Gold/Silver-Catalyzed Controllable Regioselective Vinylcarbene Insertion into O-H Bonds

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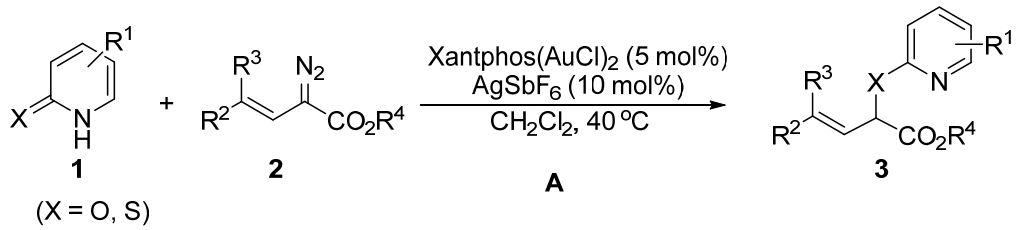
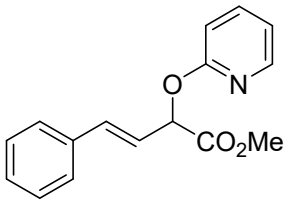
General Information

All of the reactions were carried out in flame-dried tubes under argon atmosphere. Solvents were dried prior to use. For column chromatography, 200-300 mesh silica gel was used. ^{1}H NMR were recorded on Bruker 300 MHz, 400 MHz or 500 MHz spectrometer and ^{13}C NMR were recorded on Bruker 75 MHz, 100 MHz or 125MHz spectrometer in $CDCl_3$. HRMS were performed on Agilent 6540 Q-TOF mass spectrometer (ESI). Melting points were determined on a SGW X-4B melting point apparatus. 2-pyridones and $AgSbF_6$ were commercial available. The gold catalysts [1] and diazo compounds[2] were prepared according to the literature procedures.

General procedure for table 2



To a schlenk tube was added Xantphos$(AuCl)_2$ (26 mg, 0.025 mmol), $AgSbF_6$ (17.1 mg, 0.05 mmol), **1** (0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere, the mixture was stirred at room temperature for 30 min; then a solution of **2** (0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 40 ^{o}C. The resulting mixture was stirred at 40 ^{o}C for another 4 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:50-1:10) to afford product **3**.

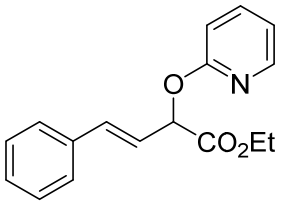


***methyl (E)-4-phenyl-2-(pyridin-2-yloxy)but-3-enoate (3a)*:**

Yellow oil (122 mg, 91 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.10 (m, 1H), 7.66 – 7.60 (m, 1H), 7.44 (d, *J* =

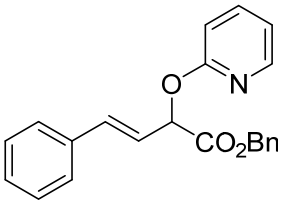
7.4 Hz, 2H), 7.38 – 7.26 (m, 3H), 6.97– 6.89 (m, 6.5 Hz, 3H), 6.43 (dd, *J* = 16.0, 6.7 Hz, 1H), 5.93 (d, *J* = 6.7 Hz, 1H), 3.78 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.75, 162.09, 146.62, 138.99, 135.96, 134.45, 128.66, 128.35, 126.84, 122.29, 117.64, 111.24,74.28, 52.50. HRMS (ESI) calcd. for $C_{16}H_{16}NO_3$ $[M+H]^+$: 270.1125, found: 270.1128.



***ethyl (E)-4-phenyl-2-(pyridin-2-yloxy)but-3-enoate (3b)*:**

Yellow oil (127 mg, 90 %).

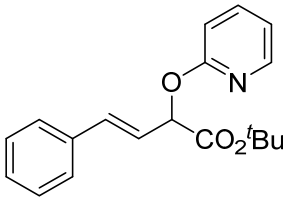
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, *J* = 4.7 Hz, 1H), 7.63 (t, *J* = 7.7 Hz, 1H), 7.44 (d, *J* = 7.5 Hz, 2H), 7.37 – 7.27 (m, 3H), 6.98– 6.88 (m, 3H), 6.43 (dd, *J* = 15.9, 6.6 Hz, 1H), 5.90 (d, *J* = 6.6 Hz, 1H), 4.24 (q, *J* = 6.9 Hz, 2H), 1.26 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.25, 162.14, 146.56, 138.94, 136.05, 134.30, 128.65, 128.30, 126.83, 122.43, 117.60, 111.23, 74.45, 61.42, 14.15. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1285.



***benzyl (E)-4-phenyl-2-(pyridin-2-yloxy)but-3-enoate (3c)*:**

Yellow oil (150 mg, 87 %).

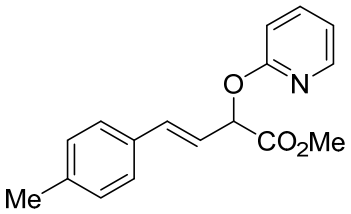
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (s, 1H), 7.62 (t, *J* = 8.0 Hz, 1H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.38 – 7.27 (m, 8H), 6.96 – 6.87 (m, 3H), 6.44 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.93 (d, *J* = 8.0 Hz, 1H), 5.23 (q, *J* = 24.0 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.17, 162.06, 146.56, 138.97, 135.97, 135.65, 134.61, 128.67, 128.50, 128.36, 128.21, 128.11, 126.86, 122.18, 117.65, 111.18, 74.53, 66.86. HRMS (ESI) calcd. for $C_{22}H_{20}NO_3$ $[M+H]^+$: 346.1438, found: 346.1440.



***tert-butyl (E)-4-phenyl-2-(pyridin-2-yloxy)but-3-enoate (3d)*:**

A white solid (134 mg, 86 %), mp: 103-105 °C.

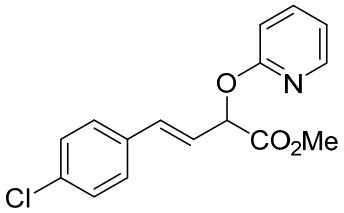
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.09 (m, 1H), 7.62 (t, *J* = 8.0 Hz, 1H), 7.44 (d, *J* = 4.0 Hz, 2H), 7.38 – 7.27 (m, 3H), 6.96 – 6.85 (m, 3H), 6.42 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.77 (d, *J* = 8.0 Hz, 1H), 1.44 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.23, 162.25, 146.46, 138.86, 136.35, 133.87, 128.63, 128.16, 126.80, 122.87, 117.45, 111.19, 81.95, 74.84, 27.98. HRMS (ESI) calcd. for $C_{19}H_{22}NO_3$ $[M+H]^+$: 312.1594, found: 312.1596.



***methyl (E)-2-(pyridin-2-yloxy)-4-(p-tolyl)but-3-enoate (3e)*:**

Yellow oil (113 mg, 80 %).

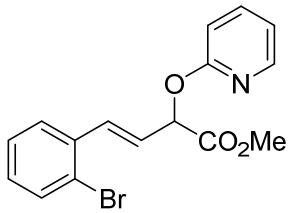
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.09 (m, 1H), 7.62 (t, *J* = 8.0 Hz, 1H), 7.33 (d, *J* = 8.0 Hz, 2H), 7.14 (d, *J* = 8.0 Hz, 2H), 6.95 – 6.86 (m, 3H), 6.37 (dd, *J* = 16.0, 4.0 Hz, 1H), 5.90 (d, *J* = 8.0 Hz, 1H), 3.77 (s, 3H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.87, 146.62, 138.96, 138.31, 137.19, 134.51, 133.17, 129.35, 126.76, 121.17, 117.60, 111.25, 74.44, 52.47, 21.30. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1282.



***methyl (E)-4-(4-chlorophenyl)-2-(pyridin-2-yloxy)but-3-enoate (3f)*:**

Yellow oil (127 mg, 84 %).

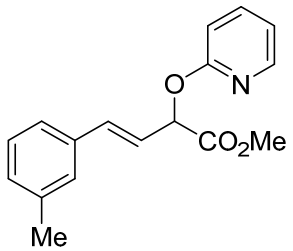
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.09 (m, 1H), 7.63 (t, *J* = 8.0 Hz, 1H), 7.38 – 7.28 (m, 4H), 6.96 – 6.84 (m, 3H), 6.40 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.93 (d, *J* = 4.0 Hz, 1H), 3.78 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.57, 161.98, 146.63, 139.05, 134.46, 134.02, 133.02, 128.85, 128.04, 122.97, 117.73, 111.20, 74.04, 52.57. HRMS (ESI) calcd. for $C_{16}H_{15}ClNO_3$ $[M+H]^+$: 304.0735, found: 304.0738.



***methyl (E)-4-(2-bromophenyl)-2-(pyridin-2-yloxy)but-3-enoate (3g)*:**

Yellow oil (150 mg, 86 %).

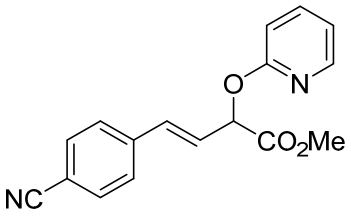
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 – 8.09 (m, 1H), 7.66 – 7.53 (m, 3H), 7.32 – 7.26 (m, 2H), 7.13 (t, *J* =8.0 Hz, 1H), 6.98 – 6.88 (m, 2H), 6.38 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.99 (d, *J* = 8.0 Hz, 1H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.51, 161.98, 146.62, 139.05, 135.85, 133.17, 133.07, 129.58, 127.59, 127.25, 125.22, 124.04, 117.74, 111.29, 74.13, 52.61. HRMS (ESI) calcd. for $C_{16}H_{15}BrNO_3$ $[M+H]^+$: 348.0230, found: 348.0234.



***methyl (E)-2-(pyridin-2-yloxy)-4-(m-tolyl)but-3-enoate (3h)*:**

Yellow oil (115 mg, 81 %).

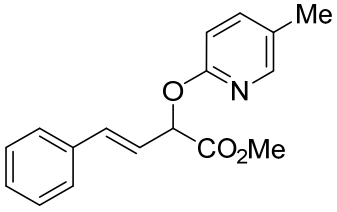
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.09 (m, 1H), 7.66 – 7.59 (m, 1H), 7.26 – 7.19 (m, 3H), 7.12 – 7.07 (m, 1H), 6.96 – 6.85 (m, 3H), 6.86 (d, *J* = 8.0 Hz, 1H), 6.40 (dd, *J* = 20.0, 8.0 Hz, 1H), 5.93 – 5.89 (m, 1H), 3.77 (s, 3H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.78, 162.06, 146.61, 138.96, 138.22, 135.90, 134.57, 129.13, 128.54, 127.51, 124.01, 122.07, 117.60, 111.25, 74.33, 52.47, 21.39. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1282.



***methyl (E)-4-(4-cyanophenyl)-2-(pyridin-2-yloxy)but-3-enoate (3i)*:**

Colorless oil (110 mg, 75 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.09 (m, 1H), 7.69 – 7.60 (m, 3H), 7.54 – 7.49 (m, 2H), 6.99 – 6.91 (m, 3H), 6.56 (dd, *J* = 24.0, 8.0 Hz, 1H), 6.01 (dd, *J* = 8.0, 4.0 Hz, 1H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.13, 161.82, 146.62, 140.44, 139.15, 132.49, 131.99, 127.29, 126.40, 118.79, 117.89, 111.53, 111.16, 73.59, 52.66. HRMS (ESI) calcd. for $C_{17}H_{15}N_2O_3$ $[M+H]^+$: 295.1077, found: 295.1081.

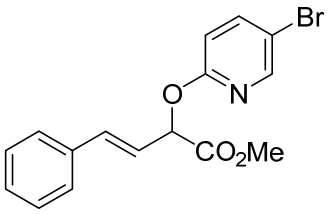


***methyl (E)-2-((5-methylpyridin-2-yl)oxy)-4-phenylbut-3-enoate (3j)*:**

Yellow oil (114 mg, 81 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (s, 1H), 7.47 – 7.41 (m, 3H), 7.37 – 7.26 m, 3H), 6.92 (d, *J* =16.0 Hz, 1H), 6.85 (d, *J* = 8.0 Hz, 1H), 6.43 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.89 (d, *J* = 4.0 Hz, 1H), 3.77 (s, 3H), 2.24 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ

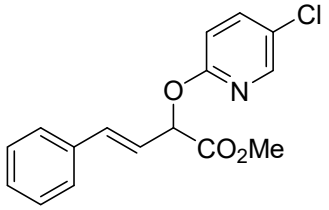
170.91, 160.35, 146.03, 140.04, 136.00, 134.33, 128.64, 128.30, 126.82, 126.64, 122.43, 110.55, 74.25, 52.47, 17.47. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1282.



***methyl (E)-2-((5-bromopyridin-2-yl)oxy)-4-phenylbut-3-enoate (3k)*:**

Yellow oil (155 mg, 89 %).

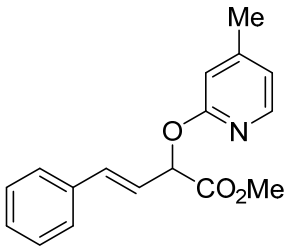
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 – 8.09 (m, 1H), 7.67 – 7.53 (m, 3H), 7.33 – 7.26 (m, 2H), 7.13 (t, *J* = 8.0 Hz, 1H), 6.98 – 6.88 (m, 2H), 6.38 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.99 (d, *J* = 8.0 Hz, 1H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.30, 160.95, 147.26, 141.60, 135.79, 134.79, 128.67, 128.45, 126.83, 121.79, 112.86, 112.76, 74.69, 52.56. HRMS (ESI) calcd. for $C_{16}H_{15}BrNO_3$ $[M+H]^+$: 348.0230, found: 348.0234.



***methyl (E)-2-((5-chloropyridin-2-yl)oxy)-4-phenylbut-3-enoate (3l)*:**

Yellow oil (128 mg, 84 %).

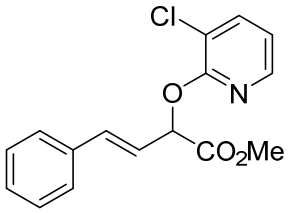
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (d, *J* = 4.0 Hz, 1H), 7.58 (dd, *J* = 12.0, 4.0 Hz, 1H), 7.46 – 7.27 (m, 5H), 6.95 – 6.88 (m, 2H), 6.39 (dd, *J* = 16.0, 4.0 Hz, 1H), 5.87 (d, *J* = 4.0 Hz, 1H), 3.77 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.36, 160.55, 144.94, 139.00, 135.80, 134.78, 128.69, 128.47, 126.84, 125.10, 121.82, 112.25, 74.75, 52.57. HRMS (ESI) calcd. for $C_{16}H_{15}ClNO_3$ $[M+H]^+$: 304.0735, found: 304.0738.



***methyl (E)-2-((4-methylpyridin-2-yl)oxy)-4-phenylbut-3-enoate (3m)*:**

Yellow oil (109 mg, 77 %).

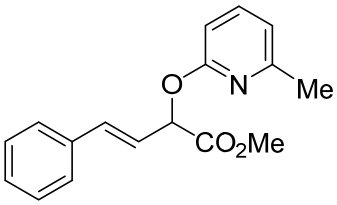
^{1}H NMR(400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 4.0 Hz, 1H), 7.43 (d, *J* = 8.0 Hz, 2H), 7.37 – 7.26 (m, 3H), 6.91 (d, *J* = 16.0 Hz, 1H), 6.77 – 6.72(m, 2H), 6.41 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.92 (d, *J* = 8.0 Hz, 1H), 3.76 (s, 3H), 2.31 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.83, 162.42, 150.41, 146.12, 136.02, 134.29, 128.64, 128.29, 126.82, 122.46, 119.19, 111.28, 74.19, 52.44, 20.96. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1284.



***methyl (E)-2-((3-chloropyridin-2-yl)oxy)-4-phenylbut-3-enoate (3n)*:**

Yellow oil (102 mg, 67 %).

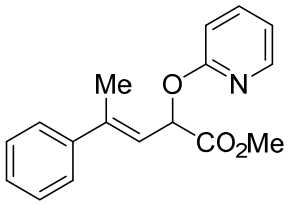
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.13 – 8.09 (m, 1H), 7.65 – 7.59 (m, 1H), 7.43 – 7.37 (m, 2H), 7.02 (t, *J* = 8.0 Hz, 2H), 6.96 – 6.85 (m, 3H), 6.34 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.92 (d, *J* = 8.0 Hz, 1H), 3.77 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.06, 157.71, 144.38, 138.77, 134.59, 128.78, 128.64, 128.37, 128.31, 126.90, 121.75, 118.29, 75.13, 52.52. HRMS (ESI) calcd. for $C_{16}H_{15}ClNO_3$ $[M+H]^+$: 304.0735, found: 304.0738.



***methyl (E)-2-((6-methylpyridin-2-yl)oxy)-4-phenylbut-3-enoate (3o)*:**

Yellow oil (108 mg, 76 %).

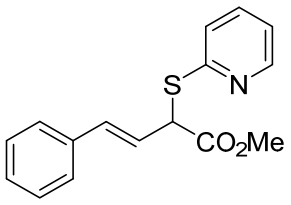
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 – 7.40 (m, 3H), 7.36 – 7.23 (m, 3H), 6.92 (d, *J* = 20.0 Hz, 1H), 6.73 (t, *J* = 8.0 Hz, 2H), 6.41 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.89 (dd, *J* =12.0, 4.0 Hz, 1H), 3.76 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.98, 161.39, 155.86, 139.20, 136.03, 134.43, 128.64, 128.30, 126.83, 122.47, 116.63, 107.62, 63.73, 52.32, 23.97. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1278.



***methyl (E)-4-phenyl-2-(pyridin-2-yloxy)pent-3-enoate (3p)*:**

A white solid (118 mg, 83 %), mp: 81-83 ^{o}C.

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.15 – 8.09 (m, 1H), 7.65 – 7.58 (m, 1H), 7.49 – 7.43 (m, 2H), 7.38 – 7.28 (m, 3H), 6.94 – 6.87 (m, 2H), 6.12 (d, *J* =12.0 Hz, 1H), 6.00 (d, *J* = 12.0 Hz, 1H), 3.76 (s, 3H), 2.29 (d, *J* = 1.2 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.20, 162.31, 146.60, 142.35, 142.17, 138.89, 128.34, 127.85, 126.03, 120.80, 117.47, 111.23, 71.70, 52.35, 17.04. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1282.

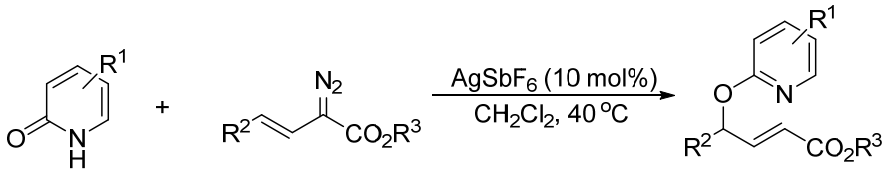


***methyl (E)-4-phenyl-2-(pyridin-2-ylthio)but-3-enoate (3q)*:**

Yellow oil (76.0 mg, 53 %).

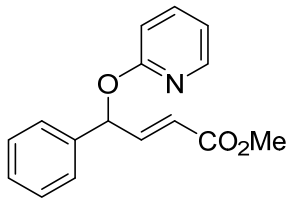
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.44 (d, *J* = 4.0 Hz, 1H), 7.53 – 7.46 (m, 1H), 7.37 (d, *J* = 12.0 Hz, 2H), 7.33 – 7.19 (m, 4H), 7.02 (dd, *J* = 8.0, 4.0 Hz, 1H), 6.74 (d, *J* = 16.0 Hz, 1H), 6.38 (dd, *J* = 16.0, 8.0 Hz, 1H), 5.41 (d, *J* = 8.0 Hz, 1H), 3.78 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.57, 161.98, 146.63, 139.05, 134.46, 134.02, 133.02, 128.85, 128.04, 122.97, 117.73, 111.20, 74.04, 52.57. HRMS (ESI) calcd. for $C_{16}H_{16}NO_2S$ $[M+H]^+$: 286.0896, found: 286.0899.

General procedure for table 3



1 **2** **B** **4**

To a schlenk tube was added $AgSbF_6$ (17.1 mg, 0.05 mmol), **1** (0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere, then a solution of **2** (0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 40 °C. The resulting mixture was stirred at 40 °C for another 4 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:60-1:10) to afford product **4**.

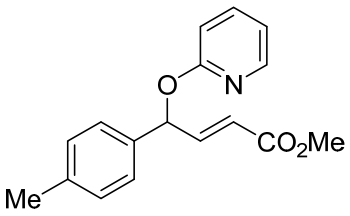


***methyl (E)-4-(pyridin-2-yloxy)-4-(p-tolyl)but-2-enoate (4a)*:**

Colorless oil (112 mg, 83 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (dd, *J* = 4.8, 1.4 Hz, 1H), 7.61 – 7.55 (m, 1H), 7.45 (d, *J* = 7.1 Hz, 2H), 7.39 – 7.28 (m, 3H), 7.16 (dd, *J* = 15.7, 4.8 Hz, 1H), 6.89 – 6.81 (m, 3H), 6.12 (dd, *J* = 15.7, 1.7 Hz, 1H), 3.72 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.75, 162.27, 146.81, 146.77, 138.92, 138.41, 128.70, 128.29, 127.39, 120.58, 117.36, 111.50, 74.62, 51.68. HRMS (ESI) calcd. for $C_{16}H_{16}NO_3$ $[M+H]^+$:

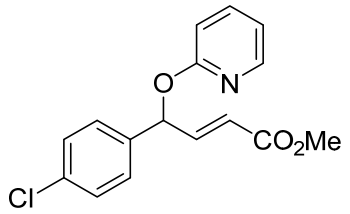
270.1125, found: 270.1128.



***methyl (E)-4-(pyridin-2-yloxy)-4-(p-tolyl)but-2-enoate (4b)*:**

Colorless oil (110 mg, 78 %).

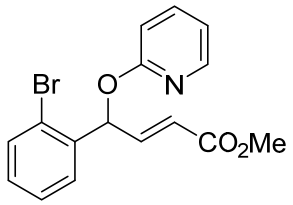
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (dd, *J* = 5.0, 1.3 Hz, 1H), 7.59 – 7.52 (m, 1H), 7.33 (d, *J* = 8.0 Hz, 2H), 7.20 – 7.12 (m, 3H), 6.83 (ddd, *J* = 17.5, 9.0, 4.4 Hz, 3H), 6.10 (dd, *J* = 15.7, 1.7 Hz, 1H), 3.71 (s, 3H), 2.33 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.79, 162.34, 146.99, 146.77, 138.87, 138.14, 135.40, 129.38, 127.41, 120.41, 117.28, 111.51, 74.52, 51.64, 21.21. HRMS (ESI) calcd. for $C_{17}H_{18}NO_3$ $[M+H]^+$: 284.1281, found: 284.1284.



***methyl (E)-4-(4-chlorophenyl)-4-(pyridin-2-yloxy)but-2-enoate (4c)*:**

Colorless oil (105 mg, 69 %).

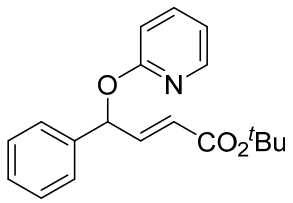
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (dd, *J* = 4.9, 1.5 Hz, 1H), 7.63 – 7.54 (m, 1H), 7.38 (d, *J* = 8.5 Hz, 2H), 7.33 (d, *J* = 8.5 Hz, 2H), 7.11 (dd, *J* = 15.7, 4.7 Hz, 1H), 6.90 – 6.85 (m, 1H), 6.84 – 6.76 (m, 2H), 6.12 (dd, *J* = 15.7, 1.6 Hz, 1H), 3.73 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.61, 162.02, 146.75, 146.20, 139.02, 137.03, 134.10, 128.88, 128.79, 120.95, 117.54, 111.45, 73.88, 51.75. HRMS (ESI) calcd. for $C_{16}H_{15}ClNO_3$ $[M+H]^+$: 304.0735, found: 304.0738.



***methyl (E)-4-(2-bromophenyl)-4-(pyridin-2-yloxy)but-2-enoate (4d)*:**

A white solid (101 mg, 58 %), mp: 74-76 ^{o}C.

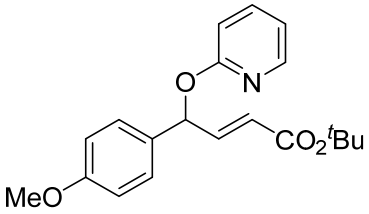
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (d, *J* = 4.9 Hz, 1H), 7.63 – 7.54 (m, 2H), 7.51 (d, *J* = 7.8 Hz, 1H), 7.30 (t, *J* = 7.8 Hz, 1H), 7.22 – 7.10 (m, 3H), 6.90 – 6.81 (m, 2H), 6.14 (d, *J* = 14.8 Hz, 1H), 3.72 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.70, 161.90, 147.05, 145.11, 138.92, 138.06, 132.92, 129.56, 128.52, 127.87, 122.78, 121.05, 117.52, 111.13, 73.70, 51.71. HRMS (ESI) calcd. for $C_{16}H_{15}BrNO_3$ $[M+H]^+$: 348.0230, found: 348.0227.



***tert-butyl (E)-4-phenyl-4-(pyridin-2-yloxy)but-2-enoate (4e)*:**

Colorless oil (132 mg, 85 %).

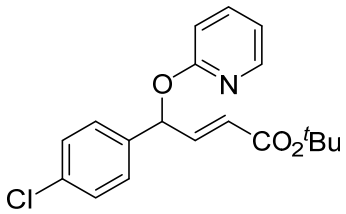
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 – 8.08 (m, 1H), 7.61 – 7.53 (m, 1H), 7.45 (d, *J* = 7.3 Hz, 2H), 7.40 – 7.28 (m, 3H), 7.05 (dd, *J* = 15.6, 4.8 Hz, 1H), 6.88 – 6.80 (m, 3H), 6.02 (dd, *J* = 15.6, 1.5 Hz, 1H), 1.46 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.62, 162.33, 146.79, 145.24, 138.87, 138.74, 128.65, 128.17, 127.38, 122.86, 117.28, 111.53, 80.60, 74.67, 28.10. HRMS (ESI) calcd. for $C_{19}H_{22}NO_3$ $[M+H]^+$: 312.1594, found: 312.1598.



***tert-butyl (E)-4-(4-methoxyphenyl)-4-(pyridin-2-yloxy)but-2-enoate (4f)*:**

A white solid (128 mg, 75 %), mp: 90-92 °C.

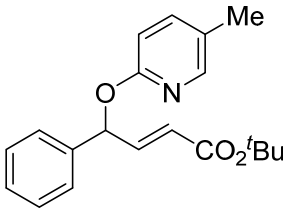
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (d, *J* = 4.3 Hz, 1H), 7.60 (t, *J* = 7.7 Hz, 1H), 7.38 (d, *J* = 8.6 Hz, 2H), 6.93 – 6.81 (m, 5H), 6.27 (dd, *J* = 15.9, 6.8 Hz, 1H), 5.73 (d, *J* = 6.8 Hz, 1H), 3.82 (s, 3H), 1.44 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.43, 162.33, 159.62, 146.44, 138.80, 133.67, 129.01, 128.05, 120.51, 117.37, 113.99, 111.17, 81.81, 75.09, 55.32, 27.96. HRMS (ESI) calcd. for $C_{20}H_{24}NO_4$ $[M+H]^+$: 342.1700, found: 342.1703.



***tert-butyl (E)-4-(4-chlorophenyl)-4-(pyridin-2-yloxy)but-2-enoate (4g)*:**

Colorless oil (111 mg, 64 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (d, *J* = 4.5 Hz, 1H), 7.63 – 7.54 (m, 1H), 7.39 (d, *J* = 8.4 Hz, 2H), 7.32 (d, *J* = 8.4 Hz, 2H), 7.00 (dd, *J* = 15.6, 4.8 Hz, 1H), 6.90 – 6.77 (m, 3H), 6.01 (d, *J* = 15.6 Hz, 1H), 1.46 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.47, 162.09, 146.76, 144.66, 138.96, 137.34, 133.96, 128.82, 128.77, 123.24, 117.45, 111.48, 80.74, 73.94, 28.09. HRMS (ESI) calcd. for $C_{19}H_{21}ClNO_3$ $[M+H]^+$: 346.1204, found: 346.1207.

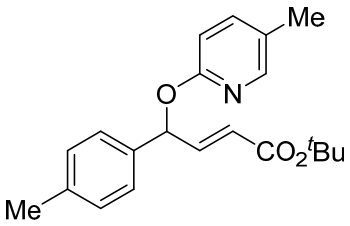


***tert-butyl (E)-4-((5-methylpyridin-2-yl)oxy)-4-phenylbut-2-enoate (4h)*:**

A white solid (132 mg, 81 %), mp: 92-94 °C.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (s, 1H), 7.44 (d, *J* = 7.2 Hz, 2H), 7.37 (dd, *J* = 17.4, 9.2 Hz, 3H), 7.30 (d, *J* = 7.2 Hz, 1H), 7.04 (dd, *J* = 15.6, 4.8 Hz, 1H), 6.75 (dd, *J* = 11.0, 6.6 Hz, 2H), 6.01 (d, *J* = 15.6 Hz, 1H), 2.22 (s, 3H), 1.46 (s, 9H). ^{13}C NMR

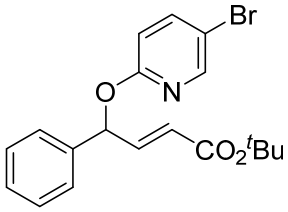
(125 MHz, $CDCl_3$) δ 165.65, 160.60, 146.21, 145.41, 139.89, 138.92, 128.62, 128.09, 127.34, 126.23, 122.80, 110.86, 80.54, 74.66, 28.10, 17.42. HRMS (ESI) calcd. for $C_{20}H_{24}NO_3$ $[M+H]^+$: 326.1751, found: 326.1755.



***tert-butyl (E)-4-((5-methylpyridin-2-yl)oxy)-4-(p-tolyl)but-2-enoate (4i)*:**

Colorless oil (141 mg, 83 %).

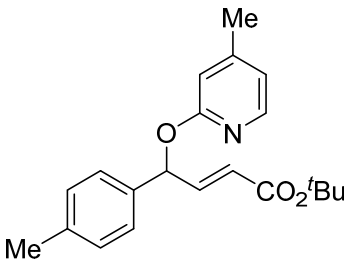
^1H NMR (400 MHz, $CDCl_3$) δ 7.90 (s, 1H), 7.40 – 7.35 (m, 1H), 7.33 (d, *J* = 8.0 Hz, 2H), 7.16 (d, *J* = 8.0 Hz, 2H), 7.03 (dd, *J* = 15.6, 4.8 Hz, 1H), 6.75 – 6.69 (m, 2H), 5.99 (dd, *J* = 15.6, 1.6 Hz, 1H), 2.33 (s, 3H), 2.21 (s, 3H), 1.45 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.69, 160.65, 146.20, 145.58, 139.85, 137.92, 135.89, 129.31, 127.35, 126.14, 122.61, 110.87, 80.48, 74.55, 28.10, 21.21, 17.43. HRMS (ESI) calcd. for $C_{21}H_{26}NO_3$ $[M+H]^+$: 340.1907, found: 340.1904.



***tert-butyl (E)-4-((5-bromopyridin-2-yl)oxy)-4-phenylbut-2-enoate (4j)*:**

A white solid (103 mg, 53 %), mp: 134-136 °C.

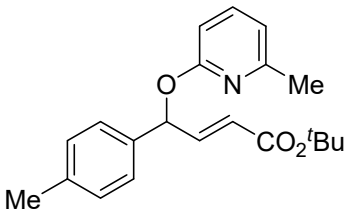
^1H NMR (400 MHz, $CDCl_3$) δ 8.14 (s, 1H), 7.70 – 7.59 (m, 1H), 7.46 – 7.28 (m, 5H), 7.01 (dd, *J* = 15.6, 4.9 Hz, 1H), 6.73 (dd, *J* = 12.8, 6.7 Hz, 2H), 6.00 (d, *J* = 15.6 Hz, 1H), 1.46 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.48, 161.17, 147.43, 144.62, 141.44, 138.30, 128.70, 128.36, 127.39, 123.15, 113.11, 112.25, 80.71, 75.40, 28.10. HRMS (ESI) calcd. for $C_{19}H_{21}BrNO_3$ $[M+H]^+$: 390.0699, found: 390.0695.



***tert-butyl (E)-4-((4-methylpyridin-2-yl)oxy)-4-(p-tolyl)but-2-enoate (4k)*:**

A yellow solid (127 mg, 75 %), mp: 78-80 °C.

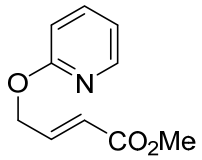
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95 (d, *J* = 5.2 Hz, 1H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.16 (d, *J* = 8.1 Hz, 2H), 7.03 (dd, *J* = 15.6, 4.7 Hz, 1H), 6.77 (dd, *J* = 4.7, 1.6 Hz, 1H), 6.70 – 6.65 (m, 1H), 6.65 – 6.61 (m, 1H), 5.99 (dd, *J* = 15.6, 1.7 Hz, 1H), 2.33 (s, 3H), 2.28 (s, 3H), 1.45 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.67, 162.74, 150.16, 146.30, 145.55, 137.90, 135.91, 129.31, 127.35, 122.64, 118.75, 111.60, 80.46, 74.46, 28.11, 21.20, 20.90. HRMS (ESI) calcd. for $C_{21}H_{26}NO_3$ $[M+H]^+$: 340.1907, found: 340.1904.



***tert-butyl (E)-4-((6-methylpyridin-2-yl)oxy)-4-(p-tolyl)but-2-enoate (4l)*:**

Colorless oil (100 mg, 59 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (t, *J* = 7.7 Hz, 1H), 7.35 (d, *J* = 7.9 Hz, 2H), 7.16 (d, *J* = 7.9 Hz, 2H), 7.03 (dd, *J* = 15.6, 4.8 Hz, 1H), 6.81 (d, *J* = 4.8 Hz, 1H), 6.68 (d, *J* = 7.2 Hz, 1H), 6.57 (d, *J* = 8.2 Hz, 1H), 6.02 (dd, *J* = 15.6, 1.0 Hz, 1H), 2.39 (s, 3H), 2.33 (s, 3H), 1.46 (s, 9H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.78, 161.75, 156.09, 145.67, 138.97, 137.87, 135.97, 129.25, 127.57, 122.66, 116.18, 107.84, 80.46, 74.22, 28.11, 24.13, 21.22. HRMS (ESI) calcd. for $C_{21}H_{26}NO_3$ $[M+H]^+$: 340.1907, found: 340.1904.



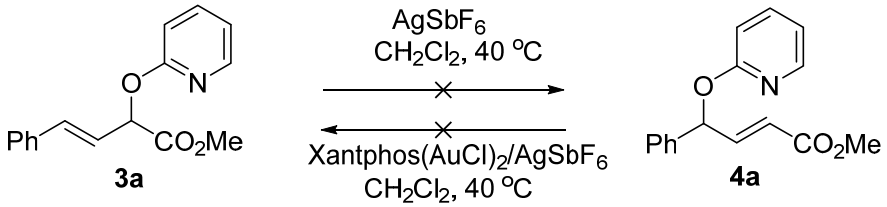
***methyl (E)-4-(pyridin-2-yloxy)but-2-enoate (4o)*:**

Yellow oil (52 mg, 54 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (d, *J* = 4.8 Hz, 1H), 7.60 (t, *J* = 7.6 Hz, 1H), 7.13 (dt, *J* = 16.0, 4.1 Hz, 1H), 6.94 – 6.86 (m, 1H), 6.80 (d, *J* = 8.3 Hz, 1H), 6.14 (d, *J* = 16.0 Hz, 1H), 5.04 (d, *J* = 2.0 Hz, 2H), 3.75 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.65, 162.79, 146.80, 143.40, 138.85, 121.13, 117.28, 111.15, 63.82, 51.64. HRMS (ESI) calcd. for $C_{10}H_{12}NO_3$ $[M+H]^+$: 194.0812, found: 194.0815.

Control experiments for Scheme 2

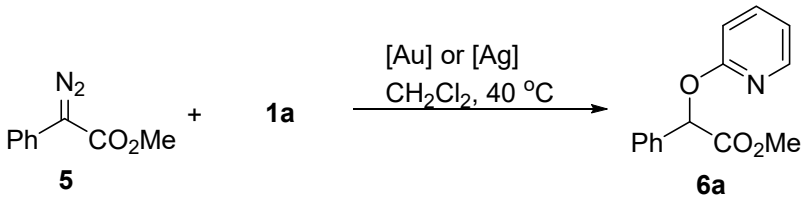
Scheme 2 - a:



To a schlenk tube was added $AgSbF_6$ (3.4 mg, 0.01 mmol), **3a** (27 mg, 0.1 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere. The resulting mixture was stirred at 40 ^{o}C for 4 h. The mixture was concentrated under vacuum and purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:20) to recovered **3a** (25.5 mg).

