An Efficient Generation of a Functionalized Tertiary-Alkyl Radical for Copper-catalyzed Tertiary-Alkylative Mizoroki-Heck type Reaction

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Supporting Information

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General Information

All reactions were carried out under nitrogen (99.95%) atmosphere. For TLC analyses precoated Kieselgel 60 F254 plates (Merck, 0.25 mm thick) were used; for column chromatography Silica *Flash*® P60 (SiliCycle, 40-63 μm) was used. Visualization was accomplished by UV light (254 nm), ^{1}H and ^{13}C NMR spectra were obtained using a JEOL 400 MHz NMR spectrometer. Chemical shifts for 1H NMR were described in parts per million (chloroform as an internal standard δ = 7.26) in $CDCl_3$, unless otherwise noted. Chemical shifts for ^{13}C NMR were expressed in parts per million in $CDCl_3$ as an internal standard (δ = 77.16), unless otherwise noted. High resolution mass analyses were obtained using a ACQUITY UPLC/ TOF-MS for ESI. Anhydrous toluene and dichloromethane were purchased from Kanto Chemical Co., Ltd. Other chemicals were purchased from TCI, Aldrich and Wako and directly used from the bottles. Copper iodide (first grade; Lot. No. H28682K) was purchased from Kishida chemicals Co., Ltd.

1. General procedure

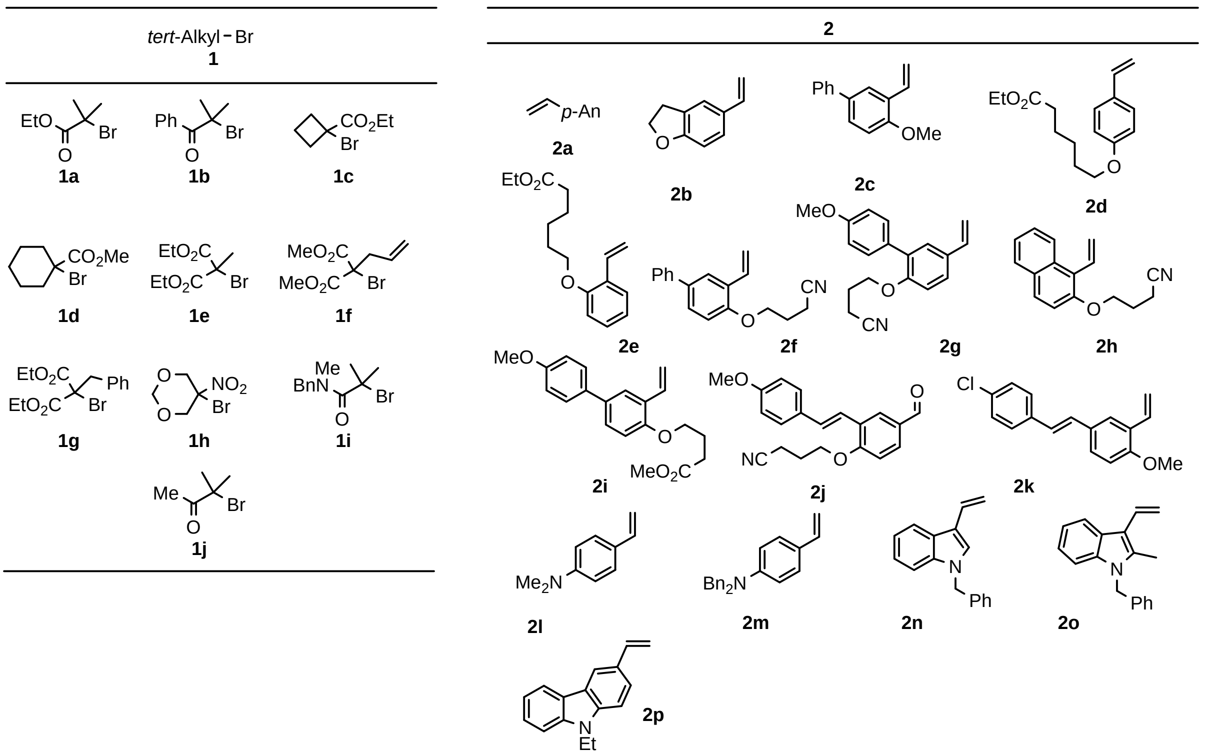
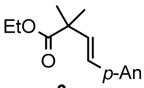


Figure 1. Starting materials.

Cu salt (0.05 mmol), and TBABr (0.25 mmol, 80 mg) were sequentially added under air to a dram vial equipped with a stir bar and a screw cap. Tert-alkyl halide **1** (1.0 mmol), substituted styrene **2** (0.5 mmol), PMDETA (N,N,N',N'',N''–pentamethyl –diethylnetriamine, **A3**, 0.5 mmol, 0.1 mL) and dried toluene (0.8 mL) were added by syringe and the resulting mixture vigorously stirred under nitrogen atmosphere for 20 h at the temperature shown in tables. After this time, the contents of the flask were filtered through the plug of silica gel, and then concentrated by rotary evaporation. The residue was purified by flash chromatography, eluting with hexane/EtOAc to afford the product **3**.

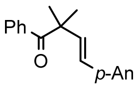
*Compound **3a** is known.[1]

2. Tertiary alkylations



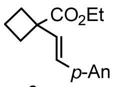
3a

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3a** (120 mg, 94%)[1]; IR (neat) ν 1724, 1510, 1240 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.23 (t, *J* = 7.3 Hz, 3H), 1.37 (s, 6H), 3.78 (s, 3H), 4.11 (q, *J* = 7.3 Hz, 2H), 6.25 (d, *J* = 16.4 Hz, 1H), 6.34 (d, *J* = 16.4 Hz, 1H), 6.82 (d, *J* = 8.7 Hz, 2H), 7.29 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 14.45, 25.42, 44.58, 55.58, 61.05, 114.30, 127.67, 127.83, 130.31, 132.75, 159.47, 176.85; HRFABMS calcd. for $C_{15}H_{20}O_3Na$ (M^+): 248.1412; found 248.1413.



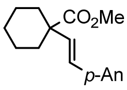
3b

Following the general procedure above, using **1b** (1.0 mmol, 227 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3b** (117 mg, 84%); IR (neat) ν 1674, 1510, 1246 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.47 (s, 6H), 3.80 (s, 3H), 3.84 (s, 6H), 6.38 (d, *J* = 16.4 Hz, 1H), 6.48 (d, *J* = 16.4 Hz, 1H), 6.85 (d, *J* = 8.8 Hz, 2H), 7.31 (d, *J* = 8.8 Hz, 2H), 7.36 (t, *J* = 7.9 Hz, 2H), 7.45 (t, *J* = 7.4 Hz, 1H), 7.88 (dd, *J* = 1.4 and 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 26.69, 49.63, 55.48, 114.28, 127.6515, 128.2588, 128.7936, 129.4510, 130.0446, 131.8356, 133.2141, 137.3774, 159.5087, 205.0453; HRESIMS calcd for $C_{19}H_{20}O_2Na$ ($M+Na^+$): 303.3567; found 303.3566.



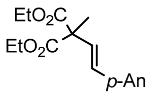
3c

Following the general procedure above, using **1c** (1.0 mmol, 207 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3c** (101 mg, 78%); IR (neat) ν 1722, 1510, 1244 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.27 (t, *J* = 7.2 Hz, 3H), 1.89-1.96 (m, 2H), 2.22-2.28 (m, 2H), 2.57-2.62 (m, 2H), 3.80 (s, 3H), 4.17 (q, *J* = 7.2 Hz, 2H), 6.32 (d, *J* = 15.9 Hz, 1H), 6.45 (d, *J* = 15.9 Hz, 1H), 6.86 (d, *J* = 8.7 Hz, 2H), 7.33 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 14.24, 15.97, 30.97, 49.97, 55.33, 60.80, 114.09, 127.59, 128.39, 129.41, 129.93, 159.28, 175.90; HRESIMS calcd. for $C_{16}H_{20}O_3Na$ ($M+Na^+$): 283.3227; found 283.3229.



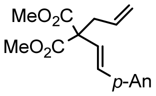
3d

Following the general procedure above, using **1d** (1.0 mmol, 221 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3d** (127 mg, 93%); IR (neat) ν 1724, 1510, 1246 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.27-1.43 (m, 3H), 1.52-1.64 (m, 5H), 2.17-2.20 (m, 2H), 3.69 (s, 3H), 3.79 (s, 3H), 6.02 (d, *J* = 16.3 Hz, 1H), 6.37 (d, *J* = 16.3 Hz, 1H), 6.84 (d, *J* = 8.7 Hz, 2H) , 7.29 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 23.25, 25.76, 34.13, 49.02, 52.03, 55.38, 114.09, 127.57, 128.89, 130.04, 131.90, 159.33, 175.92; HRESIMS calcd. for $C_{17}H_{22}O_3Na$ ($M+Na^+$): 297.3497; found 297.3490.



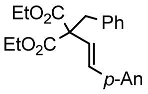
3e

Following the general procedure above, using **1e** (1.0 mmol, 253 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product (128 mg, 84%); IR (neat) ν 1732, 1512, 1246, 1228 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.26 (t, *J* = 7.1 Hz, 6H), 1.62 (s, 3H), 3.80 (s, 3H), 4.18-4.25 (m, 4H), 6.42 (d, *J* = 16.4 Hz, 1H), 6.55 (d, *J* = 16.4 Hz, 1H), 6.85 (d, *J* = 8.7 Hz, 2H), 7.34 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 14.64, 20.95, 55.86, 55.87, 56.18, 62.22, 114.53, 125.95, 128.39, 129.89, 130.77, 160.01, 171.88; HRESIMS calcd. for $C_{17}H_{22}O_5Na$ ($M+Na^+$): 329.3477; found 329.3478.



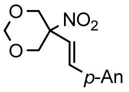
3f

Following the general procedure above, using **1f** (1.0 mmol, 125 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3f** (123 mg, 81%); IR (neat) ν 1732, 1512, 1246, 1228 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 2.89 (d, *J* = 7.2 Hz, 2H), 3.75 (s, 6H), 3.80 (s, 3H), 5.08 (dd, *J* = 1.8 and 10.1 Hz, 1H), 5.10 (dd, *J* = 1.8 and 17.0 Hz, 1H), 5.68-5.75 (m, 1H), 6.43 (d, *J* = 16.6 Hz, 1H), 6.53 (d, *J* = 16.6 Hz, 1H), 6.85 (d, *J* = 8.8 Hz, 1H), 7.34 (d, *J* = 8.8 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 40.12, 52.82, 55.40, 59.69, 114.13, 119.13, 123.59, 127.97, 129.34, 131.41, 132.61, 159.74, 170.89; HRESIMS calcd. for $C_{17}H_{20}O_5Na$ ($M+Na^+$): 327.1208; found 327.1210.



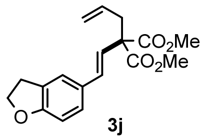
3g

Following the general procedure above, using **1g** (1.0 mmol, 328 mg mL), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3g** (139 mg, 73%); IR (neat) ν 1728, 1510, 1249, 1174 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.22 (t, *J* = 7.1 Hz, 6H), 3.44 (s, 2H), 3.78 (s, 3H), 4.20 (q, *J* = 7.1 Hz, 4H), 6.42 (d, *J* = 16.7 Hz, 1H), 6.45 (d, *J* = 16.7 Hz, 1H), 6.82 (d, *J* = 8.7 Hz, 2H), 7.08-7.10 (m, 2H), 7.17-7.20 (m, 3H), 7.29 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 13.88, 42.59, 55.20, 60.58, 61.52, 113.96, 124.57, 126.88, 127.75, 128.07, 129.36, 130.14, 135.85, 159.48, 170.27; HRESIMS calcd. for $C_{23}H_{26}O_5Na$ ($M+Na^+$): 405.1677; found 405.1678.



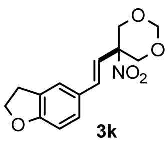
3h

Following the general procedure above, using **1h** (1.5 mmol, 315 mg), **2a** (0.50 mmol, 67 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3h** (104 mg, 79%); IR (neat) ν 1604, 1545, 1512, 1251 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 3.80 (s, 3H), 3.93 (d, *J* = 12.1 Hz, 2H), 4.73 (d, *J* = 6.1 Hz, 1H), 4.97 (d, *J* = 12.1 Hz, 2H), 5.05 (d, *J* = 6.1 Hz, 1H), 5.85 (d, *J* = 16.3 Hz, 1H), 6.63 (d, *J* = 16.3 Hz, 1H), 6.86 (d, *J* = 8.8 Hz, 2H), 7.29 (d, *J* = 8.8 Hz, 2H). ^{13}C NMR ($CDCl_3$) δ: 55.31, 70.46, 86.00, 93.76, 114.28, 117.67, 127.02, 128.36, 135.01, 160.67; HRESIMS calcd. for $C_{13}H_{15}NO_5Na$ ($M+Na^+$): 288.0847; found 288.0849.



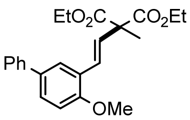
3j

Following the general procedure above, using **1f** (1.5 mmol, 187 mg), **2b** (0.50 mmol, 73 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3j** (125 mg, 73%); IR (neat) ν 1730, 1491, 1226, 1205 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 2.89 (d, *J* = 7.2 Hz, 2H), 3.18 (t, *J* = 8.7 Hz, 2H), 3.74 (s, 6H), 4.56 (t, *J* = 8.7 Hz, 2H), 5.08 (dd, *J* = 1.6 and 10.2 Hz, 1H), 5.10 (dd, *J* = 1.6 and 17.0 Hz, 1H), 5.67-5.75 (m, 1H), 6.42 (d, *J* = 16.6 Hz, 1H), 6.49 (d, *J* = 16.6 Hz, 1H), 6.71 (d, *J* = 8.2 Hz, 1H), 7.12 (dd, *J* = 1.5 and 8.2 Hz, 1H), 7.30 (s, 1H). ^{13}C NMR ($CDCl_3$) δ: 29.57, 40.09, 52.79, 59.64, 71.58, 109.33, 119.08, 122.87, 127.40, 127.69, 129.39, 131.77, 132.63, 160.37, 170.91; HRESIMS calcd. for $C_{18}H_{20}O_5Na$ (M+Na$^+$): 339.1208; found 339.1209.



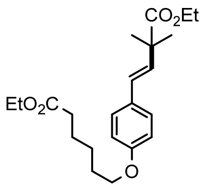
3k

Following the general procedure above, using **1h** (1.5 mmol, 315 mg), **2b** (0.50 mmol, 73 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3k** (105 mg, 76%); IR (neat) ν 1606, 1545, 1510, 1251 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 3.17 (t, *J* = 8.7 Hz, 2H), 3.92 (d, *J* = 12.0 Hz, 2H), 4.55 (t, *J* = 8.7 Hz, 2H), 4.71 (d, *J* = 6.2 Hz, 1H), 4.95 (d, *J* = 12.0 Hz, 2H), 5.03 (d, *J* = 6.2 Hz, 1H), 5.82 (d, *J* = 16.3 Hz, 1H), 6.60 (d, *J* = 16.3 Hz, 1H), 6.71 (d, *J* = 8.2 Hz, 1H), 7.09 (t, *J* = 8.2 Hz, 1H), 7.22 (s, 1H). ^{13}C NMR ($CDCl_3$) δ: 29.33, 70.52, 71.74, 86.25, 93.82, 109.58, 117.08, 123.30, 127.21, 128.07, 128.14, 135.45, 161.52; HRESIMS calcd. for $C_{14}H_{15}NO_5Na$ (M+Na$^+$): 300.0847; found 300.0849.



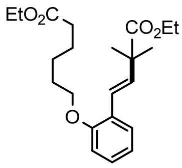
3l

Following the general procedure above, using **1e** (1.0 mmol, 252 mg), **2c** (0.50 mmol, 105 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3l** (154 mg, 79%); IR (neat) ν 1728, 1483, 1244, 1105 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.27 (t, *J* = 7.1 Hz, 6H), 1.69 (s, 3H), 3.87 (s, 3H), 4.23 (q, *J* = 7.1 Hz, 4H), 6.75 (d, *J* = 16.4 Hz, 1H), 6.90 (d, *J* = 16.4 Hz, 1H), 6.91 (d, *J* = 8.5 Hz, 1H), 7.32 (t, *J* = 7.7 Hz, 1H), 7.42 (t, *J* = 7.7 Hz, 2H), 7.43 (dd, *J* = 2.2 and 8.5 Hz, 1H), 7.55 (d, *J* = 7.3 Hz, 2H), 7.71 (d, *J* = 2.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.08, 20.48, 55.70, 56.12, 61.69, 111.31, 125.68, 125.72, 125.99, 126.91, 127.71, 128.37, 128.85, 133.90, 140.95, 156.51, 171.46; HRESIMS calcd. for $C_{23}H_{26}O_5Na$ (M+Na$^+$): 405.1677; found 405.1677.



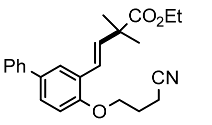
3m

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2d** (0.50 mmol, 188 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 30 °C, yielded the product **3m** (150 mg, 80%); IR (neat) ν 1726, 1510, 1244, 1174, 1138 cm^{-1}; ^{1}H NMR ($CDCl_3$) 1.23 (t, *J* = 7.1 Hz, 6H), 1.38 (s, 6H), 1.48-1.52 (m, 2H), 1.71 (q, *J* = 7.7 Hz, 2H), 1.75 (q, *J* = 7.7 Hz, 2H), 2.32 (t, *J* = 7.5 Hz, 2H), 3.94 (t, *J* = 6.5 Hz, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 4.14 (q, *J* = 7.1 Hz, 2H), 6.23 (d, *J* = 16.2 Hz, 1H), 6.36 (d, *J* = 16.2 Hz, 1H), 6.82 (d, *J* = 8.6 Hz, 2H), 7.29 (t, *J* = 8.6 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ: 14.38, 14.46, 24.92, 25.35, 29.15, 34.45, 44.50, 60.47, 60.96, 67.90, 114.80, 114.82, 127.64, 127.73, 130.11, 132.56, 158.87, 173.95, 176.78; HRESIMS calcd. for $C_{22}H_{32}O_5Na$ ($M+Na^+$): 399.2147; found 399.2137.



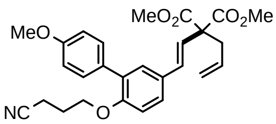
3n

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2e** (0.50 mmol, 188 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3n** (131 mg, 70%); IR (neat) ν 1726, 1510, 1244, 1174, 1138 cm^{-1}; ^{1}H NMR ($CDCl_3$) 1.25 (t, *J* = 7.1 Hz, 3H), 1.26 (t, *J* = 7.1 Hz, 3H), 1.40 (s, 6H), 1.50-1.56 (m, 2H), 1.71 (q, *J* = 7.7 Hz, 2H), 1.83 (q, *J* = 7.7 Hz, 2H), 2.34 (t, *J* = 7.7 Hz, 2H), 3.97 (t, *J* = 6.4 Hz, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 4.14 (q, *J* = 7.1 Hz, 2H), 6.41 (d, *J* = 16.4 Hz, 1H), 6.80 (d, *J* = 16.4 Hz, 1H), 6.84 (d, *J* = 8.2 Hz, 1H), 6.90 (t, *J* = 7.6 Hz, 1H), 7.18 (dt, *J* = 1.7 and 8.2 Hz, 1H), 7.43 (dd, *J* = 1.7 and 7.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.49, 14.55, 25.02, 25.44, 29.32, 34.59, 44.98, 60.58, 61.03, 68.32, 112.40, 120.99, 123.10, 126.74, 126.98, 135.20, 156.47, 174.05, 176.92; HRESIMS calcd. for $C_{22}H_{33}O_5$ ($M+H^+$): 377.2328; found377.2326



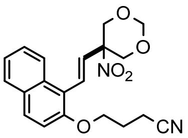
3o

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2f** (0.50 mmol, 131 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3o** (137 mg, 73%); IR (neat) ν 1722, 1469, 1242, 1138, 1126 cm^{-1}; ^{1}H NMR ($CDCl_3$) 1.27 (t, *J* = 7.2 Hz, 3H), 1.43 (s, 6H), 2.20 (q, *J* = 6.8 Hz, 2H), 2.26 (t, *J* = 7.2 Hz, 2H), 4.16 (q, *J* = 7.2 Hz, 2H), 4.17 (q, *J* = 7.2 Hz, 2H), 6.49 (d, *J* = 16.4 Hz, 1H), 6.77 (d, *J* = 16.4 Hz, 1H), 6.93 (d, *J* = 8.5 Hz, 1H), 7.32 (t, *J* = 7.6 Hz, 1H), 7.41-7.46 (m, 3H), 7.57 (d, *J* = 7.3 Hz, 2H), 7.65 (d, *J* = 2.2 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.26, 14.29, 25.25, 25.66, 44.80, 60.90, 66.06, 112.56, 119.21, 122.60, 125.87, 126.94, 127.01, 127.05, 127.27, 128.89, 134.68, 136.03, 140.90, 155.05, 176.52; HRESIMS calcd. for $C_{24}H_{27}NO_3Na$ ($M+Na^+$): 400.1888; found 400.1890.



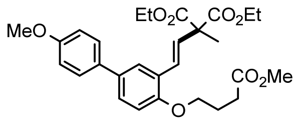
3p

Following the general procedure above, using **1f** (1.0 mmol, 251 mg), **2g** (0.50 mmol, 146 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3p** (144 mg, 62%); IR (neat) ν 1732, 1242 cm^{-1}; ^{1}H NMR ($CDCl_3$) 2.00-2.05 (m, 2H), 2.39 (t, *J* = 7.1 Hz, 2H), 2.91 (d, *J* = 7.2 Hz, 2H), 3.75 (s, 6H), 3.85 (s, 3H), 4.05 (t, *J* = 5.7 Hz, 2H), 5.07 (dd, *J* = 1.8 and 10.2 Hz, 1H), 5.10 (dd, *J* = 1.8 and 17.2 Hz, 1H), 5.68-5.76 (m, 1H), 6.52 (d, *J* = 16.6 Hz, 1H), 6.56 (d, *J* = 16.6 Hz, 1H), 6.90 (d, *J* = 8.5 Hz, 1H), 6.56 (d, *J* = 8.8 Hz, 2H), 7.30 (dd, *J* = 2.3 and 8.5 Hz, 1H), 7.36 (d, *J* = 2.3 Hz, 1H), 7.40 (d, *J* = 8.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.09, 25.50, 40.06, 52.82, 55.37, 59.72, 66.16, 113.10, 113.60, 119.17, 119.25, 124.34, 126.77, 129.10, 130.16, 130.54, 130.62, 131.27, 131.34, 132.53, 155.35, 159.02, 170.80; HRESIMS calcd. for $C_{27}H_{29}NO_6Na$ ($M+Na^+$): 486.1892; found 486.1893.



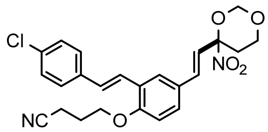
3q

Following the general procedure above, using **1h** (1.5 mmol, 315 mg), **2f** (0.50 mmol, 118 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3q** (97 mg, 53%); IR (neat) ν 1605, 1522 cm^{-1}; ^1H NMR ($CDCl_3$) 2.15 (q, *J* = 7.0 Hz, 2H), 2.60 (t, *J* = 7.0 Hz, 2H), 4.11 (d, *J* = 12.3 Hz, 2H), 4.21 (t, *J* = 5.7 Hz, 2H), 4.82 (d, *J* = 6.2 Hz, 1H), 5.01 (d, *J* = 12.3 Hz, 2H), 5.06 (d, *J* = 6.2 Hz, 1H), 6.13 (d, *J* = 16.4 Hz, 1H), 7.15 (d, *J* = 16.4 Hz, 1H), 7.23 (d, *J* = 9.0 Hz, 1H), 7.38 (t, *J* = 7.0 Hz, 1H), 7.49 (dt, *J* = 1.1 and 8.4 Hz, 1H), 7.80 (t, *J* = 8.4 Hz, 2H), 7.87 (t, *J* = 8.5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.26, 25.61, 66.90, 70.55, 86.47, 93.94, 114.03, 118.13, 123.38, 124.38, 127.16, 127.54, 128.76, 129.20, 129.44, 130.74, 132.24, 153.68; HRESIMS calcd. for $C_{20}H_{20}N_2O_5Na$ ($M+Na^+$): 391.1269; found 391.1270.



3r

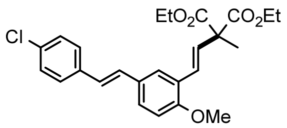
Following the general procedure above, using **1e** (1.0 mmol, 252 mg), **2i** (0.50 mmol, 163 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3r** (145 mg, 73%); IR (neat) ν 1743, 1728, 1496, 1274, 1247 cm^{-1}; ^1H NMR ($CDCl_3$) 1.27 (t, *J* = 7.1 Hz, 6H), 1.69 (s, 3H), 2.14 (q, *J* = 7.1 Hz, 2H), 2.55 (t, *J* = 7.2 Hz, 2H), 3.68 (s, 3H), 3.84, (s, 3H), 4.06 (q, *J* = 6.0 Hz, 2H), 4.18-4.27 (m, 4H), 6.76 (d, *J* = 16.5 Hz, 1H), 6.86 (d, *J* = 16.5 Hz, 1H), 6.89 (d, *J* = 8.5 Hz, 1H), 6.96 (d, *J* = 8.7 Hz, 2H), 7.37 (dd, *J* = 2.3 and 8.5 Hz, 1H), 7.48 (d, *J* = 8.7 Hz, 2H), 7.63 (d, *J* = 2.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.09, 20.48, 24.73, 30.54, 51.70, 55.43, 56.15, 61.69, 67.36, 112.44, 114.30, 125.54, 125.80, 126.07, 127.29, 127.98, 128.53, 133.53, 133.79, 155.30, 159.01, 171.44, 173.76; HRESIMS calcd. for $C_{28}H_{34}O_8Na$ ($M+Na^+$): 521.2151; found 521.2151.



3t

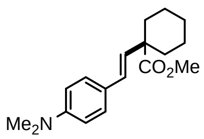
Following the general procedure above, using **1h** (1.5 mmol, 315 mg), **2j** (0.50 mmol, 161 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3t** (154 mg, 68%); IR (neat) ν 1605, 1522 cm^{-1}; ^1H NMR (DMSO) 2.09 (s, 2H), 2.71 (s, 2H), 4.10-4.12 (m, 4H), 4.77-4.97 (m, 4H), 6.28 (d, *J* = 16.4 Hz, 1H), 6.78 (d, *J* = 16.4 Hz, 1H), 7.03 (d, *J* = 8.0 Hz, 1H), 7.28 (d, *J* = 16.3 Hz, 1H), 7.38-7.40 (m, 3H), 7.47 (d, *J* = 16.3 Hz, 1H), 7.62 (d, *J* = 7.2 Hz, 2H), 7.87

(m, 1H); ^{13}C NMR (DMSO) δ: 14.60, 25.54, 67.67, 70.33, 88.33, 93.70, 93.71, 113.36, 113.37, 119.88, 121.53, 124.04, 125.62, 126.71, 128.43, 129.14, 129.18, 129.26, 129.64, 132.92, 135.13, 137.22, 157.19; HRESIMS calcd. for $C_{24}H_{24}ClN_2O_5Na$ (M+H$^+$): 455.1374; found 455.1378.



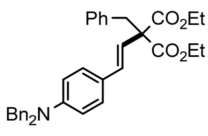
3u

Following the general procedure above, using **1a** (1.0 mmol, 252 mg), **2f** (0.50 mmol, 135 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3u** (156 mg, 71%); IR (neat) ν 1749, 1726, 1498, 1247, 1103 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.28 (t, *J* = 7.1 Hz, 6H), 1.69 (s, 3H), 3.85 (s, 3H), 4.23 (q, *J* = 7.1 Hz, 4H), 6.74 (d, *J* = 16.5 Hz, 1H), 6.85 (d, *J* = 8.4 Hz, 1H), 6.86 (d, *J* = 16.4 Hz, 1H), 6.86 (d, *J* = 7.5 Hz, 1H), 6.95 (d, *J* = 16.4 Hz, 1H), 7.03 (d, *J* = 16.4 Hz, 1H), 7.31 (d, *J* = 8.4 Hz, 2H), 7.37 (dd, *J* = 2.1 and 8.4 Hz, 1H), 7.42 (d, *J* = 8.4 Hz, 2H), 7.63 (d, *J* = 2.1 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.08, 20.46, 55.64, 56.07, 61.71, 111.39, 124.99, 125.55, 125.64, 125.93, 127.43, 127.54, 128.42, 128.88, 128.91, 129.72, 132.84, 136.26, 156.80, 171.43; HRESIMS calcd. for $C_{25}H_{27}ClO_5Na$ (M+Na$^+$): 465.1444; found 465.1445.



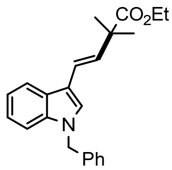
3v

Following the general procedure above, using **1l** (1.0 mmol, 220 mg), **2l** (0.50 mmol, 73 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3v** (132 mg, 92%); IR (neat) ν 2999, 1722, 1605, 1203, 1178 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.30-1.45 (m, 3H), 1.52-1.66 (m, 5H), 2.18 (d, *J* = 0.6 Hz, 2H), 2.96 (s, 6H), 3.69 (s, 3H), 5.97 (d, *J* = 16.2 Hz, 1H), 6.35 (d, *J* = 16.2 Hz, 1H), 6.60 (brs, 2H), 7.27 (brs, 2H); ^{13}C NMR ($CDCl_3$) δ: 23.26, 25.80, 34.17, 40.61, 48.89, 51.93, 112.61, 125.79, 127.29, 129.26, 129.72, 150.21, 176.12; HRESIMS calcd. for $C_{18}H_{26}NO_2$ (M+H$^+$): 288.1964; found 288.1955.



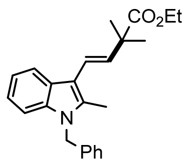
3w

Following the general procedure above, using **1g** (1.0 mmol, 329 mg), **2m** (0.50 mmol, 150 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 40 °C, yielded the product **3w** (216 mg, 79%); IR (neat) ν 2998, 1728, 1606, 1519, 1203, 1178 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.26 (t, *J* = 7.1 Hz, 6H), 3.50 (s, 2H), 4.23 (q, *J* = 7.1 Hz, 4H), 4.70 (s, 4H), 6.40 (d, *J* = 16.5 Hz, 1H), 6.46 (d, *J* = 16.5 Hz, 1H), 6.73 (d, *J* = 8.7 Hz, 2H), 7.16-7.18 (m, 2H), 7.22-7.31 (m, 11H), 7.35-7.38 (m, 4H); ^{13}C NMR ($CDCl_3$) δ: 14.05, 42.71, 54.36, 60.74, 61.57, 112.55, 122.59, 126.79, 126.96, 127.17, 127.89, 128.19, 128.85, 130.32, 131.23, 136.21, 170.60; HRESIMS calcd. for $C_{36}H_{38}NO_4$ ($M+H^+$): 548.2801; found 548.2783.



