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Copper-catalyzed three-component annulation toward pyrroles via the cleavage of two C−C bonds in 1,3-dicarbonyls

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Supporting Information

Contents

Experimental section

General

Unless otherwise noted, all experiments were performed under a N_2 atmosphere. Commercial solvents and reagents were used without further purification. Thin-layer chromatography (TLC) was performed on silica gel plates (60F-254) using UV-light (254 nm). Flash chromatography was conducted on silica gel (200-300 mesh). NMR (400 MHz for ^{1}H NMR, 100 MHz for ^{13}C NMR) spectra were recorded in $CDCl_3$ with TMS as the internal standard. Chemical shifts are reported in ppm and coupling constants are given in Hz. Data for ^{1}H NMR are recorded as follows: chemical shift (ppm), multiplicity (s, singlet; d, doublet; t, triplet; q, quarter; m, multiplet), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (δ, ppm). High-resolution mass spectra (HRMS) were obtained on an agilent mass spectrometer using ESI-TOF (electrospray ionization-time of flight). Melting points were measured with a melting point instrument without correction.

The ketoxime-enoates **1a**−**1p**, **1s** and **1t**[1] were all known compounds and synthesized according to previously reported literature procedures, while the ketoxime acetates **1q**, **1r**, **1e'** and **1f'** were prepared for the first time whose characterization data were presented. Compounds **2** and **3a** were obtained from commercial suppliers and used without further purification. All the abbreviations in the manuscript are as follows:

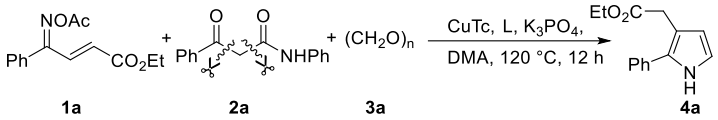
CuTc: Copper(I) thiophene-2-carboxylate
DBU: 1,8-Diazabicyclo[5.4.0]undec-7-ene
DMA: N,N-Dimethylacetamide
HSQC: heteronuclear singular quantum correlation
HMBC: heteronuclear multiple bond correlation
TEMPO: 2,2,6,6-tetramethyl-1-piperidinyloxy
BHT: butylated hydroxytoluene

Optimization of the reaction conditions

Initially, the readily available ketoxime-enoate **1a**, 2-benzoylacetanilide **2a** and paraformaldehyde **3a** were selected as the benchmark substrates, and extensive investigations were carried out to establish the optimal reaction conditions. Fortunately, the three-component coupling reaction proceeded smoothly to give pyrrole product **4a** in 61% yield in the presence of CuTc (10 mol %), and K_3PO_4 (0.9 equiv.) in DMA at 120 ^{o}C under N_2 for 12 h (Table S1, entry 1). Subsequently, a variety of bidentate pyridine-based ligands, including 2,2′-bipyridine (L1), 4,4'-di-*tert*-butyl-2,2'-bipyridine (L2), 4,4'-dimethoxy-2,2'-bipyridine (L3), 5,5'-dimethyl-2,2'-bipyridine (L4), and 1,10-phenanthroline (L5) were added into the system (Table S1, entries 2−6), and among them L2 proved to be superior to give **4a** in 75% yield (Table S1, entry 3). Other copper salts such as CuBr, CuOAc, $Cu(OTf)_2$, CuI, CuCl, CuSCN provided lower yields than CuTc (Table S2, entry 1). A brief survey of solvents suggested that DMA was still the best compared to DMF, DMSO, DCE, THF, MeCN and 1,4-dioxane (Table S2, entries 9–14). No further improvement of the yield was obtained by screening of other common inorganic and organic bases (Table S3, entries 1–5). Further exploration showed that the yield of **4a** could be improved to 83% yield with the use of K_3PO_4 (30 mol%) and

DBU (40 mol%) (Table S3, entry 7), while other ratios provided inferior results (Table S3, entries 8–11). Notably, either increasing or decreasing the reaction temperature resulted in a slightly lower yield of **4a** (Table S4, entries 1–3). Furthermore, prolonging or shortening the reaction time lead to a decrease yield (Table S4, entries 4 and 5). Finally, the stoichiometry of reactants was optimized (Table S4, entries 6–9). It should be noted that the yield slightly decreased to 70% under air atmosphere (Table S4, entry 10).

Table S1. Screening of ligands[a]

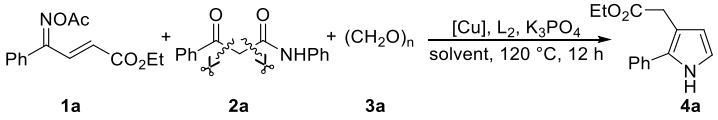


1a **2a** **3a** **4a**

entry	ligand	yield (%)[b]
1		61
2	2,2′-bipyridine (L1)	63
3	4,4'-di-*tert*-butyl-2,2'-bipyridine (L2)	75
4	4,4'-dimethoxy-2,2'-bipyridine (L3)	68
5	5,5'-dimethyl-2,2'-bipyridine (L4)	67
6	1,10-phenanthroline (L5)	50

[a]Reaction conditions: unless otherwise noted, all reactions were performed with **1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (1 mmol), CuTc (10 mol %), L (20 mol%) and K_3PO_4 (0.9 equiv.) in DMA (2 mL) at 120 °C under N_2 for 12 h. [b]Isolated yields.

Table S2. Screening of copper salts and solvents[a]

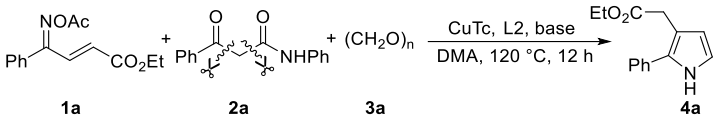


1a **2a** **3a** **4a**

entry	[Cu]	solvent	yield (%)[b]
1	CuTc	DMA	75
2	CuBr	DMA	42
3	CuOAc	DMA	40
4	$Cu(OTf)_2$	DMA	35
5	CuI	DMA	45
6	CuCl	DMA	43
7	CuSCN	DMA	38
8		DMA	N.R.
9	CuTc	DMF	67
10	CuTc	DMSO	65
11	CuTc	DCE	40
12	CuTc	THF	50
13	CuTc	MeCN	47
14	CuTc	1,4-dioxane	46

[a]Reaction conditions: unless otherwise noted, all reactions were performed with **1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (1 mmol), [Cu] (10 mol %), L2 (20 mol %) and K_3PO_4 (0.9 equiv) in solvent (2 mL) at 120 °C under N_2 for 12 h. [b]Isolated yields.

Table S3. Screening of bases[a]

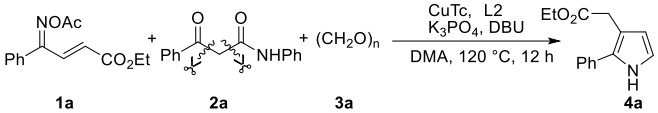


1a 2a 3a 4a

entry	base	yield (%)[b]
1	K_3PO_4	75
2	K_2CO_3	66
3	CsOAc	54
4	DBU	52
5	DMAP	30
6[c]	K_3PO_4/DBU	78
7[d]	K_3PO_4/DBU	83
8[e]	K_3PO_4/DBU	79
9[f]	K_3PO_4/DBU	75
10[g]	K_3PO_4/DBU	77
11[h]	K_3PO_4	68

[a]Reaction conditions: unless otherwise noted, all reactions were performed with **1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (1 mmol), CuTc (10 mol %), L2 (20 mol %) and base (0.9 equiv) in DMA (2 mL) at 120 °C under N_2 for 12 h. [b]Isolated yields. [c]K_3PO_4 (50 mol %), DBU (40 mol %). [d]K_3PO_4 (30 mol %), DBU (40 mol %). [e]K_3PO_4 (20 mol %), DBU (40 mol %). [f]K_3PO_4 (30 mol %), DBU (60 mol %). [g]K_3PO_4 (30 mol %), DBU (20 mol %). [h]K_3PO_4 (20 mol %)

Table S4. Screening of other conditions[a]

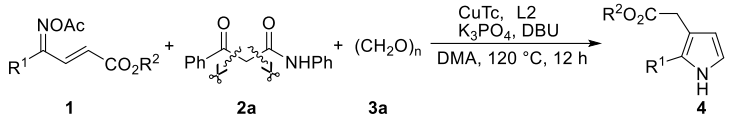


1a 2a 3a 4a

entry	T (°C)	reaction time (h)	yield (%)[b]
1	120	12	83
2	130	12	75
3	110	12	77
4	120	10	70
5	120	14	72
6[c]	120	12	52
7[d]	120	12	40
8[e]	120	12	75
9[f]	120	12	73
10[g]	120	12	70

[a]Reaction conditions: unless otherwise noted, all reactions were performed with **1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (1 mmol), CuTc (10 mol %), L2 (20 mol %), K_3PO_4 (30 mol %) and DBU (40 mol %) in DMA (2 mL) under N_2. [b]Isolated yields. [c]**1a** (0.2 mmol), **2a** (0.2 mmol), **3a** (1 mmol). [d]**1a** (0.2 mmol), **2a** (0.3 mmol), **3a** (1 mmol). [e]**1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (0.8 mmol). [f]**1a** (0.3 mmol), **2a** (0.2 mmol), **3a** (1.2 mmol). [g] Under air atmosphere.

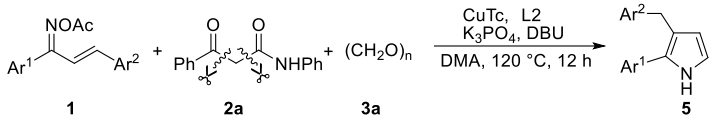
General procedure for the synthesis of 4



1 2a 3a 4

The ketoxime-enoates **1** (0.3 mmol), 2-benzoylacetanilide **2a** (47.8 mg, 0.2 mmol), paraformaldehyde **3a** (30 mg, 1 mmol), CuTc (3.8 mg, 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%) and DBU (12.2 mg, 40 mol%) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give the products **4**.

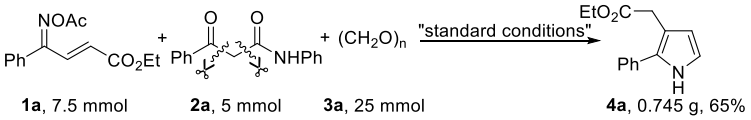
General procedure for the synthesis of 5



1 2a 3a 5

The oxime acetates **1** (0.3 mmol), 2-benzoylacetanilide **2a** (47.8 mg, 0.2 mmol), paraformaldehyde **3a** (30 mg, 1 mmol), CuTc (3.8 mg, 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%) and DBU (12.2 mg, 40 mol%) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give the products **5**.

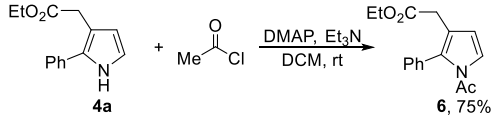
Gram-scale synthesis of 4a



1a, 7.5 mmol **2a**, 5 mmol **3a**, 25 mmol **4a**, 0.745 g, 65%

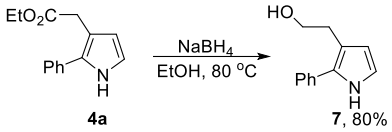
The ketoxime-enoate **1a** (1.958 g, 7.5 mmol), 2-benzoylacetanilide **2a** (1.195 g, 5 mmol), paraformaldehyde **3a** (0.750 g, 25 mmol), CuTc (0.095 g, 10 mol%), L2 (0.268 g, 20 mol%), K_3PO_4 (0.318 g, 30 mol%) and DBU (0.304 g, 40 mol%) in DMA (25 mL) were stirred at 120 ℃ (oil bath) in a 100 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (50 mL) and extracted with ethyl acetate (3 × 40 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give product **4a** in 65% yield (0.745 g).

General procedure for the synthesis of 6



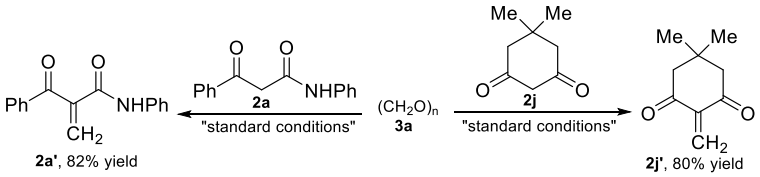
To a stirred solution of **4a** (45.8 mg, 0.2 mmol) in anhydrous CH_2Cl_2 (2 mL) at 0 °C was added Et_3N (70 μL, 0.5 mmol), DMAP (3 mg, 10 mol%) and freshly acetyl chloride (48 μL, 0.3 mmol). The temperature was allowed to warm to room temperature, and stirred for 3 h. Then water (5 mL) was added and the aqueous layer was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic layers were washed with saturated aqueous $NaHCO_3$, brine, dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give product **6** in 75% yield (41 mg).

General procedure for the synthesis of 7



To a stirred solution of **4a** (45.8 mg, 0.2 mmol) in EtOH (4 mL) was added $NaBH_4$ (15.2 mg, 0.4 mmol) and then the reaction mixture was stirred at 80 °C for 6 h. After completion of the reaction (detected by TLC), the reaction solution was concentrated under vacuum. The crude residue was purified by column chromatography on silica gel (petroleum ether/ethyl acetate) to give product **7** in 80% yield (30 mg).

General procedure for the synthesis of 2a' and 2j'

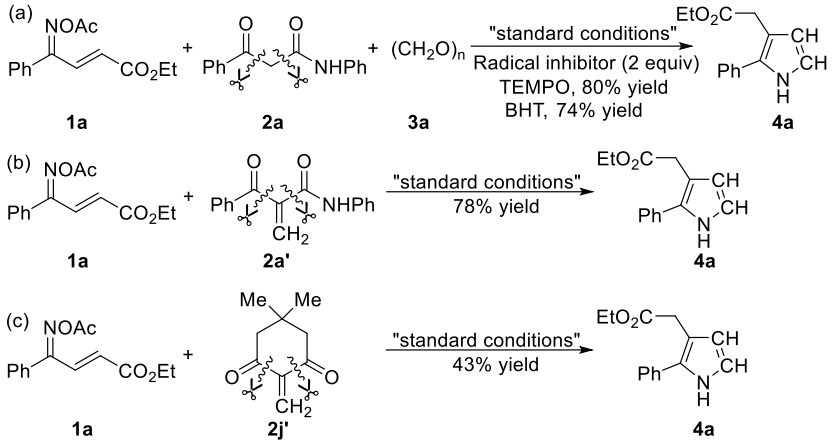


(1) 2-Benzoylacetanilide **2a** (95.6 mg, 0.4 mmol), paraformaldehyde **3a** (60 mg, 2 mmol), CuTc (7.6 mg, 10 mol%), L2 (21.4 mg, 20 mol%), K_3PO_4 (25.4 mg, 30 mol%) and DBU (24.4 mg, 40 mol%) in DMA (3 mL) were stirred at 120 °C (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give the product **2a'** in 82% yield (82 mg).

(2) 5,5-Dimethyl-1,3-cyclohexanedione **2j** (56 mg, 0.4 mmol), paraformaldehyde **3a** (60 mg, 2 mmol), CuTc (7.6 mg, 10 mol%), L2 (21.4 mg, 20 mol%), K_3PO_4 (25.4 mg, 30 mol%) and DBU (24.4 mg, 40 mol%) in DMA (3 mL) were stirred at 120 °C (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a

N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give the product **2j'** in 80% yield (48 mg).

General procedure for control experiments



(a) The ketoxime-enoate **1a** (78.3 mg, 0.3 mmol), 2-benzoylacetanilide **2a** (47.8 mg, 0.2 mmol), paraformaldehyde **3a** (30 mg, 1 mmol), CuTc (3.8 mg, 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%), DBU (12.2 mg, 40 mol%) and TEMPO (63.3 mg, 0.4 mmol) or BHT (88.1 mg, 0.4 mmol) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give product **4a**. (36.6 mg, 80% yield; 33.9 mg, 74% yield)

(b) The ketoxime-enoate **1a** (78.3 mg, 0.3 mmol), **2a'** (50.2 mg, 0.2 mmol), CuTc (3.8 mg 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%), DBU (12.2 mg, 40 mol%) and TEMPO (12.2 mg, 40 mol%) or BHT (12.2 mg, 40 mol%) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give product **4a** in 78% yield (35.7 mg).

(c) The ketoxime-enoate **1a** (78.3 mg, 0.3 mmol), **2j'** (30.4 mg, 0.2 mmol), CuTc (3.8 mg 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%), DBU (12.2 mg, 40 mol%) and TEMPO (12.2 mg, 40 mol%) or BHT (12.2 mg, 40 mol%) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated

magnetic stir bar under a N_2 atmosphere for 12 h. When the reaction was completed (detected by TLC), the mixture was cooled to room temperature. The reaction was quenched with water (10 mL) and extracted with ethyl acetate (3 × 20 mL). The combined organic layers were dried with anhydrous sodium sulfate and then concentrated under vacuum. The crude residue was purified by column chromatography (petroleum ether/ethyl acetate) on silica gel to give product **4a** in 43% yield (19.7 mg).

Electron paramagnetic resonance (EPR) experiment

The ketoxime-enoate **1a** (78.3 mg, 0.3 mmol), 2-benzoylacetanilide **2a** (47.8 mg, 0.2 mmol), paraformaldehyde **3a** (30 mg, 1 mmol), CuTc (3.8 mg, 10 mol%), L2 (10.7 mg, 20 mol%), K_3PO_4 (12.7 mg, 30 mol%) and DBU (12.2 mg, 40 mol%) in DMA (2 mL) were stirred at 120 ℃ (oil bath) in a 25 mL Schlenk tube equipped with a Teflon-coated magnetic stir bar under a N_2 atmosphere for 1 and 2 h intervals. At indicated time, the vessels were immediately immersed into ice-cold water to quench the reaction. Then the solution was taken out into a small tube and analyzed by EPR and observing an obvious Cu(II) signal.

EPR spectra was recorded at room temperature on EPR spectrometer operated at 9.868 GHz. Typical spectrometer parameters are shown as follows, sweep range: 200 G; center field set: 3518.65 G; time constant: 40.96 msec; sweep time: 81.92 sec, modulation amplitude: 1.0 G; modulation frequency: 100 kHz; receiver gain: 2.00×103; microwave power: 5.63×10^{-1} mW.

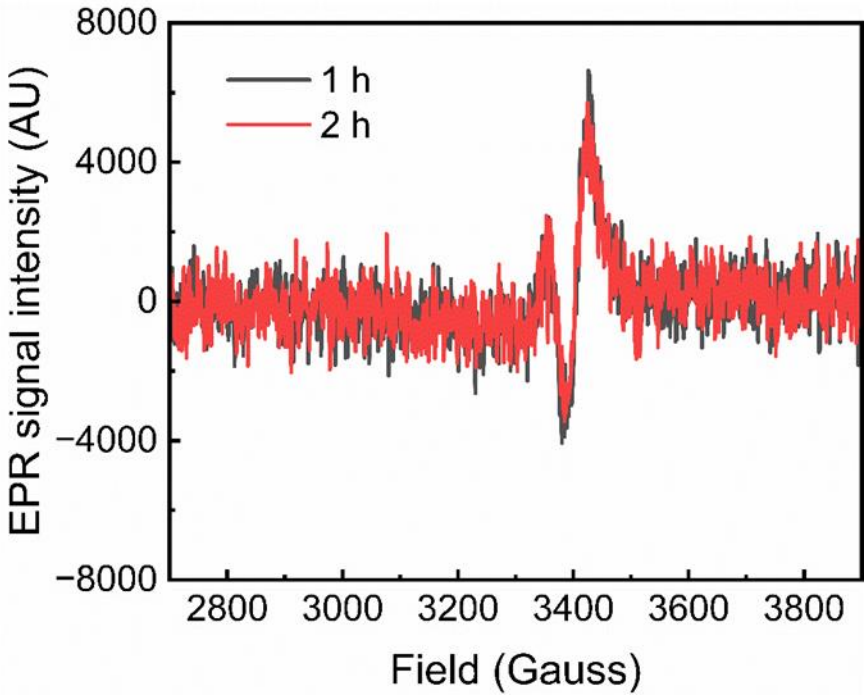
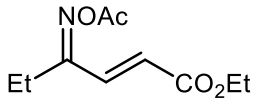


Figure S1. Electron paramagnetic resonance (EPR) spectra

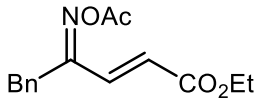
Compounds characterization

Ethyl (2E,4Z)-4-(acetoxyimino)hex-2-enoate (1q)



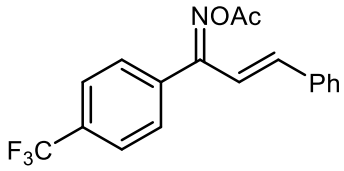
Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.38 (d, *J* = 16.3 Hz, 1H), 6.39 (d, *J* = 16.3 Hz, 1H), 4.25 (q, *J* = 6.8 Hz, 2H), 2.610 (q, *J* = 8.0 Hz, 2H), 2.25 (s, 3H), 2.23 (s, 1H), 1.31 (t, *J* = 7.1 Hz, 3H), 1.15 (t, *J* = 7.7 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 168.3, 165.4, 165.3, 138.7, 126.7, 61.1, 19.6, 19.5, 14.1, 11.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{16}NO_4$ $[M+H]^+$ 214.1074, found 214.1082.

Ethyl (2E,4Z)-4-(acetoxyimino)-5-phenylpent-2-enoate (1r)



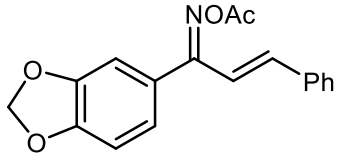
Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.98 (d, *J* = 16.0 Hz, 1H), 7.22–7.11 (m, 5H), 5.78 (d, *J* = 16.0 Hz, 1H), 4.17 (q, *J* = 7.2 Hz, 2H), 2.23 (s, 3H), 2.17 (s, 2H), 1.22 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 168.0, 165.6, 161.4, 137.0, 131.6, 131.2, 130.6, 129.9, 129.8, 125.9, 61.4, 19.7, 19.7, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_4$ $[M+H]^+$ 276.1230, found 276.1235.

(1E,2E)-3-Phenyl-1-(4-(trifluoromethyl)phenyl)prop-2-en-1-one *O*-acetyl oxime (1e')



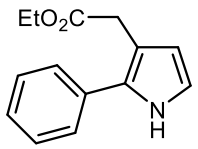
Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.74–7.69(m, 4H), 7.56 (d, *J* = 16.5 Hz, 1H), 7.54–7.50 (m, 2H), 7.40 (d, *J* = 6.8 Hz, 3H), 6.80 (d, *J* = 16.5 Hz, 1H), 2.32 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 168.5, 162.1, 143.5, 136.9, 135.0, 132.1 (q, *J* = 32.7 Hz), 130.4, 130.2, 129.0, 127.9, 125.5 (q, *J* = 3.8 Hz), 123.9 (d, *J* = 272.4 Hz), 116.8, 19.8 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{15}F_3NO_2$ $[M+H]^+$ 334.1049, found 334.1053.

(1E,2E)-1-(Benzo[d][1,3]dioxol-5-yl)-3-phenylprop-2-en-1-one *O*-acetyl oxime (1f')



Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.47–7.23 (m, 8H), 7.00 (dd, *J* = 8.0, 1.7 Hz, 1H), 6.69 (d, *J* = 7.8 Hz, 1H), 5.95 (s, 1H), 5.92 (s, 2H), 2.20 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 168.9, 162.8, 149.5, 147.8, 142.9, 135.3, 130.0, 128.9, 127.8, 127.4, 124.3, 117.5, 110.0, 108.4, 101.5, 19.9 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{16}NO_4$ $[M+H]^+$ 310.1074, found 310.1083.

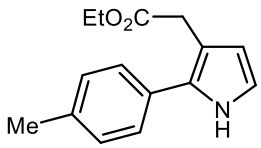
Ethyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4a)



Yield 83% (38 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 8.1 Hz, 2H), 7.50–5.44 (m, 3H), 5.77–5.69 (m, 3H), 4.16 (q, *J* = 7.1 Hz, 2H), 2.82 (dd, *J* = 15.9, 2.6 Hz, 1H), 2.57 (dd, *J* = 16.0, 7.7 Hz, 1H), 1.25 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.4, 168.9, 131.5, 130.7, 129.0, 128.1, 95.7, 80.5, 61.1, 38.6, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{16}NO_2$ $[M+H]^+$ 230.1176, found 230.1186.

