) offered **5b'** as a colorless liquid.

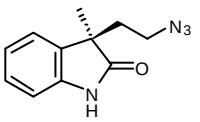
(R)-tert-butyl 3-(2-azidoethyl)-3-methyl-2-oxoindoline-1-carboxylate (5b'): colorless liquid. yield 87%, $[\alpha]_D^{20}$ +20.5 (*c* 0.73, DCM). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.86-7.89 (d, *J* = 8.1 Hz, 1H) , δ 7.28-7.35 (m, 1H), δ 7.18-7.22 (m, 2H), δ 2.94-3.11 (m, 2H), δ 2.27-2.37 (m, 1H), δ 1.96-2.05 (m, 1H), δ 1.65 (m, 9H), δ 1.44 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 178.3, 149.3, 139.1, 131.3, 128.5, 124.7, 122.4, 115.3, 84.1, 47.4, 47.0, 37.6, 28.1, 25.2. IR ν_{max} (KBr, film, cm^{-1}): 2098, 1792, 1767, 1730, 1350, 1293, 1151. HRMS (ESI): calcd for $C_{16}H_{20}N_4NaO_3$ $[M+Na]^+$ 339.1428; found: 339.1422.



To the solution of **5b'** in DCM (2ml), TFA (0.2ml) was added. The reaction system was stirred for 0.5h

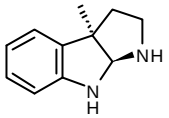
at rt. After remove solvent, FC (petroleum ether/ ethyl acetate, 4: 1) offered **5b**.

(R)-3-(2-azidoethyl)-3-methylindolin-2-one (5b): colorless liquid. yield 95%, ee 93%. $[\alpha]_D^{20}$ +41.7 (*c* 1.8, DCM). ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.39 (s, 1H), δ 7.16-7.26 (m, 2H) , δ 7.04-7.09 (t, *J* = 7.5 Hz, 1H), δ 6.97-7.00 (d, *J* = 7.8 Hz, 1H), δ 3.02-3.07 (t, *J* = 7.5 Hz, 1H), δ 2.25-2.35 (m, 1H), δ 2.00-2.09 (m, 1H), δ 1.43 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 182.9, 140.5, 133.0, 128.3, 122.8, 122.7, 110.4, 47.5, 47.3, 36.6, 24.3. IR ν_{max} (KBr, film, cm^{-1}): 3215, 2098, 1712, 1620, 1472, 1335. HRMS (ESI): calcd for $C_{11}H_{12}N_4NaO$ $[M+Na]^+$ 239.0903; found: 239.0901. HPLC analysis [Chiralcel AS-H, n-hexane/ i-propanol (90:10), 20℃, 1 mL·min^{-1}, t_R = 35.4 min (minor), 70.4 min (major)].



Under N_2 atmosphere and the ice bath, Red-Al (70 wt% in toluene, 1.2mL, 4.3mmol) was added slowly to the solution of **5b** (90mg, 0.42mmol) in 4mL dry toluene. After stirred for 1.5h at room temperature, the reaction was heated to 100℃ and maintained for 17h. The system then cooled to rt and was quenched with 10mL saturated aqueous $NaHCO_3$. Removed the solid by filtration, the mixture was extracted with ethyl acetate (3×15mL). The combined organic phase was dried over Na_2SO_4 and concentrated. Flash chromatography (DCM/MeOH/NH_3·H_2O= 100/10/1) offered **6** as the oil (53mg, 73% yield).

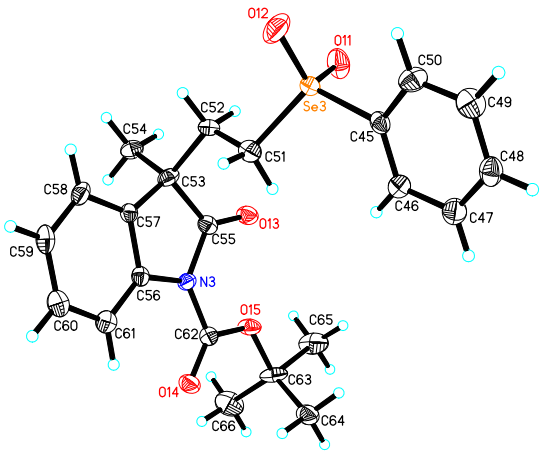
(3aR, 8aS)-3a-methyl-1, 2, 3, 3a, 8, 8a-hexahydropyrrolo[2, 3-b]indole: yellowish liquid, yield 73%, ee 96%, $[\alpha]_D^{20}$ +132.1 (*c* 1.1, DCM). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.01-7.07 (m, 2H), δ 6.72-6.77 (t, *J* = 7.2 Hz, 1H), δ 6.55-6.58 (d, *J* = 7.8 Hz, 1H), δ 4.86 (s, 1H), δ 4.13 (br, 2H), δ 3.03-3.08 (m, 1H), δ 2.74-2.83 (m, 1H), δ 2.01-2.12 (m, 1H) , δ 1.83-1.93 (m, 1H), δ1.48 (s, 3H). ^{13}C NMR (75.0 MHz, $CDCl_3$): δ 149.6, 135.2, 127.8, 123.1, 118.8, 108.6, 85.0, 54.0, 45.8, 42.5, 26.3. HRMS (ESI): calcd for $C_{11}H_{15}N_2$ $[M+H]^+$ 175.1230; found: 175.1225. HPLC analysis [Chiralcel AS-H, n-hexane/ i-propanol (90:10), 20℃, 0.5 mL·min^{-1}, t_R = 15.3 min (major), 33.1 min (minor)].

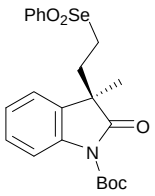


1 W. Chen, W. Du, Y.-Z. Duan, Y. Wu, S.-Y. Yang and Y.-C. Chen, *Angew. Chem.*, *Int. Ed.,* 2007, **46**, 7667.

2 J. Ye, D. J. Dixon and P. S. Hynes, *Chem. Commun.*, 2005, 4481.

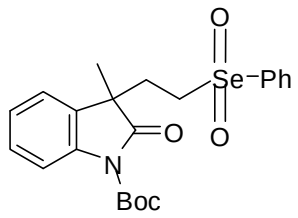
3. Crystal data for 4a

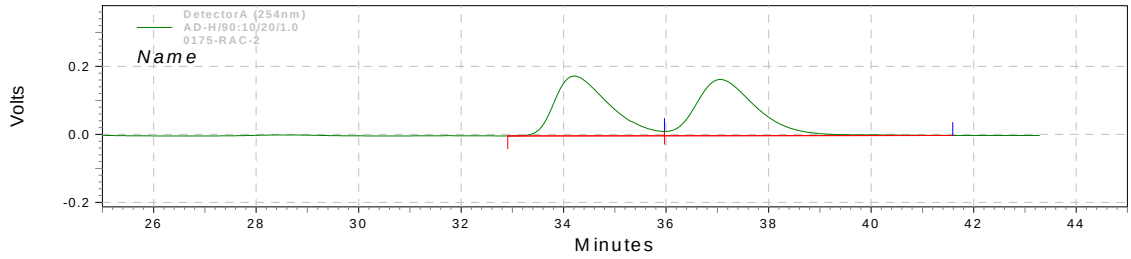




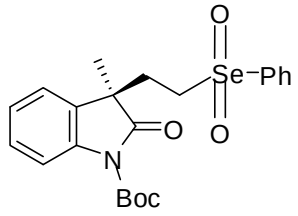
Crystal data for **4a**: $C_{89}H_{106}N_4O_{22}Se_4$, M = 1899.62, monoclinic, a = 16.835(3) Å, b = 13.587(3) Å, c = 19.790(4) Å, α = 90°, β = 101.80(3)°, γ = 90°, V = 4431.1(15) Å^3, T = 173(2) K, space group P2(1), Z = 2, 50547 reflections measured, 15407 independent reflections ($Rint$ = 0.0847). The final R_1 values were 0.0642 ($I > 2\sigma(I)$). The final $wR(F^2)$ values were 0.1319 ($I > 2\sigma(I)$). The final R_1 values were 0.0759 (all data). The final $wR(F2)$ values were 0.1419 (all data). The goodness of fit on F^2 was 1.109. CCDC number: CCDC 802111.

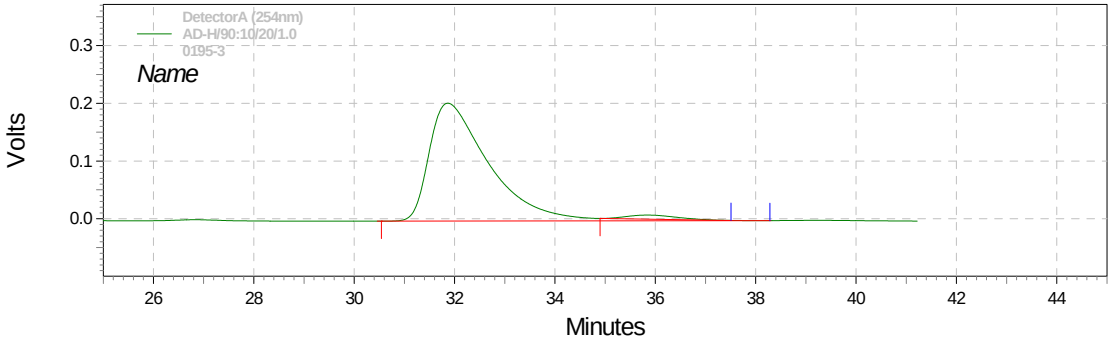
4. HPLC tracks and NMR spectrums



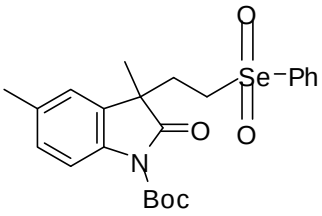


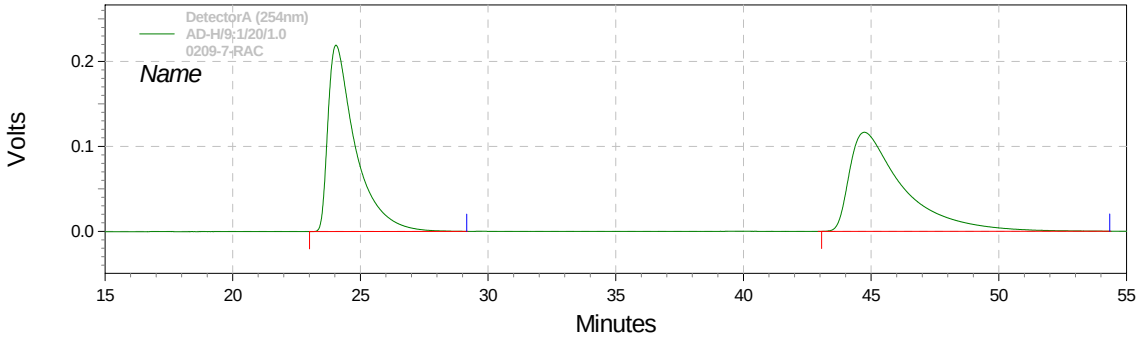
Pk #	Retention Time	Area	Area %
1	34.202	12839220	49.852
2	37.052	12915622	50.148
Totals		25754842	100.000



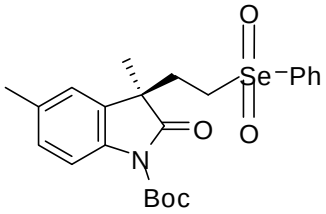


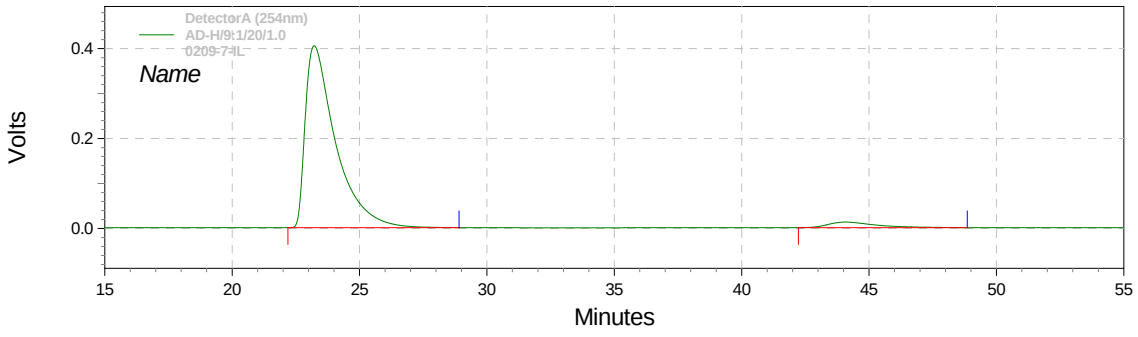
Pk #	Retention Time	Area	Area %
1	31.862	16771144	97.472
2	35.842	435054	2.528
Totals		17206198	100.000



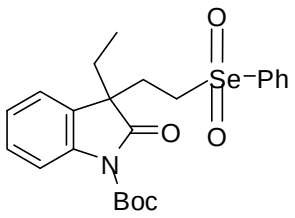


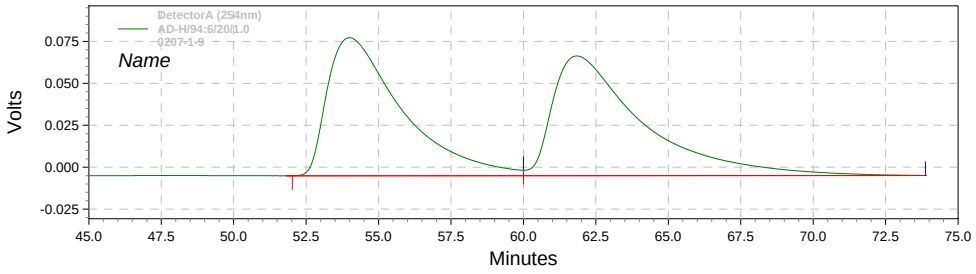
Pk #	Retention Time	Area	Area %	Height	Height %
1	24.040	16340885	49.120	219481	65.306
2	44.728	16926635	50.880	116597	34.694
Totals		33267520	100.000	336078	100.000



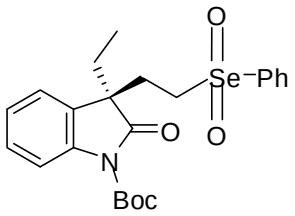


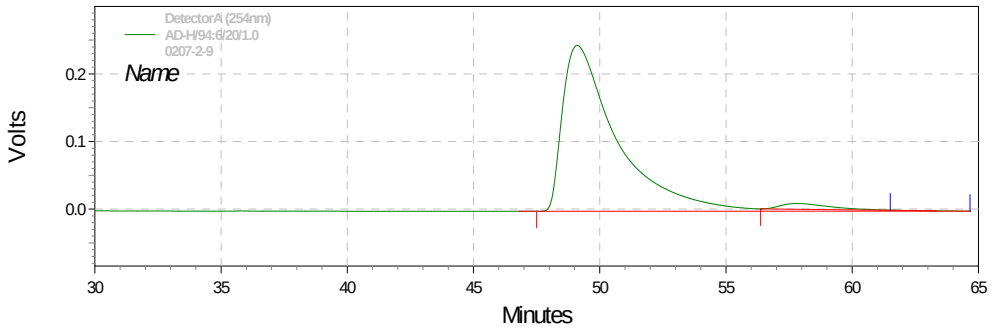
Pk #	Retention Time	Area	Area %
1	23.215	33402147	95.431
2	44.078	1599180	4.569
Totals		35001327	100.000



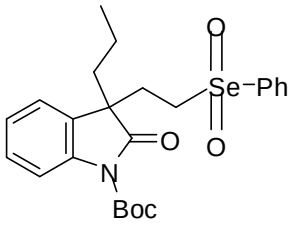


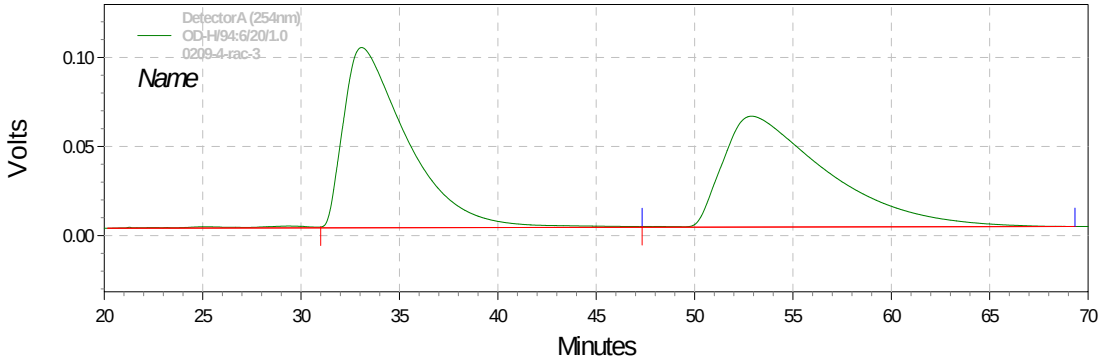
Pk #	Retention Time	Area	Area %
1	54.004	14749491	49.040
2	61.837	15326945	50.960
Totals		30076436	100.000



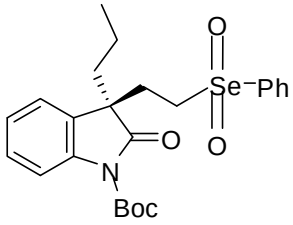


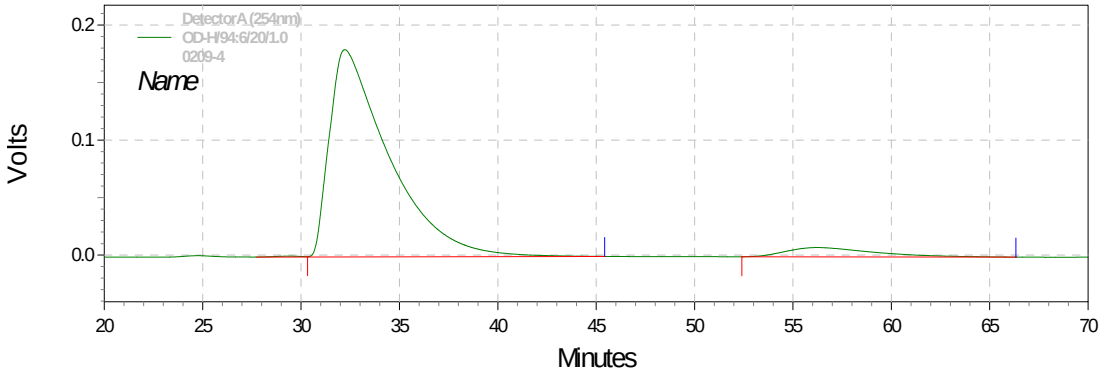
Pk #	Retention Time	Area	Area %
1	49.104	37381341	96.974
2	57.798	1166406	3.026
Totals		38547748	100.000



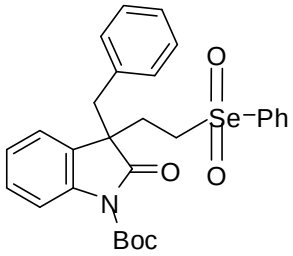


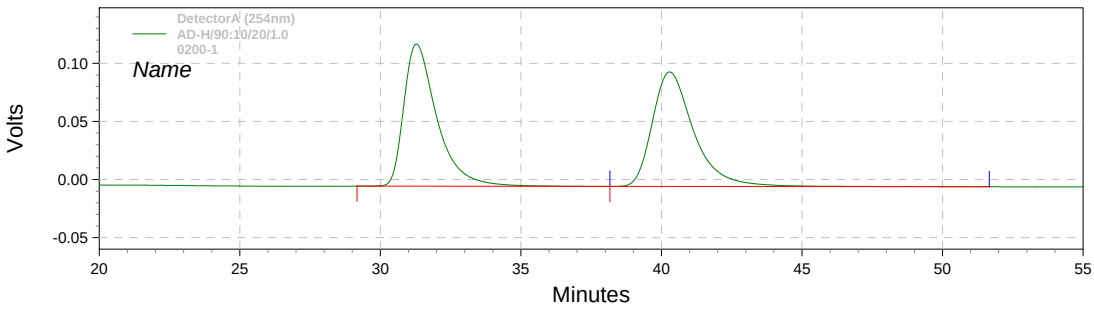
Pk #	Retention Time	Area	Area %
1	33.085	22811044	49.848
2	52.902	22950572	50.152
Totals		45761615	100.000



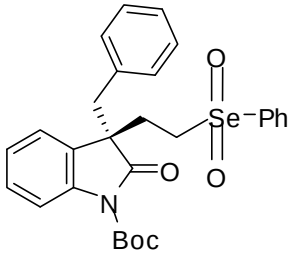


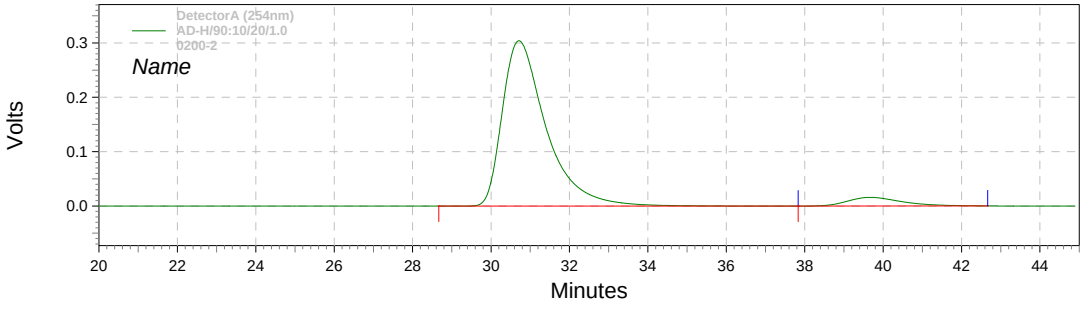
Pk #	Retention Time	Area	Area %
1	32.237	37951922	93.992
2	56.234	2426092	6.008
Totals		40378014	100.000



