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Synergistic Palladium/Copper-Catalyzed Csp^3–Csp^2 Cross-Couplings Using Aldehydes as Latent α-Alkoxyalkyl Anion Equivalents

Mitsutaka Takeda, Kenya Yabushita, Shigeo Yasuda, and Hirohisa Ohmiya*

Division of Pharmaceutical Sciences, Graduate School of Medical Sciences, Kanazawa University,
Kakuma-machi, Kanazawa 920-1192, Japan
*E-mail: ohmiya@p.kanazawa-u.ac.jp

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Instrumentation and Chemicals

NMR spectra were recorded on a JNM-ECS400, operating at 400 MHz for ^{1}H NMR and 100.5 MHz for ^{13}C NMR, and JNM-ECA600, operating at 600 MHz for ^{1}H NMR and 150.9 MHz for ^{13}C NMR. Chemical shift values for ^{1}H and ^{13}C are referenced to Me_4Si and the residual solvent resonances, respectively. Chemical shifts are reported in δ ppm. Mass spectra were obtained with JMS-T100TD (DART). TLC analyses were performed on commercial glass plates bearing 0.25-mm layer of Merck Silica gel 60F$_{254}$. Silica gel (Kanto Chemical Co., Silica gel 60 N, spherical, neutral) and aluminum oxide (Nacalai Tesuque, Alumina Activated 200) were used for column chromatography. IR spectra were measured with a Thermo Scientific iD7 ATR Accessory for the Thermo Scientific Nicolet iS5 FT-IR Spectrometer. Gel permeation chromatography (GPC) was performed by LaboACE LC-5060 (Japan Analytical Industry Ltd., two in-line JAIGEL-HR, ethyl acetate, 10 mL/min, UV and RI detectors).

All reactions were carried out under nitrogen atmosphere. Materials were obtained from commercial suppliers or prepared according to standard procedures unless otherwise noted. Pd(acac)$_2$ was purchased from Wako Pure Chemical Industries, stored under nitrogen, and used as received. Toluene was purchased from Wako Pure Chemical Indusrries, stored under nitrogen, and used as received. PhMe$_2$SiB(pin) was purchased from Tokyo Chemical Industry Co., stored under nitrogen, and used as received. NaO*t*Bu, KO*t*Bu, LiO*t*Bu, NaOMe and Na_2CO_3 were purchased from Tokyo Chemical Industry Co., stored under nitrogen, and used as received. DPPF and Xphos were purchased from Kanto Chemical Co., stored under nitrogen, and used as received. Xantphos, DPPE and PPh$_3$ were purchased from Tokyo Chemical Industry Co., stored under nitrogen, and used as received. BINAP and PCy$_3$ were purchased from Sigma-Aldrich Co., stored under nitrogen, and used as received. (IPr)CuCl, (SIPr)CuCl, (IMes)CuCl and (SIMes)CuCl are found in the literature.[1]

Aldehydes **1a**–**1g** and aryl bromides **2a**–**2h**, **2l**–**2p** were purchased from commercial suppliers unless otherwise noted. 1-(Benzyloxy)-3-bromobenzene (**2i**),[2] 2-(3-bromophenoxy)tetrahydro-2*H*-pyran (**2j**)[3] and 3-bromophenyl pivalate (**2k**)[4] were prepared according to the literatures.

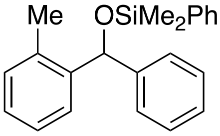
Procedure for Palladium/Copper-Catalyzed Csp^3–Csp^2 Cross-Coupling

The reaction in Table 1, entry 1 is representative. (IPr)CuCl (24.4 mg, 0.05 mmol) and NaO*t*Bu (4.8 mg, 0.05 mmol) were placed in a vial containing a magnetic stirring bar. The vial was sealed with a Teflon®-coated silicon rubber septum, and then the vial was evacuated and filled with nitrogen. Toluene (0.4 mL) was added to the vial, and then the mixture was stirred at 25 °C for 10 min. Next, $PhMe_2SiB(pin)$ (78.7 mg, 0.3 mmol) and *o*-tolualdehyde (**1a**) (36.0 mg, 0.3 mmol) were added, and the mixture (**mixture A**) was stirred at 25 °C for 40 min. Meanwhile, $Pd(acac)_2$ (3.0 mg, 0.01 mmol) and DPPF (11.1 mg, 0.02 mmol) were placed in another vial. This vial was sealed with a Teflon®-coated silicon rubber septum and then evacuated and filled with nitrogen. After toluene (0.6 mL) was added to the vial, the mixture was stirred at 25 °C for 10 min. Next, bromobenzene (**2a**) (31.4 mg, 0.2 mmol) was added to the vial, and the mixture (**mixture B**) was stirred at 25 °C for 15 min. The palladium solution (**mixture B**) was transferred to the vial (**mixture A**) containing the copper complex. Finally, NaO*t*Bu (4.8 mg × 3, total: 0.15 mmol) was added portionwise (3 times) at intervals of 1 min. After 3 h stirring at 80 °C, the reaction mixture was diluted with diethyl ether (1 mL). The reaction mixture was filtered through a short plug of aluminum oxide (1 g) with diethyl ether as an eluent. After volatiles were removed under reduced pressure, flash column chromatography on silica gel (hexane) gave **3aa** (46.3 mg, 0.14 mmol) in 70% yield.

A gram scale reaction. (IPr)CuCl (488 mg, 1 mmol) and NaO*t*Bu (96.1 mg, 1 mmol) were placed in a vial containing a magnetic stirring bar. The vial was sealed with a Teflon®-coated silicon rubber septum, and then the vial was evacuated and filled with nitrogen. Toluene (8 mL) was added to the vial, and then the mixture was stirred at 25 °C for 10 min. Next, $PhMe_2SiB(pin)$ (1.57 g, 6 mmol) and *o*-tolualdehyde (**1a**) (721 mg, 6 mmol) were added, and the mixture (**mixture A**) was stirred at 25 °C for 40 min. Meanwhile, $Pd(acac)_2$ (60.9 mg, 0.2 mmol) and DPPF (222 mg, 0.4 mmol) were placed in another vial. This vial was sealed with a Teflon®-coated silicon rubber septum and then evacuated and filled with nitrogen. After toluene (12 mL) was added to the vial, the mixture was stirred at 25 °C for 10 min. Next, 9-bromophenanthrene (**2m**) (1.03 g, 4 mmol) was added to the vial, and the mixture (**mixture B**) was stirred at 25 °C for 15 min. The palladium solution (**mixture B**) was transferred to the vial (**mixture A**) containing the copper complex. Finally, NaO*t*Bu (32.0 mg × 9, total: 3 mmol) was added portionwise (9 times) at intervals of 1 min. After 3 h stirring at 80 °C, the reaction mixture was diluted with diethyl ether (10 mL). The reaction mixture was filtered through a short plug of aluminum oxide (20 g) with diethyl ether as an eluent. After volatiles were removed under reduced pressure, flash column chromatography on silica gel (hexane) gave **3am** (1.33 g, 3.1 mmol) in 77% yield.

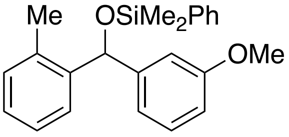
Characterization Data for Diarylmethyl Silyl Ethers

Dimethyl(phenyl)[phenyl(*o*-tolyl)methoxy]silane (3aa)



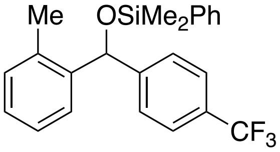
Colorless Oil. IR (neat) 783, 826, 872, 1028, 1057, 1115, 1251 cm^{-1}. ^{1}H NMR (600 MHz, CDCl$_3$) δ 0.26 (s, 3H), 0.29 (s, 3H), 2.07 (s, 3H), 5.87 (s, 1H), 7.04 (d, J = 7.8 Hz, 1H), 7.14–7.25 (m, 7H), 7.31–7.34 (m, 2H), 7.38 (m, 1H), 7.50–7.51 (m, 2H), 7.55 (m, 1H). ^{13}C NMR (150.9 MHz, CDCl$_3$) δ –1.2, –1.1, 19.4, 74.4, 125.8, 126.9, 127.0, 127.1, 127.3, 127.7, 128.1, 129.5, 130.4, 133.6, 134.9, 137.7, 142.1, 143.6. HRMS–DART (*m/z*): [M–H]$^+$ calcd for C$_{22}$H$_{23}$OSi; 331.1518, found 331.1517.

[(3-Methoxyphenyl)(*o*-tolyl)methoxy]dimethyl(phenyl)silane (3ab)



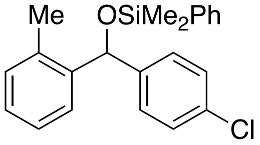
The reaction of *o*-tolualdehyde (**1a**) and 3-bromoanisole (**2b**) with PhMe$_2$SiB(pin) afforded **3ab** in 80% yield. **3ab** was purified by flash chromatography on silica gel (2% EtOAc/hexane). Colorless Oil. IR (neat) 741, 830, 875, 1047, 1116, 1252, 1487, 1599 cm^{-1}. ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.26 (s, 3H), 0.30 (s, 3H), 2.08 (s, 3H), 3.72 (s, 3H), 5.84 (s, 1H), 6.71–6.82 (m, 3H), 7.04 (d, J = 7.2 Hz, 1H), 7.12–7.25 (m, 3H), 7.30–7.40 (m, 3H), 7.50–7.53 (m, 3H). ^{13}C NMR (100.5 MHz, CDCl$_3$) δ –1.3, –1.0, 19.4, 55.1, 74.3, 112.2, 112.7, 119.4, 125.8, 127.2, 127.3, 127.7, 129.0, 129.6, 130.4, 133.6, 134.9, 137.6, 141.9, 145.3, 159.4. HRMS–DART (*m/z*): [M]$^+$ calcd for C$_{23}$H$_{26}$O$_2$Si; 362.1702, found 362.1701.

Dimethyl(phenyl){*o*-tolyl[4-(trifluoromethyl)phenyl]methoxy}silane (3ac)



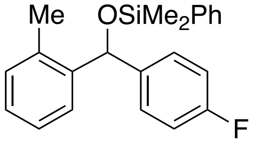
The reaction of *o*-tolualdehyde (**1a**) and 4-bromobenzotrifluoride (**2c**) with PhMe$_2$SiB(pin) afforded **3ac** in 82% yield. **3ac** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 787, 830, 874, 1067, 1118, 1164, 1254, 1325 cm^{-1}. ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.28 (s, 3H), 0.32 (s, 3H), 2.07 (s, 3H), 5.88 (s, 1H), 7.06 (d, J = 7.2 Hz, 1H), 7.15–7.23 (m, 2H), 7.31–7.41 (m, 5H), 7.46–7.50 (m, 5H). ^{13}C NMR (100.5 MHz, CDCl$_3$) δ –1.4, –1.1, 19.4, 74.0, 124.2 (q, $J_{\text{C–F}}$ = 270.3 Hz), 125.1 (q, $J_{\text{C–F}}$ = 4.2 Hz), 126.0, 127.0, 127.5, 127.6, 127.8, 129.1 (q, $J_{\text{C–F}}$ = 31.8 Hz), 129.8, 130.7, 133.5, 134.9, 137.2, 141.3, 147.8. HRMS–DART (*m/z*): [M–H]$^+$ calcd for C$_{23}$H$_{22}$F$_3$OSi; 399.1392, found 399.1392.

[(4-Chlorophenyl)(*o*-tolyl)methoxy]dimethyl(phenyl)silane (3ad)



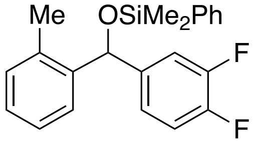
The reaction of *o*-tolualdehyde (**1a**) and 1-bromo-4-chlorobenzene (**2d**) with $PhMe_2SiB(pin)$ afforded **3ad** in 73% yield. **3ad** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 750, 856, 874, 1014, 1063, 1116, 1252, 1488 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.26 (s, 3H), 0.30 (s, 3H), 2.05 (s, 3H), 5.81 (s, 1H), 7.05 (d, J = 7.2 Hz, 1H), 7.13–7.24 (m, 6H), 7.31–7.41 (m, 3H), 7.47–7.51 (m, 3H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ –1.4, –1.1, 19.4, 73.9, 125.9, 127.2, 127.4, 127.8, 128.2, 128.3, 129.7, 130.5, 132.6, 133.6, 134.8, 137.4, 141.6, 142.2. HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{22}H_{22}ClOSi$; 365.1128, found 365.1127.

[(4-Fluorophenyl)(*o*-tolyl)methoxy]dimethyl(phenyl)silane (3ae)



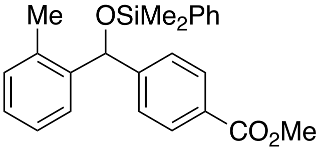
The reaction of *o*-tolualdehyde (**1a**) and 1-bromo-4-fluorobenzene (**2e**) with $PhMe_2SiB(pin)$ afforded **3ae** in 75% yield. **3ae** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 743, 785, 830, 875, 1066, 1116, 1252, 1507 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.26 (s, 3H), 0.30 (s, 3H), 2.04 (s, 3H), 5.83 (s, 1H), 6.90–6.94 (m, 2H), 7.05 (d, J = 7.2 Hz, 1H), 7.14–7.18 (m, 3H), 7.21 (t, J = 7.2 Hz, 1H), 7.32–7.34 (m, 2H), 7.38 (m, 1H), 7.48–7.50 (m, 2H), 7.54 (d, J = 6.6 Hz, 1H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ –1.3, –1.1, 19.3, 73.8, 114.9 (d, $J_{C–F}$ = 21.6 Hz), 125.9, 127.1, 127.3, 127.8, 128.6 (d, $J_{C–F}$ = 8.6 Hz), 129.6, 130.5, 133.6, 134.8, 137.5, 139.4 (d, $J_{C–F}$ = 2.8 Hz), 141.9, 161.8 (d, $J_{C–F}$ = 245.6 Hz). HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{22}H_{22}FOSi$; 349.1423, found 349.1423.

[(3,4-Difluorophenyl)(*o*-tolyl)methoxy]dimethyl(phenyl)silane (3af)



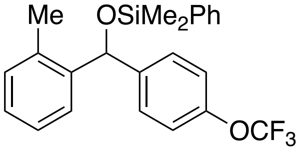
The reaction of *o*-tolualdehyde (**1a**) and 1-bromo-3,4-difluorobenzene (**2f**) with $PhMe_2SiB(pin)$ afforded **3af** in 66% yield. **3af** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 785, 827, 1064, 1110, 1252, 1279, 1427, 1513 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.27 (s, 3H), 0.31 (s, 3H), 2.05 (s, 3H), 5.78 (s, 1H), 6.88 (m, 1H), 6.97–7.06 (m, 3H), 7.15–7.22 (m, 2H), 7.32–7.34 (m, 2H), 7.38 (m, 1H), 7.46–7.49 (m, 3H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ –1.5, –1.1, 19.3, 73.5, 115.8 (d, $J_{C–F}$ = 18.0 Hz), 116.7 (d, $J_{C–F}$ = 18.0 Hz), 122.6 (dd, $J_{C–F}$ = 3.0, 7.2 Hz), 126.0, 127.3, 127.6, 127.8, 129.8, 130.6, 133.5, 134.9, 137.1, 141.0 (dd, $J_{C–F}$ = 4.2, 4.2 Hz), 141.2, 149.3 (dd, $J_{C–F}$ = 13.2, 250.2 Hz), 150.1 (dd, $J_{C–F}$ = 13.2, 250.2 Hz). HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{22}H_{21}F_2OSi$; 367.1329, found 367.1327.

Methyl 4-{[(Dimethyl(phenyl)silyl)oxy](*o*-tolyl)methyl}benzoate (3ag)



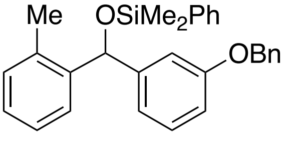
The reaction of *o*-tolualdehyde (**1a**) and methyl 4-bromobenzoate (**2g**) with $PhMe_2SiB$(pin) afforded **3ag** in 64% yield. **3ag** was purified by flash chromatography on silica gel (1% EtOAc/hexane). Colorless Oil. IR (neat) 748, 786, 830, 1068, 1114, 1253, 1277, 1722 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.27 (s, 3H), 0.30 (s, 3H), 2.06 (s, 3H), 3.88 (s, 3H), 5.88 (s, 1H), 7.05 (d, J = 7.2 Hz, 1H), 7.15–7.21 (m, 2H), 7.30–7.34 (m, 4H), 7.38 (m, 1H), 7.47–7.50 (m, 3H), 7.92 (d, J = 8.2 Hz, 2H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ –1.4, –1.1, 19.4, 52.0, 74.3, 126.0, 126.7, 127.5, 127.6, 127.8, 128.7, 129.5, 129.7, 130.6, 133.5, 135.0, 137.3, 141.4, 148.9, 167.0. HRMS–DART (*m*/*z*): $[M+H]^+$ calcd for $C_{24}H_{27}O_3Si$; 391.1729, found 391.1731.

Dimethyl(phenyl){*o*-tolyl[4-(trifluoromethoxy)phenyl]methoxy}silane (3ah)



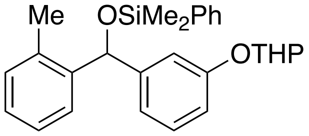
The reaction of *o*-tolualdehyde (**1a**) and 1-bromo-4-(trifluoromethoxy)benzene (**2h**) with $PhMe_2SiB$(pin) afforded **3ah** in 70% yield. **3ah** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 785, 830, 1065, 1116, 1164, 1221, 1254, 1506 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.27 (s, 3H), 0.31 (s, 3H), 2.05 (s, 3H), 5.85 (s, 1H), 7.05–7.08 (m, 3H), 7.15–7.23 (m, 4H), 7.31–7.34 (m, 2H), 7.38 (m, 1H), 7.48–7.51 (m, 3H). ^{13}C NMR (100.5 MHz, $CDCl_3$) δ –1.4, –1.1, 19.4, 73.8, 120.4 (q, J_{C-F} = 256.8 Hz), 120.5, 126.0, 127.3, 127.4, 127.8, 128.2, 130.0, 130.5, 133.6, 134.8, 137.3, 141.6, 142.4, 148.1 (q, J_{C-F} = 2.0 Hz). HRMS–DART (*m*/*z*): $[M-H]^+$ calcd for $C_{23}H_{22}F_3O_2Si$; 415.1341, found 415.1339.

{[3-(Benzyloxy)phenyl](*o*-tolyl)methoxy}dimethyl(phenyl)silane (3ai)



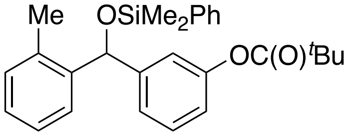
The reaction of *o*-tolualdehyde (**1a**) and 1-(benzyloxy)-3-bromobenzene (**2i**) with $PhMe_2SiB$(pin) afforded **3ai** in 66% yield. **3ai** was purified by flash chromatography on silica gel (1% EtOAc/hexane). Colorless Oil. IR (neat) 784, 829, 874, 1046, 1116, 1251, 1486, 1598 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.25 (s, 3H), 0.29 (s, 3H), 2.05 (s, 3H), 4.96 (s, 2H), 5.83 (s, 1H), 6.78–6.81 (m, 2H), 6.88 (s, 1H), 7.04 (d, J = 7.2 Hz, 1H), 7.13–7.21 (m, 3H), 7.29–7.39 (m, 8H), 7.49–7.52 (m, 3H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ –1.3, –1.0, 19.4, 69.9, 74.3, 113.3, 113.6, 119.6, 125.9, 127.2, 127.3, 127.5, 127.7, 127.9, 128.5, 129.1, 129.6, 130.4, 133.6, 134.9, 137.0, 137.7, 141.9, 145.3, 158.6. HRMS–DART (*m*/*z*): $[M]^+$ calcd for $C_{29}H_{30}O_2Si$; 438.2015, found 438.2013.

Dimethyl(phenyl){(3-[(tetrahydro-2*H*-pyran-2-yl)oxy]phenyl)(*o*-tolyl)methoxy}silane (3aj) (Diastereomeric ratio 1:1)



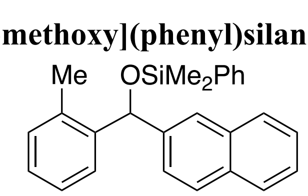
The reaction of *o*-tolualdehyde (**1a**) and 2-(3-bromophenoxy)tetrahydro-2*H*-pyran (**2j**) with PhMe$_2$SiB(pin) afforded **3aj** in 82% yield. **3aj** was purified by flash chromatography on silica gel (1% EtOAc/hexane). Colorless Oil. IR (neat) 784, 829, 872, 1038, 1112, 1250, 1485, 1585 cm^{-1}. ^{1}H NMR (600 MHz, CDCl$_3$) δ 0.258 (s, 0.5 × 3H), 0.261 (s, 0.5 × 3H), 0.297 (s, 0.5 × 3H), 0.301 (s, 0.5 × 3H), 1.56–1.68 (m, 0.5 × 3H, 0.5 × 3H), 1.78–1.86 (m, 0.5 × 2H, 0.5 × 2H), 1.94–2.01 (m, 0.5 × 1H, 0.5 × 1H), 2.08 (s, 0.5 × 3H, 0.5 × 3H), 3.53–3.56 (m, 0.5 × 1H, 0.5 × 1H), 3.86–3.90 (m, 0.5 × 1H, 0.5 × 1H), 5.31 (ddd, J = 8.6, 3.8, 3.1 Hz, 0.5 × 1H, 0.5 × 1H), 5.83 (s, 0.5 × 1H, 0.5 × 1H), 6.80–6.84 (m, 0.5 × 1H, 0.5 × 1H), 6.88–6.90 (m, 0.5 × 1H, 0.5 × 1H), 6.96–6.98 (m, 0.5 × 1H, 0.5 × 1H), 7.04 (d, J = 7.2 Hz, 0.5 × 1H, 0.5 × 1H), 7.12–7.15 (m, 0.5 × 2H, 0.5 × 2H), 7.19 (t, J = 7.2 Hz, 0.5 × 1H, 0.5 × 1H), 7.32 (t, J = 7.2 Hz, 0.5 × 2H, 0.5 × 2H), 7.35–7.38 (m, 0.5 × 1H, 0.5 × 1H), 7.50–7.54 (m, 0.5 × 3H, 0.5 × 3H). ^{13}C NMR (150.9 MHz, CDCl$_3$) δ –1.2, –1.1, 18.9, 18.9, 19.4, 25.2, 30.4, 62.1, 62.1, 74.3, 74.3, 96.5, 96.5, 114.7, 115.5, 115.5, 120.2, 120.2, 125.8, 127.1, 127.3, 127.3, 127.7, 128.9, 129.5, 130.3, 133.6, 134.9, 137.7, 142.0, 145.2, 145.2, 156.9, 156.9. HRMS–DART (*m/z*): [M–H]$^+$ calcd for C$_{27}$H$_{31}$O$_3$Si; 431.2042, found 431.2038.

3-{[(Dimethyl(phenyl)silyl)oxy](*o*-tolyl)methyl}phenyl Pivalate (3ak)



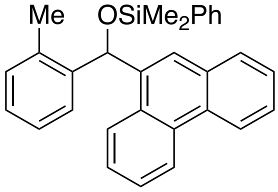
The reaction of *o*-tolualdehyde (**1a**) and 3-bromophenyl pivalate (**2k**) with PhMe$_2$SiB(pin) afforded **3ak** in 54% yield. **3ak** was purified by flash chromatography on silica gel (1% EtOAc/hexane). Colorless Oil. IR (neat) 785, 830, 873, 1064, 1139, 1252, 1480, 1753 cm^{-1}. ^{1}H NMR (600 MHz, CDCl$_3$) δ 0.26 (s, 3H), 0.30 (s, 3H), 1.33 (s, 9H), 2.08 (s, 3H), 5.85 (s, 1H), 6.89 (m, 1H), 6.93 (s, 1H), 7.03–7.06 (m, 2H), 7.15–7.24 (m, 3H), 7.32–7.39 (m, 3H), 7.49–7.51 (m, 3H). ^{13}C NMR (150.9 MHz, CDCl$_3$) δ –1.3, –1.1, 19.4, 27.1, 39.0, 74.1, 119.9, 120.0, 124.0, 125.9, 127.3, 127.5, 127.8, 128.9, 129.6, 130.5, 133.6, 135.1, 137.5, 141.6, 145.4, 151.0, 177.0. HRMS–DART (*m/z*): [M]$^+$ calcd for C$_{27}$H$_{32}$O$_3$Si; 432.2120, found 432.2119.

Dimethyl[naphthalen-2-yl(*o*-tolyl)methoxy](phenyl)silane (3al)



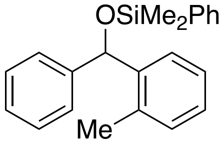
The reaction of *o*-tolualdehyde (**1a**) and 2-bromonaphthalene (**2l**) with PhMe$_2$SiB(pin) afforded **3al** in 78% yield. **3al** was purified by flash chromatography on silica gel (hexane) follwed by GPC (CHCl$_3$). Colorless Oil. IR (neat) 741, 785, 829, 874, 898, 1064, 1117, 1252 cm^{-1}. ^{1}H NMR (600 MHz, CDCl$_3$) δ 0.29 (s, 3H), 0.32 (s, 3H), 2.10 (s, 3H), 6.02 (s, 1H), 7.05 (d, J = 7.2 Hz, 1H), 7.17 (m, 1H), 7.23 (t, J = 7.2 Hz, 1H), 7.32–7.34 (m, 3H), 7.38 (m, 1H), 7.41–7,45 (m, 2H), 7.52–7.53 (m, 2H), 7.62 (d, J = 7.2 Hz, 1H), 7.66 (s, 1H), 7.71 (d, J = 8.4 Hz, 1H), 7.74–7.78 (m, 2H).^{13}C NMR (100.5 MHz, $CDCl_3$) δ −1.2, −1.0, 19.5, 74.6, 125.3, 125.5, 125.7, 125.86, 125.89, 127.2, 127.4, 127.6, 127.8, 127.9, 128.0, 129.6, 130.4, 132.6, 133.1, 133.6, 135.0, 137.6, 140.9, 141.9. HRMS–DART (*m/z*): $[M]^+$ calcd for $C_{26}H_{26}OSi$; 382.1752, found 382.1752.

Dimethyl[phenanthren-9-yl(*o*-tolyl)methoxy](phenyl)silane (3am)



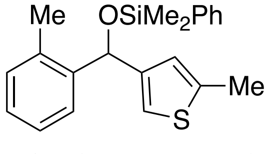
The reaction of *o*-tolualdehyde (**1a**) and 9-bromophenanthrene (**2m**) with $PhMe_2SiB(pin)$ afforded **3am** in 88% yield. **3am** was purified by flash chromatography on silica gel (hexane). White Solid. M.p. 111.5–115.1 °C. IR (neat) 785, 828, 897, 1013, 1065, 1116, 1250, 1427 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.35 (s, 3H), 0.36 (s, 3H), 2.17 (s, 3H), 6.59 (s, 1H), 7.11–7.19 (m, 3H), 7.29–7.32 (m, 2H), 7.36–7.46 (m, 3H), 7.50–7.63 (m, 5H), 7.72 (s, 1H), 7.75 (d, J = 7.8 Hz, 1H), 7.83 (d, J = 7.8 Hz, 1H), 8.64 (d, J = 7.8 Hz, 1H), 8.70 (d, J = 7.8 Hz, 1H). ^{13}C NMR (100.5 MHz, $CDCl_3$) δ −1.0, –0.9, 19.4, 71.9, 122.4, 123.1, 124.6, 125.9, 126.1, 126.3, 126.56, 126.65, 126.8, 127.5, 127.8, 128.0, 129.0, 129.7, 130.1, 130.2, 130.5, 130.7, 131.3, 133.7, 135.4, 136.8, 137.3, 141.0. HRMS–DART (*m/z*): $[M]^+$ calcd for $C_{30}H_{28}OSi$; 432.1909, found 432.1910.