To a schlenk tube was added Xantphos$(AuCl)_2$ (5.2 mg, 0.005 mmol), $AgSbF_6$ (3.4 mg, 0.01 mmol), **4a** (27 mg, 0.1 mmol) and dry CH_2Cl_2 (2 mL) under argon atmosphere; the resulting solution was stirred at 40 ^{o}C for 4 h. The mixture was concentrated under vacuum and purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:15) to recovered **4a** (26 mg).

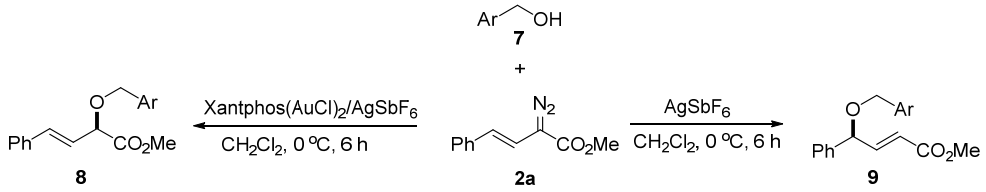
Scheme 2 - b:



To a schlenk tube was added Xantphos$(AuCl)_2$ (26 mg, 0.025 mmol), $AgSbF_6$ (17.1 mg, 0.05 mmol), **1a** (57 mg, 0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere, the mixture was stirred at room temperature for 30 min; then a solution of **5** (88 mg, 0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 40 °C. The resulting mixture was stirred at 40 °C for another 4 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:15) to give **6a** (112 mg, yield: 92 %) as colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, J = 4.7 Hz, 1H), 7.66 – 7.55 (m, 3H) 3H), 7.45 – 7.3 (m, 3H), 6.91 (dd, J = 14.2, 7.4 Hz, 2H), 6.23 (s, 1H), 3.71 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.89, 162.35, 146.62, 138.94, 135.15, 128.97, 128.74, 127.70, 117.63, 111.34, 75.58, 52.41. HRMS (ESI) calcd. for $C_{14}H_{14}NO_3$ $[M+H]^+$: 244.0968, found: 244.0965.

To a schlenk tube was added $AgSbF_6$ (17.1 mg, 0.05 mmol), **1a** (57 mg, 0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere, then a solution of **5** (0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 40 °C. The resulting mixture was stirred at 40 °C for another 4 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:15) to afford product **6a** (109 mg, yield: 90 %) as colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, J = 4.7 Hz, 1H), 7.66 – 7.55 (m, 3H) 3H), 7.45 – 7.3 (m, 3H), 6.91 (dd, J = 14.2, 7.4 Hz, 2H), 6.23 (s, 1H), 3.71 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.89, 162.35, 146.62, 138.94, 135.15, 128.97, 128.74, 127.70, 117.63, 111.34, 75.58, 52.41. HRMS (ESI) calcd. for $C_{14}H_{14}NO_3$ $[M+H]^+$: 244.0968, found: 244.0965.

Carbene insertion into O-H bonds of benzyl alcohols for Scheme 3

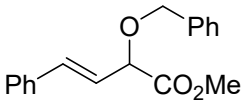


General procedure for gold-catalyzed O-H insertion of benzyl alcohols:

To a schlenk tube was added Xantphos(AuCl)$_2$ (26 mg, 0.025 mmol), $AgSbF_6$ (17.1 mg, 0.05 mmol), **7** (0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere, the mixture was stirred at room temperature for 30 min. The reaction was cooled to 0 ^oC and a solution of **2a** (101 mg, 0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 0 ^oC. The resulting mixture was stirred at 0 ^oC for 6 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:30-1:20) to afford product **8**.

General procedure B for silver-catalyzed O-H insertion of benzyl alcohols:

To a schlenk tube was added $AgSbF_6$ (17.1 mg, 0.05 mmol), **7** (0.6 mmol) and dry CH_2Cl_2 (2.5 mL) under argon atmosphere at 0 ^oC, then a solution of **2a** (101 mg, 0.5 mmol) in dry CH_2Cl_2 (2.5 mL) was added via syringe pump over 30 min at 0 ^oC. The resulting mixture was stirred at 0 ^oC for 6 h. The mixture was concentrated under vacuum; the crude residue was purified by column chromatography (silica gel, eluted with EtOAc: Petroleum ether=1:20-1:15) to afford product **9**.

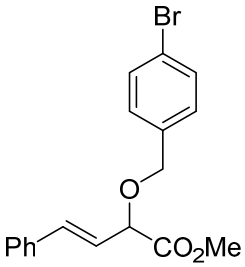


methyl (E)-2-(benzyloxy)-4-phenylbut-3-enoate (8a)[3]**:**

Yellow oil (95 mg, 67 %).

^1H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.21 (m, 10H), 6.77 (d, J = 16.0 Hz, 1H), 6.25 (dd, J = 16.0, 6.9 Hz, 1H), 4.75 – 4.55 (m, 3H), 3.78 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.14, 137.15, 135.91, 134.44, 128.64, 128.52, 128.29, 128.07, 127.99,

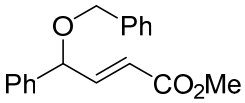
126.77, 123.71, 78.58, 71.33, 52.37.



***methyl (E)-2-((4-bromobenzyl)oxy)-4-phenylbut-3-enoate (8b)*:**

Yellow oil (105 mg, 58 %).

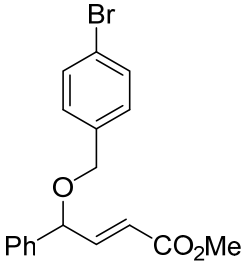
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (d, *J* = 7.9 Hz, 2H), 7.40 (d, *J* = 7.6 Hz, 2H), 7.36 – 7.23 (m, 5H), 6.75 (d, *J* = 15.9 Hz, 1H), 6.24 (dd, *J* = 15.9, 7.0 Hz, 1H), 4.66 – 4.54 (m, 3H), 3.78 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.93, 136.26, 135.80, 134.65, 131.64, 129.64, 128.67, 128.39, 126.79, 123.46, 121.90, 78.79, 70.56, 52.41. HRMS (ESI) calcd. for $C_{18}H_{18}BrO_3$ $[M+H]^+$: 361.0434, found: 361.0438.



***methyl (E)-4-(benzyloxy)-4-phenylbut-2-enoate (9a)*[3]:**

Yellow oil (96 mg, 68 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 – 7.24 (m, 10H), 7.01 (dd, *J* = 15.6, 5.2 Hz, 1H), 6.15 (d, *J* = 15.6 Hz, 1H), 4.98 (d, *J* = 5.2 Hz, 1H), 4.49 (q, *J* = 12.1 Hz, 2H), 3.71 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.83, 147.78, 138.91, 137.87, 128.83, 128.47, 128.39, 127.76, 127.65, 127.30, 120.49, 79.72, 70.39, 51.66.



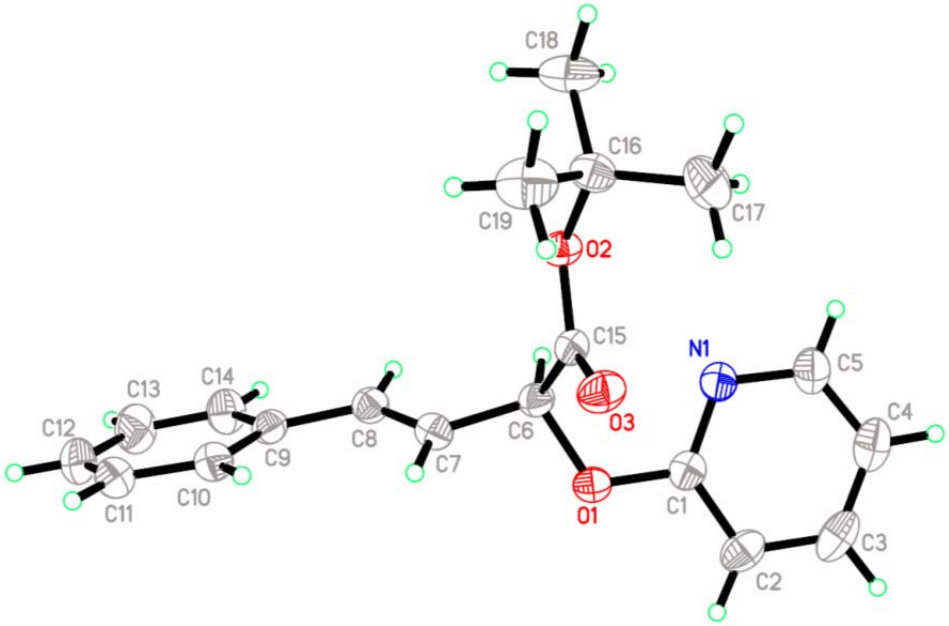
***methyl (E)-4-((4-bromobenzyl)oxy)-4-phenylbut-2-enoate (9b)*:**

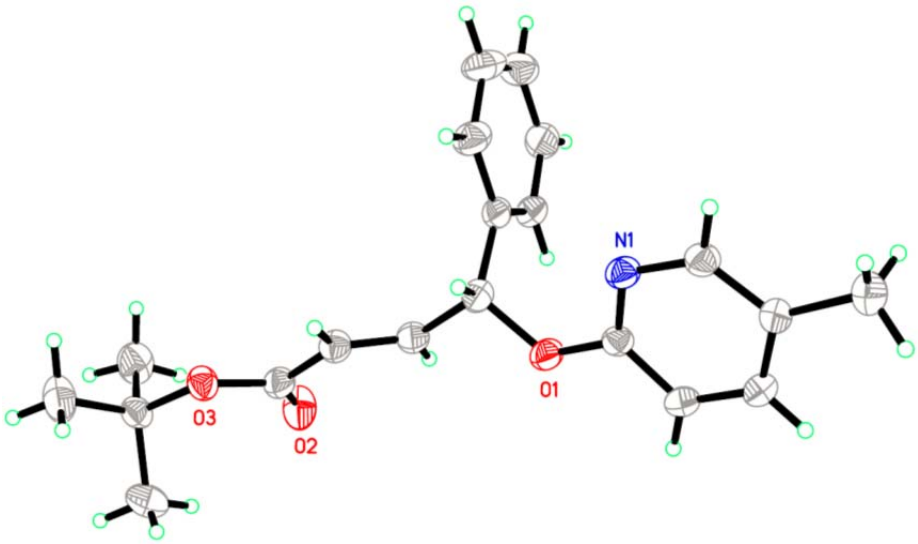
Yellow oil (116 mg, 64 %).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.1 Hz, 2H), 7.41 – 7.28 (m, 5H), 7.19 (d, *J* = 8.1 Hz, 2H), 6.99 (dd, *J* = 15.6, 5.2 Hz, 1H), 6.13 (d, *J* = 15.6 Hz, 1H), 4.96 (d, *J* = 5.1 Hz, 1H), 4.43 (q, *J* = 12.1 Hz, 2H), 3.72 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.72, 147.45, 138.65, 136.90, 131.57, 129.24, 128.88, 128.50, 127.25, 121.61, 120.59, 79.94, 69.65, 51.69. HRMS (ESI) calcd. for $C_{18}H_{18}BrO_3$ $[M+H]^+$: 361.0434, found: 361.0438.

X-ray structure of 3d and 4h

The crystal structures have been deposited at the Cambridge Crystallographic Data Centre (CCDC 1445771, **3d**) and (CCDC 1523822, **4h**). The data can be obtained free of charge via the internet at www.ccdc.cam.ac.uk/data_request/cif.



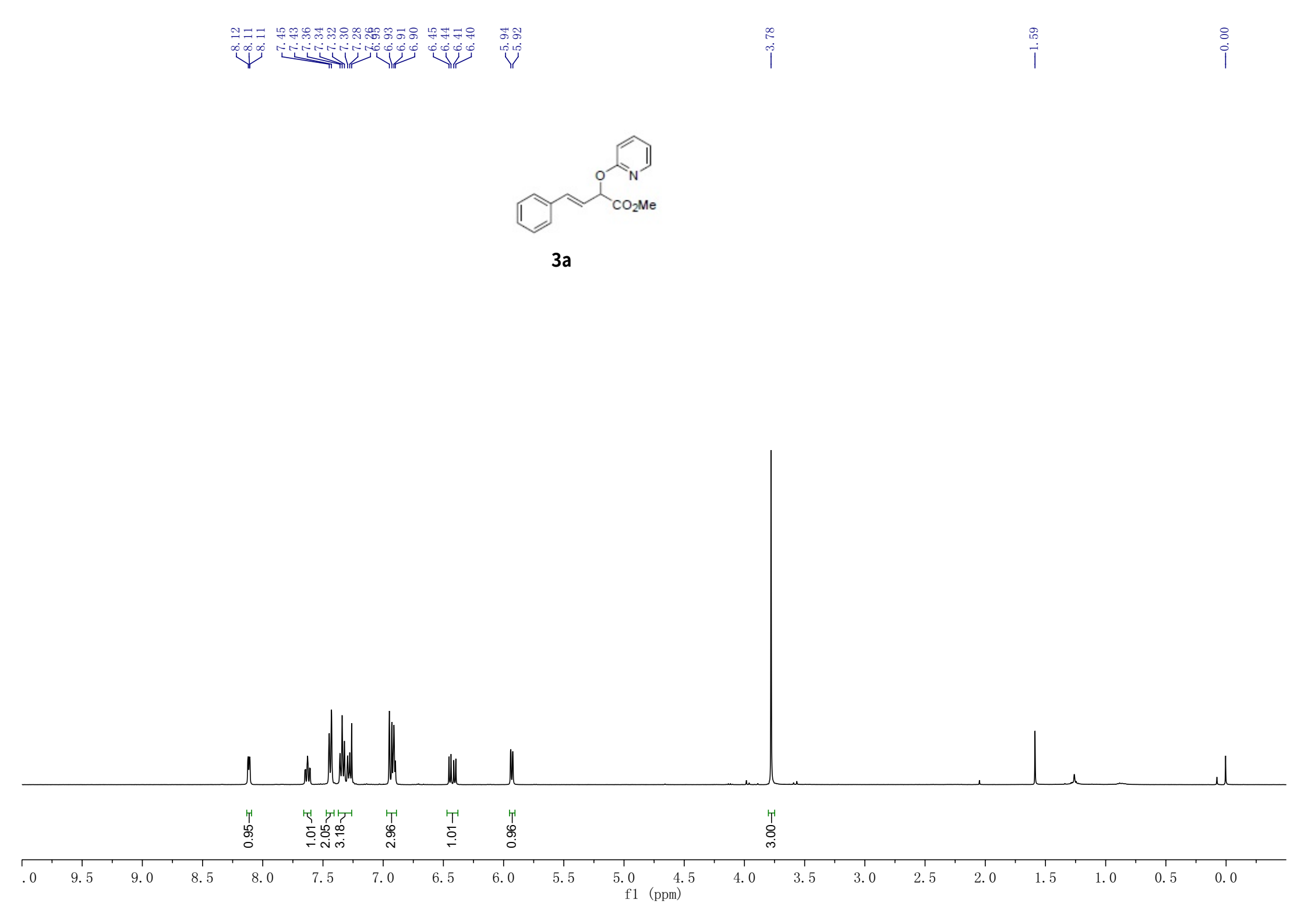


References:

[1] (a) Huang, L.; Yang, H.-B.; Zhang, D.-H.; Zhang, Zh.; Tang, X.-Y.; Xu, Q.; Shi, M. *Angew. Chem. Int. Ed.* **2013**, *52*, 6767. (b) Handa, S.; Lippincott, D. J.; Aue, D. H.; Lipshutz, B. H. *Angew. Chem. Int. Ed.* **2014**, *53*, 10658. (c) LaLonde, R. L.; Wang, Z. J.; Mba, M.; Lackner, A. D.; Toste, F. D. *Angew. Chem. Int. Ed.* **2010**, *49*, 598. (d) Deák, A.; Megyes, T.; Tárkányi, G.; Király, P.; Biczók, L.; Pálinkás, G.; Stang, P. J. *J. Am. Chem. Soc*. **2006**, *128*, 12668.

[2] (a) Manning, J. R.; Davies, H. M. L. *J. Am. Chem. Soc*. **2008**, *130*, 8602. (b) Manning, J. R.; Davies, H. M. L. *Org. Synth.* **2007**, *84*, 334. (c) Davies, H. M. L.; Yang, J.; Manning, J. R. *Tetrahedron: Asymmetry* **2006**, *17*, 665. (d) Davies, H. M. L.; Smith, H. D.; Hu, B.; Klenzak, S. M.; Hegner, F. J. *J. Org. Chem.* **1992**, *57*, 6900. (e) Wang, H.; Guptill, D. M.; Varela-Alvarez, A.; Musaev, D. G.; Davies, H. M. L. *Chem. Sci.* **2013**, *4*, 2844.

[3] Hansen, J. H.; Davies, H. M. L. *Chem. Sci.* **2011**, *2*, 457.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6.90
6.45
6.44
6.41
6.40
5.94
5.92
3.78
1.59
0.00
O
N
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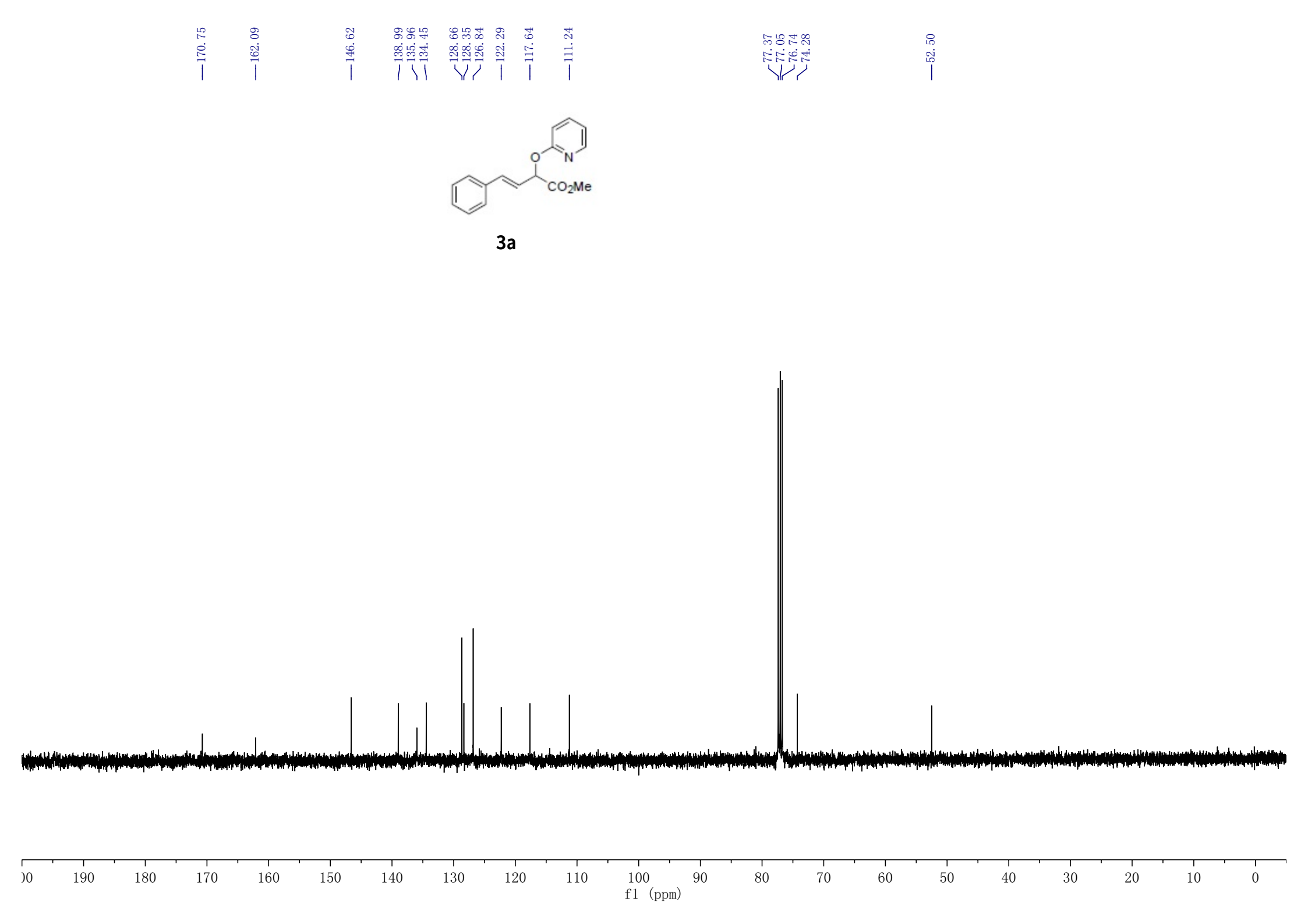
1.01
2.05
3.18
2.96
1.01
0.96
3.00
f1 (ppm)

3a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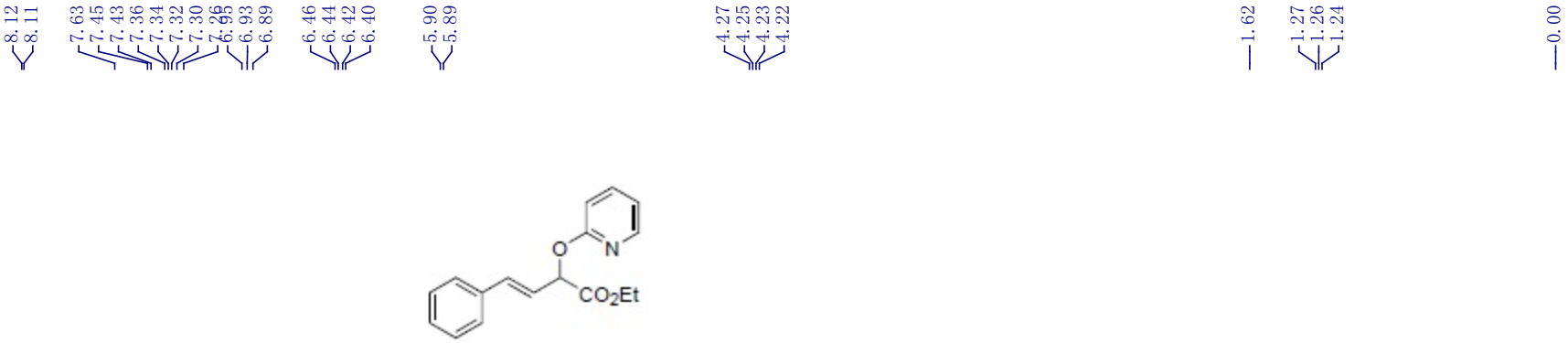
52.50
O
N
CO2Me
3a
f1 (ppm)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5.89
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4.25
4.23
4.22
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1.26
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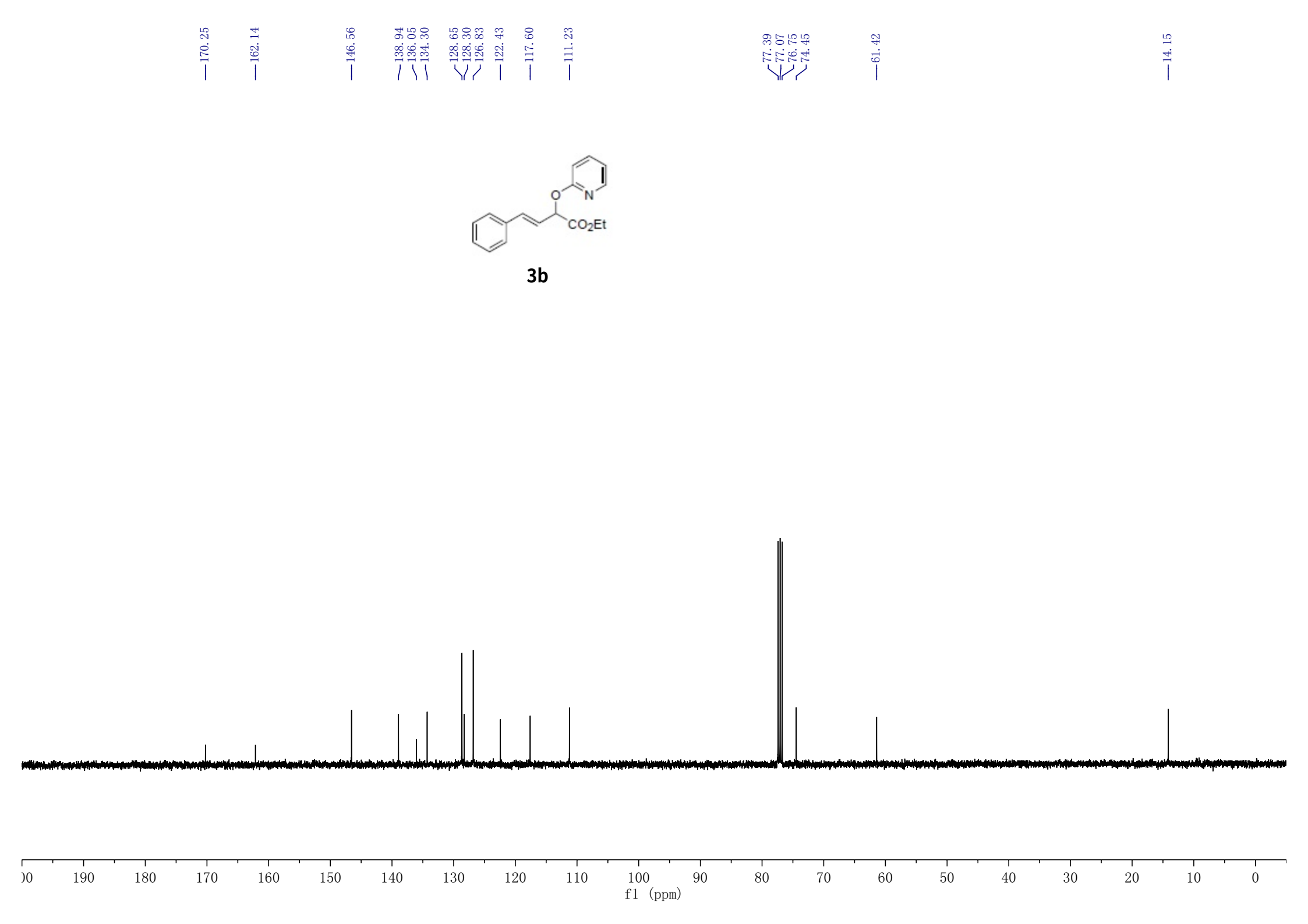
f1 (ppm)

