Supporting Information

Nano copper catalysed highly regioselective synthesis of 2,4-disubstituted pyrroles from terminal alkynes and isocyanides

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General Techniques:

All reagents were purchased from Sigma Aldrich and Alfa Aesar and were used without further purification. All the experiments for cycloaddition reaction of aromatic acetylenes were performed under nitrogen atmosphere whereas aliphatic acetylenes were performed under oxygen atmosphere. All the solvents used for the reaction were distilled before use. The product purification by column chromatography was accomplished using silica gel 100-200 mesh. Analytical TLC was performed with Merck silica gel 60 F254 plates, and the products were visualized by UV detection. The ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker-Avance (300 MHz); Inova (400 MHz) and Avance (500 MHz) spectrophotometer using $CDCl_3$ and TMS as the internal standard. Chemical shifts (δ =) are reported in ppm using TMS as an internal standard, and spin -spin coupling constants (J) are given in Hz. Multiplicities in the ^{1}H NMR spectra are described as: s = singlet, d = doublet, t = triplet, q = quartet, qt = quintet, m = multiplet, bs = broad singlet; coupling constants are reported in Hz. Low (MS) and high (HRMS) resolution mass spectra were recorded on a Waters 2695 and Thermo Scientific Exactive spectrometer respectively and mass/charge (m/z) ratios are reported as values in atomic mass units. All the melting points are uncorrected. X-ray powder diffraction (XRD) data were collected on a Simens/D-5000 diffractometer using Cu Kα radiation. XPS spectra were recorded on a Kratos AXIS 165 with a dual anode (Mg and Al) apparatus using the Mg Kα anode. The pressure in the spectrometer was about 10^{-9} Torr. The particle size and external morphology of the samples were observed on a JEOL JEM-2100 high resolution transmission electron microscope (HRTEM). Auger electron spectroscopic (AES) analysis is conducted, at a base pressure of 10^{-10} Torr, within the K.E. range of 110-700 eV (beam voltage of 3 kV, eV/step 1 eV, time/step 50 ms). X-ray absorption spectra were recorded using a Rigaku spectrometer with a rotating anode X-ray generator (Ru-200B, Rigaku, Japan).

2. Preparation of Cu_{nano}/Al_2O_3:

Copper-Aluminum hydrotalcites [(Cu-Al HT) Cu:Al 2.5:1] was prepared by co-precipitation employing $NaOH/Na_2CO_3$ as described in the literature.[1] The thermal reduction of copper aluminium hydrotalcite to nano copper(0) on alumina was achieved by using our previously published procedure.[2]

Copper: Aluminium ratio (Cu:Al) in the synthesized catalysts was determined by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICPMS) and it is found to be 2.49:1.

The Cu loading of $Cu(0)/Al_2O_3$ is estimated out as 8 wt% from atomic absorption analysis (AAS). The average particle size of $Cu(0)/Al_2O_3$ was estimated to be 7.6 nm which is well matched with transmission electron microscopy.

The formation of a nano Cu(0) on alumina was confirmed by XRD, XPS analysis and TEM analysis.

3. Catalyst Characterization:

3.1 XRD- analysis

The powder XRD patterns of Cu(0) nanoparticles sythesized catalyst are shown in Fig. 1. In XRD pattern of the Cu(0) nanoparticles (Figure 1A) contains peaks that are clearly distinguishable (Fig 1B). According to the diffraction data card (JCPDS, 06-0246), all the peaks are perfectly indexed to Cu (0) in peak position.

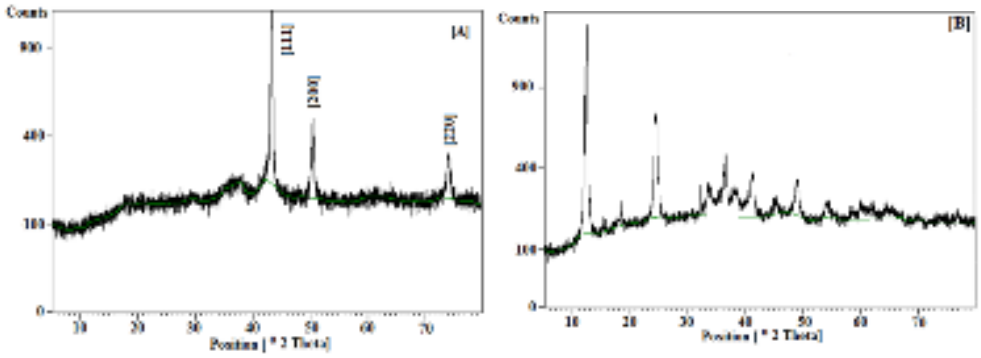


Figure 1. XRD patterns of $Cu(0)/Al_2O_3$ [A] and XRD patterns of Cu(II)-Al HT [B].

3.2 XPS analysis

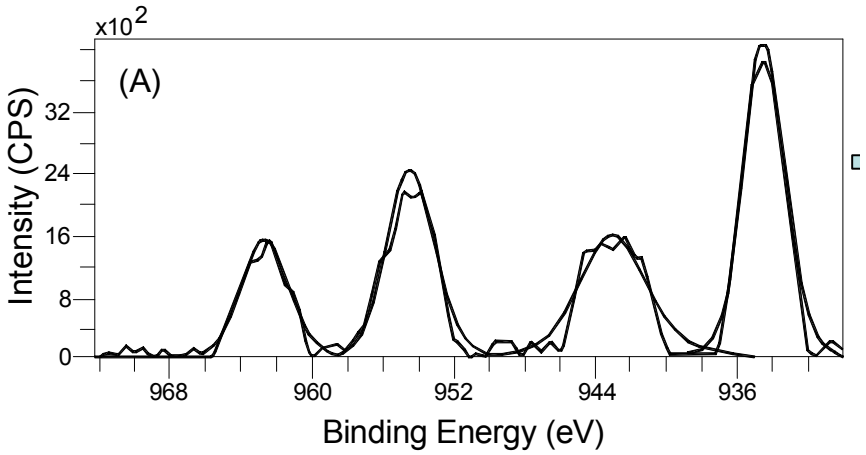


Figure 2.[A] XPS spectra of Cu(II)-Al HT

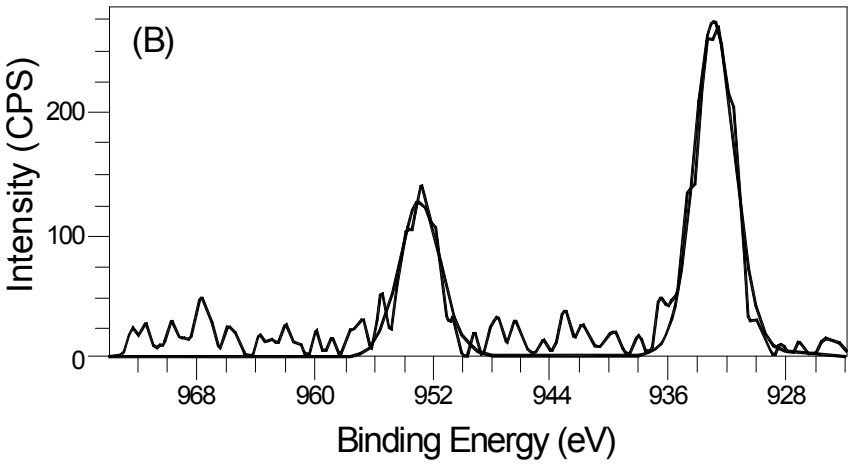


Figure 2.[B] XPS spectra of Cu(0)/Al_2O_3

The X-ray photoelectron spectroscopic (XPS) analysis of fresh Cu(0)/Al_2O_3 (Fig. 2**[B],** and Cu(II)-Al HT (Fig. 2**[A]**) shows that there is change in oxidation state of copper from +2 to 0. XPS investigation of Cu(0)/Al_2O_3 and Cu(II)-Al HT and catalyst at the Cu 2p level shows 2p3/2 line at 932.3, and 934.7 and 952.2 and 954.6 eV for 2p1/2, which corresponds to 0 and +2 oxidation state of Cu. XPS of the used catalyst (reaction carried out under atmospheric

condition) Cu 2p level also shows 2p3/2 line at 933.4 eV, which indicates that the copper is in the reduced form.

3.3 TEM Analysis

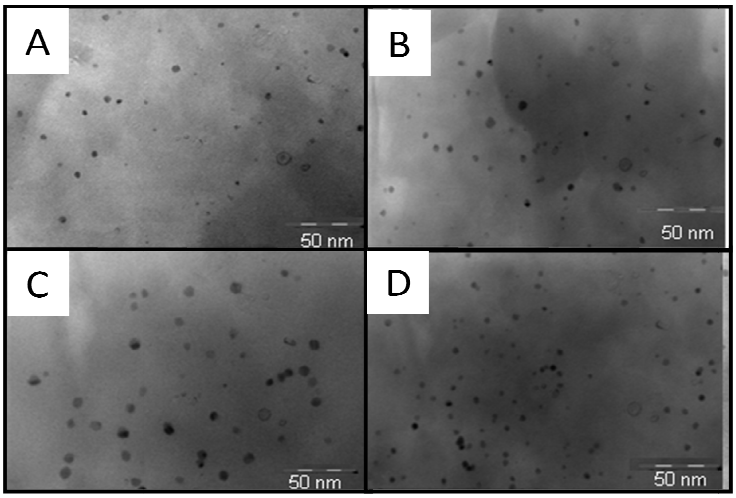
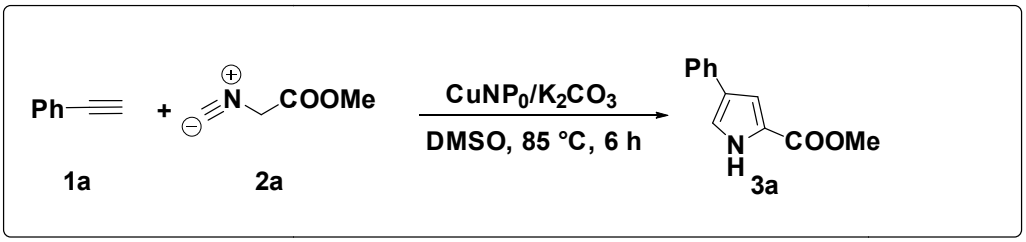


Figure 3. TEM pictures of fresh $Cu(0)/Al_2O_3$ [A-D].

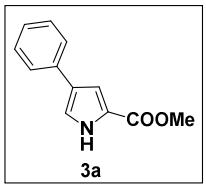
4. Experimental procedure for the synthesis of methyl 4-phenyl-1H-pyrrole-2-carboxylate (3a):[b]



In a 25 mL two-neck round bottom flask equipped with condenser connected to N_2 balloon, to a mixture of phenyl acetylene (**1a**, 0.11 mL, 1.0 mmol), methyl 2-isocyanoacetate (**2a**, 0.10 mL, 1.0 mmol) and Cu_{nano} catalyst (30 mg, 8 wt%; 3.75 mol%) in DMSO (4 mL) was slowly added K_2CO_3 (0.20 g, 1.5 mmol) through solid addition tube over a period of 2 hrs at 85 °C. The reaction mixture was stirred for another 4 hrs at the same temperature. The mixture was then allowed to attain room temperature and diluted with ethyl acetate (50 mL). The catalyst was filtered and the organic layer was washed with water (10 mL) and brine (10 mL). The organic layer was dried over anhydrous sodium sulphate and evaporated under reduce

pressure to produce crude **3a** which was purified by silica gel (100-200) chromatography using mixture of EtOAc (10%) and petroleum ether (90%) as eluent.

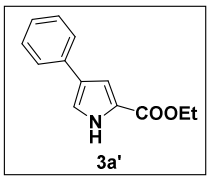
4.1- Methyl 4-phenyl-1*H*-pyrrole-2-carboxylate (3a):



3a

Yield: 75%, white solid, m. p. 178 – 180 °C, (lit. 176 – 180 °C);[3] .**^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.27 (s, 1H), 7.52 (dd, *J* = 8.1, 1.01 Hz, 2H), 7.36 (t, *J* = 7.70 Hz, 2H), 7.26 - 7.22 (m, 2H), 7.21 - 7.20 (m, 1H), 3.89 (s, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.28, 134.46, 129.19, 128.91, 126.45, 125.15, 123.49, 119.47, 112.57, 51.78; **FT-IR** (neat): 3315, 2975, 1695, 1266, 1213, 760 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{12}H_{11}NO_2$ $[M+Na]^+$ is 224.1273 and found 224.1287.

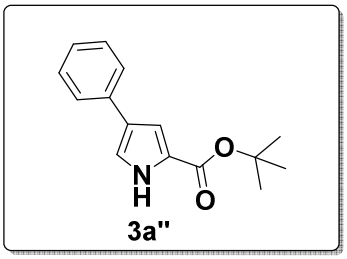
4.2- Ethyl 4-phenyl-1*H*-pyrrole-2-carboxylate (3a'):



3a'

Yield: 71%, white solid, m. p. 97 - 99 °C (lit. 98 - 99 °C);[4] **^{1}H NMR** (400 MHz, $CDCl_3$) δ = 9.23 (s, 1H), 7.53 (dd, *J* = 7.6, 1.3 Hz, 2H), 7.36 (t, *J* = 7.8 Hz, 2H), 7.24 (dd, *J* = 1.9, 0.9 Hz, 1H), 7.23 – 7.22 (m, 1H), 7.21 (dd, *J* = 2.5, 1.6 Hz, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 1.38 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.14, 134.51, 128.91, 126.27, 125.29, 123.75, 119.29, 112.38, 60.52, 14.46; **FT-IR** (neat): 3310, 2982, 1688, 1266, 1213, 760 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{14}NO_2$ $[M+Na]^+$ is 238.0839 and found 238.0837.

4.3-*tert*-butyl 4-phenyl-1H-pyrrole-2-carboxylate: (3a''):

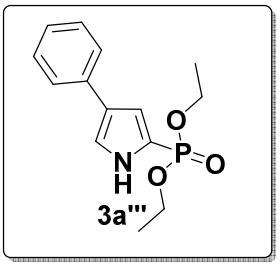


3a''

Yield: 69%, colourless oil; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.15 (s, 1H), 7.52 (d, *J* = 7.6 Hz, 2H), 7.35 (t, *J* = 7.7 Hz, 2H), 7.24 – 7.18 (m, 2H), 7.13 – 7.10 (m, 1H), 1.59 (s, 9H);

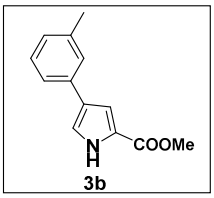
^{13}CNMR (100 MHz, $CDCl_3$) δ = 160.59, 134.73, 129.04, 128.74, 126.81, 126.19, 125.32, 118.72, 111.93, 81.14, 28.42; **FT-IR** (neat): 3345, 2979, 1698, 1276, 1225, 761 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{15}H_{17}NO_2$ $[M+Na]^+$ is 266.1152 and found 266.1148.

4.4- Diethyl (4-phenyl-1*H*-pyrrol-2-yl)phosphonate (3a''')



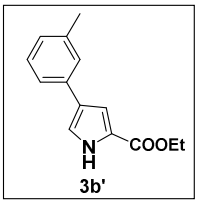
Yield: 65%, colourless oil; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 7.50 (d, *J* = 7.2 Hz, 3H), 7.41-7.39 (m, 1H), 7.32-7.39 (m, 3H), 4.31 – 4.03 (m, 4H), 1.34 (t, *J* = 7.1 Hz, 6H); **^{13}CNMR** (100 MHz, $CDCl_3$) δ = 137.85, 131.53, 128.97, 127.50, 124.76, 119.76, 119.60, 107.74, 107.60, 62.54, 62.50, 16.32, 16.26; **FT-IR** (neat): 3313, 2964, 1675, 1268, 1215, 760 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{14}H_{18}NO_3P$ [M+H] is 280.1097 and found 280.1091.

4.5- Methyl 4-(m-tolyl)-1*H*-pyrrole-2-carboxylate (3b):



Yield: 70%, white solid, m. p. 207 - 209 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.34 (s, 1H), 7.34 - 7.32 (m, 2H), 7.25 (dd, *J* = 3.7, 1.9 Hz, 1H), 7.21 - 7.19 (dd, *J* = 3.9, 1.8 Hz, 1H), 7.04 (d, *J* = 7.4 Hz, 1H), 3.89 (s, 3H), 2.38 (s, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.65, 138.35, 134.40, 128.71, 127.12, 126.12, 123.31, 122.43, 119.62, 112.66, 51.63, 21.53; **FT-IR** (neat): 3315, 2989, 1685, 1256, 1211, 758 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{14}NO_2$ $[M+H]^+$ is 216.1019 and found 216.1018.

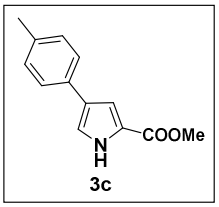
4.6- Ethyl 4-(m-tolyl)-1*H*-pyrrole-2-carboxylate (3b'):



Yield: 68%, white solid, m. p. 164 - 166 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.21 (s, 1H), 7.33 (d, *J* = 8.9 Hz, 2H), 7.27 (d, *J* = 8.9 Hz, 1H), 7.23 (dd, *J* = 2.9, 1.8 Hz, 1H), 7.20 (dd, *J* = 3.8, 2.1 Hz, 1H), 7.05 (d, *J* = 7.3 Hz, 1H), 4.35 (q, *J* =7.1 Hz, 2H), 2.38 (s, 3H), 1.39 (t, *J* =

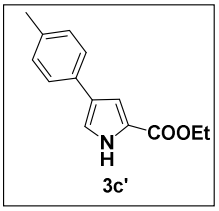
7.2 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.08, 138.13, 134.22, 128.68, 127.06, 126.08, 122.38, 119.46, 112.46, 60.57, 21.53, 14.49; **FT-IR** (neat): 3308, 2985, 1681, 1270, 1219, 766 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{14}H_{16}NO_2$ $[M+H]^+$ is 230.1176 and found 230.1175.

4.7- Methyl 4-(*p*-tolyl)-1*H*-pyrrole-2-carboxylate (3c):



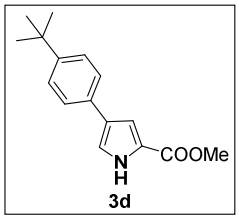
Yield: 69%, white solid, m. p. 163 - 165 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.15 (s, 1H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.20 (dd, *J* = 2.8, 1.8 Hz, 1H), 7.19 - 7.16 (m, 3H), 3.88 (s, 3H), 2.35 (s, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.65, 135.92, 131.55, 129.41, 126.80, 125.15, 123.15, 119.38, 112.45, 51.59, 21.07; **FT-IR** (KBr): 3333, 2920, 1683, 1376, 1136, 806 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{14}NO_2$ $[M+H]^+$ is 216.1019 and found 216.1018.

4.8- Ethyl 4-(*p*-tolyl)-1*H*-pyrrole-2-carboxylate (3c'):



Yield: 73%, white solid, m. p. 165 - 167 °C (lit. 165-166 °C);[4] **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.16 (s, 1H), 7.42 (d, *J* = 8.1 Hz, 2H), 7.21 - 7.16 (m, 4H), 4.35 (q, *J* = 7.2 Hz, 2H), 2.35 (s, 3H), 1.38 (t, *J* = 7.1 Hz, 3H).**^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.18, 136.22, 131.76, 129.47, 126.82, 125.22, 123.61, 119.22, 112.34, 60.54, 21.14, 14.51; **FT-IR** (KBr): 3247, 2926, 1672, 1387, 1268, 1139, 772 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{14}H_{16}NO_2$ $[M+H]^+$ is 230.1175 and found 230.1174.

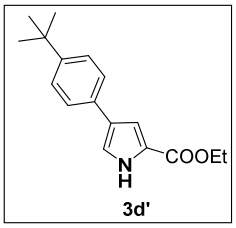
4.9- Methyl 4-(4-(*tert*-butyl)phenyl)-1*H*-pyrrole-2-carboxylate (3d):



Yield: 72%, white solid, m. p. 101 - 103 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.15 (s, 9H), 7.46 (dd, *J* = 8.5, 2.1 Hz, 2H), 7.39 (dd, *J* = 8.6, 2.0 Hz, 2H), 7.22 (dd, *J* = 2.9, 1.7 Hz, 1H),

7.18 (dd, *J* = 2.5, 1.7 Hz, 1H), 3.88 (s, 3H), 1.34 (s, 9H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 160.93, 149.24, 131.65, 126.84, 125.72, 125.06, 123.26, 119.42, 112.55, 51.64, 34.51, 31.38; **FT-IR** (KBr): 3415, 2920, 1693, 1440, 1267, 1080, 969, 832 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{16}H_{20}NO_2$ $[M+H]^+$ is 258.1489 and found 258.1488.

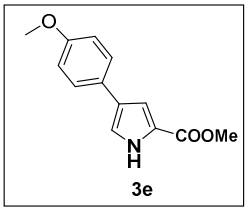
4.10- Ethyl 4-(4-(*tert*-butyl)phenyl)-1*H*-pyrrole-2-carboxylate (3d'):



3d'

Yield: 68%, white solid, m. p. 102 - 104 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.16 (s, 1H), 7.47 (d, *J* = 8.4 Hz, 2H), 7.39 (d, *J* = 8.4 Hz, 2H), 7.18 (dd, *J* = 2.8, 1.8 Hz, 1H), 7.12 (dd, *J* = 2.4, 1.7 Hz, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 1.39 (t, *J* = 7.2 Hz, 3H), 1.34 (s, 9H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.22, 149.28, 126.81, 125.69, 125.06, 123.65, 119.22, 112.40, 60.52, 34.51, 31.38, 14.51; **FT-IR** (KBr): 3291, 2956, 1687, 1404, 1291, 1145, 825, 771 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{17}H_{22}NO_2$ $[M+H]^+$ is 272.1645 and found 272.1646.

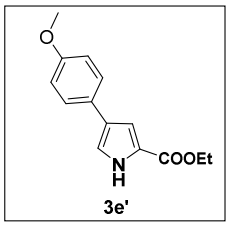
4.11- Methyl 4-(4-methoxyphenyl)-1*H*-pyrrole-2-carboxylate (3e):



3e

Yield 69%, sticky solid; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.11 (s, 1H), 7.42 (dd, *J* = 8.7, 2.1 Hz, 2H), 7.16 (dd, *J* = 2.8, 1.7 Hz, 1H), 7.14 (dd, *J* = 3.8, 1.8 Hz, 1H), 6.91 (dd, *J* = 8.8, 1.9 Hz, 2H), 3.88 (s, 3H), 3.83 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.57, 158.35, 127.26, 126.73, 126.48, 123.26, 118.90, 114.24, 112.35, 55.36, 51.60; **FT-IR** (KBr): 3288, 2947, 1685, 1409, 1275, 1163, 829, 763 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{14}NO_3$ $[M+H]^+$ is 232.0968 and found 232.0967.

4.12- Ethyl 4-(4-methoxyphenyl)-1*H*-pyrrole-2-carboxylate (3e'):

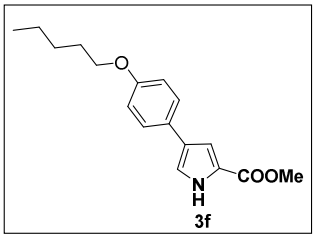


3e'

Yield: 73%, white solid, m. p. 130-132 °C (lit. 132-133 °C);[4] **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.17 (s, 1H), 7.45 (d, *J* = 8.7 Hz, 2H), 7.15 (dd, *J* = 2.7, 1.6 Hz, 1H), 7.14 (d, *J* = 2.4, 1.5

Hz, 1H), 6.91 (d, *J* = 8.7 Hz, 2H), 4.35 (q, *J* = 7.1 Hz, 2H), 3.83 (s, 3H), 1.38 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.25, 158.29, 127.35, 126.61, 126.46, 123.58, 118.83, 114.22, 112.20, 60.50, 55.36, 14.50. HRMS (ESI, Orbitrap) calcd for $C_{14}H_{16}NO_3$ $[M+H]^+$ is 246.1124 and found 246.1123.

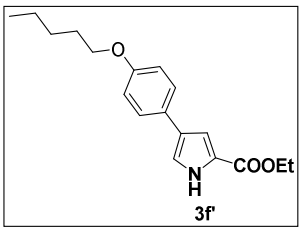
4.13- Methyl 4-(4-(pentyloxy)phenyl)-1*H*-pyrrole-2-carboxylate (3f):



3f

Yield: 71%, white solid, m. p. 110-112 °C. **^{1}H NMR (500 MHz, $CDCl_3$)** δ = 9.24 (s, 1H), 7.42 (d, *J* = 8.8 Hz, 2H), 7.16 (dd, *J* = 2.9, 1.7 Hz, 1H), 7.13 (dd, *J* = 2.5, 1.7 Hz, 1H), 6.90 (d, *J* = 8.8 Hz, 2H), 3.97 (t, *J* = 6.6 Hz, 2H), 3.88 (s, 3H), 1.79 (dq, *J* = 13.3, 6.6 Hz, 2H), 1.48 - 1.35 (m, 4H), 0.94 (t, *J* = 7.0 Hz, 3H); **^{13}C NMR** (126 MHz, $CDCl_3$) δ = 161.74, 157.91, 128.00, 127.05, 126.76, 126.43, 123.17, 119.06, 114.85, 113.03, 112.39, 68.12, 51.65, 29.04, 28.25, 22.52, 14.08; **FT-IR** (KBr): 3308, 2937, 1686, 1469, 1382, 1253, 1140, 830, 769 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{17}H_{22}NO_3$ $[M+H]^+$ is 288.1594 and found 288.1593.