Dimethyl(phenyl)[phenyl(*o*-tolyl)methoxy]silane (3bn)



The reaction of benzaldehyde (**1b**) and 2-bromotoluene (**2n**) with $PhMe_2SiB(pin)$ afforded **3bn** in 71% yield. **3bn** was purified by flash chromatography on silica gel (hexane).

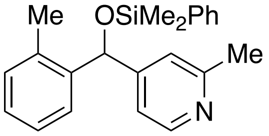
Dimethyl[(5-methylthiophen-3-yl)(*o*-tolyl)methoxy](phenyl)silane (3ao)



The reaction of *o*-tolualdehyde (**1a**) and 4-bromo-2-methylthiophene (**2o**) with $PhMe_2SiB(pin)$ afforded **3ao** in 60% yield. **3ao** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 733, 785, 829, 881, 1061, 1116, 1251, 1428 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.26 (s, 3H), 0.32 (s, 3H), 2.09 (s, 3H), 2.36 (s, 3H), 5.80 (s, 1H), 6.48 (s, 1H), 6.66 (s, 1H), 7.04 (d, J = 7.2 Hz, 1H), 7.15 (m, 1H), 7.20 (t, J = 7.2 Hz, 1H), 7.31–7.34 (m, 2H), 7.38 (m, 1H), 7.50–7.52 (m, 2H), 7.55 (d, J = 7.2 Hz, 1H). ^{13}C NMR (150.9 MHz, $CDCl_3$)

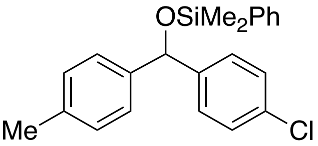
δ −1.4, −1.1, 15.3, 19.1, 70.9, 119.3, 125.0, 125.9, 126.8, 127.1, 127.7, 129.5, 130.2, 133.6, 134.6, 137.7, 139.9, 141.8, 144.8. HRMS–DART (*m/z*): $[M]^+$ calcd for $C_{21}H_{24}OSSi$; 352.1317, found 352.1315.

4-{[(Dimethyl(phenyl)silyl)oxy](*o*-tolyl)methyl}-2-methylpyridine (3ap)



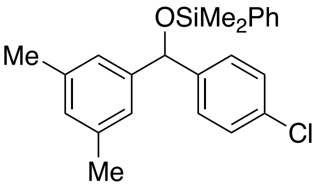
The reaction of *o*-tolualdehyde (**1a**) and 4-bromo-2-methylpyridine (**2p**) with $PhMe_2SiB(pin)$ afforded **3ap** in 55% yield. **3ap** was purified by flash chromatography on silica gel (10% EtOAc/hexane). Colorless Oil. IR (neat) 785, 829, 873, 1071, 1117, 1252, 1428, 1601 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.27 (s, 3H), 0.32 (s, 3H), 2.08 (s, 3H), 2.48 (s, 3H), 5.77 (s, 1H), 6.97–6.99 (m, 2H), 7.07 (m, 1H), 7.16–7.21 (m, 2H), 7.32–7.41 (m, 4H), 7.47–7.49 (m, 2H), 8.36 (d, J = 4.8 Hz, 1H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ −1.5, −1.1, 19.4, 24.5, 73.6, 118.6, 120.9, 126.0, 127.7, 127.8, 127.9, 129.8, 130.7, 133.5, 135.1, 137.1, 140.7, 148.9, 153.0, 158.2. HRMS–DART (*m/z*): $[M+H]^+$ calcd for $C_{22}H_{26}NOSi$; 348.1783, found 348.1784.

[(4-Chlorophenyl)(*p*-tolyl)methoxy]dimethyl(phenyl)silane (3cd)



The reaction of *p*-tolualdehyde (**1c**) and 1-bromo-4-chlorobenzene (**2d**) with $PhMe_2SiB(pin)$ afforded **3cd** in 62% yield. **3cd** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 786, 829, 868, 1014, 1070, 1116, 1252, 1488 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.28 (s, 6H), 2.30 (s, 3H), 5.66 (s, 1H), 7.08 (d, J = 8.0 Hz, 2H), 7.14 (d, J = 8.0 Hz, 2H), 7.22 (s, 4H), 7.31–7.41 (m, 3H), 7.49–7.51 (m, 2H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ −1.2, −1.0, 21.1, 76.0, 126.4, 127.76, 127.78, 128.3, 129.0, 129.6, 132.6, 133.5, 136.9, 137.5, 141.2, 143.4. HRMS–DART (*m/z*): $[M-H]^+$ calcd for $C_{22}H_{22}OSi$; 365.1128, found 365.1127.

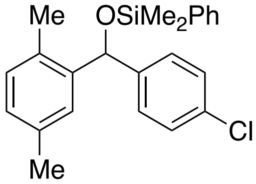
[(4-Chlorophenyl)(3,5-dimethylphenyl)methoxy]dimethyl(phenyl)silane (3dd)



The reaction of 3,5-dimethylbenzaldehyde (**1d**) and 1-bromo-4-chlorobenzene (**2d**) with $PhMe_2SiB(pin)$ afforded **3dd** in 64% yield. **3dd** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 785, 829, 869, 1013, 1086, 1117, 1252, 1488 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.28 (s, 3H), 0.29 (s, 3H), 2.25 (s, 6H), 5.62 (s, 1H), 6.84 (s, 3H), 7.23 (s, 4H), 7.31–7.39 (m, 3H), 7.48–7.51 (m, 2H). ^{13}C NMR (150.9 MHz, $CDCl_3$)

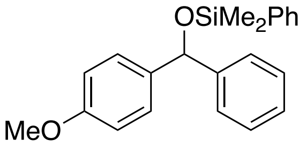
δ −1.2, −1.1, 21.3, 76.3, 124.3, 127.7, 127.8, 128.3, 128.9, 129.6, 132.6, 133.6, 137.5, 137.7, 143.4, 144.0. HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{23}H_{24}ClOSi$; 379.1284, found 379.1288.

[(4-Chlorophenyl)(2,5-dimethylphenyl)methoxy]dimethyl(phenyl)silane (3ed)



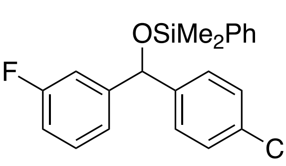
The reaction of 2,5-dimethylbenzaldehyde (**1e**) and 1-bromo-4-chlorobenzene (**2d**) with $PhMe_2SiB(pin)$ afforded **3ed** in 65% yield. **3ed** was purified by flash chromatography on silica gel (hexane). Colorless Oil. IR (neat) 783, 808, 828, 875, 1058, 1116, 1251, 1488 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.27 (s, 3H), 0.30 (s, 3H), 2.01 (s, 3H), 2.30 (s, 3H), 5.79 (s, 1H), 6.93 (d, *J* = 7.8 Hz, 1H), 6.96 (d, *J* = 7.8 Hz, 1H), 7.15 (d, *J* = 8.4 Hz, 2H), 7.19–7.22 (m, 2H), 7.26 (s, 1H), 7.31–7.33 (m, 2H), 7.37 (m, 1H), 7.48–7.49 (m, 2H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ −1.3, −1.1, 18.9, 21.1, 73.8, 127.8, 128.00, 128.04, 128.17, 128.19, 129.6, 130.4, 131.7, 132.5, 133.6, 135.3, 137.4, 141.3, 142.4. HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{23}H_{24}ClOSi$; 379.1284, found 379.1281.

[(4-Methoxyphenyl)(phenyl)methoxy]dimethyl(phenyl)silane (3fa)



The reaction of *p*-anisaldehyde(**1f**) and bromobenzene (**2a**) with $PhMe_2SiB(pin)$ afforded **3fa** in 61% yield. **3fa** was purified by flash chromatography on silica gel (1% EtOAc/hexane). Colorless Oil. IR (neat) 784, 830, 876, 1062, 1082, 1172, 1510, 1610 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.28 (s, 6H), 3.77 (s, 3H), 5.70 (s, 1H), 6.79–6.81 (m, 2H), 7.18–7.21 (m, 3H), 7.25–7.30 (m, 4H), 7.32–7.34 (m, 2H), 7.38 (m, 1H), 7.51–7.53 (m, 2H). ^{13}C NMR (150.9 MHz, $CDCl_3$) δ −1.08, −1.06, 55.2, 76.4, 113.5, 126.4, 126.9, 127.7, 127.8, 128.1, 129.5, 133.6, 137.0, 137.8, 144.9, 158.7. HRMS–DART (*m/z*): $[M–H]^+$ calcd for $C_{22}H_{23}O_2Si$; 347.1467, found 347.1467.

[(4-Chlorophenyl)(3-fluorophenyl)methoxy]dimethyl(phenyl)silane (3gd)



The reaction of 3-fluorobenzaldehyde (**1g**) and 1-bromo-4-chlorobenzene (**2d**) with $PhMe_2SiB(pin)$ afforded **3gd** in 73% yield. **3gd** was purified by flash chromatography on silica gel (2% EtOAc/hexane). Colorless Oil. IR (neat) 785, 830, 868, 1064, 1087, 1254, 1488, 1591 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.30 (s, 3H), 0.31 (s, 3H), 5.65 (s, 1H), 6.89 (m, 1H), 7.00–7.03 (m, 2H), 7.19–7.24 (m, 5H), 7.32–7.34 (m, 2H), 7.38 (m, 1H), 7.48–7.49 (m, 2H). ^{13}C NMR (150.9 MHz, CDCl$_3$) δ –1.3, –1.2, 75.6, 113.2 (d, $J_{C–F}$ = 21.0 Hz), 114.1 (d, $J_{C–F}$ = 21.0 Hz), 121.91, 121.93, 127.9 (d, $J_{C–F}$ = 3.0 Hz), 128.5, 129.75 (d, $J_{C–F}$ = 8.7 Hz), 129.80, 133.1, 133.5, 137.0, 142.6, 146.9 (d, $J_{C–F}$ = 7.2 Hz), 162.8 (d, $J_{C–F}$ = 246.0 Hz). HRMS–DART (*m/z*): [M–H]$^+$ calcd for $C_{21}H_{19}ClFOSi$; 369.0877, found 369.0879.

Palladium-Catalyzed Reaction Using Stoichiometric α-Silyloxyalkylcopper(I) Complex.

(IPr)CuCl (48.8 mg, 0.1 mmol) and NaO*t*Bu (9.6 mg, 0.1 mmol) were placed in a vial containing a magnetic stirring bar. The vial was sealed with a Teflon®-coated silicon rubber septum, and then the vial was evacuated and filled with nitrogen. Toluene (0.6 mL) was added to the vial, and then the mixture was stirred at 25 °C for 10 min. Next, $PhMe_2SiB(pin)$ (26.2 mg, 0.1 mmol) and *p*-tolualdehyde (**1c**) (12.0 mg, 0.1 mmol) were added, and then the mixture (**mixture A**) was stirred at 25 °C for 40 min. The ^{1}H NMR spectrum of the mixture showed signals corresponding to α-silyloxybenzylcopper(I) complex (**4**) (Figure S1).[5] Meanwhile, Pd(acac)$_2$ (1.5 mg, 0.005 mmol) and DPPF (5.5 mg, 0.01 mmol) were placed in another vial. This vial was sealed with a Teflon®-coated silicon rubber septum and then evacuated and filled with nitrogen. After toluene (0.4 mL) was added to the vial, the mixture was stirred at 25 °C for 10 min. Next, 1-bromo-4-chlorobenzene (**2d**) (19.1 mg, 0.1 mmol) was added to the vial, and the mixture (**mixture B**) was stirred at 25 °C for 15 min. Finally, the palladium solution (**mixture B**) was transferred to the vial (**mixture A**) containing the copper complex. After 3 h stirring at 80 °C, the reaction mixture was diluted with diethyl ether (1 mL). The reaction mixture was filtered through a short plug of aluminum oxide (1 g) with diethyl ether as an eluent. After volatiles were removed under reduced pressure, flash column chromatography on silica gel (hexane) gave **3cd** (24.9 mg, 0.068 mmol) in 68% yield.

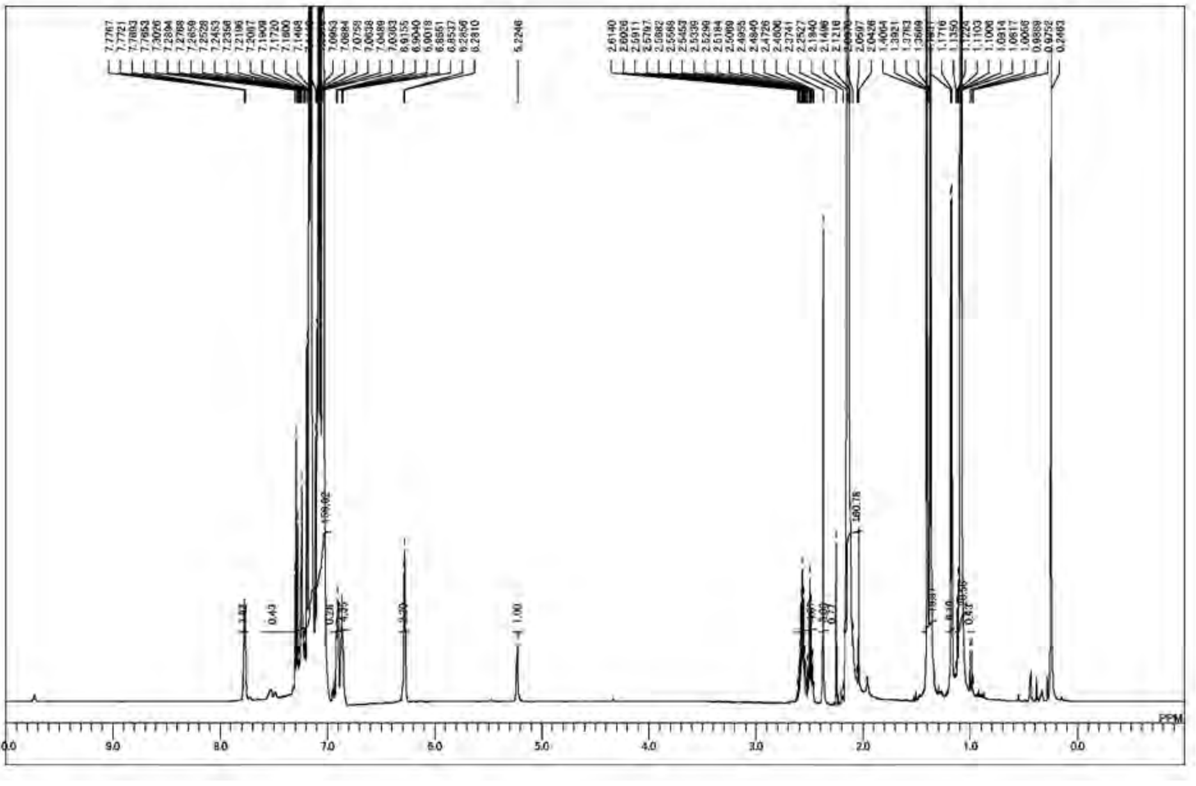


Figure S1. ^{1}H NMR spectrum for for the reaction of (IPr)CuCl, NaO*t*Bu, $PhMe_2SiB(pin)$ and *p*-tolualdehyde (**1c**) (1/1/1/1) (400 MHz, C_6D_6)

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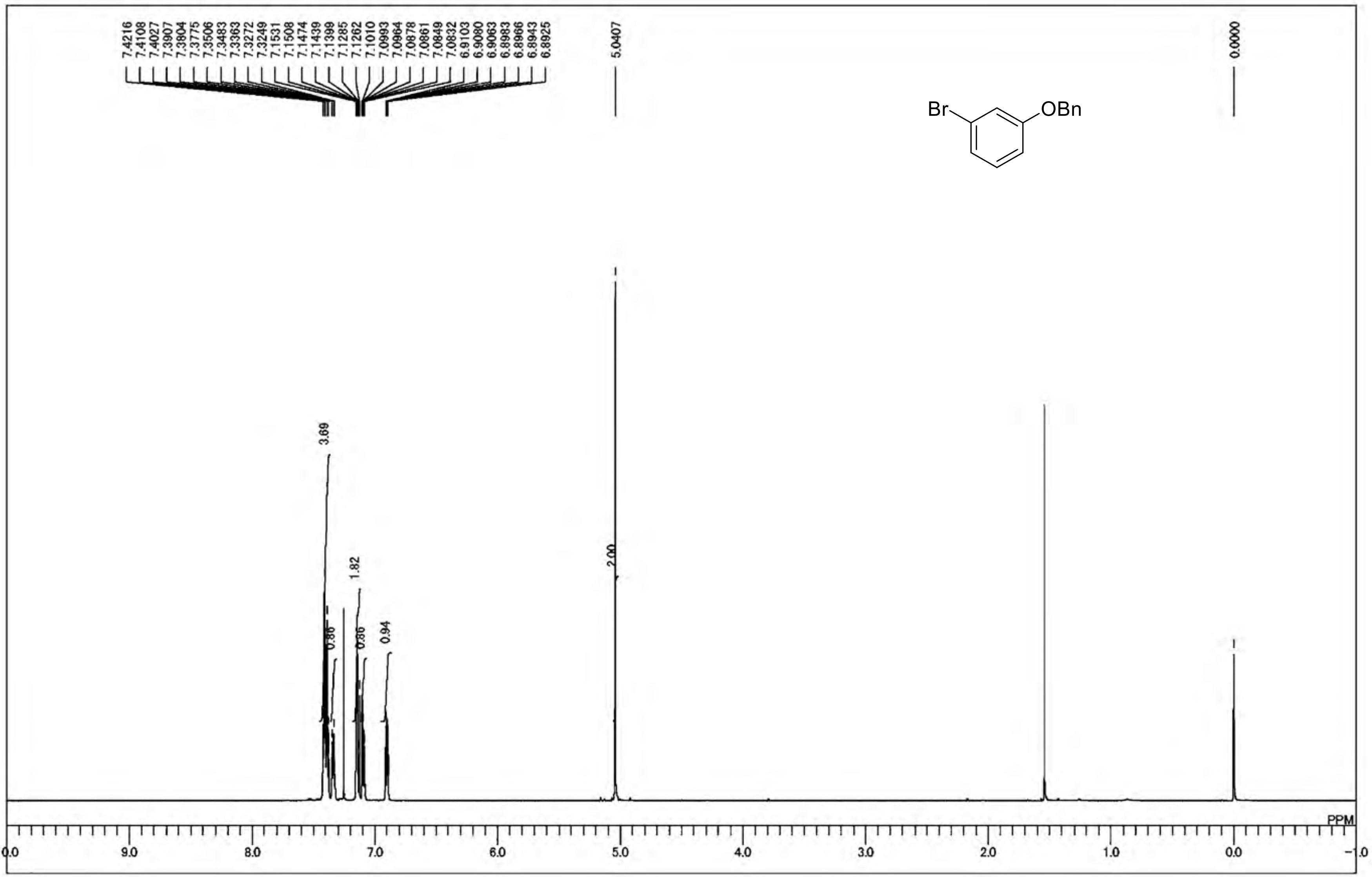
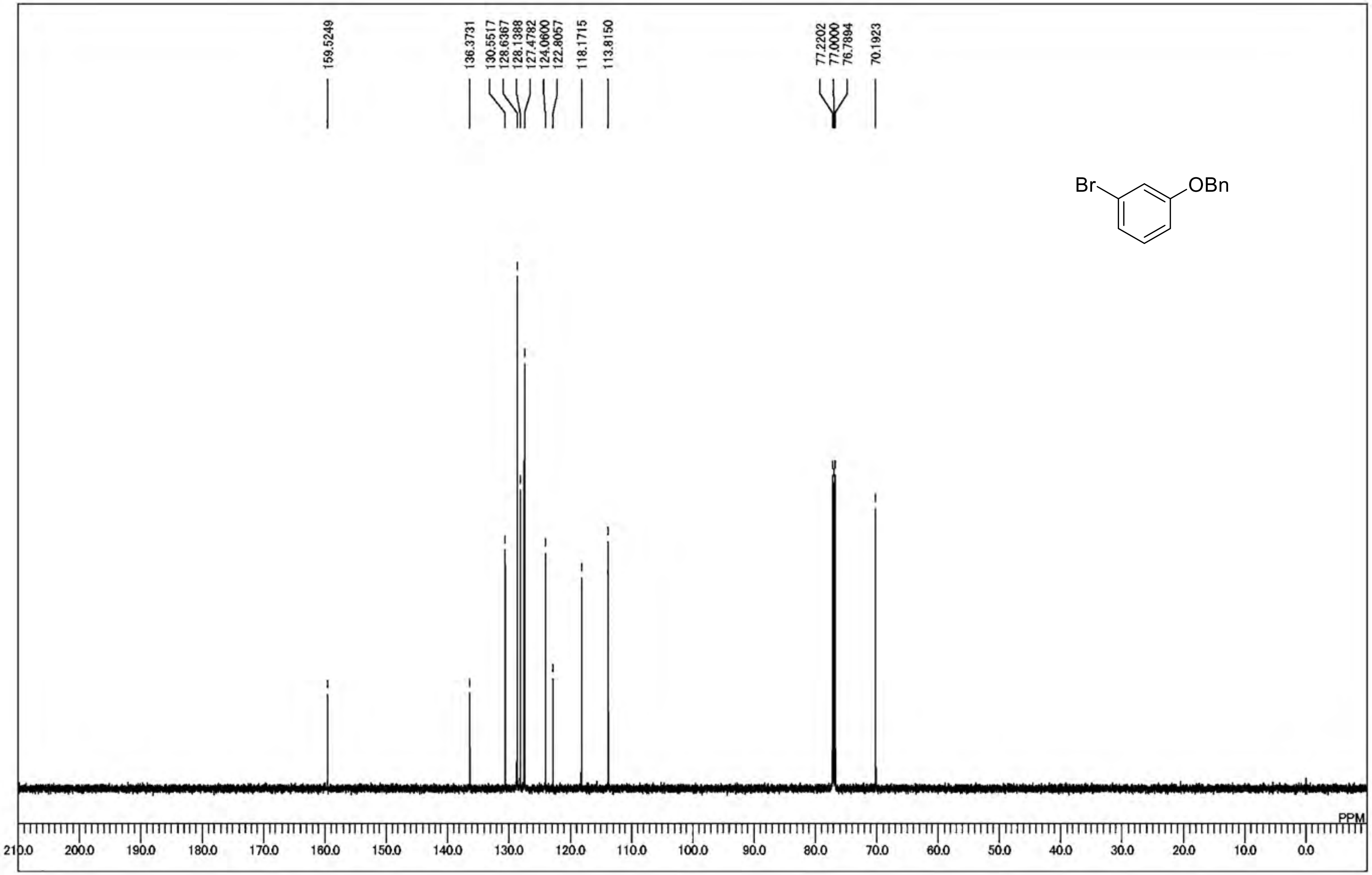
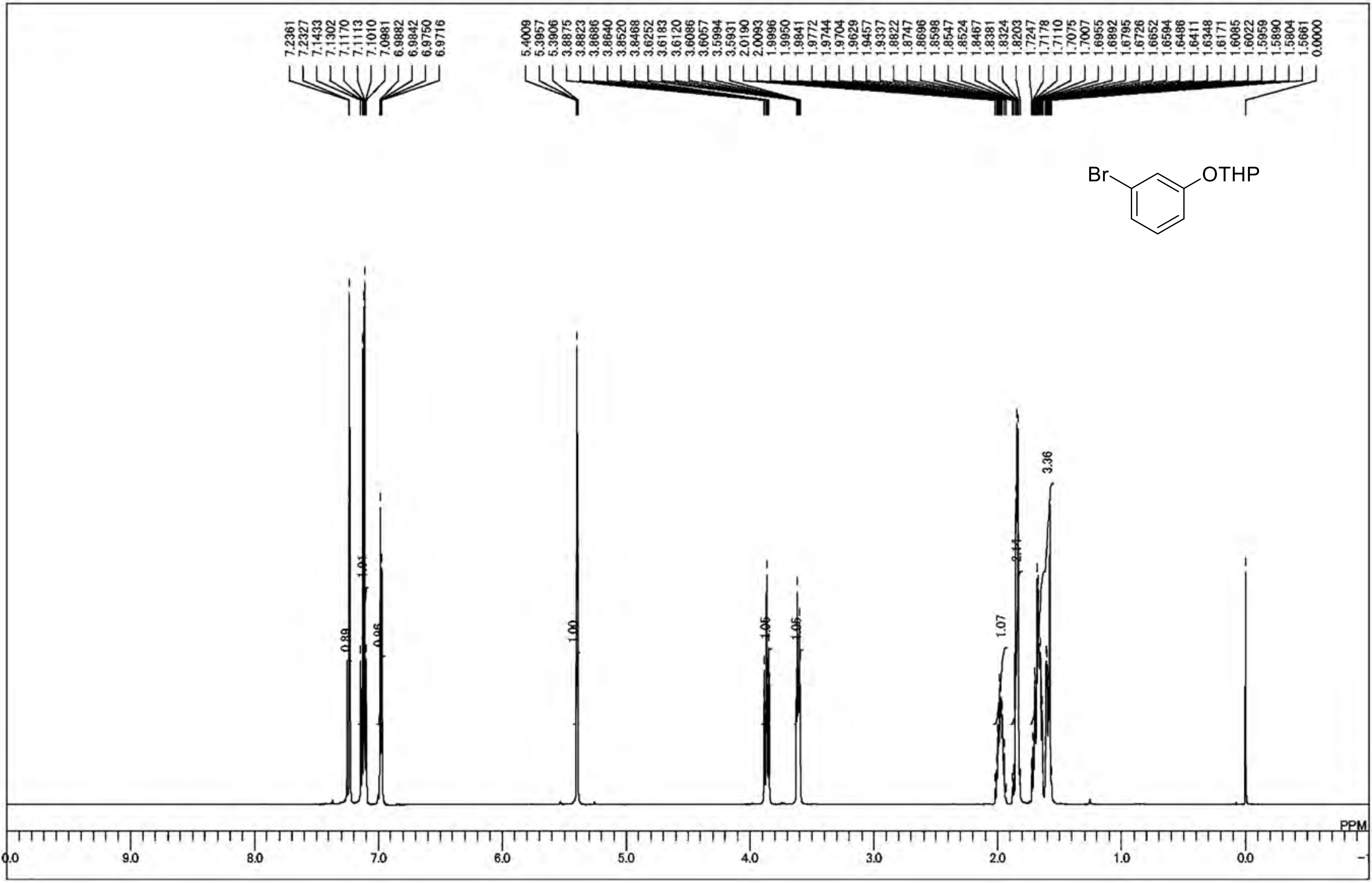
(5) Kleeberg, C.; Feldmann, E.; Hartmann, E.; Vyas, D. J.; Oestreich, M. *Chem. Eur. J.* **2011**, *17*, 13538.