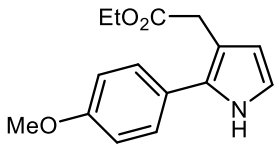
Ethyl 2-(2-(*p*-tolyl)-1*H*-pyrrol-3-yl)acetate (4b)

Yield 80% (39 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.65 (d, *J* = 8.1 Hz, 2H), 7.27 (s, 2H), 5.74–5.66 (m,



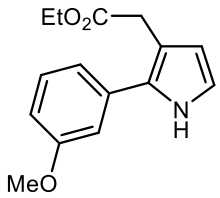
3H), 4.17 (q, *J* = 6.5, 5.8 Hz, 2H), 2.81 (dd, *J* = 15.9, 2.5 Hz, 1H), 2.55 (dd, *J* = 15.9, 8.0 Hz, 1H), 2.40 (s, 3H), 1.25 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.3, 168.7, 141.8, 129.6, 127.9, 127.8, 95.4, 80.4, 61.0, 38.5, 21.5, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_2$ $[M+H]^+$ 244.1332, found 244.1337.

Ethyl 2-(2-(4-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4c)



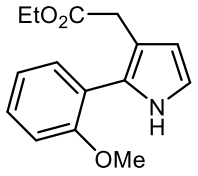
Yield 75% (39 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.71 (d, *J* = 8.9 Hz, 2H), 6.94 (d, *J* = 8.9 Hz, 2H), 5.72–5.64 (m, 3H), 4.16 (q, *J* = 7.1 Hz, 2H), 3.84 (s, 3H), 2.79 (dd, *J* = 15.9, 2.6 Hz, 1H), 2.54 (dd, *J* = 15.9, 8.1 Hz, 1H), 1.24 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.4, 168.1, 162.0, 129.7, 123.1, 114.3, 95.3, 80.3, 61.0, 55.4, 38.6, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_3$ $[M+H]^+$ 260.1281, found 260.1292.

Ethyl 2-(2-(3-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4d)



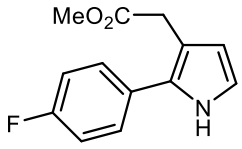
Yield 60% (31 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.36 (d, *J* = 15.9 Hz, 2H), 7.24 (s, 1H), 7.04 (d, *J* = 10.4 Hz, 1H), 5.76–5.66 (m, 3H), 4.17 (q, *J* = 7.2 Hz, 2H), 3.86 (s, 3H), 2.83 (dd, *J* = 15.9, 2.9 Hz, 1H), 2.57 (dd, *J* = 15.9, 8.0 Hz, 1H), 1.25 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.4, 169.0, 160.1, 132.0, 130.0, 120.5, 117.9, 112.7, 95.6, 80.7, 61.1, 55.6, 38.6, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_3$ $[M+H]^+$ 260.1281, found 260.1291.

Ethyl 2-(2-(2-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4e)



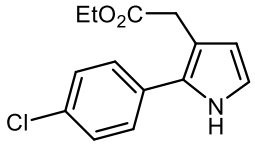
Yield 50% (26 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.87 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.46–7.39 (m, 1H), 7.02 (t, *J* = 7.3 Hz, 1H), 6.93 (d, *J* = 8.4 Hz, 1H), 5.74–5.89 (m, 3H), 4.09 (s, 2H), 3.85 (s, 3H), 2.70 (dd, *J* = 16.4, 3.6 Hz, 1H), 2.44 (dd, *J* = 15.8, 7.8 Hz, 1H), 1.22 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.8, 169.1, 157.7, 132.6, 130.9, 121.3, 120.4, 111.4, 94.4, 82.5, 60.8, 55.5, 38.0, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_3$ $[M+H]^+$ 260.1281, found 260.1291.

Ethyl 2-(2-(4-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4f)



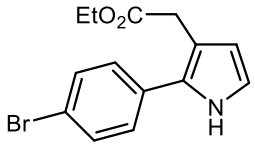
Yield 70% (35 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.76 (dd, *J* = 8.8, 5.3 Hz, 2H), 7.13 (t, *J* = 8.6 Hz, 2H), 5.73–5.62 (m, 3H), 4.15 (q, *J* = 7.1 Hz, 2H), 2.78 (dd, *J* = 15.9, 2.8 Hz, 1H), 2.56 (dd, *J* = 15.9, 7.9 Hz, 1H), 1.24 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 167.7, 164.5 (d, *J* = 252.6 Hz), 130.1 (d, *J* = 8.8 Hz), 126.8 (d, *J* = 3.3 Hz), 116.1 (d, *J* = 22.0 Hz), 95.5, 80.4, 61.1, 38.4, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}FNO_2$ $[M+H]^+$ 248.1081, found 248.1094.

Ethyl 2-(2-(4-chlorophenyl)-1*H*-pyrrol-3-yl)acetate (4g)



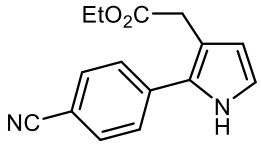
Yield 68% (36 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.71 (d, *J* = 8.6 Hz, 2H), 7.44 (d, *J* = 8.6 Hz, 2H), 5.76–5.62 (m, 3H), 4.16 (q, *J* = 7.1 Hz, 2H), 2.79 (dd, *J* = 15.9, 3.0 Hz, 1H), 2.57 (dd, *J* = 15.9, 7.8 Hz, 1H), 1.25 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 167.9, 137.7, 129.4, 129.1, 95.7, 80.5, 61.2, 38.4, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}ClNO_2$ $[M+H]^+$ 264.0786, found 264.0794.

Ethyl 2-(2-(4-bromophenyl)-1*H*-pyrrol-3-yl)acetate (4h)



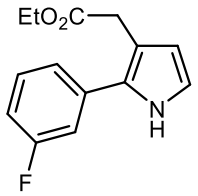
Yield 65% (40 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.62 (q, *J* = 8.6 Hz, 4H), 5.75–5.62 (m, 3H), 4.16 (q, *J* = 7.1 Hz, 2H), 2.78 (dd, *J* = 15.9, 3.0 Hz, 1H), 2.57 (dd, *J* = 16.0, 7.8 Hz, 1H), 1.25 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 168.1, 132.3, 129.5, 126.1, 95.6, 80.5, 61.2, 38.4, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}BrNO_2$ $[M+H]^+$ 308.0281, found 308.0288.

Ethyl 2-(2-(4-cyanophenyl)-1*H*-pyrrol-3-yl)acetate (4i)



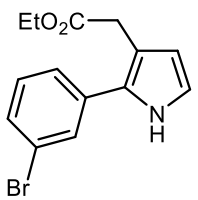
Yield 50% (25 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 5:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.88 (d, *J* = 8.3 Hz, 2H), 7.76 (d, *J* = 8.4 Hz, 2H), 5.80–5.63 (m, 3H), 4.15 (q, *J* = 7.1 Hz, 2H), 2.79 (dd, *J* = 16.0, 3.3 Hz, 1H), 2.60 (dd, *J* = 16.0, 7.5 Hz, 1H), 1.23 (d, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.0, 167.6, 134.8, 132.8, 128.7, 118.2, 115.0, 95.9, 80.6, 61.3, 38.3, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{15}N_2O_2$ $[M+H]^+$ 255.1128, found 255.1135.

Ethyl 2-(2-(3-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4j)



Yield 55% (27 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.50 (d, *J* = 19.2 Hz, 2H), 7.46 (s, 1H), 7.19 (d, *J* = 18.1 Hz, 1H), 5.77–5.62 (m, 3H), 4.16 (q, *J* = 7.2 Hz, 2H), 2.81 (dd, *J* = 16.0, 3.1 Hz, 1H), 2.58 (dd, *J* = 15.9, 8.0 Hz, 1H), 1.25 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 168.0 (d, *J* = 2.8 Hz), 163.0 (d, *J* = 247.6 Hz), 132.8 (d, *J* = 7.8 Hz), 130.7 (d, *J* = 8.1 Hz), 123.8 (d, *J* = 3.0 Hz), 118.6 (d, *J* = 21.3 Hz), 115.0 (d, *J* = 22.8 Hz), 95.7, 80.6, 61.2, 38.5, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}FNO_2$ $[M+H]^+$ 248.1081, found 248.1089.

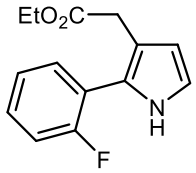
Ethyl 2-(2-(3-bromophenyl)-1*H*-pyrrol-3-yl)acetate (4k)



Yield 50% (31 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.94 (s, 1H), 7.66–7.61 (m, 2H), 7.33 (t, *J* = 7.9 Hz, 1H), 5.77–5.61 (m, 3H), 4.16 (q, *J* = 7.2 Hz, 2H), 2.79 (dd, *J* = 15.9, 3.2 Hz, 1H), 2.57 (dd, *J* = 15.9, 7.9 Hz, 1H), 1.26 (d, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 167.8, 134.5, 132.7, 131.0, 130.6, 126.6, 123.3, 95.7, 80.5,

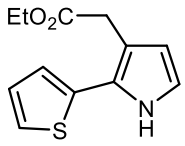
61.3, 38.4, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}BrNO_2$ $[M+H]^+$ 308.0281, found 308.0293.

Ethyl 2-(2-(2-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4l)



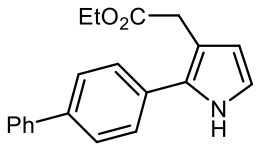
Yield 45% (22 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.00–7.97 (m, 1H), 7.51–7.45(m, 1H), 7.28–7.24 (m, 1H), 7.16–7.11 (m, 1H), 5.75–5.60 (m, 3H), 4.13 (q, *J* = 7.1 Hz, 2H), 2.80 (ddd, *J* = 15.9, 3.1, 1.5 Hz, 1H), 2.55 (dd, *J* = 16.0, 7.2 Hz, 1H), 1.23 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 166.2 (d, *J* = 2.8 Hz), 160.8 (d, *J* = 251.9 Hz), 133.2 (d, *J* = 8.7 Hz), 1130.8 (d, *J* = 3.6 Hz), 125.0 (d, *J* = 3.2 Hz), 119.1 (d, *J* = 12.8 Hz), 116.4 (d, *J* = 22.2 Hz), 94.9, 82.0 (d, *J* = 7.4 Hz), 60.9, 37.9, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{15}FNO_2$ $[M+H]^+$ 248.1081, found 248.1088.

Ethyl 2-(2-(thiophen-2-yl)-1*H*-pyrrol-3-yl)acetate (4m)



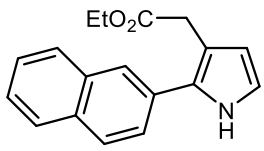
Yield 64% (30 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.53 (d, *J* = 5.1 Hz, 1H), 7.35 (d, *J* = 3.6 Hz, 1H), 7.11 (dd, *J* = 5.0, 3.8 Hz, 1H), 5.67 (d, *J* = 3.8 Hz, 2H), 5.59–5.55 (m, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 2.91 (dd, *J* = 16.0, 3.1 Hz, 1H), 2.66 (dd, *J* = 16.0, 8.4 Hz, 1H), 1.26 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.1, 163.1, 134.5, 130.4, 129.7, 127.8, 95.0, 80.7, 61.0, 38.8, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{14}H_{14}NO_2S$ $[M+H]^+$ 236.0740, found 236.0732.

2-([1,1'-Biphenyl]-4-yl)-3-(2-(ethylperoxy)-2l2-ethyl)-1*H*-pyrrole (4n)



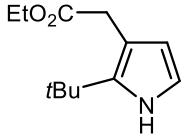
Yield 72% (44 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.84 (d, *J* = 8.3 Hz, 2H), 7.68 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 8.7 Hz, 2H), 7.48 (d, *J* = 7.2 Hz, 2H), 7.40 (d, *J* = 7.3 Hz, 1H), 5.80–5.71 (m, 3H), 4.18 (q, *J* = 7.1 Hz, 2H), 2.86 (dd, *J* = 15.9, 2.6 Hz, 1H), 2.60 (dd, *J* = 16.0, 7.6 Hz, 1H), 1.25 (d, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.3, 168.5, 144.1, 140.0, 129.4, 129.0 128.4, 128.1, 127.6, 127.2, 95.6, 80.5, 61.0, 38.5, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{20}H_{20}NO_2$ $[M+H]^+$ 306.1489, found 306.1485.

Ethyl 2-(2-(naphthalen-2-yl)-1*H*-pyrrol-3-yl)acetate (4o)



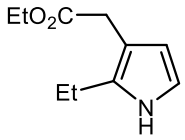
Yield 70% (39 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.10 (s, 1H), 7.98 (d, *J* = 10.3 Hz, 1H), 7.93–7.86 (m, 3H), 7.59–7.53 (m, 3H), 5.86–5.74 (m, 3H), 4.18 (q, *J* = 7.1, 1.2 Hz, 2H), 2.91 (dd, *J* = 16.0, 3.0 Hz, 1H), 2.64 (dd, *J* = 16.0, 8.4 Hz, 1H), 1.25 (t, *J* = 7.2 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.5, 168.9, 134.7, 132.9, 129.0, 128.9, 128.6, 128.1, 128.0, 127.9, 127.0, 124.6, 95.7, 80.6, 61.2, 38.7, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{18}NO_2$ $[M+H]^+$ 280.1332, found 280.1342.

Ethyl 2-(2-(*tert*-butyl)-1*H*-pyrrol-3-yl)acetate (4p)



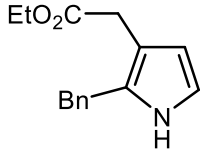
Yield 40% (22 mg); Yellow oil; R_f = 0.4 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 5.75–5.67 (m, 3H), 4.17 (q, *J* = 7.2 Hz, 2H), 2.81–2.76 (m, 1H), 2.63–2.57 (m, 1H), 1.38 (s, 9H), 1.18 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.7, 148.0, 129.6, 95.6, 80.7, 61.2, 33.0, 30.7, 30.7, 14.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{12}H_{20}NO_2$ $[M+H]^+$ 280.1332, found 280.1345.

Ethyl 2-(2-ethyl-1H-pyrrol-3-yl)acetate (4q)



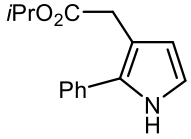
Yield 40% (13 mg); Yellow oil; R_f = 0.4 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 5.80–5.71 (m, 3H), 4.08 (q, *J* = 7.1 Hz, 2H), 2.71 (dd, *J* = 15.9, 3.0 Hz, 1H), 2.52–2.46 (m, 2H), 2.39 (q, *J* = 7.5 Hz, 1H), 1.23 (t, *J* = 7.0 Hz, 3H), 1.19 (t, *J* = 7.2 Hz, 3H) ppm;^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.3, 137.2, 122.4, 95.2, 80.1, 61.1, 38.7, 22.6, 19.6, 14.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{10}H_{16}NO_2$ $[M+H]^+$ 182.1176, found 182.1185.

Ethyl 2-(2-benzyl-1*H*-pyrrol-3-yl)acetate (4r)



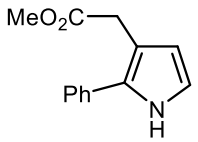
Yield 40% (13 mg); Yellow oil; R_f = 0.4 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.25–7.21 (m, 3H), 7.17–7.10 (m, 2H), 5.70 (q, *J* = 11.4 Hz, 2H), 5.56–5.52 (m, 1H), 4.06–4.00 (m, 2H), 2.58 (dd, *J* = 15.9, 3.7 Hz, 1H), 2.45 (s, 2H), 2.43–2.40 (m, 1H), 1.15 (t, *J* = 7.1 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.2, 170.0, 131.6, 130.1, 128.5, 125.9, 96.1, 82.1, 60.9, 38.0, 21.0, 14.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_2$ $[M+H]^+$ 244.1332, found 244.1341.

Isopropyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4s)



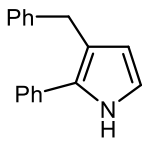
Yield 74% (36 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.68 (d, *J* = 8.1 Hz, 2H), 7.38 (d, *J* = 24.6 Hz, 3H), 5.68–5.60 (m, 3H), 4.95 (p, *J* = 6.3 Hz, 1H), 2.72 (dd, *J* = 15.8, 2.7 Hz, 1H), 2.47 (dd, *J* = 15.9, 7.8 Hz, 1H), 1.14 (dd, *J* = 11.1, 6.3 Hz, 6H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 169.8, 168.9, 131.3, 130.6, 128.9, 128.0, 95.5, 80.5, 68.5, 38.7, 30.6, 21.8 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{18}NO_2$ $[M+H]^+$ 244.1332, found 244.1346.

Methyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4t)



Yield 68% (29 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 6.7 Hz, 2H), 7.48 (d, *J* = 30.7 Hz, 3H), 5.78–5.69 (m, 3H), 3.71 (s, 3H), 2.84 (d, *J* = 18.3 Hz, 1H), 2.57 (d, *J* = 23.8 Hz, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.9, 168.8, 131.5, 130.6, 129.1, 128.1, 95.7, 80.50 52.2, 38.4 ppm; HRMS (ESI-TOF): m/z calcd for $C_{13}H_{14}NO_2$ $[M+H]^+$ 216.1019, found 216.1012.

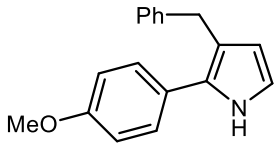
3-Benzyl-2-phenyl-1*H*-pyrrole (5a)



Yield 55% (26 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.57–7.54 (m, 2H), 7.44–7.43 (m, 8H), 5.51 (s, 1H), 5.42 (d, *J* = 2.5 Hz, 2H), 5.38 (s, 1H), 5.16 (s, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.8, 138.1, 138.0,

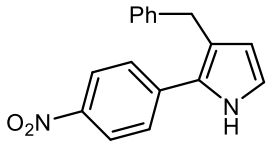
137.9, 129.4, 128.6, 128.5, 128.5, 128.3, 127.7, 121.9, 79.8, 77.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{17}H_{16}N$ $[M+H]^+$ 234.1277, found 234.1289.

3-Benzyl-2-(4-methoxyphenyl)-1*H*-pyrrole (5b)



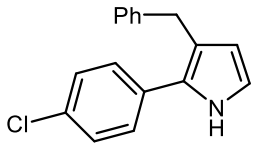
Yield 57% (30 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.52 (d, *J* = 8.7 Hz, 2H), 7.40 (d, *J* = 4.3 Hz, 5H), 6.93 (d, *J* = 8.8 Hz, 2H), 5.53 (s, 1H), 5.40 (d, *J* = 2.6 Hz, 2H), 5.36 (s, 1H), 5.14 (s, 1H), 3.84 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.2, 160.8, 138.3, 138.2, 130.7, 130.2, 128.7, 128.5, 127.7, 121.7, 113.7, 80.0, 77.4, 55.5 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{18}NO$ $[M+H]^+$ 264.1383, found 264.1389.

3-Benzyl-2-(4-nitrophenyl)-1*H*-pyrrole (5c)



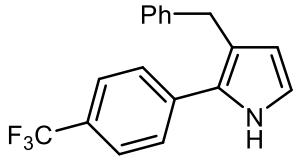
Yield 40% (18 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 5:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.55–7.52 (m, 2H), 7.44–7.42 (m, 3H), 7.40–7.35 (m, 4H), 5.41 (d, *J* = 2.6 Hz, 2H), 5.37 (s, 1H), 5.15 (s, 1H), 3.85 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.5, 161.1, 138.6, 138.5, 131.0, 130.5, 129.03, 128.8, 128.0, 122.0, 114.0, 80.3, 77.7 ppm; HRMS (ESI-TOF): m/z calcd for $C_{17}H_{15}N_2O_2$ $[M+H]^+$ 279.1128, found 279.1139.

3-Benzyl-2-(4-chlorophenyl)-1*H*-pyrrole (5d)



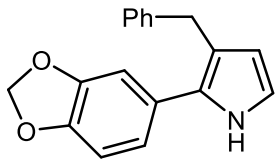
Yield 48% (26 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.55–7.52 (m, 2H), 7.43–7.35 (m, 7H), 5.51 (s, 1H), 5.42 (d, *J* = 1.7 Hz, 2H), 5.35 (s, 1H), 5.12 (s, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 164.2, 138.5, 138.3, 137.1, 134.9, 130.1, 129.6, 129.4, 129.1, 128.9, 122.6, 80.5, 77.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{17}H_{15}ClN$ $[M+H]^+$ 268.0888, found 268.0893.

3-Benzyl-2-(4-(trifluoromethyl)phenyl)-1*H*-pyrrole (5e)



Yield 39% (23 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.43 (d, *J* = 8.0 Hz, 2H), 7.71–7.26 (m, 5H), 6.84 (d, *J* = 8.4 Hz, 2H), 5.63 (s, 1H), 5.49 (s, 1H), 7.37–7.33 (m, 2H)5.26 (d, *J* = 16.9 Hz, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 169.0, 143.9, 137.3, 135.4, 132.6 (q, *J* = 32.4 Hz), 130.8, 130.7, 129.4, 128.4, 126.0 (q, *J* = 3.7 Hz), 124.3 (d, *J* = 272.6 Hz), 117.2, 80.3, 77.7 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{15}F_3N$ $[M+H]^+$ 302.1151, found 302.1159.

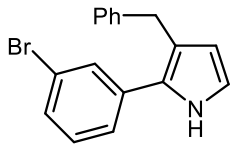
2-(Benzo[d][1,3]dioxol-5-yl)-3-benzyl-1*H*-pyrrole (5f)



Yield 37% (20 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.44–7.42 (m, 2H), 7.31–7.29 (m, 3H), 7.00 (s, 1H), 6.84–6.78 (m, 2H), 5.94 (s, 2H), 5.53 (s, 1H), 5.40 (d, *J* = 2.2 Hz, 2H), 5.36 (s, 1H), 5.15 (s, 1H), 3.84 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 168.4, 151.9, 148.7, 141.2, 133.7, 131.6, 130.2, 129.5, 128.5, 128.5,

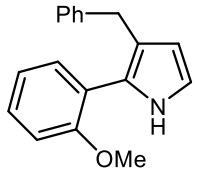
127.8, 126.4, 124.8, 101.9, 77.2, 74.7 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{16}NO_2$ $[M+H]^+$ 278.1176, found 278.1183.

3-Benzyl-2-(3-bromophenyl)-1*H*-pyrrole (5g)



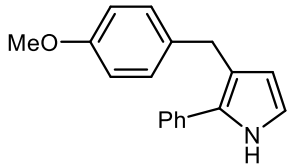
Yield 35% (22 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.67 (d, *J* = 6.6 Hz, 3H), 7.42 (t, *J* = 7.6 Hz, 2H), 7.30 (t, *J* = 7.4 Hz, 1H), 6.93 (s, 3H), 5.47 (s, 1H), 5.36 (s, 2H), 5.32 (s, 1H), 5.09 (s, 1H), 2.35 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 169.5, 148.4, 141.3, 136.8, 133.5, 132.0, 130.5, 128.3, 127.2, 127.1, 123.4, 121.1, 120.8, 79.9, 77.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{17}H_{15}BrN$ $[M+H]^+$ 312.0382, found 312.0395.

3-Benzyl-2-(2-methoxyphenyl)-1*H*-pyrrole (5h)



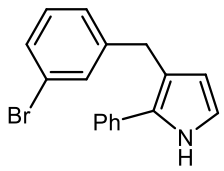
Yield 30% (16 mg); Yellow oil; R_f = 0.4 (petroleum ether/ethyl acetate = 5:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.49 (d, *J* = 7.2 Hz, 2H), 7.42–7.35 (m, 4H), 7.28 (d, *J* = 1.6 Hz, 1H), 7.01 (t, *J* = 7.4 Hz, 1H), 6.94 (d, *J* = 8.3 Hz, 1H), 5.44 (s, 1H), 5.41 – 5.27 (m, 2H), 5.20 (s, 1H), 5.03 (s, 1H), 3.82 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.2, 156.8, 138.3, 130.1, 129.8, 128.5, 128.4, 128.1, 127.5, 120.8, 120.7, 111.0, 77.2, 55.6 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{18}NO$ $[M+H]^+$ 264.1383, found 264.1392.

