Supporting Information

for

Copper-catalyzed synthesis of spiro-indolofurobenzopyrans: tandem reactions of diazoamides and *O*-propargyl salicylaldehydes

Sengodagounder Muthusamy[a,*] Ammasi Prabu[a] and Eringathodi Suresh[b]

[a]*School of Chemistry, Bharathidasan University, Tiruchirappalli-620 024, India*

[b]*CSIR-Central Salt & Marine Chemicals Research Institute, Bhavnagar-364002, India*

* Tel: +91-431-2407053; Fax: +91-431-2407045; E-mail: muthu@bdu.ac.in

CONTENTS

General information

Melting points were determined on a capillary melting point apparatus and uncorrected. IR spectra were recorded using ATR technique on a Bruker Alpha FT-IR spectrophotometer. All compounds were fully characterized. Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded at 400 MHz using $CDCl_3$ in ppm (δ) related to tetramethylsilane (δ=0.00) as an internal standard and are reported as follows; chemical shift (ppm), multiplicity (br = broad, s = singlet, d = doublet, t = triplet, dd = doublet of doublet, m = multiplet), ABq = AB quartet, ABqd = AB quartet of doublet and coupling constant (Hz). Carbon-13 nuclear magnetic resonance (^{13}C NMR) spectra were recorded at 100 MHz in $CDCl_3$. Chemical shifts are reported in delta (δ) units, parts per million (ppm) relative to the center of the triplet at 77.7 ppm for $CDCl_3$. Carbon types were determined from ^{13}C NMR and DEPT experiments. The residual solvent signals were used as references and the chemical shifts converted to the TMS scale ($CDCl_3$: δ_H = 7.26 ppm, δ_C = 77.7 ppm). High resolution mass analyses were performed using electrospray ionization (ESI) technique on a Thermo Exactive Orbitrap mass spectrometer. All solvents were purified by distillation following standard procedure. Thin layer chromatography was performed on silica or alumina plates and components visualized by observation under iodine/UV light at 254 nm. Column chromatography was performed on silica gel (100-200 mesh). All the reactions were conducted in oven-dried glassware under a positive pressure of nitrogen with magnetic stirring. Reagents were added via syringes through septa. The propargyl bromide (80% solution in toluene), DMAD, NPM, $Rh_2(OAc)_4$, Cu(I)TC and other commercial chemicals were purchased from M/s Sigma Aldrich and used as provided. The *o*-hydroxyaldehydes were purchased from Aldrich and Alfa Aesar Chemicals. K_2CO_3 was dried by heating at 110 °C for 12 h and left to cool under nitrogen atmosphere.

Experimental Section

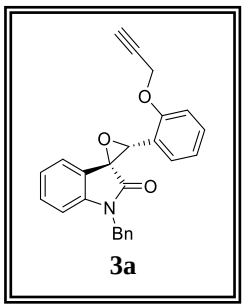
General experimental procedure I for the synthesis of spiro-indolooxiranes (3)

To an oven-dried flask, a solution containing the appropriate aldehyde **2** (1.1 mmol) and 5 mol% of copper(I) thiophenecarboxylate dissolved in 5 mL of dry DCE under a nitrogen atmosphere was added a solution of 3-diazoindol-2-one **1** (1 mmol) in dry DCE (4 mL) at ambient temperature to afford until the reaction completed (monitored using TLC). After the completion

of reaction, the solvent was removed under reduced pressure. The residue was subjected to column chromatography (silica gel, 100-200 mesh, EtOAc/hexane 30:70) to furnish spiro-indolooxiranes **3**.

Synthesis of 1-benzyl-3'-(2-(prop-2-yn-1-yloxy)phenyl)spiro[indoline-3,2'-oxiran]-2-one (3a)

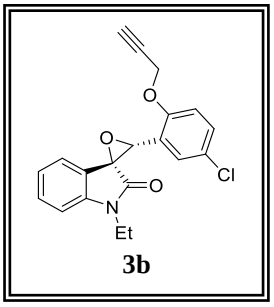
A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added quickly to a solution containing 2-[(prop-2-yn-1-yl)oxy]benzaldehyde **2a** (71 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at ambient temperature to afford **3a** (130 mg, 85%) as a white solid according to general procedure I. R_f = 0.28 (EtOAc/hexane = 1:4, v/v); mp 104-105 °C; IR (neat): ν_{max} 3287, 2924, 2118(w), 1724, 1610, 1462, 1354, 1022, 748 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 2.41 (t, J = 2.4 Hz, 1H, ≡CH), 4.62 (ABqd, $\Delta\delta_{AB}$ = 0.03, J_1 = 16 Hz, J_2 = 2 Hz, 2H, OCH_2), 4.81-4.89 (m, 3H, NCH_2/OCH), 6.77 (d, J = 8 Hz, 1H, ArH), 7.00 (d, J = 8.4 Hz, 1H, ArH), 7.07-7.15 (m, 2H, ArH), 7.24-7.31 (m, 7H, ArH), 7.33-7.37 (m, 1H, ArH), 7.78 (d, J = 7.6 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.0, 56.0, 61.5, 64.0, 75.7, 78.4, 109.6, 111.5, 121.1, 121.6, 121.9, 122.6, 123.7, 127.4, 127.7, 128.8, 129.0, 129.6, 130.0, 135.6, 143.8, 155.5, 170.3 ppm; HRMS (ESI) Calculated for $C_{25}H_{19}NO_3$ $(M+Na)^+$: 404.1263 found: 404.1251.



3a

Synthesis of 3'-(5-chloro-2-(prop-2-yn-1-yloxy)phenyl)-1-ethylspiro[indoline-3,2'-oxiran]-2-one (3b)

A solution of 3-diazo-1-ethylindolin-2-one **1b** (100 mg, 0.53 mmol) in dry dichloroethane (4 mL) was added quickly to a solution containing 5-chloro-2-(prop-2-yn-1-yloxy)benzaldehyde **2b** (114 mg, 0.58 mmol)) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at ambient temperature to afford **3b** (148 mg, 79%) as a white solid according to general procedure I. R_f = 0.33 (EtOAc/hexane = 1:4, v/v); mp 157-158 °C; IR (neat): ν_{max} 3292, 2924, 2123(w), 1727, 1617, 1484, 1364, 1019, 761 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 1.22 (t, J = 7.2 Hz, 3H, CH_3), 2.42 (t, J = 2.4 Hz, 1H, ≡CH), 3.66-3.76 (m, 2H, NCH_2), 4.55-4.64 (m, 2H, OCH_2), 4.74 (s, 1H, CH), 6.90-6.93 (m, 2H, ArH), 7.09-7.13 (m, 1H, ArH), 7.23-7.29 (m, 2H, ArH), 7.40 (td, J_1 = 7.6 Hz, J_2 = 1.2 Hz, 1H, ArH), 7.75 (d, J = 2.4 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 12.6, 35.0, 56.3, 61.4, 62.9,

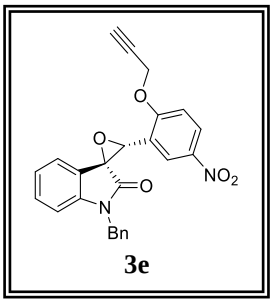


3b

76.1, 77.9, 108.8, 112.9, 122.1, 122.5, 123.4, 123.5, 126.3, 129.1, 129.3, 130.2, 143.9, 154.1, 169.5 ppm; HRMS (ESI) Calculated for $C_{20}H_{16}{}^{35}ClNO_3$ $(M+Na)^+$: 376.0716 found: 376.0715.

Synthesis of 1-benzyl-3'-(5-nitro-2-(prop-2-yn-1-yloxy)phenyl)spiro[indoline-3,2'-oxiran]-2-one (3e)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added quickly to a solution containing 5-nitro-2-(prop-2-yn-1-yloxy)benzaldehyde **2d** (90 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at ambient temperature conditions to afford **3e** (138 mg, 81%) as a white solid according to general procedure I. R_f = 0.21 (EtOAc/hexane = 1.5:3.5, v/v); mp 187-189 °C; IR (neat): ν_{max} 3287, 2923, 2124(w), 1725, 1613, 1418, 1341, 1268, 1006, 742 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 2.52 (t, J = 2.4 Hz, 1H, ≡CH), 4.73-4.74 (m, 2H, OCH_2), 4.79-4.89 (m, 3H, OCH/NCH_2), 6.81 (d, J = 8 Hz, 1H, ArH), 7.08-7.13 (m, 2H, ArH), 7.23-7.32 (m, 8H, ArH), 8.26 (dd, J_1 = 6.8 Hz, J_2 = 2.4 Hz, 1H, ArH), 8.68 (d, J = 2.8 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 56.6, 61.4, 62.5, 76.8, 77.4, 109.8, 111.4, 122.1. 122.8, 122.9, 125.5, 125.7, 127.3, 127.8, 128.9, 130.5, 135.3, 141.8, 143.9, 159.8, 169.7 ppm; HRMS (ESI) Calculated for $C_{25}H_{18}N_2O_5$ $(M+H)^+$: 427.1294 found: 427.1285.

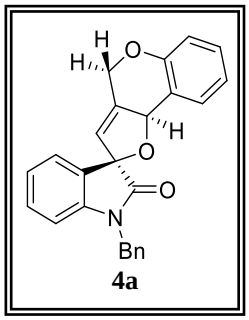


3e

General experimental procedure II for the synthesis of spiro-indolofurobenzopyrans (4)

To an oven-dried flask, a solution containing the appropriate aldehyde **2** (1.1 mmol) and 5 mol% of copper(I) thiophenecarboxylate dissolved in 5 mL of dry dichloroethane under a nitrogen atmosphere was added a solution of 3-diazoindol-2-one **1** (1 mmol) in dry DCE (4 mL) using syringe pump with the rate of addition of 0.5 mL/h at reflux conditions and continued until the reaction completed (monitored using TLC). After the completion of reaction, the solvent was removed under reduced pressure. The residue was subjected to column chromatography (silica gel, 100-200 mesh, EtOAc/hexane 15:85) to furnish spiro-indolobenzofuropyrans **4**.

Synthesis of 1'-benzyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4a)



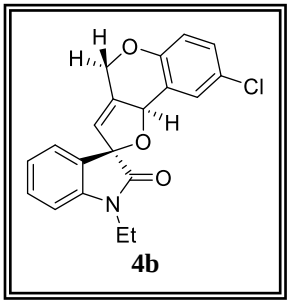
4a

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-[(prop-2-yn-1-yl)oxy]benzaldehyde **2a** (71 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux

conditions to afford **4a** (129 mg, 84%) as a white solid according to general procedure II. R_f = 0.35 (EtOAc/hexane = 1:4, v/v); mp 114-115 °C; IR (neat): ν_{max} 2924, 1723, 1613, 1490, 1360, 1215, 745 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.90 (ABq, $\Delta\delta_{AB}$ = 0.04, J = 15.6 Hz, 2H, CH_2), 5.62 (s, 1H, CH), 6.30 (s, 1H, CH), 6.70 (d, J = 8 Hz, 1H, ArH), 6.89-6.99 (m, 4H, ArH), 7.15-7.27 (m, 4H, ArH), 7.28-7.38 (m, 4H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 63.7, 81.4, 92.7, 109.5, 116.8, 121.5, 121.8, 123.4, 125.5, 126.0, 126.8, 127.4, 127.8, 128.3, 128.9, 129.2, 130.4, 135.4, 139.9, 142.7, 152.8, 175.2 ppm; HRMS (ESI) Calculated for $C_{25}H_{19}NO_3$ $(M+H)^+$: 382.1443 found: 382.1439.

Synthesis of 7-chloro-1'-ethyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4b)

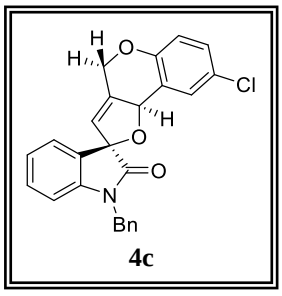
A solution of 3-diazo-1-ethylindolin-2-one **1b** (100 mg, 0.53 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 5-chloro-2-(prop-2-yn-1-yloxy)benzaldehyde **2b** (114 mg, 0.58 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at reflux conditions to afford **4b** (135 mg, 72%) as a white solid according to general procedure II. R_f = 0.23 (EtOAc/hexane = 1:4, v/v); mp 186-187 °C; IR (neat): ν_{max} 2929, 1722, 1612, 1474, 1361, 1216, 754 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 1.30 (t, J = 7.2 Hz, 3H, CH_3), 3.68-3.84 (m, 2H, NCH_2), 4.96 (s, 2H, CH_2), 5.59 (s, 1H, CH), 6.19 (s, 1H, CH), 6.82-6.86 (m, 2H, ArH), 6.92-6.94 (m, 1H, ArH) 6.97-7.10 (m, 1H, ArH), 7.17 (dd, J_1 = 8.8 Hz, J_2 = 2.8 Hz, 1H, ArH), 7.29-7.34 (m, 2H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 12.6, 35.0, 63.8, 80.8, 92.7, 108.6, 118.2, 122.4, 123.2, 125.6, 126.3, 126.4, 127.4, 128.2, 129.2, 130.6, 138.8, 142.7, 151.4, 174.4 ppm; HRMS (ESI) Calculated for $C_{20}H_{16}{}^{35}ClNO_3$ $(M+H)^+$: 354.0897 found: 354.0896.



4b

Synthesis of 7-chloro-1'-benzyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4c)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 5-chloro-2-(prop-2-yn-1-yloxy)benzaldehyde **2b** (85 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford **4c** (114 mg, 69%) as a white solid according to general procedure II. R_f = 0.29 (EtOAc/hexane = 1:4, v/v);

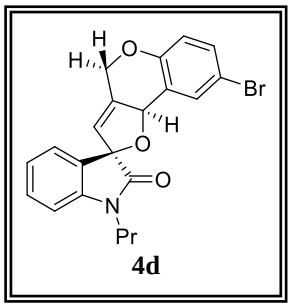


4c

mp 201-202 °C; IR (neat): ν_{max} 2966, 1724, 1650, 1470, 1361, 1211, 751 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.91-5.06 (m, 4H, CH_2), 5.69 (s, 1H, CH), 6.28 (s, 1H, CH), 6.76 (d, *J* = 7.6 Hz, 1H, ArH), 6.89 (d, *J* = 8.8 Hz, 1H, ArH), 6.97-7.03 (m, 2H, ArH), 7.20-7.26 (m, 2H, ArH), 7.30-7.39 (m, 6H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 63.8, 80.9, 92.8, 109.6, 118.3, 122.4, 123.5, 125.5, 126.3, 126.5, 127.3, 127.4, 127.8, 127.9, 128.9, 129.2, 130.6, 135.3, 139.1, 142.7, 151.4, 174.9 ppm; HRMS (ESI) Calculated for $C_{25}H_{18}{}^{35}ClNO_3$ $(M+H)^+$: 416.1054 found: 416.1054.

Synthesis of 7-bromo-1'-propyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4d)

A solution of 3-diazo-1-propylindolin-2-one **1c** (100 mg, 0.50 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 5-bromo-2-(prop-2-yn-1-yloxy)benzaldehyde **2c** (130 mg, 0.55 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at reflux conditions to afford **4d** (126 mg, 61%) as a white solid according to general procedure II. R_f = 0.29 (EtOAc/hexane = 1:4, v/v); mp 167-168 °C; IR (neat): ν_{max} 2923, 1725, 1613, 1472, 1341, 1090, 744 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 0.99 (t, *J* = 7.4 Hz, 3H, CH_3), 1.69-1.78 (m, 2H, CH_2), 3.67 (t, *J* = 7.2 Hz, 2H, CH_2), 4.96 (ABq distorted, 2H, CH_2), 5.60 (s, 1H, CH), 6.19 (s, 1H, CH), 6.78 (d, *J* = 8.8 Hz, 1H, ArH), 6.84 (d, *J* = 7.8 Hz, 1H, ArH), 6.92-6.94 (m, 1H, ArH), 6.97-7.01 (m, 1H, ArH), 7.29-7.33 (m, 2H, ArH), 7.46 (s, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 11.4, 20.7, 41.9, 63.8, 80.7, 92.7, 108.8, 113.5, 118.7, 122.5, 123.2, 125.6, 127.8, 128.0, 129.4, 130.6, 132.1, 138.8, 143.1, 151.9, 174.7 ppm; HRMS (ESI) Calculated for $C_{21}H_{18}{}^{79}BrNO_3$ $(M+Na)^+$: 434.0368 found: 434.0364.

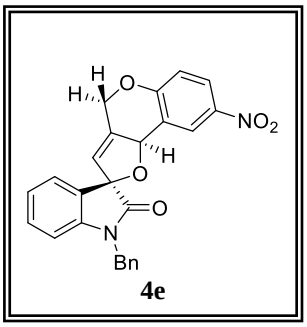


4d

Synthesis of 7-nitro-1'-benzyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4e)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 5-nitro-2-(prop-2-yn-1-yloxy)benzaldehyde **2d** (90 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford **4e** (121 mg, 71%) as a white solid according to general procedure II. R_f = 0.19 (EtOAc/hexane = 1.5:3.5, v/v); mp 199-200 °C; IR (neat): ν_{max} 2981, 1718, 1612, 1465, 1357, 1213, 1088, 734 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.96 (s, 2H,

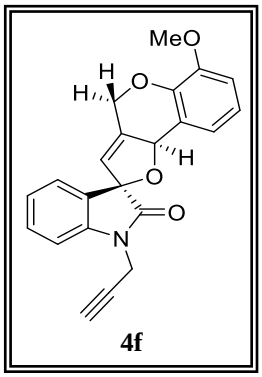
CH_2), 5.16 (ABq, $\Delta\delta_{AB}$ = 0.04, J = 13.2 Hz, 2H, CH_2), 5.78 (s, 1H, CH), 6.31 (s, 1H, CH), 6.77 (d, J = 8 Hz, 1H, ArH), 6.91 -6.93 (m, 1H, ArH), 6.97-7.04 (m, 2H, ArH), 7.23-7.27 (m, 1H, ArH), 7.33-7.42 (m, 5H, ArH), 8.17 (dd, J_1 = 9.2 Hz, J_2 = 2.8 Hz, 1H, ArH), 8.34 (d, J = 2.8 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 64.5, 80.1, 92.9, 109.7, 117.6, 123.42, 123.46, 123.6, 125.1, 125.3, 126.2, 127.3, 127.9, 129.0, 130.7, 135.2, 137.5, 142.0, 142.8, 158.0, 174.56 ppm; HRMS (ESI) Calculated for $C_{25}H_{18}N_2O_5$ $(M+H)^+$: 427.1294 found: 427.1281.



4e

Synthesis of 6-methoxy-1'-(prop-2-yn-1-yl)-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4f)

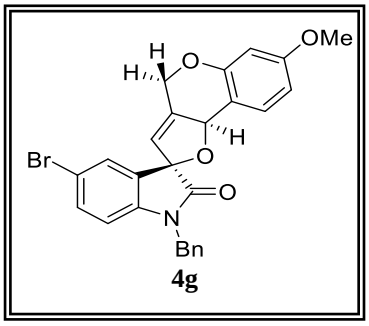
A solution of 3-diazo-1-(prop-2-yn-1-yl)indolin-2-one **1d** (100 mg, 0.51 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 3-methoxy-2-(prop-2-yn-1-yloxy)benzaldehyde **2e** (106 mg, 0.56 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at reflux conditions to afford **4f** (119 mg, 65%) as a white solid according to general procedure II. R_f = 0.13 (EtOAc/hexane = 1:4, v/v); mp 195-196 °C; IR (neat): ν_{max} 3291, 2930, 1725, 1614, 1362, 1264, 1020, 733 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 2.27 (s, 1H, CH), 3.90 (s, 3H, CH_3), 4.49 (ABqd, $\Delta\delta_{AB}$ = 0.13, J_1 = 18 Hz, J_2 = 2 Hz, 2H, CH_2), 5.04 (ABq, $\Delta\delta_{AB}$ = 0.08, J = 13.2 Hz, 2H, CH_2), 5.60 (s, 1H, CH), 6.26 (s, 1H, CH), 6.84-7.05 (m, 6H, ArH), 7.30-7.34 (m, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 29.6, 56.0, 64.0, 72.8, 76.6, 81.3, 92.6, 109.5, 110.9, 118.5, 121.3, 121.7, 123.7, 125.5, 126.6, 128.1, 130.5, 139.7, 141.7, 142.1, 148.2, 174.0 ppm; HRMS (ESI) Calculated for $C_{22}H_{17}NO_4$ $(M+Na)^+$: 382.1053 found: 382.1049.



4f

Synthesis of 5'-bromo-1'-benzyl-7-methoxy-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4g)

A solution of 1-benzyl-5-bromo-3-diazoindolin-2-one **1e** (100 mg, 0.30 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 4-methoxy-2-(prop-2-yn-1-yloxy)benzaldehyde **2f** (103 mg, 0.33 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (3 mg, 5 mol%) at reflux conditions to afford **4g** (102 mg, 70%) as a white solid according to general procedure II. R_f = 0.30 (EtOAc/hexane = 1:4, v/v); mp 195-196 °C; IR

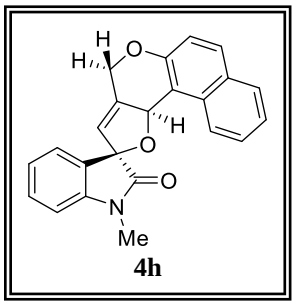


4g

(neat): ν_{max} 2924, 1729, 1644, 1433, 1161, 1030, 809 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 3.80 (s, 3H, CH_3), 4.87 (s, 2H, CH_2), 4.94 (ABq, $\Delta\delta_{AB}$ = 0.04, J = 12.8 Hz, 2H, CH_2), 5.62 (s, 1H, CH), 6.28 (s, 1H, CH), 6.45 (s, 1H, ArH), 6.54-6.59 (m, 2H, ArH), 7.06 (s, 1H, ArH), 7.23-7.35 (m, 7H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 55.4, 63.7, 81.3, 92.1, 101.7, 108.5, 111.0, 116.1, 117.6, 121.7, 127.3, 127.89, 127.98, 128.7, 129.0, 130.2, 133.2, 134.9, 140.7, 141.7, 153.9, 160.6, 174.7 ppm; HRMS (ESI) Calculated for $C_{26}H_{20}{}^{79}BrNO_4$ $(M+H)^+$: 490.0654 found: 490.0648.

Synthesis of 1'-methyl-4*H*,11c*H*-spiro[furo[2,3-*d*]naphtho[2,1-*b*]pyran-2,3'-indol]-2'(1'*H*)-one (4h)

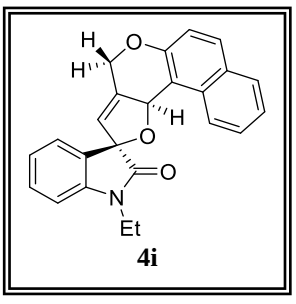
A solution of 3-diazo-1-methylindolin-2-one **1f** (100 mg, 0.58 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-(prop-2-yn-1-yloxy)-1-naphthaldehyde **2g** (134 mg, 0.64 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (6 mg, 5 mol%) at reflux conditions to afford **4h** (171 mg, 83%) as a white solid according to general procedure II. R_f = 0.39 (EtOAc/hexane = 1:4, v/v); mp 186-187 °C; IR (neat): ν_{max} 2254, 1720, 1617, 1466, 1088, 1015, 753 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 3.23 (s, 3H, CH_3), 4.95 (ABq, $\Delta\delta_{AB}$ = 0.13, J = 12 Hz, 2H, CH_2), 5.76 (s, 1H, CH), 6.77-6.81 (m, 2H, ArH), 6.87-6.90 (m, 1H, ArH), 6.93-6.95 (m, 1H, ArH), 7.08 (d, J = 9.2 Hz, 1H, ArH), 7.23-7.27 (m, 1H, ArH), 7.31-7.35 (m, 1H, ArH), 7.40-7.44 (m, 1H, ArH), 7.71-7.75 (m, 2H, ArH), 8.21 (d, J = 8.4 Hz, 1H, ArH), ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ 26.4, 63.9, 80.29, 92.0, 108.3, 116.8, 118.7, 123.3, 123.8, 123.9, 125.3, 125.6, 126.8, 128.0, 128.2, 129.4, 130.3, 130.4, 132.6, 140.2, 143.7, 151.8, 175.3 ppm; HRMS (ESI) Calculated for $C_{23}H_{17}NO_3$ $(M+H)^+$: 356.1287 found: 356.1280.



4h

Synthesis of 1'-ethyl-4*H*,11*cH*-spiro[furo[2,3-*d*]naphtho[2,1-*b*]pyran-2,3'-indol]-2'(1'*H*)-one (4i)

A solution of 3-diazo-1-ethylindolin-2-one **1b** (100 mg, 0.53 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-(prop-2-yn-1-yloxy)-1-naphthaldehyde **2g** (123 mg, 0.58 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at reflux conditions to afford **4i** (158 mg, 81%) as a white solid according to general procedure II. R_f = 0.44 (EtOAc/hexane = 1:4, v/v);



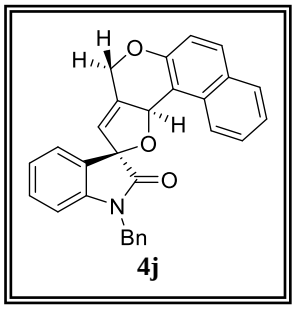
4i

mp 174-175 °C; IR (neat): ν_{max} 2976, 1722, 1464, 1360, 1216, 1033, 754 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ =1.33 (t, J = 7.2, 3H, CH_3), 3.78 (q, J = 7.2 Hz, 2H, CH_2), 4.95 (ABq, $\Delta\delta_{AB}$ = 0.12, J = 12 Hz, 2H, CH_2), 5.76 (s, 1H, CH), 6.80-6.82 (m, 2H, ArH), 6.85-6.89 (m, 1H, ArH), 6.93-6.96 (m, 1H, ArH), 7.08 (d, J = 9.2 Hz, 1H, ArH), 7.22-7.26 (m, 1H, ArH), 7.31-7.35 (m, 1H, ArH), 7.41-7.45 (m, 1H, ArH), 7.71-7.75 (m, 2H, ArH), 8.23 (d, J = 8.4 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ 12.7, 34.9, 63.8, 80.32, 92.0, 108.5, 116.9, 118.7, 123.0, 123.9, 125.4, 125.7, 126.8, 128.0 128.5, 129.4, 130.24, 130.28, 130.29, 132.6, 140.1, 142.8, 151.8, 174.9 ppm; HRMS (ESI) Calculated for $C_{24}H_{19}NO_3$ $(M+Na)^+$: 370.1443 found: 370.1425.

Crystal data for compound (**4i**): (CCDC 1580080) $C_{24}H_{19}NO_3$, white colour, diamond, M = 699.64, 0.28 × 0.19 × 0.11 mm, Triclinic, space group P-1 with a = 9.0014(13) Å, b = 9.5478(13) Å, c = 23.864(3) Å, α = 91.650(2) (2)°, β = 95.150(2) (2)°, γ = 113.925(2) (2)°, V = 1862.4(5) $Å^3$, T = 150(2) K, R_1 = 0.0465, wR_2 = 0.1282 on observed data, z = 2, D_{calcd} = 1.317 g/cm^3, *F(000)* = 776, Absorption coefficient = 0.087 mm^{-1}, λ = 0.71073 Å, 6462 reflections were collected on a smart apex CCD single crystal diffractometer 5683 observed reflections ($I \geq 2\sigma(I)$). The largest difference peak and hole = 0.249 and -0.226 e.$Å^{-3}$, respectively. The structure was solved by direct methods and refined by full-matrix least squares on $F2$ using SHELXL–97 software.

Synthesis of 1'-benzyl-4*H*,11*cH*-spiro[furo[2,3-*d*][1]naptho[2,1-b]pyran-2,3'-indol]-2'(1'*H*)-one (4j)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-(prop-2-yn-1-yloxy)-1-naphthaldehyde **2g** (92 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford **4j** (131 mg, 76%) as a white solid according to general procedure II. R_f = 0.34 (EtOAc/hexane = 1:4, v/v); mp 189-190 °C; IR (neat): ν_{max} 2933, 1728, 1610, 1475, 1180, 1033, 699 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.74-4.77 (m, 1H, CH), 4.82-4.85 (m, 1H, CH), 4.93-4.98 (m, 2H, CH_2), 5.74 (s, 1H, CH), 6.61 (d, J = 7.6 Hz, 1H, CH), 6.77-6.80 (m, 2H, ArH), 6.88 (d, J = 6.8 Hz, 1H, ArH), 7.01-7.08 (m, 2H, ArH), 7.18-7.29 (m, 6H, ArH), 7.36-7.40 (m, 1H, ArH), 7.65-7.69 (m, 2H, ArH), 8.18 (d, J = 8.4 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.1, 63.8, 80.4, 92.0, 109.3, 116.7, 118.7, 123.3, 123.9, 124.0, 125.4, 125.6, 126.7, 127.5, 127.8,

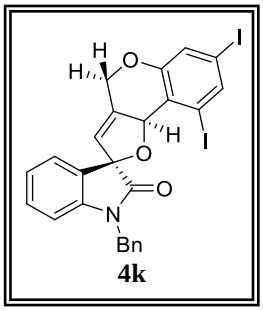


4j

128.0, 128.3, 128.9, 129.4, 130.26, 130.3, 132.6, 135.5, 140.3, 142.8, 151.8, 175.5 ppm ; HRMS (ESI) Calculated for $C_{29}H_{21}NO_3$ $(M+H)^+$: 432.1600 found: 432.1595.

Synthesis of 1'-benzyl-6,8-diiodo-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4k)

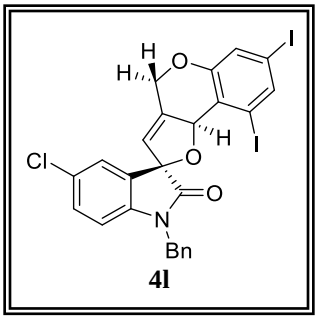
A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 3,5-diiodo-2-(prop-2-yn-1-yloxy)benzaldehyde **2h** (180 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford **4k** (189 mg, 75%) as a white solid according to general procedure II. R_f = 0.09 (EtOAc/hexane = 1.5:3.5, v/v); mp 215-216 °C; IR (neat): ν_{max} 2923, 1728, 1611, 1484, 1432, 1161, 667 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.94 (s, 2H, CH_2), 5.14 (ABq, $\Delta\delta_{AB}$ = 0.05, J = 13.2 Hz, 2H, CH_2), 5.72 (s, 1H, CH), 6.27 (s, 1H, CH), 6.76 (d, J = 8 Hz, 1H, ArH), 6.99-7.05 (m, 2H, ArH), 7.24-7.41 (m, 6H, ArH), 7.67 (s, 1H, ArH), 8.04 (s, 1H, ArH) ppm ; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 64.6, 80.5, 84.1, 86.2, 93.0, 109.6, 122.9, 123.5, 125.5, 127.4, 127.6, 127.9, 128.3, 129.0, 130.7, 135.3, 135.5, 138.4, 142.8, 146.2, 151.8, 174.6 ppm; HRMS (ESI) Calculated for $C_{25}H_{17}I_2NO_3$ $(M+Na)^+$: 655.9196 found: 655.9193.



4k

Synthesis of 5'-chloro-1'-benzyl-7,9-diiodo-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4l)

A solution of 1-benzyl-5-chloro-3-diazoindolin-2-one **1g** (100 mg, 0.35 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 3,5-diiodo-2-(prop-2-yn-1-yloxy)benzaldehyde **2h** (160 mg, 0.39 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford (189 mg, 81%) of **4l** as a white solid according to general procedure II. R_f = 0.48 (EtOAc/hexane = 1.5:3.5, v/v); mp 229-230 °C; IR (neat): ν_{max} 2933, 1724, 1614, 1500, 1159, 1022, 754 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.88 (ABq, $\Delta\delta_{AB}$ = 0.02, J = 16 Hz, 2H, CH_2), 5.08 (ABq, $\Delta\delta_{AB}$ = 0.06, J = 13.6 Hz, 2H, CH_2), 5.67 (s, 1H, CH), 6.23 (s, 1H, CH), 6.62 (d, J = 8.4 Hz, 1H, ArH), 6.95 (s, 1H, ArH), 7.17 (d, J = 8.4 Hz, 1H, ArH), 7.27-7.34 (m, 5H, ArH), 7.61 (s, 1H, ArH), 8.00 (s, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.2, 64.5, 80.6, 84.3, 86.3, 92.6, 110.7, 122.3, 126.0, 127.3, 127.8, 128.0, 129.00, 129.04, 129.1,

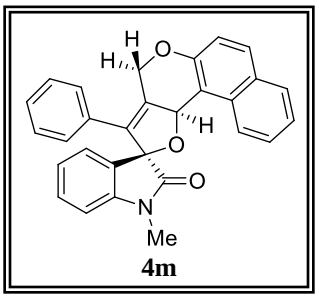


4l

130.6, 134.8, 135.5, 139.1, 141.3, 146.4, 151.7, 174.2 ppm; HRMS (ESI) Calculated for $C_{25}H_{16}{}^{35}ClI_2NO_3$ $(M+H)^+$: 667.8986 found: 667.8979.