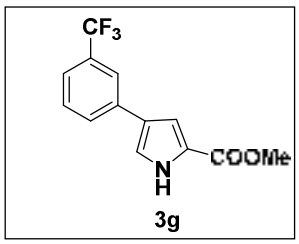
4.14- Ethyl 4-(4-(pentyloxy)phenyl)-1*H*-pyrrole-2-carboxylate (3f'):



3f'

Yield: 67%, white solid, m. p. 109 - 112 °C. **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.17 (s, 1H), 7.43 (dd, *J* = 8.8, 2.1 Hz, 2H), 7.15 (dd, *J* = 2.9, 1.7 Hz, 1H), 7.13 (dd, *J* = 3.1, 1.7 Hz, 1H), 6.90 (dd, *J* = 8.7, 1.9 Hz, 2H), 4.35 (q, *J* = 7.1 Hz, 2H), 3.97 (t, *J* = 6.6 Hz, 2H), 1.83 - 1.75 (m, 2H), 1.48 - 1.41 (m, 4H), 1.38 (t, *J* = 7.1 Hz, 3H), 0.94 (t, *J* = 7.2 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.25, 157.87, 127.09, 126.70, 126.42, 123.55, 118.76, 114.81, 112.19, 68.09, 60.50, 29.04, 28.24, 22.52, 14.51, 14.08. **FT-IR** (KBr): 3289, 2938, 1687, 1571, 1470, 1386, 1270, 1021, 830, 769 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{18}H_{24}NO_3$ $[M+H]^+$ is 302.1751 and found 302.1757.

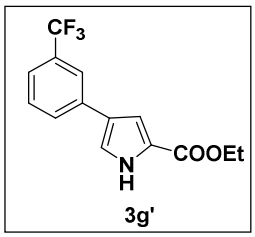
4.15- Methyl 4-(3-(trifluoromethyl)phenyl)-1*H*-pyrrole-2-carboxylate (3g):



3g

Yield: 73%, white solid, m. p. 80 - 83 °C. **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.25 (s, 1H), 7.73 (d, *J* = 7.8 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 1H), 7.46 - 7.36 (m, 2H), 7.06 (d, *J* = 15.1 Hz, 2H), 3.88 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.67, 134.47, 132.31, 131.57, 128.24 (q, *J* = 29.43 Hz), 126.84, 126.26 (q, *J* = 5.40 Hz), 125.40 (q, *J* = 273.6 Hz), 123.99, 122.59, 122.21, 115.94, 51.65; **FT-IR** (KBr) 3304, 2922, 1698, 1608, 1445, 1331, 1120, 842, 749 cm^{-1}; HRMS (ESI, Orbitrap) calcd for $C_{13}H_{10}F_3NO_2$ $[M+Na]^+$ is 292.0556 and found 292.0551.

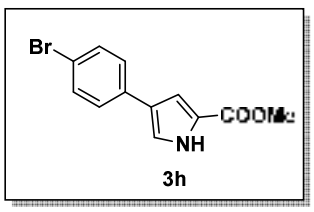
4.16- <u>Ethyl 4-(3-(trifluoromethyl)phenyl)-1*H*-pyrrole-2-carboxylate (3g'):</u>



3g'

Yield: 72%, white solid, m. p. 104 - 107 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.45 (s, 1H), 7.72 (d, *J* = 7.9 Hz, 1H), 7.52 (t, *J* = 7.5 Hz, 1H), 7.45 - 7.37 (m, 2H), 7.10 - 708 (m, 1H), 7.08 - 7.04 (m, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 1.38 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.51, 134.59, 132.34, 131.56, 128.23 (q, *J* = 29.78 Hz), 126.77, 126.25 (q, *J* = 5.50 Hz), 123.85 (q, *J* = 271.50 Hz), 122.87, 122.54, 122.29, 115.86, 60.64, 14.45; **FT-IR** (KBr): 3291, 2922, 1687, 1577, 1404, 1213, 1015, 825 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{14}H_{12}F_3NO_2$ $[M+Na]^+$ is 306.0712 and found 306.0706.

4.17- <u>Methyl 4-(4-bromophenyl)-1H-pyrrole-2-carboxylate (3h)</u>

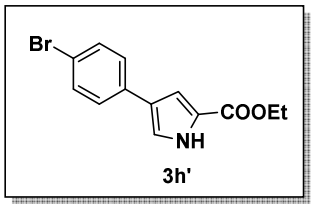


3h

Yield: 70%, white solid, m.p. 156 - 158 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.30 (s, 1H), 7.48 (d, *J* = 8.5 Hz, 2H), 7.38 (d, *J* = 8.5 Hz, 2H), 7.23 (dd, *J* = 2.8, 1.6 Hz, 1H), 7.16 (dd, *J* = 2.5, 1.7 Hz, 1H), 3.89 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.02, 133.37, 131.86, 126.87, 125.85, 123.66, 119.95, 119.54, 112.42, 51.73; **FT-IR** (KBr): 3275, 2935, 1691,

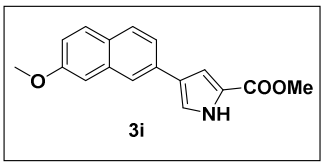
1567, 1424, 1211, 1015, 825cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{12}H_{11}BrNO_2$ $[M+H]^+$ is 279.9967 and found 279.9965.

4.18- Ethyl 4-(4-bromophenyl)-1*H*-pyrrole-2-carboxylate (3h')



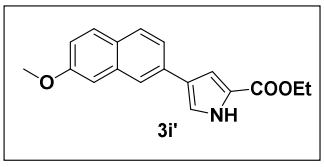
Yield: 72%, white solid, m. p. 159-161°C (lit 159-160 °C);[4] **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.25 (s, 1H), 7.48 (d, *J* = 8.5 Hz, 2H), 7.39 (m, *J* = 8.5 Hz, 2H), 7.22 (dd, *J* = 2.9, 1.7 Hz, 1H), 7.17 (dd, *J* = 2.8, 1.7 Hz, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 1.38 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ = 161.05, 133.85, 133.55, 131.83, 126.86, 125.73, 124.04, 119.90, 119.33, 112.24, 60.64, 14.48; **FT-IR** (KBr) 3271, 2942, 1689, 1569, 1431, 1215, 1019, 823cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{13}BrNO_2$ $[M+H]^+$ is 294.0124 and found 294.0125

4.19- Methyl 4-(7-methoxynaphthalen-2-yl)-1*H*-pyrrole-2-carboxylate (3i):



Yield: 69%, white solid, m. p. 148 - 150 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.22 (bs, 1H), 7.89 (s, 1H), 7.73 (dd, *J* = 8.5, 1.8 Hz, 2H), 7.63 (dd, *J* = 8.5, 1.7 Hz, 1H), 7.35 - 7.29 (m, 2H), 7.16 - 7.12 (m, 2H), 3.93 (s, 3H), 3.90 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 161.53, 157.38, 129.75, 129.27, 127.24, 127.06, 124.82, 123.51, 123.16, 119.49, 119.09, 112.60, 105.77, 55.35, 51.66; **FT-IR** (KBr): 3301, 2918, 1697, 1599, 1441, 1337, 1120, 845, 747 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{17}H_{15}NO_3$ $[M+Na]^+$ is 304.0944 and found 304.0945.

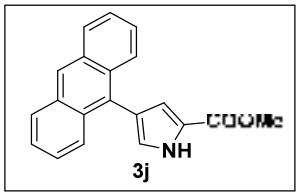
4.20- Ethyl 4-(7-methoxynaphthalen-2-yl)-1*H*-pyrrole-2-carboxylate (3i'):



Yield: 71%, white solid, m. p. 151-153 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.24 (s, 1H), 7.89 (s, 1H), 7.73 (dd, *J* = 8.5, 1.8 Hz, 2H), 7.63 (dd, *J* = 8.5, 1.5 Hz, 1H), 7.31 (dd, *J* = 3.9, 2.0 Hz, 2H), 7.19 - 7.08 (m, 3H), 4.37 (q, *J* = 7.1 Hz, 2H), 3.92 (s, 3H), 1.40 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.20, 157.38, 133.44, 129.86, 129.26, 127.20, 126.98, 124.84, 123.87, 123.13, 119.36, 119.05, 112.45, 105.81, 60.55, 55.33, 14.50; **FT-IR**

(KBr): 3301, 2918, 1697, 1599, 1441, 1337, 1120, 845, 747 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{18}H_{17}NO_3$ $[M+Na]^+$ is 318.1100 and found 318.10950.

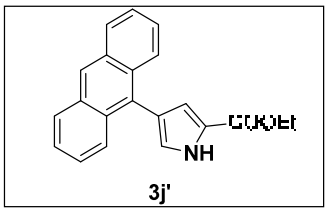
4.21- Methyl 4-(anthracen-9-yl)-1*H*-pyrrole-2-carboxylate (3j):



3j

Yield 68%, white solid, m. p. 110 - 112 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.42 (s, 1H), 8.71 (dd, *J* = 14.8, 7.5 Hz, 2H), 8.26 (d, *J* = 7.5 Hz, 1H), 7.91 - 7.83 (m, 1H), 7.72 (s, 1H), 7.71 - 7.55 (m, 4H), 7.23 (dd, *J* = 8.3, 2.3 Hz, 2H), 3.92 (s, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.74, 131.66, 131.24, 130.71, 129.83, 128.46, 127.37, 126.81, 126.58, 126.47, 125.33, 122.97, 122.53, 116.53, 51.68; **FT-IR** (KBr): 3303, 2923, 1695, 1596, 1441, 1334, 1125, 845, 747 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{20}H_{16}NO_2$ $[M+H]^+$ is 302.1175 and found 302.1176

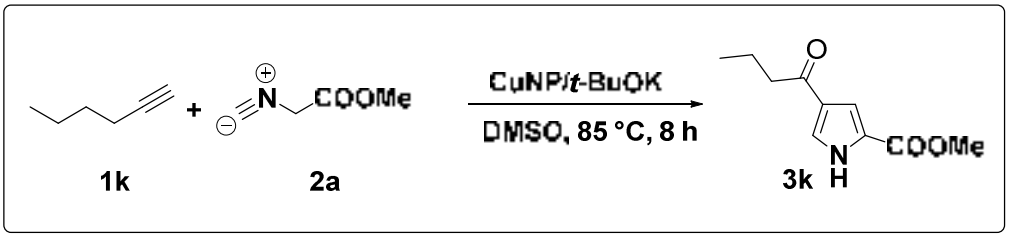
4.22- Ethyl 4-(anthracen-9-yl)-1*H*-pyrrole-2-carboxylate (3j')



3j'

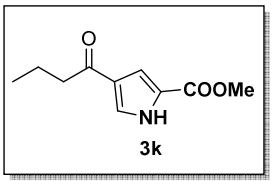
Yield: 64%, yellow sticky solid, **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.38 (s, 1H), 8.76 (d, *J* = 8.2 Hz, 1H), 8.70 (d, *J* = 8.3 Hz, 2H), 8.33 - 8.22 (m, 1H), 7.86 (dd, *J* = 7.8, 1.4 Hz, 1H), 7.73 (s, 1H), 7.70 - 7.56 (m, 4H), 7.23 (dd, *J* = 8.3, 3.2 Hz, 2H), 4.39 (q, *J* = 7.2 Hz, 2H), 1.40 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ = 161.34, 131.66, 128.40, 127.31, 126.76, 126.55, 126.41, 126.36, 122.92, 122.48, 122.29, 116.33, 60.59, 14.48; **FT-IR** (KBr): 3301, 2931, 1699, 1586, 1445, 1336, 1126, 843, 742 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{21}H_{18}NO_2$ $[M+H]^+$ is 316.1332 and found 316.1333.

Experimental procedure for the synthesis of methyl 4-butyryl-1H-pyrrole-2-carboxylate (3k):



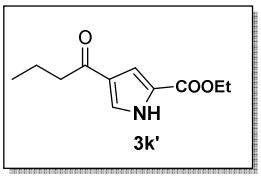
In a 25 mL two-neck round bottom flask equipped with condenser connected to N_2 balloon, to a mixture of hexyne-1 **(1k,** 0.11 mL, 1.0 mmol), **2a** (0.10 mL, 1.0 mmol) and Cu_{nano} catalyst (30 mg; 8 wt%; 3.75 mol%) in DMSO (4 mL) was slowly added *t*-BuOK (0.17 g, 1.5 mmol) in portions over a period of 2 hrs (added ~ 42 mg of *t*-BuOK at an interval of 30 min.) at 85 °C. The reaction mixture was stirred for another 6 hrs at the same temperature. The mixture was then allowed to attain room temperature and diluted with ethyl acetate (50 mL). The catalyst was filtered and the organic layer was washed with water (10 mL) and brine (10 mL). The organic layer was dried over anhydrous sodium sulphate and evaporated under reduce pressure to produce crude **3k** which was purified by silica gel (100-200) chromatography using mixture of EtOAc (15%) and petroleum ether (85 %) as eluent.

4.23- <u>Methyl 4-butyryl-1*H*-pyrrole-2-carboxylate (3k):</u>



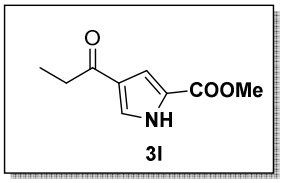
Yield: 46%, colourless oil, **^{1}H NMR** (300 MHz, $CDCl_3$) δ = 9.57 (s, 1H), 7.54 (dd, *J* = 3.6, 1.4 Hz, 1H), 7.29 (dd, *J* = 3.6, 1.5 Hz, 1H), 3.89 (s, 3H), 2.75 (t, *J* = 7.4 Hz, 2H), 1.74 (m, 2H), 0.99 (t, *J* = 7.4 Hz, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 196.02, 161.32, 127.30, 125.98, 123.78, 114.83, 51.94, 41.73, 18.04, 13.95; **FT-IR** (KBr): 3420, 2960, 1705, 1681, 1571, 1261, 1139 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{10}H_{14}NO_3$ $[M+H]^+$ is 196.0968 and found 196.0962.

4.24- <u>Ethyl 4-butyryl-1*H*-pyrrole-2-carboxylate (3k')</u>



Yield: 51%, white crystalline solid, m.p. 70 - 72 °C (lit 71 - 72 °C)[5]; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.43 (s, 1H), 7.54 (dd, *J* = 3.2, 1.5 Hz, 1H), 7.29 (dd, *J* = 3.2, 1.5 Hz, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 2.75 (t, *J* = 7.4, 2H), 1.74 (m, 2H), 1.38 (t, *J* = 7.1 Hz, 3H), 0.99 (t, *J* = 7.4 Hz, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ = 196.13, 161.06, 127.20, 126.01, 124.11, 114.75, 61.00, 41.73, 18.07, 14.39, 13.96; **FT-IR** (KBr): 3426, 2927, 1709, 1693, 1560, 1280, 1200 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{11}H_{16}NO_3$ $[M+H]^+$ is 210.1125 and found 210.1124.

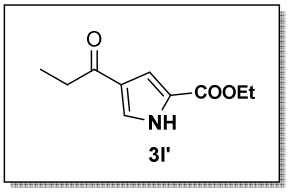
4.25- <u>Methyl 4-propionyl-1*H*-pyrrole-2-carboxylate (3l):</u>



3l

Yield: 44%, white solid, m.p. 115 - 118 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 10.39 (s, 1H), 7.60 (dd, *J* = 3.2, 1.5 Hz, 1H), 7.32 (dd, *J* = 3.6, 2.2 Hz, 1H), 2.82 (t, *J* = 7.3 Hz, 2H), 1.21 (t, *J* = 7.2 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ = 196.86, 161.65, 126.67, 126.56, 123.71, 114.99, 51.94, 32.84, 8.41; **FT-IR** (KBr): 3298, 1710, 1653, 1556, 1443, 1266, 1073 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_9H_{12}NO_3$ $[M+H]^+$ is 182.0812 and found 182.0811.

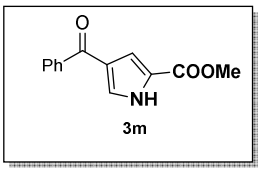
4.26- <u>Methyl 4-propionyl-1*H*-pyrrole-2-carboxylate (3l'):</u>



3l'

Yield: 56%, white solid, 96 - 98 °C; **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 9.72 (s, 1H), 7.53 (dd, *J* = 3.2, 1.6 Hz, 1H), 7.30 (dd, *J* = 3.4, 2.3 Hz, 1H), 4.35 (q, *J* = 7.1 Hz, 2H), 2.81 (q, *J* = 7.4 Hz, 2H), 1.37 (t, *J* = 7.1 Hz, 3H), 1.20 (t, *J* = 7.4 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ = 196.73, 161.21, 126.73, 126.19, 124.07, 114.77, 61.01, 32.86, 14.38, 8.42 cm^{-1}; **FT-IR** (KBr) 3287, 1705, 1645, 1532, 1386, 1201, 1021; **HRMS** (ESI, Orbitrap) calcd for $C_{10}H_{14}NO_3$ $[M+H]^+$ is 196.0968 and found 196.0967.

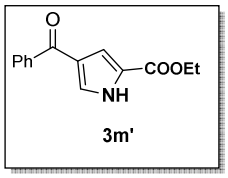
4.27- <u>Methyl 4-benzoyl-1*H*-pyrrole-2-carboxylate (3m):</u>



3m

Yield: 67%, white solid, m.p. 144-146 °C (lit 145-146 °C);[6] **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 10.39 (s, 1H), 7.84 (dd, *J* = 8.2, 1.3 Hz, 2H), 7.59-7.55 (m, 2H), 7.51 - 7.46 (m, 2H), 7.37 (dd, *J* = 2.4, 1.6, 1H), 3.89 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ = 190.57, 161.67, 139.02, 132.04, 129.02, 128.63, 128.51, 128.42, 125.86, 123.78, 116.89, 52.05; **FT-IR** (KBr): 3313, 2925, 1715, 1623, 1556, 1277 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{13}H_{12}NO_3$ $[M+H]^+$ is 230.0811 and found 230.0812.

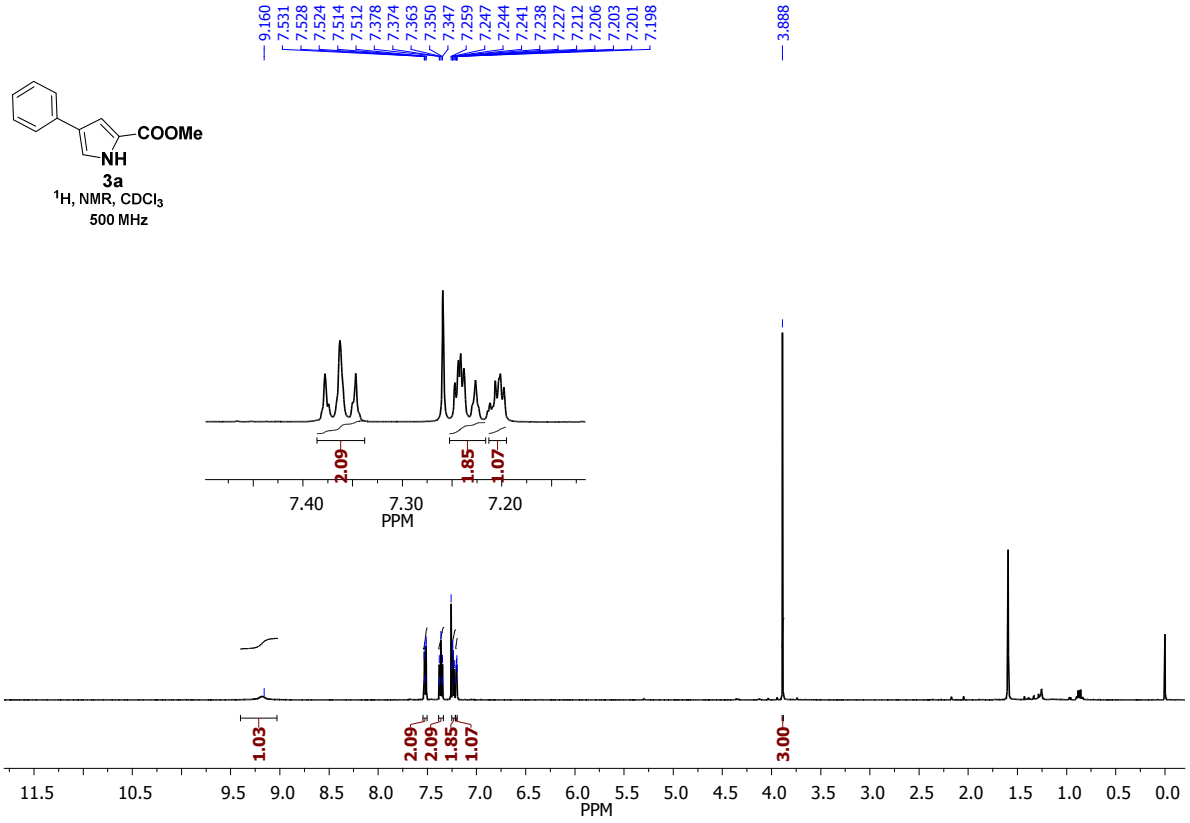
4.28- <u>Ethyl 4-benzoyl-1*H*-pyrrole-2-carboxylate (3m):</u>

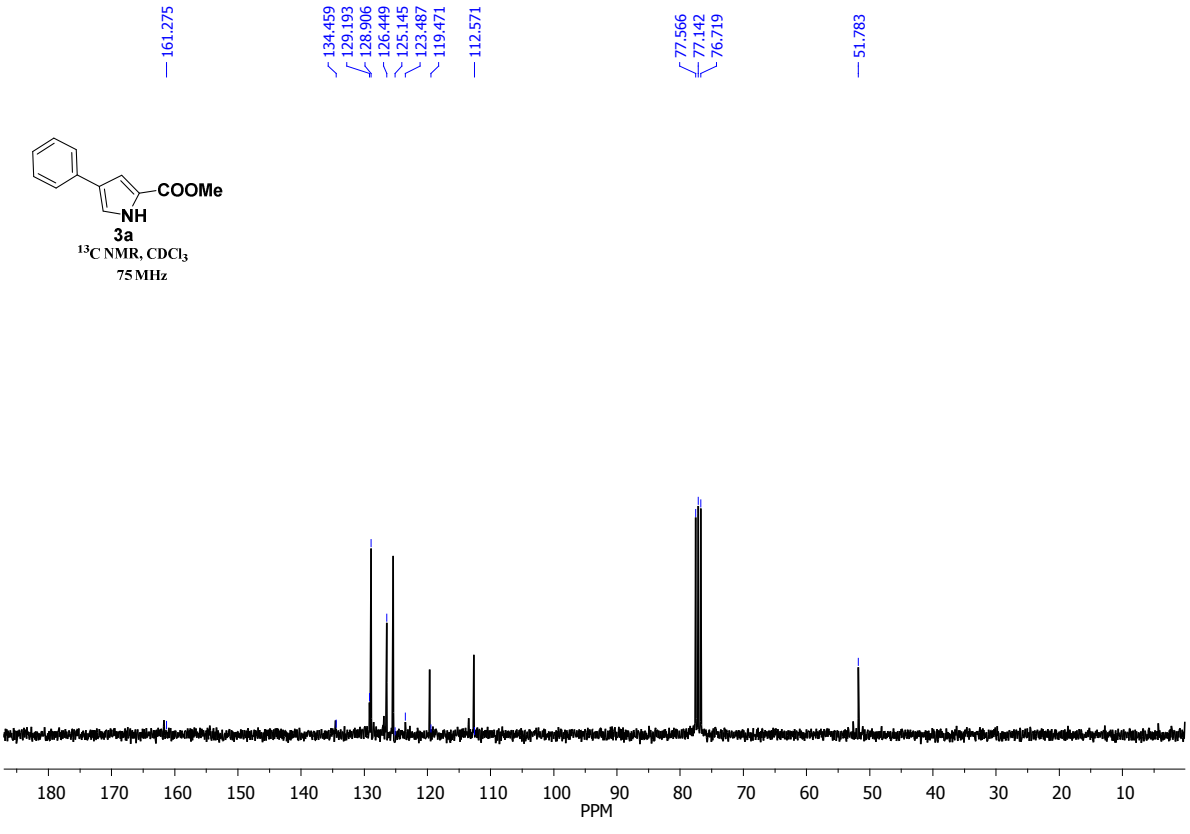


3m'