3-(4-Methoxybenzyl)-2-phenyl-1*H*-pyrrole (5i)



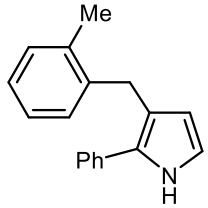
Yield 45% (24 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.53 (d, *J* = 8.8 Hz, 2H), 7.38 (d, *J* = 25.5 Hz, 5H), 6.94 (d, *J* = 8.8 Hz, 2H), 5.54 (s, 1H), 5.41 (d, *J* = 2.2 Hz, 2H), 5.36 (s, 1H), 5.15 (s, 1H), 3.84 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.2, 160.8, 138.3, 138.2, 137.7, 130.7, 130.2, 128.7, 128.5, 127.7, 121.7, 113.7, 80.0, 79.0, 77.4, 55.5 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{18}NO$ $[M+H]^+$ 264.1383, found 264.1396.

3-(3-Bromobenzyl)-2-phenyl-1*H*-pyrrole (5j)



Yield 30% (19 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.65 (s, 1H), 7.53–7.50 (m, 3H), 7.38–7.35 (m, 2H), 7.28–7.27 (m, 1H), 7.25 (d, *J* = 3.6 Hz, 1H), 7.09–7.07 (m, 1H), 5.54 (s, 1H), 5.41 (d, *J* = 2.6 Hz, 2H), 5.37 (s, 1H), 5.16 (s, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 169.7, 148.7, 138.6, 137.9, 136.2, 135.7, 133.2, 129.9, 129.7, 129.6, 126.7, 122.8, 121.9, 121.8, 79.9, 77.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{17}H_{15}BrN$ $[M+H]^+$ 312.0382, found 312.0392.

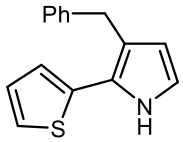
3-(2-Methylbenzyl)-2-phenyl-1*H*-pyrrole (5k)



Yield 27% (13 mg); Yellow oil; R_f = 0.2 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.38 (d, *J* = 4.8 Hz, 3H), 7.34–7.28 (m, 4H), 7.22 (t, *J* = 9.9 Hz, 2H), 5.48 (s, 1H), 5.37 (s, 2H), 5.33 (s, 1H), 5.10 (s, 1H), 2.36 (s, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.9, 138.1, 138.1, 138.1, 138.0, 130.2,

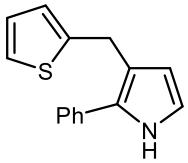
129.1, 128.6, 128.4, 128.0, 127.7, 125.7, 121.9, 79.9, 77.3, 21.4 ppm; HRMS (ESI-TOF): m/z calcd for $C_{18}H_{18}N$ $[M+H]^+$ 248.1434, found 248.1445.

3-Benzyl-2-(thiophen-2-yl)-1*H*-pyrrole (5l)



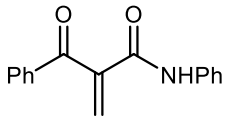
Yield 45% (21 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.56 (dd, *J* = 6.5, 3.1 Hz, 2H), 7.44–7.43 (m, 3H), 7.36 (dd, *J* = 5.0, 1.2 Hz, 1H), 7.08 (d, *J* = 3.5 Hz, 1H), 7.03 (d, *J* = 8.6 Hz, 1H), 5.72 (s, 1H), 5.58 (s, 1H), 5.43 (d, *J* = 12.6 Hz, 2H), 5.37 (s, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.1, 141.3, 138.1, 136.6, 129.6, 128.6, 128.4, 126.9, 126.6, 126.5, 122.0, 78.4, 73.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{14}NS$ $[M+H]^+$ 240.0841, found 240.0832.

2-Phenyl-3-(thiophen-2-ylmethyl)-1*H*-pyrrole (5m)



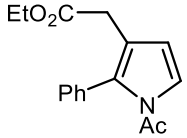
Yield 36% (17 mg); Yellow oil; R_f = 0.3 (petroleum ether/ethyl acetate = 10:1); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.56–7.54 (m, 2H), 7.43–7.41 (m, 3H), 7.35 (dd, *J* = 5.0, 1.2 Hz, 1H), 7.07 (d, *J* = 3.5 Hz, 1H), 7.03–7.01 (m, 1H), 5.48 (s, 1H), 5.38 (s, 2H), 5.34 (s, 1H), 5.11 (s, 1H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 163.4, 141.6, 138.4, 136.9, 129.9, 128.9, 128.7, 127.2, 126.9, 126.8, 122.4, 78.7, 73.34 ppm; HRMS (ESI-TOF): m/z calcd for $C_{15}H_{14}NS$ $[M+H]^+$ 240.0841, found 240.0849.

2-Benzoyl-*N*-phenylacrylamide (2a')



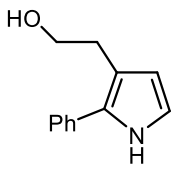
Yield 82% (82 mg); Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.87 (d, *J* = 7.3 Hz, 2H), 7.84 (s, 1H), 7.65 (d, *J* = 8.0 Hz, 2H), 7.56 (t, *J* = 7.2 Hz, 1H), 7.49 (t, *J* = 7.4 Hz, 2H), 7.38 (t, *J* = 7.9 Hz, 2H), 7.14 (s, 1H), 6.41 (s, 2H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 194.5, 164.8, 139.4, 138.5, 137.0, 130.3, 130.1, 129.4, 128.8, 127.3, 125.2, 119.6 ppm; HRMS (ESI-TOF): m/z calcd for $C_{16}H_{14}NO_2$ $[M+H]^+$ 252.1019, found 252.1028.

Ethyl 2-(1-acetyl-2-phenyl-1*H*-pyrrol-3-yl)acetate (6)



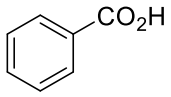
Yield 75% (40.7 mg); Yellow oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.69 (dd, *J* = 8.0, 1.6 Hz, 2H), 7.42–7.38 (m, 3H), 6.10 (s, 2H), 4.16 (q, *J* = 6.6 Hz, 2H), 2.81 (d, *J* = 15.5 Hz, 1H), 2.55 (dd, *J* = 15.7, 7.7 Hz, 1H), 2.40 (s, 3H), 1.25 (t, *J* = 6.8 Hz, 3H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 170.8, 168.7, 162.5, 130.6, 130.1, 128.9, 123.5, 114.7, 95.7, 80.8, 61.5, 55.9, 39.0, 14.6 ppm; HRMS (ESI-TOF): m/z calcd for $C_{16}H_{18}NO_3$ $[M+H]^+$ 272.1281, found 272.1290.

2-(2-Phenyl-1*H*-pyrrol-3-yl)ethan-1-ol (7)



Yield 80% (30 mg); White oil; ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.86 (s, 1H), 7.70 (d, *J* = 7.3 Hz, 2H), 7.45–7.38 (m, 4H), 7.34 (t, *J* = 7.4 Hz, 1H), 4.01 (t, *J* = 6.4 Hz, 2H), 3.18 (t, *J* = 6.4 Hz, 2H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 149.6, 144.9, 131.6, 128.7, 128.6, 127.8, 127.0, 126.3, 60.8, 29.4 ppm; HRMS (ESI-TOF): m/z calcd for $C_{12}H_{14}NO$ $[M+H]^+$ 188.1070, found 188.1083.

Benzoic acid (8)



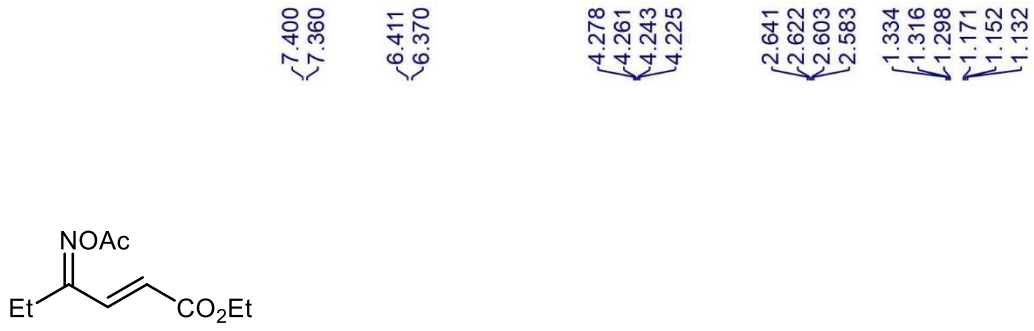
^{1}H NMR (400 MHz, Chloroform-*d*) δ 12.48 (s, 1H), 8.13 (d, *J* = 7.9 Hz, 2H), 7.61 (t, *J* = 7.3 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 2H) ppm; ^{13}C NMR (100 MHz, Chloroform-*d*) δ 172.6, 133.9, 130.3, 129.4, 128.5 ppm.

References

1. (a) Duan, J.; Zhang, L.; Xu, G.; Chen, H.; Ding, X.; Mao, Y.; Rong, B.; Zhu, N.; Guo, K. *J. Org. Chem*. **2020**, *85*, 8157. (b) Zhang, L.; Duan, J.; Xu, G.; Ding, X.; Mao, Y.; Rong, B.; Zhu, N.; Fang, Z.; Li, Z.; Guo, K. *J. Org. Chem*. **2020**, *85*, 2532. (c) Miao, C.; Qiang, X.; Xu, X.; Song, X.; Zhou, S.; Lyu, X.; Yang, H. *Org. Lett*. **2022**, *24*, 3828.

NMR Spectra of compounds

Ethyl (2E,4Z)-4-(acetoxyimino)hex-2-enoate (1q)



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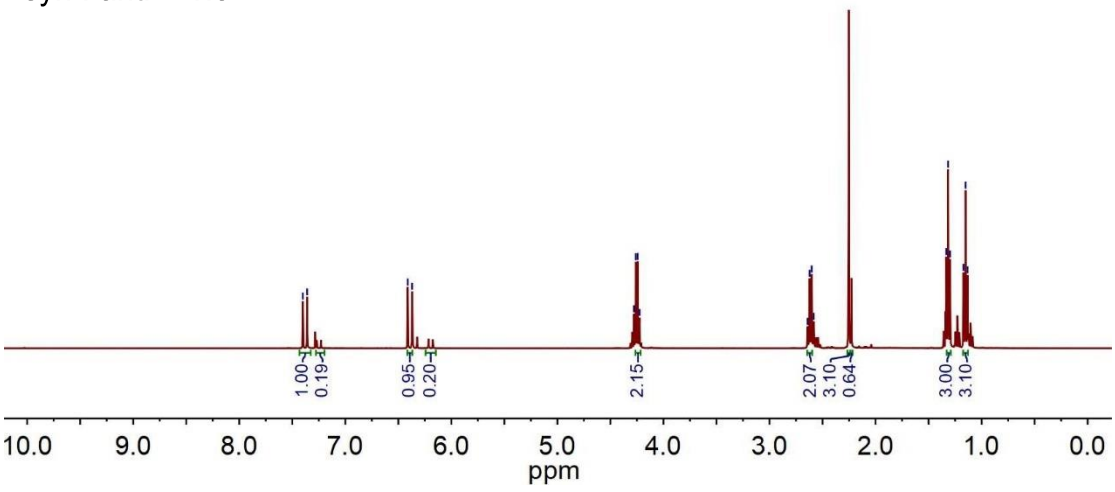

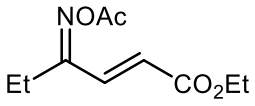

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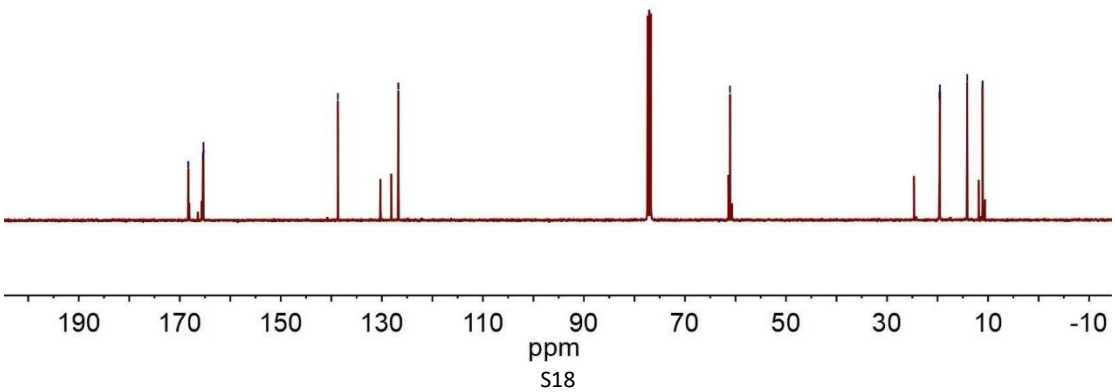
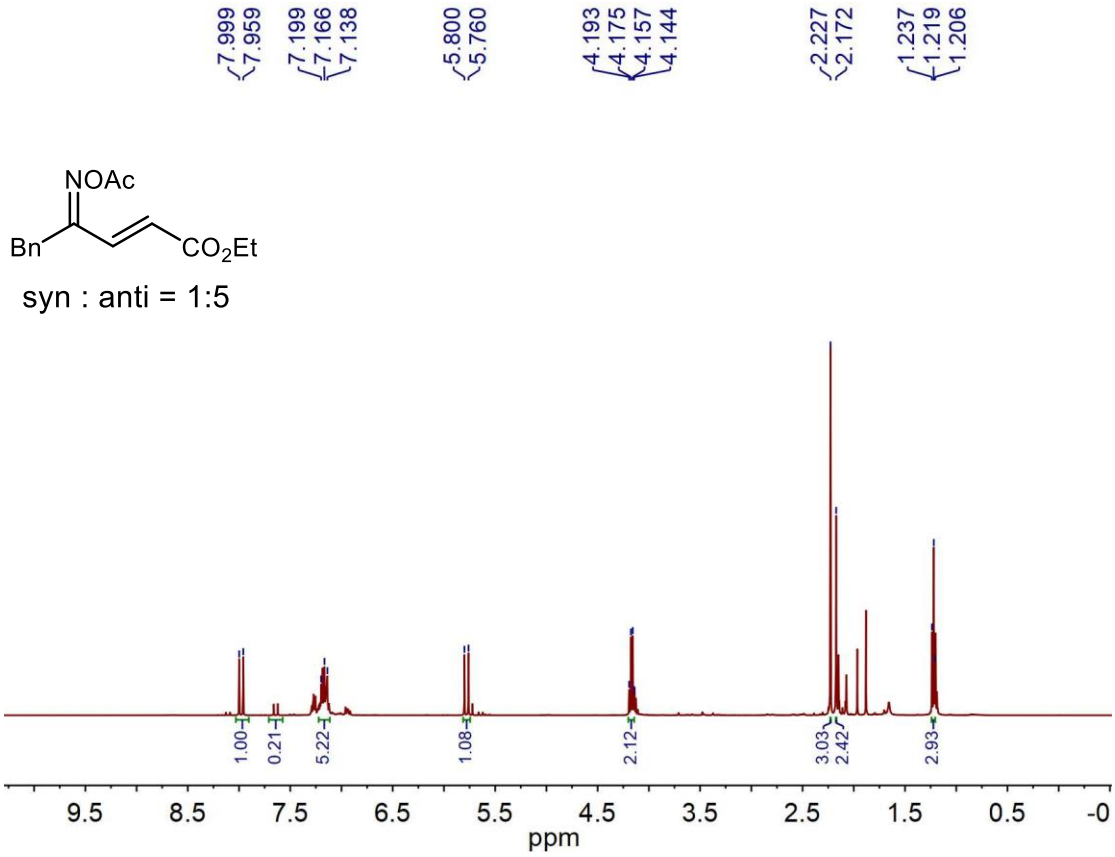
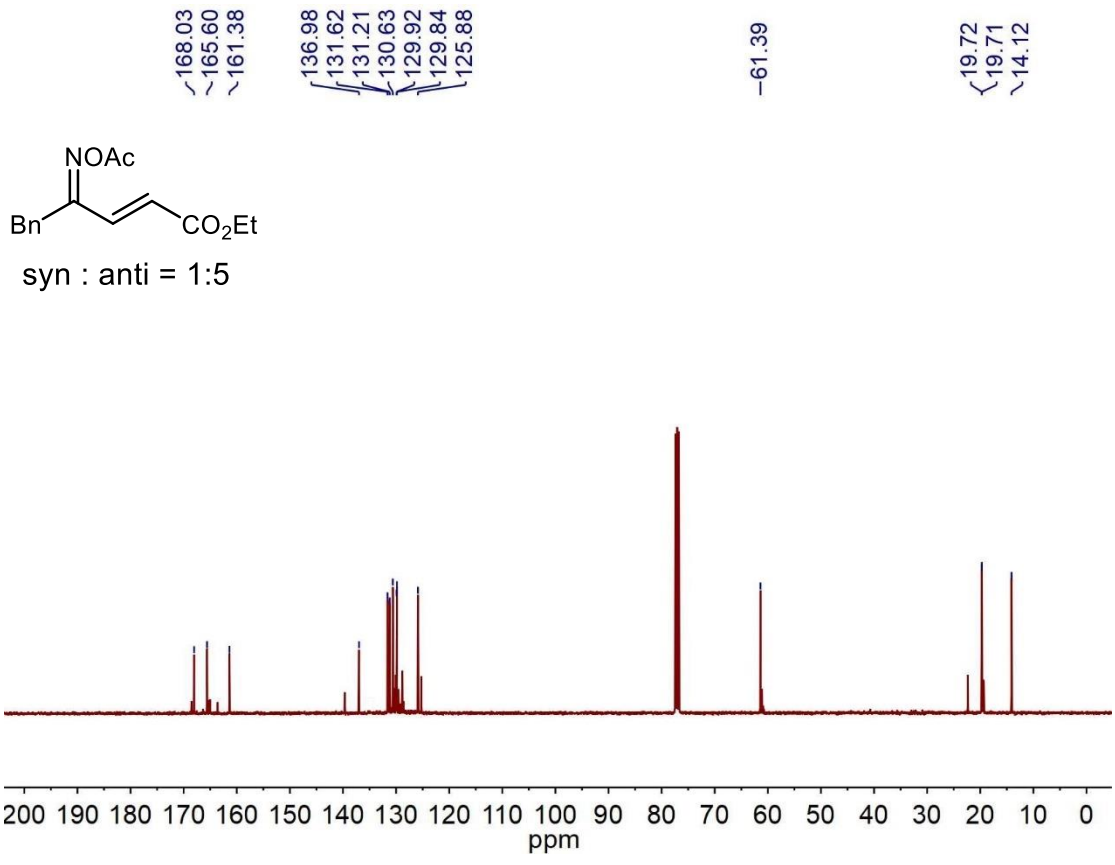
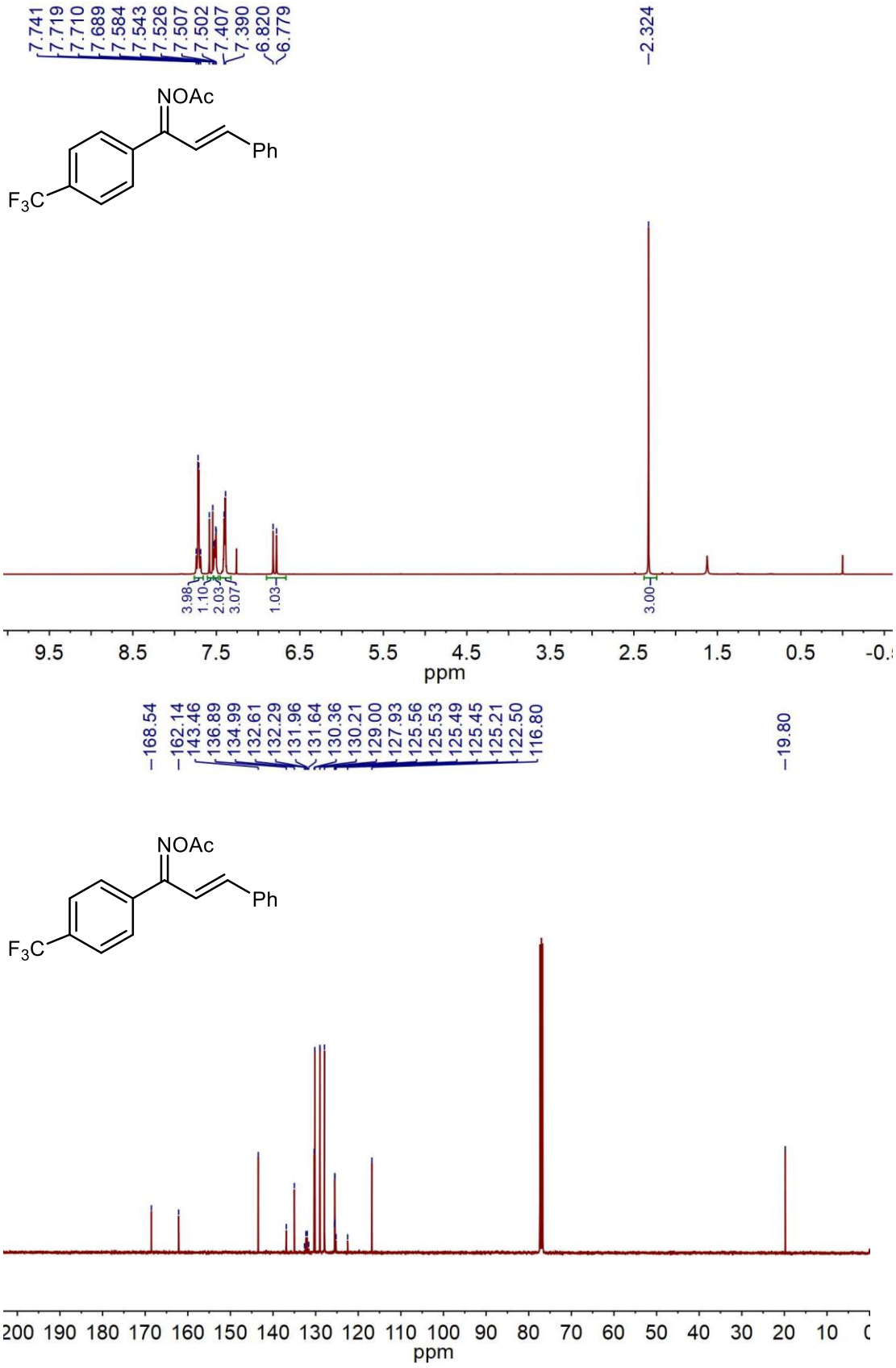


Ethyl (2E,4Z)-4-(acetoxyimino)-5-phenylpent-2-enoate (1r)