3b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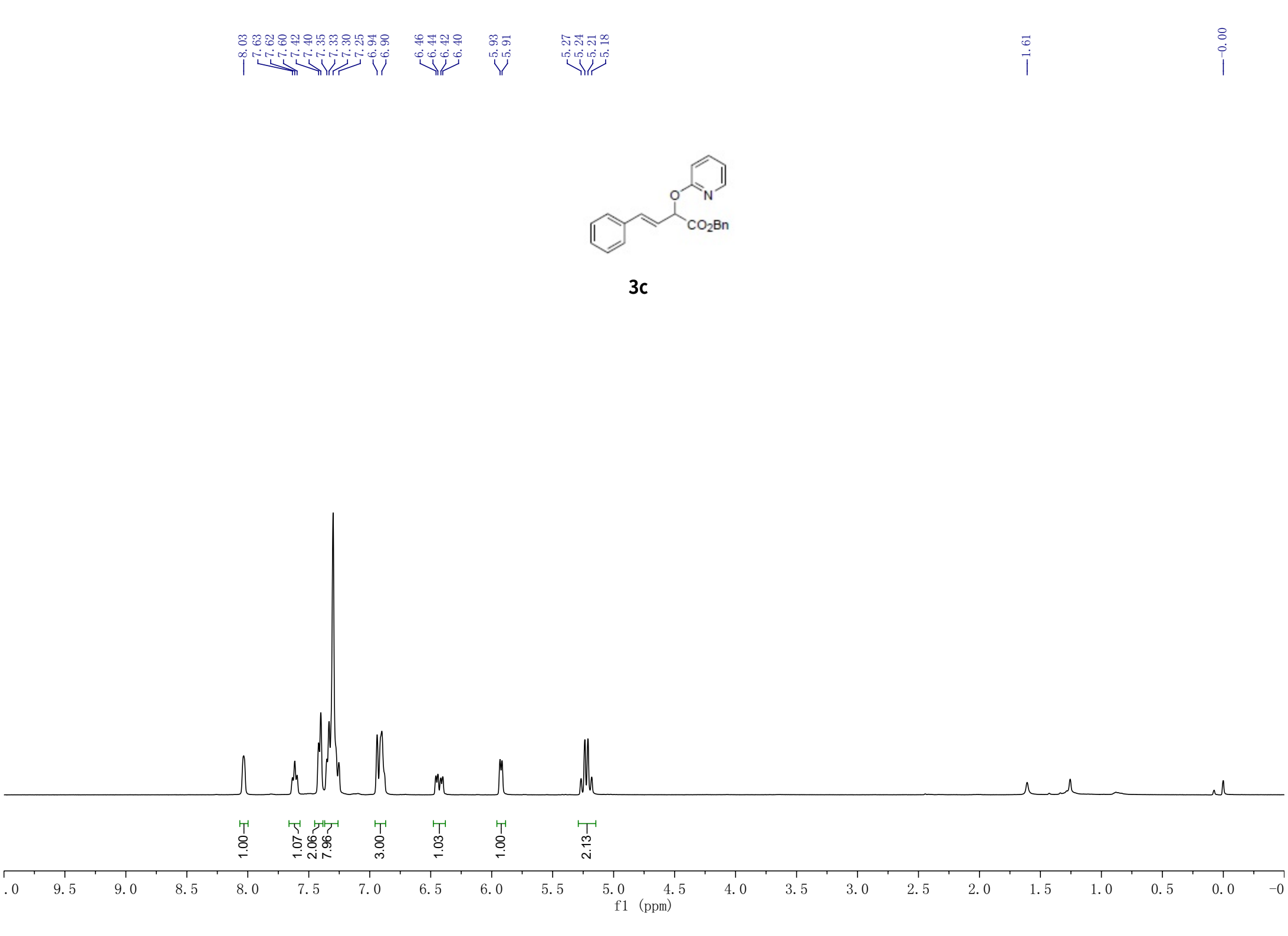
14.15
O
N
CO2Et
3b
f1 (ppm)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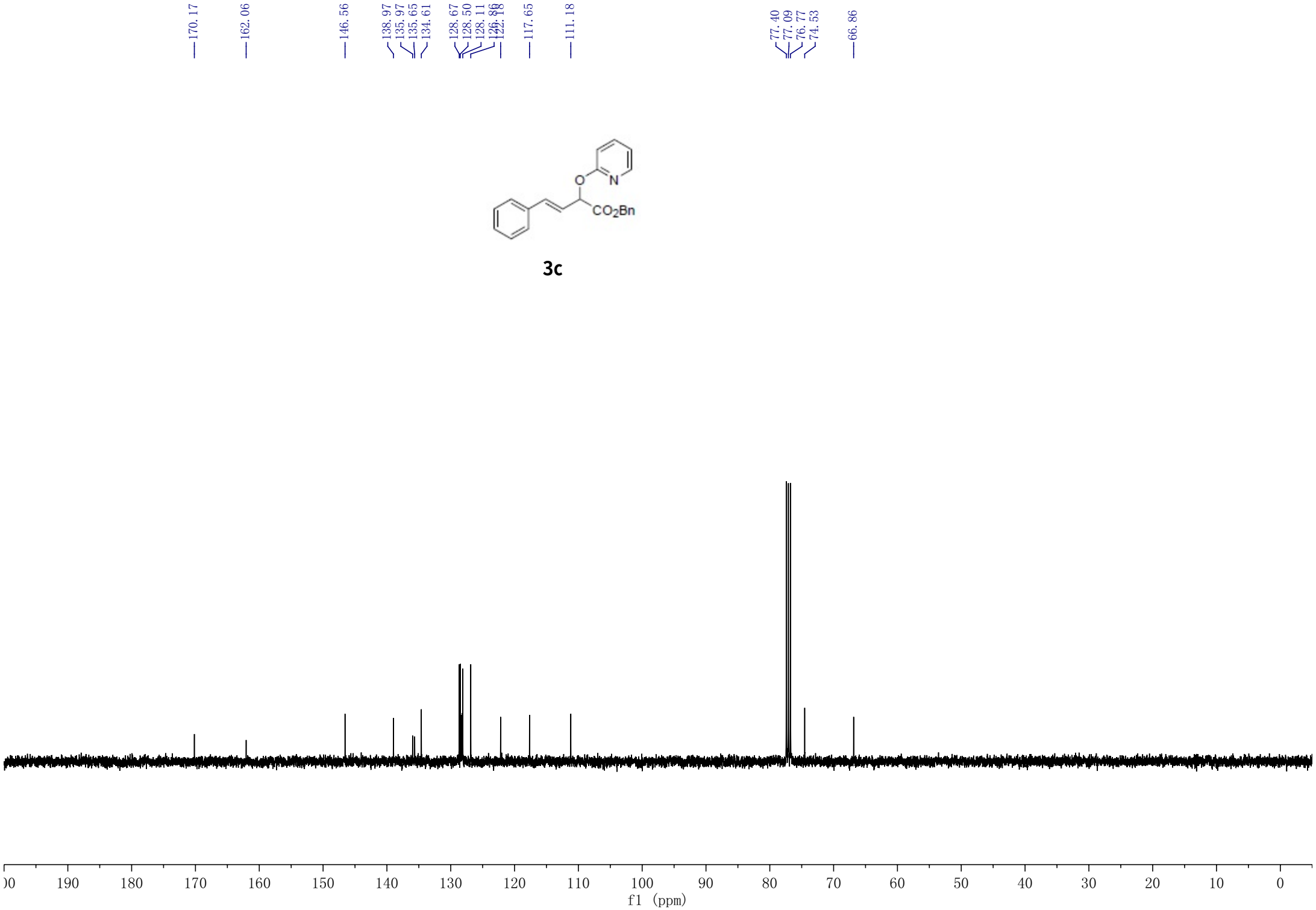
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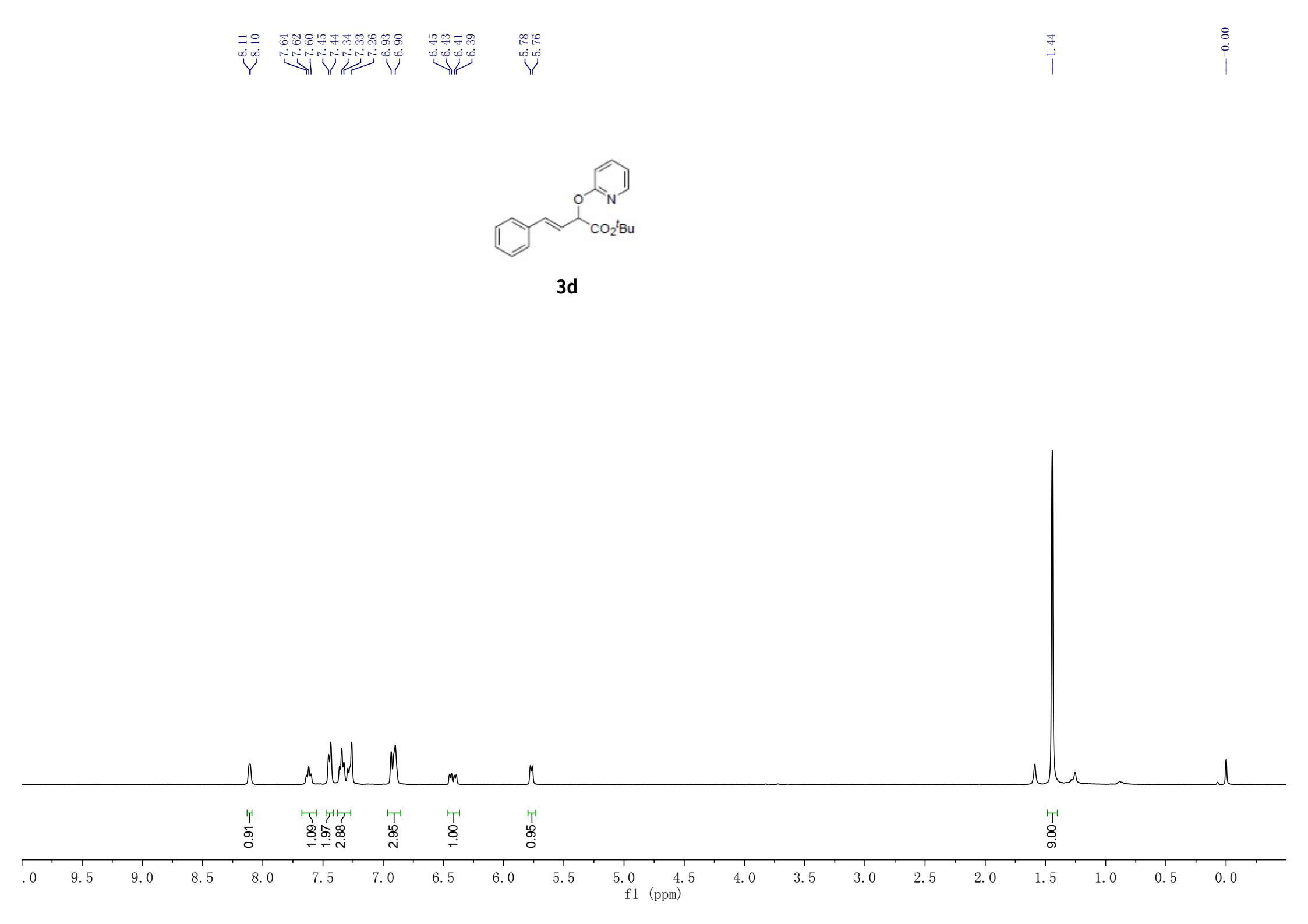
CO2Bn
3c
f1 (ppm)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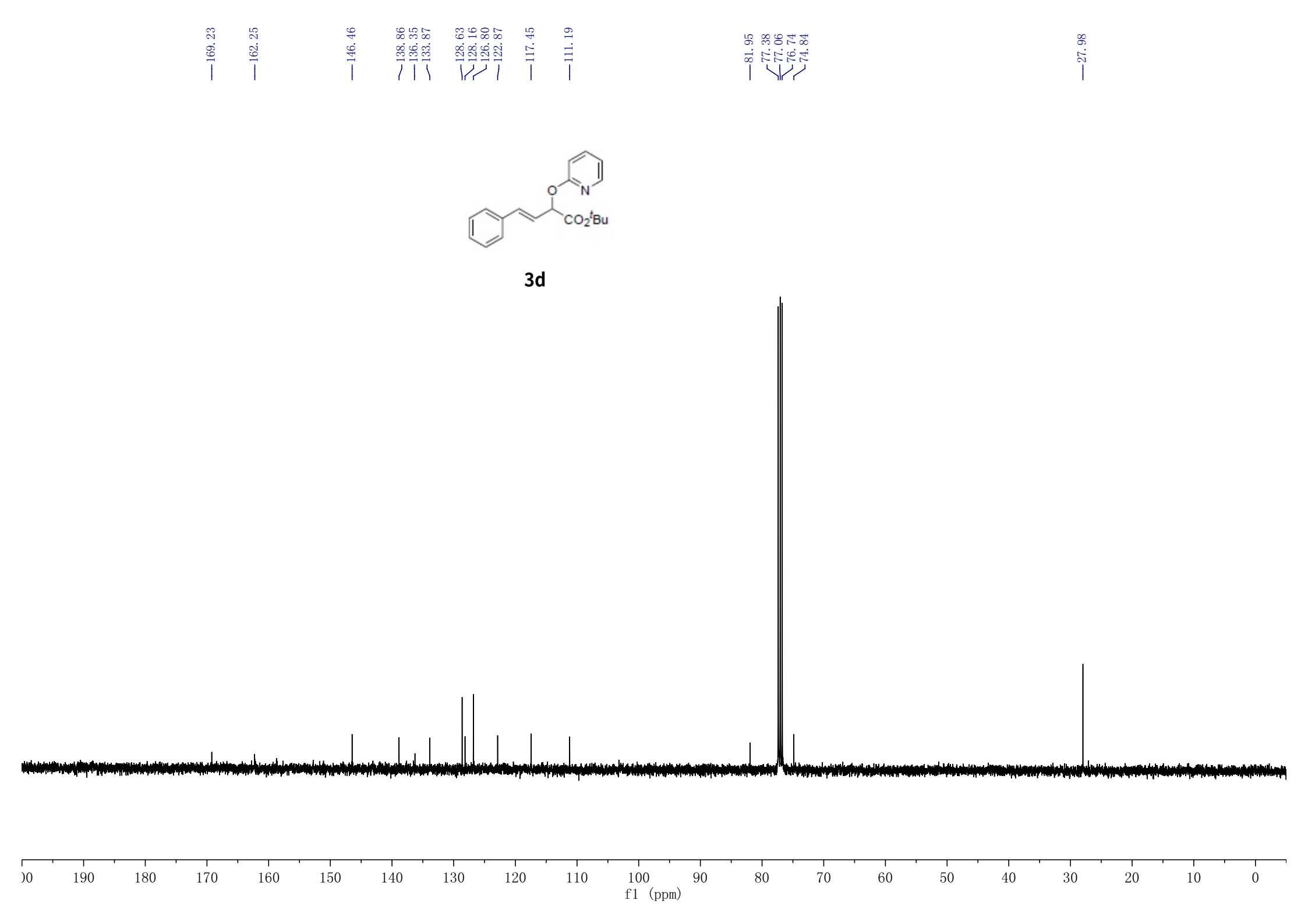
3d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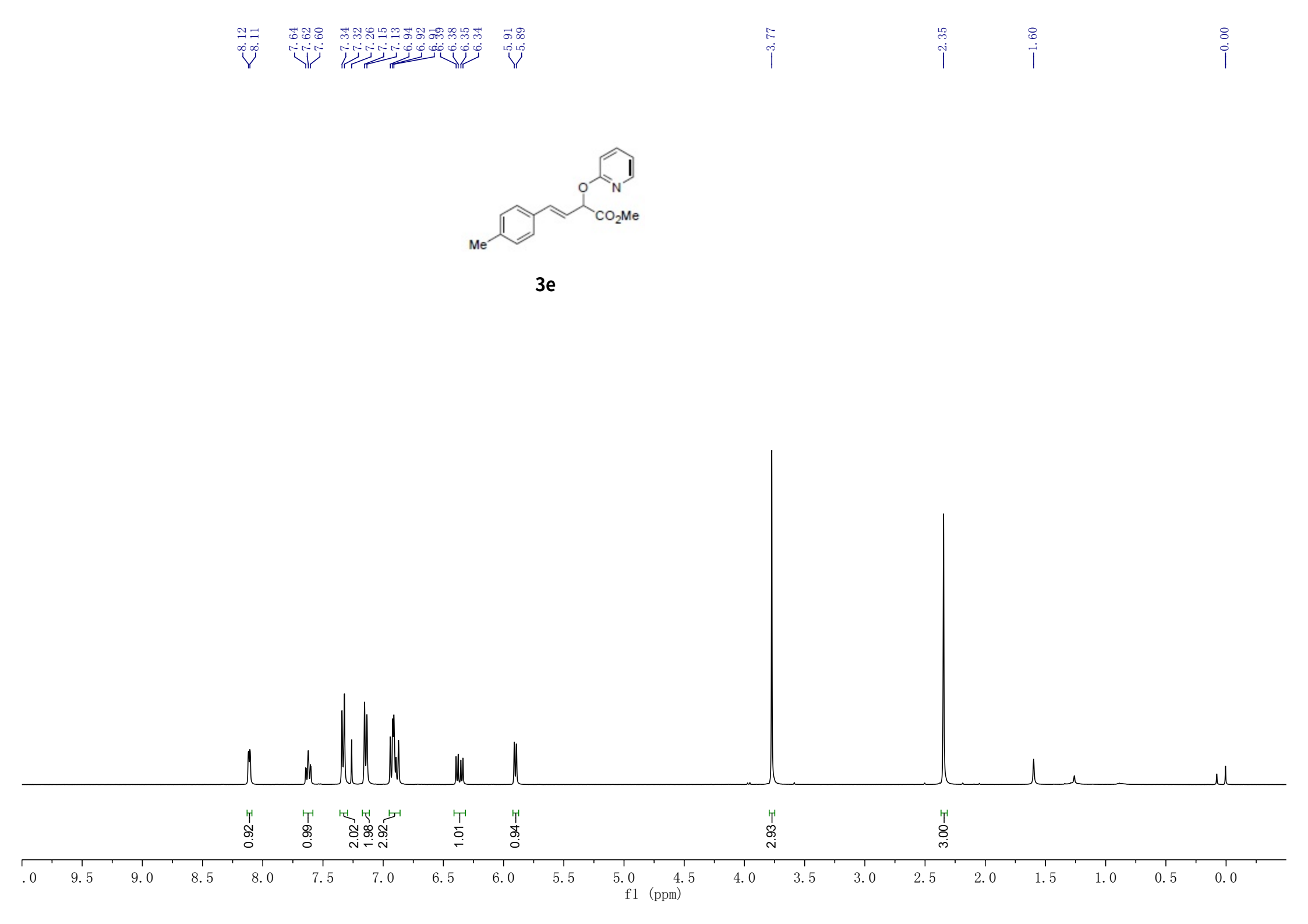
f1 (ppm)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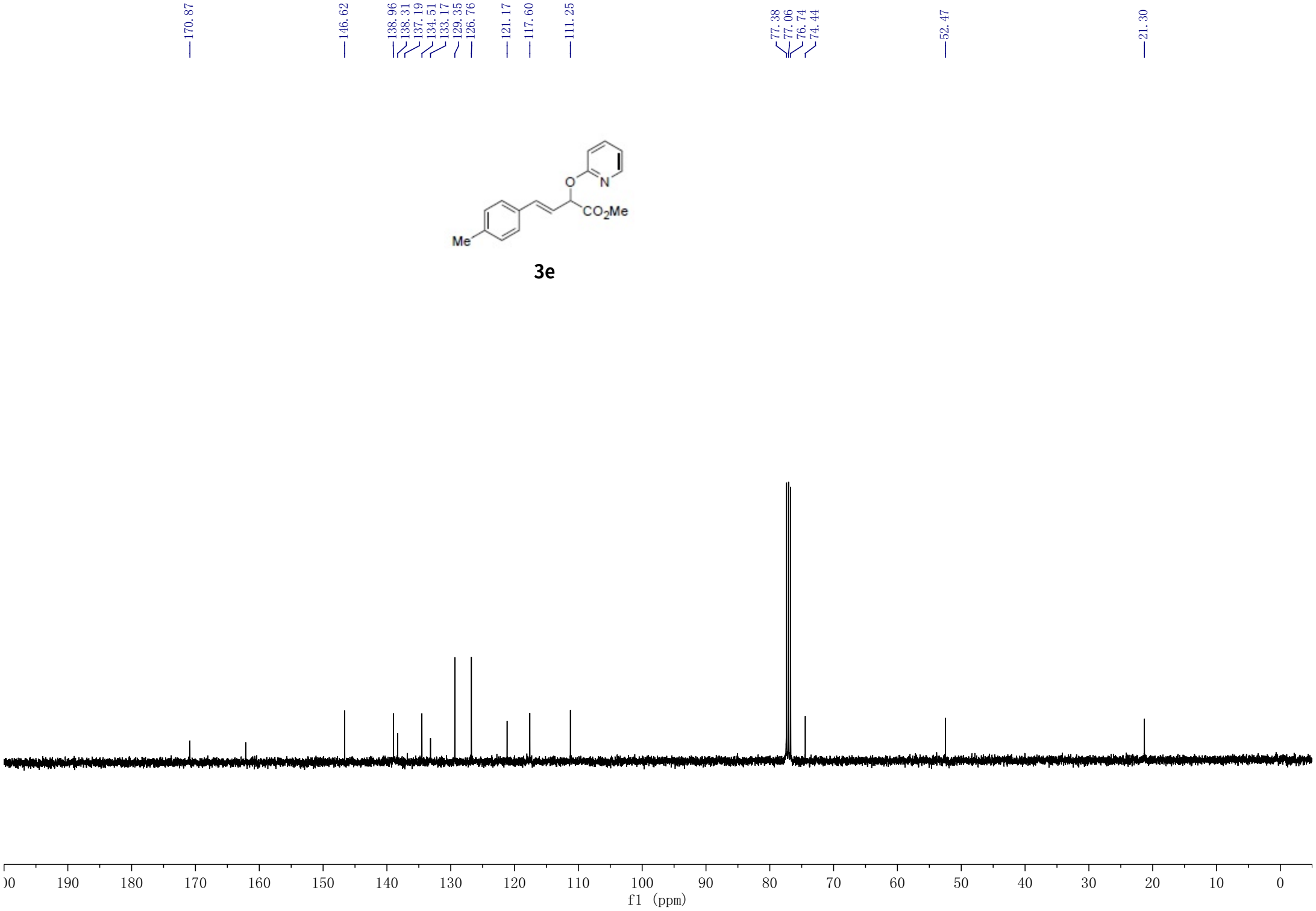
f1 (ppm)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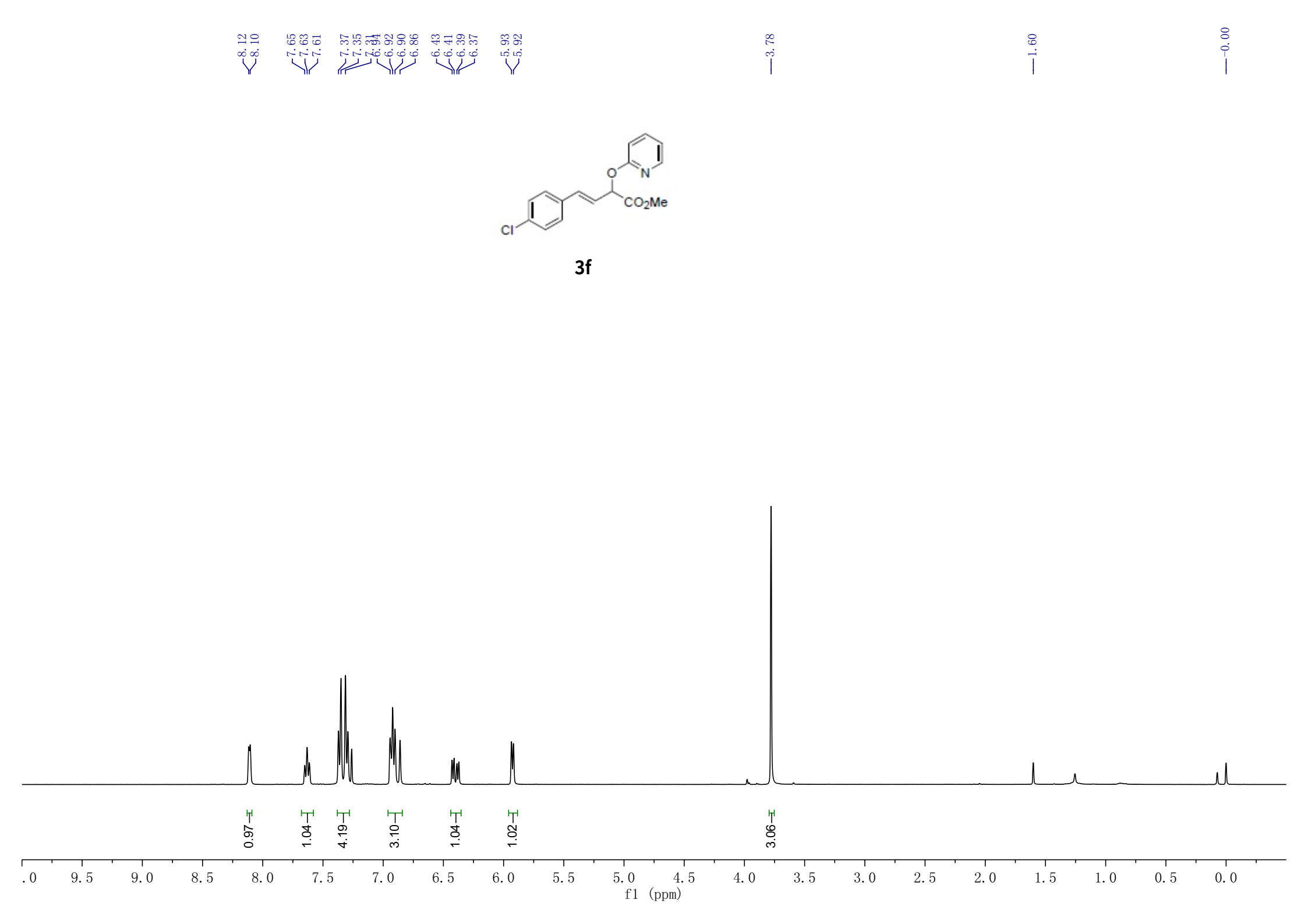
f1 (ppm)

3e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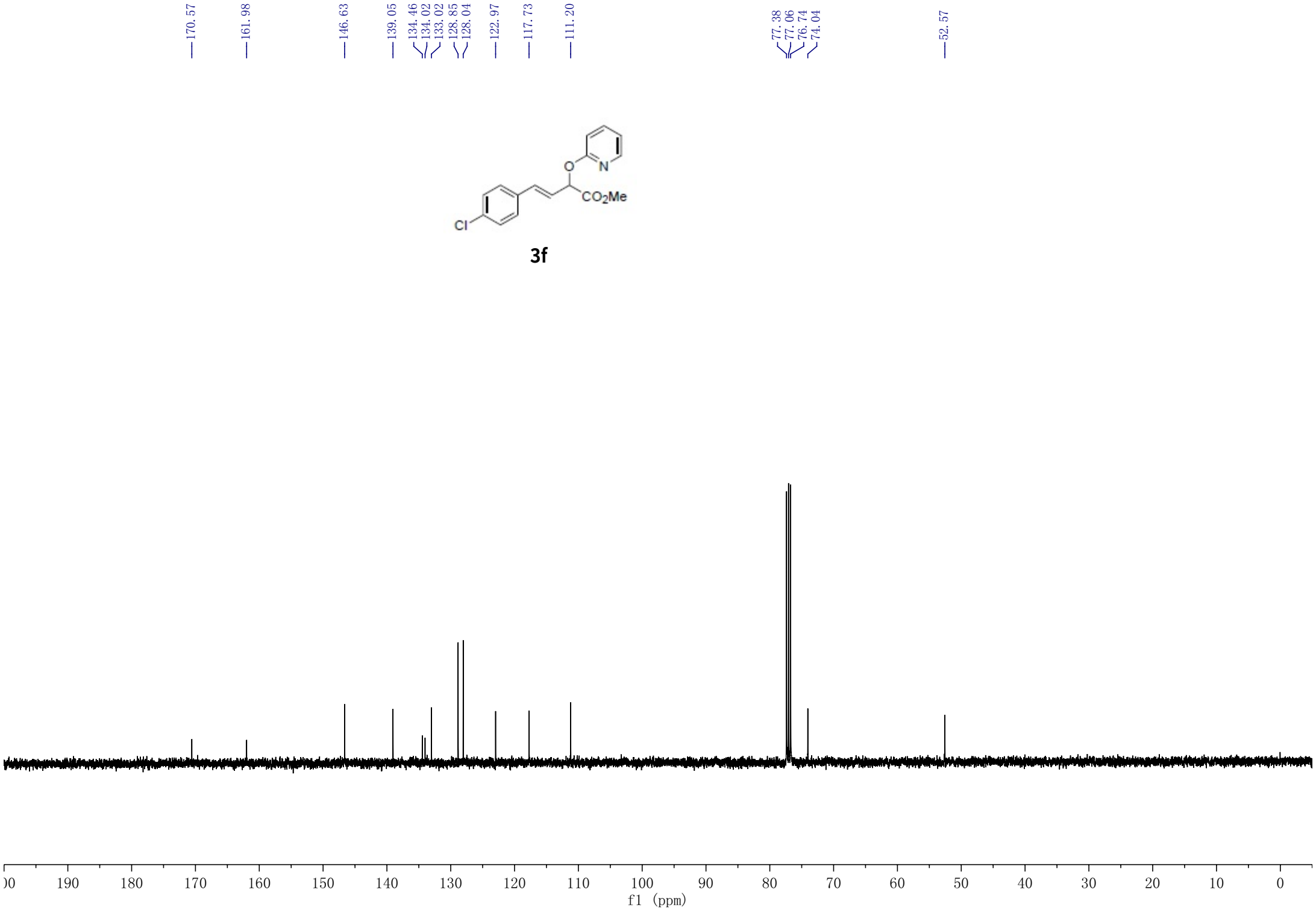
3f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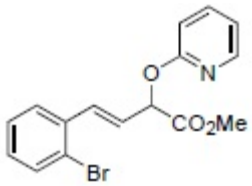
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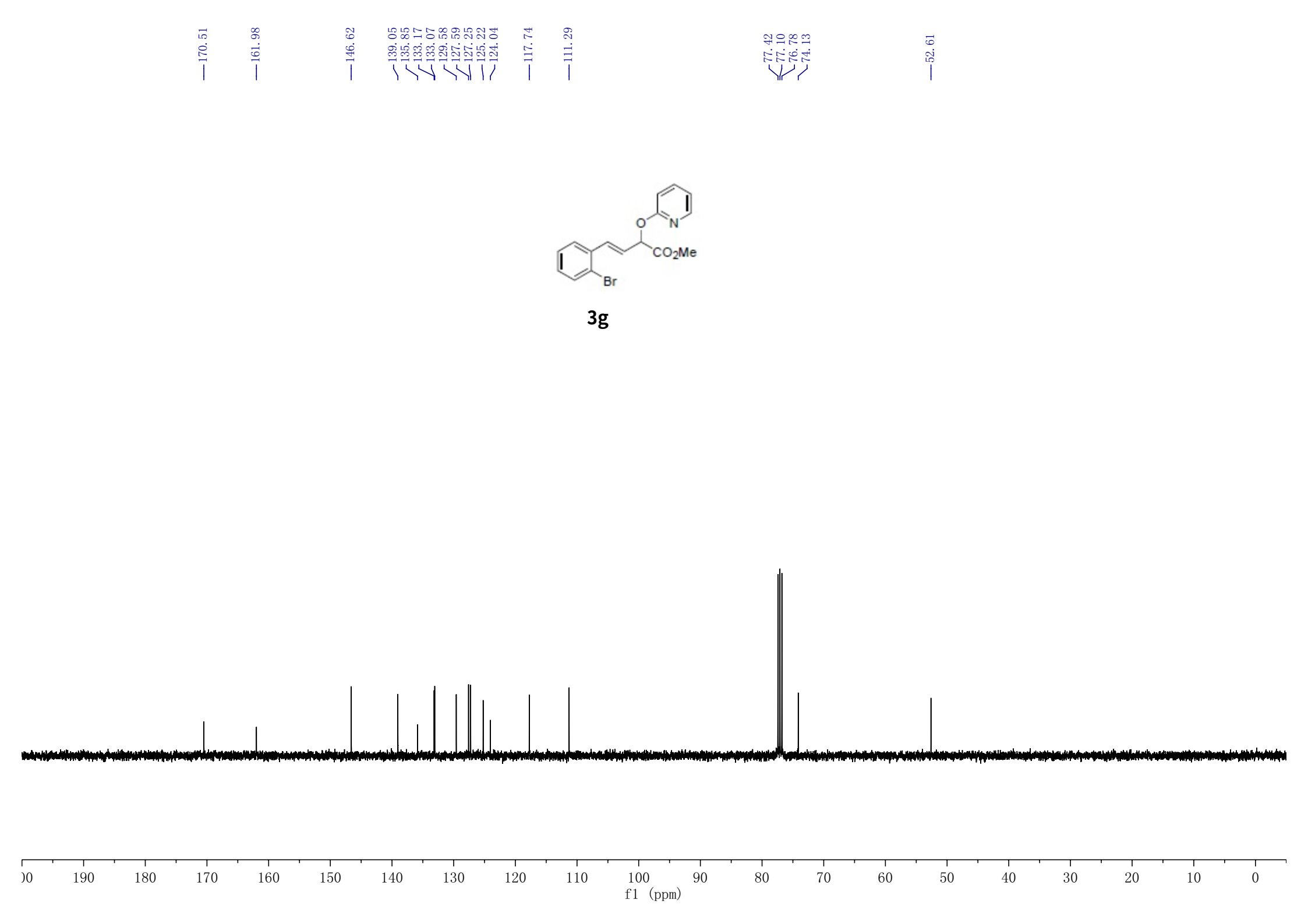
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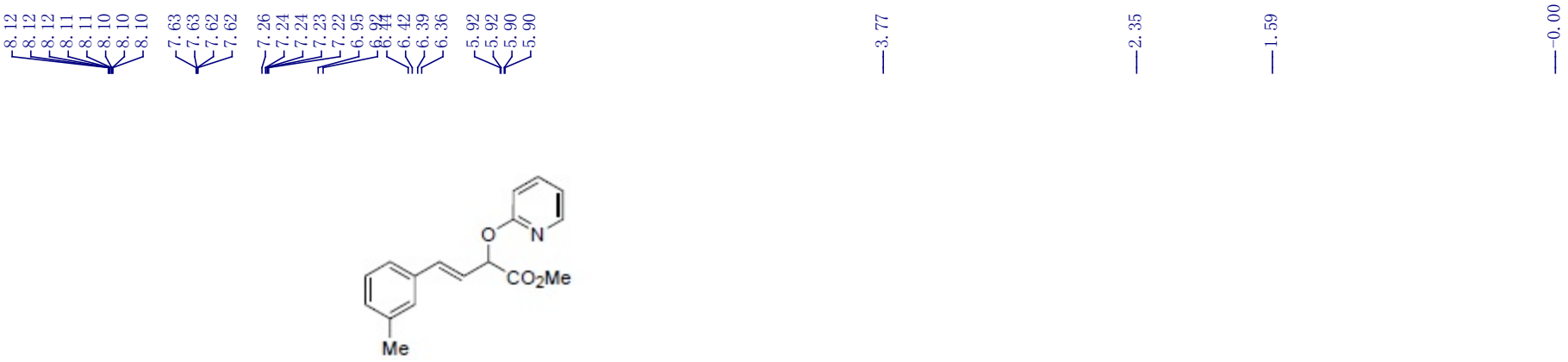
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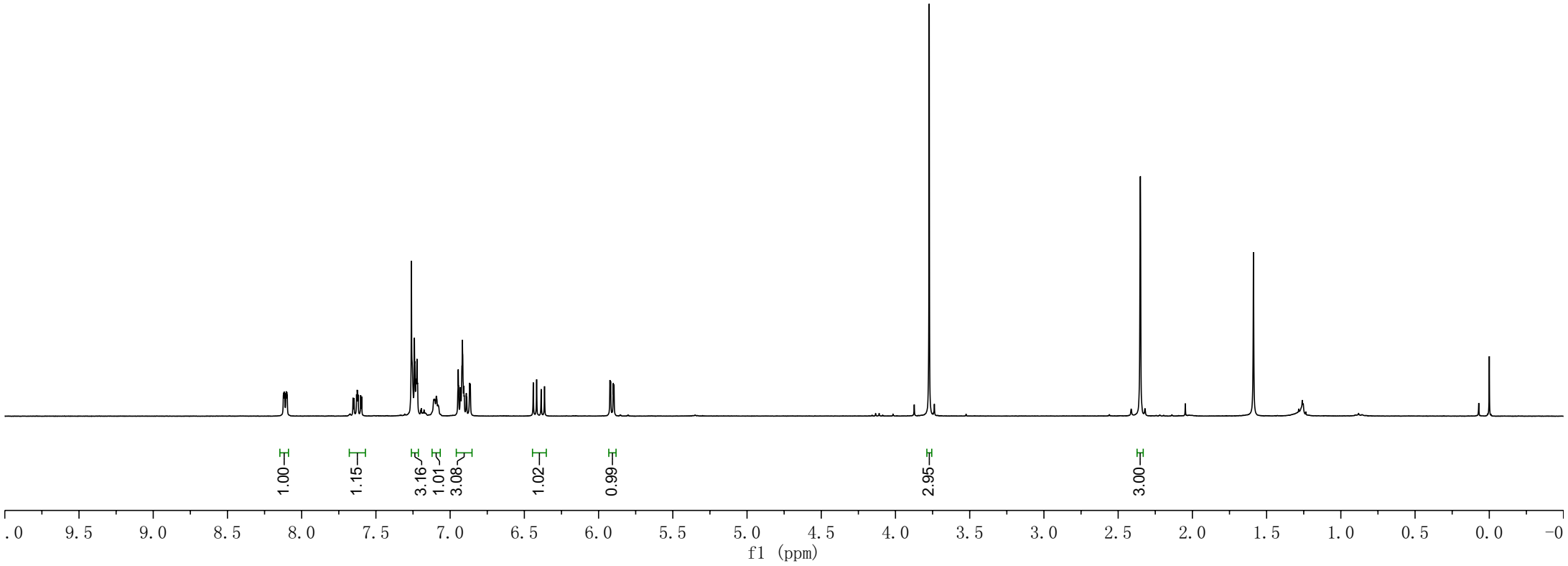
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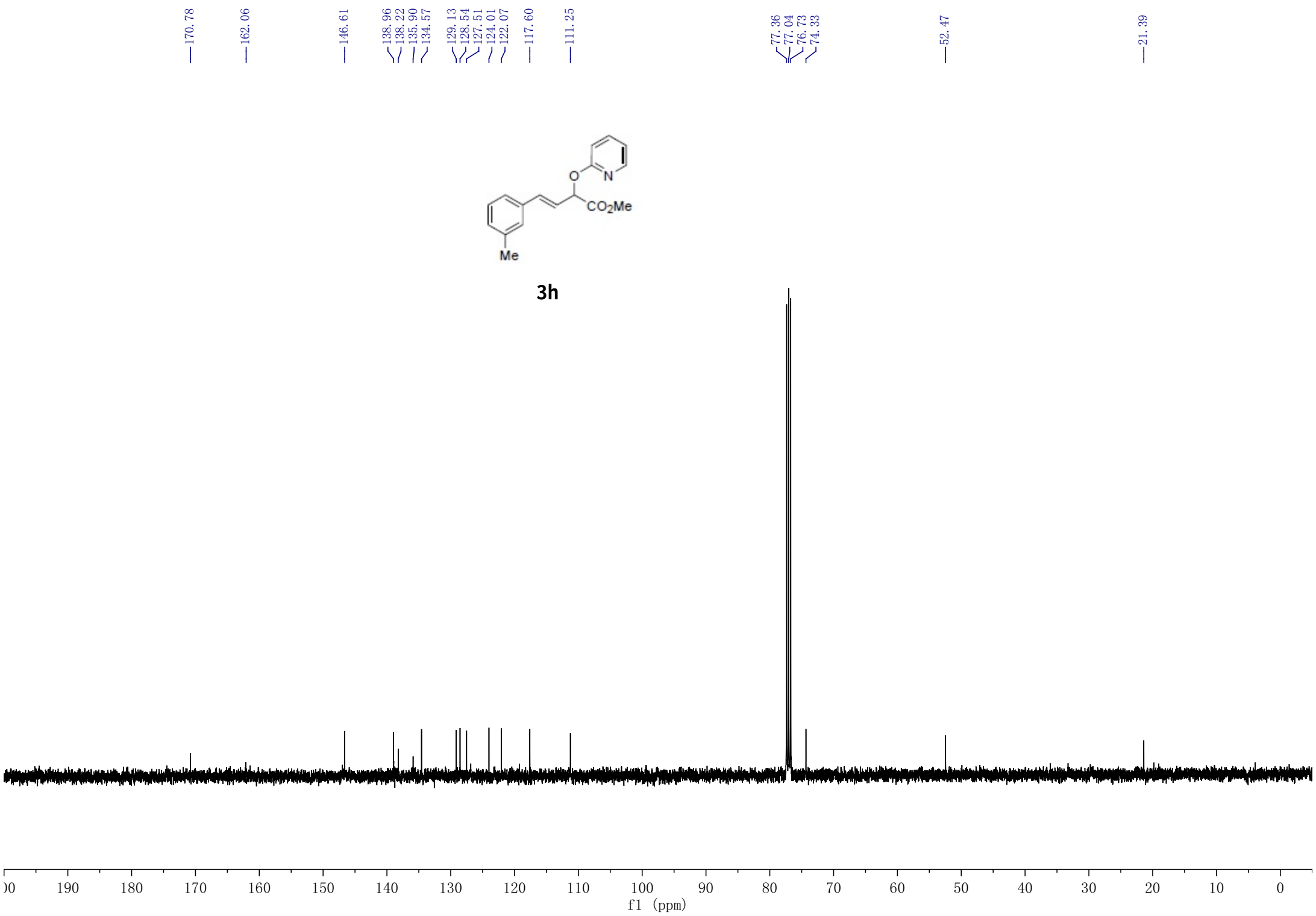
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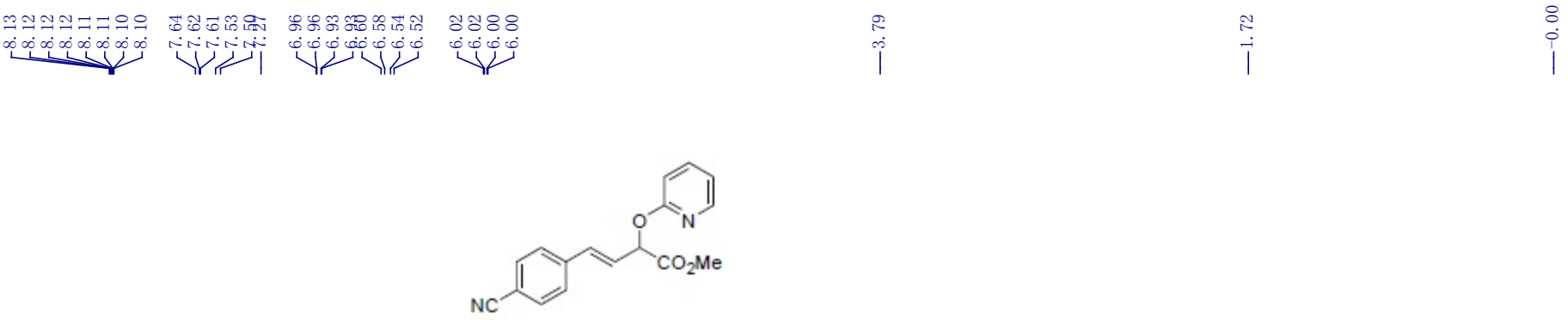
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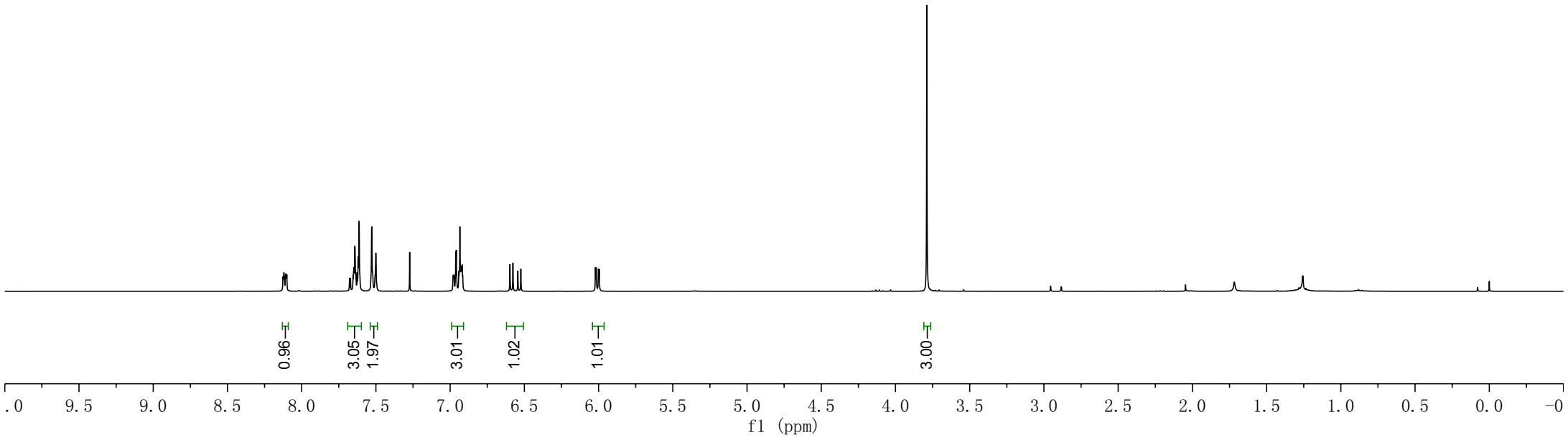
NC