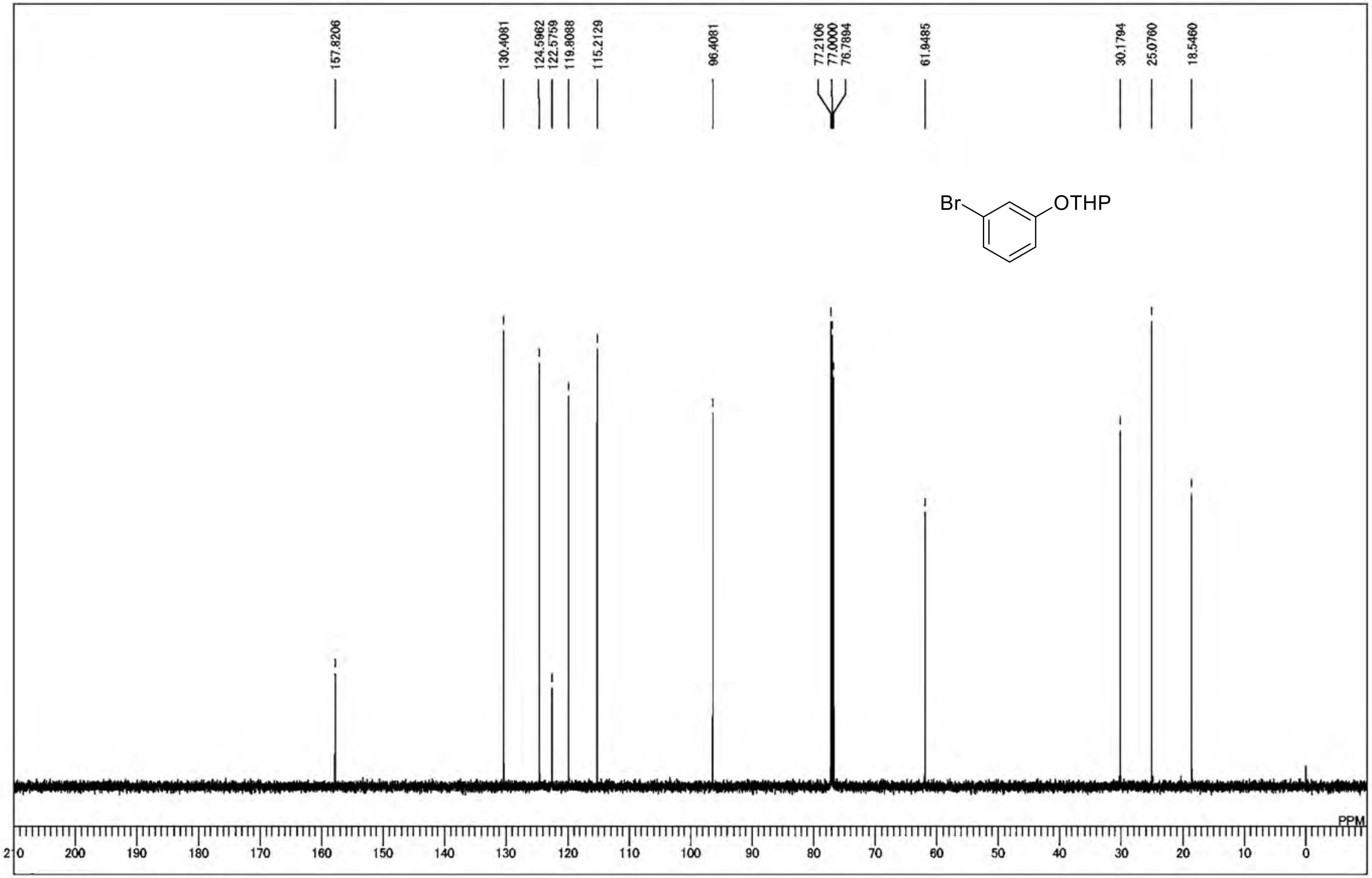
^{1}H NMR spectrum of **2i**



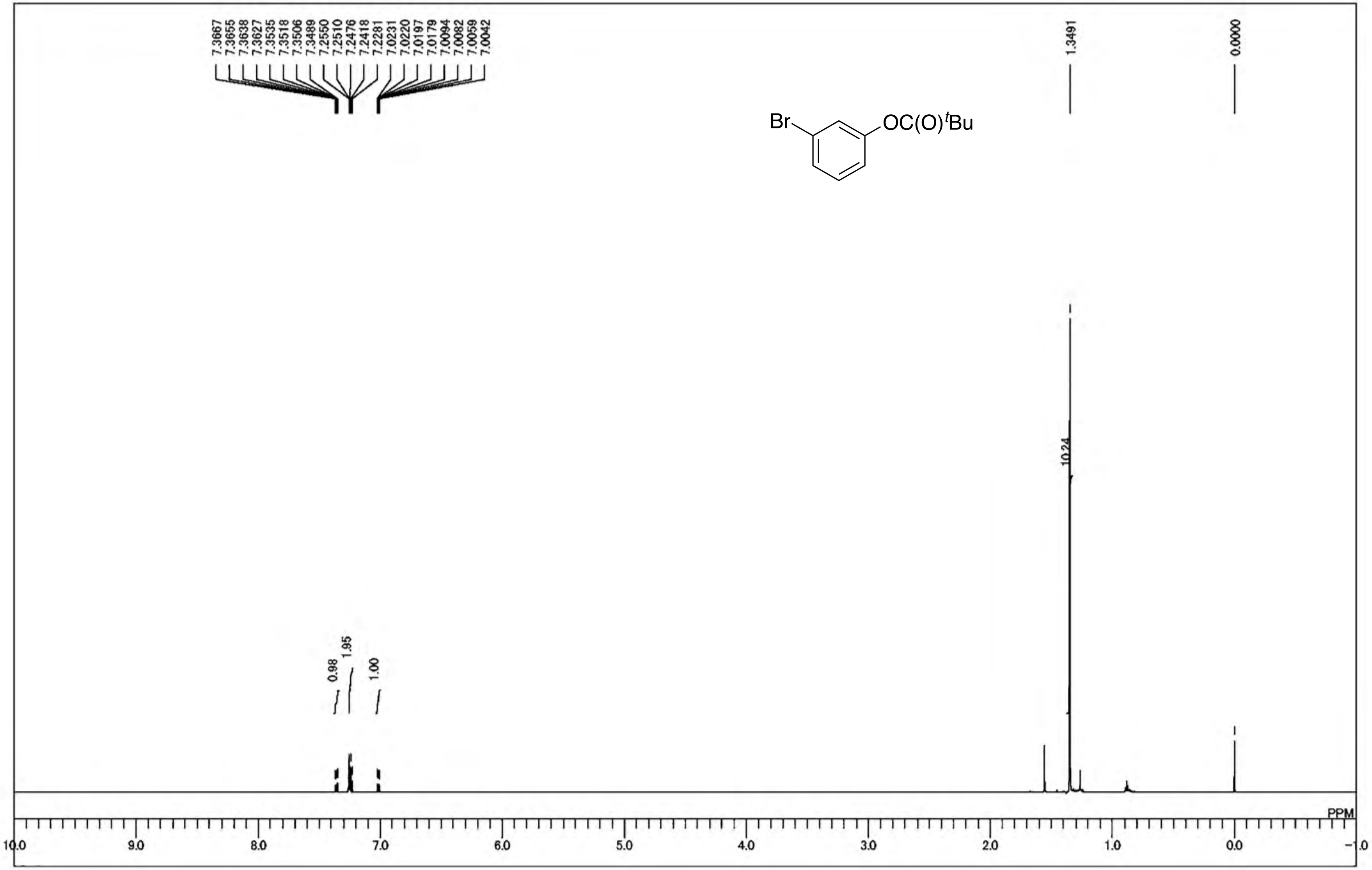
^{13}C NMR spectrum of **2i**



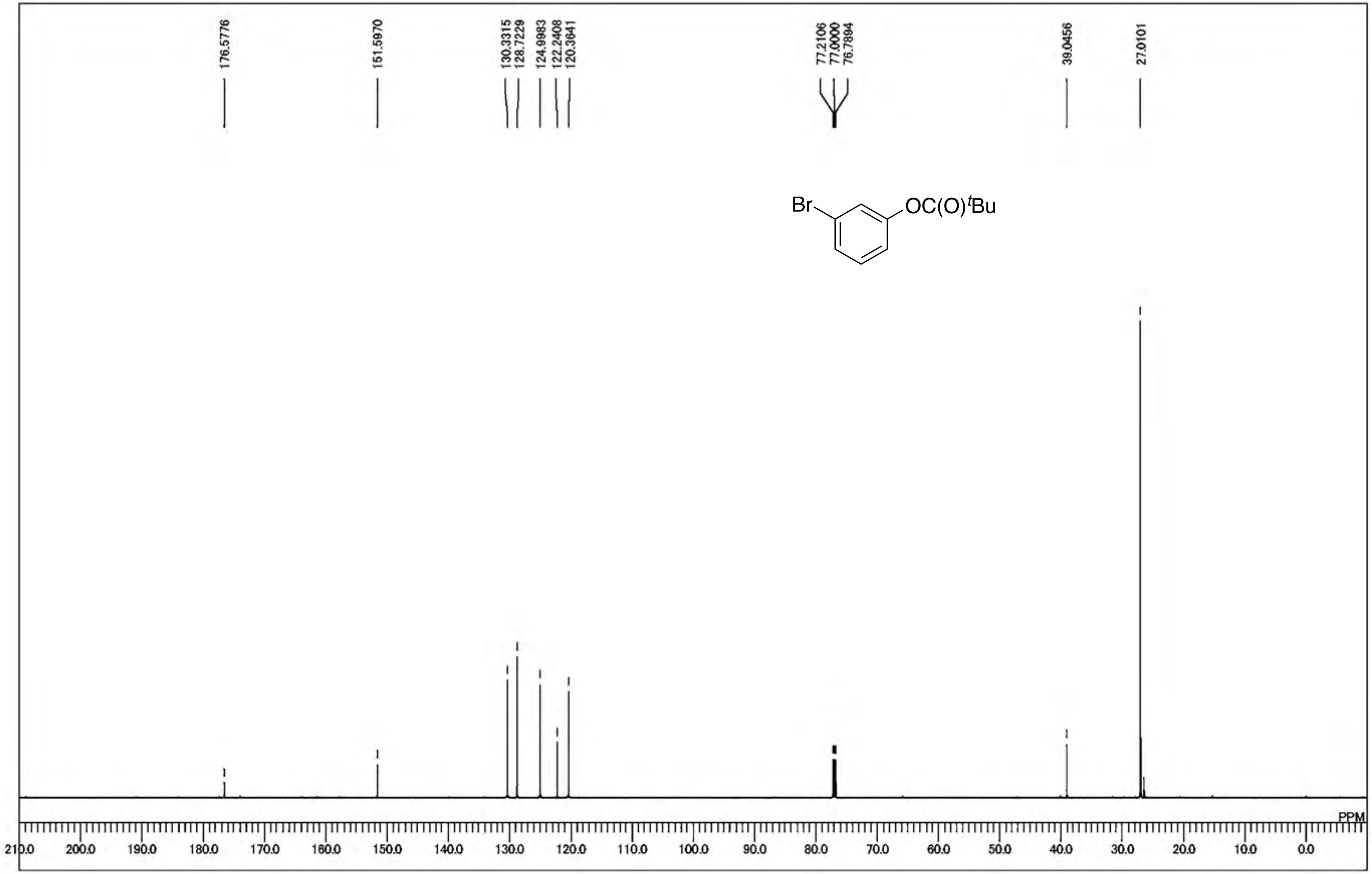
^{1}H NMR spectrum of **2j**



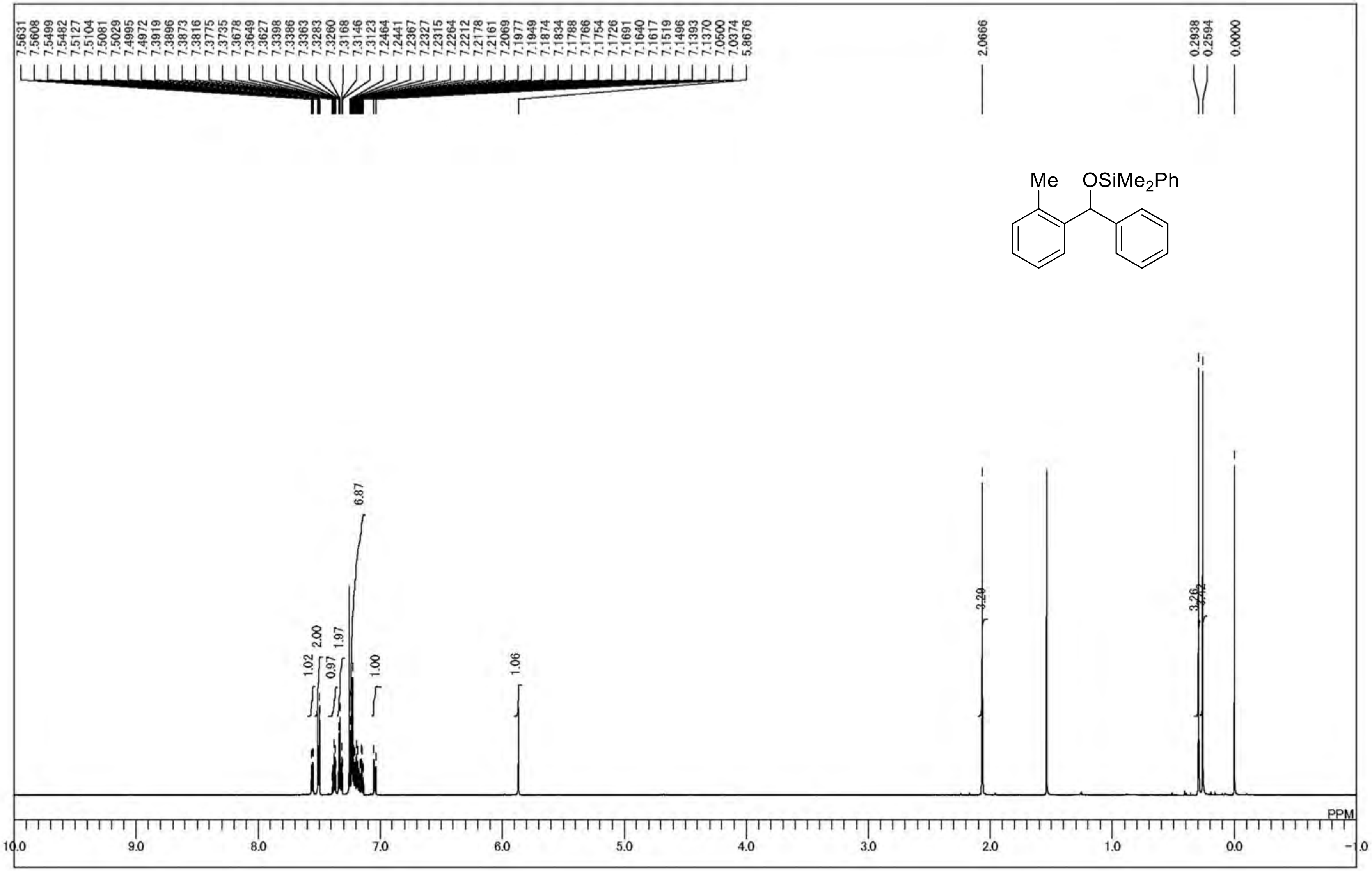
^{13}C NMR spectrum of **2j**



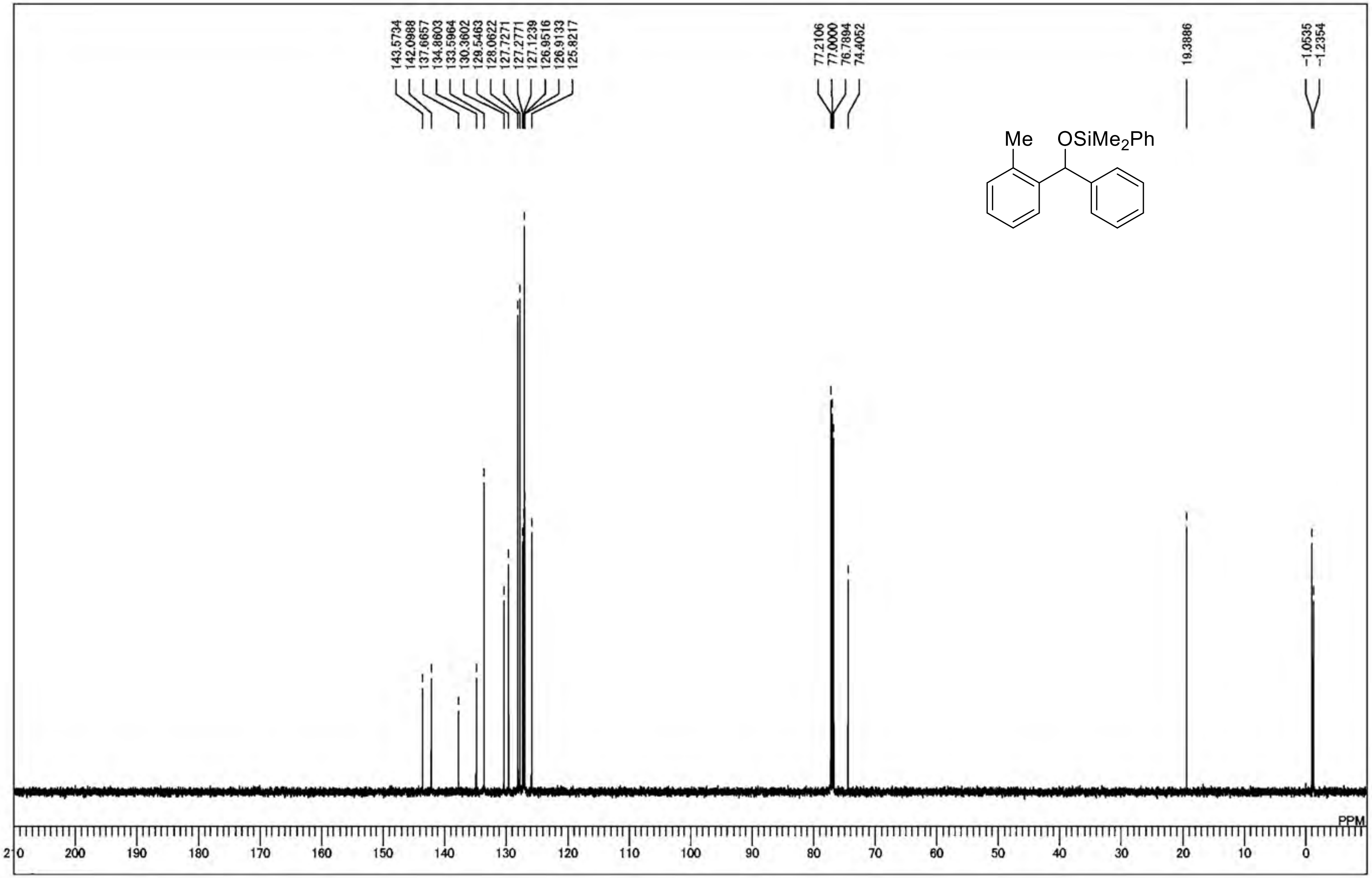
^{1}H NMR spectrum of **2k**



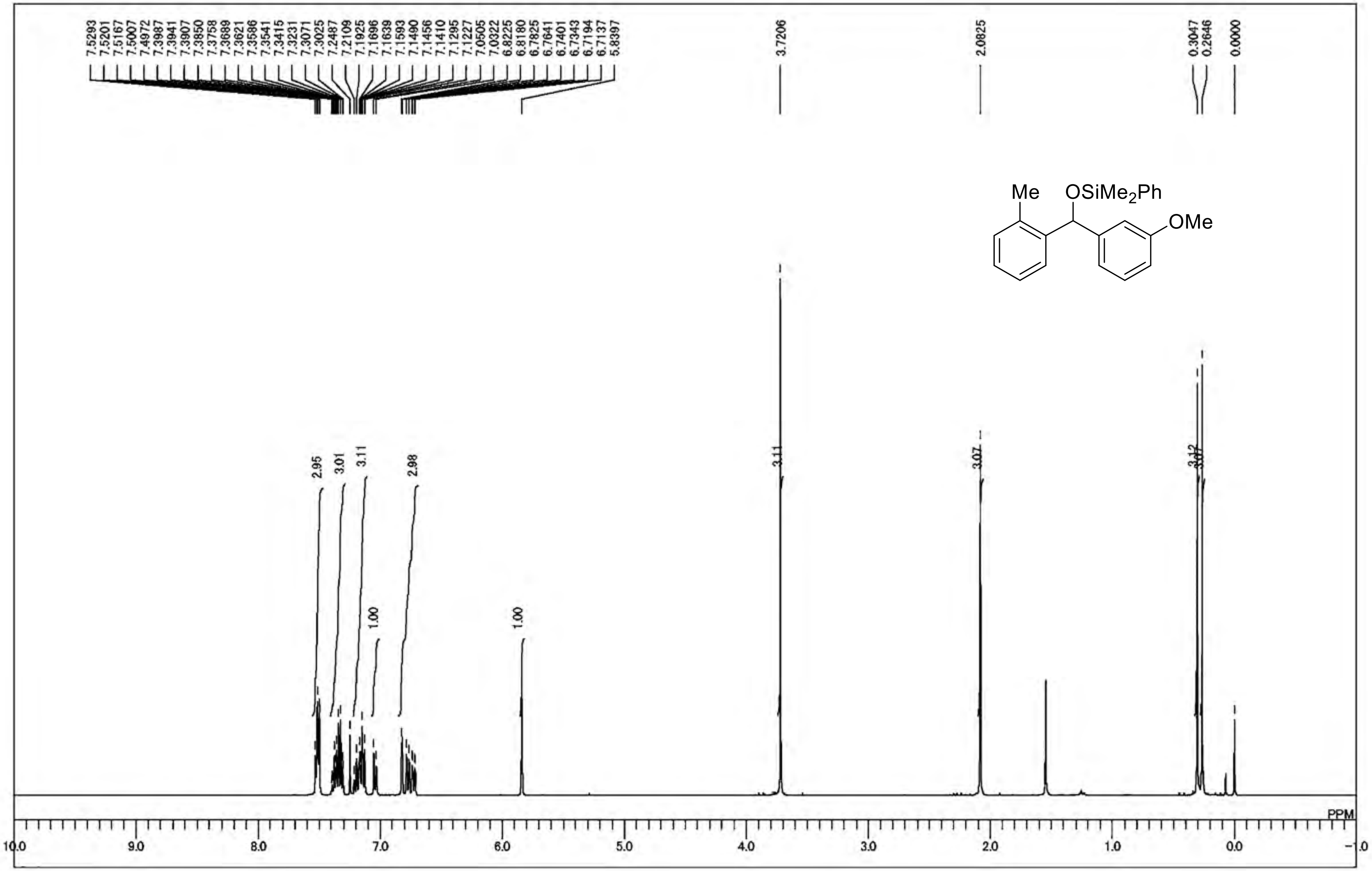
^{13}C NMR spectrum of **2k**



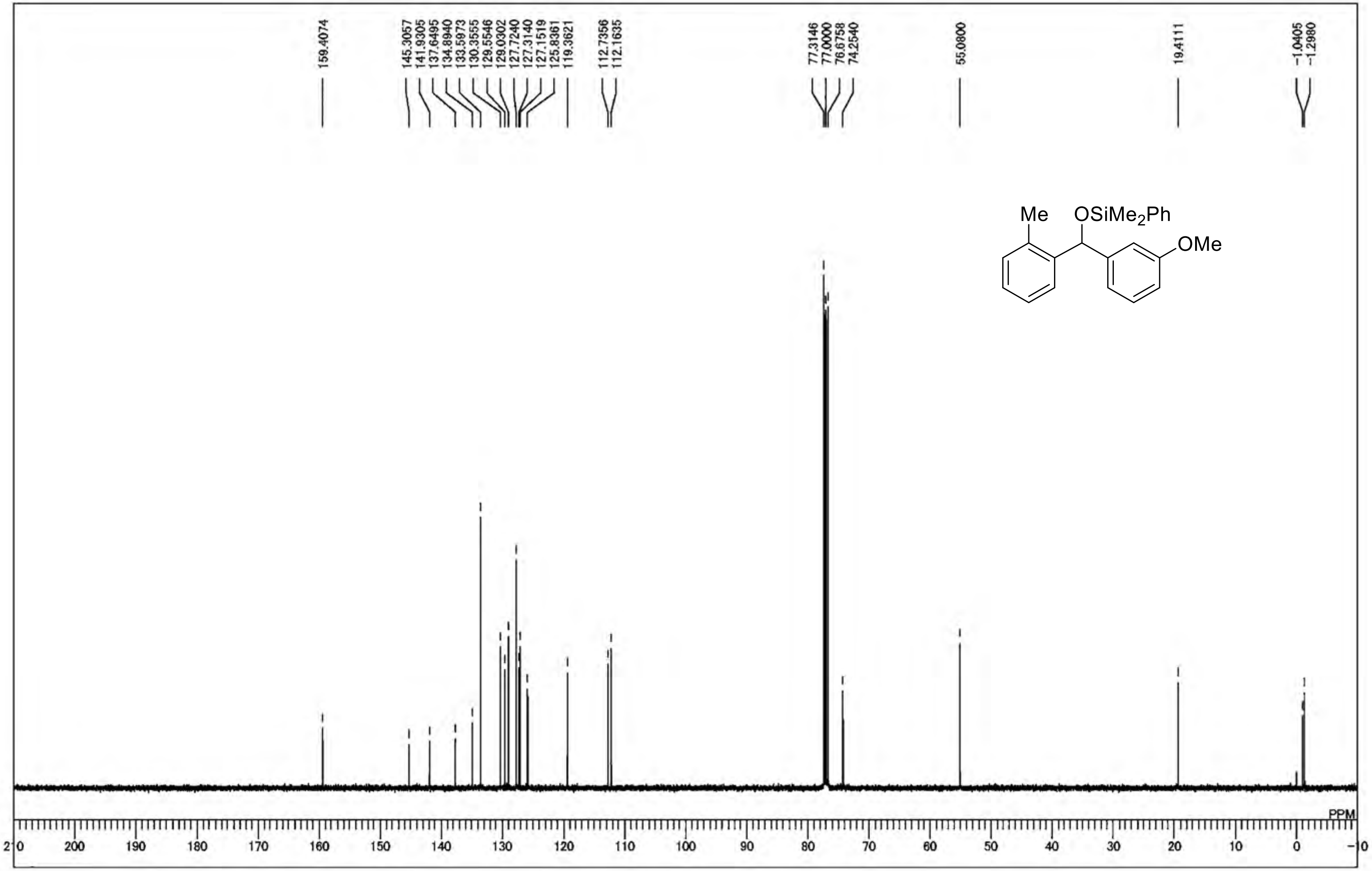
^{1}H NMR spectrum of **3aa**



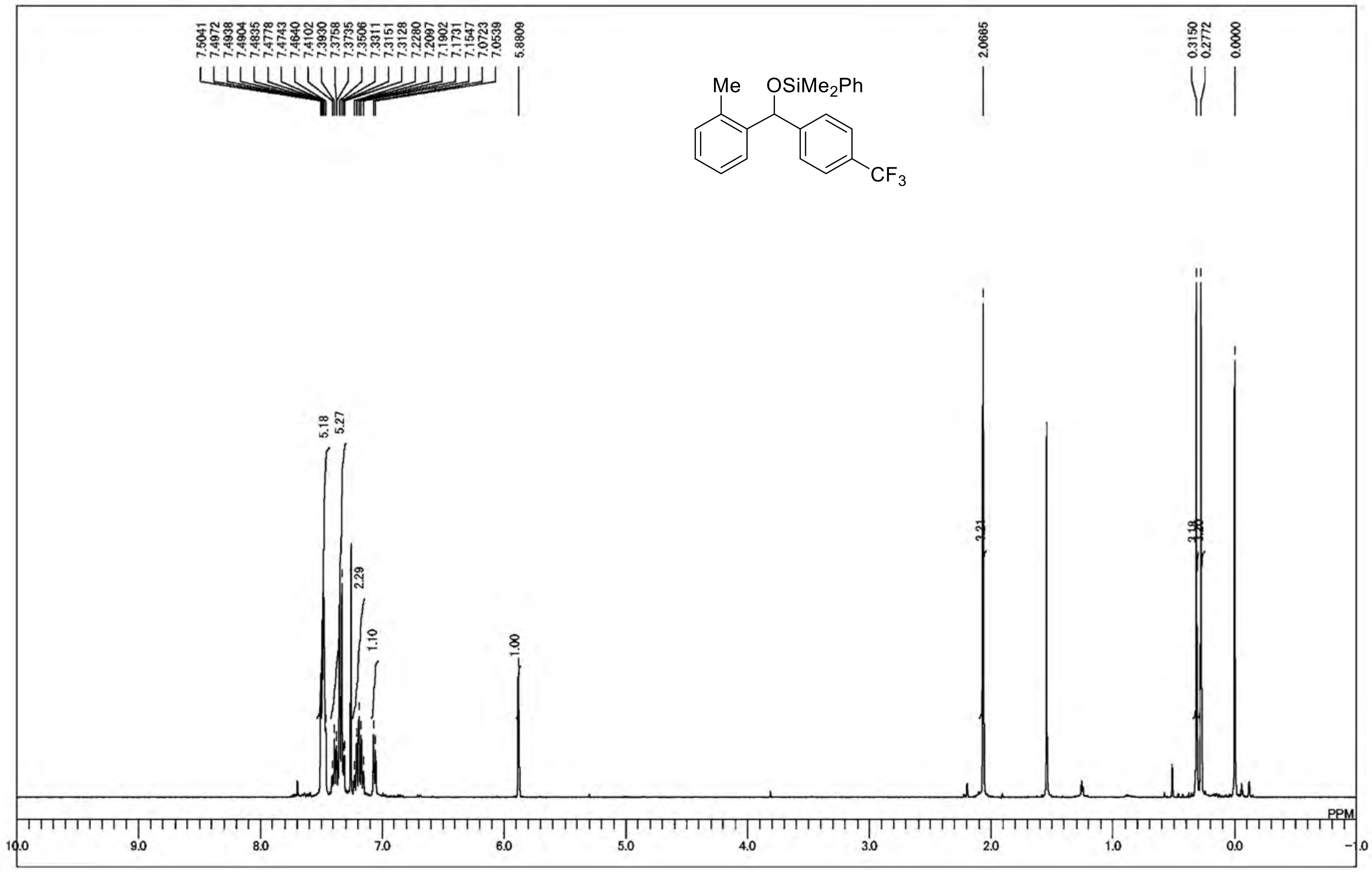