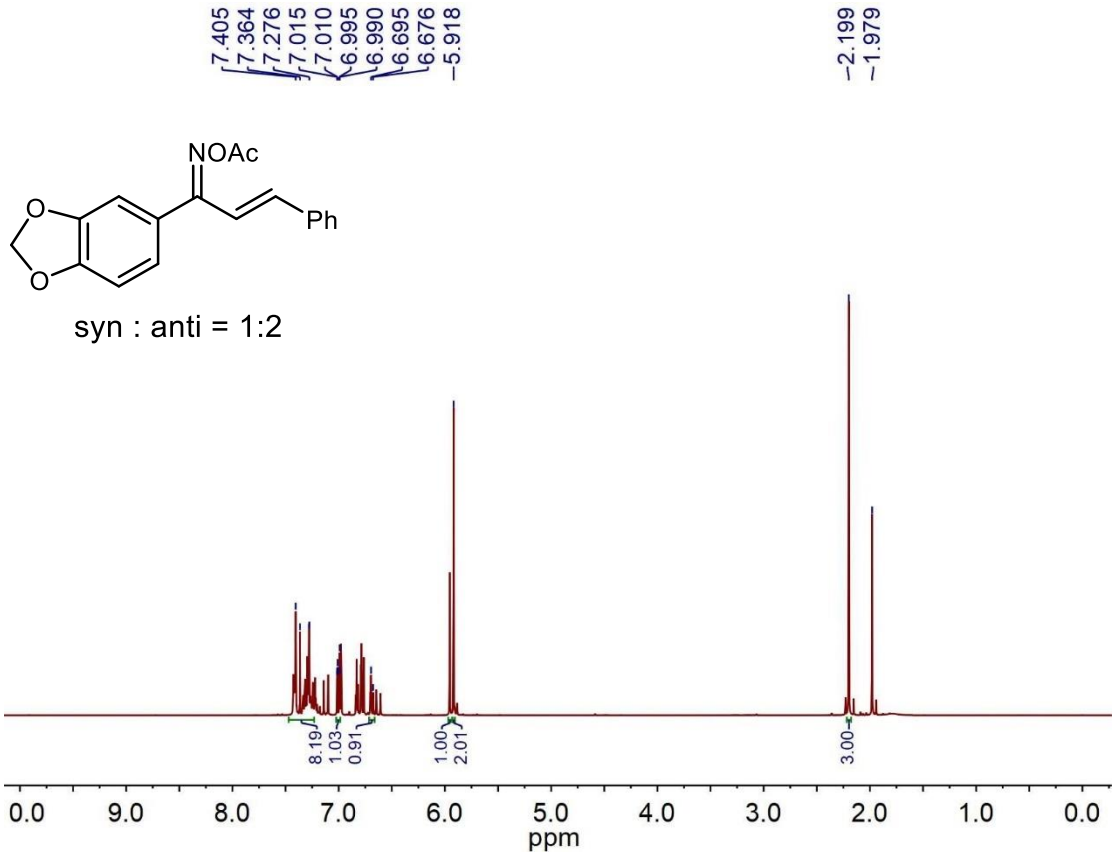


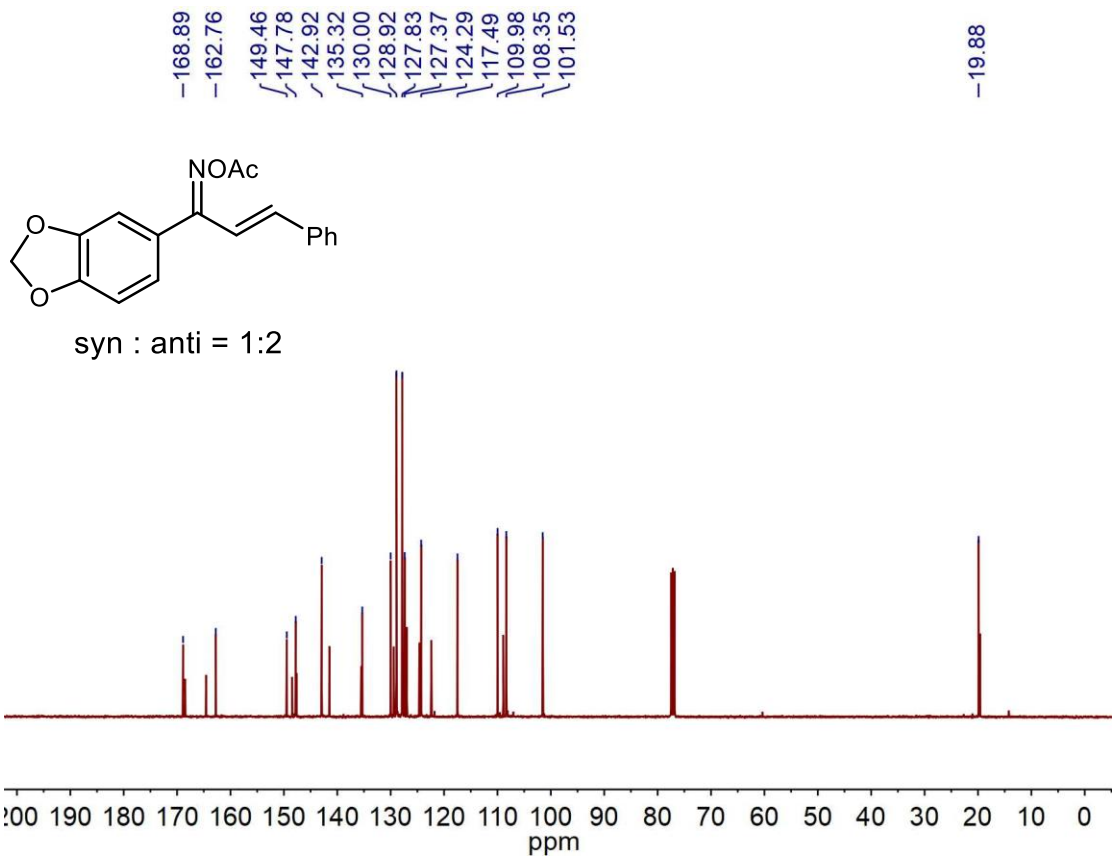


(1E,2E)-3-phenyl-1-(4-(trifluoromethyl)phenyl)prop-2-en-1-one *O*-acetyl oxime (1e')

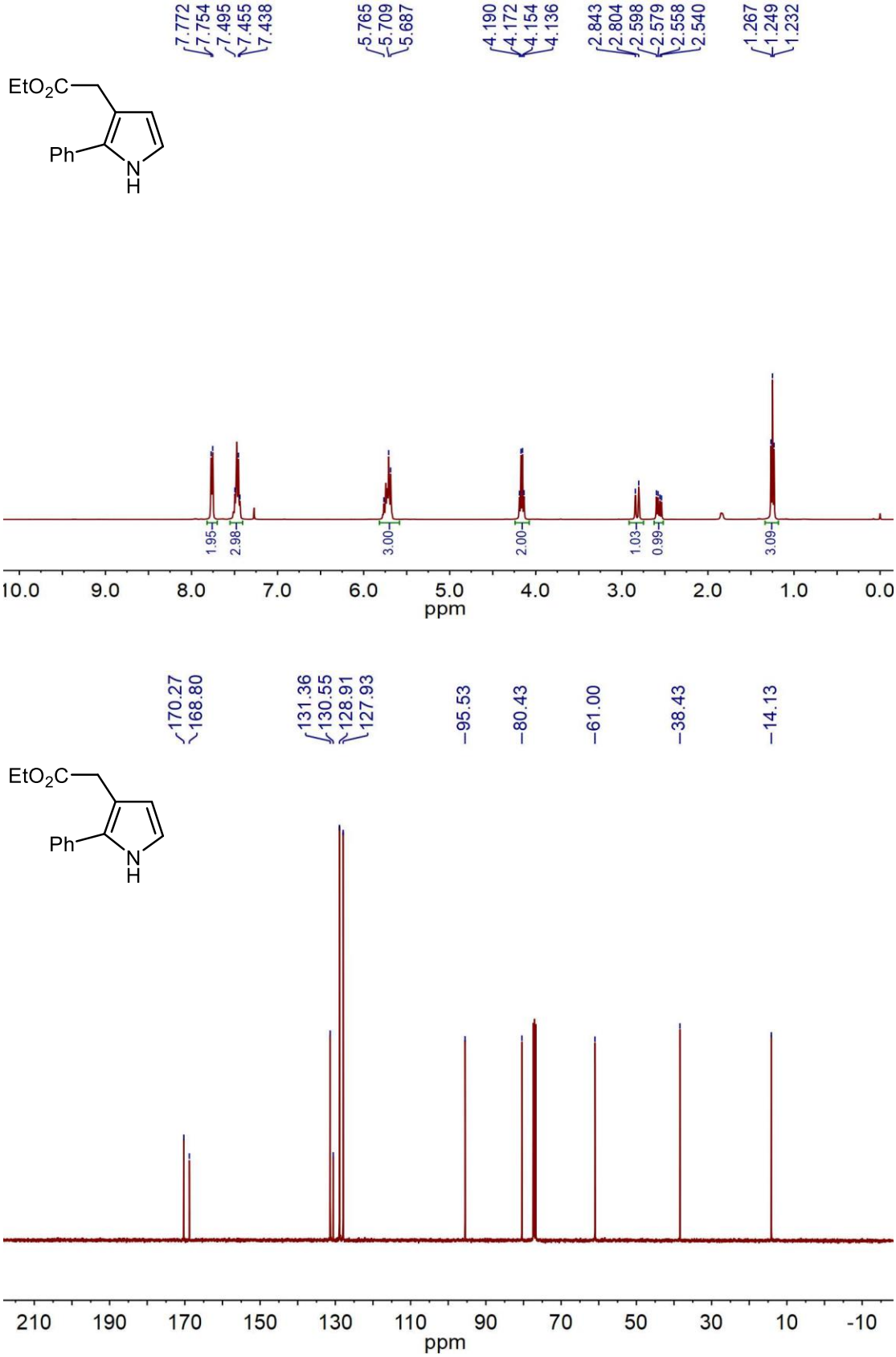


(1E,2E)-1-(benzo[d][1,3]dioxol-5-yl)-3-phenylprop-2-en-1-one *O*-acetyl oxime (1f')

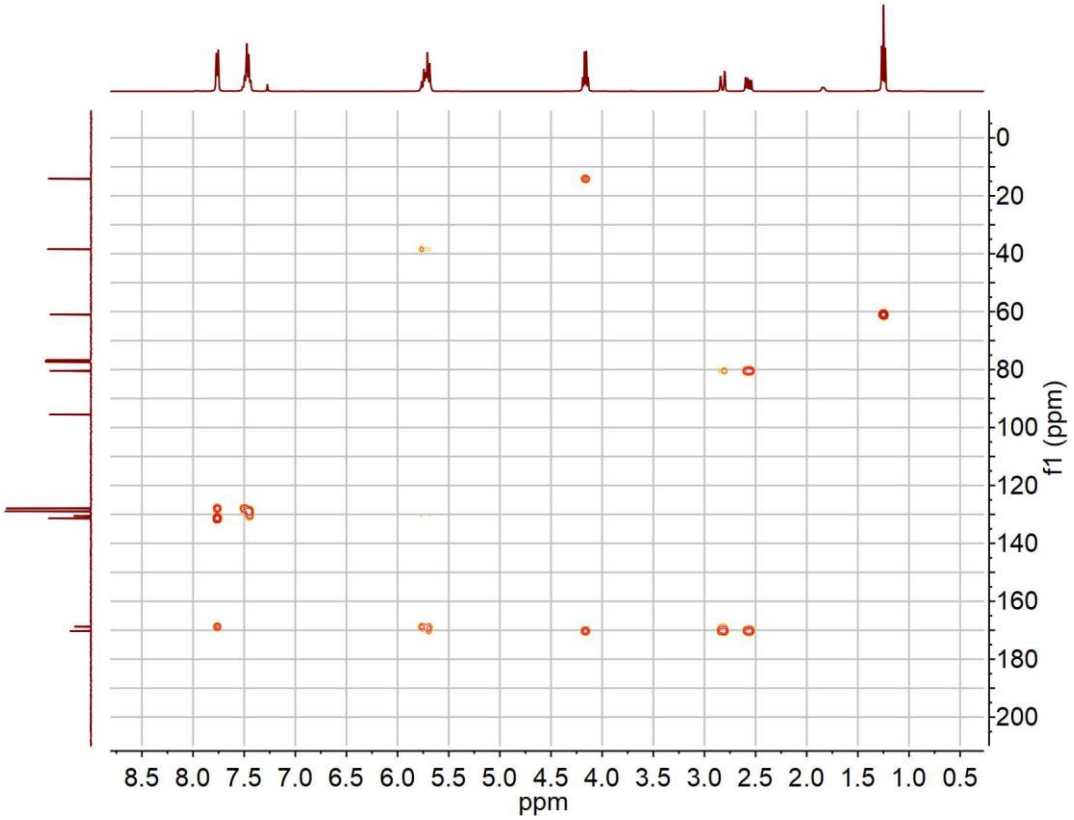




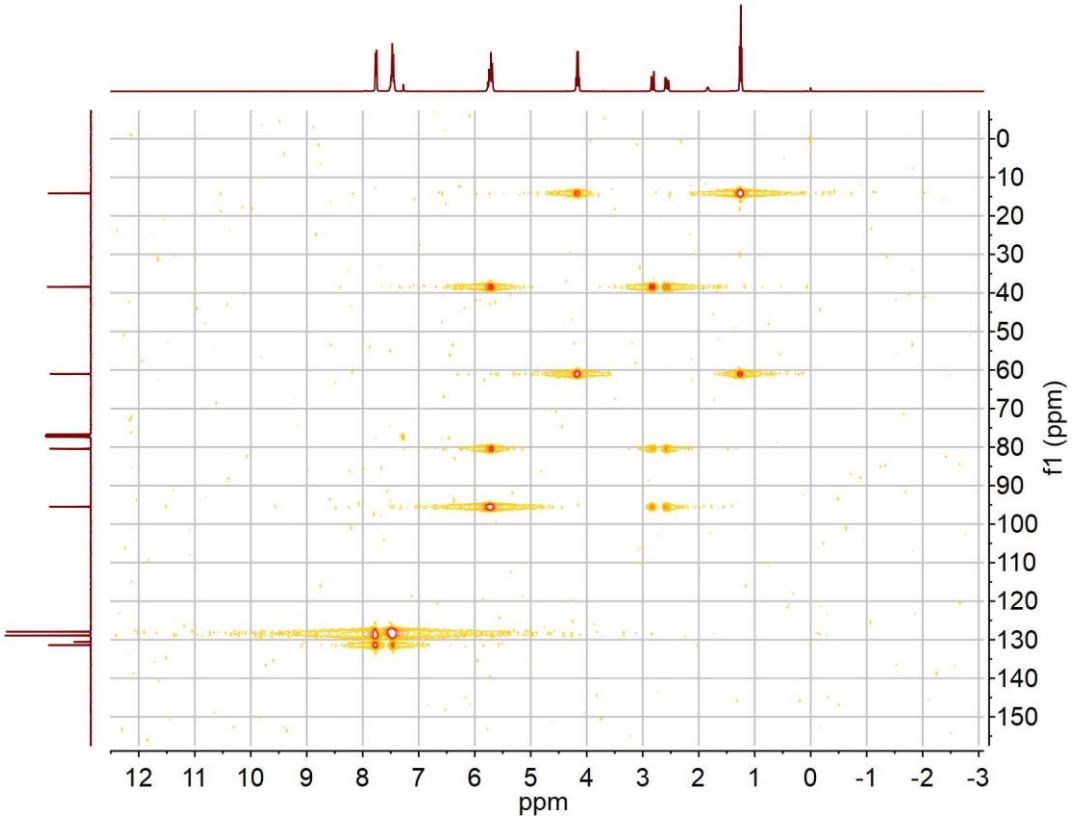
Ethyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4a)



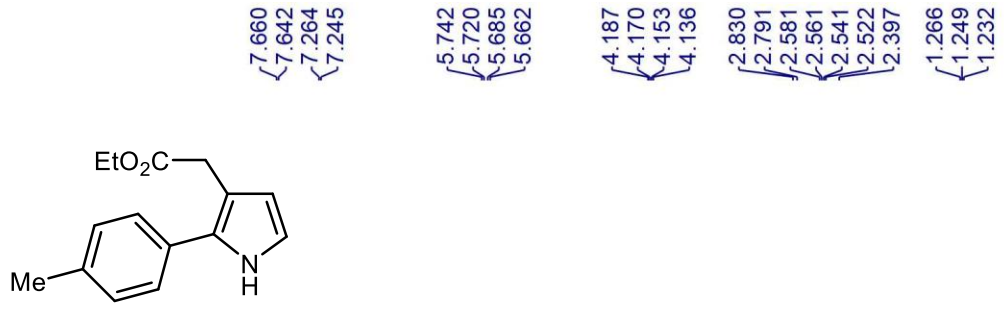
^{1}H–^{13}C HSQC of 4a

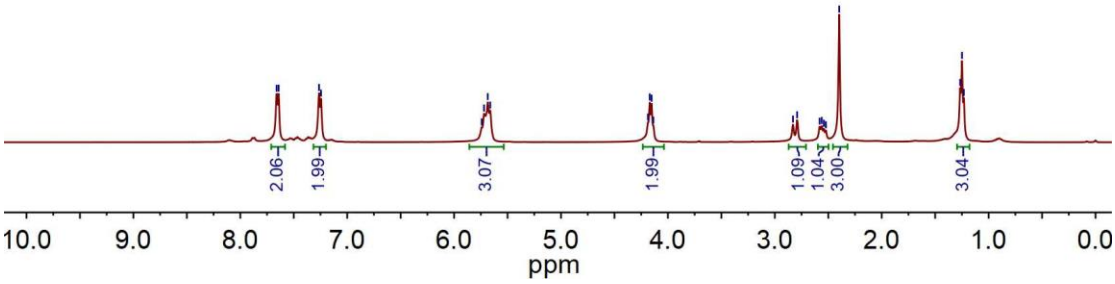


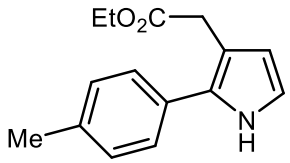
^{1}H–^{13}C HMBC of 4a

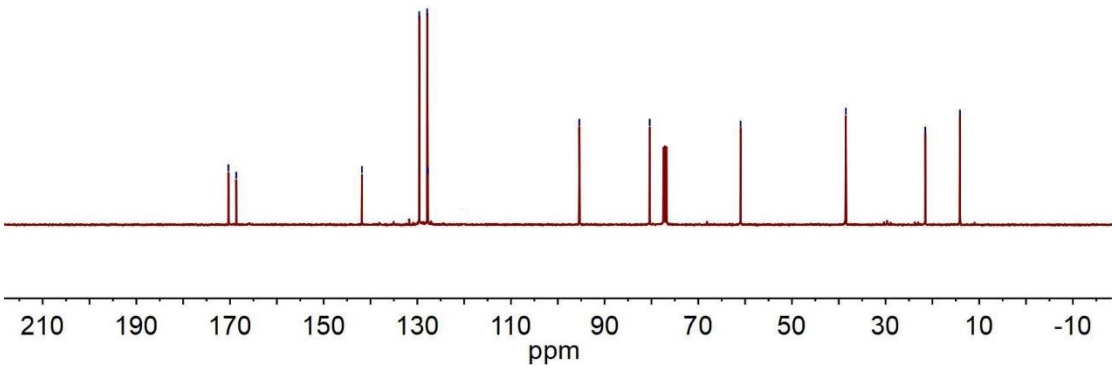


Ethyl 2-(2-(*p*-tolyl)-1*H*-pyrrol-3-yl)acetate (4b)

