Direct Synthesis of Highly Substituted Thiophenes through Copper(I)-Catalyzed Tandem Reactions of Alkylidenethiiranes with Terminal Alkynes

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Contents

Experimental section

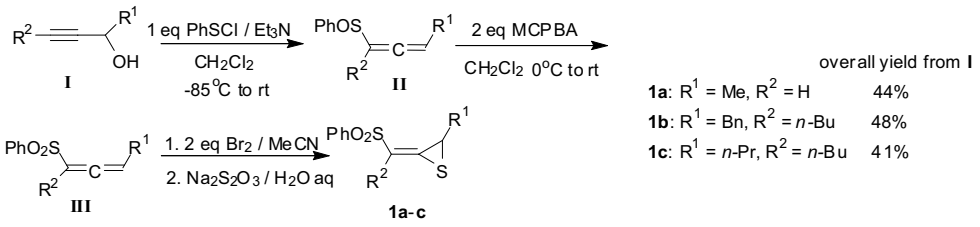
General:

All reactions were carried out under argon atmosphere. All reactions were monitored by thin-layer chromatography (TLC) on Merck silica gel plates (60F-254) using UV-light (254 and 365 nm). Flash chromatography was performed on silica gel (300-400 mesh) unless otherwise specified. NMR spectra were recorded on AM400 or AM500 (Bruker) instruments in $CDCl_3$ with TMS as the internal standard. High resolution mass spectral (HRMS) analyses were measured on a Bruker 7-tesla FT-ICR MS using ESI or EI techniques. Infrared spectra were recorded on a Nicolet 470 FT-IR Spectrometer. All the solid products were recrystallized from CH_2Cl_2 and hexane, and melting points were uncorrected.

Unless otherwise mentioned, all chemicals were purchased from commercial sources, and not purified prior to use. Terminal alkynes **2g**[1], **2m**[2] and **2n**[3] were prepared according to literature method.

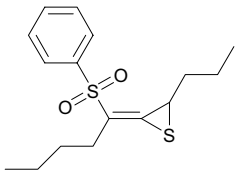
Synthesis of starting materials **1**:

Alkylidenethiiranes **1a–c** were prepared from substituted propargyl alcohol (50 mmol) according to literatures (Scheme 1).[4]



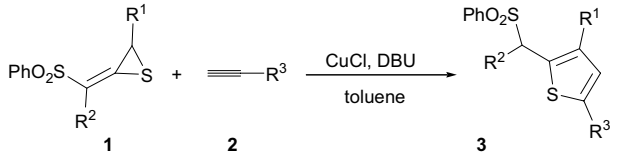
Scheme 1

2-(1-(Phenylsulfonyl)pentylidene)-3-propylthiirane 1c:



From dec-5-yn-4-ol (7.70 g, 50 mmol), 6.83g thiirane **1c** was obtained in 41 % yield over 3 steps. Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.85 (d, *J* = 7.6 Hz, 2H), 7.61 (t, *J* = 7.6 Hz, 1H), 7.53 (t, *J* = 7.6 Hz, 2H), 3.76 (dd, *J* = 3.2, 6.0 Hz, 1H), 2.69–2.77 (m, 1H), 2.34 (t, J = 7.6 Hz, 2H), 1.54–1.65 (m, 2H), 1.37–1.50 (m, 3H), 1.19–1.27 (m, 2H), 1.03 (t, *J* = 7.6 Hz, 3H), 0.81 ppm (t, *J* = 7.6 Hz, 3H); **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 145.0, 140.6, 133.1, 129.1, 127.7, 124.1, 42.2, 37.0, 29.5, 29.2, 22.2, 21.6, 13.6, 13.3 ppm; **IR** (neat): *ν* 2958, 2873, 1707, 1446, 1316, 1153, 1083, 689 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{16}H_{22}O_2S_2Na$ ([M+Na]$^+$), 333.0953, Found, 333.0959.

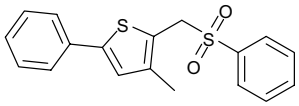
Preparation and characterization data for **3a**–**n**



General procedure

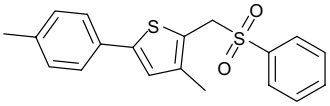
To a suspension of CuCl (9.9 mg, 0.1 mmol) and alkylidenethiirane **1a** (113 mg, 0.5mmol) in toluene (10 mL) was added terminal alkynes (0.75 mmol), DBU (7.6 mg, 0.05 mmol) under argon. The reaction temperature was then raised slowly to 50 ^{o}C, and the solution was stirred for additional several hours. The solvent was removed under reduced pressure and the resulting oil was purified by column chromatography using appropriate hexane-ethyl acetate solvent mixture to afford the products **3a–n**.

3-Methyl-5-phenyl-2-(phenylsulfonylmethyl)thiophene 3a:



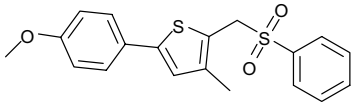
White solid; m.p. 94–96 ^{o}C; **^{1}H-NMR** (500 MHz, $CDCl_3$, TMS) δ = 7.75 (d, *J* = 7.5 Hz, 2H), 7.63 (t, *J* = 7.3 Hz, 1H), 7.50 (dd, *J* = 8.5 Hz, 4H), 7.35 (t, *J* = 7.5 Hz, 2H), 7.27 (t, *J* = 7.5 Hz, 1H), 6.97 (s, 1H), 4.45 (s, 2H), 1.84 (s, 3H) ppm; **^{13}C-NMR** (125 MHz, $CDCl_3$, TMS) δ = 144.8, 140.2, 138.0, 134.2, 133.9, 129.3, 129.1, 129.0, 128.1, 126.0, 125.8, 122.0, 56.2, 13.8 ppm; **IR** (KBr): *ν* 3066, 2926, 1449, 1308, 1137, 1085, 760, 747 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{18}H_{16}O_2SNa$ ([M+Na]$^{+}$), 351.0484, Found, 351.0489.

3-Methyl-2-(phenylsulfonylmethyl)-5-p-tolylthiophene 3b:



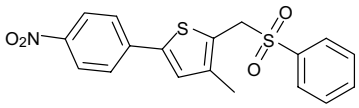
White solid; m.p. 122–123 ^{o}C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.75 (d, *J* = 7.6 Hz, 2H), 7.62 (t, *J* = 7.2 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.40 (d, *J* = 7.6 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 6.92 (s, 1H), 4.44 (s, 2H), 2.35 (s, 3H), 1.82 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 144.7, 139.8, 137.7, 137.7, 133.8, 130.9, 129.5, 129.0, 128.7, 125.4, 125.2, 121.1, 56.0, 21.1, 13.5 ppm; **IR** (KBr): *ν* 2961, 2907, 1448, 1306, 1165, 1137, 537, 807 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{19}H_{18}O_2S_2Na$ ([M+Na]$^{+}$), 365.0640, Found, 365.0641.

5-(4-Methoxyphenyl)-3-methyl-2-(phenylsulfonylmethyl)thiophene 3c:



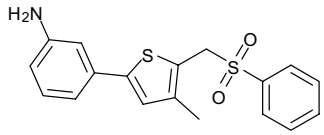
White solid; m.p. 137–138 ^{o}C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.75 (d, *J* = 7.6 Hz, 2H), 7.63 (t, *J* = 7.4 Hz, 1H), 7.48 (t, *J* = 7.8 Hz, 2H), 7.44 (d, *J* = 8.8 Hz, 2H), 6.88 (d, *J* = 8.8 Hz, 3H), 4.44 (s, 2H), 3.82 (s, 3H), 1.81(s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 159.5, 144.6, 139.9, 137.8, 133.9, 129.1, 128.7, 126.9, 126.6, 124.7, 120.6, 114.3, 56.0, 55.3, 13.6 ppm; **IR** (KBr): *ν* 2961, 1607, 1517, 1298, 1253, 1134, 819, 529 cm^{-1} **ESI-HRMS**: Calcd. for $C_{19}H_{18}O_3S_2Na$ ([M+Na]$^{+}$), 381.0590, Found, 381.0594.

3-Methyl-5-(4-nitrophenyl)-2-(phenylsulfonylmethyl)thiophene 3d:



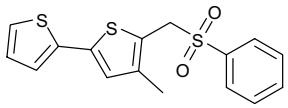
Yellow solid; m.p. 169–170 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 8.21 (d, *J* = 8.8 Hz, 2H), 7.79 (d, *J* = 7.6 Hz, 2H), 7.63–7.69 (m, 3H), 7.53 (t, *J* = 7.6 Hz, 2H), 7.15 (s, 1H), 4.49 (s, 2H), 1.90 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 146.8, 141.5, 140.6, 139.8, 137.7, 134.1, 129.2, 128.6, 128.2, 125.7, 125.0, 124.3, 77.3, 77.0, 76.7, 55.8, 13.6 ppm; **IR** (KBr): *ν* 3062, 2924, 1598, 1447, 1308, 1140, 1084, 741 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{18}H_{15}NO_4S_2Na$ ($[M+Na]^+$), 396.0335, Found, 396.0341.

5-(3-Aminophenyl)-3-methyl-2-(phenylsulfonylmethyl)thiophene 3e:



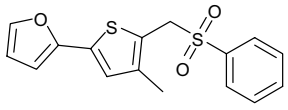
Pale yellow crystalline solid; m.p. 126–128 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.74 (d, *J* = 7.2 Hz, 2H), 7.63 (t, *J* = 7.6 Hz, 1H), 7.49 (t, *J*=7.8 Hz, 2H), 7.13 (t, *J* = 7.6 Hz, 1H), 6.92 (d, *J* = 6.0 Hz, 2H), 6.84 (t, *J* = 1.8 Hz, 1H), 6.61 (dd, *J* = 6.0, 2.0 Hz, 1H), 4.45 (s, 2H), 2.94 (bs, 2H), 1.82 ppm (s, 3H); **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 146.7, 144.7, 139.7, 137.5, 134.5, 133.8, 129.7, 128.9, 128.6, 125.5, 121.3, 115.9, 114.5, 112.0, 55.9, 13.4 ppm; **IR** (neat): *ν* 3388, 2920, 1623, 1447, 1304, 1136, 743, 558 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{18}H_{17}NO_2S_2Na$ ($[M+Na]^+$), 366.0593, Found, 366.0590.

4-Methyl-5-(phenylsulfonylmethyl)-2,2'-bithiophene 3f:



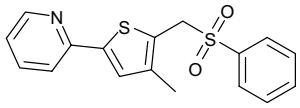
Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.76 (d, *J* = 7.2 Hz, 2H), 7.64 (t, *J* = 7.6 Hz, 1H), 7.50 (t, *J* = 7.4 Hz, 2H), 7.20 (d, *J* = 4.4 Hz, 1H), 7.11 (d, *J* = 2.8 Hz, 1H), 6.99 (dd, *J* = 0.8, 4.0 Hz, 1H), 6.82 (s, 1H), 4.42 (s, 2H), 1.80 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 139.6, 137.7, 137.6, 136.6, 133.8, 129.0, 128.6, 127.7, 126.0, 124.6, 123.9, 121.1, 55.8, 13.3 ppm; **IR** (neat): *ν* 3066, 2922, 1732, 1447, 1308, 1138, 1084, 687 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{16}H_{14}O_2S_3Na$ ($[M+Na]^+$), 357.0048, Found, 357.0045.

2-(Furan-2-yl)-4-methyl-5-(phenylsulfonylmethyl)thiophene 3g:



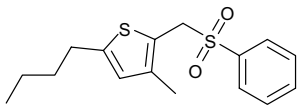
Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.74 (d, *J* = 8.0 Hz, 2H), 7.63 (t, *J* = 6.9 Hz, 1H), 7.49 (t, *J* = 7.8 Hz, 2H), 7.37 (s, 1H), 6.89 (s, 1H), 6.41–6.46 (m, 2H), 4.43 (s, 2H), 1.79 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 148.7, 141.7, 139.5, 137.6, 133.8, 129.0, 128.6, 124.8, 121.0, 111.6, 105.4, 55.8, 13.3 ppm; **IR** (KBr): *ν* 3102, 2909, 1446, 1321, 1163, 741, 560, 524 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{16}H_{14}O_3S_2Na$ ($[M+Na]^+$), 341.0277, Found, 342.0281.

4-Methyl-5-(phenylsulfonylmethyl)-2-(pyridin-2-yl)-thiophene 3h:



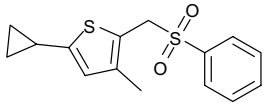
Pale yellow crystalline solid; m.p. 112–113 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 8.52 (d, *J* = 4.0 Hz, 1H), 7.75 (d, *J* = 7.6 Hz, 2H), 7.6–7.68 (m, 2H), 7.55 (d, *J* = 8.4 Hz, 1H), 7.48 (t, *J* = 7.8 Hz, 2H), 7.27 (s, 1H), 7.12–7.15 (dd, *J* = 1.6, 5.6 Hz, 1H), 4.48 (s, 2H), 1.87 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 151.8, 149.5, 144.6, 140.0, 137.8, 136.7, 134.0, 129.1, 128.7, 127.2, 124.6, 122.2, 118.7, 56.1, 13.7 ppm; **IR** (KBr): *ν* 3056, 2921, 1585, 1487, 1307, 1142, 777, 510 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{17}H_{15}NO_2S_2Na$ ($[M+Na]^+$), 352.0436, Found, 352.0431.

5-Butyl-3-methyl-2-(phenylsulfonylmethyl)thiophene 3i:



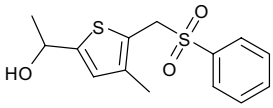
Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.71 (d, *J* = 7.6 Hz, 2H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.47 (t, *J* = 7.8 Hz, 2H), 6.43 (s, 1H), 4.38 (s, 2H), 2.69 (t, *J* = 7.6 Hz, 2H), 1.77 (s, 3H), 1.53–1.62 (m, 2H), 1.29–1.39 (m, 2H), 0.92 (t, *J* = 7.2 Hz, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 146.6, 138.6, 137.8, 133.7, 128.9, 128.6, 127.0, 119.3, 55.9, 33.5, 29.6, 21.9, 13.7, 13.4 ppm; **IR** (neat): *ν* 2957, 2928, 2857, 1447, 1319, 1144, 744, 688 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{16}H_{20}O_2S_2Na$ ($[M+Na]^+$), 331.0797, Found, 331.0793.

5-Cyclopropyl-3-methyl-2-(phenylsulfonylmethyl)thiophene 3j:



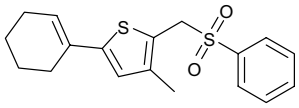
Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.71 (d, *J* = 7.6 Hz, 2H), 7.63 (t, *J* = 7.6 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 2H), 6.41 (s, 1H), 4.36 (s, 2H), 1.94–1.98 (m, 1H), 1.73 (s, 3H), 0.92–0.97 (m, 2H), 0.62–0.67 (m, 2H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 149.4, 138.7, 137.8, 133.7, 128.9, 128.6, 125.5, 118.3, 55.9, 13.4, 11.1, 9.9 ppm; **IR** (neat): *ν* 2924, 1446, 1308, 1138, 1804, 1252, 742, 655 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{15}H_{16}O_2S_2Na$ ($[M+Na]^+$), 315.0484, Found, 315.0481.

3-Methyl-5-(1-hydroxyethyl)-2-(phenylsulfonylmethyl)thiophene 3k:



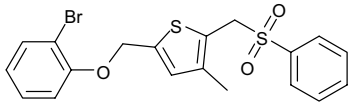
Pale yellow oil; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.71 (d, *J* = 8.4 Hz, 2H), 7.63 (t, *J* = 7.2 Hz, 1H), 7.49 (t, *J* = 7.6 Hz, 2H), 6.63 (s, 1H), 4.98 (q, *J* = 6.8 Hz, 1H), 4.39 (s, 2H), 2.35 (bs, 1H), 1.80 (s, 3H), 1.51 ppm (d, *J* = 6.0 Hz, 3H); **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 150.6, 138.7, 137.7, 133.9, 129.0, 128.6, 125.9, 121.0, 66.0, 55.8, 25.1, 13.5 ppm; **IR** (neat): *ν* 3479, 2924, 1447, 1307, 1147, 1084, 746, 687 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{14}H_{16}O_3S_2Na$ ($[M+Na]^+$), 319.0433, Found, 319.0427.

5-Cyclohexenyl-3-methyl-2-(phenylsulfonylmethyl)thiophene 3l:



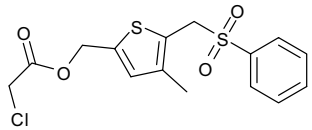
Flash chromatography was performed on neutral Al_2O_3; colorless crystalline solid; m.p. 109–111 ^oC; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.72 (d, *J* = 8 Hz, 2H), 7.63 (t, *J* = 7.6 Hz, 1H), 7.48 (t, *J* = 7.6Hz, 2H), 6.11 (s, 1H), 4.39 (s, 2H), 2.28–2.34 (m, 2H), 2.12–2.19 (m, 2H), 1.69–1.78 (m, 5H), 1.59–1.66 (m, 2H) ppm; **^{13}C- NMR** (100 MHz, $CDCl_3$, TMS) δ = 147.3, 139.0, 137.9, 133.8, 130.7, 129.0, 128.7, 124.8, 123.8, 119.3, 56.0, 27.1, 25.6, 22.6, 22.0, 13.5 ppm; **IR** (neat): *ν* 2927, 2858, 1447, 1319, 1139, 1085, 745, 688 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{18}H_{20}O_2S_2Na$ ($[M+Na]^+$), 355.0797, Found, 355.0801.

5-((2-Bromophenoxy)methyl)-3-methyl-2-(phenylsulfonylmethyl)thiophene 3m:



Pale yellow crystalline solid; m.p. 141–142 ^oC; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.69 (d, *J* = 7.6 Hz, 2H), 7.60 (t, *J* = 7.4 Hz, 1H), 7.55 (d, *J* = 7.6 Hz, 1H), 7.44 (t, *J* = 7.8 Hz, 2H), 7.25 (t, *J* = 7.6 Hz, 1H), 6.93 (d, *J* = 7.6 Hz, 1H), 6.87 (t, *J* = 7.8 Hz, 1H), 6.78 (s, 1H), 5.16 (s, 2H), 4.42 (s, 2H), 1.85 (s, 3H) ppm; **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 154.4, 139.2, 138.7, 137.4, 133.8, 133.4, 129.3, 128.9, 128.5, 128.2, 123.1, 122.6, 114.2, 112.7, 65.9, 55.7, 13.4 ppm; **IR** (KBr): *ν* 2927, 1584, 1477, 1308, 1147, 1054, 747, 687 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{19}H_{17}BrO_3S_2Na$ ($[M+Na]^+$), 458.9695, Found, 458.9700.

5-(2-Chloroacetoxy)-3-methyl-2-(phenylsulfonylmethyl)thiophene 3n:

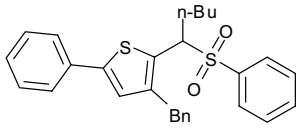


Colorless crystalline solid; m.p. 96–97 ^oC; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.72 (d, *J* = 8 Hz, 2H), 7.66 (t, *J* = 7.2 Hz, 1H), 7.51 (t, *J* = 7.6 Hz, 2H), 6.80 (s, 1H), 5.23 (s, 2H), 4.42 (s, 2H), 4.08 (s, 2H), 1.84 (s, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 166.9, 139.0, 137.6, 137.1, 134.0, 131.5, 129.1, 128.5, 124.3, 61.7, 55.6, 40.7, 13.4 ppm; **IR** (neat): *ν* 2958, 2924, 1755, 1447, 1309, 1150, 1084, 747 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{15}H_{15}ClO_4S_2Na$ ($[M+Na]^+$), 380.9992, Found, 380.9987.

Preparation and characterization data for **3o–3r**, and **5**

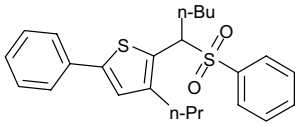
To a suspension of CuCl (9.9 mg, 0.1 mmol) and alkylidenethiiranes (0.5mmol) in toluene (10 mL) was added terminal alkynes (0.75 mmol), DBU (7.6mg, 0.05 mmol) under argon. The reaction mixture was then stirred at refluxing temperature for additional several hours. The solvent was removed under reduced pressure and the resulting oil was purified by column chromatography using appropriate hexane-ethyl acetate solvent mixtures to afford the products **3o–3r** and **5**, respectively.

3-Benzyl-5-phenyl-2-(1-(phenylsulfonyl)pentyl)thiophene 3o:



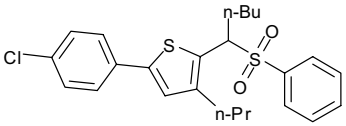
Alkylidenethiirane **1b** (179 mg, 0.5 mmol) was used. White solid; m.p. 144–145 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.72 (d, *J* = 7.2 Hz, 2H), 7.63 (t, *J* = 7.4 Hz, 1H), 7.53 (d, *J* = 7.6 Hz, 2H), 7.47 (t, *J* = 7.8 Hz, 2H), 7.34 (t, *J* = 7.4 Hz, 2H), 7.15–7.28 (m, 4H), 6.93 (d, *J* = 7.2 Hz, 2H), 6.83 (s, 1H), 4.41 (dd, *J* = 3.2, 8.8 Hz, 1H), 3.37 (s, 2H), 2.36–2.47 (m, 1H), 1.98–2.08 (m, 1H), 1.16–1.27 (m, 3H), 0.95–1.06 (m, 1H), 0.79 (t, *J* = 7.0 Hz, 3H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 144.4, 143.4, 139.3, 137.4, 133.7, 133.6, 129.1, 128.8, 128.8, 128.5, 128.4, 127.8, 126.3, 125.4, 124.8, 65.3, 33.9, 29.1, 28.7, 22.1, 13.6 ppm; **IR** (KBr): *ν* 2955, 2927, 1495, 1448, 1307, 1145, 727, 687 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{28}H_{28}O_2S_2Na$ ($[M+Na]^+$), 483.1423, Found, 483.1429.