^{13}C NMR spectrum of **3aa**



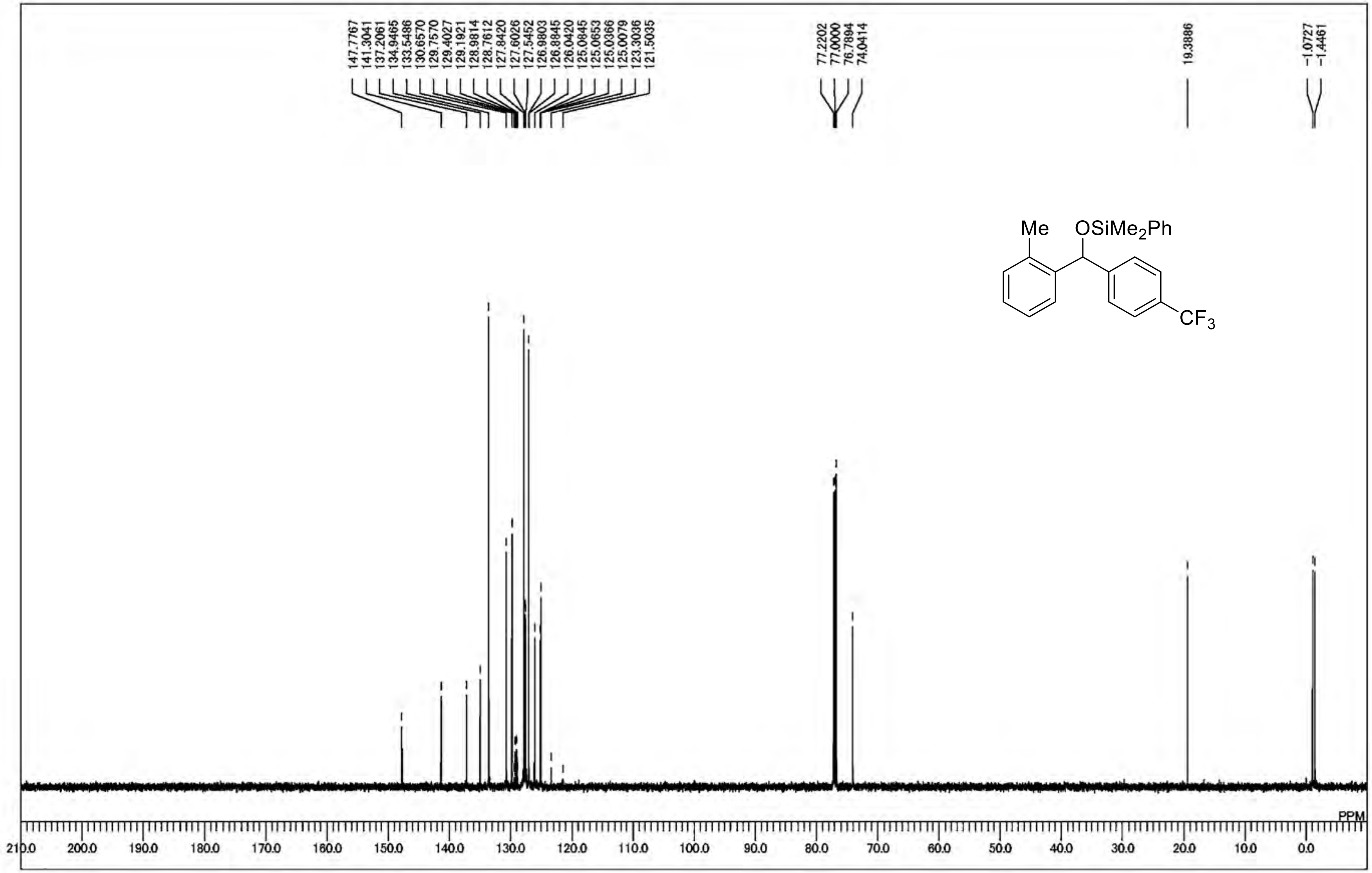
^{1}H NMR spectrum of **3ab**



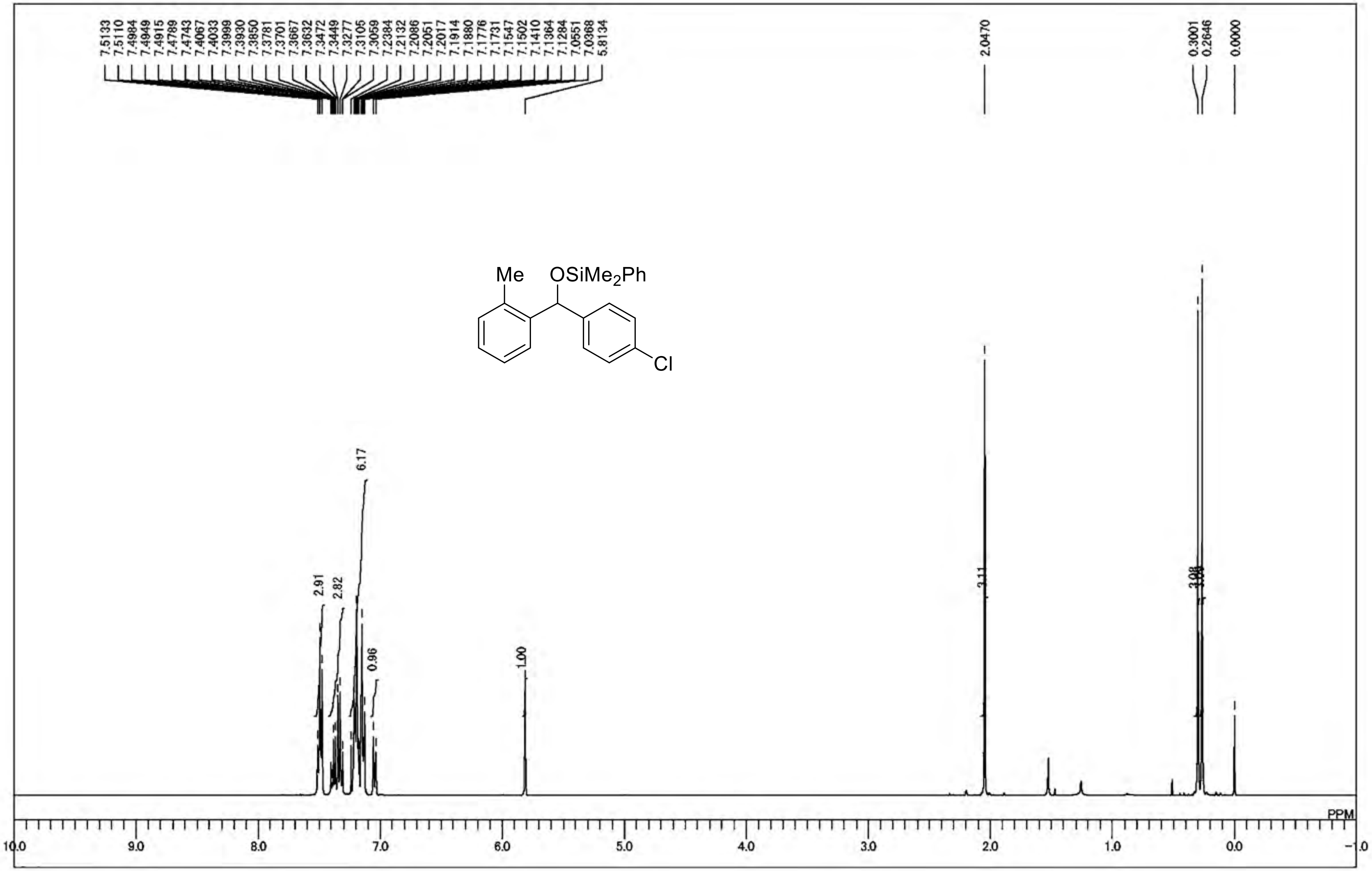
^{13}C NMR spectrum of **3ab**



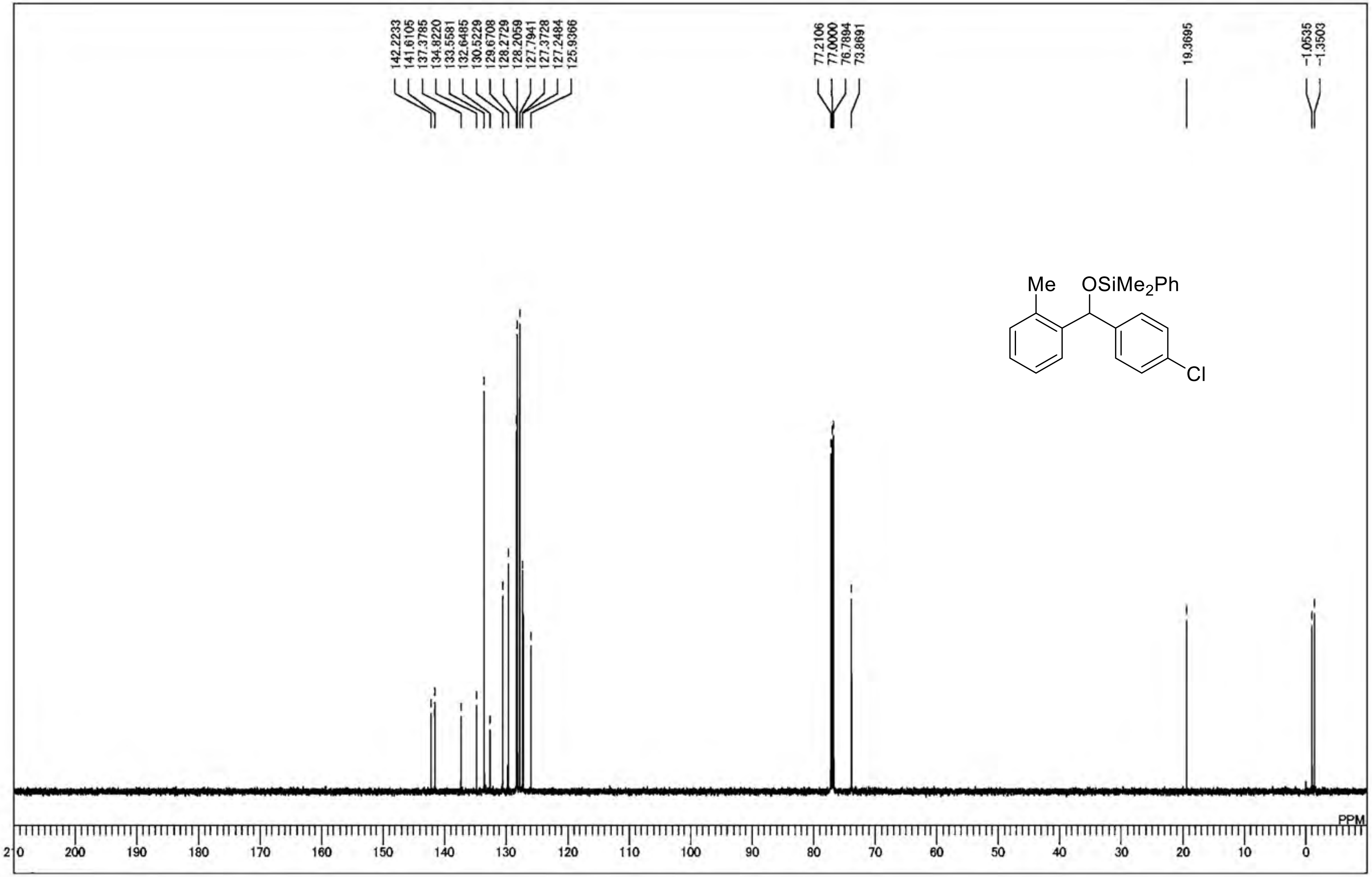
^{1}H NMR spectrum of **3ac**



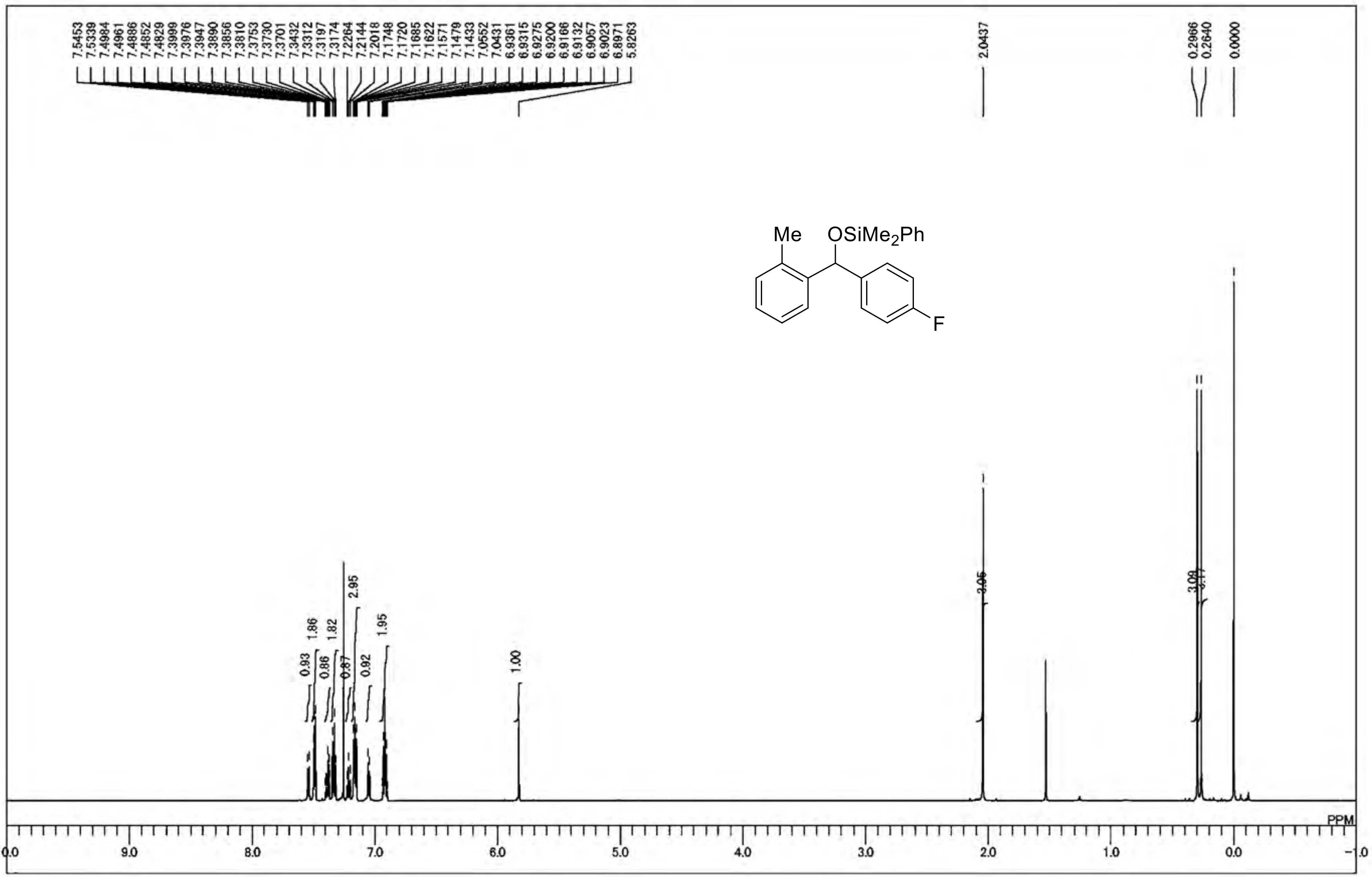
^{13}C NMR spectrum of **3ac**



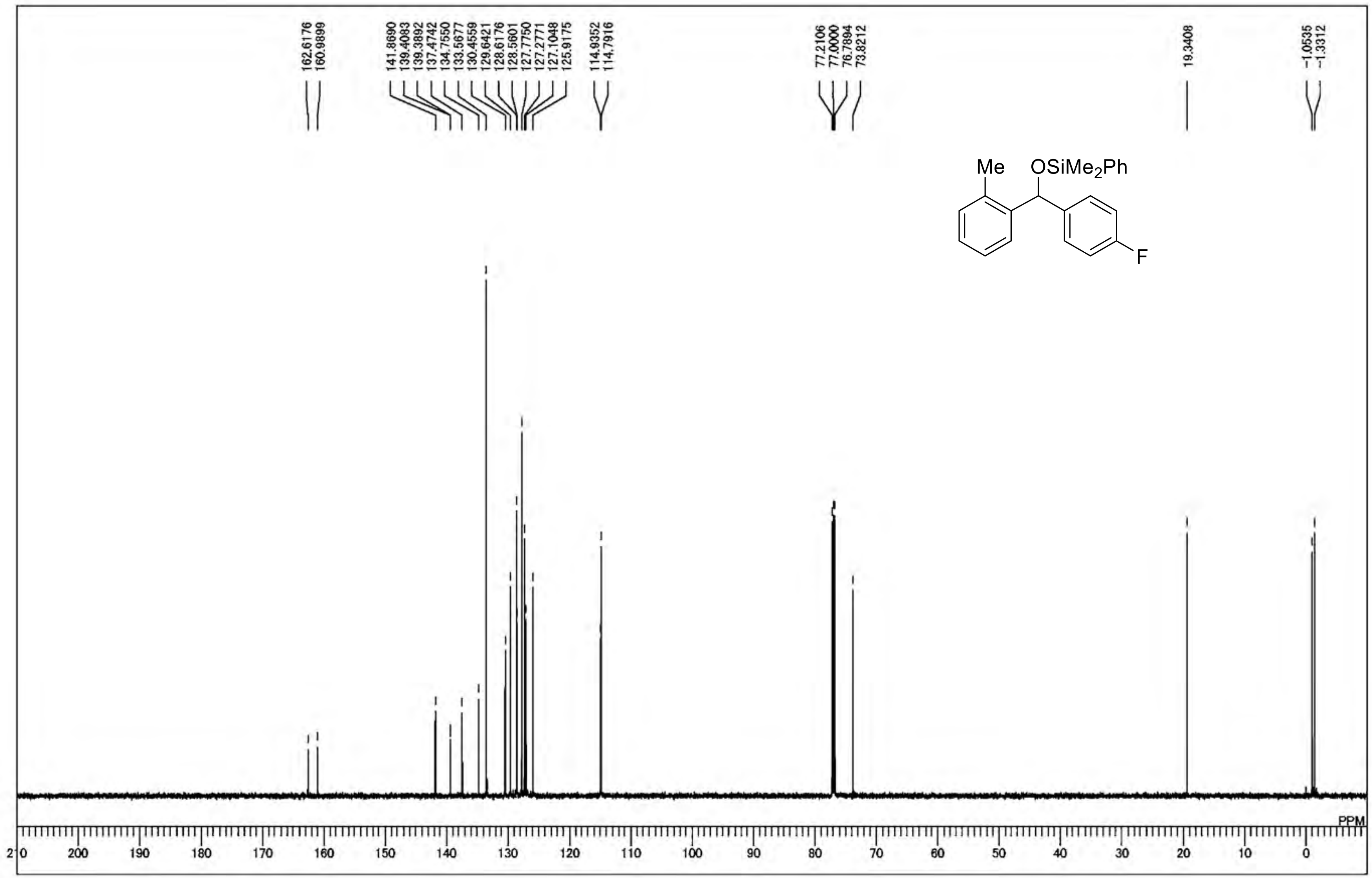
^{1}H NMR spectrum of **3ad**



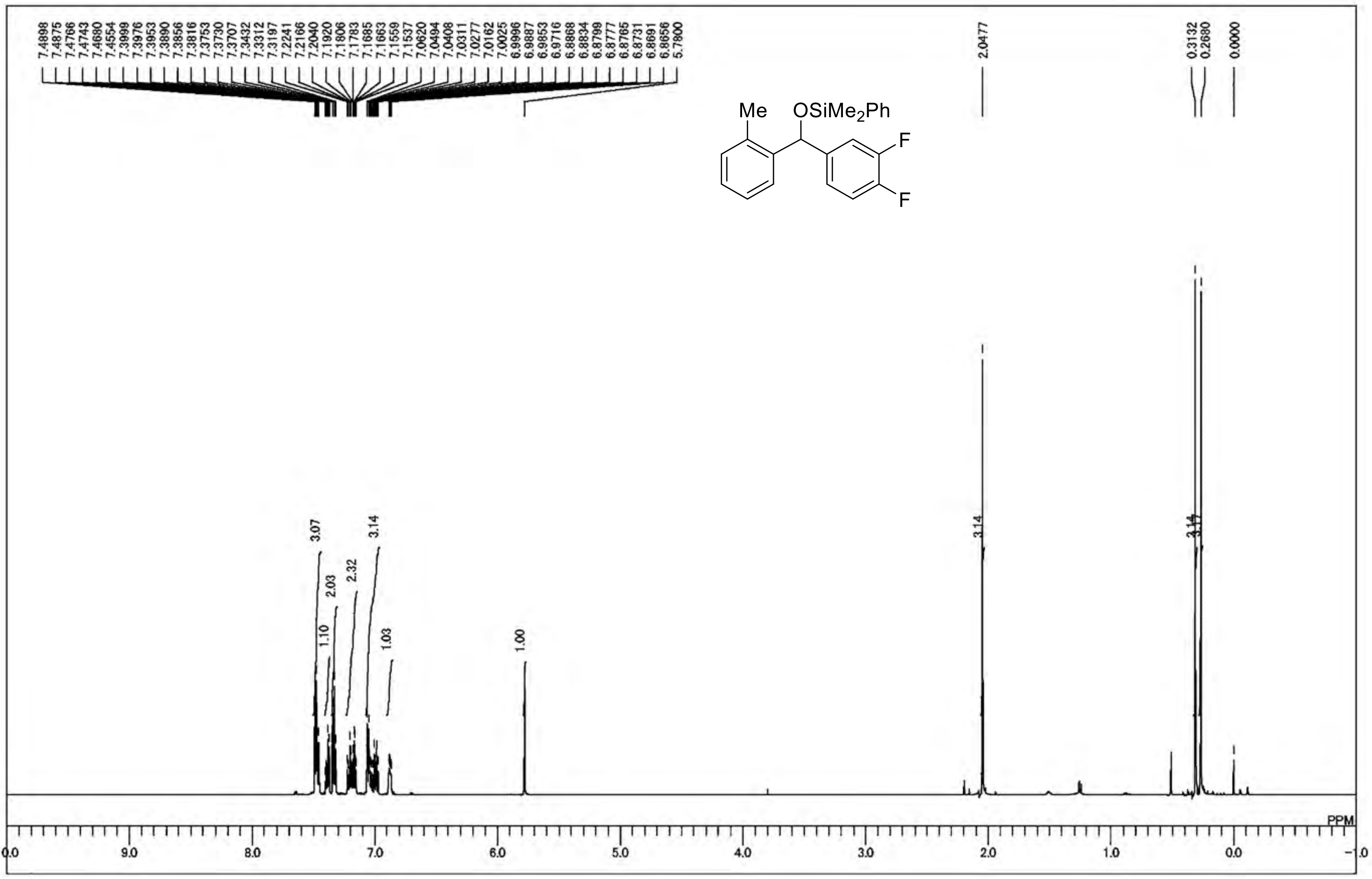
^{13}C NMR spectrum of **3ad**



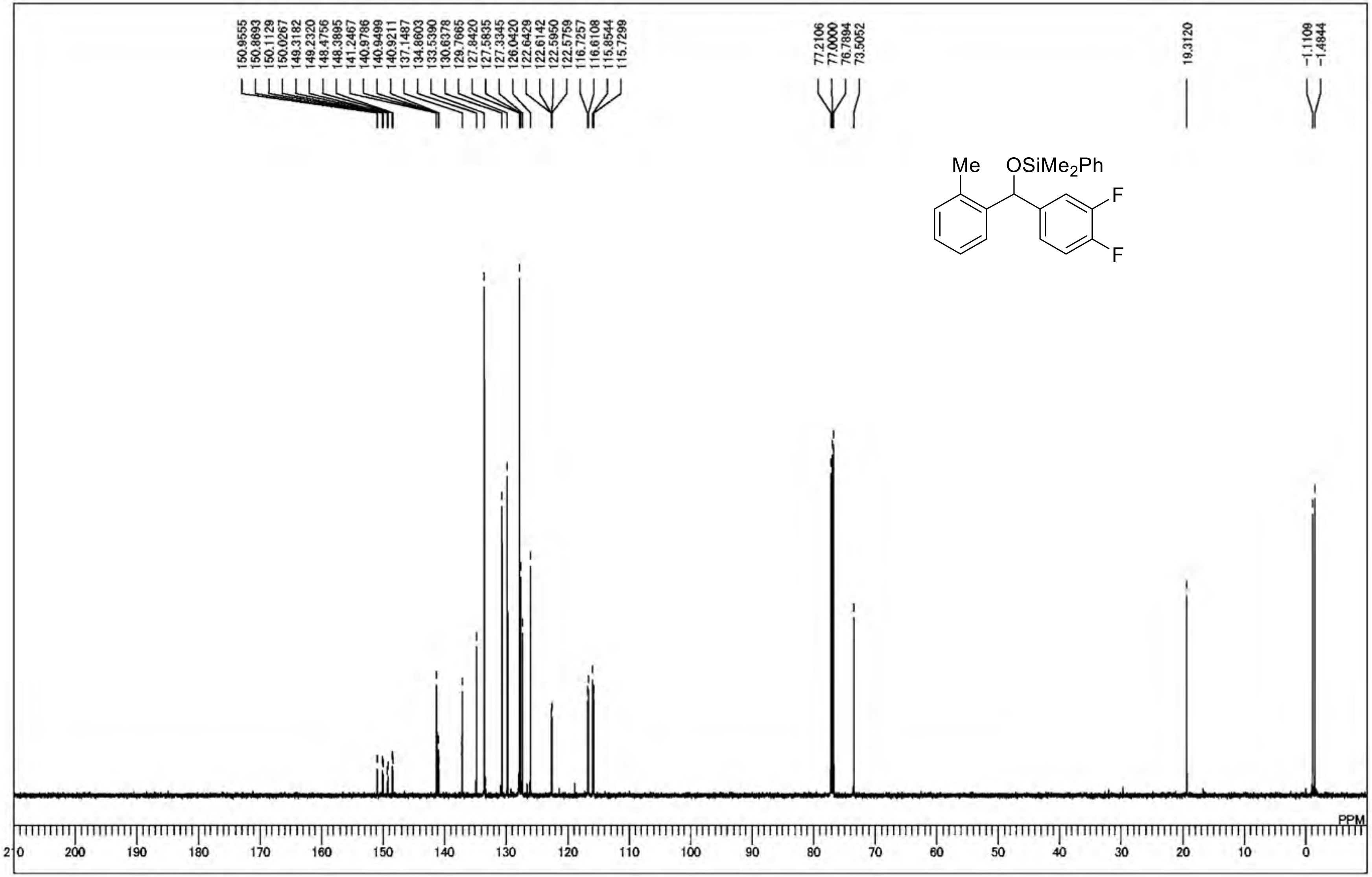
^{1}H NMR spectrum of **3ae**