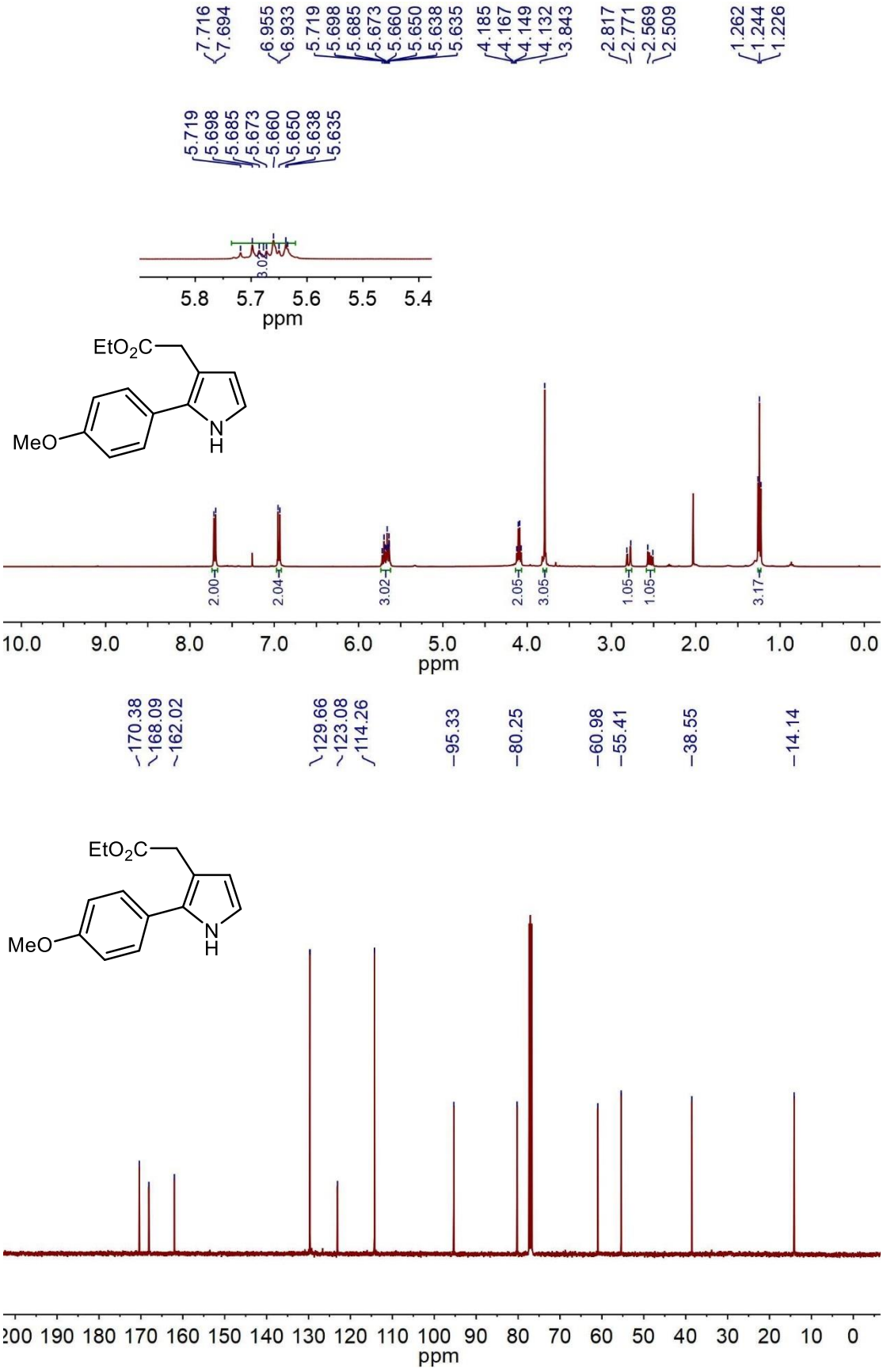




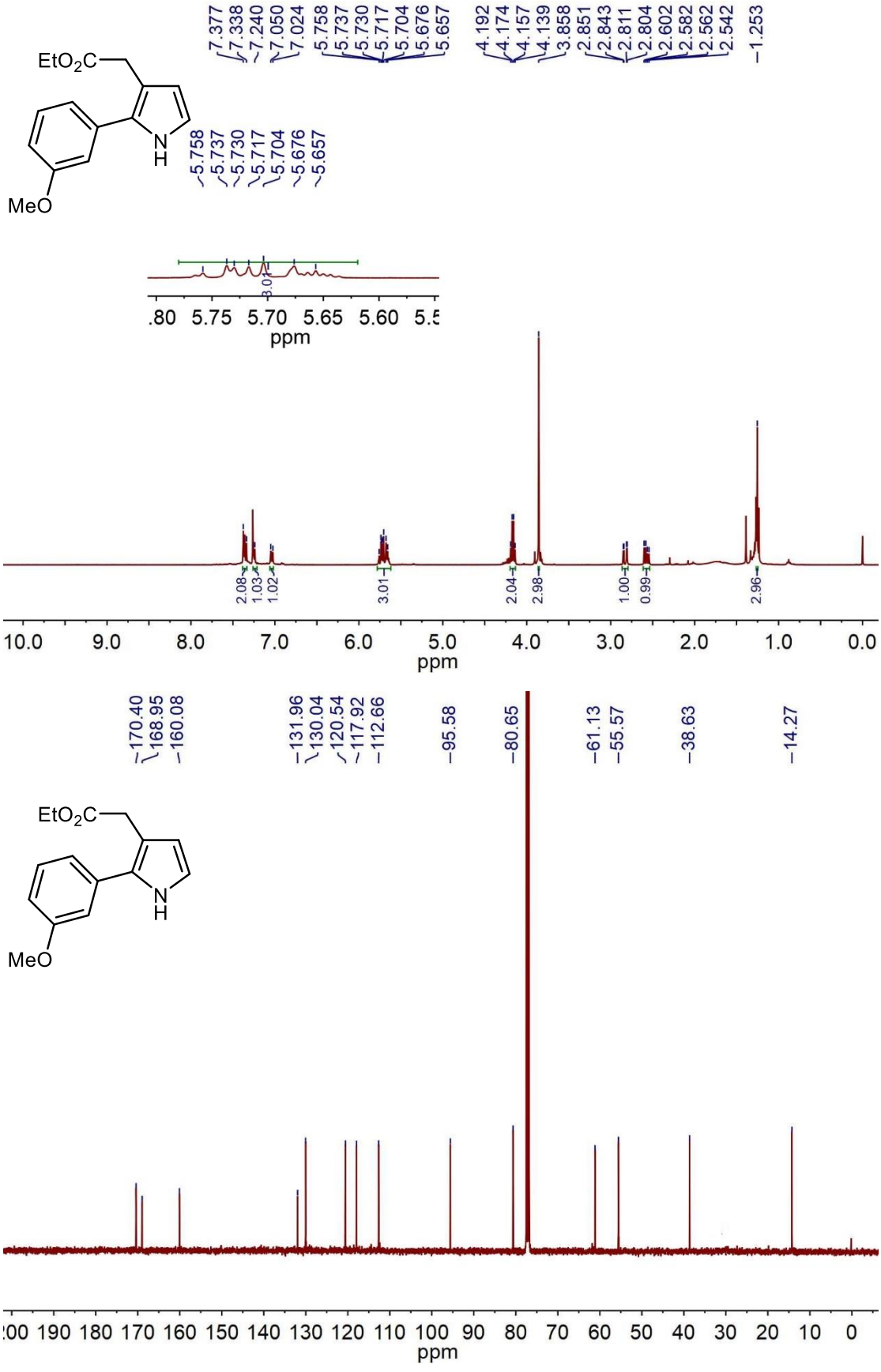




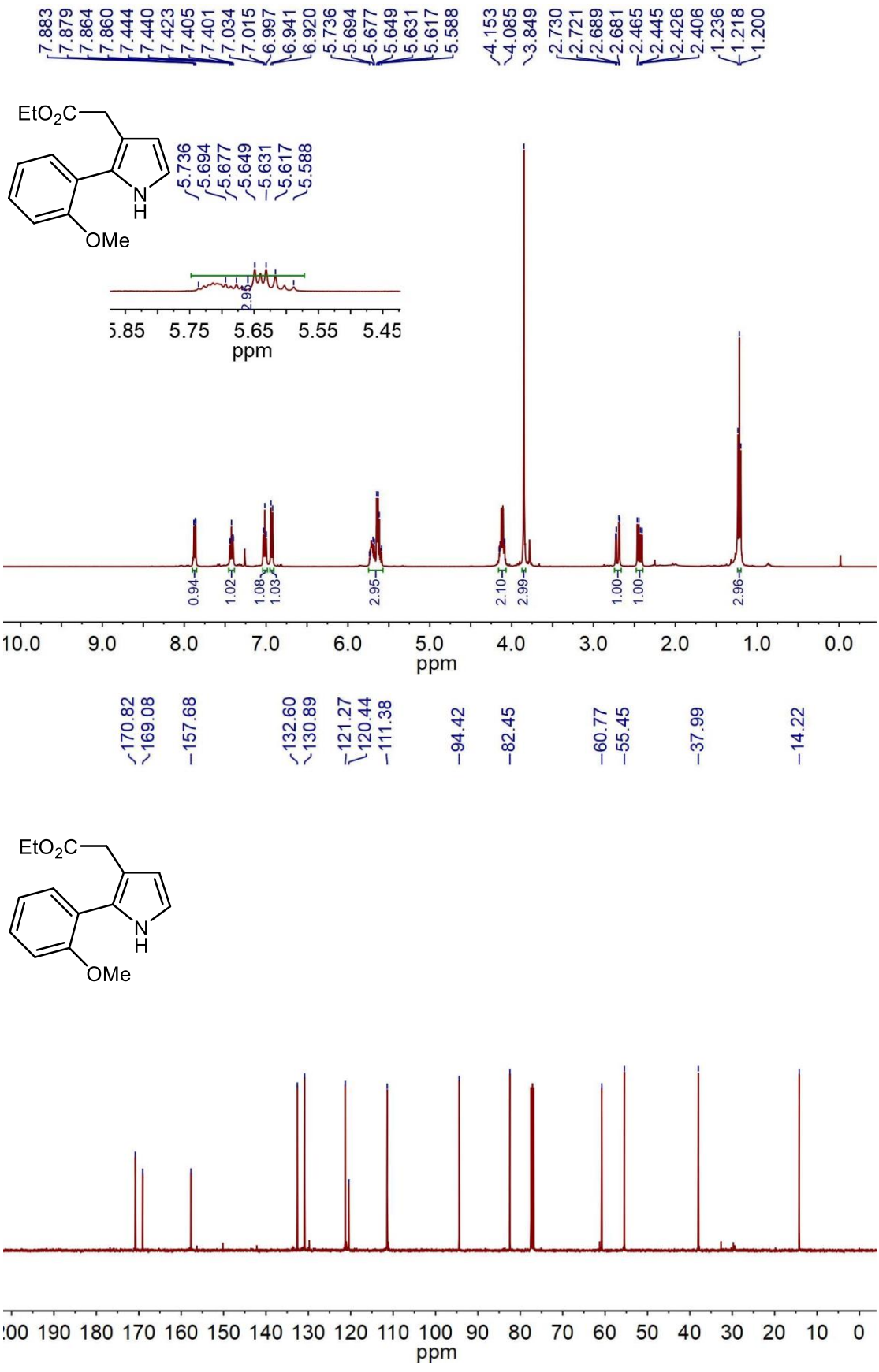
Ethyl 2-(2-(4-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4c)



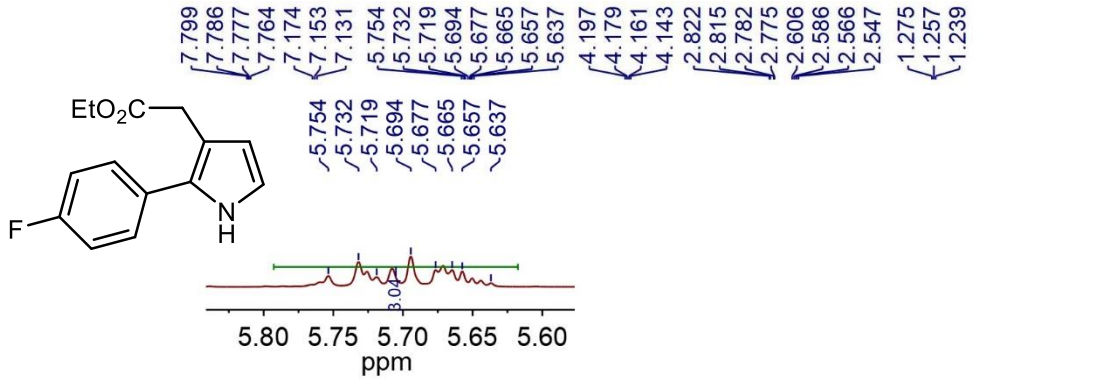
Ethyl 2-(2-(3-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4d)

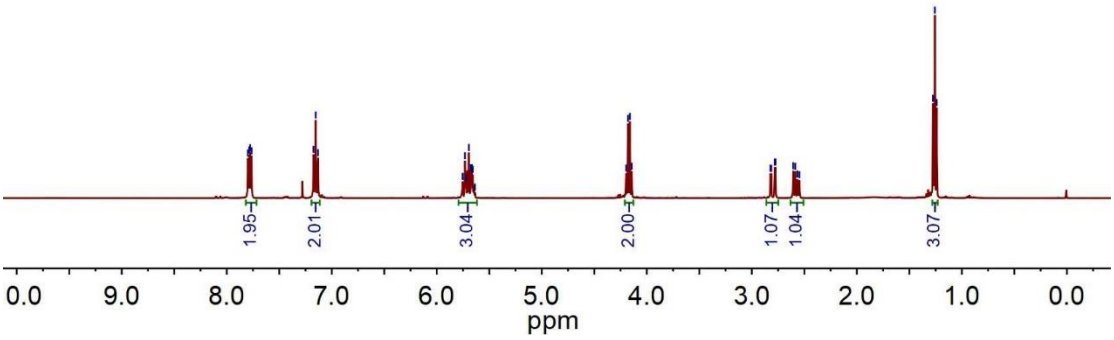


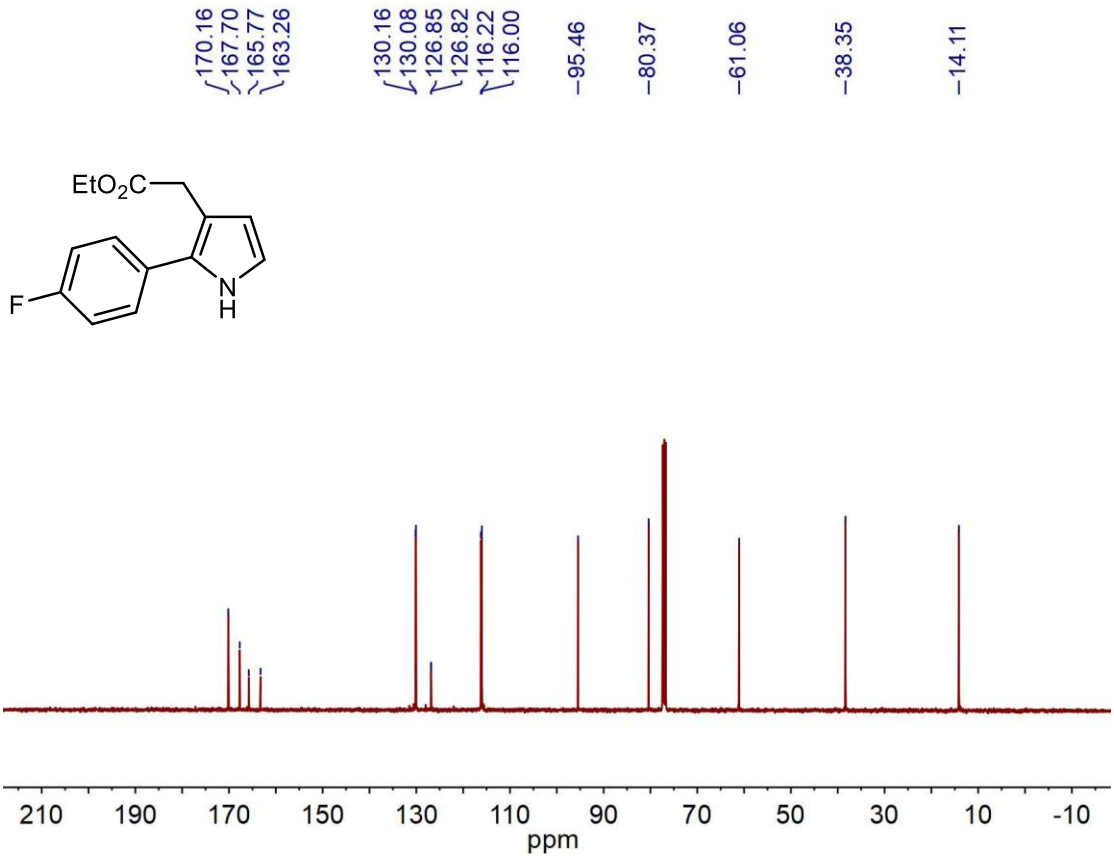
Ethyl 2-(2-(2-methoxyphenyl)-1*H*-pyrrol-3-yl)acetate (4e)



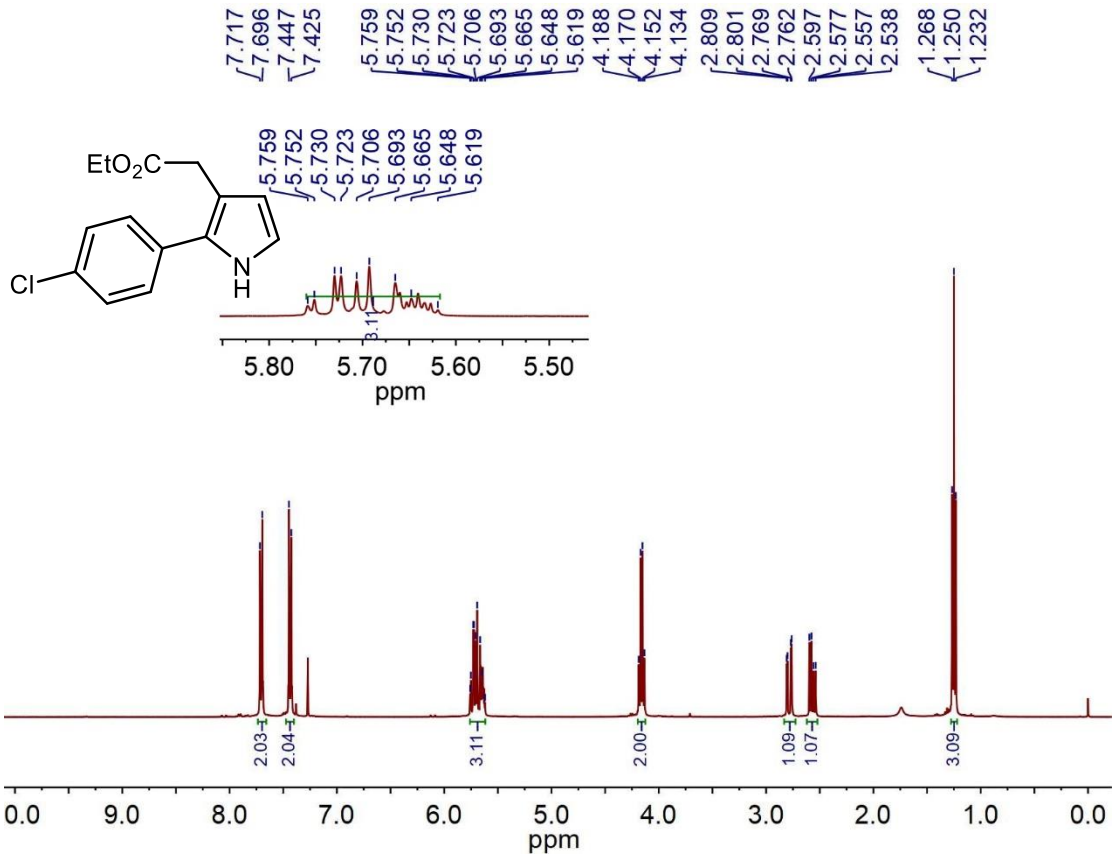
Ethyl 2-(2-(4-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4f)

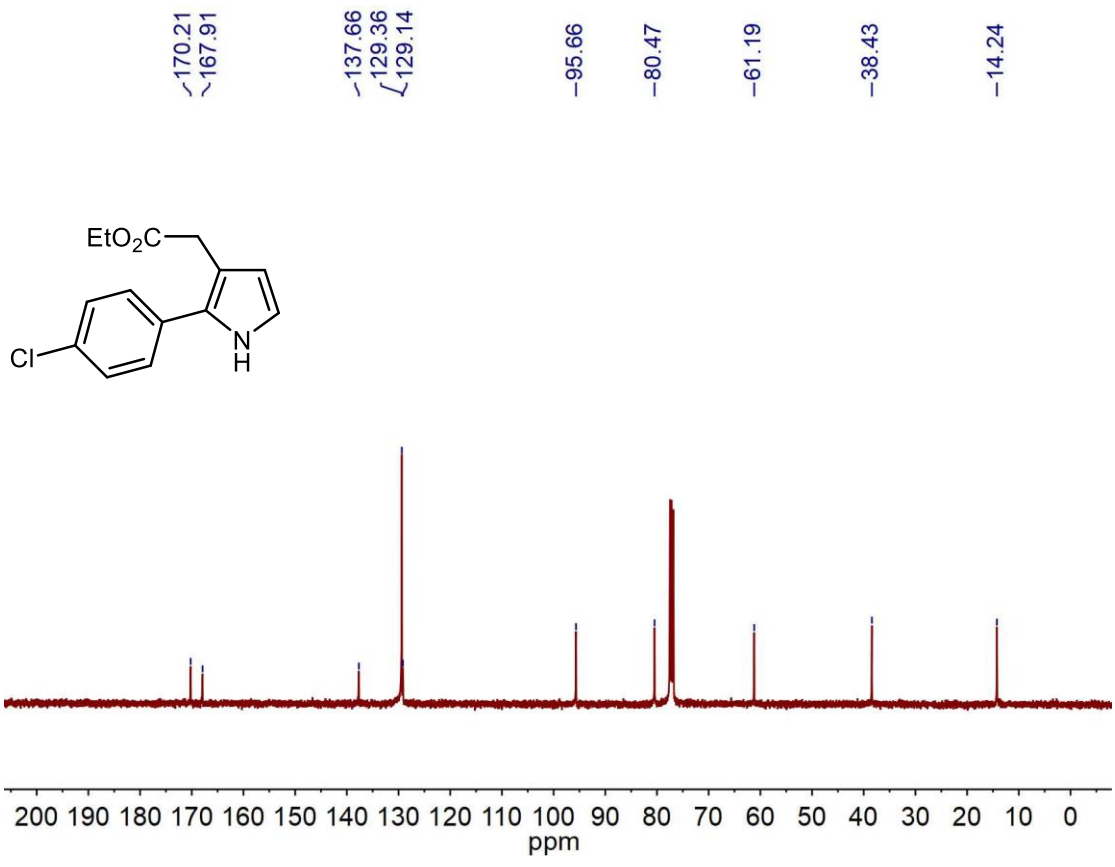




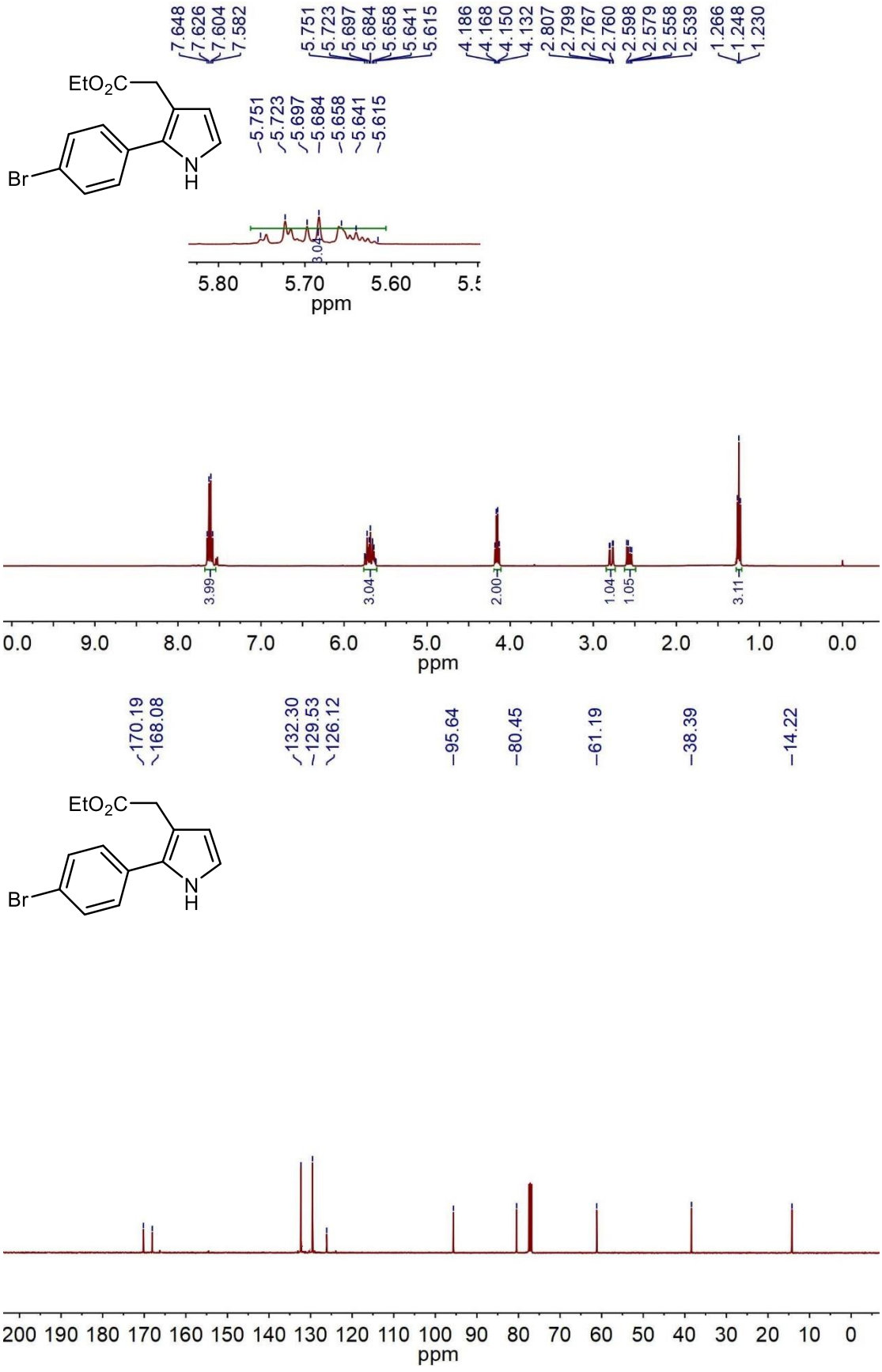


Ethyl 2-(2-(4-chlorophenyl)-1*H*-pyrrol-3-yl)acetate (4g)