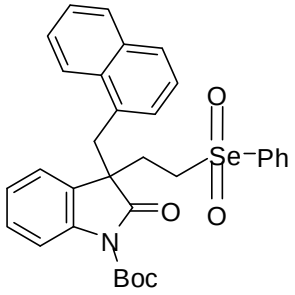


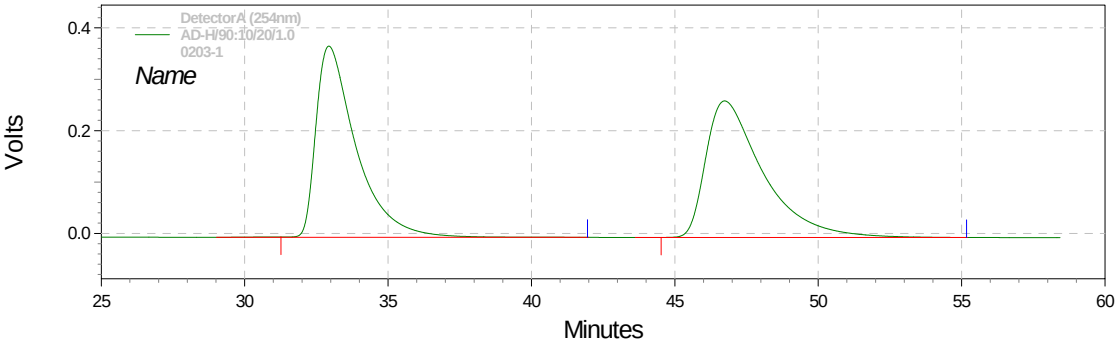
Pk #	Retention Time	Area	Area %
1	31.286	10031860	49.766
2	40.290	10126152	50.234
Totals		20158012	100.000



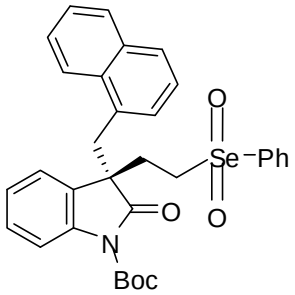


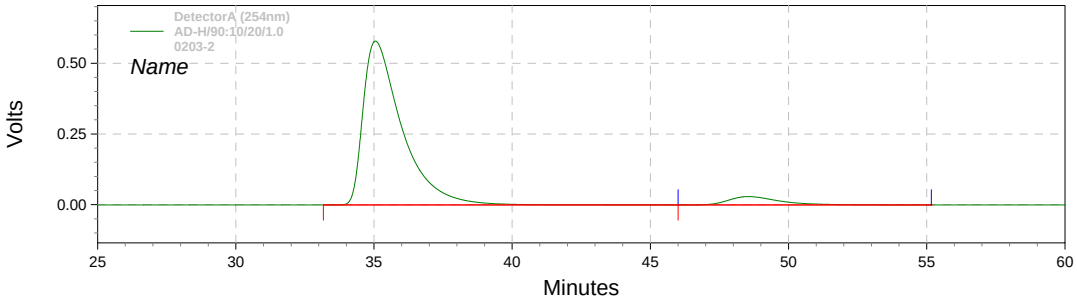
Pk #	Retention Time	Area	Area %
1	30.717	23614533	93.978
2	39.671	1513080	6.022
Totals		25127613	100.000



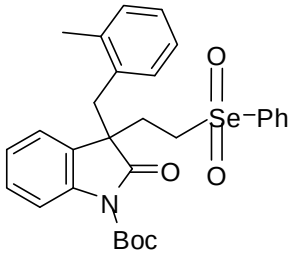


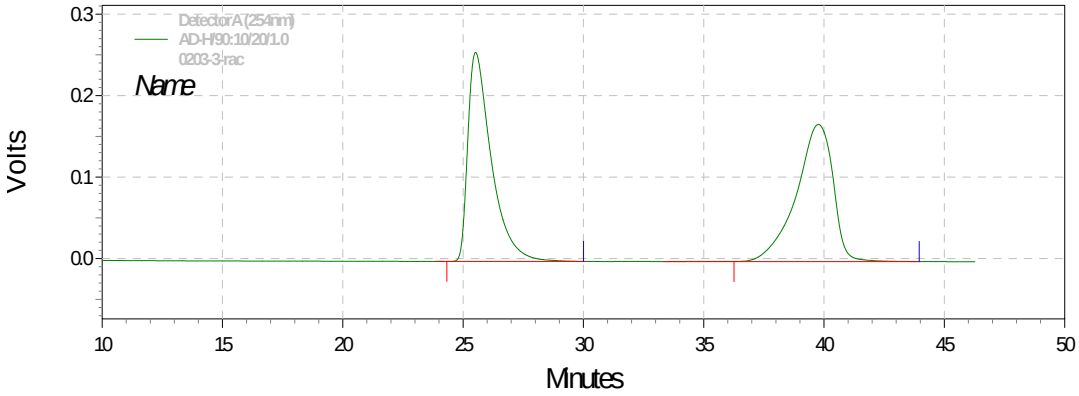
Pk #	Retention Time	Area	Area %
1	32.931	36140588	49.551
2	46.733	36794820	50.449
Totals		72935408	100.000



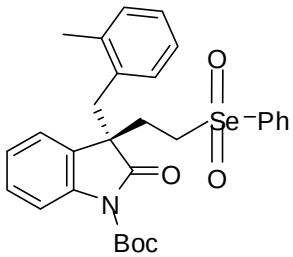


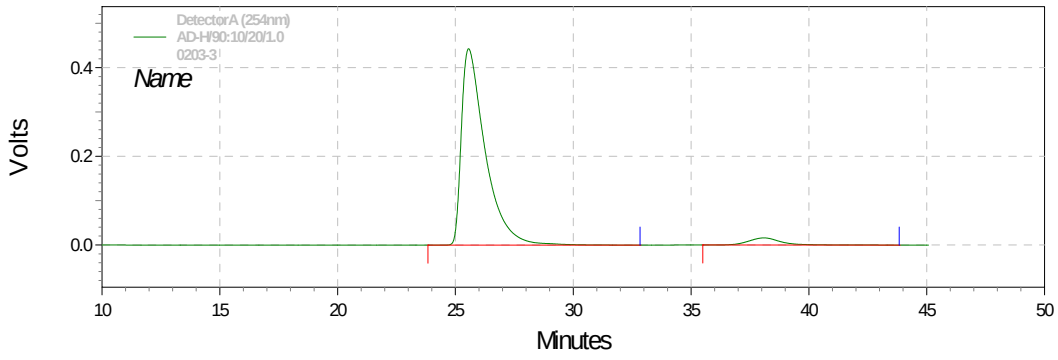
Pk #	Retention Time	Area	Area %
1	35.062	56362565	93.928
2	48.548	3643533	6.072
Totals		60006098	100.000



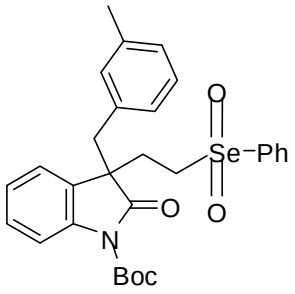


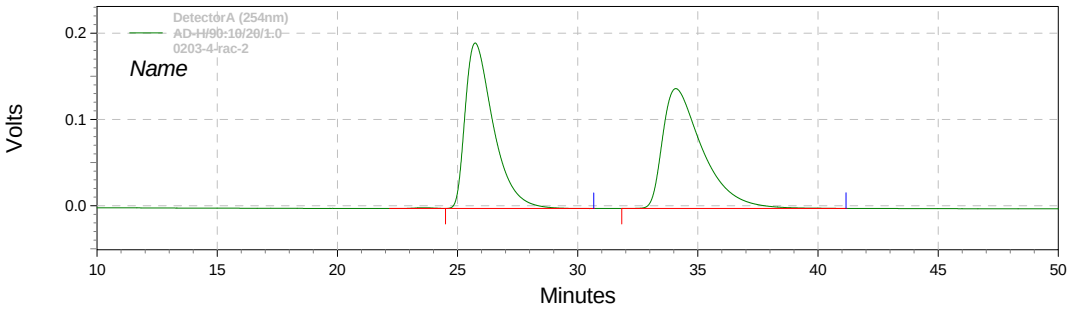
Pk #	Retention Time	Area	Area %
1	25.514	17403925	49.349
2	39.759	17863084	50.651
Totals		35267009	100.000



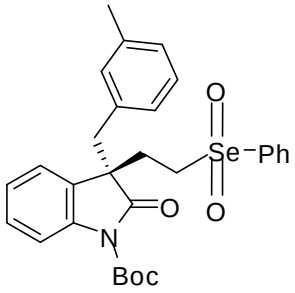


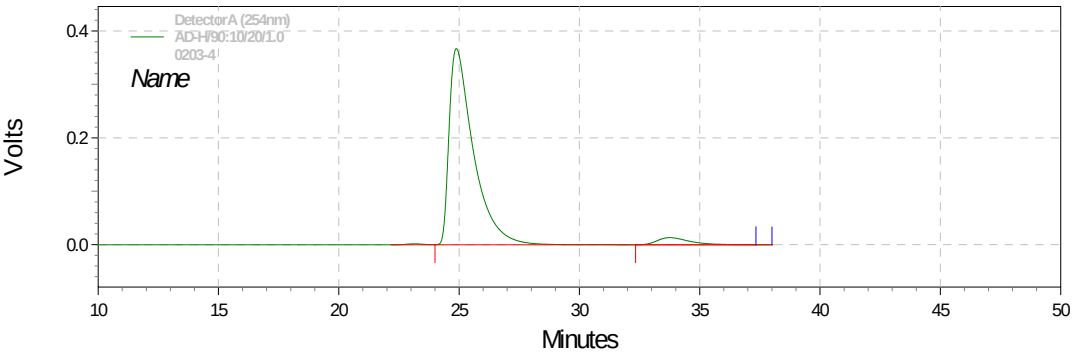
Pk #	Retention Time	Area	Area %
1	25.582	31101139	95.534
2	38.086	1454045	4.466
Totals		32555184	100.000



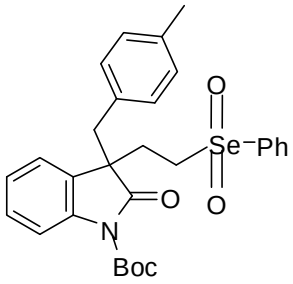


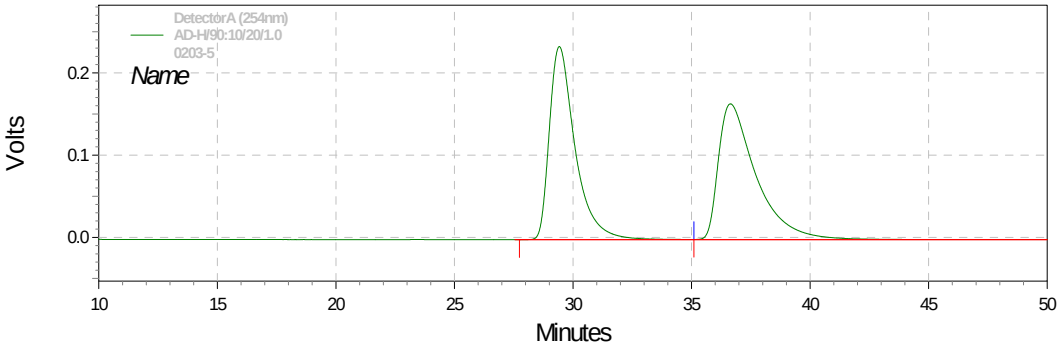
Pk #	Retention Time	Area	Area %
1	25.744	15650979	49.428
2	34.091	16013117	50.572
Totals		31664096	100.000



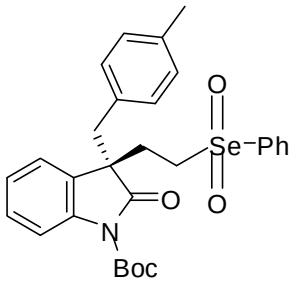


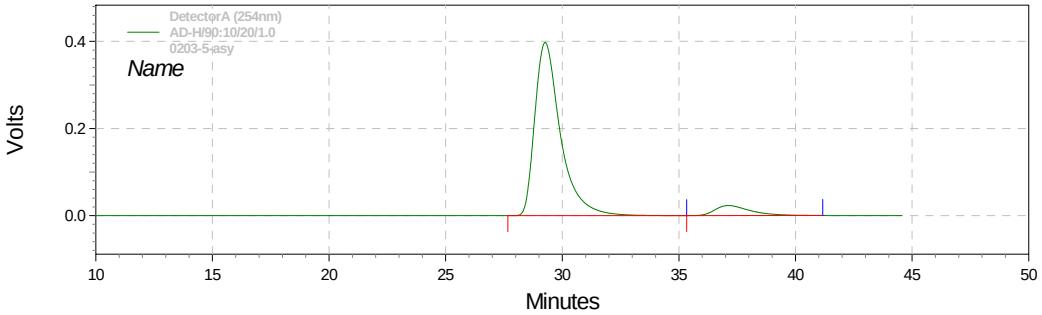
Pk #	Retention Time	Area	Area %
1	24.909	25772972	95.393
2	33.762	1244759	4.607
Totals		27017731	100.000



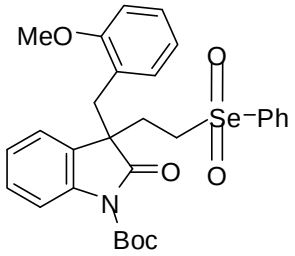


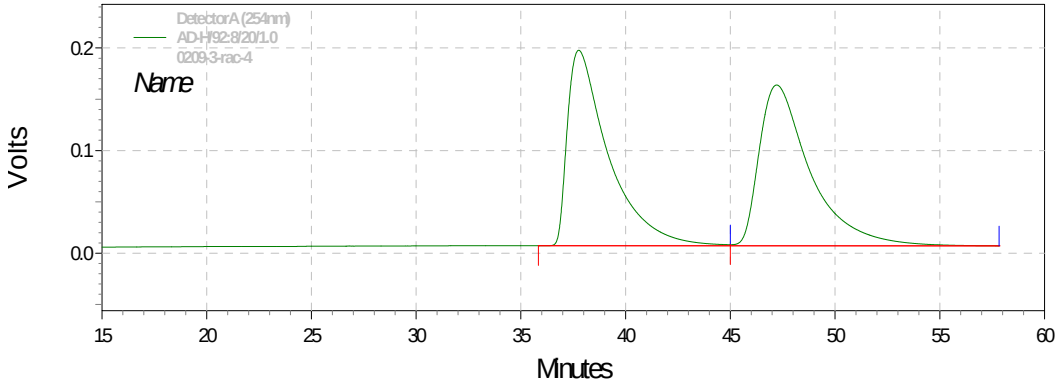
Pk #	Retention Time	Area	Area %
1	29.418	17713477	49.202
2	36.636	18288406	50.798
Totals		36001883	100.000



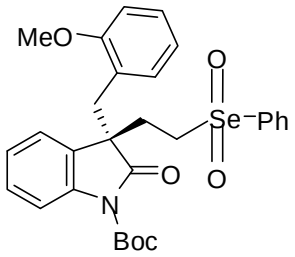


Pk #	Retention Time	Area	Area %
1	29.267	30383495	92.646
2	37.125	2411779	7.354
Totals		32795274	100.000

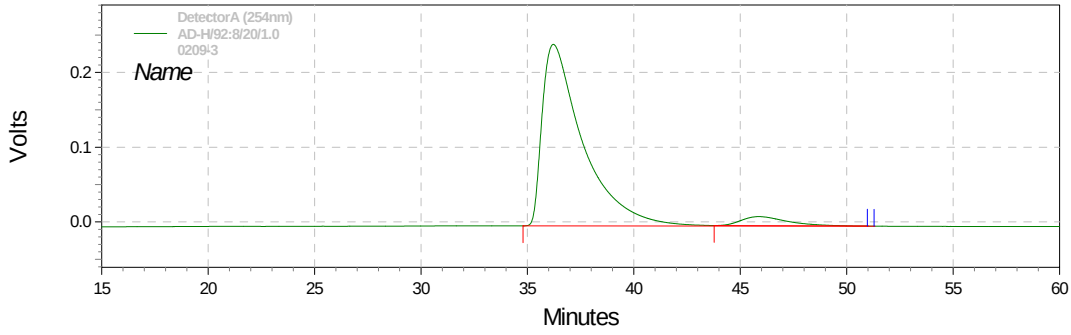




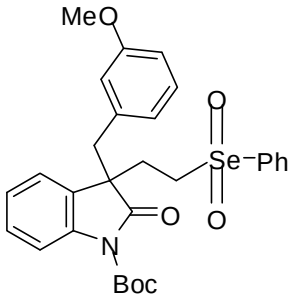
Pk #	Retention Time	Area	Area %
1	37.772	26047320	49.548
2	47.214	26522723	50.452
Totals		52570044	100.000

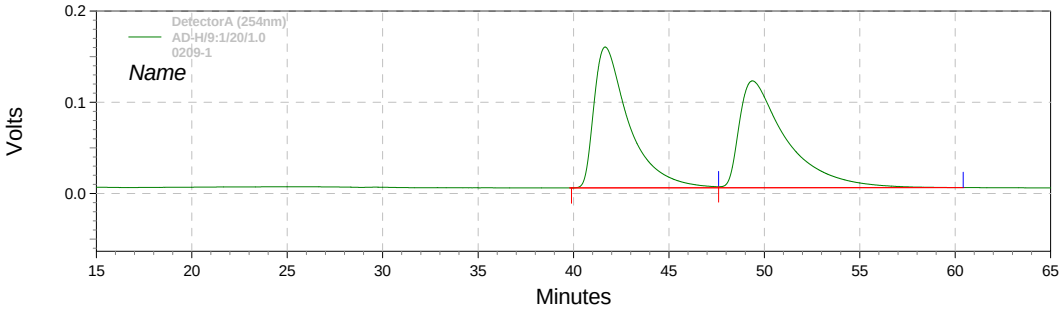


.