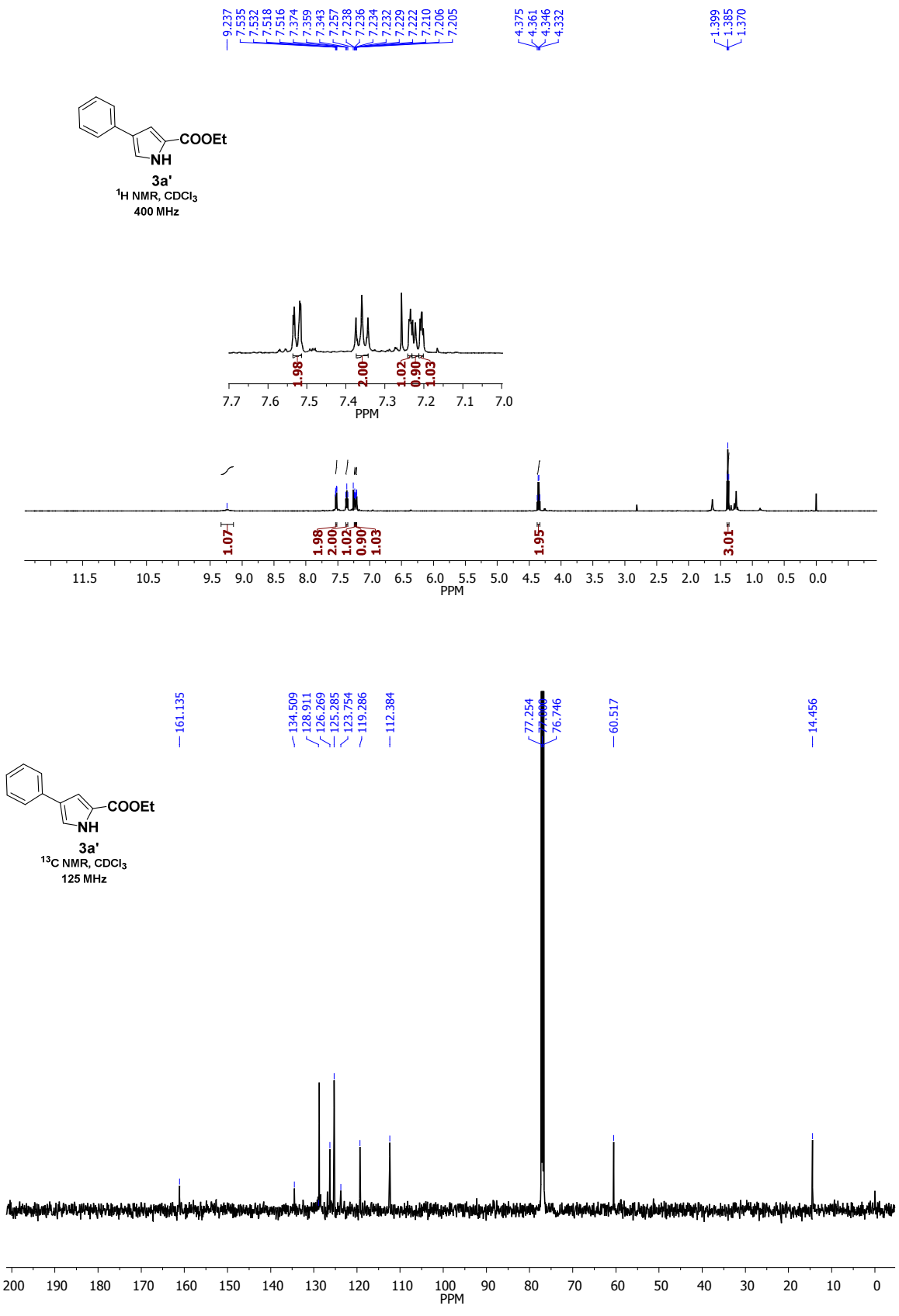
Yield: 69%, white solid, m.p. 100-102 °C (lit 99.5-101 °C)[5]; **^{1}H NMR** (500 MHz, $CDCl_3$) = 10.41 (s, 1H), 7.85 (dd, *J* = 8.3, 1.3 Hz, 2H), 7.59 - 7.54 (m, 2H), 7.51 - 7.46 (m, 2H), 7.38 (dd, *J* = 2.3, 1.7 Hz, 1H), 4.36 (q, *J* = 7.1 Hz, 2H), 1.37 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ = 190.59, 161.30, 139.08, 131.99, 130.16, 129.01, 128.48, 128.41, 125.82, 124.15, 116.71, 61.11, 14.37; **FT-IR** (KBr): 3324, 2854, 1719, 1615, 1559, 1387, 1226, 1182 cm^{-1}; **HRMS** (ESI, Orbitrap) calcd for $C_{14}H_{14}NO_3$ $[M+H]^+$ is 244.0968 and found 244.0967.