5-Phenyl-2-(1-(phenylsulfonyl)pentyl)-3-propylthiophene 3p:



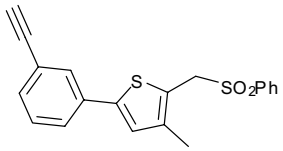
Alkylidenethiirane **1c** (155 mg, 0.5 mmol) was used. White solid; m.p. 73–75 °C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.66 (d, *J* = 8.0 Hz, m, 2H), 7.57 (t, *J* = 8.0 Hz, 3H), 7.34–7.43 (m, 4H), 7.27 (t, *J* = 7.6 Hz, 1H), 6.93 (s, 1H), 4.40 (dd, *J* = 3.2, 8.4 Hz, 1H), 2.48–2.56 (m, 1H), 1.99–2.13 (m, 2H), 1.82–1.90 (m, 1H), 1.29–1.41 (m, 4H), 1.17–1.28 (m, 2H), 0.866 (t, *J* = 7.2 Hz, 3H), 0.78 (t, *J*=7.2 Hz, 3H) ppm; **^{13}C- NMR** (100 MHz, $CDCl_3$, TMS) δ = 145.2, 144.3, 137.5, 133.9, 133.6, 129.1, 128.9, 128.7, 128.3, 127.7, 125.5, 123.8, 65.4, 30.0, 29.0, 28.8, 23.3, 22.3, 13.9, 13.7 ppm; **IR** (neat): *ν* 2958, 1871, 1555, 1462, 1446, 1306, 1147, 689 cm^{-1}; **ESI-HRMS**: Calcd for $C_{24}H_{28}O_2S_2Na$ ($[M+Na]^+$), 435.1423, Found, 435.1429.

5-(4-Chlorophenyl)-2-(1-(phenylsulfonyl)pentyl)-3-propylthiophene 3q:



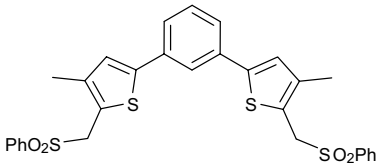
Alkylidenethiirane **1c** (155 mg, 0.5 mmol) was used. Flash chromatography was performed on neutral Al_2O_3; white solid; m.p. 118–119 °C; **^{1}H NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.67 (d, *J* = 7.2 Hz, 2H), 7.58 (t, *J* = 7.2 Hz, 1H), 7.50 (d, *J* = 8.4 Hz, 2H), 7.43 (t, *J* = 8.0 Hz, 2H), 7.33 (d, *J* = 8.4 Hz, 2H), 6.91 (s, 1H), 4.39 (dd, *J* = 3.2, 8.8 Hz, 1H), 2.45–2.55 (m, 1H), 1.98–2.12 (m, 2H), 1.82–1.92 (m, 1H), 1.26–1.41 (m, 4H), 1.17–1.26 (m, 2H), 0.86 (t, *J* = 7.0 Hz, 3H), 0.78 (t, *J* = 7.4 Hz, 3H) ppm; **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 145.3, 142.9, 137.3, 133.6, 133.4, 132.4, 129.1, 129.0, 128.7, 126.7, 124.1, 65.2, 29.9, 29.0, 28.8, 23.2, 22.3, 13.8, 13.7 ppm; **IR** (neat): *ν* 2958, 2871, 1497, 1447, 1306, 1147, 1084, 823 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{24}H_{27}ClO_2S_2Na$ ($[M+Na]^+$), 469.1033, Found, 469.1036.

5-(3-Ethynylphenyl)-3-methyl-2-(phenylsulfonylmethyl)thiophene 3r:



The reaction of alkylidenethiirane **1a** (113 mg, 0.5 mmol) and 1,3-Diethynylbenzene (3 eq, 189 mg, 1.5 mmol) afforded 125 mg of **3r** (71 %)**:** Pale yellow solid; m.p. 110–111 ^{o}C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.76 (d, *J* = 7.6 Hz, 2H), 7.64 (t, *J* = 7.8 Hz, 2H), 7.50 (t, *J* = 7.8 Hz, 3H), 7.39 (d, *J* = 7.6 Hz, 1H), 7.31 (t, *J* = 7.8 Hz, 1H), 6.98 (s, 1H), 4.46 (s, 2H), 3.11 (s, 1H), 1.85 (s, 3H) ppm; **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 143.3, 140.1, 137.7, 134.0, 133.9, 131.3, 129.1, 128.9, 128.7, 126.2, 126.0, 122.8, 122.4, 83.1, 77.7, 56.0, 13.6 ppm; **IR** (neat): ν 3291, 2922, 1597, 1447, 1308, 1159, 1085, 686 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{20}H_{16}O_2S_2Na$ ([M+Na]$^{+}$), 375.0484, Found, 375.0486.

1,3-Bis(4-methyl-5-(phenylsulfonylmethyl)thiophen-2-yl)benzene 5:

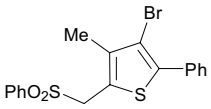


The reaction of alkylidenethiirane **1a** (113 mg, 0.5 mmol) with 1,3-diethynylbenzene (0.33eq, 20.8 mg, 0.165 mmol) afforded 61.9 mg of **5** (65 %, based on the amount of 1,3-diethynylbenzene**)**: white solid; m.p. 196–197 ^{o}C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.77 (d, *J* = 7.6 Hz, 4H), 7.66 (m, 3H), 7.51 (t, *J* = 7.8 Hz, 4H), 7.43 (d, *J* = 6.8 Hz, 2H), 7.35 (t, *J* = 3.6 Hz, 1H), 7.02 (s, 2H), 4.47 (s, 4H), 1.84 (s, 6H) ppm; **^{13}C-NMR** (100 MHz, $CDCl_3$, TMS) δ = 143.9, 140.0, 137.8, 134.4, 134.0, 129.5, 129.1, 128.7, 126.1, 125.0, 122.8, 122.2, 56.0, 13.5 ppm; **IR** (neat): ν 2925, 1732, 1599, 1447, 1308, 1139, 742, 687 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{30}H_{26}O_4S_4Na$ ([M+Na]$^{+}$), 601.0607, Found, 601.0602.

Procedure for the reaction of **3a** with NBS-$FeCl_3$[5]

To a solution of **3a** (164 mg, 0.5 mmol) in 5 mL CH_2Cl_2 was added $FeCl_3$ (8.1 mg, 0.05 mmol), NBS (89 mg, 0.5 mmol) was added at 0 ^{o}C, and the reaction mixture was stirred for additional 1 hours in the ice-water bath. After complete consumption of **3a**, the solution was diluted with ethyl acetate (20 mL), washed with brine, and dried with $MgSO_4$. The solvent was removed under reduced pressure and the resulting oil was purified by column chromatography using hexane-ethyl acetate solvent mixture to afford the product **6** as a pale yellow crystalline solid.

3-Bromo-4-methyl-2-phenyl-5-(phenylsulfonylmethyl)thiophene 6:



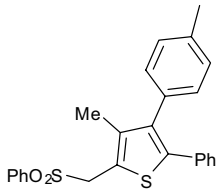
m.p. 146–148 ^{o}C; **^{1}H-NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.78 (d, *J* = 7.2 Hz, 2H), 7.67 (t, *J* = 7.2 Hz, 1H), 7.51–7.59 (m, 4H), 7.35–7.44 (m, 3H), 4.50 (s, 2H), 1.93 (s, 3H) ppm; **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 139.4, 139.1, 137.6, 134.2, 132.7, 129.2, 129.1, 128.7, 128.5, 128.5, 121.8, 111.0, 56.3, 14.7 ppm; **IR** (KBr): ν 3057, 2924, 1449, 1315, 1146, 1086, 748, 601 cm^{-1}; **ESI-HRMS**: Calcd.

for $C_{18}H_{15}BrO_2S_2Na$ ([M+Na]$^+$), 428.9589, Found, 428.9594.

Coupling reaction of **6** with *p*-tolylboronic acid

A Schlenk flask was charged with **6** (203 mg, 0.5 mmol), *p*-tolylboronic acid (136 mg, 1 mmol), K_3PO_4 (424mg, 2 mmol), $Pd(PPh_3)_4$ (57.8mg, 0.05 mmol). DMF (5 mL) was then added into the flask. The mixture was stirred and purged with argon for 2 min and then heated at 100 ^oC for 4 h. The reaction was allowed to cool to ambient temperature and diluted with 20 mL of Et_2O. After washed twice with H_2O (10mL), the organic solution was concentrated and purified by silica gel chromatography to give the product **7** as a pale yellow crystalline solid.

3-Methyl-5-phenyl-2-(phenylsulfonylmethyl)-4-p-tolylthiophene 7:

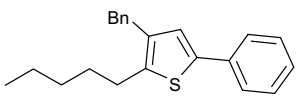


m.p. 172–173 ^oC; **^{1}H NMR** (400 MHz, $CDCl_3$, TMS) δ = 7.81 (d, *J* = 8.0 Hz, 2H), 7.65 (t, *J* = 7.2 Hz, 1H), 7.52 (t, *J* = 7.6 Hz, 2H), 7.10–7.18 (m, 7H), 6.93 (d, *J* = 7.6 Hz, 2H), 4.52 (s, 2H), 2.35 (s, 3H), 1.64 (s, 3H) ppm; **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 139.4, 139.1, 137.6, 134.2, 132.7, 129.2, 129.1, 128.7, 128.5, 128.5, 121.8, 111.0, 56.3, 14.7 ppm; **IR** (KBr): *ν* 3062, 2923, 1446, 1320, 1306, 1149, 1085, 752 cm^{-1}; **ESI-HRMS**: Calcd. for $C_{25}H_{22}O_2S_2Na$ ([M+Na]$^+$), 441.0953, Found, 441.0954.

Procedure for desulfonylation of **3o**[6]

Into a Schlenk flask containing **3o** (230 mg, 0.5 mmol) in DMF (10 mL) at room temperature was added 10 mL of HOAc/NaOAc (1:1) buffer solution (8 mol/L). Magnesium turnings (182 mg, 7.5 mmol) were added in portions. The reaction mixture was stirred at room temperature for 24 hours followed by adding 20 mL water. The mixture was extracted with Et_2O (3×20 mL). The combined organic phase was washed with saturated $NaHCO_3$ solution, brine, and dried with $MgSO_4$. The organic solution was concentrated and purified by silica gel chromatography to give the product **8** as pale yellow oil.

3-Benzyl-2-pentyl-5-phenylthiophene 8:



^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ = 7.50 (d, *J* = 7.6 Hz, 2H), 7.28 (dd, *J* = 8.0 Hz, 4H), 7.17–7.22 (m, 4H), 6.95 (s, 1H), 3.89 (s, 2H), 2.76 (t, *J* = 7.6 Hz, 2H), 1.60–1.68 (m, 2H), 1.29–1.39 (m, 4H), 0.89 ppm (t, *J* = 6.8 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$, TMS) δ = 140.7, 140.0, 139.8, 136.6, 134.6, 128.7, 128.5, 128.4, 126.9, 126.0, 125.4, 125.3, 77.3, 77.0, 76.7, 34.3, 31.5, 31.4, **IR** (neat): *ν* 3026, 2927, 1601, 1495, 1453, 1030, 756, 699 cm^{-1}; **EI-HRMS**: Calcd. for $C_{22}H_{24}S$, 320.1599, Found, 320.1602.

Reference

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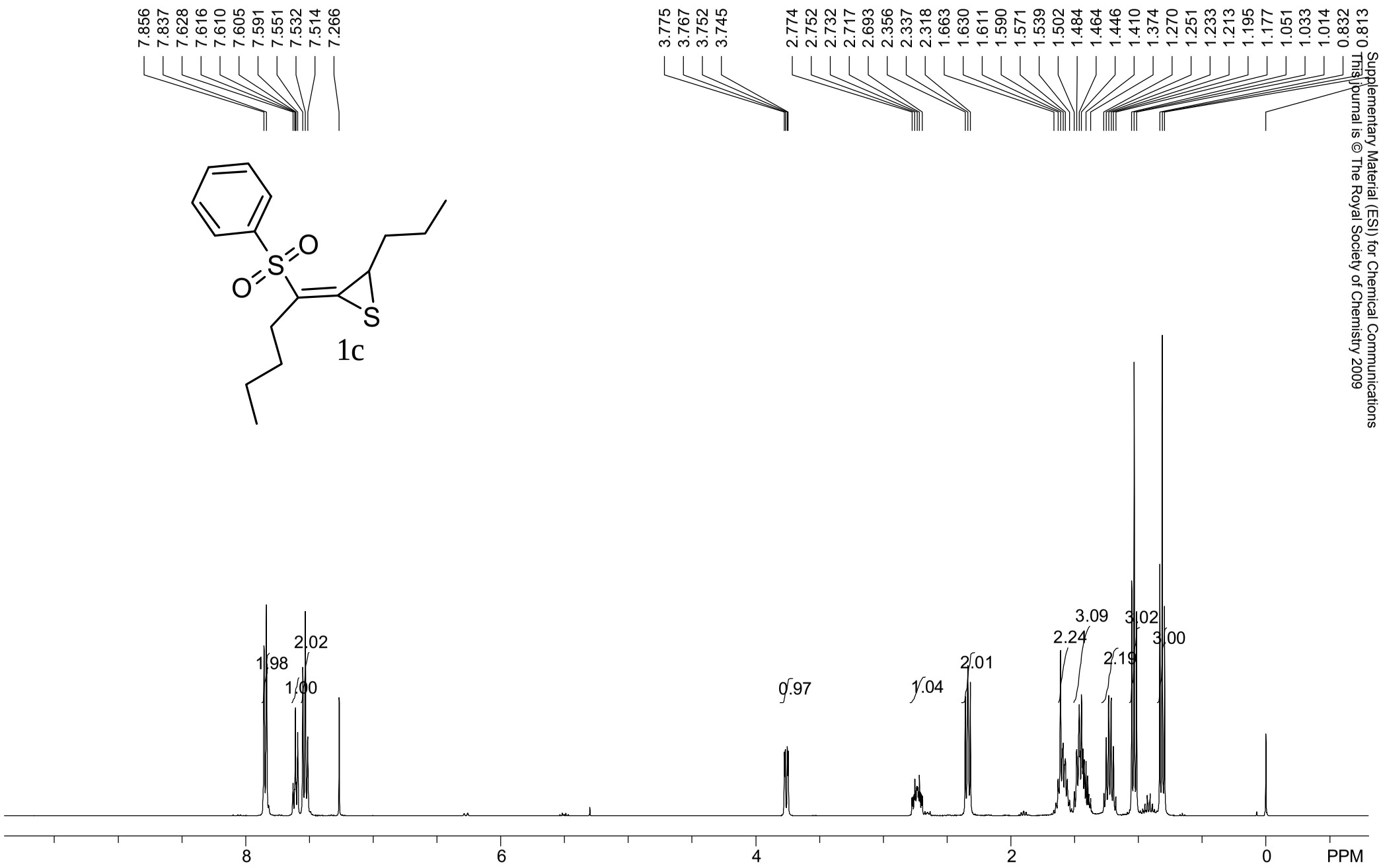