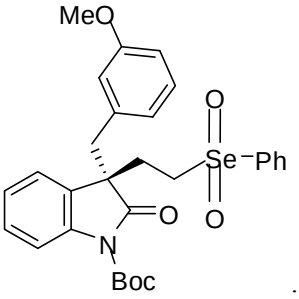


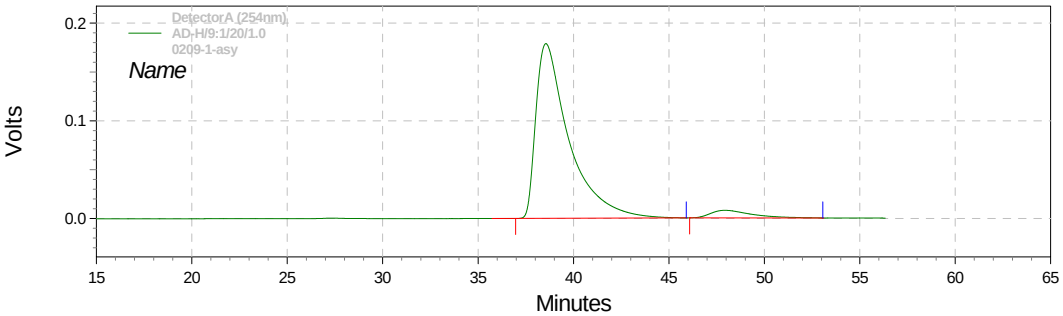
Pk #	Retention Time	Area	Area %
1	36.227	32333671	94.956
2	45.875	1717572	5.044
Totals		34051244	100.000



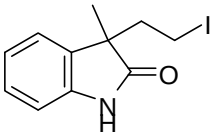


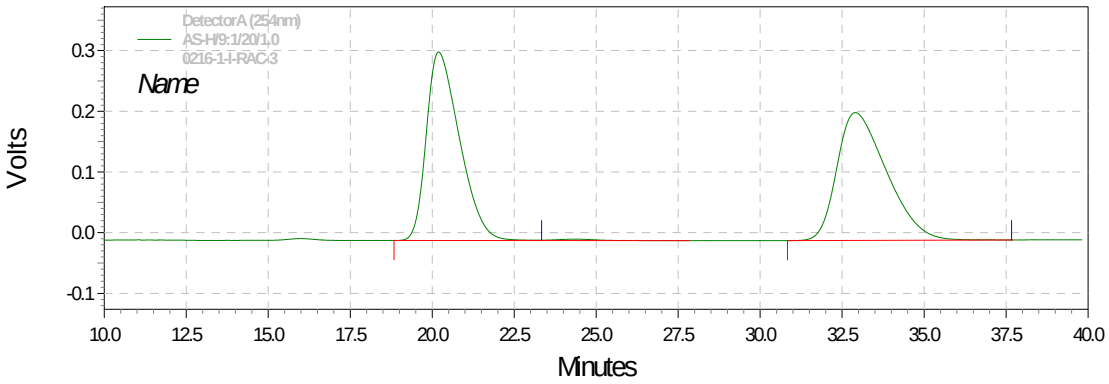
Pk #	Retention Time	Area	Area %
1	41.658	19642100	49.483
2	49.368	20052489	50.517
Totals		39694590	100.000



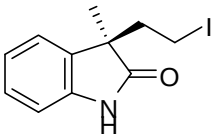


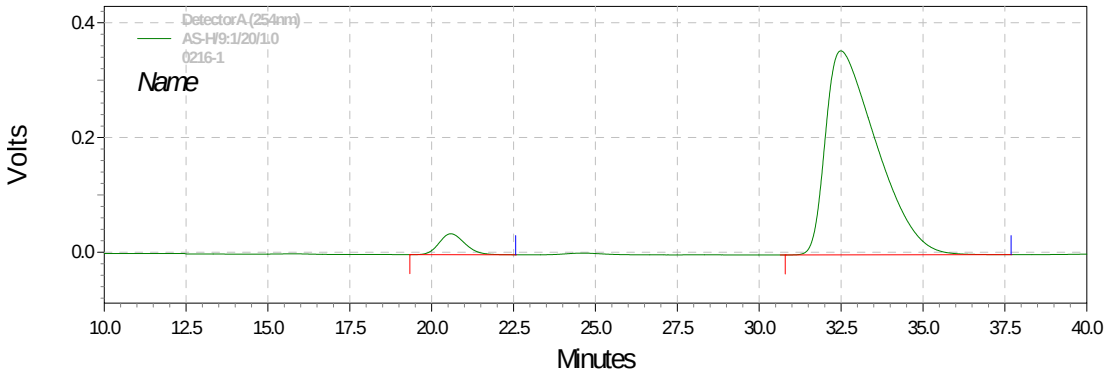
Pk #	Retention Time	Area	Area %
1	38.547	21559294	94.942
2	47.940	1148612	5.058
Totals		22707906	100.000



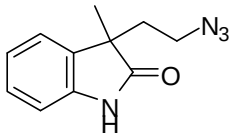


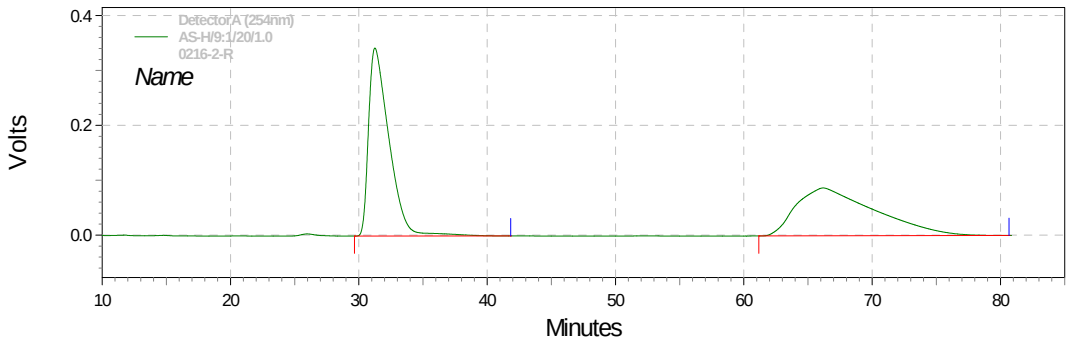
Pk #	Retention Time	Area	Area %
1	20.209	21856845	49.795
2	32.912	22037082	50.205
Totals		43893927	100.000



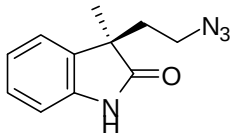


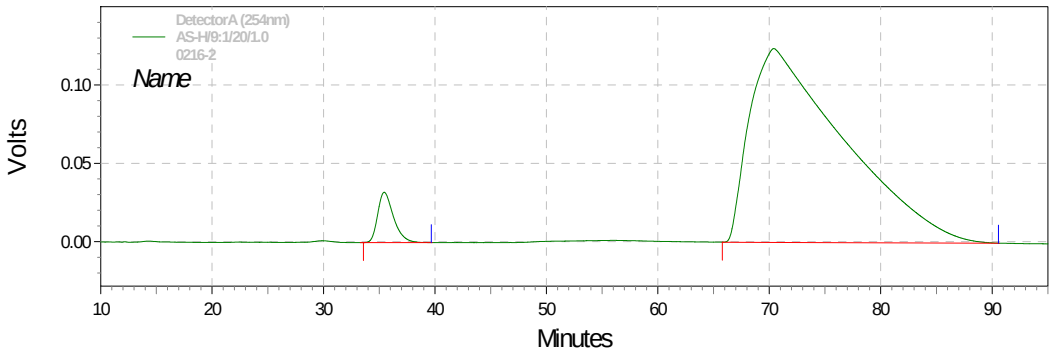
Pk #	Retention Time	Area	Area %
1	20.586	1436334	3.595
2	32.499	38519984	96.405
Totals		39956317	100.000



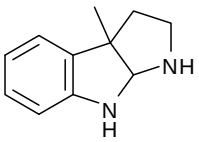


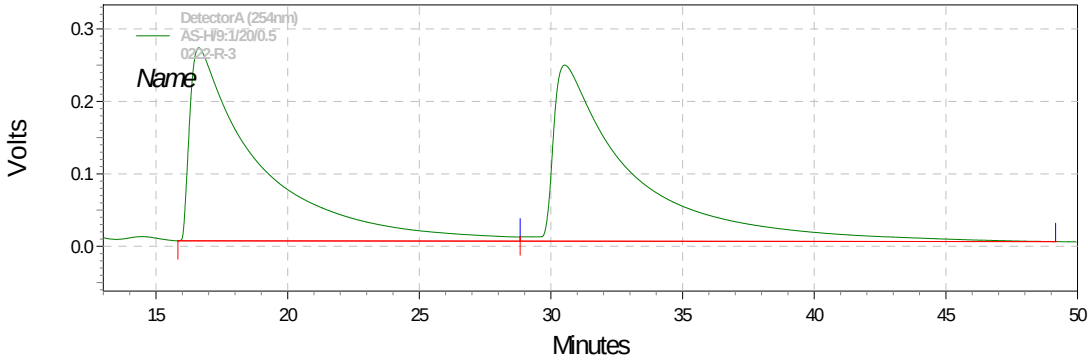
Pk #	Retention Time	Area	Area %
1	31.267	37989551	50.583
2	66.180	37114295	49.417
Totals		75103846	100.000



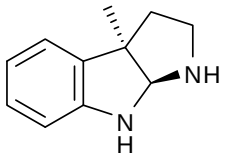


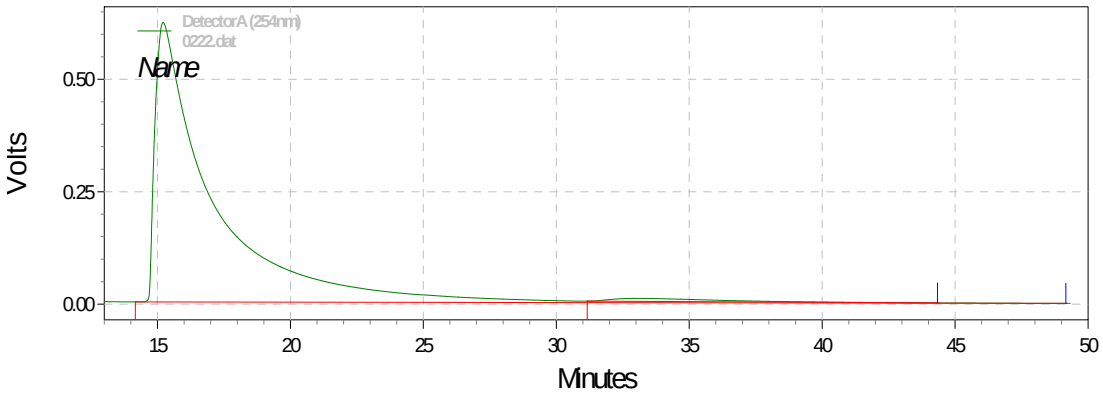
Pk #	Retention Time	Area	Area %
1	35.443	2675808	3.550
2	70.410	72709303	96.450
Totals		75385111	100.000





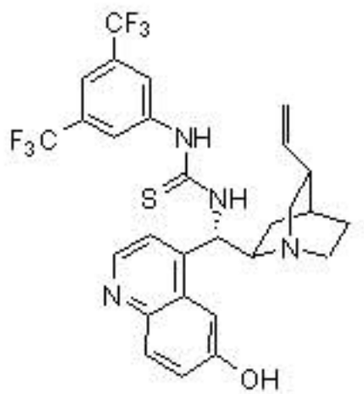
Pk #	Retention Time	Area	Area %
1	16.647	48650626	49.283
2	30.543	50066184	50.717
Totals		98716810	100.000

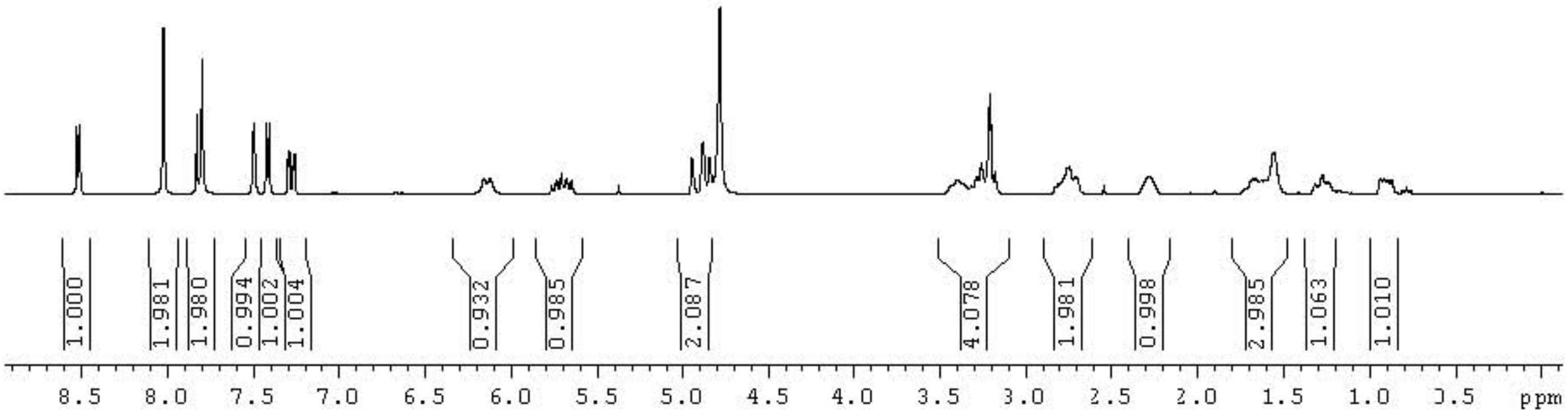


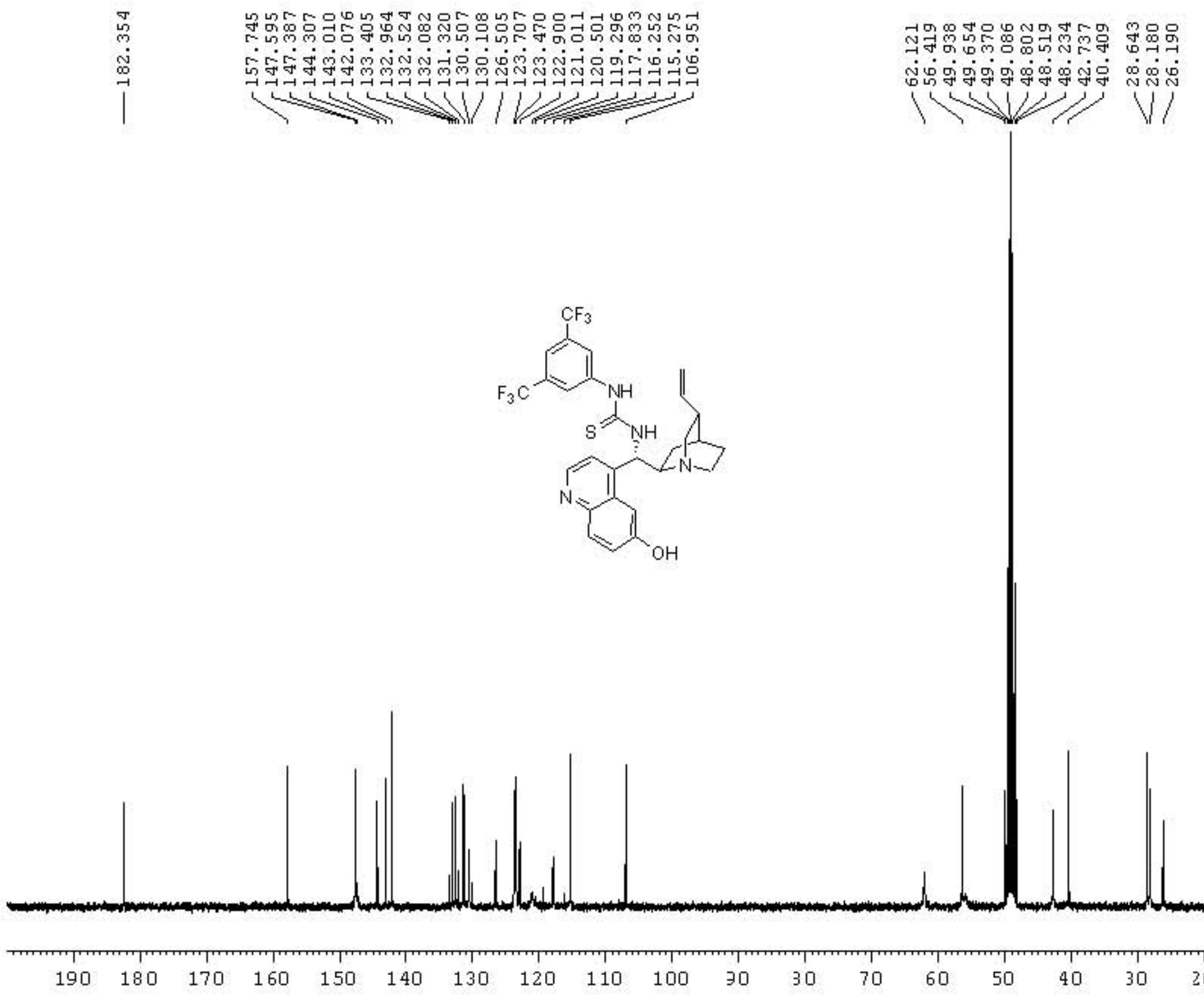


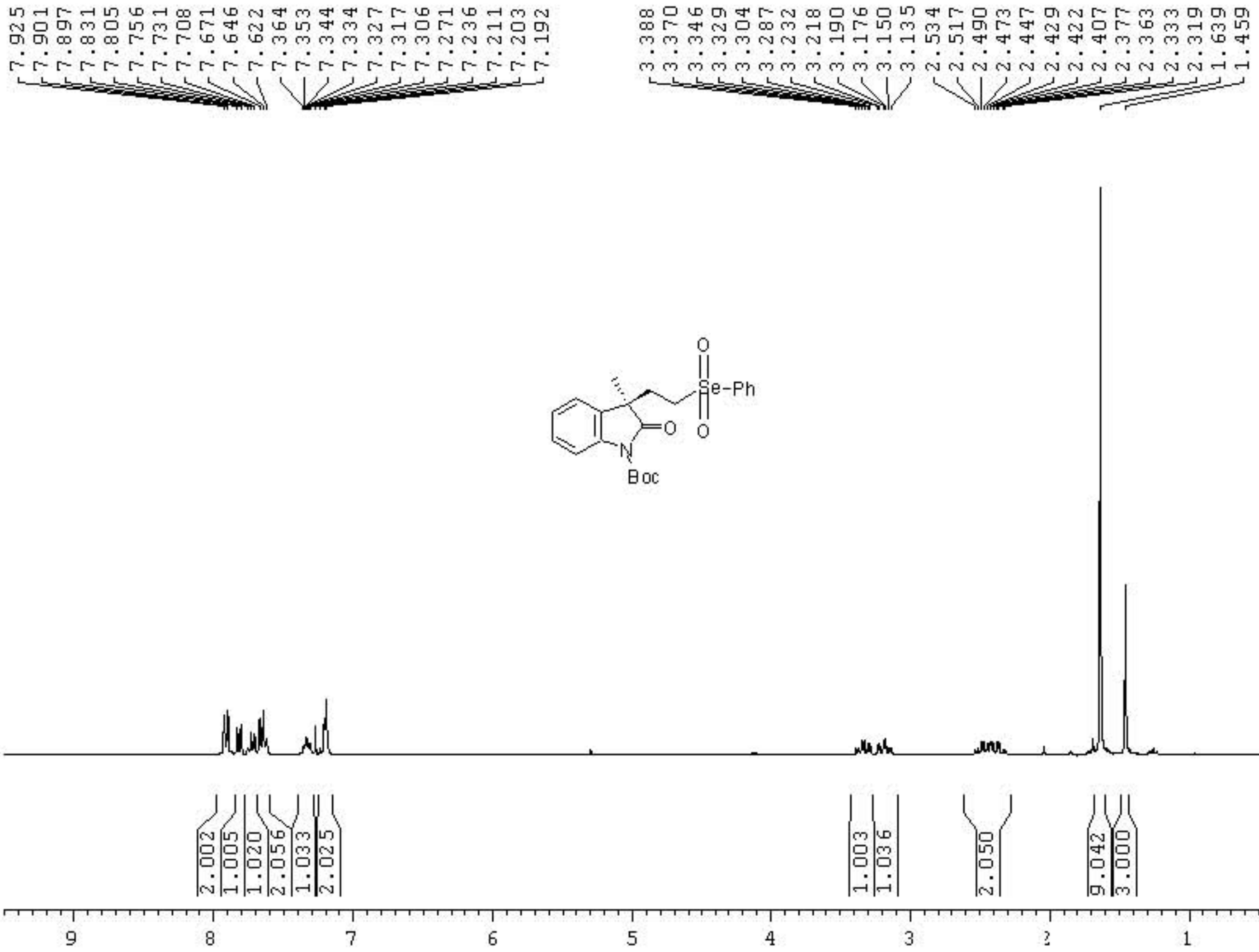
Pk #	Retention Time	Area	Area %
1	15.250	94522718	98.055
2	33.094	1874663	1.945
Totals		96397381	100.000

8.528
8.512
8.025
7.831
7.800
7.499
7.426
7.410
7.300
7.292
7.269
7.261
6.160
6.125
5.770
5.745
5.736
5.712
5.688
5.678
5.654
4.952
4.890
4.886
4.851
4.789
3.398
3.317
3.284
3.261
3.248
3.219
3.214
3.209
3.204
3.198
3.182
2.830
2.813
2.761
2.749
2.714
2.704
2.285
1.727
1.681
1.668
1.633
1.612
1.558
1.319
1.276
1.242
0.940
0.918
0.897

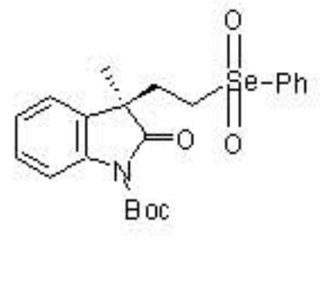


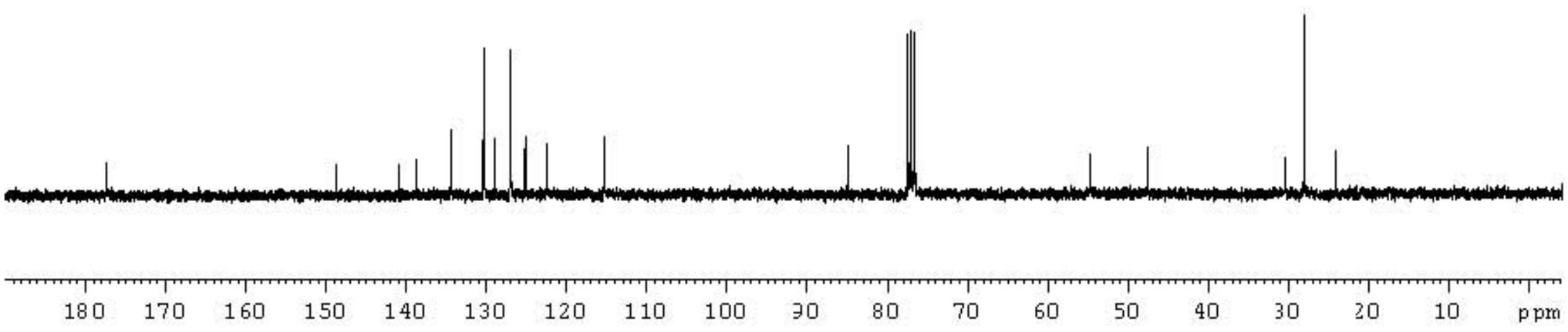


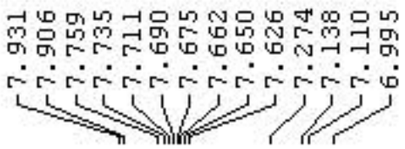

182.354
157.745
147.595
147.387
144.307
143.010
142.076
133.405
132.964
132.524
132.082
131.320
130.507
130.108
126.505
123.707
123.470
122.900
121.011
120.501
119.296
117.833
116.252
115.275
106.951
62.121
56.419
49.938
49.654
49.370
49.086
48.802
48.519
48.234
42.737
40.409
28.643
28.180
26.190
CF3
F3C
NH
S
NH
N
N
OH
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm