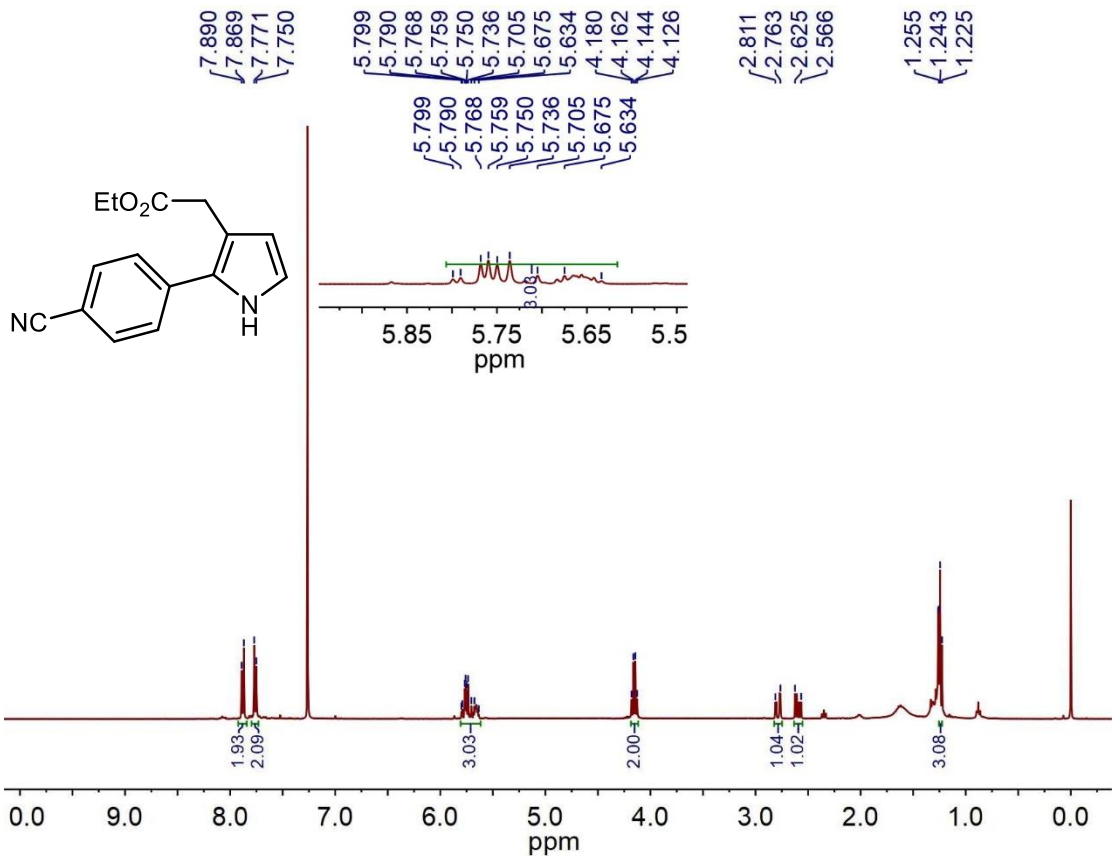


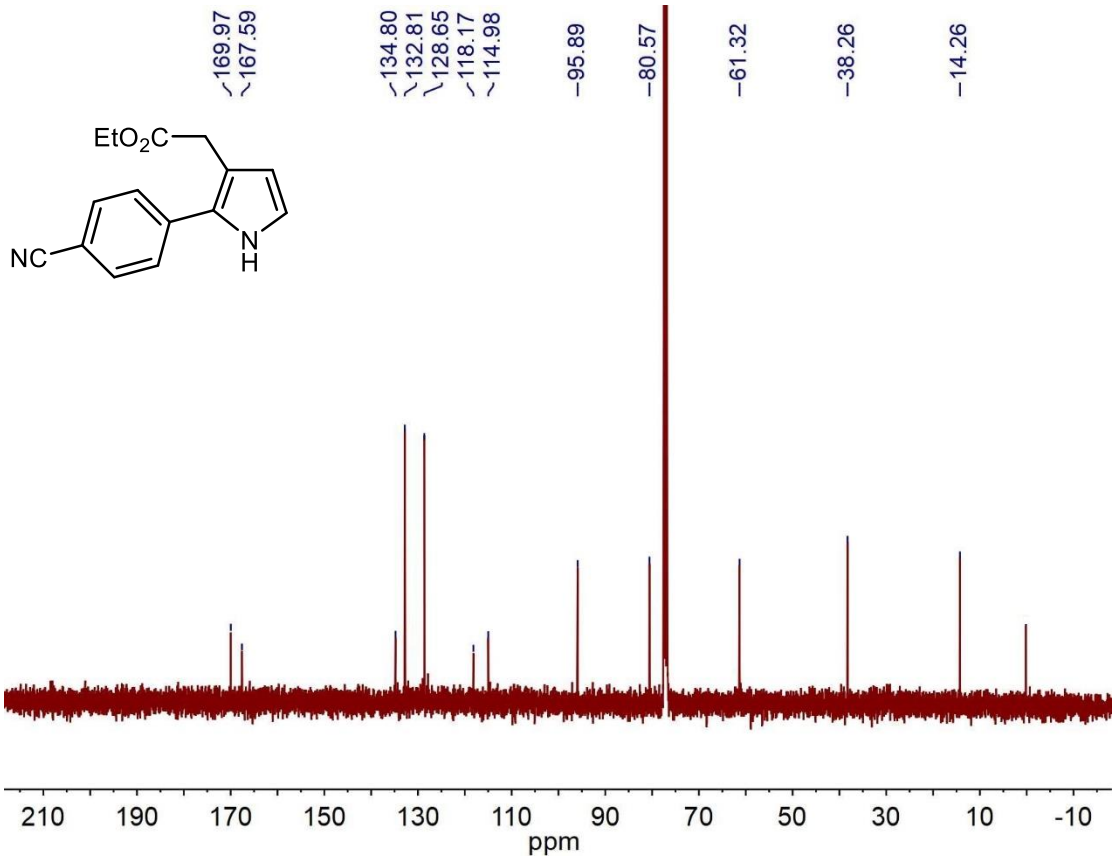


Ethyl 2-(2-(4-bromophenyl)-1*H*-pyrrol-3-yl)acetate (4h)

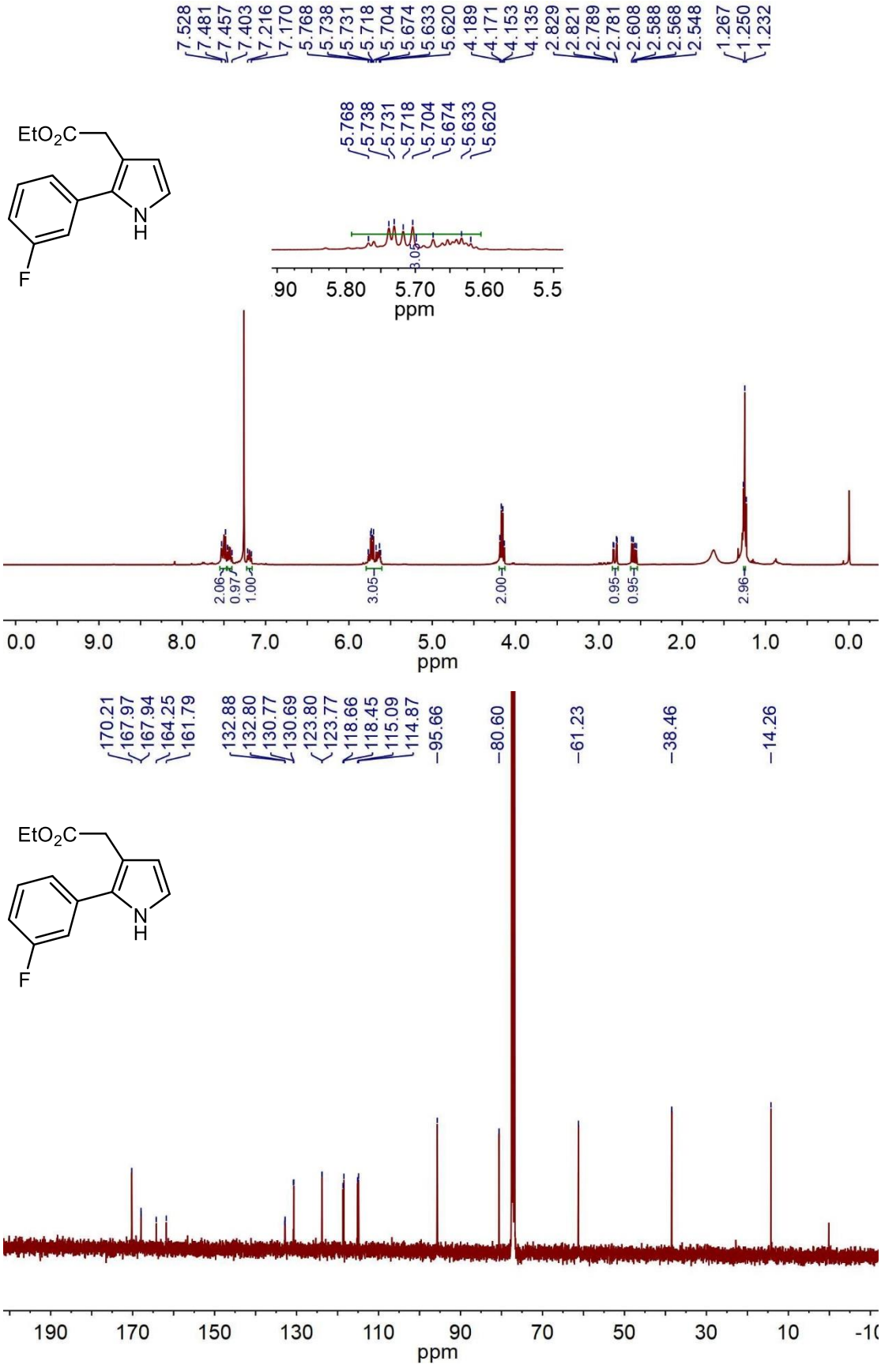


Ethyl 2-(2-(4-cyanophenyl)-1*H*-pyrrol-3-yl)acetate (4i)





Ethyl 2-(2-(3-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4j)



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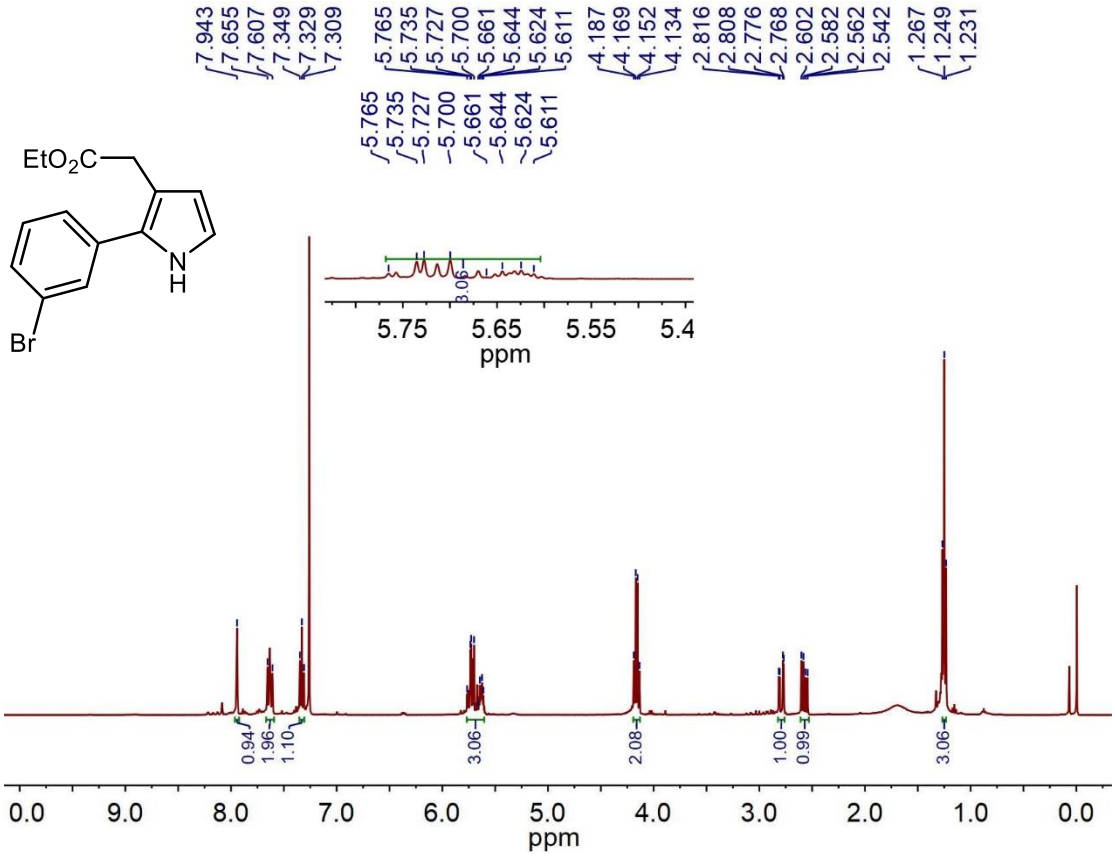
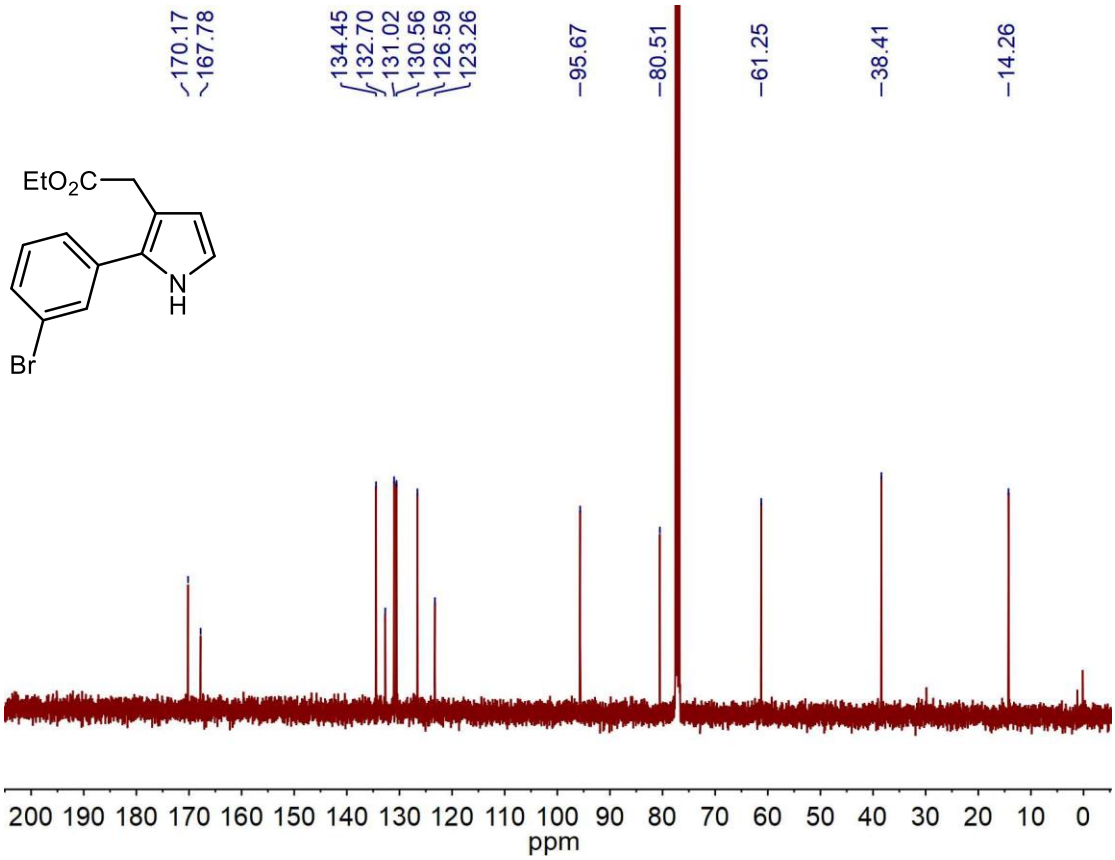
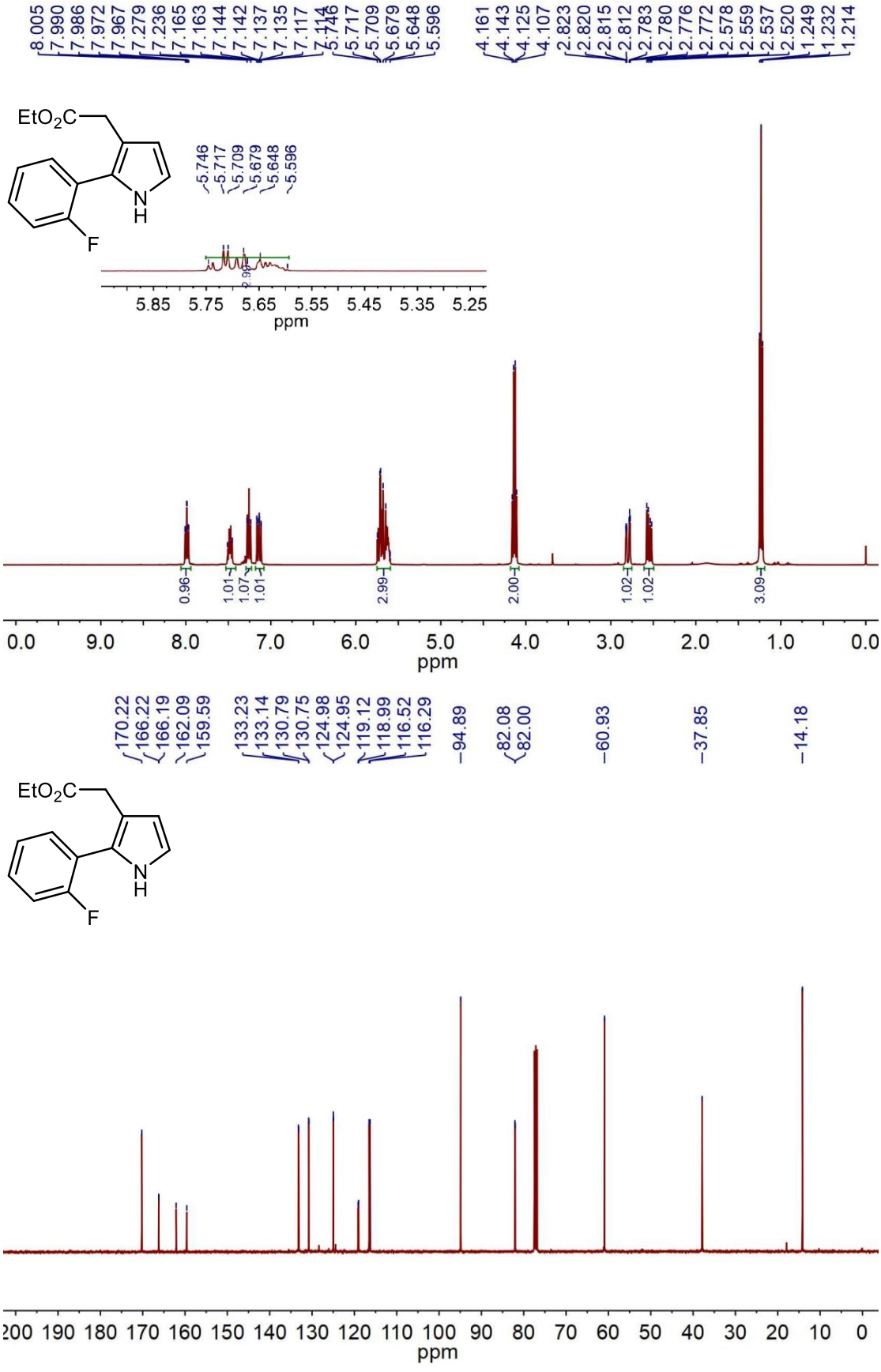
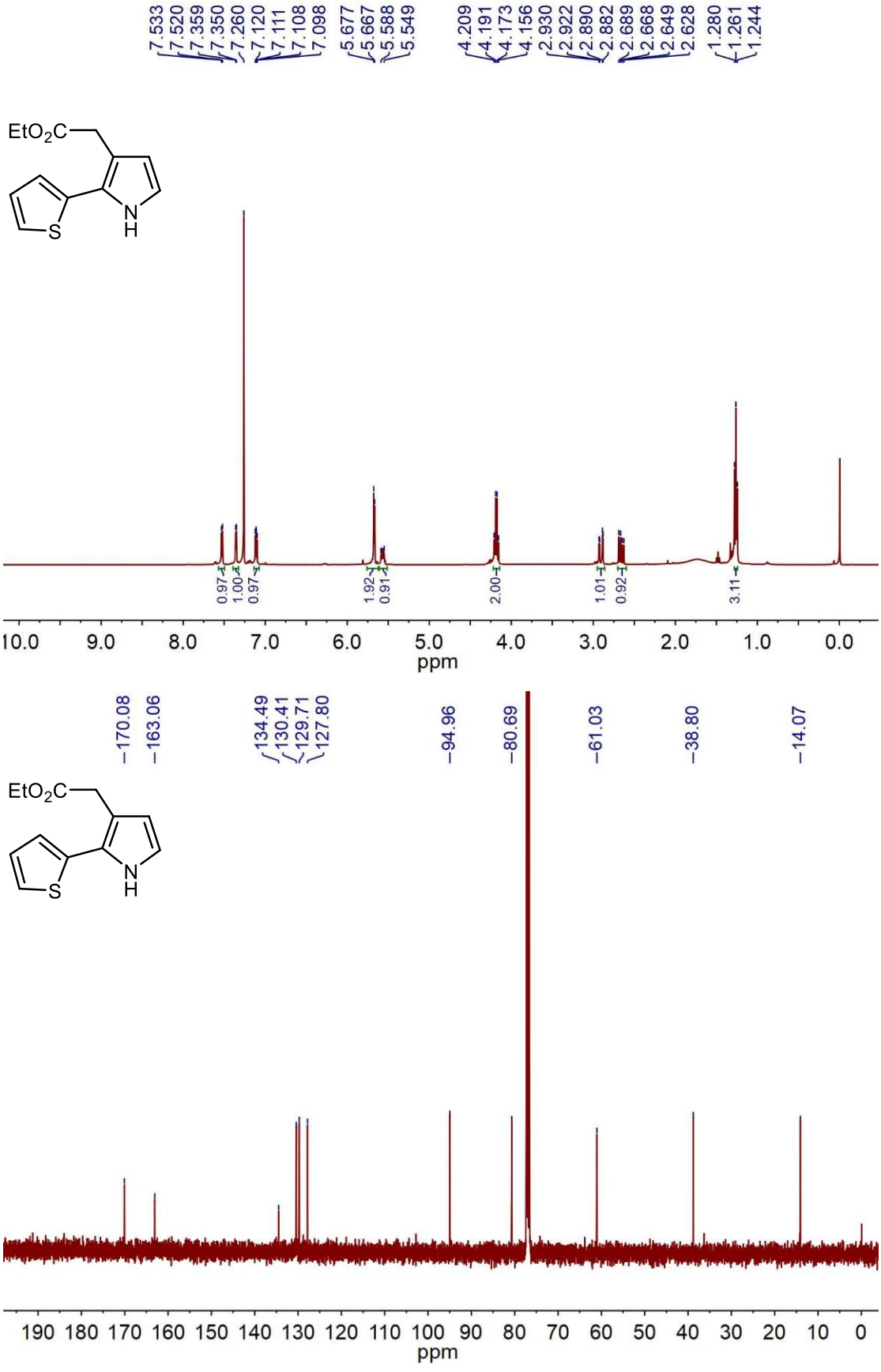




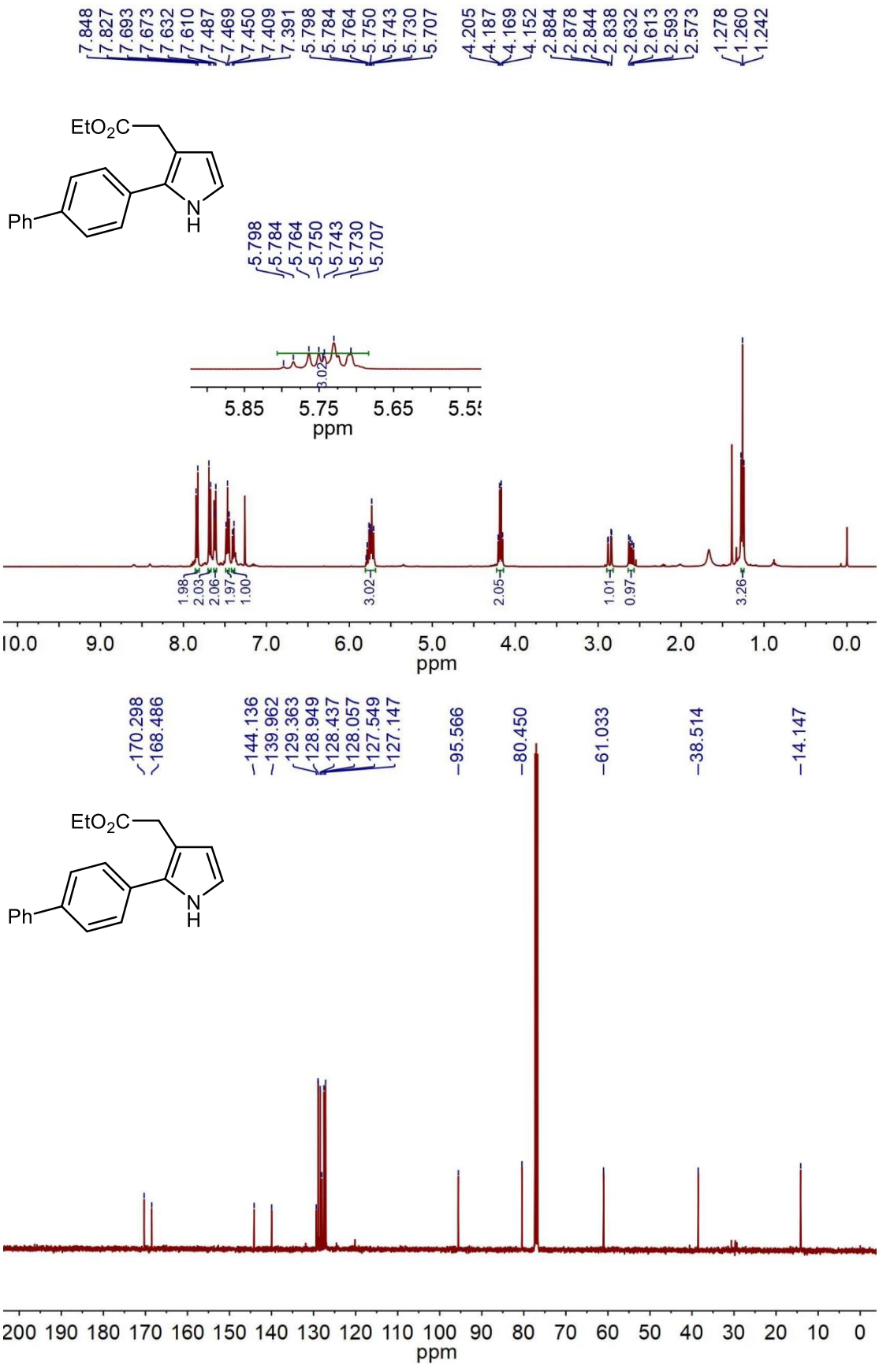
Ethyl 2-(2-(2-fluorophenyl)-1*H*-pyrrol-3-yl)acetate (4l)