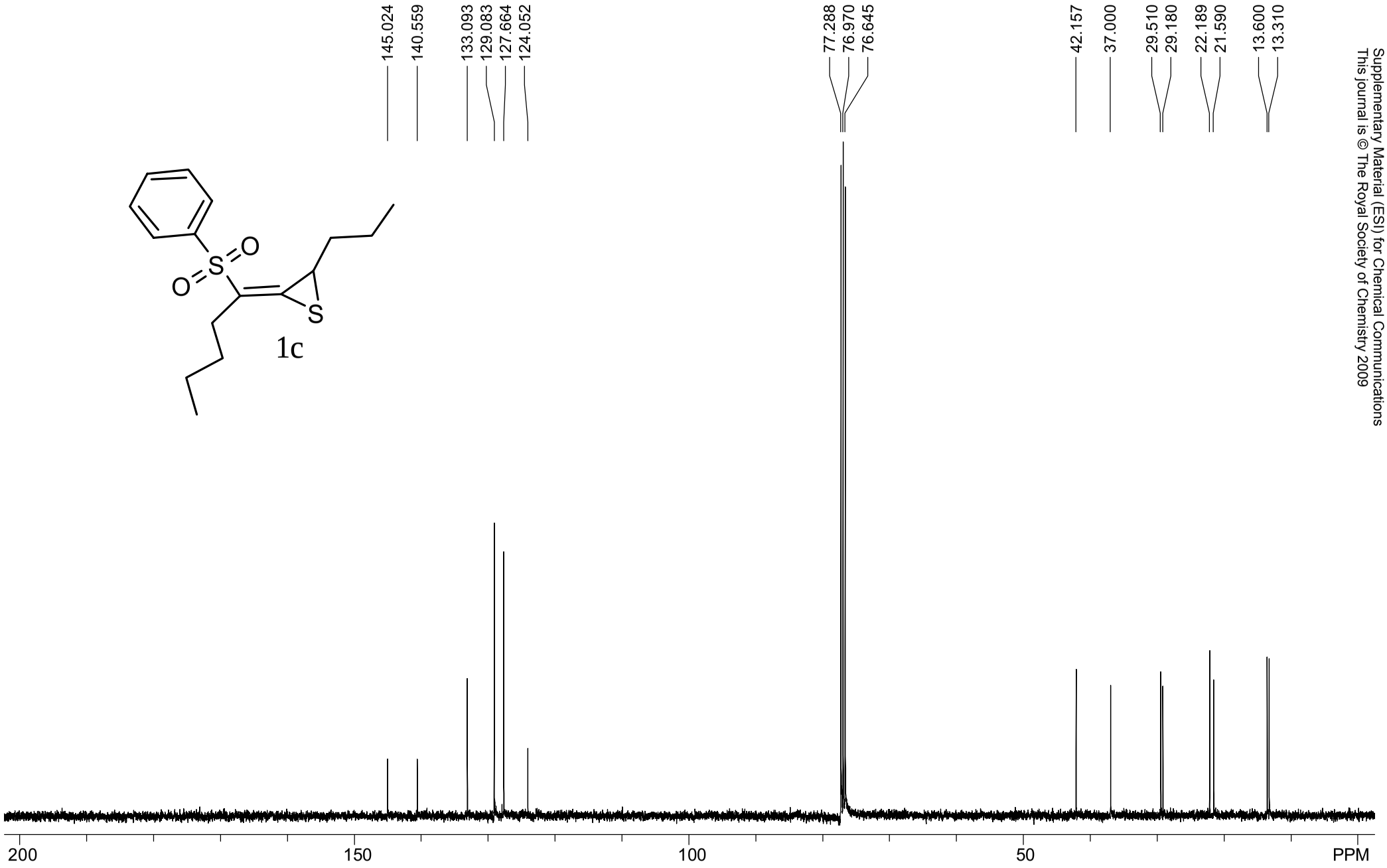

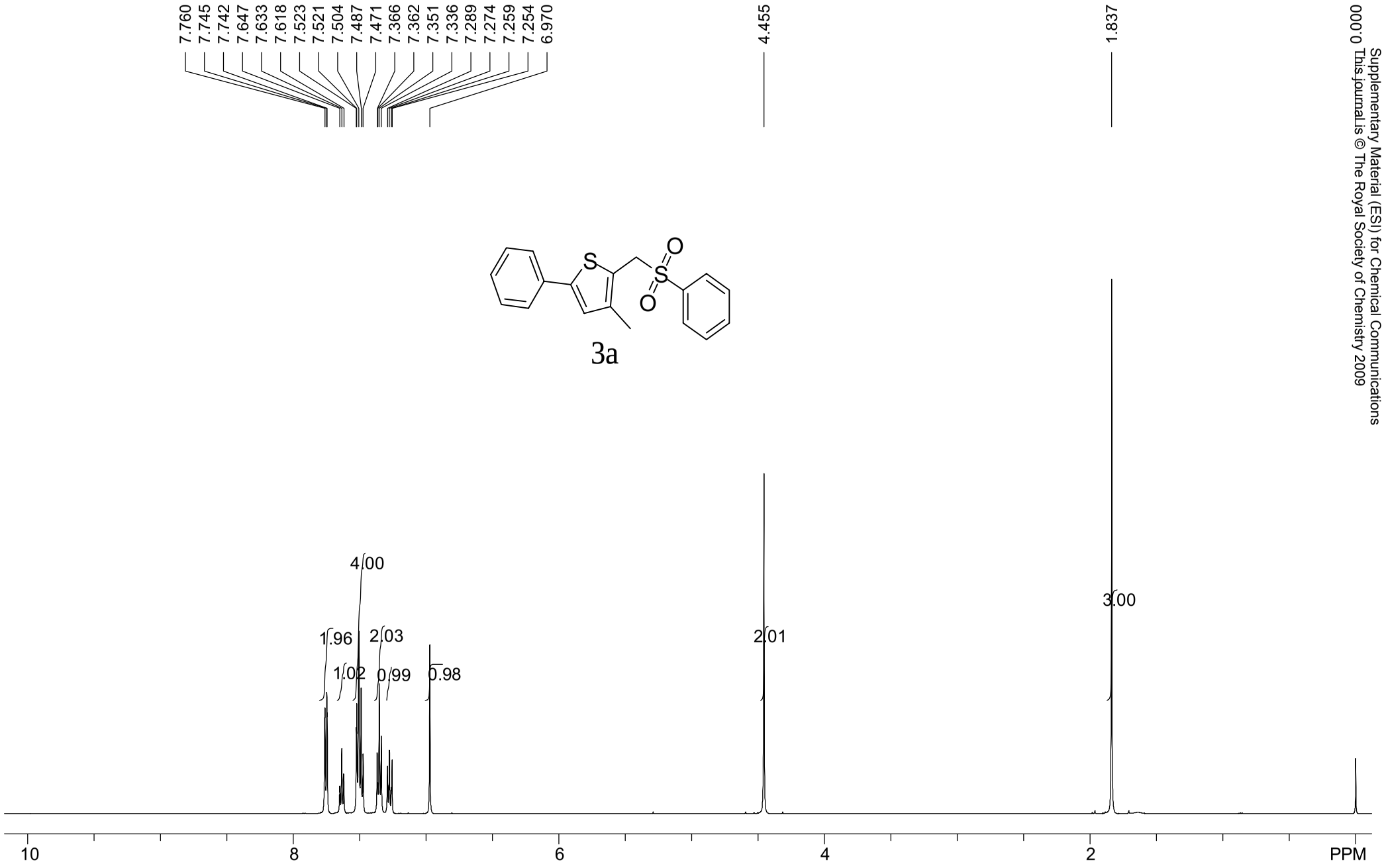

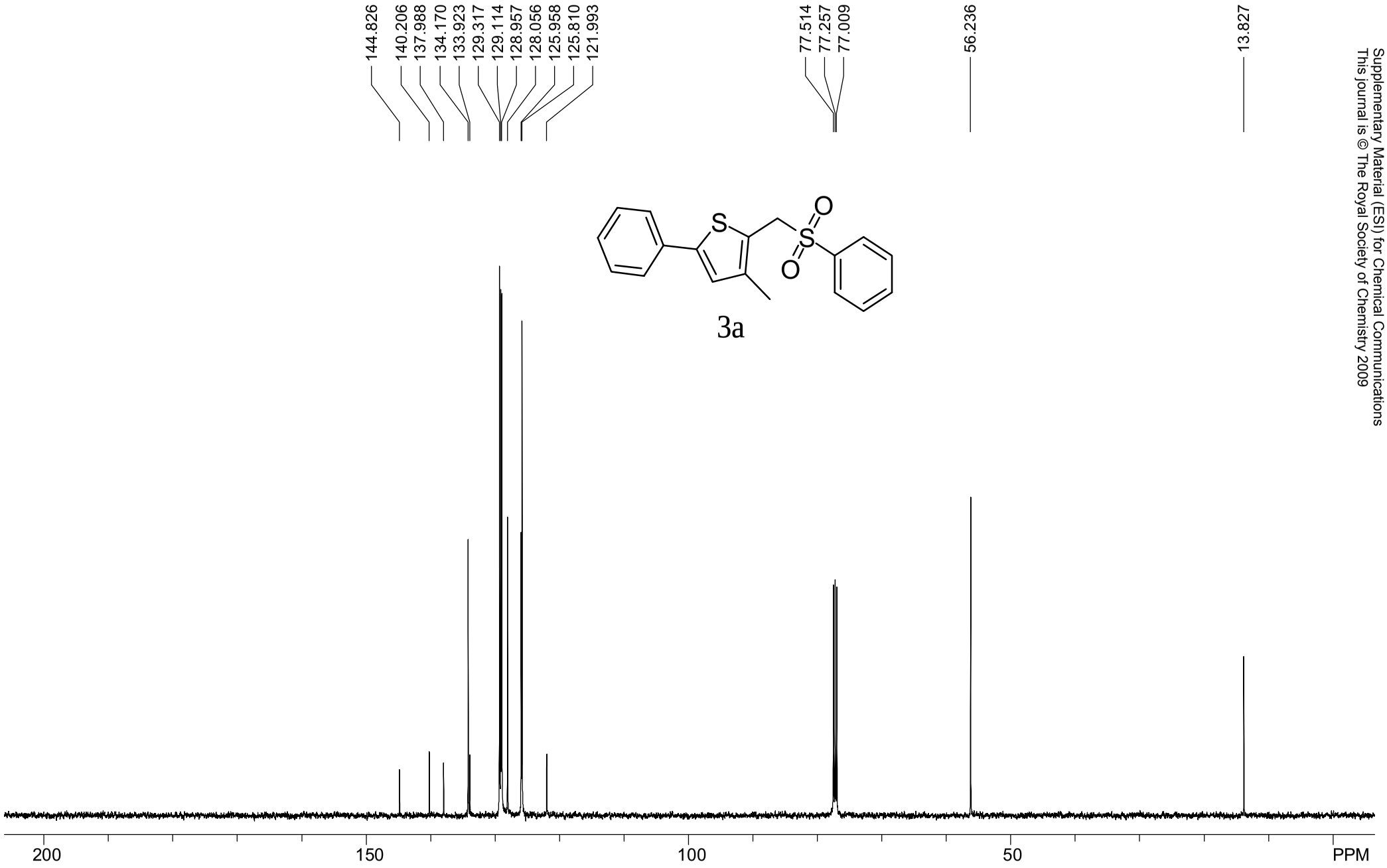

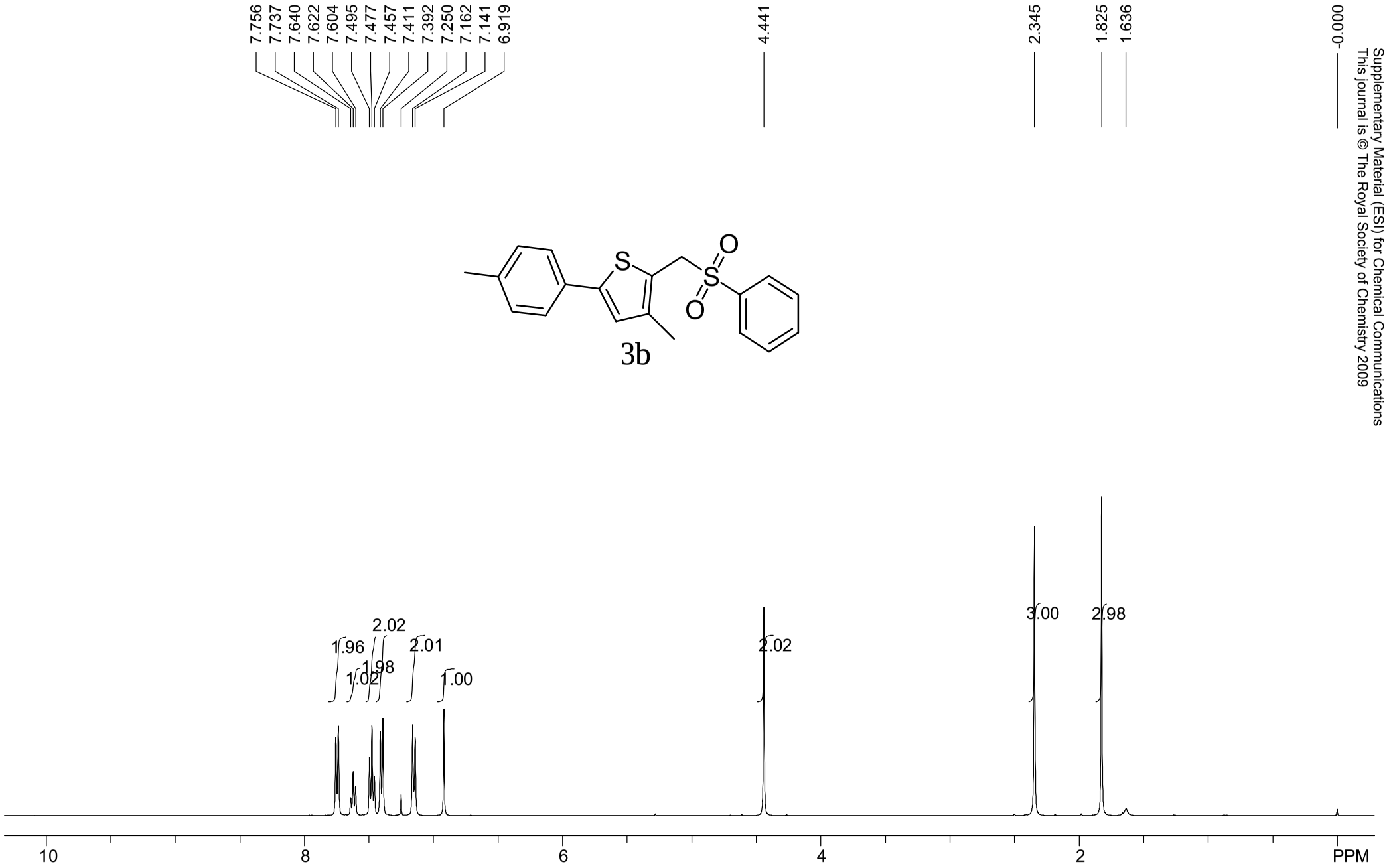

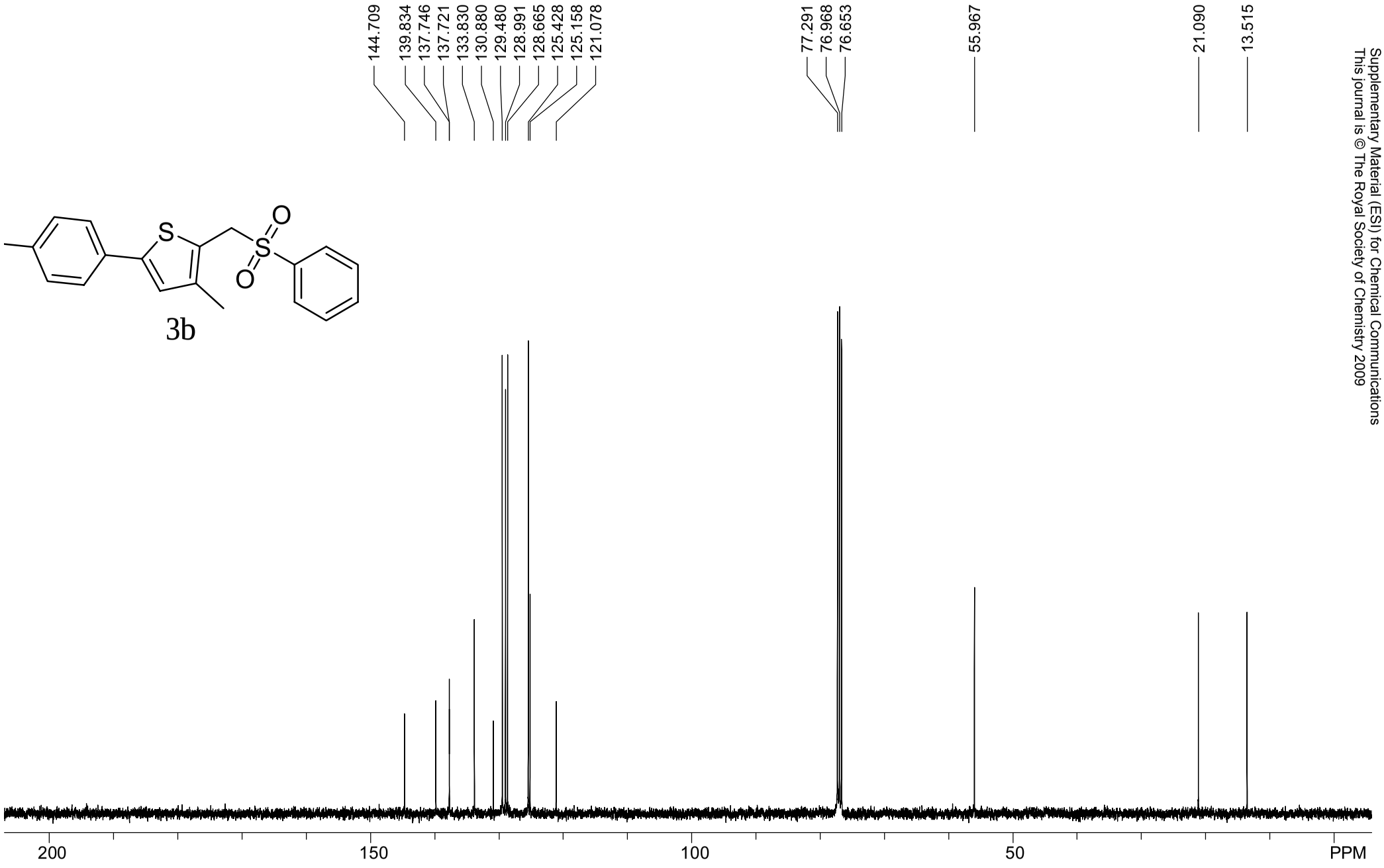

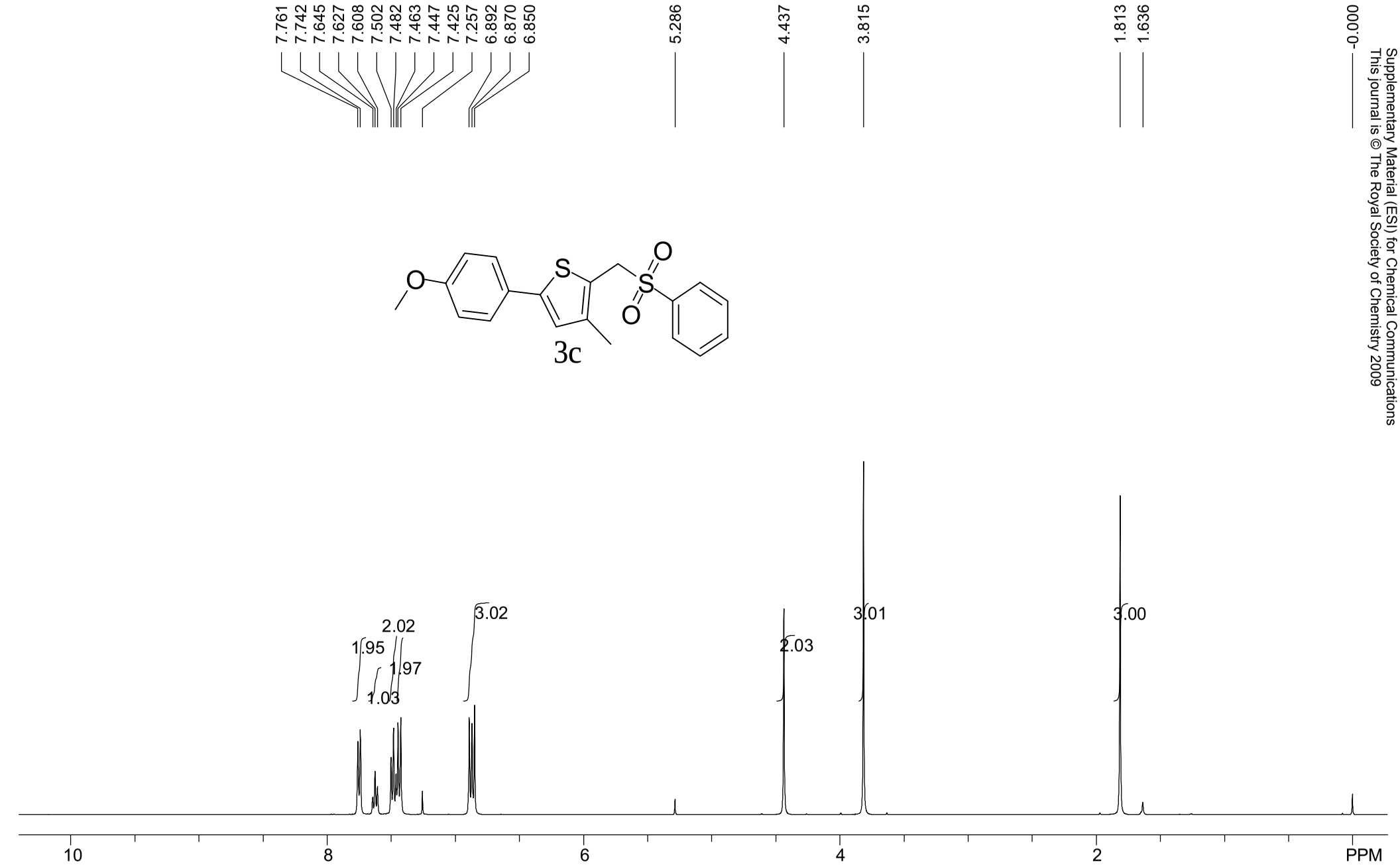