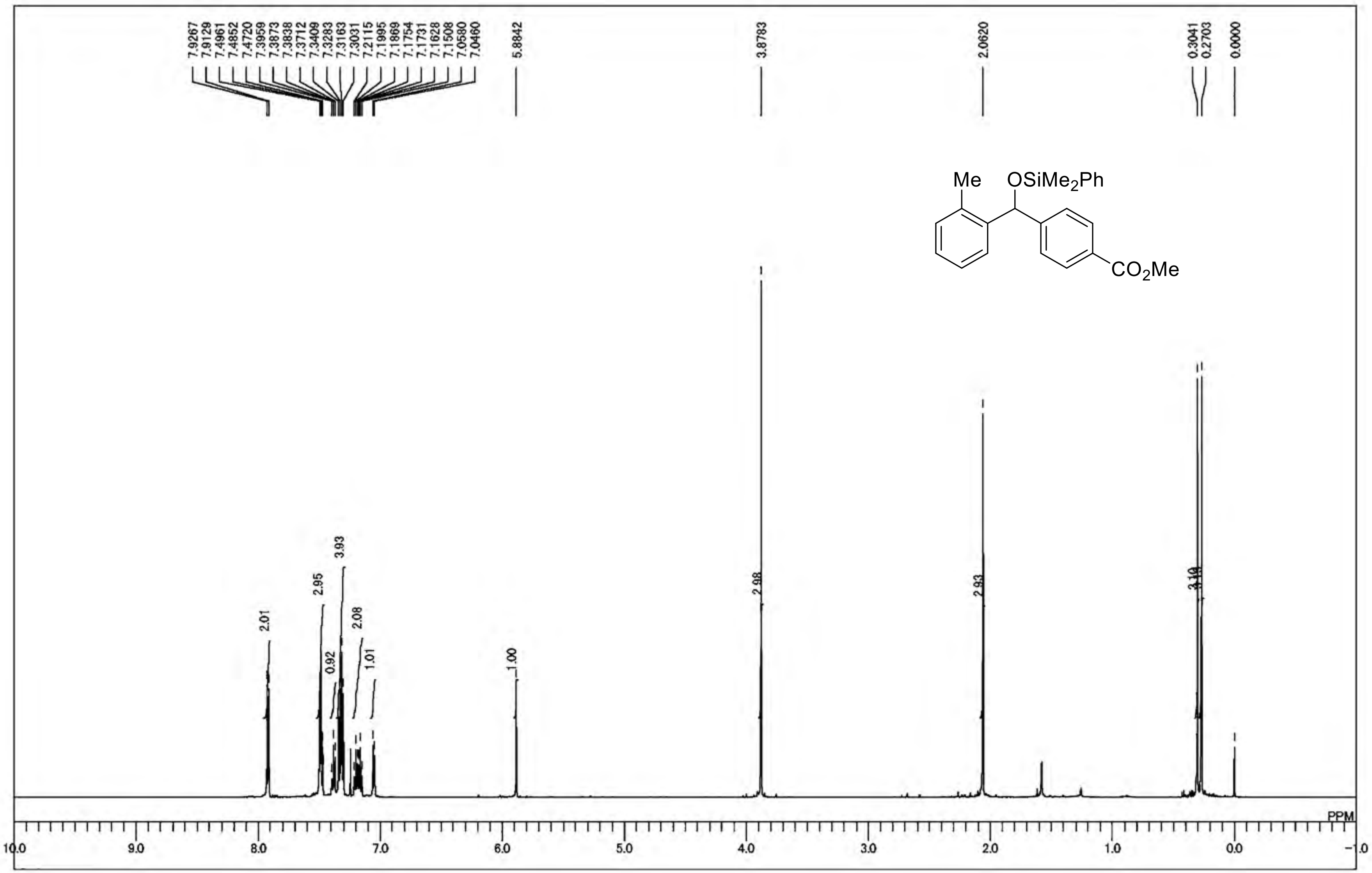
^{13}C NMR spectrum of **3ae**



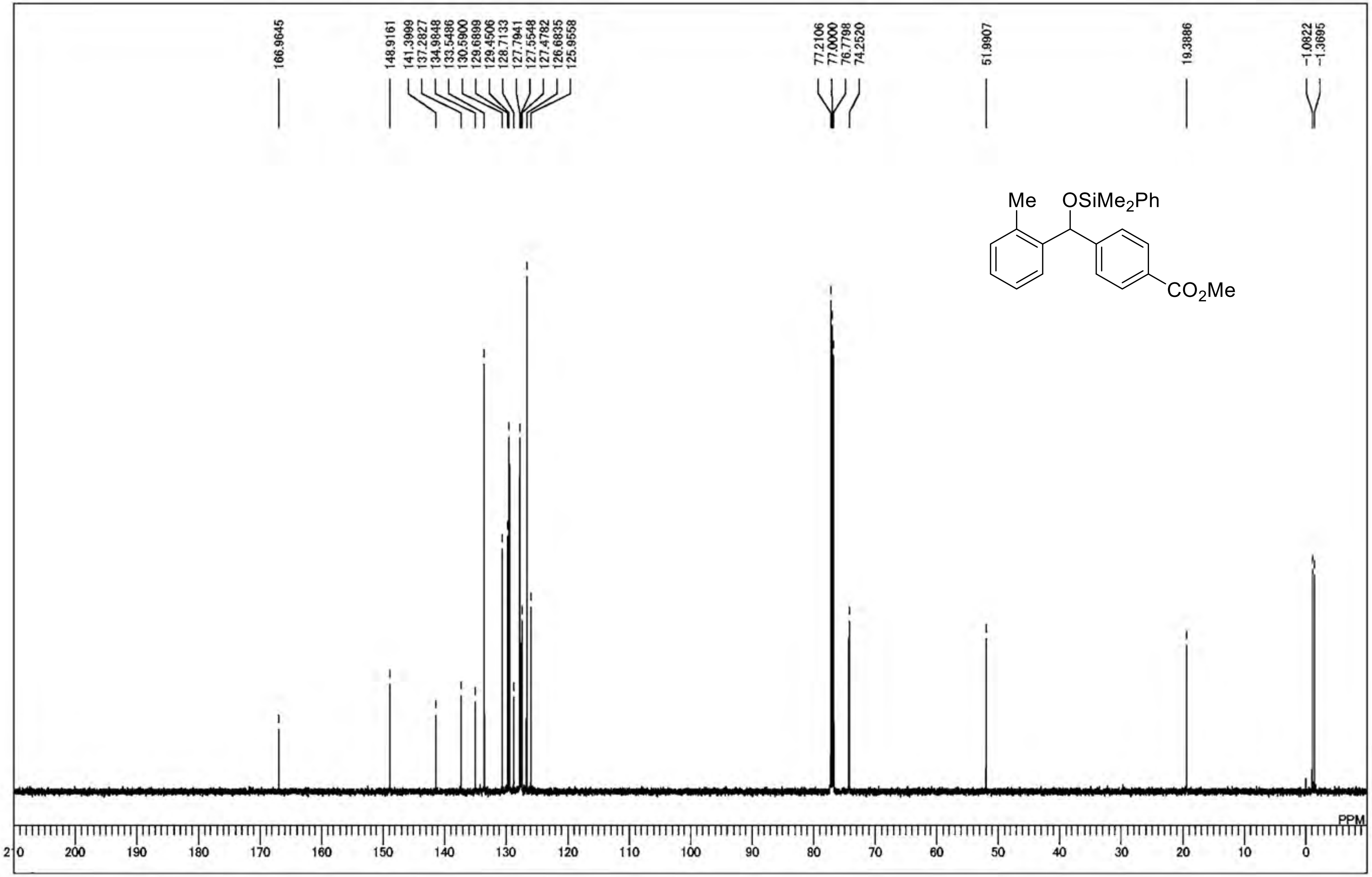
^{1}H NMR spectrum of **3af**



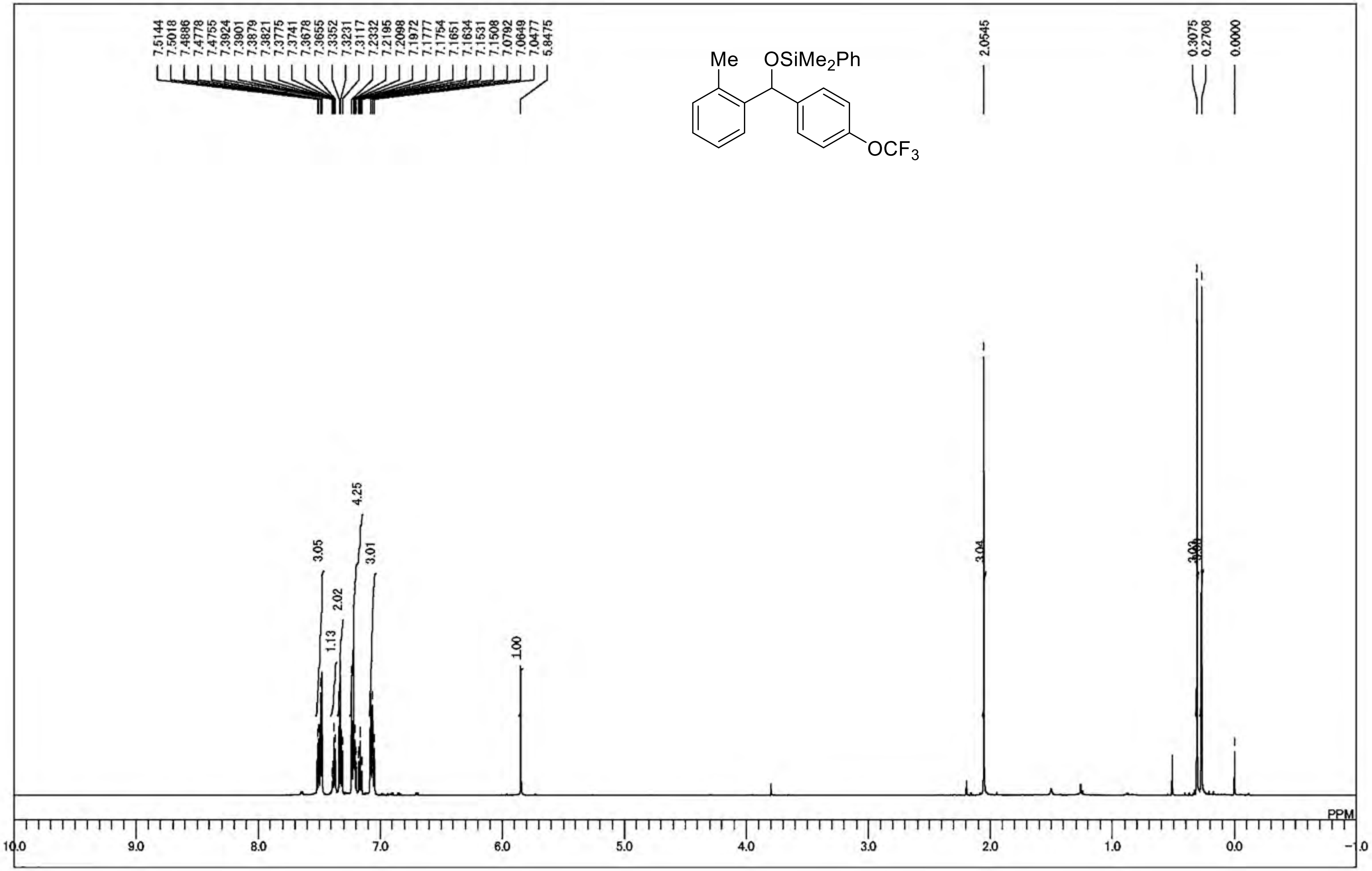
^{13}C NMR spectrum of **3af**



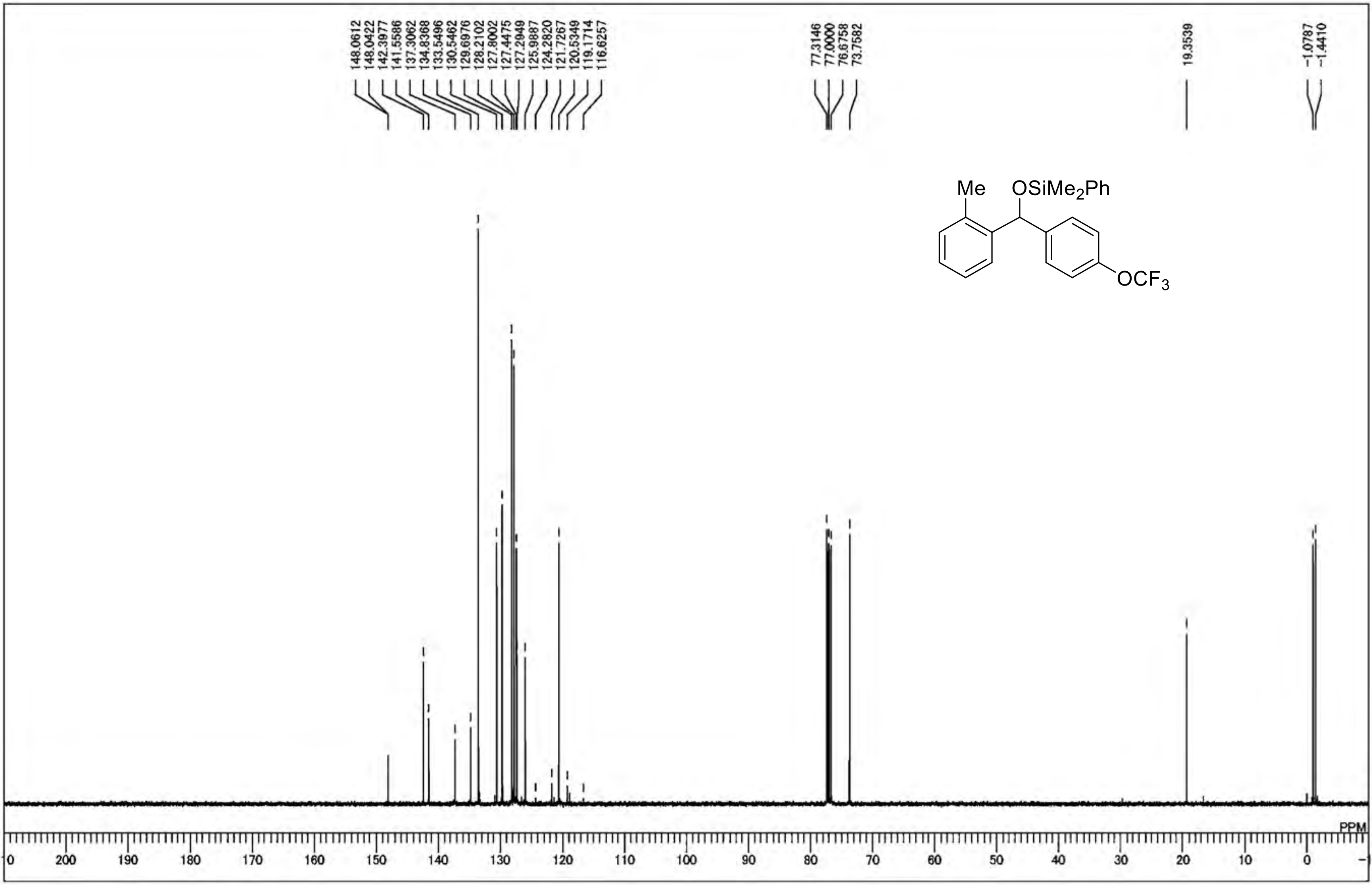
^{1}H NMR spectrum of **3ag**



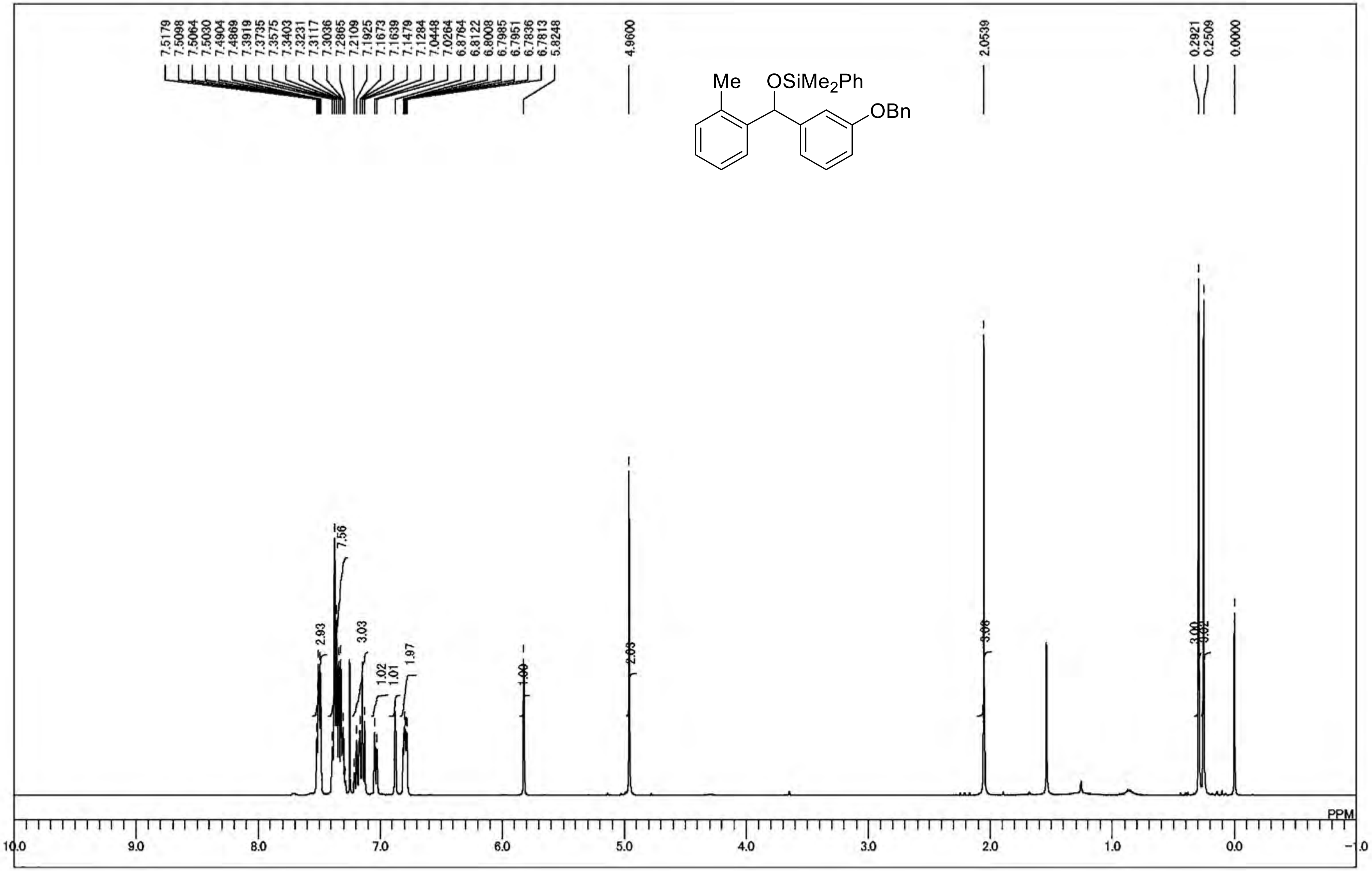
^{13}C NMR spectrum of **3ag**



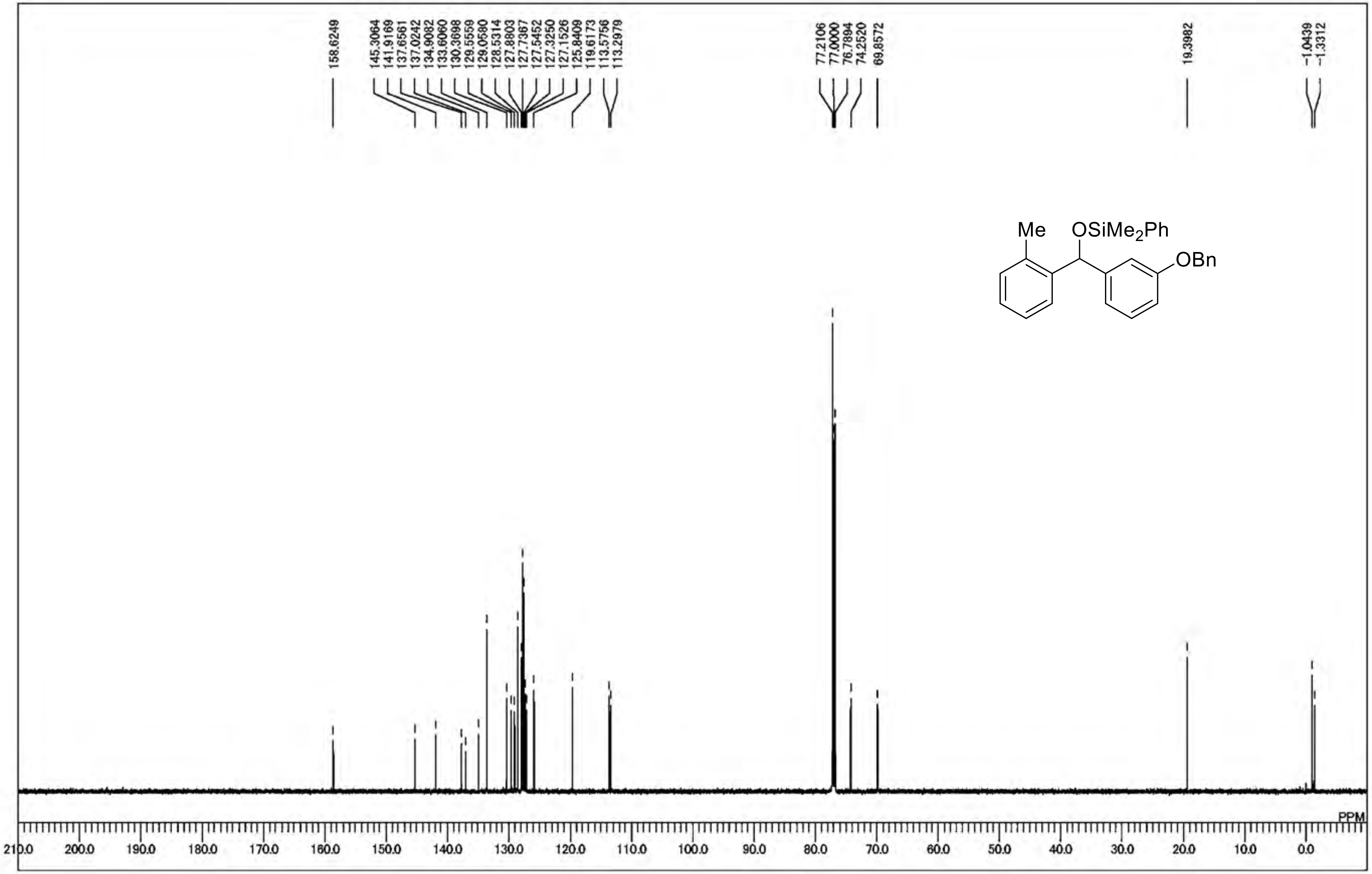
^{1}H NMR spectrum of **3ah**



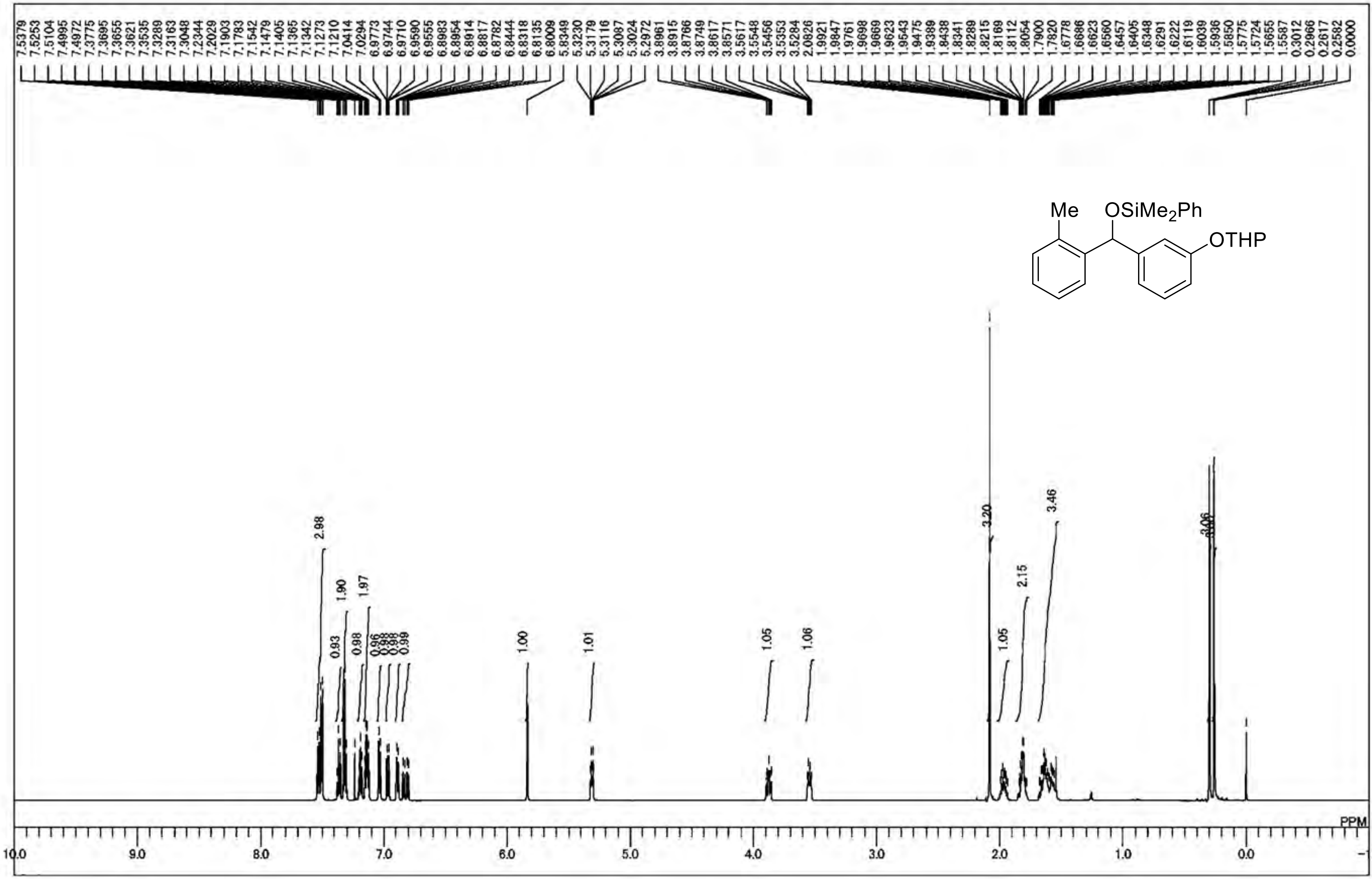
^{13}C NMR spectrum of **3ah**



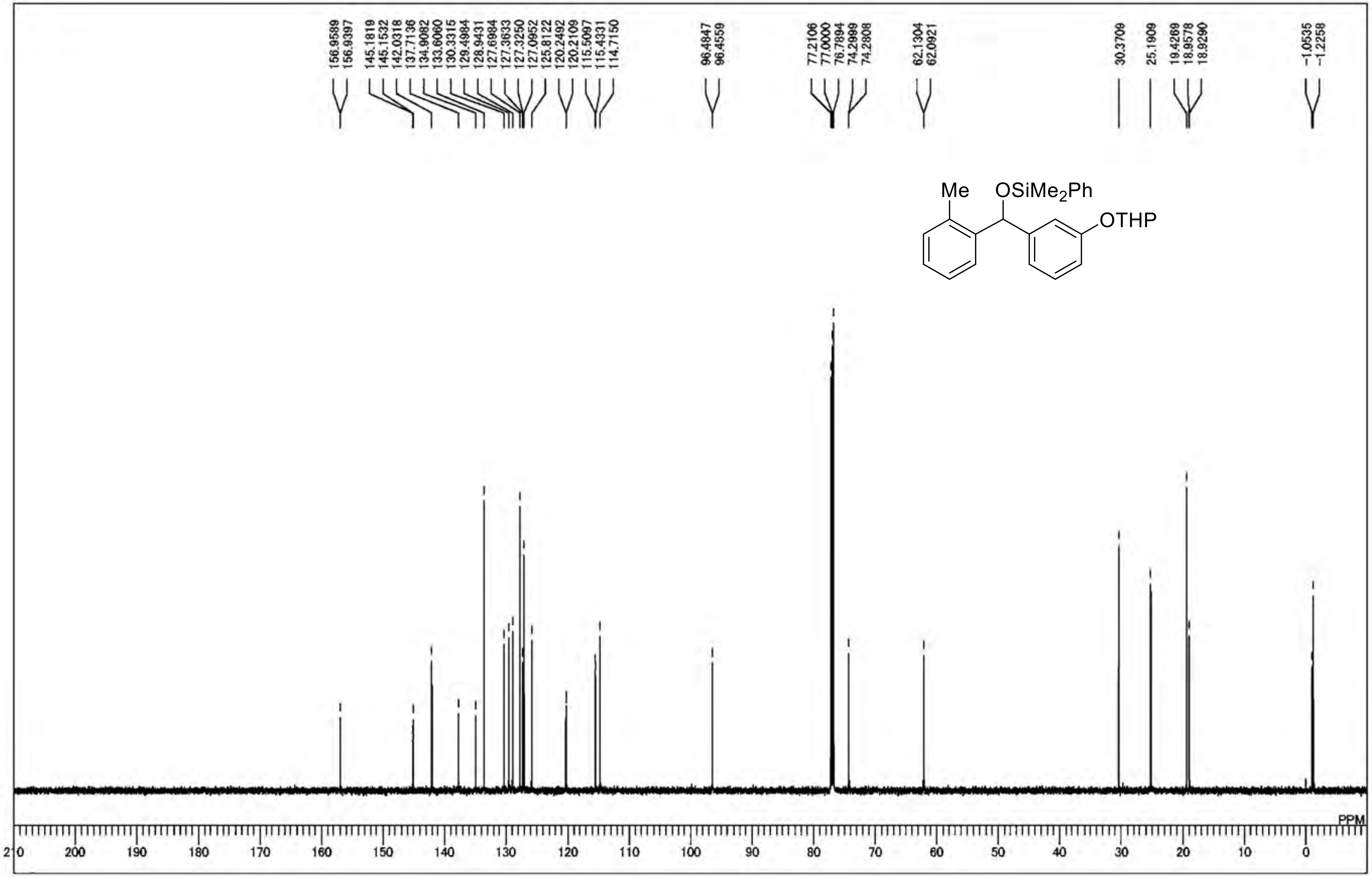