5.1 ^{1}H and ^{13}C NMR of **3a**

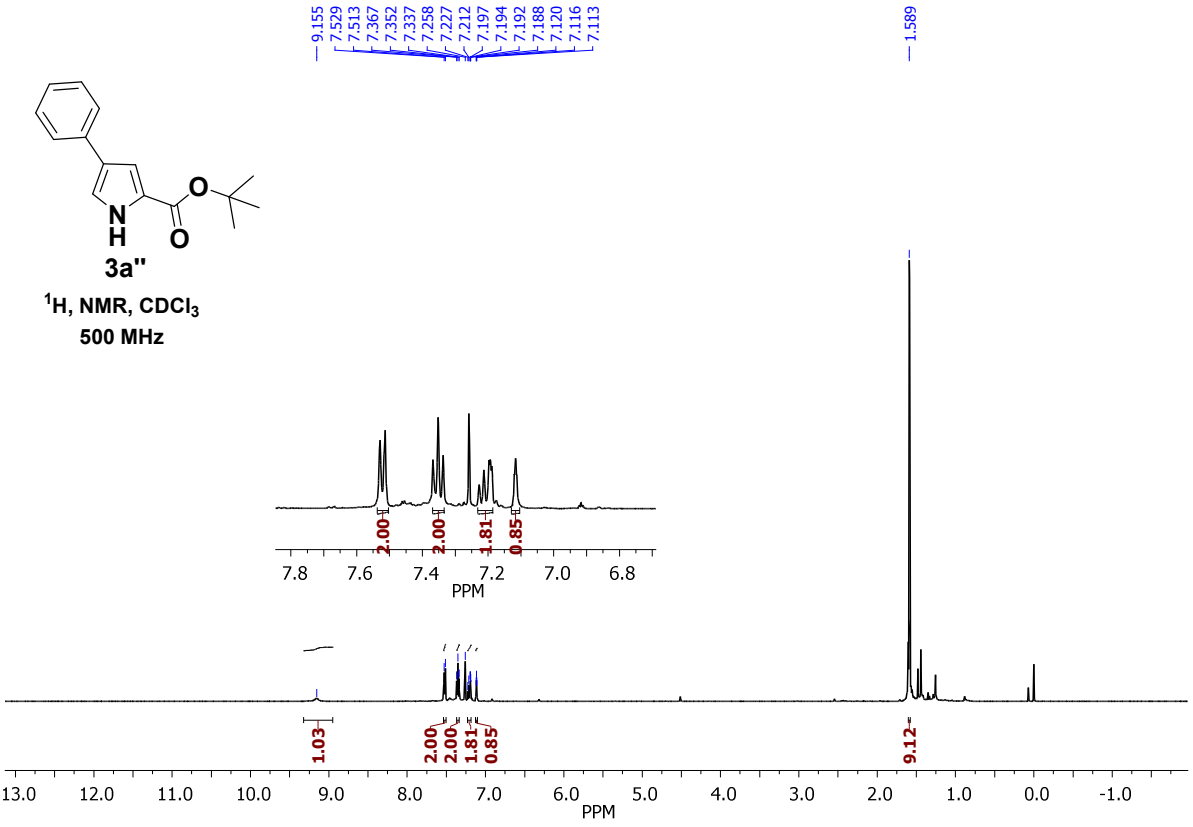


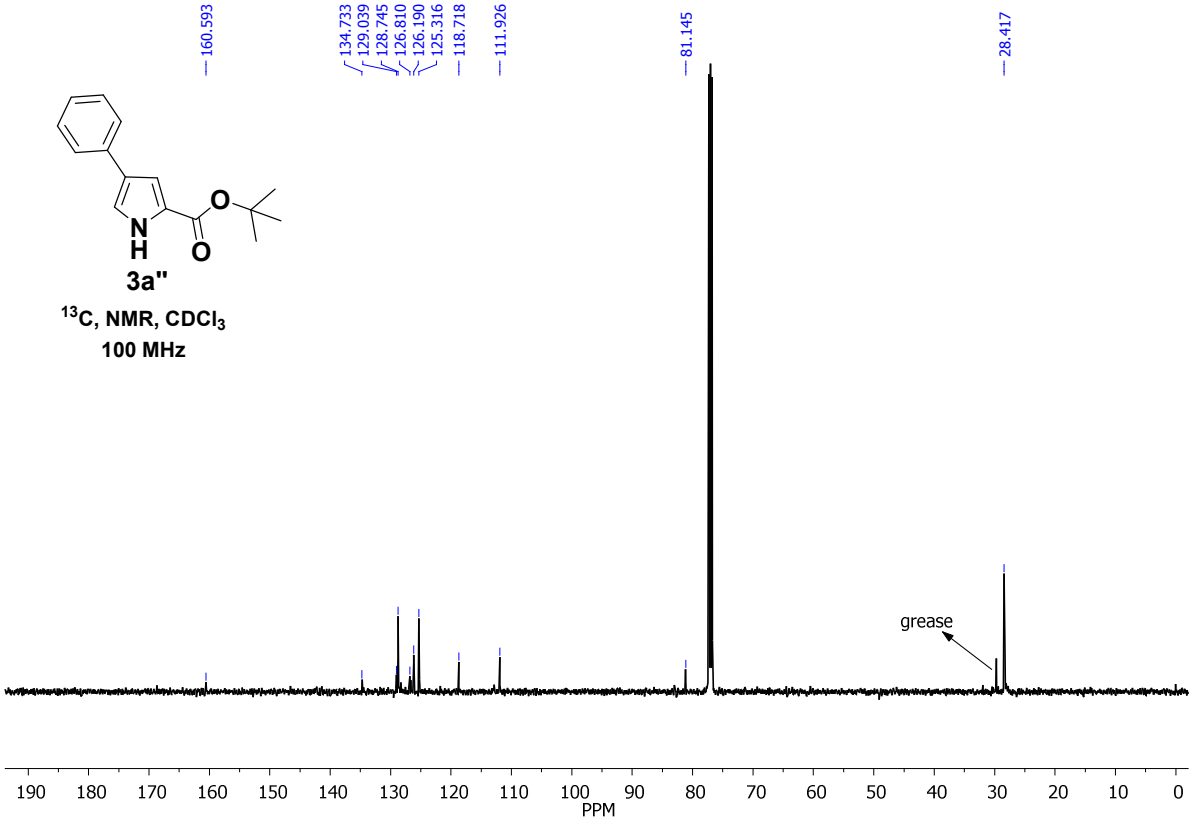


5.2 ^{1}H and ^{13}C NMR of **3a'**

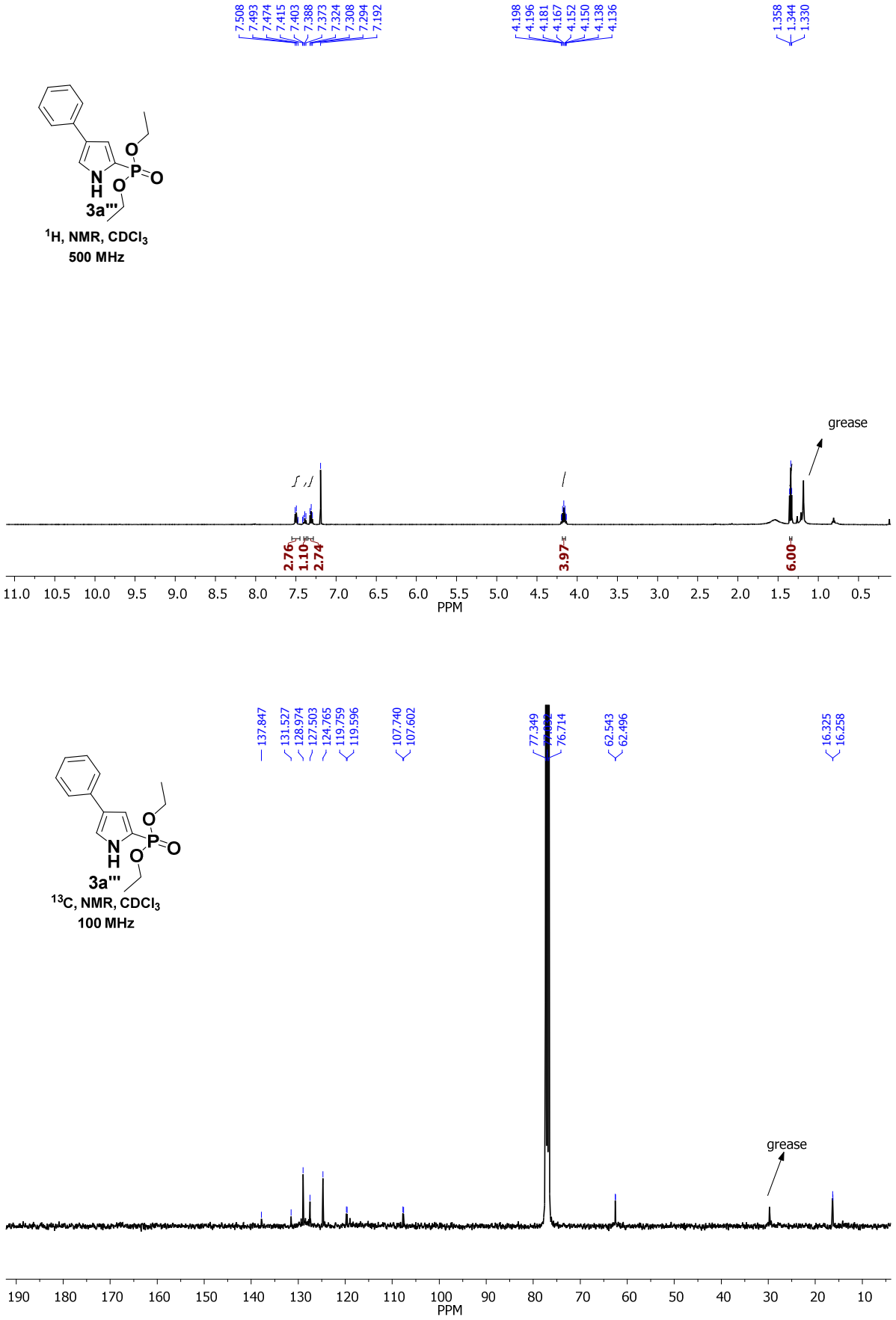


5.3 ^{1}H and ^{13}C NMR of **3a''**

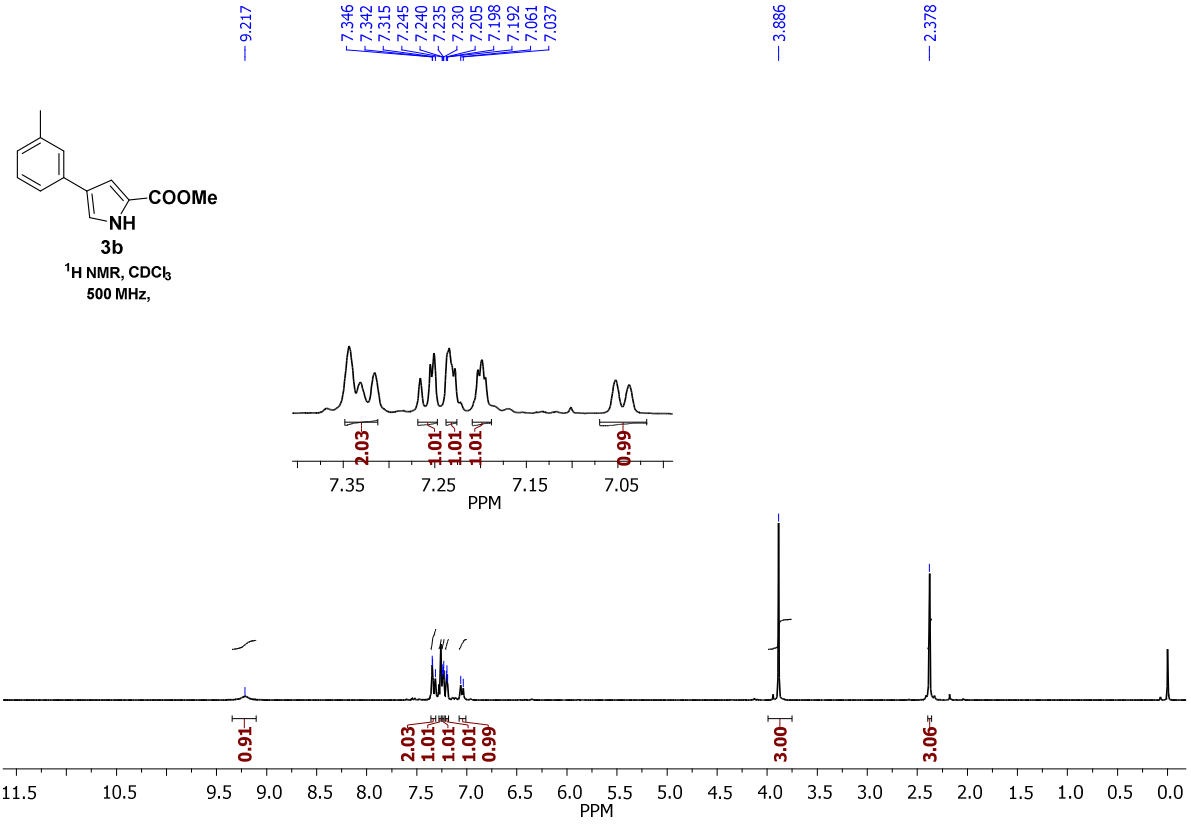


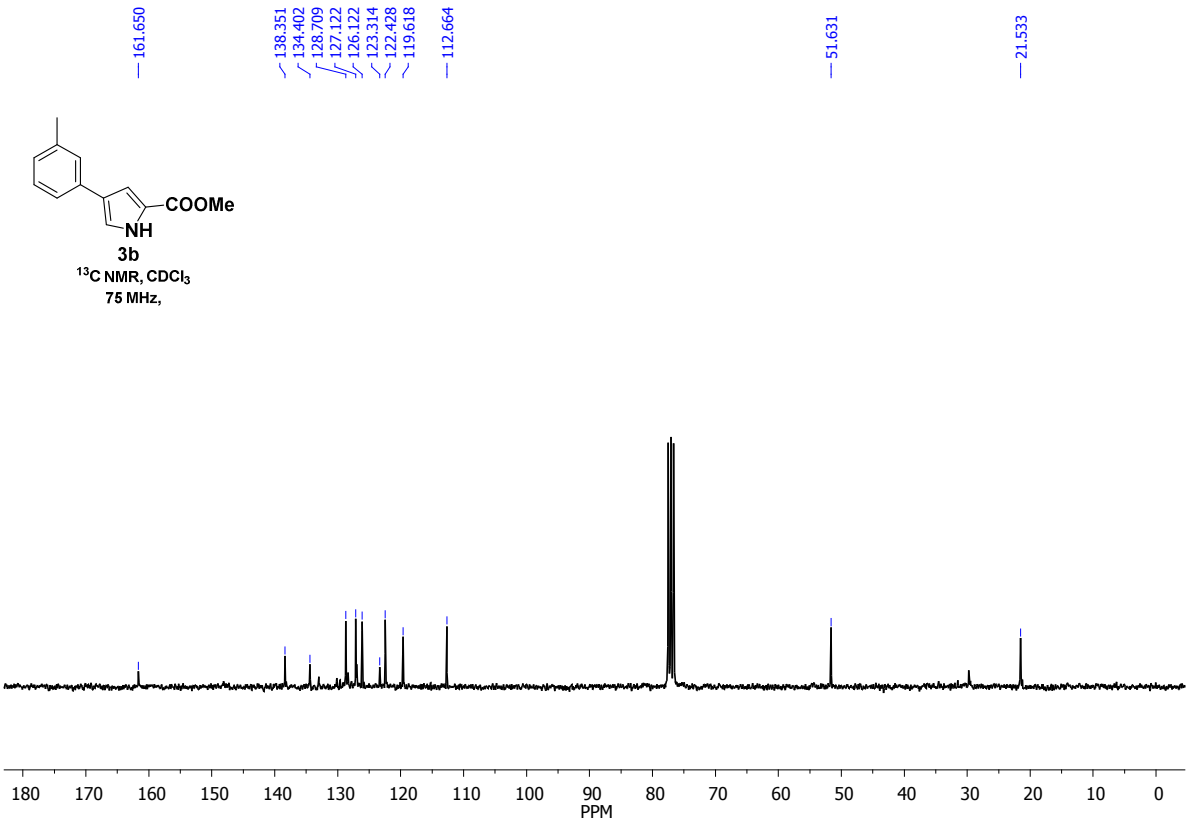


5.4 ^{1}H and ^{13}C NMR of **3a'''**

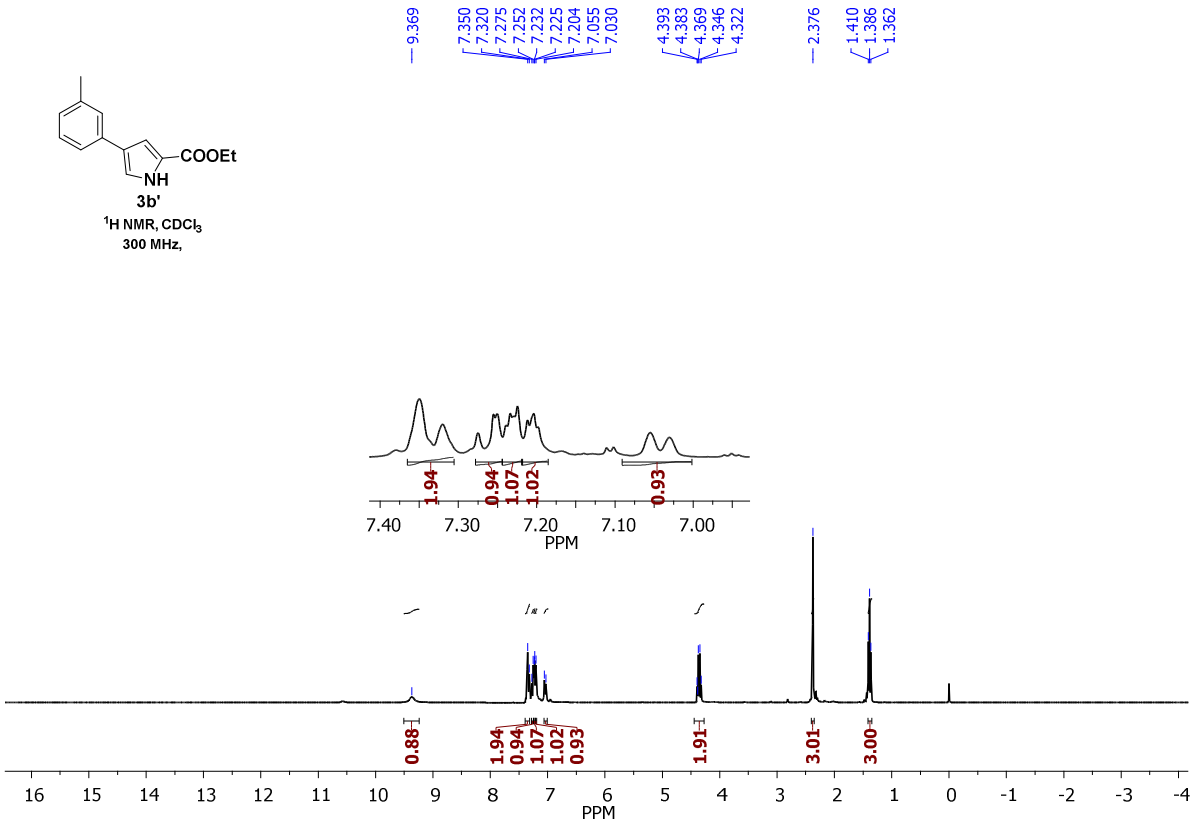


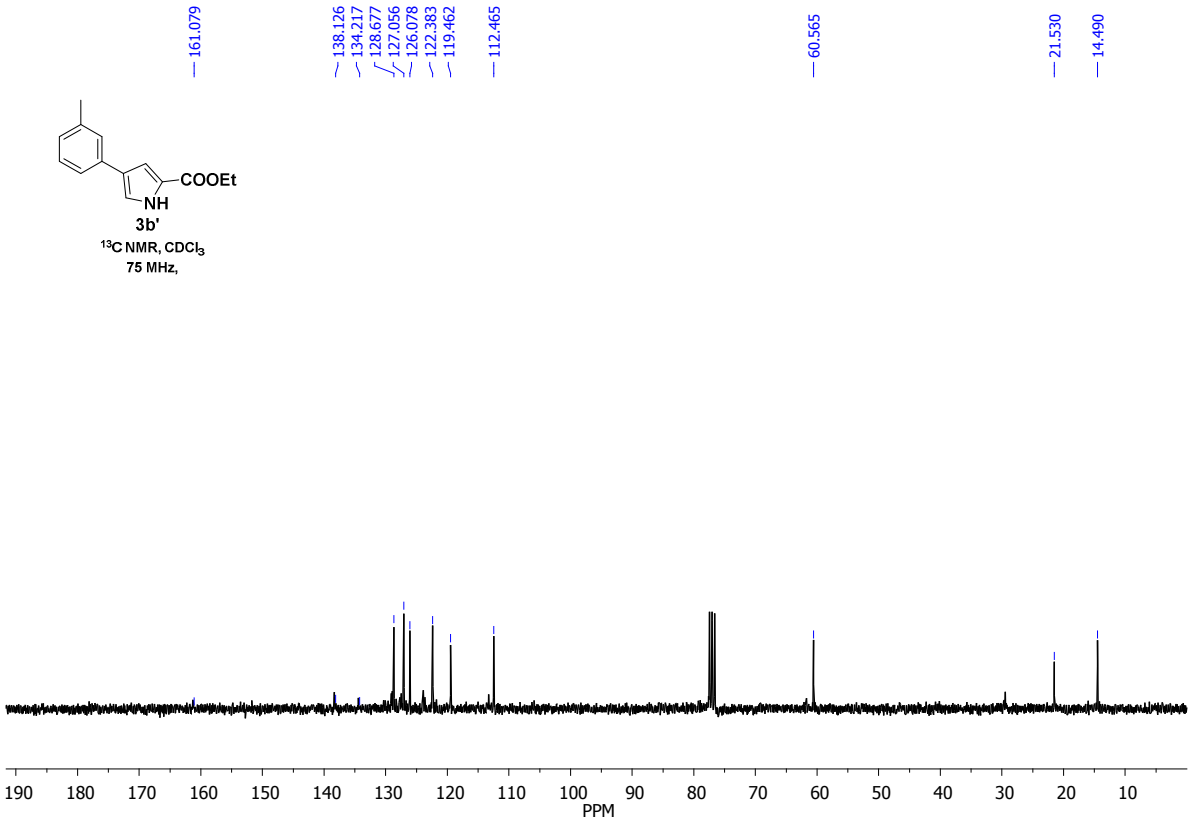
5.5 ^{1}H and ^{13}C NMR of **3b**



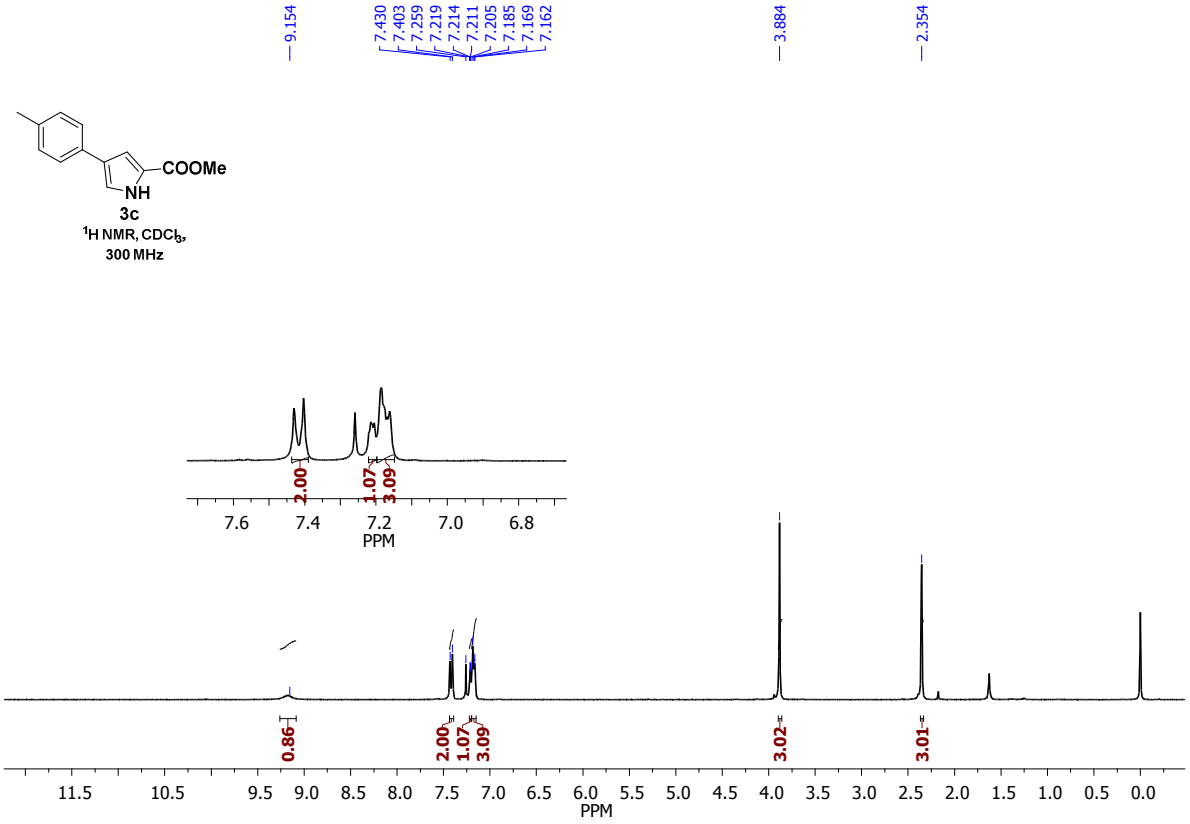


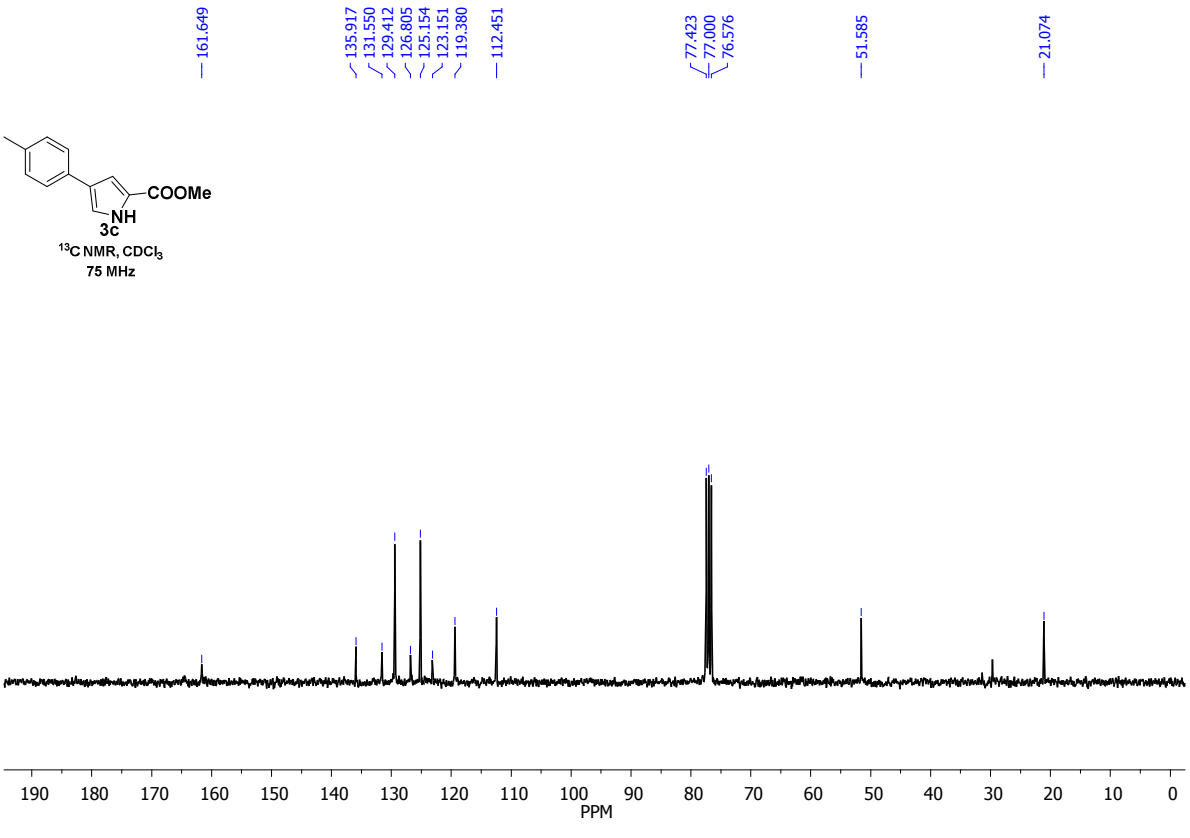
5.6 ^{1}H and ^{13}C NMR of **3b'**



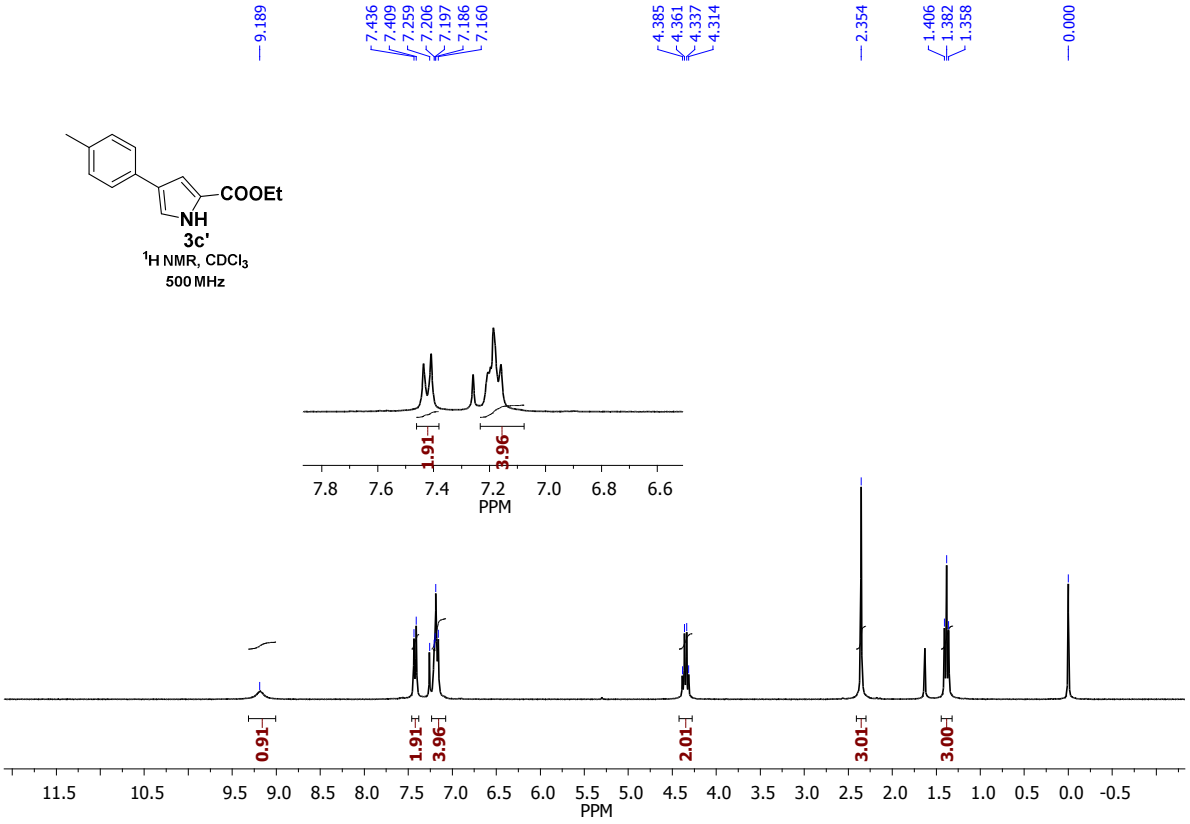


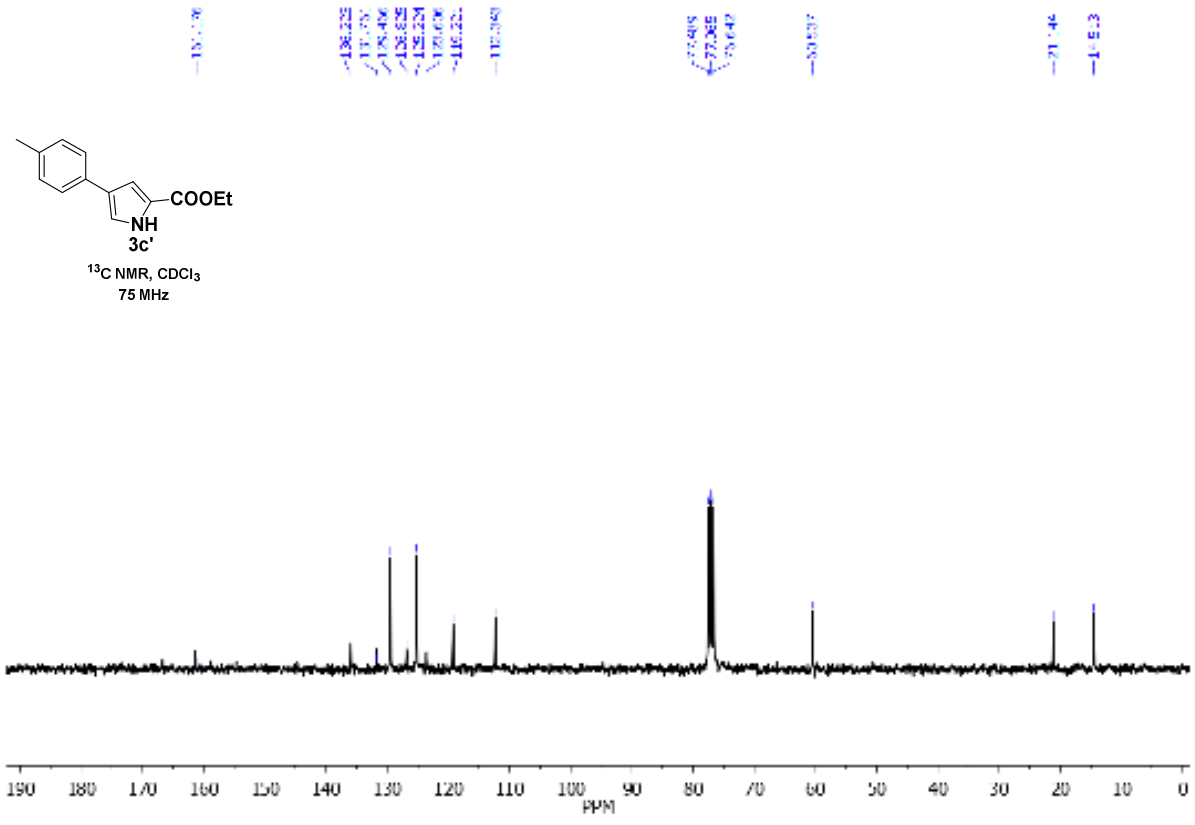