Synthesis of 3-benzyl-1'-methyl-4*H*,11c*H*-spiro[furo[2,3-*d*]naphtho[2,1-*b*]pyran-2,3'-indol]-2'(1'*H*)-one (4m)

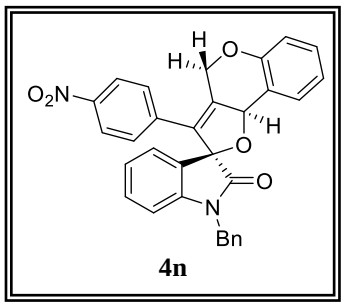
A solution of 3-diazo-1-methylindolin-2-one **1f** (100 mg, 0.58 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-((3-phenylprop-2-yn-1-yl)oxy)-1-naphthaldehyde **2i** (183 mg, 0.64 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (6 mg, 5 mol%) at reflux conditions to afford (210 mg, 84%) of **4m** as a white solid according to general procedure II. R_f = 0.25 (EtOAc/hexane = 1.5:3.5, v/v); mp 230-231 °C; IR (neat): ν_{max} 2923, 1728, 1611, 1433, 1341, 1166, 737 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 3.08 (s, 3H, CH_3), 4.93 (ABq, $\Delta\delta_{AB}$ = 0.07, J = 12.1 Hz, 2H, CH_2), 6.62 (d, J = 8 Hz, 1H, CH), 6.80-6.84 (m, 1H, ArH), 6.90-6.96 (m, 4H, ArH), 7.08 (d, J = 8.8 Hz, 1H, ArH), 7.13-7.21 (m, 4H, ArH), 7.29-7.33 (m, 1H, ArH), 7.39-7.43 (m, 1H, ArH), 7.69-7.74 (m, 2H, ArH), 8.26 (d, J = 8.4 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 26.4, 63.1, 80.5, 94.4, 108.4, 117.2, 118.8, 123.3, 123.9, 125.5, 125.8, 126.8, 128.0, 128.04, 128.4, 128.6, 128.7, 129.4, 130.3, 130.4, 130.9, 132.7, 135.1, 136.5, 144.1, 152.0, 175.3 ppm; HRMS (ESI) Calculated for $C_{29}H_{21}NO_3$ $(M+Na)^+$: 454.1419 found: 454.1409.



4m

Synthesis of 5'-bromo-3-(4-nitrophenyl)-1'-benzyl-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4n)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-((3-(4-nitrophenyl)prop-2-yn-1-yl)oxy)benzaldehyde **2j** (124 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford (163 mg, 81%) of **4n** as a white solid according to general procedure II. R_f = 0.44 (EtOAc/hexane = 1.5:3.5, v/v); mp 248-249 °C IR (neat): ν_{max} 2923, 1705, 1601, 1457, 1335, 1166, 744 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.57 (d, 1H, J = 15.6 Hz, CH), 4.86 (d, J = 13.6 Hz, 1H, CH), 5.01-5.09 (m, 2H, CH_2), 6.45 (s, 1H, OCH), 6.67 (d, 1H, J = 7.6 Hz, ArH), 6.91-7.05 (m, 8H, ArH), 7.13-7.29 (m, 4H, ArH), 7.43 (d, J = 7.6 Hz, 1H, ArH), 7.96 (d, J = 9.2 Hz, 2H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 43.9, 62.8, 81.8, 94.7,

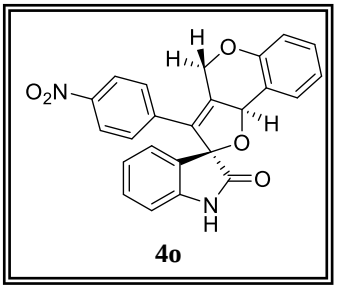


4n

109.7, 116.8, 121.8, 123.7, 123.74, 125.6, 126.0, 126.6, 127.2, 127.4, 127.9, 128.7, 129.38, 129.44, 131.0, 132.7, 135.0, 137.3, 137.6, 142.9, 147.8, 152.7, 174.5 ppm; HRMS (ESI) Calculated for $C_{29}H_{21}NO_3$ $(M+Na)^+$: 525.1426 found: 525.1427.

Synthesis of 3-(4-nitrophenyl)-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4o)

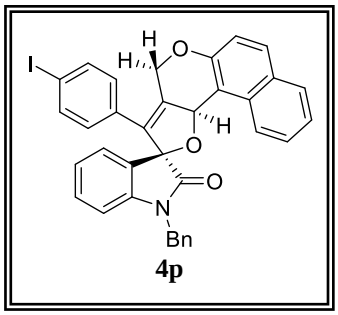
A solution of 3-diazoindolin-2-one **1h** (100 mg, 0.63 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-((3-(4-nitrophenyl)prop-2-yn-1-yl)oxy)benzaldehyde **2j** (195 mg, 0.69 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (6 mg, 5 mol%) at reflux conditions to afford (203 mg, 78%) of **4o** as a white solid according to general procedure II. R_f = 0.76 (EtOAc/hexane = 2:3, v/v); mp 230-231 °C; IR (neat): ν_{max} 3004, 2253, 1441, 1377, 1039, 918, 743 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.94 (ABq, $\Delta\delta_{AB}$ = 0.18, J = 13.4 Hz, 2H, CH_2 6.38 (s, 1H, CH), 6.82 (d, J = 7.6 Hz, 1H, ArH), 6.91-7.06 (m, 5H, ArH), 7.23-7.28 (m, 3H, ArH), 7.40 (d, J = 7.6 Hz, 1H, ArH), 8.05 (d, J = 8.8 Hz, 2H, ArH), 8.27 (br s, 1H, NH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 62.9, 81.8, 94.8, 110.7, 116.9, 121.8, 123.8, 123.9, 125.9, 126.0, 126.5, 127.9, 129.1, 129.5, 131.1, 132.2, 137.4, 138.1, 140.9, 147.8, 152.6, 176.6 ppm; HRMS (ESI) Calculated for $C_{24}H_{16}N_2O_5$ $(M-H)^+$: 411.0986 found: 411.0976.



4o

Synthesis of 1'-benzyl-3-(4-iodophenyl)-4*H*,11c*H*-spiro[furo[2,3-*d*]naphtho[2,1-*b*]pyran-2,3'-indol]-2'(1'H)-one (4p)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-((3-(4-iodophenyl)prop-2-yn-1-yl)oxy)-1-naphthaldehyde **2k** (181 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford (210 mg, 83%) of **4p** as a white solid according to general procedure II. R_f = 0.41 (EtOAc/hexane = 1.5:3.5, v/v); mp 245-246 °C; IR (neat): ν_{max} 2924, 1722, 1613, 1469, 1353, 1216, 952, 753 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 4.43 (d, J = 16 Hz, 1H, CH_2), 4.92 (ABq, $\Delta\delta_{AB}$ = 0.02, J = 12.2 Hz, 2H, CH_2), 5.16 (d, J = 15.7, 1H, CH_2), 6.52-6.57 (m, 3H, ArH), 6.82-6.87 (m, 3H, ArH), 6.96-7.00 (m, 2H, ArH), 7.07-7.11 (m, 2H, ArH), 7.17-7.24 (m, 3H, ArH), 7.33-7.37 (m, 1H, ArH), 7.44-7.50 (m, 3H, ArH), 7.72-7.77 (m, 2H, ArH),

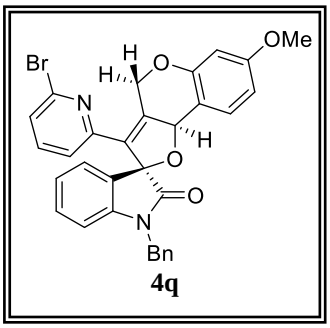


4p

8.29 (d, J = 8.4 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 43.7, 62.9, 80.8, 94.6, 95.2, 109.6, 117.0, 118.7, 123.4, 124.0, 125.4, 125.7, 126.8, 126.9, 127.6, 127.7, 128.1, 128.8, 129.4, 130.1, 130.4, 130.6, 132.6, 135.0, 135.4, 135.9, 137.8, 143.0, 151.8, 175.2 ppm; HRMS (ESI) Calculated for $C_{35}H_{24}INO_3$ $(M+H)^+$: 634.0879 found: 634.0874.

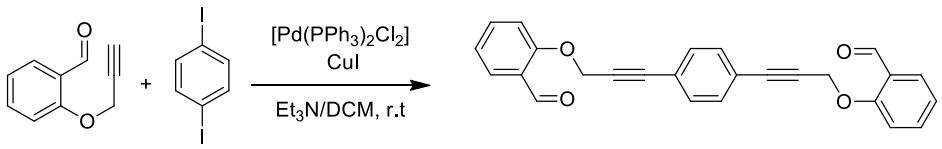
Synthesis of 1'-benzyl-3-(6-bromopyridin-2-yl)-7-methoxy-4*H*,9b*H*-spiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (4q)

A solution of 1-benzyl-3-diazoindolin-2-one **1a** (100 mg, 0.40 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2-((3-(6-bromopyridin-2-yl)prop-2-yn-1-yl)oxy)-4-methoxybenzaldehyde **2l** (152 mg, 0.44 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (4 mg, 5 mol%) at reflux conditions to afford (186 mg, 82%) of **4q** as a white solid according to general procedure II. R_f = 0.40 (EtOAc/hexane = 1.5:3.5, v/v); mp 226-227 °C; IR (neat): ν_{max} 2924, 1725, 1611, 1436, 1259, 1159, 1116, 1029, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 3.80 (s, 3H CH_3), 4.98 (ABq, $\Delta\delta_{AB}$ = 0.10, J = 15.6 Hz, 2H, CH_2), 5.25-5.29 (m, 1H, CH_2), 5.66 (d, J = 15.2 Hz, 1H, CH_2), 6.35 (s, 1H, CH), 6.51-6.61 (m, 3H, ArH), 6.79-6.81 (m, 1H, ArH), 6.87-6.94 (m, 2H, ArH), 7.12-7. 37 (m, 9H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.3, 55.5, 65.4, 81.5, 92.7, 102.2, 108.5, 109.6, 119.7, 119.8, 123.5, 125.4, 126.2, 126.7, 127.75, 127.8, 128.4, 128.9, 129.0, 130.6, 135.7, 138.6, 141.5, 143.0, 143.5, 151.1, 154.0, 160.4, 174.9 ppm; HRMS (ESI) Calculated for $C_{31}H_{23}{}^{79}BrN_2O_4$ $(M+Na)^+$: 589.0739 found: 589.0724.



4q

Procedure for the synthesis of compound 5

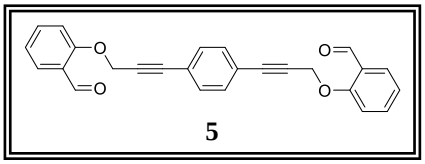


2a **5**

Synthesis of 2,2'-((1,4-phenylenebis(prop-2-yne-3,1-diyl))bis(oxy))dibenzaldehyde (5)

To a mixture of compound **2a** (1 g, 6.24 mmol), 1,4-diiodobene (1.029 g, 3.12 mmol) in dry triethylamine / dichloromethane (4:1) (5 mL) under a nitrogen atmosphere were added $[Pd(PPh_3)_2Cl_2]$ (175 mg, 0.25 mmol) and CuI (24 mg, 0.12 mmol) successively. The reaction mixture was stirred at room temperature for 6 h. After that, the solvent was removed under reduced pressure, added water and extracted with dichloromethane. The crude product was

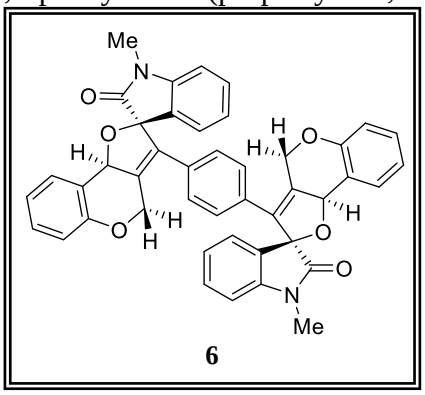
purified by column chromatography using silica gel to afford the bis-aldehyde derivative (1.4 g, 58%) of **5** as a white solid. R_f = 0.19 (EtOAc/hexane = 1:4, v/v); mp 153-154 °C; IR (neat): ν_{max} 2861, 1681, 1594, 1455, 1212, 1007, 834, cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 5.05 (s, 2H, CH_2), 7.09 (t, J = 7.6 Hz, 1H, ArH), 7.17 (d, J = 8.4 Hz, 1H, ArH), 7.36 (s, 2H, ArH), 7.56-7.60 (m, 1H, ArH), 7.87 (dd, J_1 = 7.6 Hz, J_2 = 1.6 Hz, 1H, ArH) 10.52 (s, 1H, CH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 57.25, 85.03, 87.41, 113.39, 121.69, 122.43, 125.59, 128.65, 131.74, 135.77, 159.98, 189.65 ppm; HRMS (ESI) Calculated for $C_{26}H_{18}O_4$ $(M+Na)^+$: 417.1103 found: 417.1098.



5

Synthesis of 1'-methyl-3-[4-(1'-methyl-2'-oxo-1',2',3'*a*,7'*a*-tetrahydro-4*H*,9b*H*-spiro[furo [3,2-*c*][1]benzopyran-2,3'-indol]-3-yl)phenyl]9a,9bdihydro4*H*,5aHspiro[furo[3,2-*c*][1]benzopyran-2,3'-indol]-2'(1'*H*)-one (6)

A solution of 1-methyl-3-diazoindolin-2-one **1f** (100 mg, 0.58 mmol) in dry dichloroethane (4 mL) was added dropwise to a solution containing 2,2'-((1,4-phenylenebis(prop-2-yne-3,1-diyl))bis(oxy))dibenzaldehyde **5** (115 mg, 0.029 mmol) dissolved in dry DCE (5 mL) and copper(I) thiophenecarboxylate (6 mg, 5 mol%) at reflux conditions to afford **6** (157 mg, 79%) as a white solid according to general procedure II. R_f = 0.06 (EtOAc/hexane = 1.5:3.5, v/v); mp 231-232 °C; IR (neat): ν_{max} 2923, 1716, 1608, 1471, 1215, 1109, 755 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 3.09 (s, 3H, CH_3), 4.79-4.84 (m, 1H, CH_2), 4.94-5.00 (m, 1H, CH_2), 6.31 (s, 1H, CH), 6.57 (s, 1H, CH), 6.23 (s, 1H, CH), 6.74 (t, J = 8.4 Hz, 1H, ArH), 6.85-6.91 (m, 2H, ArH), 6.93-6.99 (m, 2H, ArH), 7.20-7.35 (m, 3H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 26.5, 63.2, 81.2, 94.3, 108.7, 116.7, 121.5, 123.5, 125.6, 126.4, 126.5, 126.6, 128.2, 128.3, 129.2, 130.7, 131.1, 133.5, 135.5, 144.0, 152.7, 174.8 ppm (due to the C_2 Symmetry we observed half-half the signal); HRMS (ESI) Calculated for $C_{44}H_{32}N_2O_6$ $(M+Na)^+$: 685.2339 found: 685.2337.

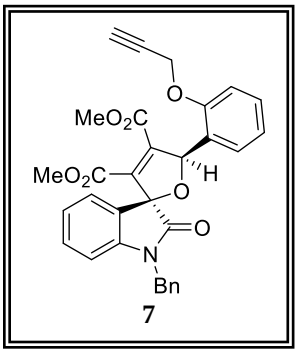


6

Synthesis of dimethyl 1'-benzyl-2'-oxo-5-(2-(prop-2-yn-1-yloxy)phenyl)-5*H*-spiro[furan-2,3'-indoline]-3,4-dicarboxylate (7)

To a mixture of spiro-indolooxirane **3a** (100 mg, 0.26 mmol) and dimethyl acetylenedicarboxylate (41 mg, 0.29 mmol) in dry toluene (5 mL) was stirred at reflux conditions for 32 hours to afford **7** (90 mg, 66%) as a colorless liquid. R_f = 0.13 (EtOAc/hexane = 1:4, v/v);

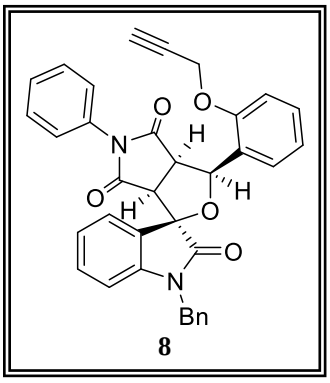
IR (neat): ν_{max} 3282, 2952, 2123(w), 1723, 1611, 1259, 1022, 754. cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 2.52 (s, 1H, ≡CH), 3.48 (s, 3H, CH_3), 3.75 (s, 3H, CH_3), 4.63-4.74 (m, 3H, CH_2), 5.07 (d, J = 16 Hz, 1H, CH_2), 6.68 (d, J = 7.6 Hz, 1H, CH), 6.91 (s, 1H, ArH), 7.00-7.07 (m, 3H, ArH), 7.18-7.42 (m, 8H, ArH), 7.56 (d, J = 7.2 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 44.1, 52.4, 52.7, 56.1, 76.02, 78.4, 83.7, 89.5, 109.6, 112.1, 121.8, 123.2, 125.3, 126.2, 127.3, 127.4, 127.7, 128.2, 128.8, 130.1, 130.9, 135.5, 143.8, 147.3, 155.1, 161.0, 163.1, 173.8 2 ppm; HRMS (ESI) Calculated for $C_{31}H_{25}NO_7$ $(M+H)^+$: 524.1709 found: 524.1712.



7

Synthesis of 1'-ethyl-5-phenyl-3-(2-(prop-2-yn-1-yloxy)phenyl)-3a,6a-dihydrospiro[furo [3,4-*c*]pyrrole-1,3'-indoline]-2',4,6(3*H*,5*H*)-trione (8)

To a mixture of spiro-indolooxirane **3a** (100 mg, 0.26 mmol) and *N*-phenylmaleimide (50 mg, 0.30 mmol) in dry toluene (5 mL) was stirred at reflux conditions for 27 hours to afford **8** (94 mg, 65%) as a white solid. R_f = 0.13 (EtOAc/hexane = 1:4, v/v); mp 186-187 °C; IR (neat): ν_{max} 3289, 2923, 2125(w), 1714, 1614, 1339, 1267, 1006, 734 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 2.55 (t, J = 2.4 Hz, 1H, ≡CH), 3.87 (d, J = 8 Hz, 1H, CH), 4.45 (t, J = 8.1 Hz, 1H, CH), 4.83-4.87 (m, 3H, CH_2), 4.98 (d, J = 15.6 Hz, 1H, CH_2), 6.54 (d, J = 8 Hz, 1H, ArH), 6.78 (d, J = 8 Hz, 1H, ArH), 6.99-7.12 (m, 5H, ArH), 7.24-7.41 (m, 11H, ArH), 7.47 (d, J = 7.6 Hz, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 43.8, 49.5, 52.0, 56.4, 75.7, 78.7, 83.9, 109.8, 111.6, 121.3, 123.1, 123.4, 125.1, 125.5, 126.1, 126.7, 127.3, 127.9, 128.6, 129.0, 129.2, 131.0, 131.6, 135.1, 143.4, 154.9, 172.9, 173.1, 175.8 ppm; HRMS (ESI) Calculated for $C_{31}H_{26}N_2O_5$ $(M+Na)^+$: 577.1739 found: 577.1734.

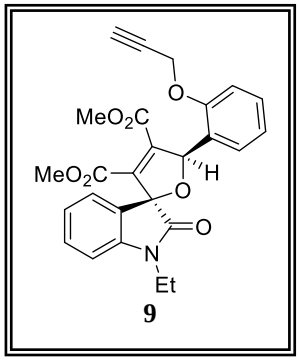


8

Synthesis of dimethyl 1'-ethyl-2'-oxo-5-(2-(prop-2-yn-1-yloxy)phenyl)-*5H*-spiro[furan-2,3'-indoline]-3,4-dicarboxylate (9)

A solution of 3-diazo-1-ethylindolin-2-one **1b** (100 mg, 0.53 mmol) in dry dichloroethane or toluene (4 mL) was added dropwise to a mixture of solution containing 2-[(prop-2-yn-1-yl)oxy]benzaldehyde **2a** (93 mg, 0.58 mmol), dimethyl acetylenedicarboxylate (83 mg, 0.58 mmol) and copper(I) thiophenecarboxylate (5 mg, 5 mol%) at reflux conditions for 1 hour to afford **9** (164 mg, 67%) as a colorless liquid. R_f = 0.09 (EtOAc/hexane = 1:4, v/v); IR (neat): ν_{max}

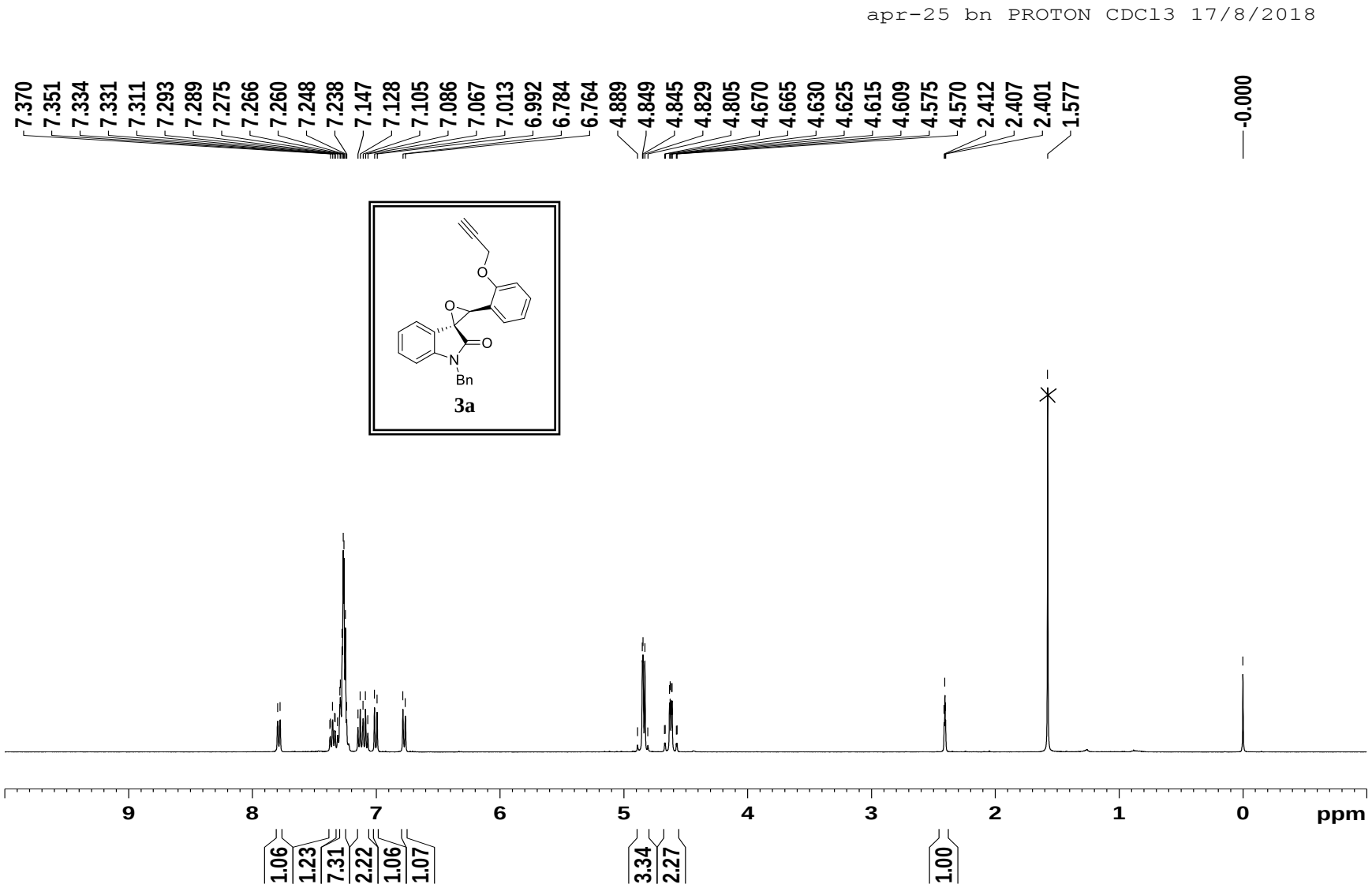
3281, 2923, 2123, 1720, 1610, 1257, 1018, 742 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ = 1.33 (t, J = 7.2 Hz, 3H, CH_3), 2.57 (t, J = 2.4 Hz, 1H, ≡CH), 3.60 (s, 3H, CH_3), 3.71-3.78 (m, 1H, CH), 3.81 (s, 3H, CH_3), 3.84-3.93 (m, 1H, CH), 4.72 (ABqd, $\Delta\delta_{AB}$ = 0.06, J_1 = 15.8 Hz, J_2 = 2.3 Hz, 2H, CH_2), 6.88-6.91 (m, 2H, ArH), 7.07-7.13 (m, 3H, ArH), 7.37-7.45 (m, 3H, ArH), 7.58-7.60 (m, 1H, ArH) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 12.3, 34.9, 52.3, 52.6, 56.1, 75.9, 78.4, 83.7, 89.5, 108.5, 112.1, 121.8, 122.9, 125.4, 126.3, 127.5, 128.2, 130.1, 130.8, 132.1, 143.7, 146.8, 155.1, 160.9, 163.1, 173.2 ppm; HRMS (ESI) Calculated for $C_{26}H_{23}NO_7$ $(M+Na)^+$: 484.1372 found: 484.1377.