3i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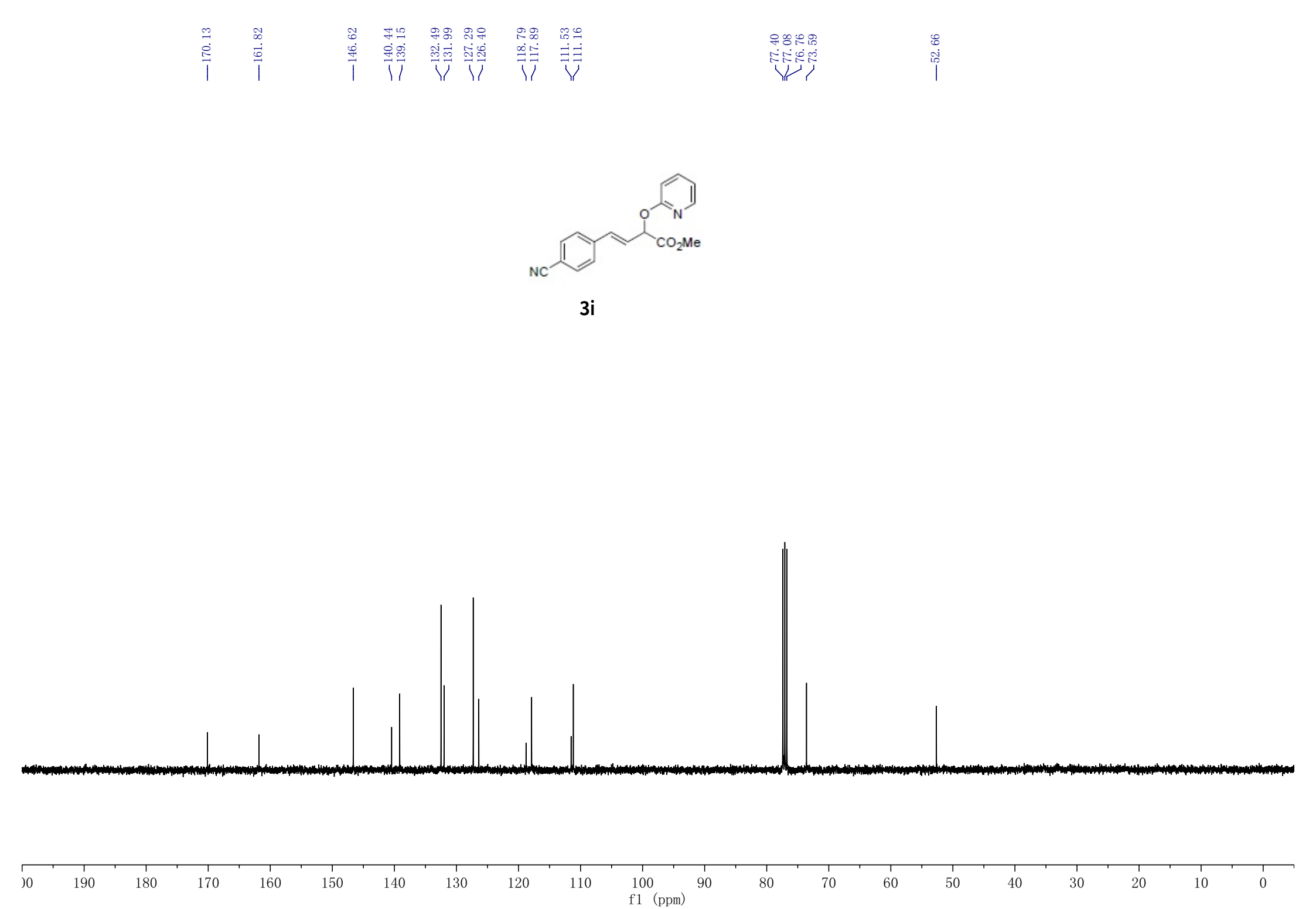
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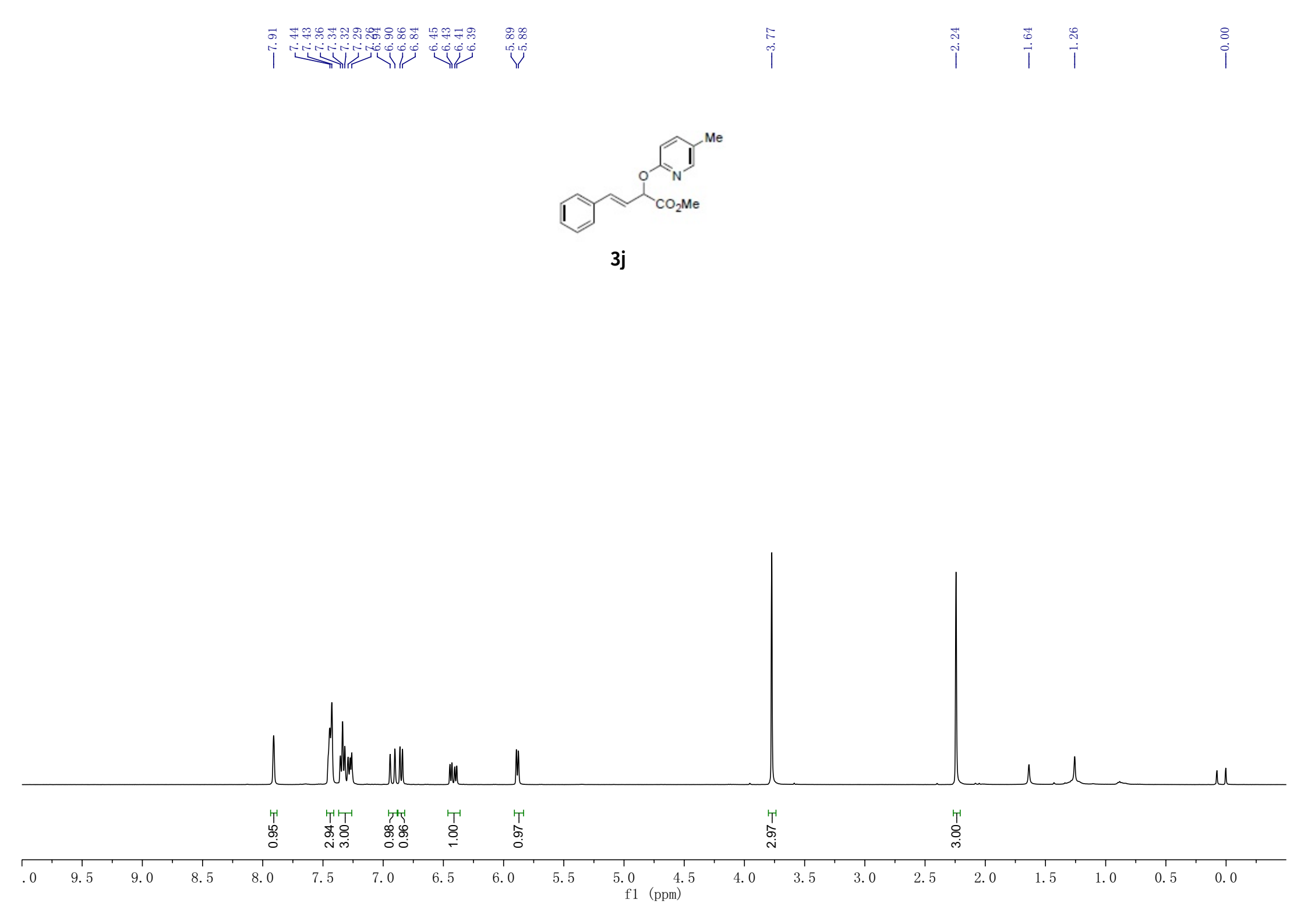
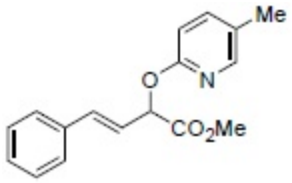
73.59
52.66
O
N
CO2Me
NC
f1 (ppm)

3i

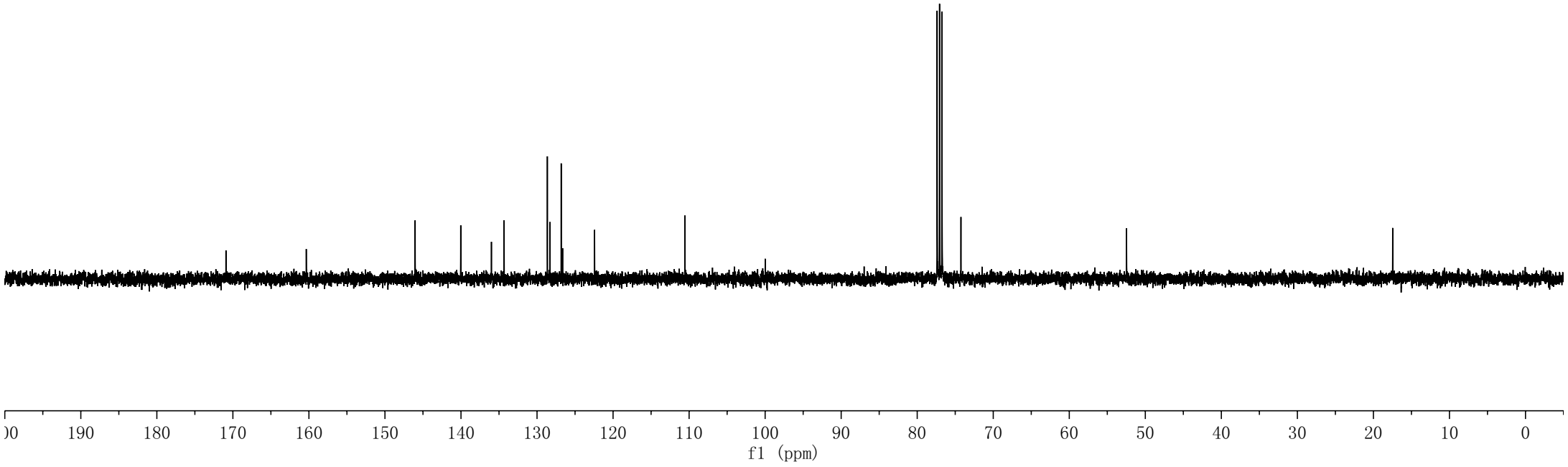

7.91
7.44
7.43
7.36
7.34
7.32
7.29
6.90
6.86
6.84
6.45
6.43
6.41
6.39
5.89
5.88
3.77
2.24
1.64
1.26
0.00
Me
O
N
CO2Me
0.95
2.94
3.00
0.98
0.96
1.00
0.97
2.97
3.00
f1 (ppm)

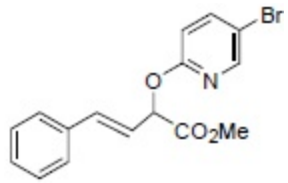
3j

170.91
160.35
146.03
140.04
136.00
134.33
128.64
128.30
126.82
126.64
122.43
110.55
99.99
77.38
77.06
76.74
74.25
52.47
17.47



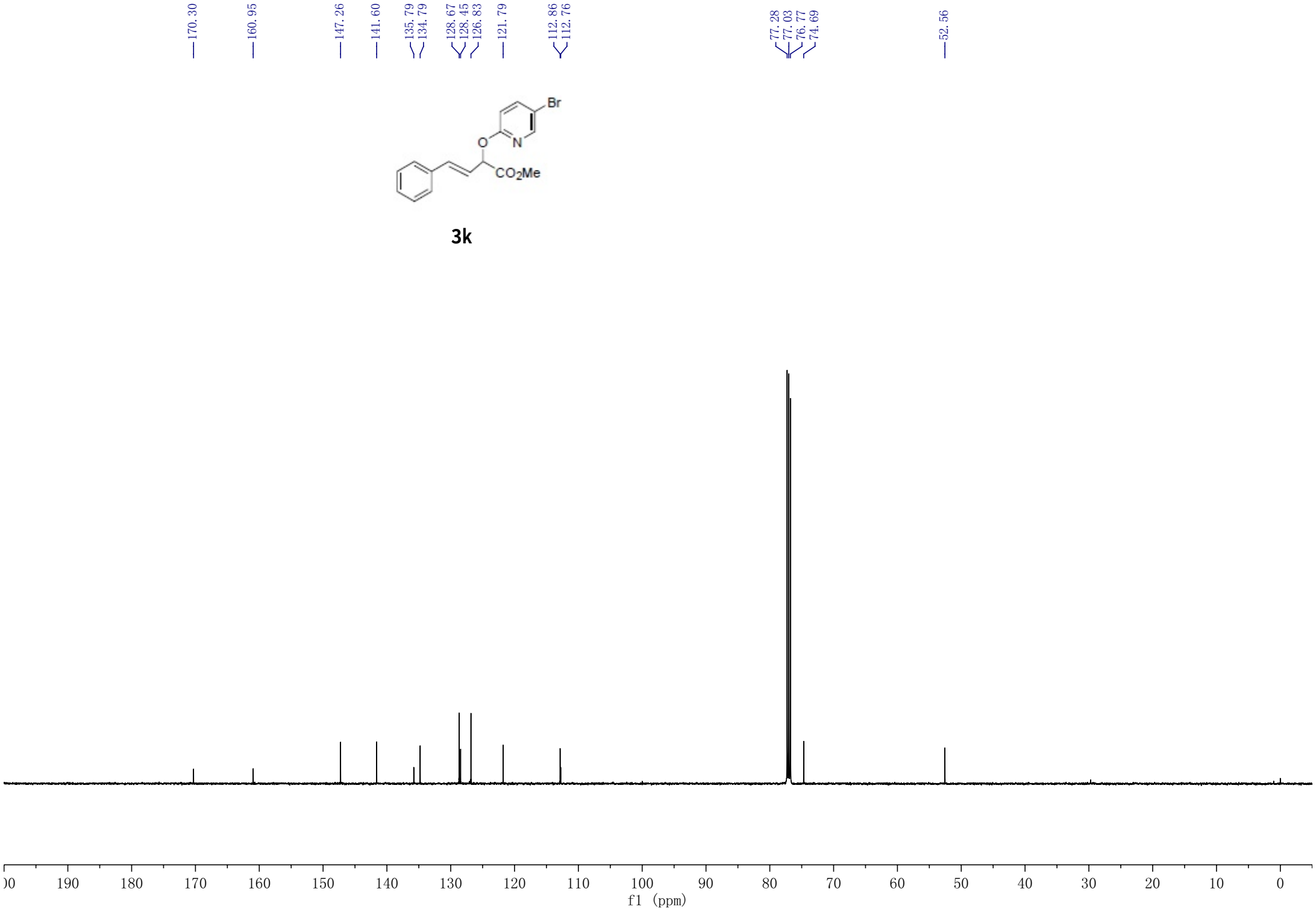
3j



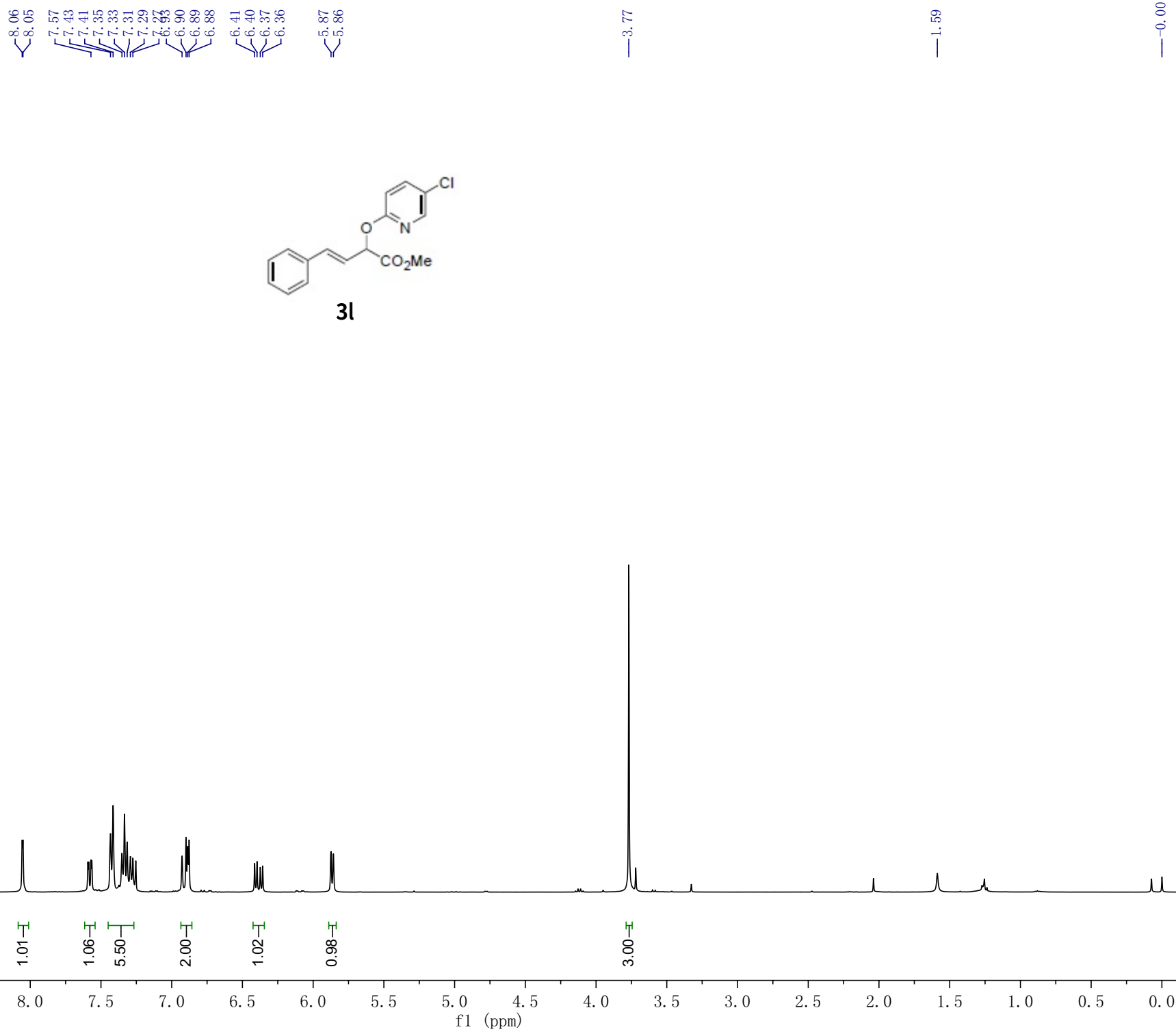

Br
O
N
CO2Me

3k

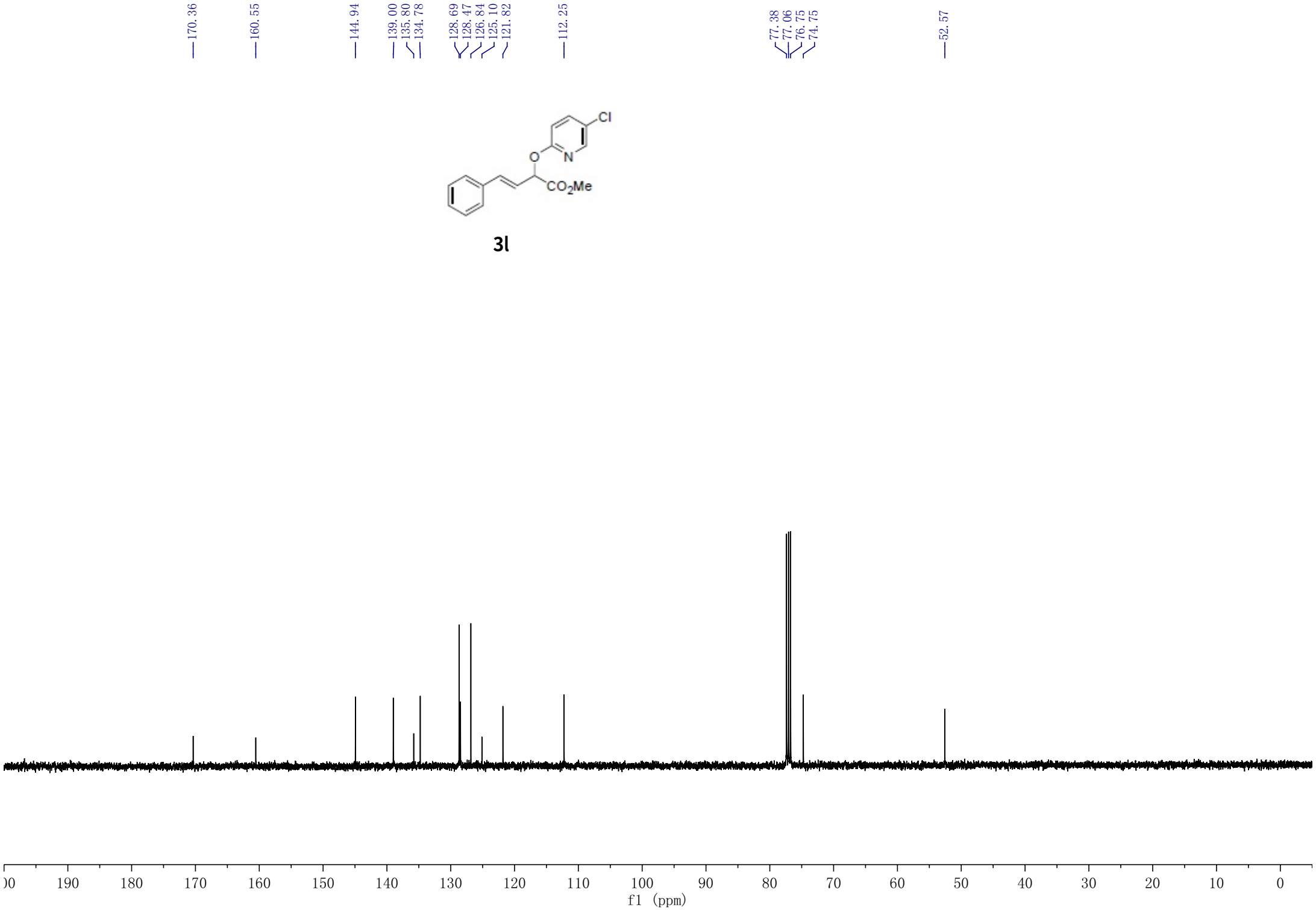
8.11
7.65
7.63
7.61
7.57
7.55
7.31
7.28
7.27
7.13
6.96
6.94
6.92
6.41
6.39
6.37
6.36
6.00
5.98
3.79
1.67
0.00
0.98
3.02
2.19
1.01
2.06
1.00
0.95
3.00
f1 (ppm)

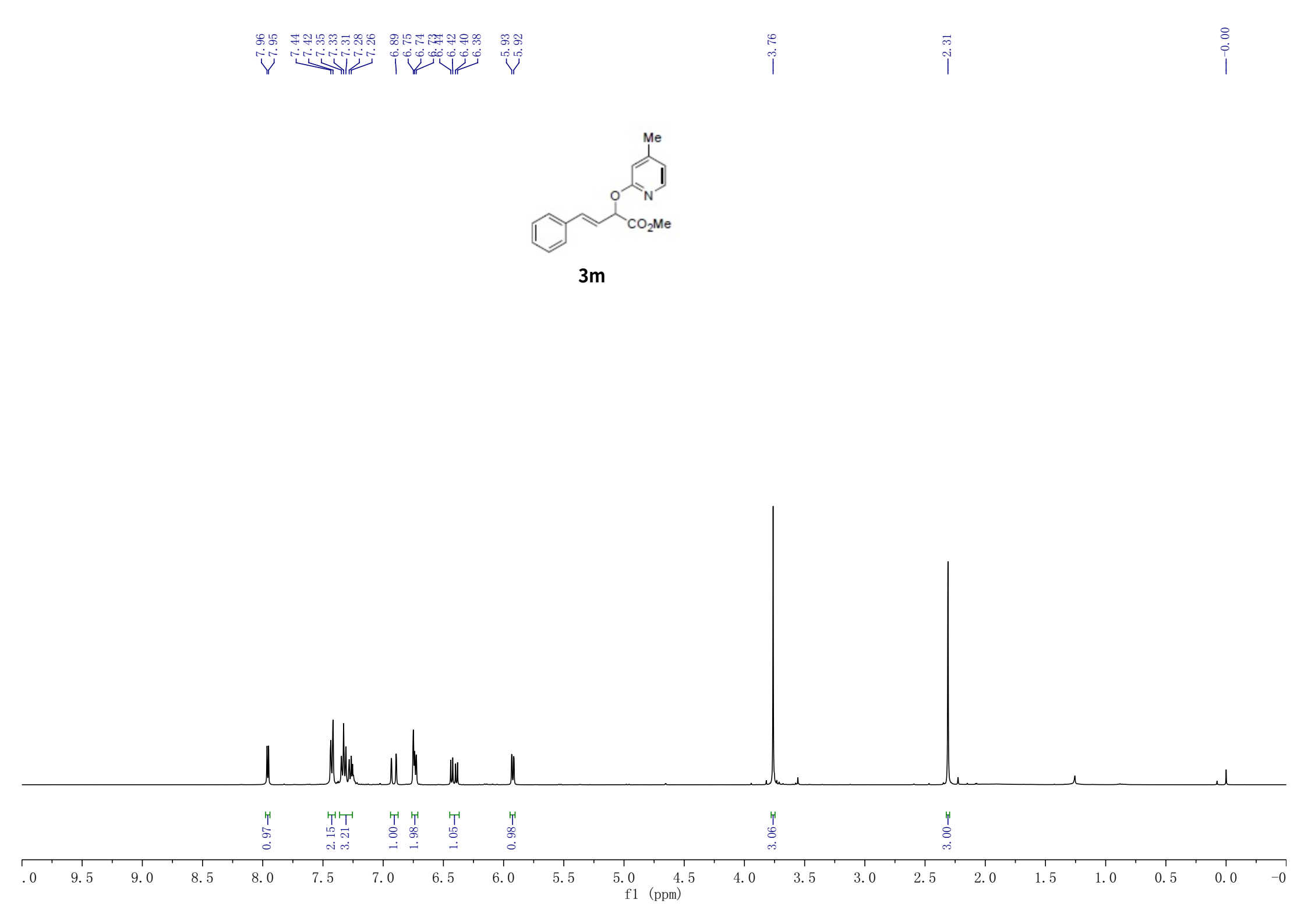

170.30
160.95
147.26
141.60
135.79
134.79
128.67
128.45
126.83
121.79
112.86
112.76
77.28
77.03
76.77
74.69
52.56
Br
O
N
CO2Me
f1 (ppm)

3k

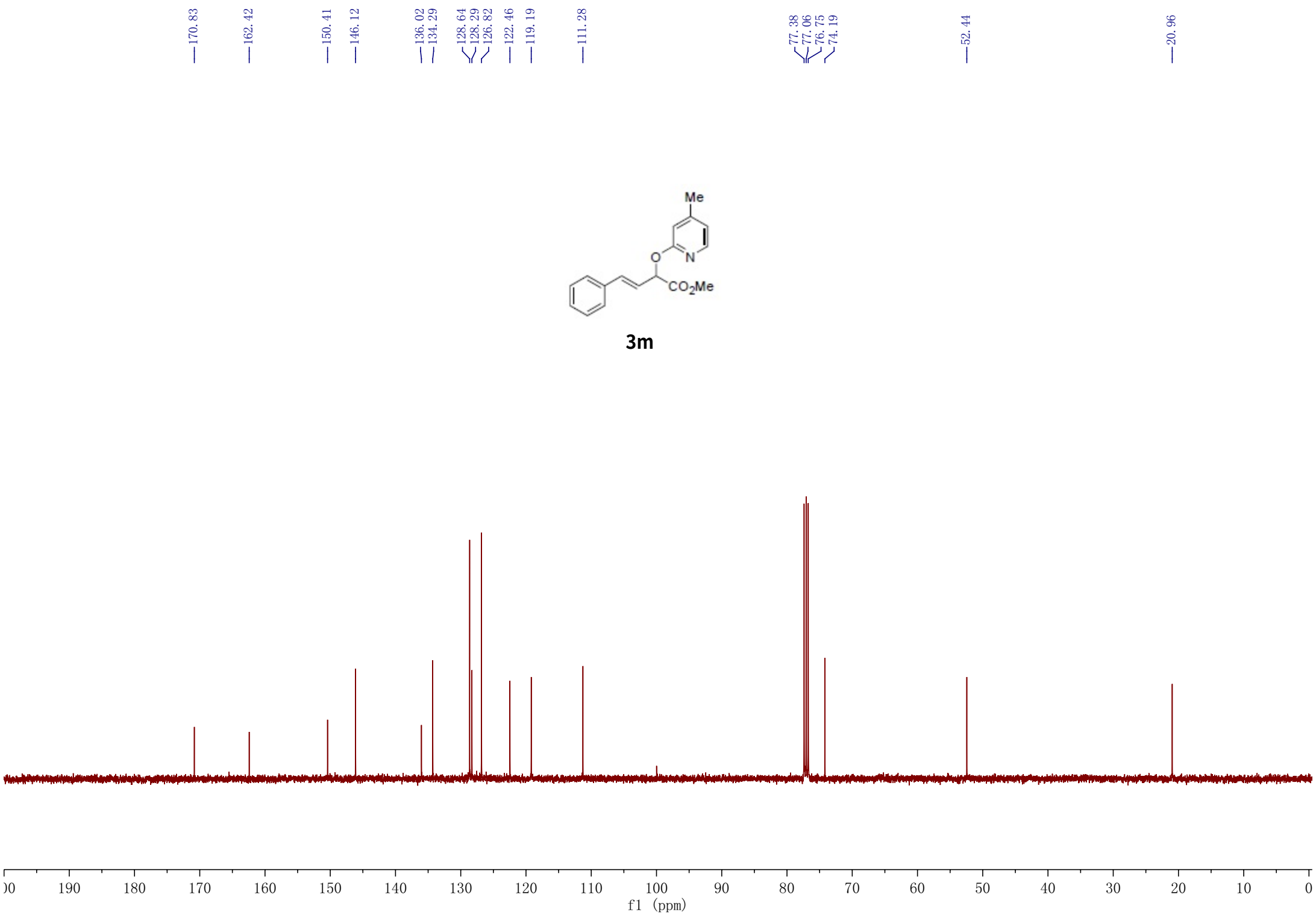

8.06
8.05
7.57
7.43
7.41
7.35
7.33
7.31
7.29
6.90
6.89
6.88
6.41
6.40
6.37
6.36
5.87
5.86
3.77
1.59
0.00
Cl
O
N
CO2Me
1.01
1.06
5.50
2.00
1.02
0.98
3.00
f1 (ppm)

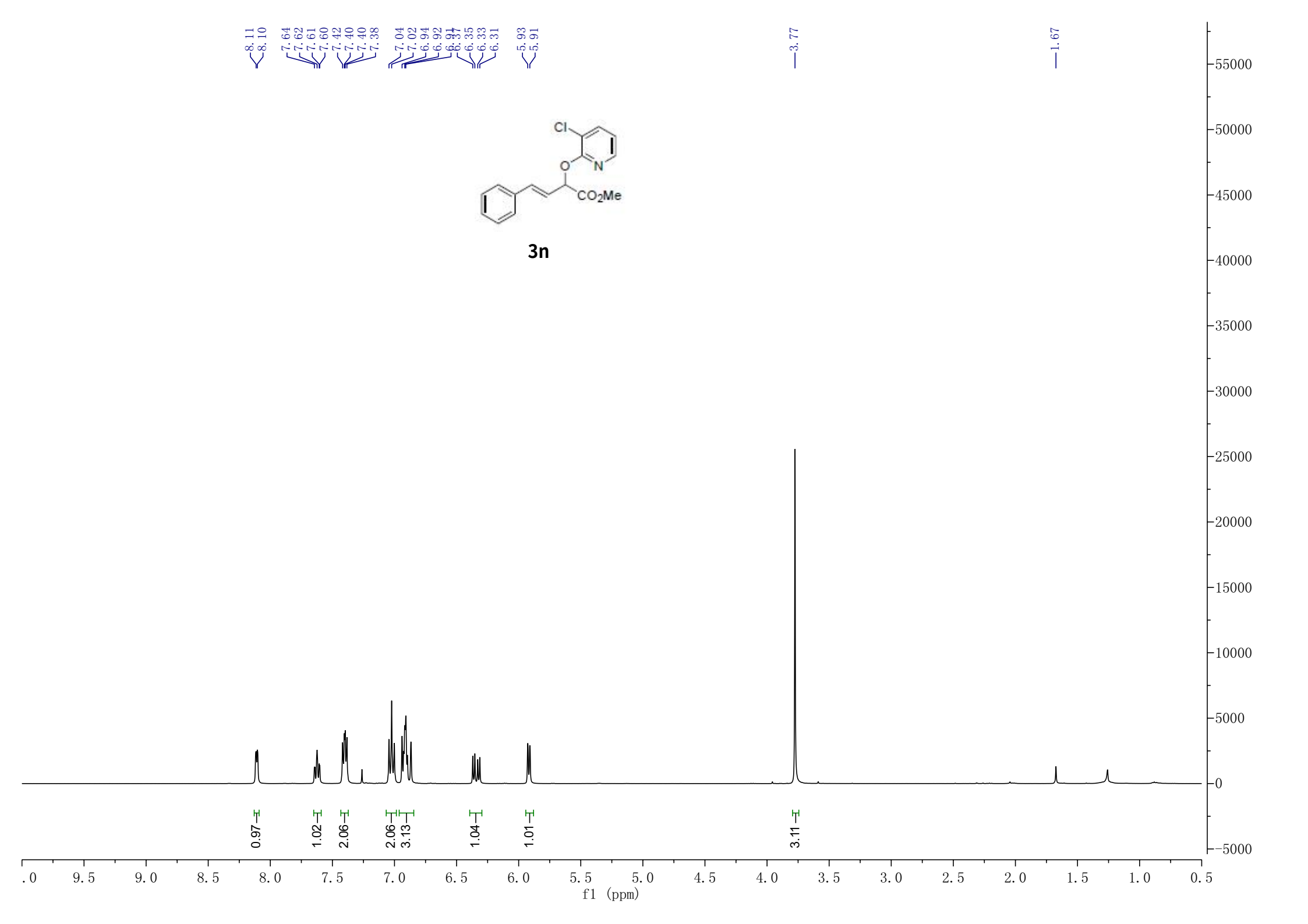
3l

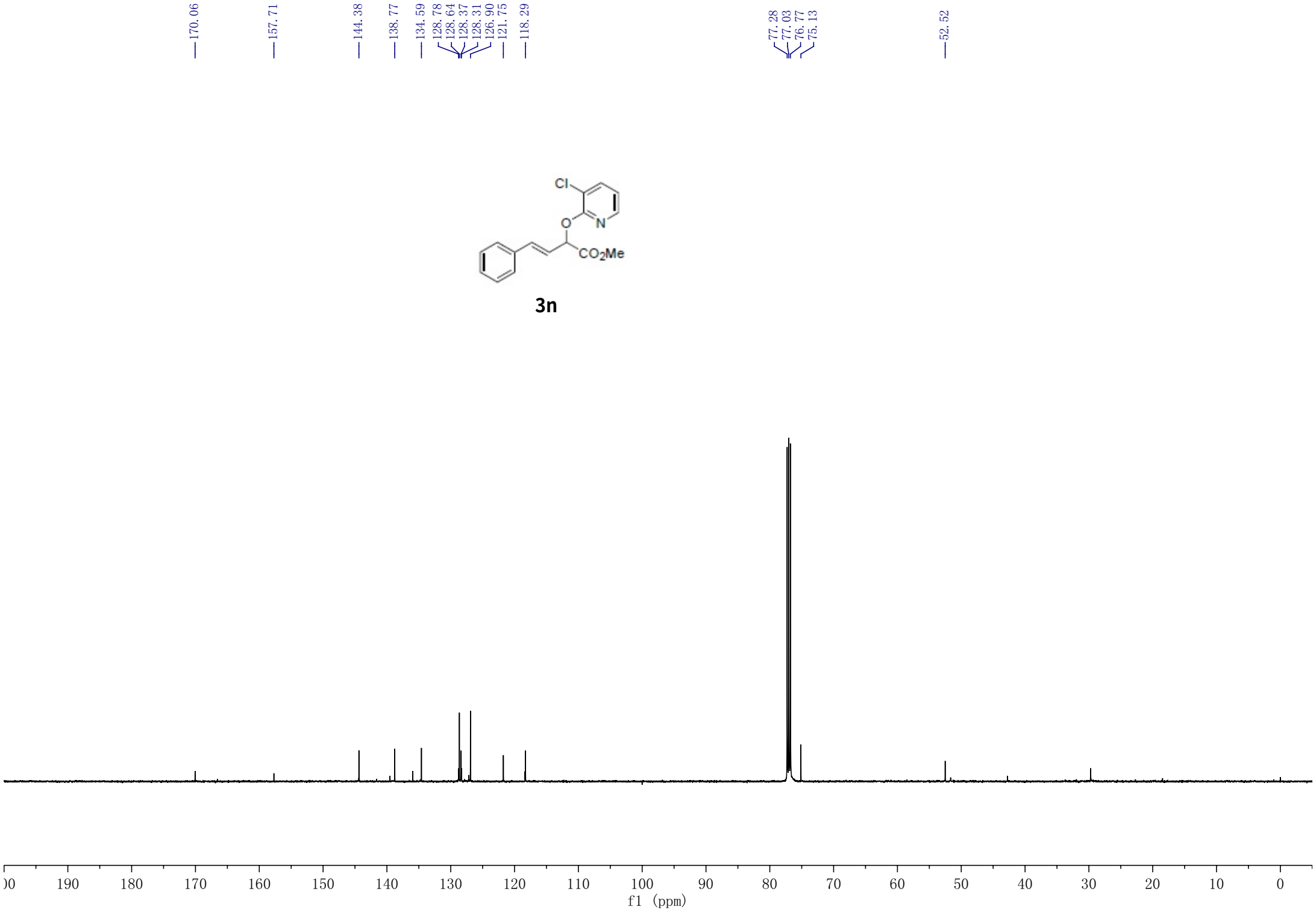

170.36
160.55
144.94
139.00
135.80
134.78
128.69
128.47
126.84
125.10
121.82
112.25
77.38
77.06
76.75
74.75
52.57
Cl
N
O
CO2Me
3l
f1 (ppm)