7.925
7.901
7.897
7.831
7.805
7.756
7.731
7.708
7.671
7.646
7.622
7.364
7.353
7.344
7.334
7.327
7.317
7.306
7.271
7.236
7.211
7.203
7.192
3.388
3.370
3.346
3.329
3.304
3.287
3.232
3.218
3.190
3.176
3.150
3.135
2.534
2.517
2.490
2.473
2.447
2.429
2.422
2.407
2.377
2.363
2.333
2.319
1.639
1.459
O
Se-Ph
O
O
N
Boc
2.002
1.005
1.020
2.056
1.033
2.025
1.003
1.036
2.050
9.042
3.000
9
8
7
6
5
4
3
2
1
0
ppm

177.337
148.790
140.871
138.779
134.501
130.370
129.038
127.043
125.198
122.540
115.387
84.985
77.505
77.081
76.657
54.761
47.606
30.393
28.053
24.140

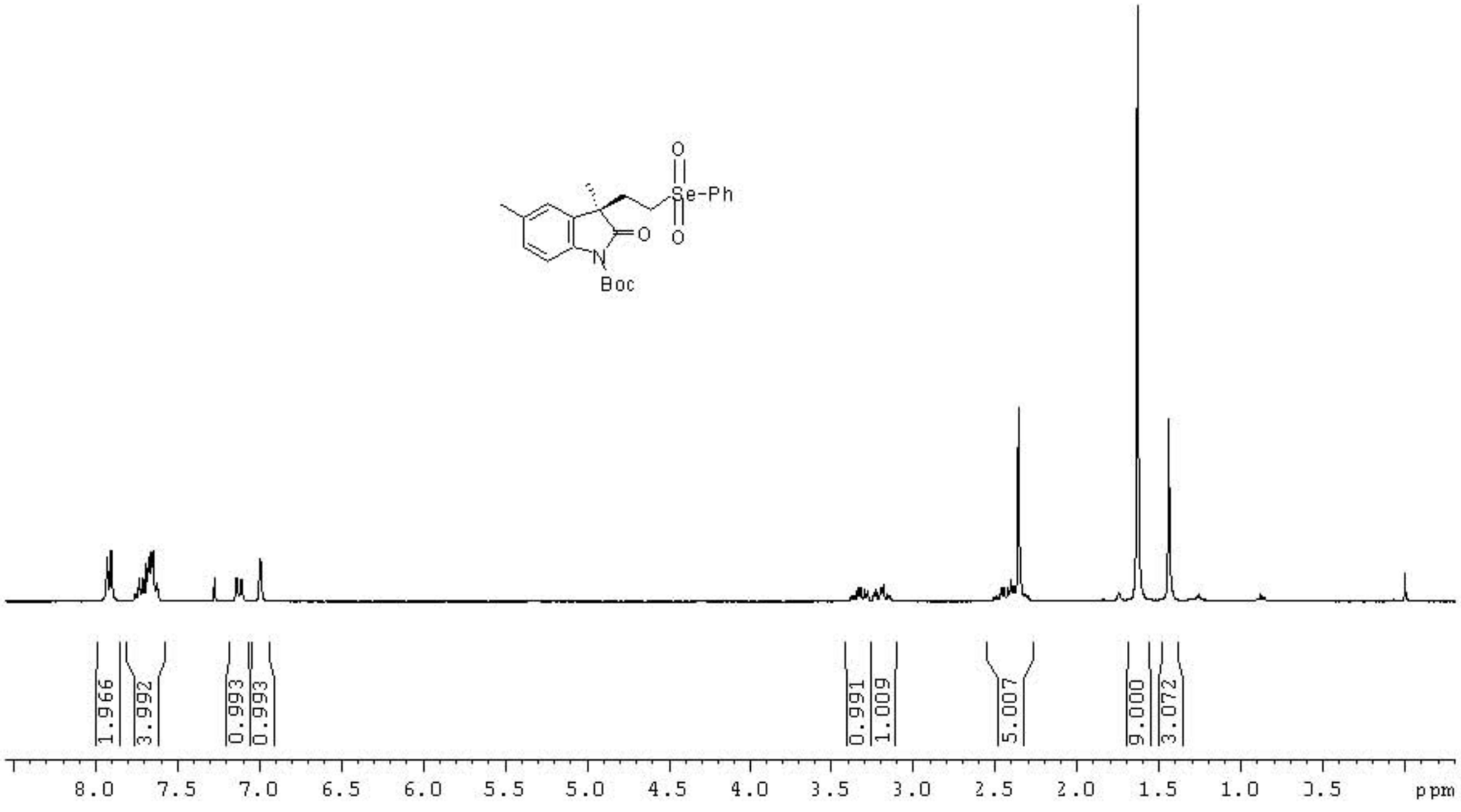




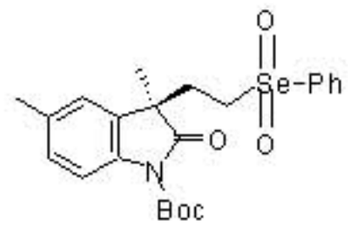

7.931
7.906
7.759
7.735
7.711
7.690
7.675
7.662
7.650
7.626
7.274
7.138
7.110
6.995

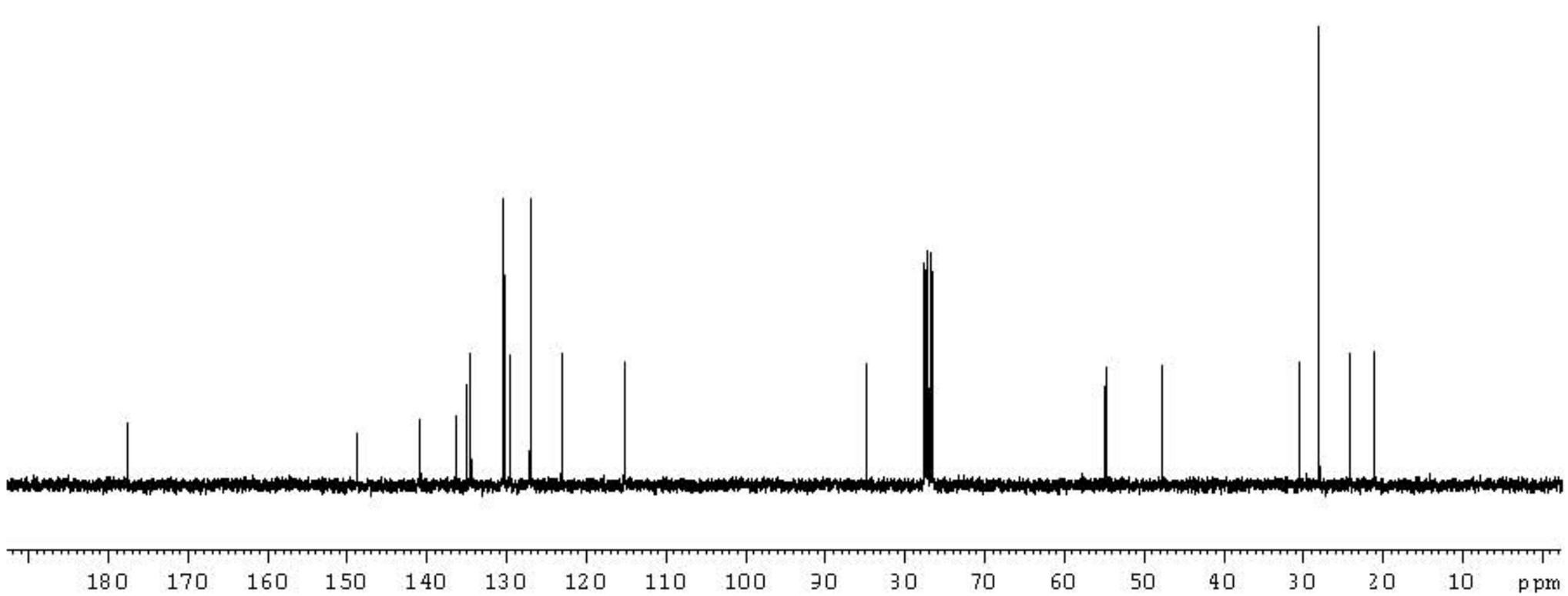

3.380
3.362
3.339
3.322
3.297
3.279
3.240
3.226
3.198
3.184
3.158
3.143
2.509
2.491
2.464
2.447
2.422
2.404
2.358
2.316
2.301
1.632
1.441

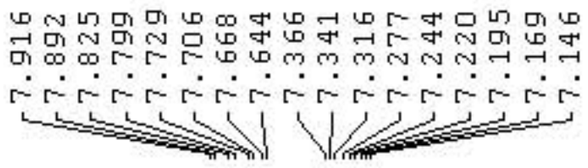
O
Se-Ph
O
O
N
Boc

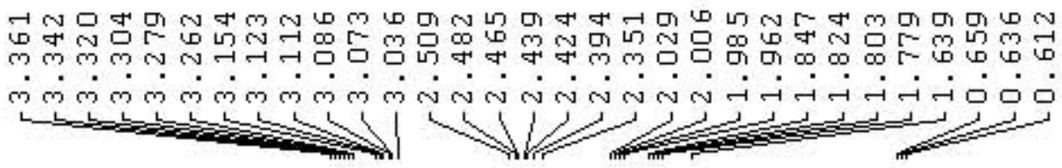

1.966
3.992
0.993
0.993
0.991
1.009
5.007
9.000
3.072
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

177.539
148.820
140.847
136.345
135.003
134.510
130.368
130.325
129.529
127.046
123.095
115.188
84.810
77.529
77.104
76.680
54.835
47.664
30.454
28.060
24.215
21.065

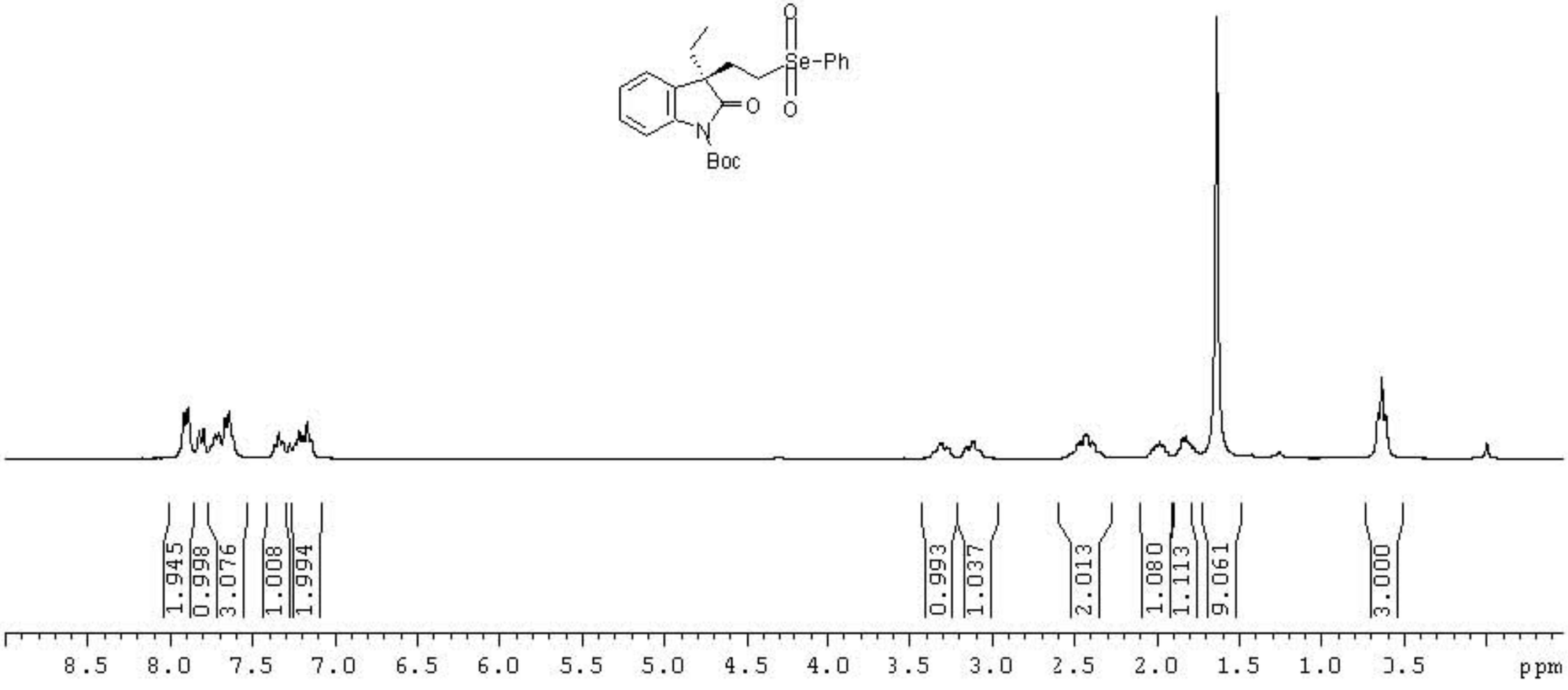




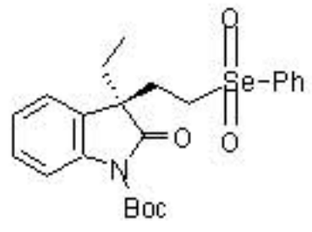

7.916
7.892
7.825
7.799
7.729
7.706
7.668
7.644
7.366
7.341
7.316
7.277
7.244
7.220
7.195
7.169
7.146

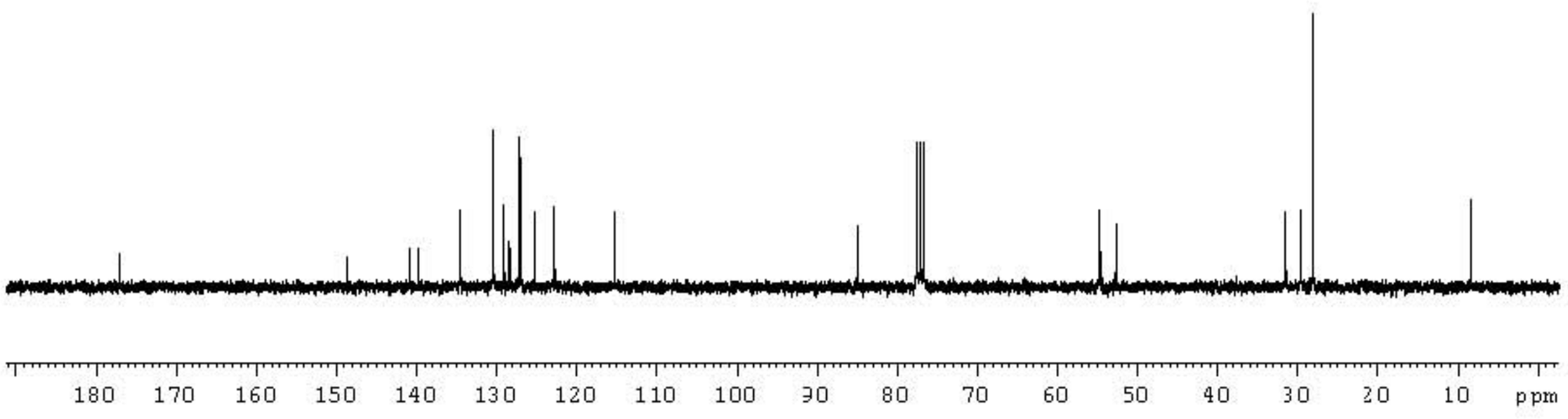

3.361
3.342
3.320
3.304
3.279
3.262
3.154
3.123
3.112
3.086
3.073
3.036
2.509
2.482
2.465
2.439
2.424
2.394
2.351
2.029
2.006
1.985
1.962
1.847
1.824
1.803
1.779
1.639
0.659
0.636
0.612

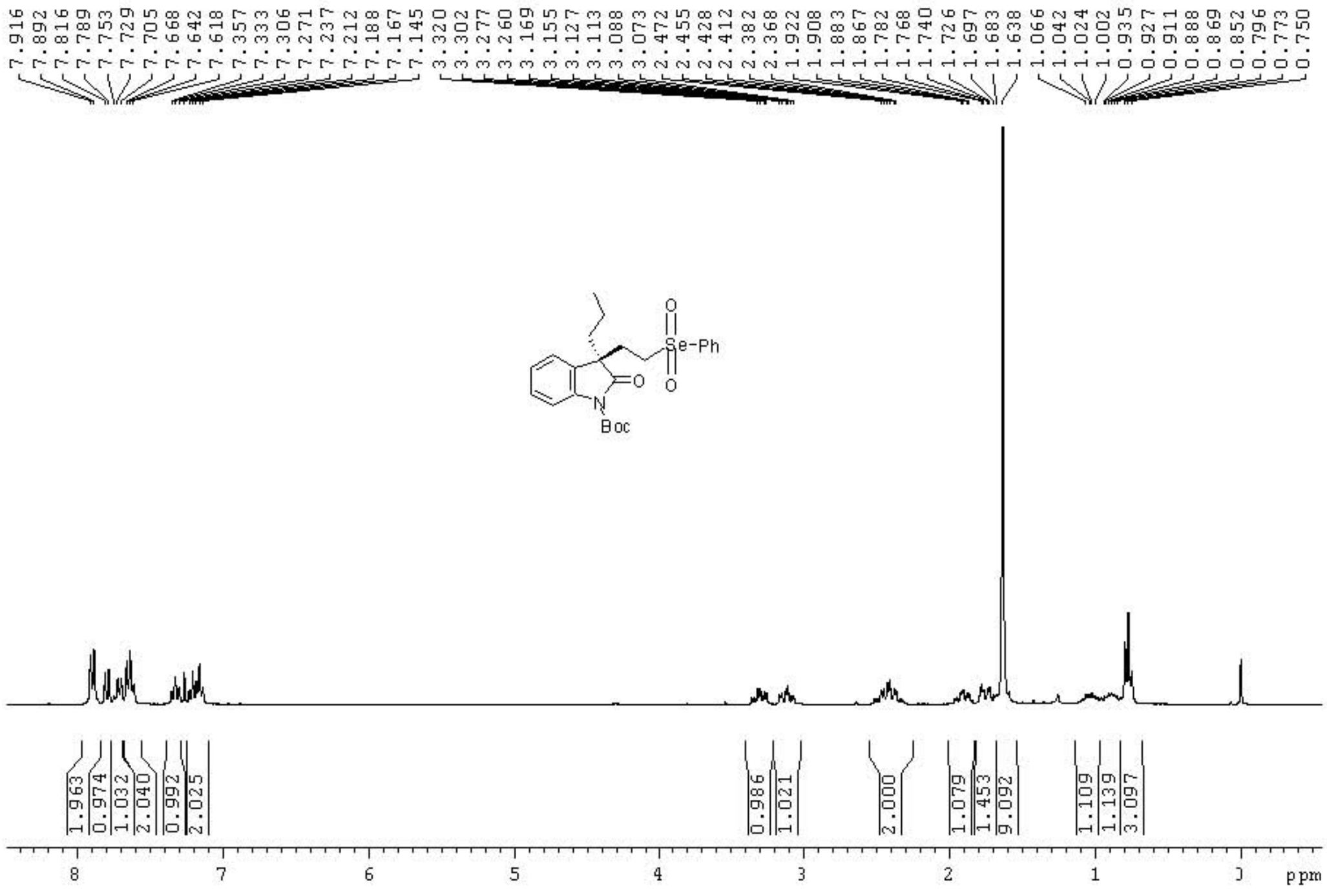
Se-Ph
O
O
O
N
Boc


1.945
0.998
3.076
1.008
1.994
0.993
1.037
2.013
1.080
1.113
9.061
3.000
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

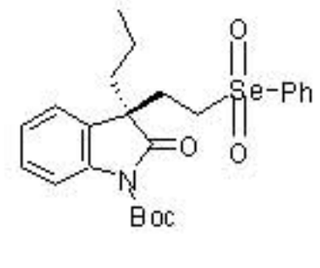
176.992
148.654
140.838
139.762
134.493
130.359
129.039
128.357
127.042
125.171
122.747
115.233
84.955
77.514
77.090
76.666
54.688
52.668
31.478
29.576
28.068
8.397