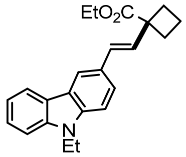
3x

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2n** (0.50 mmol, 166 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3x** (84 mg, 49%); IR (neat) ν 2978, 1720, 1465, 1138 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.37 (t, *J* = 7.1 Hz, 3H), 1.53 (s, 6H), 4.25 (q, *J* = 7.1 Hz, 2H), 5.37 (s, 2H), 6.48 (d, *J* = 16.4 Hz, 1H), 6.72 (d, *J* = 16.4 Hz, 1H), 7.22 (d, *J* = 7.1 Hz, 2H), 7.26-7.31 (m, 3H), 7.35-7.41 (m, 4H), 7.97 (d, *J* = 7.7 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 14.28, 25.32, 44.62, 50.13, 60.80, 110.05, 114.18, 120.18, 120.33, 120.49, 122.41, 126.56, 127.05, 127.20, 127.89, 128.98, 131.39, 137.35, 137.36, 177.01; HRESIMS calcd. for $C_{23}H_{25}NO_2Na$ ($M+Na^+$): 370.1783; found 370.1783.



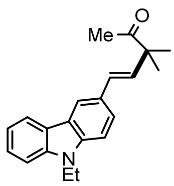
3y

Following the general procedure above, using **1a** (1.0 mmol, 195 mg), **2o** (0.50 mmol, 123 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3y** (127 mg, 71%); IR (neat) ν 2978, 1465, 1454, 1421, 1249, 1138 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.27 (t, *J* = 7.2 Hz, 3H), 1.47 (s, 6H), 2.37 (s, 3H), 4.17 (q, *J* = 7.2 Hz, 2H), 5.31 (s, 2H), 6.39 (d, *J* = 16.4 Hz, 1H), 6.63 (d, *J* = 16.4 Hz, 1H), 7.15 (d, *J* = 7.1 Hz, 2H), 7.14-7.16(m, 2H), 7.21-7.27 (m, 4H), 7.88 (d, *J* = 7.1 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ: 10.71, 14.30, 25.41, 44.82, 46.61, 60.79, 109.40, 110.48, 119.69, 120.25, 120.49, 121.63, 126.14, 126.30, 127.52, 128.97, 132.02, 135.21, 137.12, 137.70, 177.14; HRESIMS calcd. for $C_{24}H_{27}NO_2Na$ ($M+Na^+$): 348.1939; found 348.1930.



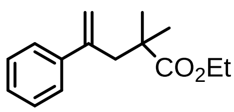
3z

Following the general procedure above, using **1c** (1.0 mmol, 205 mg), **2p** (0.50 mmol, 110 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3z** (112 mg, 65%); IR (neat) ν 2976, 1722, 1232, 1099 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.29 (t, *J* = 7.2 Hz, 3H), 1.41 (t, *J* = 7.2 Hz, 3H), 1.92-1.99 (m, 2H), 2.29-2.36 (m, 2H), 2.60-2.66 (m, 2H), 4.20 (q, *J* = 7.2 Hz, 2H), 4.36 (q, *J* = 7.2 Hz, 2H), 6.47 (d, *J* = 16.0 Hz, 1H), 6.70 (d, *J* = 16.0 Hz, 1H), 7.22 (t, *J* = 7.3 Hz, 1H), 7.35 (t, *J* = 8.4 Hz, 1H), 7.40 (t, *J* = 8.1 Hz, 1H), 7.46 (t, *J* = 7.8 Hz, 1H), 7.56 (dd, *J* = 1.3 and 8.4 Hz, 1H), 8.10 (d, *J* = 7.8 Hz, 1H), 8.11 (s, 1H); ^{13}C NMR ($CDCl_3$) δ: 13.84, 14.32, 16.07, 31.12, 37.65, 50.15, 60.86, 108.61, 108.71, 118.60, 119.05, 120.60, 123.12, 123.33, 124.38, 125.89, 128.35, 128.83, 129.78, 139.73, 140.48, 176.16; HRESIMS calcd. for $C_{23}H_{25}NO_2Na$ ($M+Na^+$): 370.1783; found 370.1775.



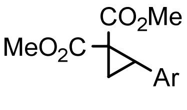
3aa

Following the general procedure above, using **1j** (1.0 mmol, 165 mg), **2p** (0.50 mmol, 110 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product **3aa** (106 mg, 70%); IR (neat) ν 2986, 1697, 1489, 1471, 1230 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.38 (s, 6H), 1.42 (t, *J* = 7.2 Hz, 3H), 2.20 (s, 3H), 4.36 (q, *J* = 7.2 Hz, 2H), 6.28 (d, *J* = 16.1 Hz, 1H), 6.67 (d, *J* = 16.1 Hz, 1H), 7.23 (dt, *J* = 0.8 and 7.6 Hz, 1H), 7.35 (d, *J* = 7.8 Hz, 1H), 7.40 (d, *J* = 8.1 Hz, 1H), 7.43 (dt, *J* = 1.1 and 7.6 Hz, 1H), 7.53 (dd, *J* = 1.6 and 8.4 Hz, 1H), 8.09-8.10 (m, 2H); ^{13}C NMR ($CDCl_3$) δ: 13.85, 24.24, 25.73, 37.67, 50.62, 108.67, 108.75, 118.57, 119.12, 120.60, 123.07, 123.36, 124.27, 125.97, 128.24, 130.32, 131.37, 139.80, 140.50, 211.73; HRESIMS calcd. for $C_{21}H_{23}NONa$ ($M+Na^+$): 328.1677; found 328.1674.



Following the general procedure above, using **1a** (1.0 mmol, 165 mg), α-methylstyrene (0.50 mmol, 110 mg), CuI (0.05 mmol, 9.5 mg), TBABr (0.25mmol, 80 mg), **A3** (0.50 mmol, 0.1 mL), and dried toluene (0.8 mL) at 60 °C, yielded the product ethyl 2,2-dimethyl-4-phenylpent-4-enoate (84 mg, 73%);^{1}H NMR ($CDCl_3$) δ: 1.10 (s, 6H), 1.10 (t, *J* = 7.3 Hz, 3H), 2.78 (s, 2H), 3.78 (s, 3H), 3.71 (q, *J* = 7.3 Hz, 2H), 5.04 (s, 1H), 5.22 (d, *J* = 1.8 Hz, 1H), 7.22-7.33 (m, 5H). ^{13}C NMR ($CDCl_3$) δ: 14.20, 25.75, 42.72, 46.08, 60.42, 117.29, 127.08, 127.57, 128.37, 142.68, 146.52, 177.59; HRFABMS calcd. for $C_{15}H_{20}O_2Na$ ($M+Na^+$): 255.1361; found 255.1363.

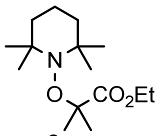
3. Cycloproapanation



5

Cu salt (0.05 mmol or 0.5 mmol), and TBABr (0.25 mmol, 80 mg) were sequentially added under air to a dram vial equipped with a stir bar and a screw cap. **1a** (0.5 mmol), dimethyl bromomalonate (1.0 mmol), PMDETA (N,N,N',N",N"–pentamethyldiethylenetriamine, **A3**, 0.5 mmol, 0.1 mL) and dried toluene (0.8 mL) were added by syringe and the resulting mixture vigorously stirred under nitrogen atmosphere for 20 h at room temperature. After this time, the contents of the flask were filtered through the plug of silica gel, and then concentrated by rotary evaporation. The residue was purified by flash chromatography, eluting with hexane/EtOAc to afford the product **5** (67%)·All spectral data were matched with previously reported[2]; ^{1}H NMR ($CDCl_3$) δ: 1.70 (dd, *J* = 5.0 and 9.1 Hz, 1H), 2.13 (dd, *J* = 5.0 and 8.1 Hz, 1H), 3.18 (t, *J* = 8.8 Hz, 1H), 3.37 (s, 3H), 3.76 (s, 3H), 3.77 (s, 3H), 6.80 (m, *J* = 8.6 Hz,2H), 7.11 (d, *J* = 8.6 Hz,2H).

4. TEMPO capture



6

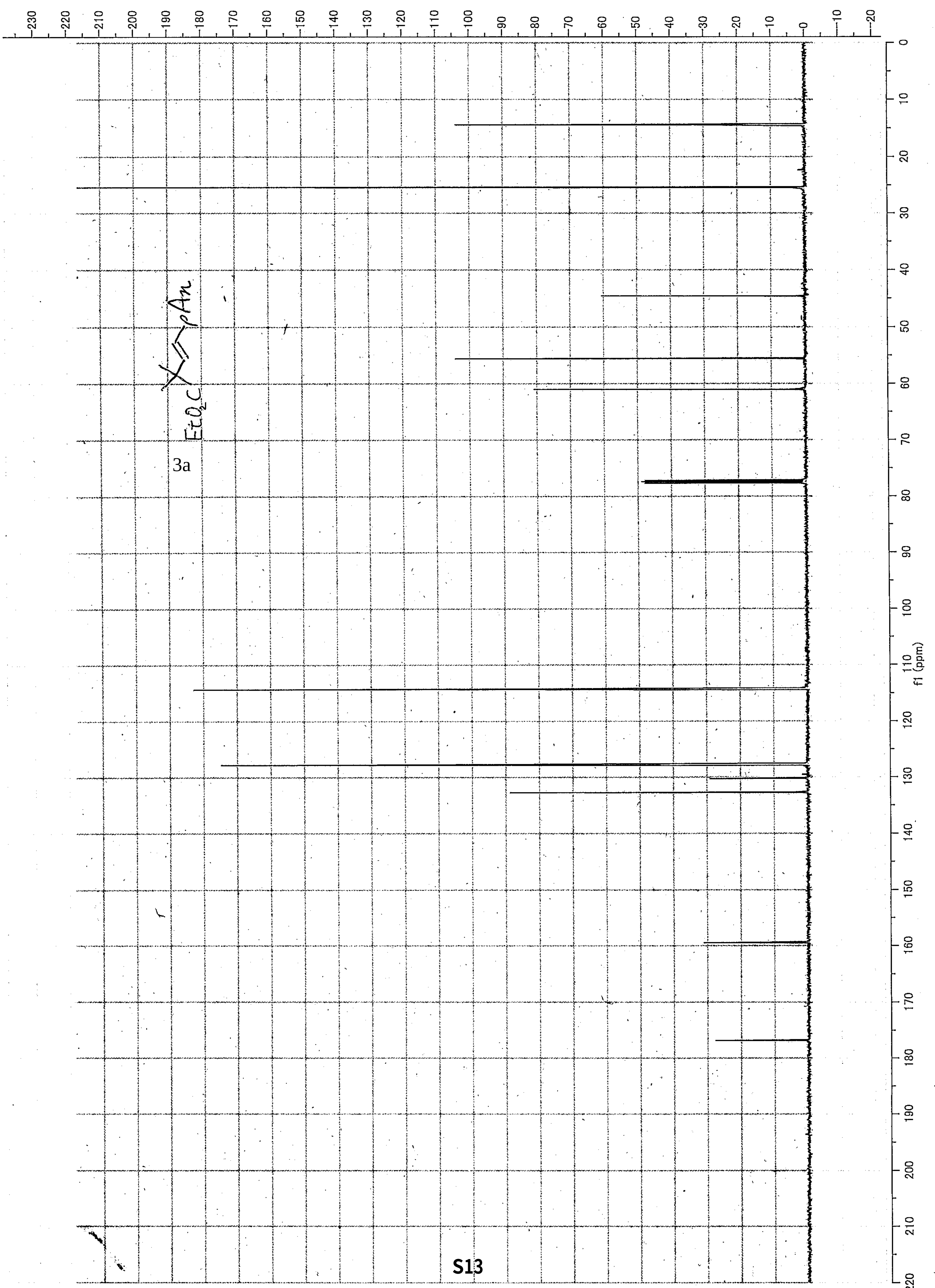
Cu salt (0.05 mmol or 0.5 mmol), and TBABr (0.25 mmol, 80 mg) were sequentially added under air to a dram vial equipped with a stir bar and a screw cap. Tert-alkyl halide **1a** (0.5 mmol), TEMPO (0.6 mmol), PMDETA (N,N,N',N",N" –pentamethyldiethylenetriamine, **A3**, 0.5 mmol, 0.1 mL) and dried toluene (0.8 mL) were added by syringe and the resulting mixture vigorously stirred under nitrogen atmosphere for 1 h at room temperature. After this time, the contents of the flask were filtered through the plug of silica gel, and then concentrated by rotary evaporation. The residue was purified by flash chromatography, eluting with hexane/EtOAc to afford the product **6** (5.9%(10 mol% CuI), and 42%(1 equiv CuI)). All spectral data were matched with previously reported[3]; IR (neat) ν 1722, 1469, 1242, 1138, 1126 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 1.00 (s, 6H), 1.14 (s, 6H), 1.23-1.28 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 3H), 1.46 (s, 10H), 4.14 (q, *J* = 7.1 Hz, 2H); HRESIMS calcd. for $C_{15}H_{30}NO_3$ ($M+H^+$): 272.2226; found 272.2212.

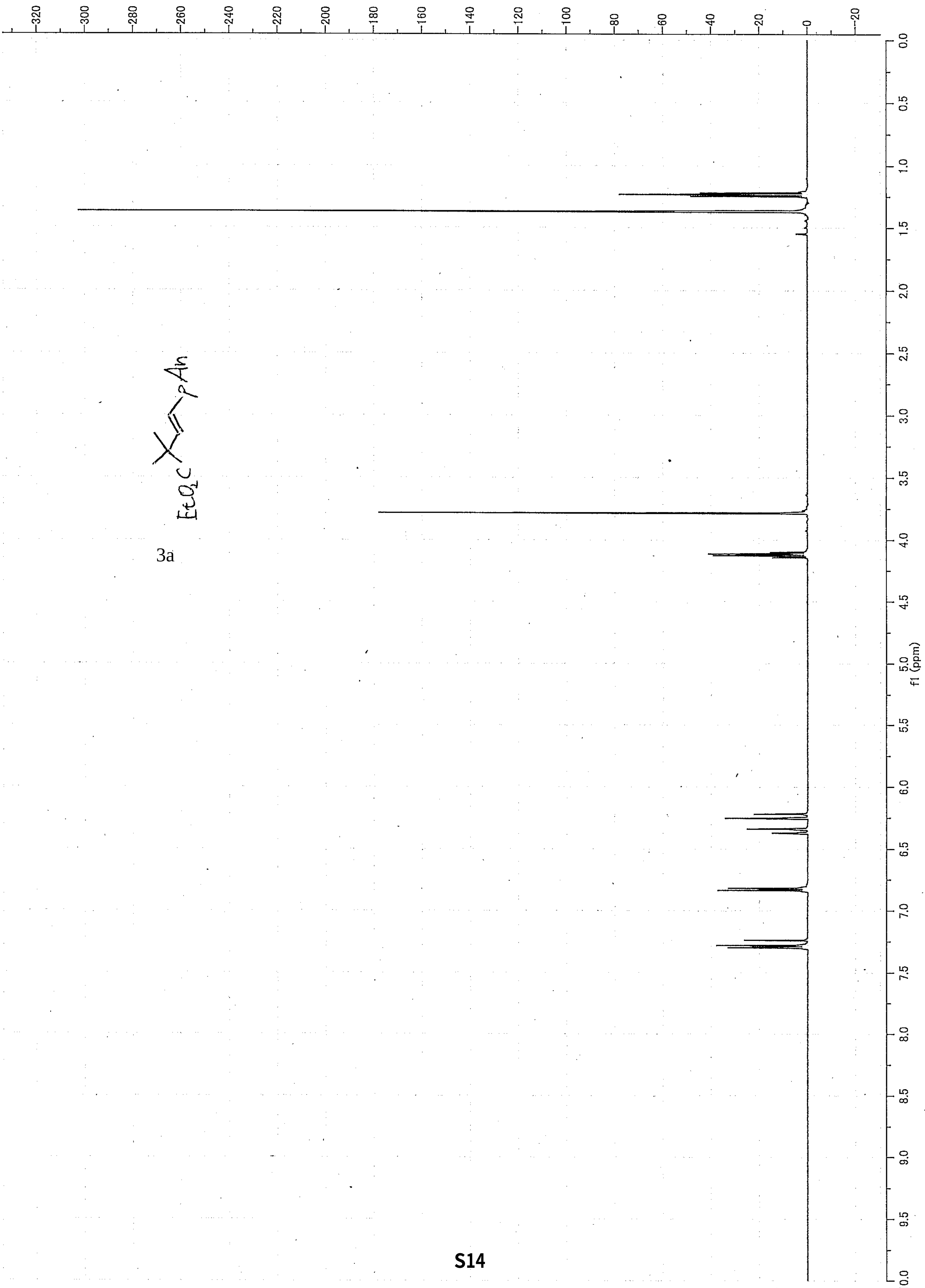
5.References

1. C. Liu, S. Tang, D. Liu, J. Yuan, L. Zheng, L. Meng, A. Lei, *Angew. Chem., Int. Ed.* **2012**, *51*, 3638.

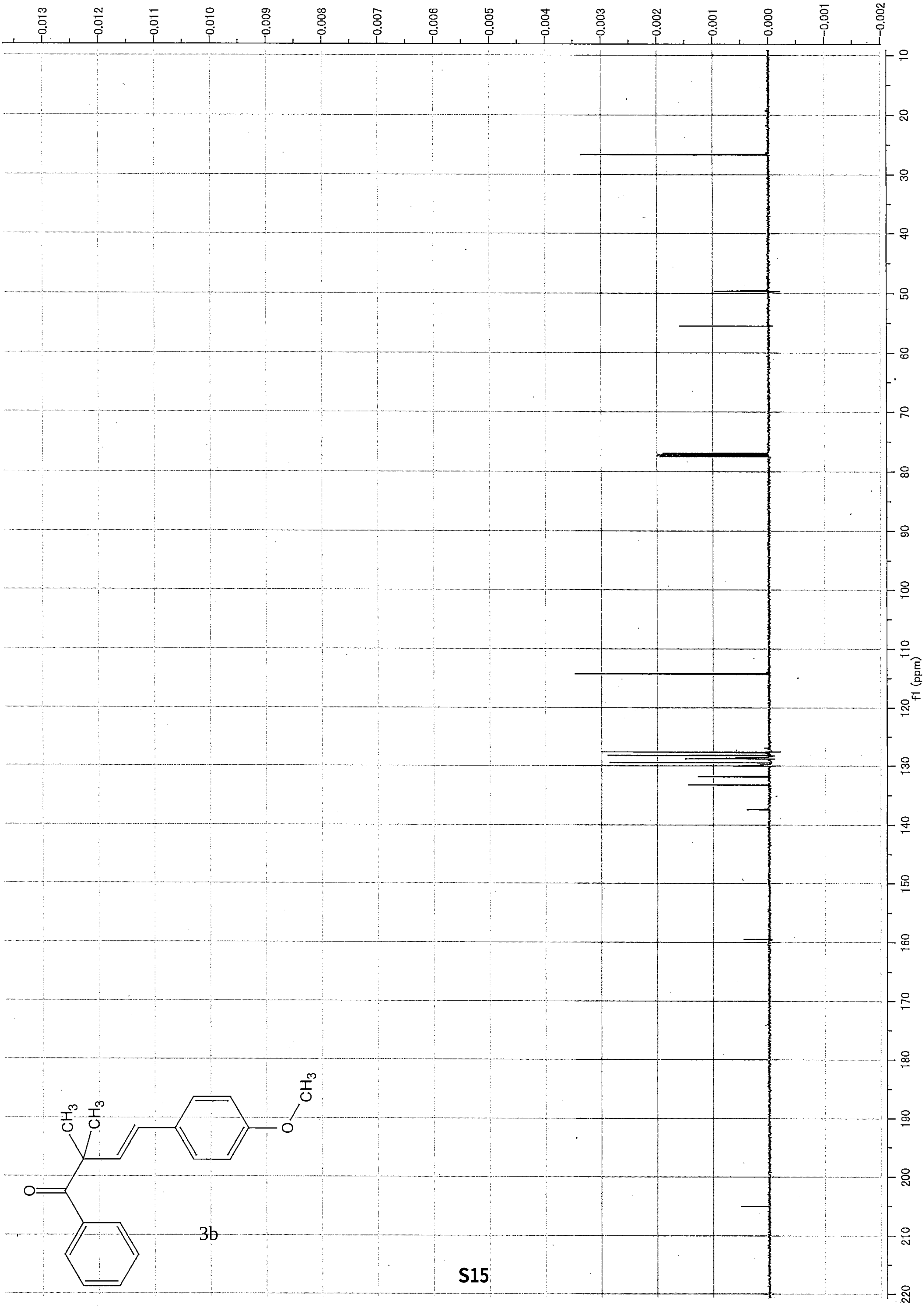
2. S. R. Goudreau, D. Marcoux, A. B. Charette, *J. Org. Chem.* **2009**, *74*, 470.

3. S. Yamago, Y. Ukai, A. Matsumoto, Y. Nakamura, *J. Am. Chem. Soc.* **2009**, *131*, 2100.

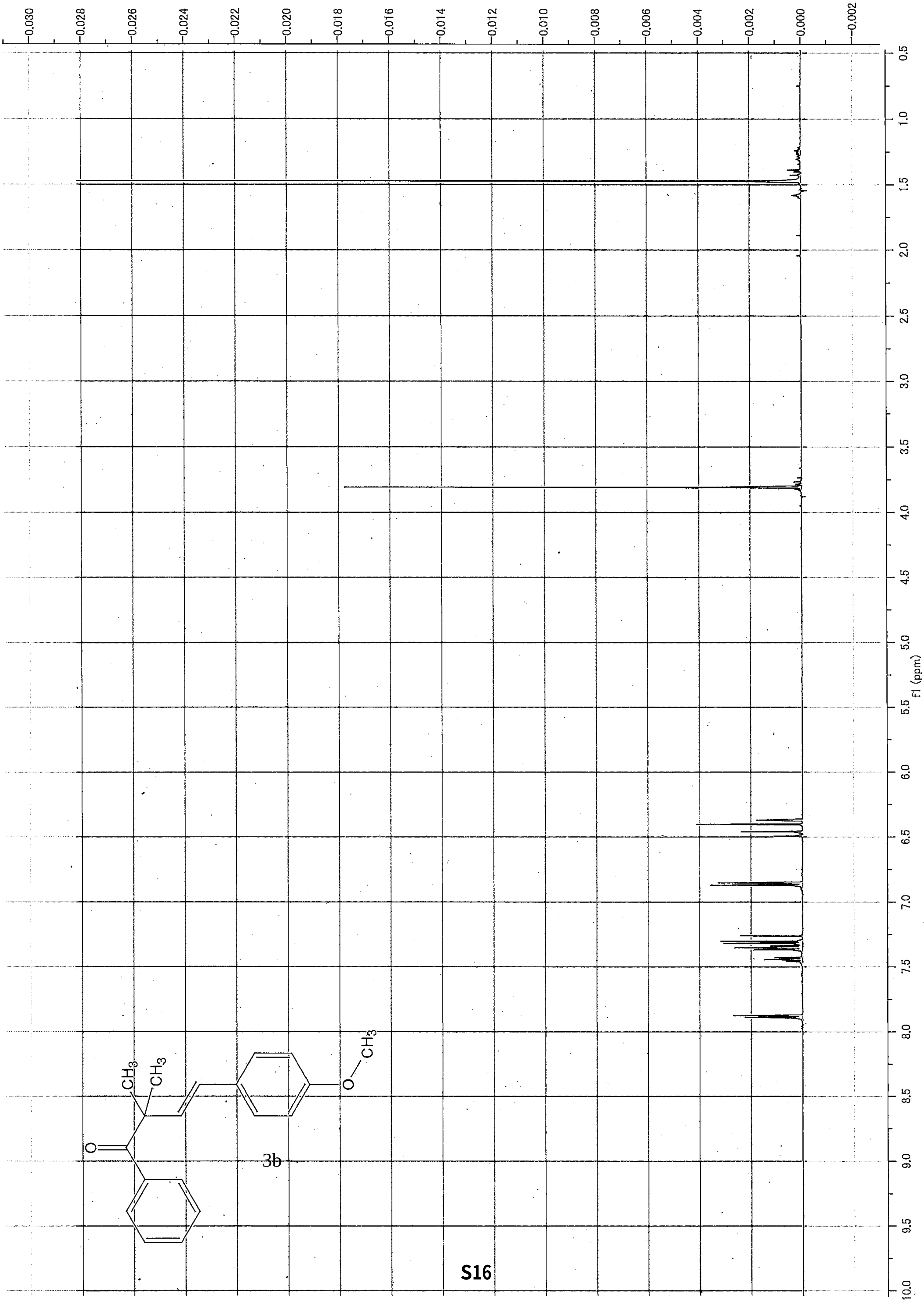

f1 (ppm)
3a



3a



0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-0.001
-0.002
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
f1 (ppm)
CH3
CH3
O
O
CH3
3b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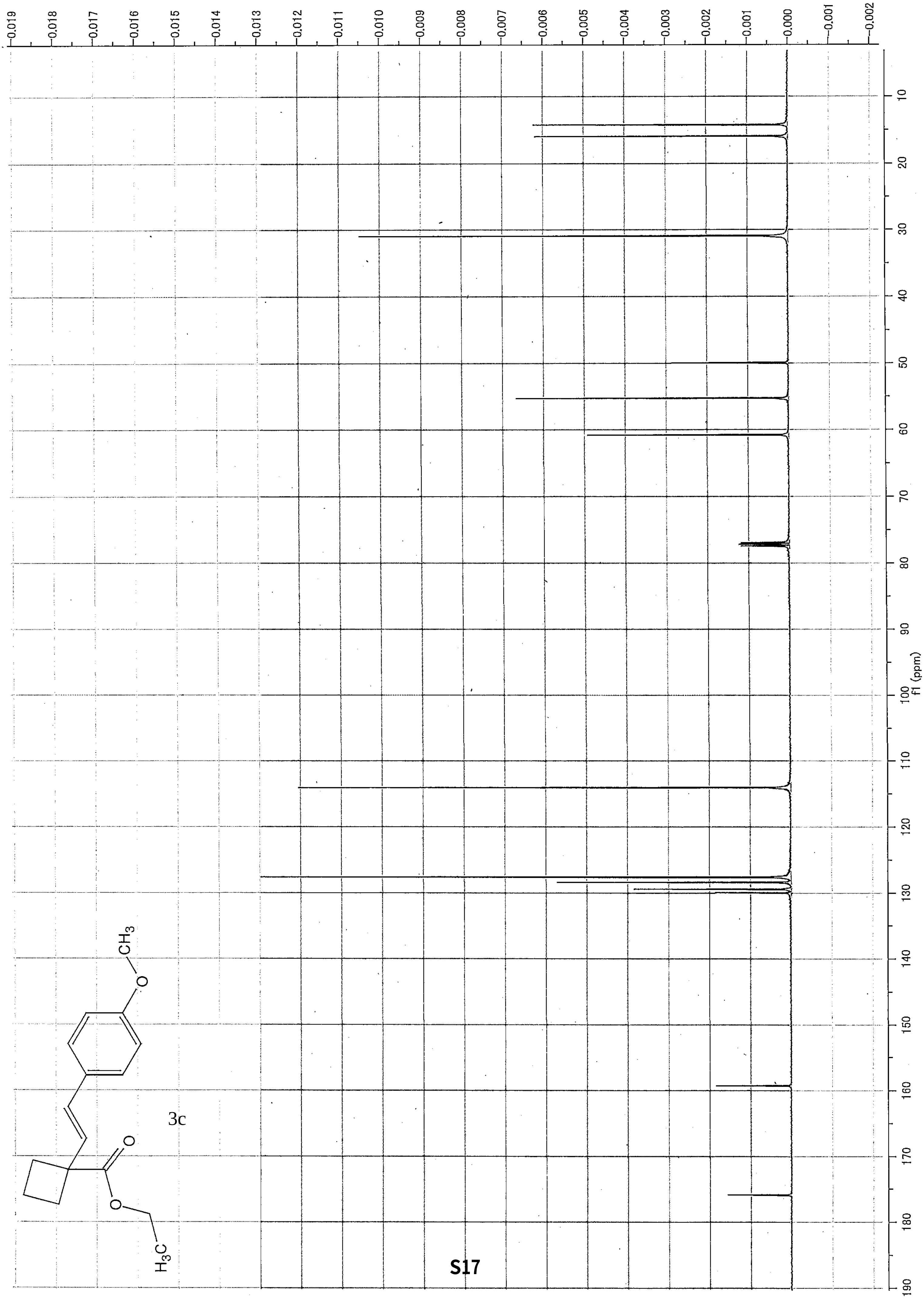
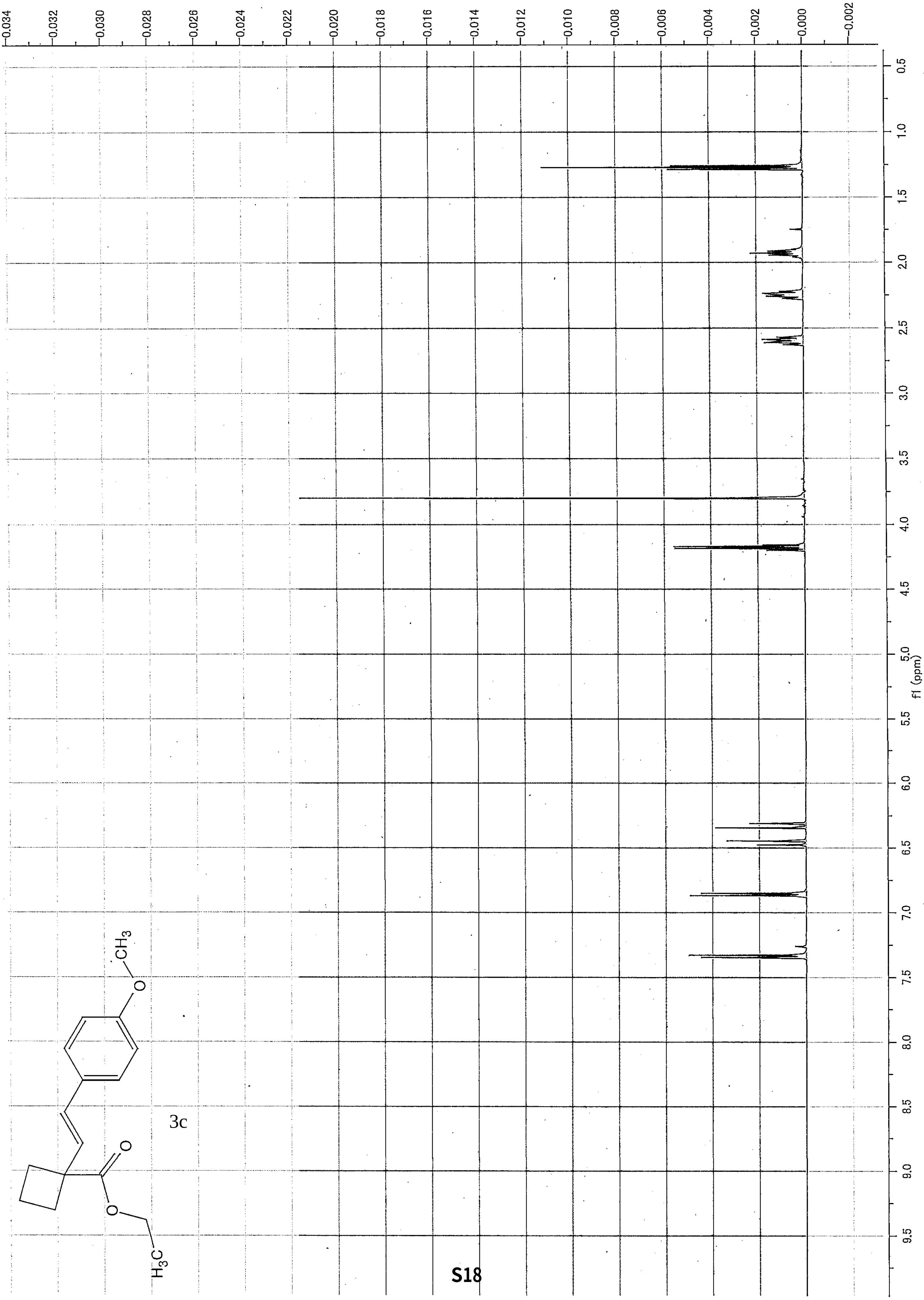
CH3
O