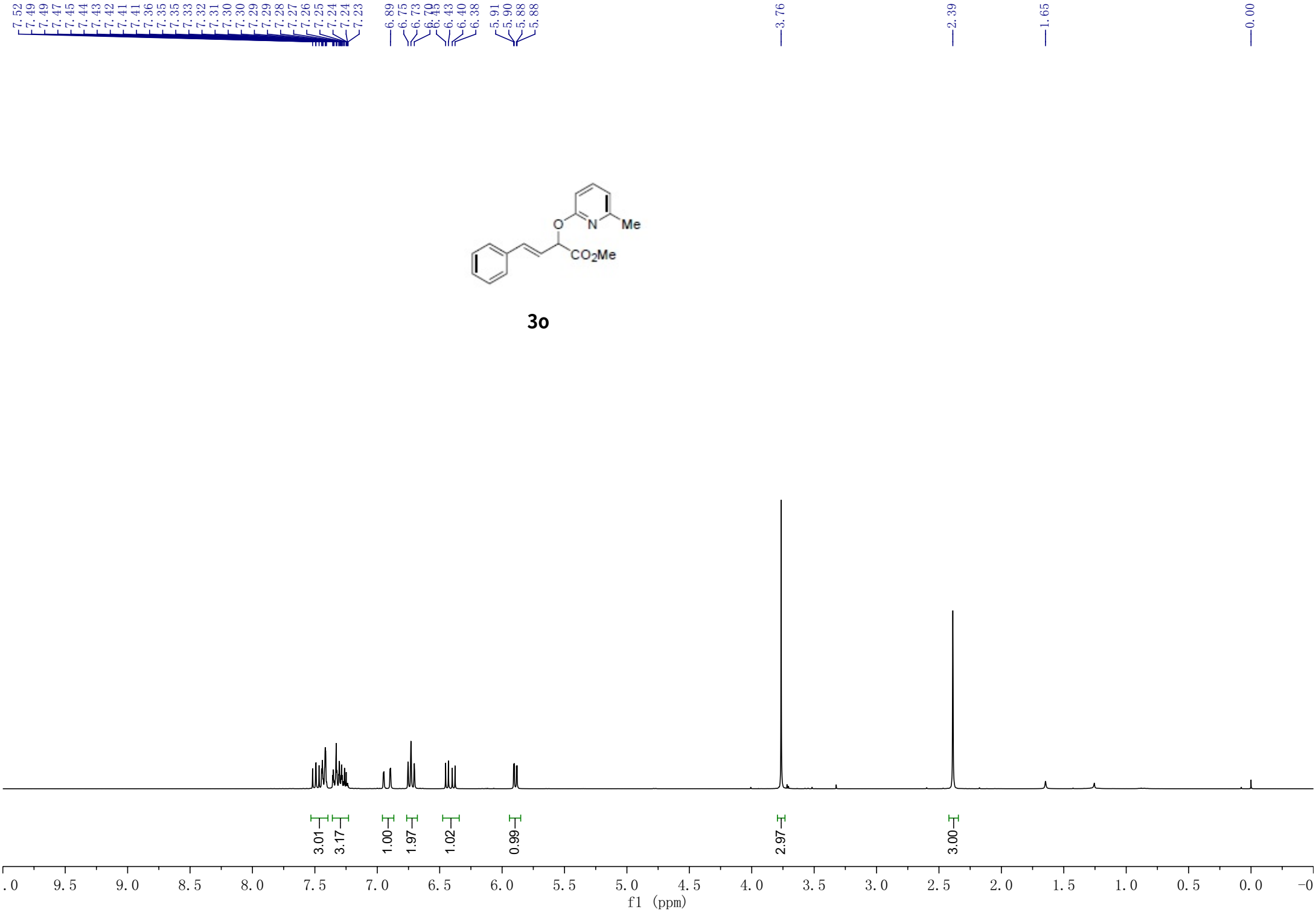

7.96
7.95
7.44
7.42
7.35
7.33
7.31
7.28
7.26
6.89
6.75
6.74
6.73
6.42
6.40
6.38
5.93
5.92
3.76
2.31
0.00
Me
O
N
CO2Me
0.97
2.15
3.21
1.00
1.98
1.05
0.98
3.06
3.00
f1 (ppm)

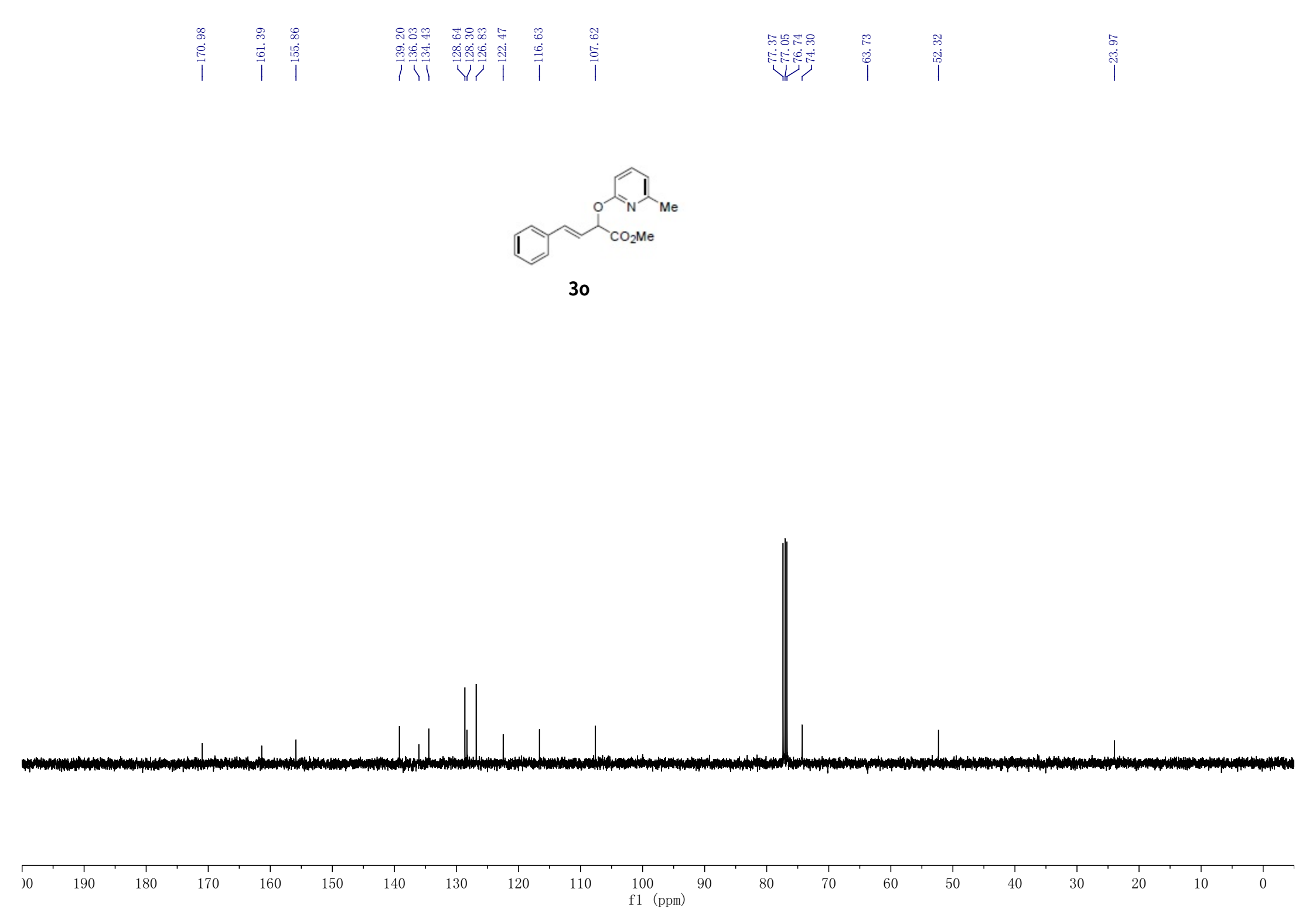
3m

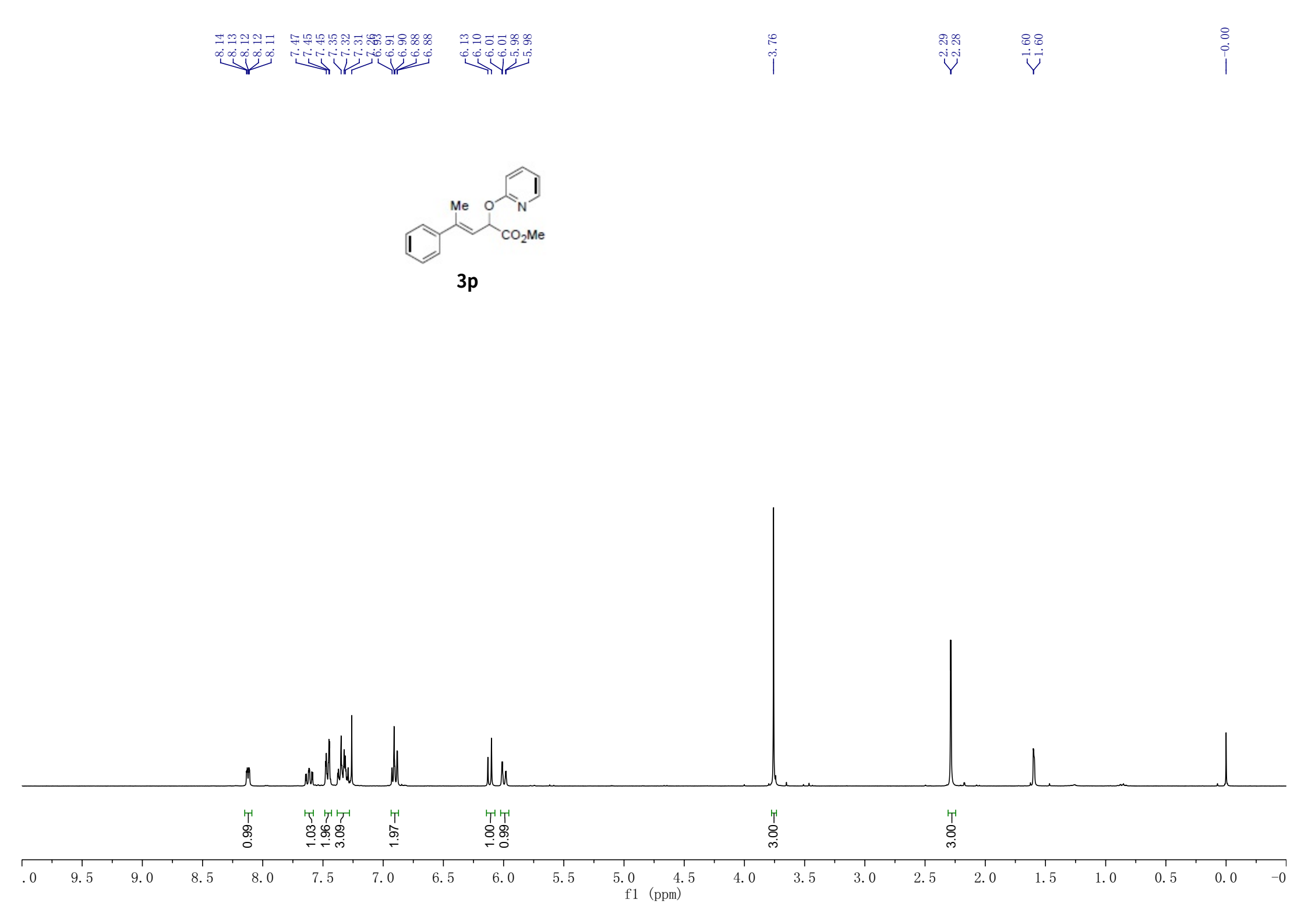

170.83
162.42
150.41
146.12
136.02
134.29
128.64
128.29
126.82
122.46
119.19
111.28
77.38
77.06
76.75
74.19
52.44
20.96
Me
O
N
CO2Me
3m
f1 (ppm)

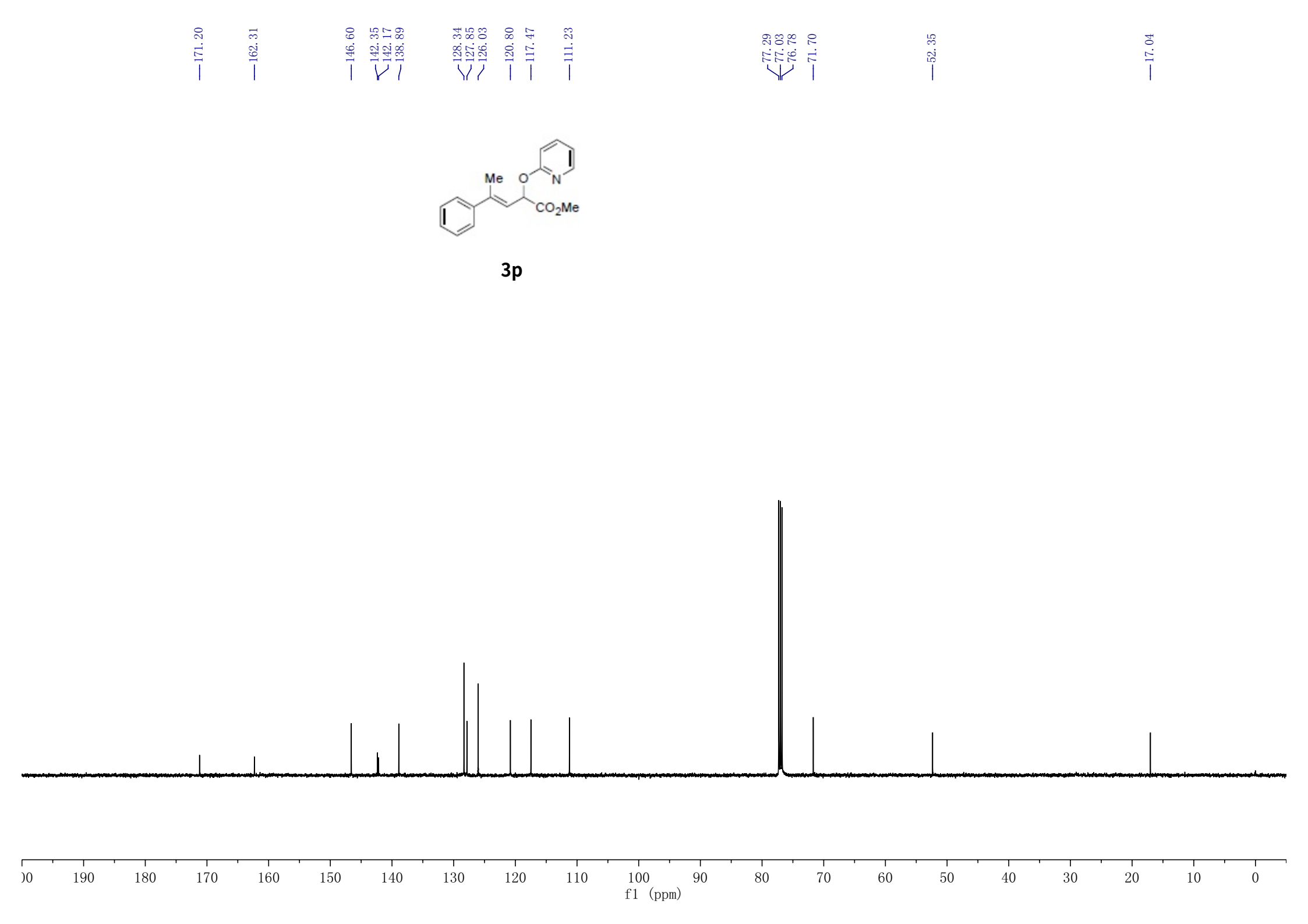

8.11
8.10
7.64
7.62
7.61
7.60
7.42
7.40
7.40
7.38
7.04
7.02
6.94
6.92
6.35
6.33
6.31
5.93
5.91
3.77
1.67
Cl
O
N
CO2Me
3n
0.97
1.02
2.06
2.06
3.13
1.04
1.01
3.11
f1 (ppm)

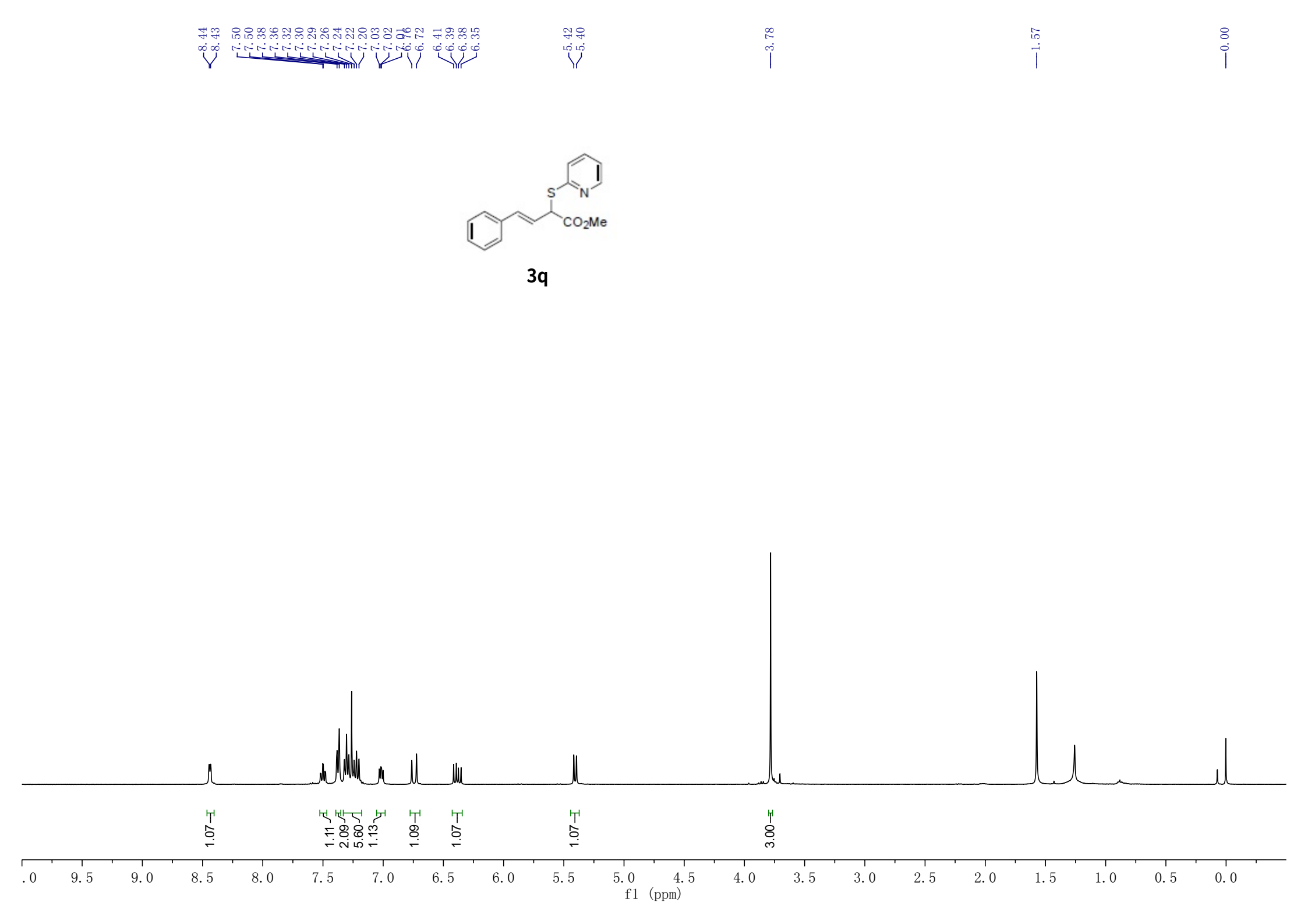

170.06
157.71
144.38
138.77
134.59
128.78
128.64
128.37
128.31
126.90
121.75
118.29
77.28
77.03
76.77
75.13
52.52
Cl
O
N
CO2Me
3n
f1 (ppm)


7.52
7.49
7.49
7.47
7.45
7.44
7.43
7.42
7.41
7.41
7.36
7.35
7.35
7.33
7.32
7.31
7.30
7.30
7.29
7.29
7.28
7.27
7.26
7.25
7.24
7.24
7.23
6.89
6.75
6.73
6.70
6.43
6.40
6.38
5.91
5.90
5.88
5.88
3.76
2.39
1.65
0.00
O
N
Me
CO2Me
3o
3.01
3.17
1.00
1.97
1.02
0.99
2.97
3.00
f1 (ppm)

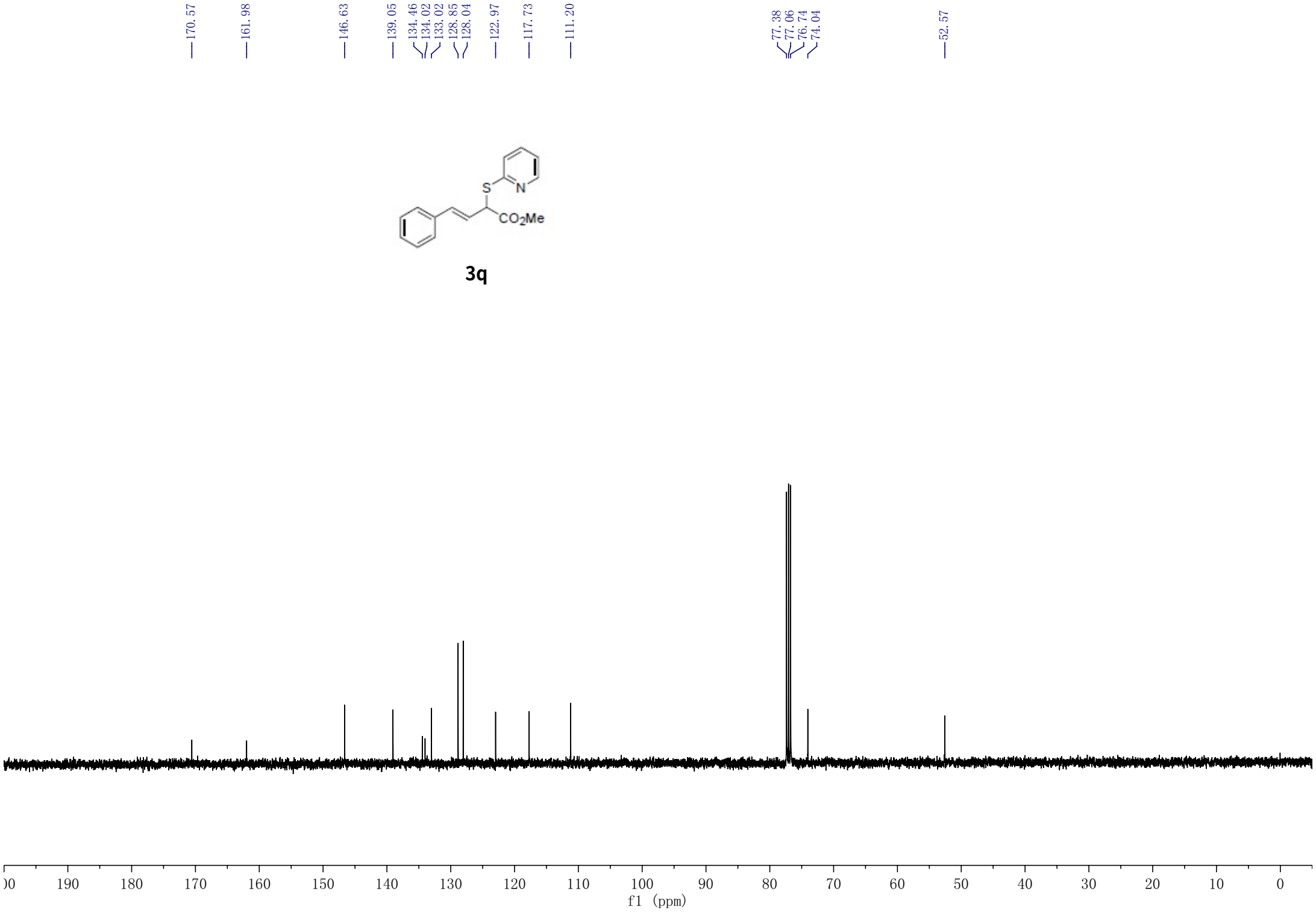

170.98
161.39
155.86
139.20
136.03
134.43
128.64
128.30
126.83
122.47
116.63
107.62
77.37
77.05
76.74
74.30
63.73
52.32
23.97
O
N
Me
CO2Me
3o
f1 (ppm)

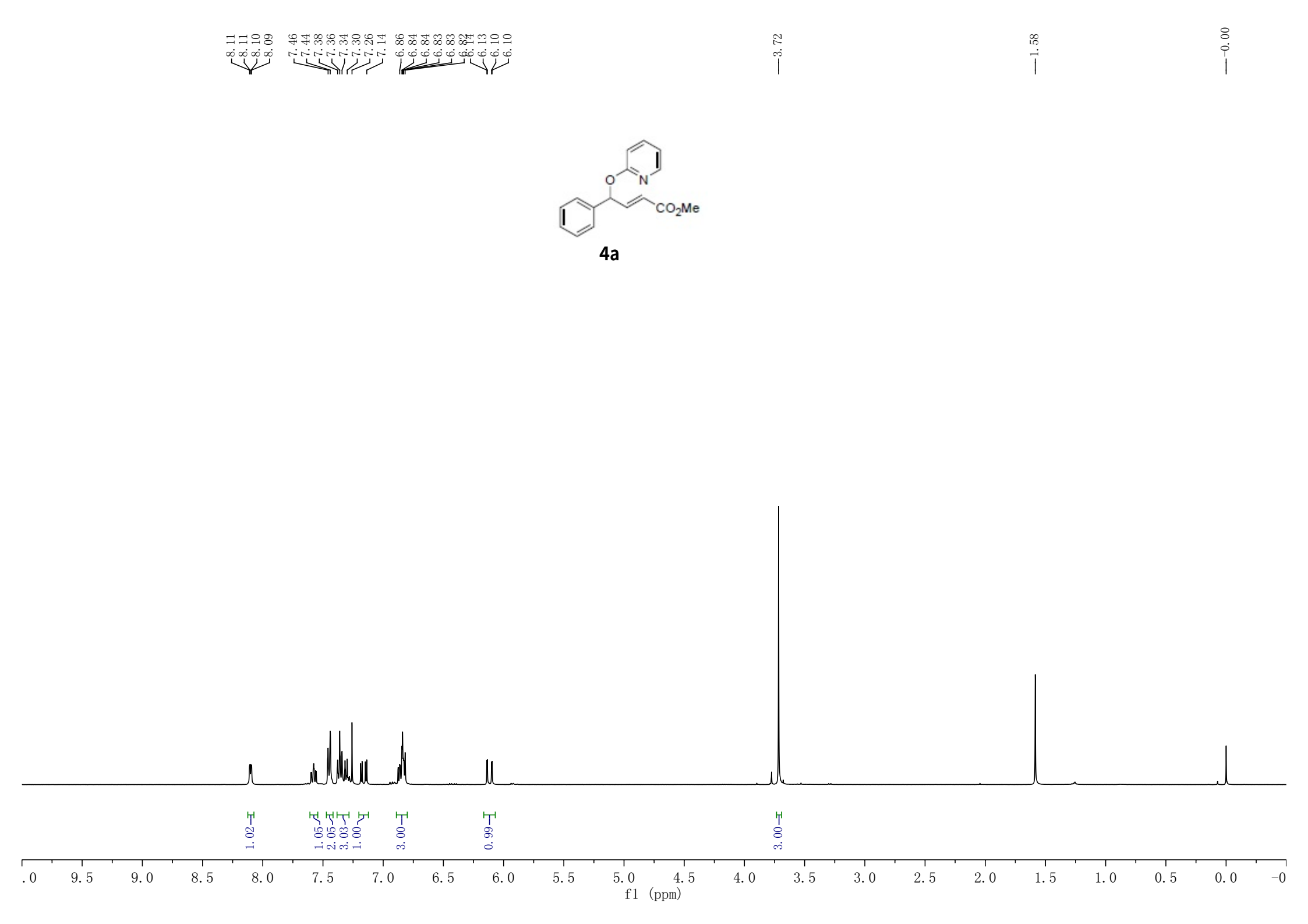

8.14
8.13
8.12
8.12
8.11
7.47
7.45
7.45
7.35
7.32
7.31
6.93
6.91
6.90
6.88
6.88
6.13
6.10
6.01
6.01
5.98
5.98
3.76
2.29
2.28
1.60
1.60
0.00
Me
O
N
CO2Me
3p
0.99
1.03
1.96
3.09
1.97
1.00
0.99
3.00
3.00
f1 (ppm)


171.20
162.31
146.60
142.35
142.17
138.89
128.34
127.85
126.03
120.80
117.47
111.23
77.29
77.03
76.78
71.70
52.35
17.04
Me
O
N
CO2Me
3p
f1 (ppm)

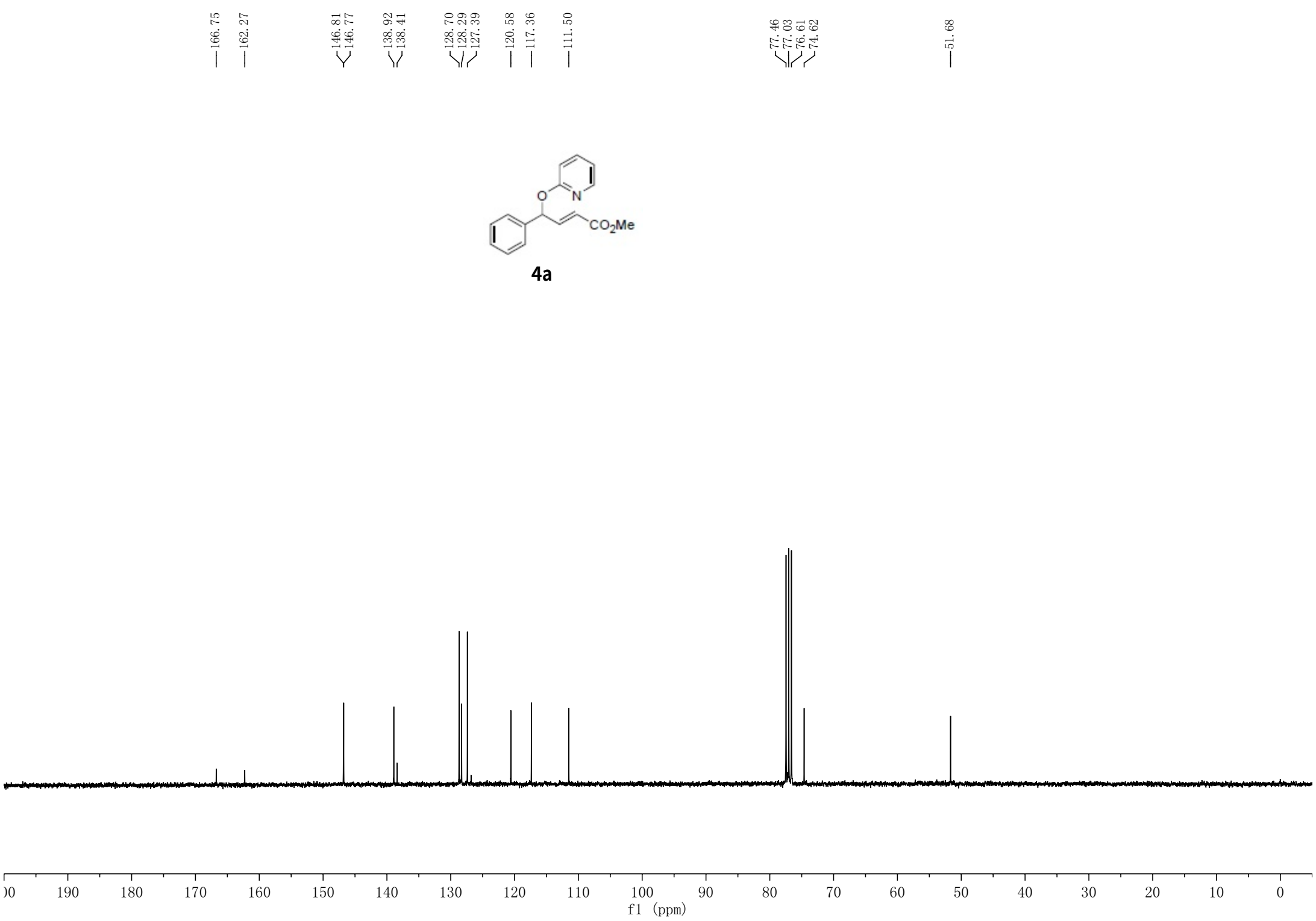

8.44
8.43
7.50
7.50
7.38
7.36
7.32
7.30
7.29
7.26
7.24
7.22
7.20
7.03
7.02
7.01
6.76
6.72
6.41
6.39
6.38
6.35
5.42
5.40
3.78
1.57
0.00
S
N
CO2Me
1.07
1.11
2.09
5.60
1.13
1.09
1.07
1.07
3.00
f1 (ppm)

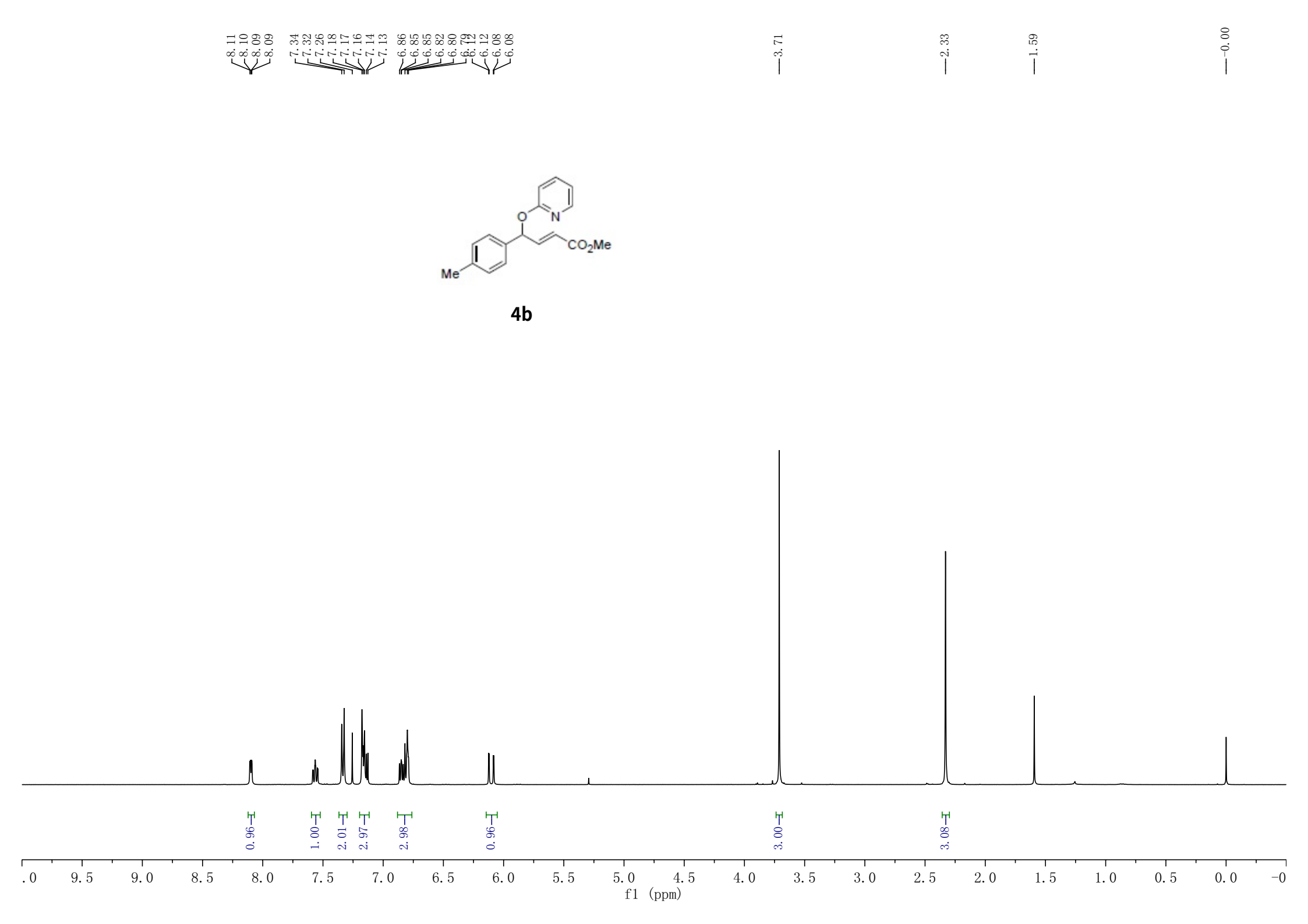
3q


170.57
161.98
146.63
139.05
134.46
134.02
133.02
128.85
128.04
122.97
117.73
111.20
77.38
77.06
76.74
74.04
52.57
S
N
CO2Me
3q
f1 (ppm)