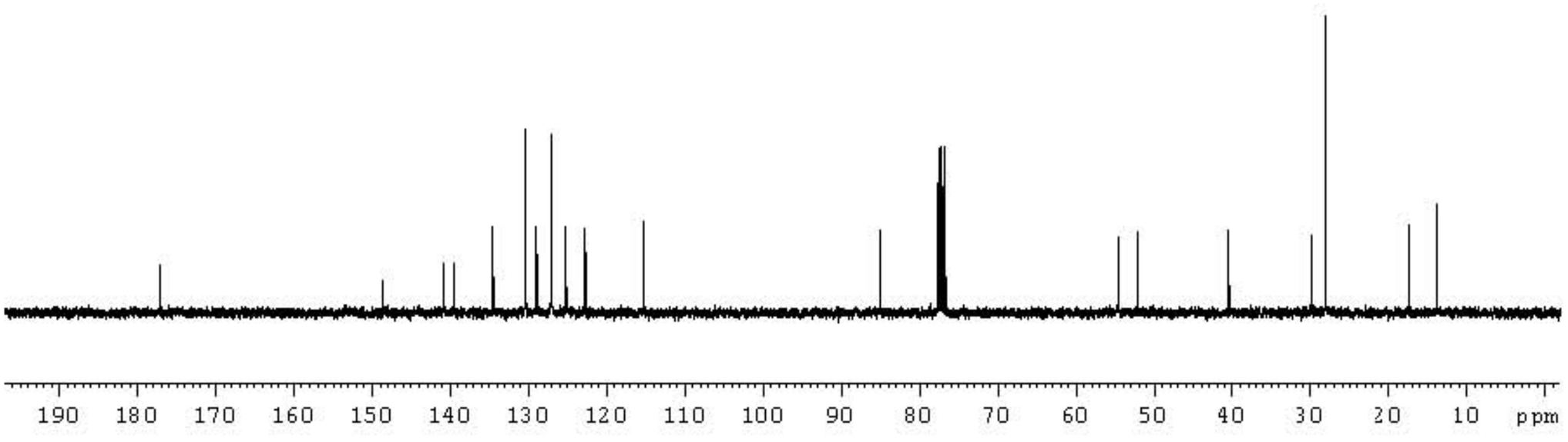


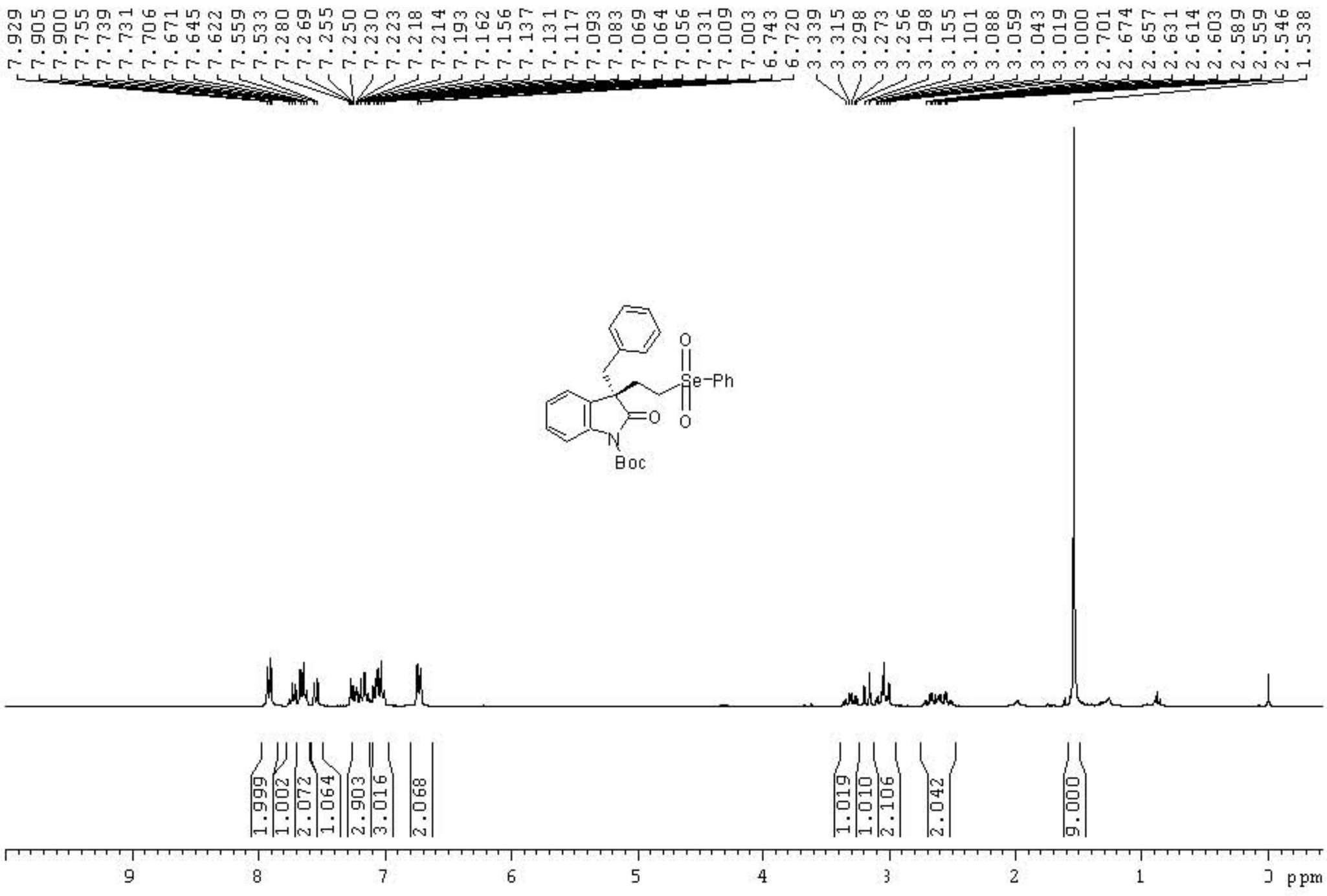



7.916
7.892
7.816
7.789
7.753
7.729
7.705
7.668
7.642
7.618
7.357
7.333
7.306
7.271
7.237
7.212
7.188
7.167
7.145
3.320
3.302
3.277
3.260
3.169
3.155
3.127
3.113
3.088
3.073
2.472
2.455
2.428
2.412
2.382
2.368
1.922
1.908
1.883
1.867
1.782
1.768
1.740
1.726
1.697
1.683
1.638
1.066
1.042
1.024
1.002
0.935
0.927
0.911
0.888
0.869
0.852
0.796
0.773
0.750
Se-Ph
O
O
O
N
Boc
1.963
0.974
1.032
2.040
0.992
2.025
0.986
1.021
2.000
1.079
1.453
9.092
1.109
1.139
3.097
8
7
6
5
4
3
2
1
0
ppm

177.091
148.658
140.806
139.582
134.499
130.360
128.985
128.741
127.042
125.159
122.712
115.234
84.956
77.537
77.113
76.689
54.608
52.172
40.458
29.905
28.063
17.372
13.906






7.929
7.905
7.900
7.755
7.739
7.731
7.706
7.671
7.645
7.622
7.559
7.533
7.280
7.269
7.255
7.250
7.230
7.223
7.218
7.214
7.193
7.162
7.156
7.137
7.131
7.117
7.093
7.083
7.069
7.064
7.056
7.031
7.009
7.003
6.743
6.720
3.339
3.315
3.298
3.273
3.256
3.198
3.155
3.101
3.088
3.059
3.043
3.019
3.000
2.701
2.674
2.657
2.631
2.614
2.603
2.589
2.559
2.546
1.538
O
Se-Ph
O
O
N
Boc
1.999
1.002
2.072
1.064
2.903
3.016
2.068
1.019
1.010
2.106
2.042
9.000
9
8
7
6
5
4
3
2
1
0
ppm

176.444

148.225
140.906
139.687
134.506
133.781
130.375
129.731
129.161
127.831
127.294
127.122
127.055
124.791
123.330
115.118

84.550
77.533
77.109
76.685

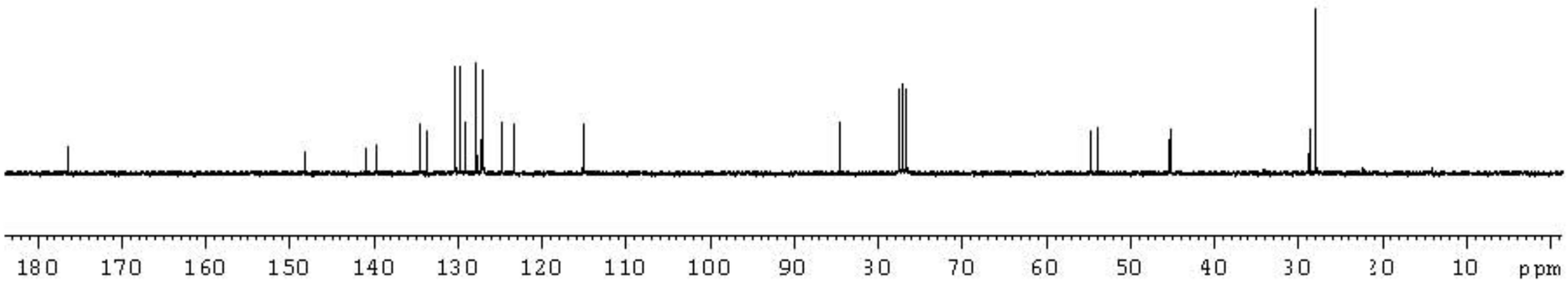
54.765
53.892

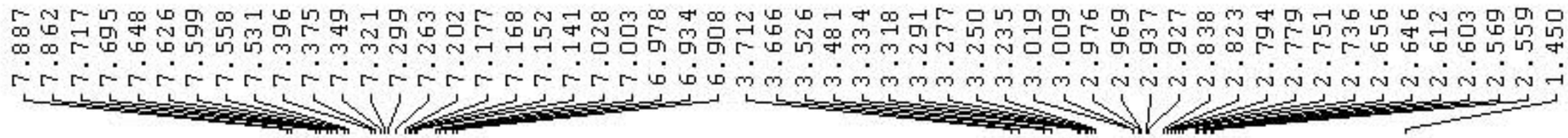
45.269

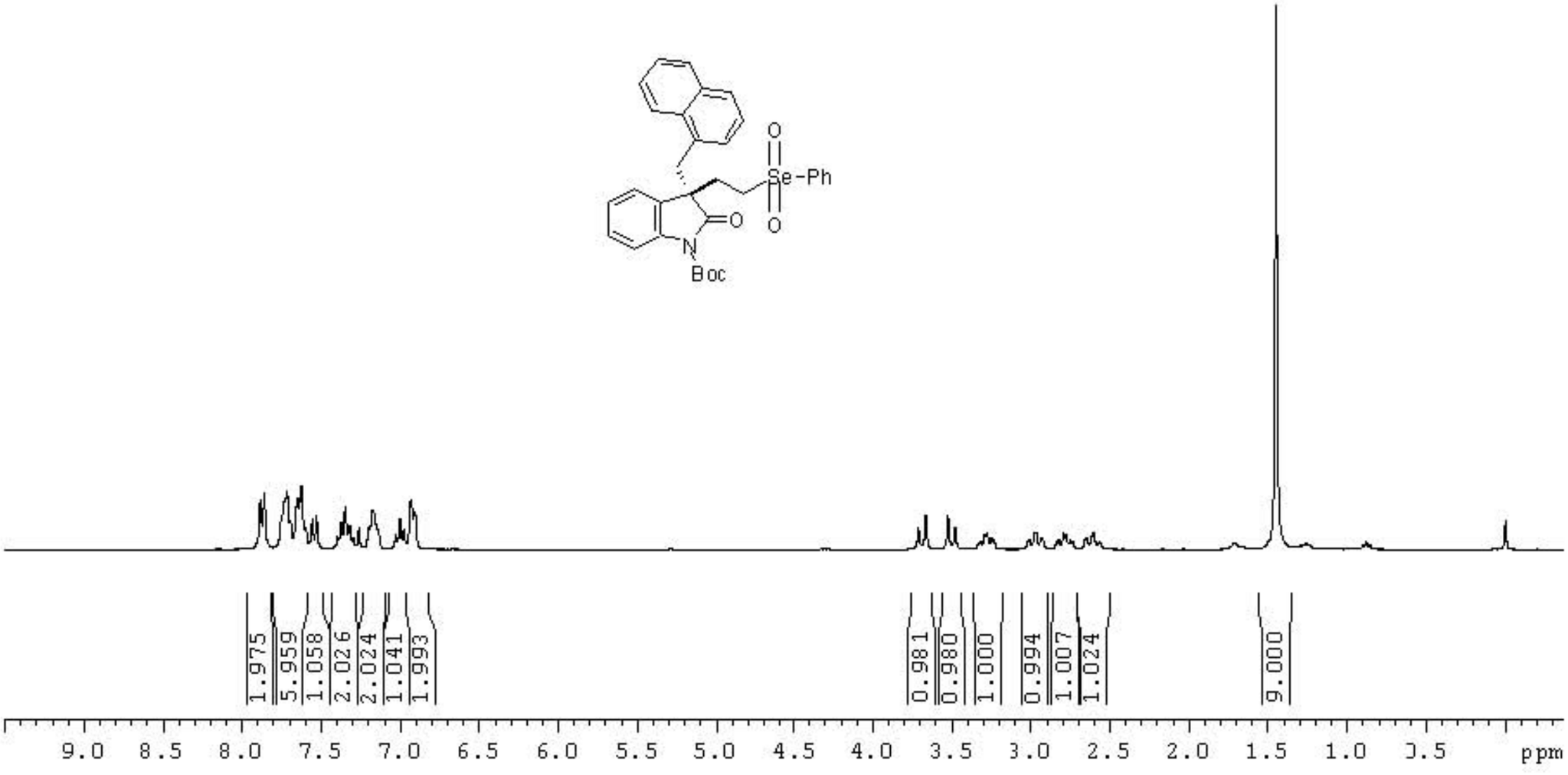
28.687
27.962

22.308

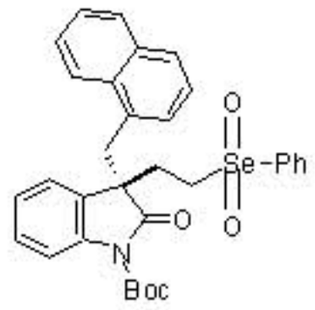
14.053

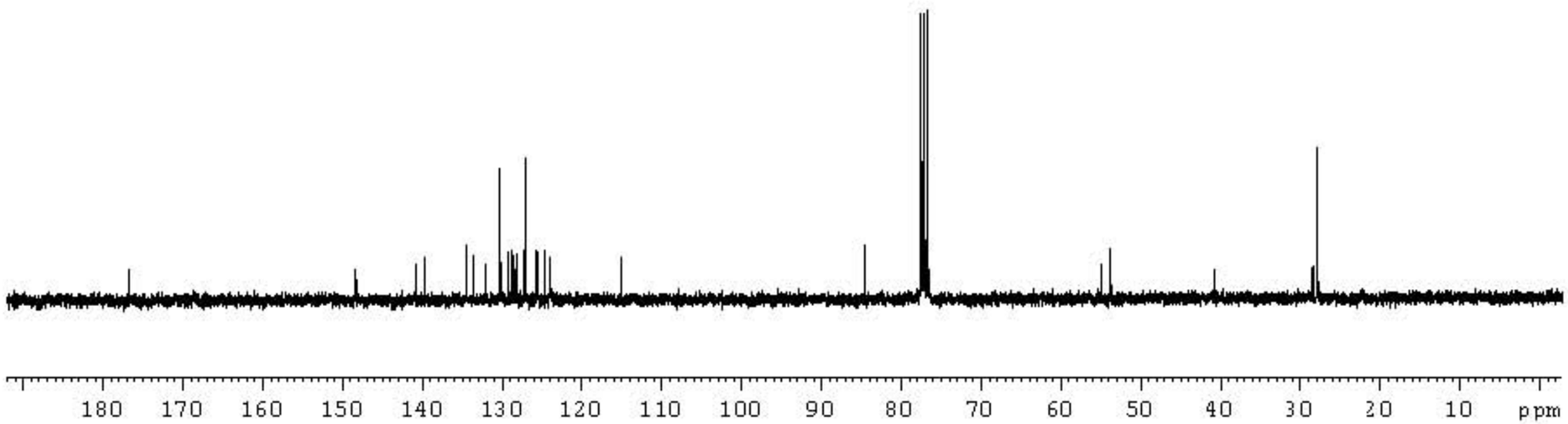


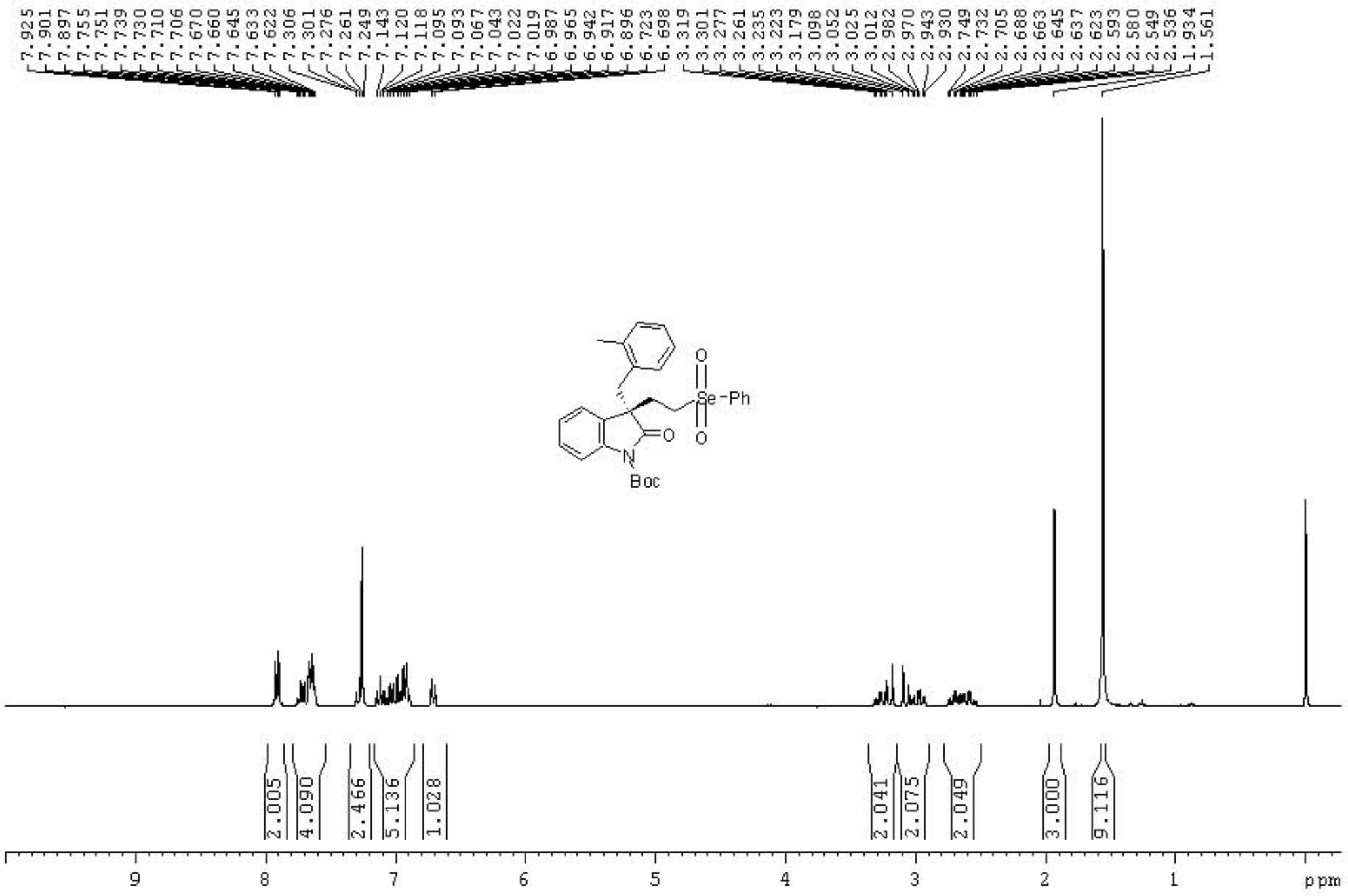

7.887
7.862
7.717
7.695
7.648
7.626
7.599
7.558
7.531
7.396
7.375
7.349
7.321
7.299
7.263
7.202
7.177
7.168
7.152
7.141
7.028
7.003
6.978
6.934
6.908
3.712
3.666
3.526
3.481
3.334
3.318
3.291
3.277
3.250
3.235
3.019
3.009
2.976
2.969
2.937
2.927
2.838
2.823
2.794
2.779
2.751
2.736
2.656
2.646
2.612
2.603
2.569
2.559
1.450


O
Se-Ph
O
O
N
Boc
1.975
5.959
1.058
2.026
2.024
1.041
1.993
0.981
0.980
1.000
0.994
1.007
1.024
9.000
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

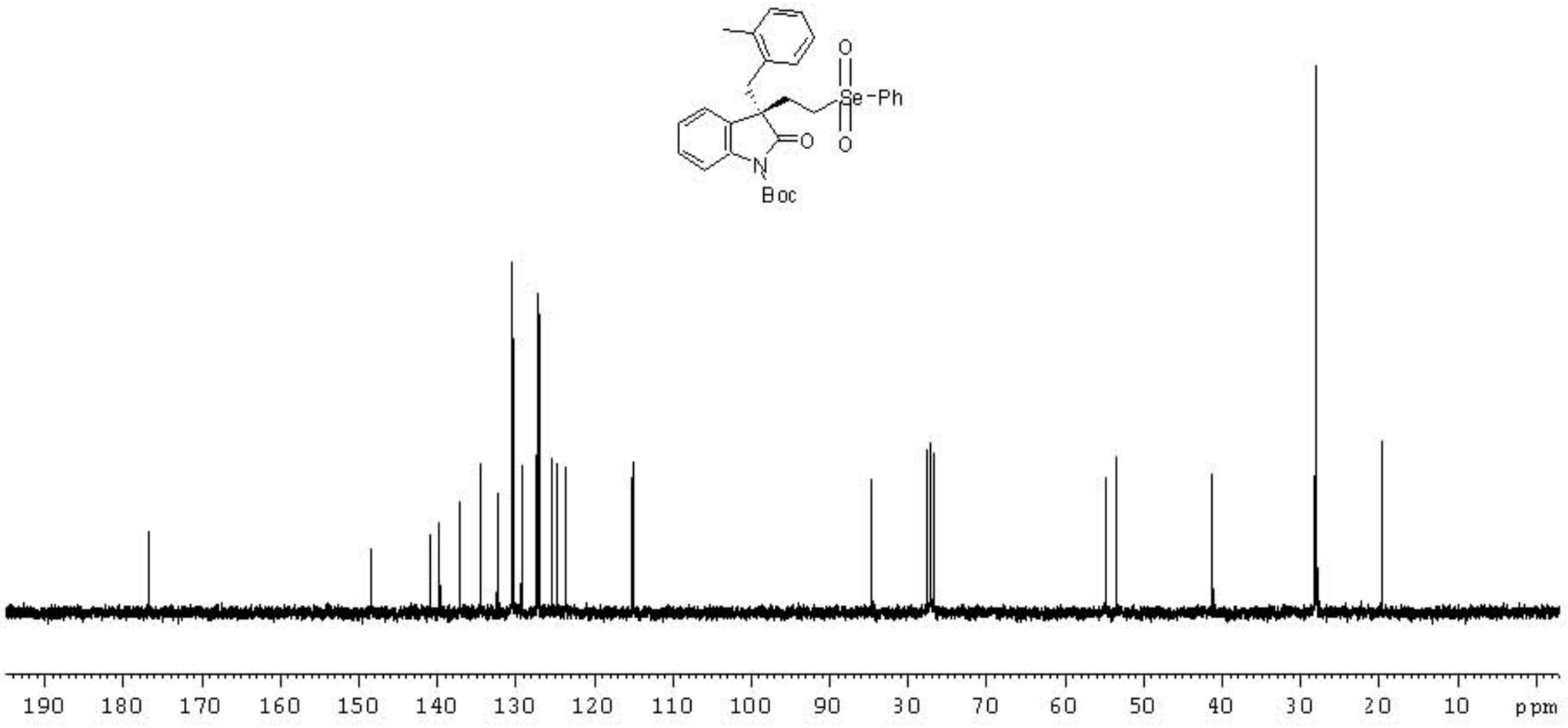
176.667
148.311
140.824
139.635
134.464
133.584
132.101
130.347
130.209
129.144
128.670
128.458
128.143
127.177
127.086
125.620
125.432
124.634
124.561
124.005
123.920
115.043
84.492
77.473
77.049
76.626
54.960
53.749
40.825
28.435
27.842