5.7 ^{1}H and ^{13}C NMR of **3c**



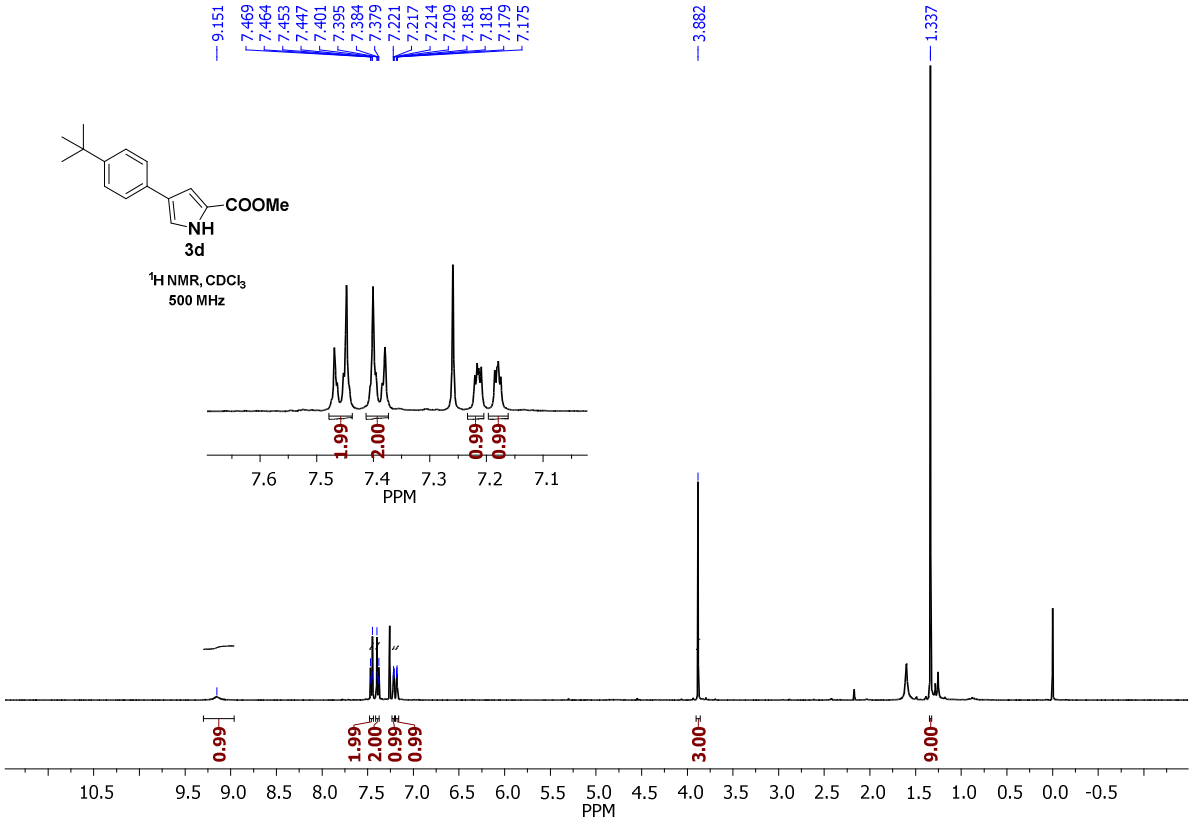


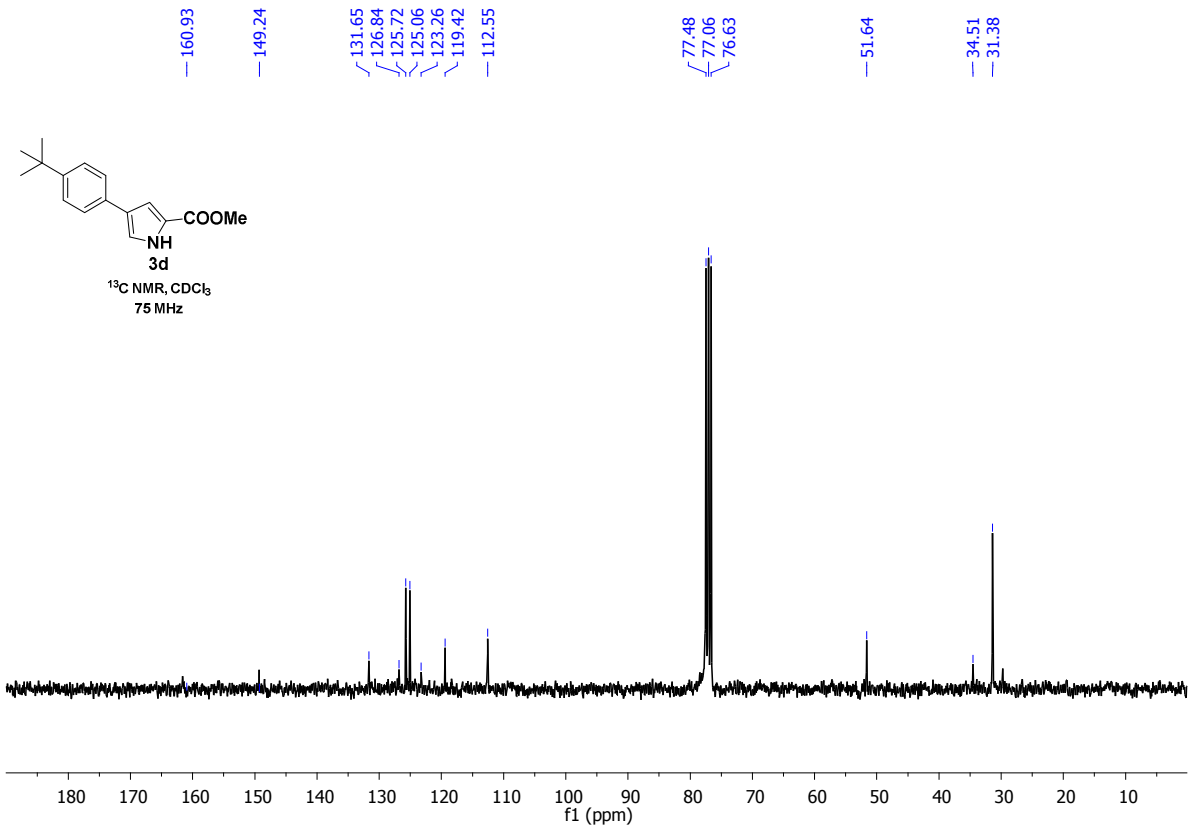
5.8 ^{1}H and ^{13}C NMR of **3c'**



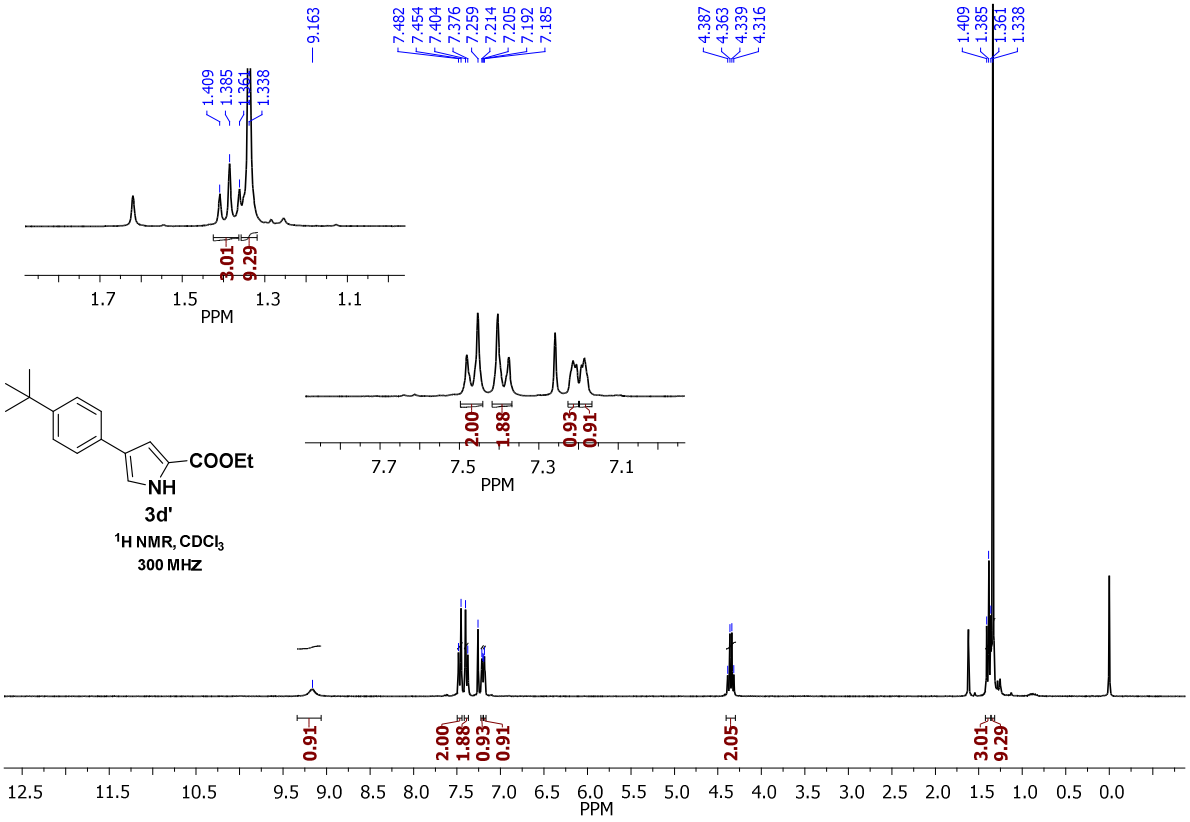


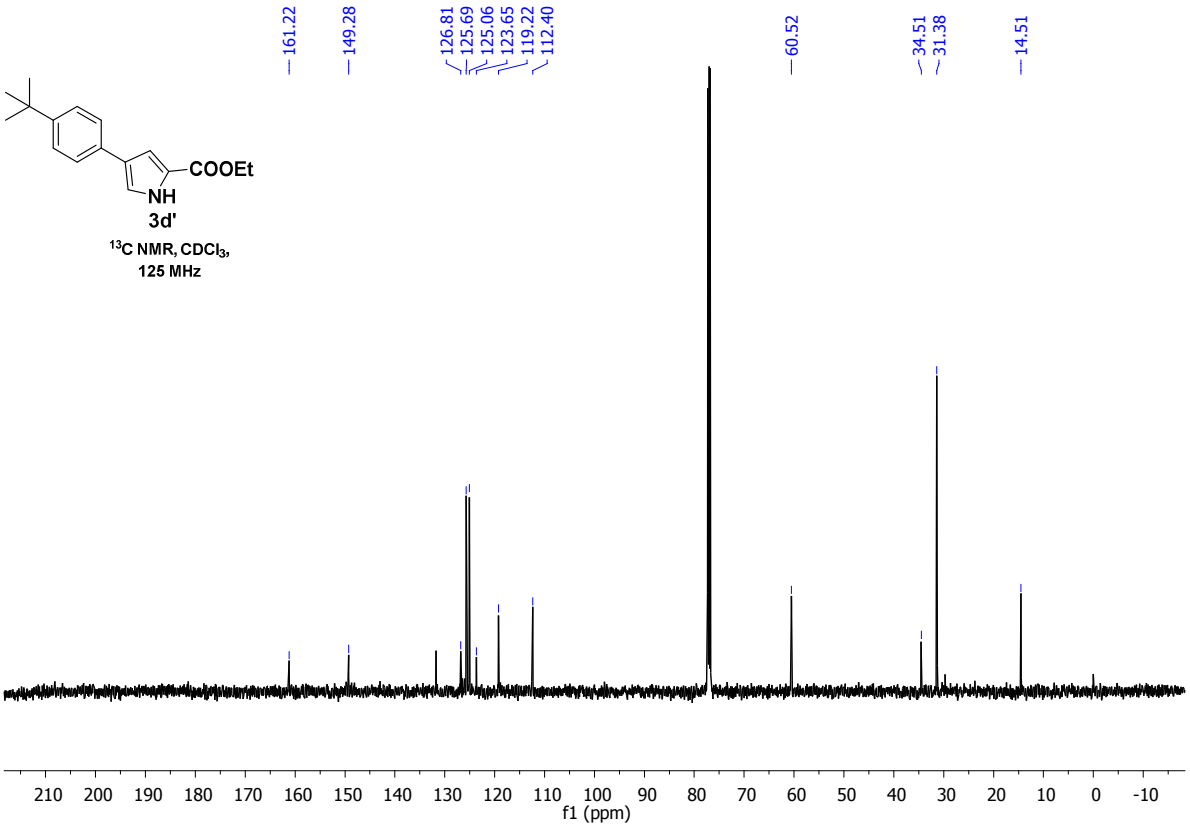
5.9 ^{1}H and ^{13}C NMR of **3d**



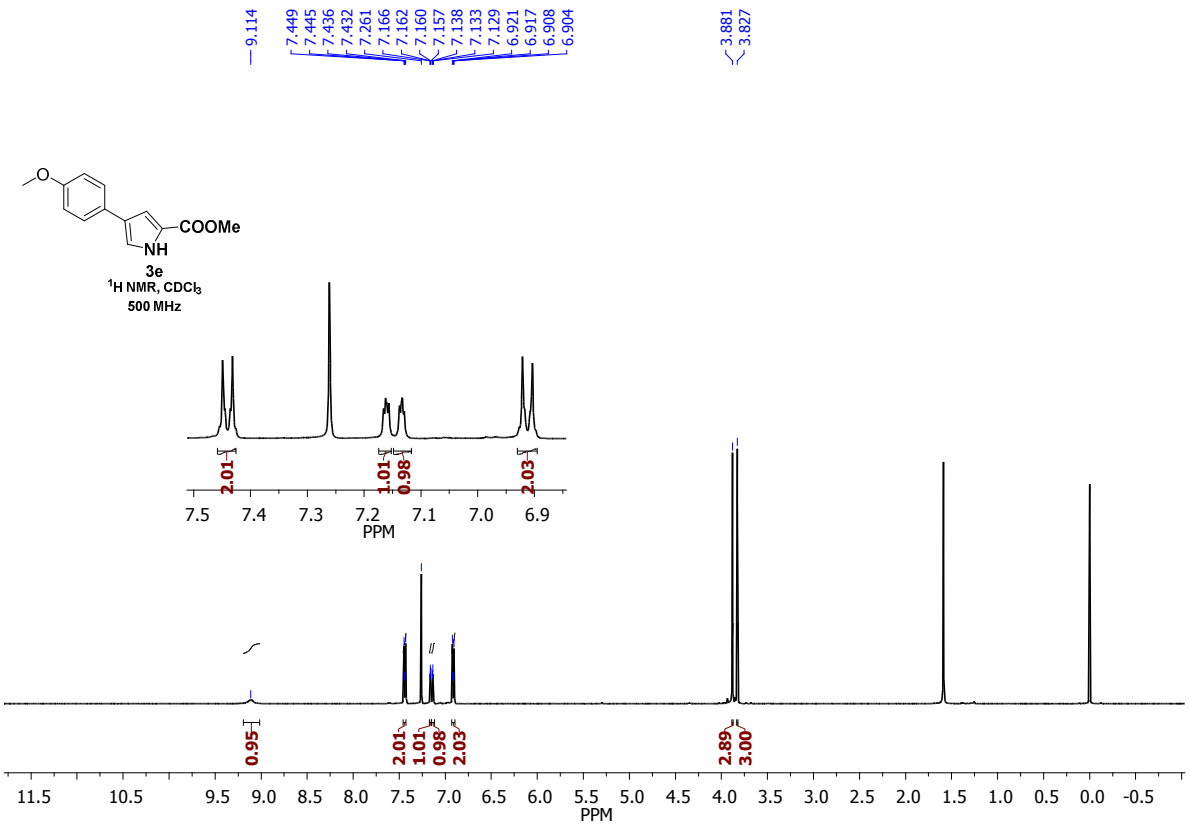


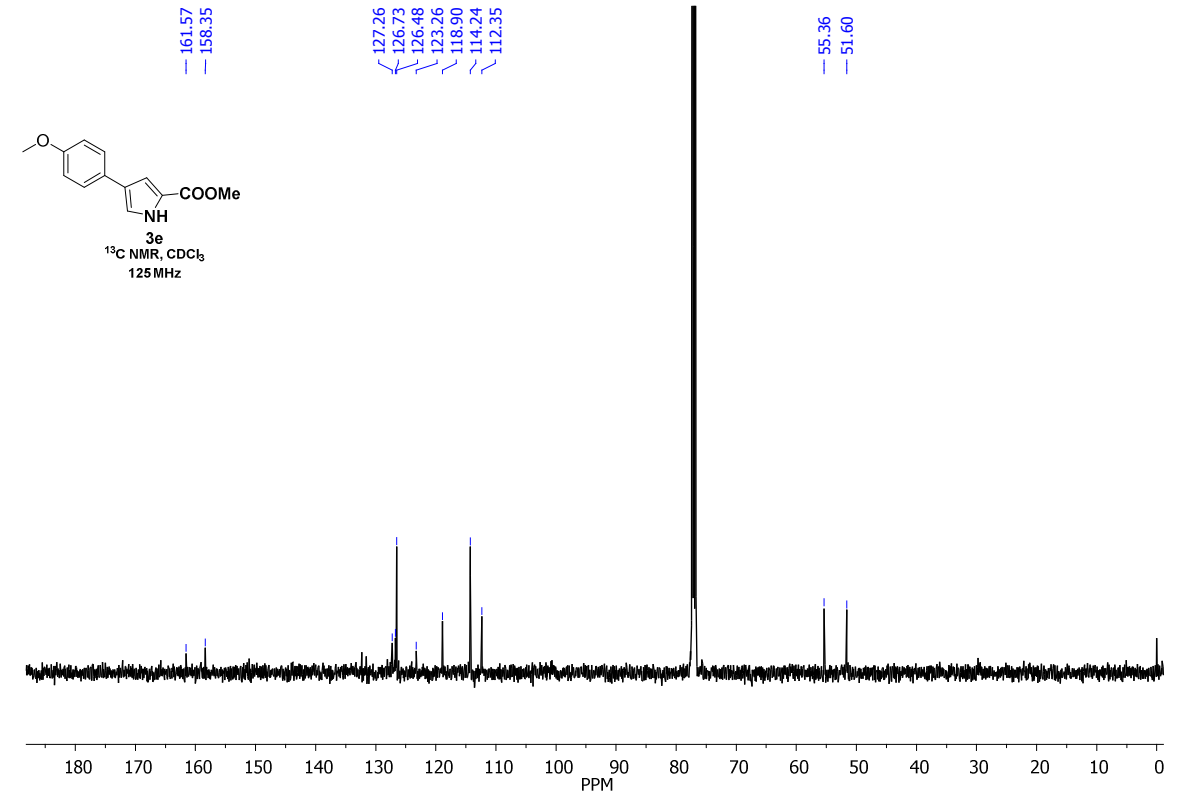
5.10 ^{1}H and ^{13}C NMR of **3d'**



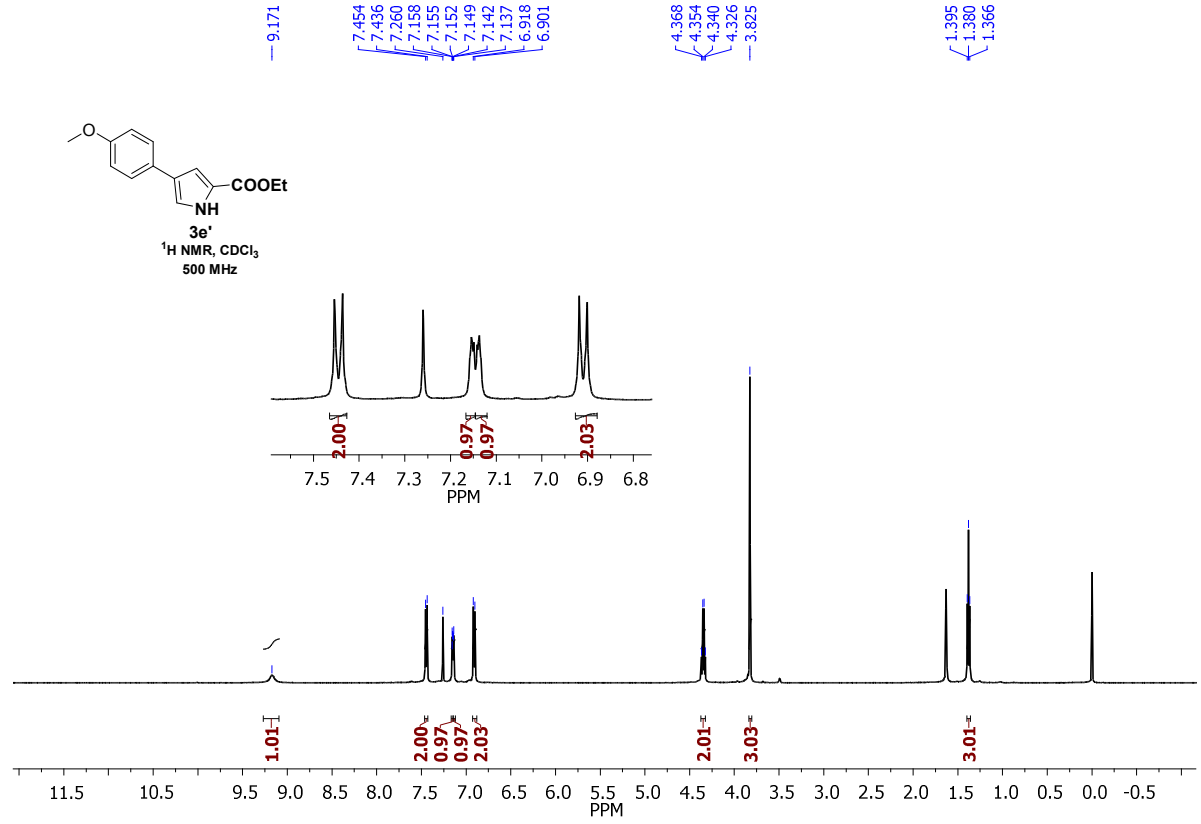


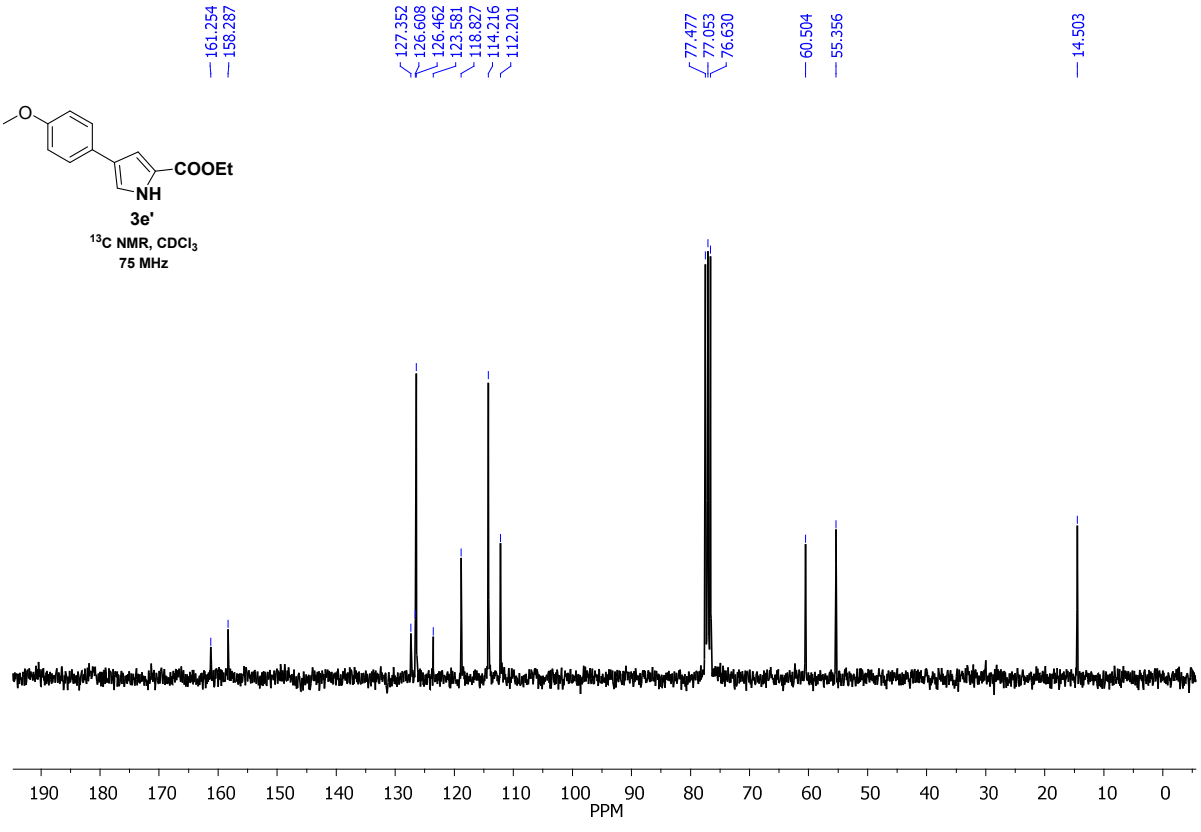
5.11 ^{1}H and ^{13}C NMR of **3e**



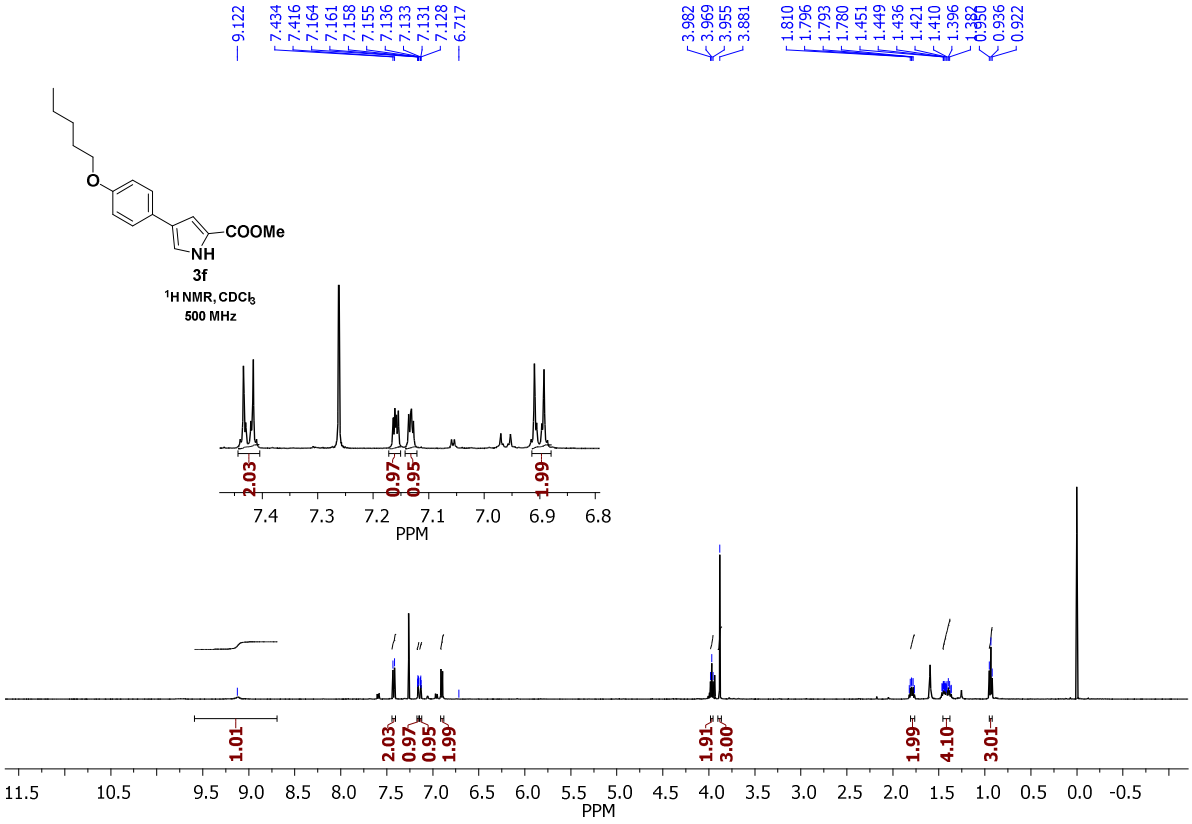


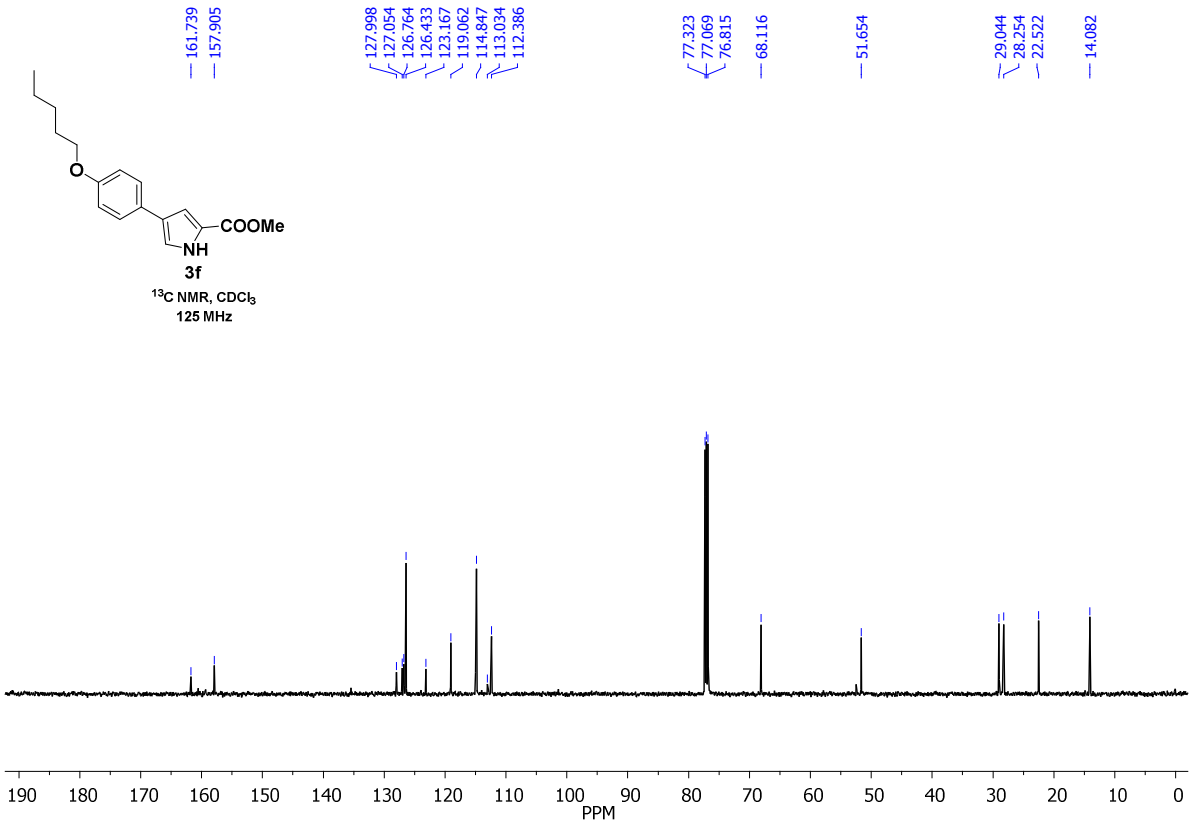
5.12 ^{1}H and ^{13}C NMR of **3e'**



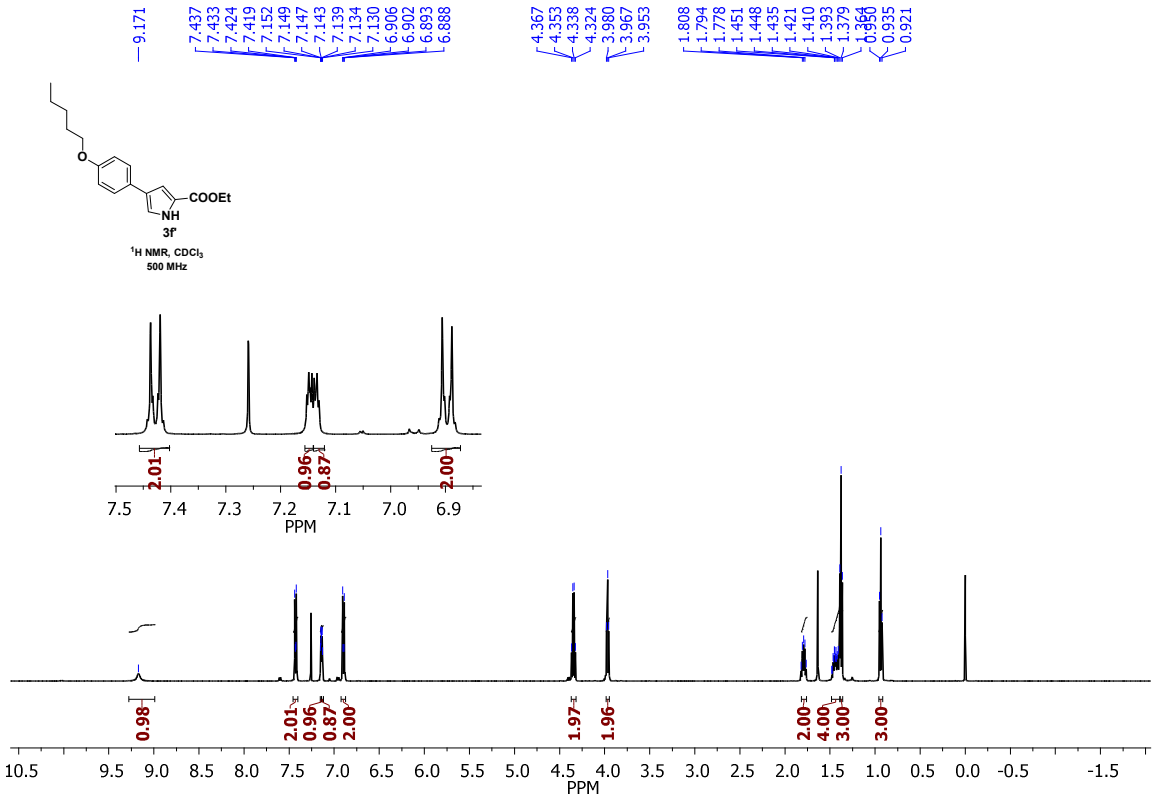


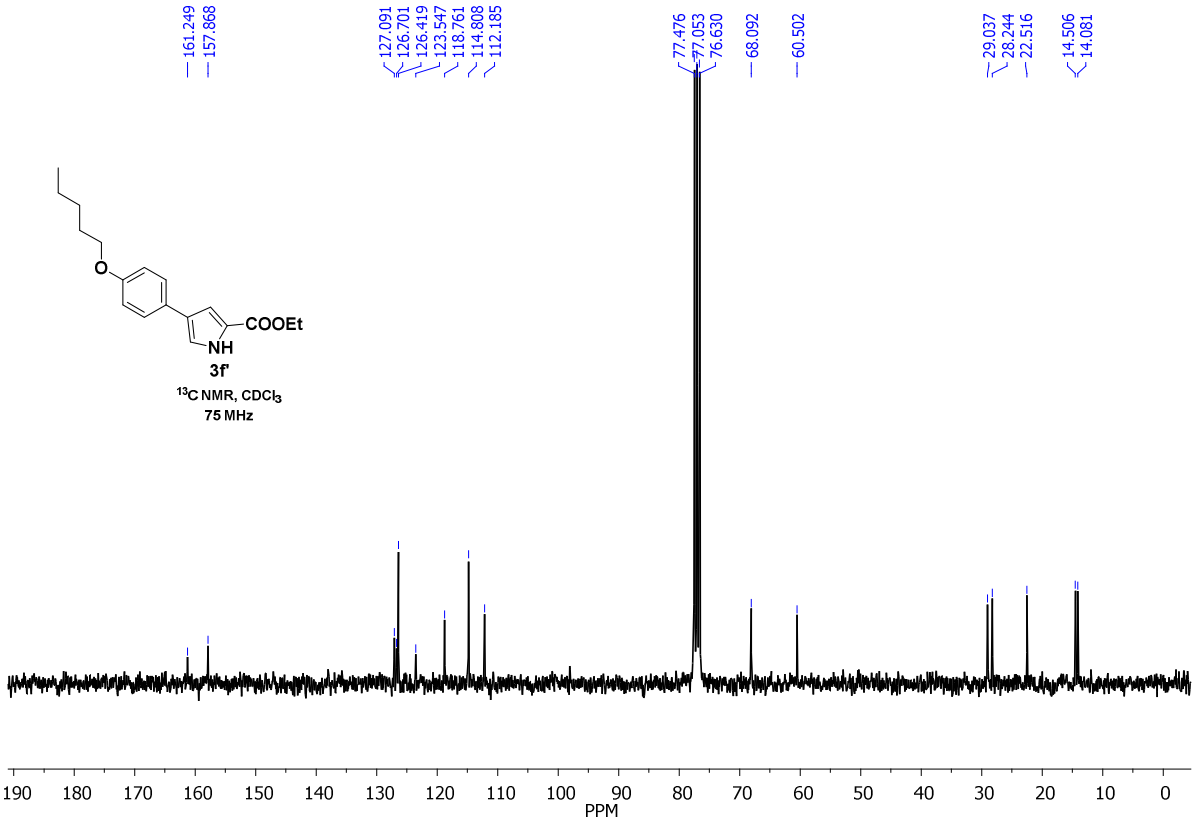