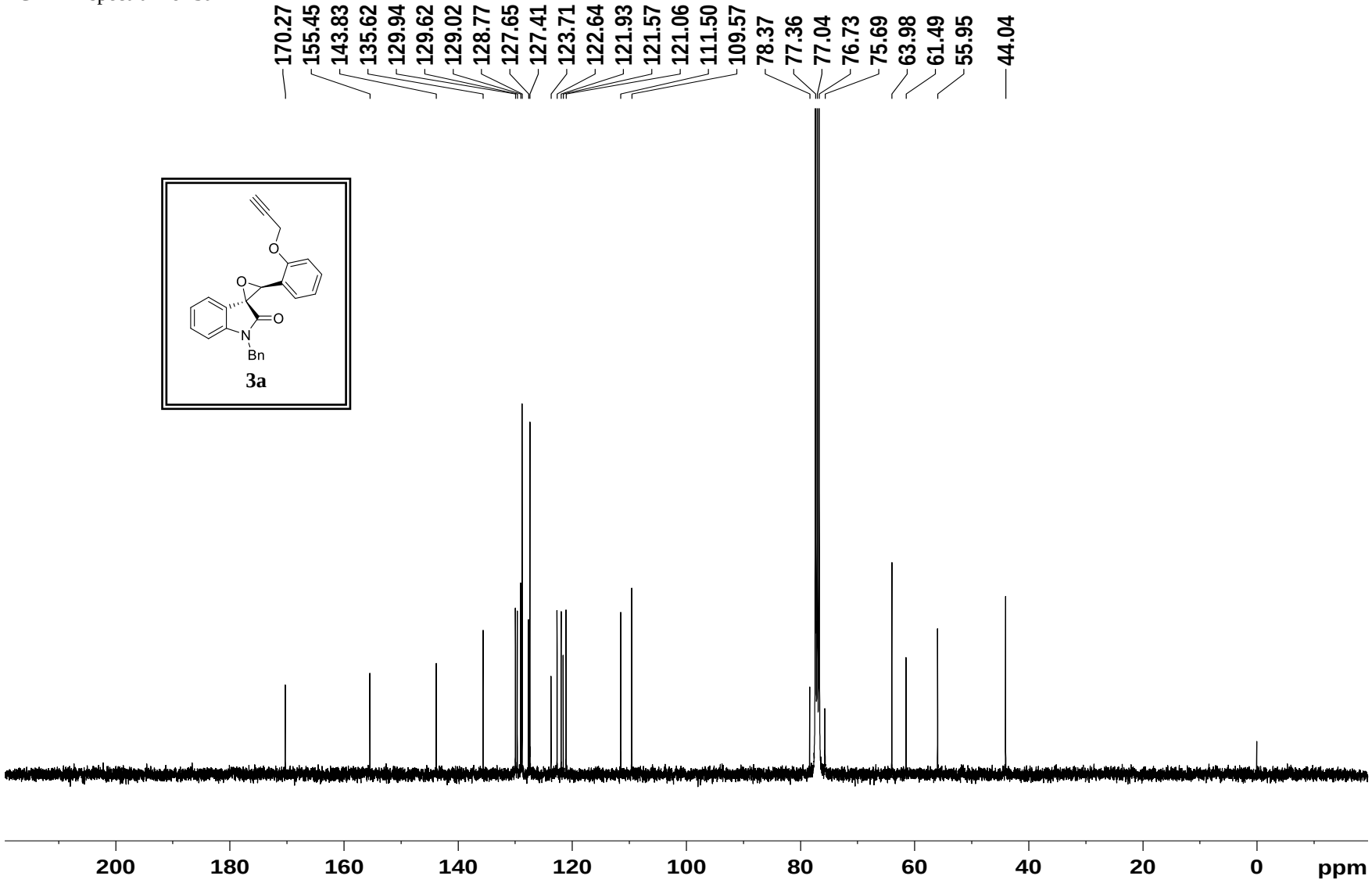
9

Copies of ^{1}H and ^{13}C NMR spectra

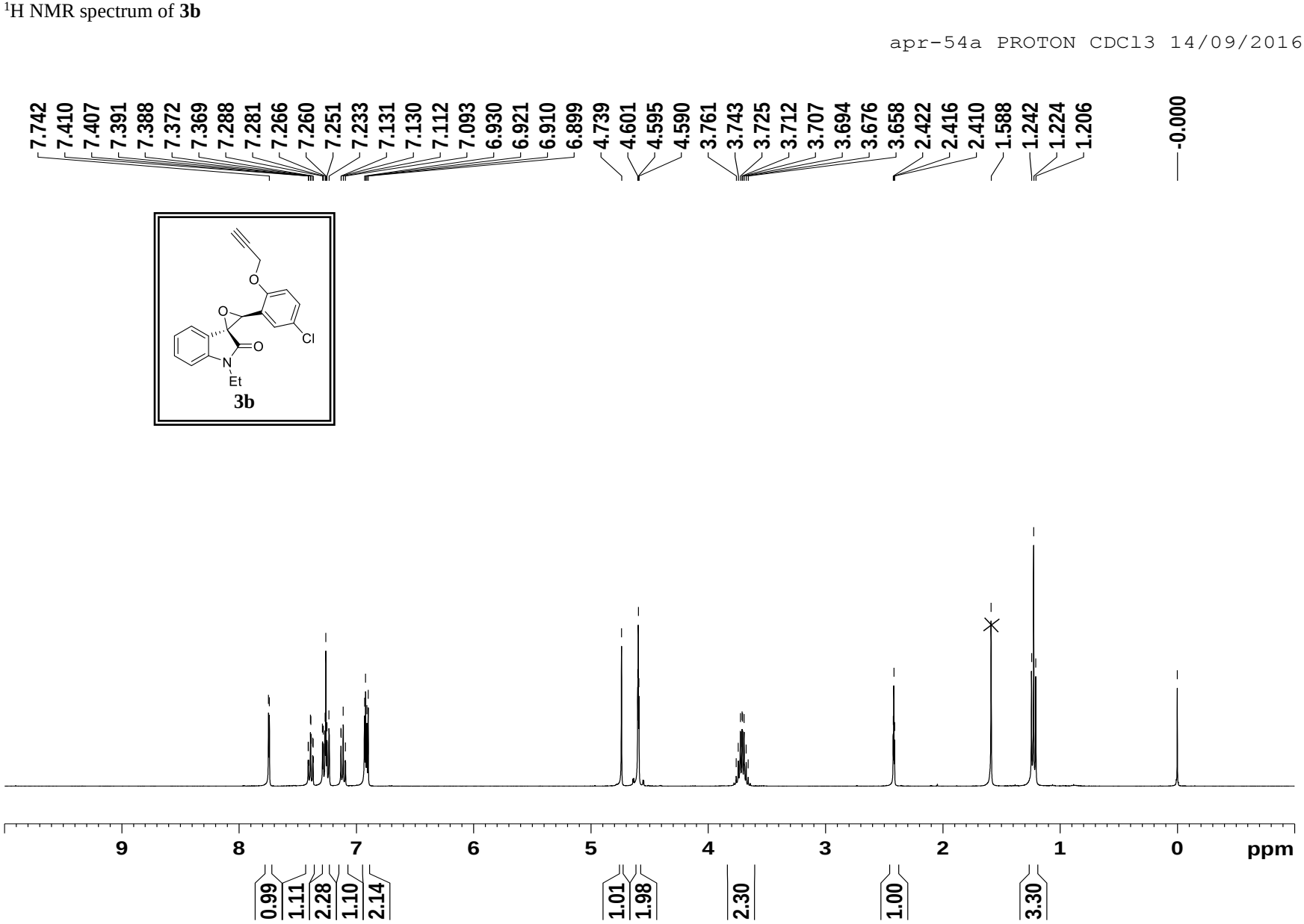
^{1}H NMR spectrum of **3a**



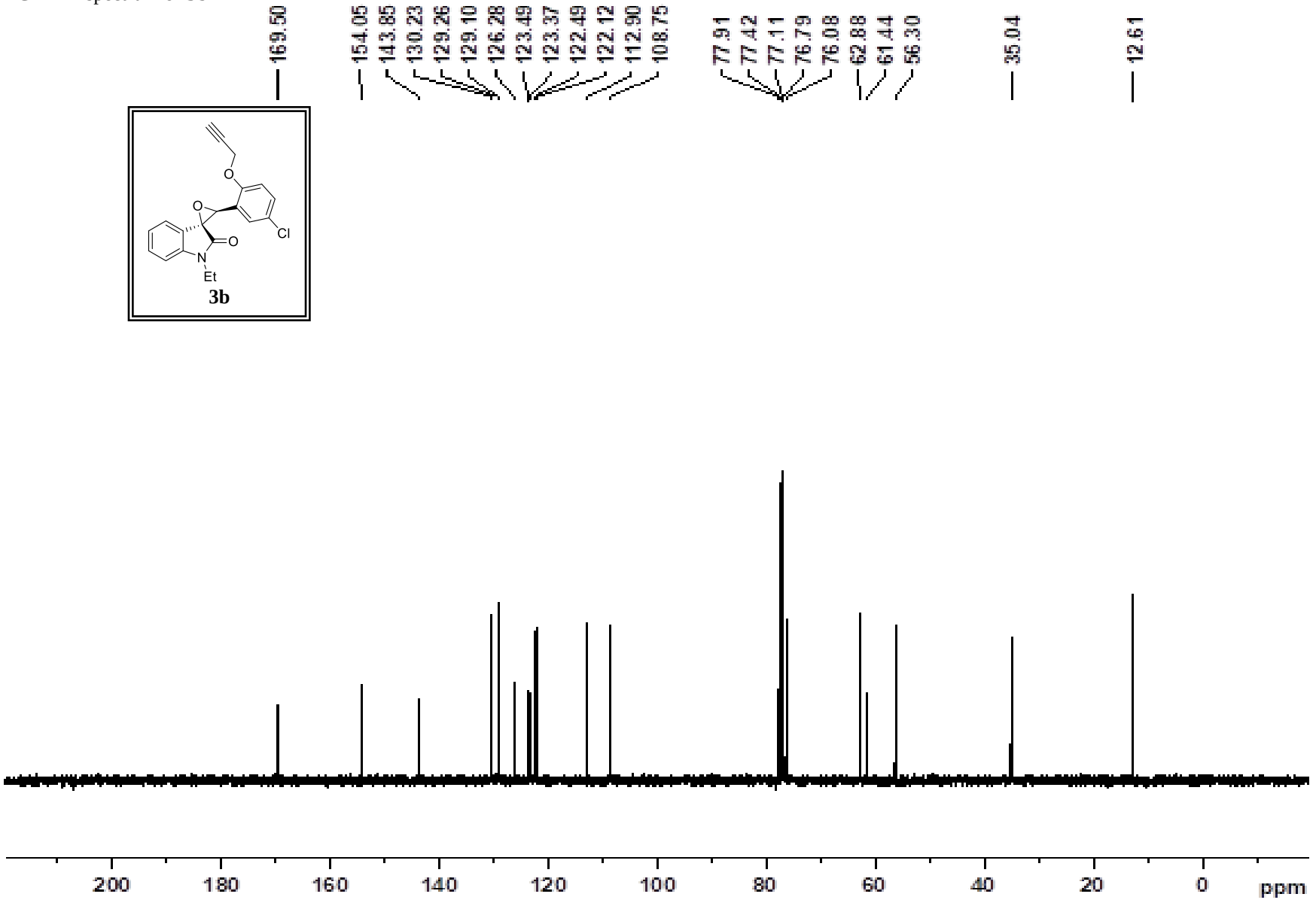
^{13}C NMR spectrum of **3a**



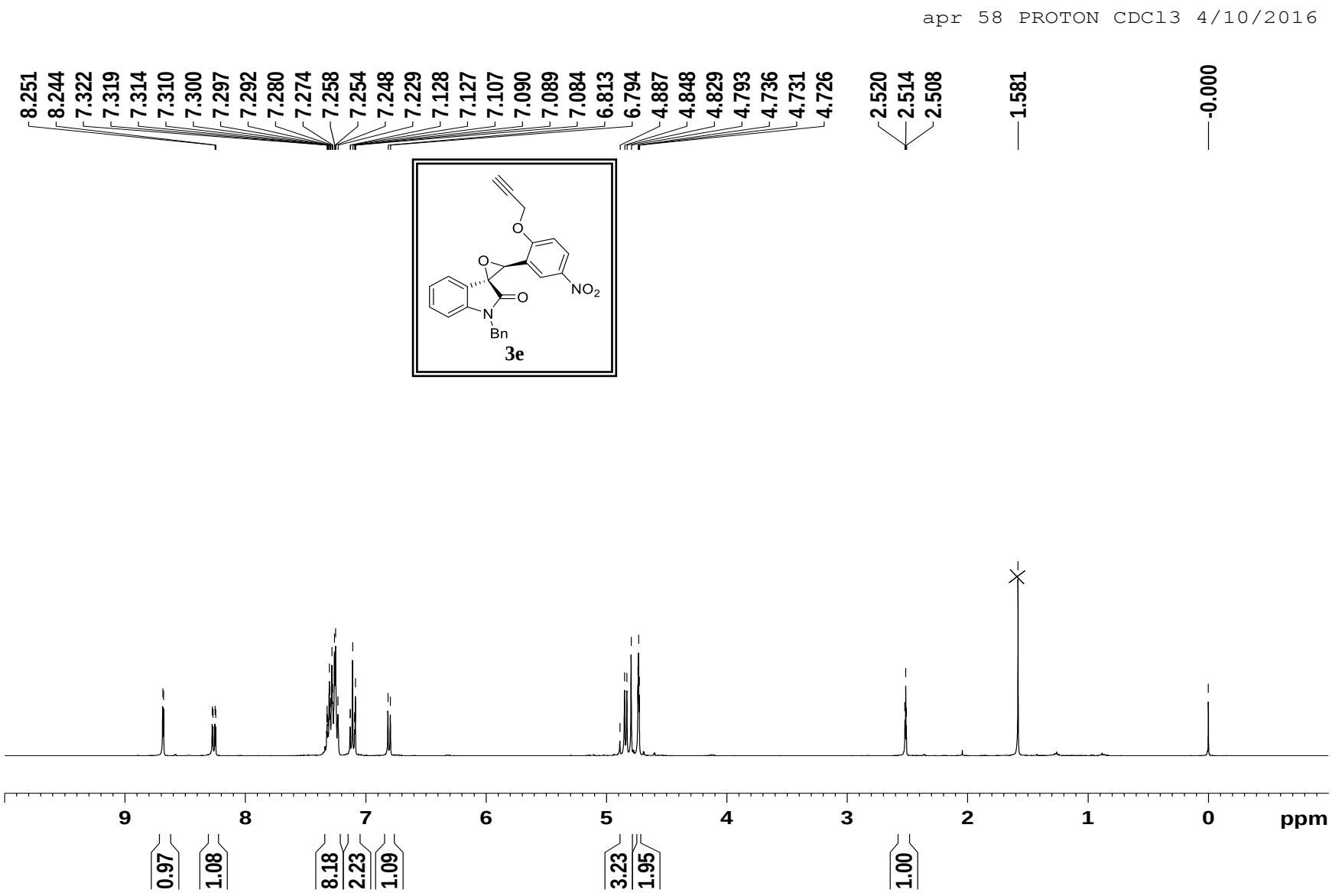
^{1}H NMR spectrum of **3b**



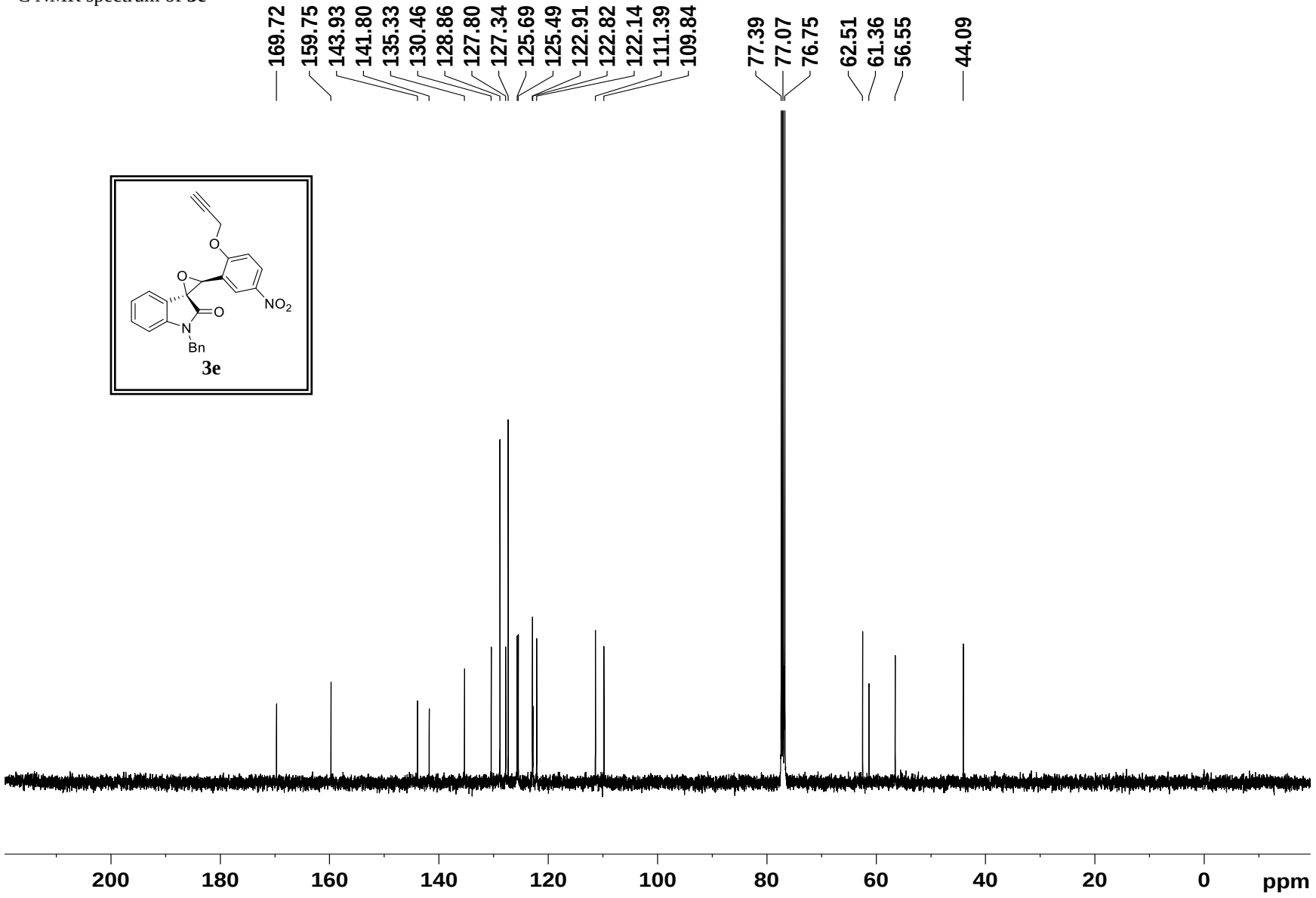
^{13}C NMR spectrum of **3b**



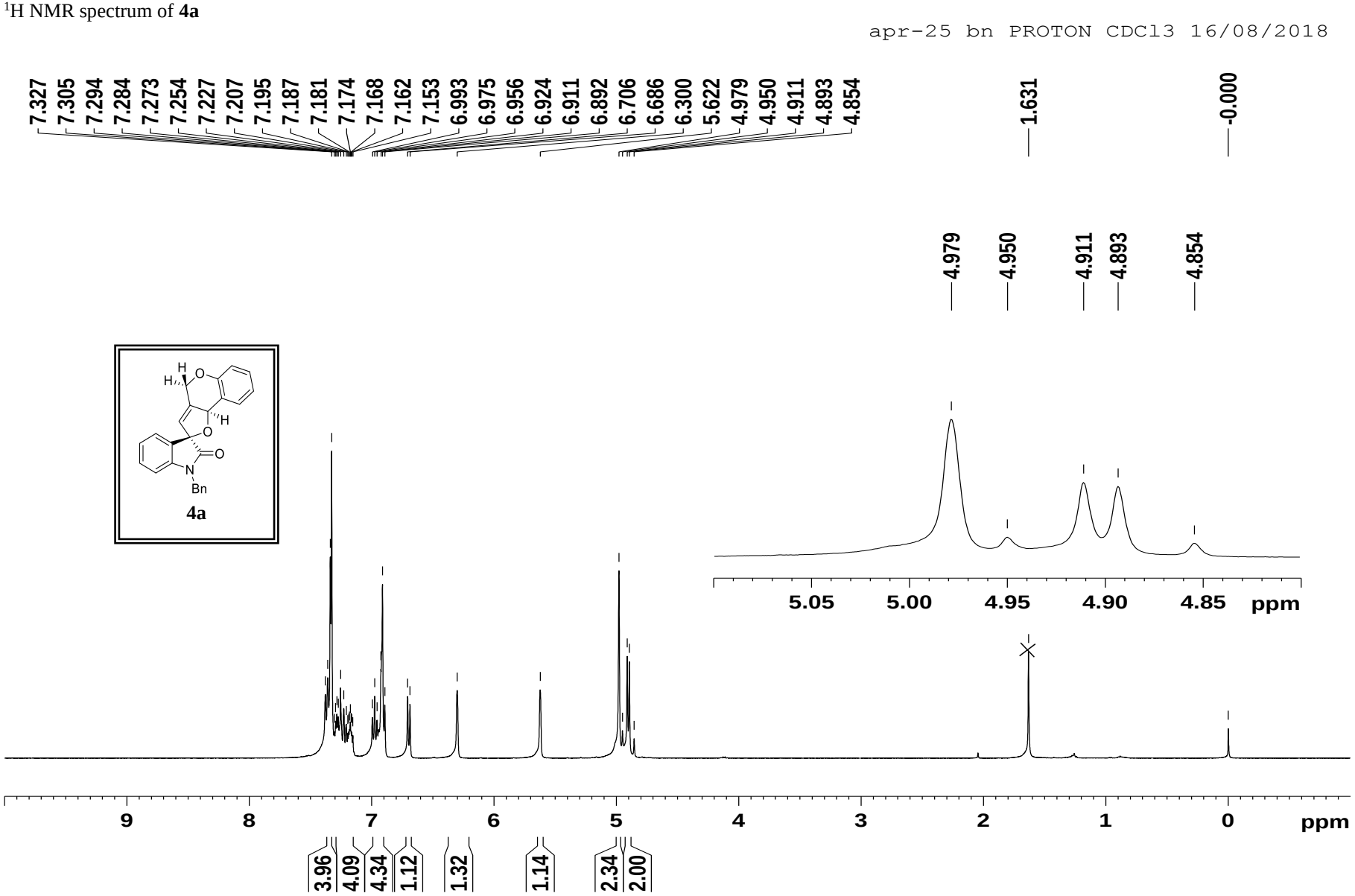
^{1}H NMR spectrum of **3e**



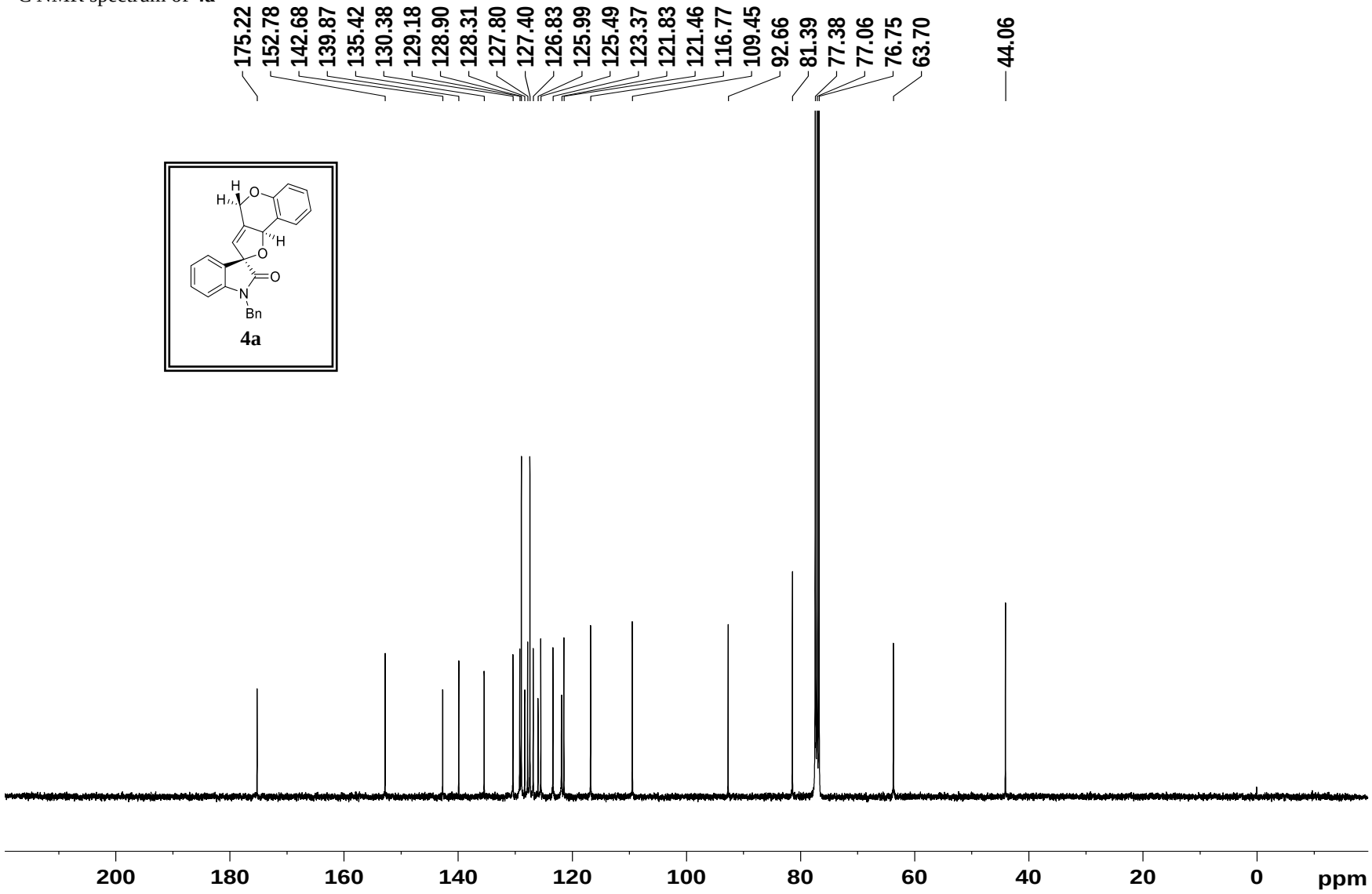
^{13}C NMR spectrum of **3e**



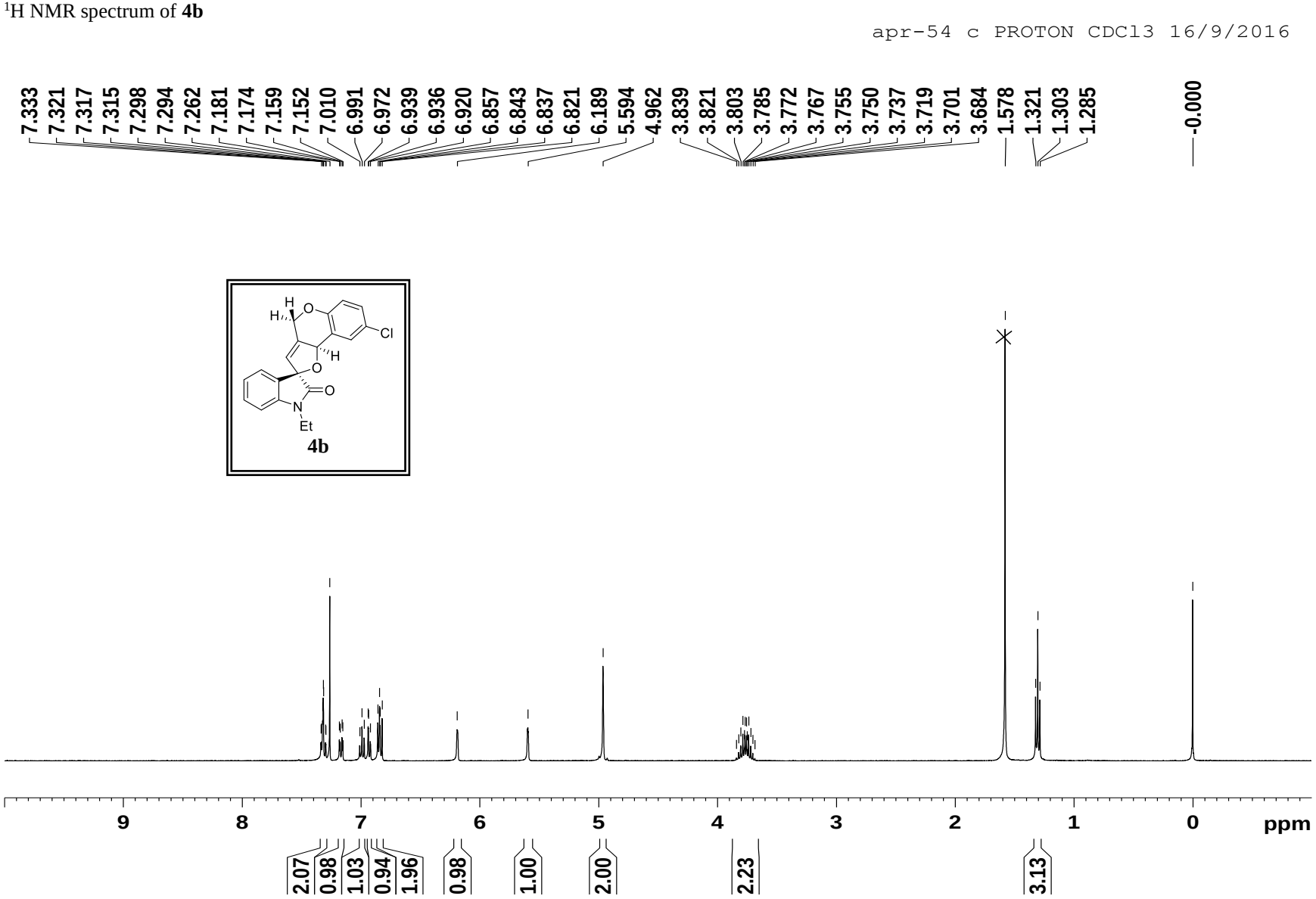
^{1}H NMR spectrum of **4a**



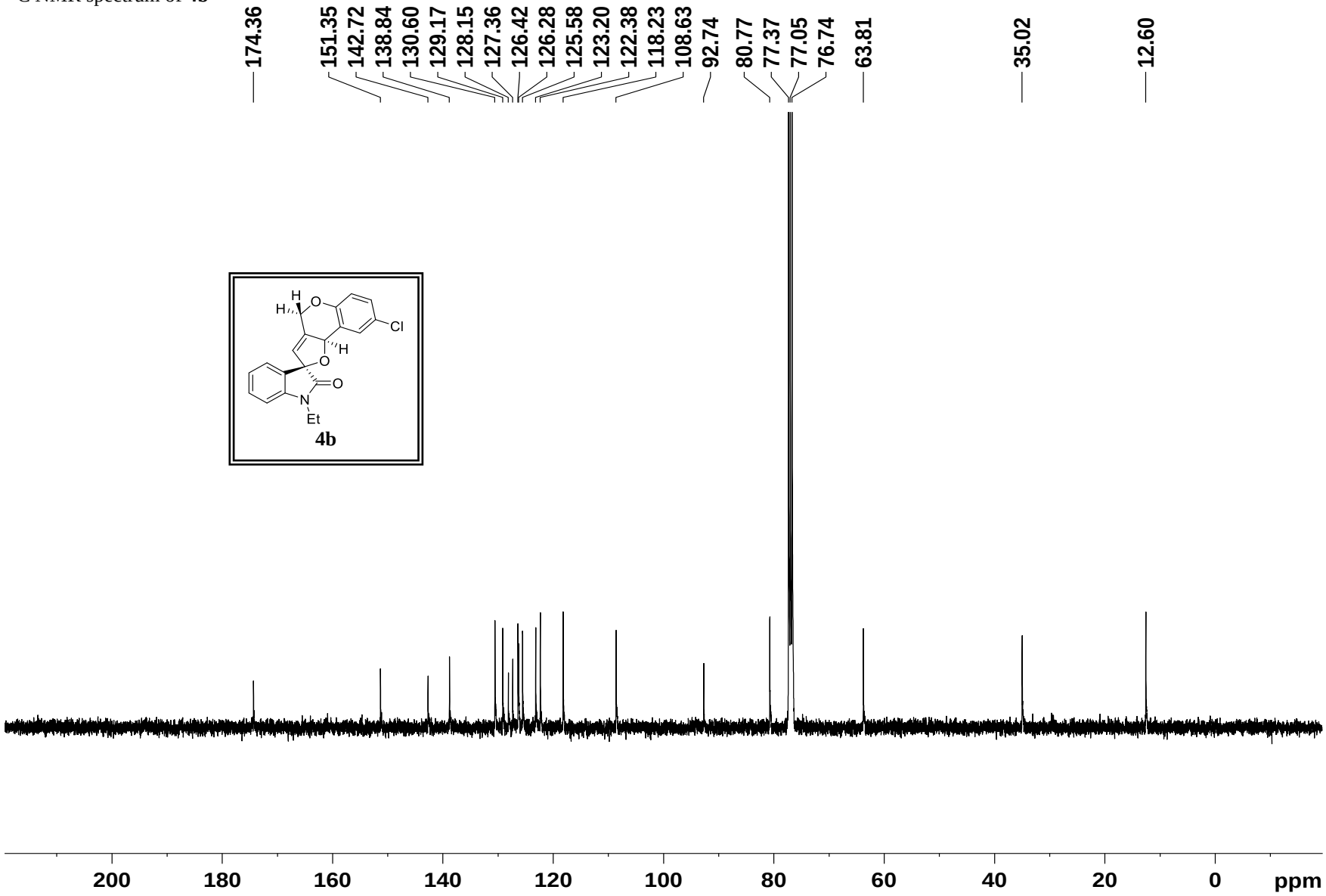
^{13}C NMR spectrum of **4a**



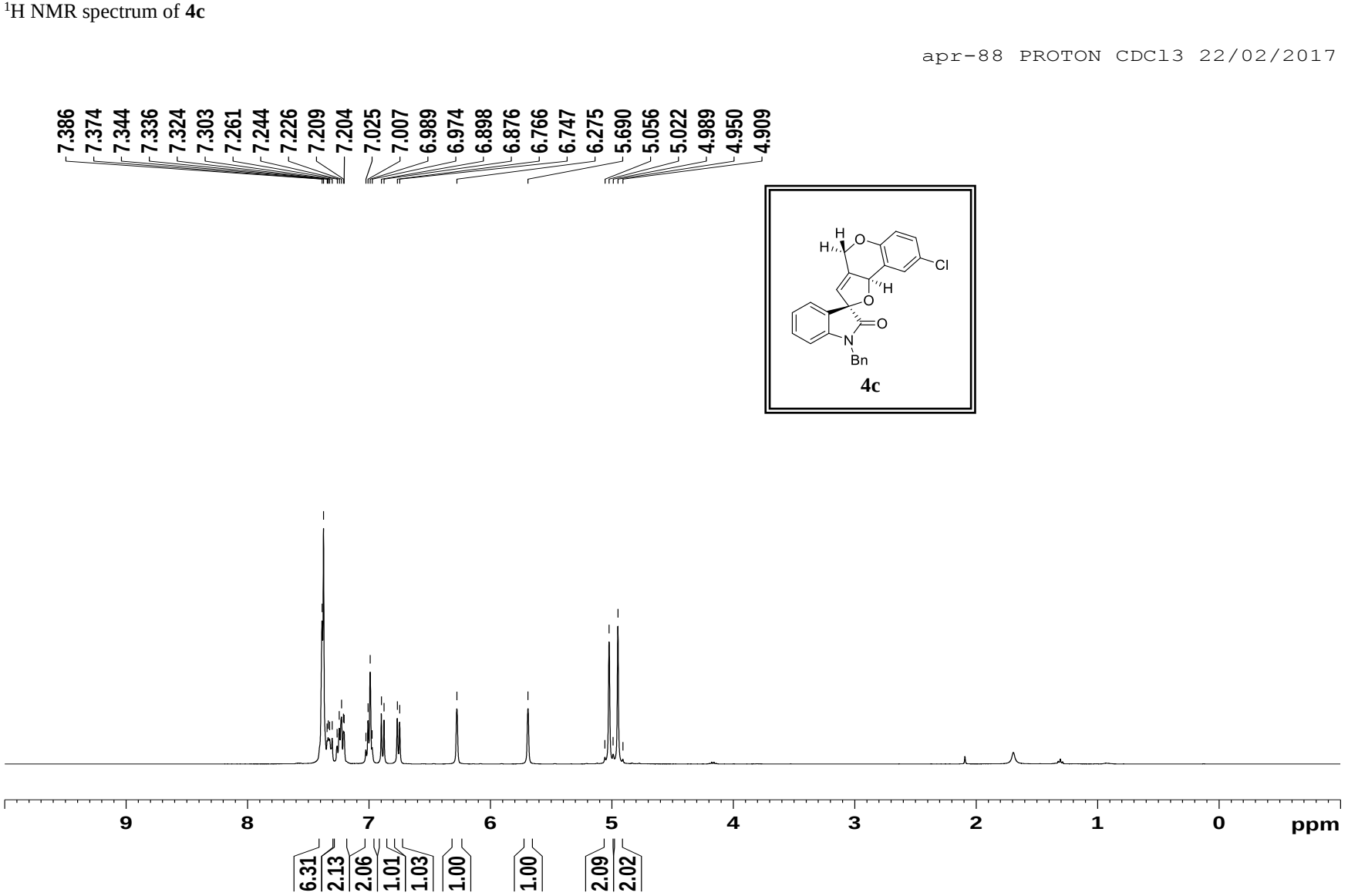
^{1}H NMR spectrum of **4b**



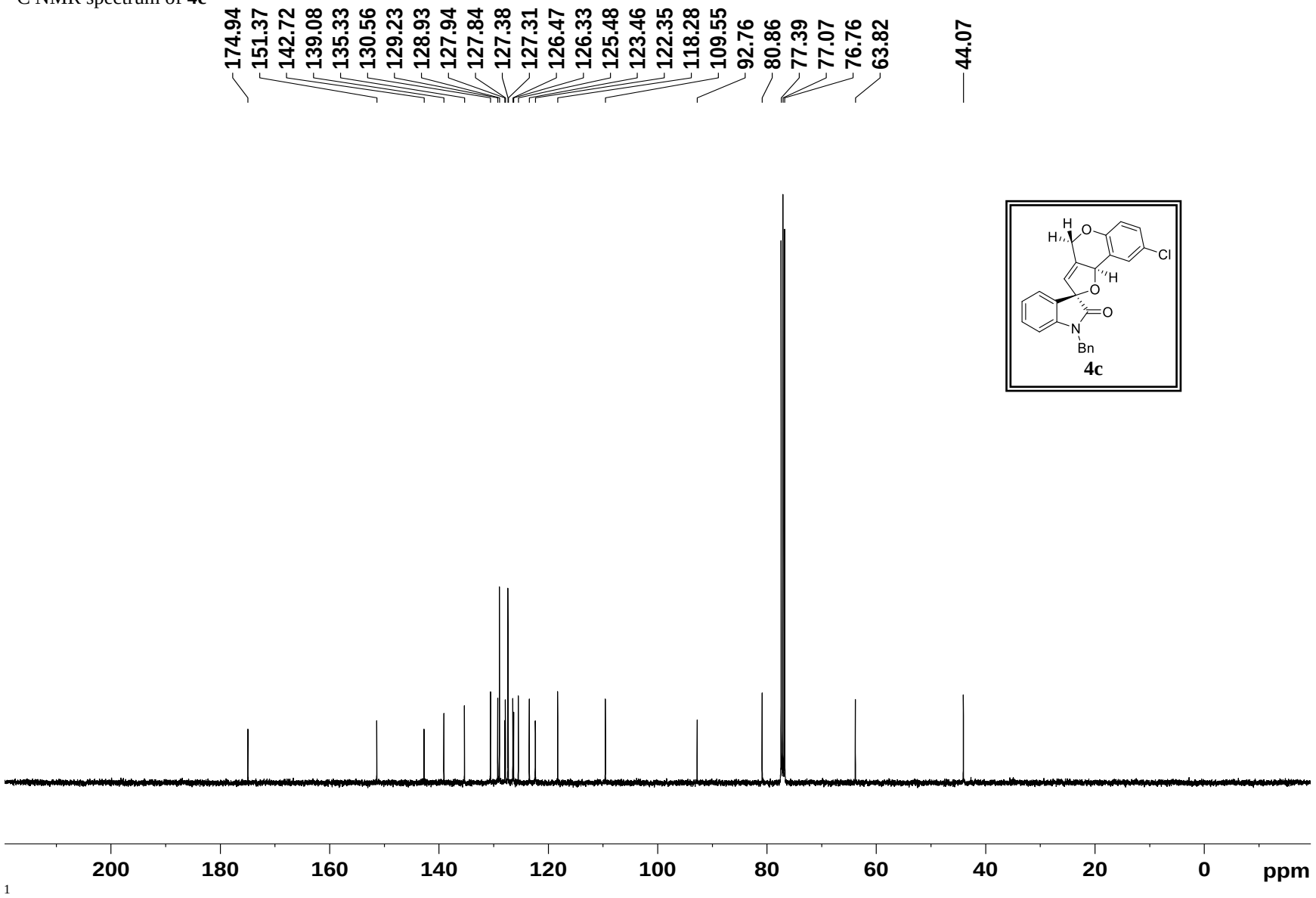
^{13}C NMR spectrum of **4b**



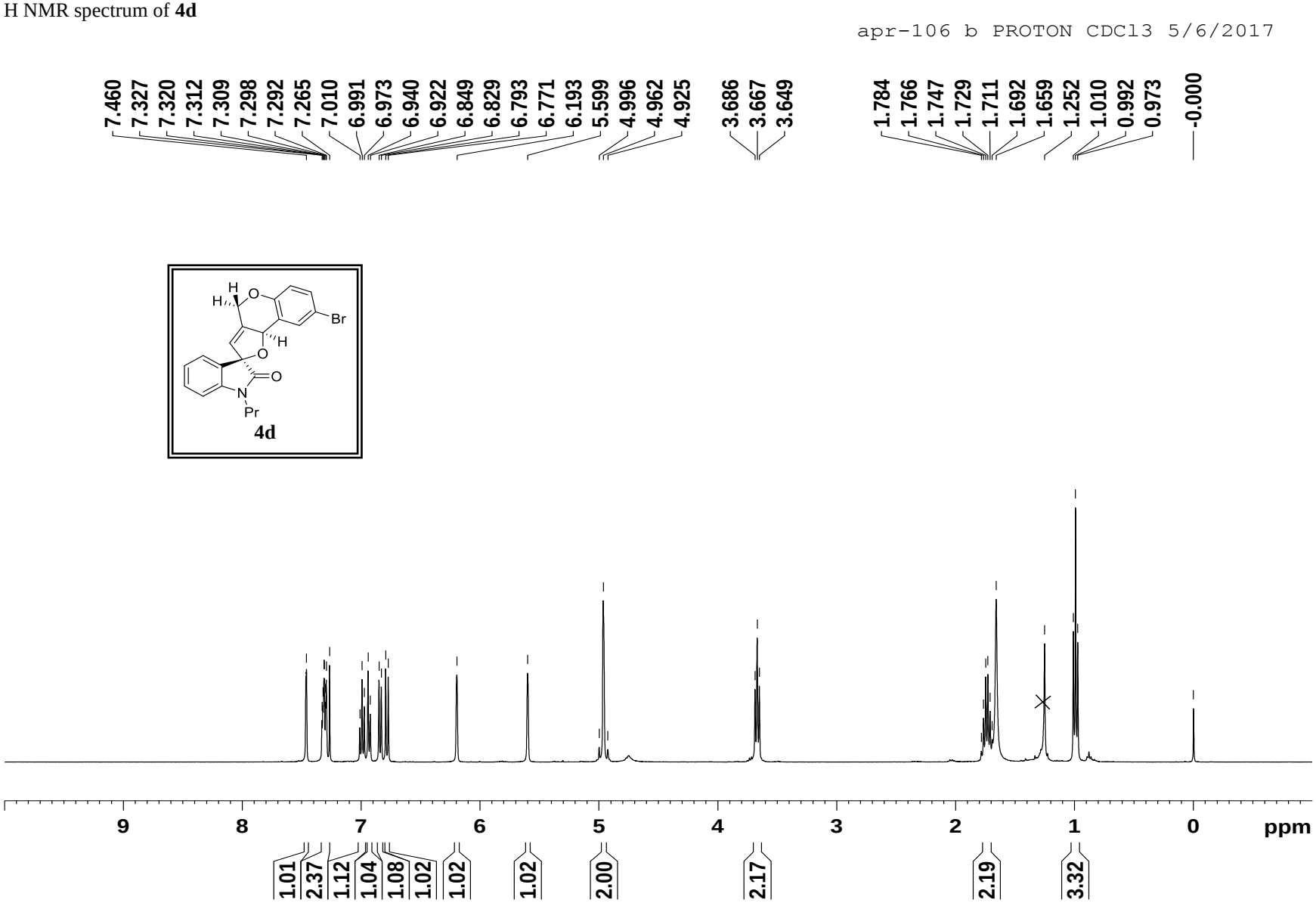
^{1}H NMR spectrum of **4c**



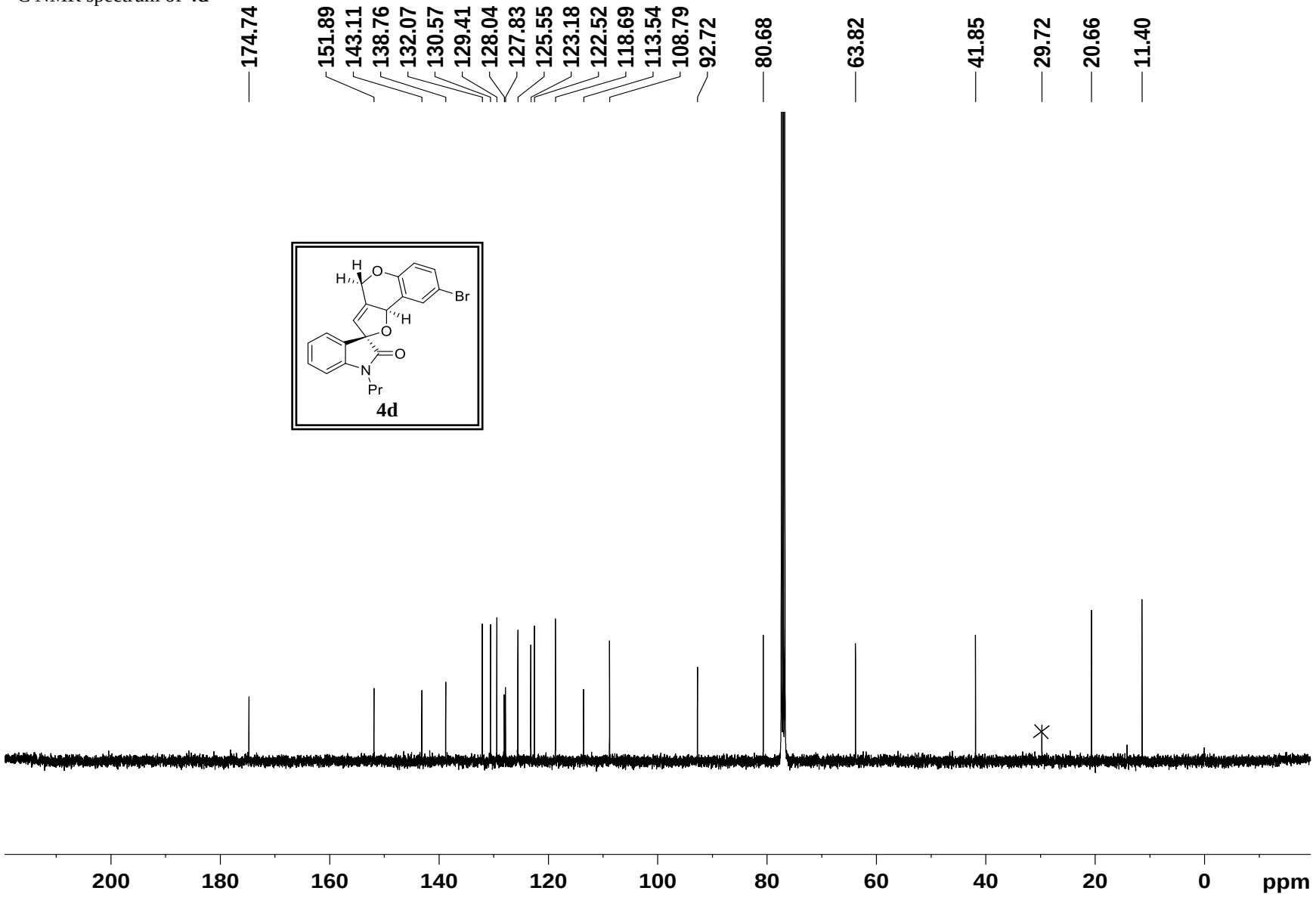