3c
f1 (ppm)



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-0.026
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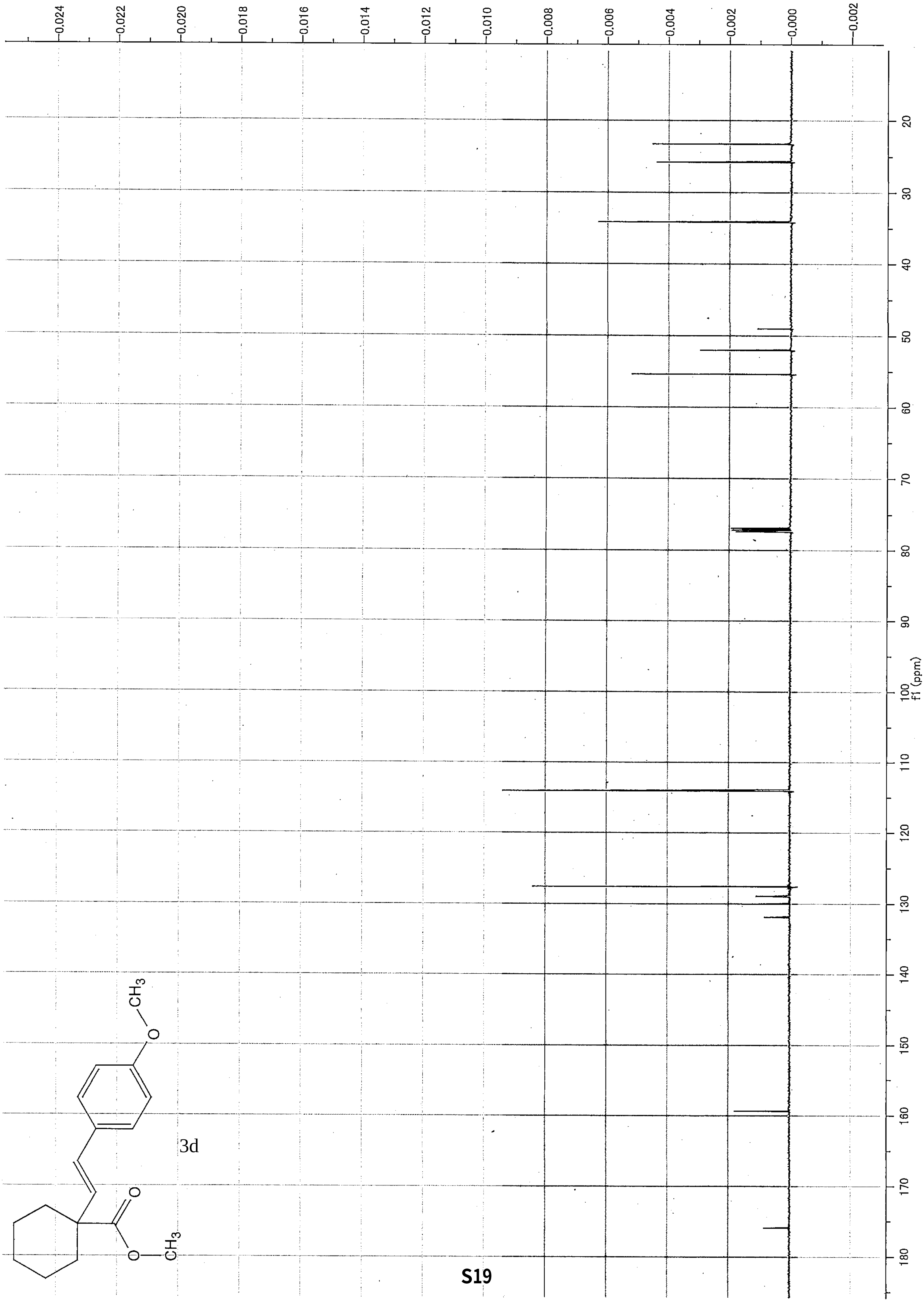
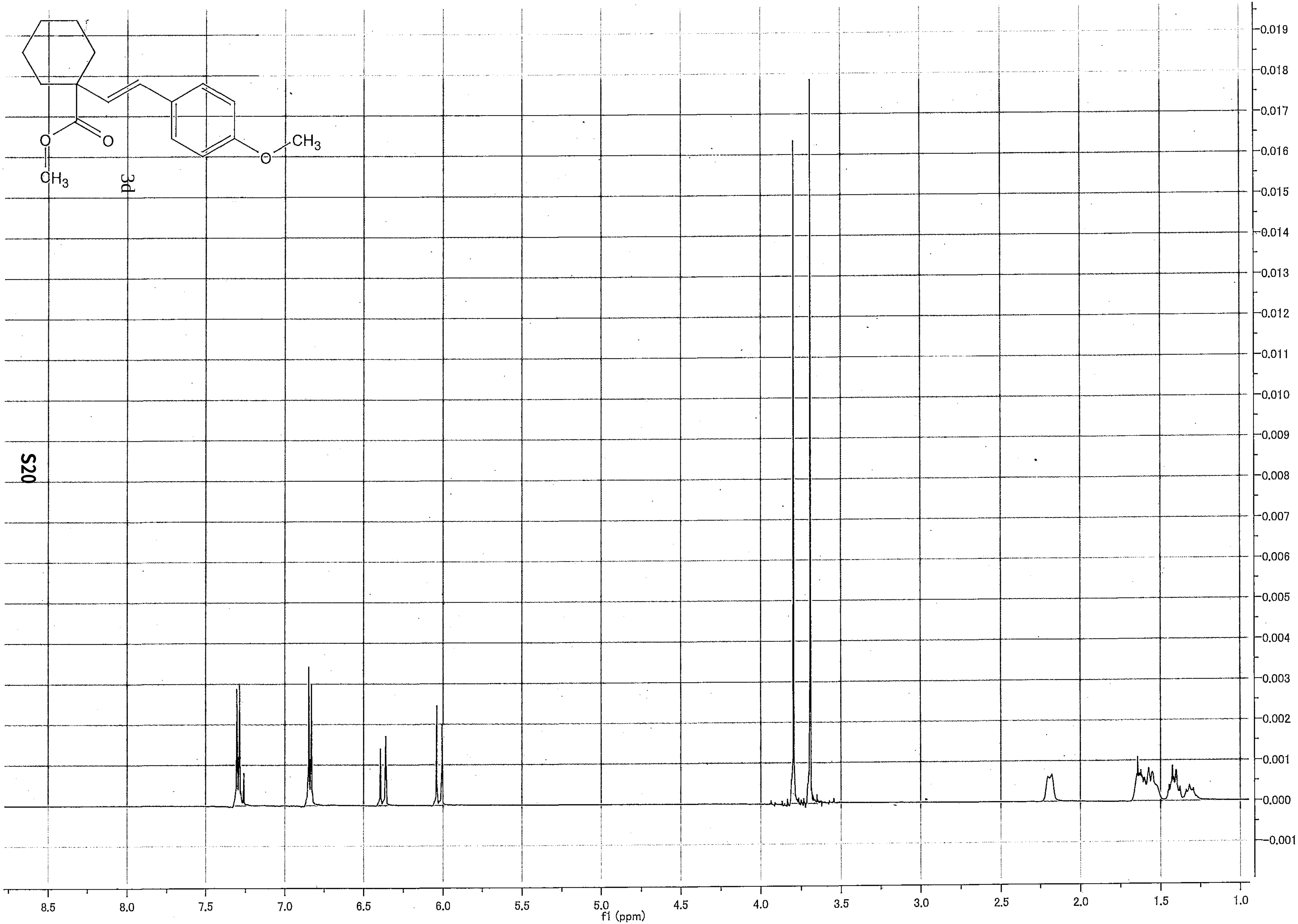
-0.022
-0.020
-0.018
-0.016
-0.014
-0.012
-0.010
-0.008
-0.006
-0.004
-0.002
0.000
-0.002
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
f1 (ppm)
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
CH3
O
O
O
H3C
3c



3d



O
CH3
O
CH3
f1 (ppm)
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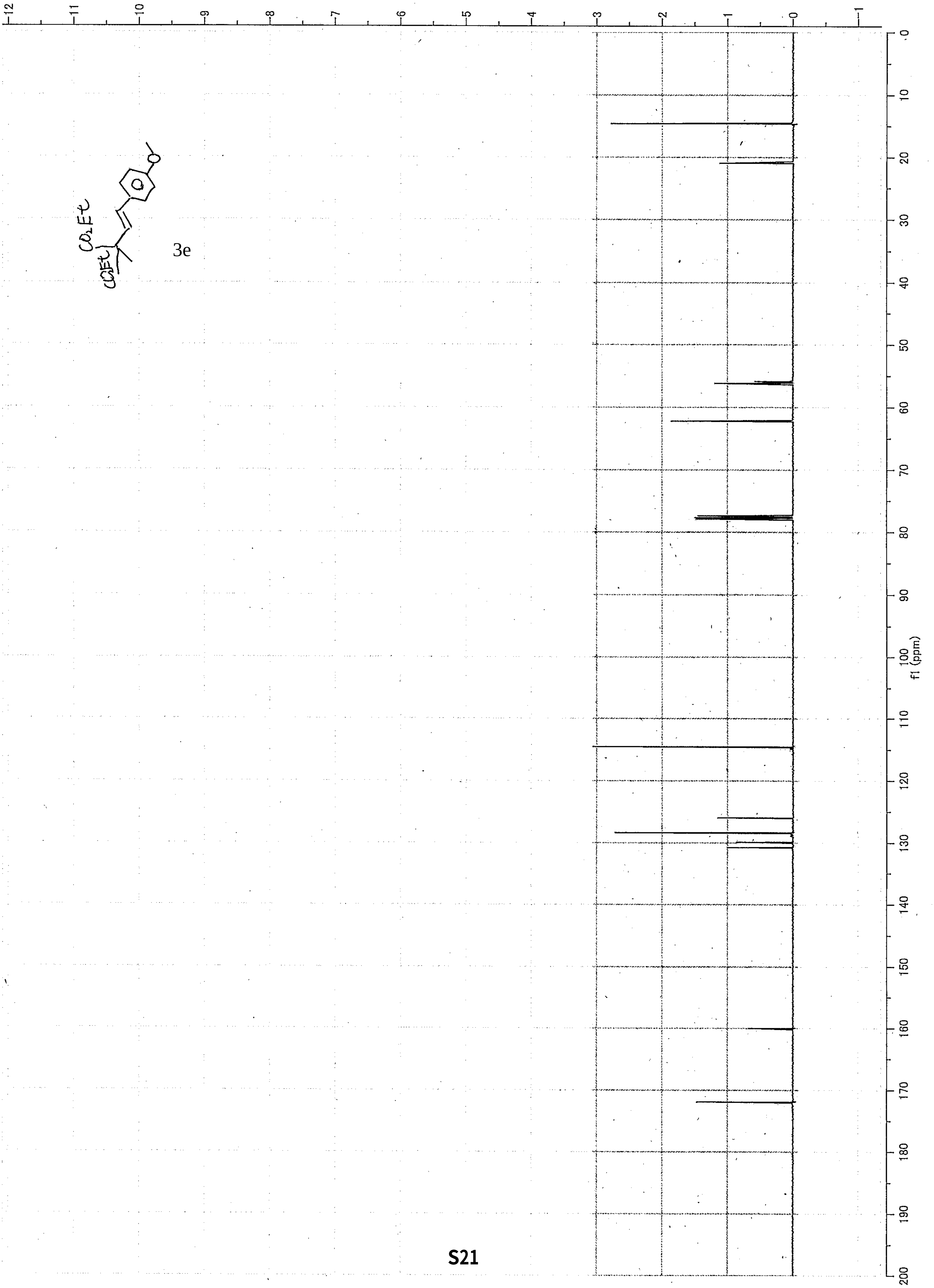
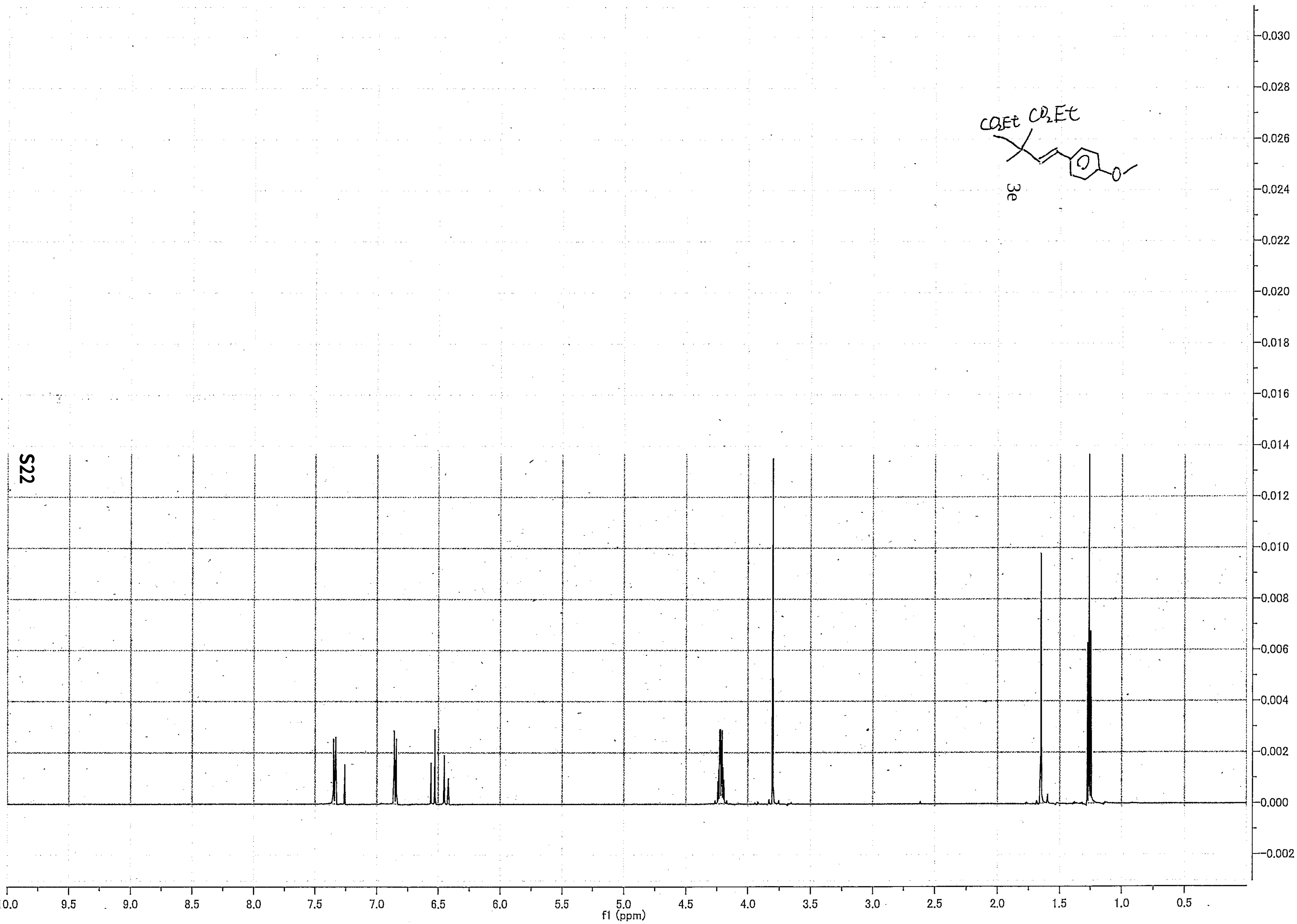
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-0.001

3d


3e
f1 (ppm)


CO2Et CO2Et
3e
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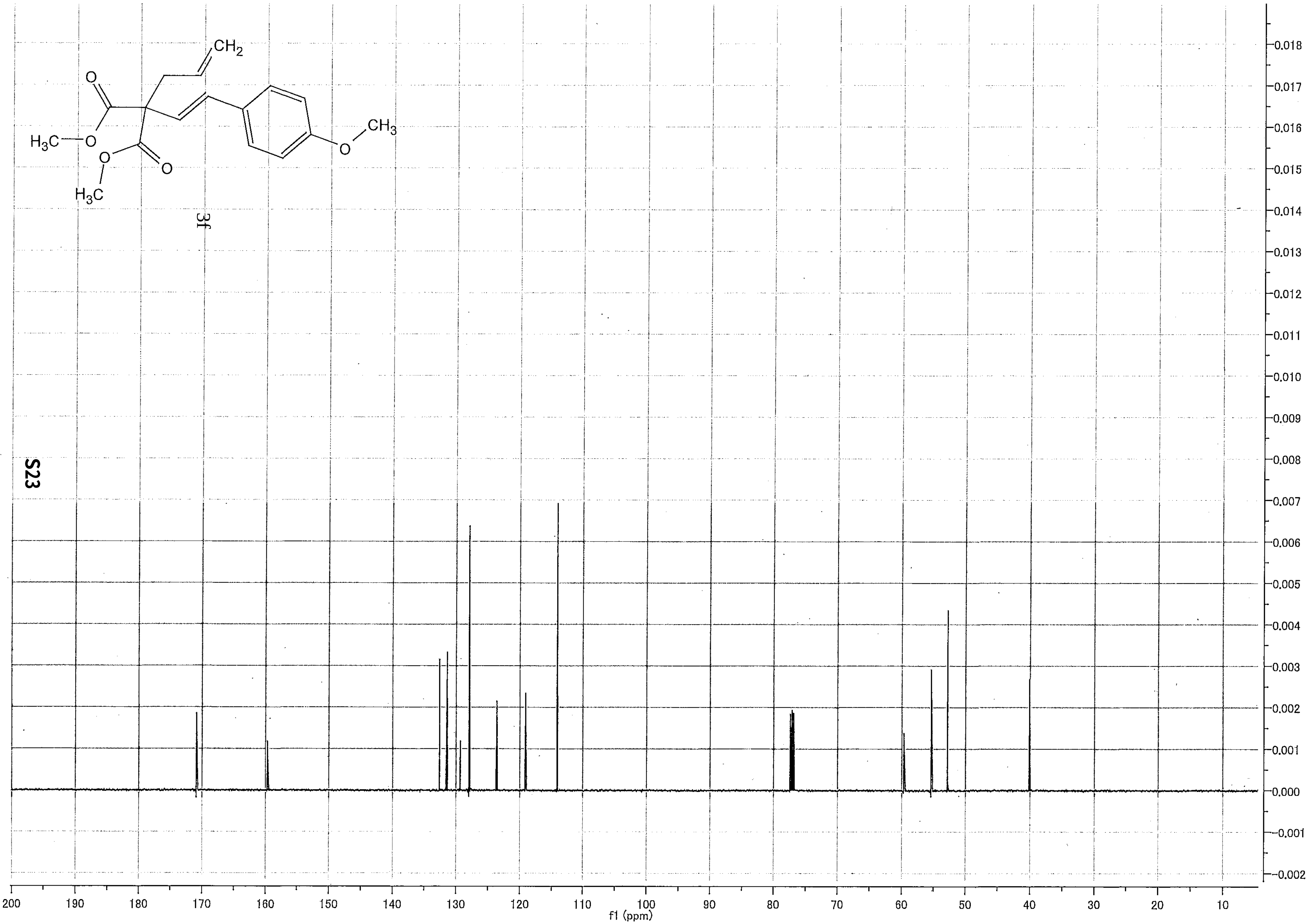
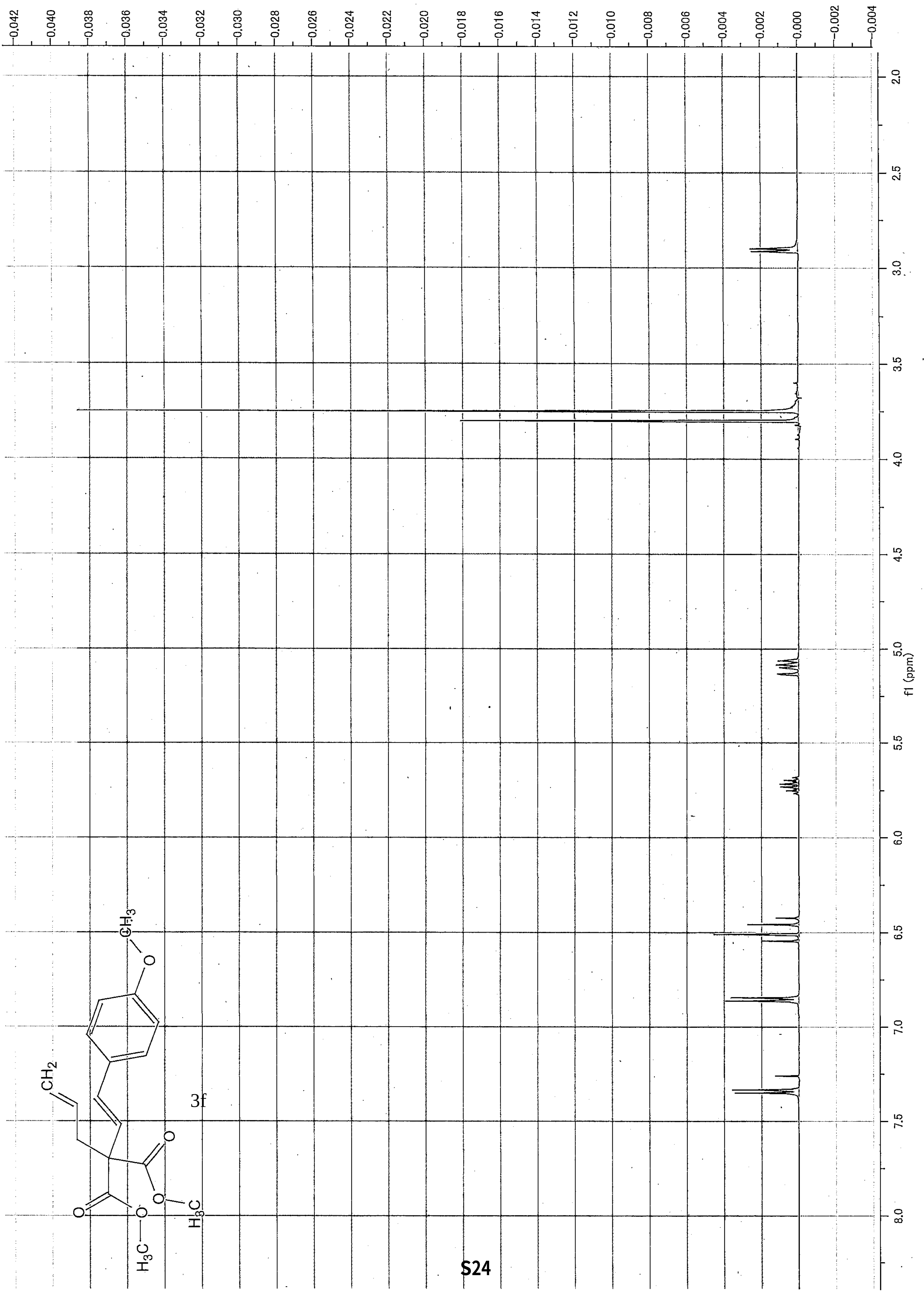
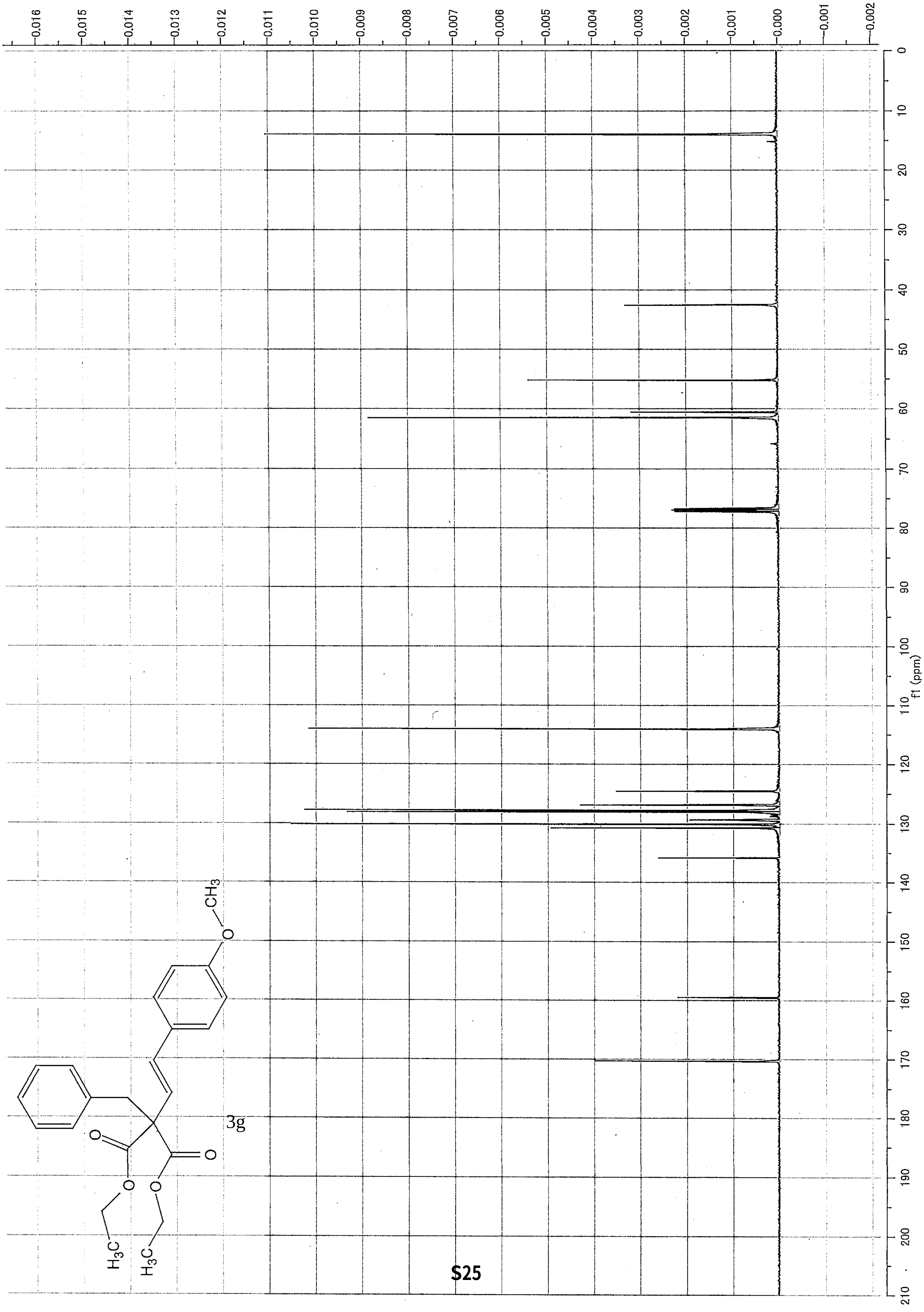
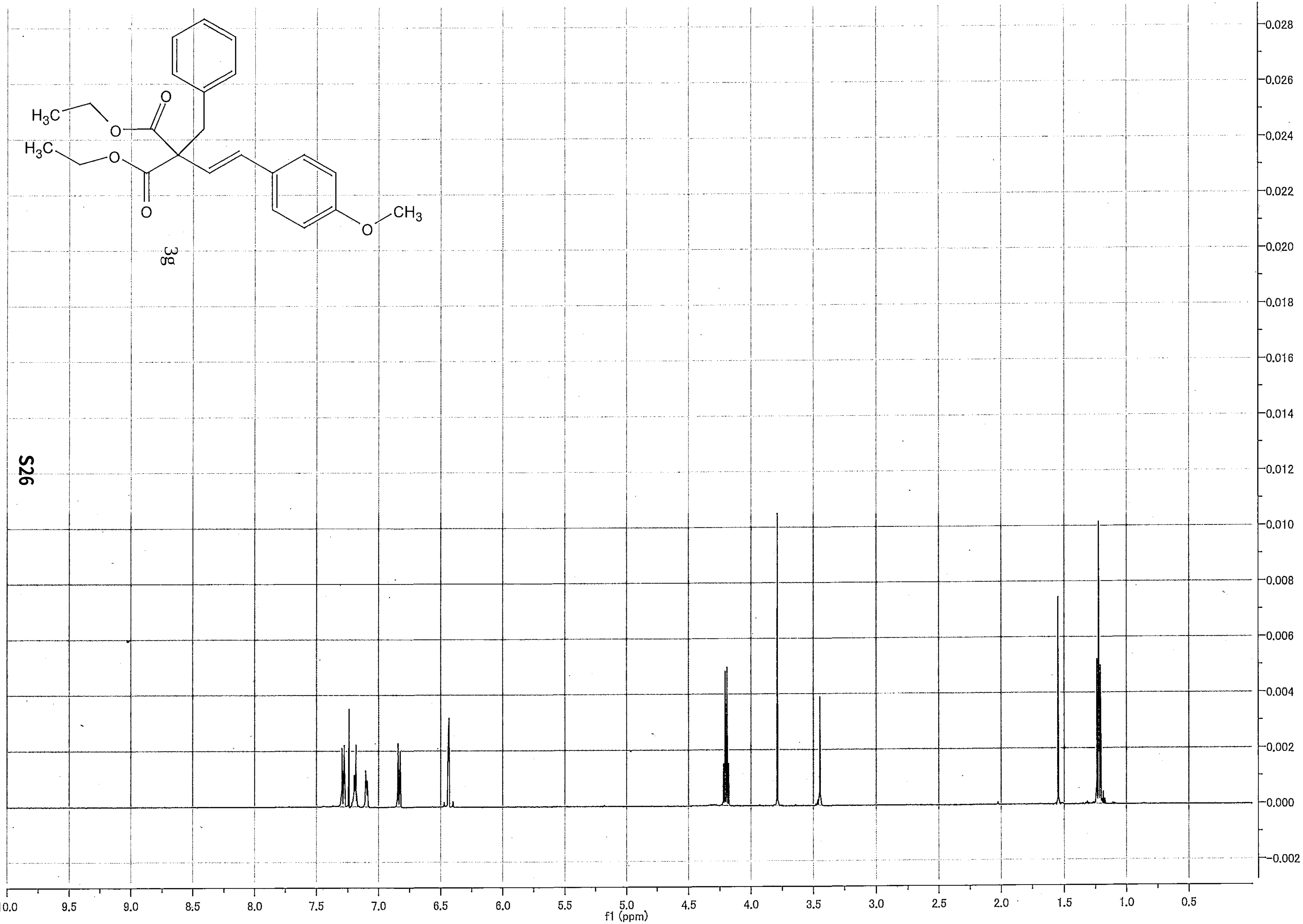