5.13 ^{1}H and ^{13}C NMR of **3f**



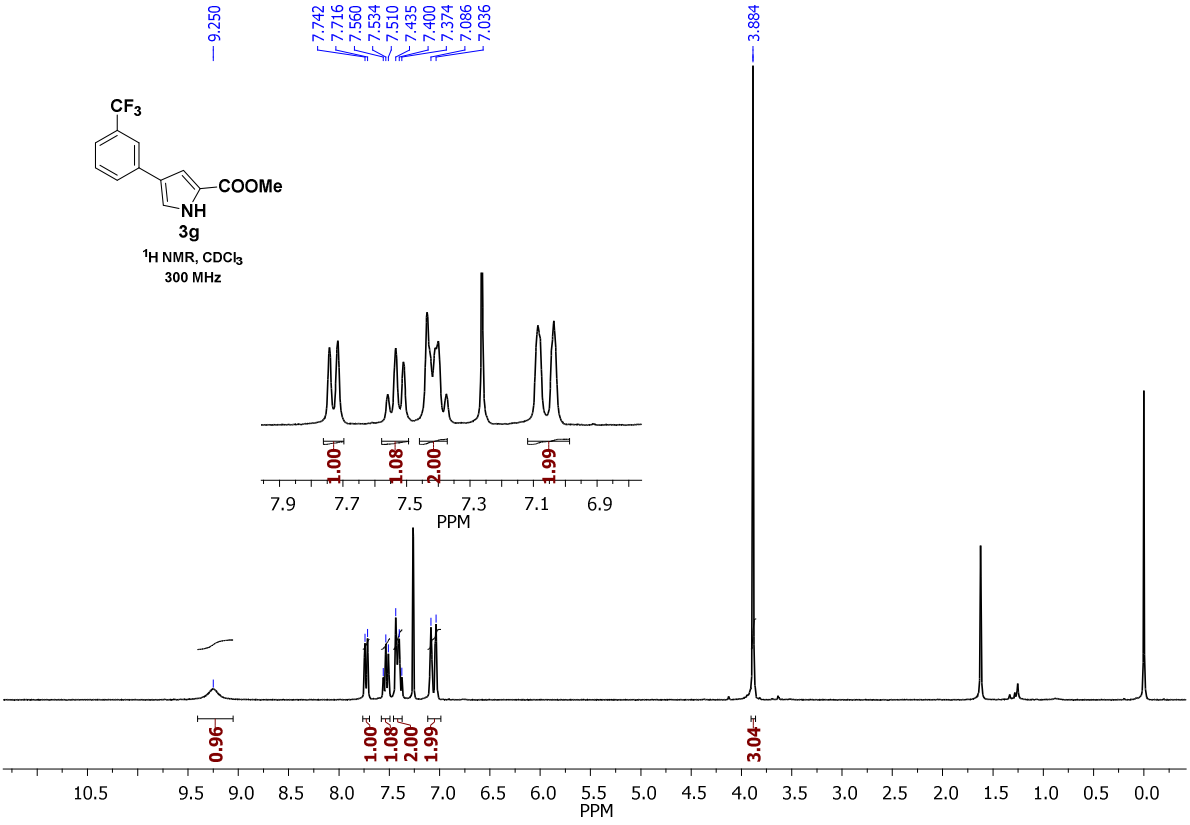


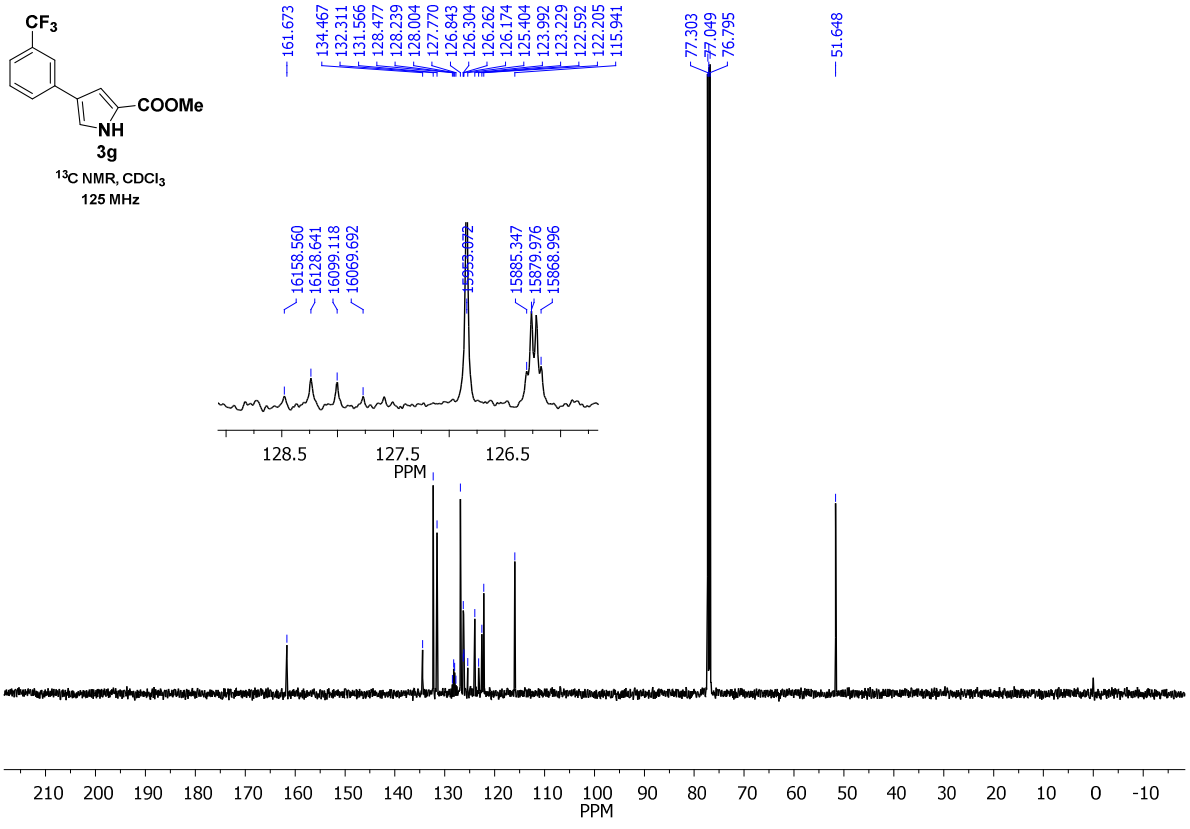
5.14 ^{1}H and ^{13}C NMR of **3f'**



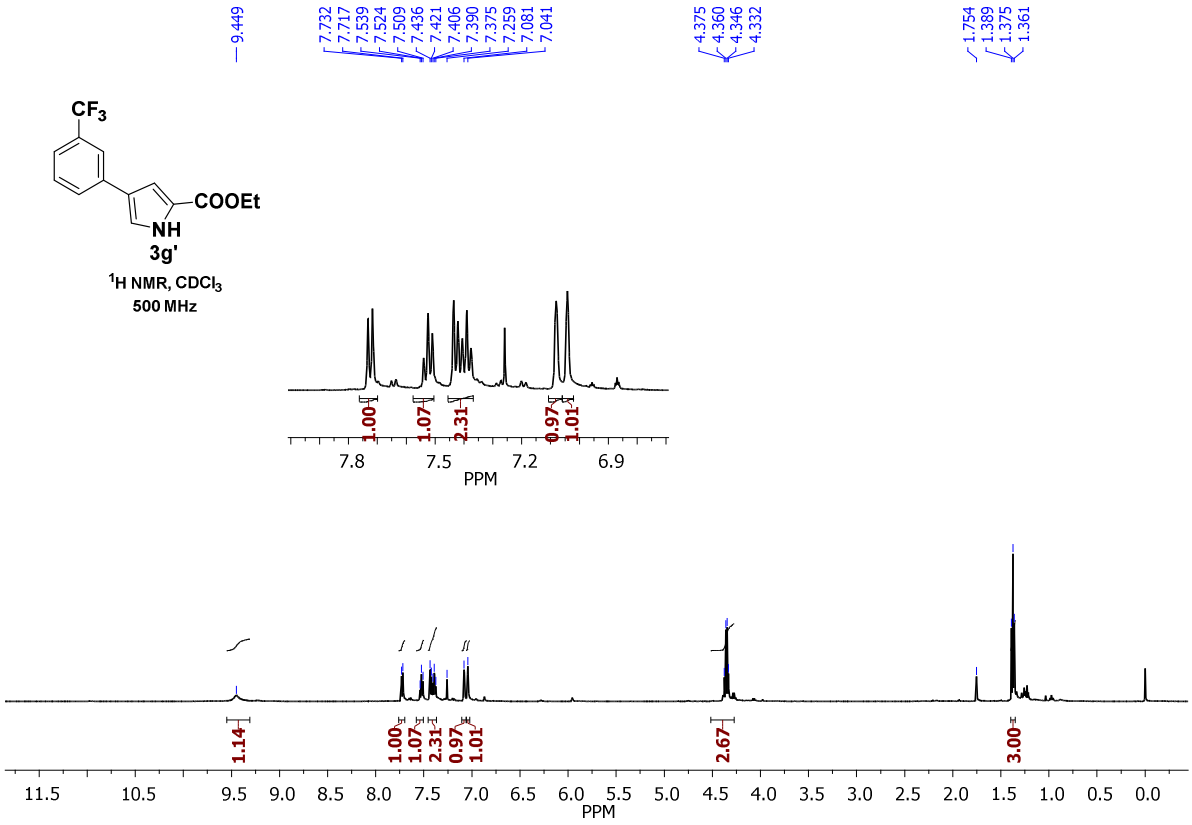


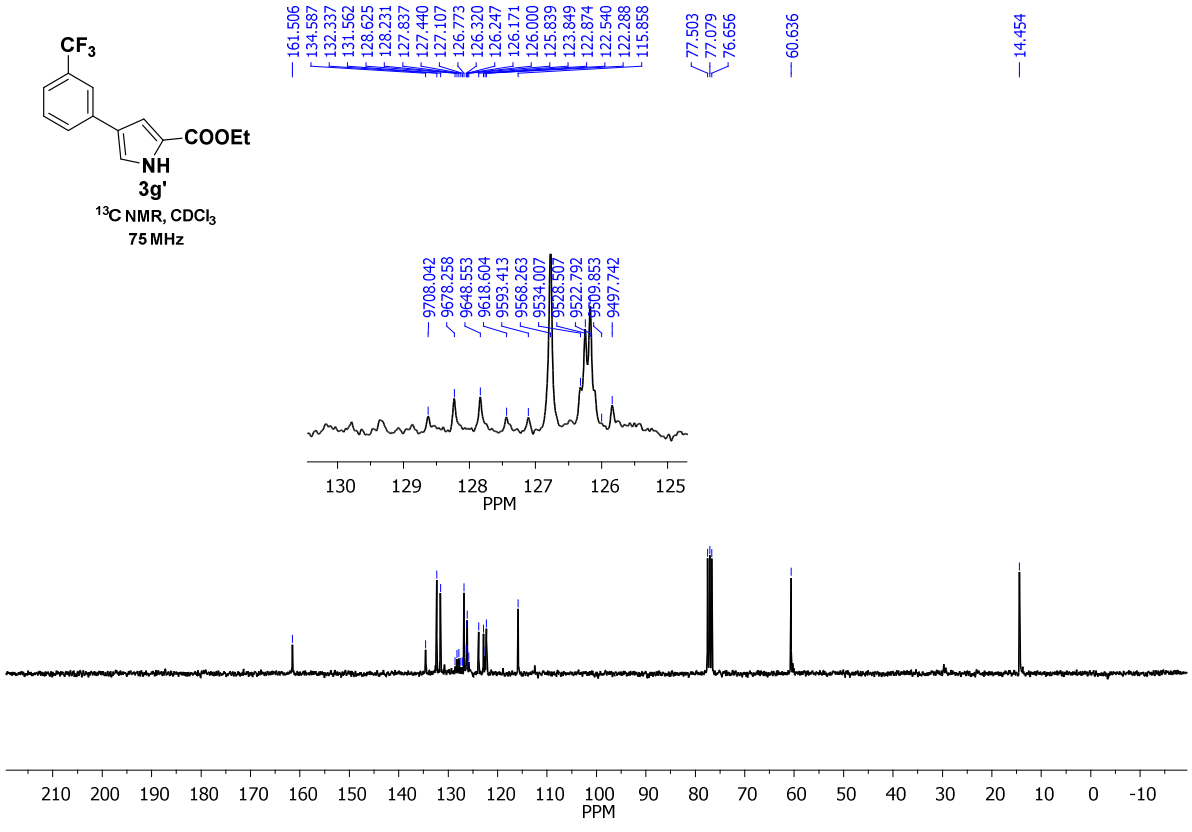
5.15 ^{1}H and ^{13}C NMR of **3g**



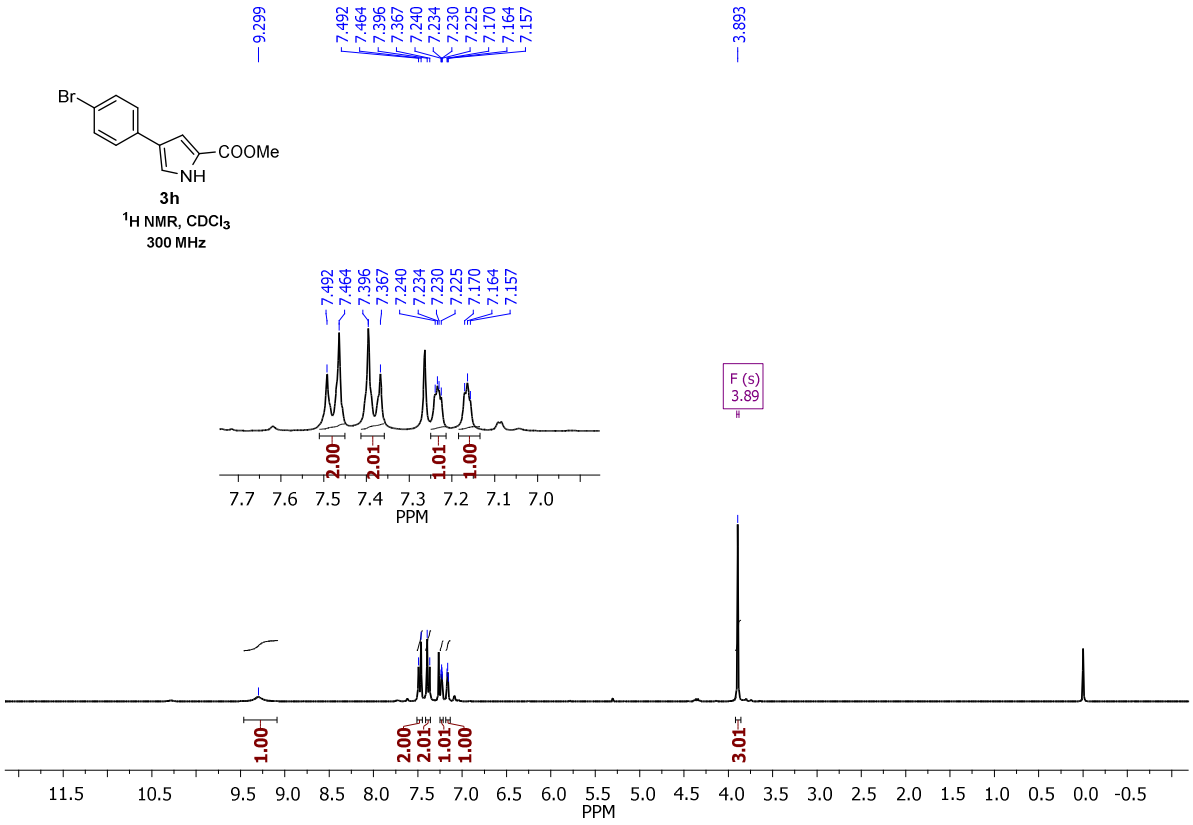


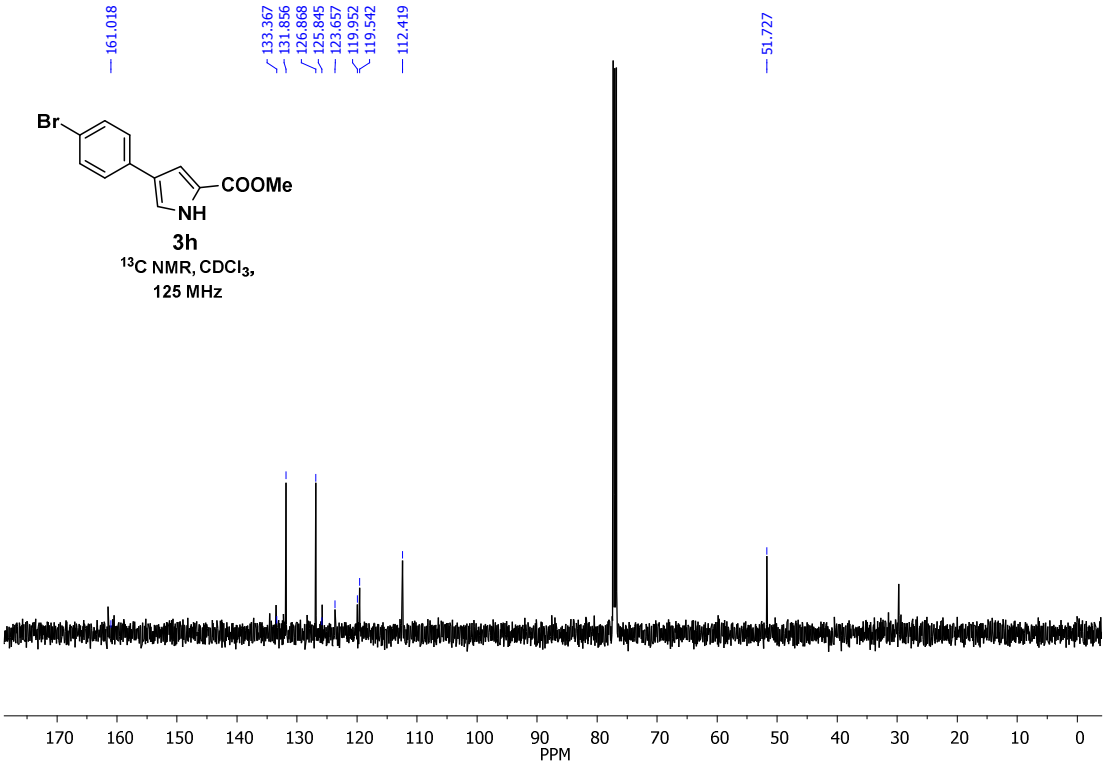
5.16 ^{1}H and ^{13}C NMR of **3g'**



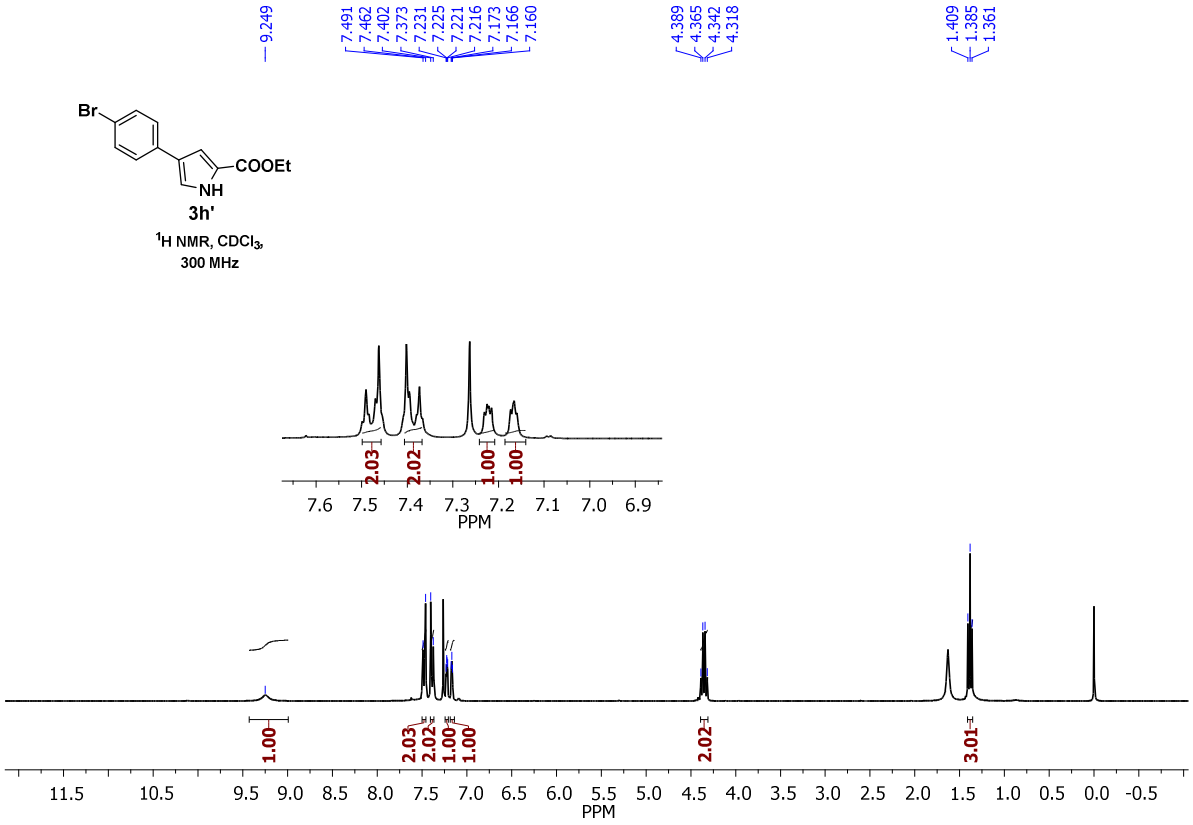


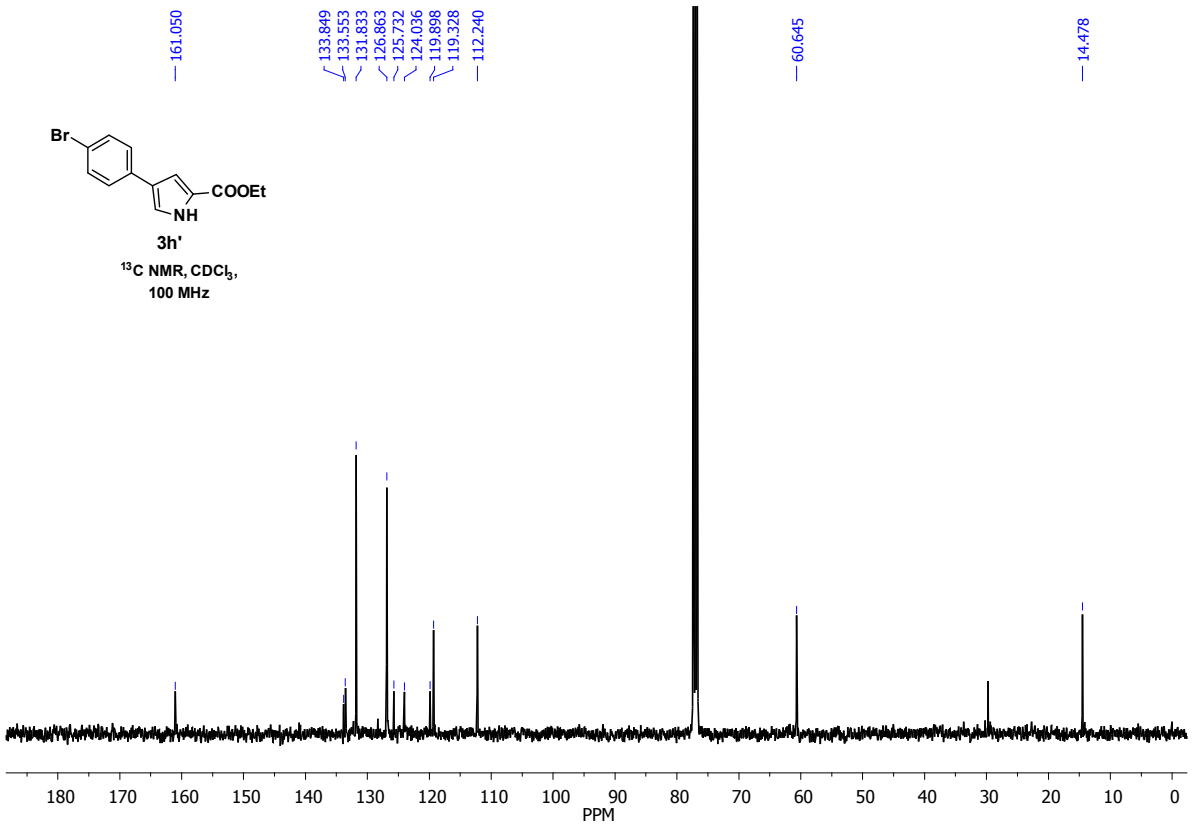
5.17 ^{1}H and ^{13}C NMR of **3h**



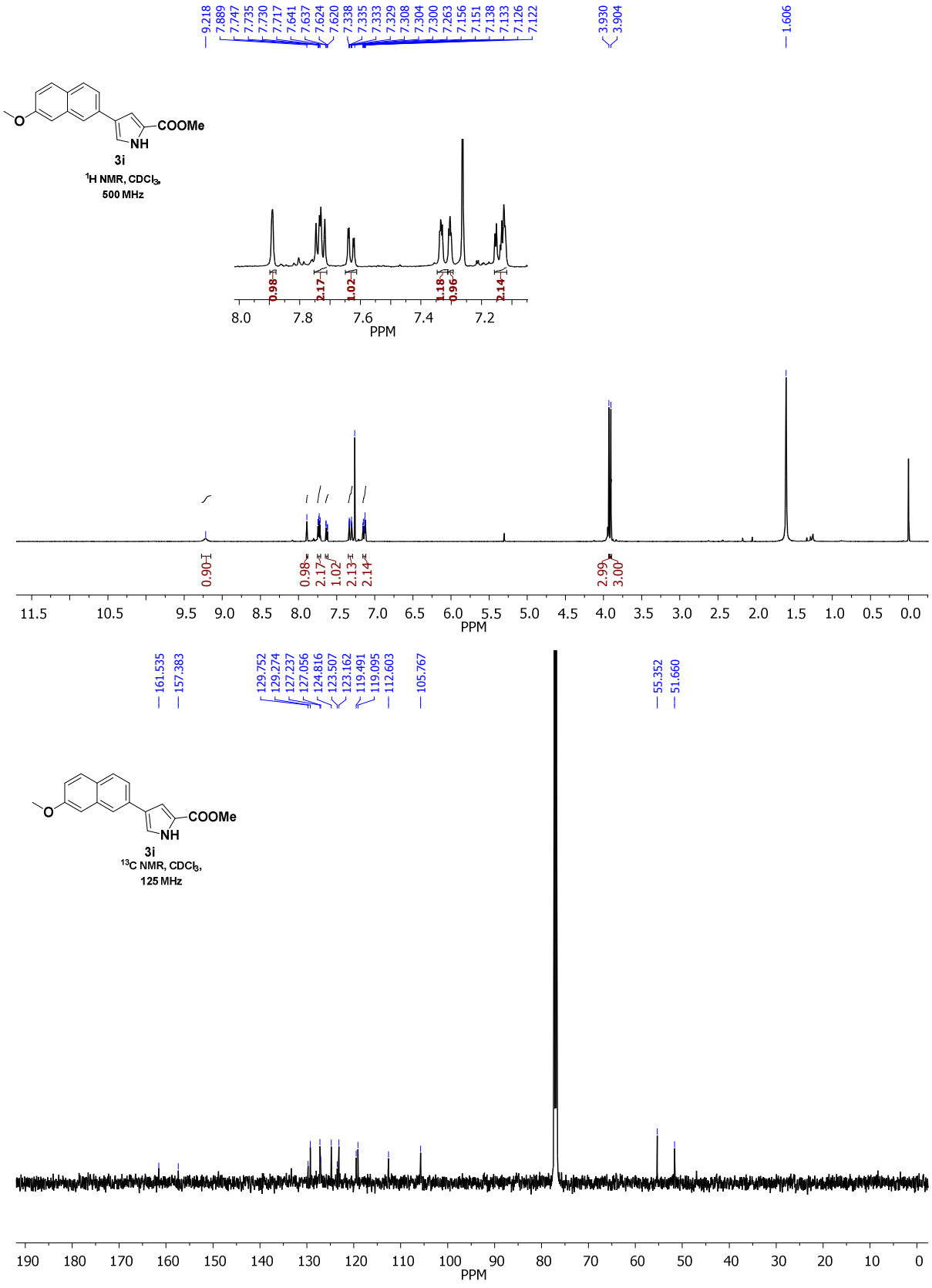


5.18 ^{1}H and ^{13}C NMR of **3h'**

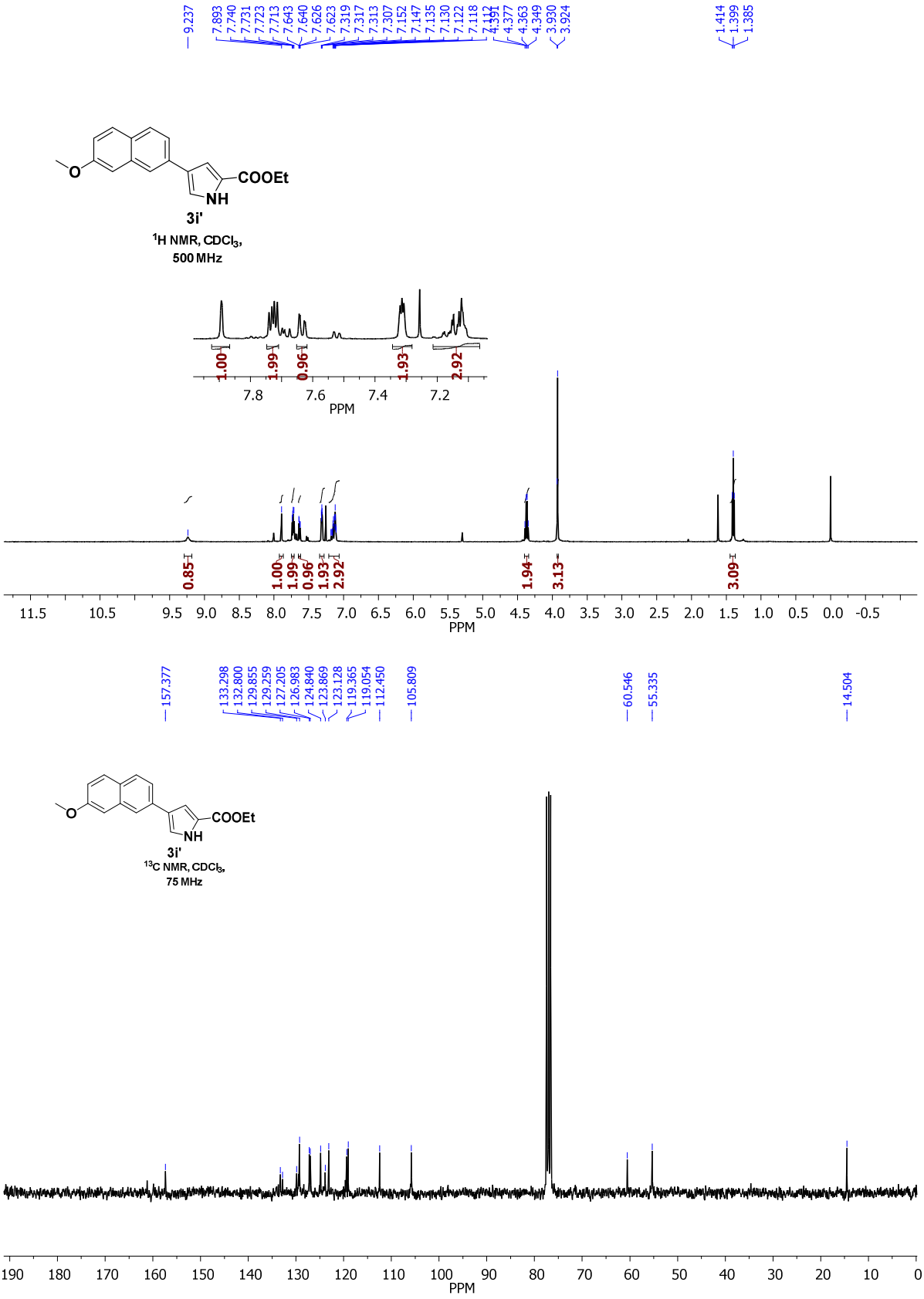




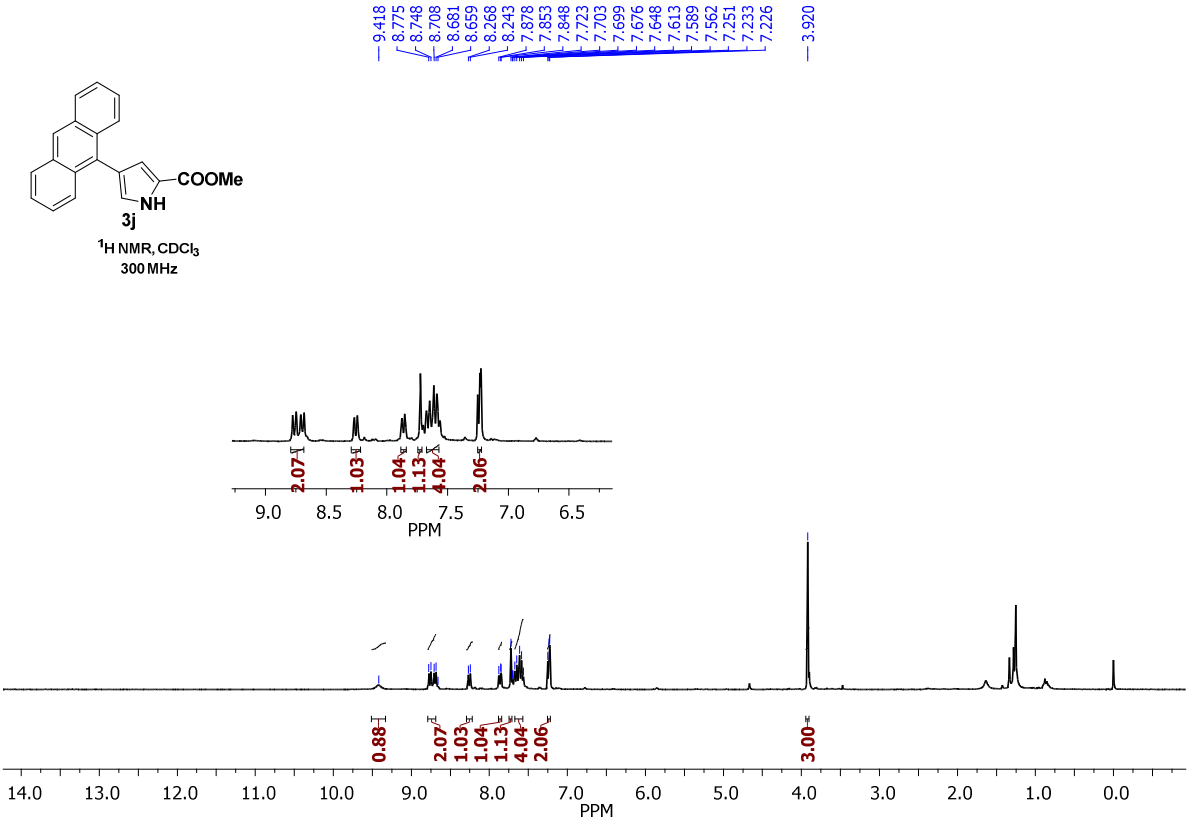