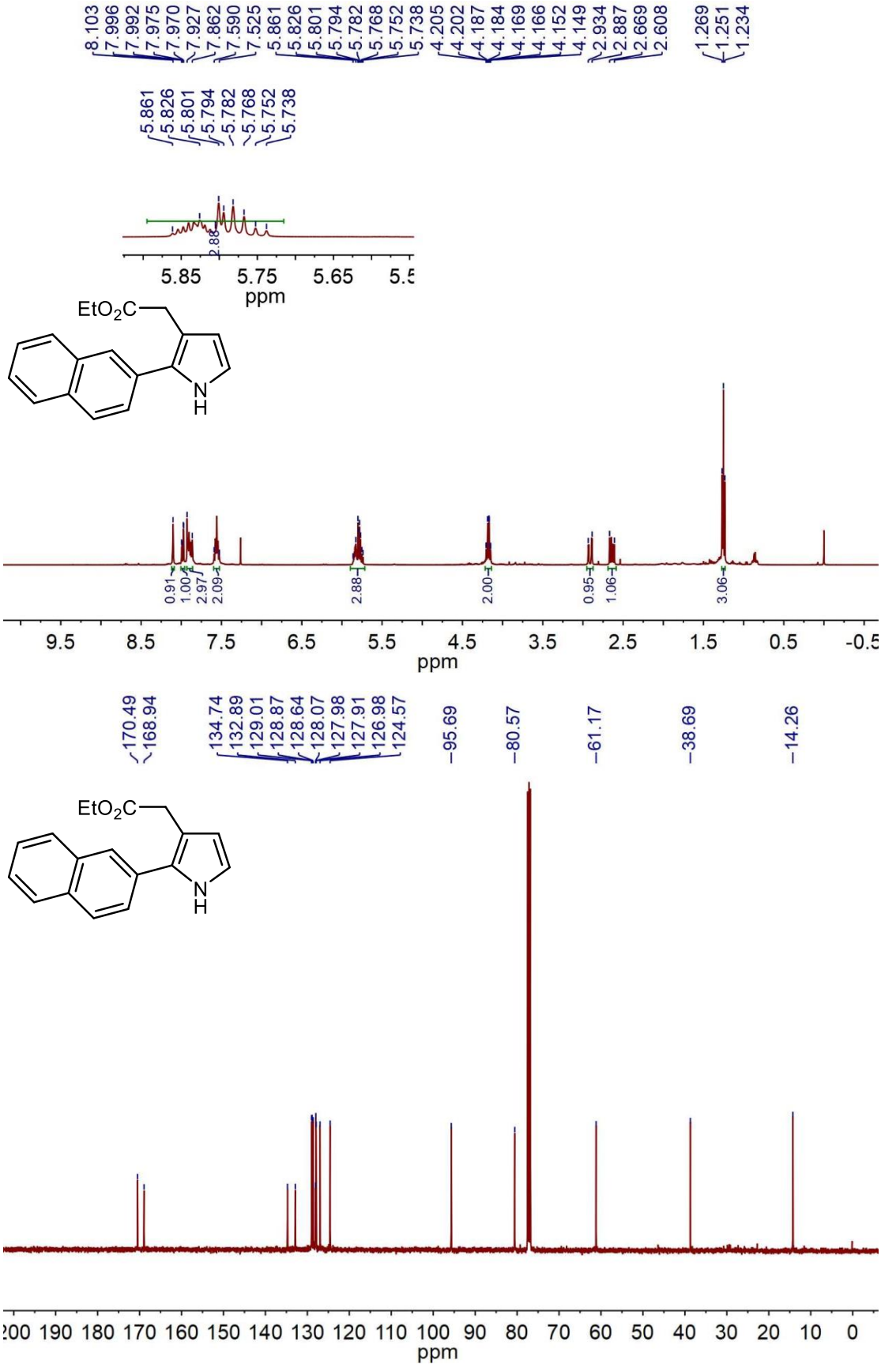
Ethyl 2-(2-(thiophen-2-yl)-1*H*-pyrrol-3-yl)acetate (4m)



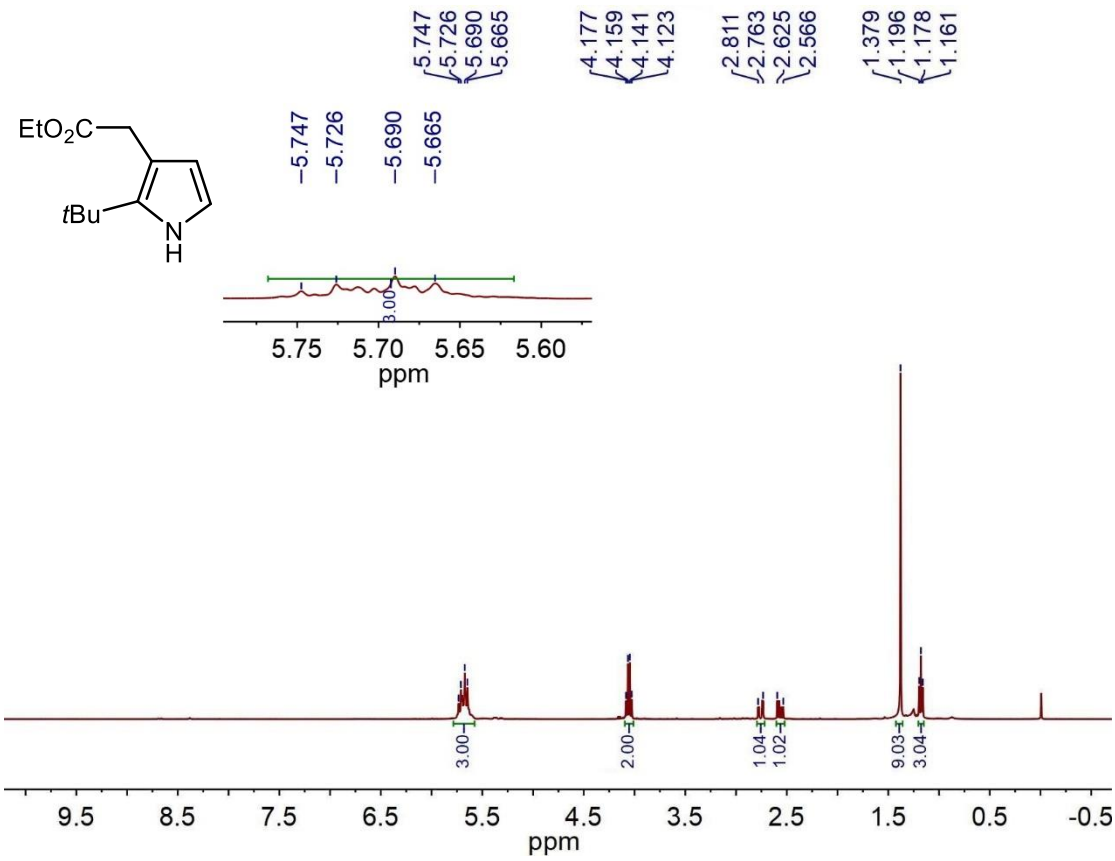
2-([1,1'-Biphenyl]-4-yl)-3-(2-(ethylperoxy)-2l2-ethyl)-1*H*-pyrrole (4n)

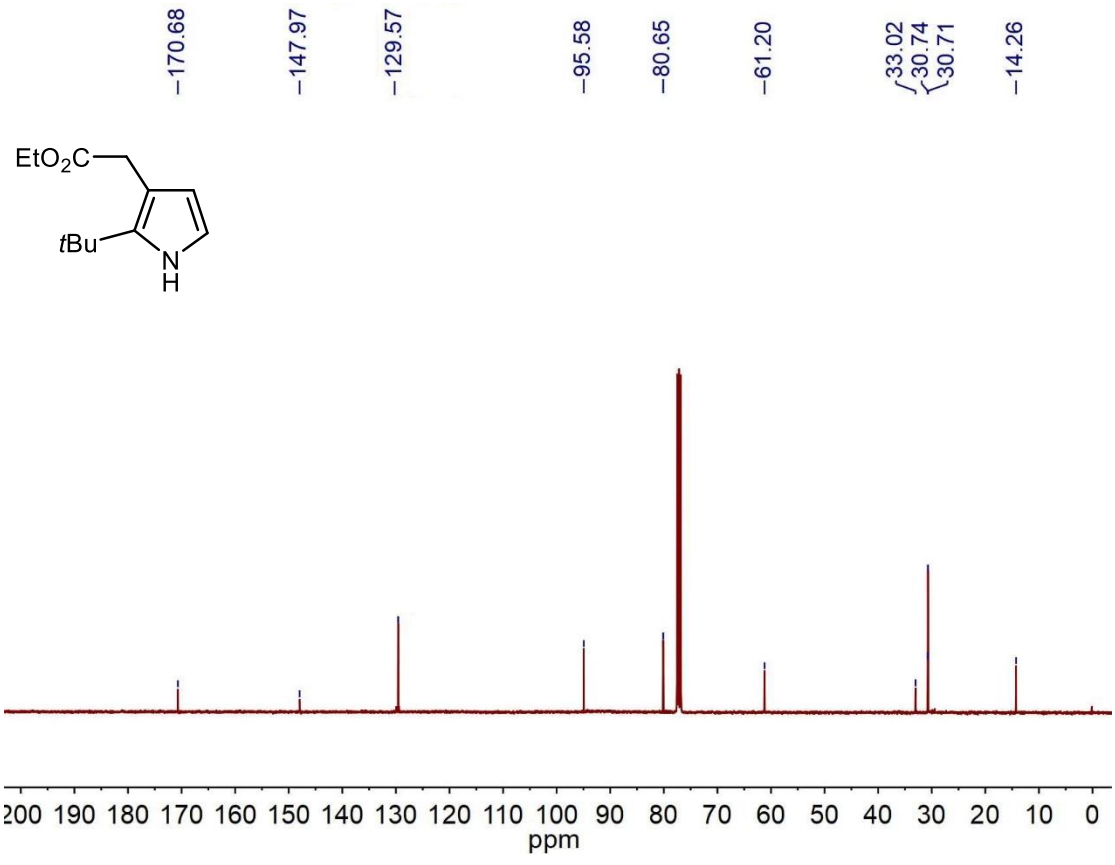


Ethyl 2-(2-(naphthalen-2-yl)-1*H*-pyrrol-3-yl)acetate (4o)

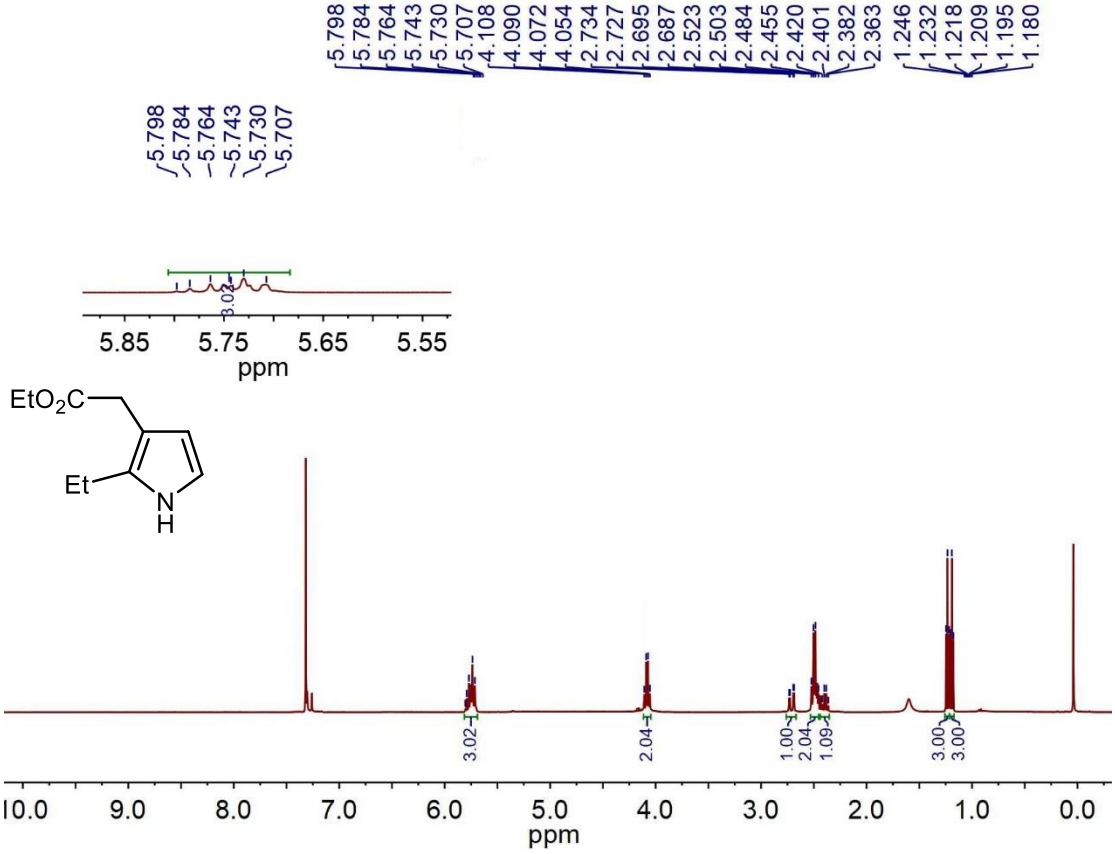


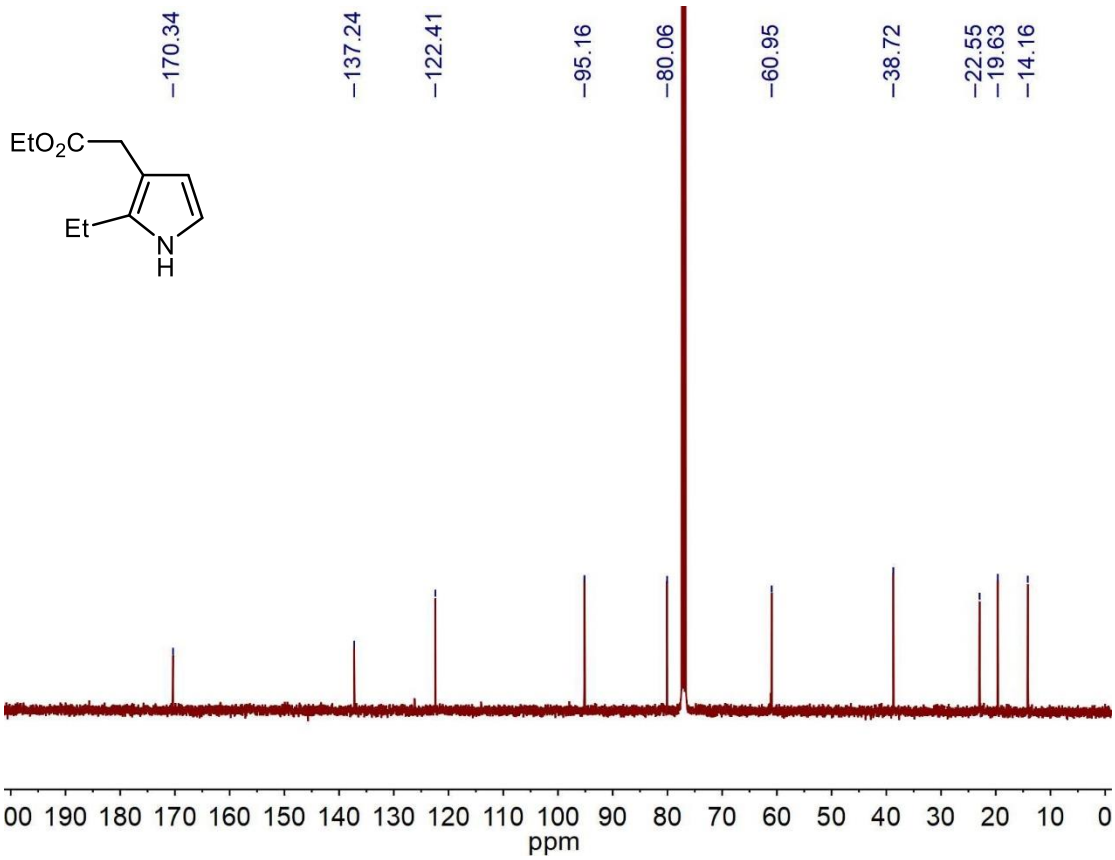
Ethyl 2-(2-(*tert*-butyl)-1*H*-pyrrol-3-yl)acetate (4p)



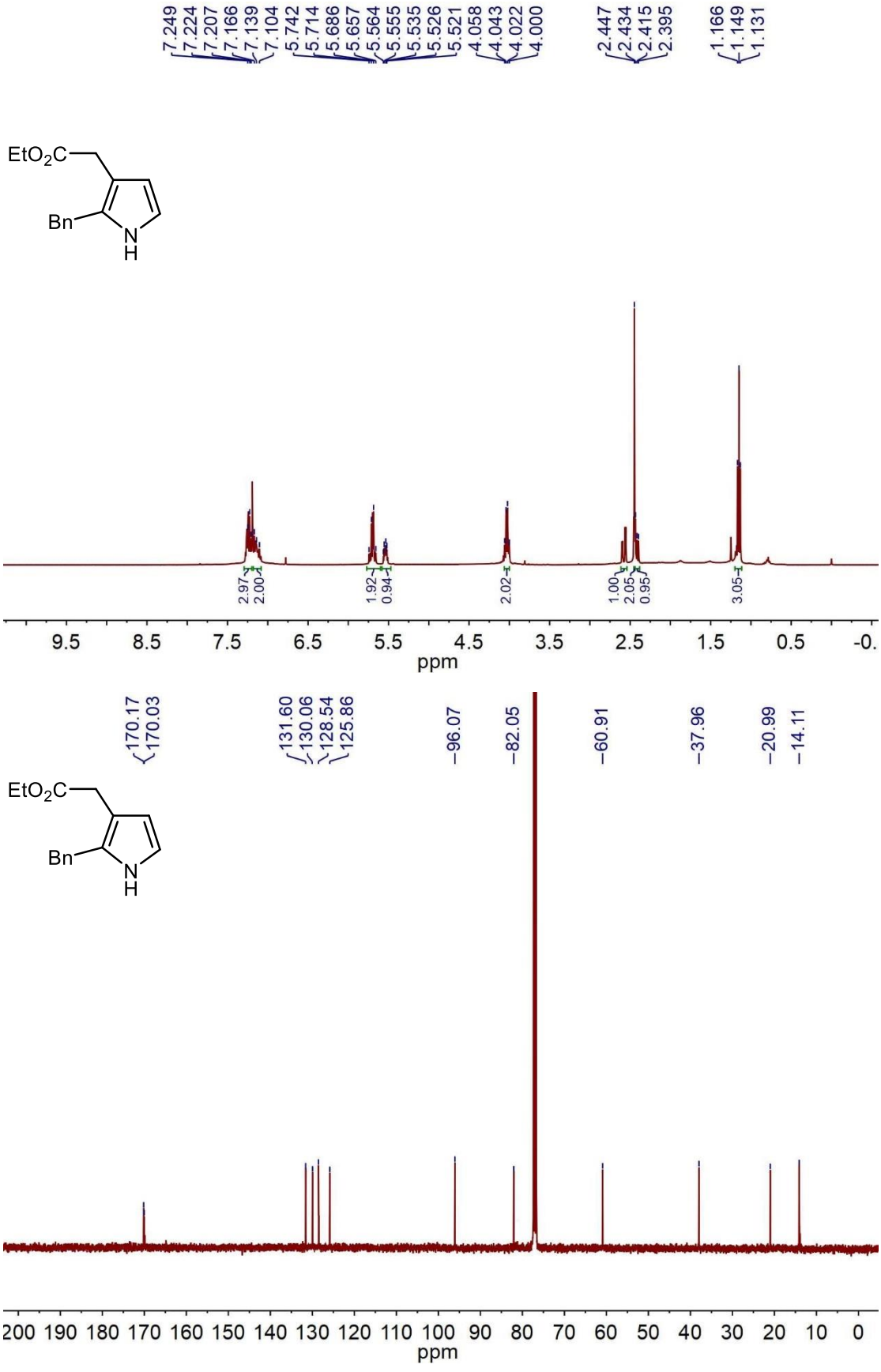


Ethyl 2-(2-ethyl-1*H*-pyrrol-3-yl)acetate (4q)