3f
f1 (ppm)



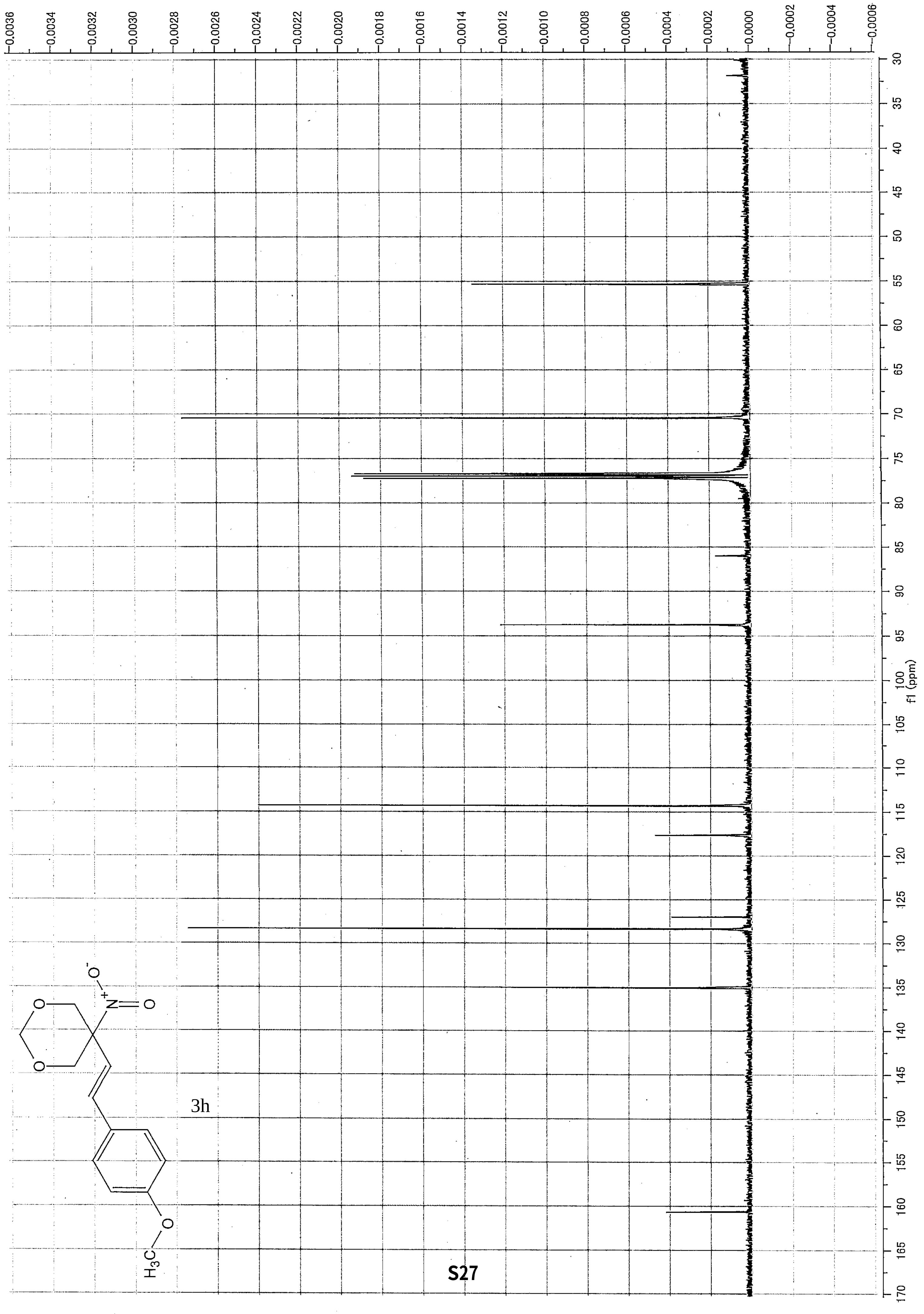
f1 (ppm)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
-0.042
-0.040
-0.038
-0.036
-0.034
-0.032
-0.030
-0.028
-0.026
-0.024
-0.022
-0.020
-0.018
-0.016
-0.014
-0.012
-0.010
-0.008
-0.006
-0.004
-0.002
0.000
-0.002
-0.004
3f


3g
f1 (ppm)



0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

3g



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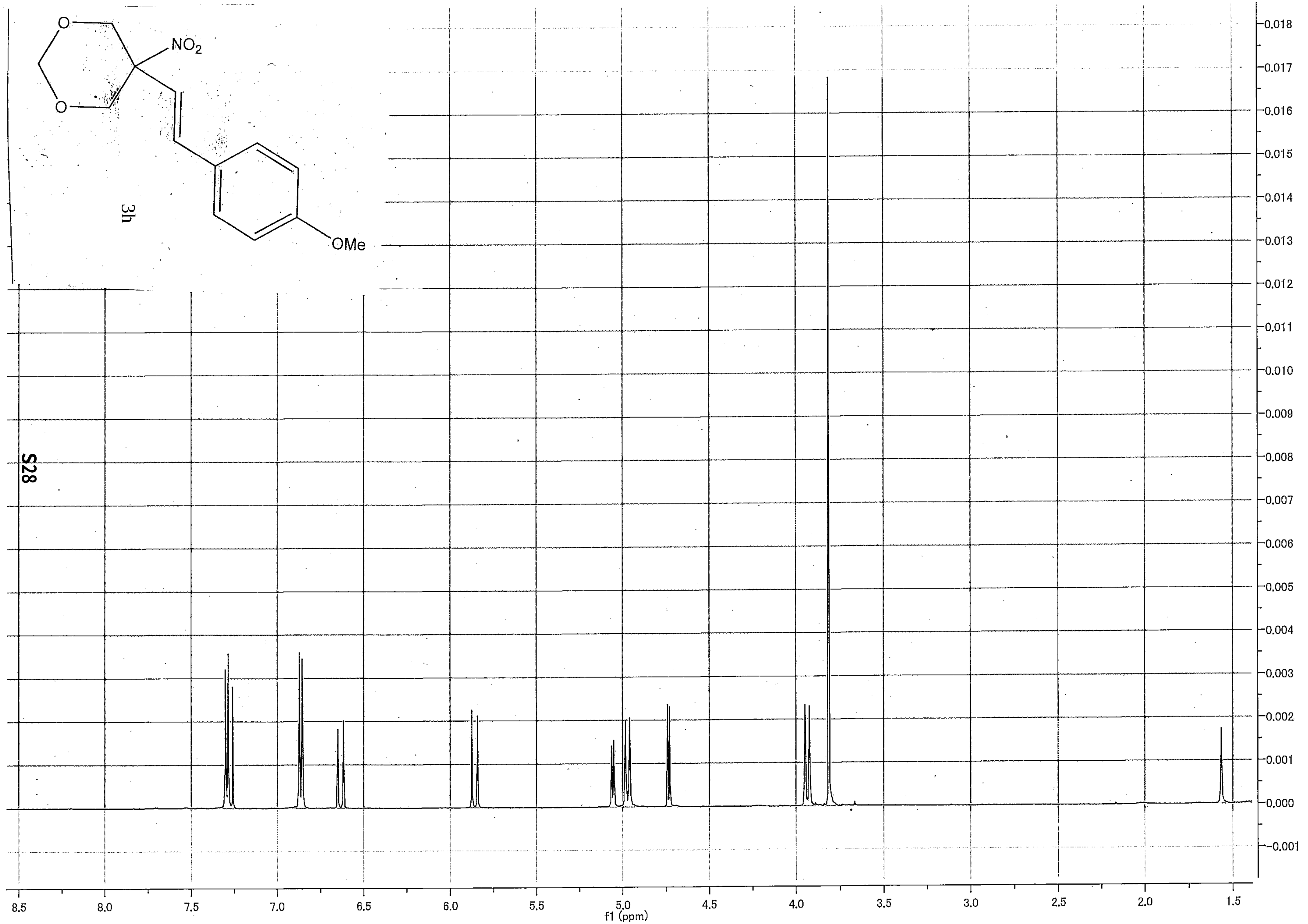

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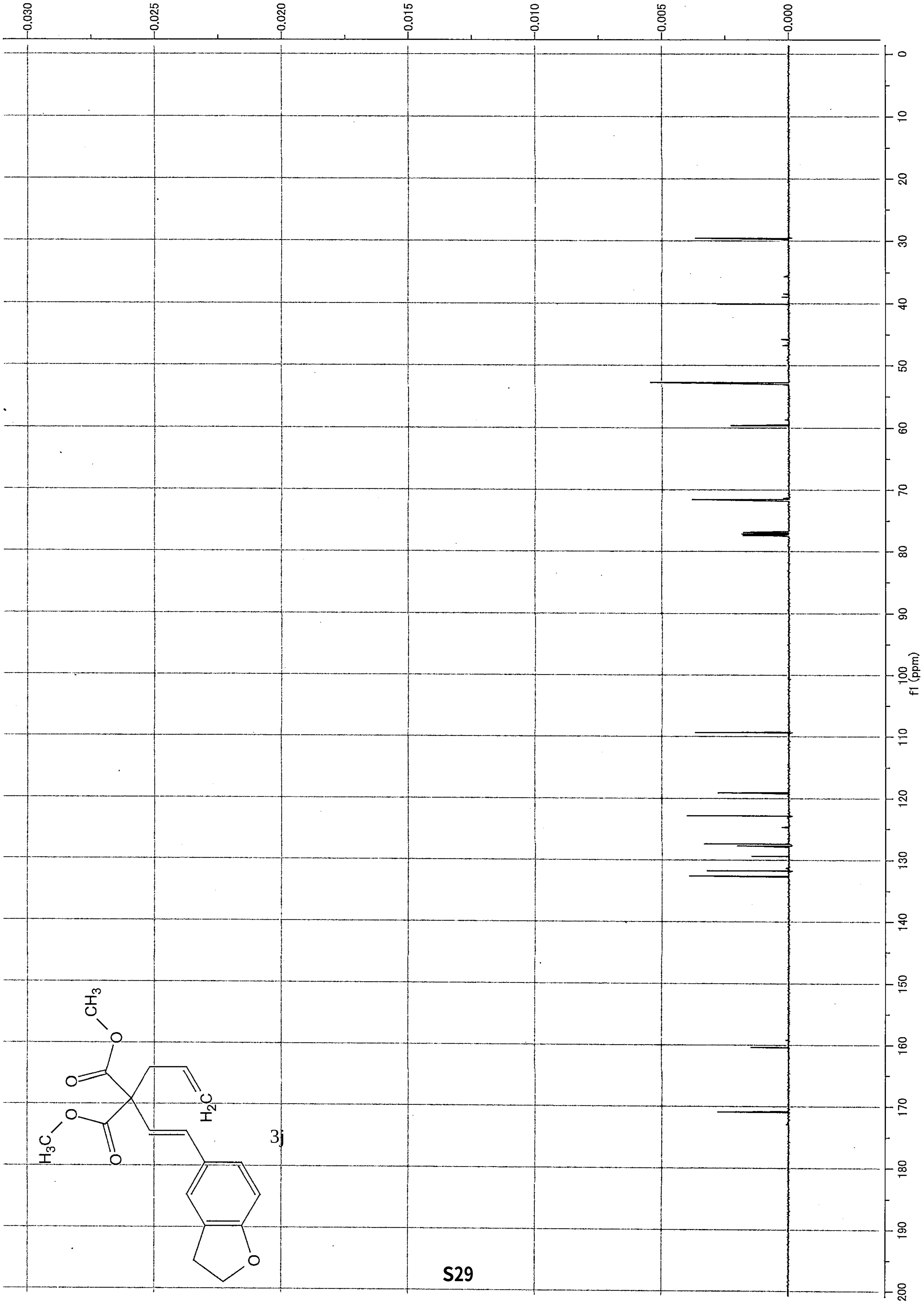
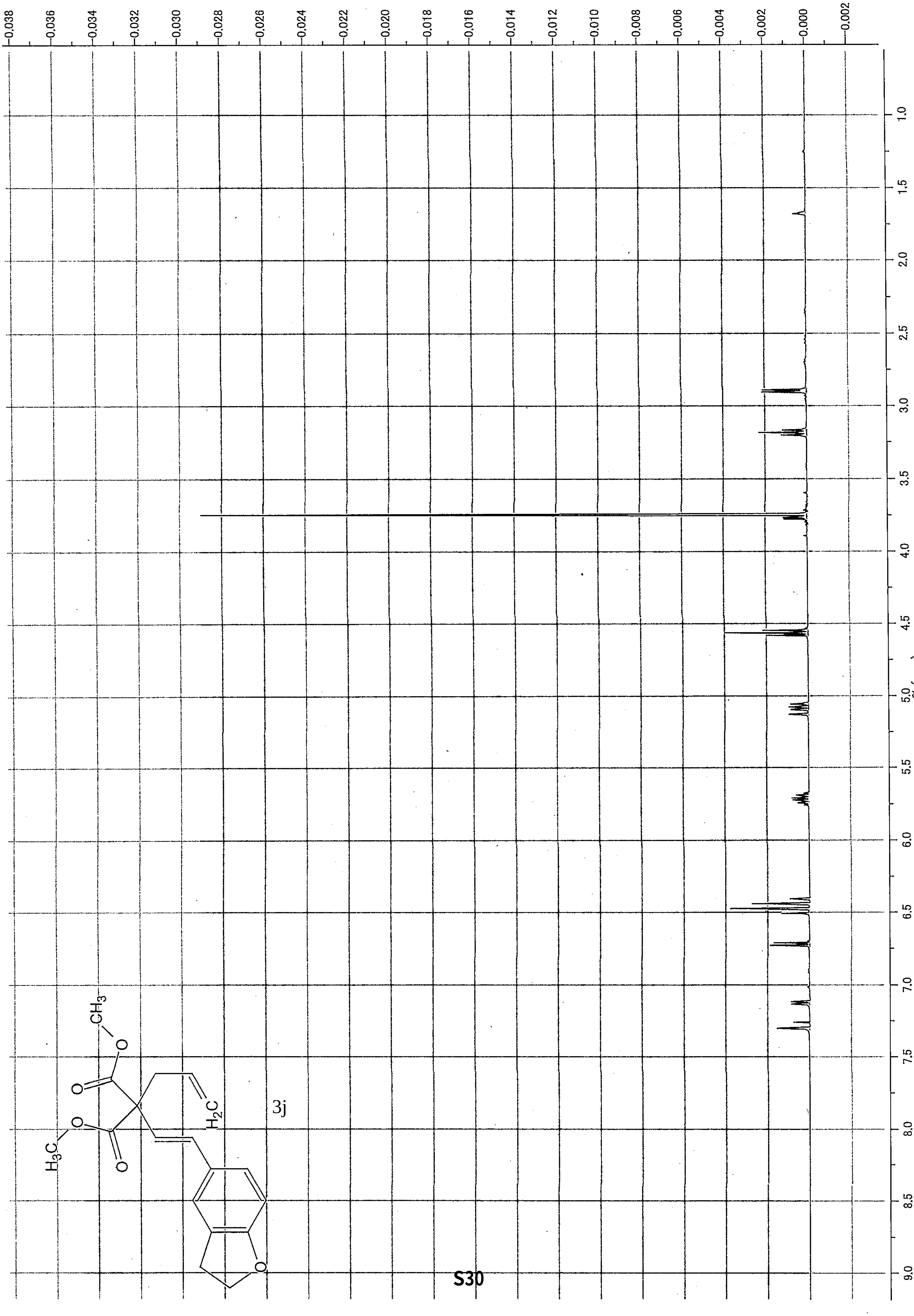

3j
f1 (ppm)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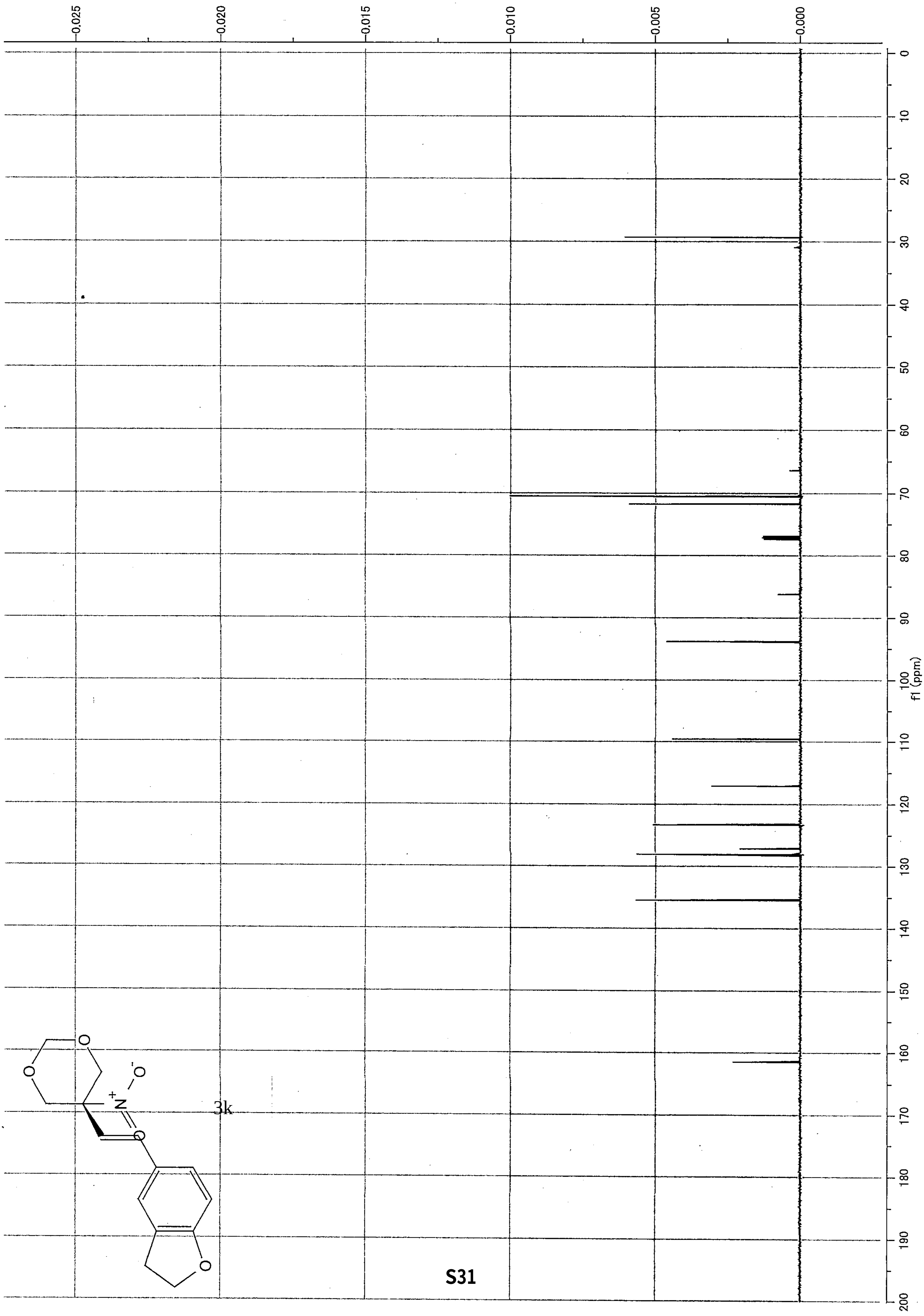
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10
20
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50
60
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80
90
100
f1 (ppm)
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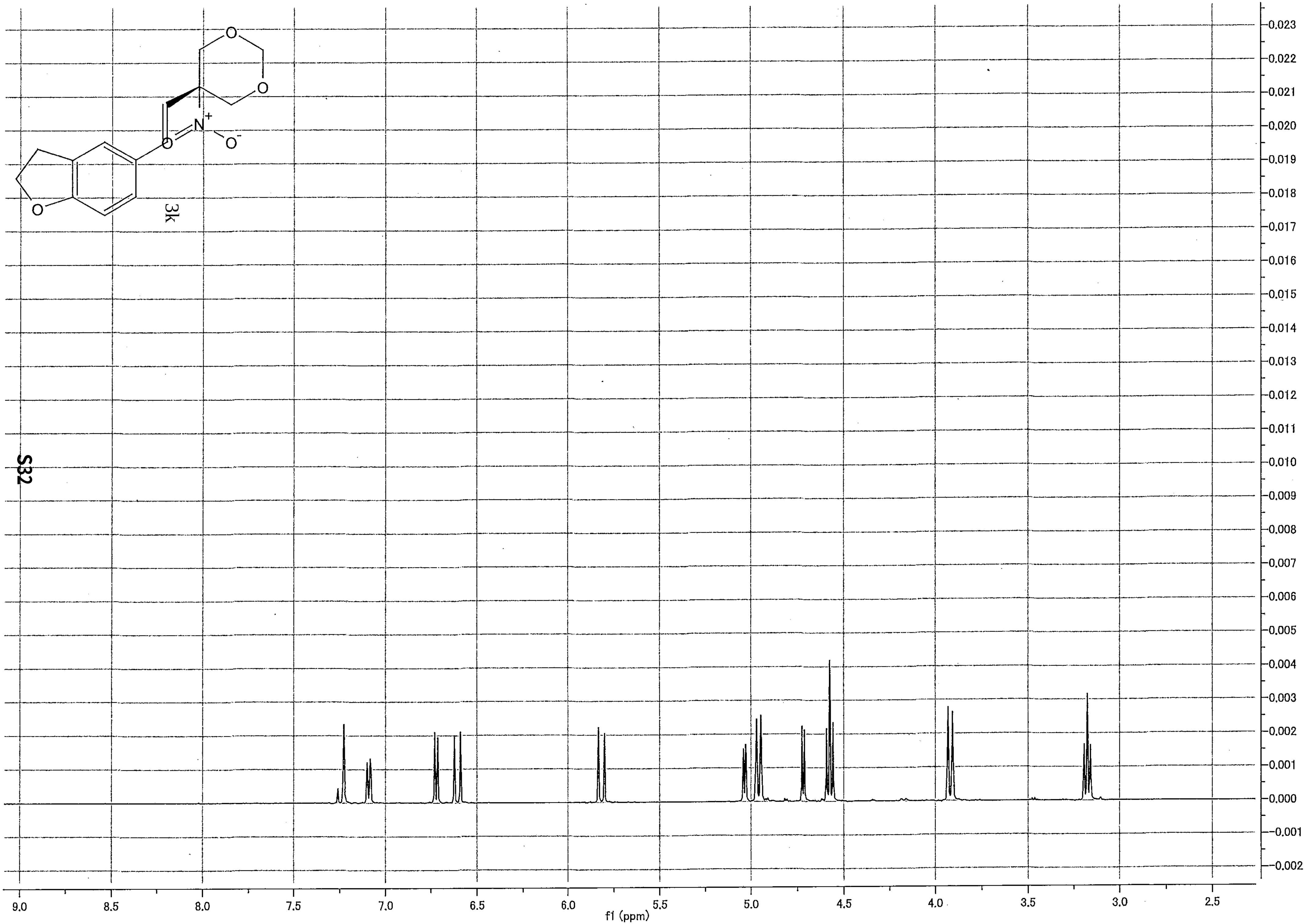
170
180
190
200
3k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f1 (ppm)
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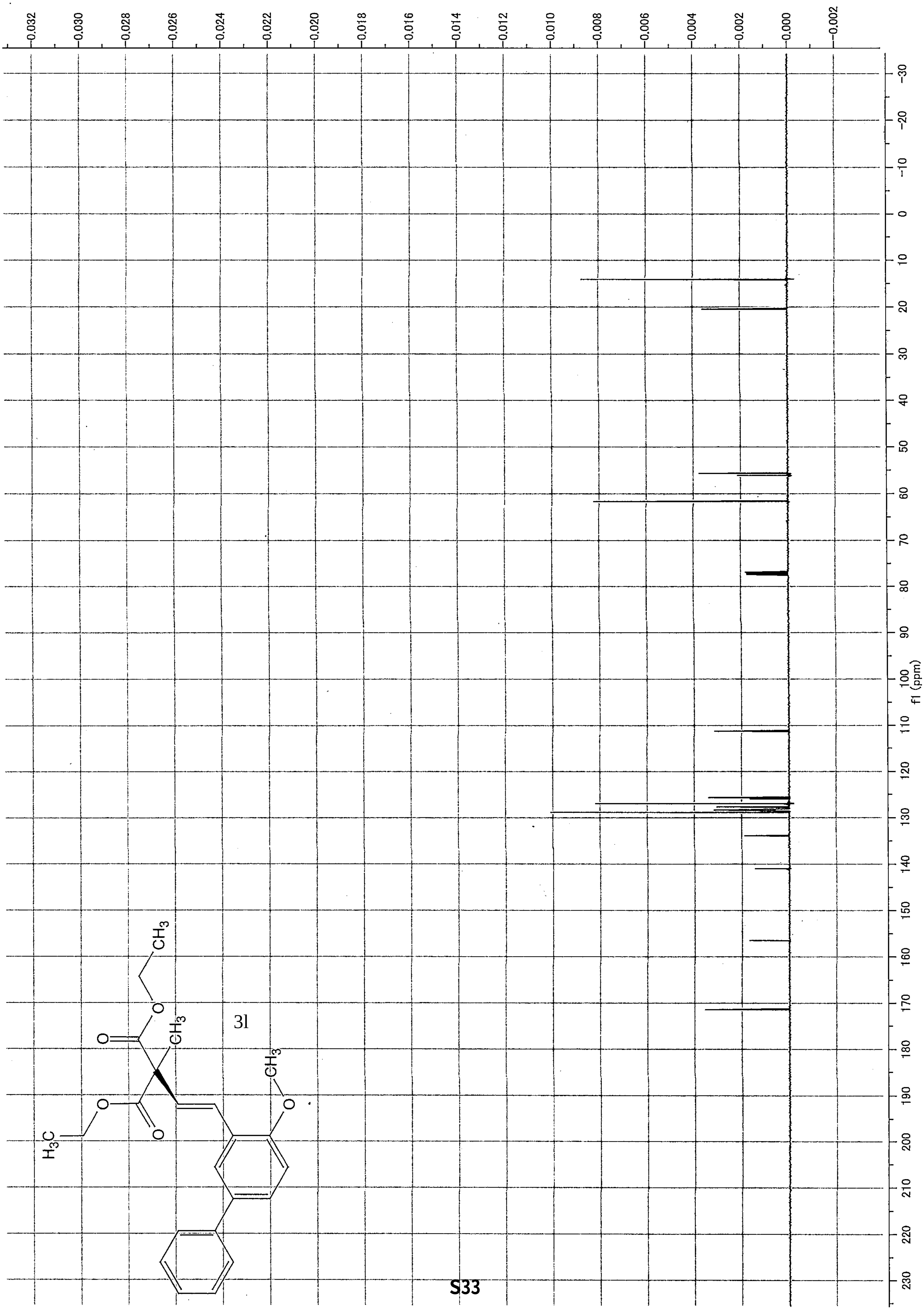
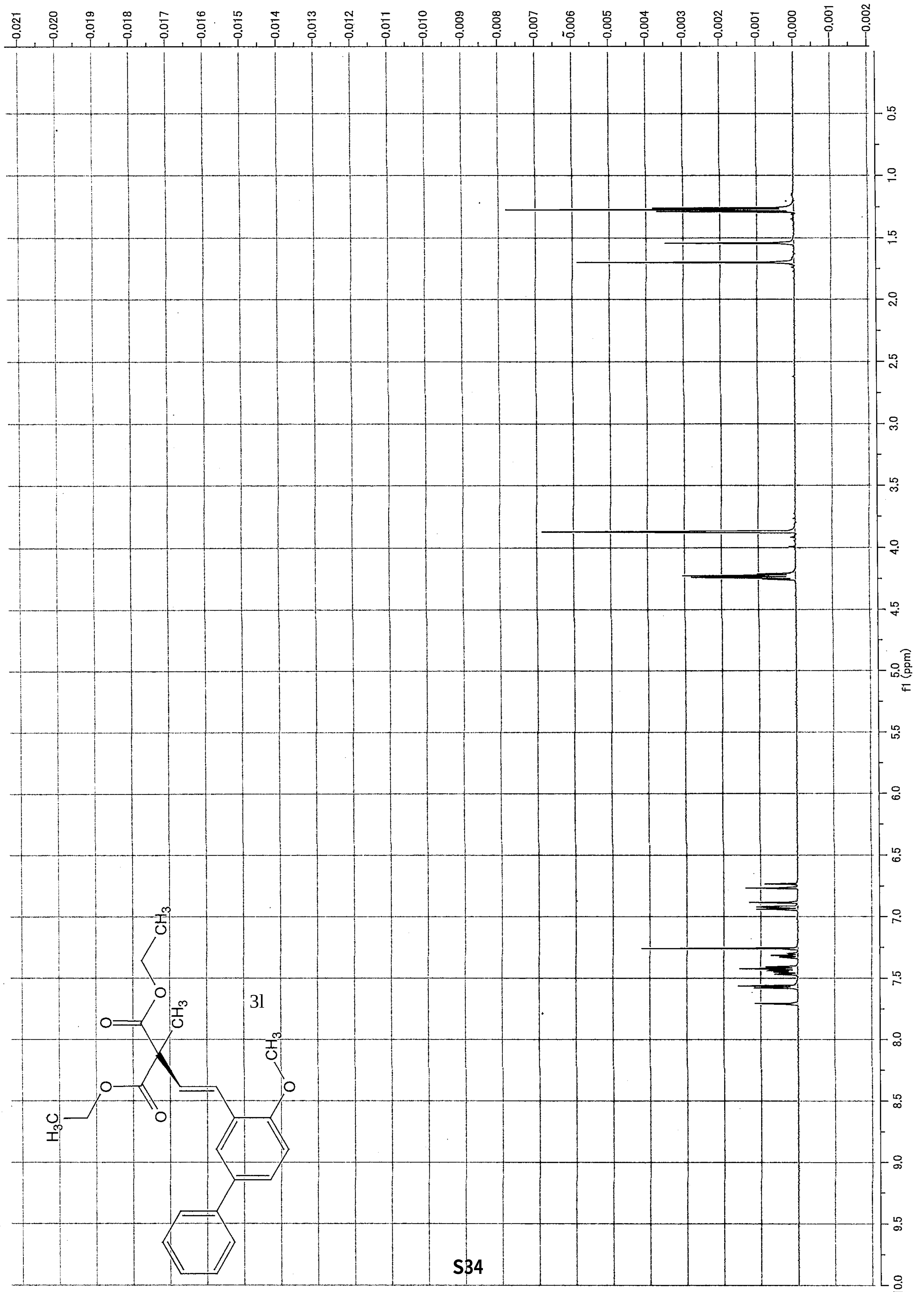
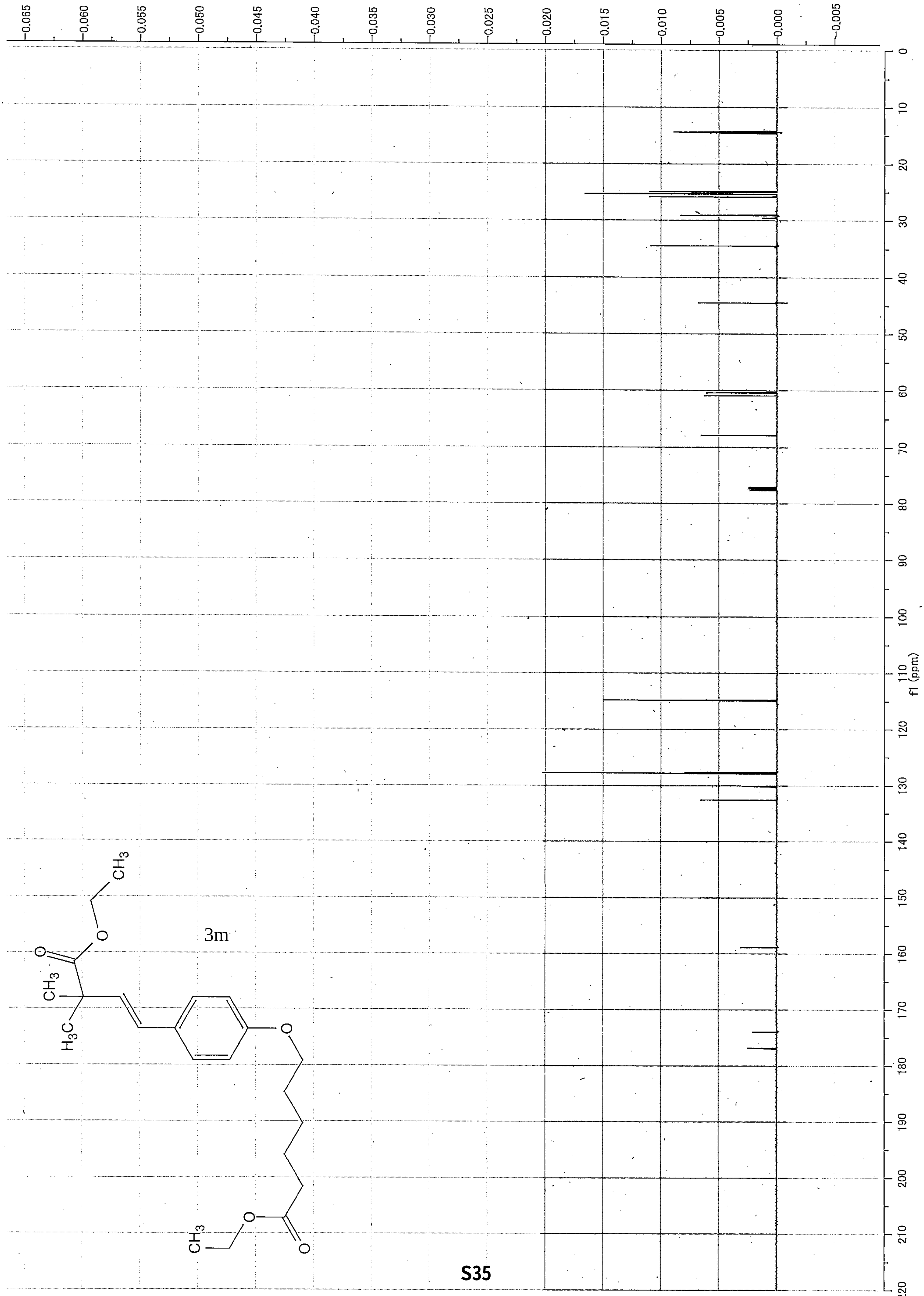
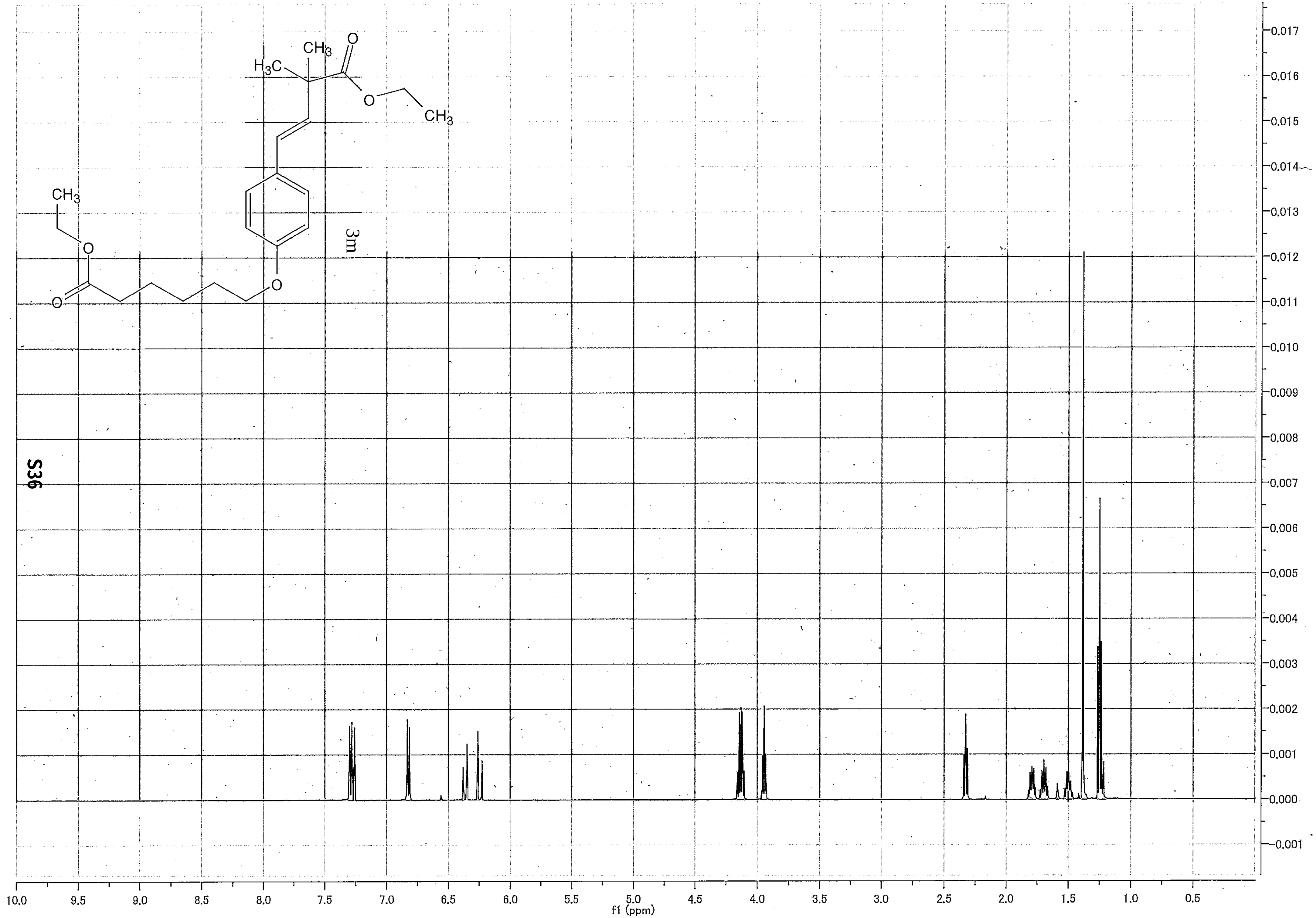
0.023 0.022 0.021 0.020 0.019 0.018 0.017 0.016 0.015 0.014 0.013 0.012 0.011 0.010 0.009 0.008 0.007 0.006 0.005 0.004 0.003 0.002 0.001 0.000 −0.001 −0.002