5.19 ^{1}H and ^{13}C NMR of **3i**

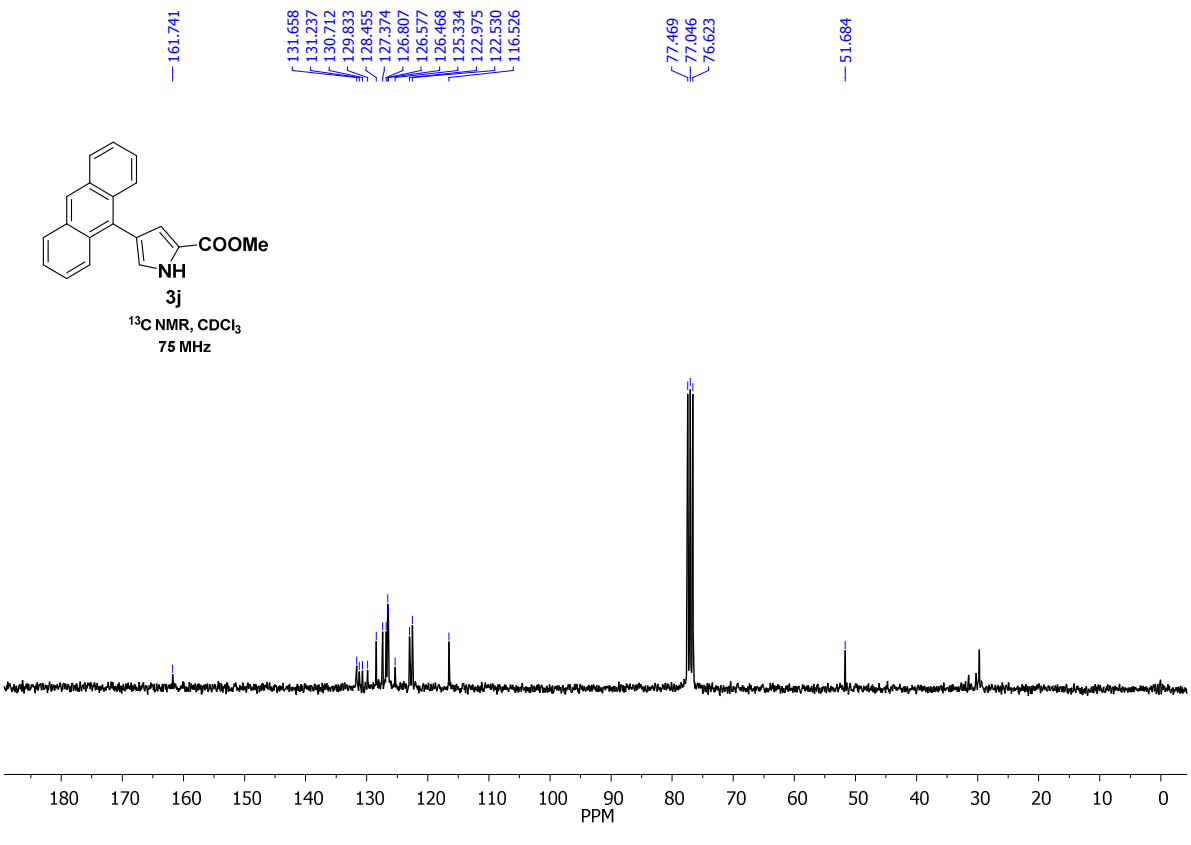


5.20 ^{1}H and ^{13}C NMR of **3i'**

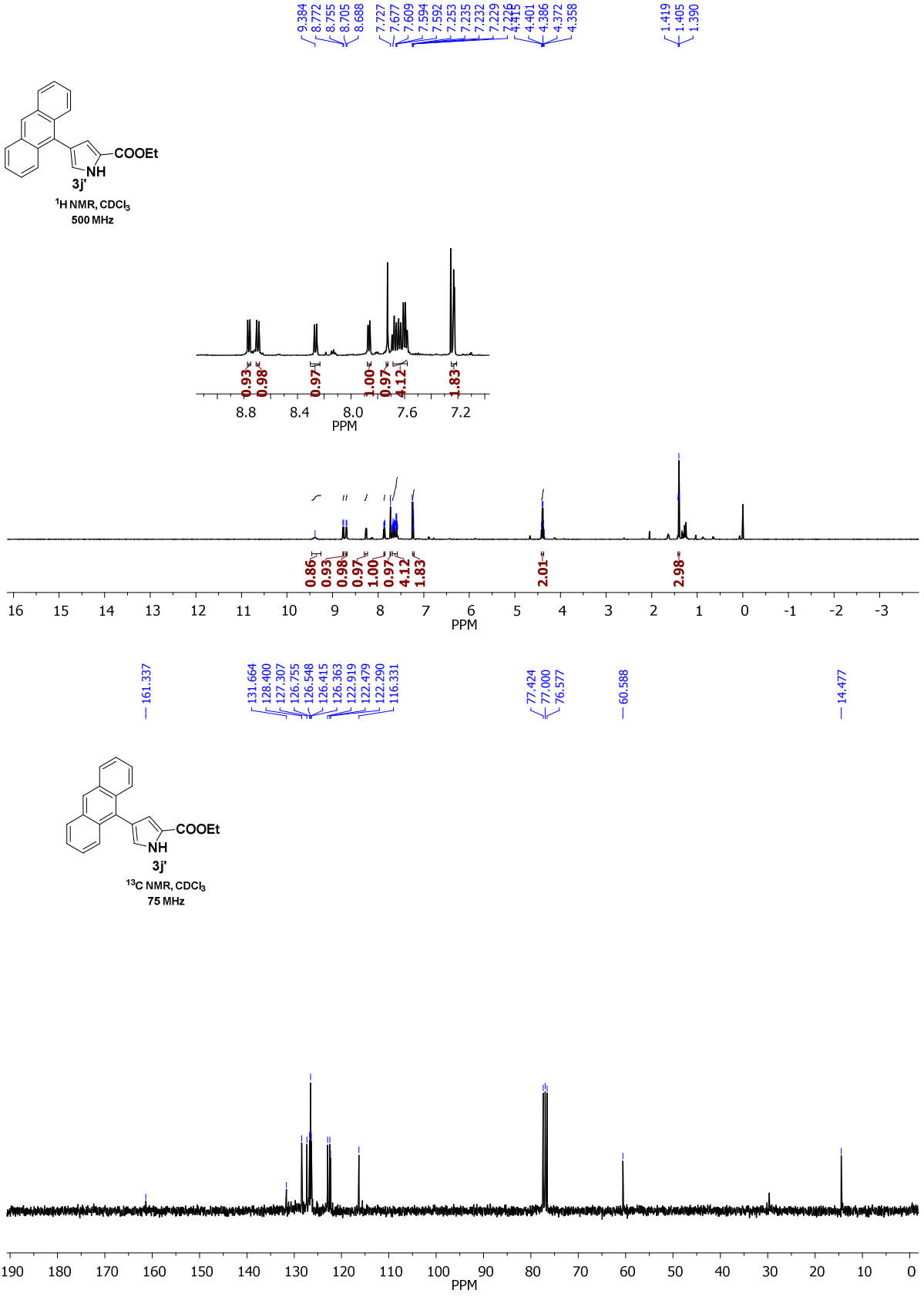


5.21 ^{1}H and ^{13}C NMR of **3j**

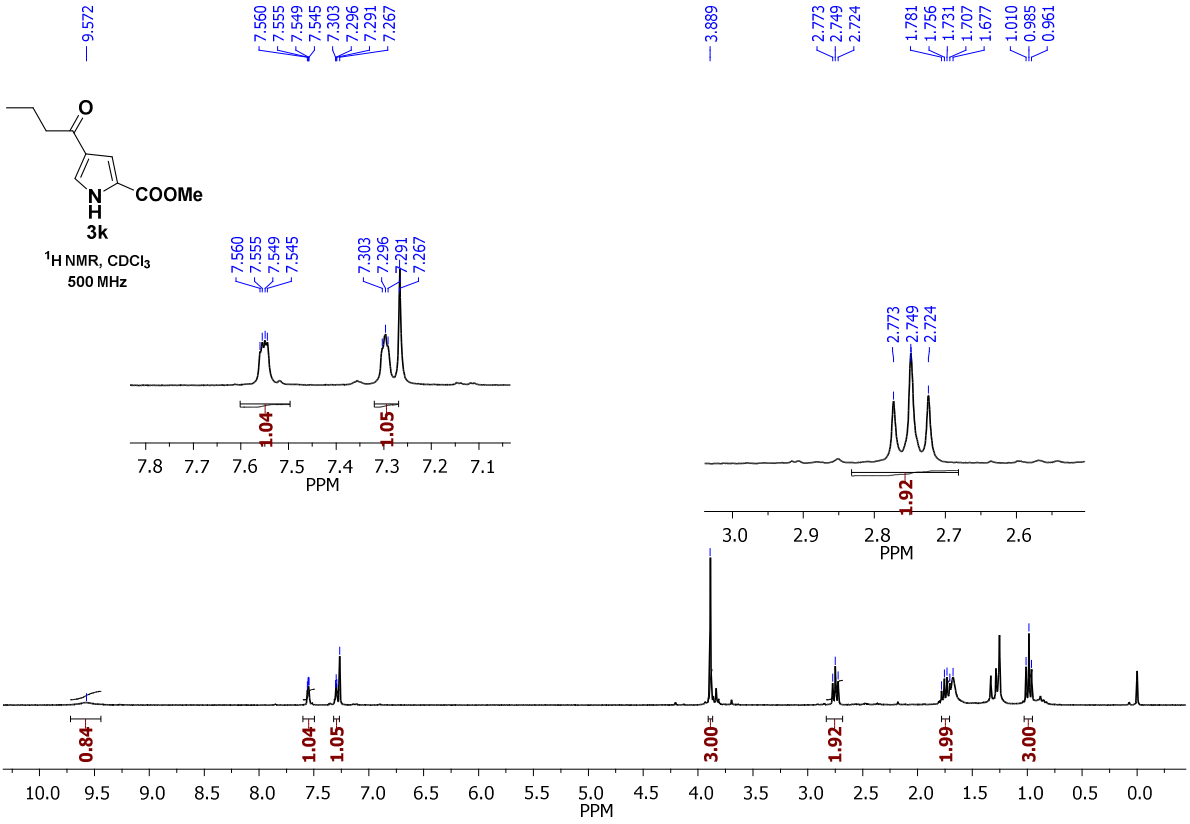


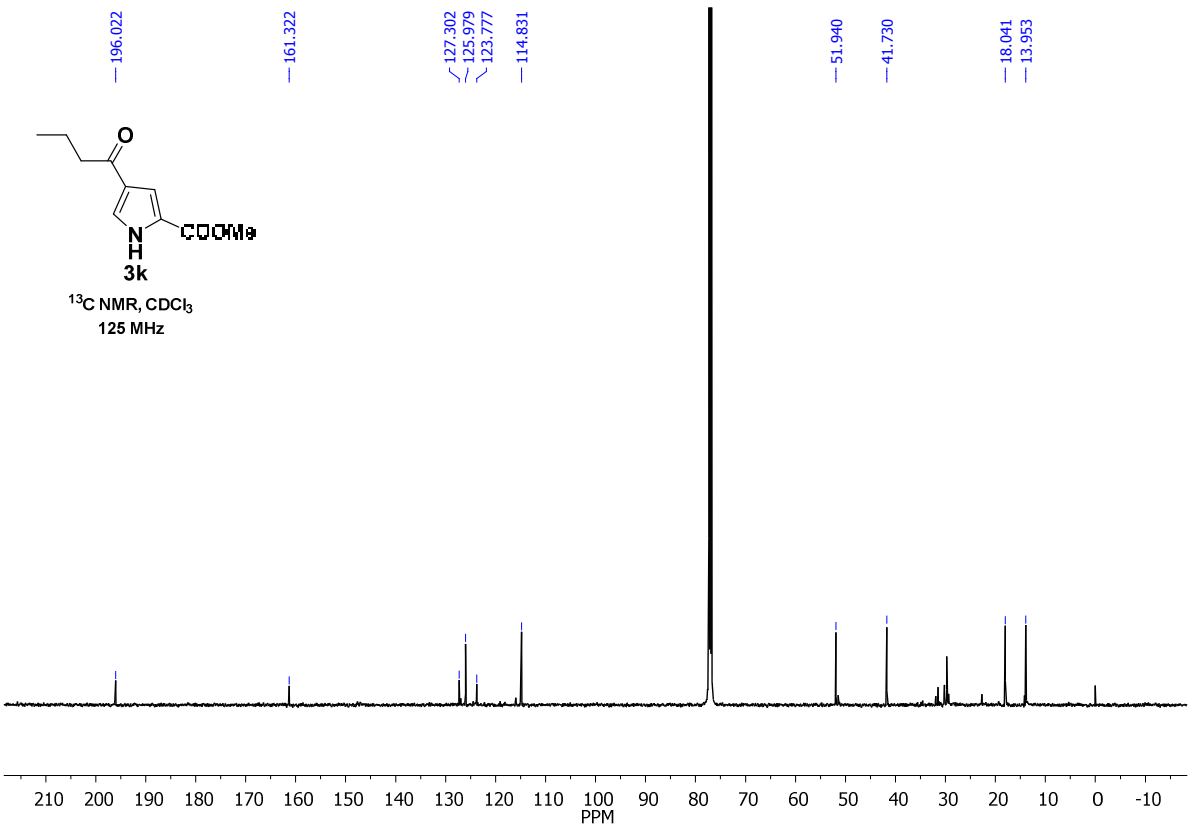


5.22 ^{1}H and ^{13}C NMR of **3j'**

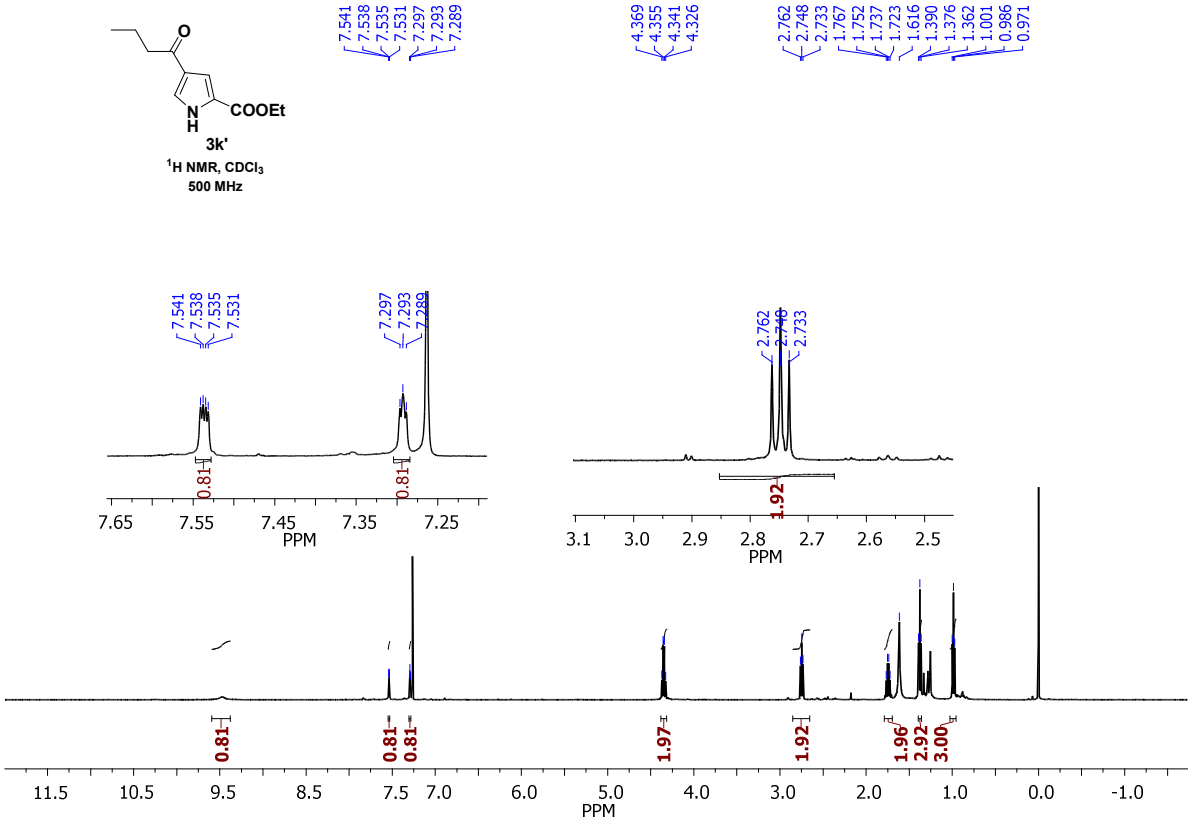


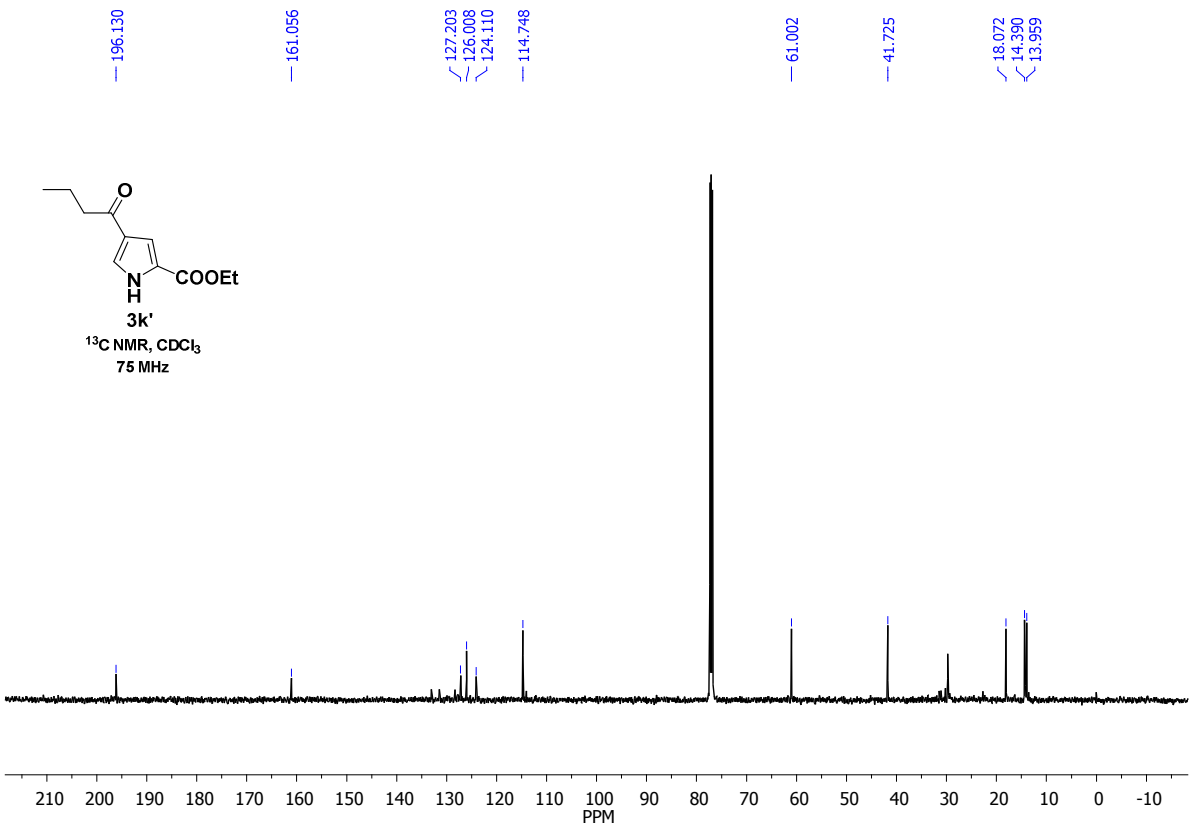
5.23 ^{1}H and ^{13}C NMR of **3k**



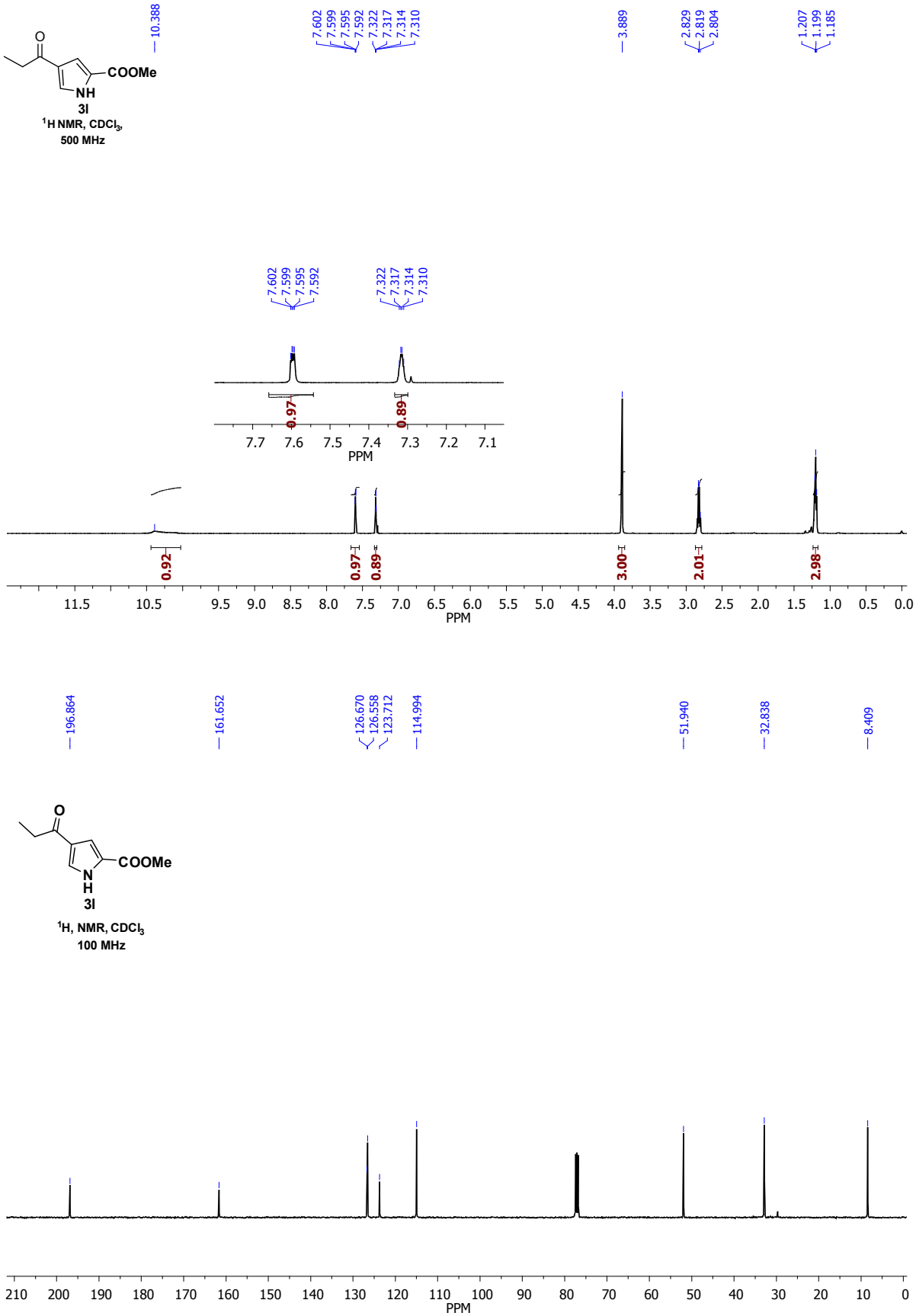


5.24 ^{1}H and ^{13}C NMR of **3k'**

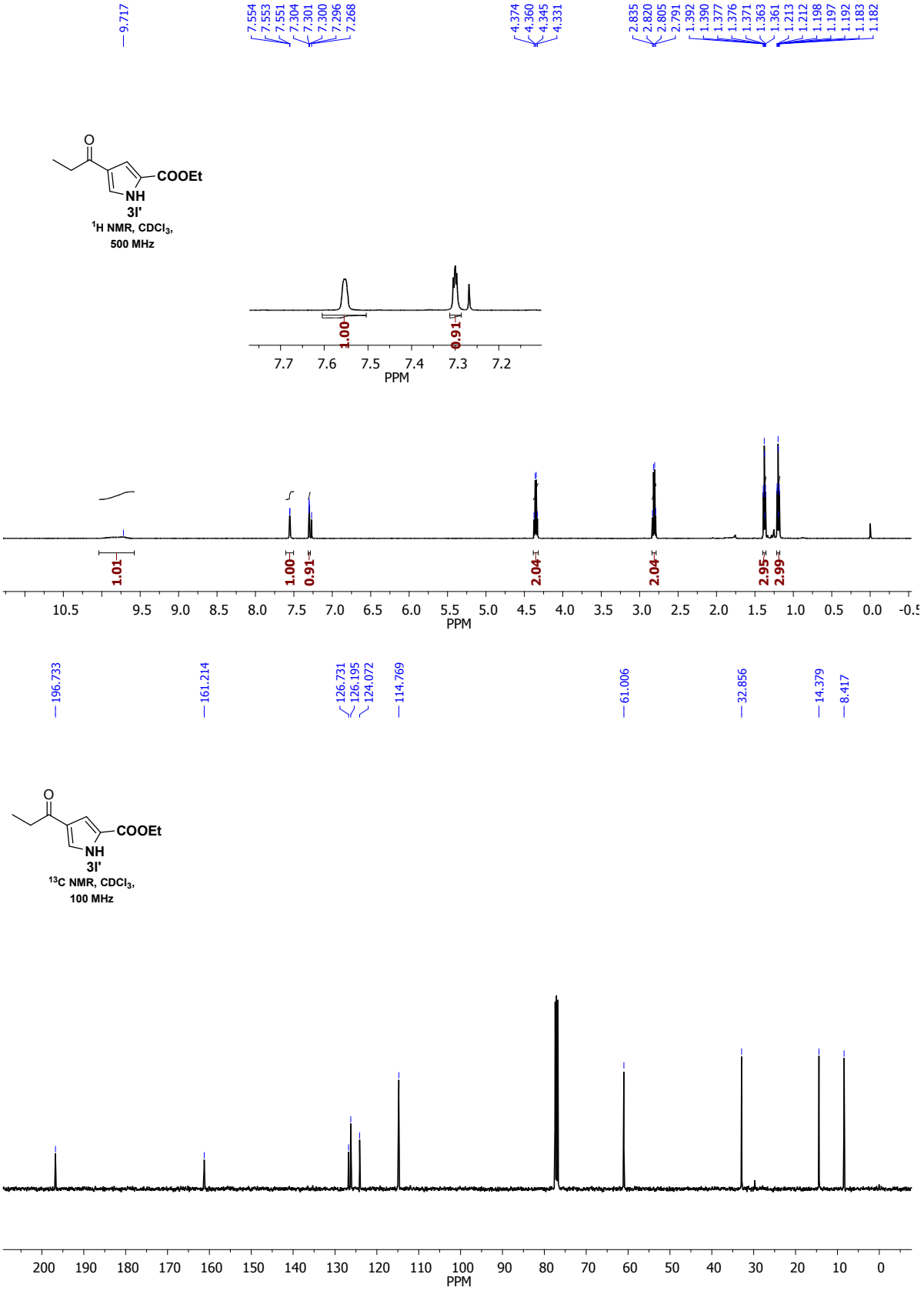




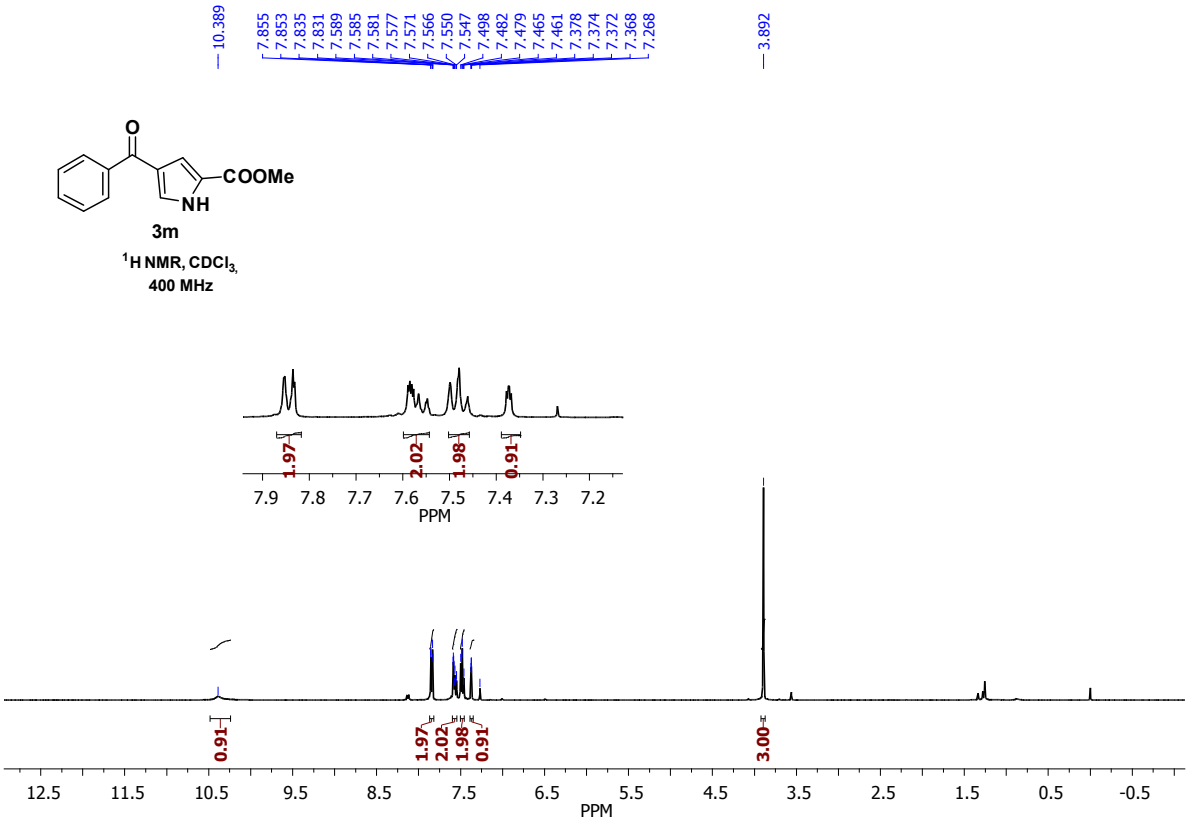
5.25 ^{1}H and ^{13}C NMR of **3l**

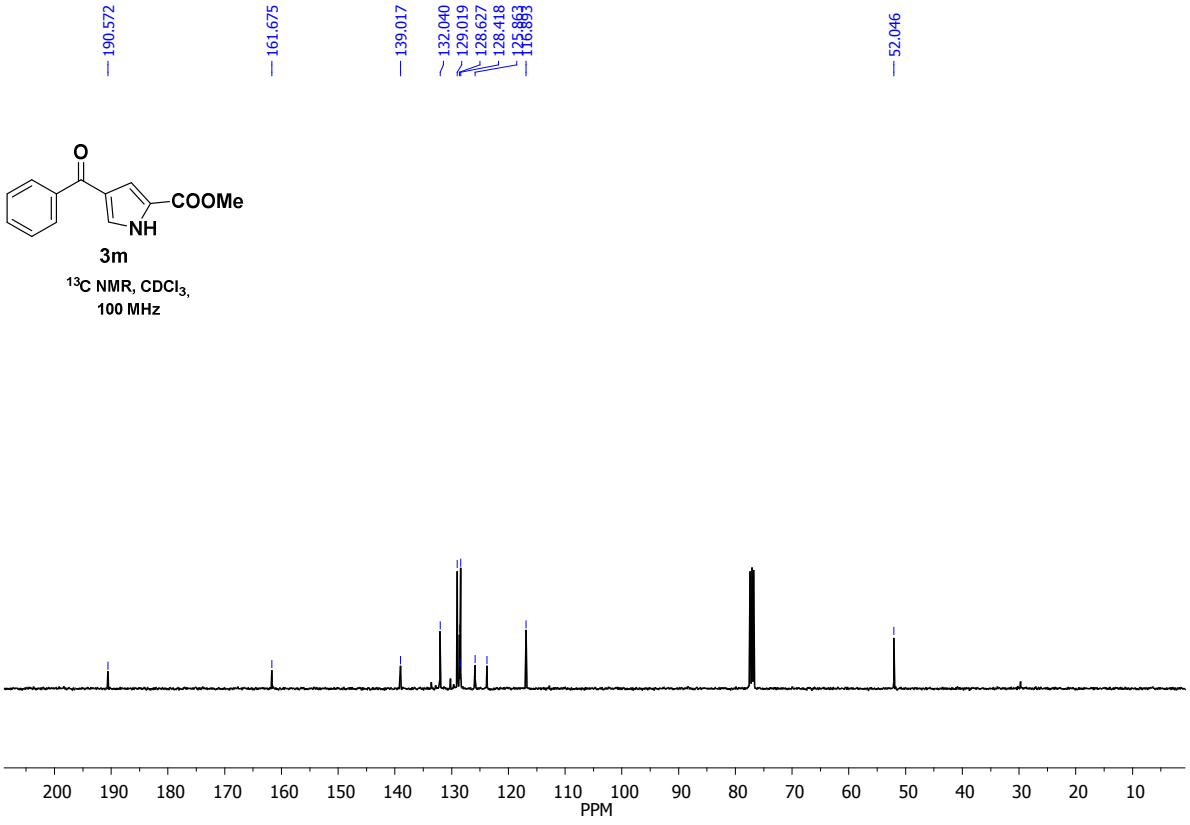