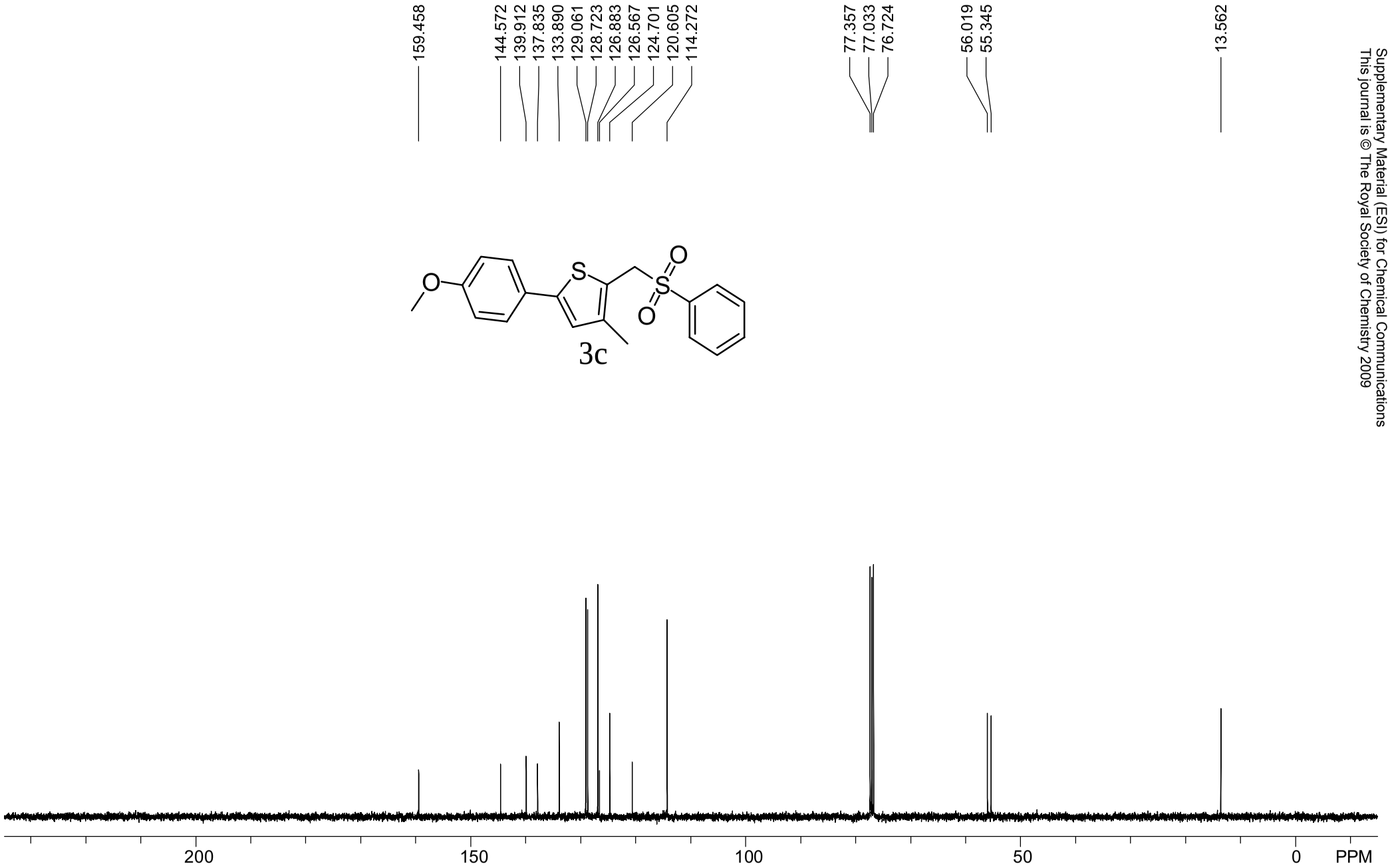

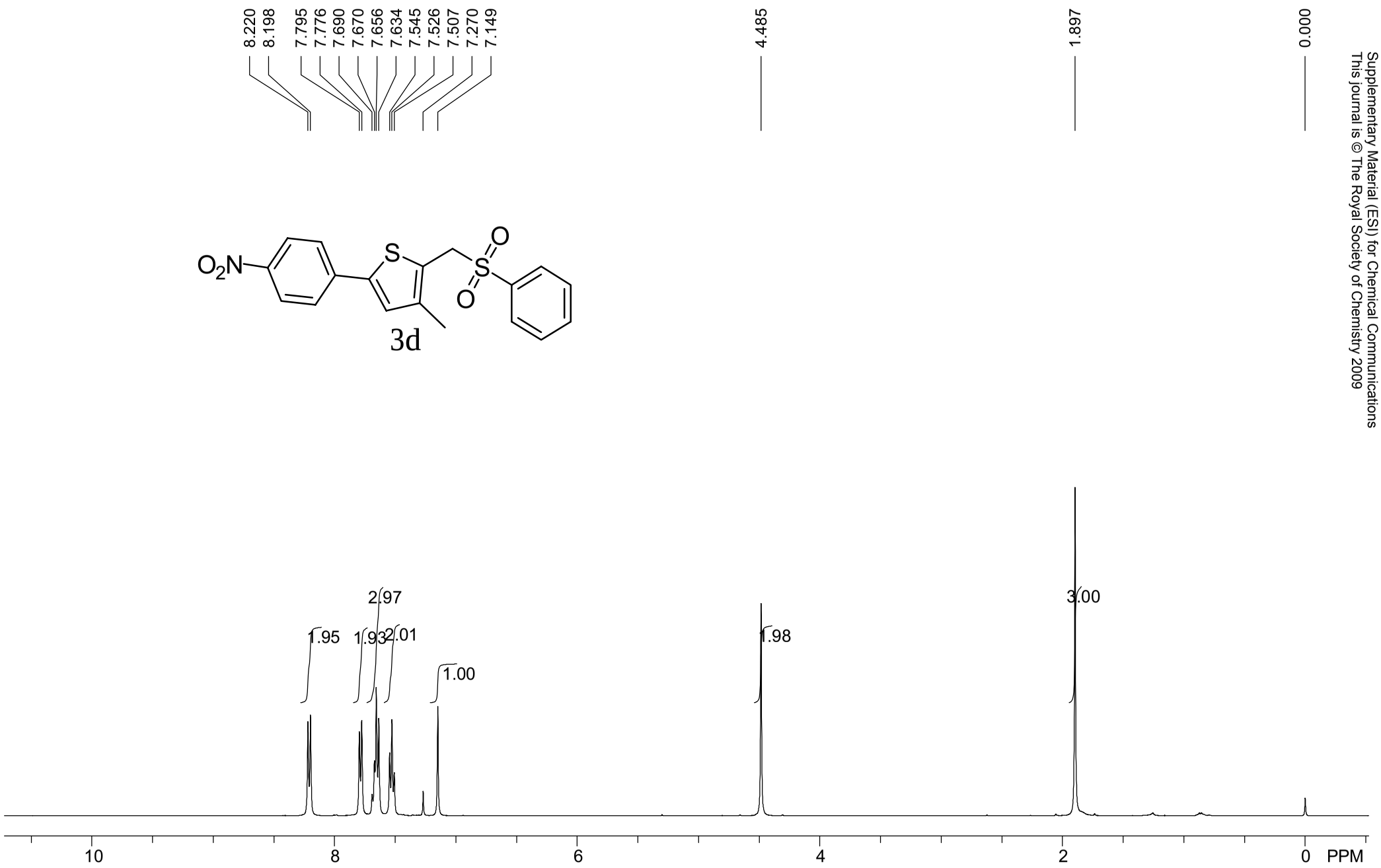

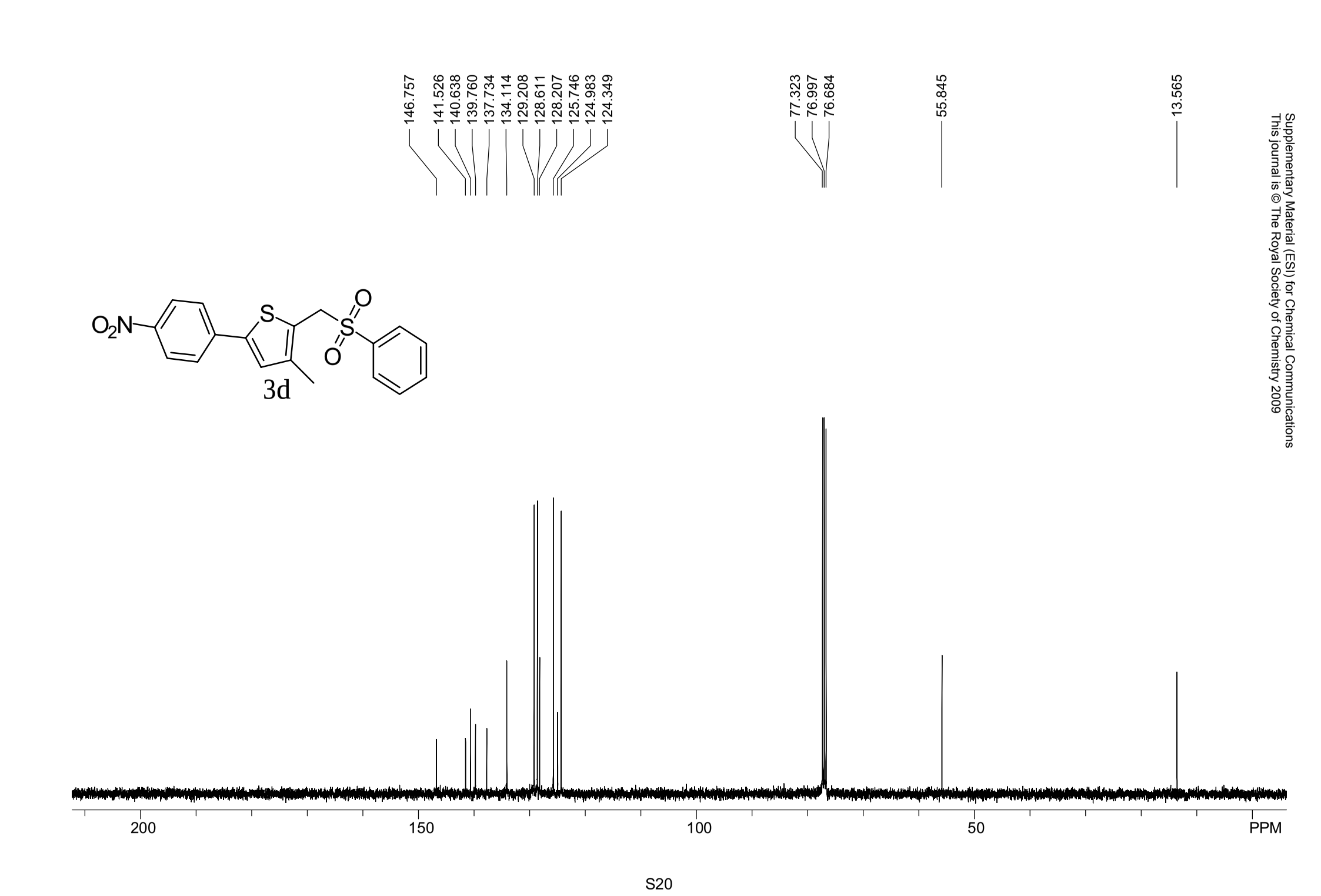

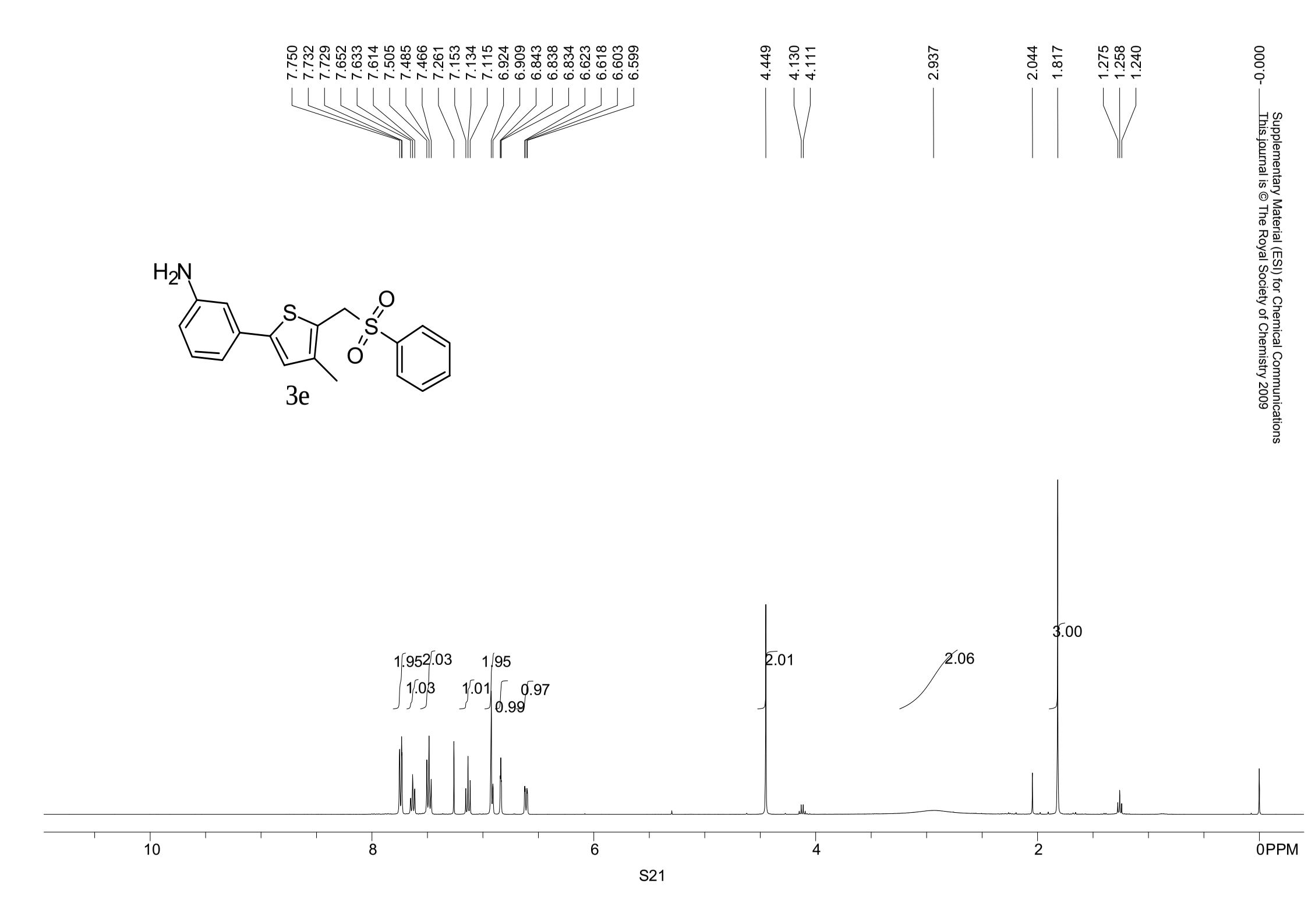

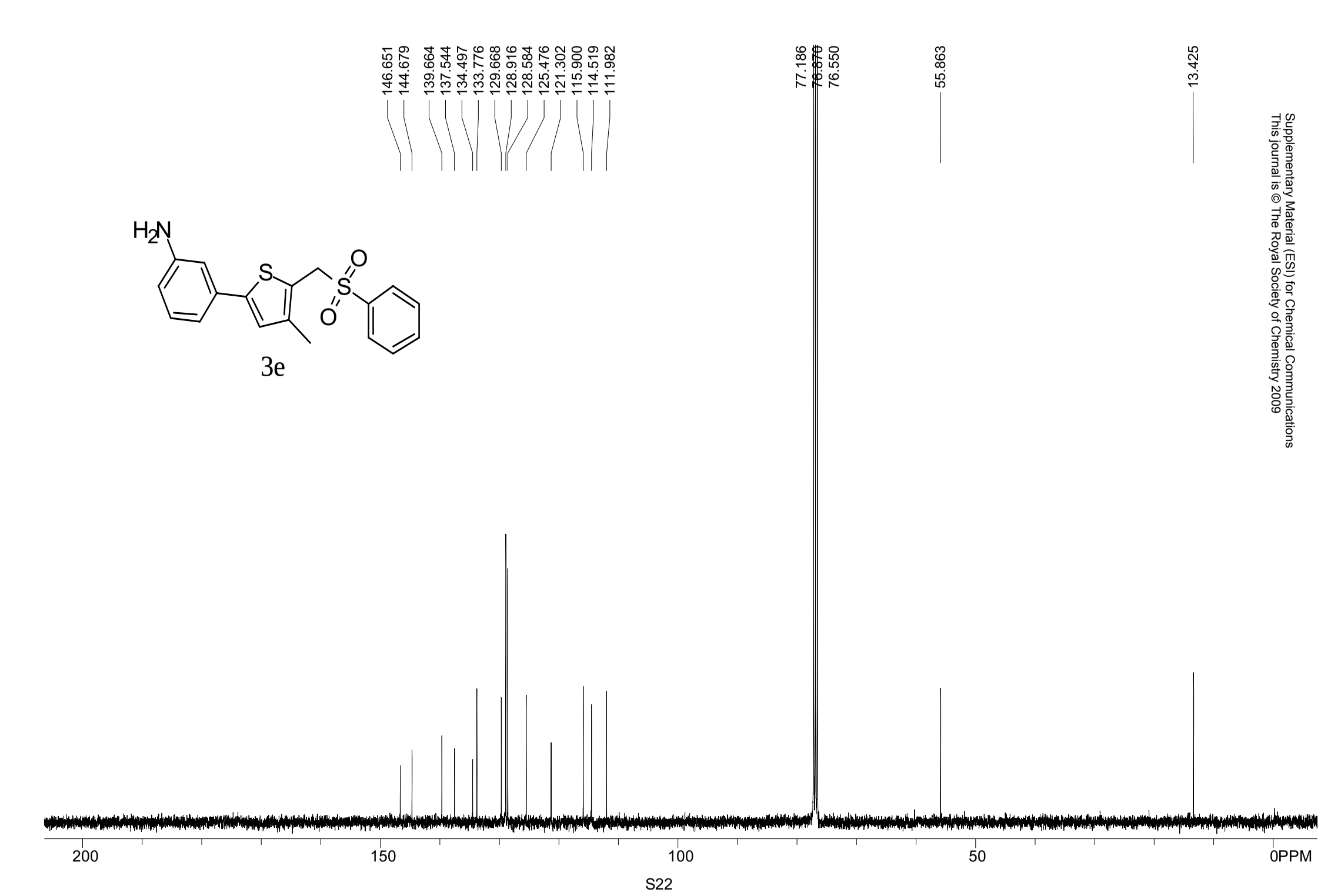

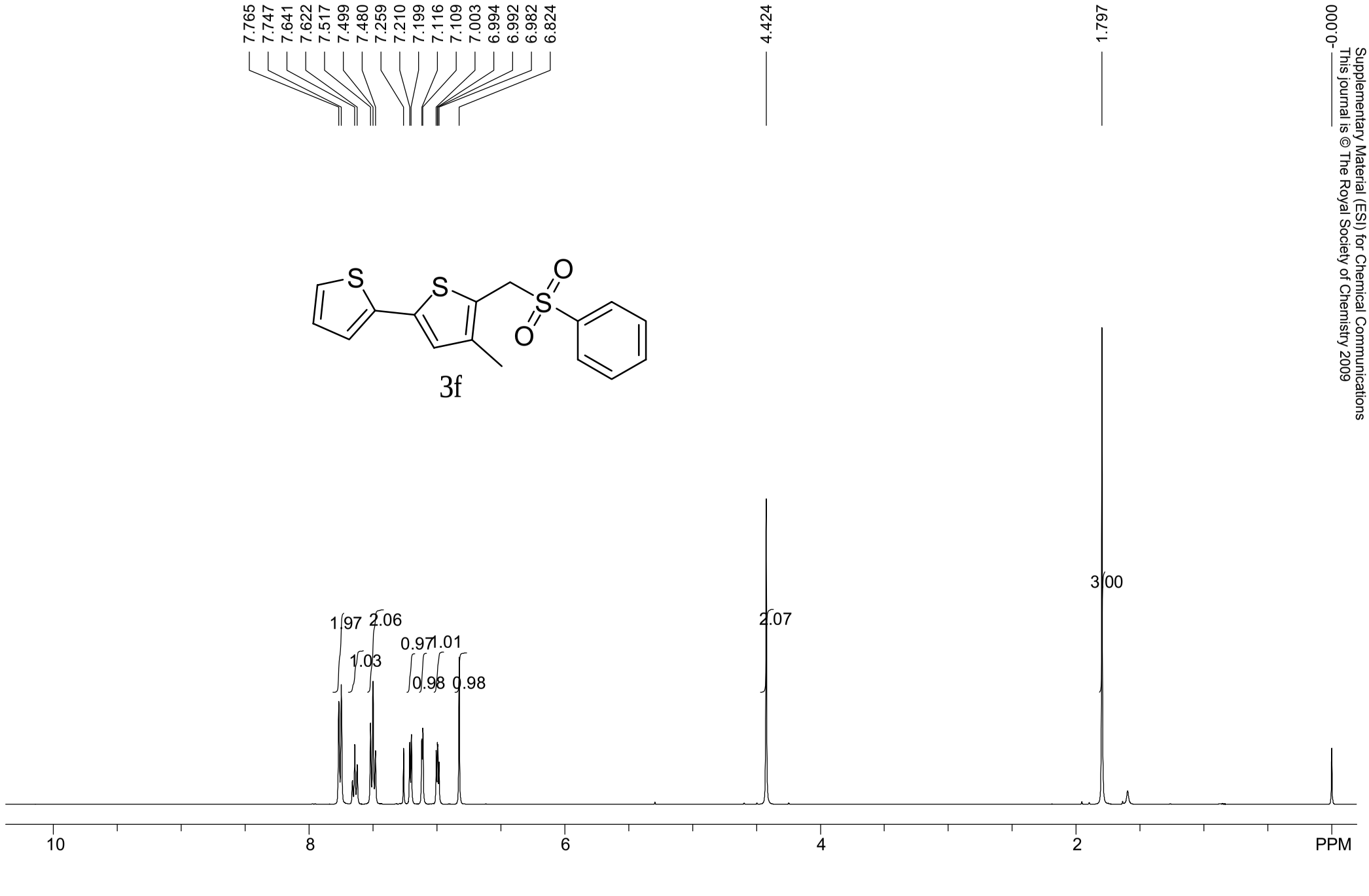

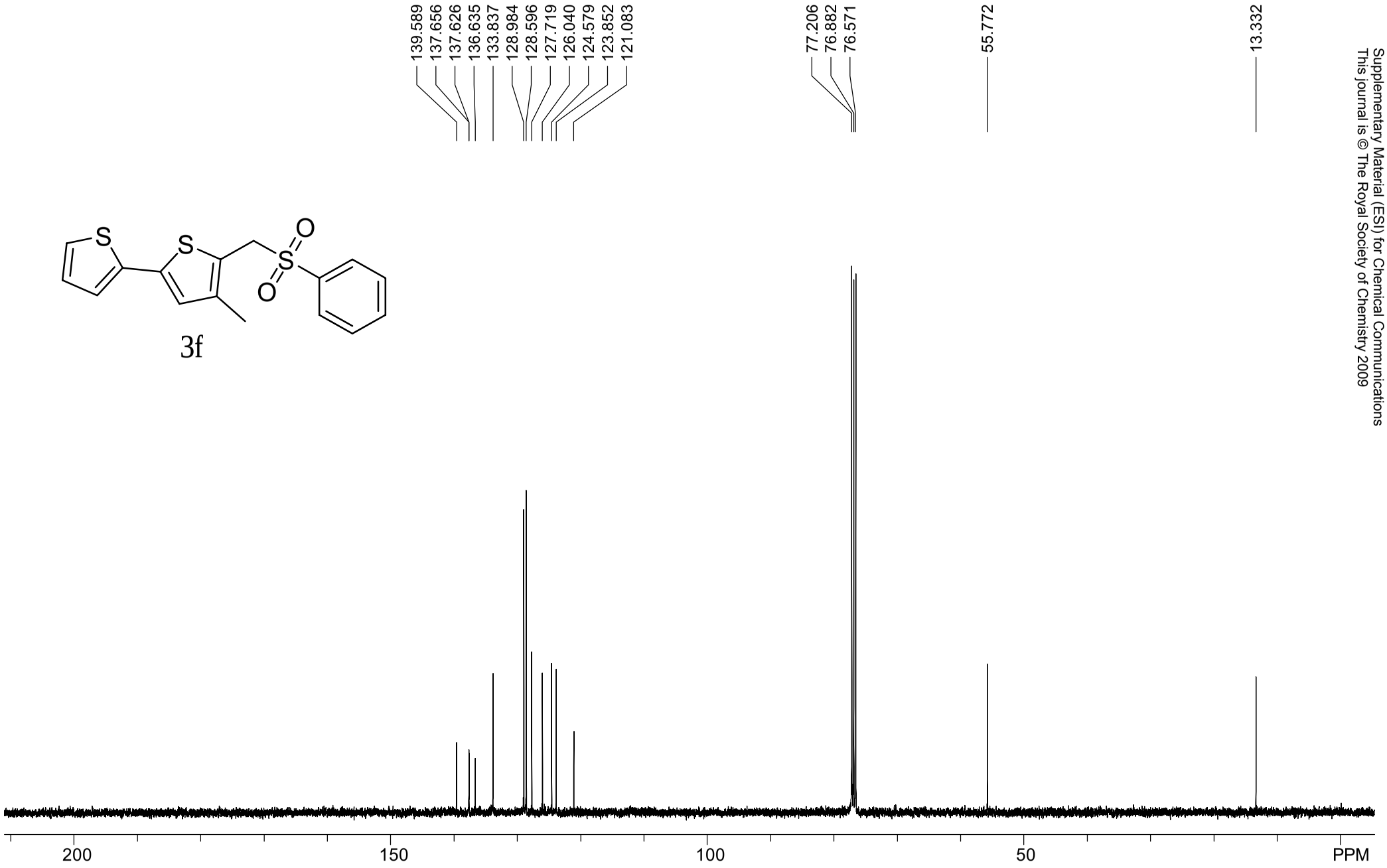