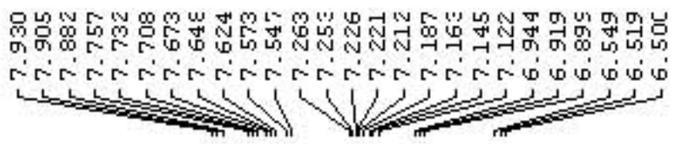


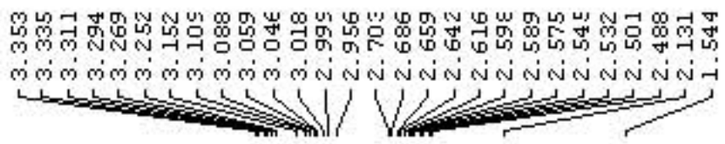


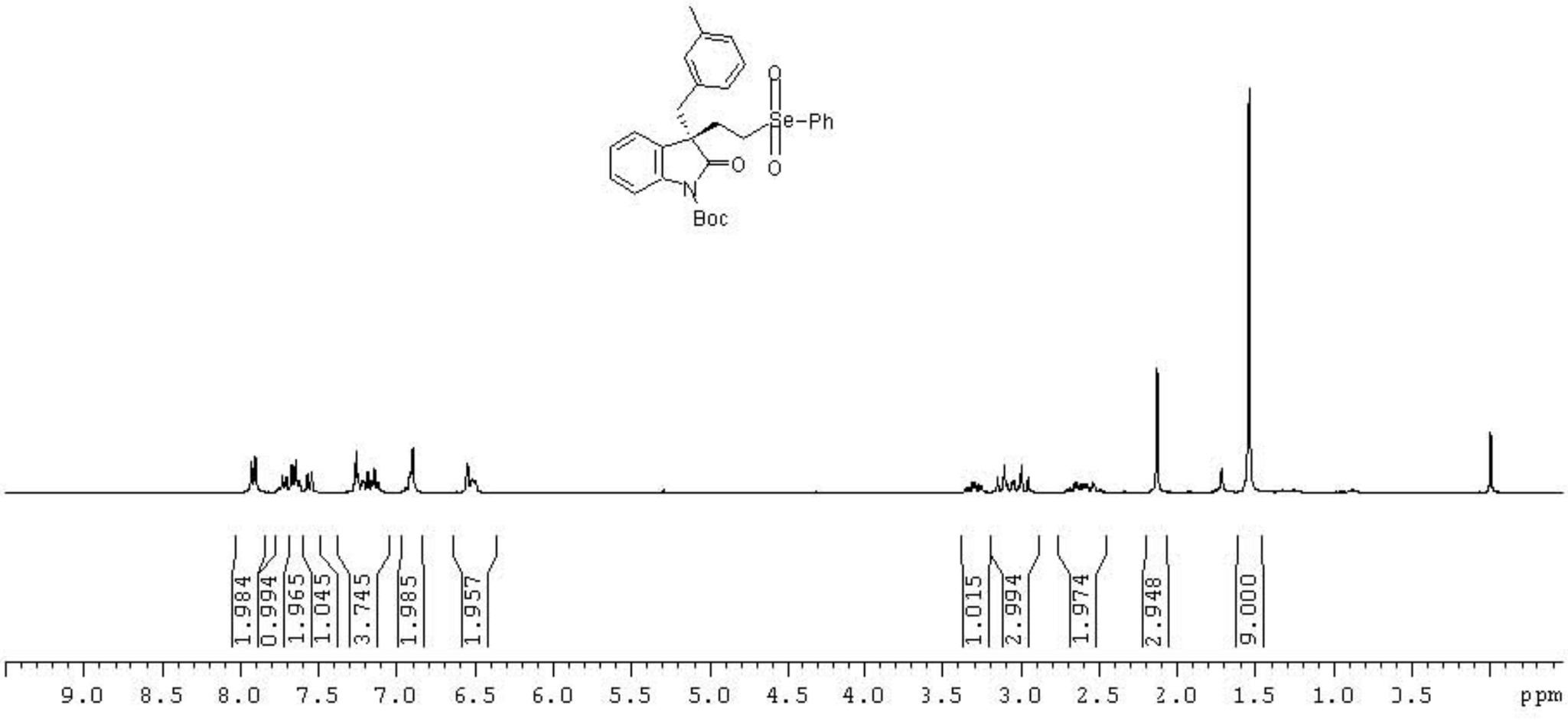

7.925
7.901
7.897
7.755
7.751
7.739
7.730
7.710
7.706
7.670
7.660
7.645
7.633
7.622
7.306
7.301
7.276
7.261
7.249
7.143
7.120
7.118
7.095
7.093
7.067
7.043
7.022
7.019
6.987
6.965
6.942
6.917
6.896
6.723
6.698
3.319
3.301
3.277
3.261
3.235
3.223
3.179
3.098
3.052
3.025
3.012
2.982
2.970
2.943
2.930
2.749
2.732
2.705
2.688
2.663
2.645
2.637
2.623
2.593
2.580
2.549
2.536
1.934
1.561
O
Se-Ph
O
O
N
Boc
2.005
4.090
2.466
5.136
1.028
2.041
2.075
2.049
3.000
9.116
9
8
7
6
5
4
3
2
1
ppm

176.733
148.410
140.882
139.679
137.112
134.499
132.320
130.494
130.368
130.334
129.244
127.304
127.279
127.044
125.372
124.667
123.624
115.089
84.586
77.583
77.158
76.735
54.840
53.421
41.230
28.235
27.973
19.676

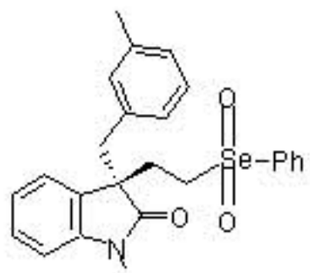



7.930
7.905
7.882
7.757
7.732
7.708
7.673
7.648
7.624
7.573
7.547
7.263
7.253
7.226
7.221
7.212
7.187
7.163
7.145
7.122
6.944
6.919
6.895
6.549
6.519
6.500

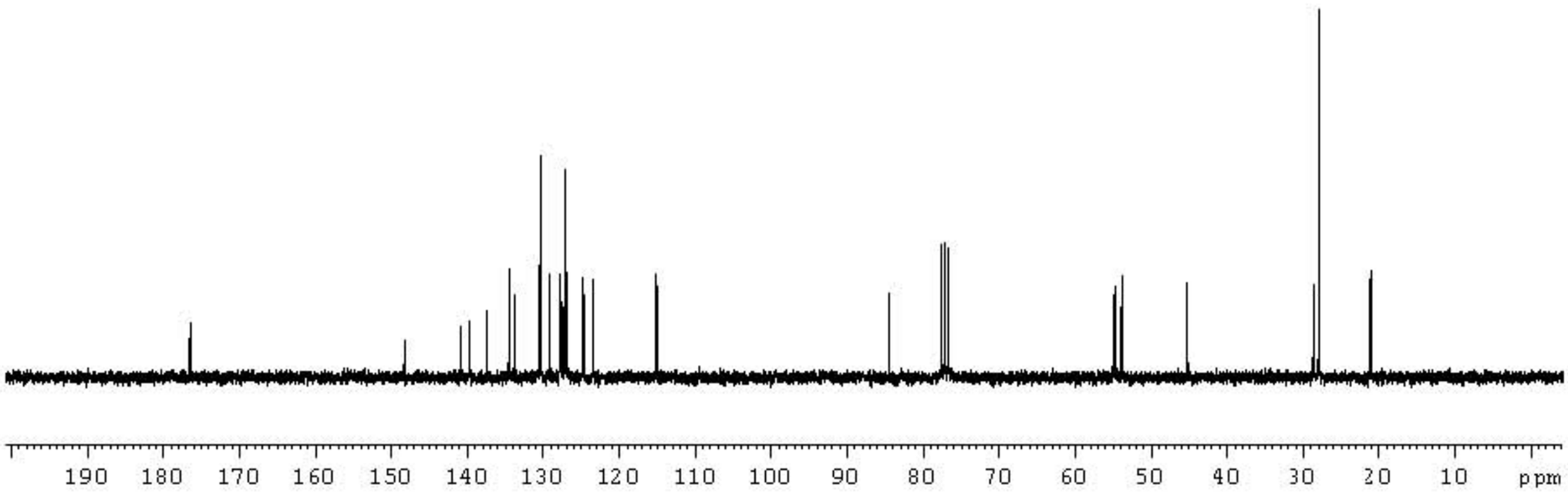

3.353
3.335
3.311
3.294
3.269
3.252
3.152
3.105
3.088
3.059
3.046
3.018
2.995
2.956
2.703
2.686
2.659
2.642
2.616
2.593
2.589
2.575
2.545
2.532
2.501
2.488
2.131
1.544

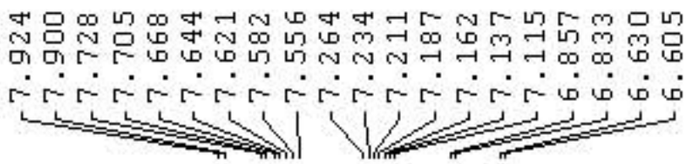

Se-Ph
O
O
O
N
Boc
1.984
0.994
1.965
1.045
3.745
1.985
1.957
1.015
2.994
1.974
2.948
9.000
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

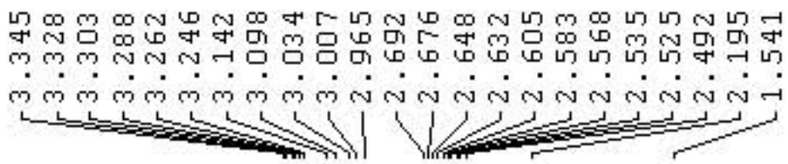
176.472
148.277
140.905
139.720
137.362
134.493
133.662
130.493
130.363
129.092
127.791
127.666
127.409
127.056
126.780
124.687
123.376
115.054
84.469
77.538
77.112
76.688
54.802
53.871
45.230
28.636
27.952
21.130

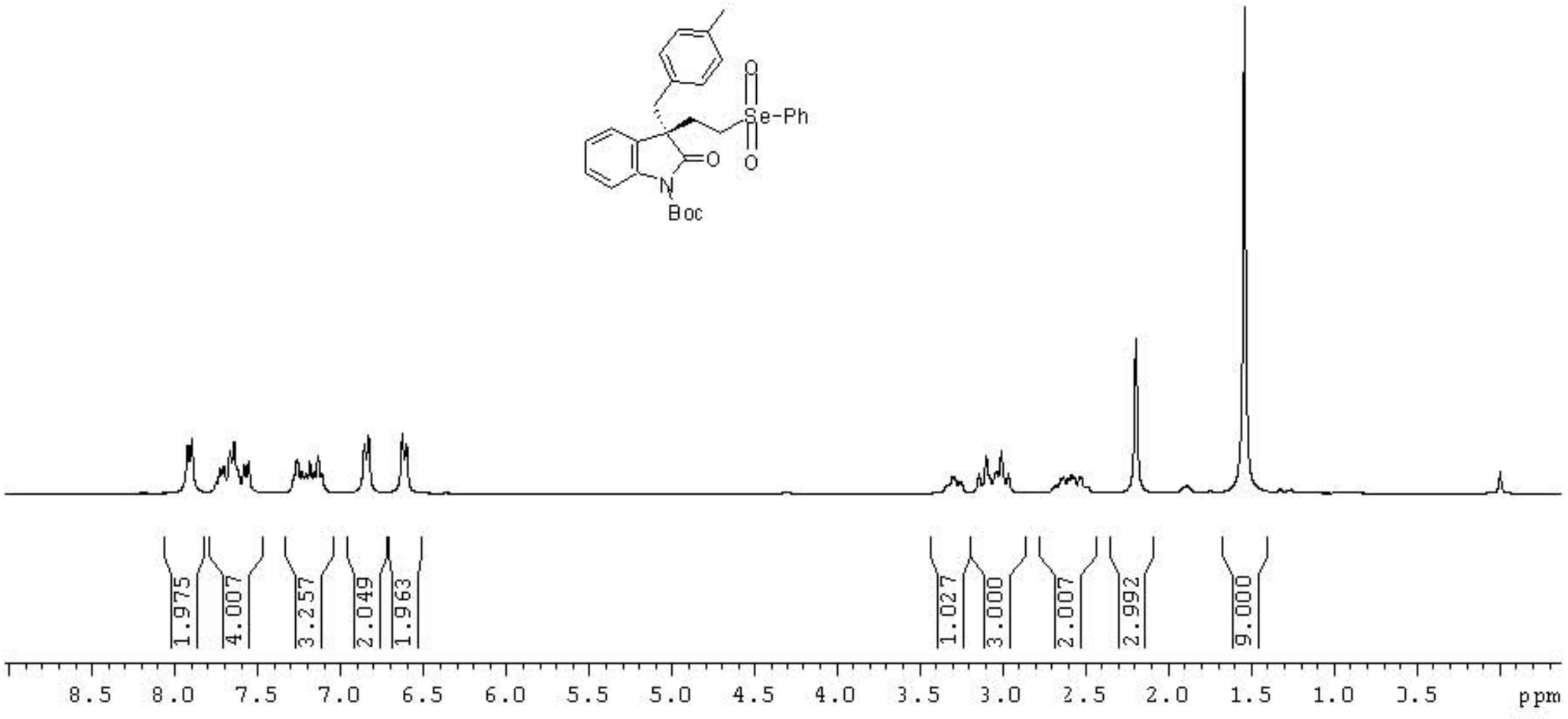


Boc

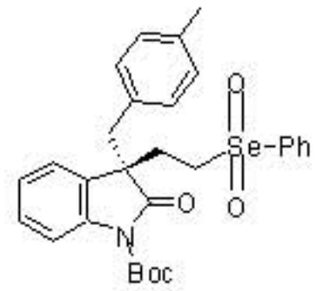


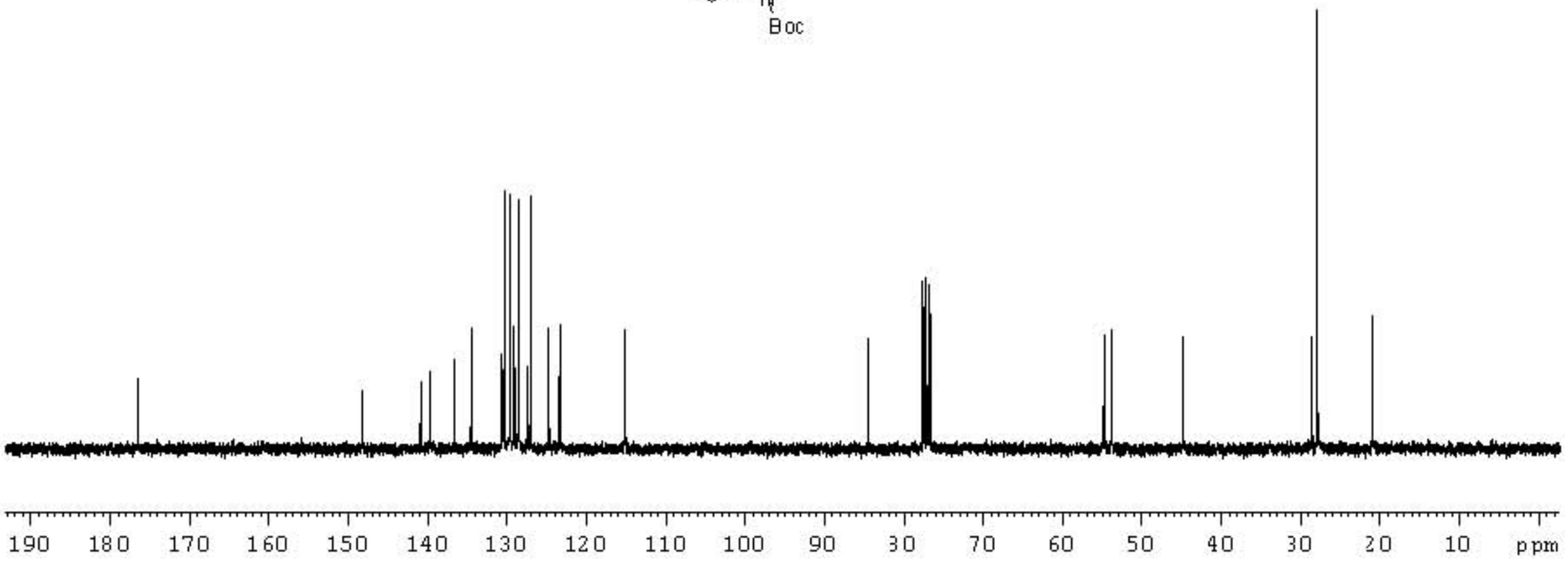

7.924
7.900
7.728
7.705
7.668
7.644
7.621
7.582
7.556
7.264
7.234
7.211
7.187
7.162
7.137
7.115
6.857
6.833
6.630
6.605


3.345
3.328
3.303
3.288
3.262
3.246
3.142
3.098
3.034
3.007
2.965
2.692
2.676
2.648
2.632
2.605
2.583
2.568
2.535
2.525
2.492
2.195
1.541


Se-Ph
O
O
O
N
Boc
1.975
4.007
3.257
2.049
1.963
1.027
3.000
2.007
2.992
9.000
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

176.532
148.269
140.874
139.693
136.631
134.496
130.650
130.365
129.625
129.085
128.533
127.439
127.042
124.751
123.359
115.127
84.463
77.597
77.173
76.748
54.794
53.863
44.842
28.607
27.942
20.946

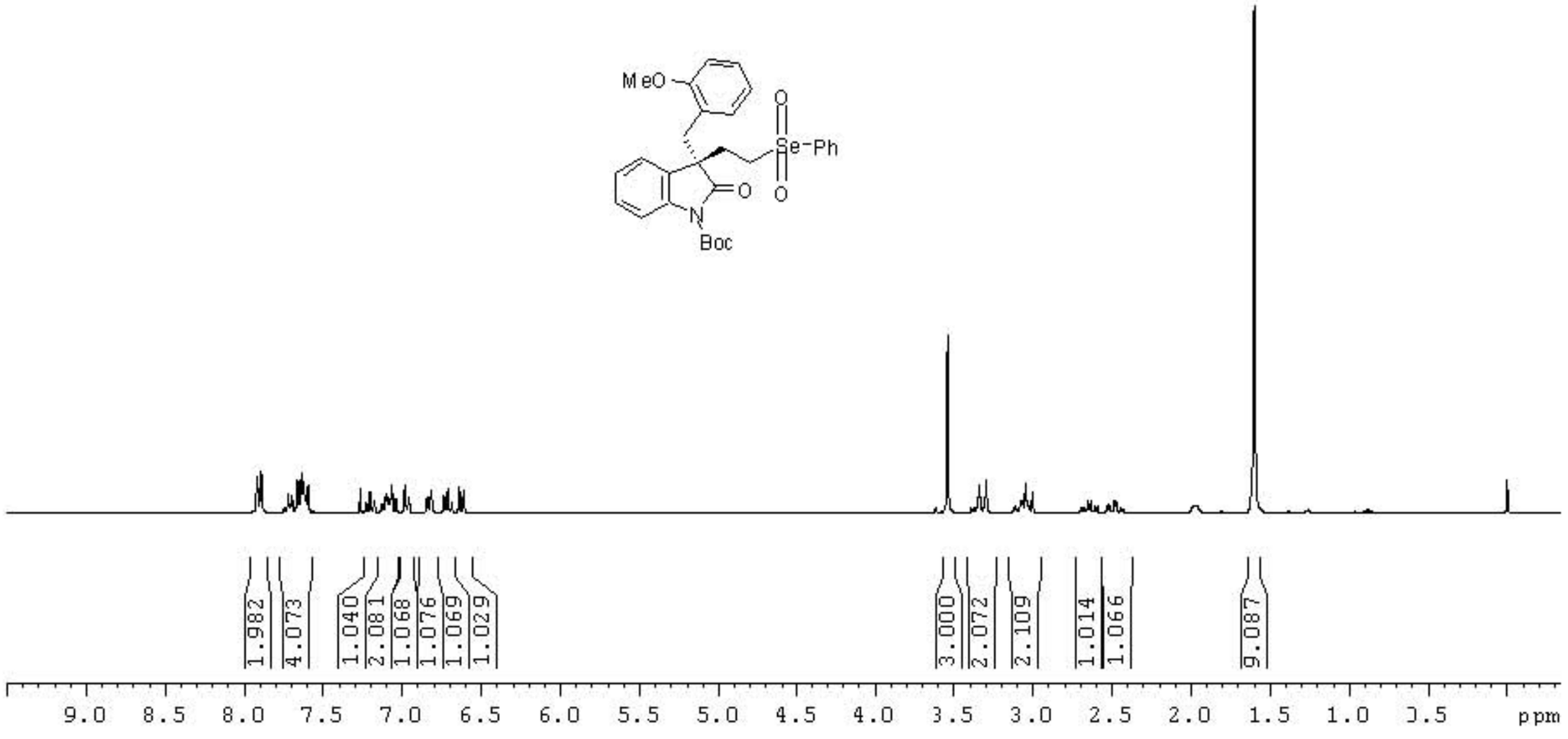




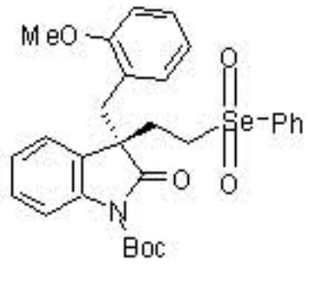

7.919
7.894
7.747
7.723
7.699
7.663
7.637
7.624
7.614
7.597
7.267
7.230
7.204
7.178
7.131
7.127
7.103
7.091
7.079
7.066
7.041
6.984
6.960
6.841
6.820
6.737
6.712
6.688
6.640
6.612