^{1}H NMR spectrum of **3ai**



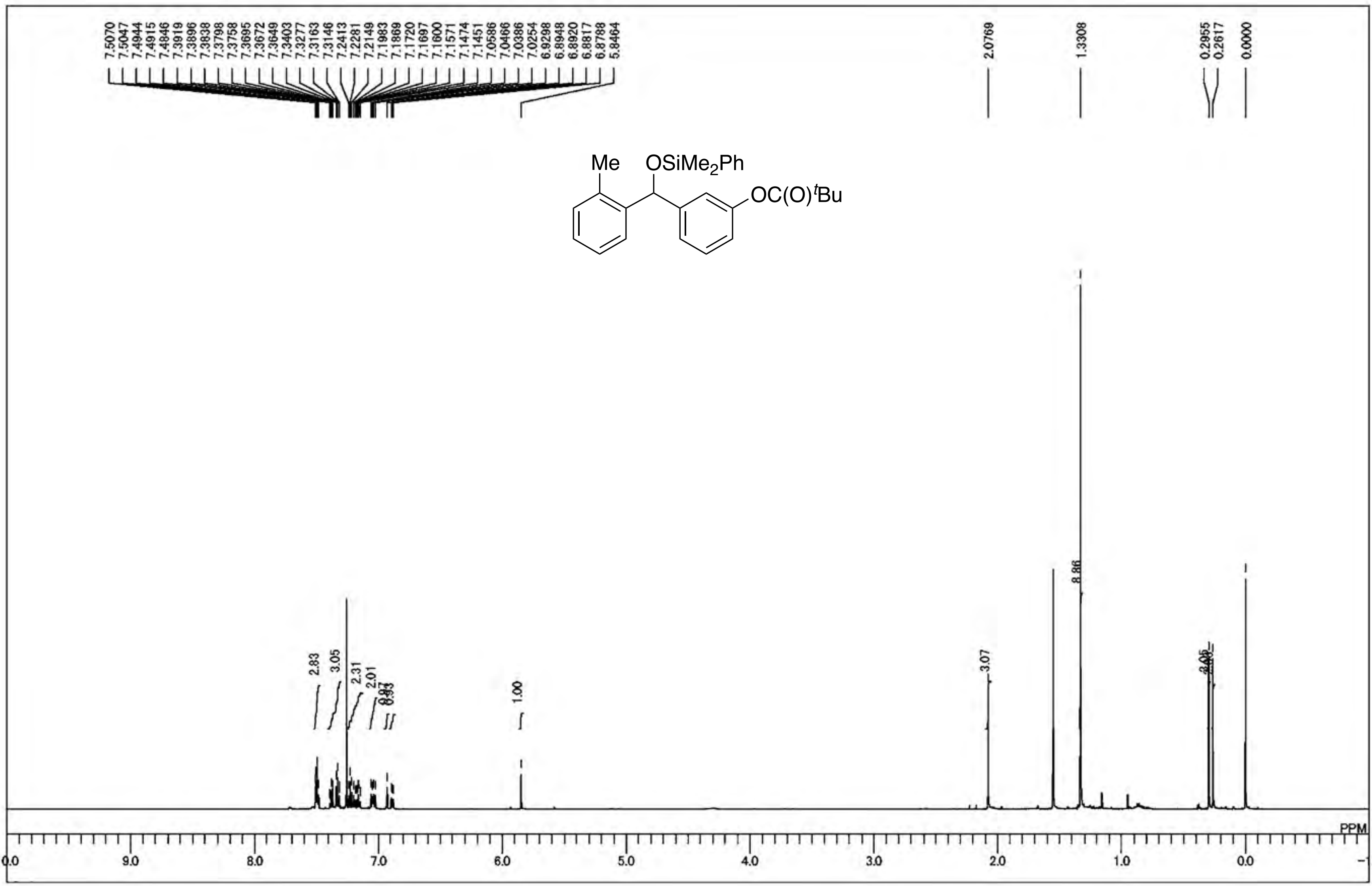
^{13}C NMR spectrum of **3ai**



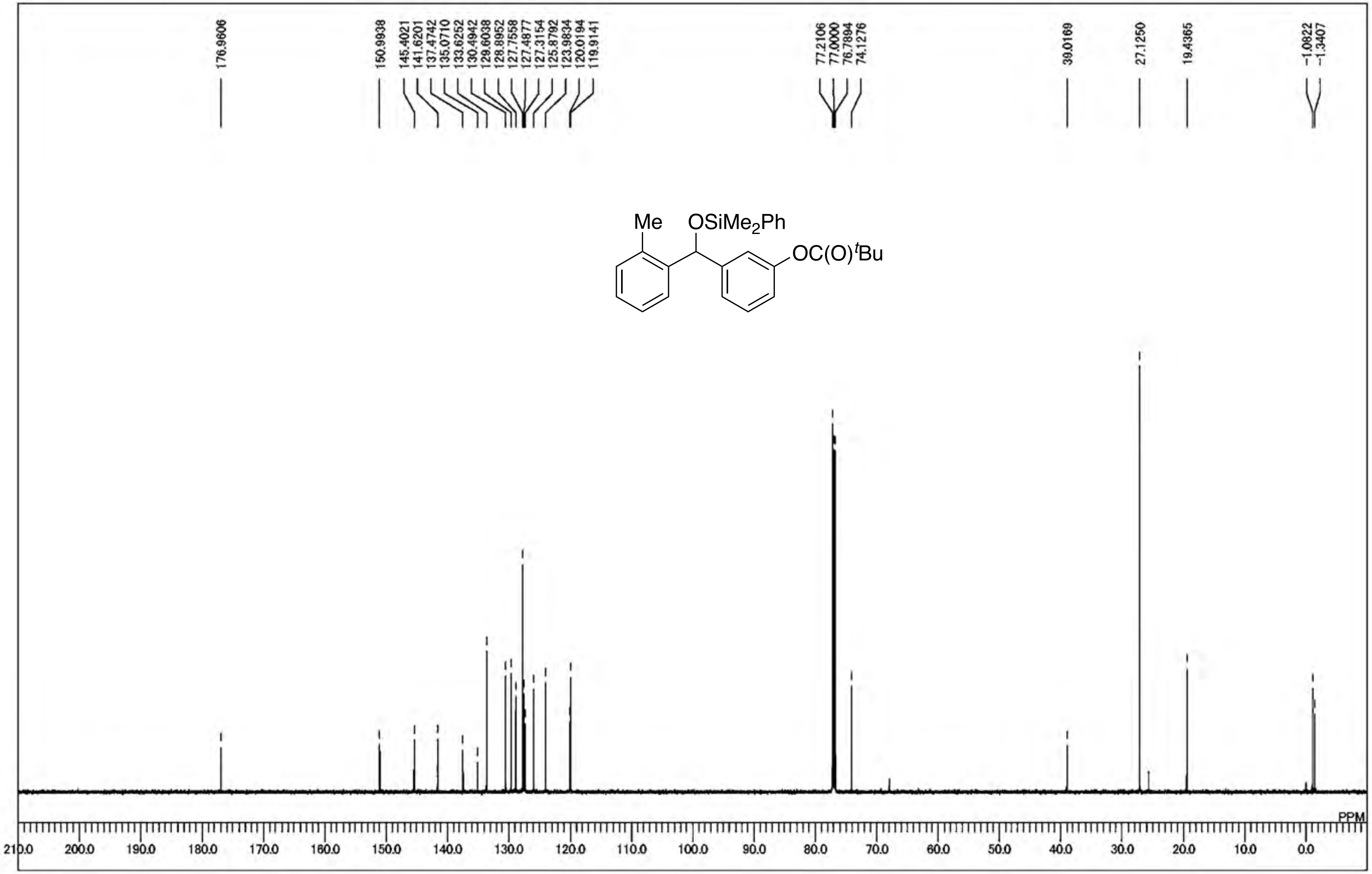
^{1}H NMR spectrum of **3aj**



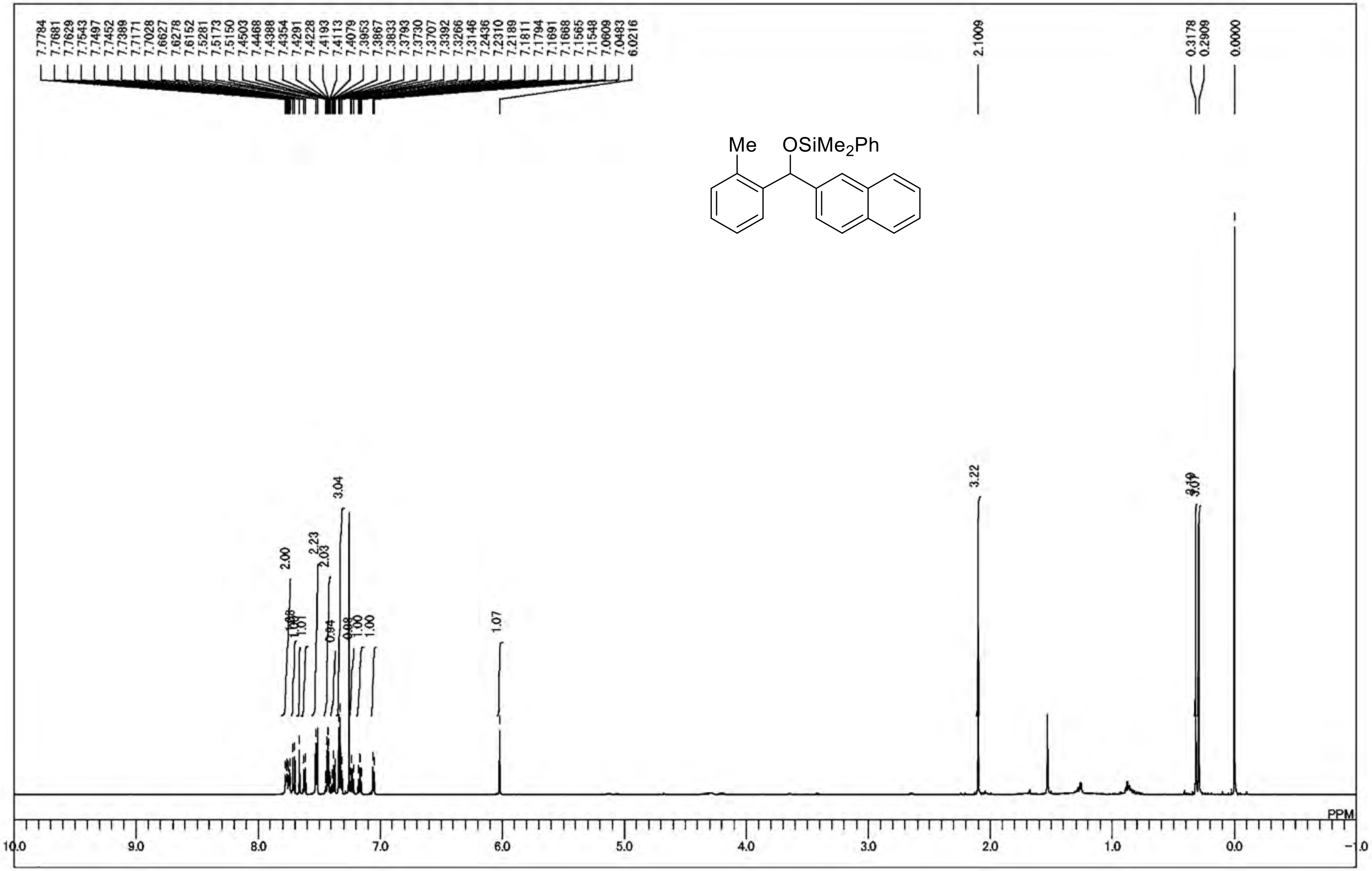
^{13}C NMR spectrum of **3aj**



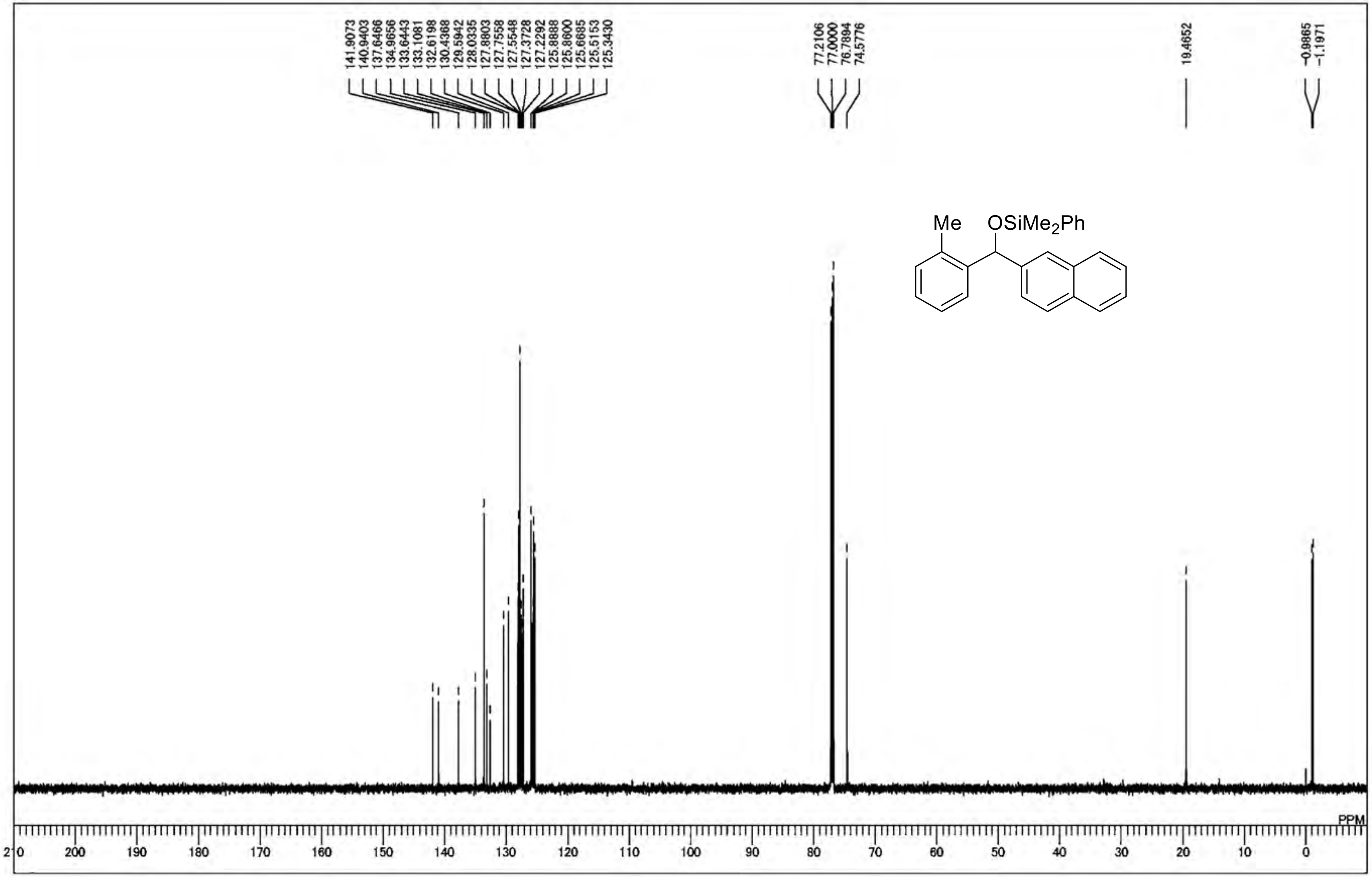
^{1}H NMR spectrum of **3ak**



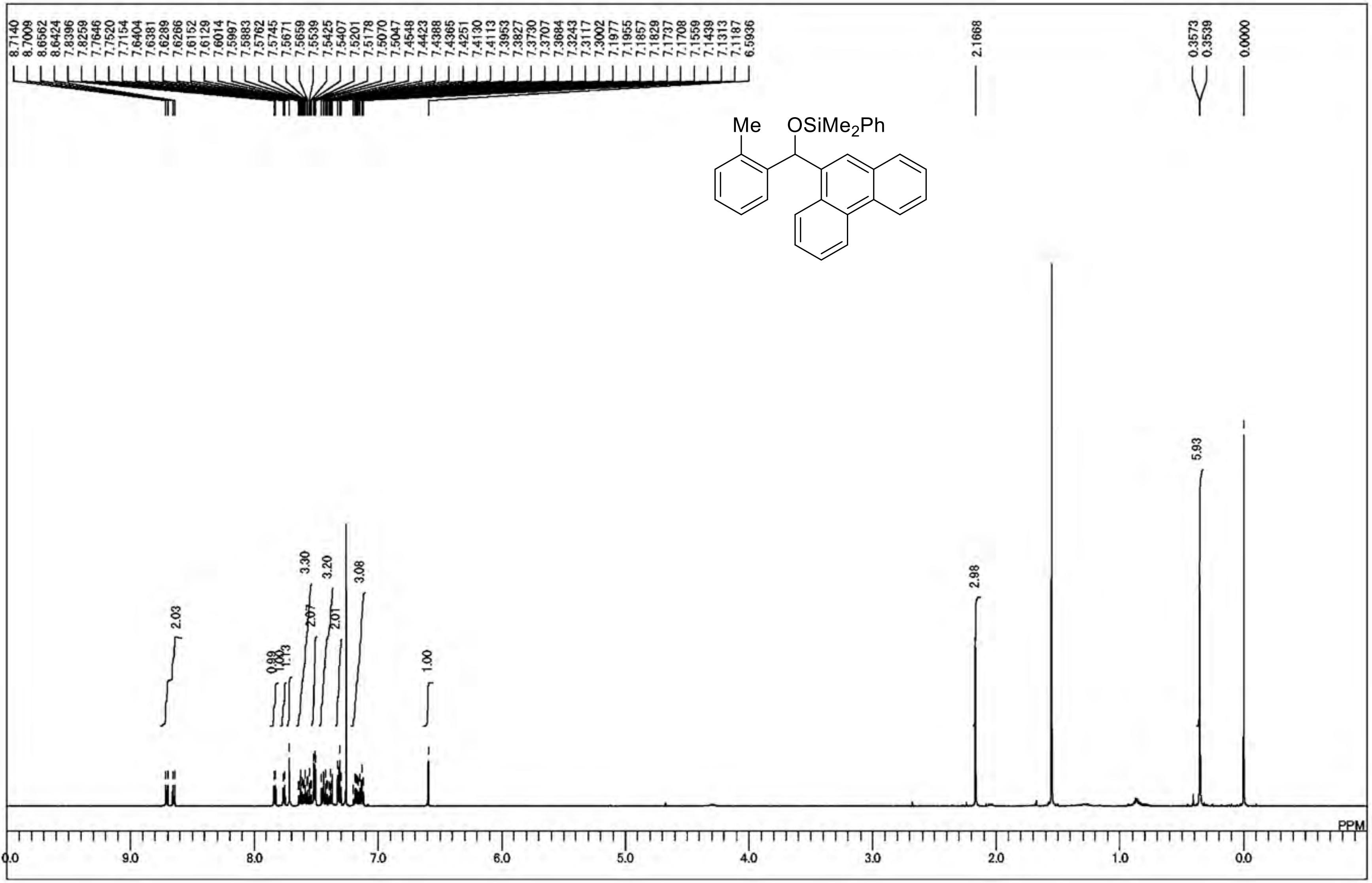
^{13}C NMR spectrum of **3ak**



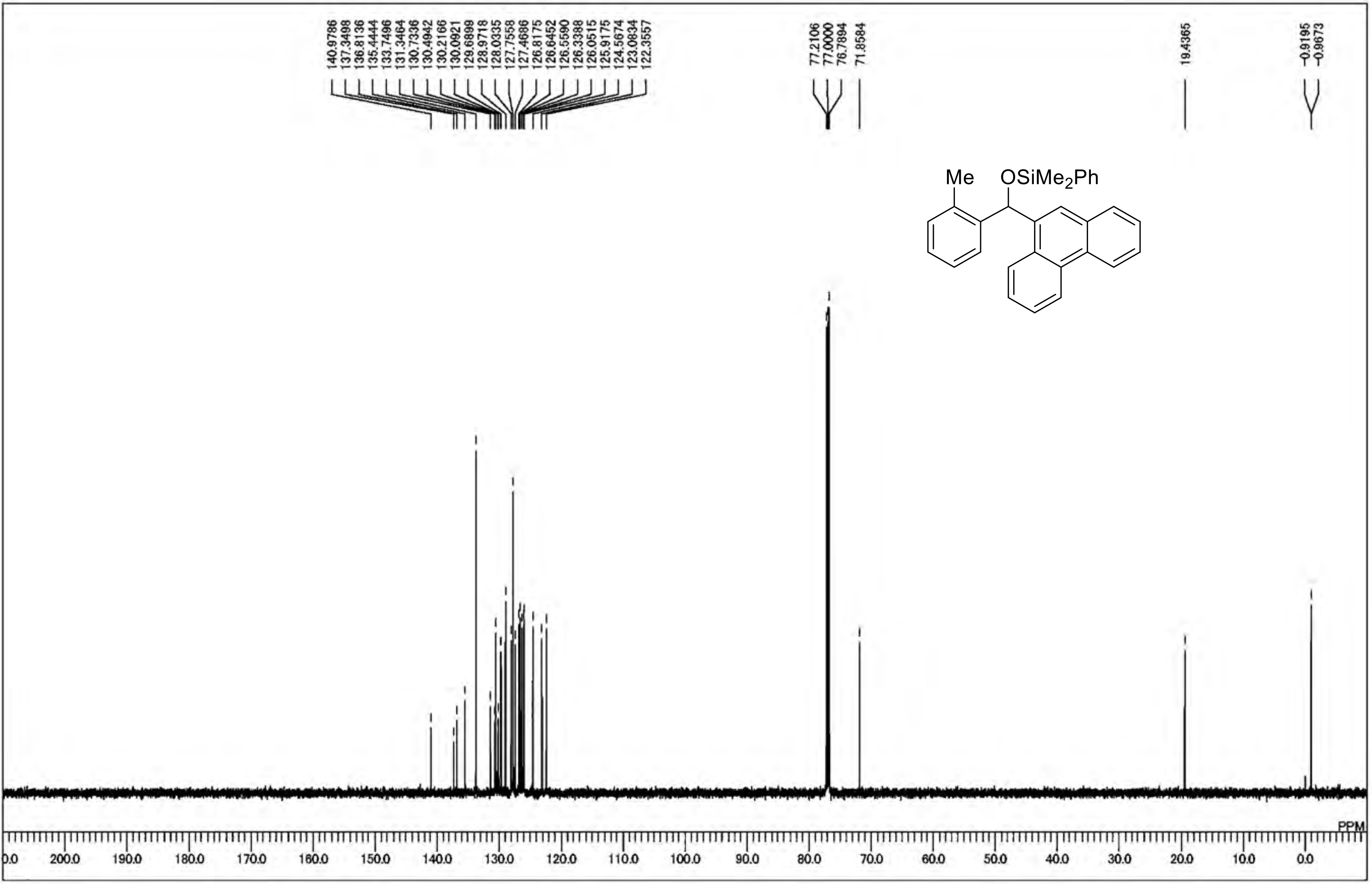
^{1}H NMR spectrum of **3al**



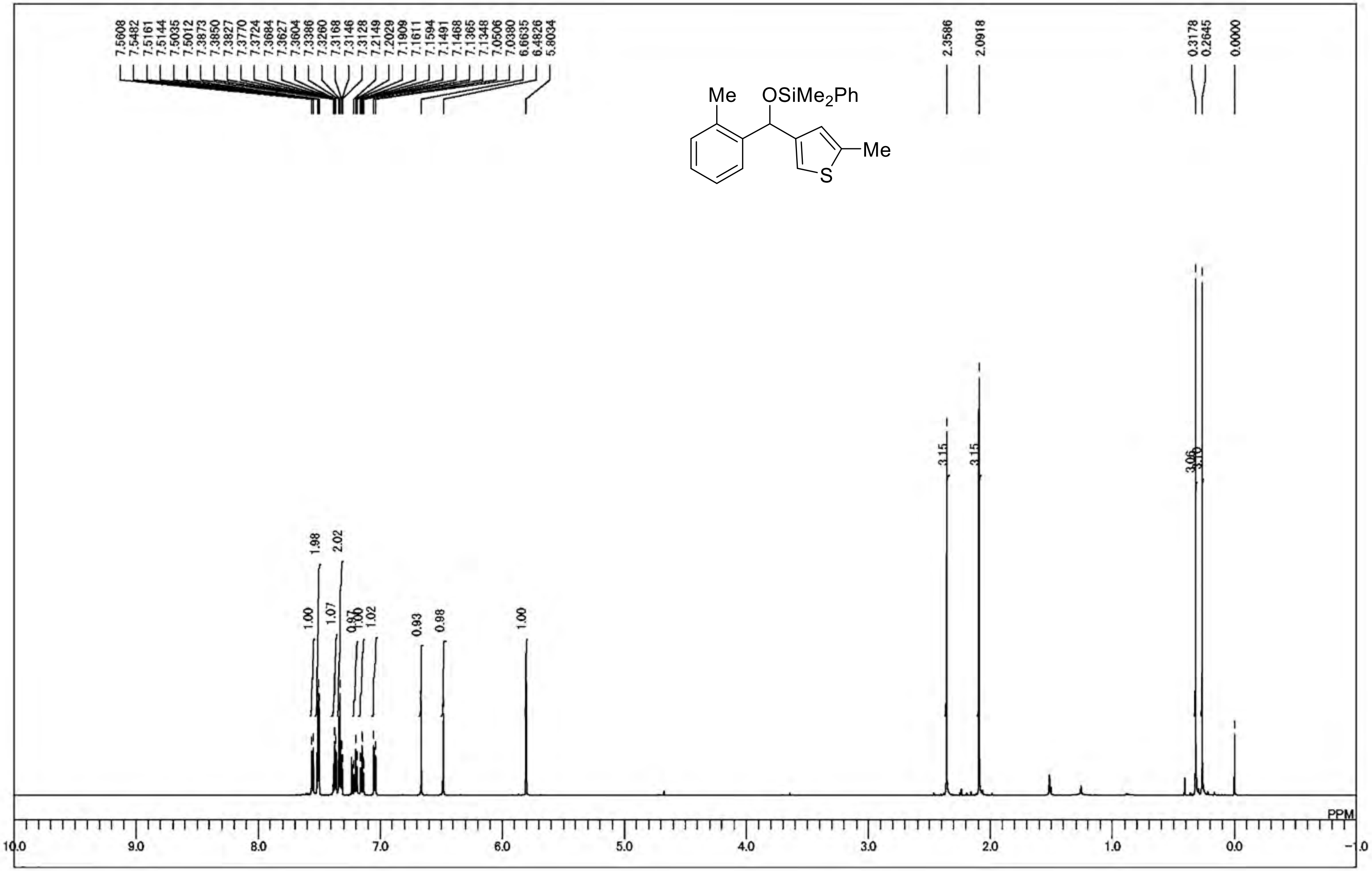
^{13}C NMR spectrum of **3al**