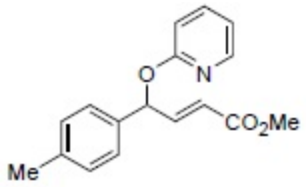

8.11
8.11
8.10
8.09
7.46
7.44
7.38
7.36
7.34
7.30
7.26
7.14
6.86
6.84
6.84
6.83
6.83
6.82
6.14
6.13
6.10
6.10
3.72
1.58
0.00
O
N
CO2Me
1.02
1.05
2.05
3.03
1.00
3.00
0.99
3.00
f1 (ppm)

4a

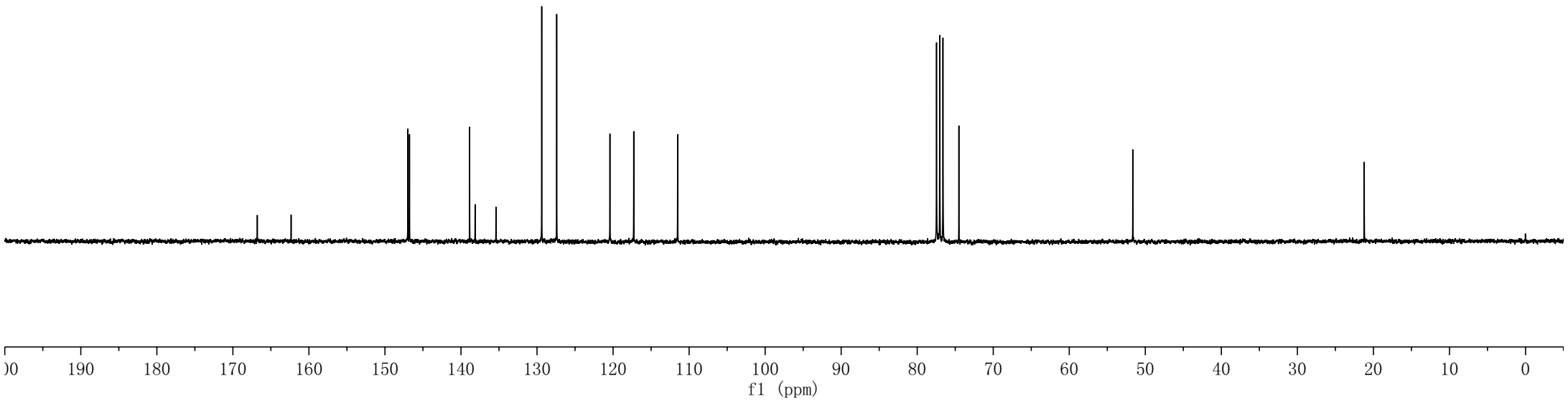

166.75
162.27
146.81
146.77
138.92
138.41
128.70
128.29
127.39
120.58
117.36
111.50
77.46
77.03
76.61
74.62
51.68
O
N
CO2Me
4a
f1 (ppm)

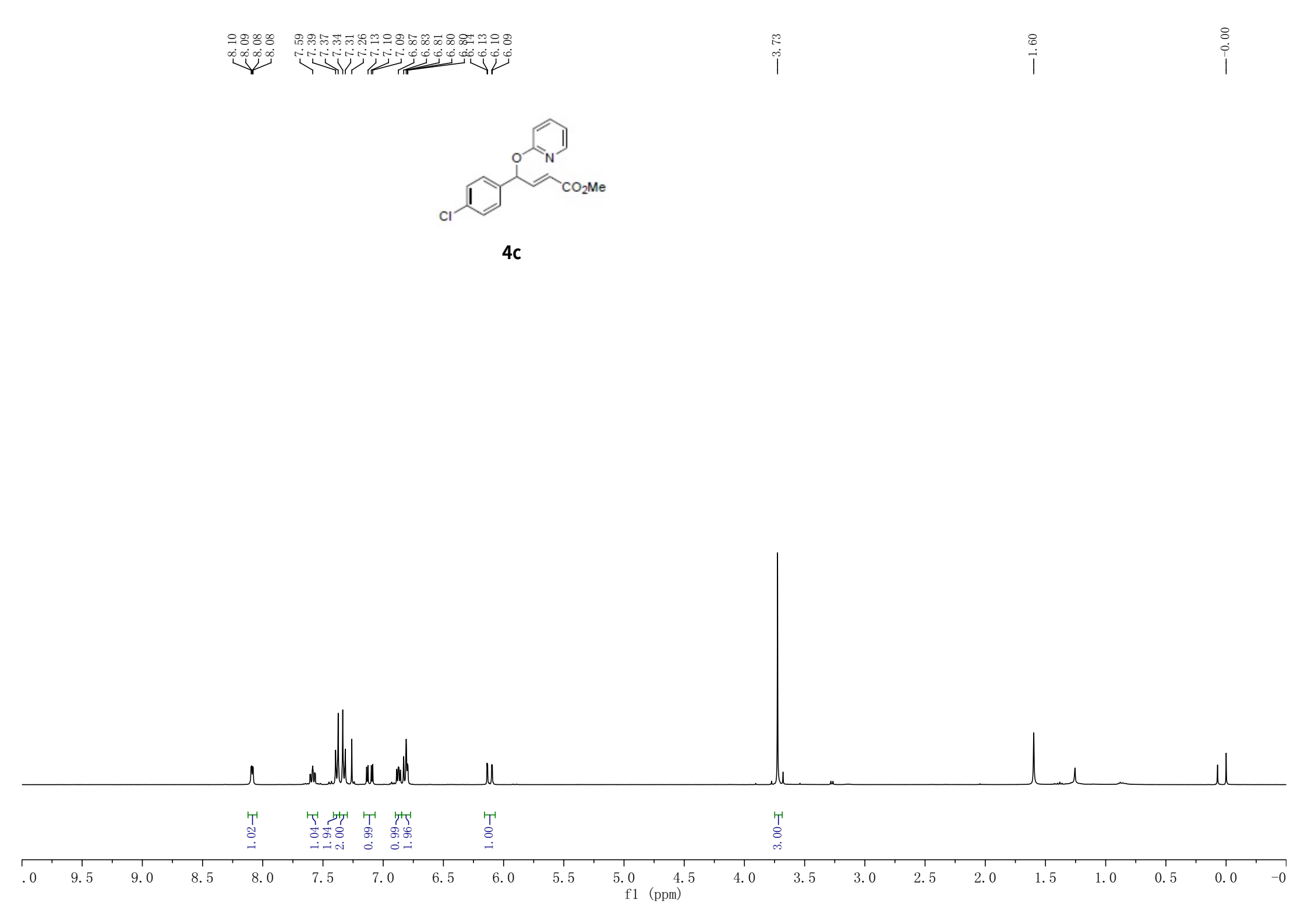

8.11
8.10
8.09
8.09
7.34
7.32
7.26
7.18
7.17
7.16
7.14
7.13
6.86
6.85
6.85
6.82
6.80
6.79
6.12
6.12
6.08
6.08
3.71
2.33
1.59
0.00
O
N
CO2Me
Me
4b
0.96
1.00
2.01
2.97
2.98
0.96
3.00
3.08
f1 (ppm)

166.79
162.34
146.99
146.77
138.87
138.14
135.40
129.38
127.41
120.41
117.28
111.51
77.46
77.04
76.61
74.52
51.64
21.21

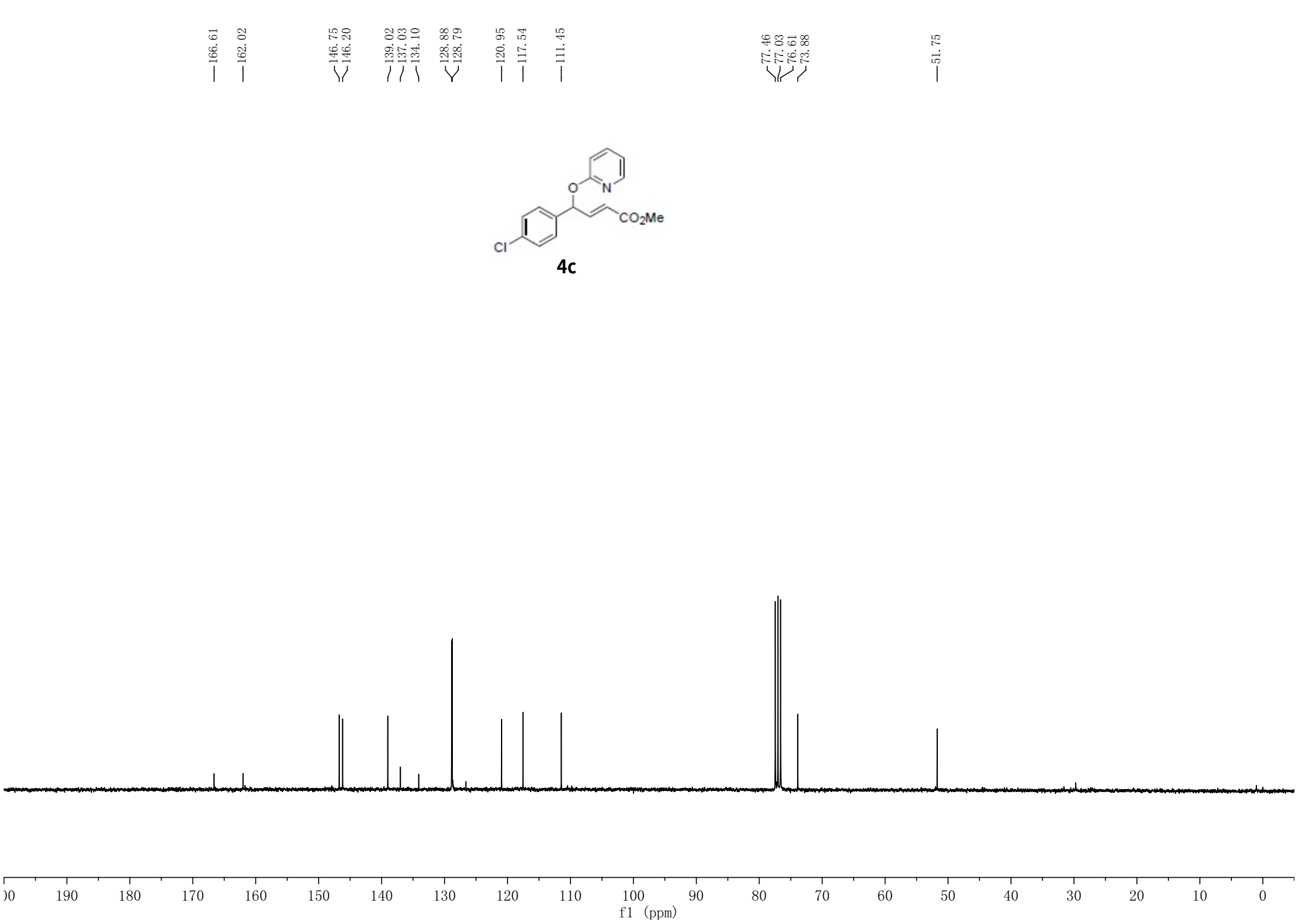


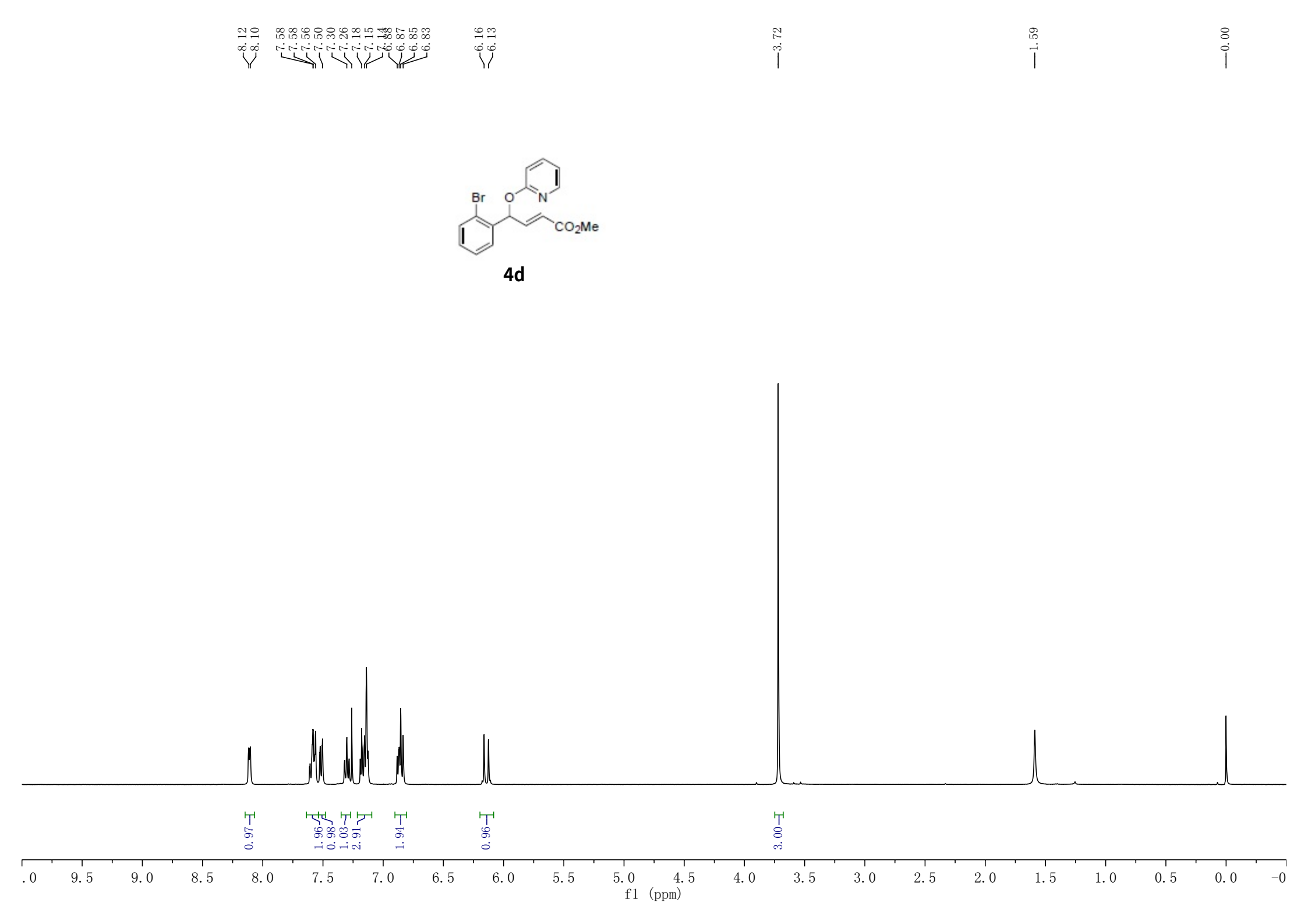
4b



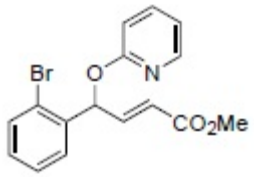

8.10
8.09
8.08
8.08
7.59
7.39
7.37
7.34
7.31
7.26
7.13
7.10
7.09
6.87
6.83
6.81
6.80
6.80
6.14
6.13
6.10
6.09
3.73
1.60
0.00
O
N
CO2Me
Cl
1.02
1.04
1.94
2.00
0.99
0.99
1.96
1.00
3.00
f1 (ppm)

4c

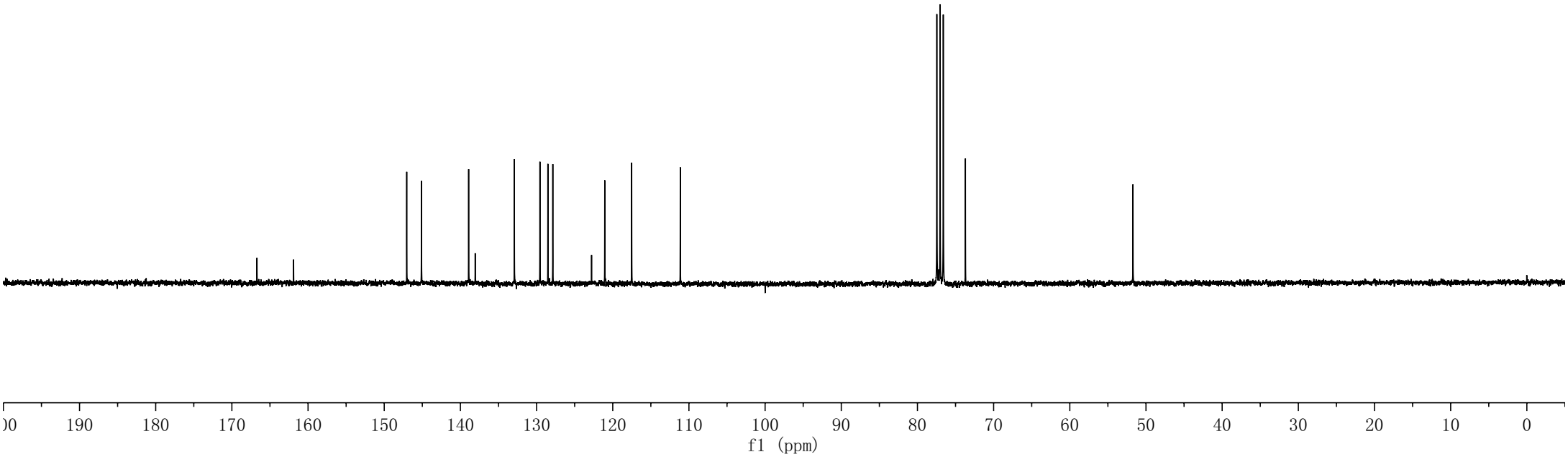

166.61
162.02
146.75
146.20
139.02
137.03
134.10
128.88
128.79
120.95
117.54
111.45
77.46
77.03
76.61
73.88
51.75
O
N
CO2Me
Cl
4c
f1 (ppm)

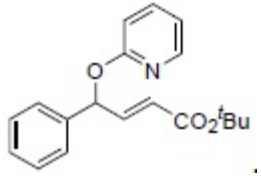

8.12
8.10
7.58
7.58
7.56
7.50
7.30
7.26
7.18
7.15
6.87
6.85
6.83
6.16
6.13
3.72
1.59
0.00
Br
O
N
CO2Me
4d
0.97
1.96
0.98
1.03
2.91
1.94
0.96
3.00
f1 (ppm)

166.70
161.90
147.05
145.11
138.92
138.06
132.92
129.56
128.52
127.87
122.78
121.05
117.52
111.13
77.45
77.03
76.61
73.70
51.71



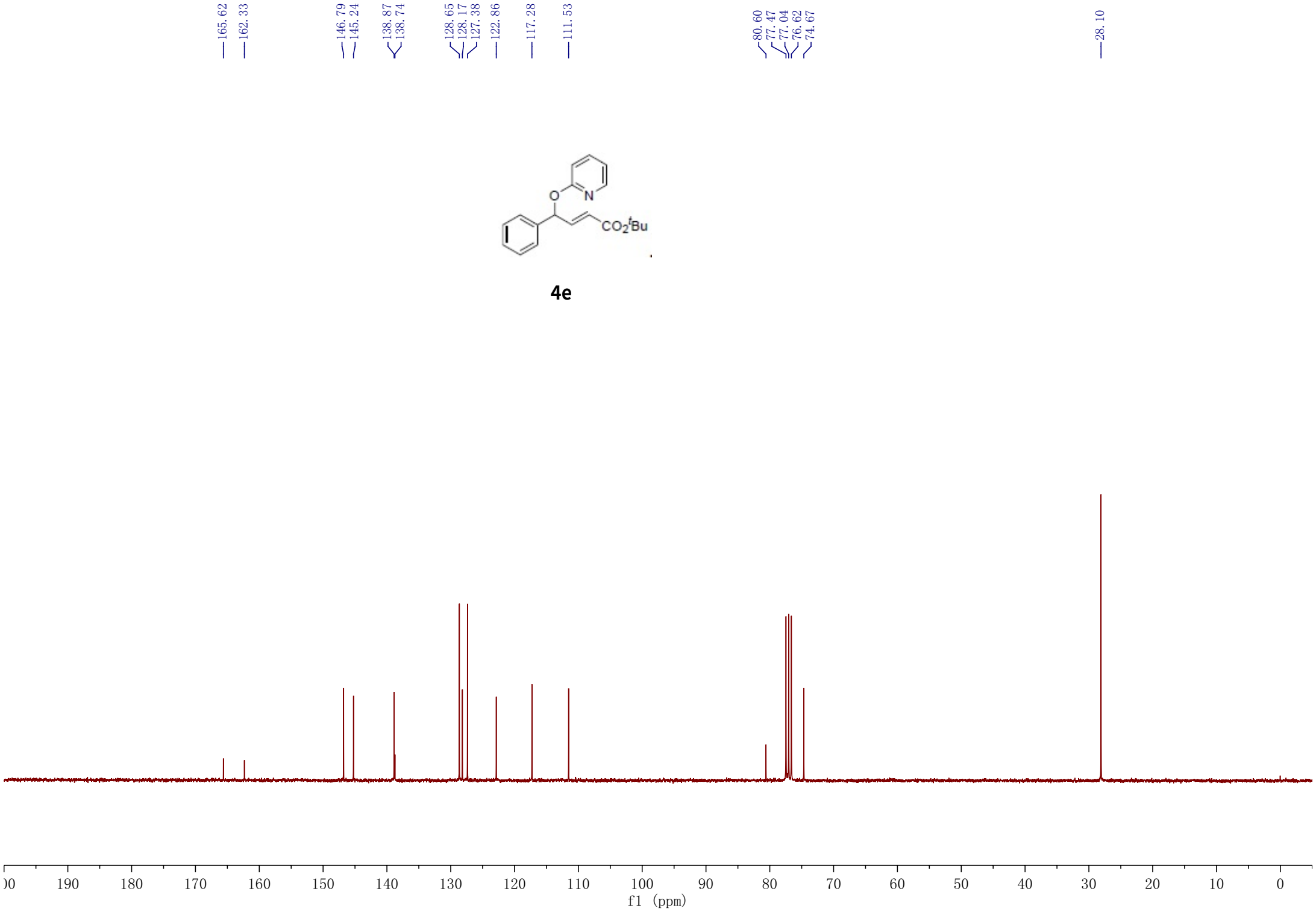
4d



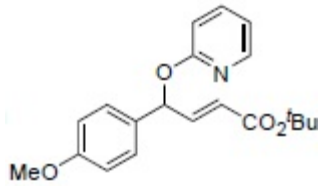

O
N
CO2tBu

4e

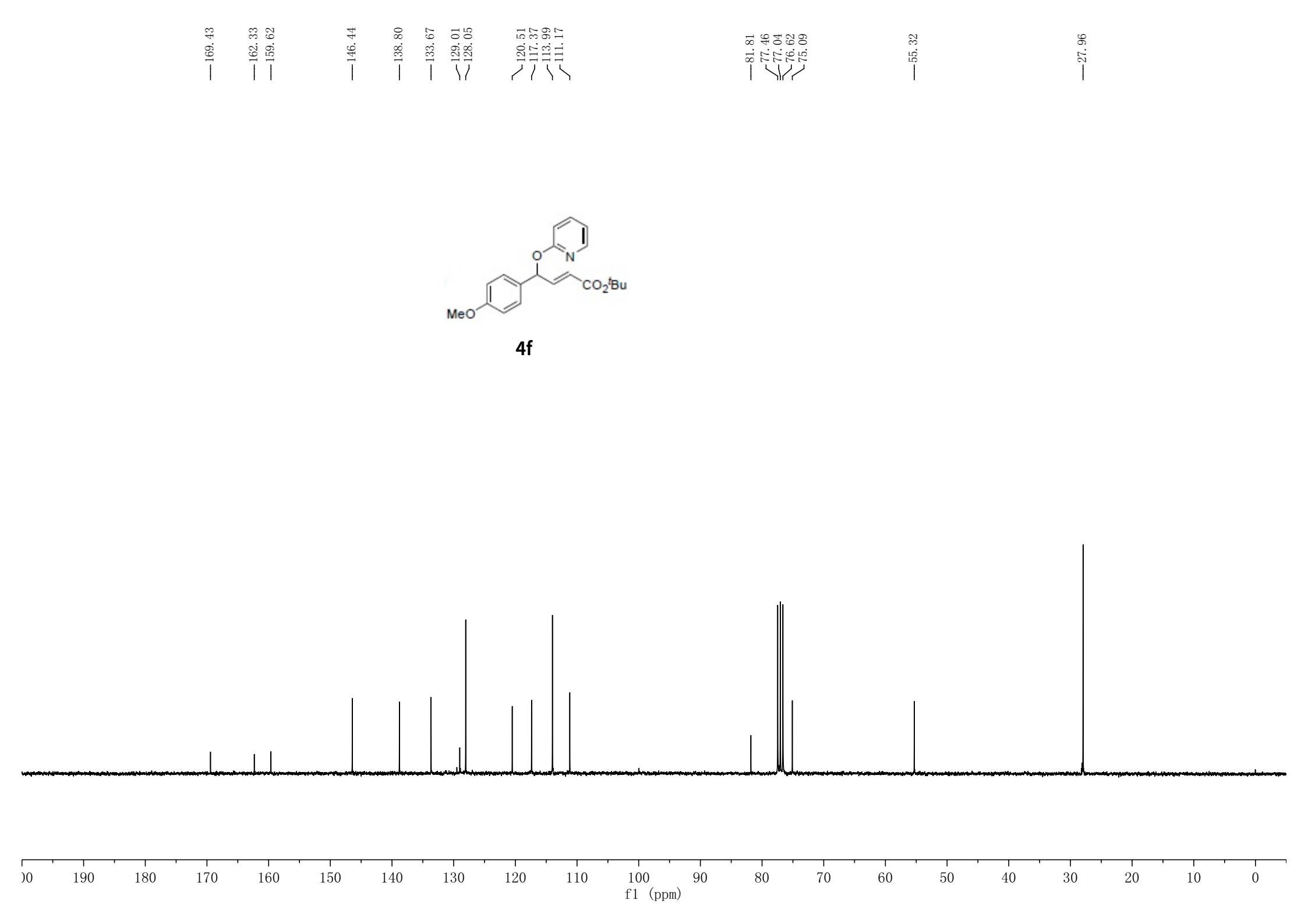
8.11
8.10
8.09
7.57
7.46
7.44
7.38
7.36
7.34
7.31
7.29
7.26
7.06
7.03
7.02
6.85
6.85
6.83
6.81
6.04
6.03
6.00
6.00
1.60
1.46
0.00
0.99
1.05
2.01
3.00
1.02
3.05
1.01
9.00
f1 (ppm)

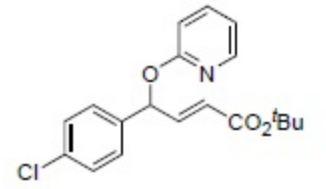

165.62
162.33
146.79
145.24
138.87
138.74
128.65
128.17
127.38
122.86
117.28
111.53
80.60
77.47
77.04
76.62
74.67
28.10
O
N
CO2tBu
f1 (ppm)

4e



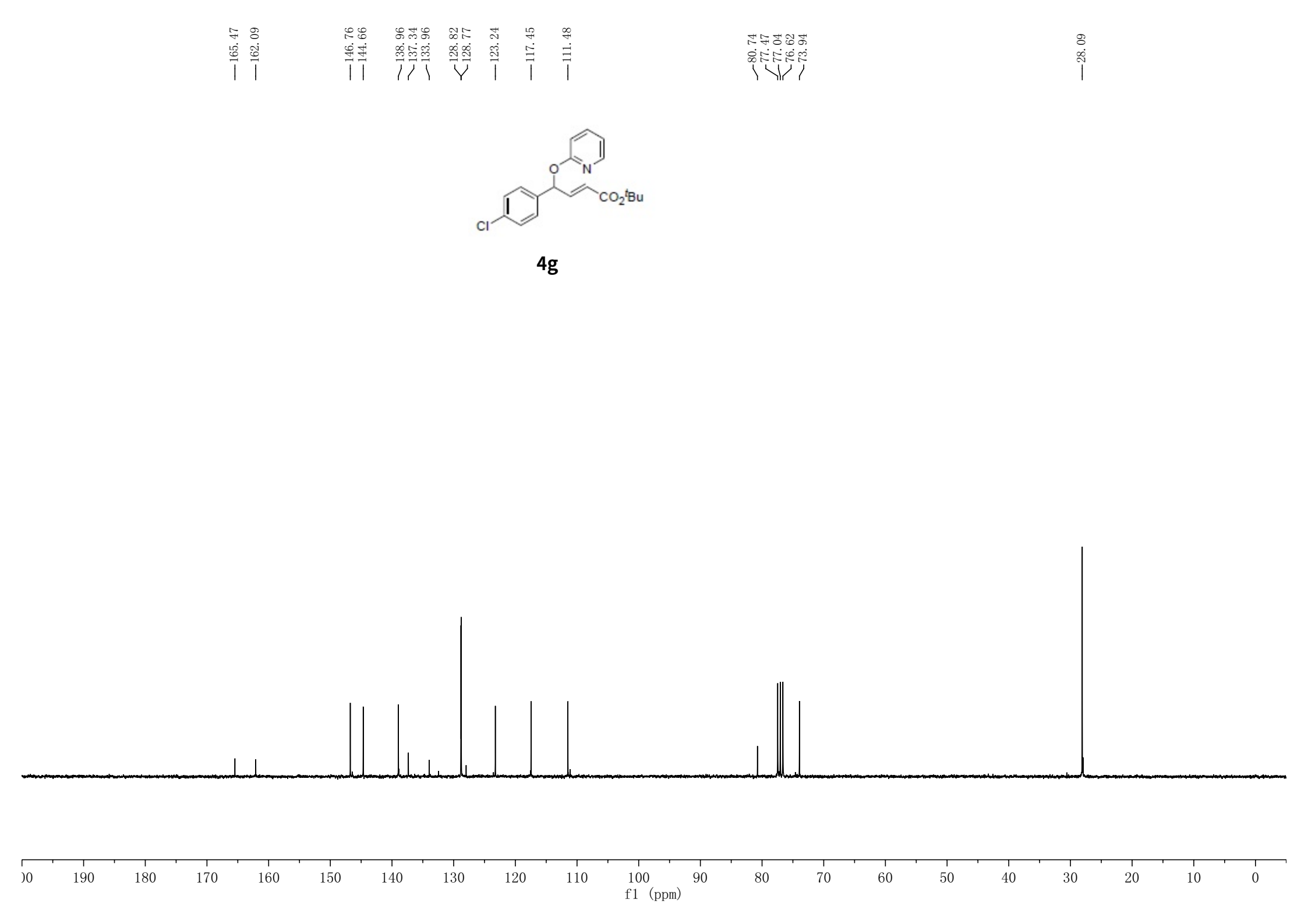
4f

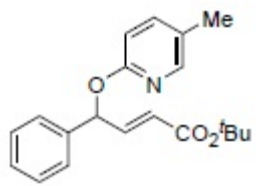

169.43
162.33
159.62
146.44
138.80
133.67
129.01
128.05
120.51
117.37
113.99
111.17
81.81
77.46
77.04
76.62
75.09
55.32
27.96
O
N
CO2tBu
MeO
4f
f1 (ppm)


O
N
CO2tBu
Cl

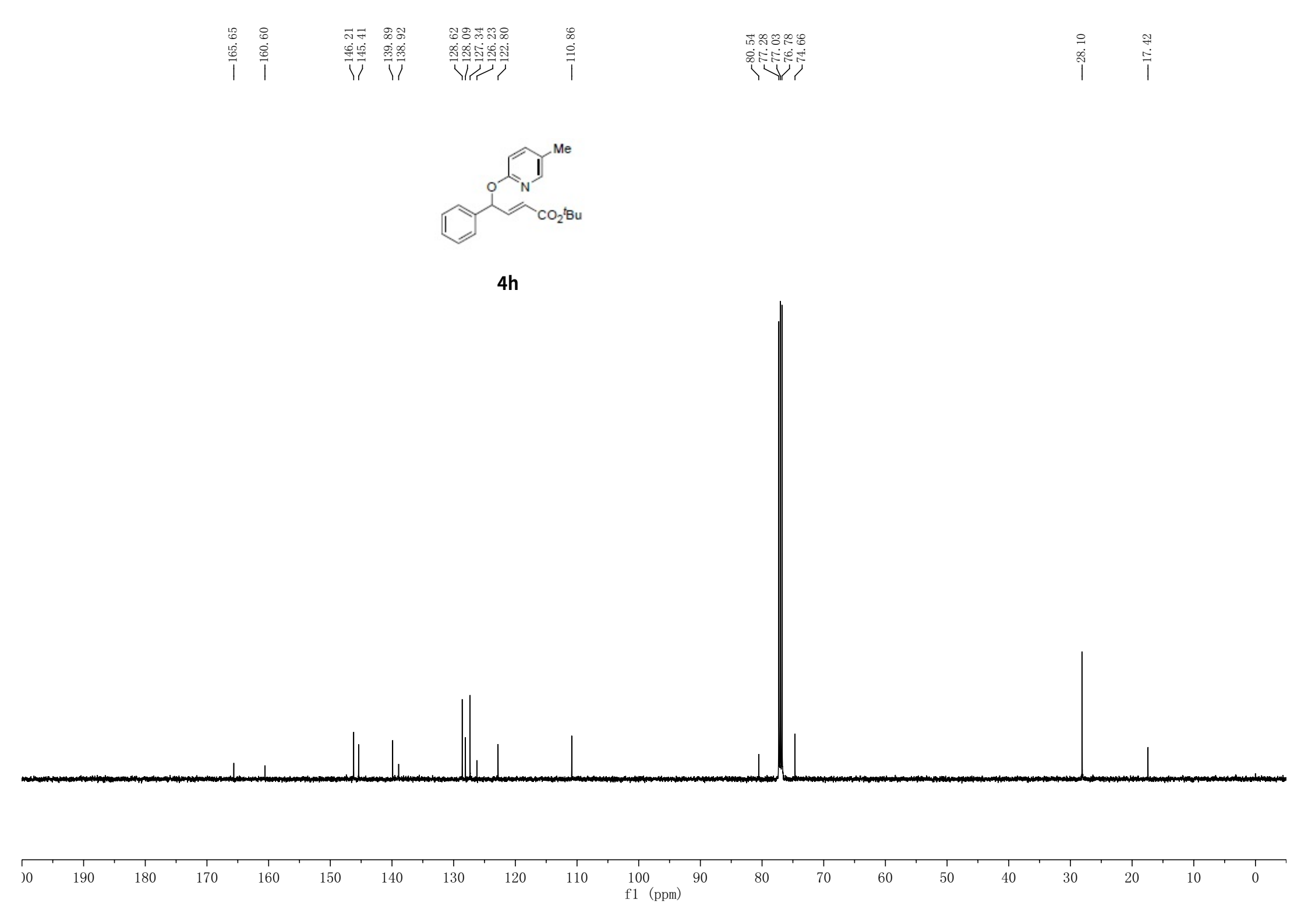
4g

8.10
8.08
7.60
7.58
7.56
7.40
7.37
7.33
7.31
7.26
7.01
6.98
6.97
6.86
6.85
6.83
6.80
6.79
6.78
6.03
5.99
1.60
1.46
0.00
1.07
1.04
2.03
2.05
1.00
3.13
0.99
9.00
f1 (ppm)


165.47
162.09
146.76
144.66
138.96
137.34
133.96
128.82
128.77
123.24
117.45
111.48
80.74
77.47
77.04
76.62
73.94
28.09
O
N
CO2tBu
Cl
4g
f1 (ppm)