^{13}C NMR spectrum of **4c**



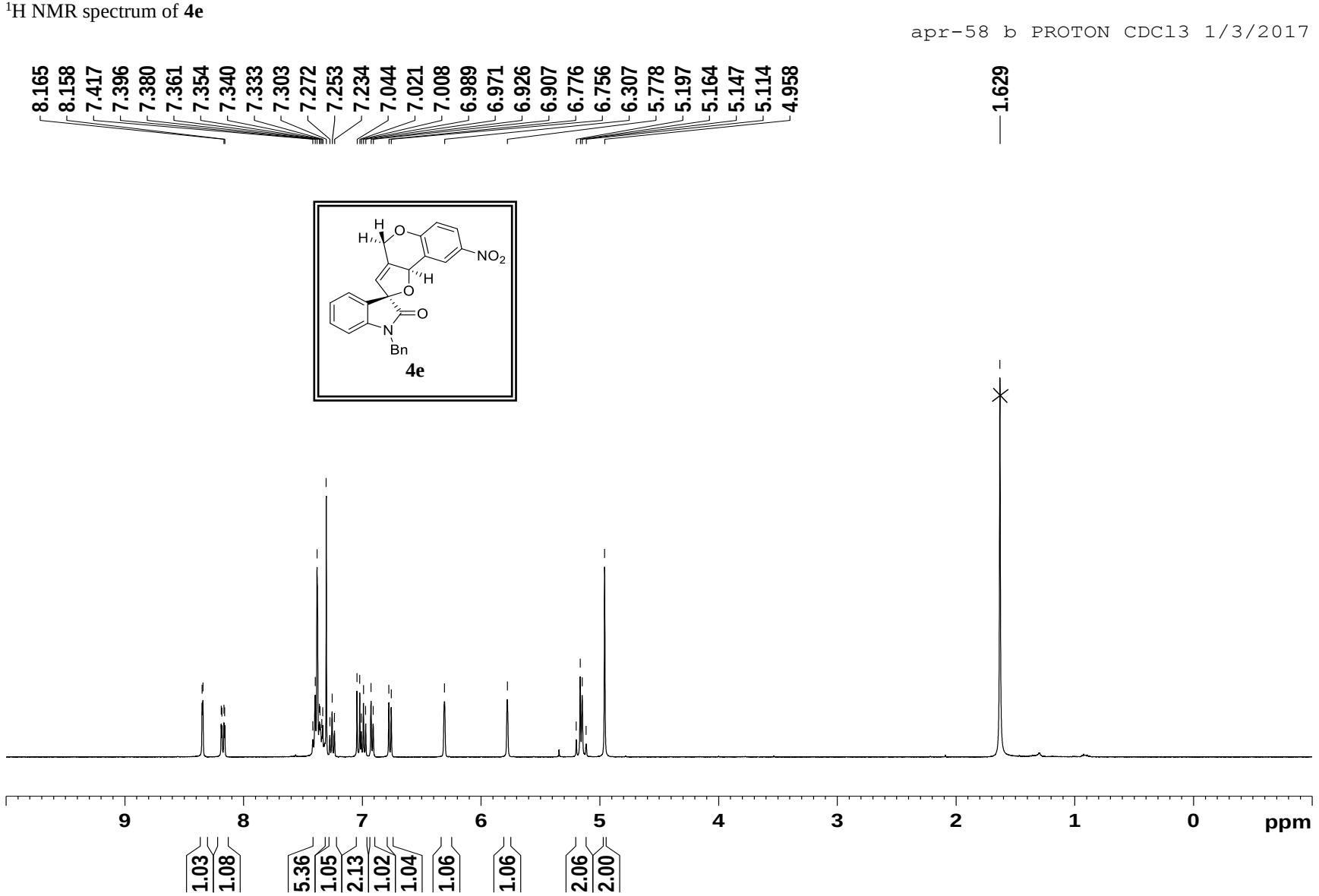
H NMR spectrum of **4d**



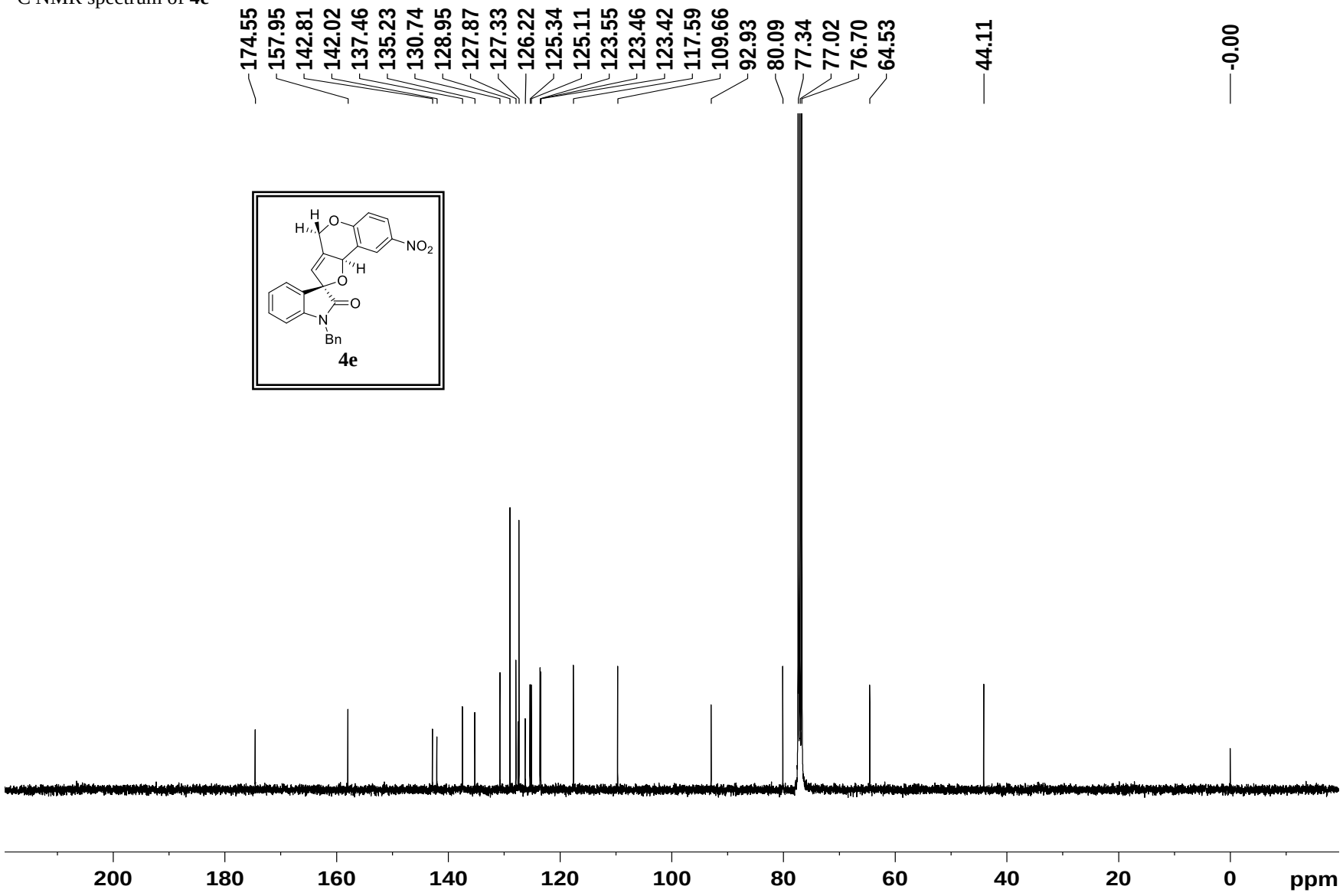
^{13}C NMR spectrum of **4d**



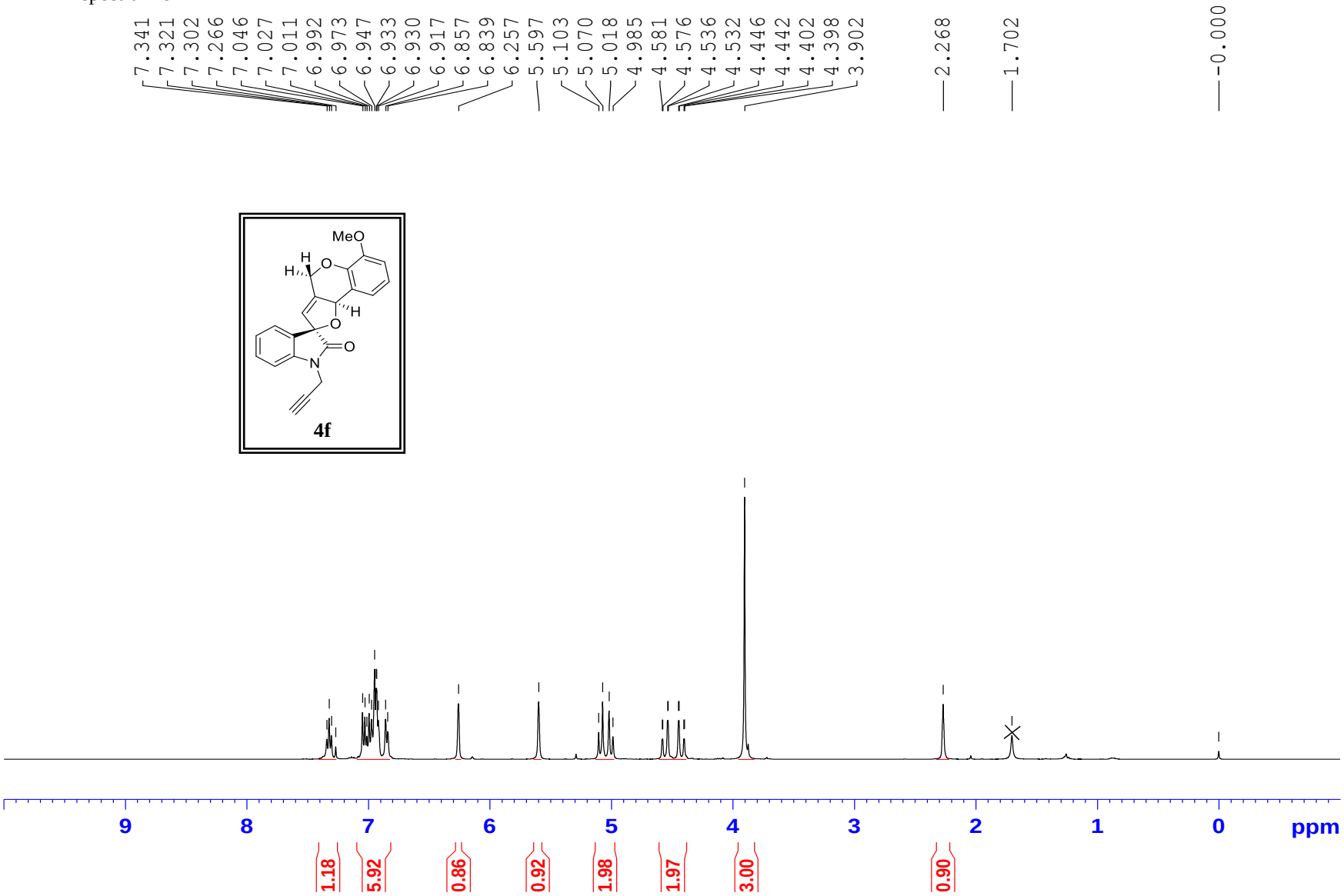
^{1}H NMR spectrum of **4e**



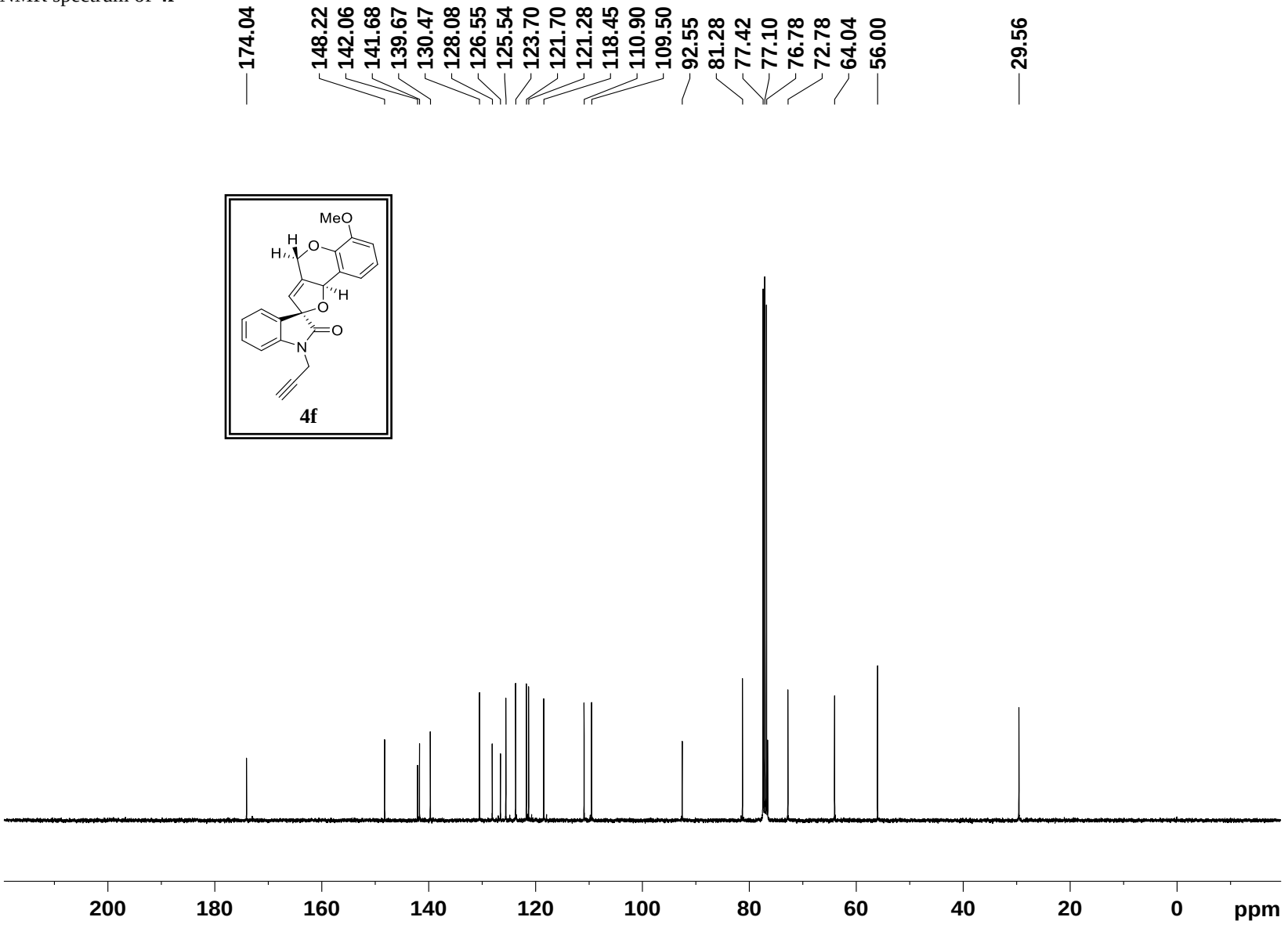
^{13}C NMR spectrum of **4e**



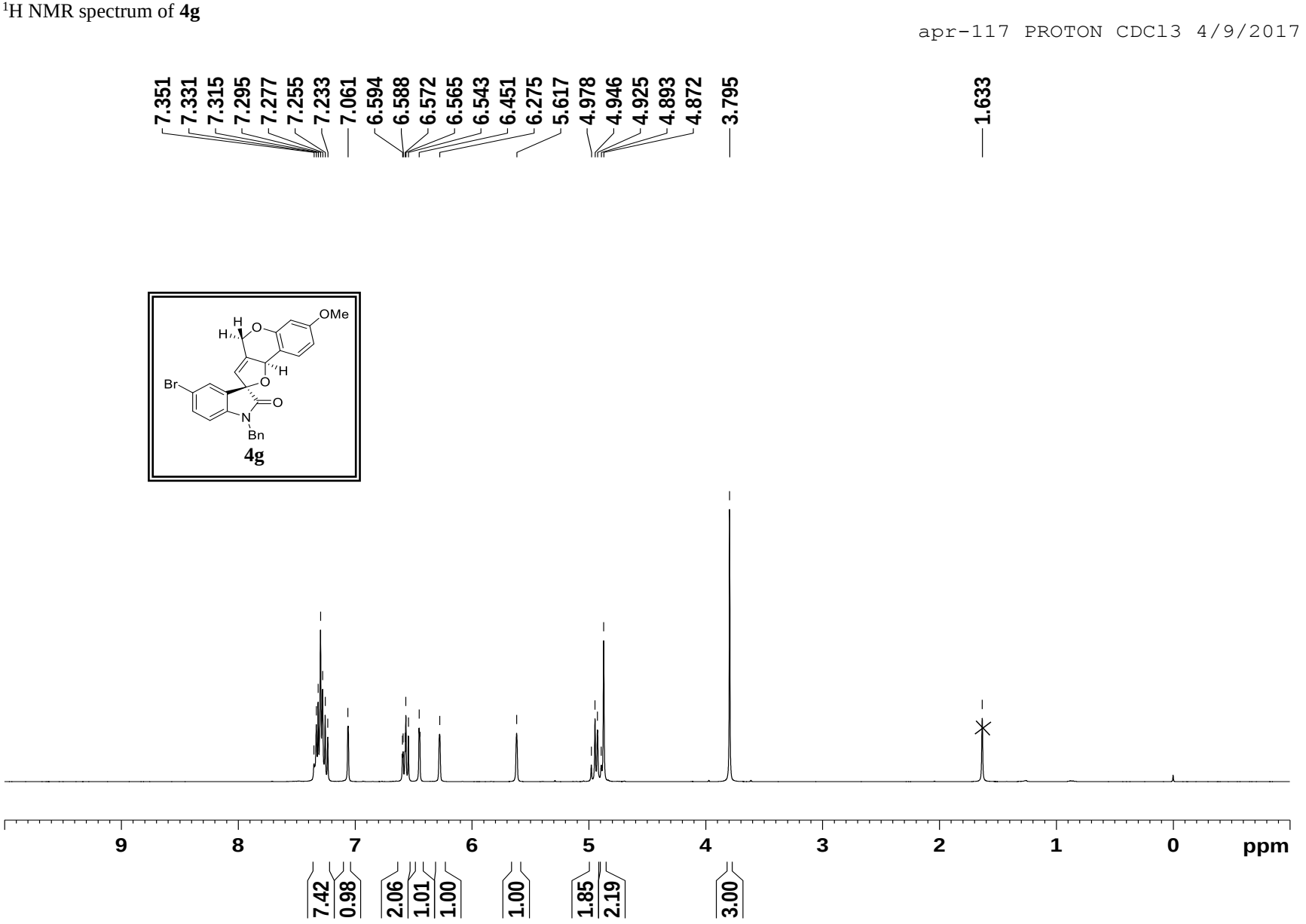
^{1}H NMR spectrum of **4f**



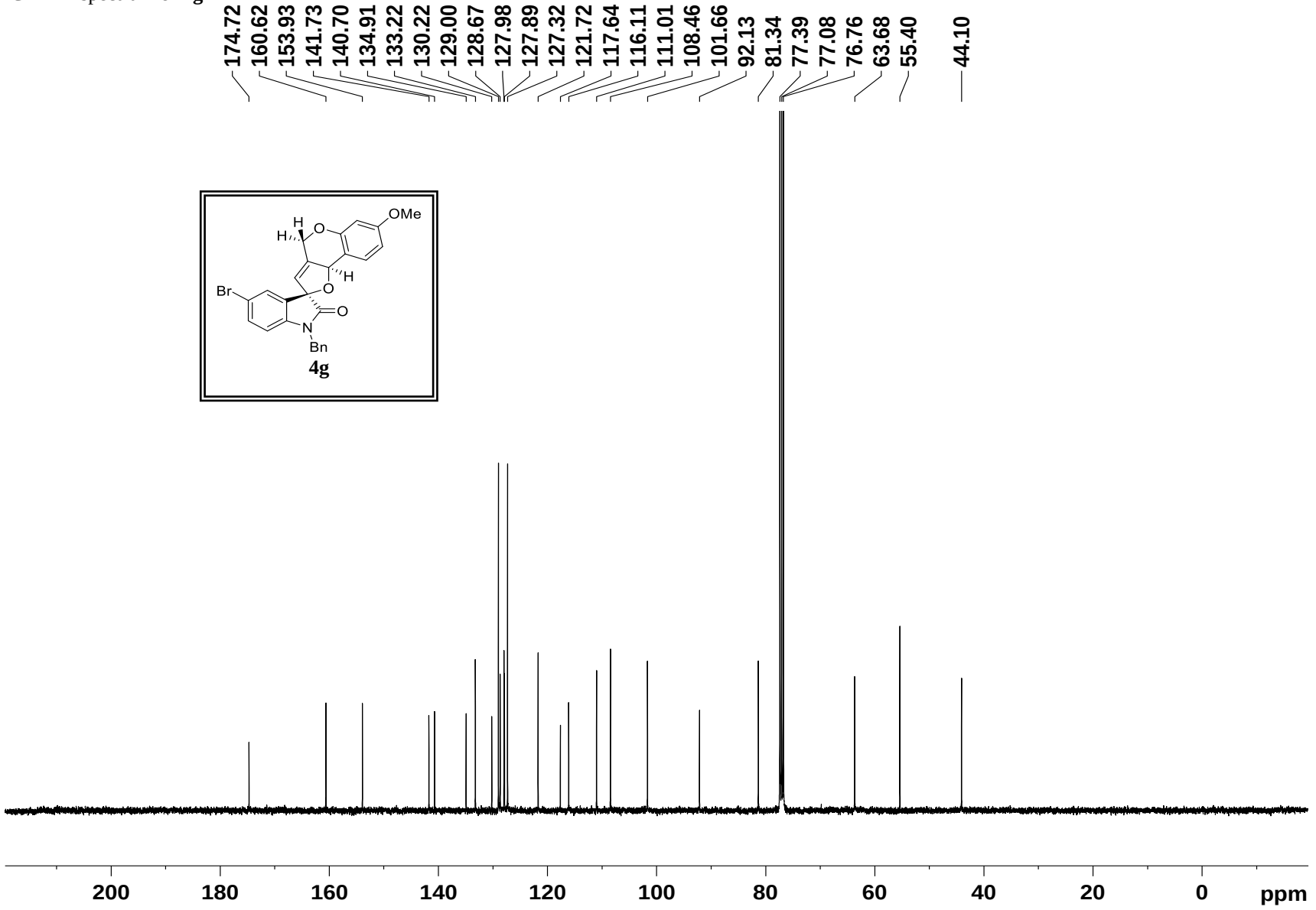
^{13}C NMR spectrum of **4f**



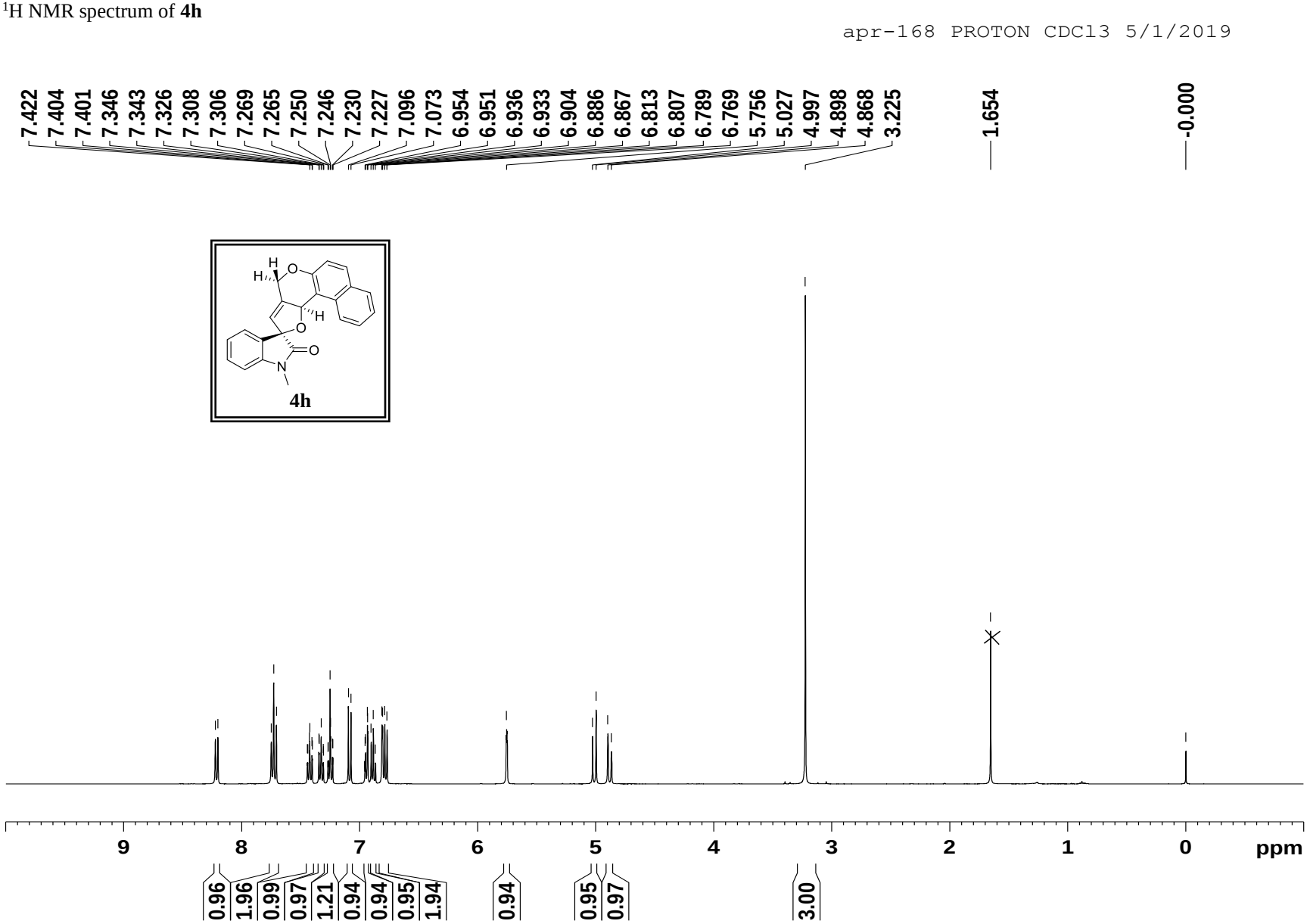
^{1}H NMR spectrum of **4g**



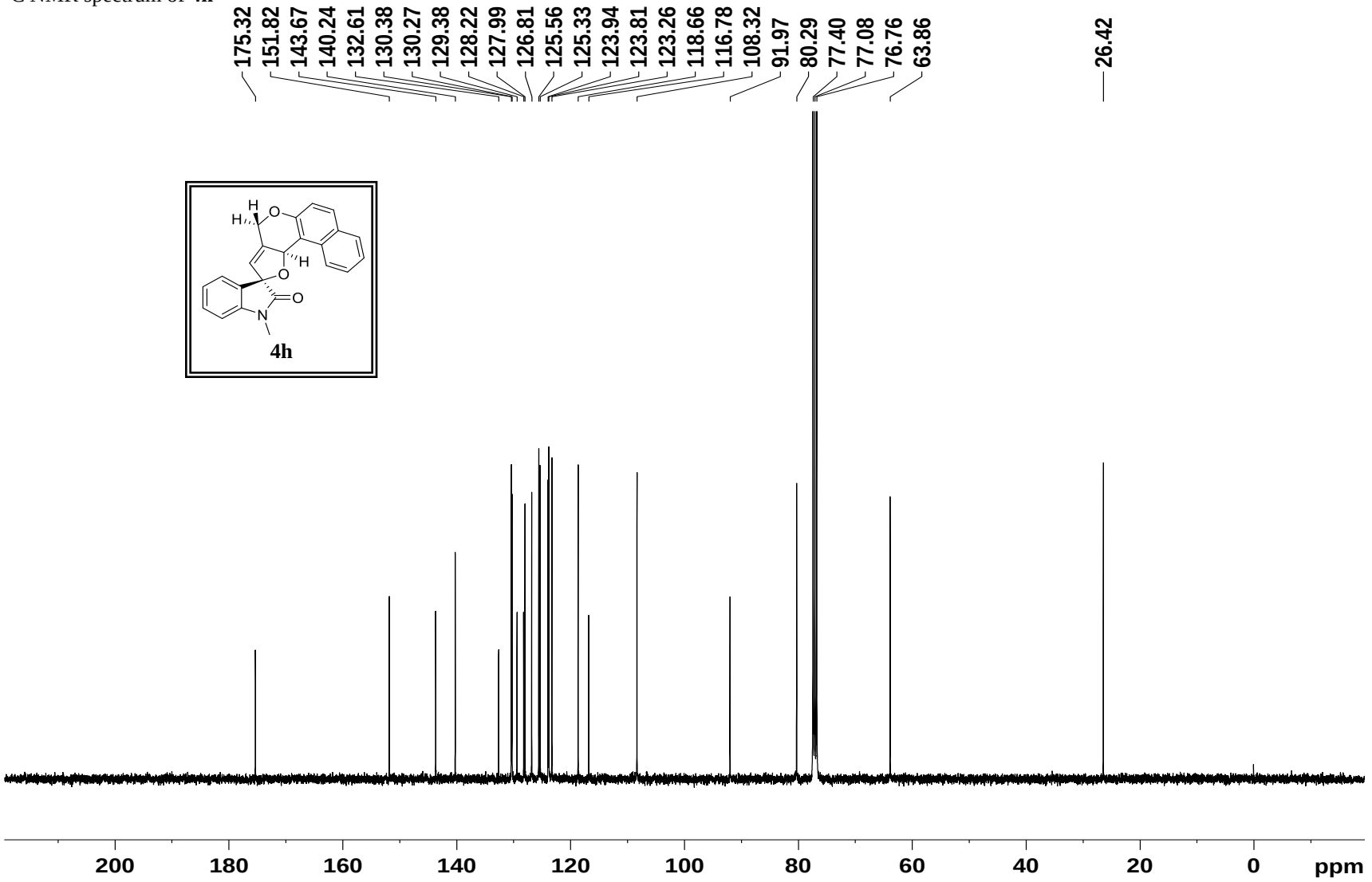
^{13}C NMR spectrum of **4g**



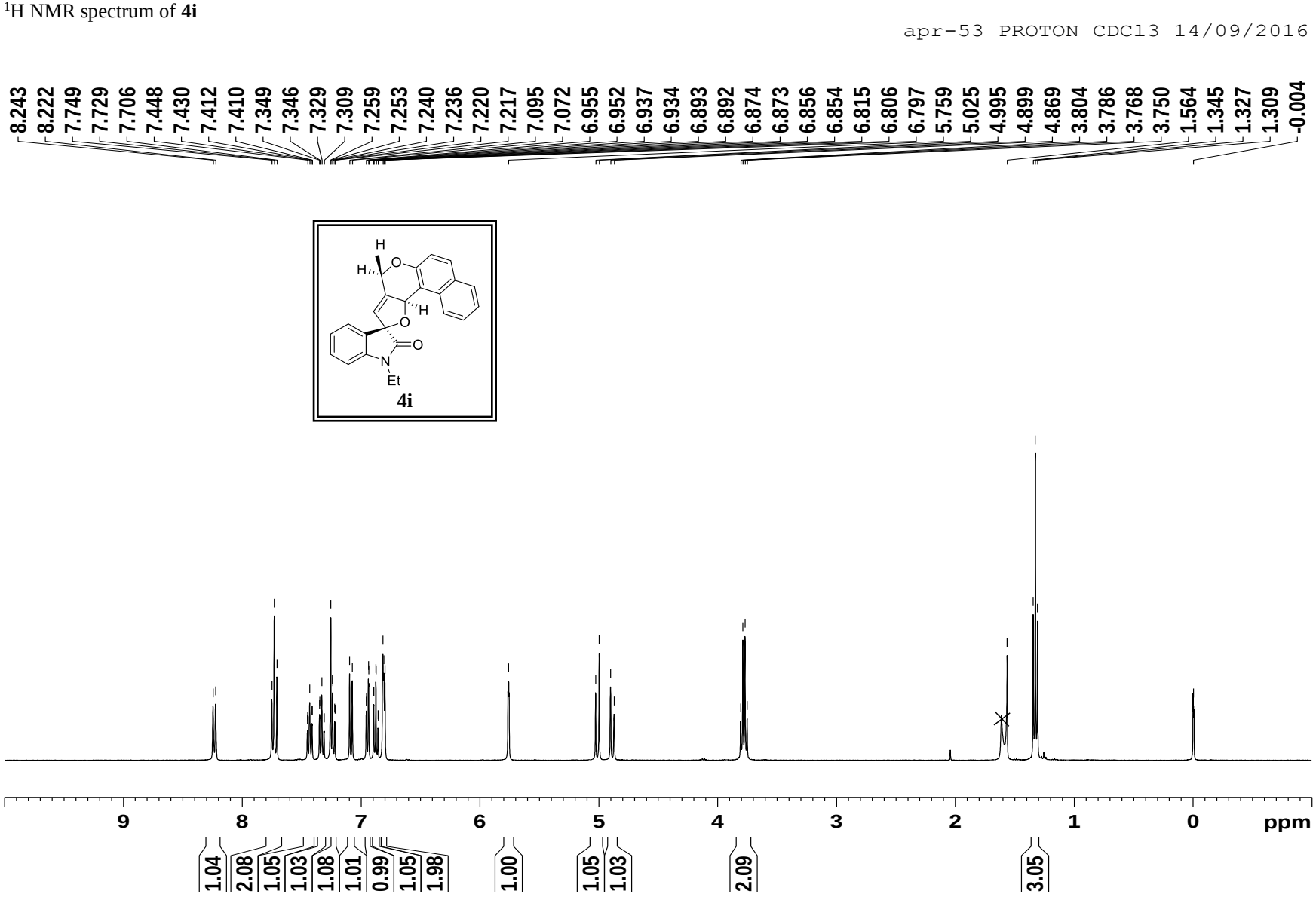
^{1}H NMR spectrum of **4h**



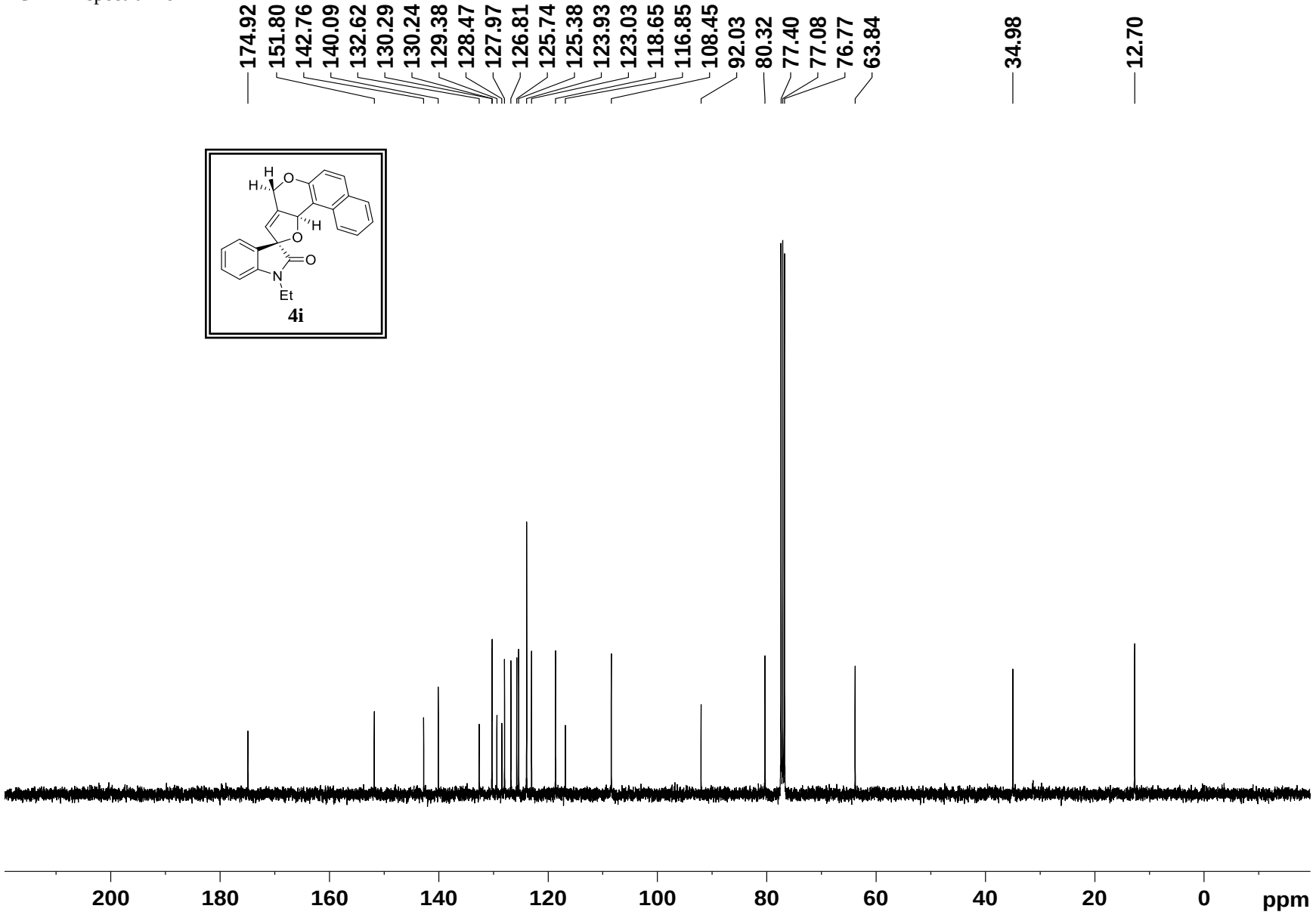
^{13}C NMR spectrum of **4h**



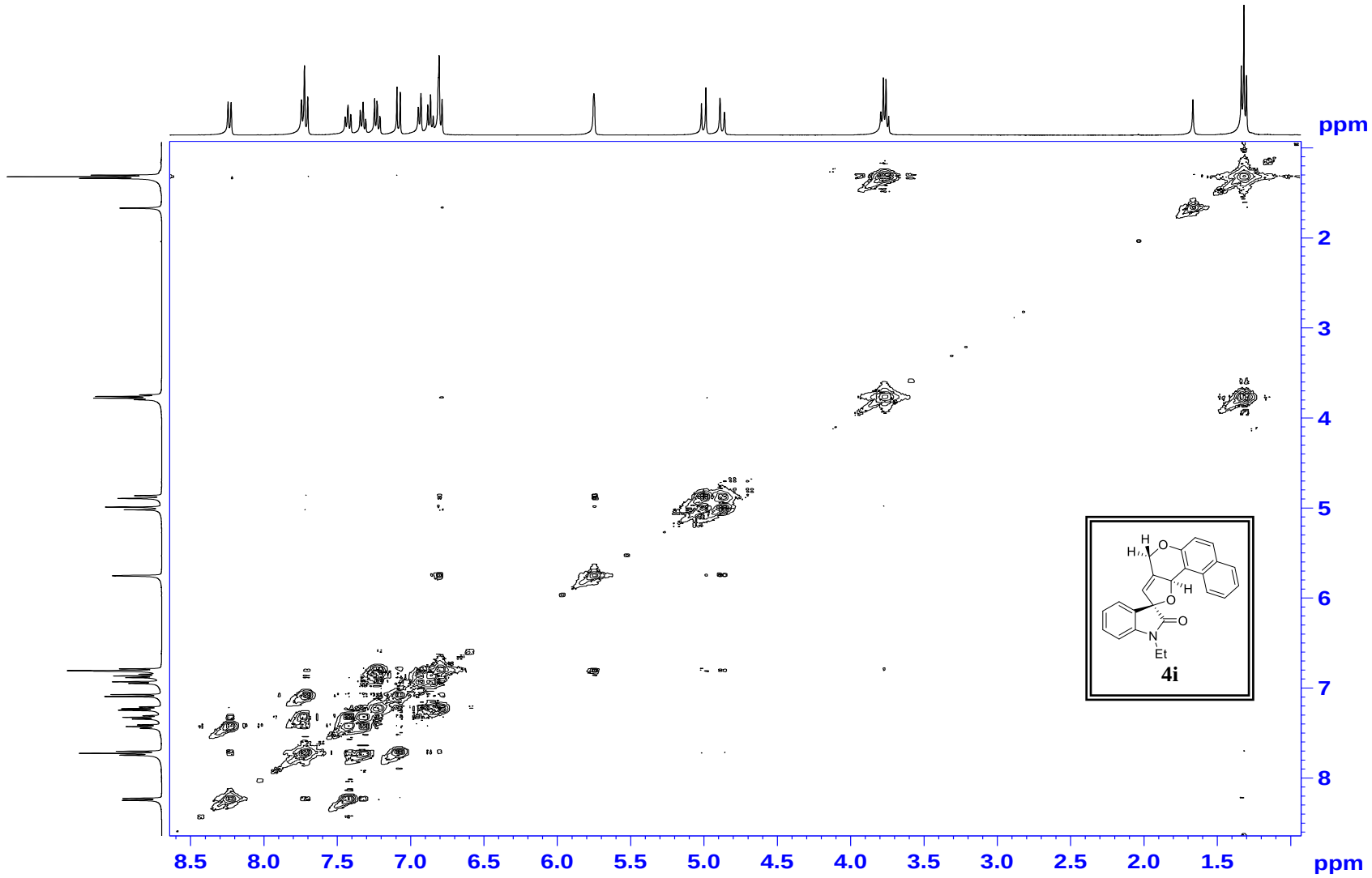
^{1}H NMR spectrum of **4i**



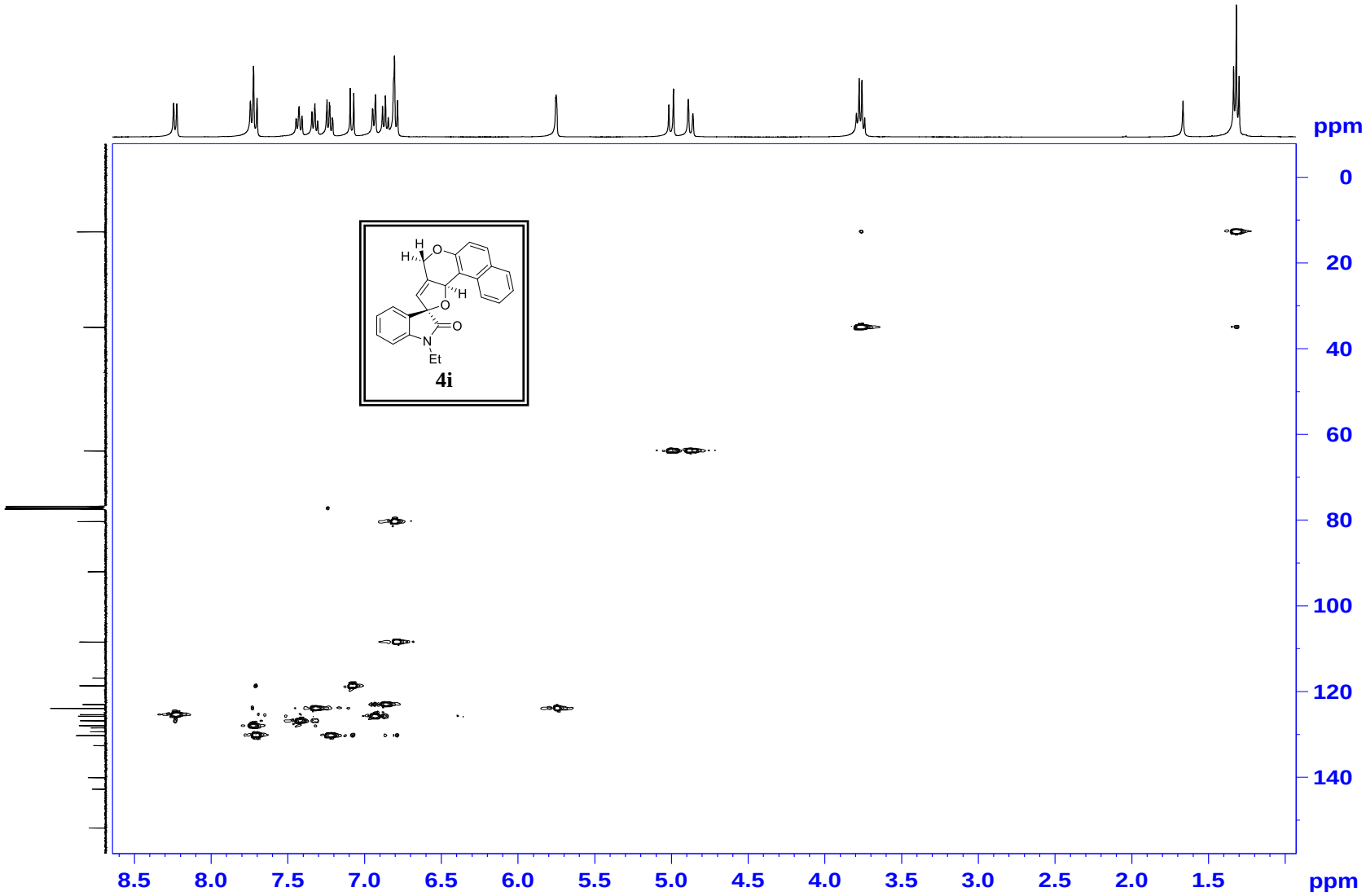
^{13}C NMR spectrum of **4i**



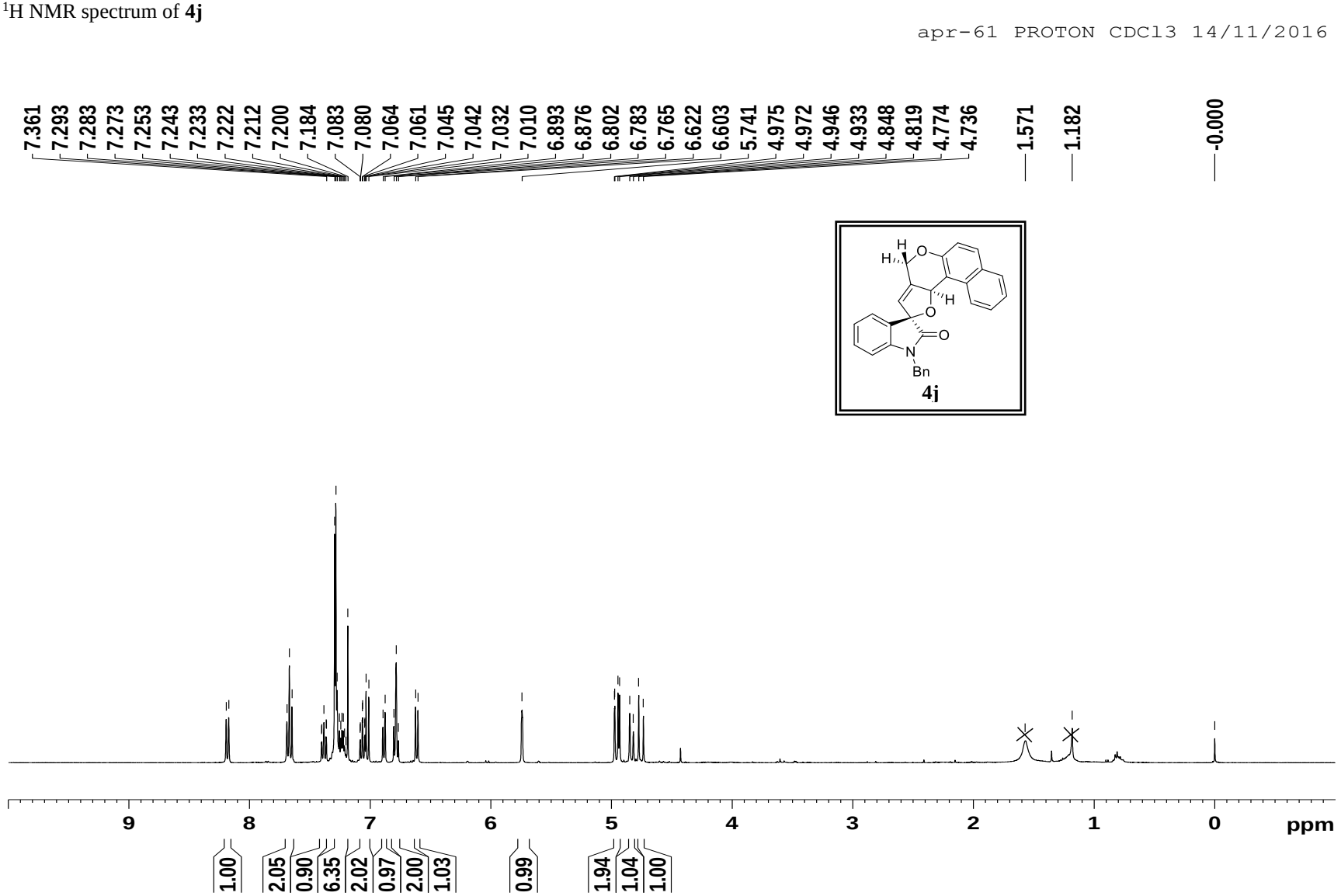