5.26 ^{1}H and ^{13}C NMR of **3l'**

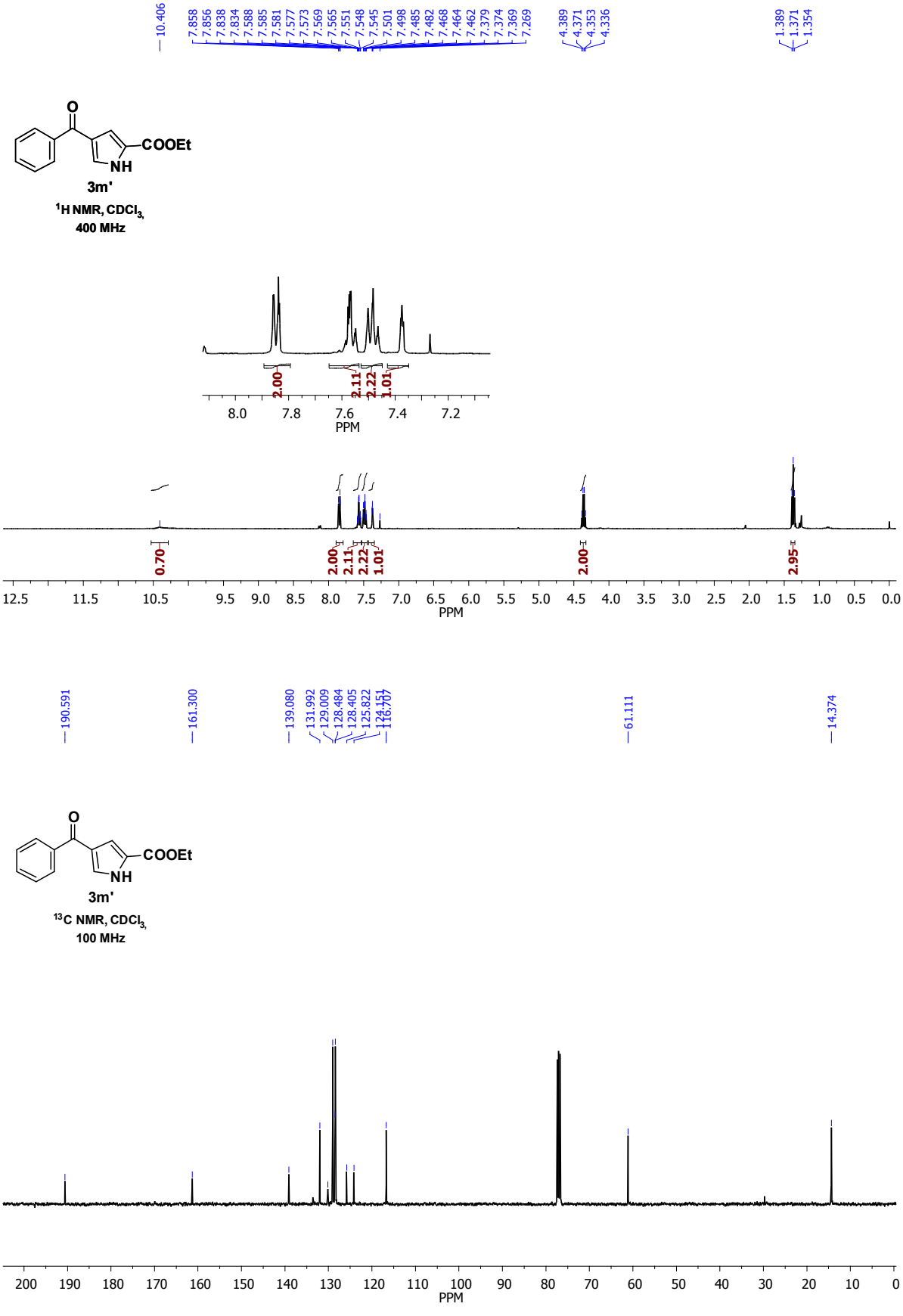


5.27 ^{1}H and ^{13}C NMR of **3m**





5.28 ^{1}H and ^{13}C NMR of **3m'**



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2. R. Arundhathi, D. Damodara, M. Lakshmi Kantam and Pravin R. Likhar, *Adv. Synth. Catal.* 2013*, **355**,* 751.
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4. J. T. Gupton, D. A. Krolikowski, R. H. Yu, S. W. Riesinger, J. A. Sikorski, *J. Org. Chem*. 1990, **55**, 4735 - 4740;
5. M. Tani, T. Ariyasu, C. Nishiyama, H. Hagiwara, T. Watanabe, Y. Yokoyama, Y. Murakami, *Chem. Pharm. Bull.* 1996, **44***,* 48-54;
6. J. K. Groves, H. J. Anderson, H. Nagy, *Can. J. Chem.* 1971, **49**, 2427 - 2432.