4h


165.65
160.60
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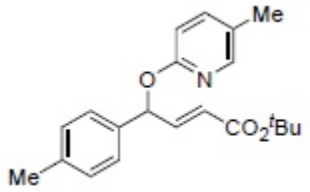
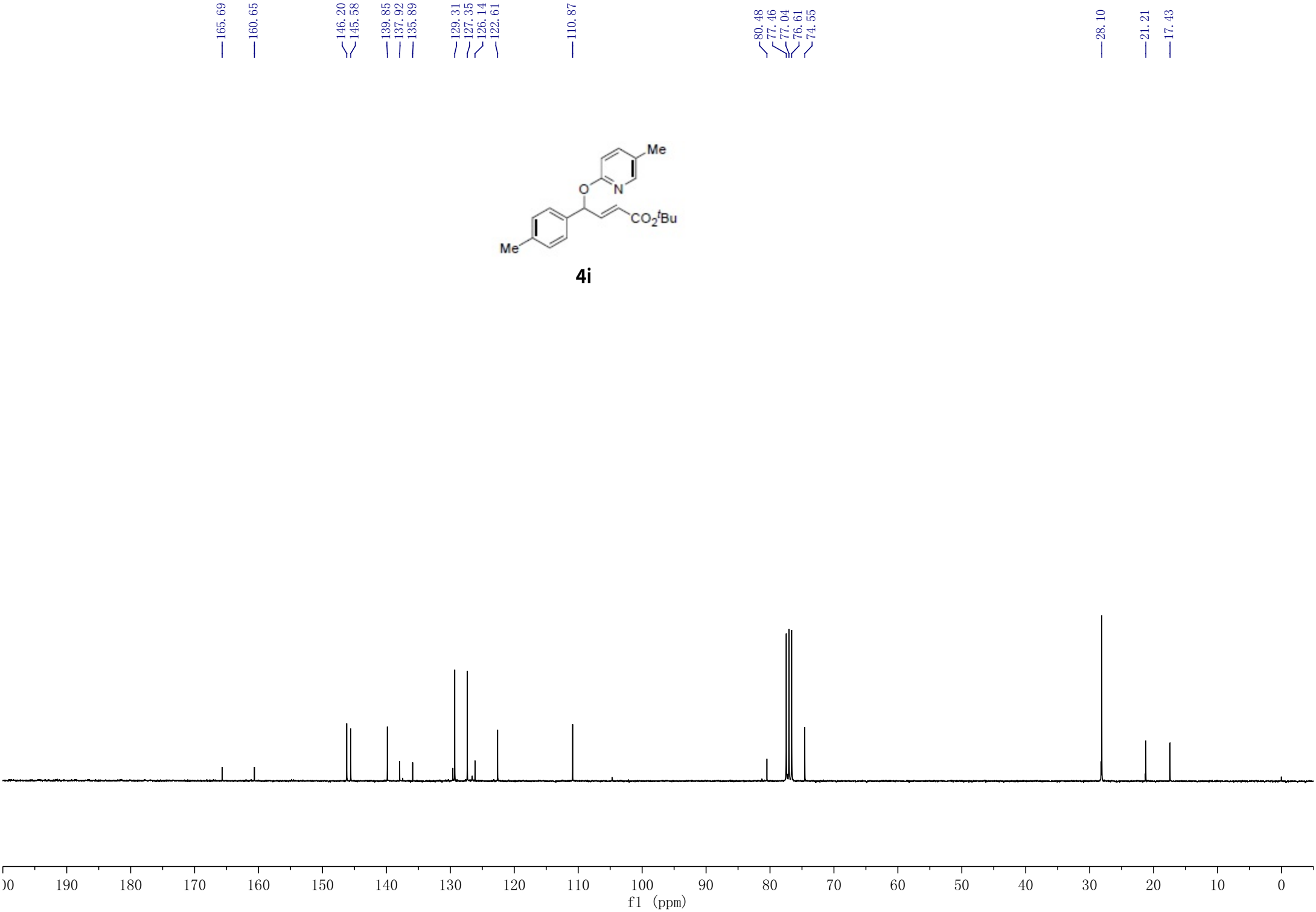
138.92
128.62
128.09
127.34
126.23
122.80
110.86
80.54
77.28
77.03
76.78
74.66
28.10
17.42
Me
O
N
CO2tBu
4h
f1 (ppm)



4i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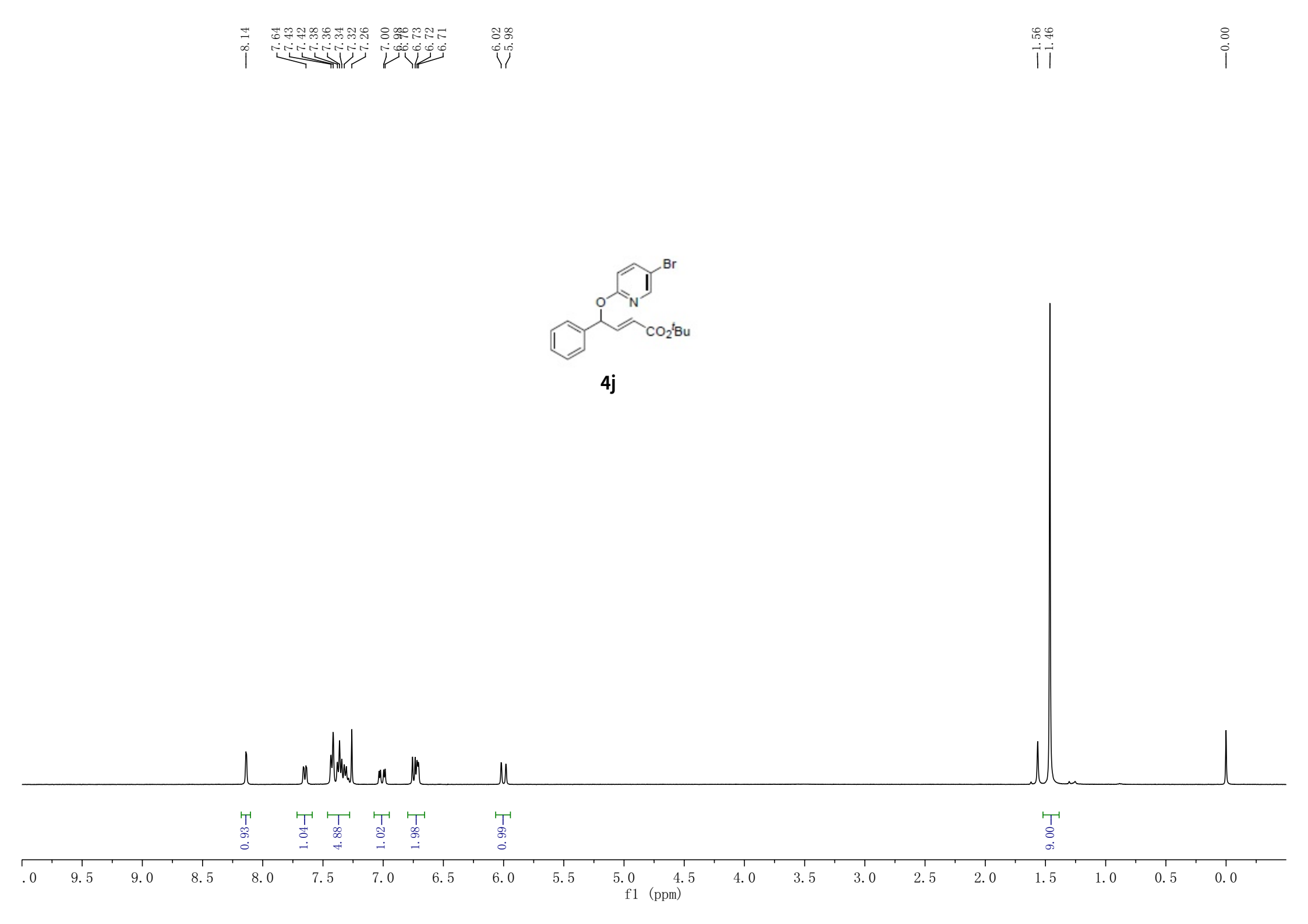
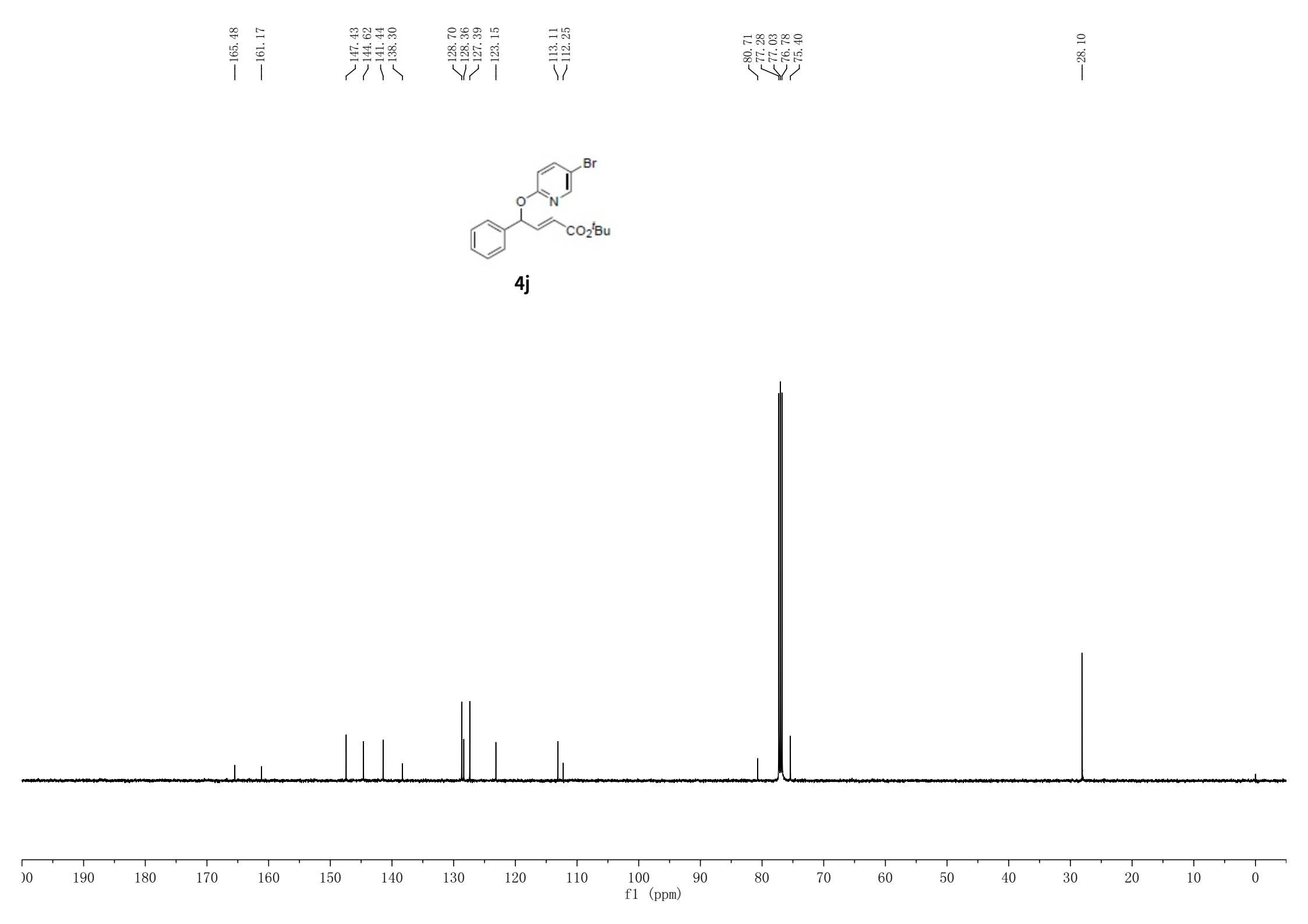
160.65
146.20
145.58
139.85
137.92
135.89
129.31
127.35
126.14
122.61
110.87
80.48
77.46
77.04
76.61
74.55
28.10
21.21
17.43
Me
O
N
CO2tBu
Me
4i
f1 (ppm)


8.14
7.64
7.43
7.42
7.38
7.36
7.34
7.32
7.26
7.00
6.98
6.73
6.72
6.71
6.02
5.98
1.56
1.46
0.00
Br
O
N
CO2tBu
4j
0.93
1.04
4.88
1.02
1.98
0.99
9.00
f1 (ppm)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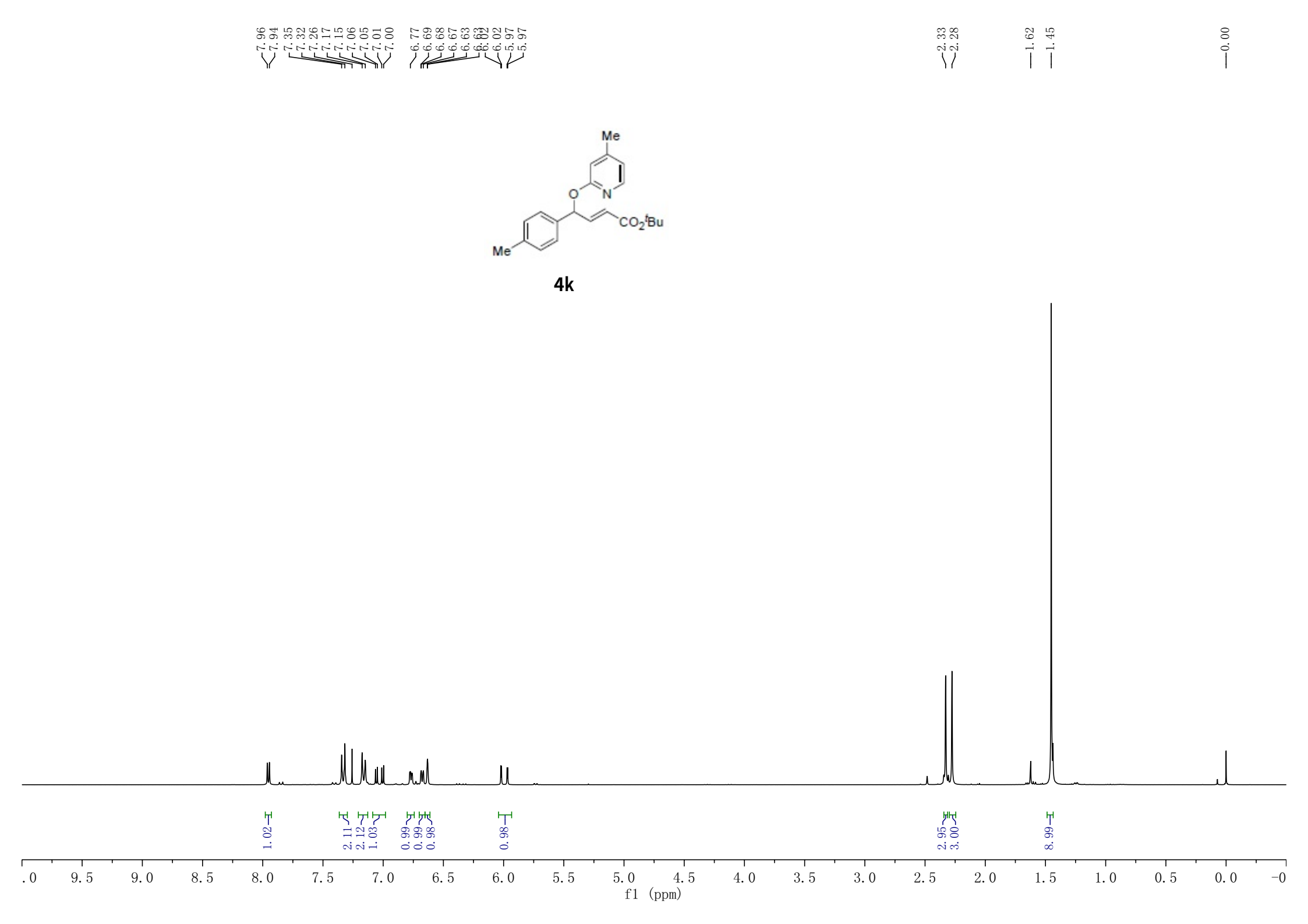
161.17
147.43
144.62
141.44
138.30
128.70
128.36
127.39
123.15
113.11
112.25
80.71
77.28
77.03
76.78
75.40
28.10
Br
O
N
CO2tBu
4j
f1 (ppm)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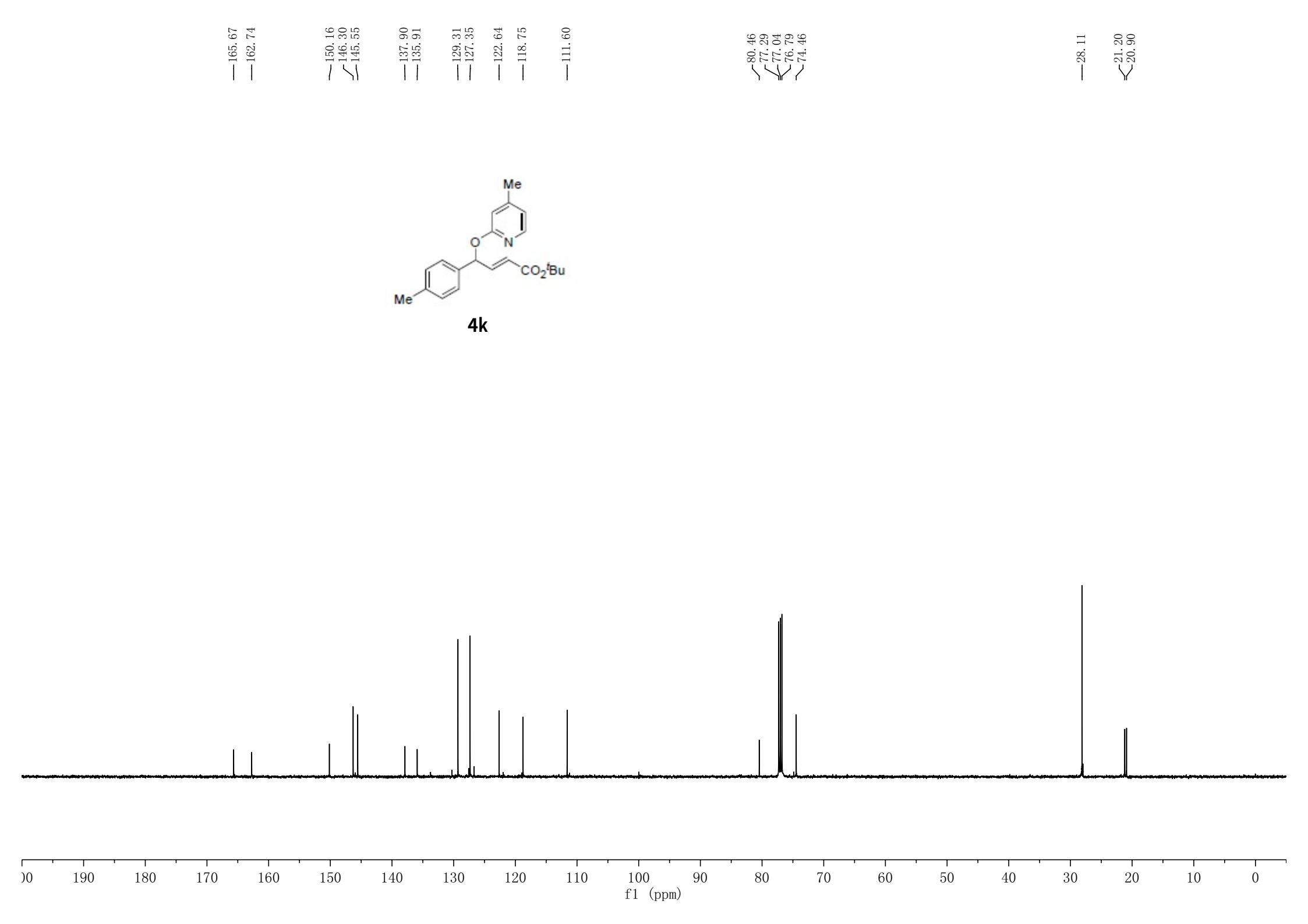
7.94
7.35
7.32
7.26
7.17
7.15
7.06
7.05
7.01
7.00
6.77
6.69
6.68
6.67
6.63
6.02
5.97
5.97
2.33
2.28
1.62
1.45
0.00
Me
O
N
CO2tBu
Me
4k
1.02
2.11
2.12
1.03
0.99
0.99
0.98
0.98
2.95
3.00
8.99
f1 (ppm)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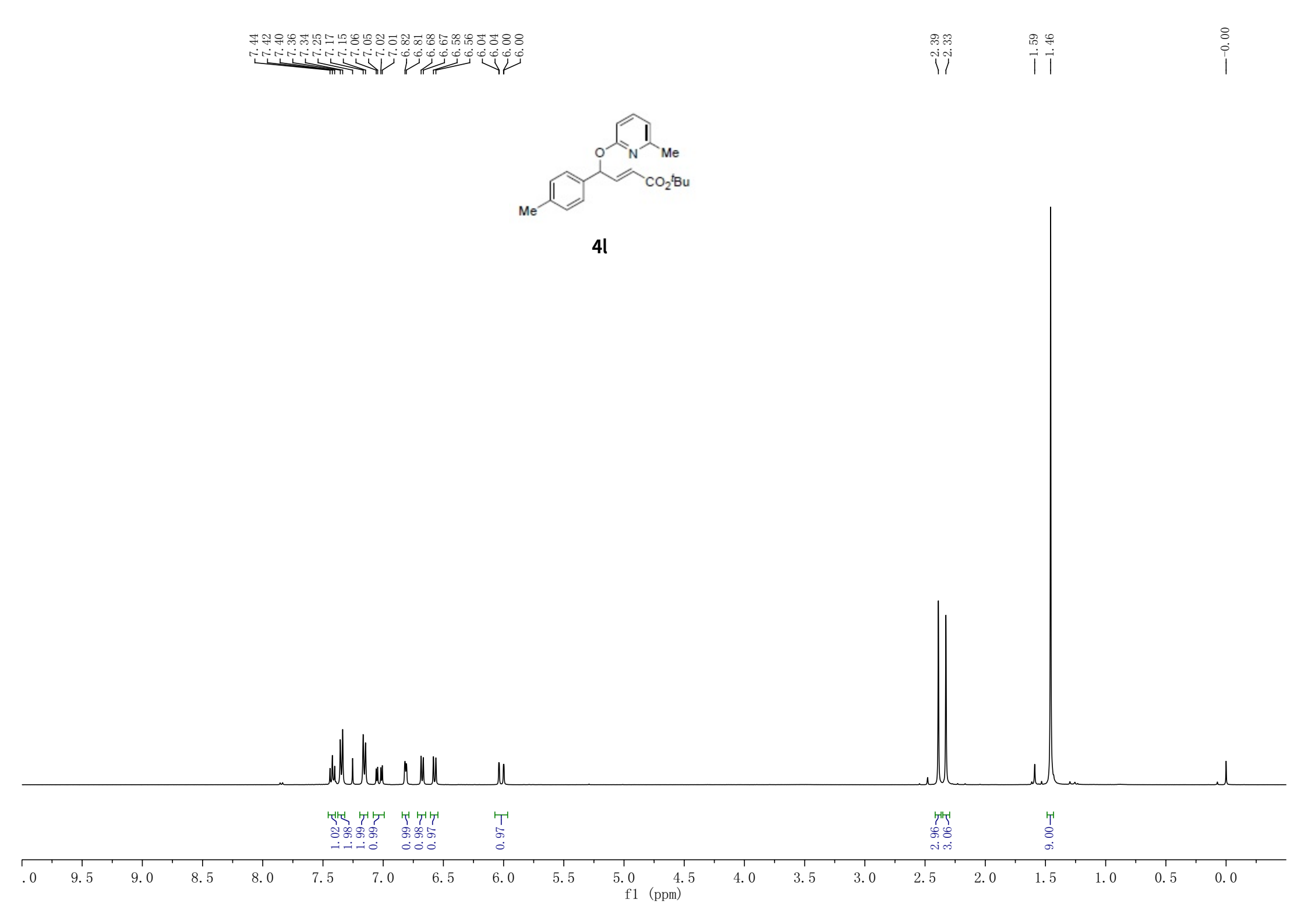
137.90
135.91
129.31
127.35
122.64
118.75
111.60
80.46
77.29
77.04
76.79
74.46
28.11
21.20
20.90
Me
O
N
CO2tBu
Me
4k
f1 (ppm)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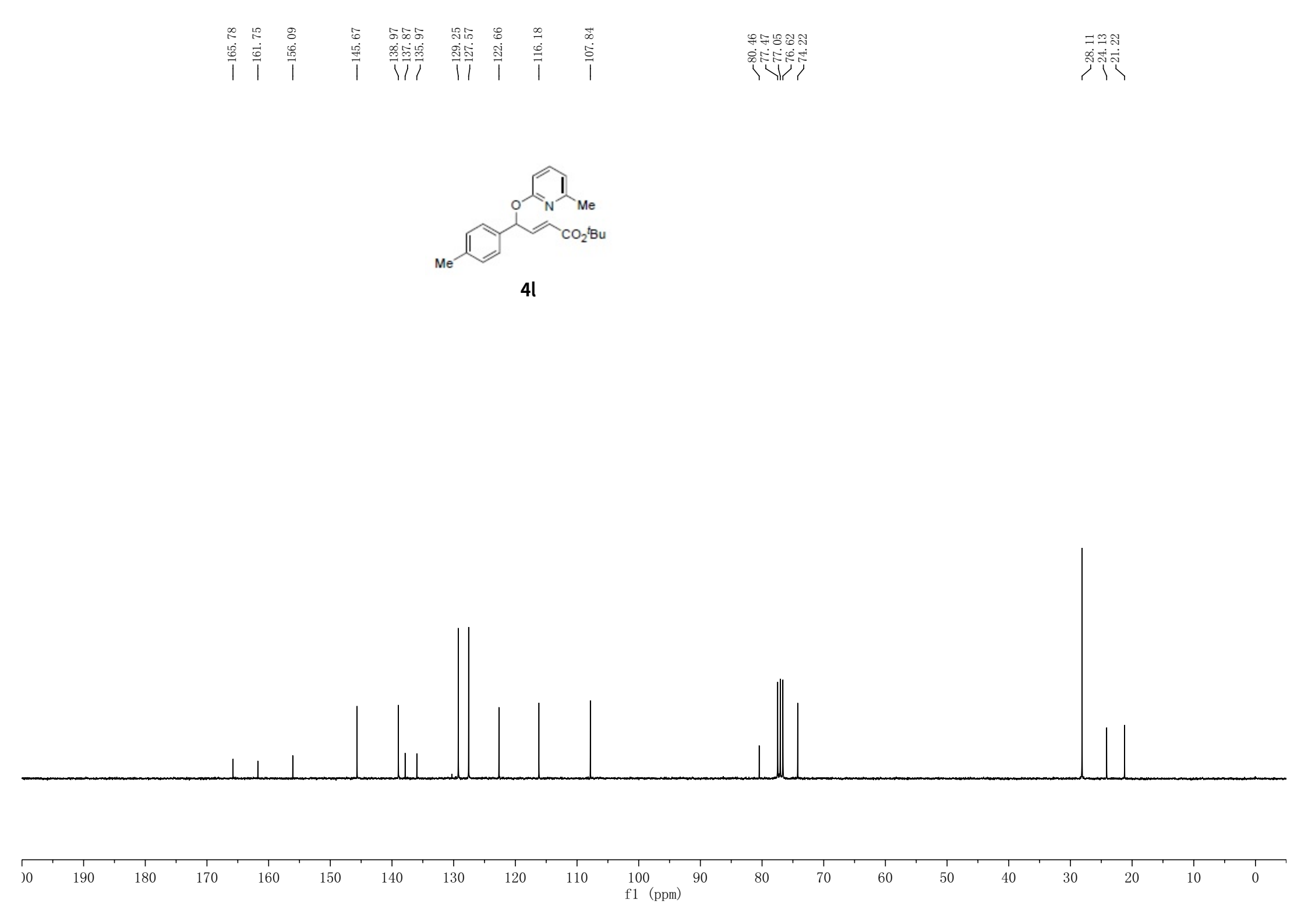
7.42
7.40
7.36
7.34
7.25
7.17
7.15
7.06
7.05
7.02
7.01
6.82
6.81
6.68
6.67
6.58
6.56
6.04
6.04
6.00
6.00
2.39
2.33
1.59
1.46
0.00
O
N
Me
CO2tBu
Me
4l
1.02
1.98
1.99
0.99
0.99
0.98
0.97
0.97
2.96
3.06
9.00
f1 (ppm)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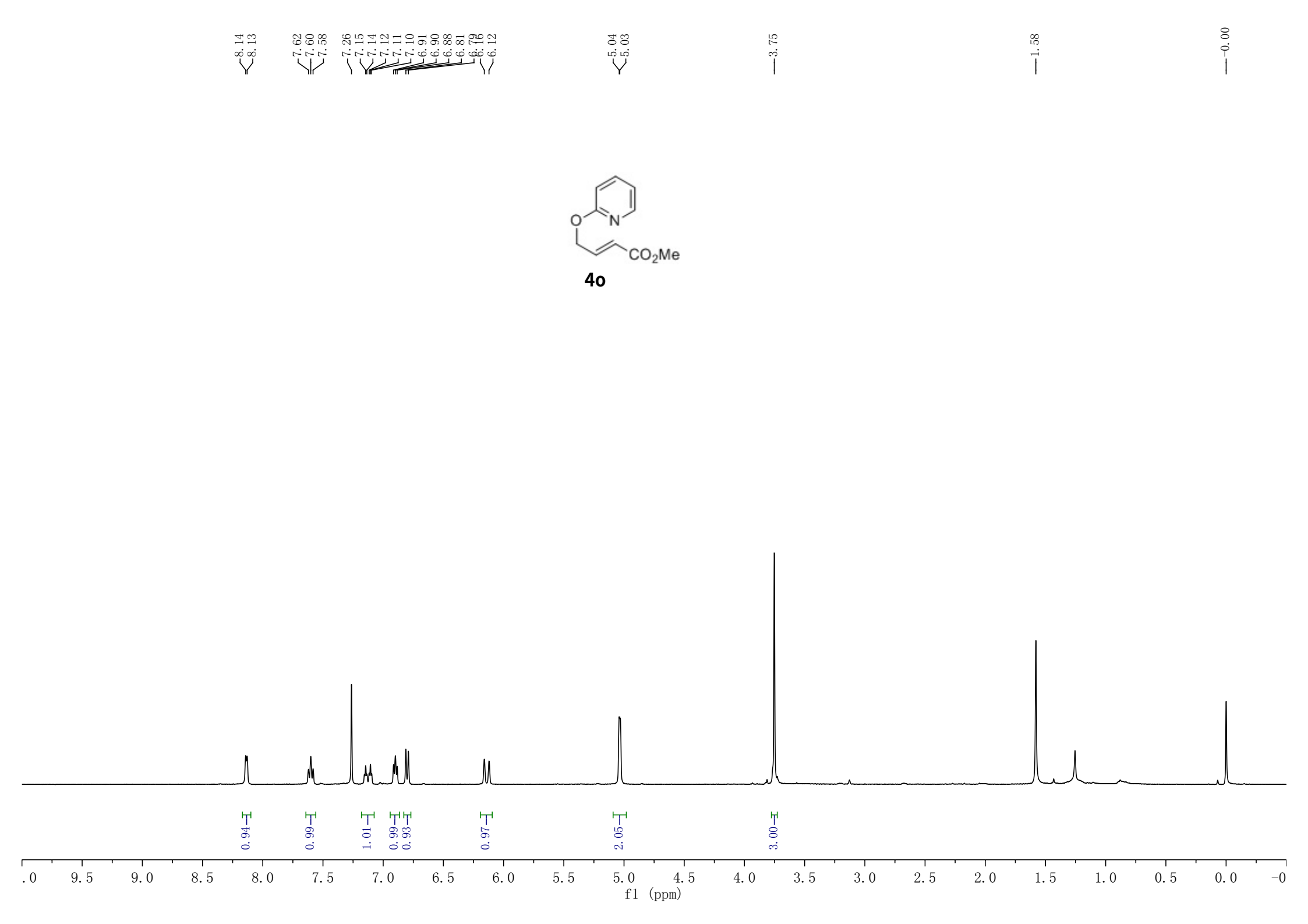
138.97
137.87
135.97
129.25
127.57
122.66
116.18
107.84
80.46
77.47
77.05
76.62
74.22
28.11
24.13
21.22
O
N
Me
CO2tBu
Me
f1 (ppm)