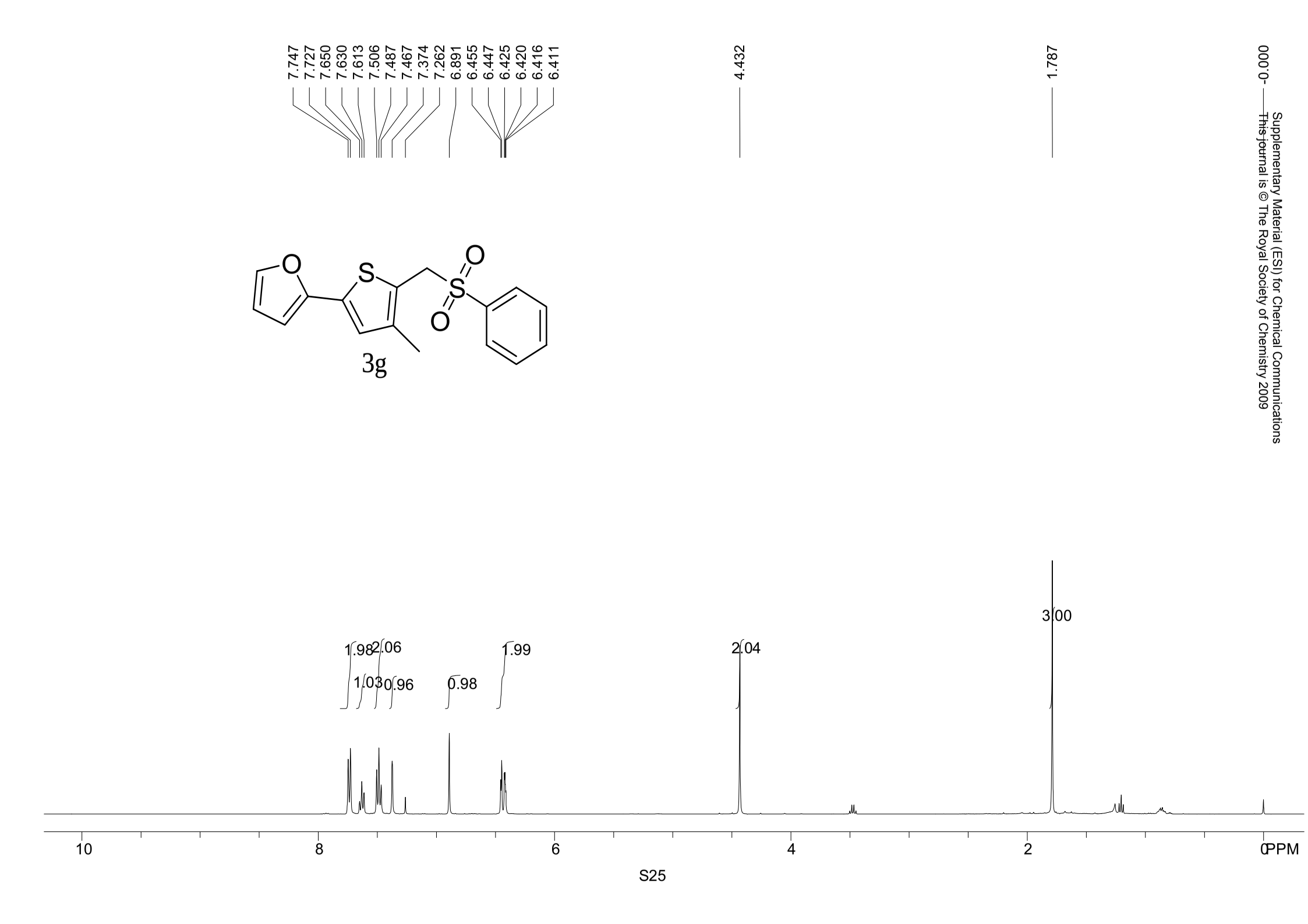

13.314
55.780
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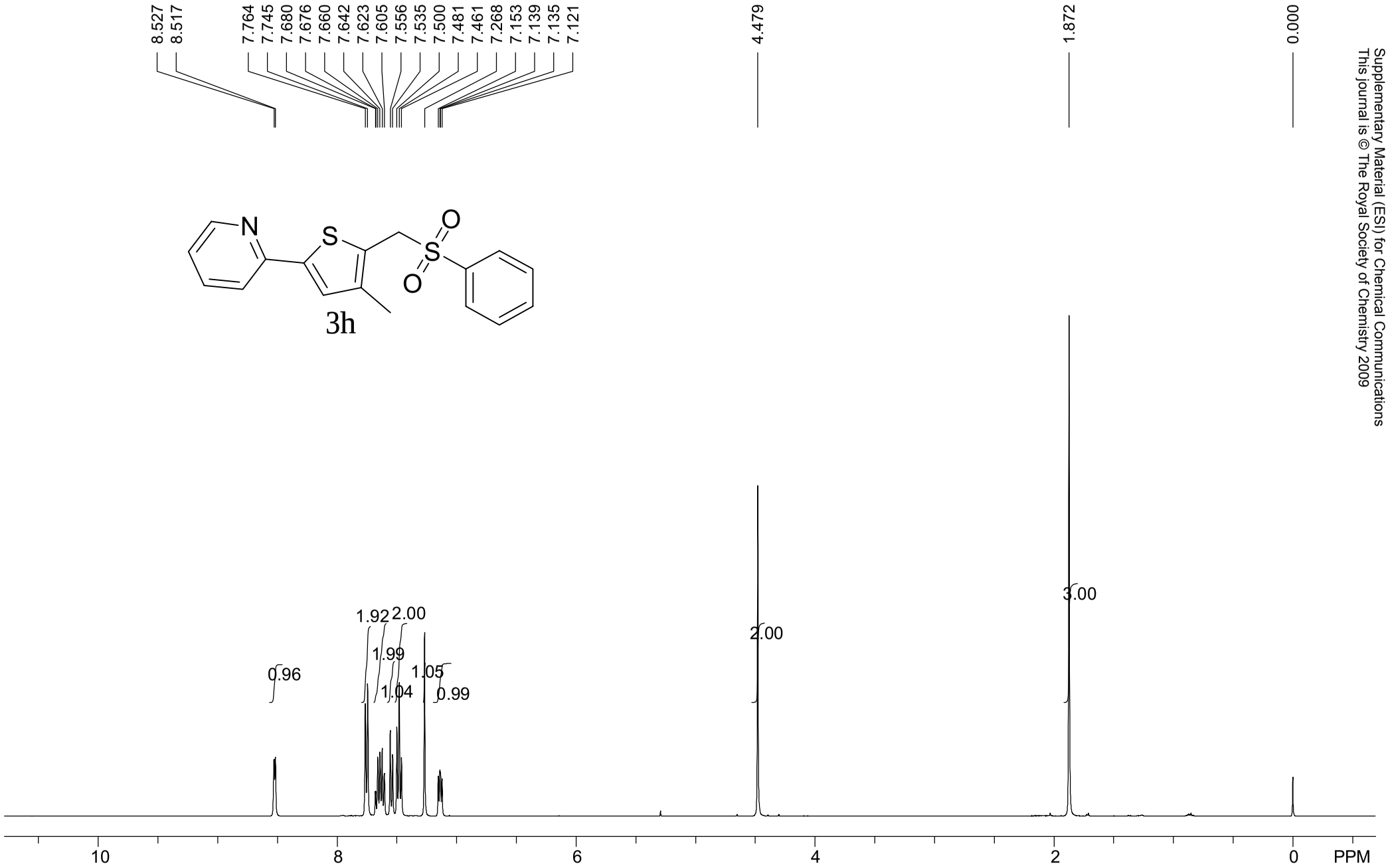

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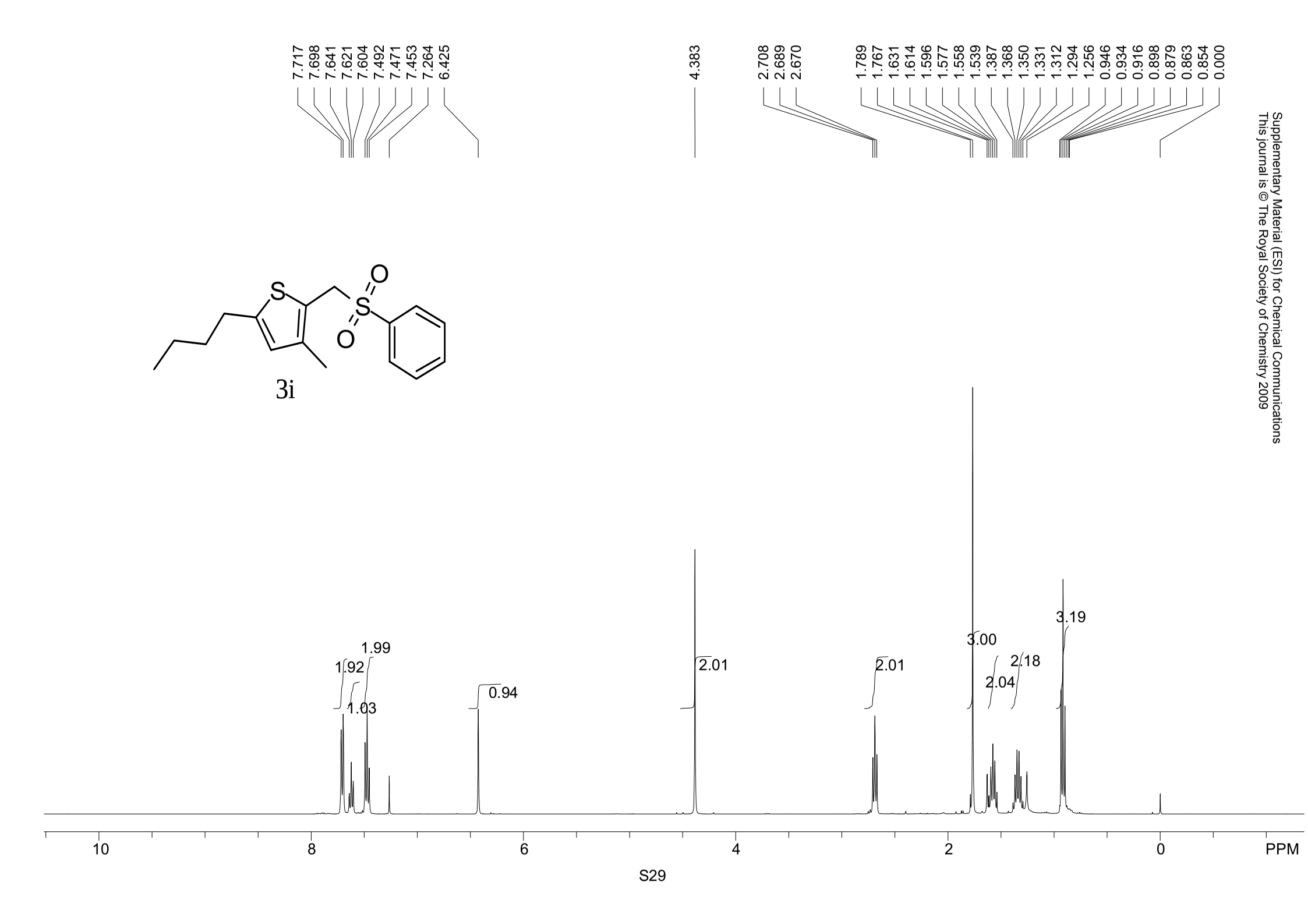