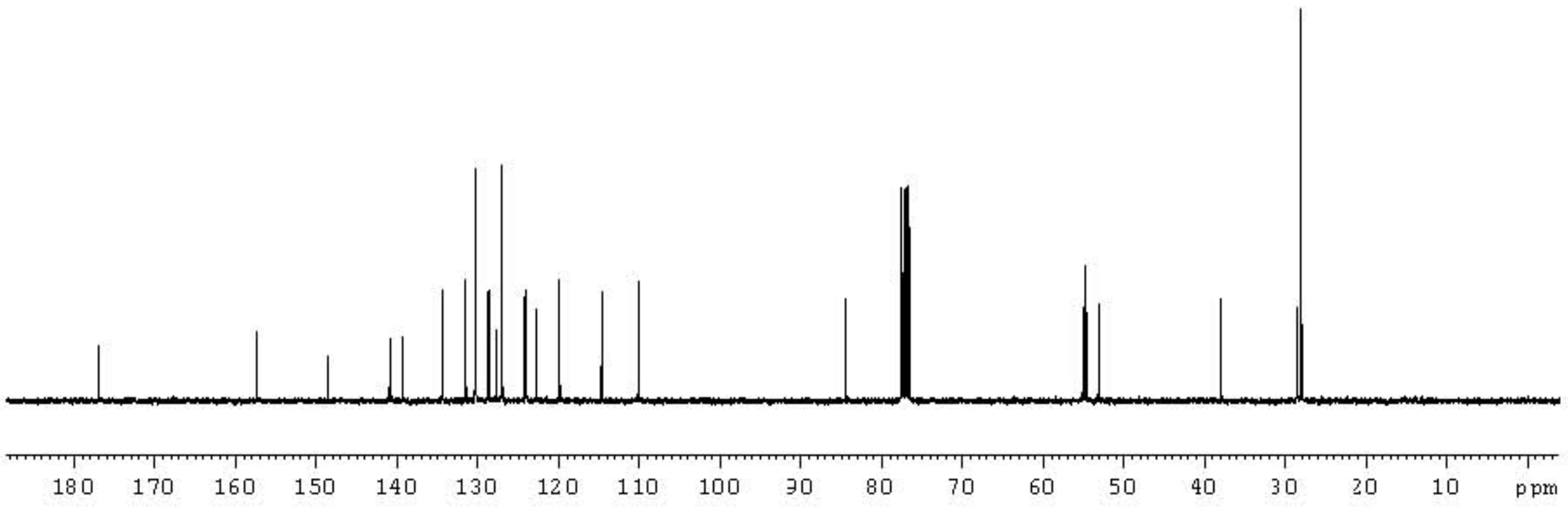
3.540
3.392
3.375
3.340
3.307
3.296
3.121
3.109
3.078
3.067
3.047
3.026
3.003
2.695
2.679
2.651
2.635
2.607
2.591
2.530
2.517
2.485
2.473
2.441
2.428
1.599

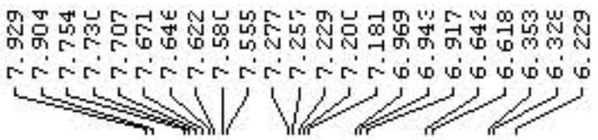
MeO
O
Se-Ph
O
O
N
Boc

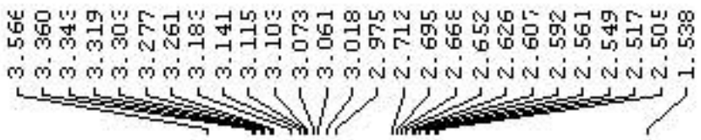

1.982
4.073
1.040
2.081
1.068
1.076
1.069
1.029
3.000
2.072
2.109
1.014
1.066
9.087
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

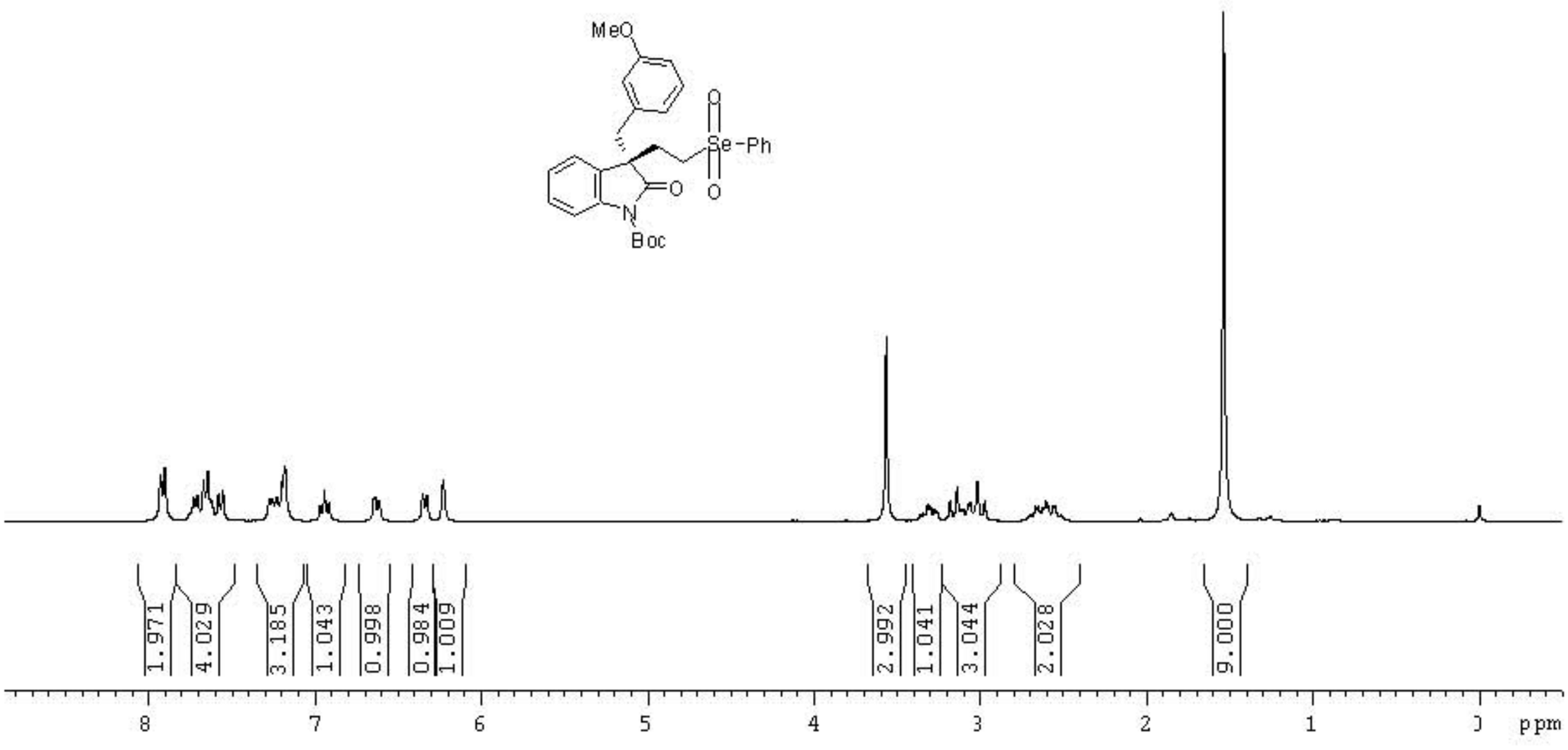
176.942
157.355
148.626
140.930
139.328
134.429
131.511
130.320
130.229
128.736
128.650
127.717
127.066
124.207
124.037
122.777
119.898
114.688
110.235
110.056
84.522
77.522
77.297
77.098
76.674
55.287
55.054
54.716
53.177
37.996
28.600
28.052



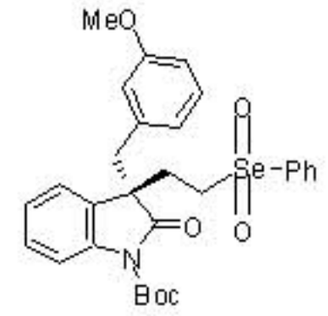


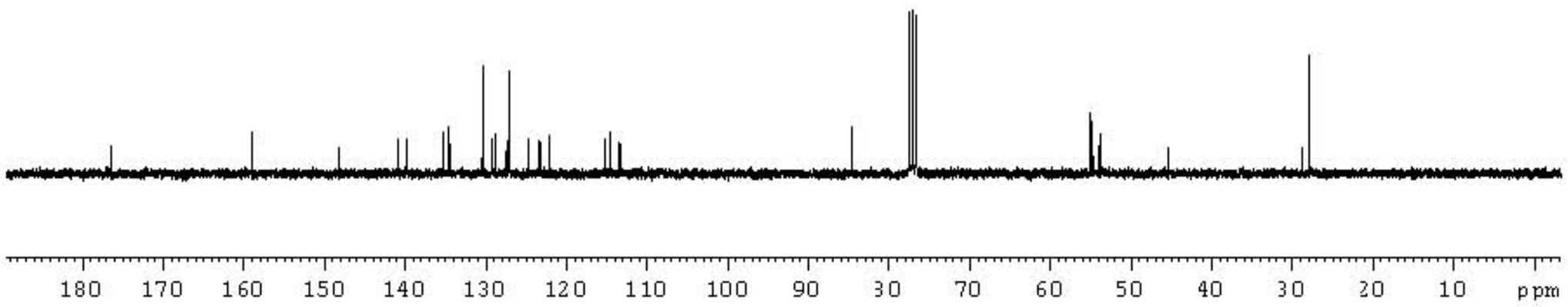

7.929
7.904
7.754
7.730
7.707
7.671
7.646
7.622
7.580
7.555
7.277
7.257
7.229
7.200
7.181
6.969
6.943
6.917
6.642
6.618
6.353
6.323
6.229

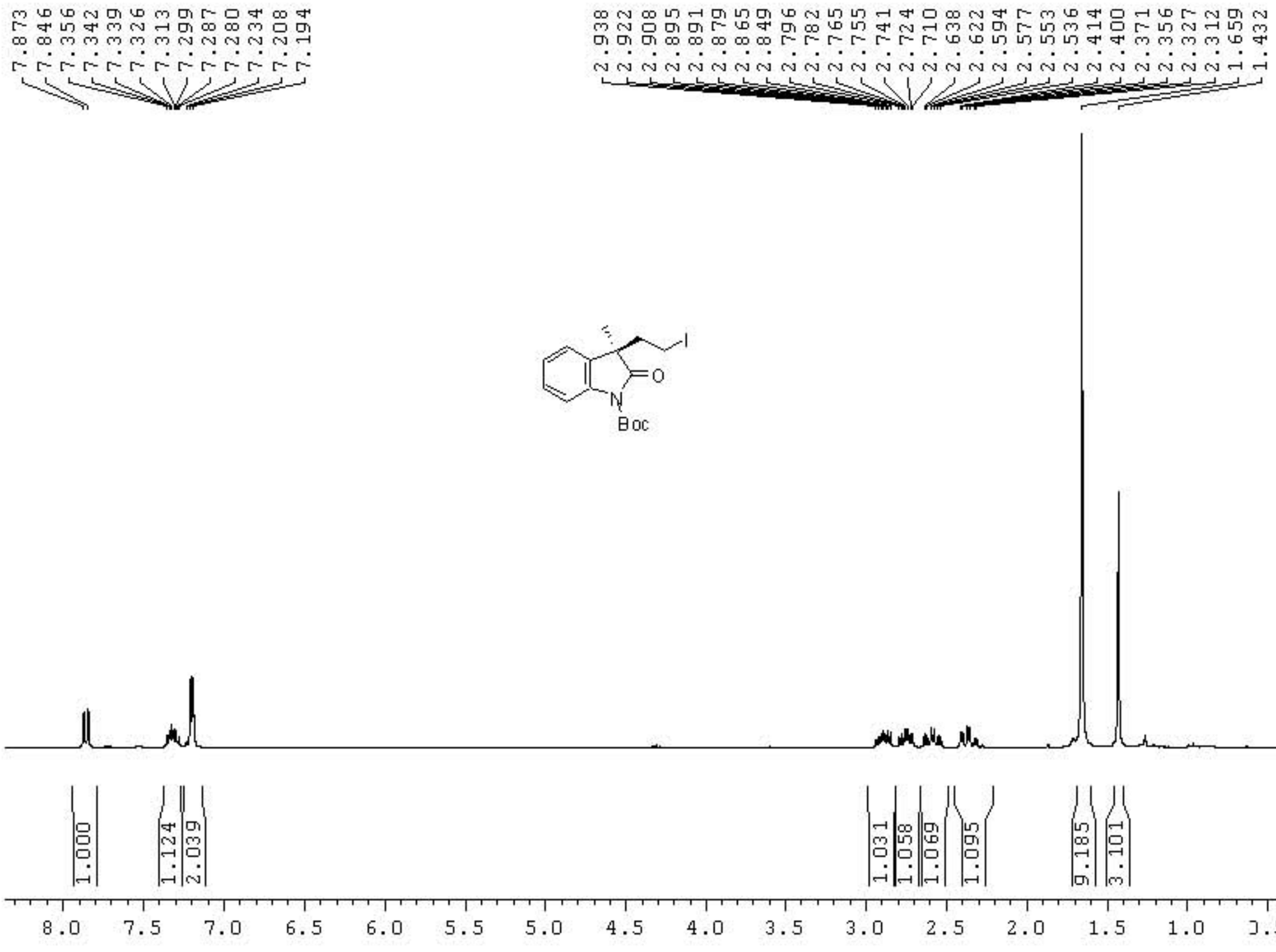

3.566
3.360
3.343
3.319
3.303
3.277
3.261
3.183
3.141
3.115
3.103
3.073
3.061
3.018
2.975
2.712
2.695
2.663
2.652
2.626
2.607
2.592
2.561
2.549
2.517
2.505
1.538

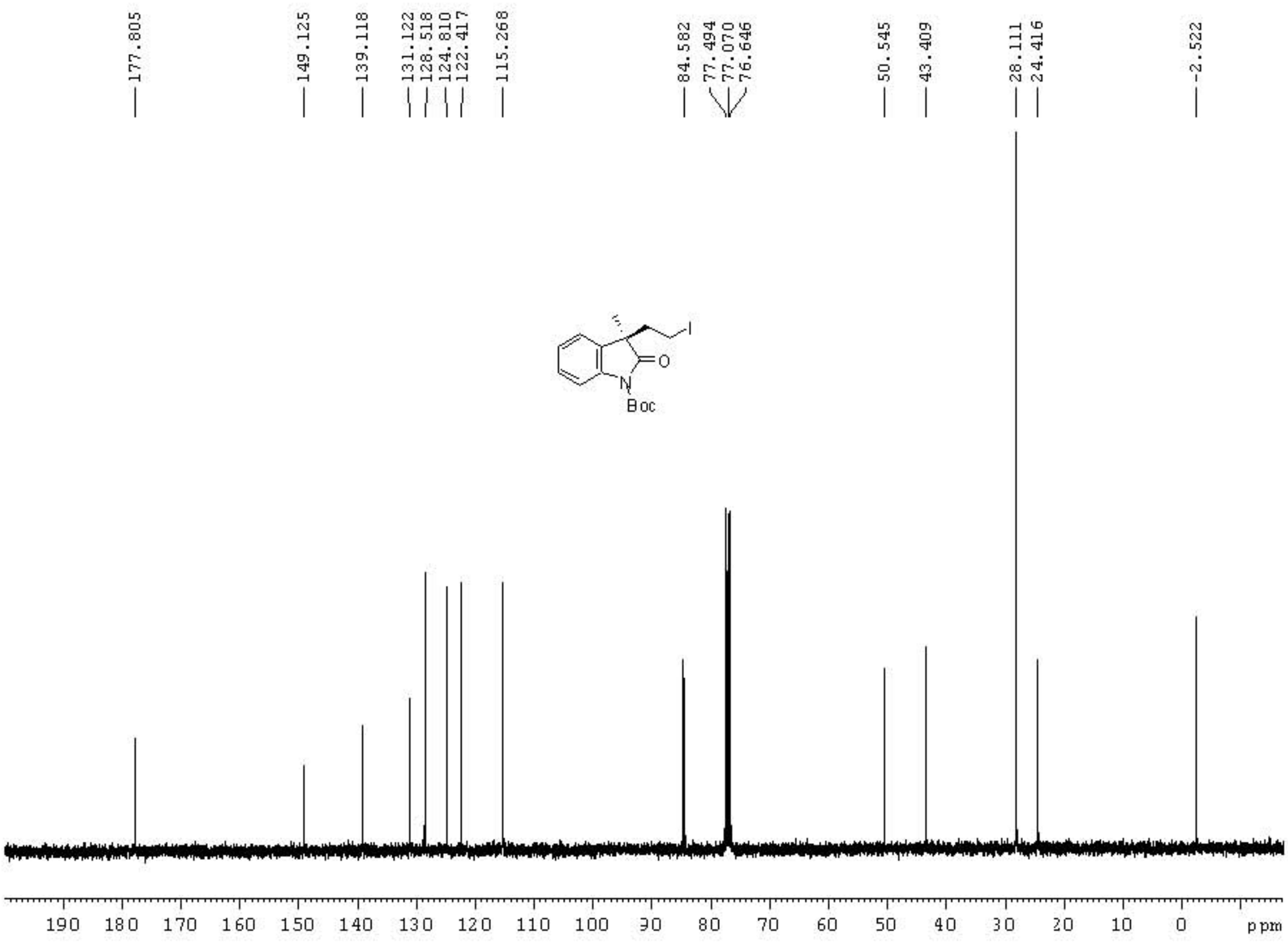

MeO
O
Se-Ph
O
O
N
Boc
1.971
4.029
3.185
1.043
0.998
0.984
1.009
2.992
1.041
3.044
2.028
9.000
8
7
6
5
4
3
2
1
0
ppm

176.418
158.984
148.250
140.900
139.809
135.210
134.513
130.383
129.180
128.804
127.388
127.060
124.771
123.298
122.135
115.188
114.549
113.397
84.586
77.501
77.077
76.653
54.959
54.745
53.886
45.325
28.747
27.919





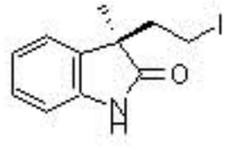

7.873
7.846
7.356
7.342
7.339
7.326
7.313
7.299
7.287
7.280
7.234
7.208
7.194
2.938
2.922
2.908
2.895
2.891
2.879
2.865
2.849
2.796
2.782
2.765
2.755
2.741
2.724
2.710
2.638
2.622
2.594
2.577
2.553
2.536
2.414
2.400
2.371
2.356
2.327
2.312
1.659
1.432
I
O
N
Boc
1.000
1.124
2.039
1.031
1.058
1.069
1.095
9.185
3.101
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