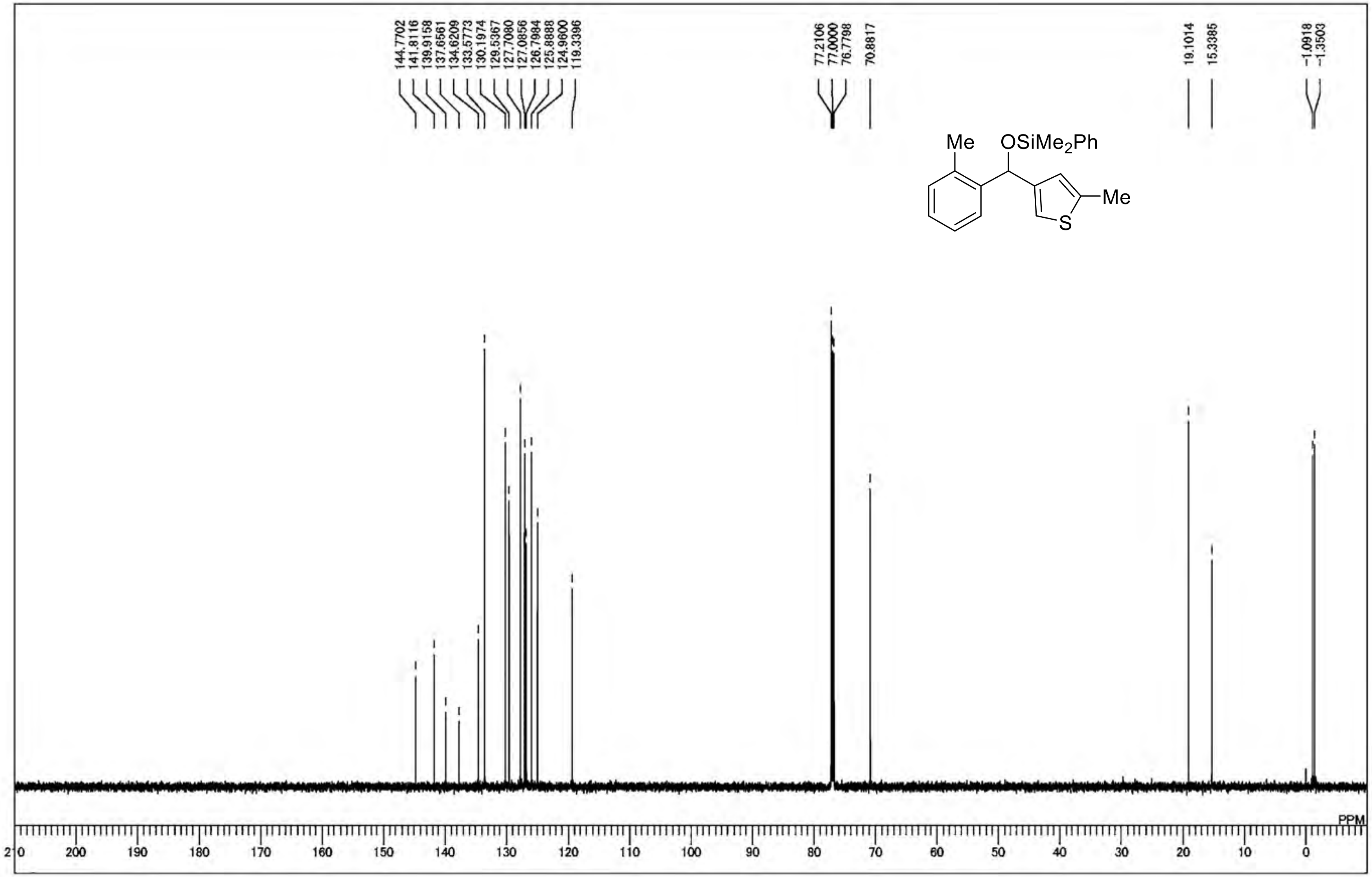
^{1}H NMR spectrum of **3am**



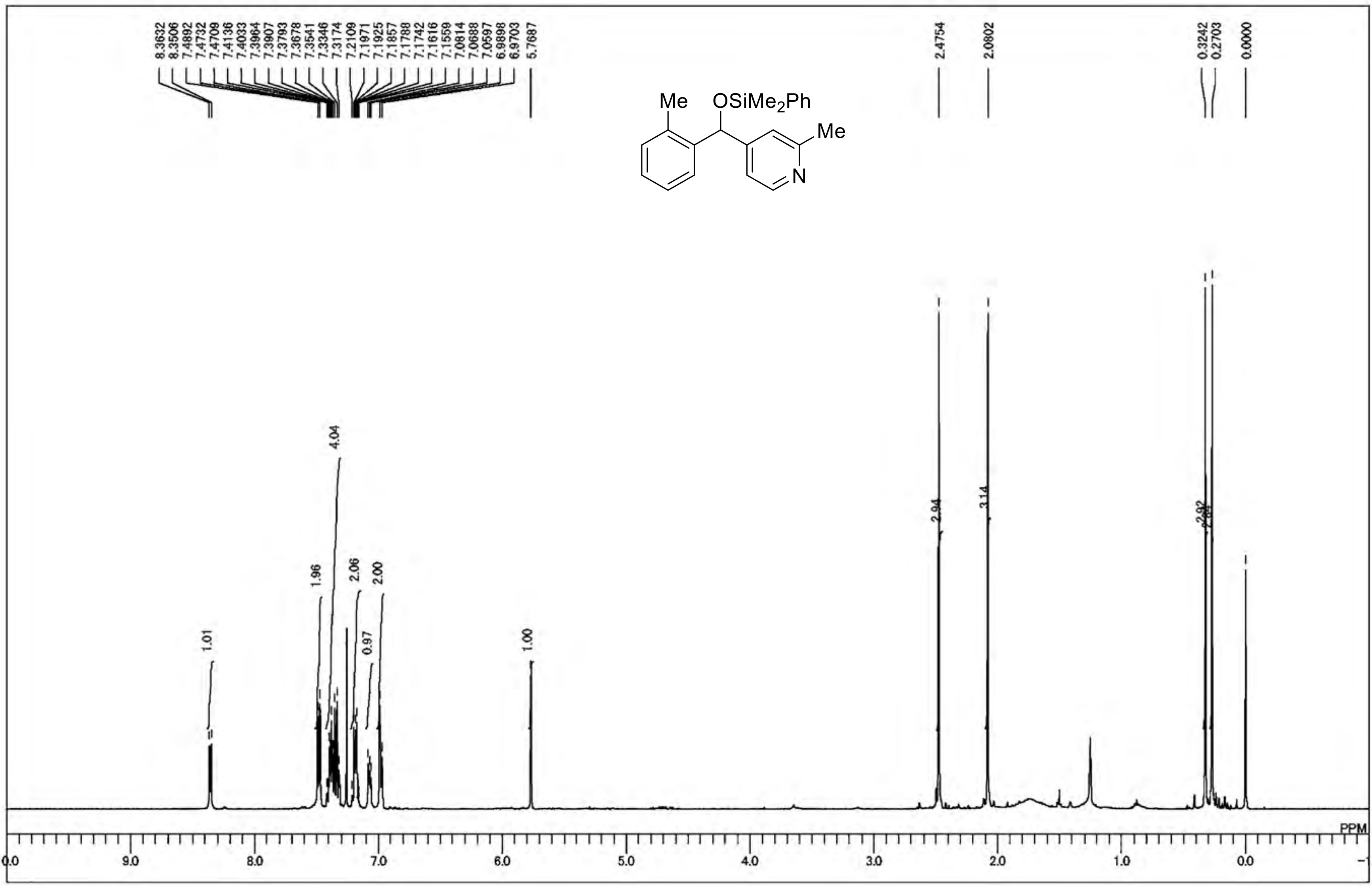
^{13}C NMR spectrum of **3am**



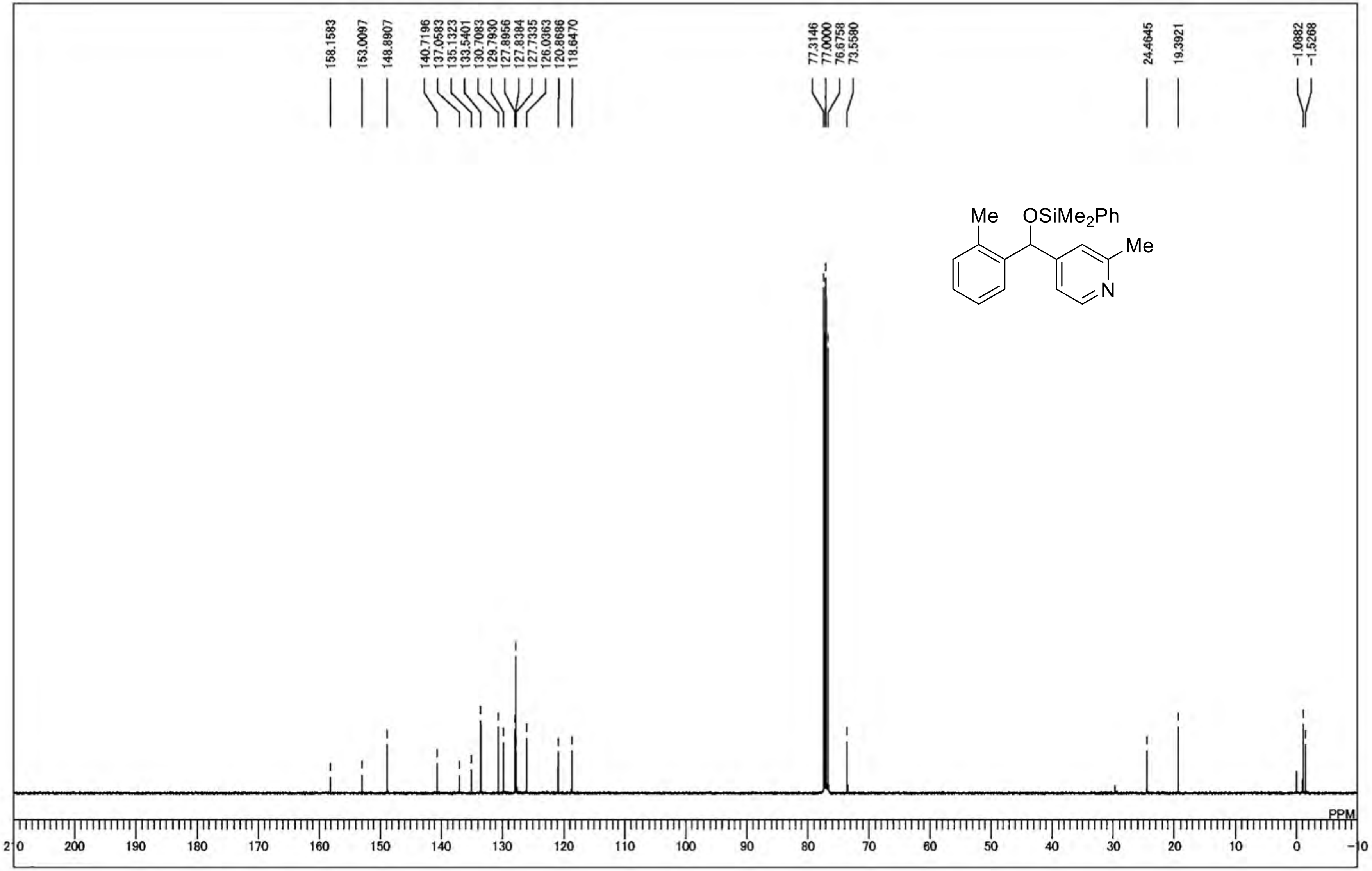
^{1}H NMR spectrum of **3ao**



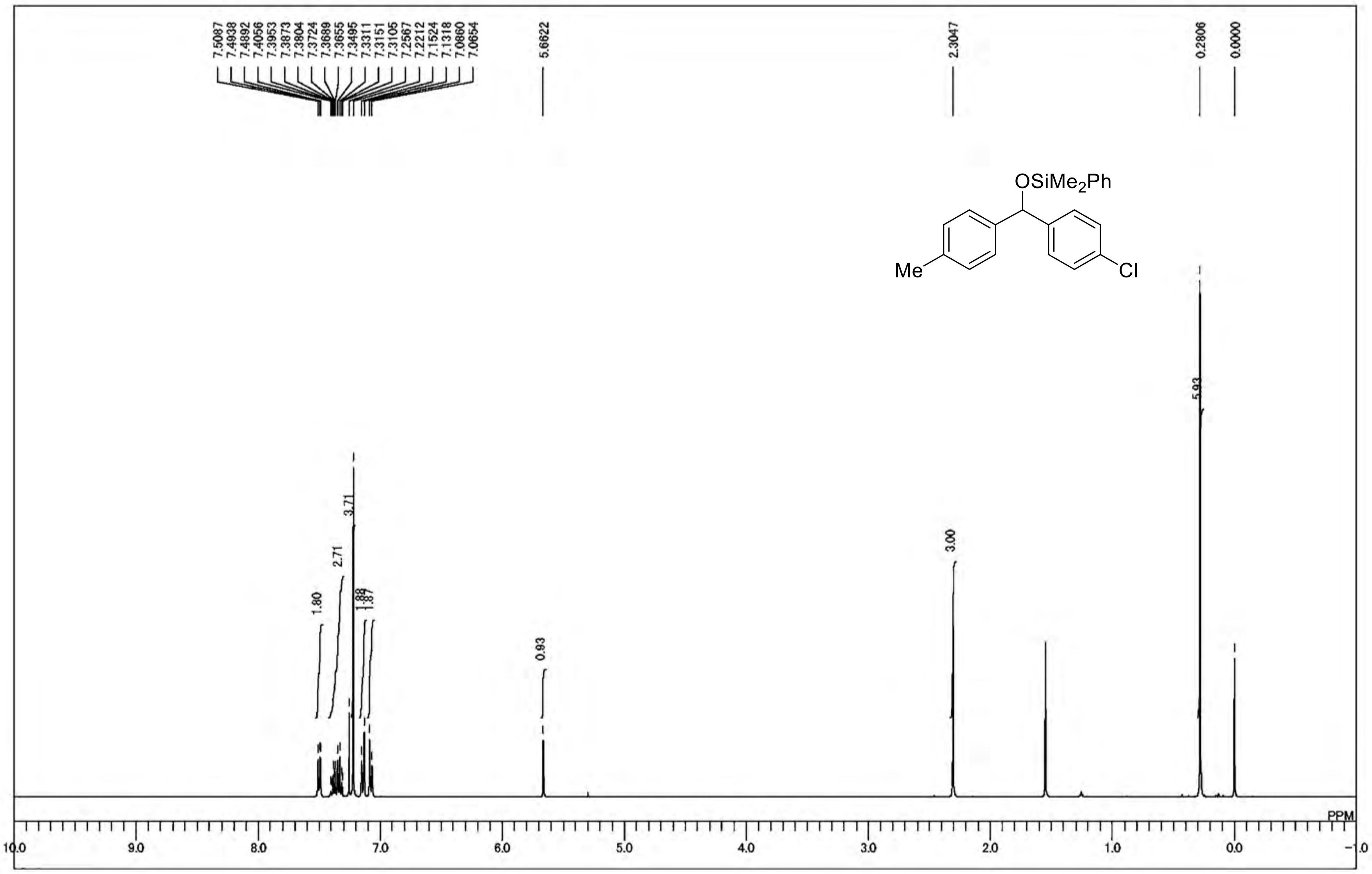
^{13}C NMR spectrum of **3ao**



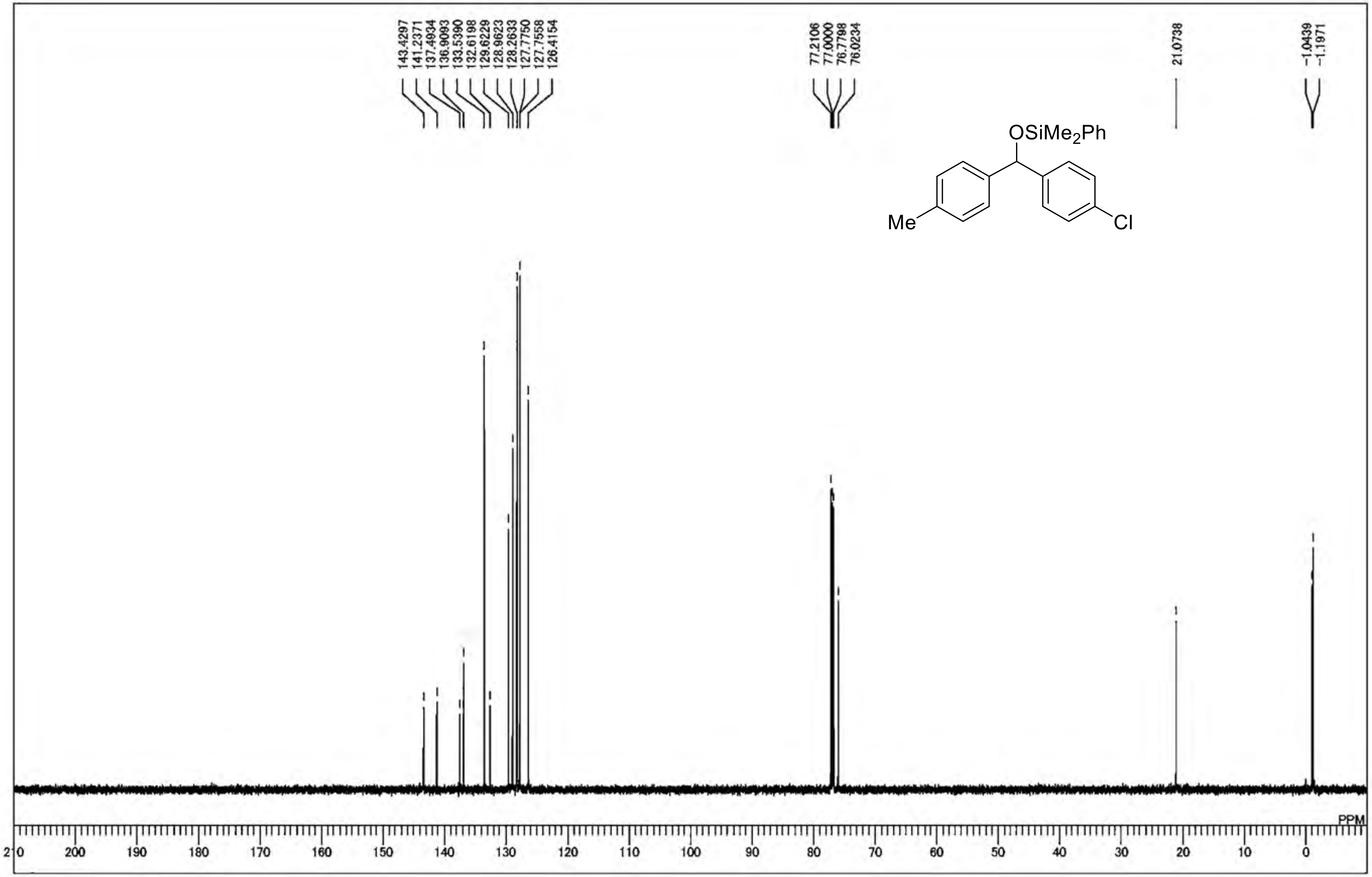
^{1}H NMR spectrum of **3ap**



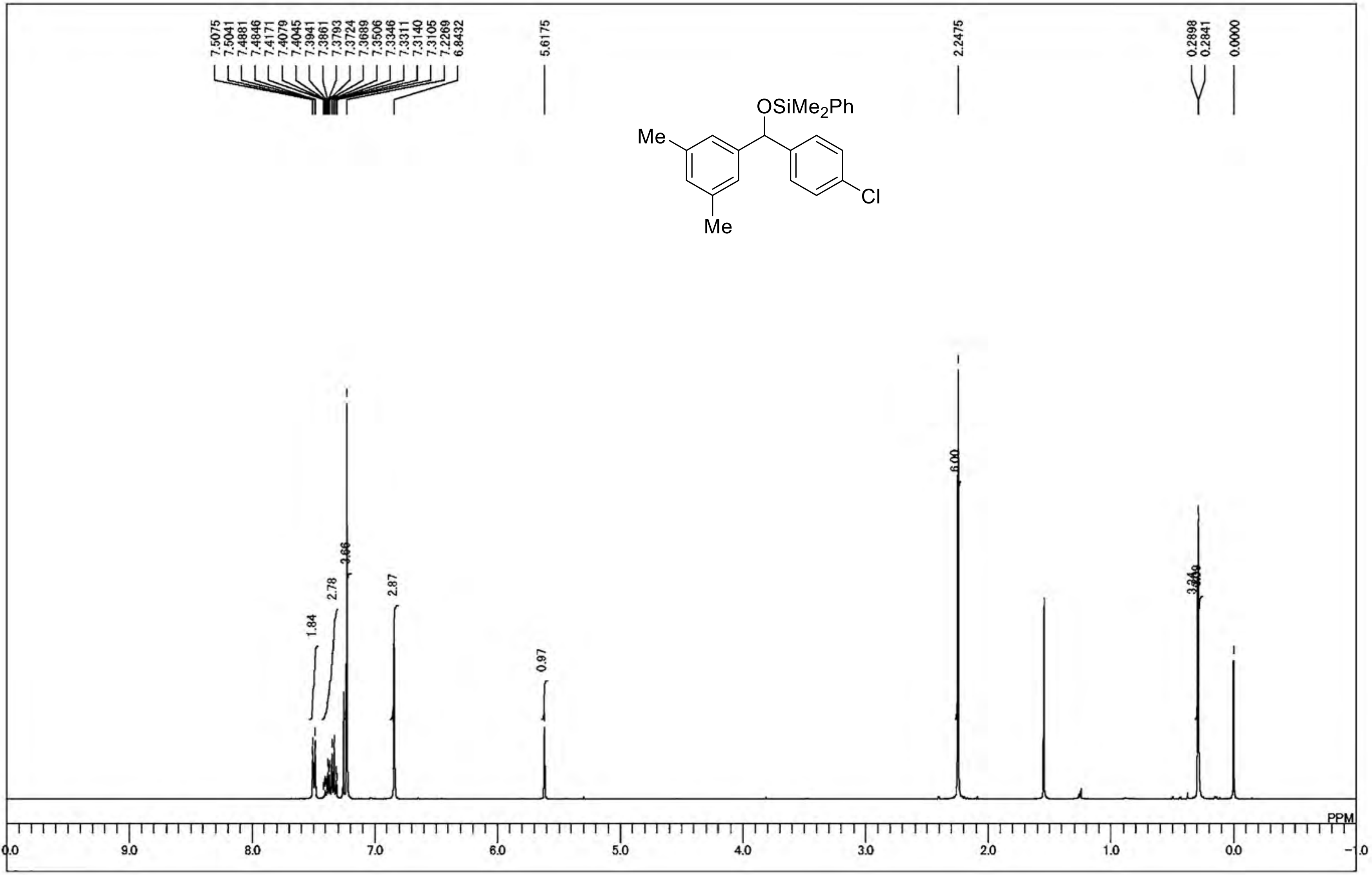
^{13}C NMR spectrum of **3ap**



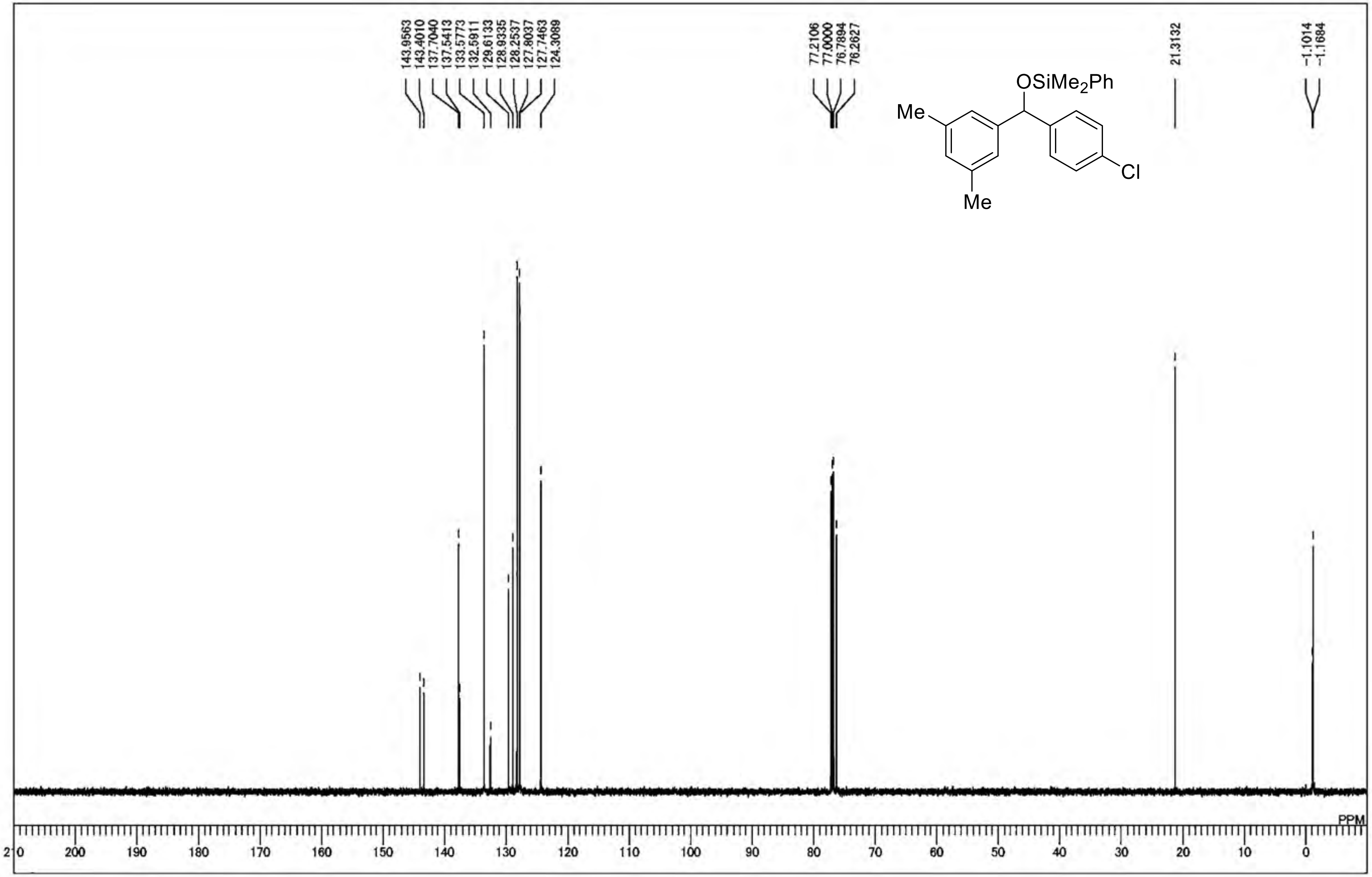
^{1}H NMR spectrum of **3cd**



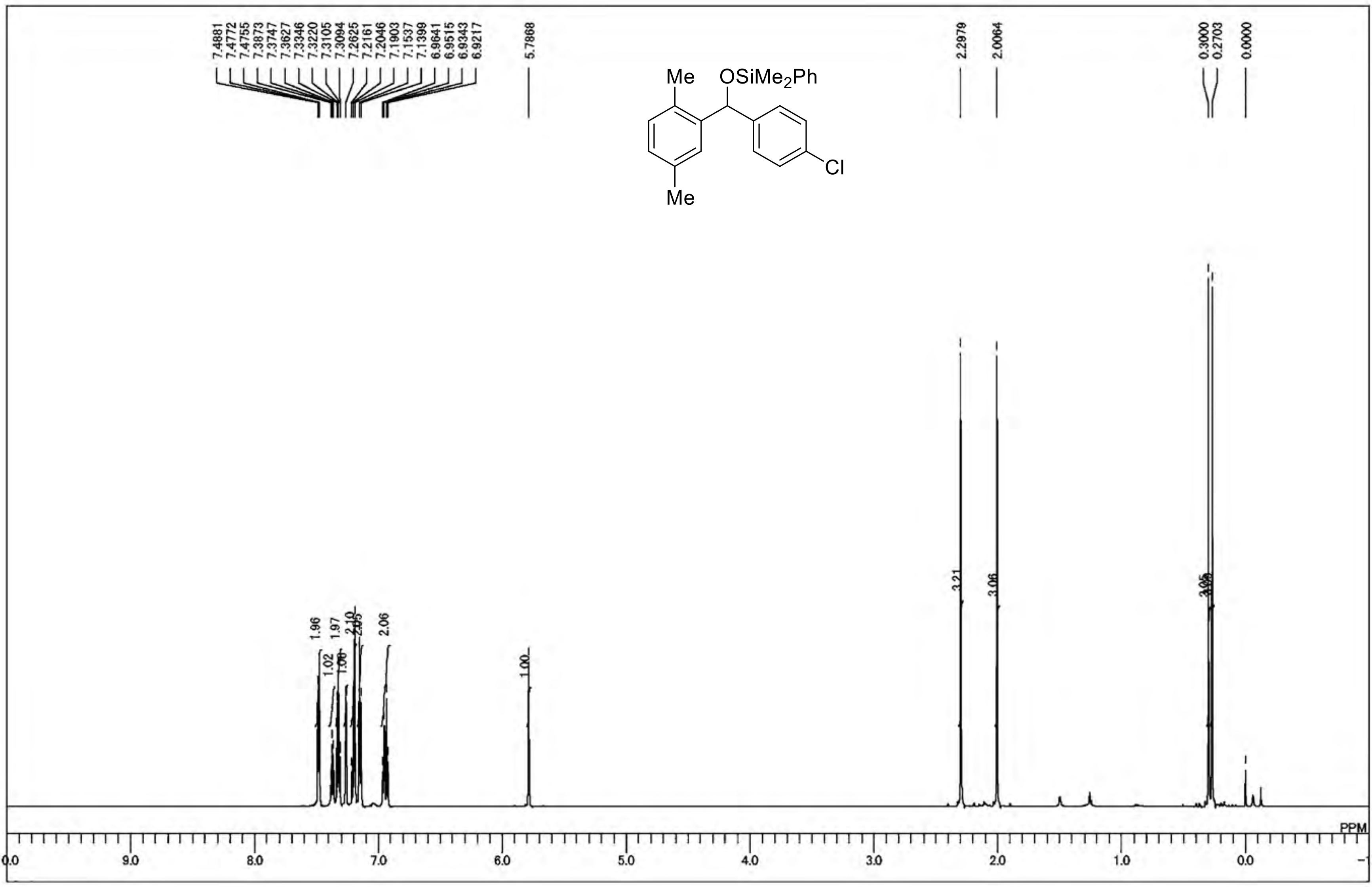