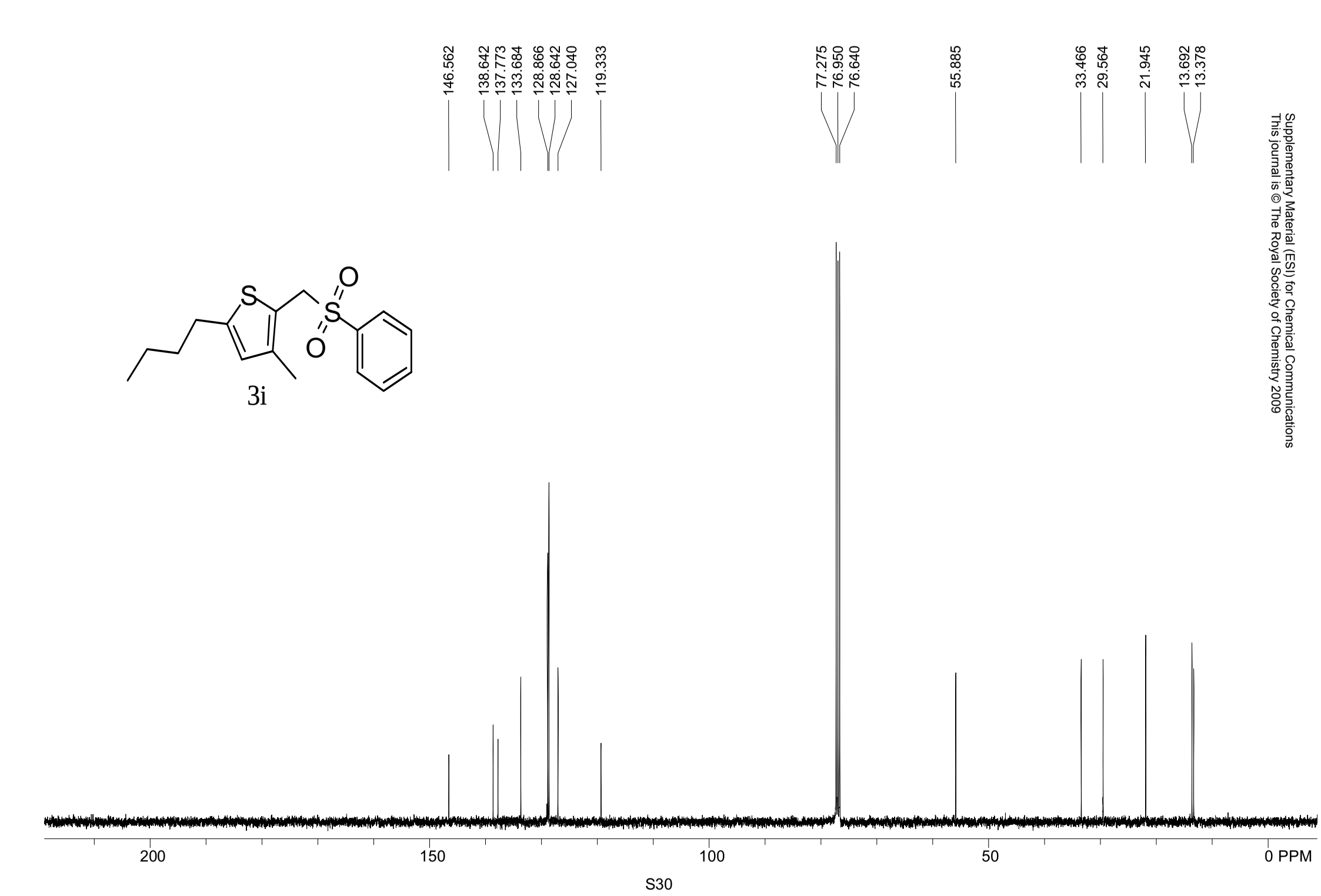

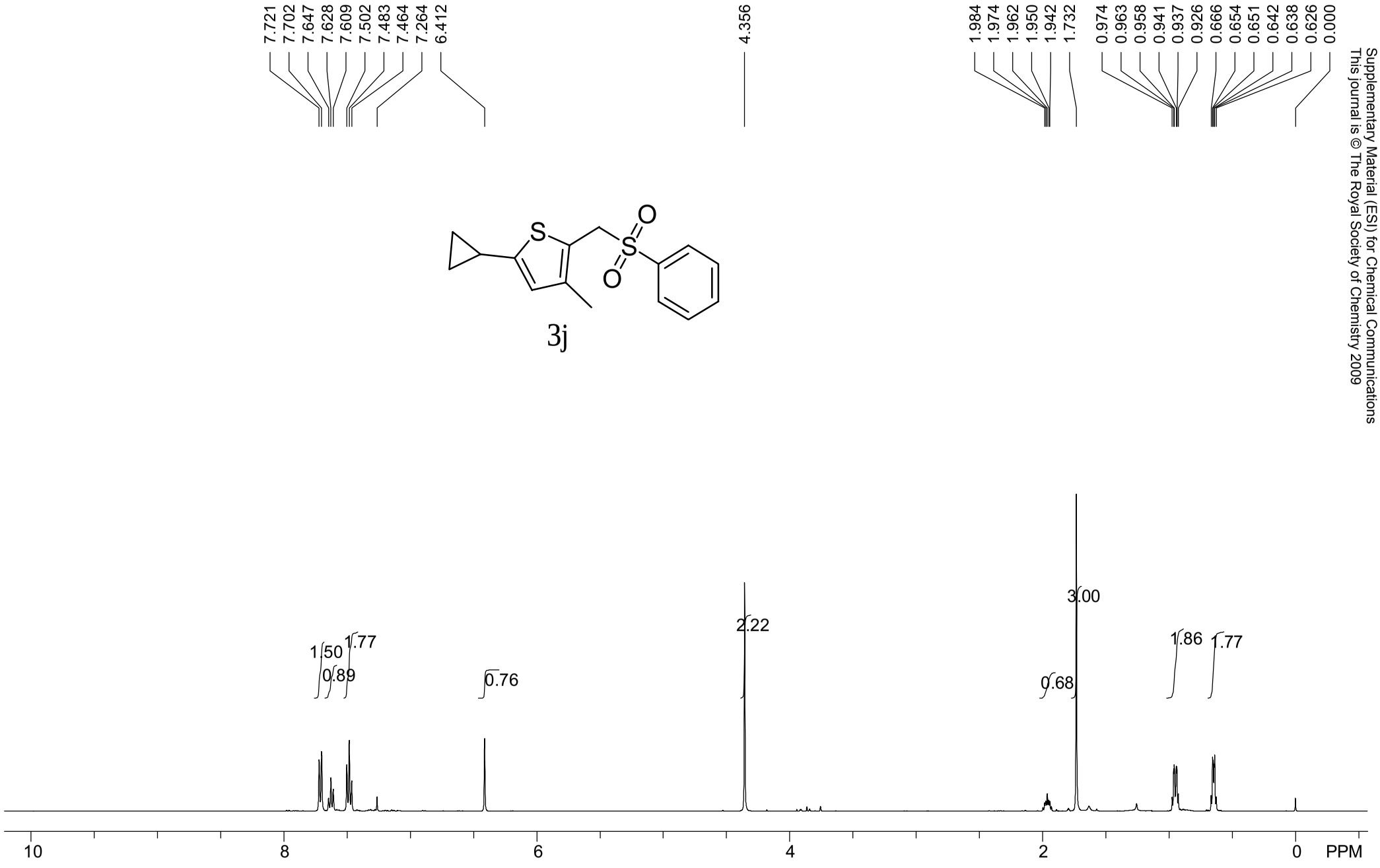

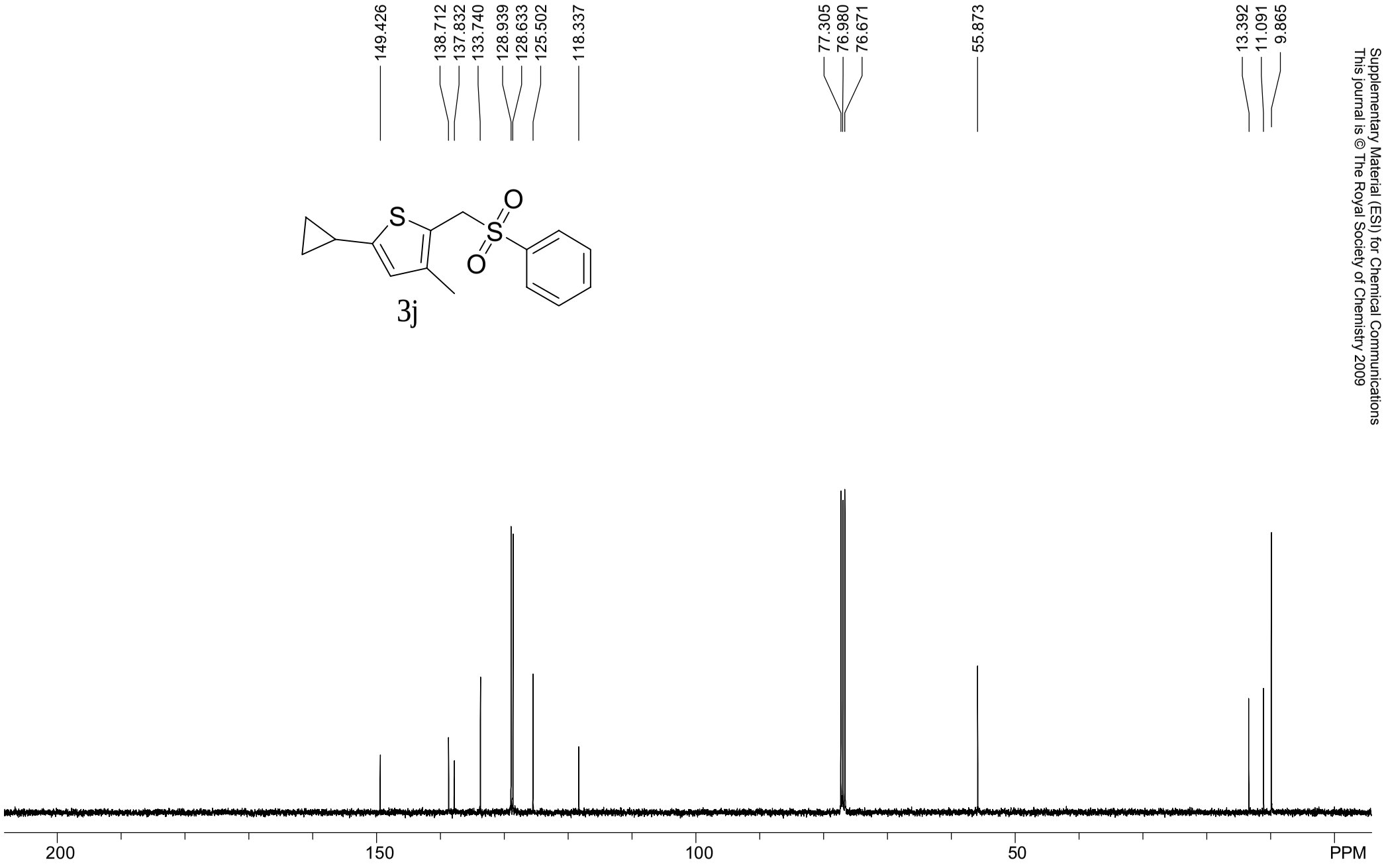

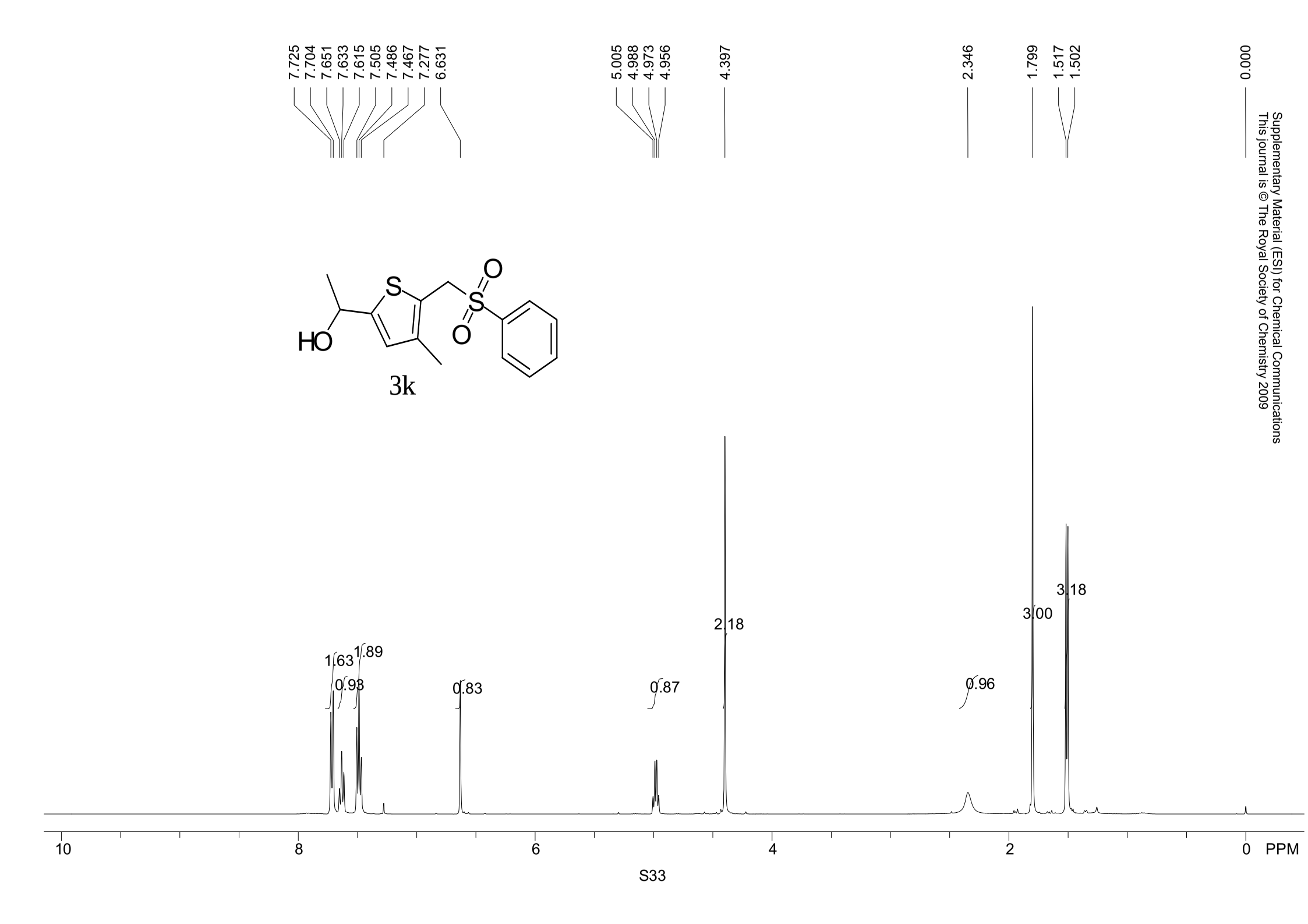

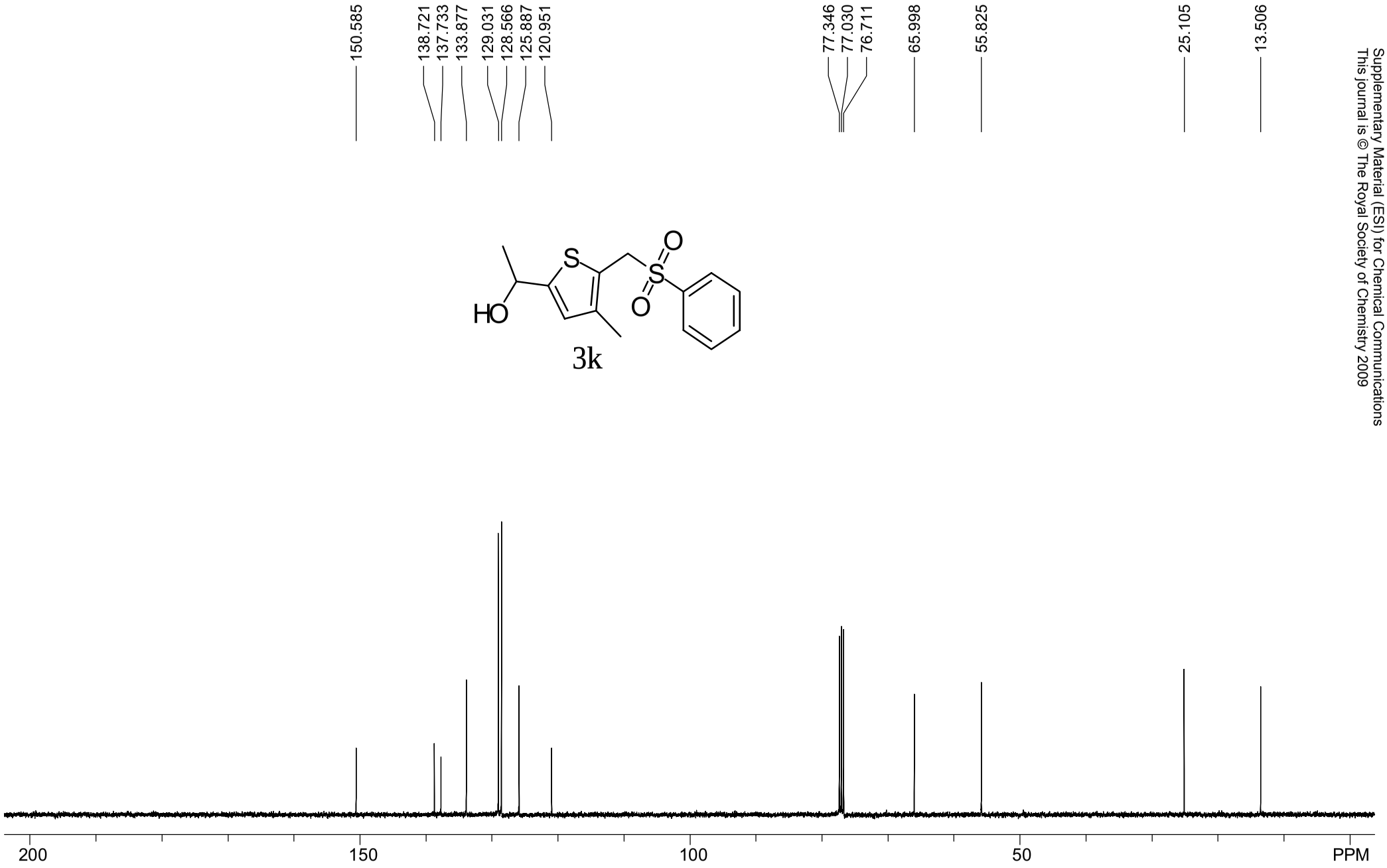

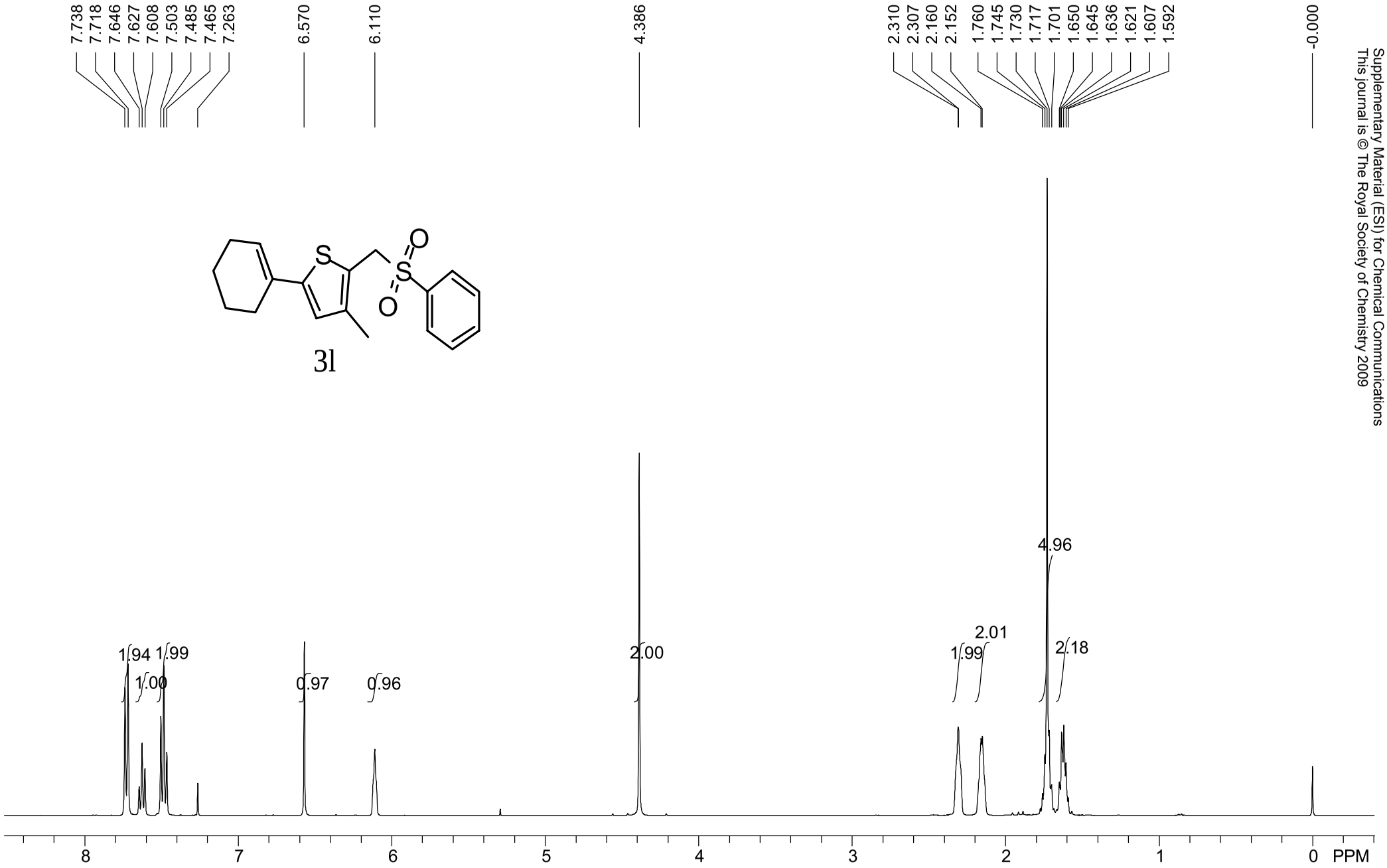

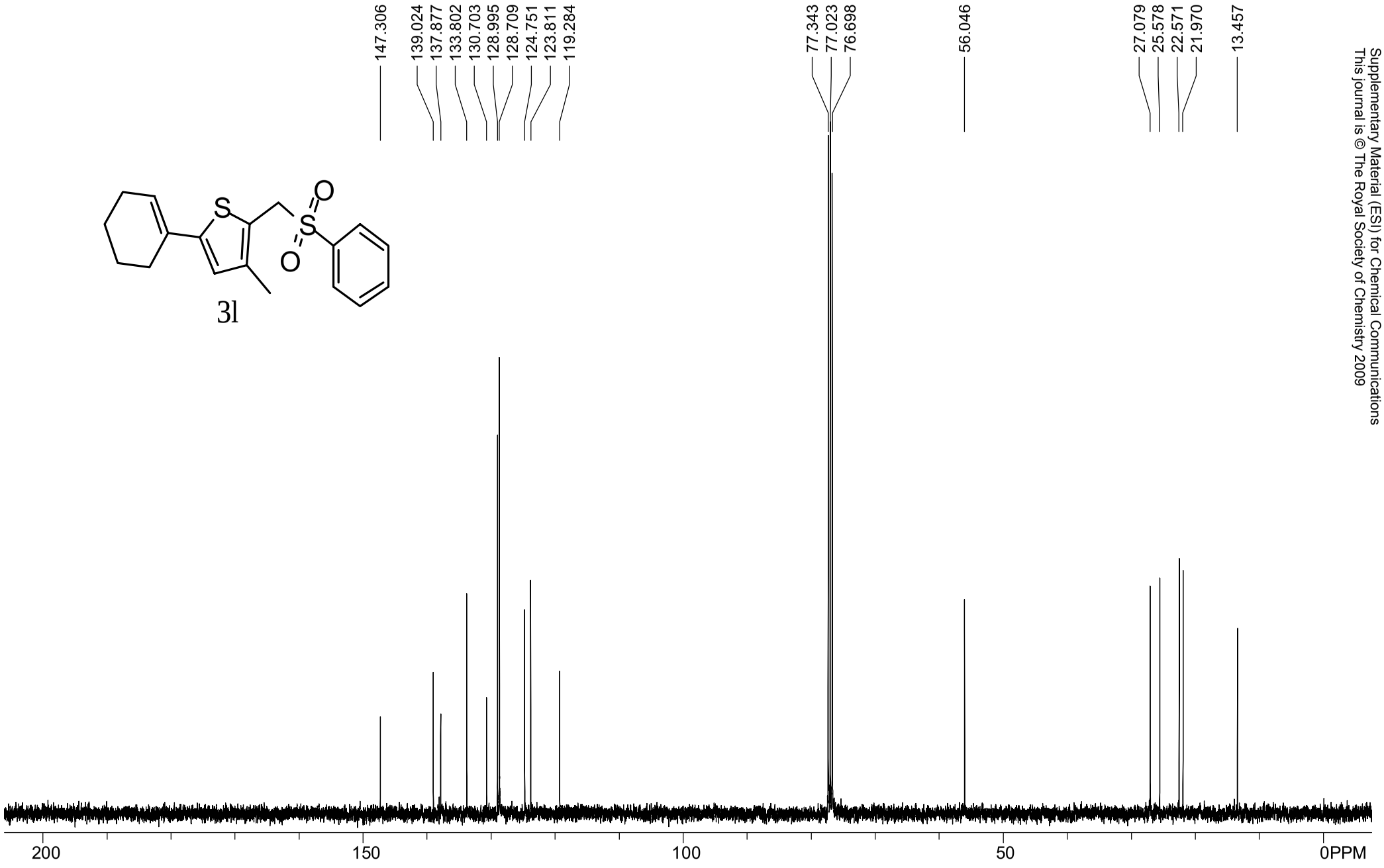

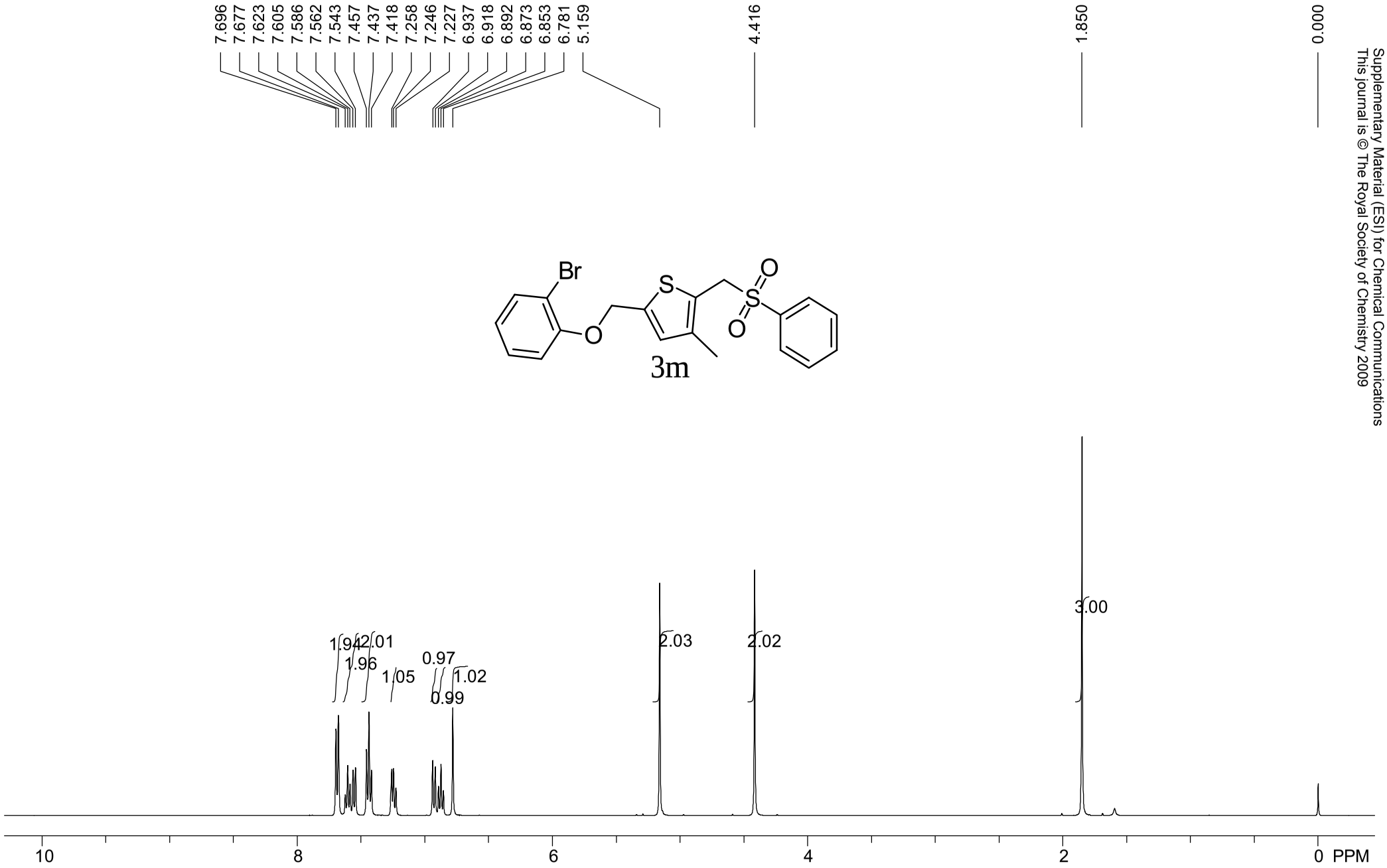