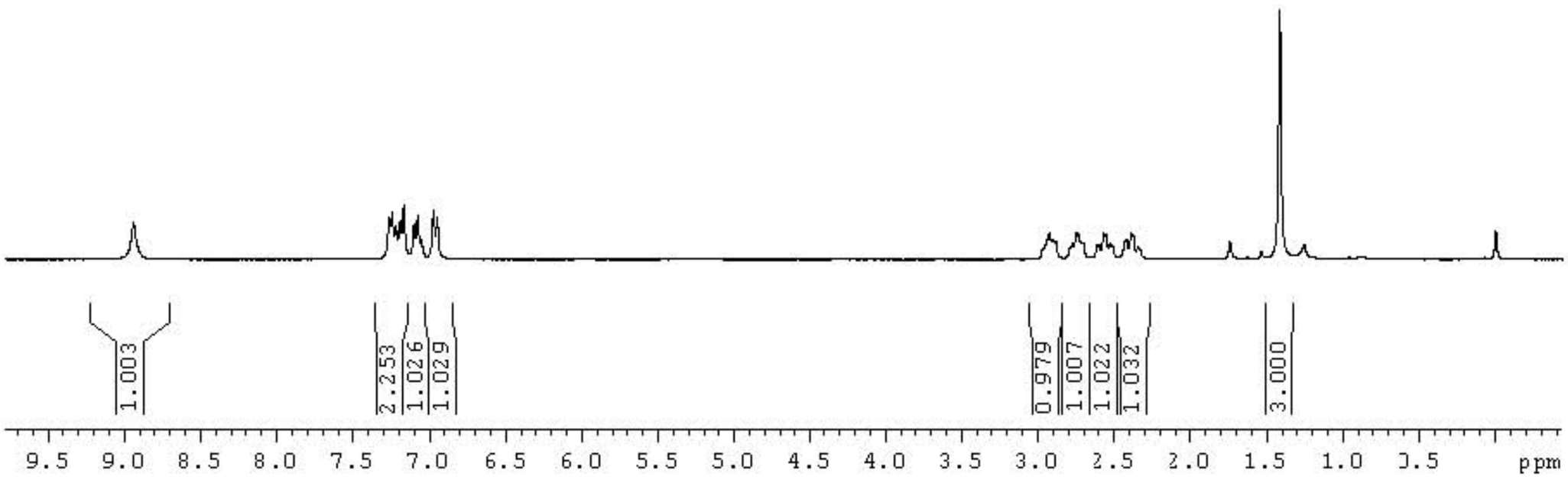

177.805
149.125
139.118
131.122
128.518
124.810
122.417
115.268
84.582
77.494
77.070
76.646
50.545
43.409
28.111
24.416
-2.522
I
O
N
Boc
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

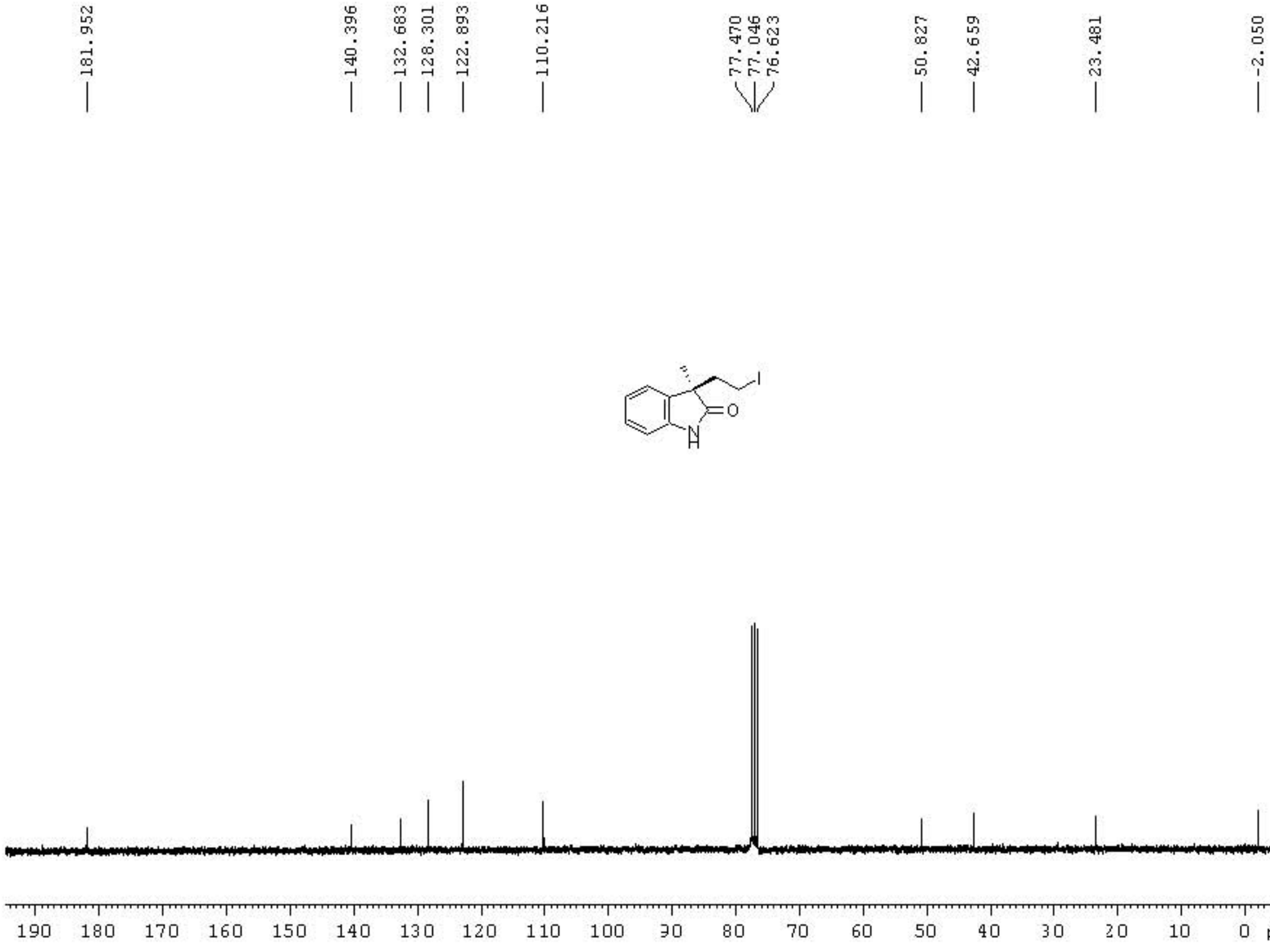
8.941

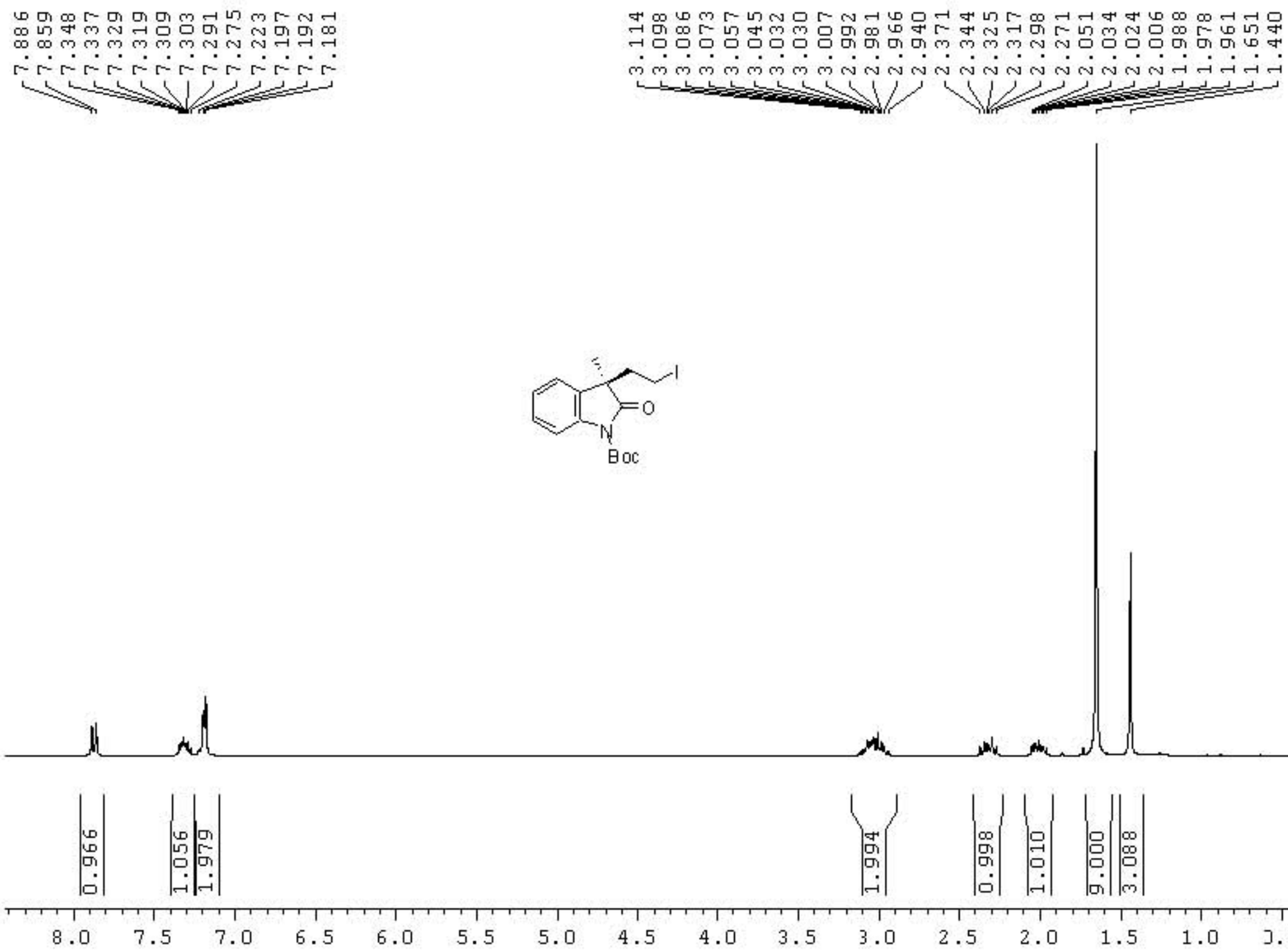
7.264
7.246
7.221
7.194
7.170
7.102
7.078
7.053
6.976
6.950

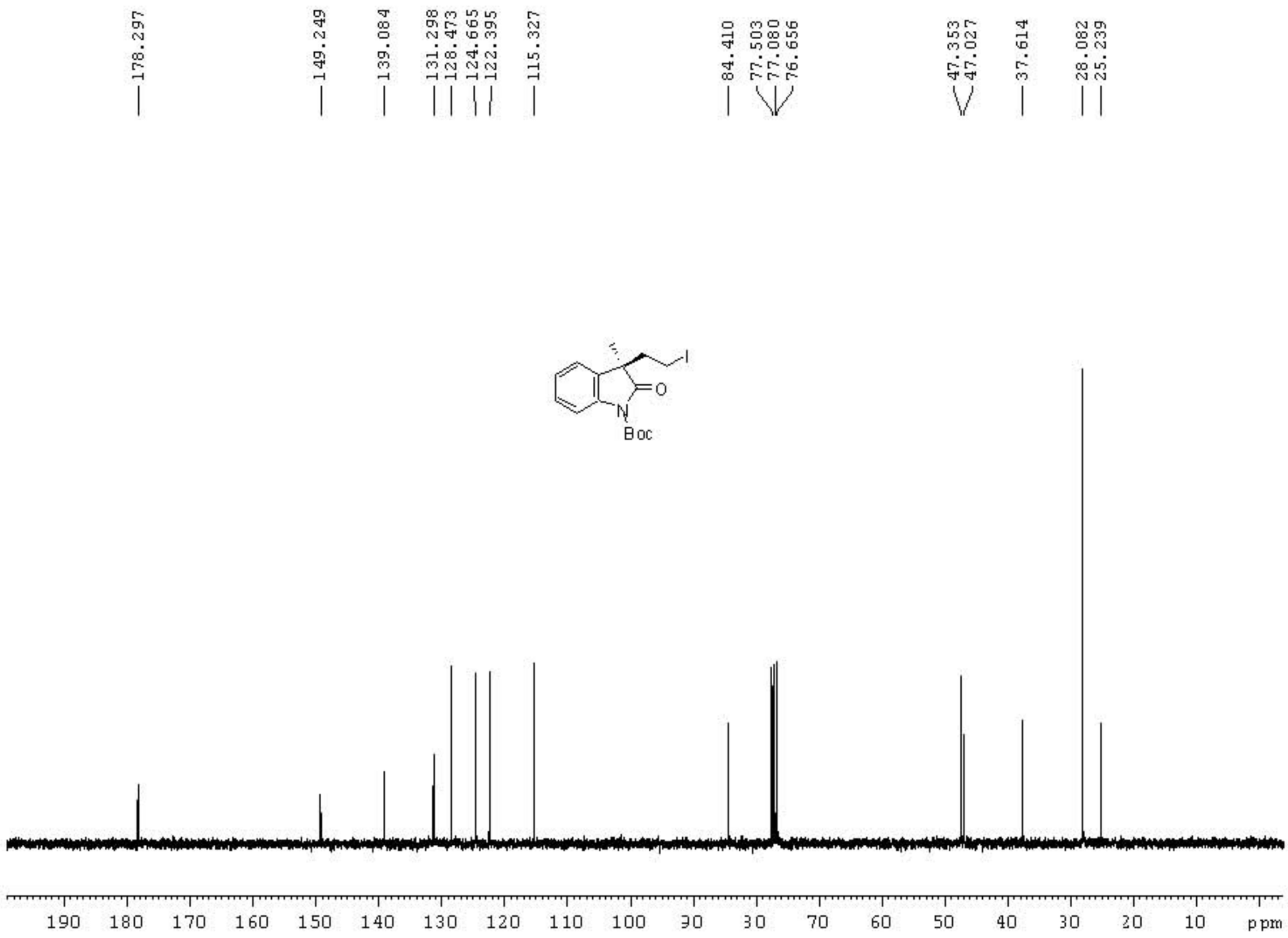
2.970
2.926
2.898
2.883
2.789
2.775
2.747
2.735
2.718
2.705
2.613
2.599
2.570
2.555
2.528
2.513
2.433
2.420
2.390
2.377
2.347
2.334
1.415






181.952
140.396
132.683
128.301
122.893
110.216
77.470
77.046
76.623
50.827
42.659
23.481
-2.050
O
N
H
I
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

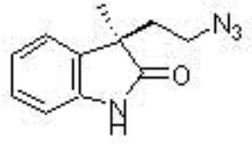

7.886
7.859
7.348
7.337
7.329
7.319
7.309
7.303
7.291
7.275
7.223
7.197
7.192
7.181
3.114
3.098
3.086
3.073
3.057
3.045
3.032
3.030
3.007
2.992
2.981
2.966
2.940
2.371
2.344
2.325
2.317
2.298
2.271
2.051
2.034
2.024
2.006
1.988
1.978
1.961
1.651
1.440
O
N
Boc
0.966
1.056
1.979
1.994
0.998
1.010
9.000
3.088
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm

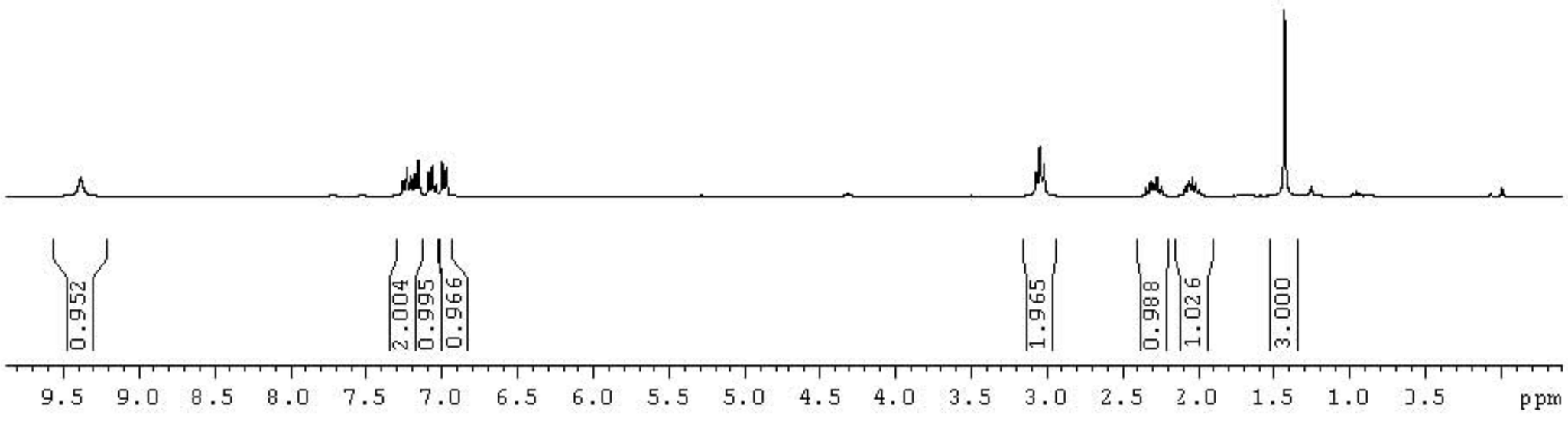

178.297
149.249
139.084
131.298
128.473
124.665
122.395
115.327
84.410
77.503
77.080
76.656
47.353
47.027
37.614
28.082
25.239
I
O
N
Boc
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

9.385

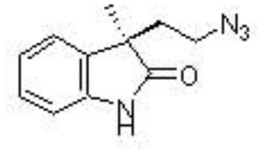
7.261
7.231
7.206
7.181
7.157
7.090
7.066
7.041
6.999
6.973

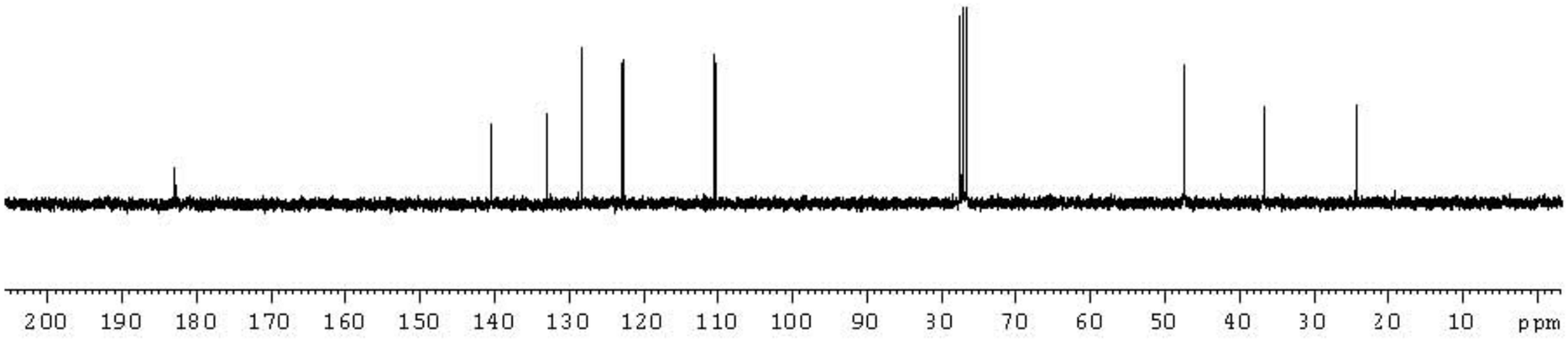
3.070
3.047
3.021
2.346
2.320
2.300
2.274
2.247
2.089
2.067
2.043
2.021
1.997
1.433





182.882
140.474
132.973
128.257
122.794
122.739
110.406
77.490
77.066
76.642
47.452
47.349
36.628
24.315



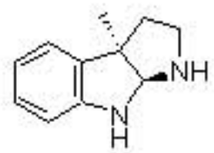


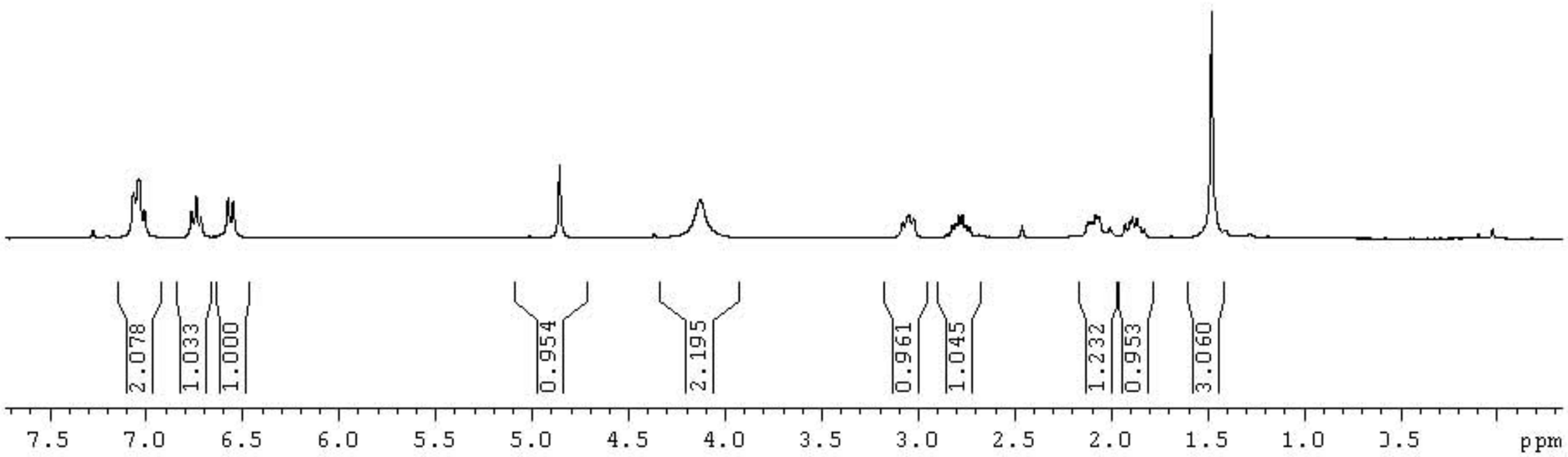
7.069
7.044
7.039
7.011
6.767
6.743
6.719
6.578
6.552

4.860

4.131

3.082
3.051
3.027
2.827
2.808
2.791
2.772
2.755
2.736
2.120
2.103
2.080
2.066
2.037
2.008
1.930
1.907
1.892
1.869
1.854
1.831
1.482





149.643
135.217
127.796
123.080
118.757
108.597
84.992
77.541
77.117
76.694
53.980
45.760
42.547
26.273