COSY spectrum of **4i**



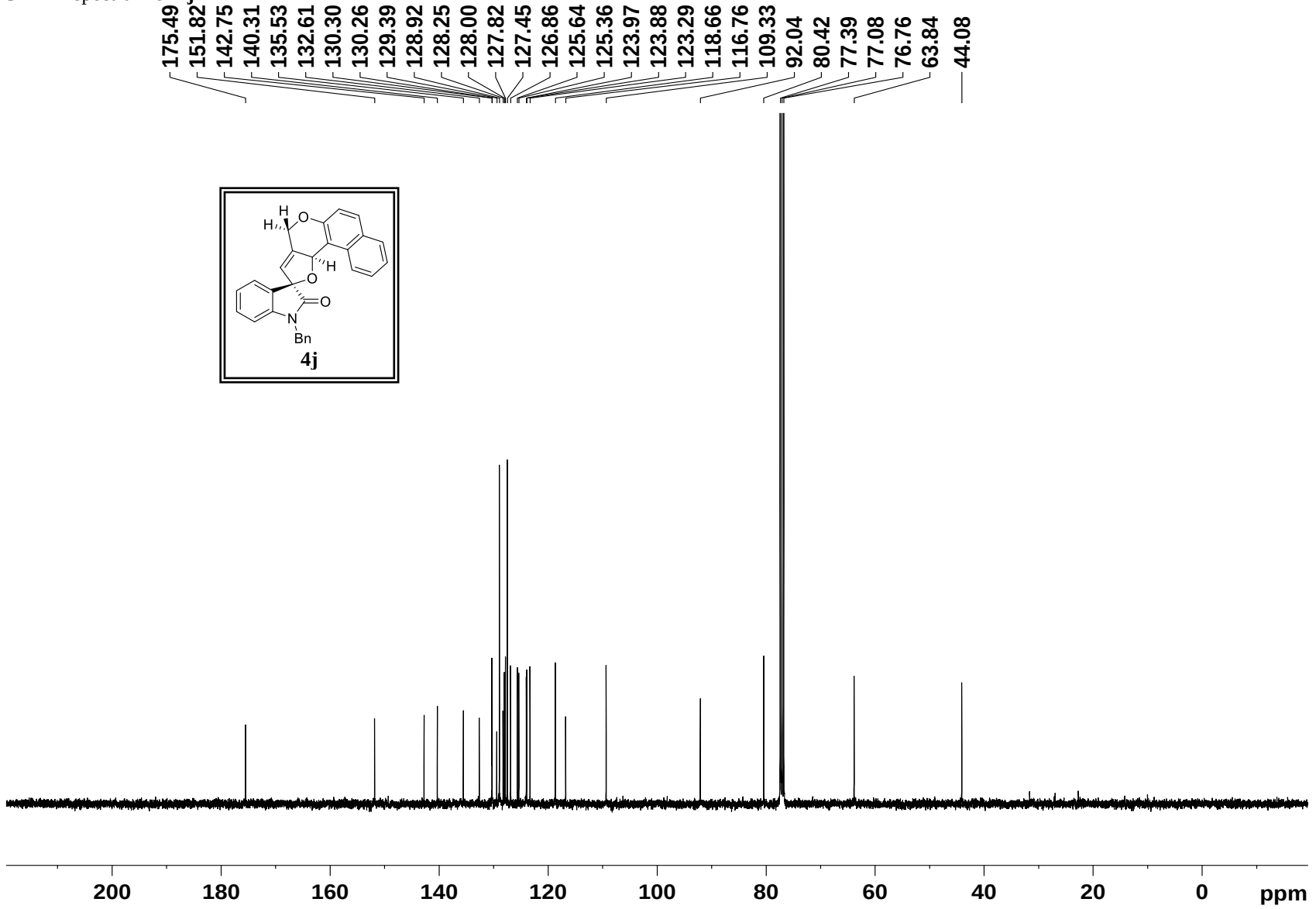
HSQC spectrum of **4i**



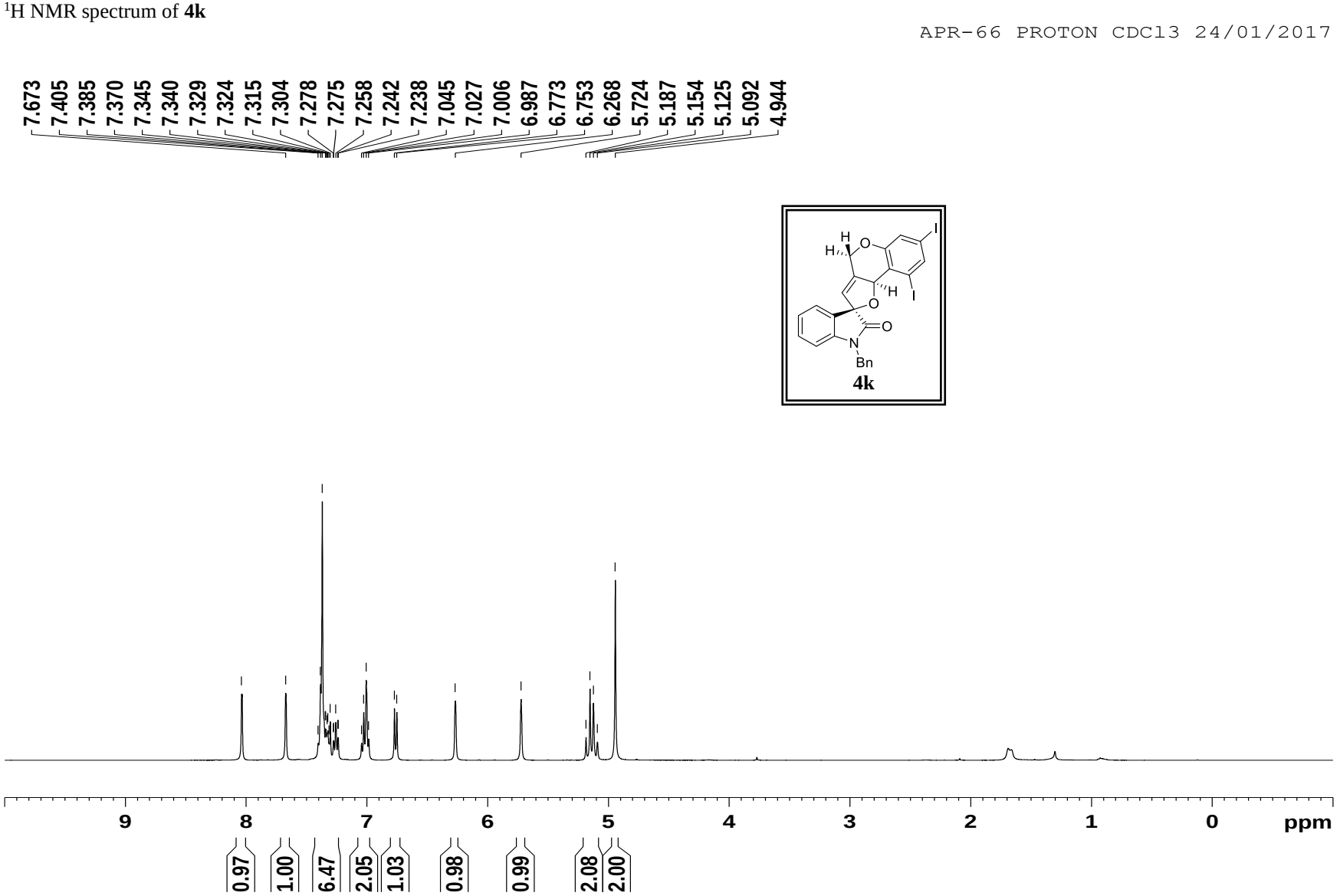
^{1}H NMR spectrum of **4j**



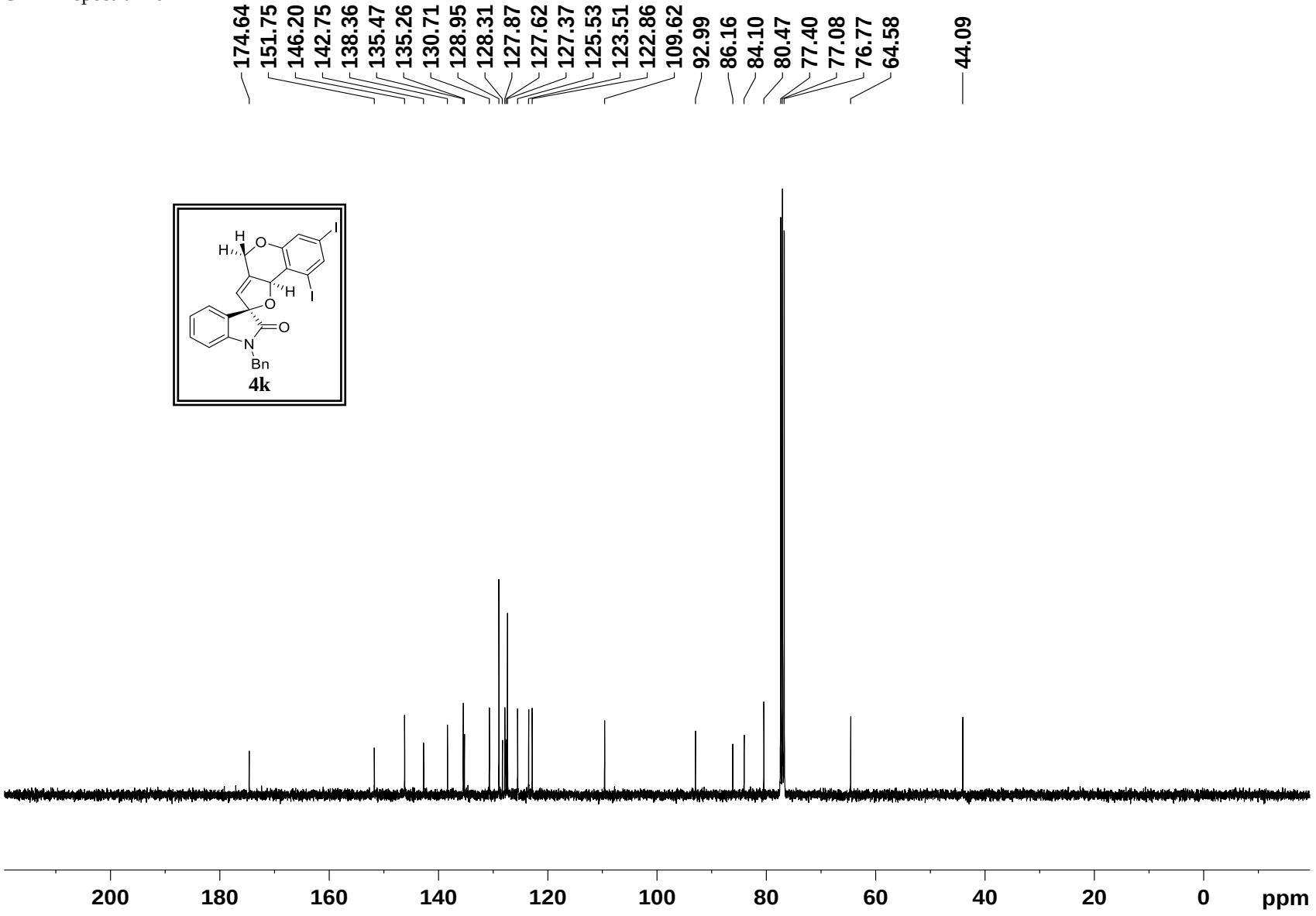
^{13}C NMR spectrum of **4j**



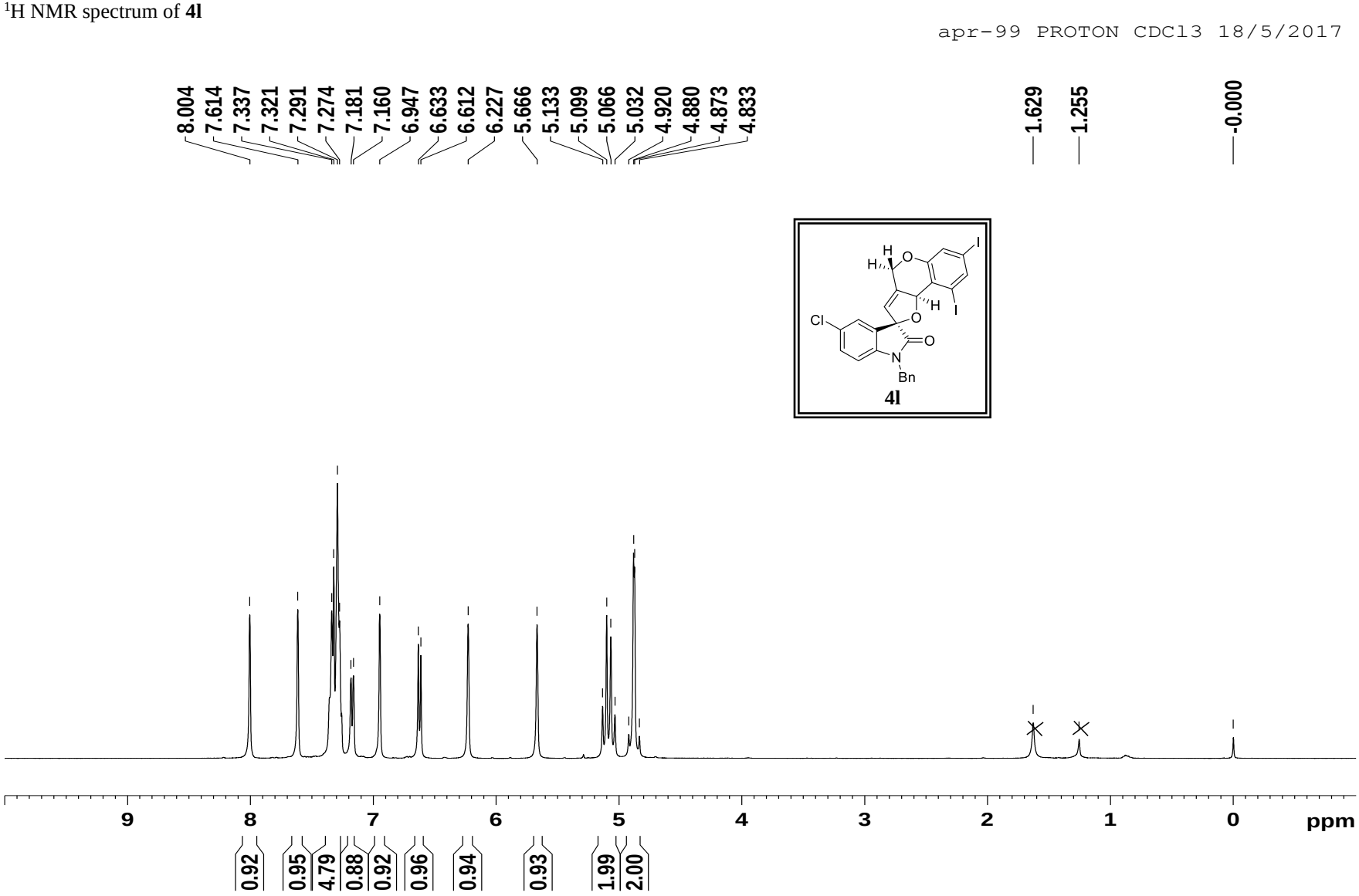
^{1}H NMR spectrum of **4k**



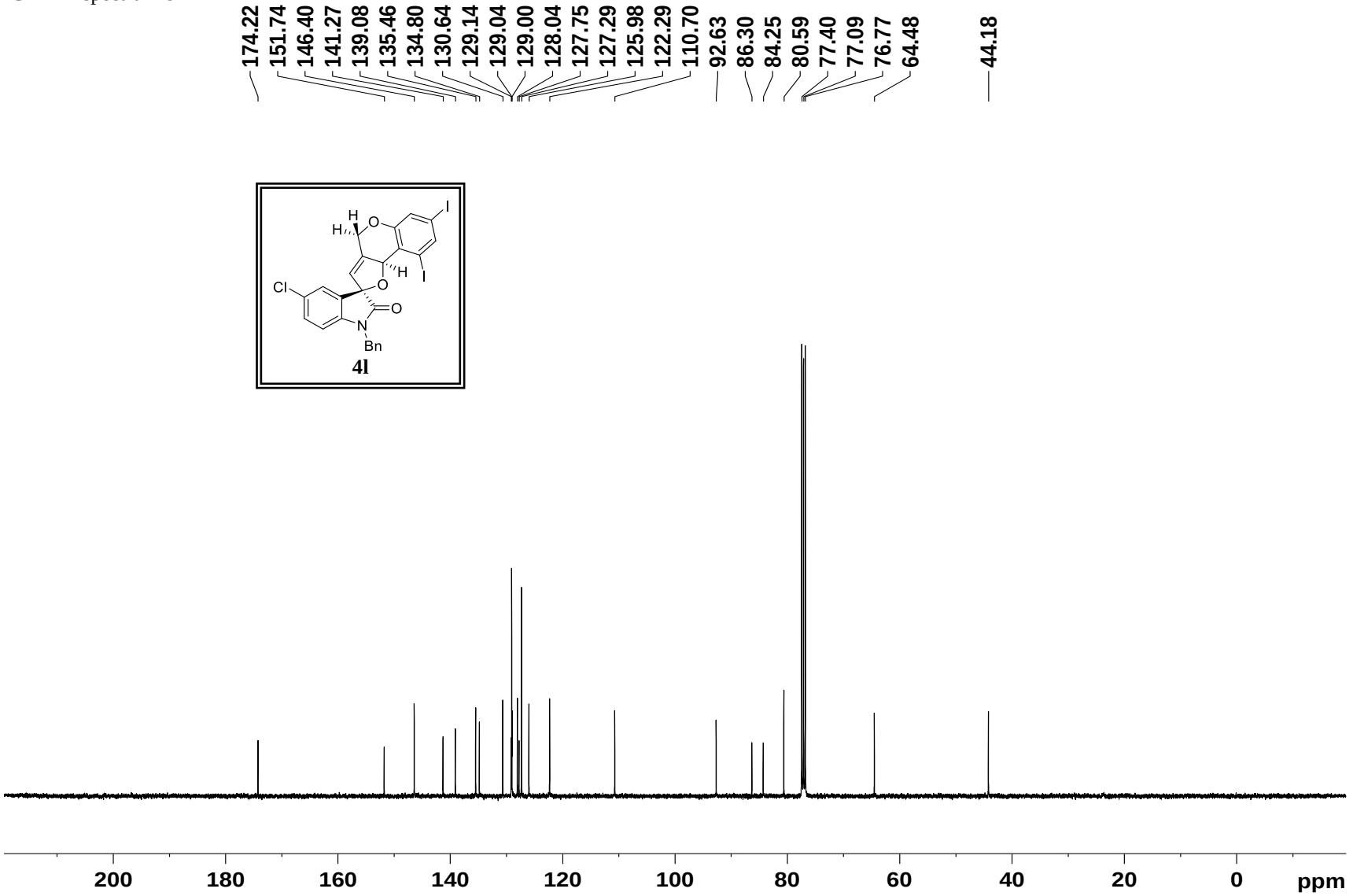
^{13}C NMR spectrum of **4k**



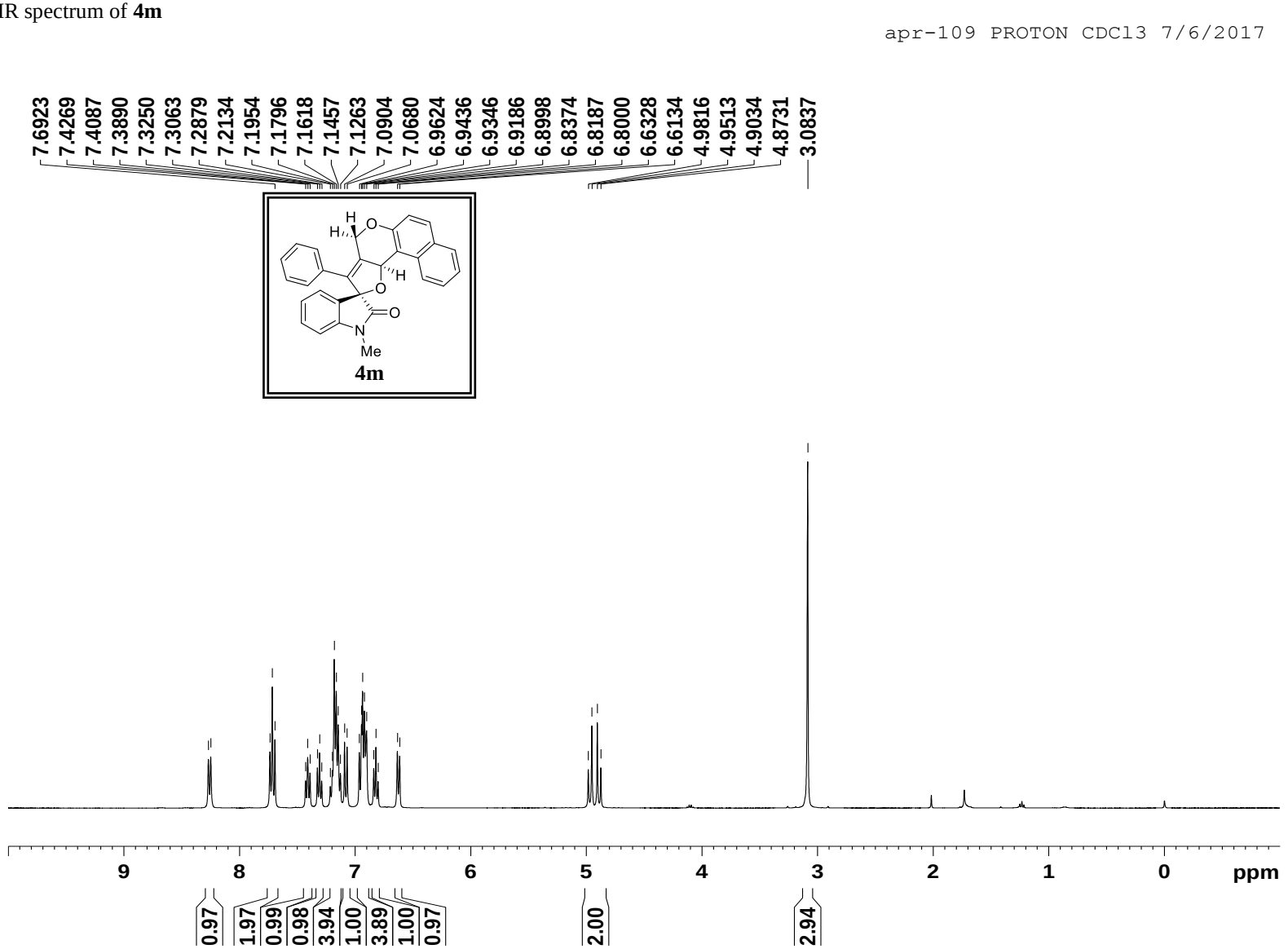
^{1}H NMR spectrum of **4l**



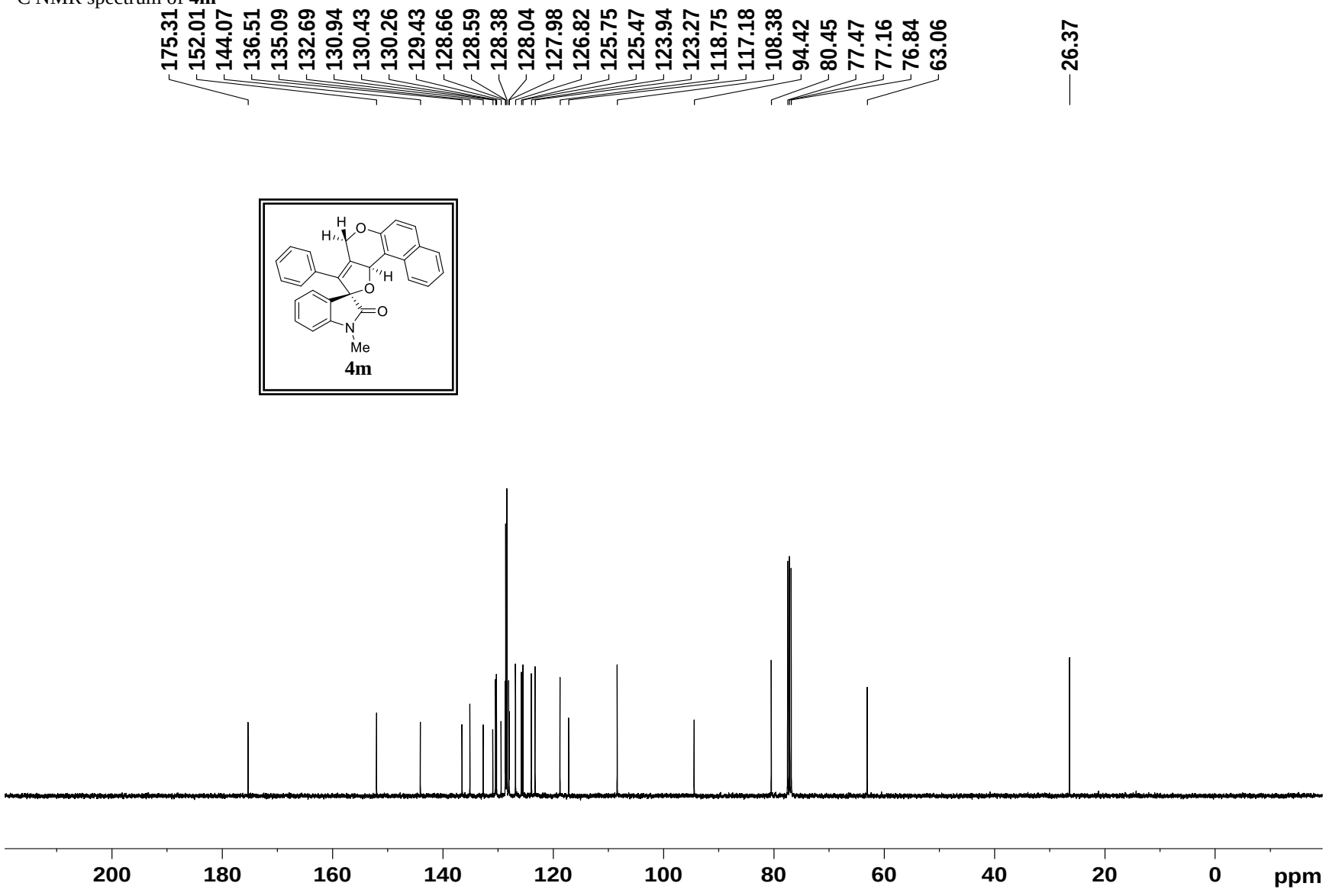
^{13}C NMR spectrum of **4l**



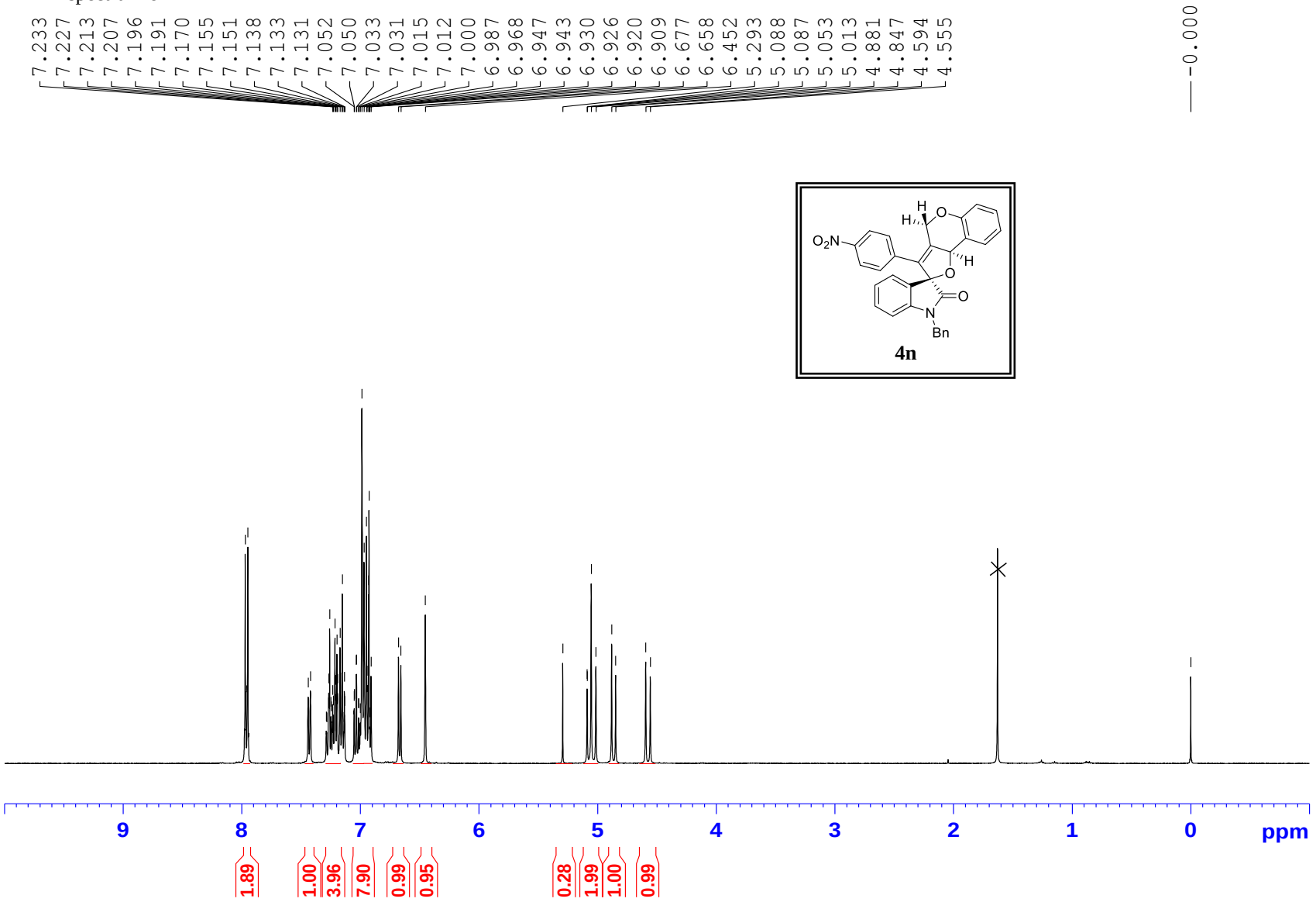
^{1}H NMR spectrum of **4m**



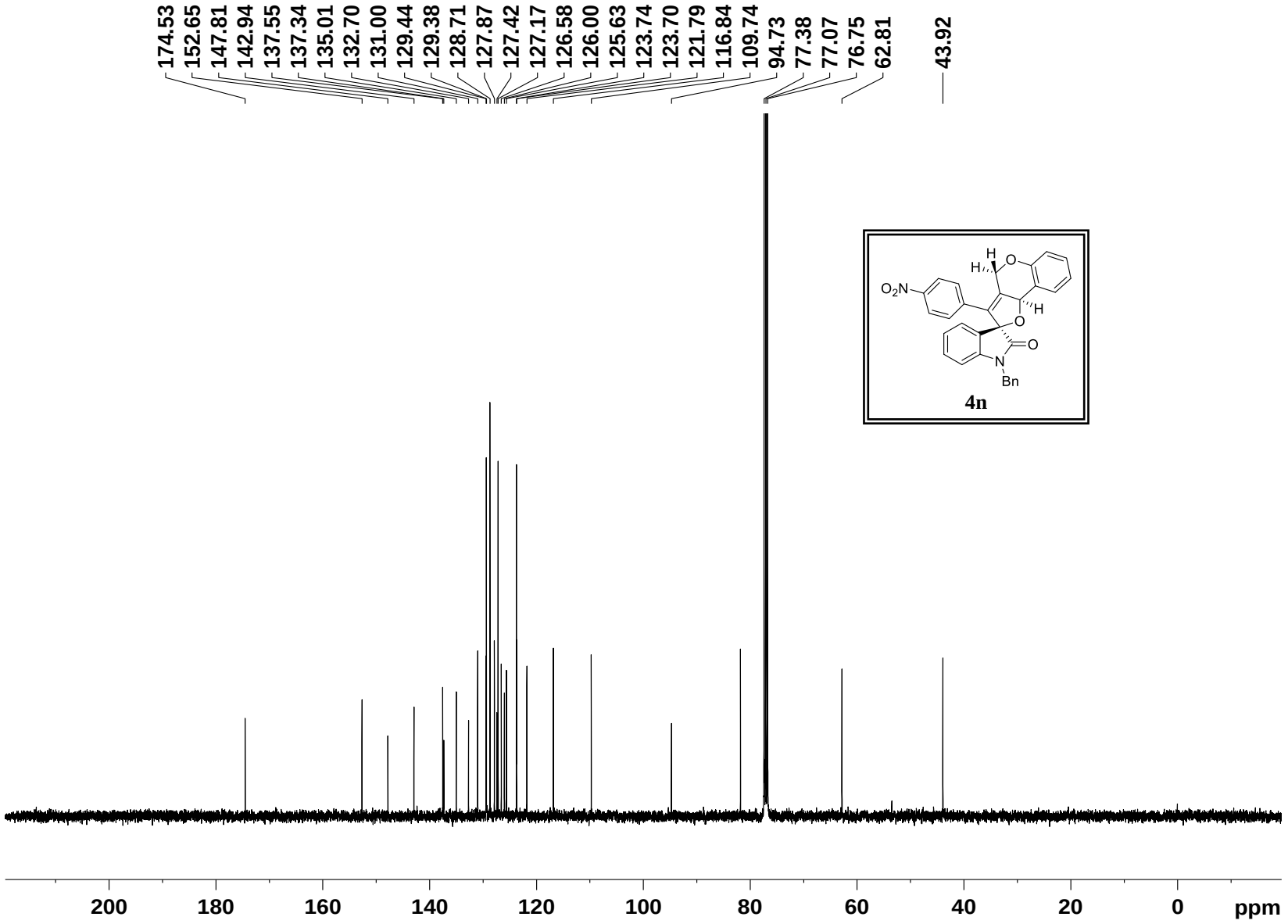
^{13}C NMR spectrum of **4m**



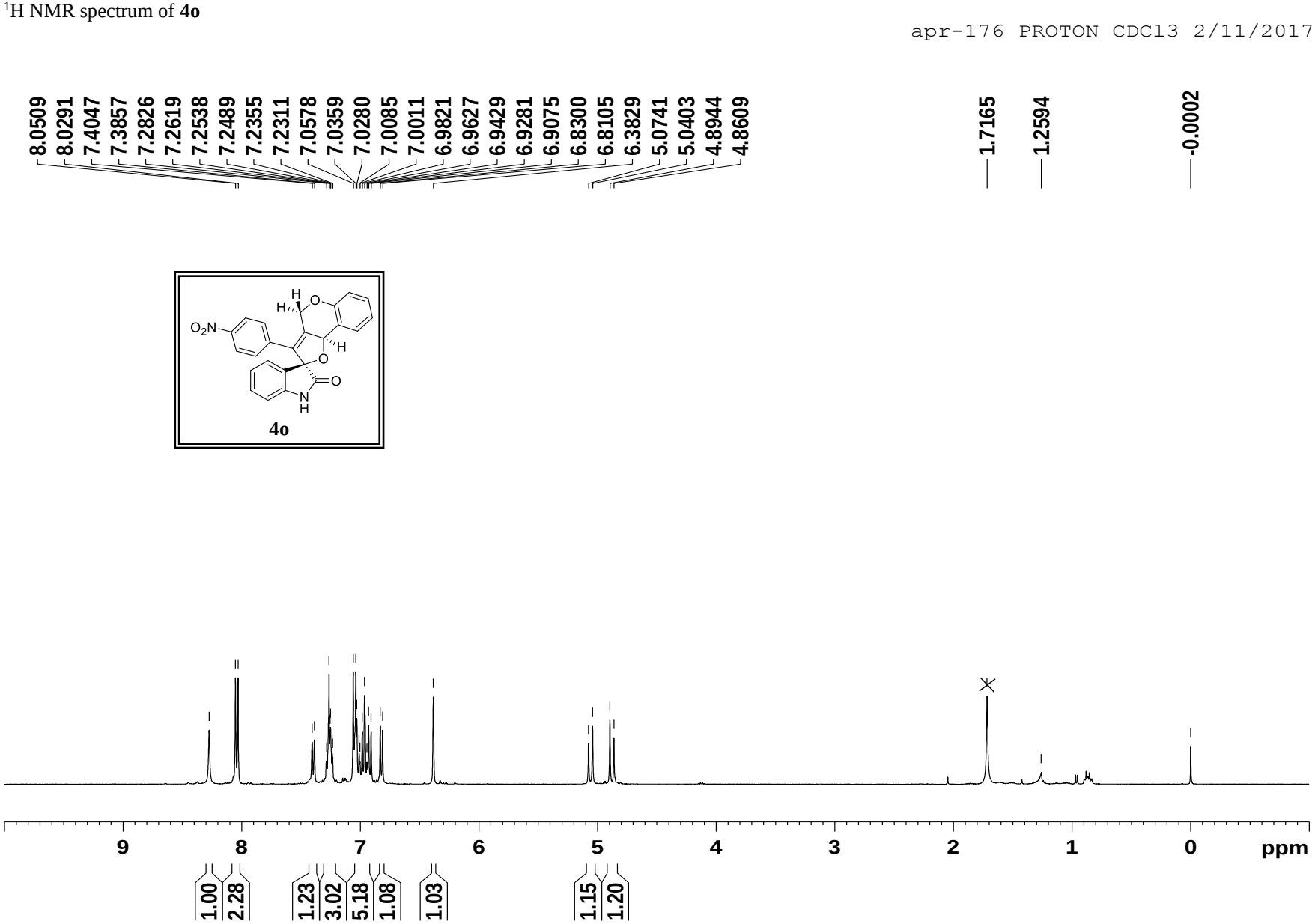
^{1}H NMR spectrum of **4n**



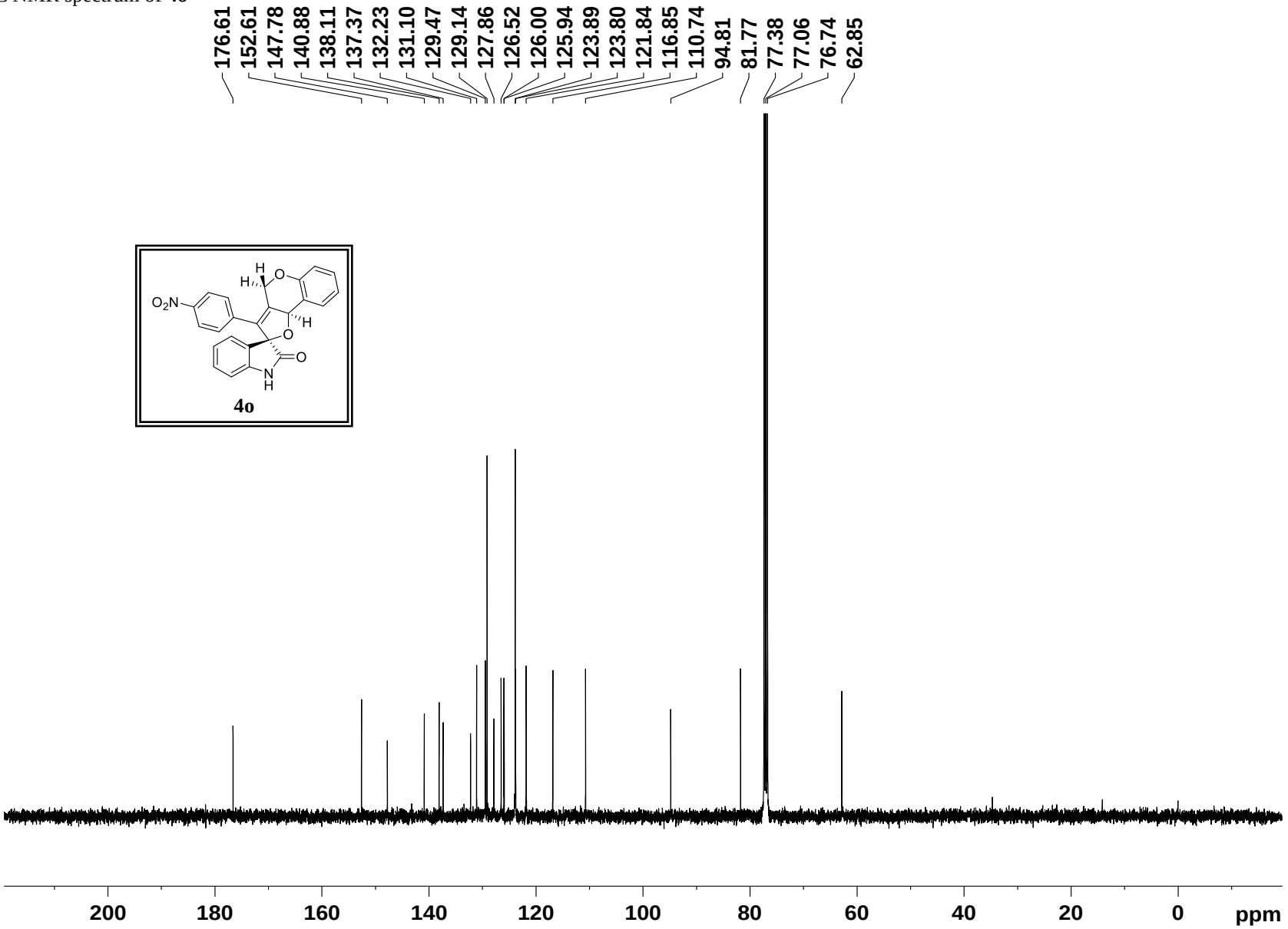
^{13}C NMR spectrum of **4n**



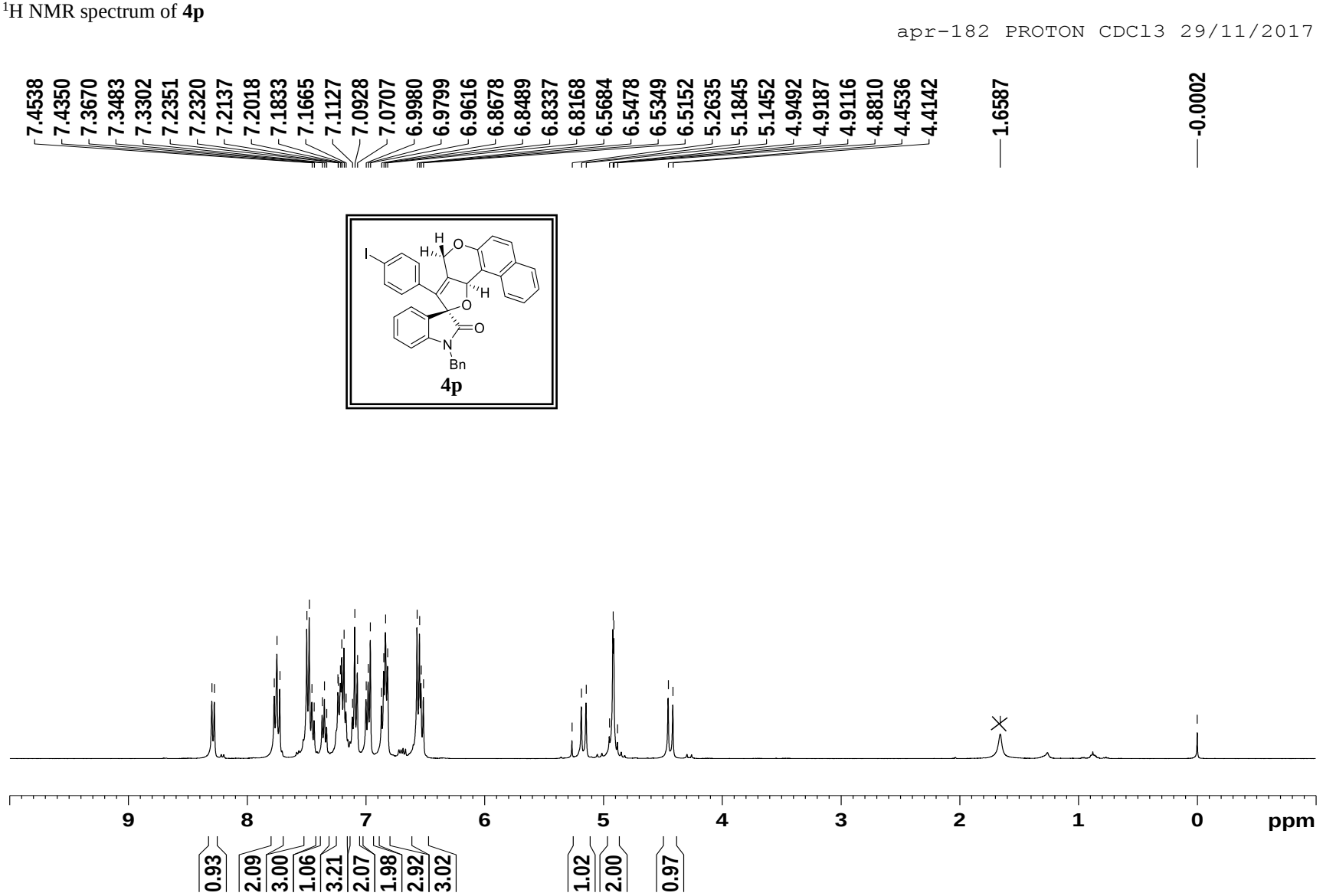
^{1}H NMR spectrum of **4o**



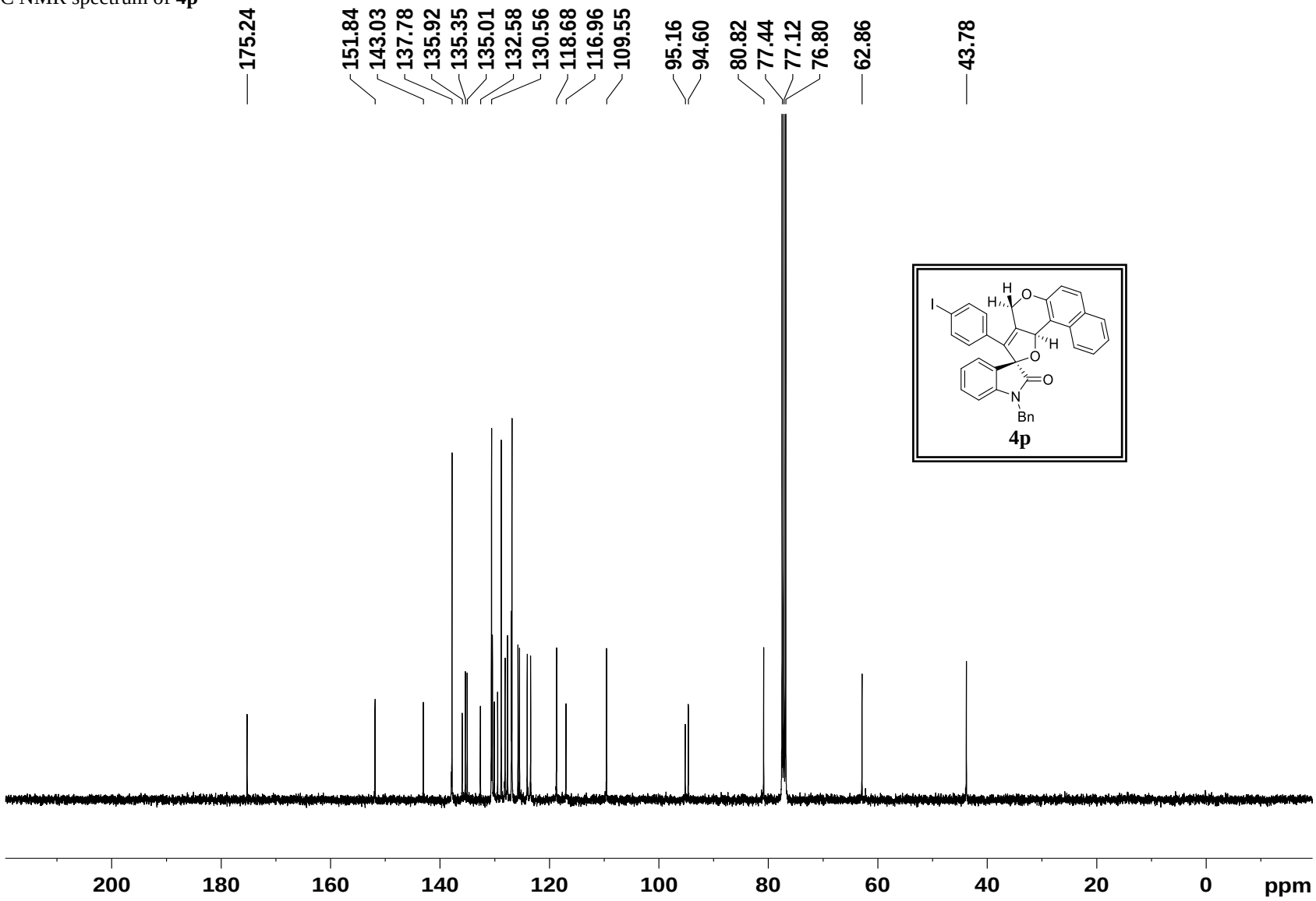