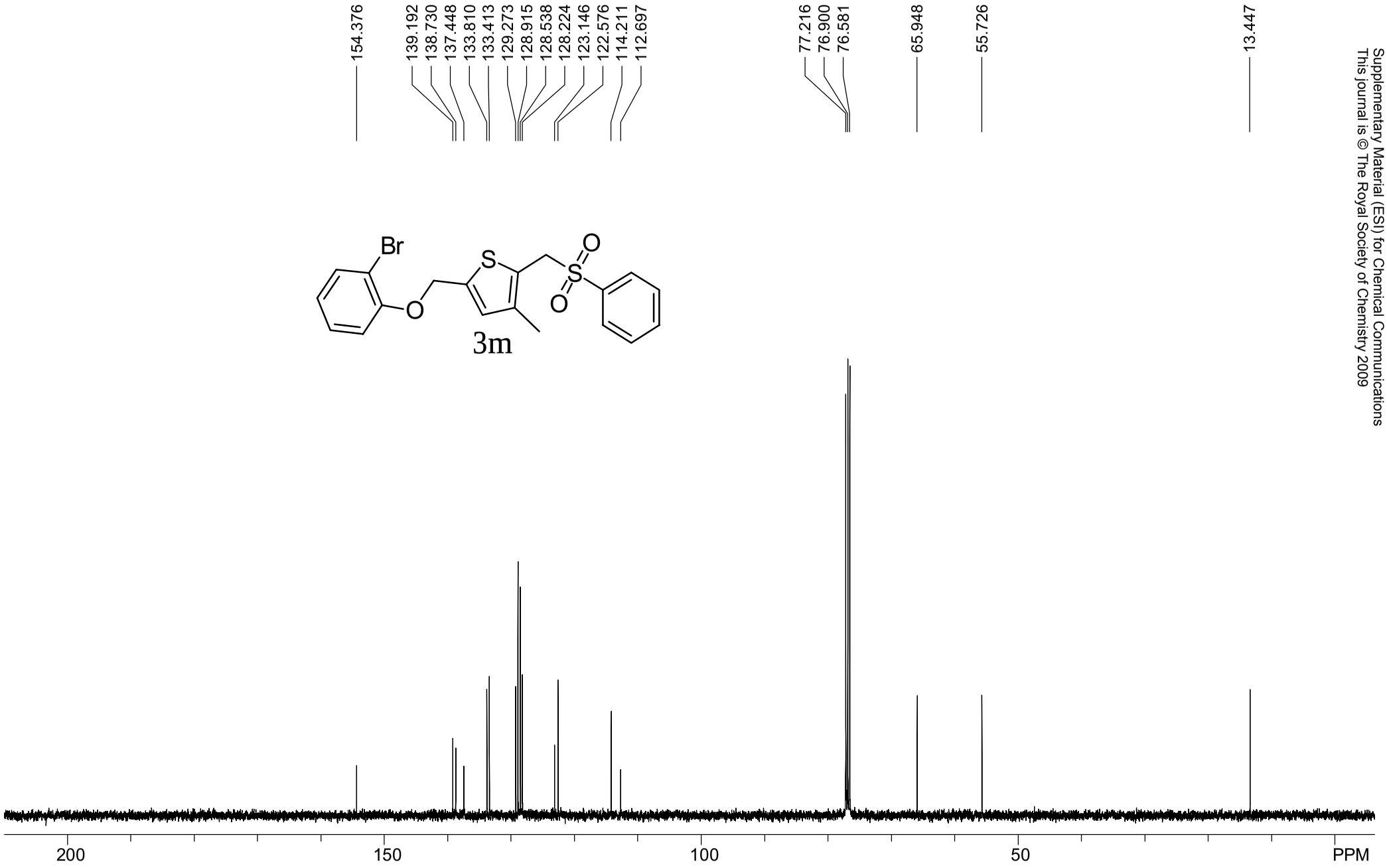

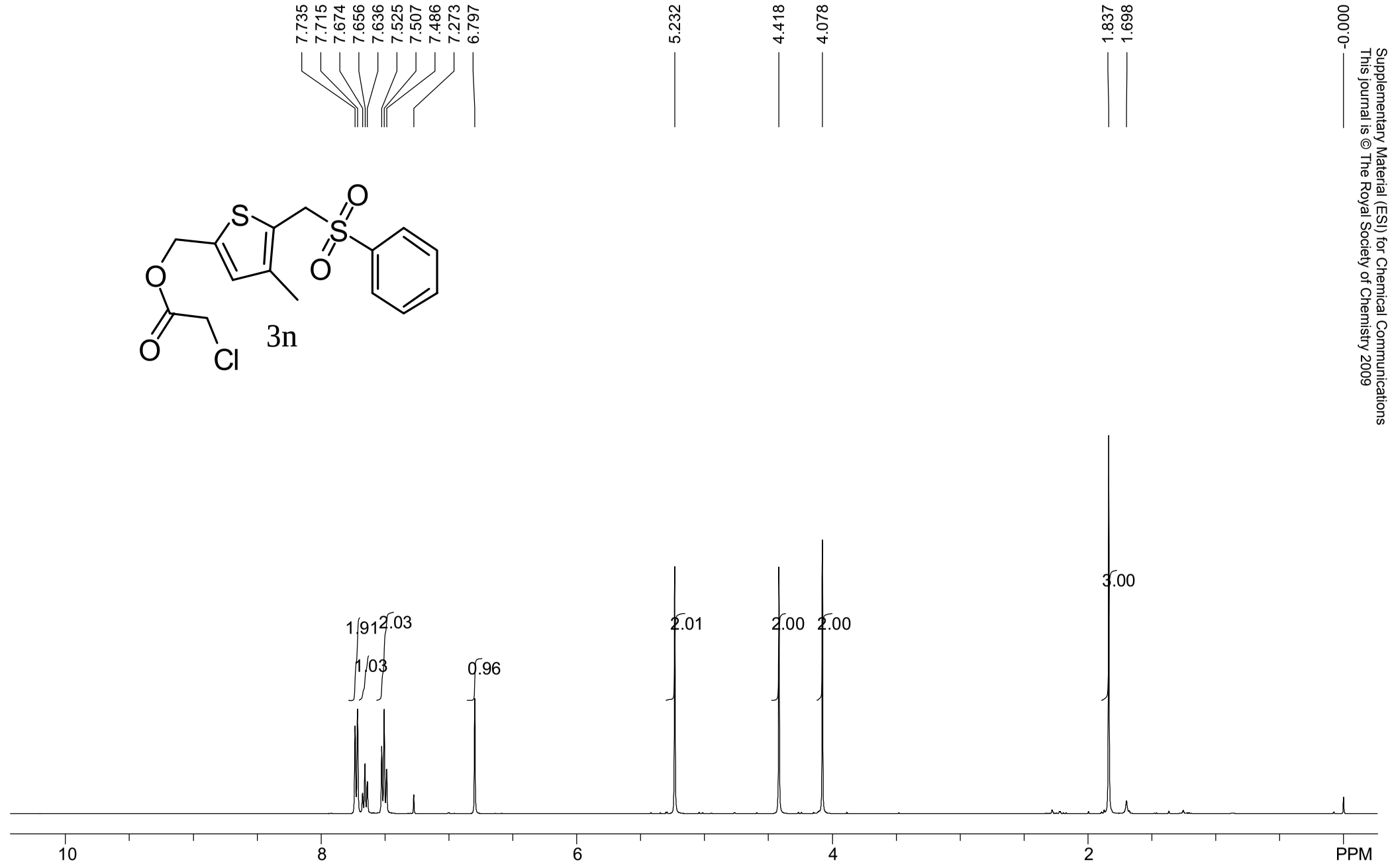

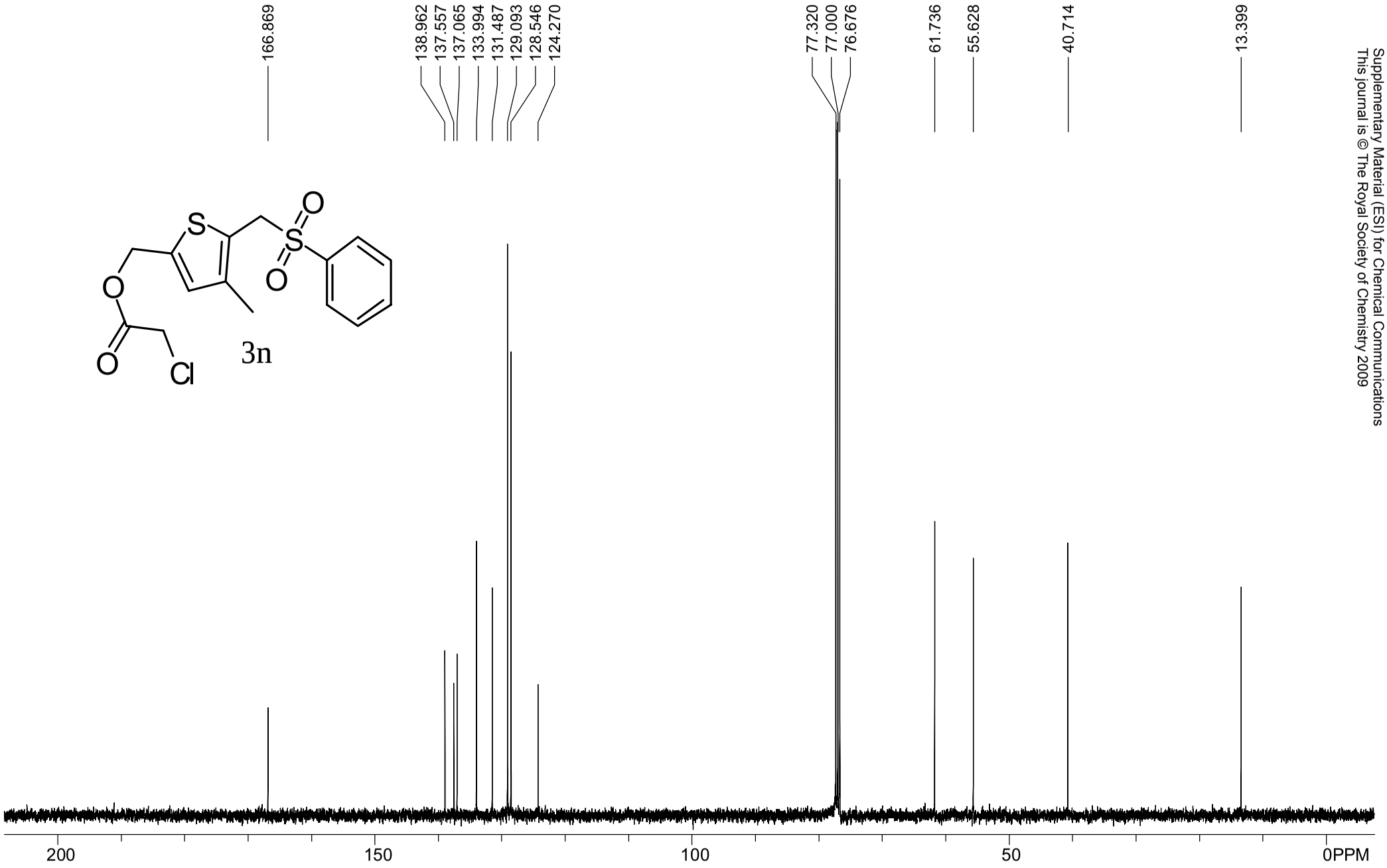

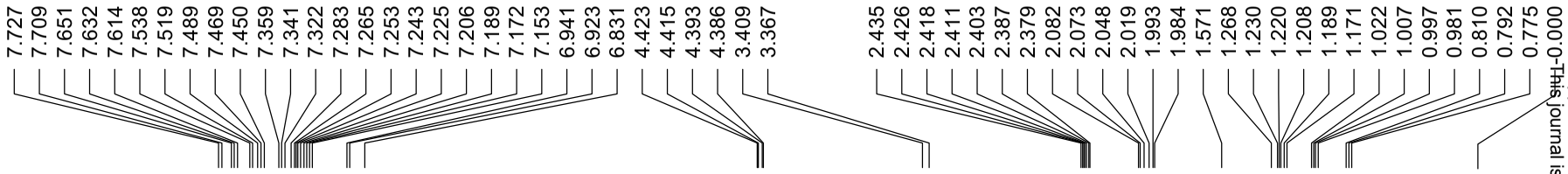

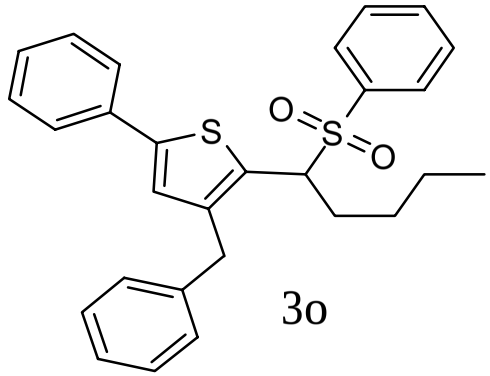

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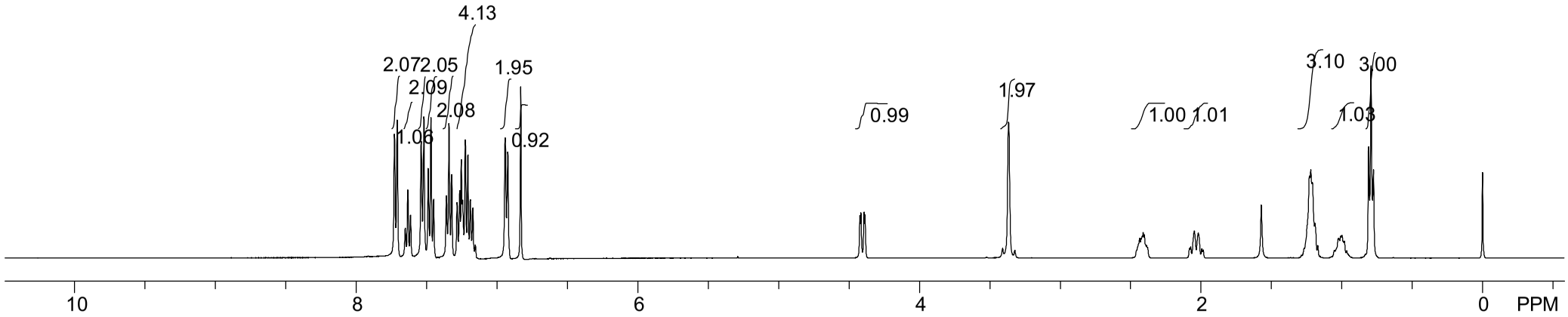