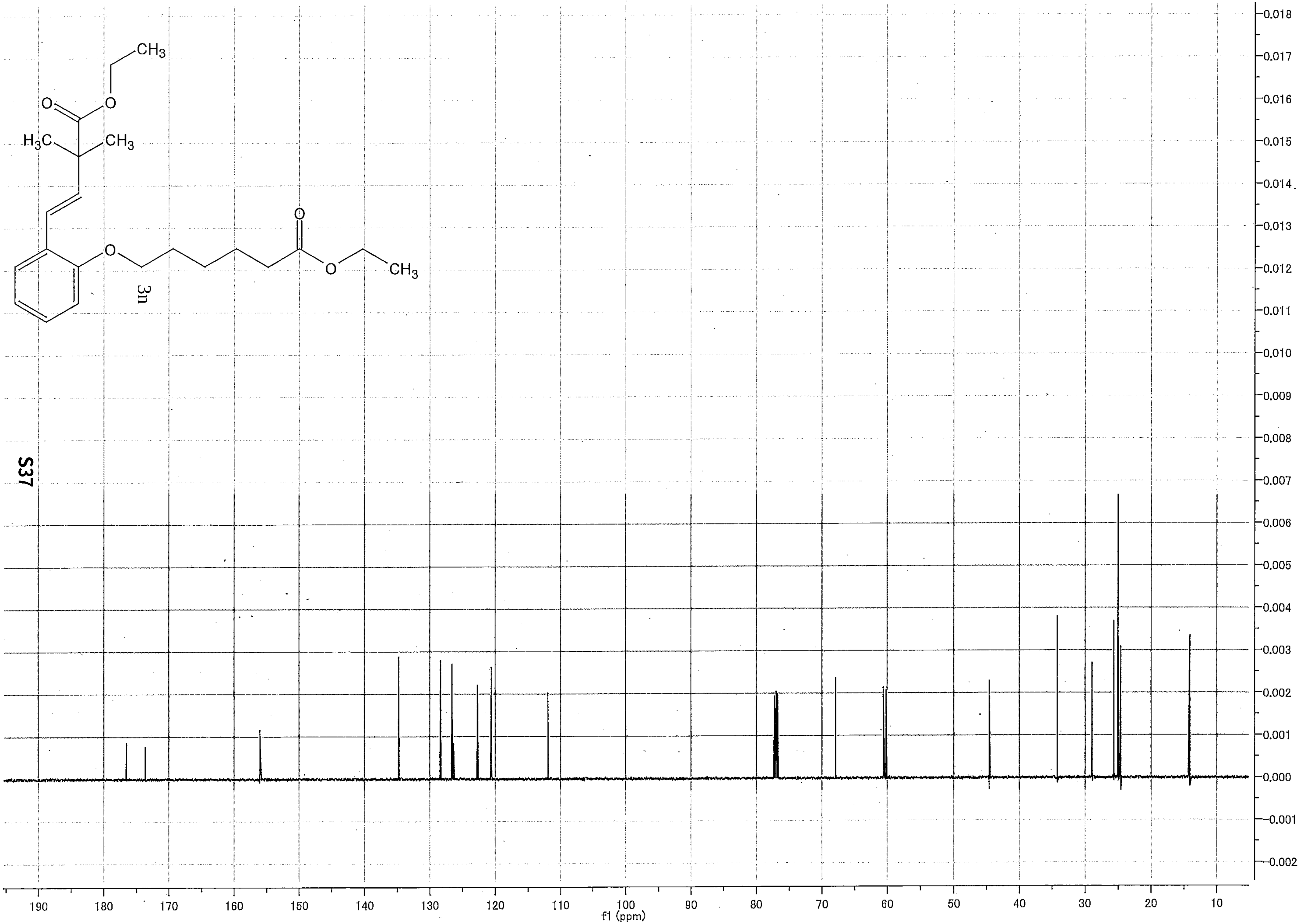

3l
f1 (ppm)


3l
f1 (ppm)


3m
f1 (ppm)



CH3
H3C
O
CH3
CH3
O
O
O
O
3m
f1 (ppm)



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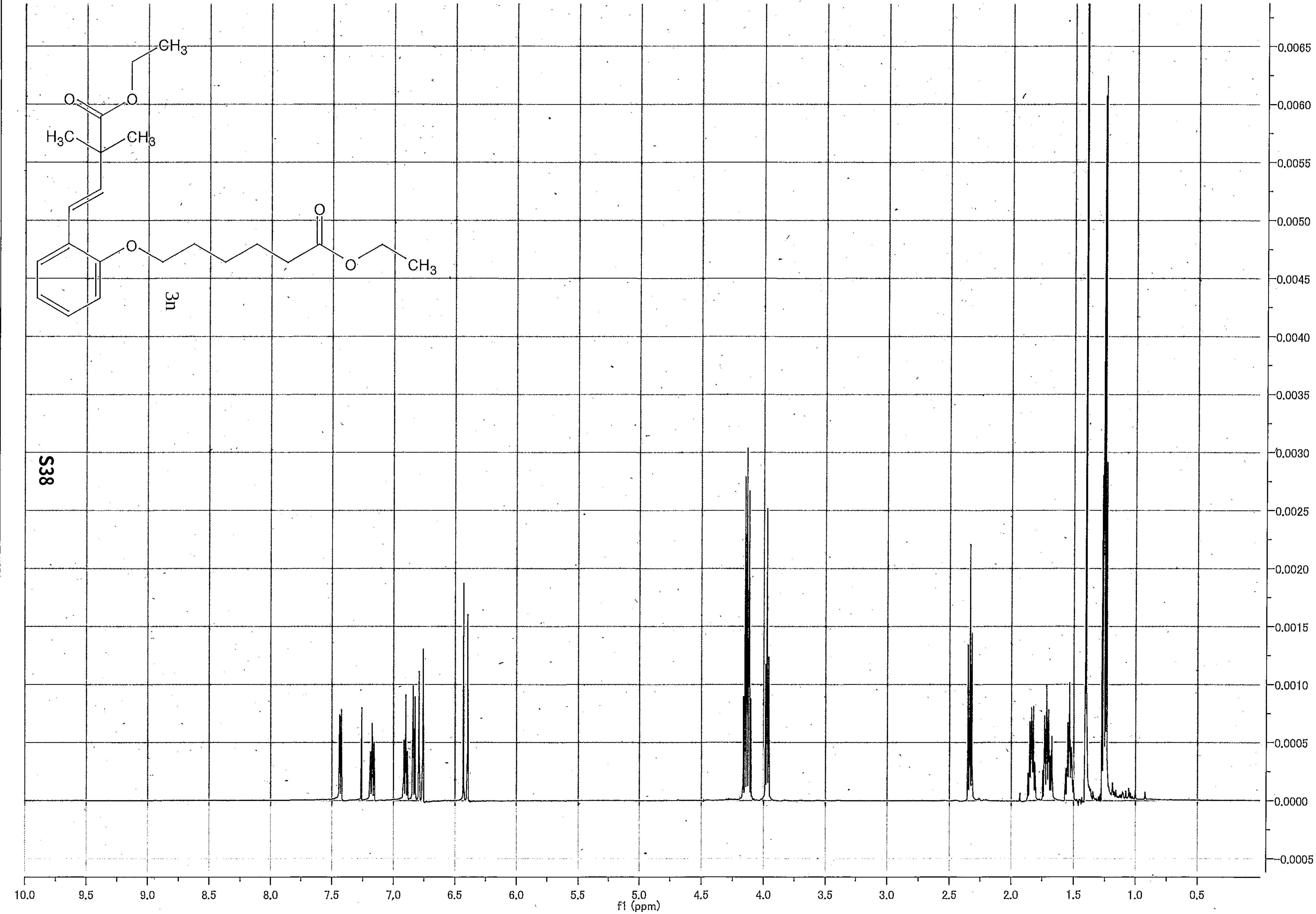
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O
O
H3C
CH3
O
O
O
CH3
3n
f1 (ppm)
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9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0065
0.0060
0.0055
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0.0030
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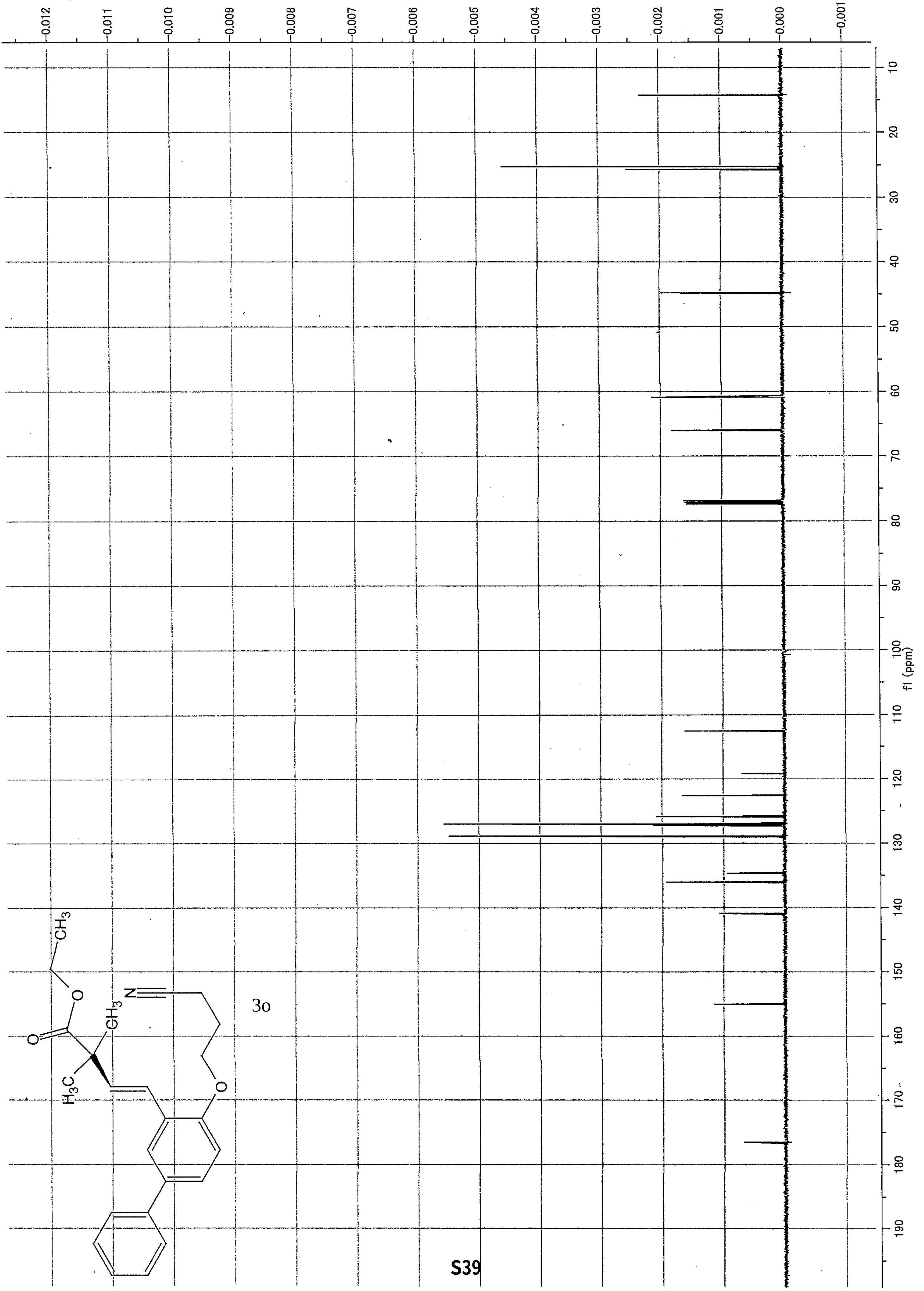
0.0020
0.0015
0.0010
0.0005
0.0000
-0.0005



0.012
0.011
0.010
0.009
0.008
0.007
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0.005
0.004
0.003
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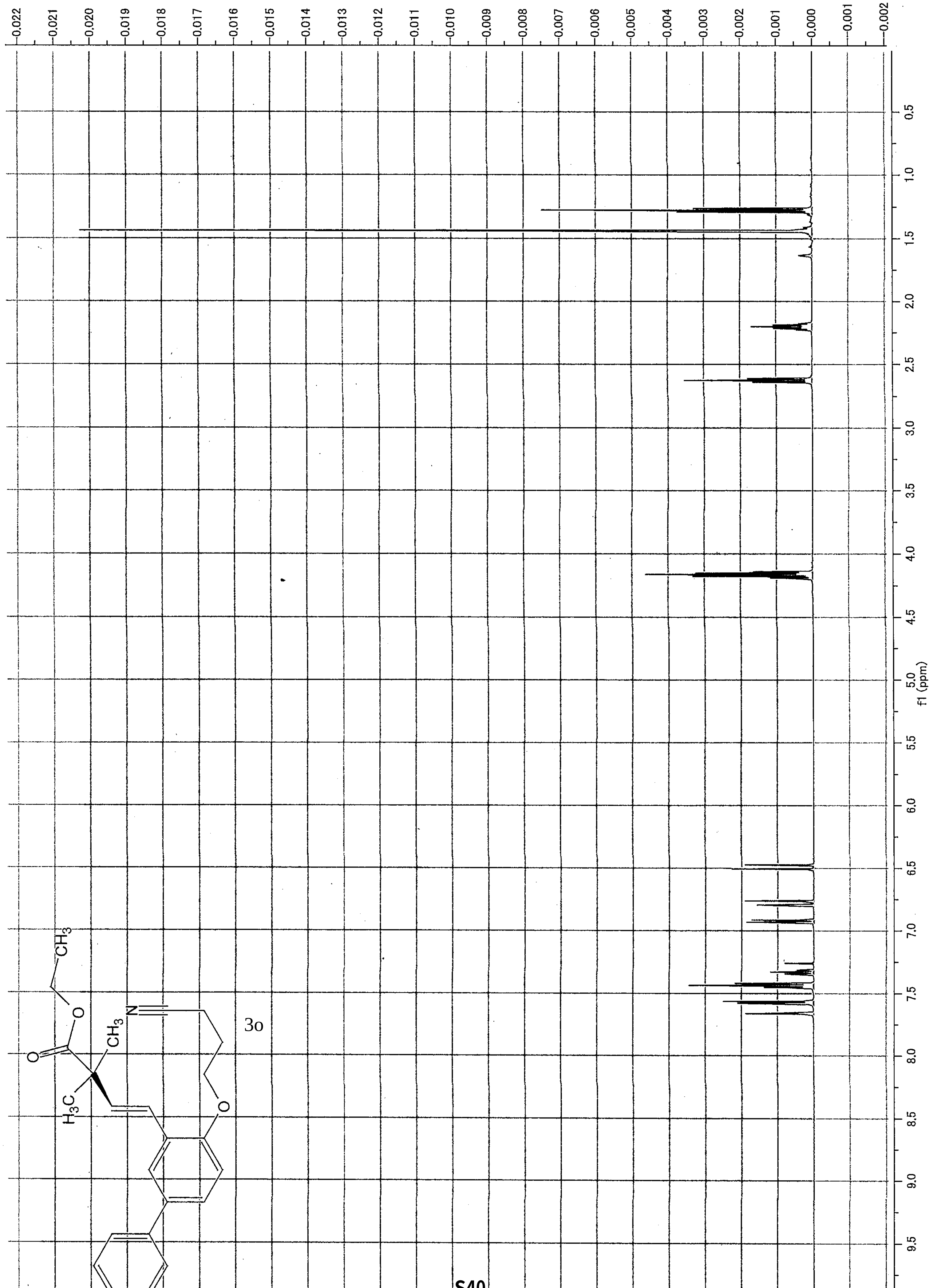
0.000
-0.001
f1 (ppm)

3o



f1 (ppm)
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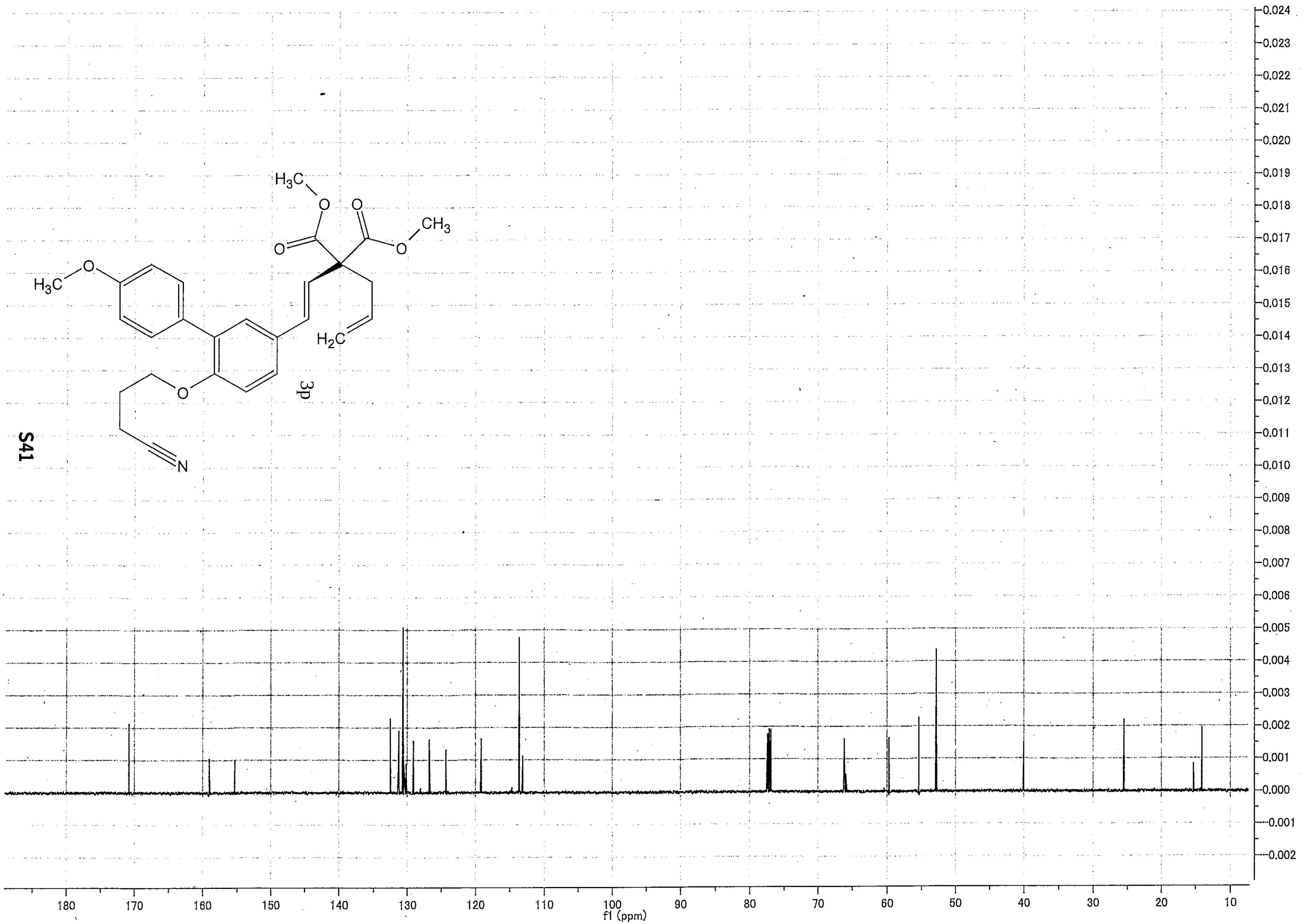
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-0.022
-0.021
-0.020
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-0.018
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-0.016
-0.015
-0.014
-0.013
-0.012
-0.011
-0.010
-0.009
-0.008
-0.007
-0.006
-0.005
-0.004
-0.003
-0.002
-0.001
0.000
--0.001
--0.002
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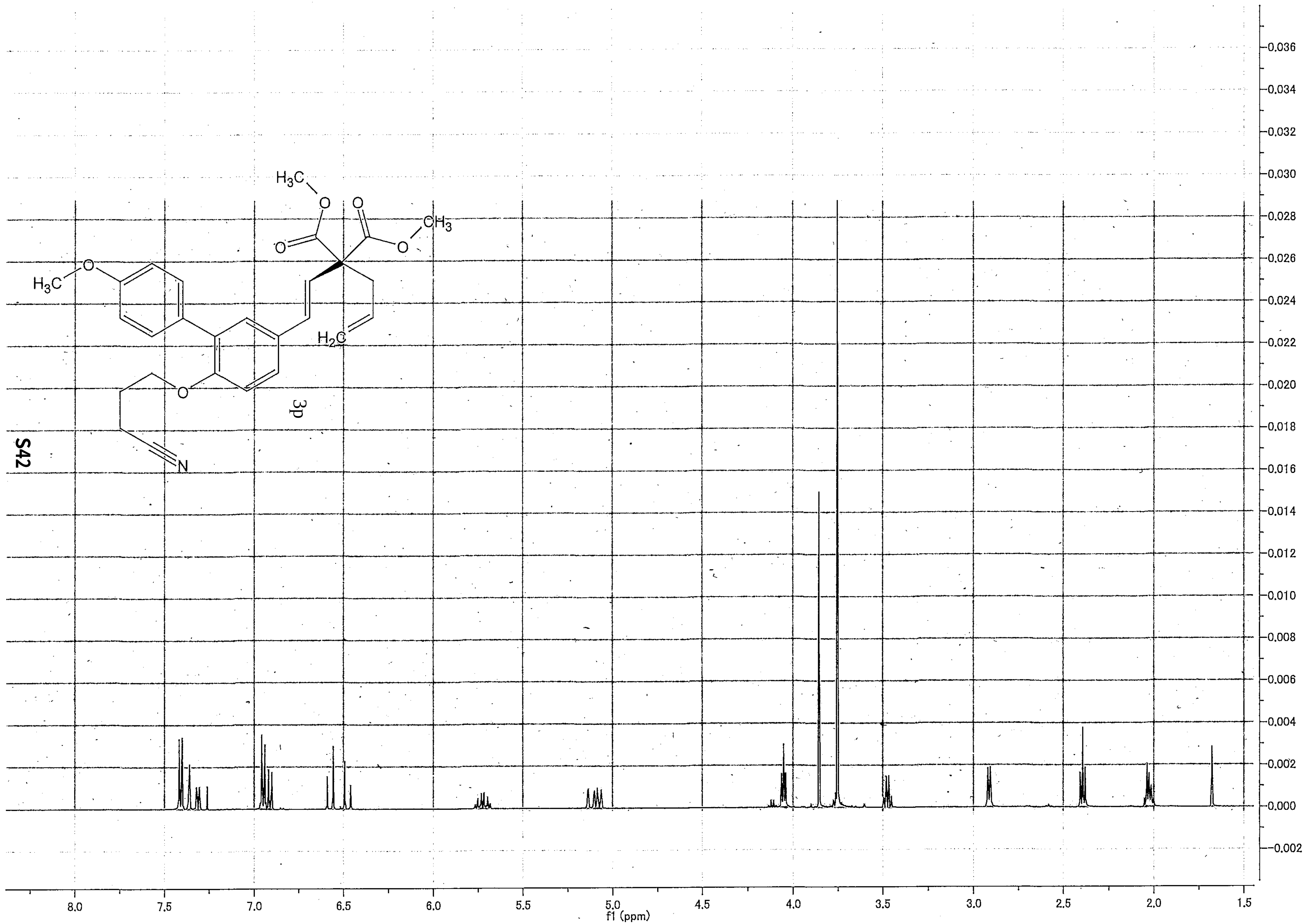
f1 (ppm)