^{13}C NMR spectrum of **4o**



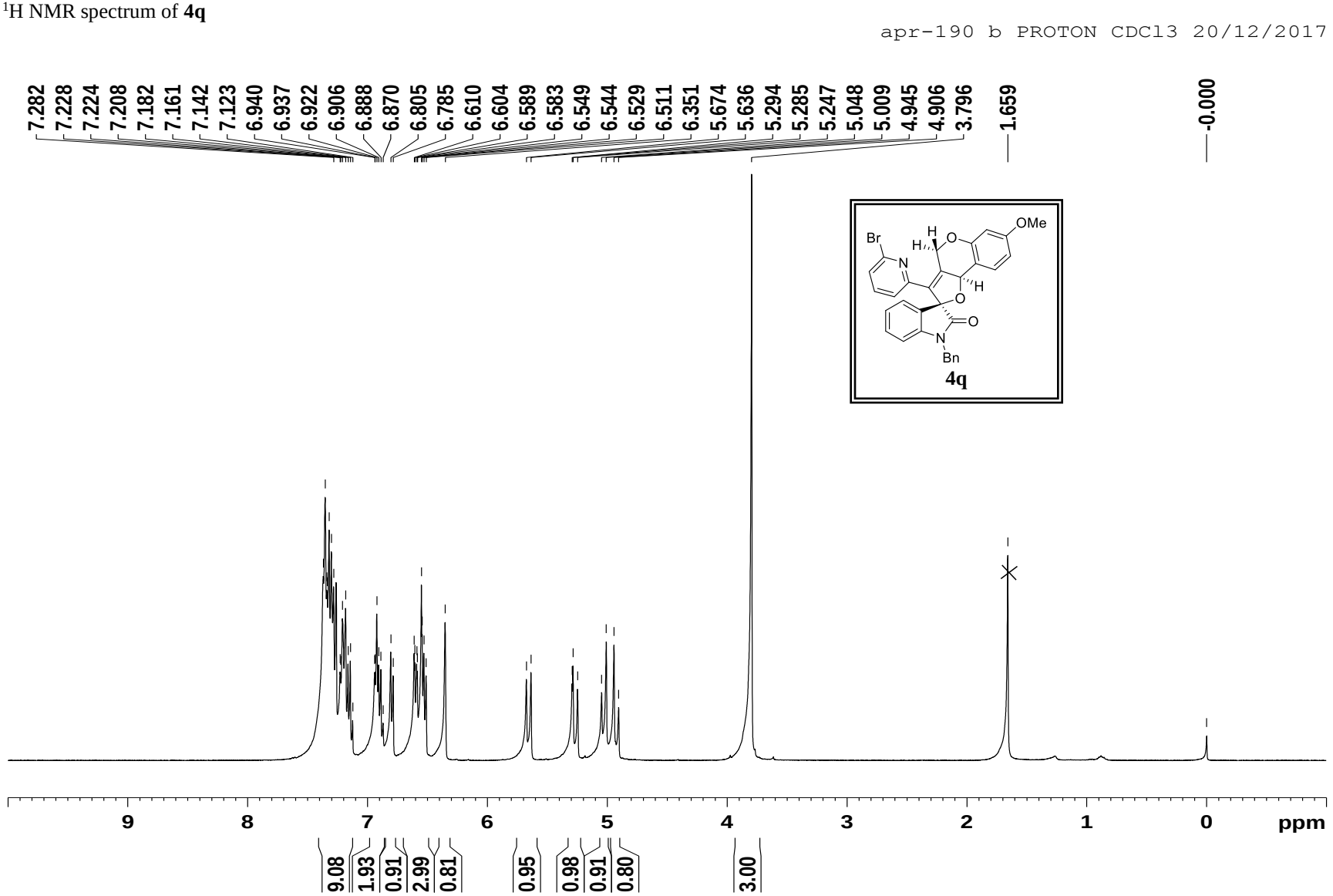
^{1}H NMR spectrum of **4p**



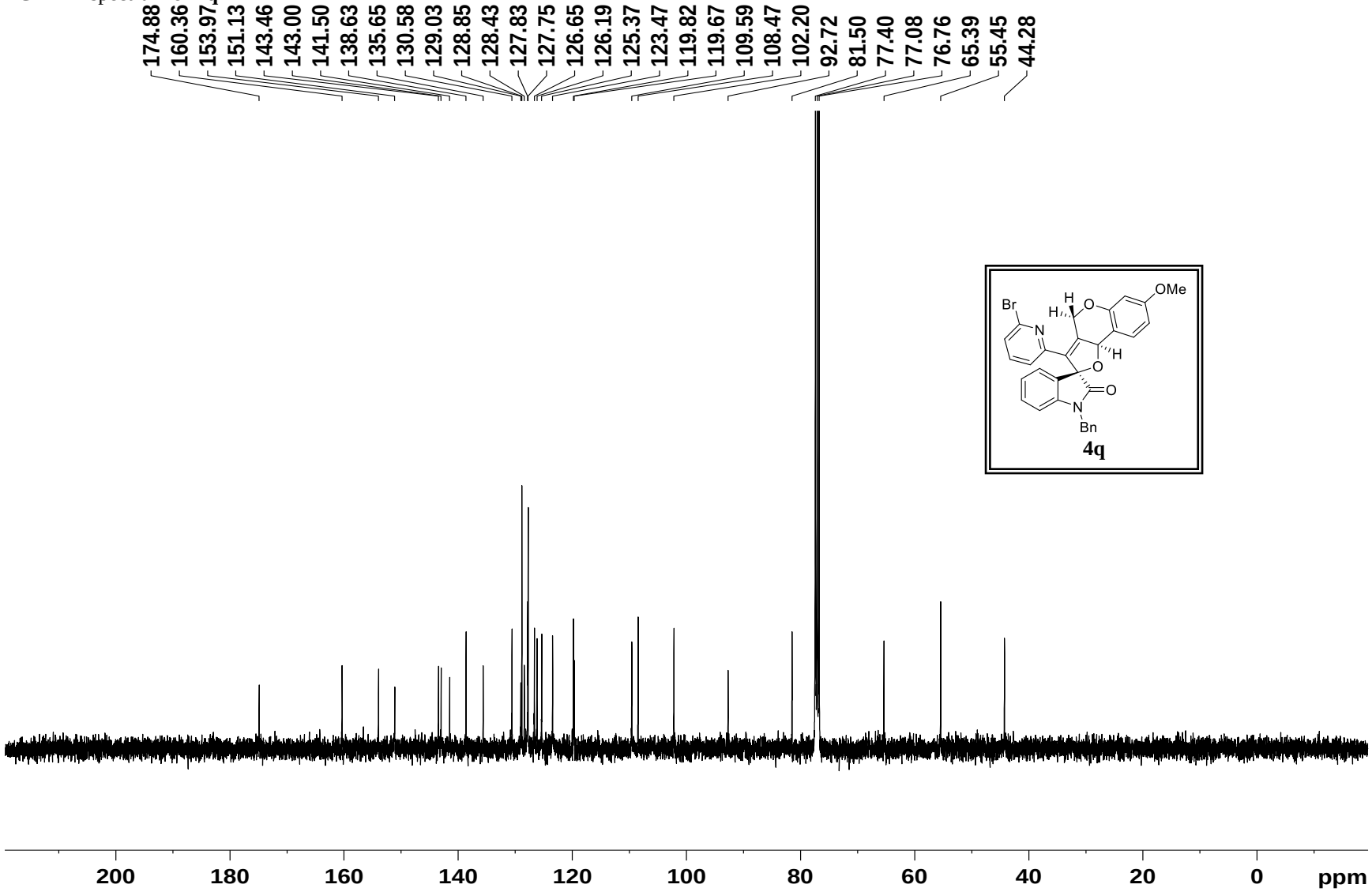
^{13}C NMR spectrum of **4p**



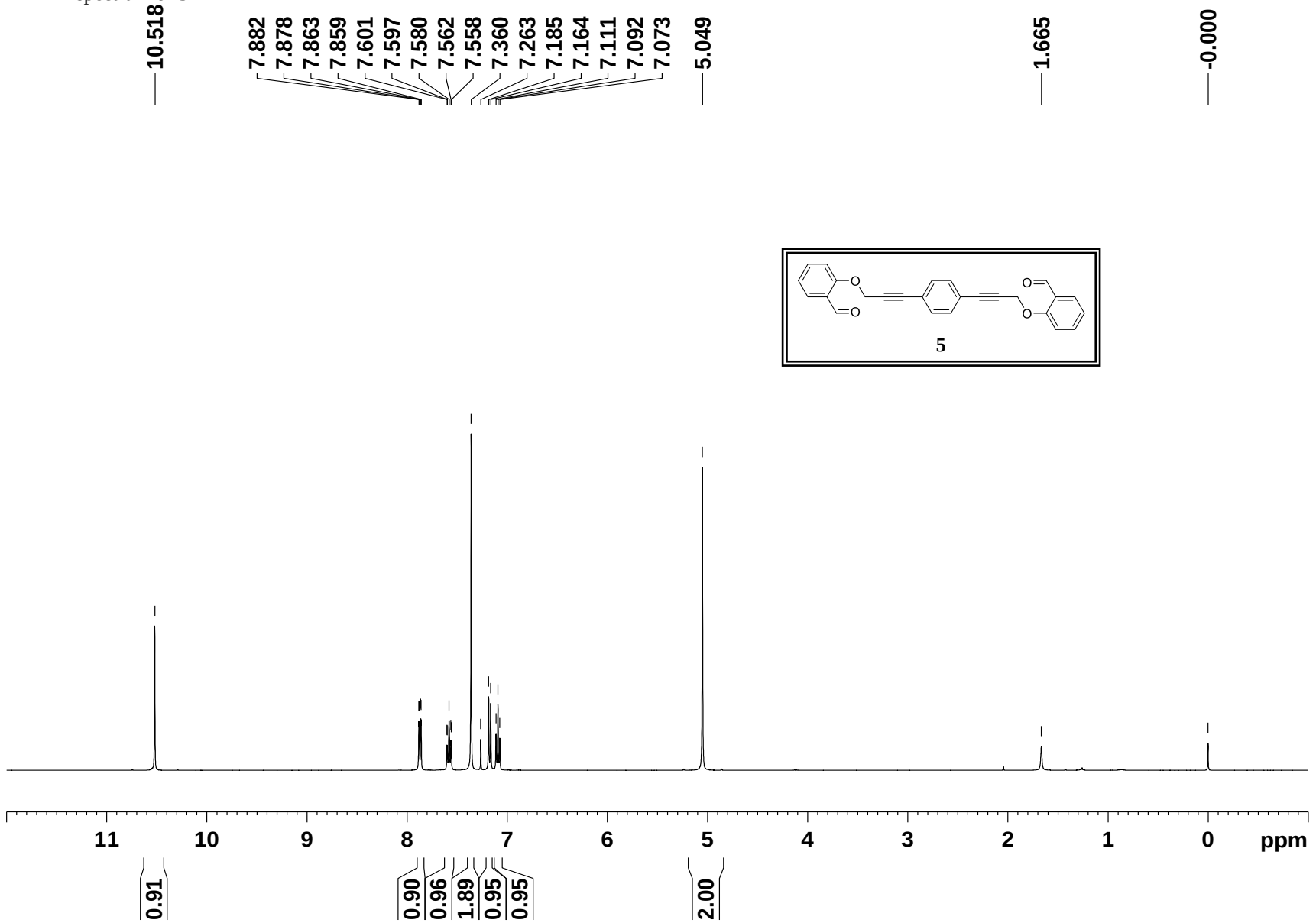
^{1}H NMR spectrum of **4q**



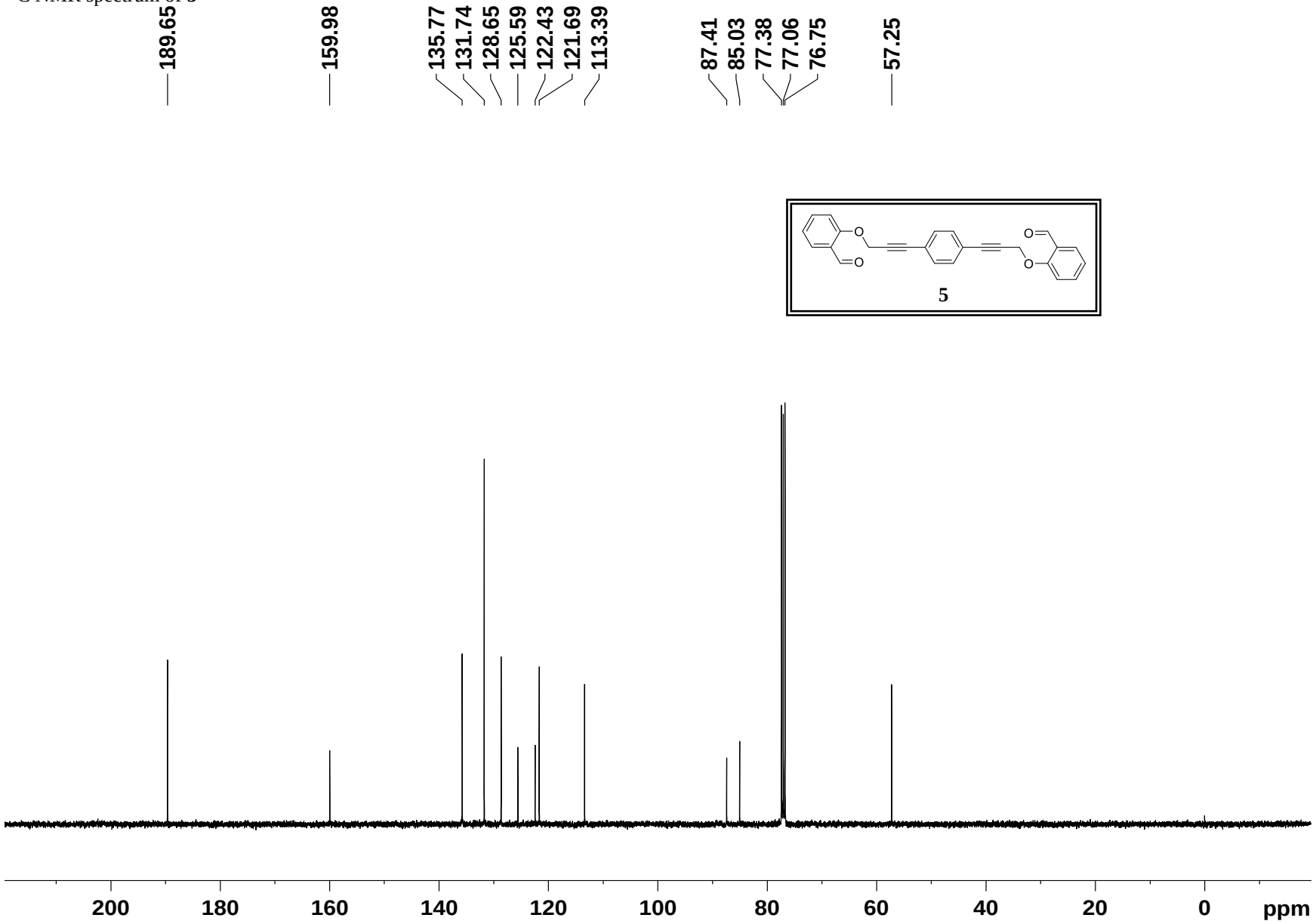
^{13}C NMR spectrum of **4q**



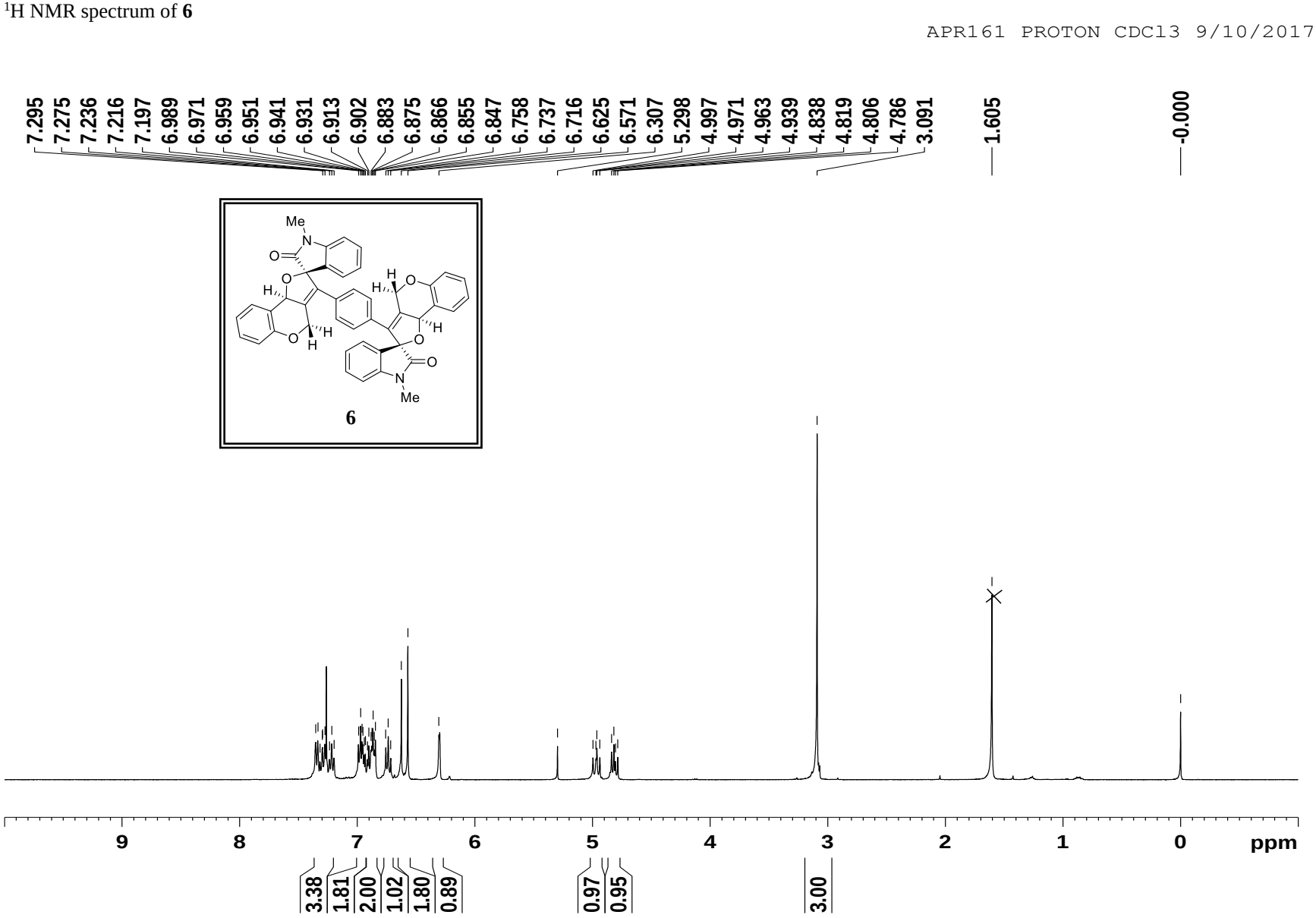
^{1}H NMR spectrum of **5**



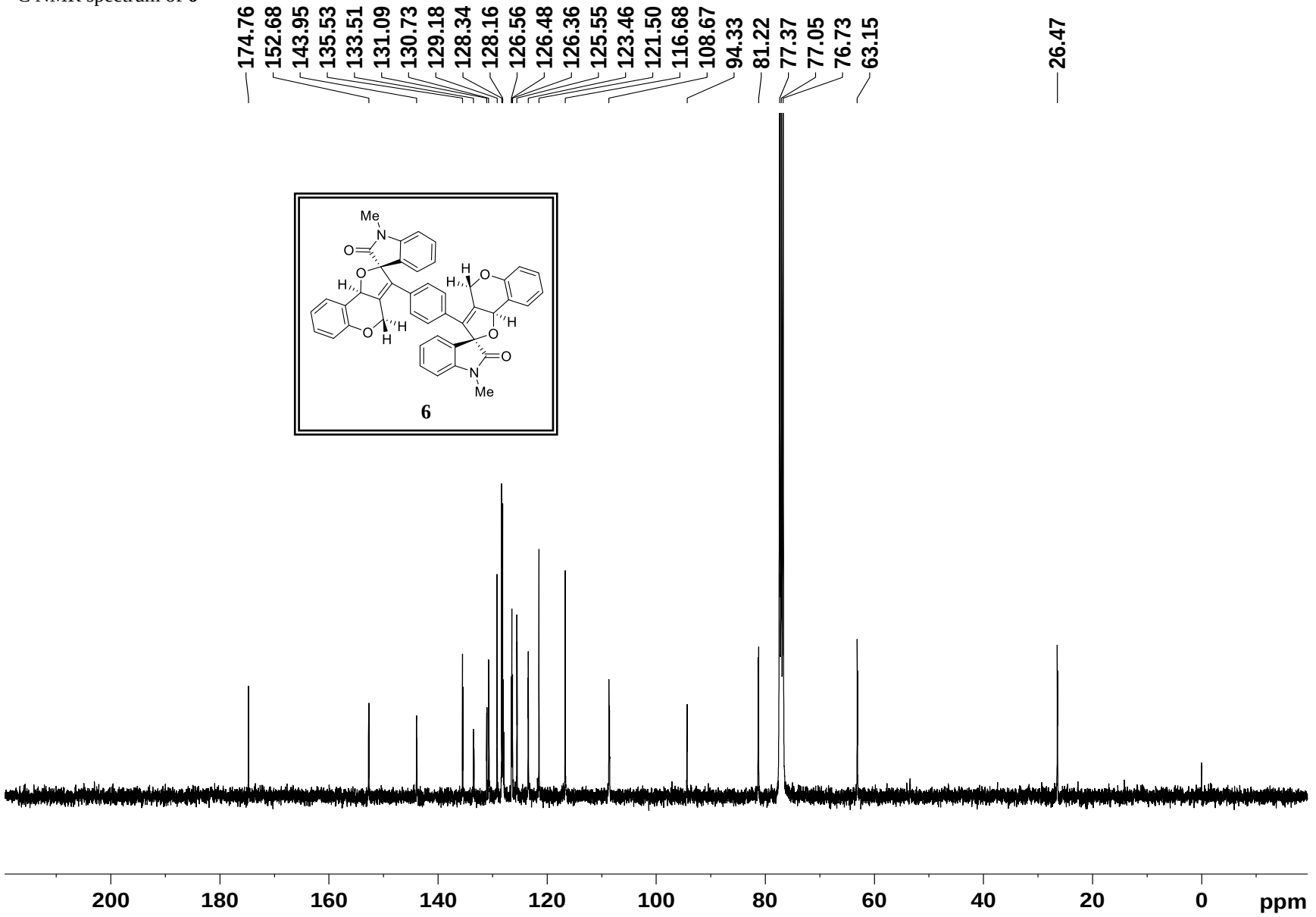
^{13}C NMR spectrum of **5**



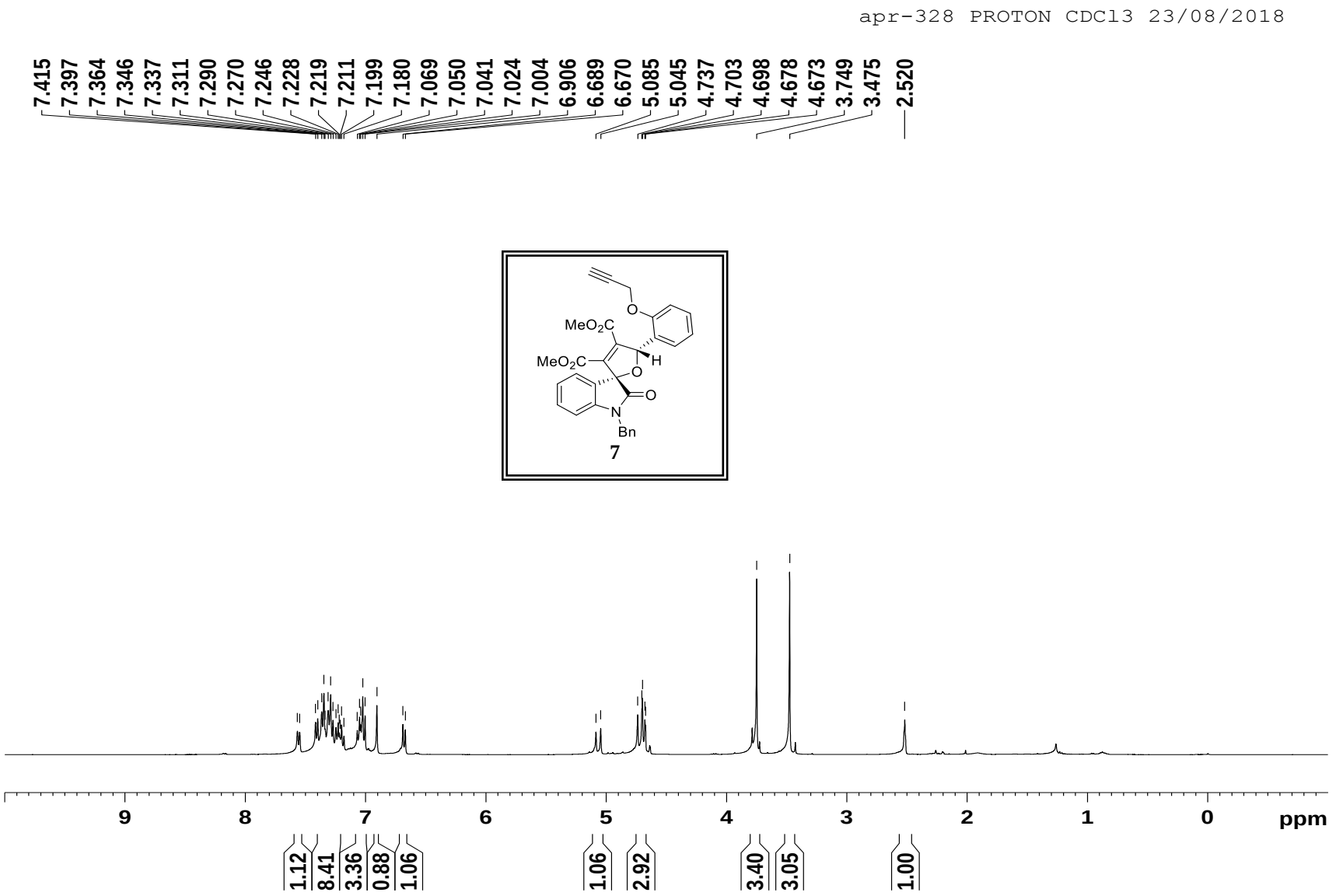
^{1}H NMR spectrum of **6**



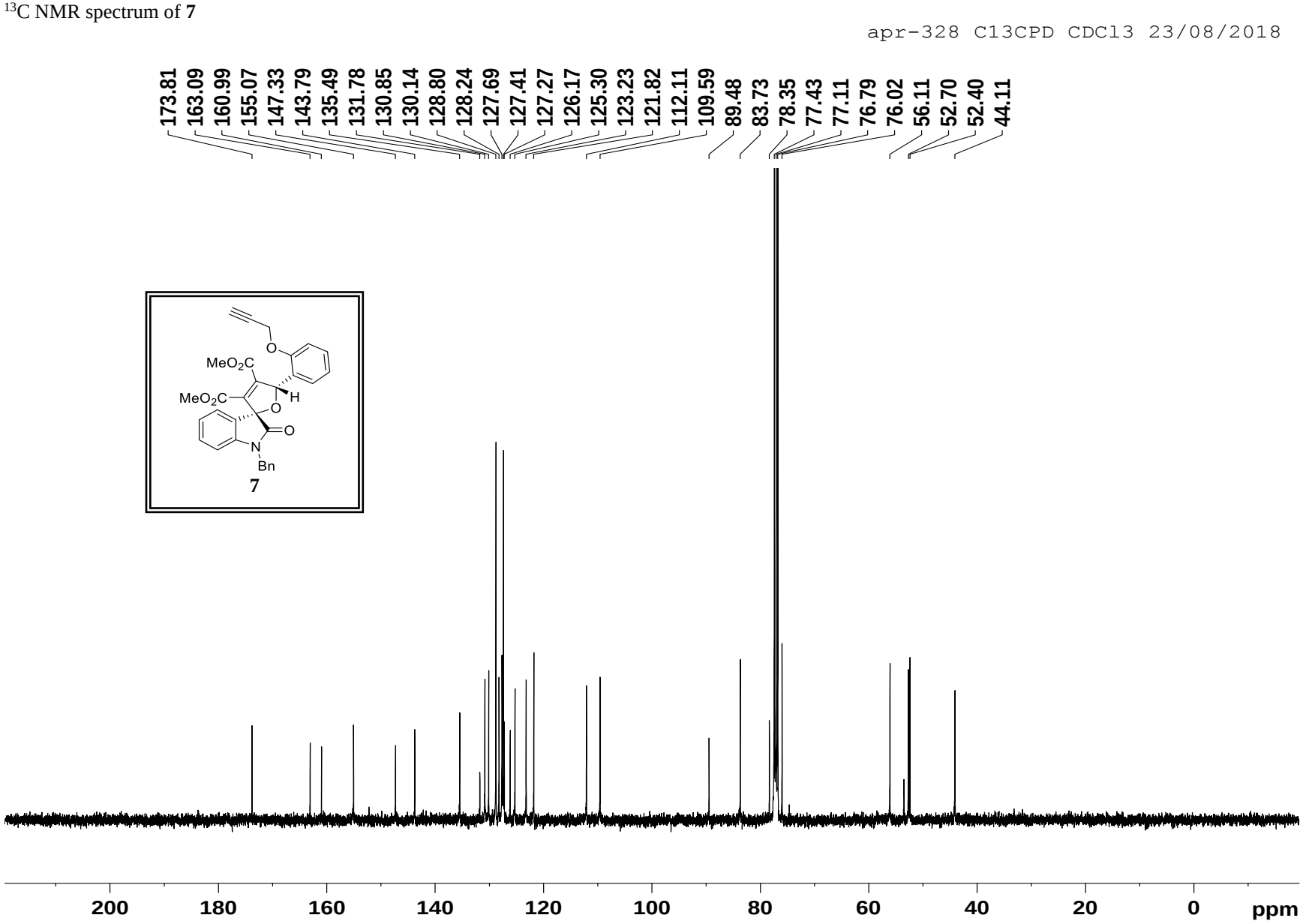
^{13}C NMR spectrum of **6**



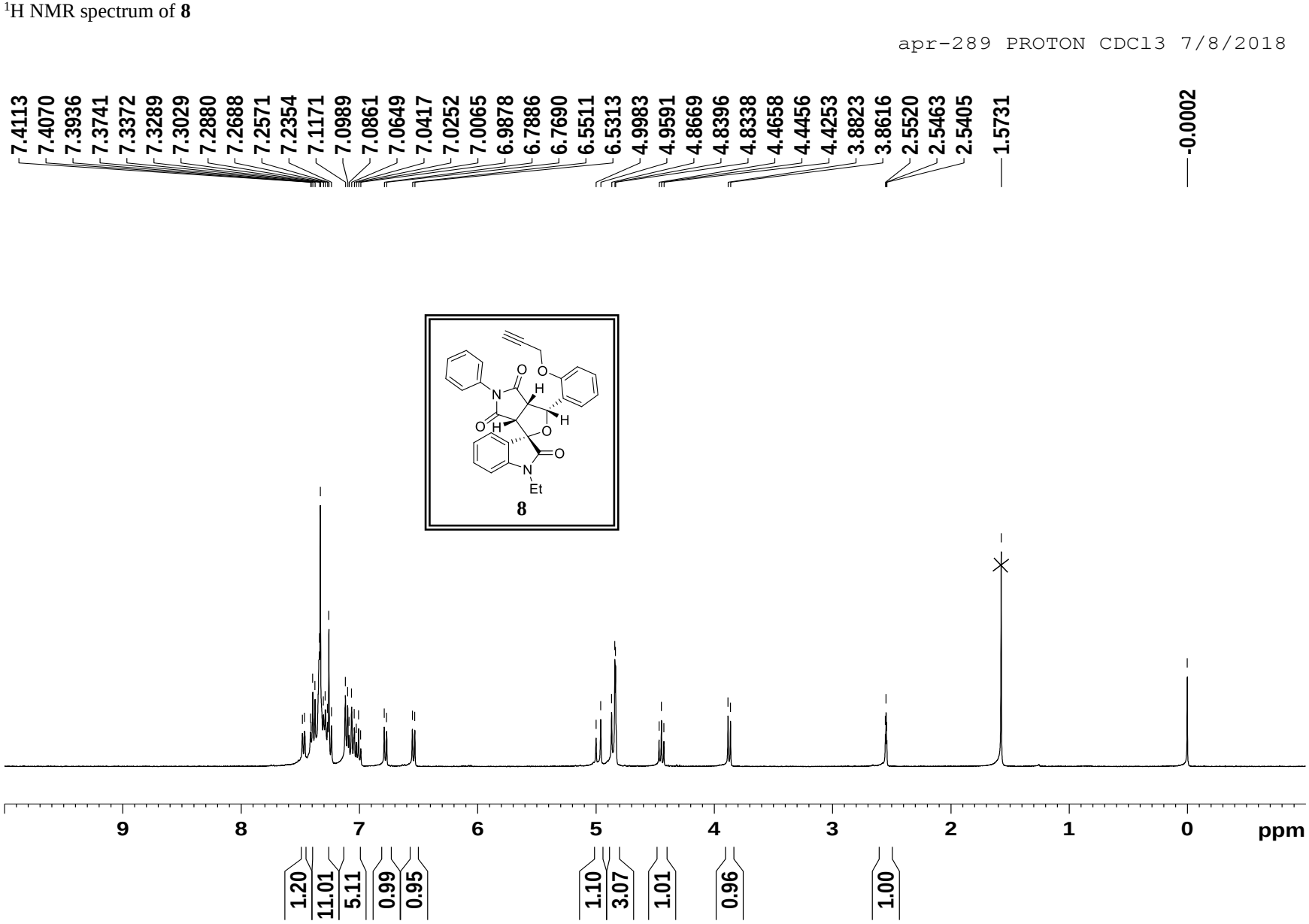
^{1}H NMR spectrum of **7**



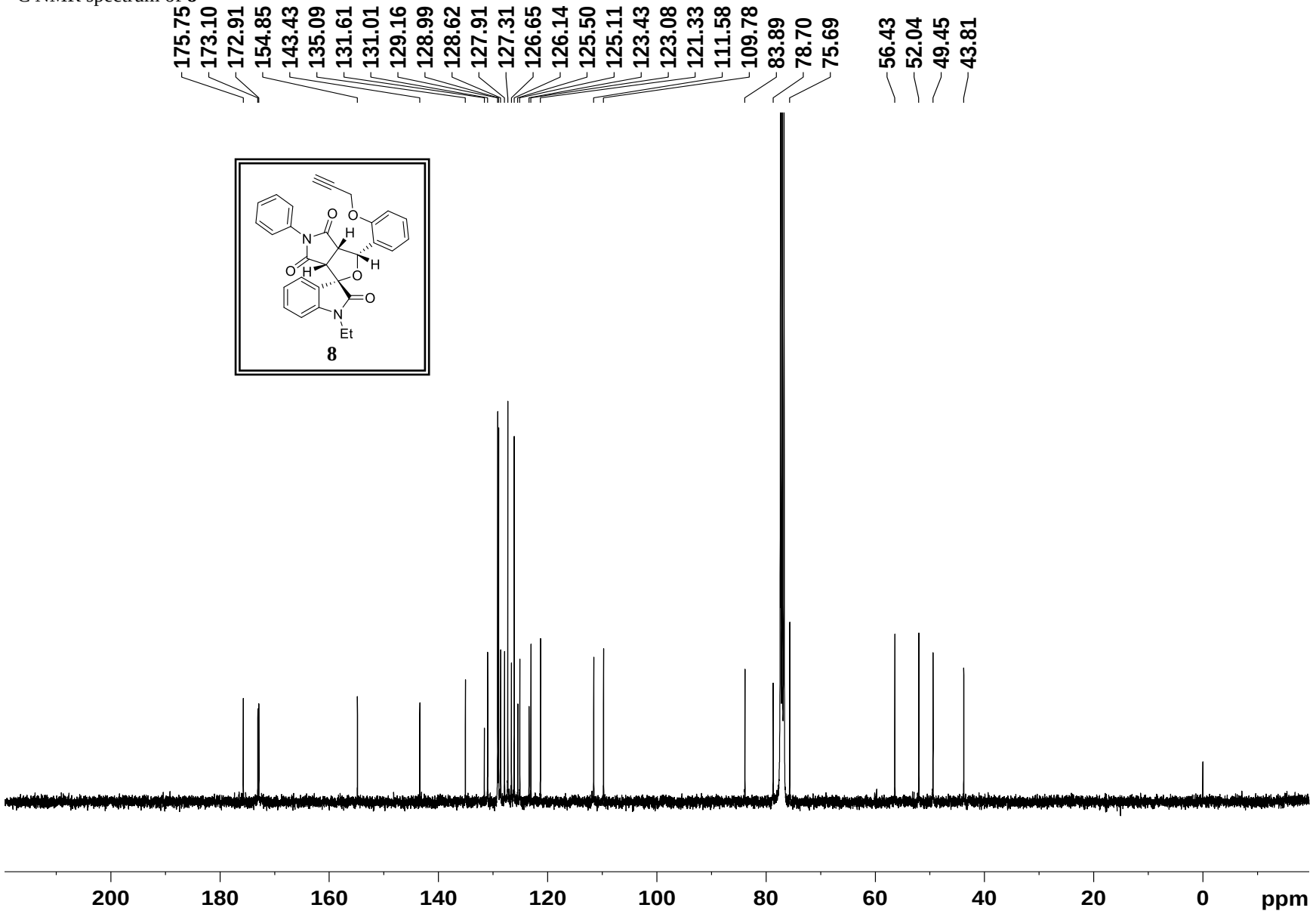
^{13}C NMR spectrum of **7**



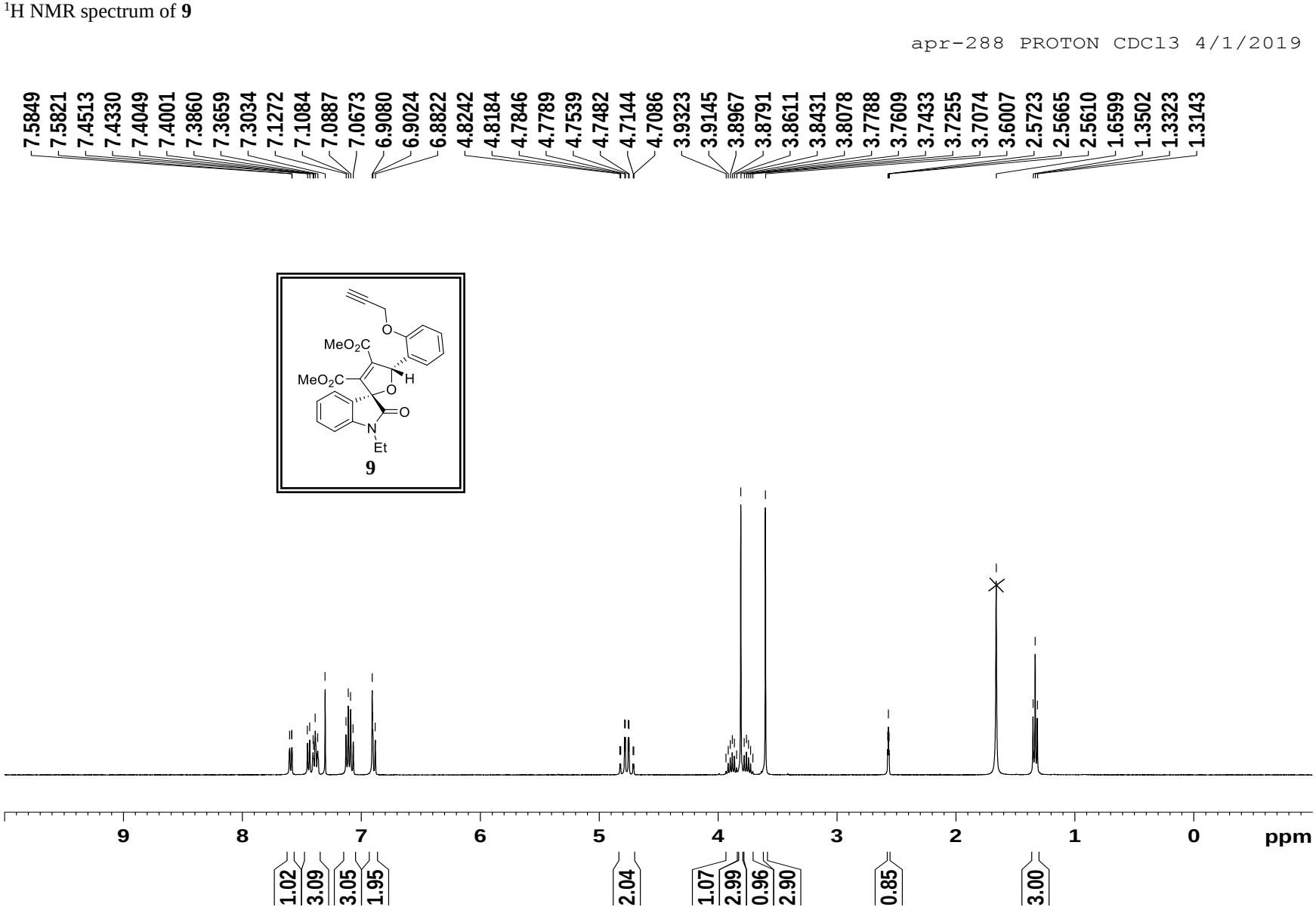
^{1}H NMR spectrum of **8**



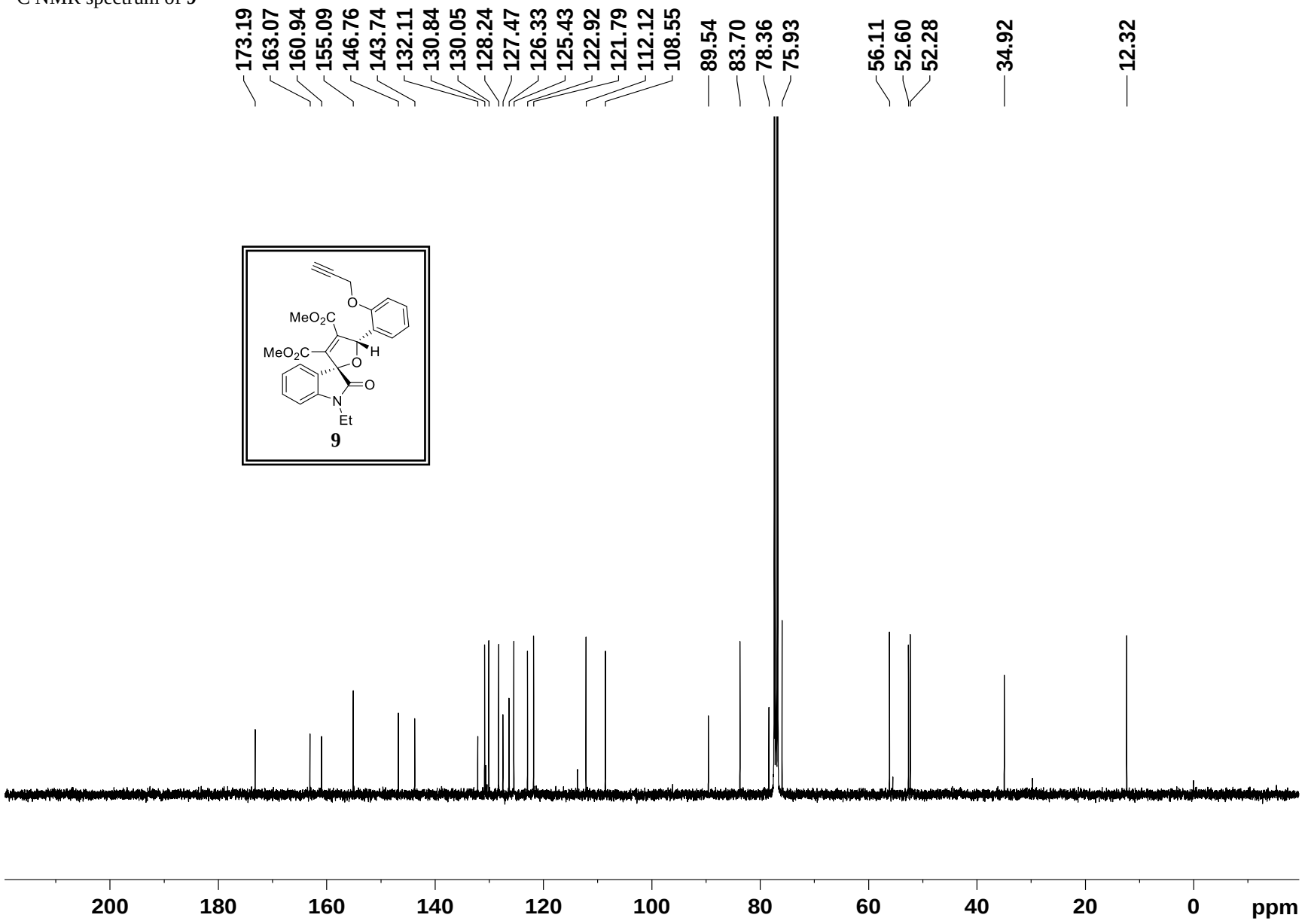
^{13}C NMR spectrum of **8**



^{1}H NMR spectrum of **9**