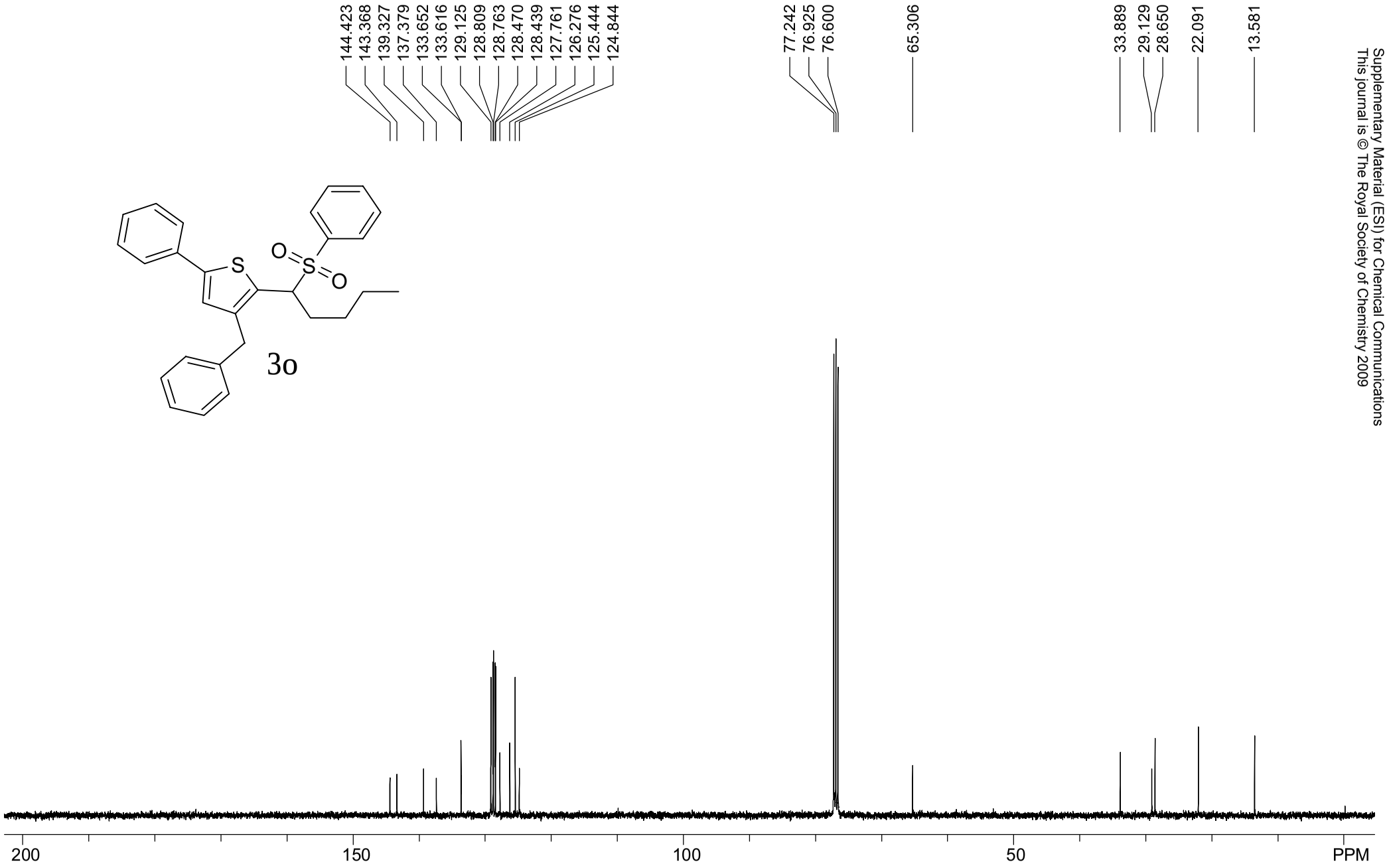

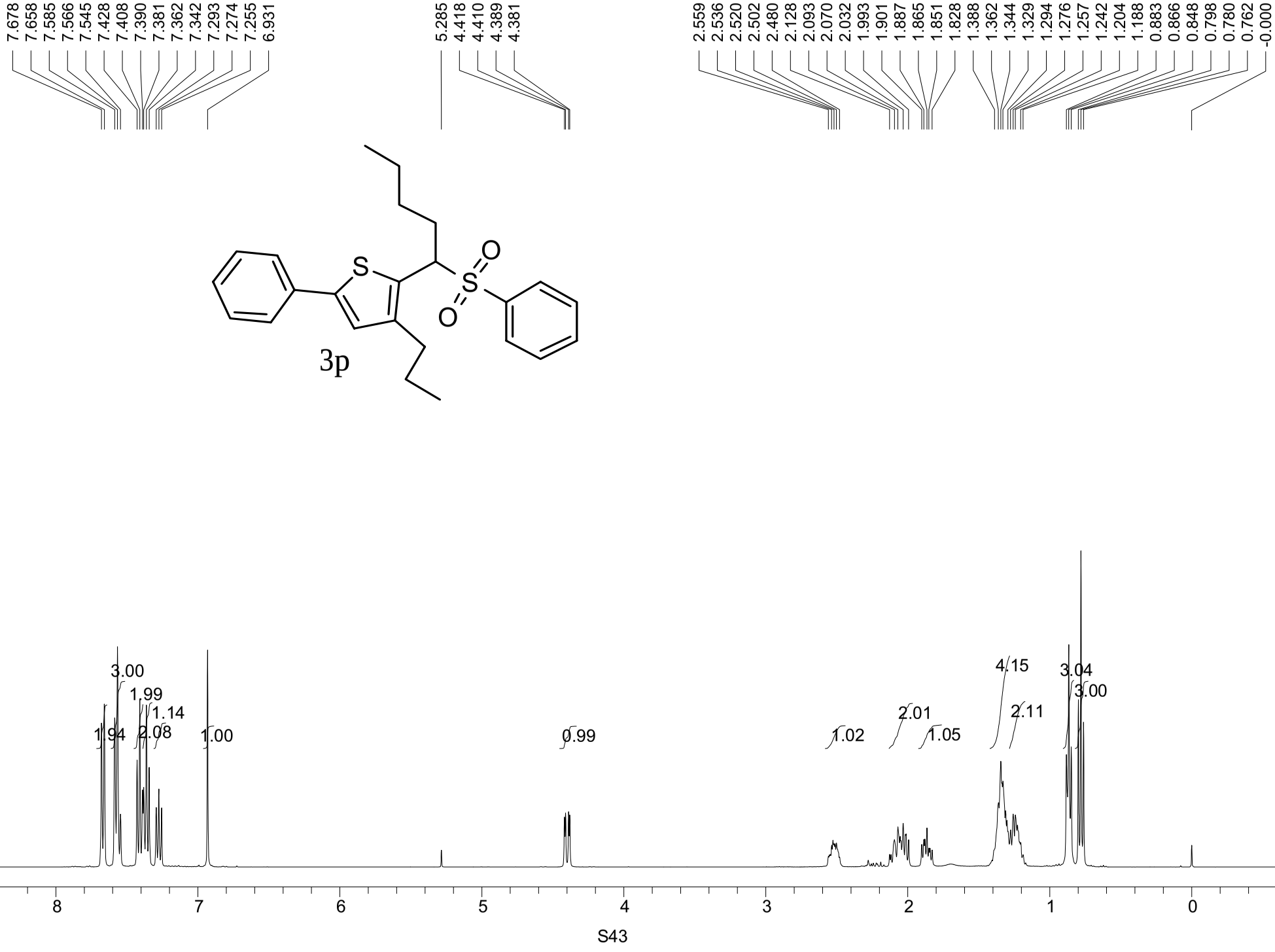

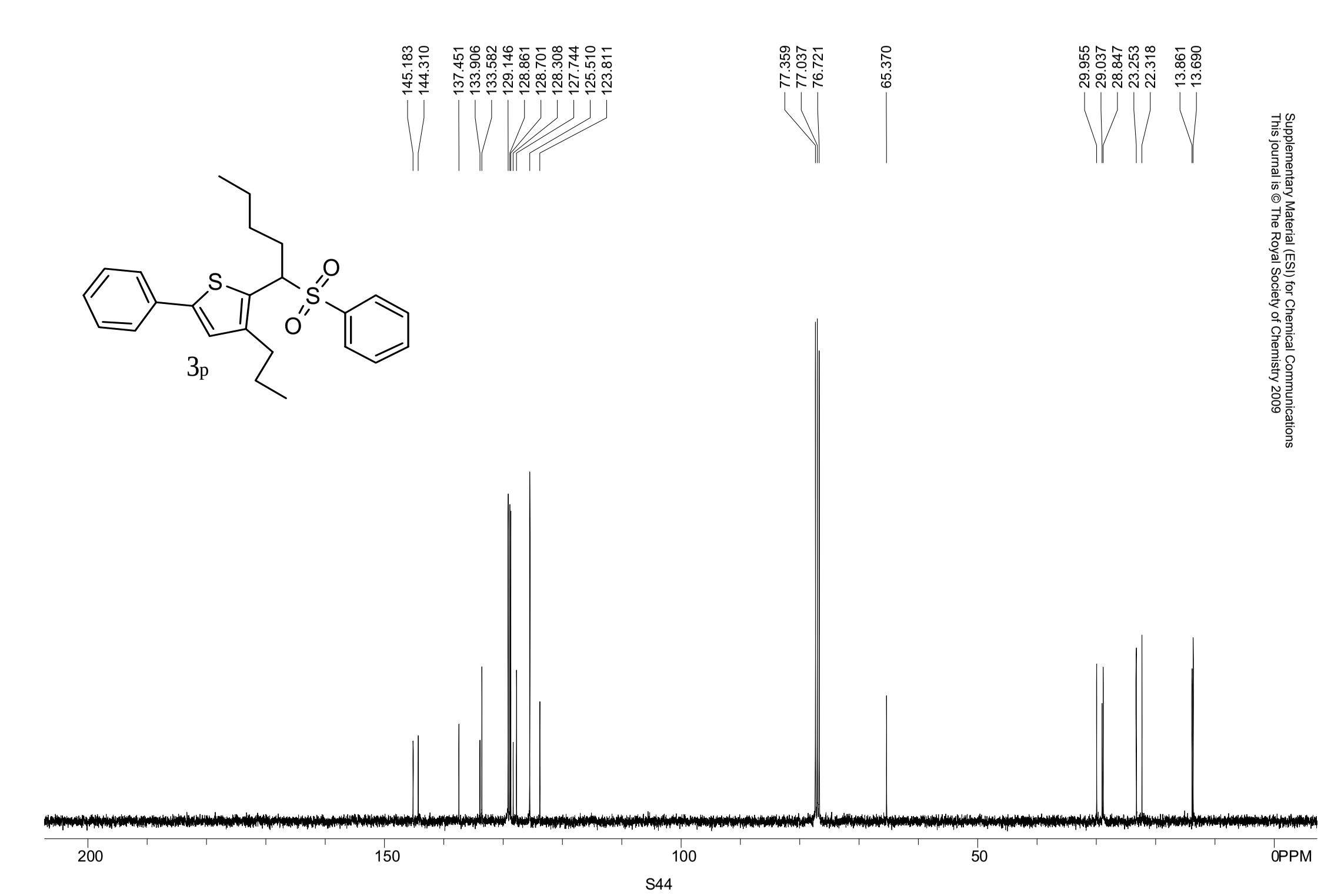

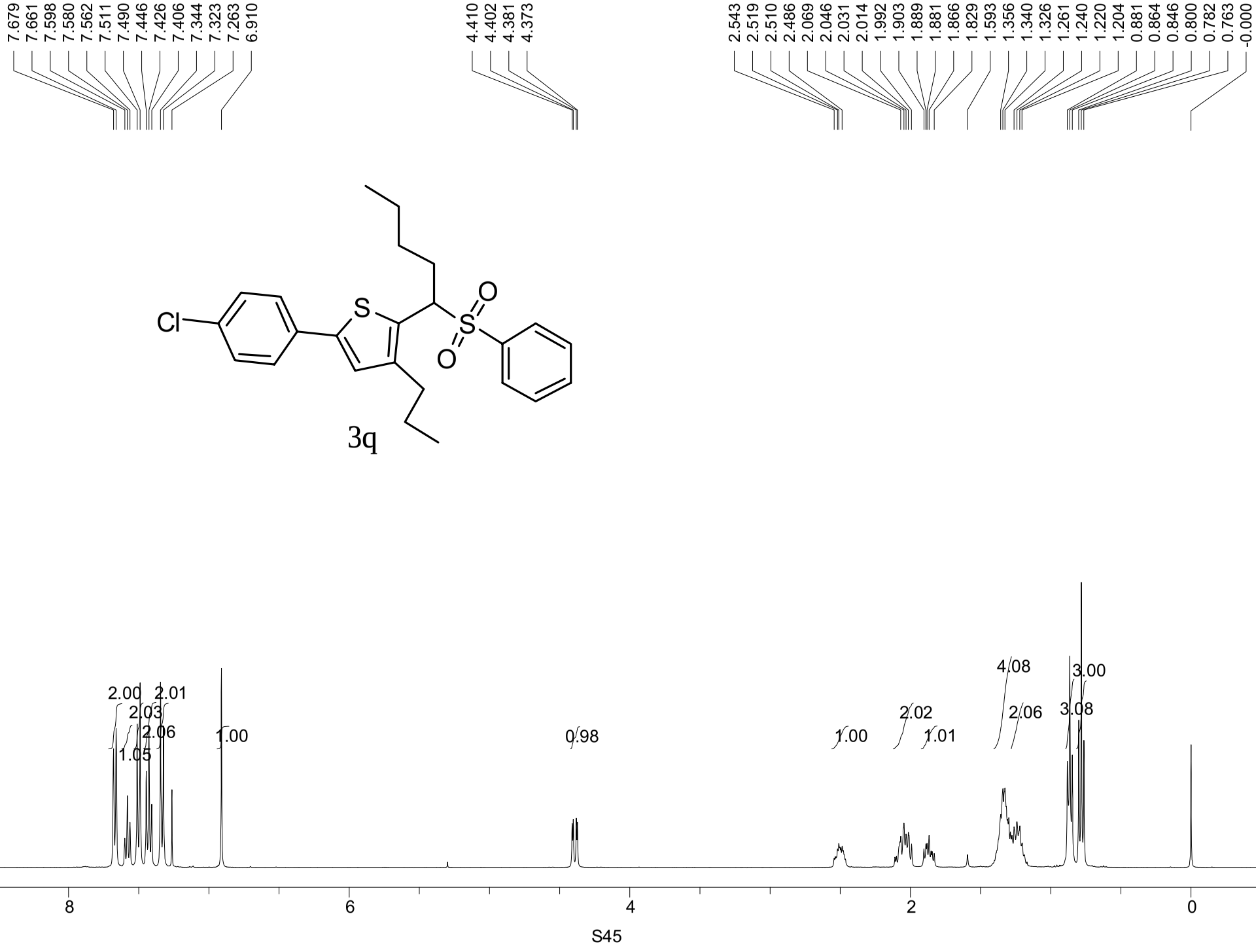

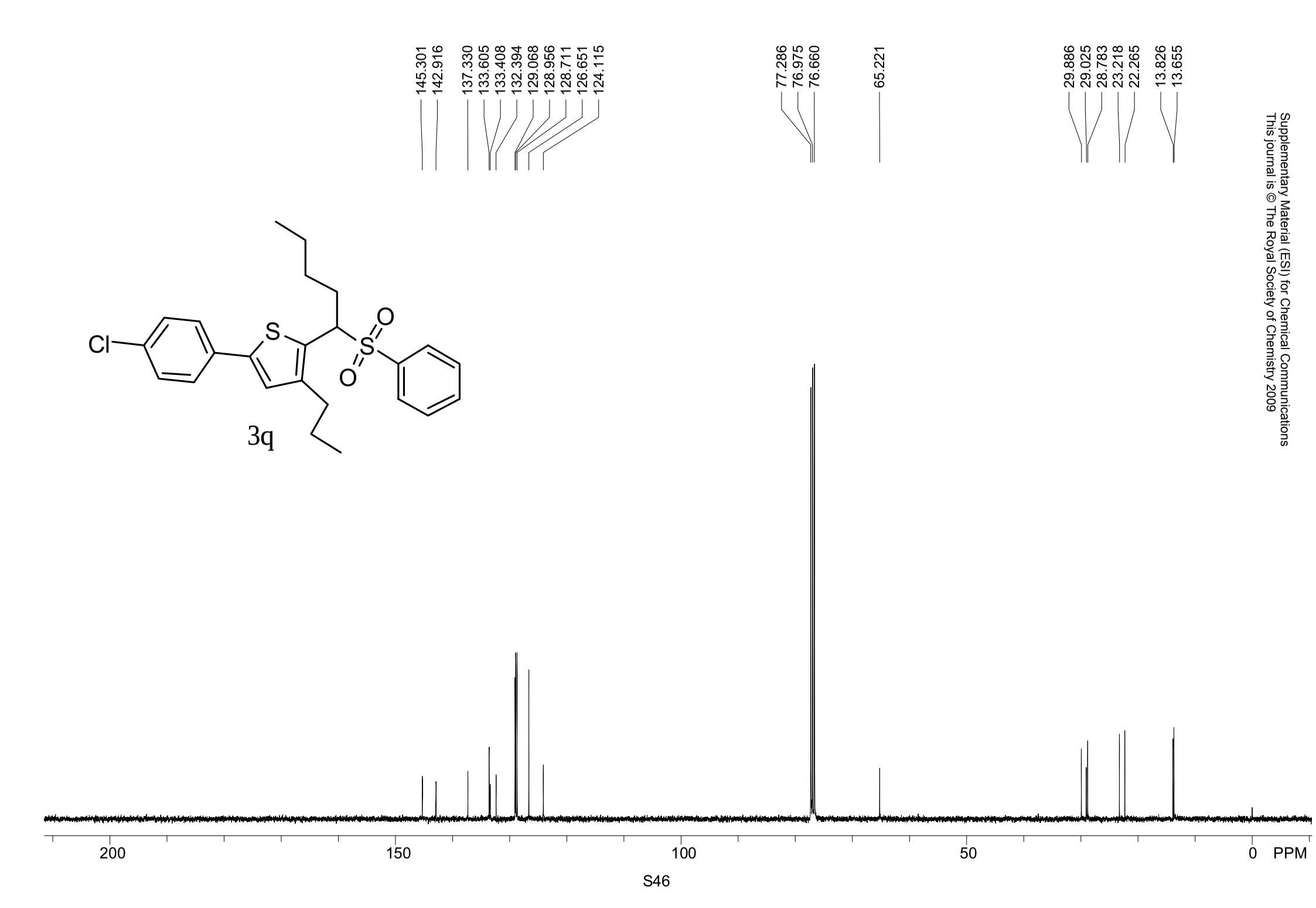

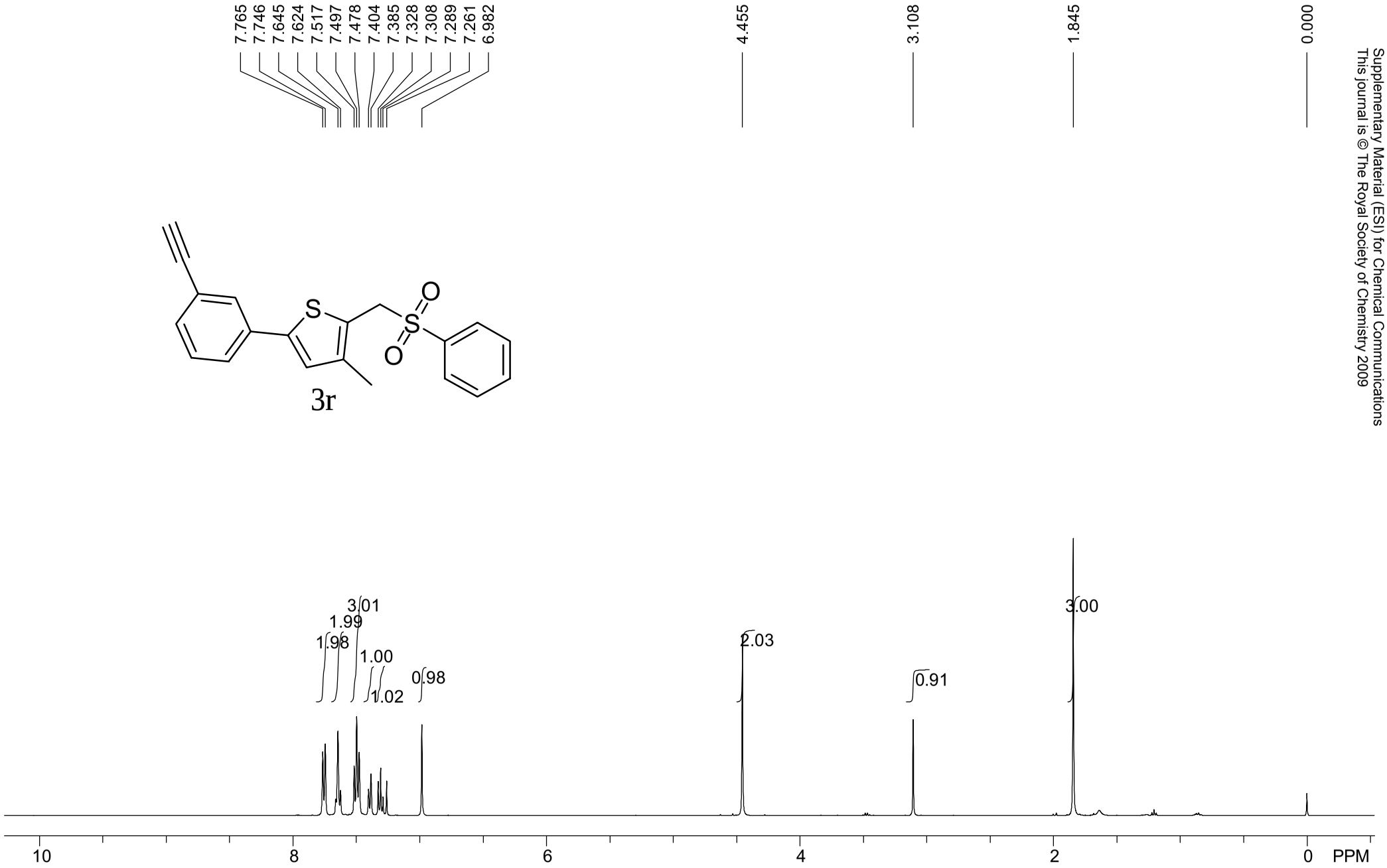

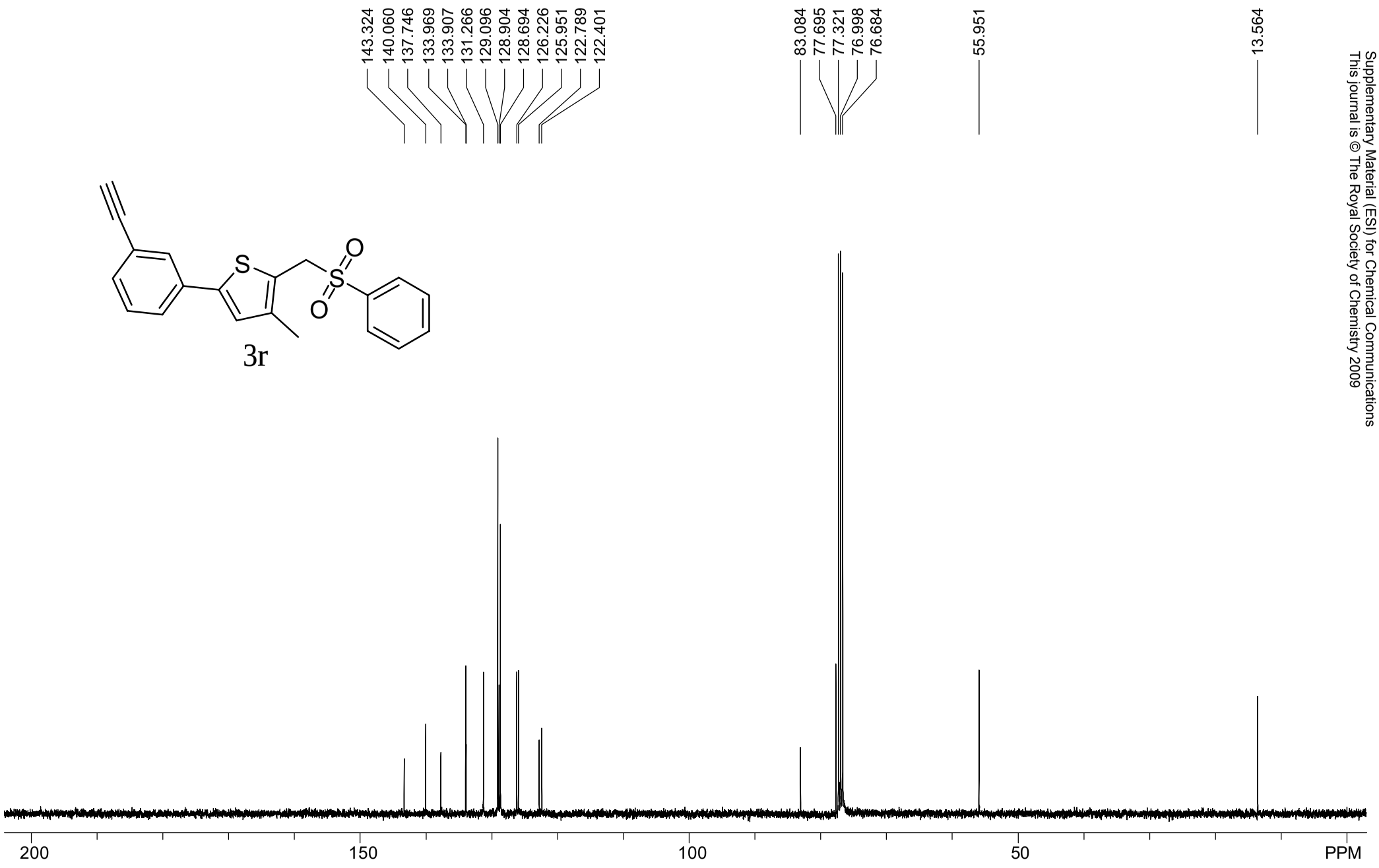

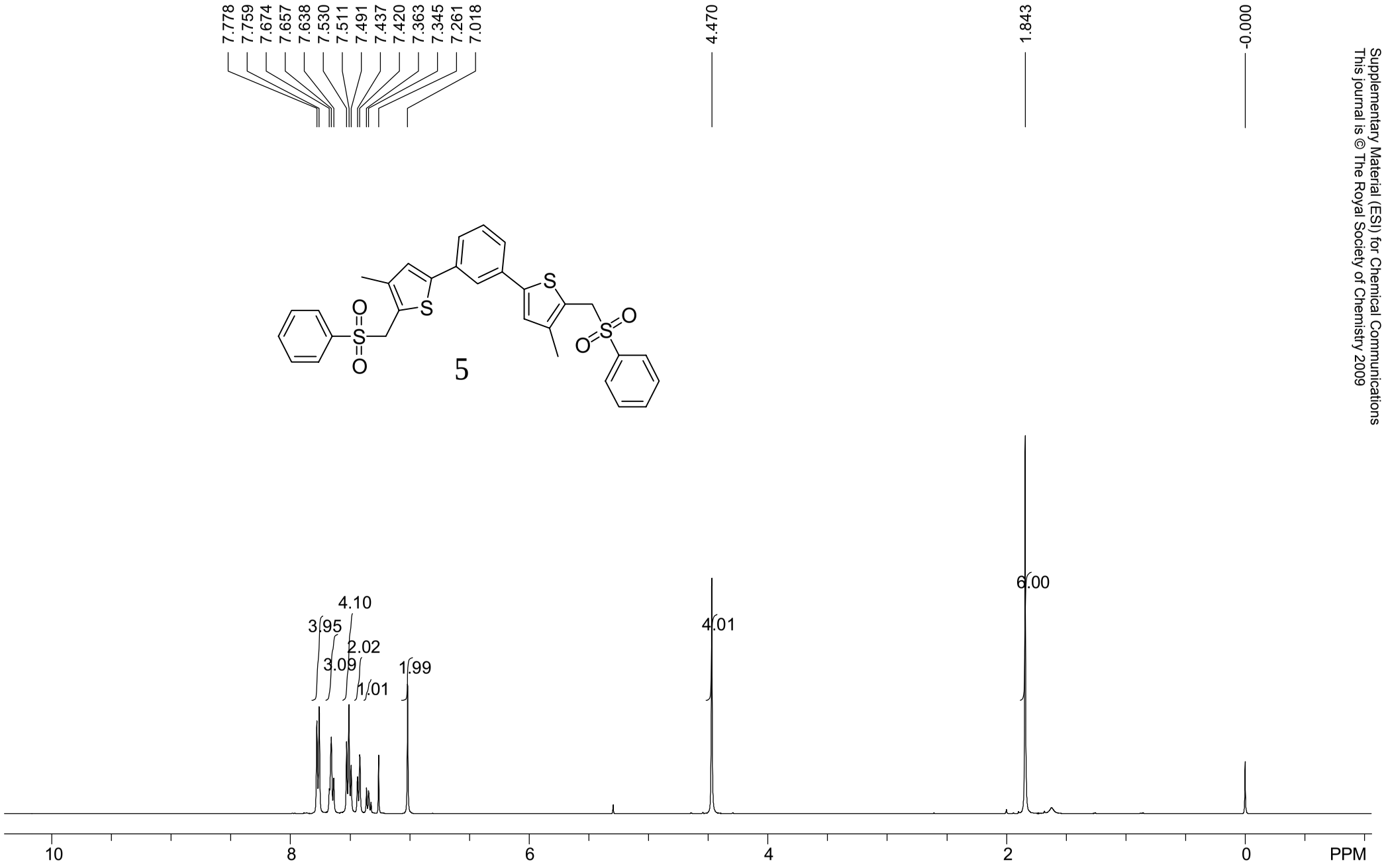

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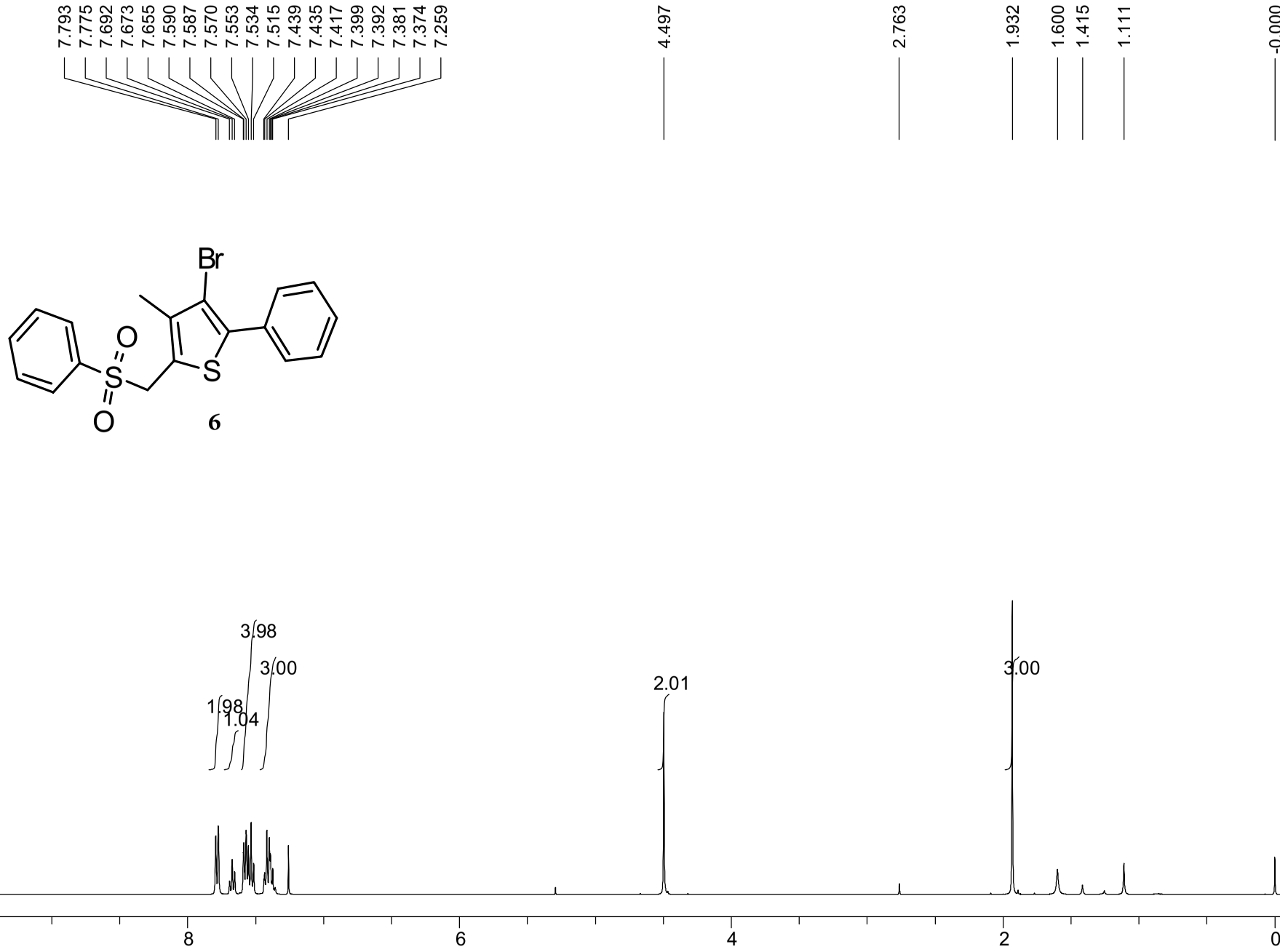

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