3p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7.0
6.5
6.0
5.5
5.0
4.5
4.0
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3.0
2.5
2.0
1.5
0.036
0.034
0.032
0.030
0.028
0.026
0.024
0.022
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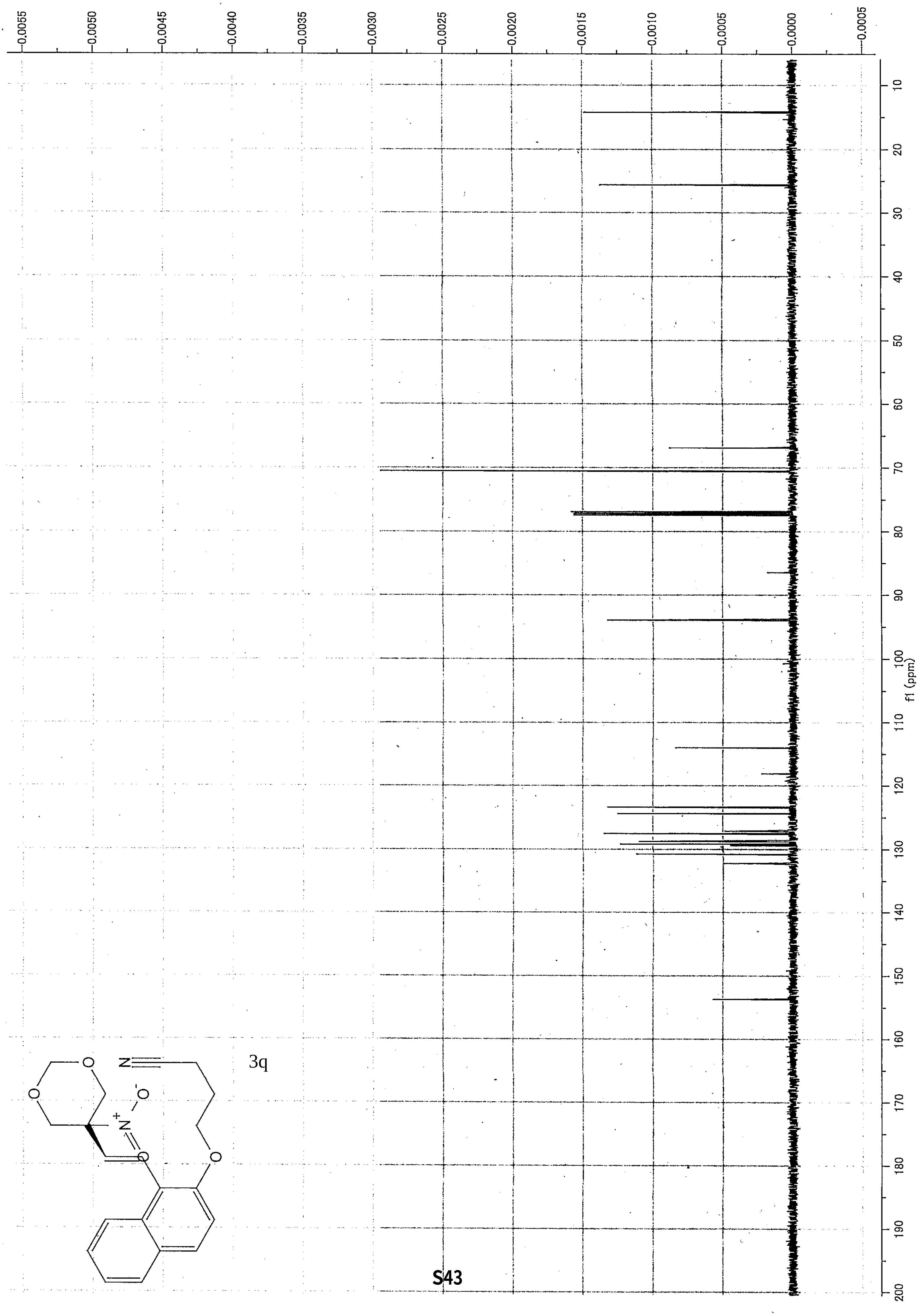
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-0.0020
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-0.0000
--0.0005
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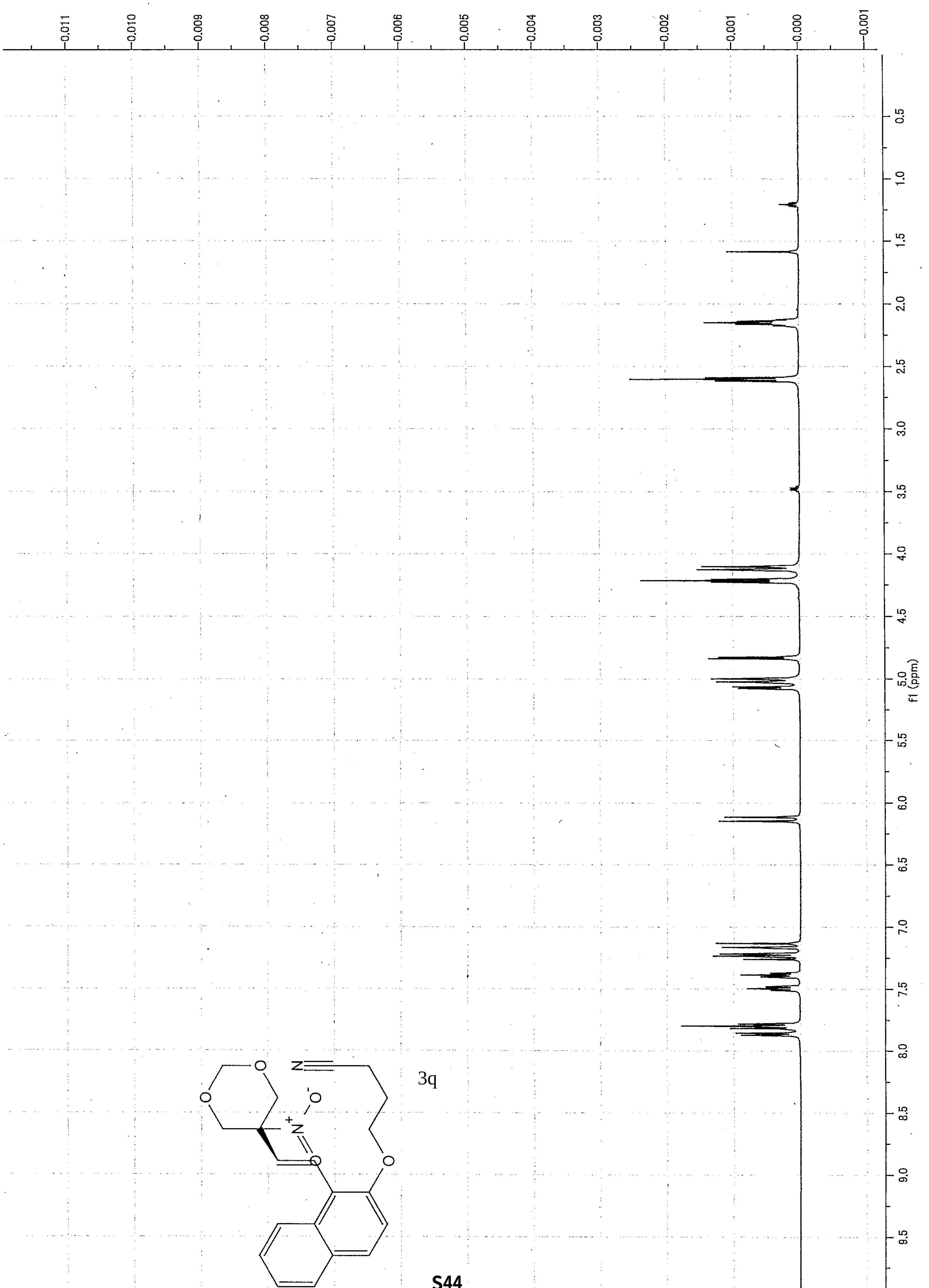
f1 (ppm)

3q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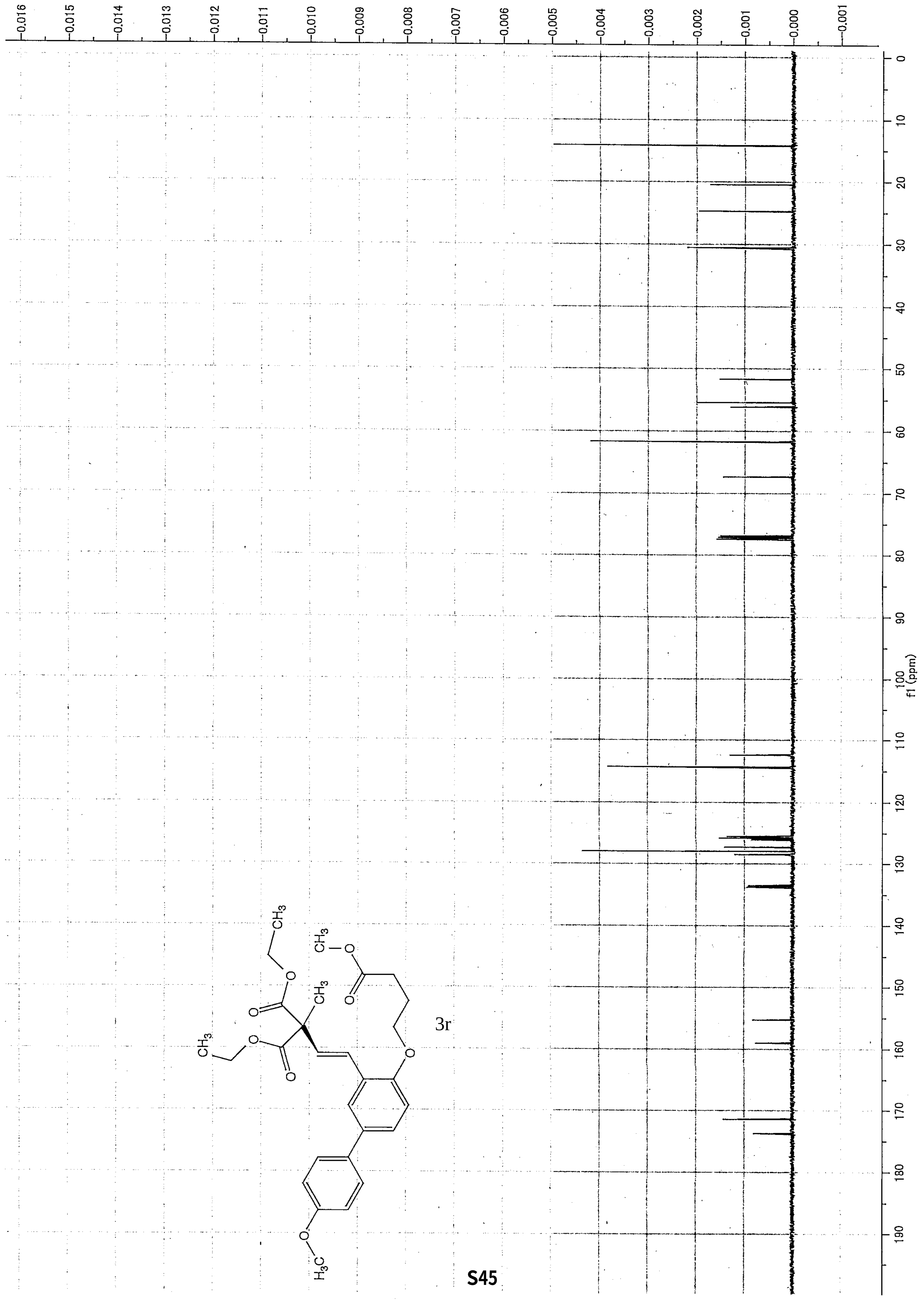
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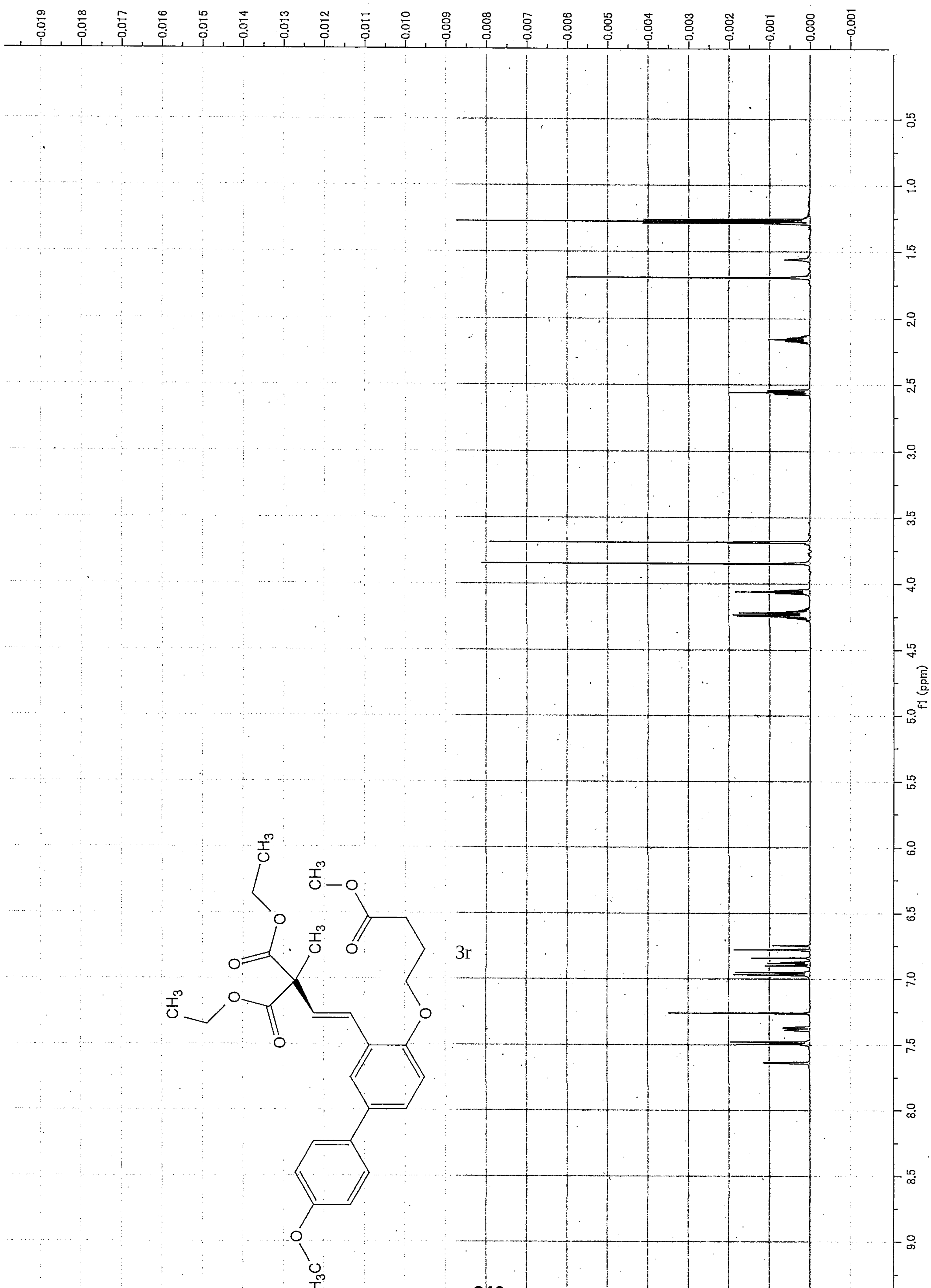

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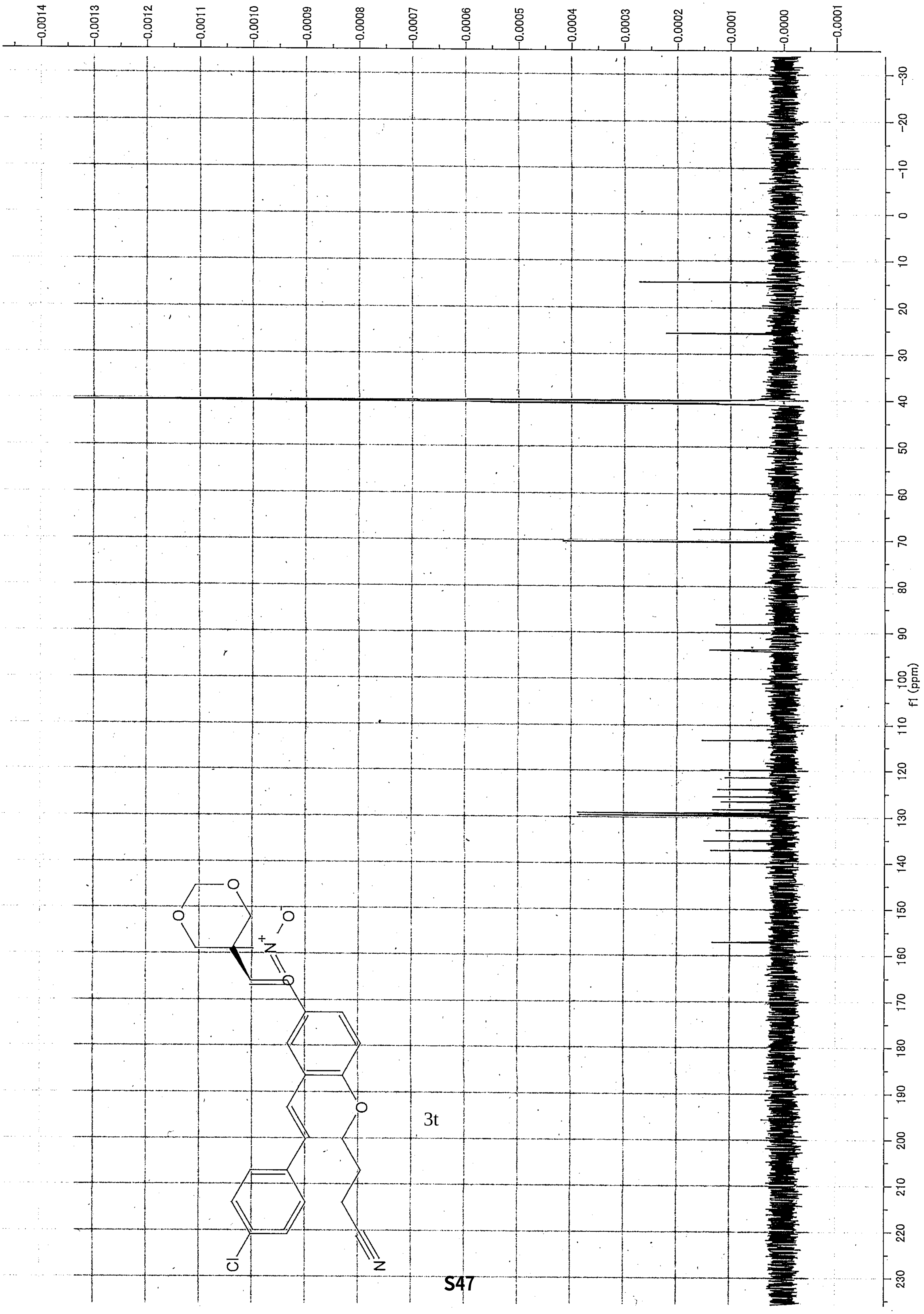

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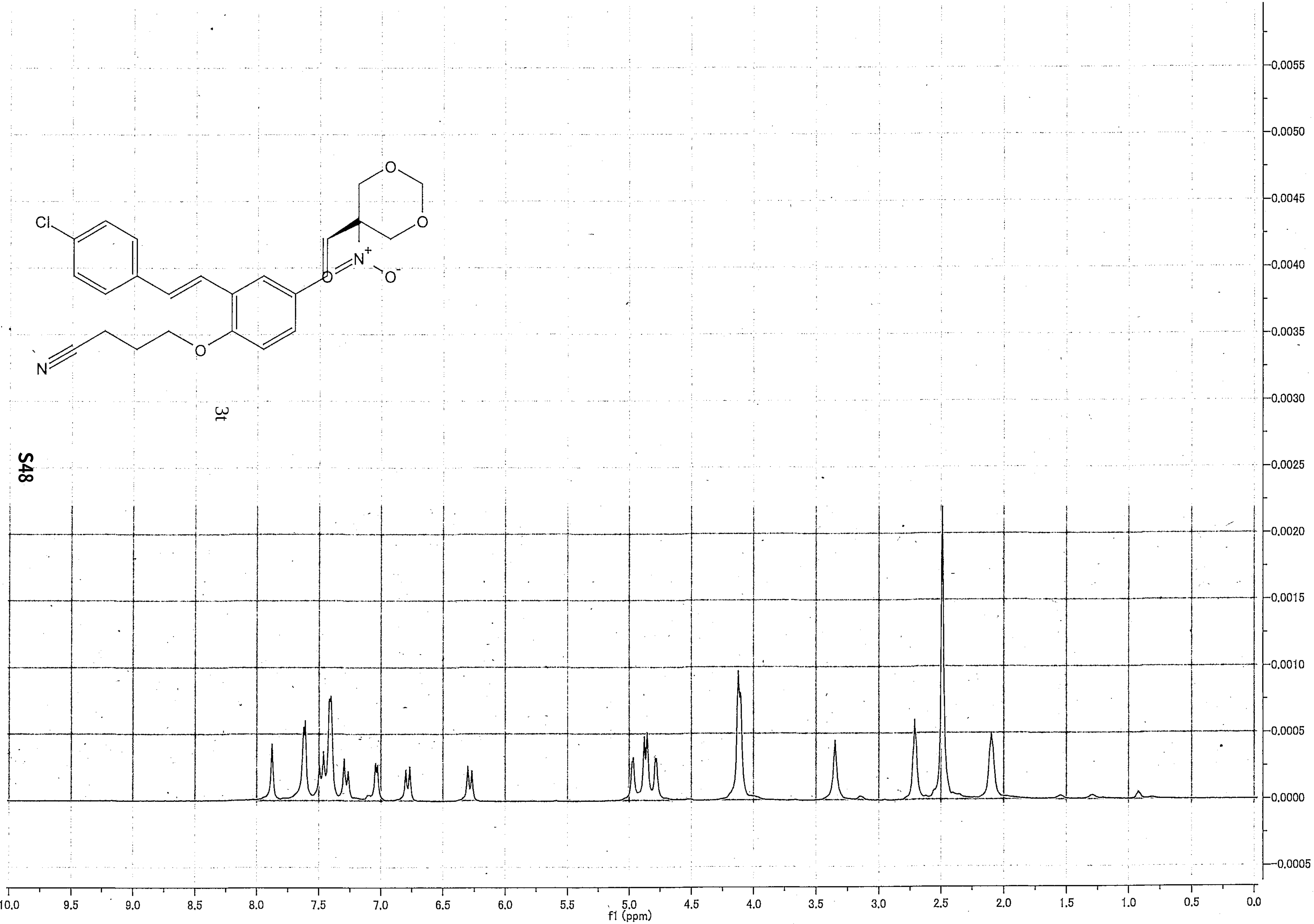
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O
O
N+
O-
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6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)
0.0055
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0.0015
0.0010
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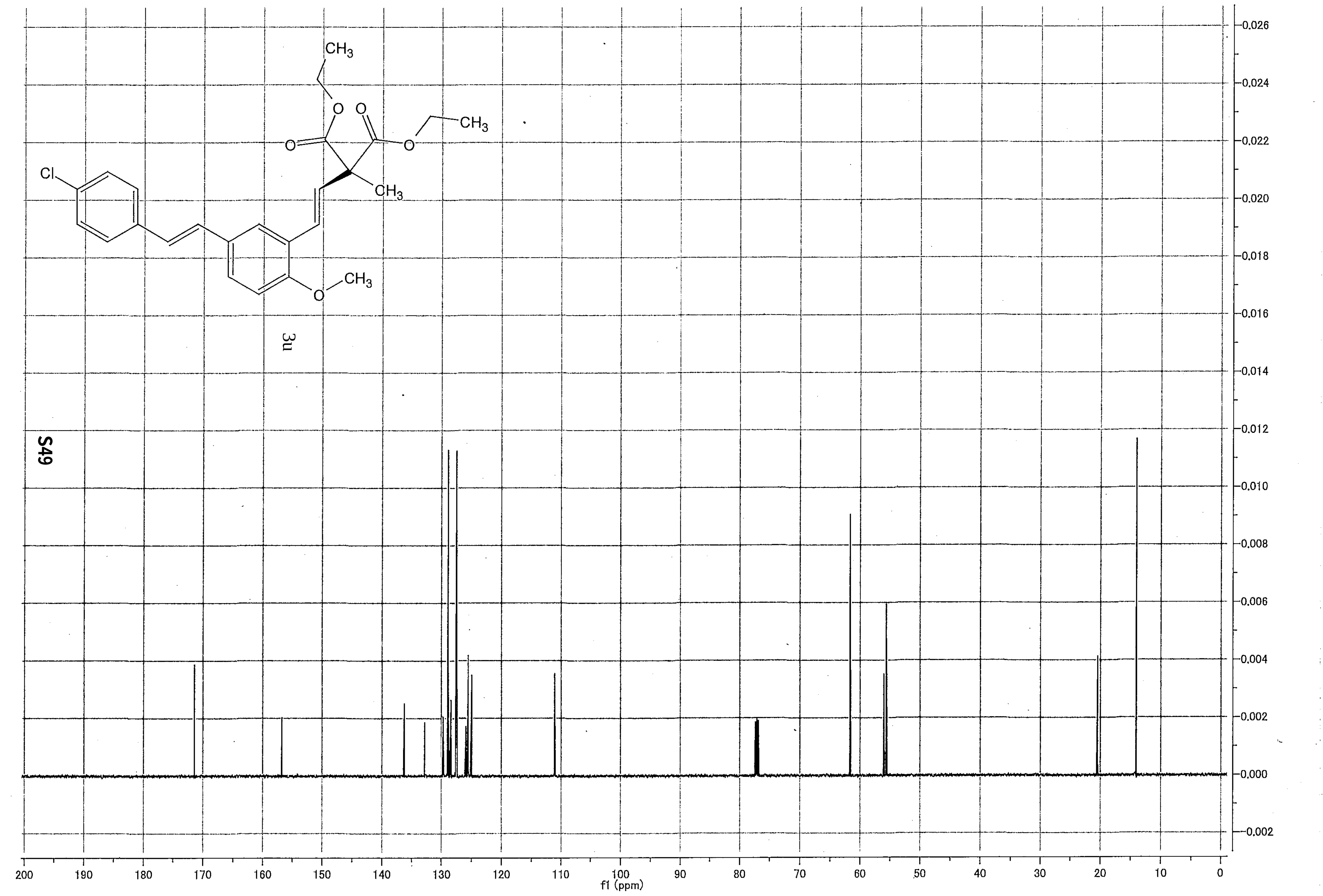
-0.0005