4l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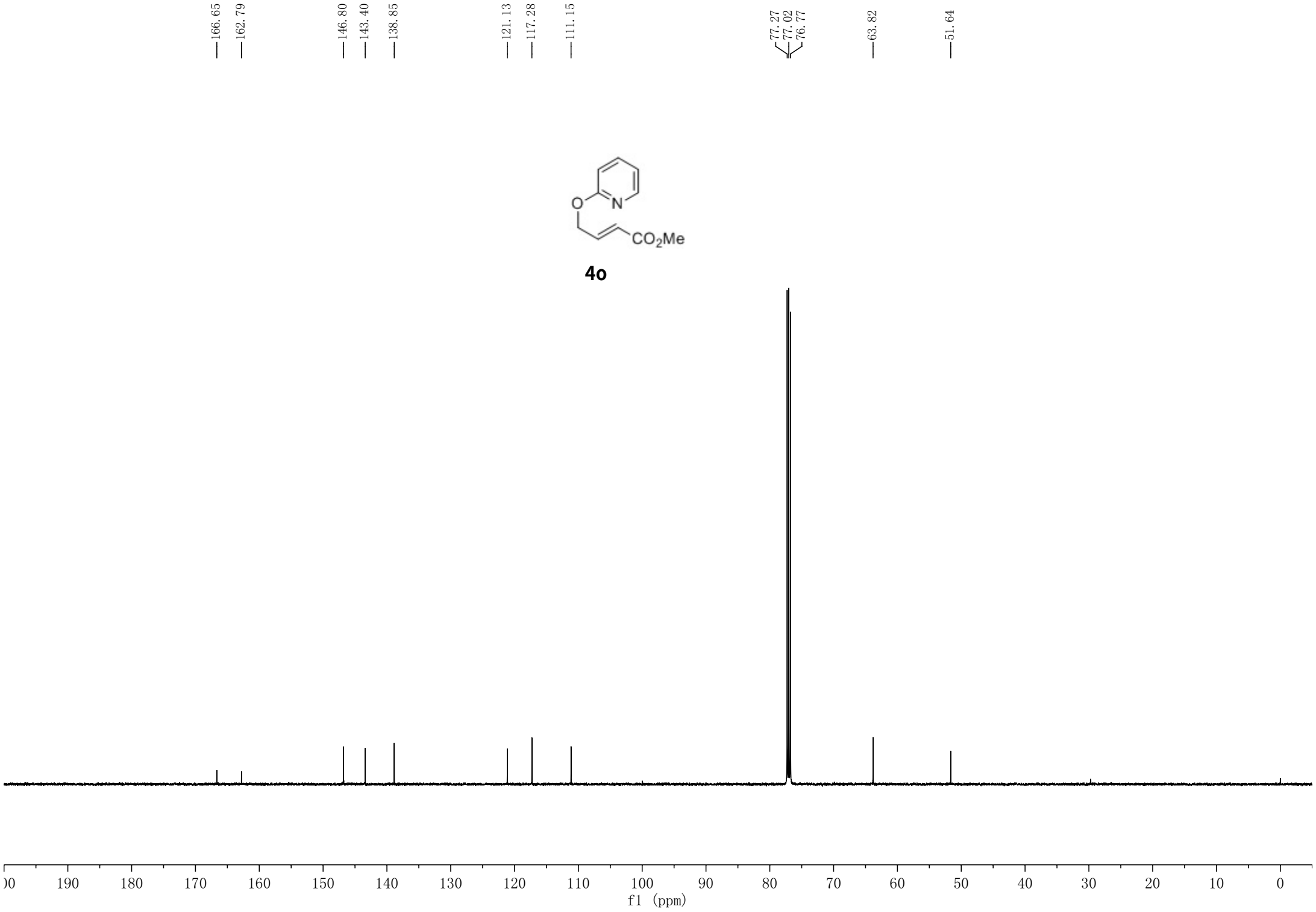
8.13
7.62
7.60
7.58
7.26
7.15
7.14
7.12
7.11
7.10
6.91
6.90
6.88
6.81
6.79
6.16
6.12
5.04
5.03
3.75
1.58
0.00
O
N
CO2Me
4o
0.94
0.99
1.01
0.99
0.93
0.97
2.05
3.00
f1 (ppm)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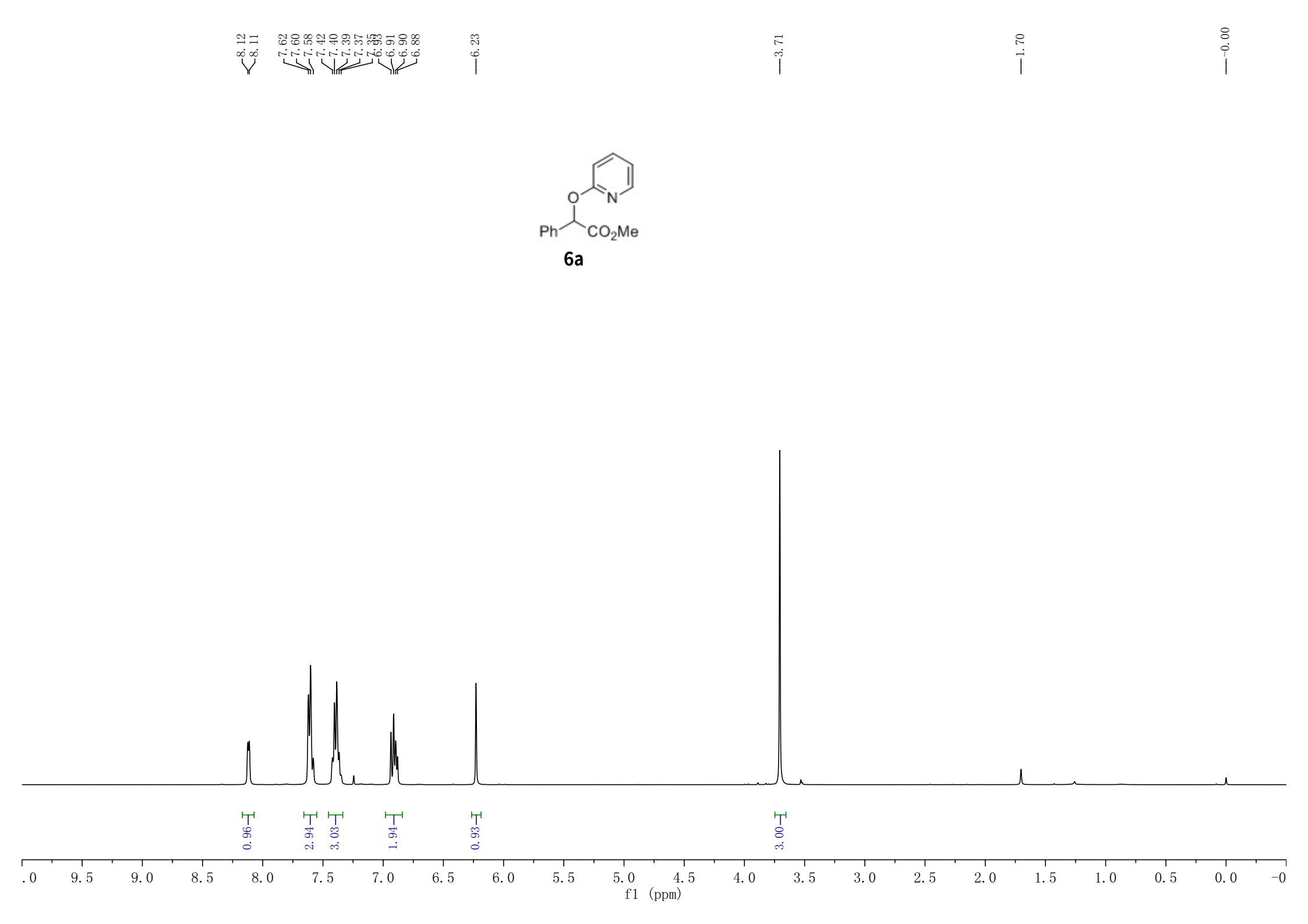
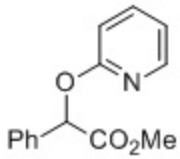
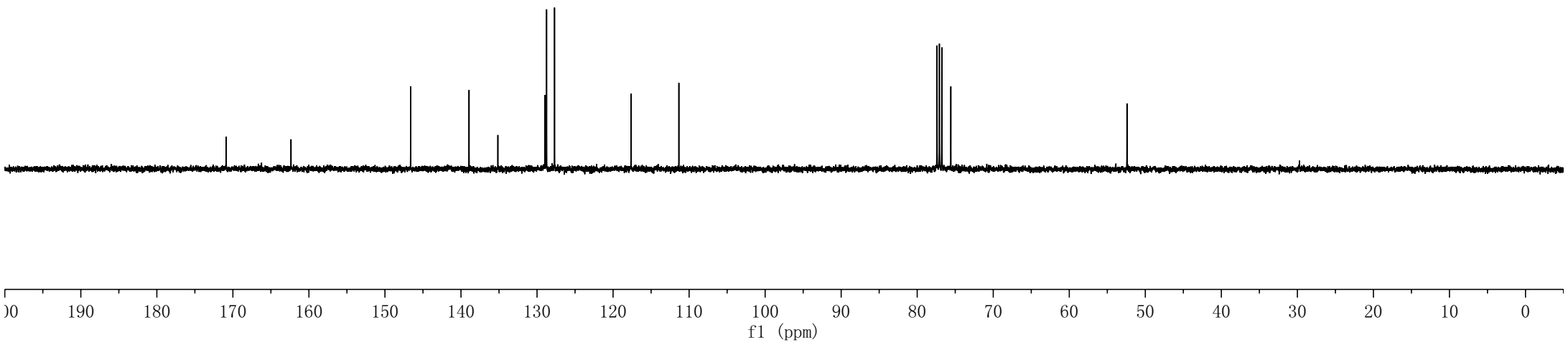
143.40
138.85
121.13
117.28
111.15
77.27
77.02
76.77
63.82
51.64
O
N
CO2Me
4o
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

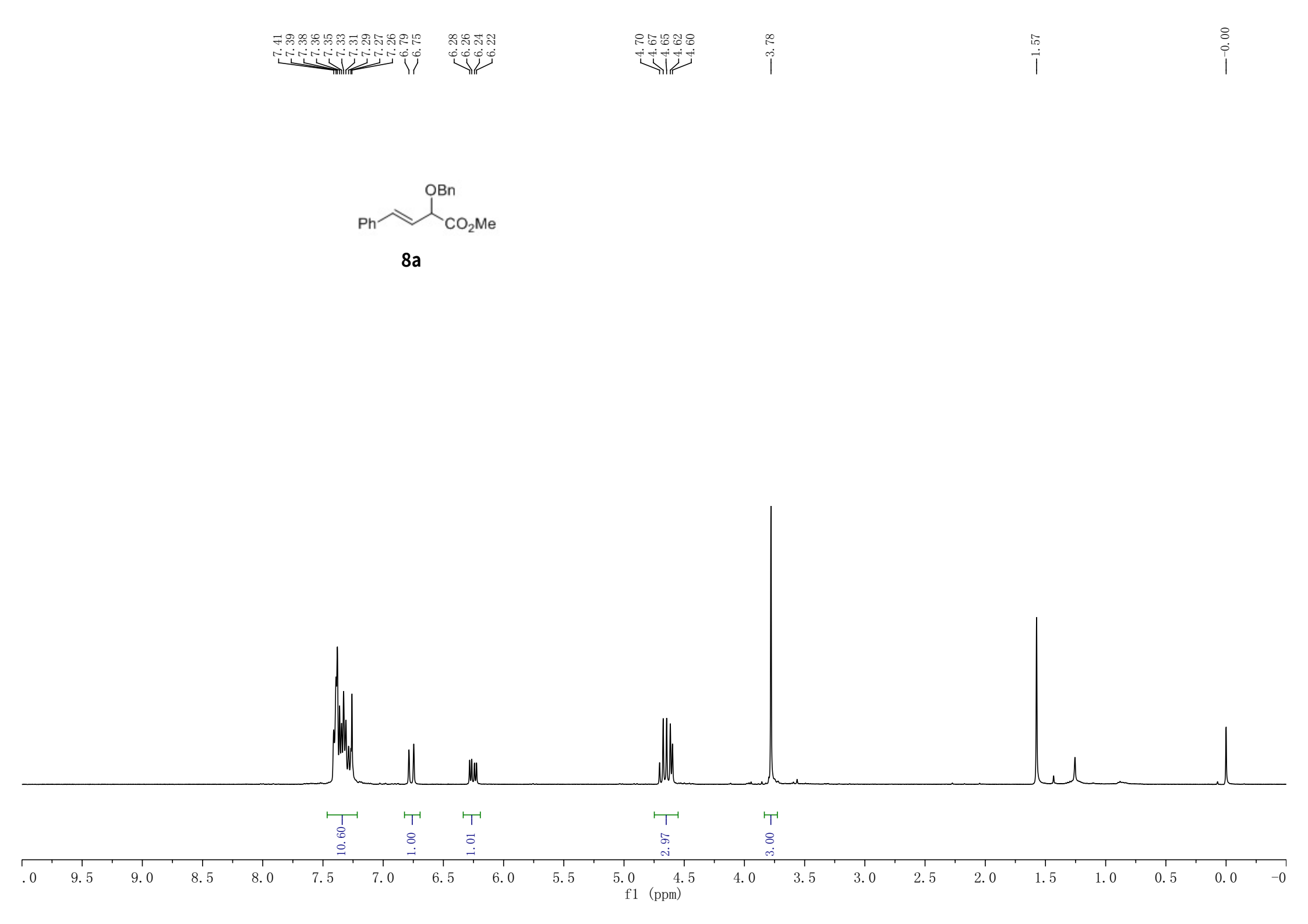

8.12
8.11
7.62
7.60
7.58
7.42
7.40
7.39
7.37
7.35
7.33
6.91
6.90
6.88
6.23
3.71
1.70
0.00
O
N
Ph
CO2Me
6a
0.96
2.94
3.03
1.94
0.93
3.00
f1 (ppm)

170.89
162.35
146.62
138.94
135.15
128.97
128.74
127.70
117.63
111.34
77.40
77.08
76.76
75.58
52.41



6a

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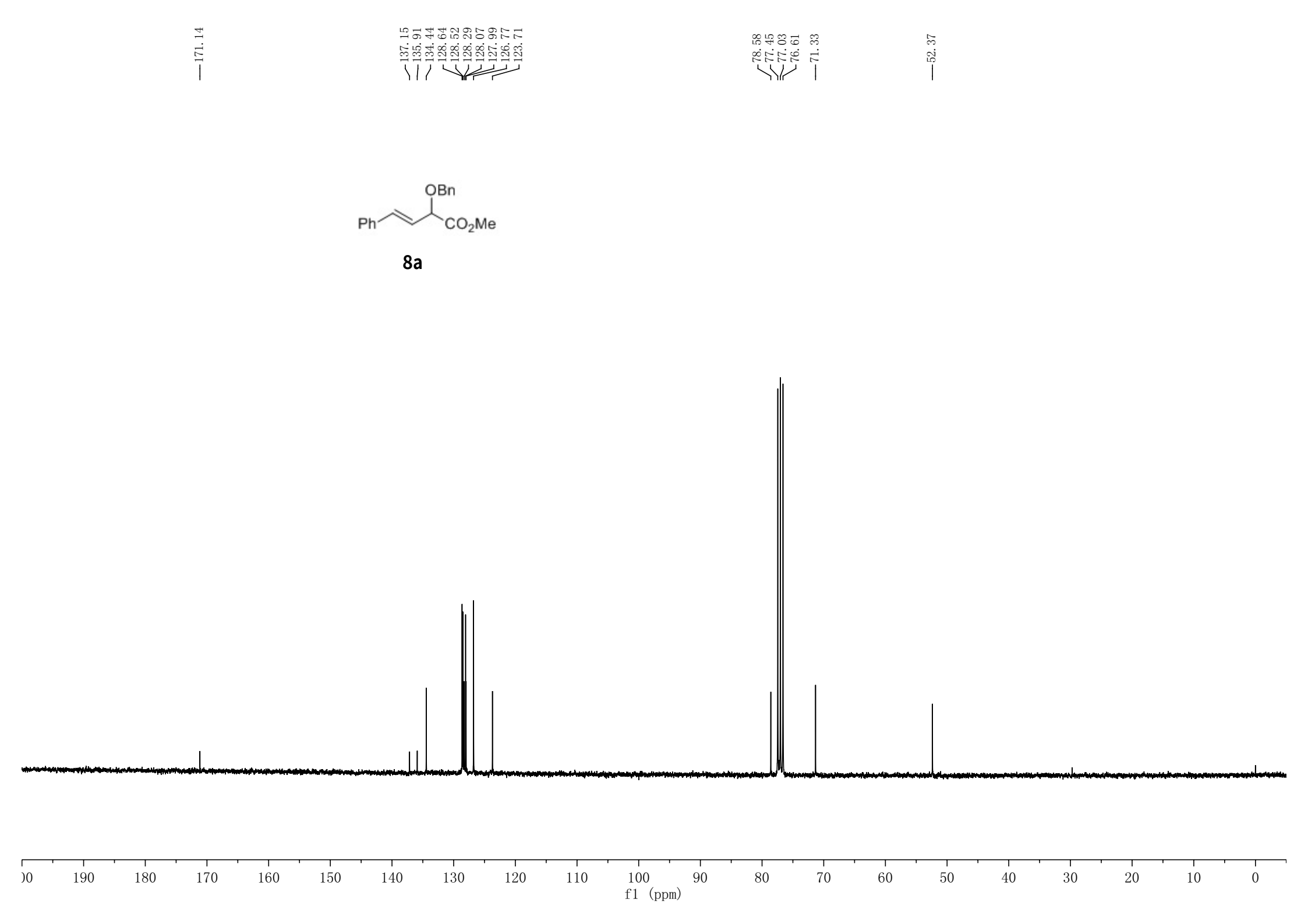
7.38
7.36
7.35
7.33
7.31
7.29
7.27
7.26
6.79
6.75
6.28
6.26
6.24
6.22
4.70
4.67
4.65
4.62
4.60
3.78
1.57
0.00
OBn
Ph
CO2Me
8a
10.60
1.00
1.01
2.97
3.00
f1 (ppm)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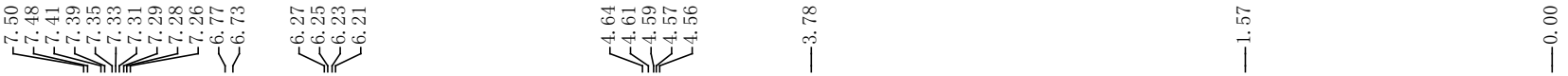
128.64
128.52
128.29
128.07
127.99
126.77
123.71
78.58
77.45
77.03
76.61
71.33
52.37
OBn
Ph
CO2Me
8a
f1 (ppm)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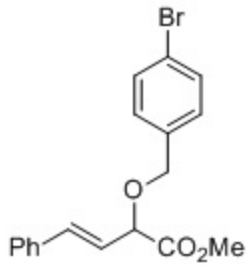
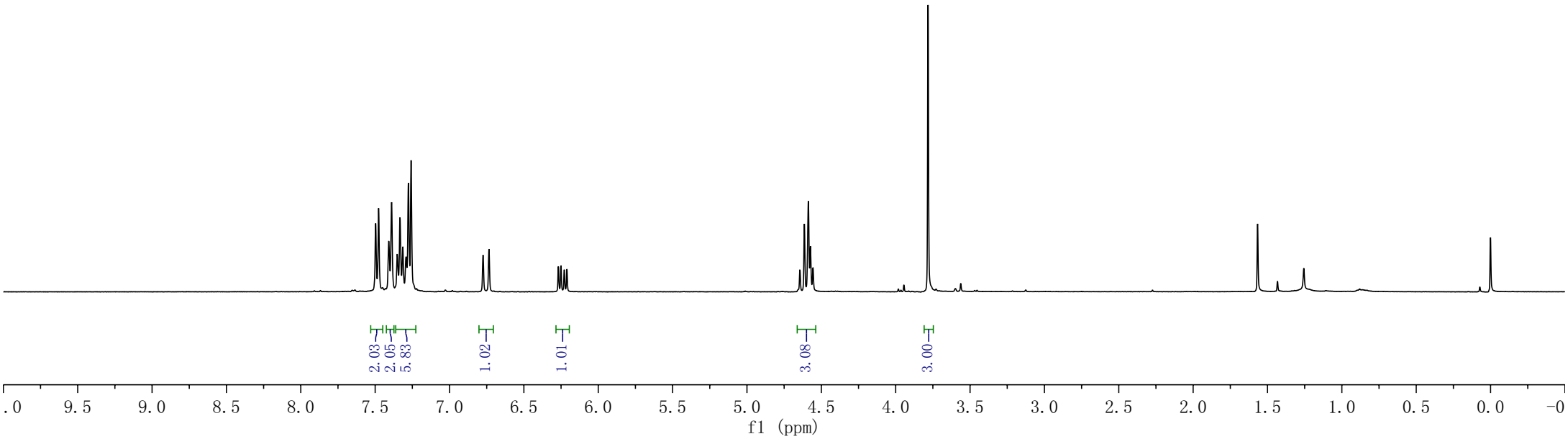
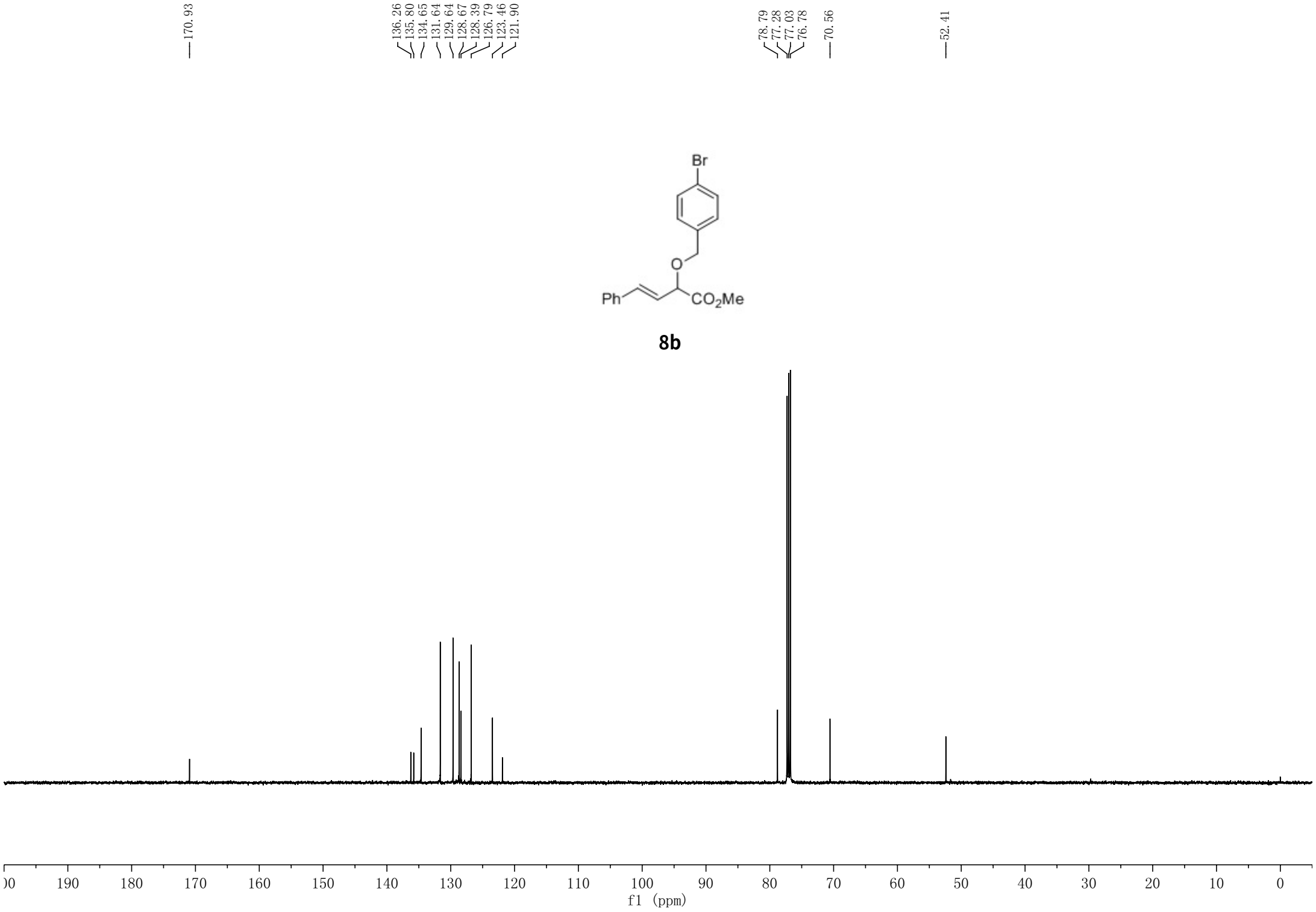
7.48
7.41
7.39
7.35
7.33
7.31
7.29
7.28
7.26
6.77
6.73
6.27
6.25
6.23
6.21
4.64
4.61
4.59
4.57
4.56
3.78
1.57
0.00


Br
O
Ph
CO2Me

8b


2.03
2.05
5.83
1.02
1.01
3.08
3.00
.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0
f1 (ppm)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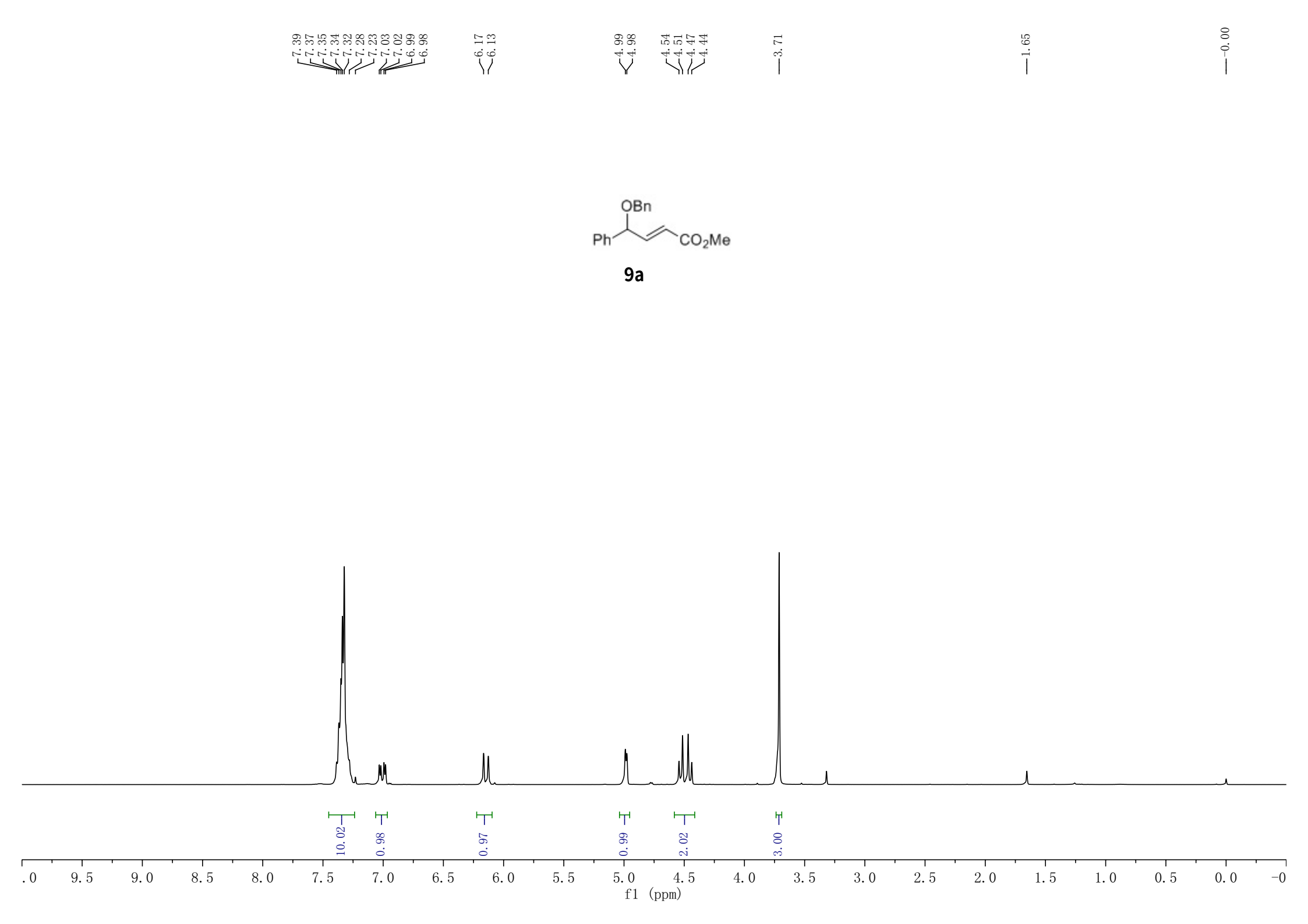
134.65
131.64
129.64
128.67
128.39
126.79
123.46
121.90
78.79
77.28
77.03
76.78
70.56
52.41
Br
O
Ph
CO2Me
f1 (ppm)

8b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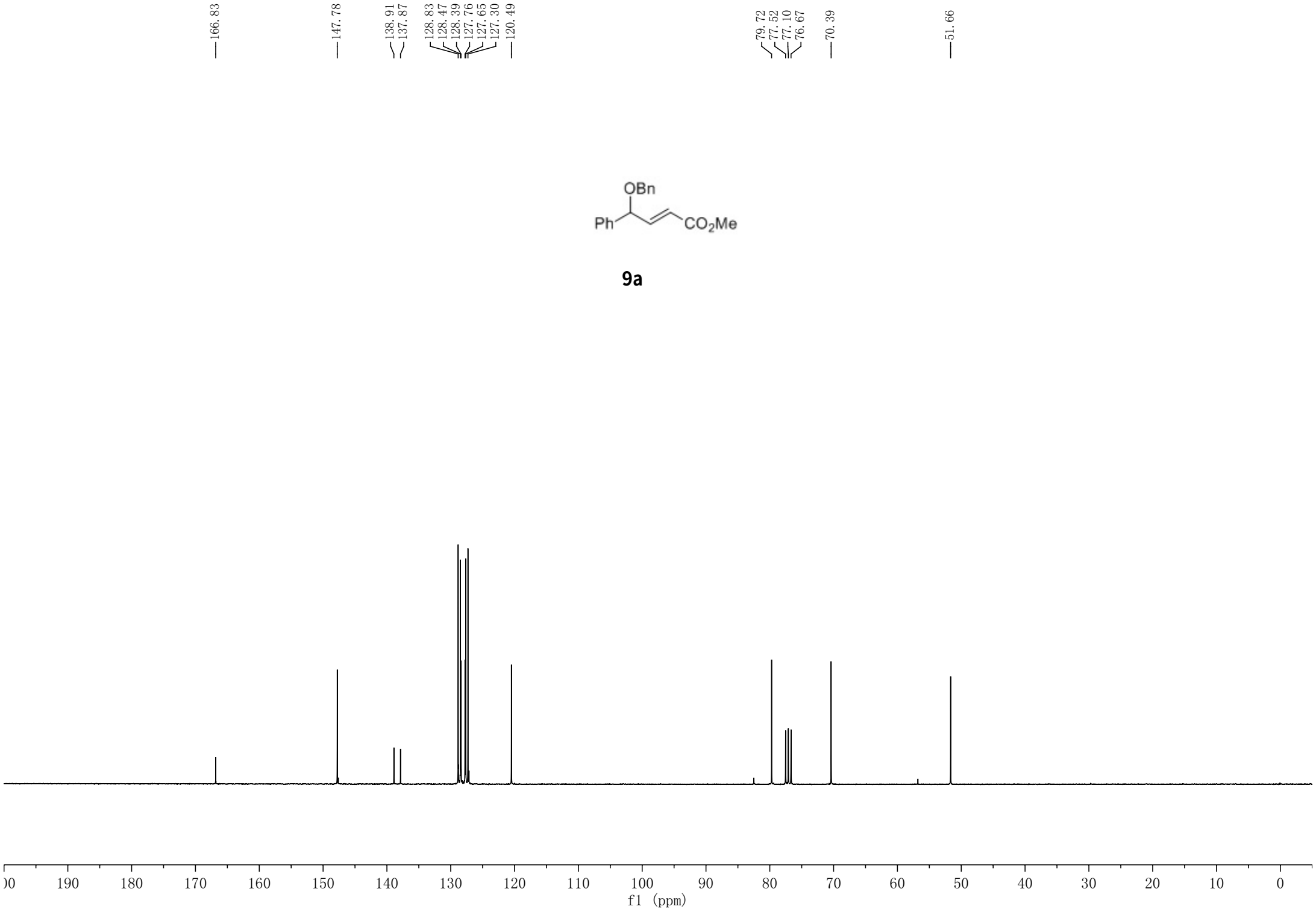
7.37
7.35
7.34
7.32
7.28
7.23
7.03
7.02
6.99
6.98
6.17
6.13
4.99
4.98
4.54
4.51
4.47
4.44
3.71
1.65
0.00
OBn
Ph
CO2Me
9a
10.02
0.98
0.97
0.99
2.02
3.00
f1 (ppm)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137.87
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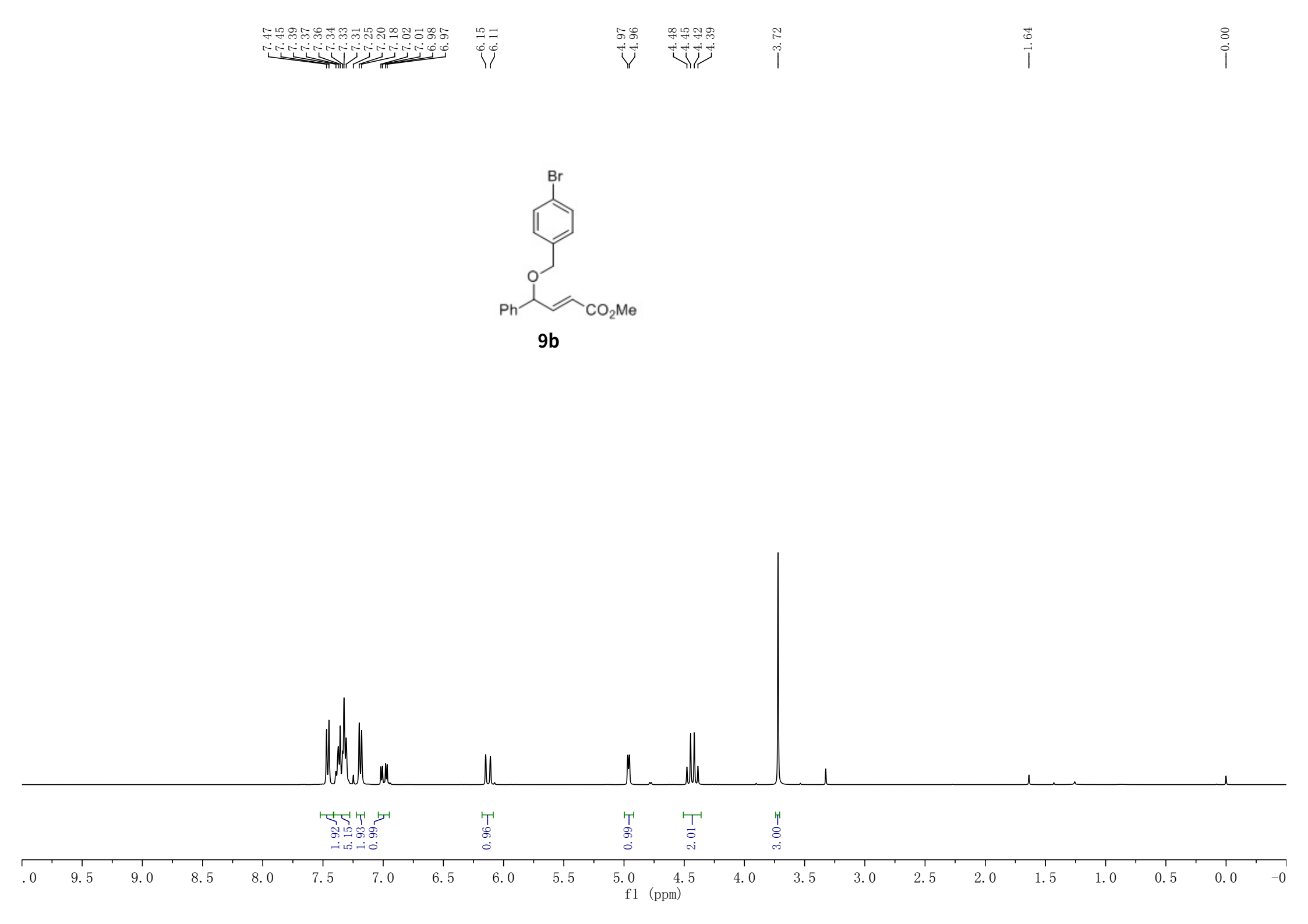
128.47
128.39
127.76
127.65
127.30
120.49
79.72
77.52
77.10
76.67
70.39
51.66
OBn
Ph
CO2Me
9a
f1 (ppm)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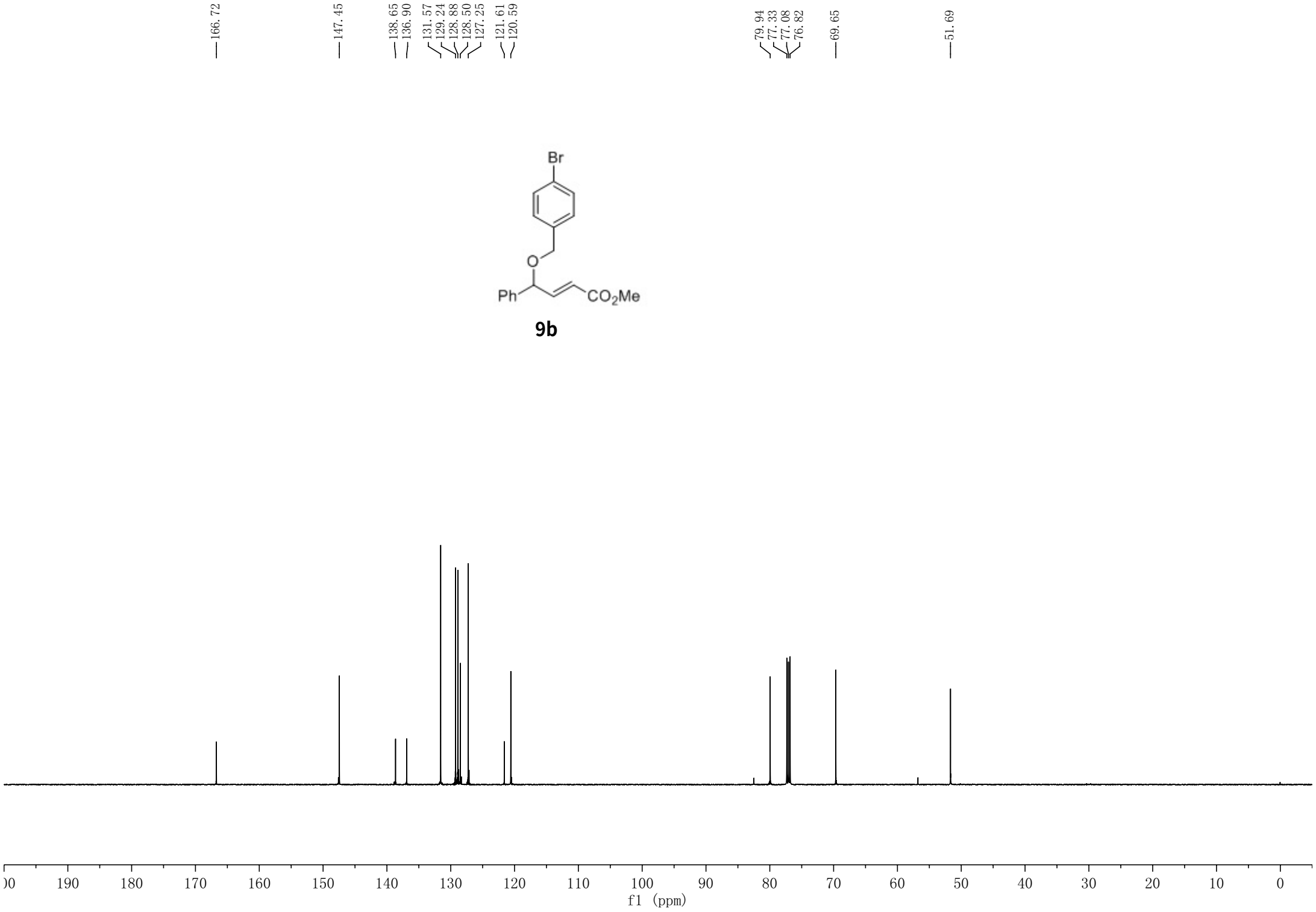
7.36
7.34
7.33
7.31
7.25
7.20
7.18
7.02
7.01
6.98
6.97
6.15
6.11
4.97
4.96
4.48
4.45
4.42
4.39
3.72
1.64
0.00
Br
O
Ph
CO2Me
9b
1.92
5.15
1.93
0.99
0.96
0.99
2.01
3.00
f1 (ppm)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136.90
131.57
129.24
128.88
128.50
127.25
121.61
120.59
79.94
77.33
77.08
76.82
69.65
51.69
Br
O
Ph
CO2Me
9b
f1 (ppm)