^{13}C NMR spectrum of **9**



Solid-state arrangements of compound 4i

A unit cell contains two asymmetric units of **4i**. The solid-state arrangements of compound **4i** divulged a number of close intermolecular links between the molecules, which are associated via intermolecular five C-H---O hydrogen bonding interactions that are described as given below:

For C(14)–H(14)---O(4): H(14)---O(4) = 2.480 Å and < C(14)–H(14)---O(4) = 134.75^{o}

For C(20)-H(20)---O(3): H(42)---O(3) = 2.360 Å and < C(20)-H(20)---O(3) = 162.77^{o}

For C(28)-H(28)---O(6): H(28)---O(6) = 2.689 Å and < C(28)-H(28)---O(6) = 147.28 ^{o}

For C(38)-H(38)---O(1): H(38)---O(1) = 2.569 Å and < C(38)-H(38)---O(1) = 133.23^{o}

For C(42)-H(42)---O(6): H(42)---O(6) = 2.448 Å and < C(42)-H(42)---O(6) = 168.65^{o}

The three C–H···π interactions that are described as given below:

1. C(35)-H(35B)---Cg(1); H(35B)---Cg(1) = 2.586 Å and <C(35)-H(35B)---Cg(1) = 172.34°

2. C(11)-H(11B)---Cg(3); H(11B)---Cg(3) = 2.569 Å and <C(11)-H(11B)---Cg(3) = 164.15°

3. C(37)-H(37)---Cg(2); H(37)---Cg(2) = 2.707Å and <C(37)-H(37)---Cg(2) = 152.93°

The molecules are arranged in three-dimensional network with the presence of three C–H···π interactions and five intermolecular hydrogen bondings. The C–H···π interactions are shown below figure 2.

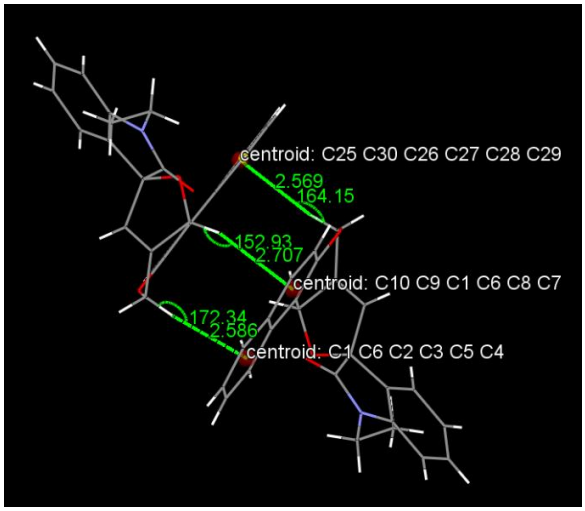


Figure 2. A partial packing view of **4i** showing C-H-π interactions in solid state arrangement

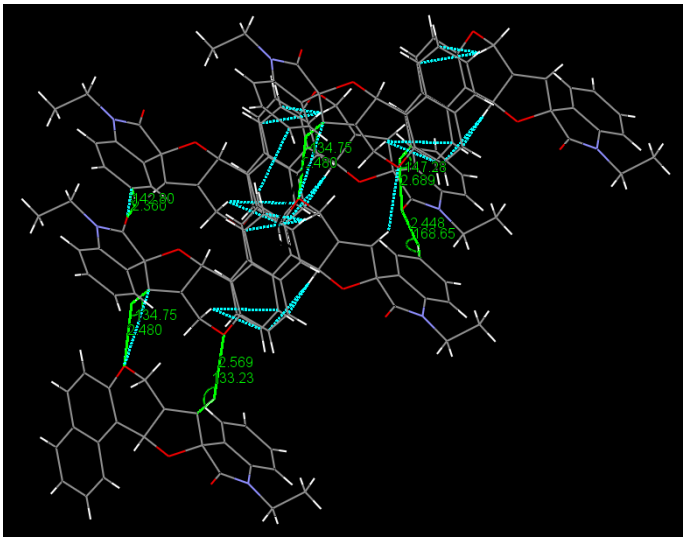


Figure 3. A partial packing view of **4i** showing hydrogen bondings

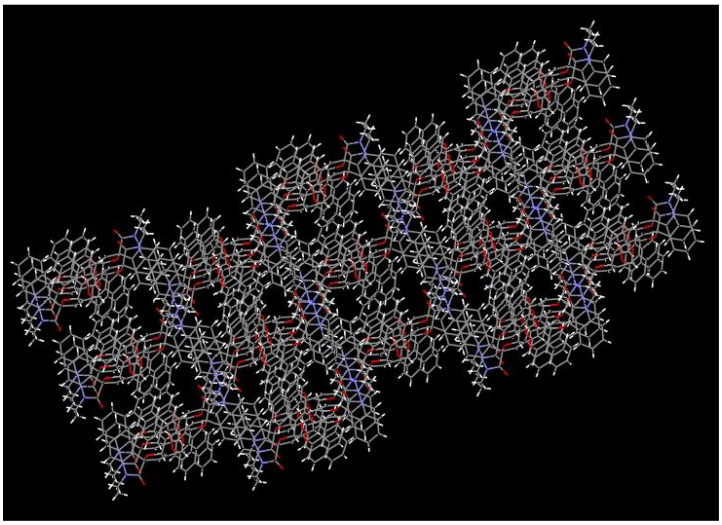


Figure 4. The molecular arrangement of compound **4i** viewed through *b*-axis.

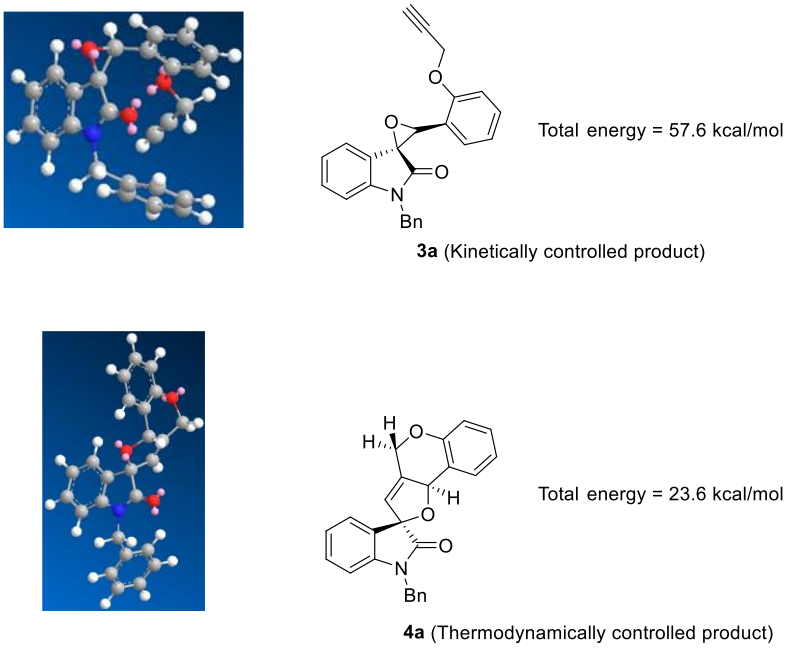


Figure 5. Energy minimization based on MM2 calculations for **3a** and **4a**

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