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O
CH3
O
O
Cl
CH3
O
CH3
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0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
200
190
180
170
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30
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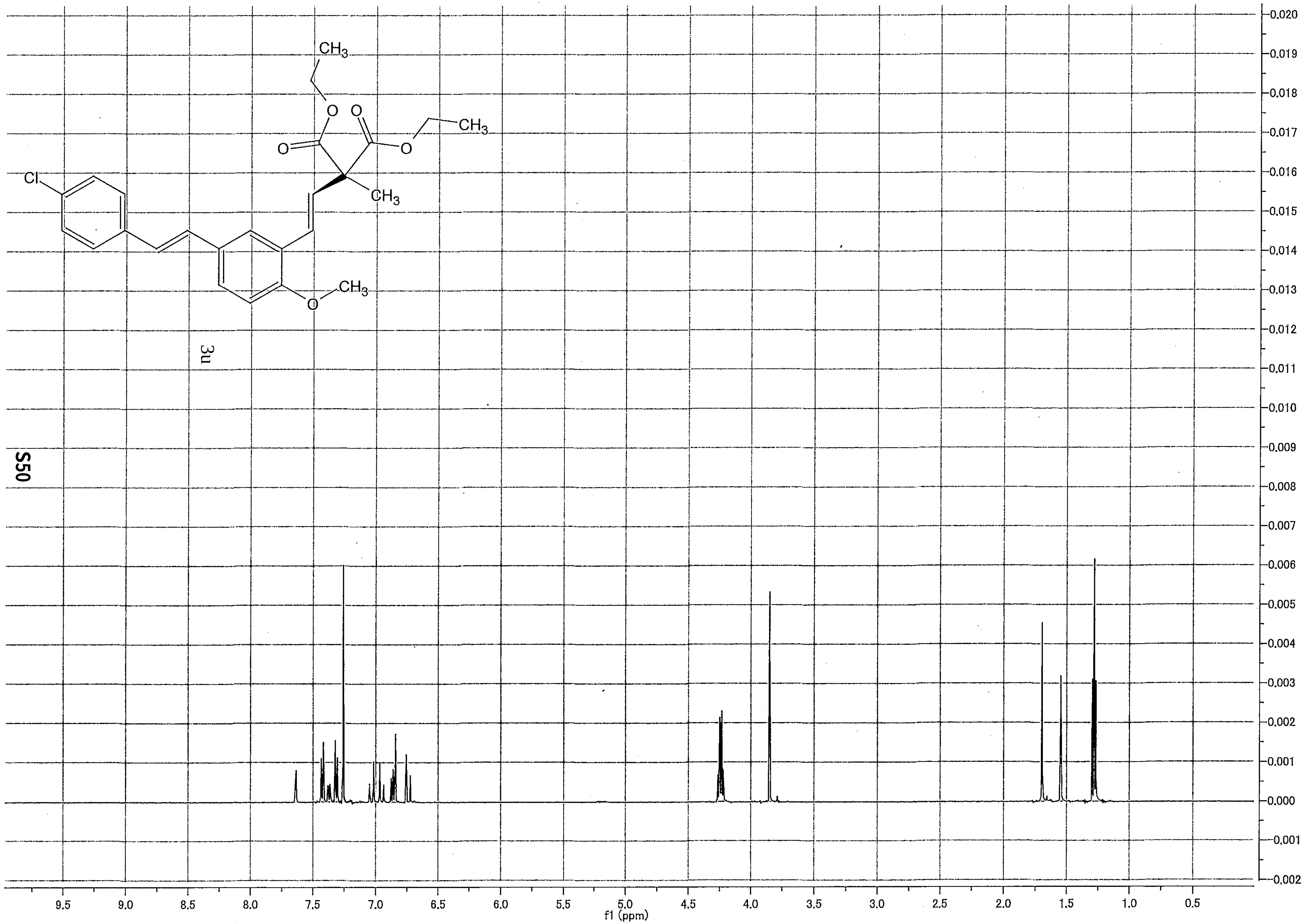
10
0
f1 (ppm)

3u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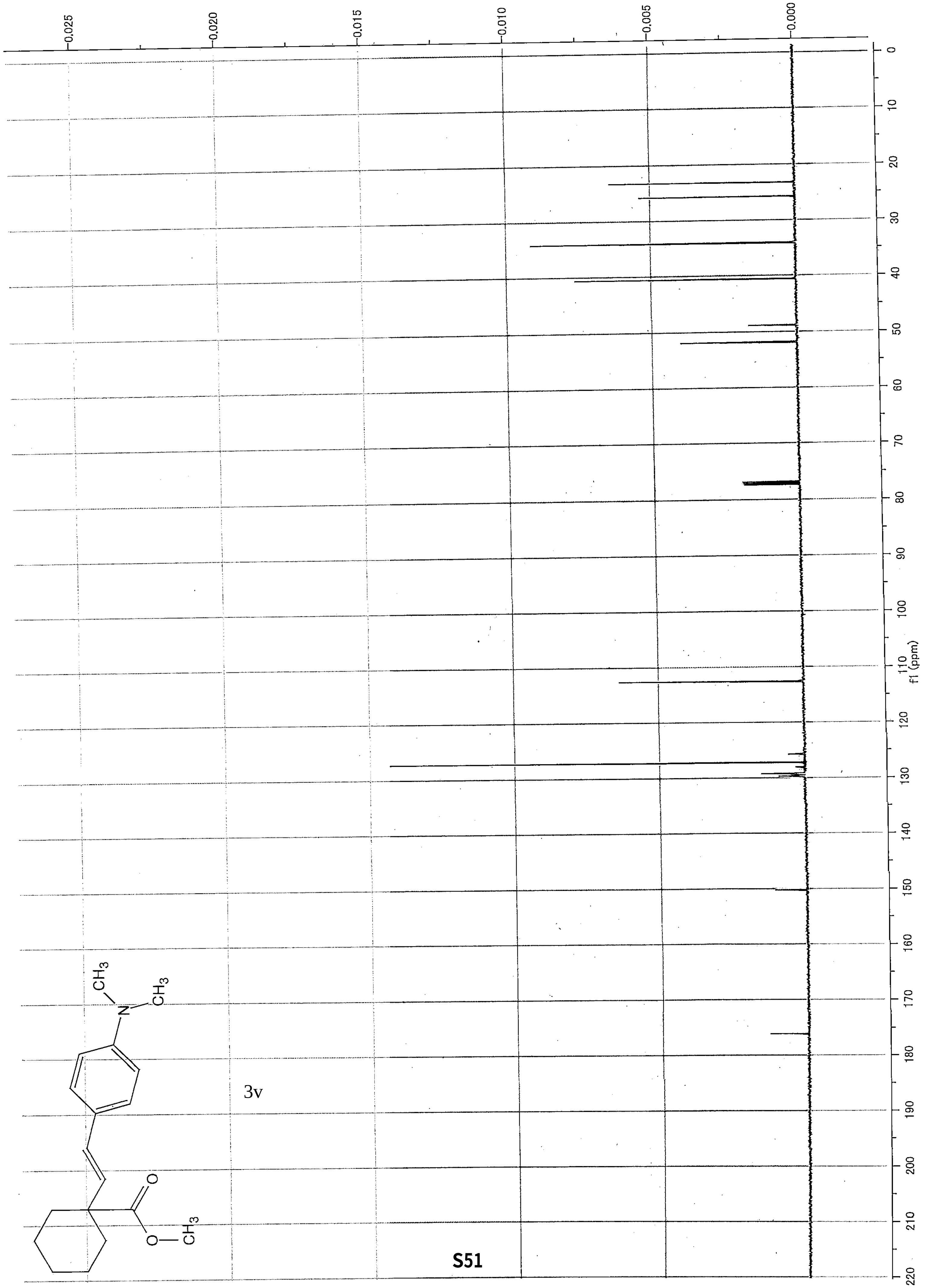
f1 (ppm)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100
110
120
130
140
150
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190
200
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220
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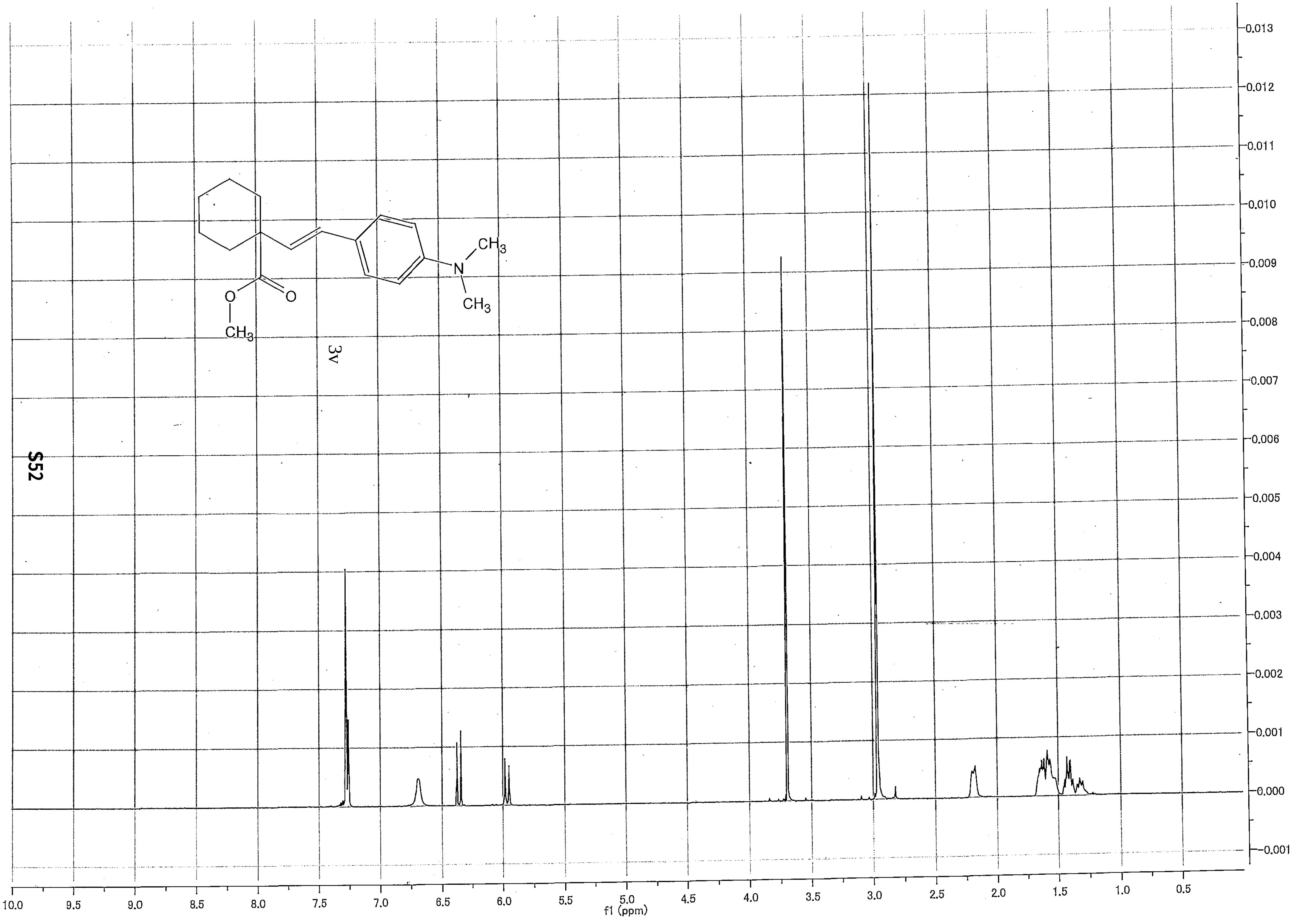
CH_3
O
O
CH_3
3v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CH3
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O
CH3
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0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-0.001
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
f1 (ppm)
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3.5
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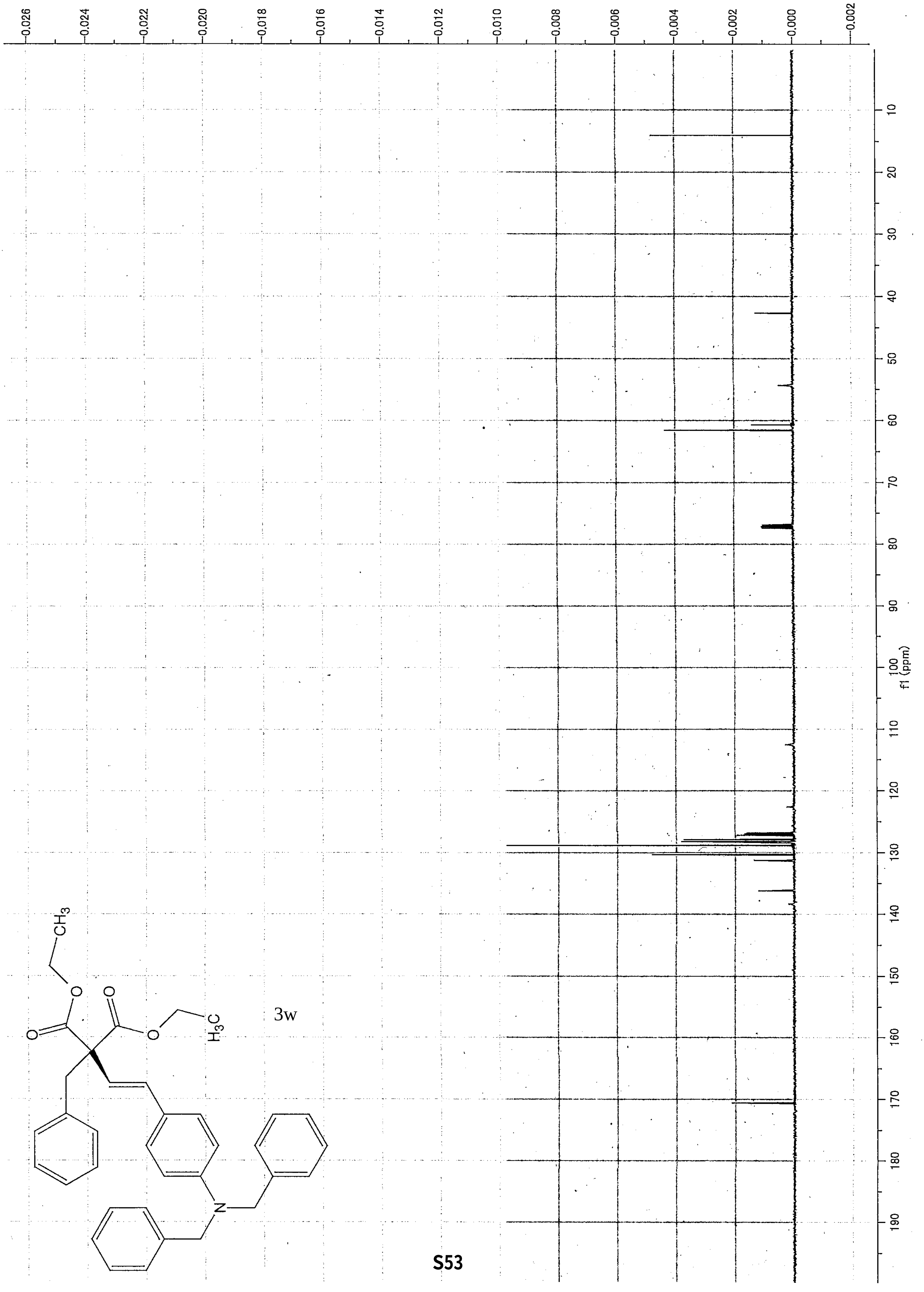
2.0
1.5
1.0
0.5

3v


3w
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20
30
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50
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70
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90
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170
180
190
0.026
0.024
0.022
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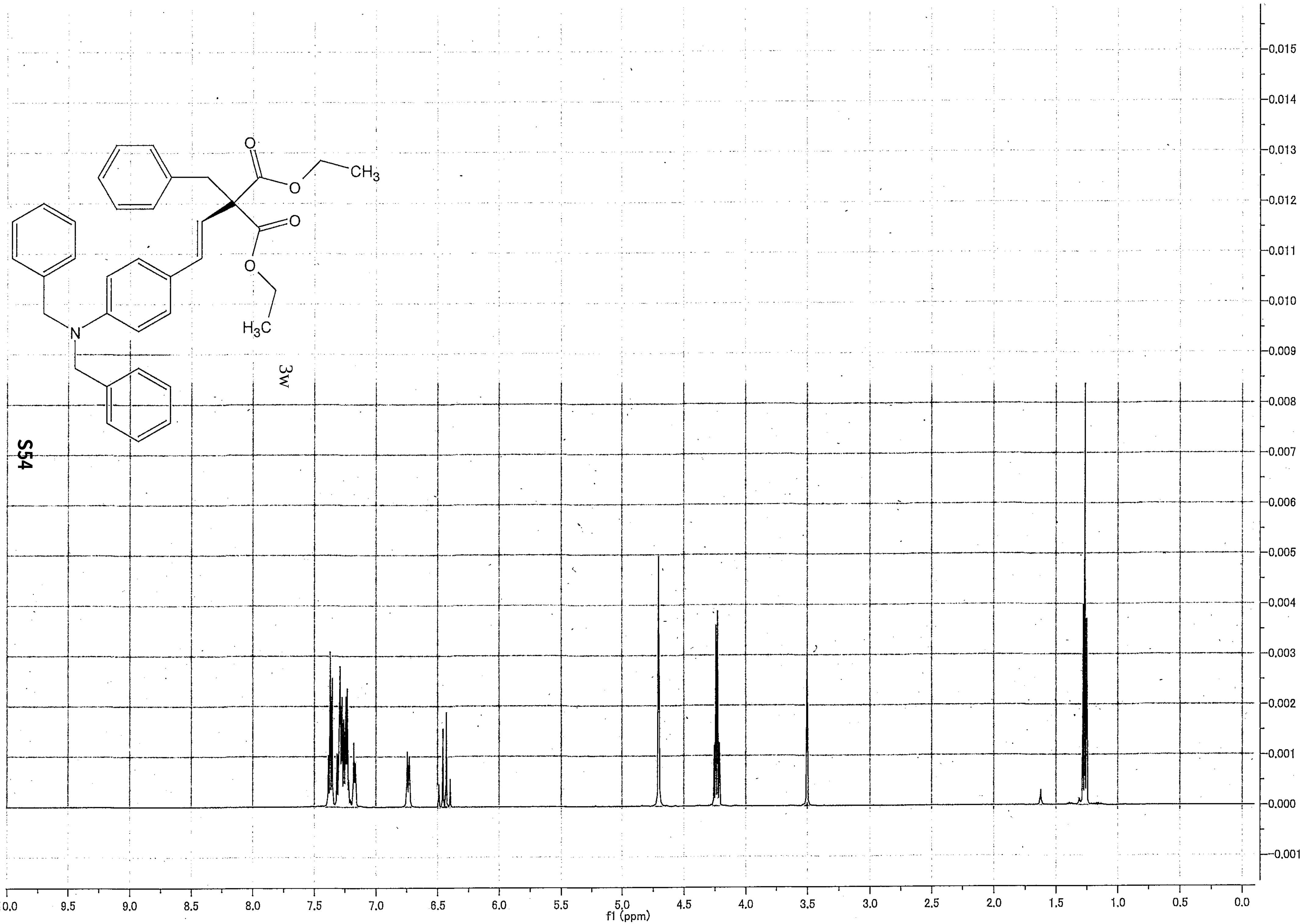
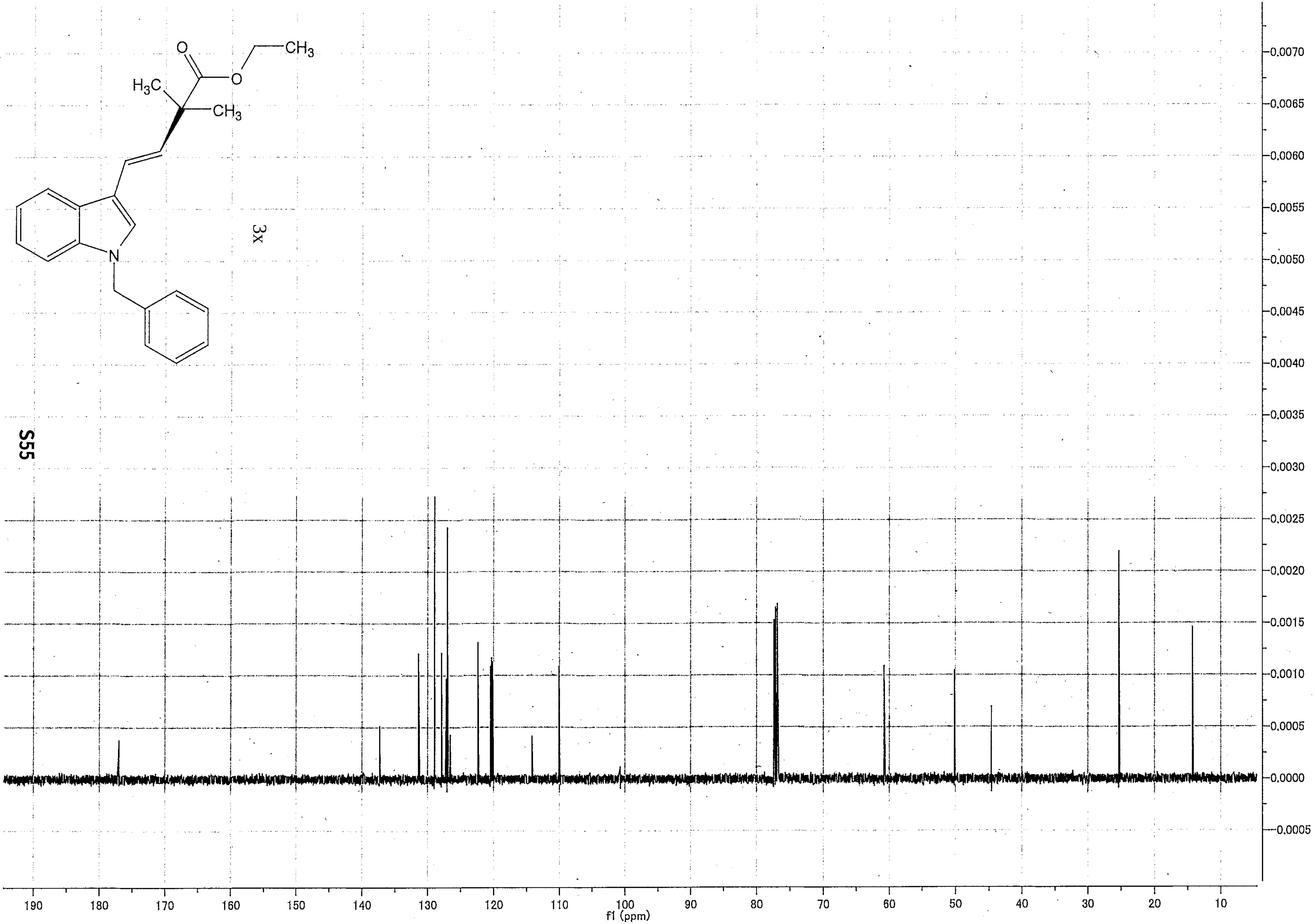
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002



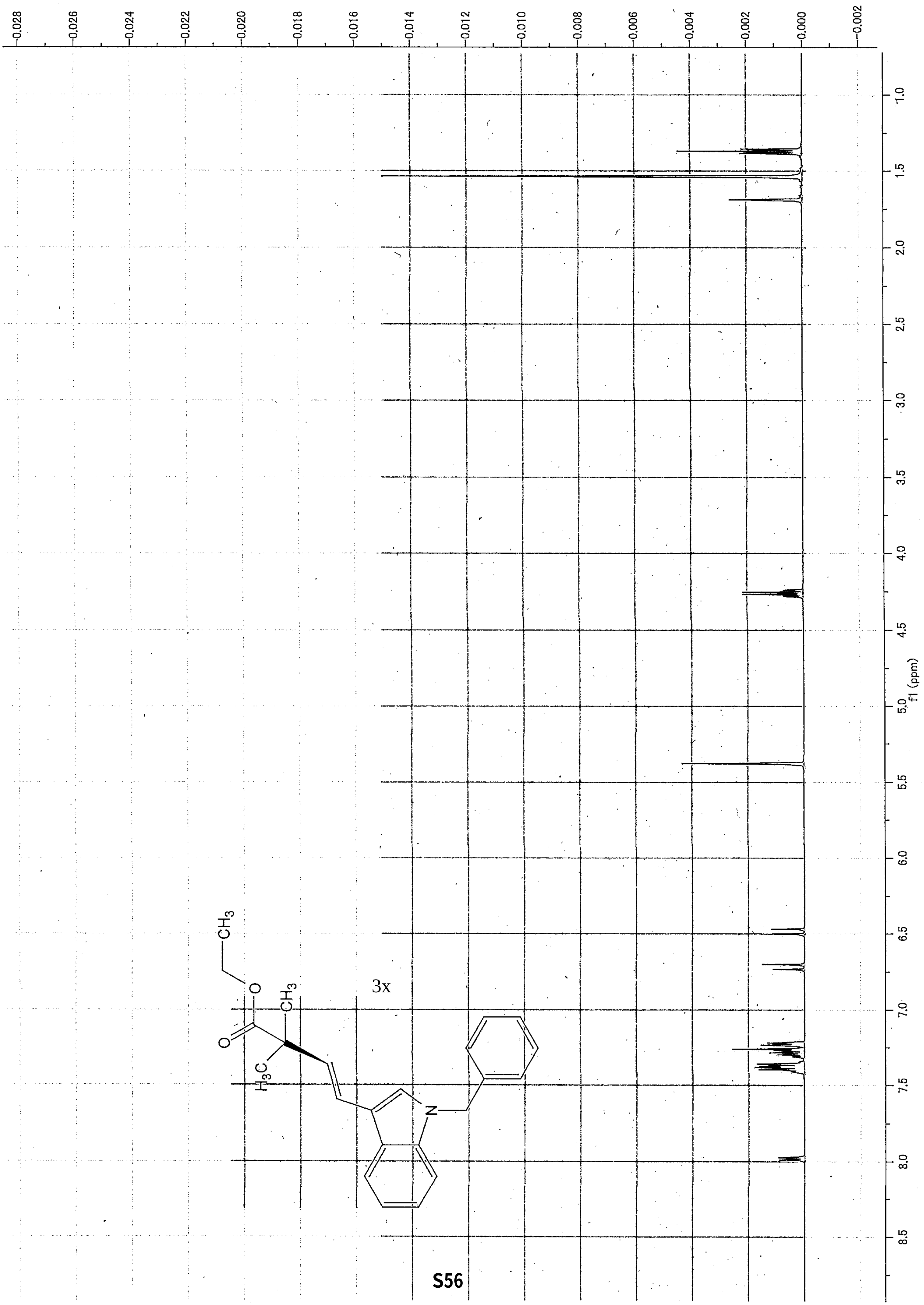
CH3
O
O
O
O
H3C
N
-0.015
-0.014
-0.013
-0.012
-0.011
-0.010
-0.009
-0.008
-0.007
-0.006
-0.005
-0.004
-0.003
-0.002
-0.001
-0.000
--0.001
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

3w

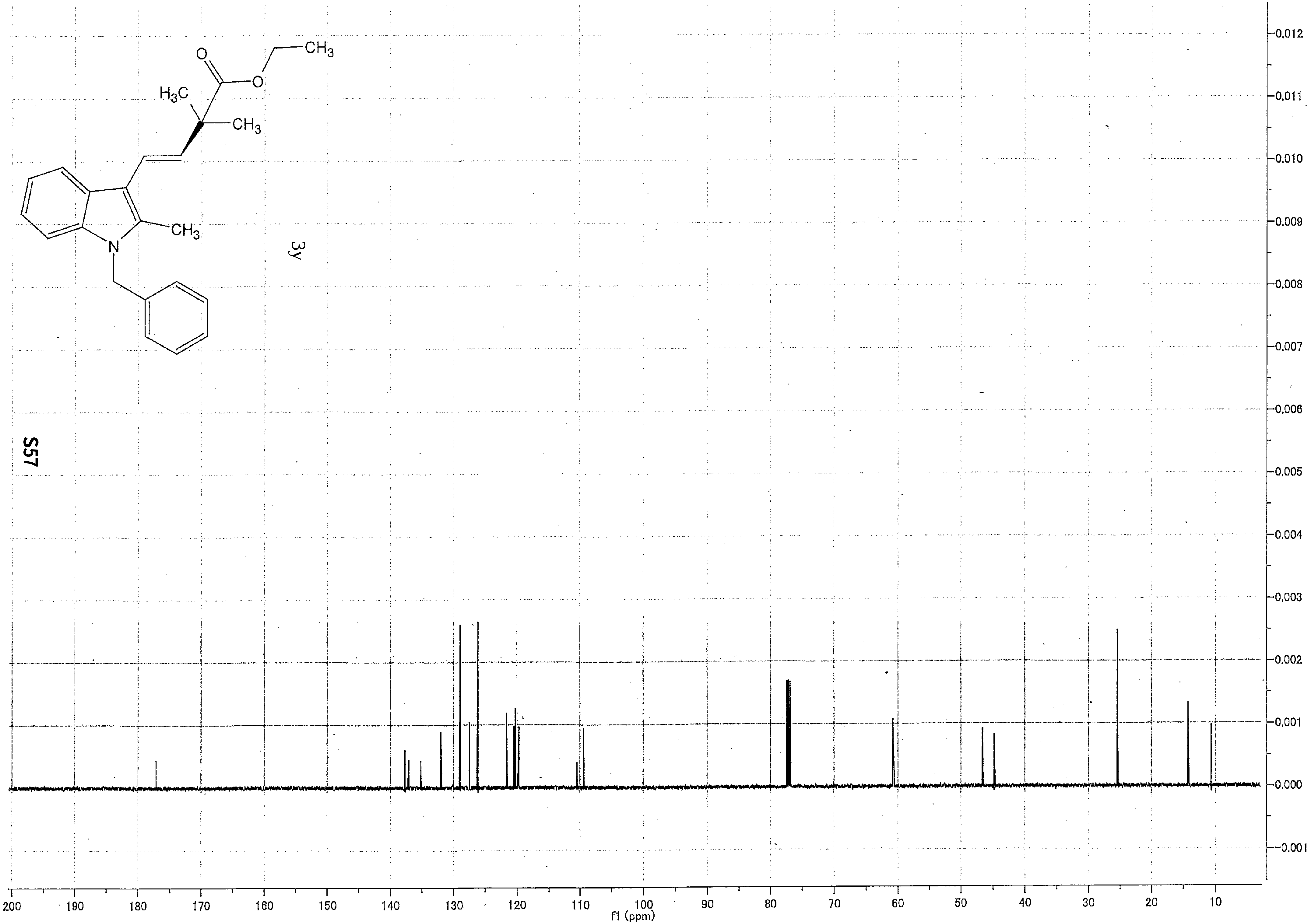


CH3
O
O
H3C
CH3
N
-0.0070
-0.0065
-0.0060
-0.0055
-0.0050
-0.0045
-0.0040
-0.0035
-0.0030
-0.0025
-0.0020
-0.0015
-0.0010
-0.0005
-0.0000
--0.0005
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