^{13}C NMR spectrum of **3cd**



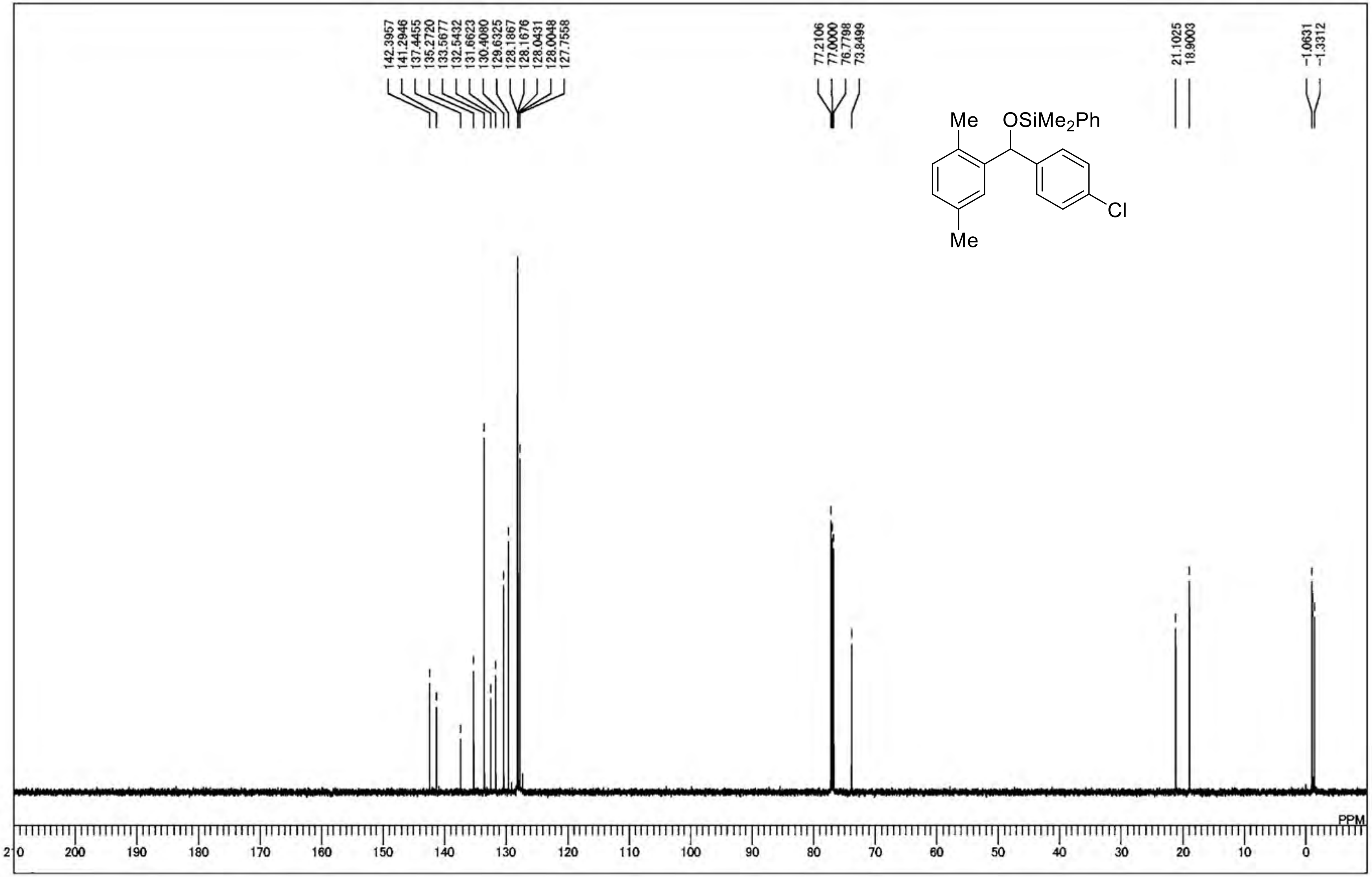
^{1}H NMR spectrum of **3dd**



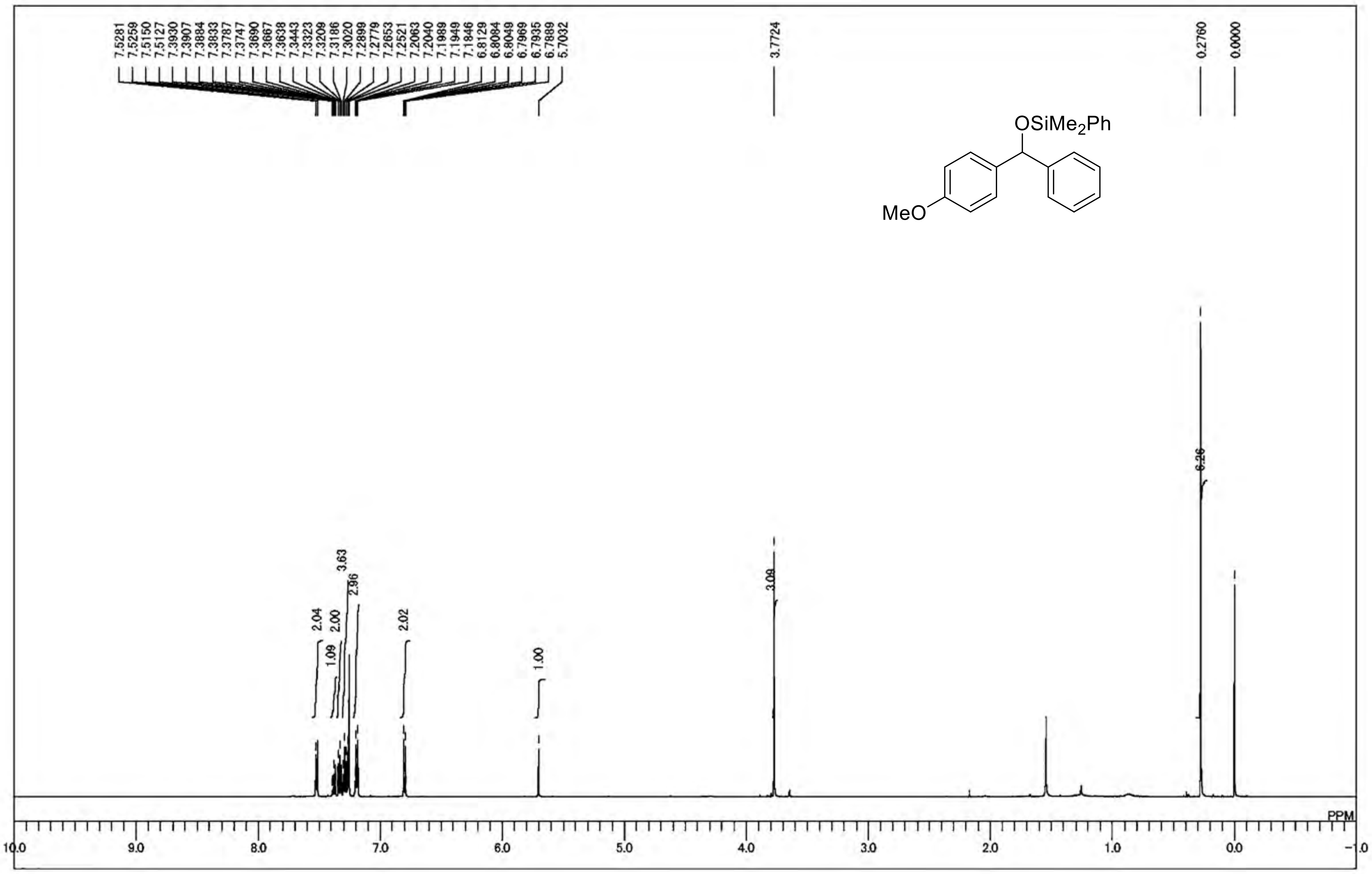
^{13}C NMR spectrum of **3dd**



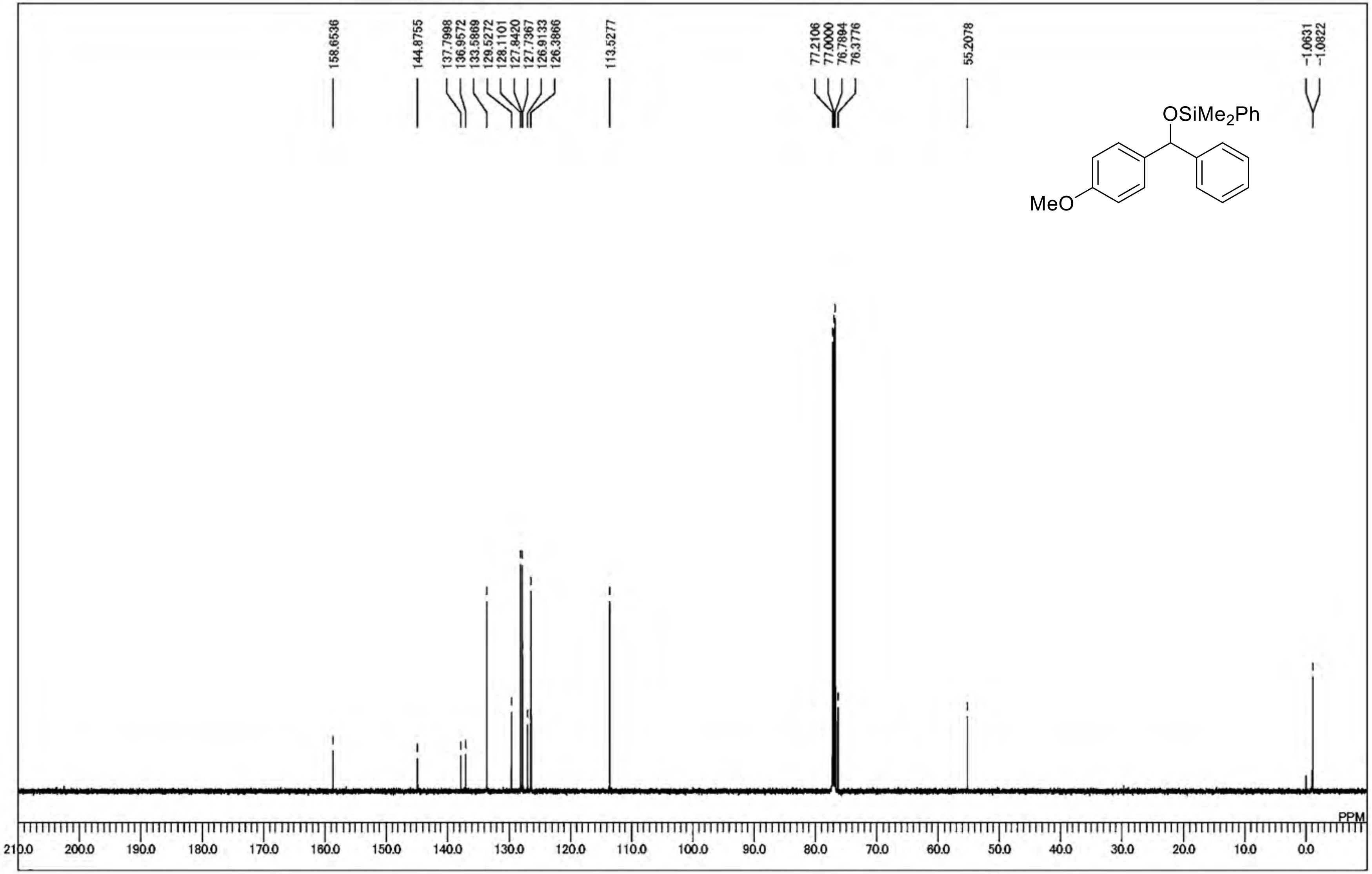
^{1}H NMR spectrum of **3ed**



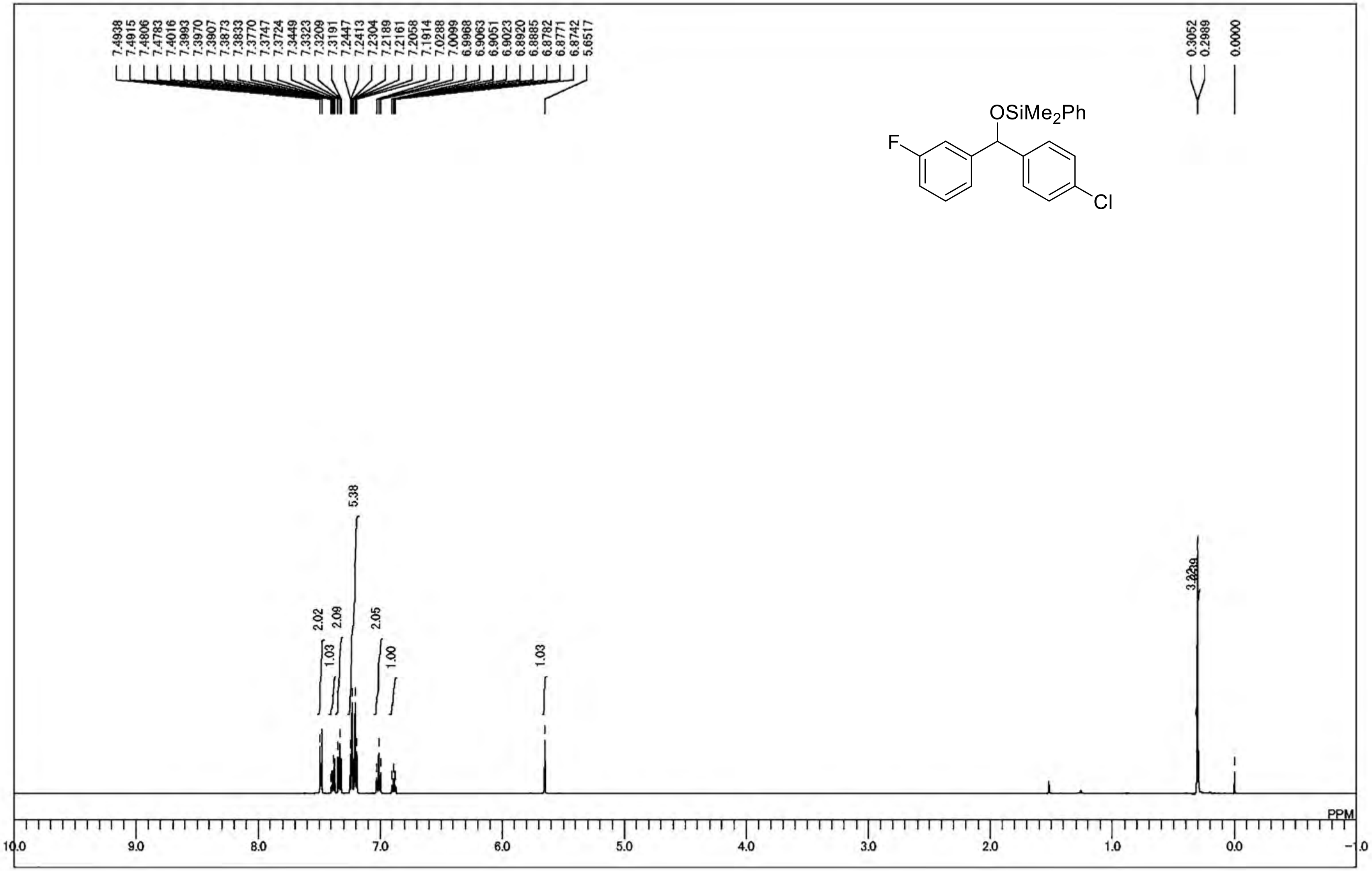
^{13}C NMR spectrum of **3ed**



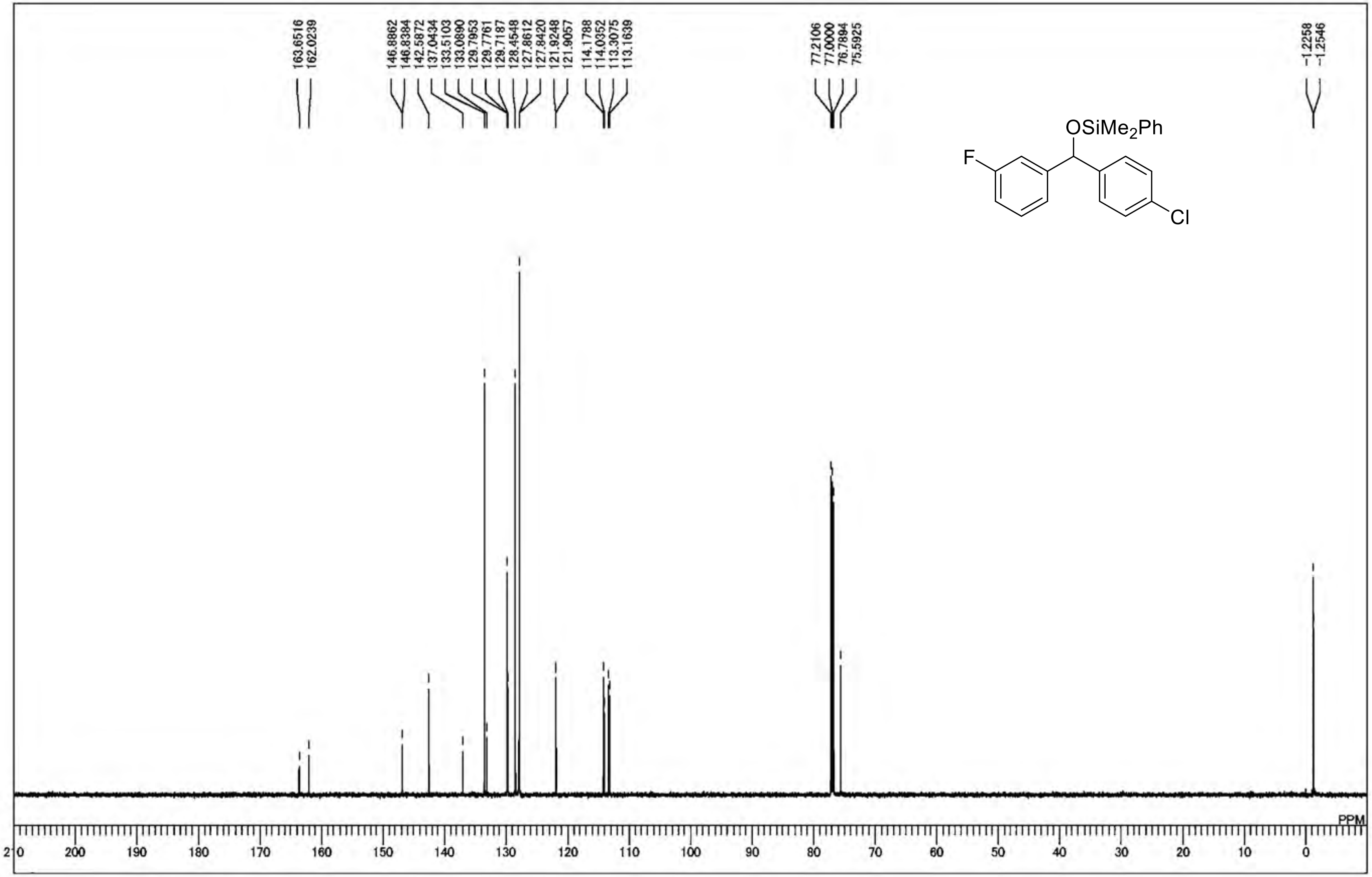
^{1}H NMR spectrum of **3fa**



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



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



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