3x

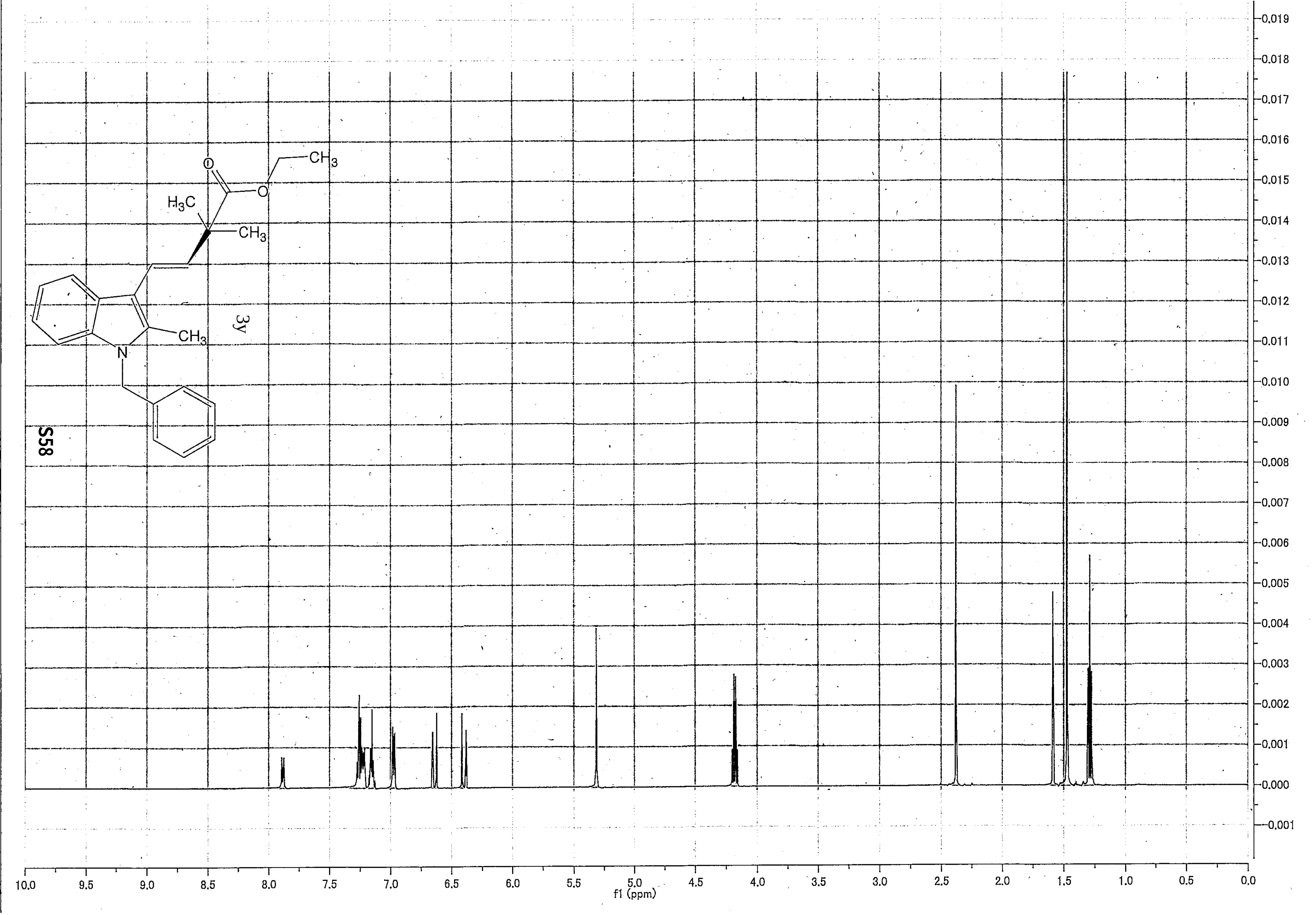


3x
f1 (ppm)

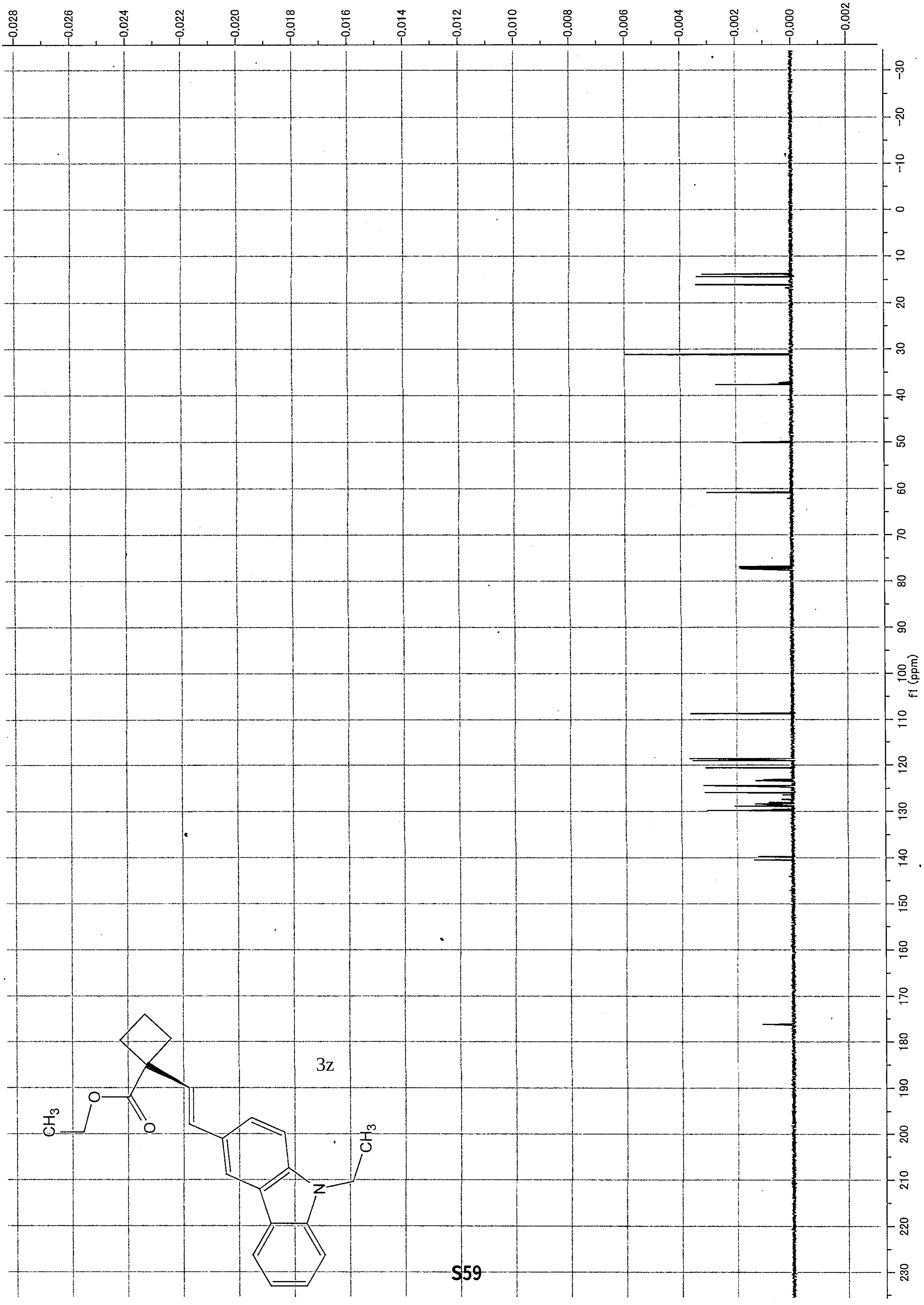


O
O
CH3
H3C
CH3
CH3
N
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-0.001
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

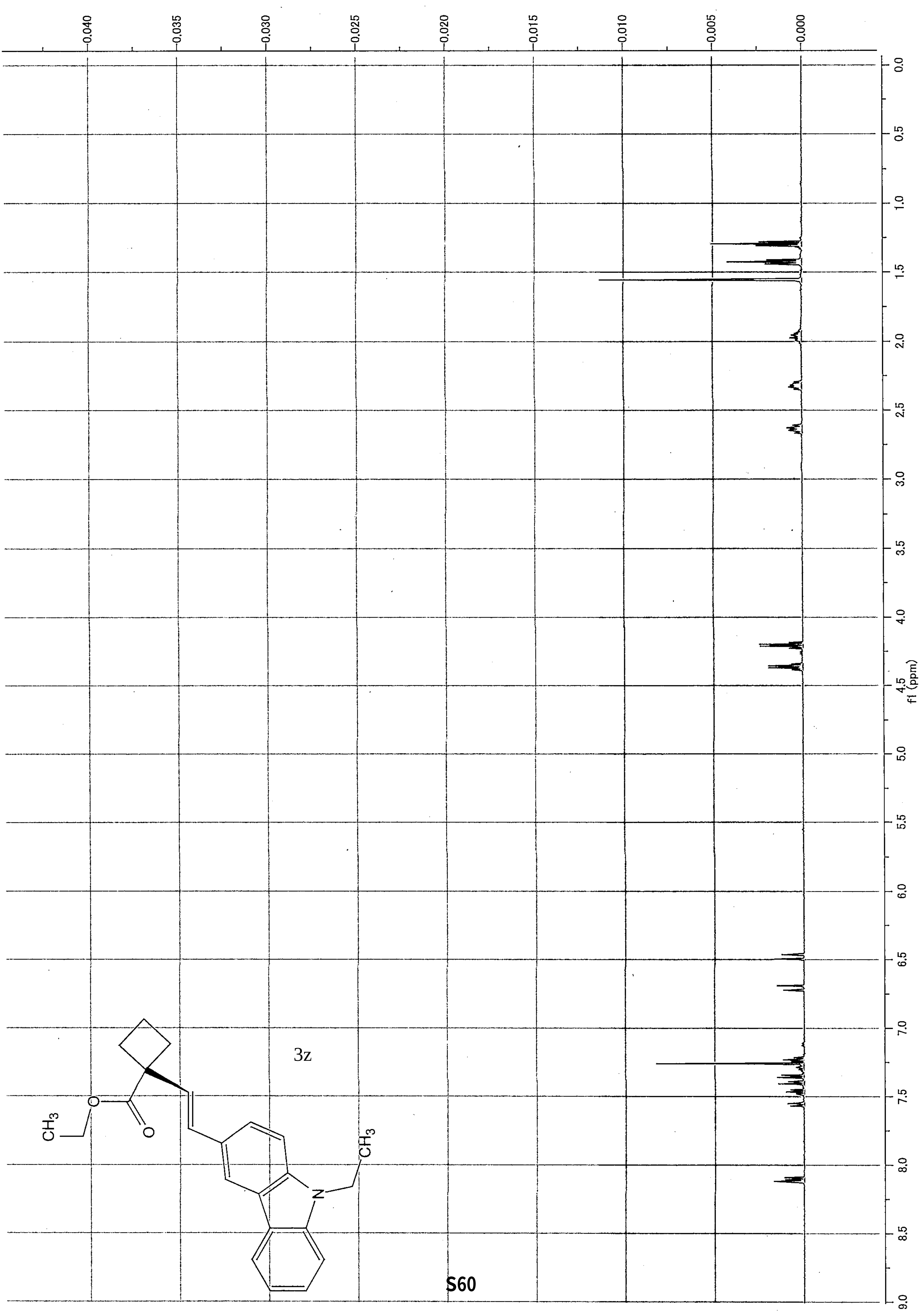
3y

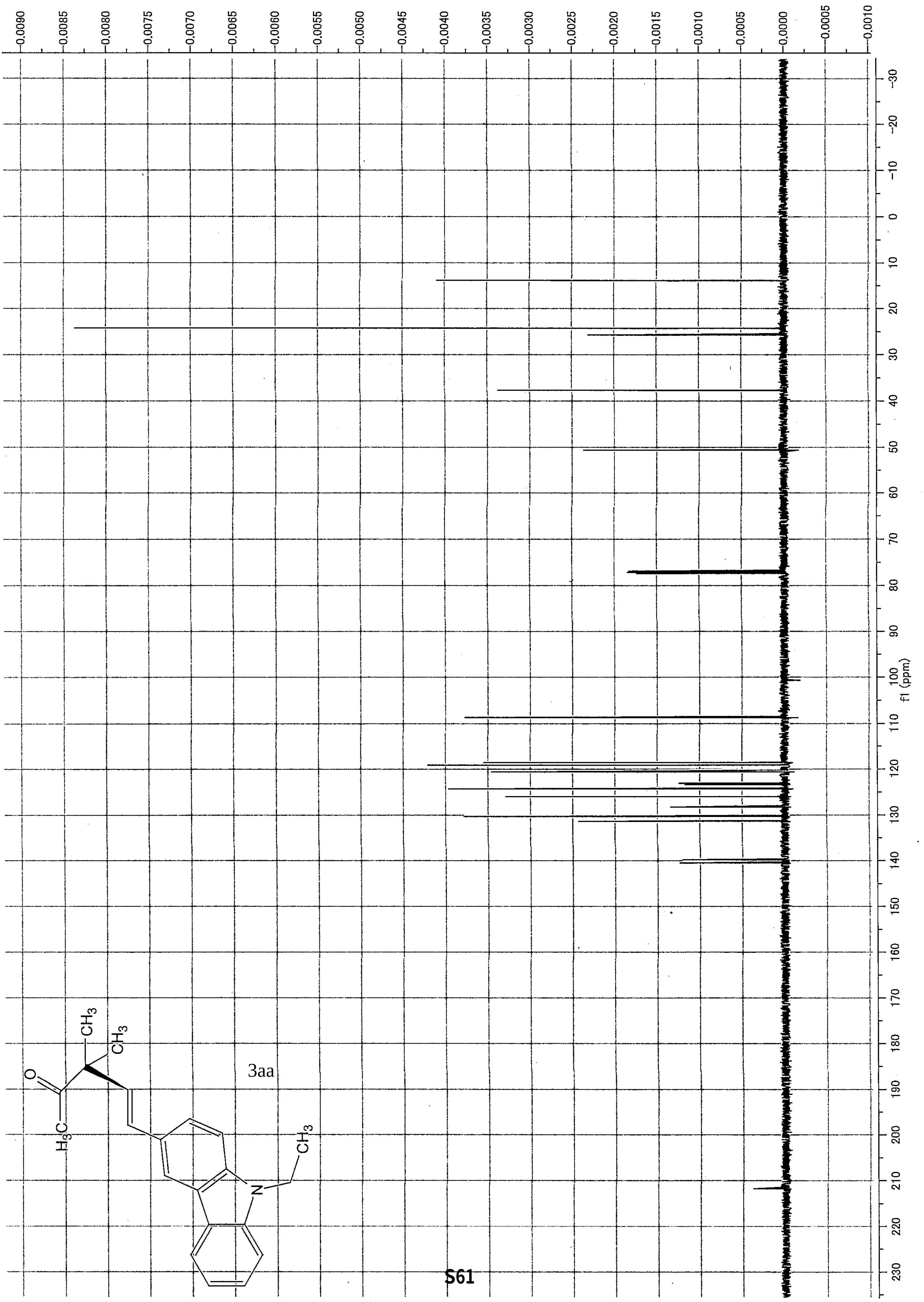


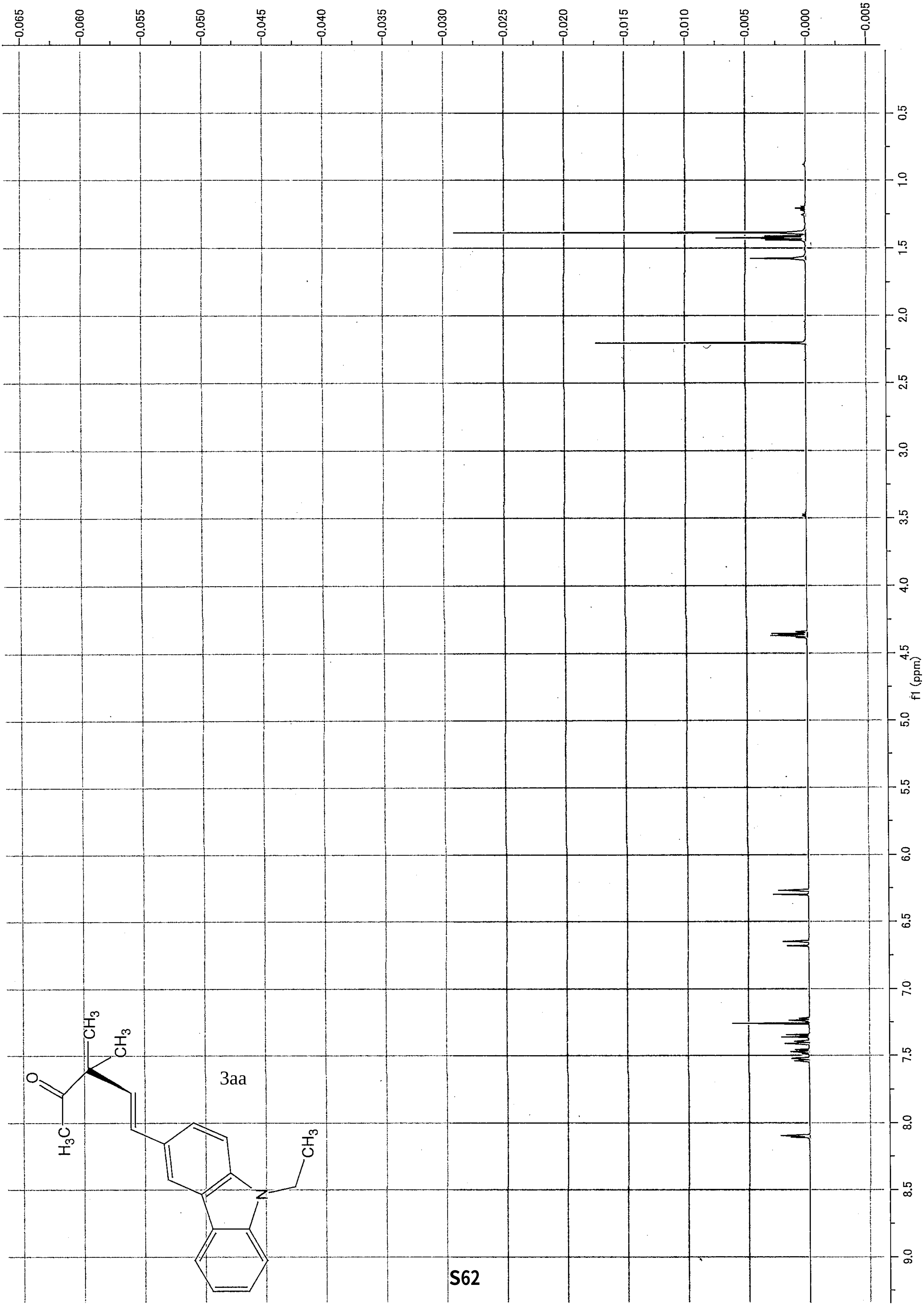
H3C
CH3
O
O
CH3
CH3
N
3y
S58
f1 (ppm)

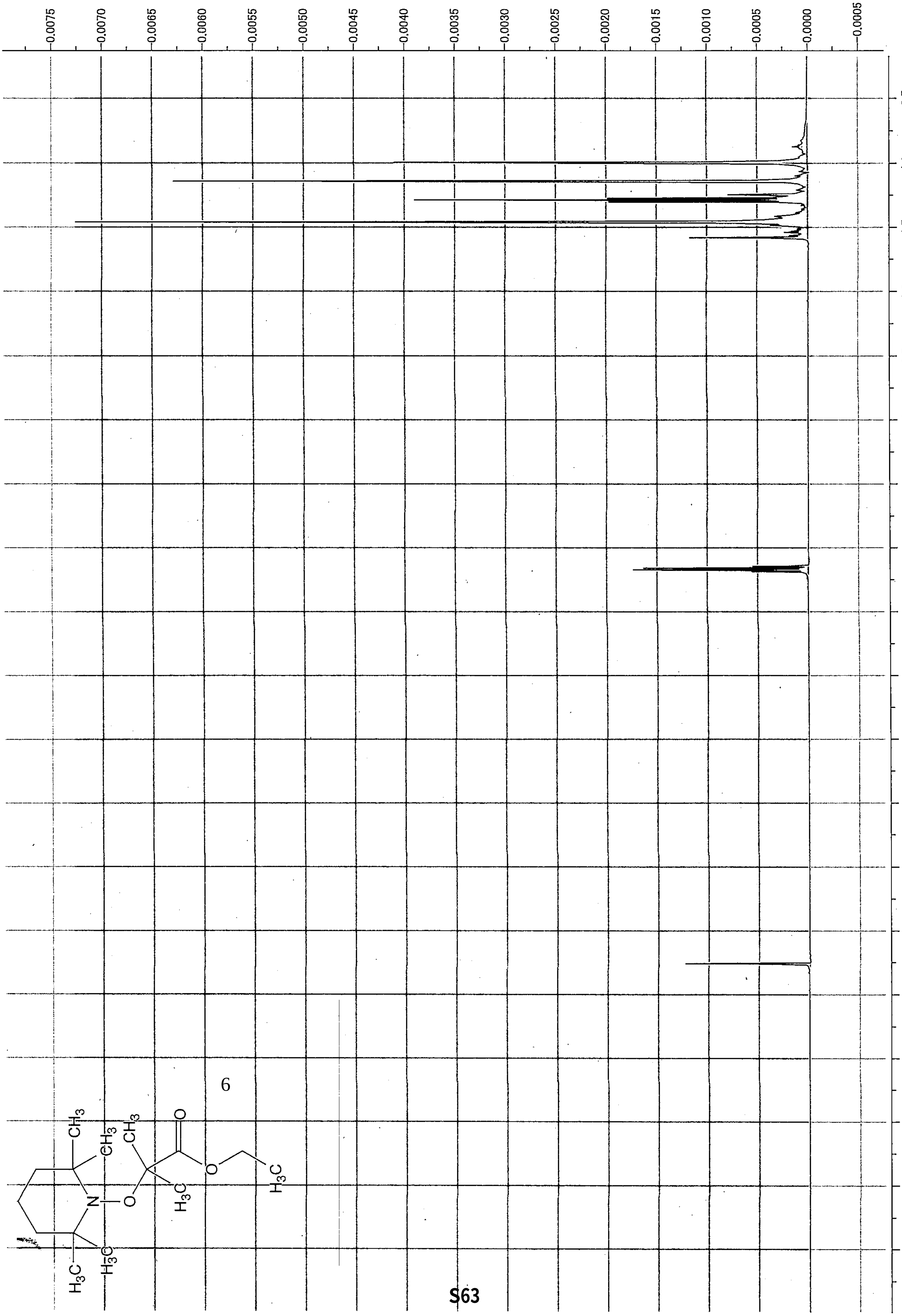


3z


3z
f1 (ppm)
CH3
O
N
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0

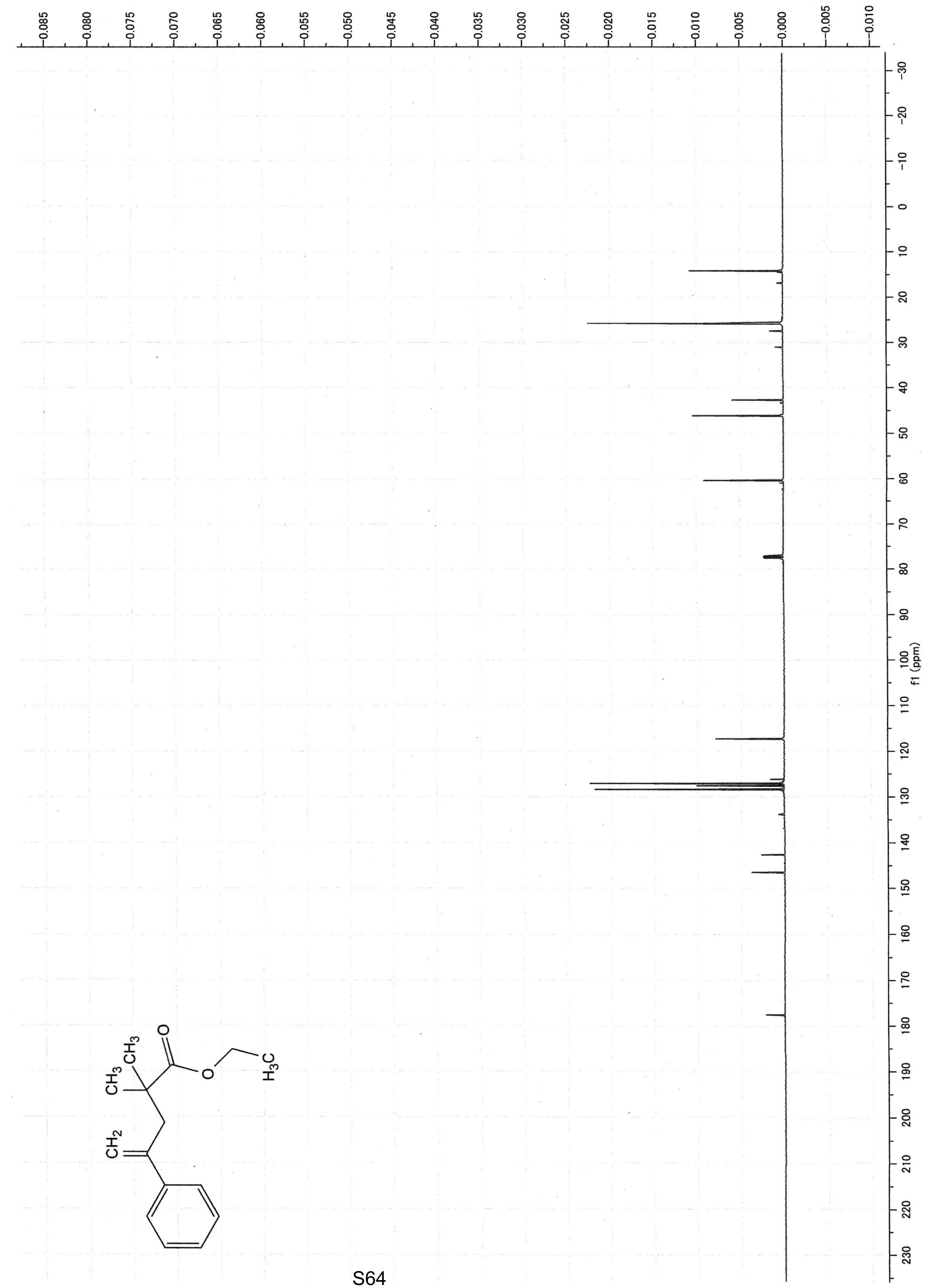

3aa
f1 (ppm)


f1 (ppm)
3aa

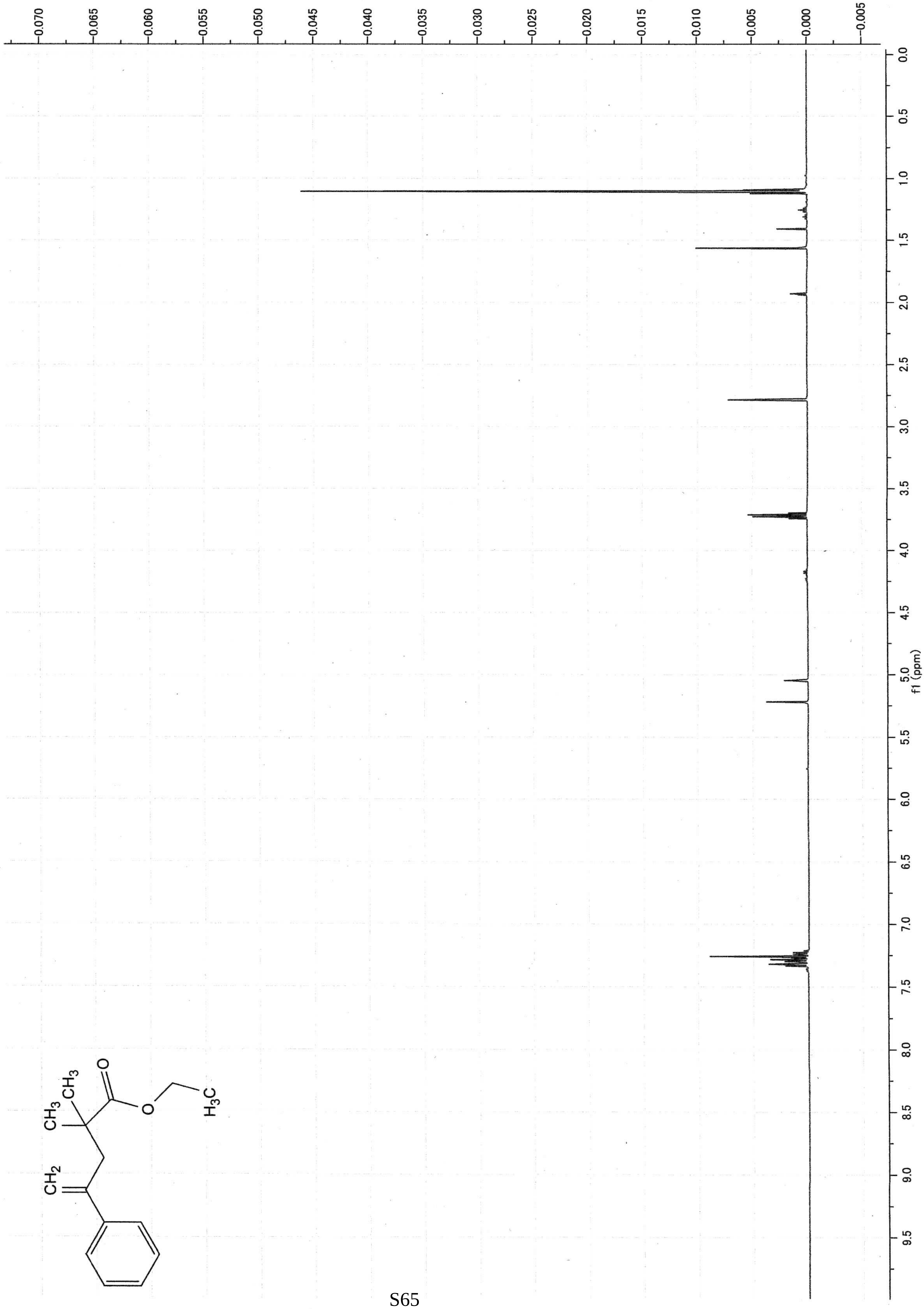


f1 (ppm)
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
0.0075 0.0070 0.0065 0.0060 0.0055 0.0050 0.0045 0.0040 0.0035 0.0030 0.0025 0.0020 0.0015 0.0010 0.0005 0.0000 -0.0005

6



f1 (ppm)
CH2
CH3
CH3
O
O
H3C


f1 (ppm)
CH2
CH3
CH3
O
O
H3C