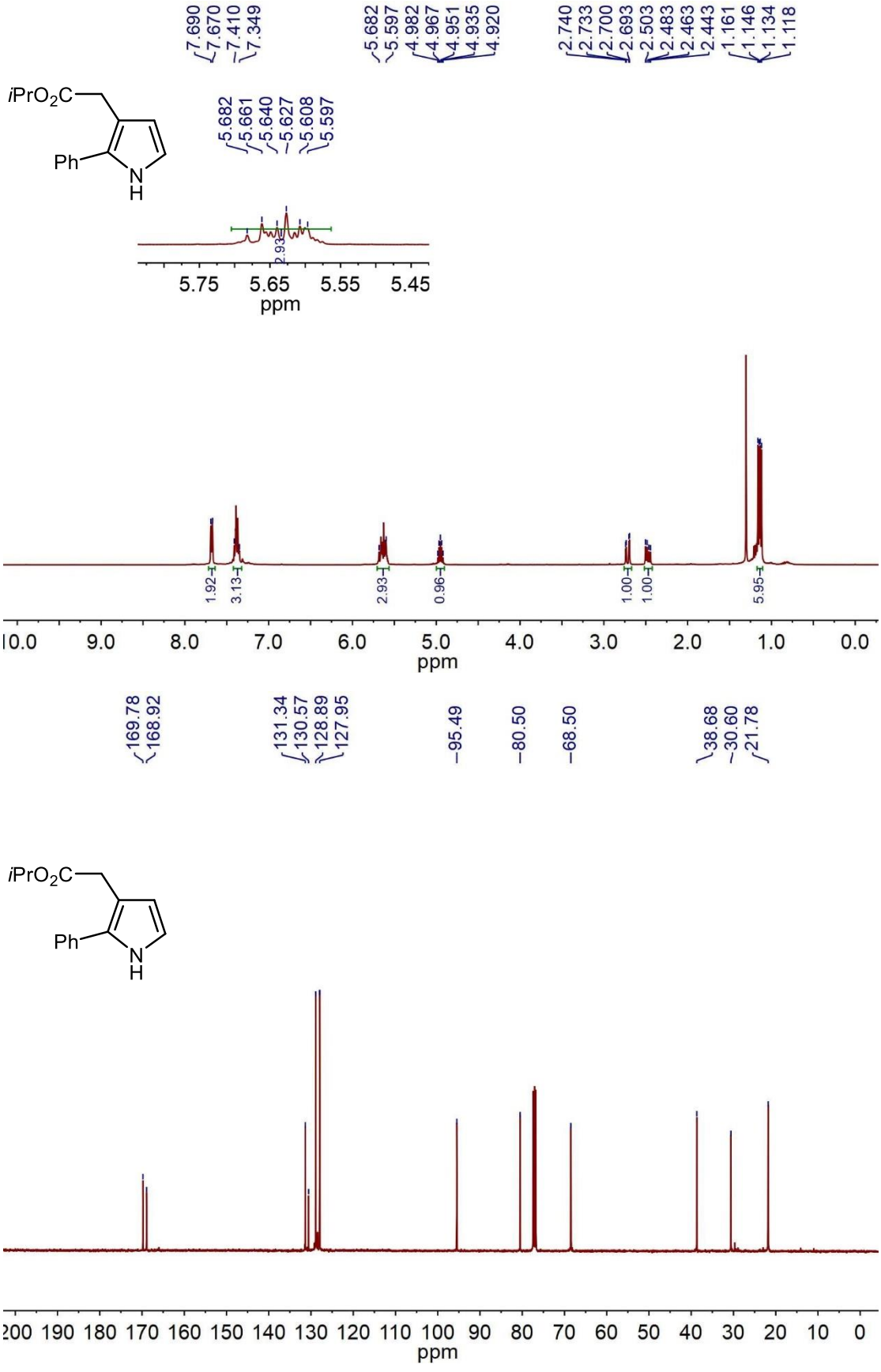




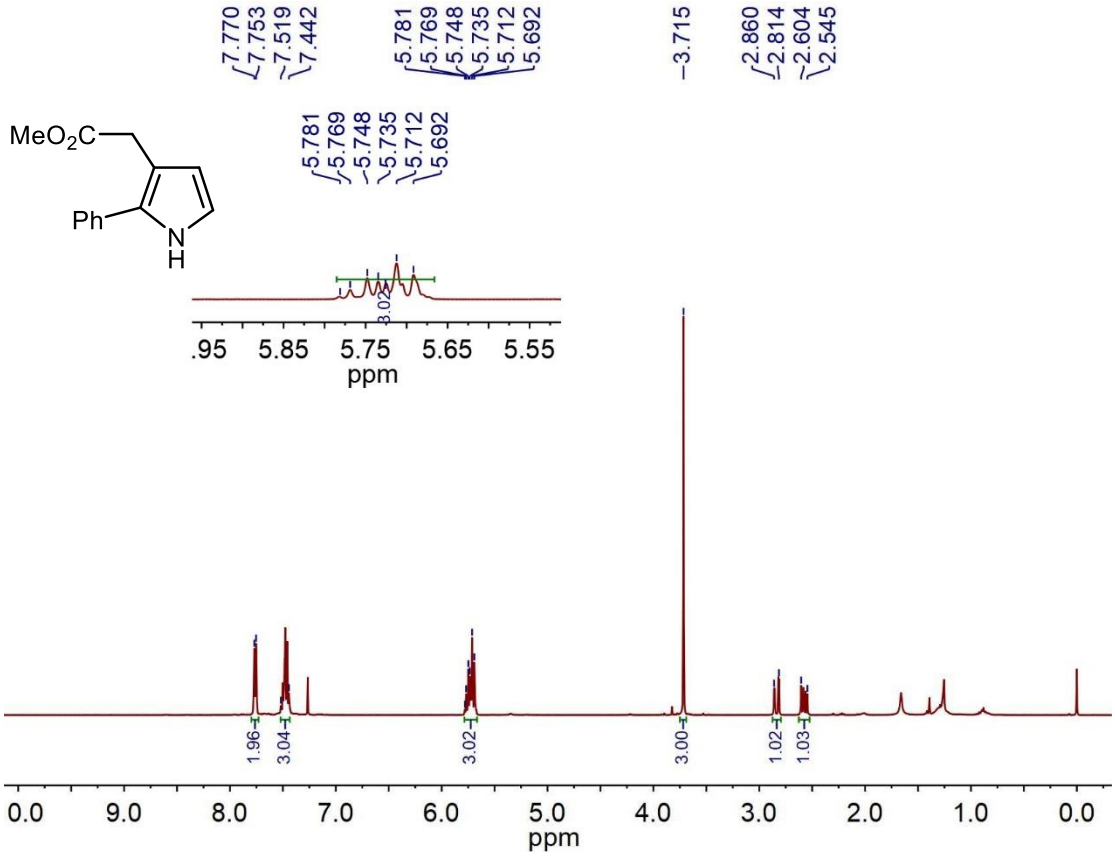
Ethyl 2-(2-benzyl-1*H*-pyrrol-3-yl)acetate (4r)

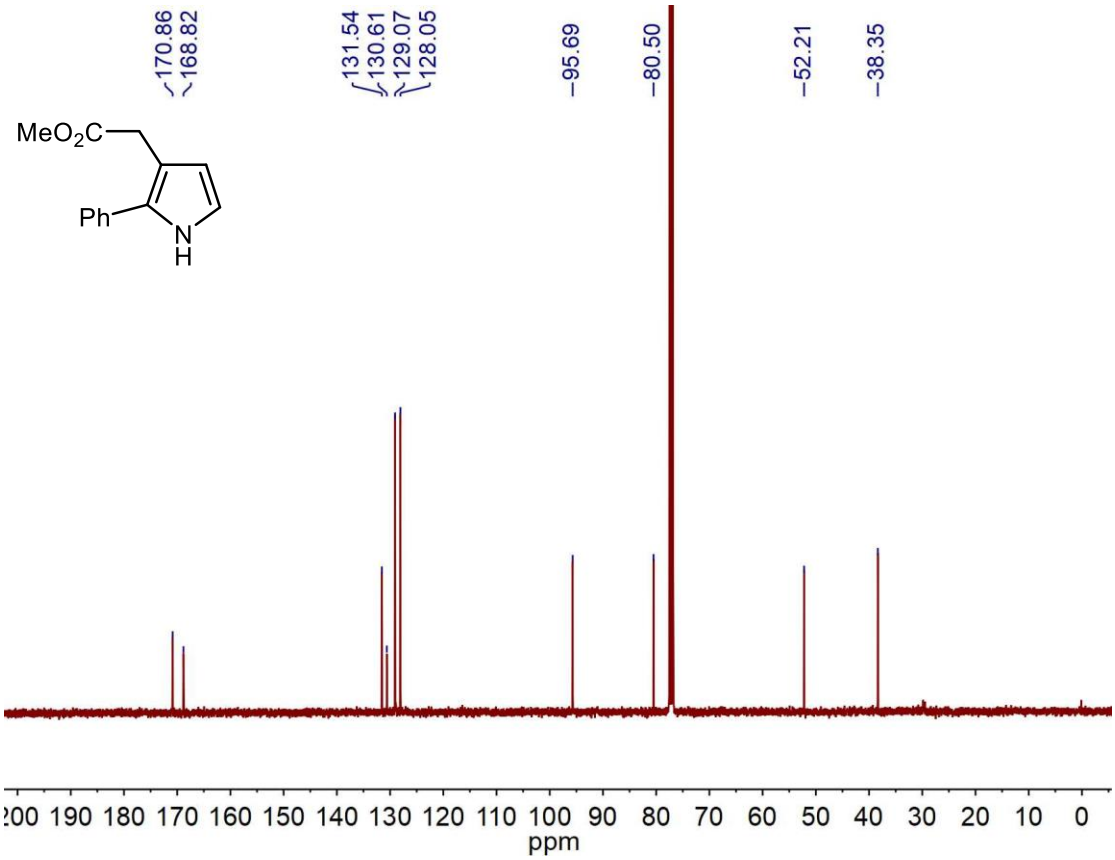


Isopropyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4s)

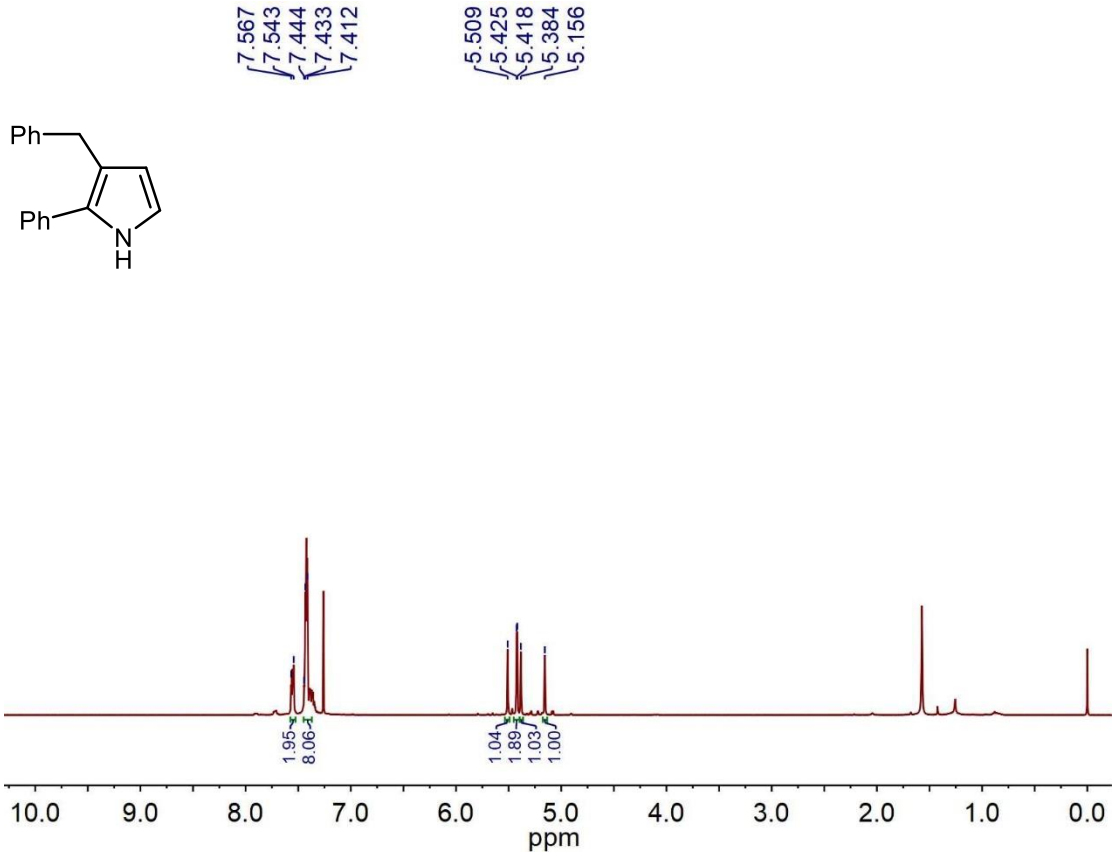


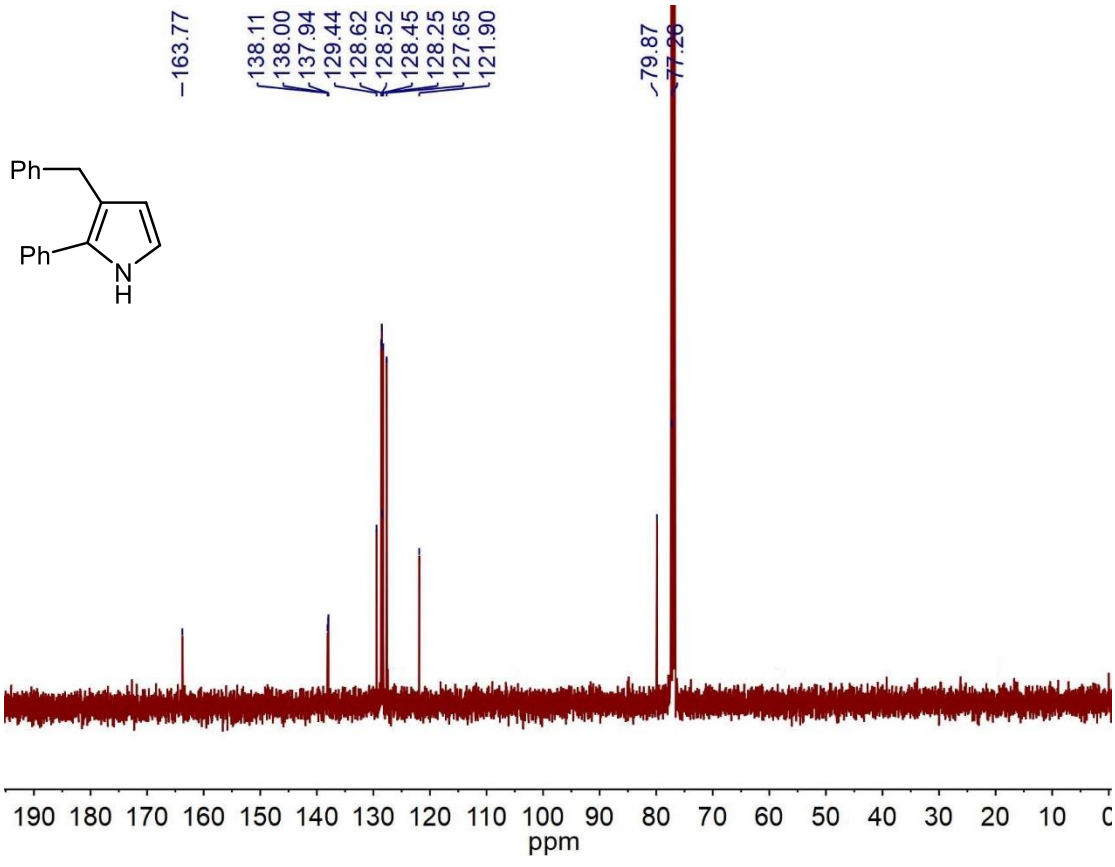
Methyl 2-(2-phenyl-1*H*-pyrrol-3-yl)acetate (4t)



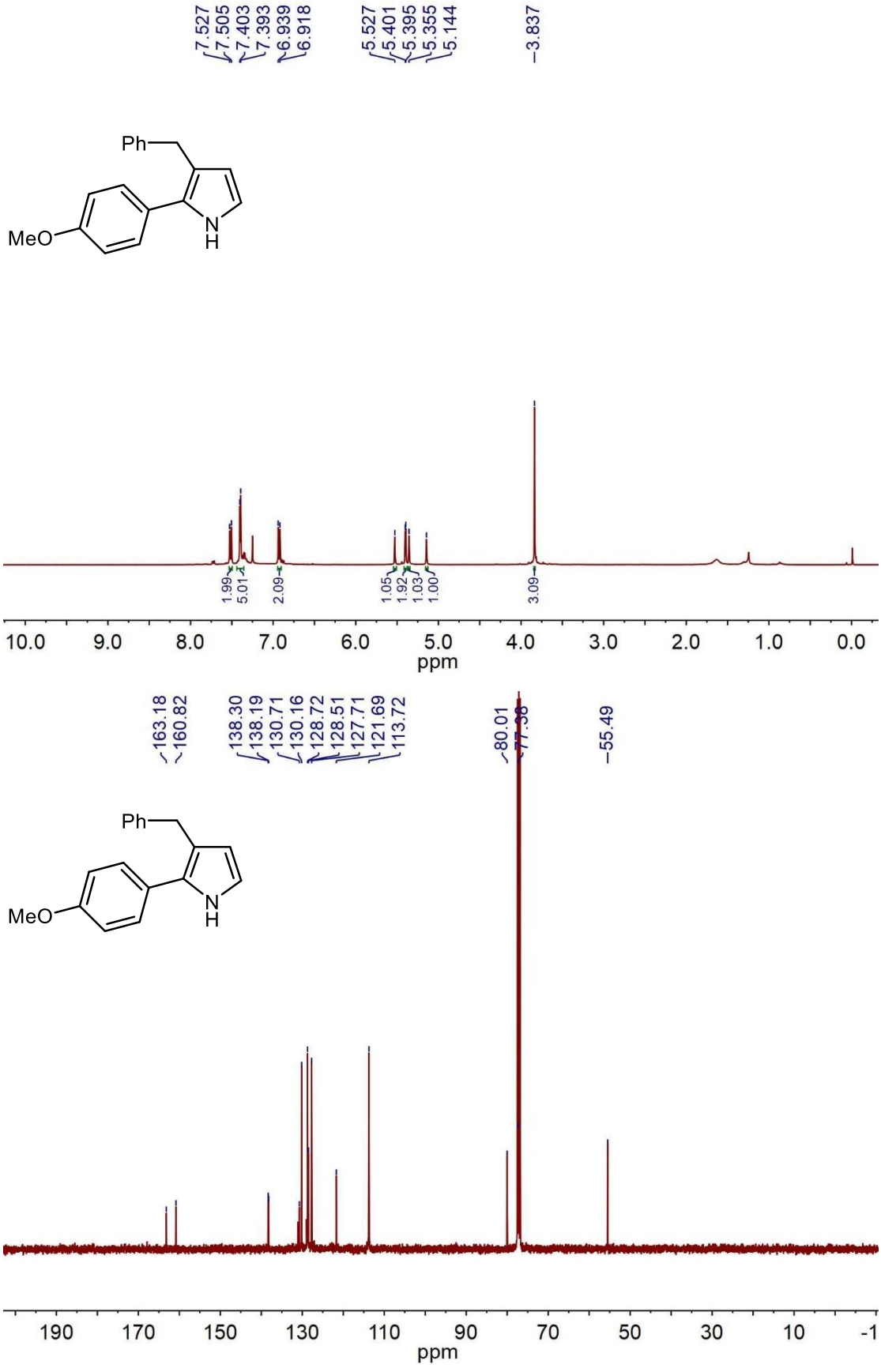


3-Benzyl-2-phenyl-1*H*-pyrrole (5a)

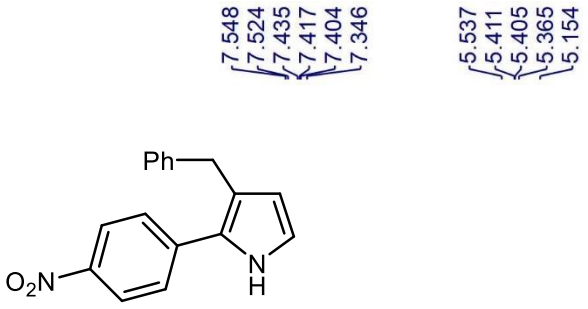


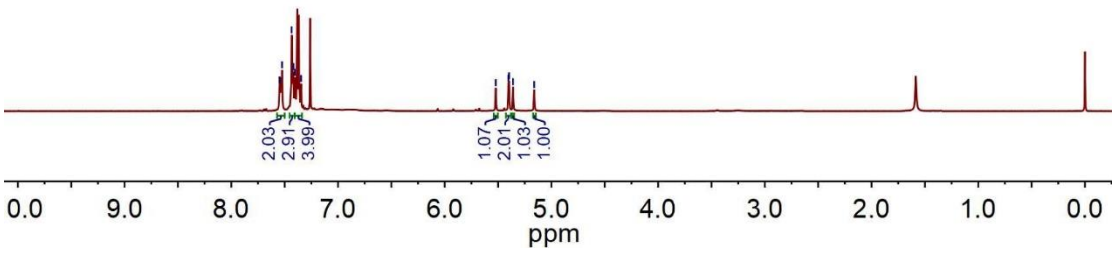


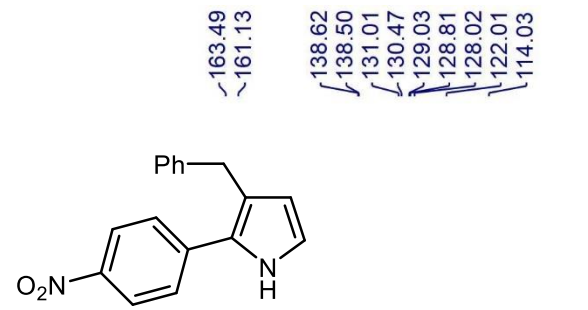
3-Benzyl-2-(4-methoxyphenyl)-1*H*-pyrrole (5b)

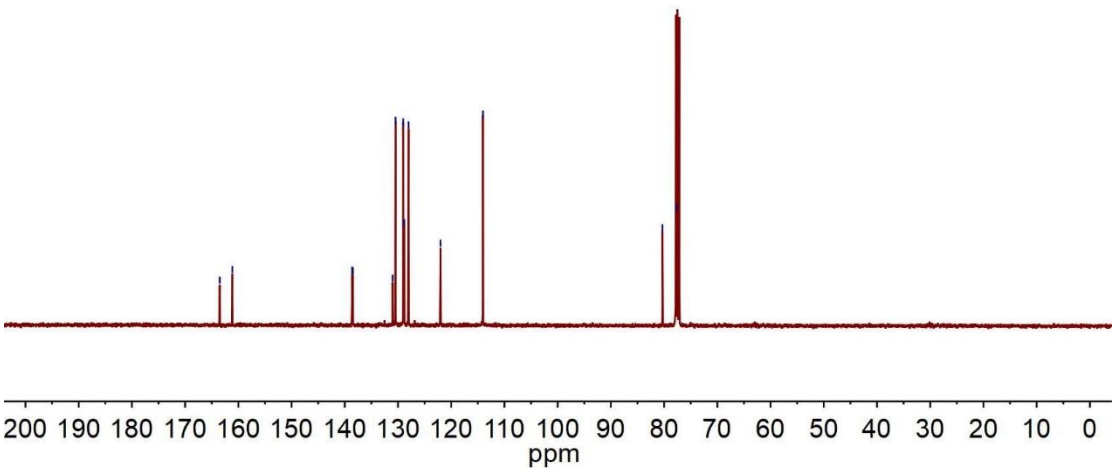


3-Benzyl-2-(4-nitrophenyl)-1*H*-pyrrole (5c)

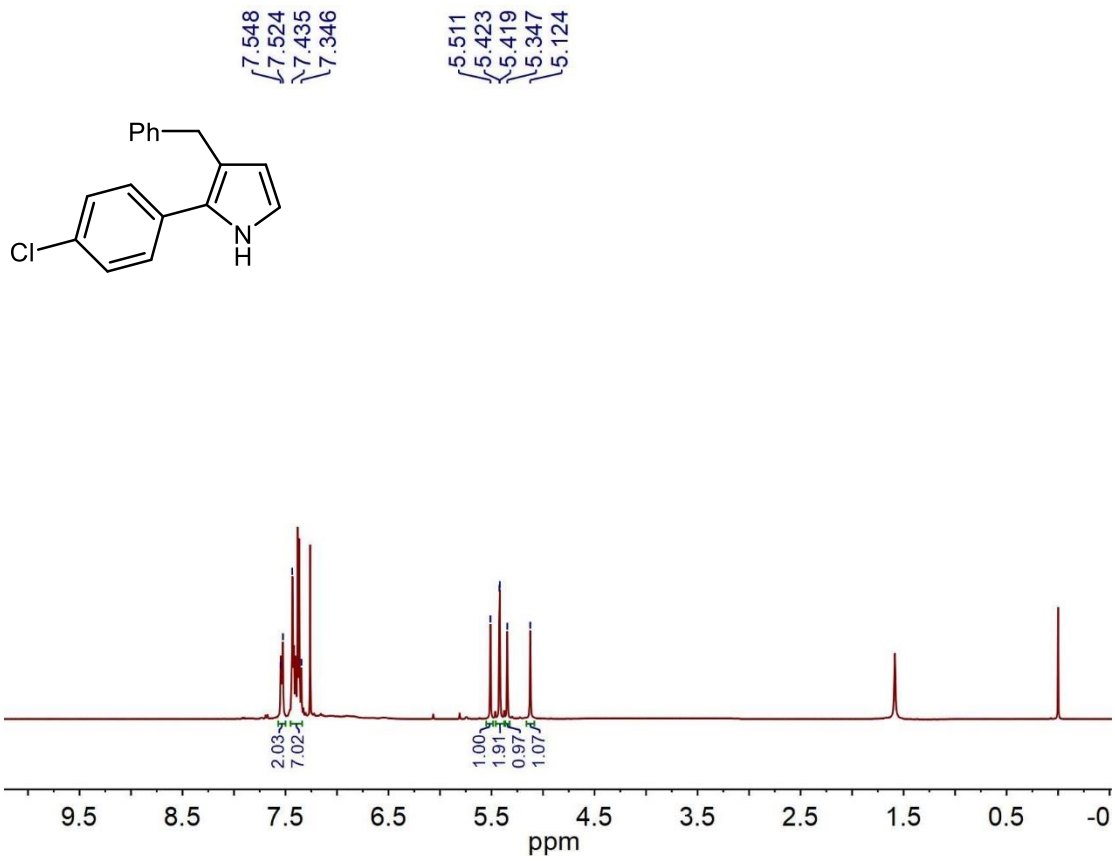


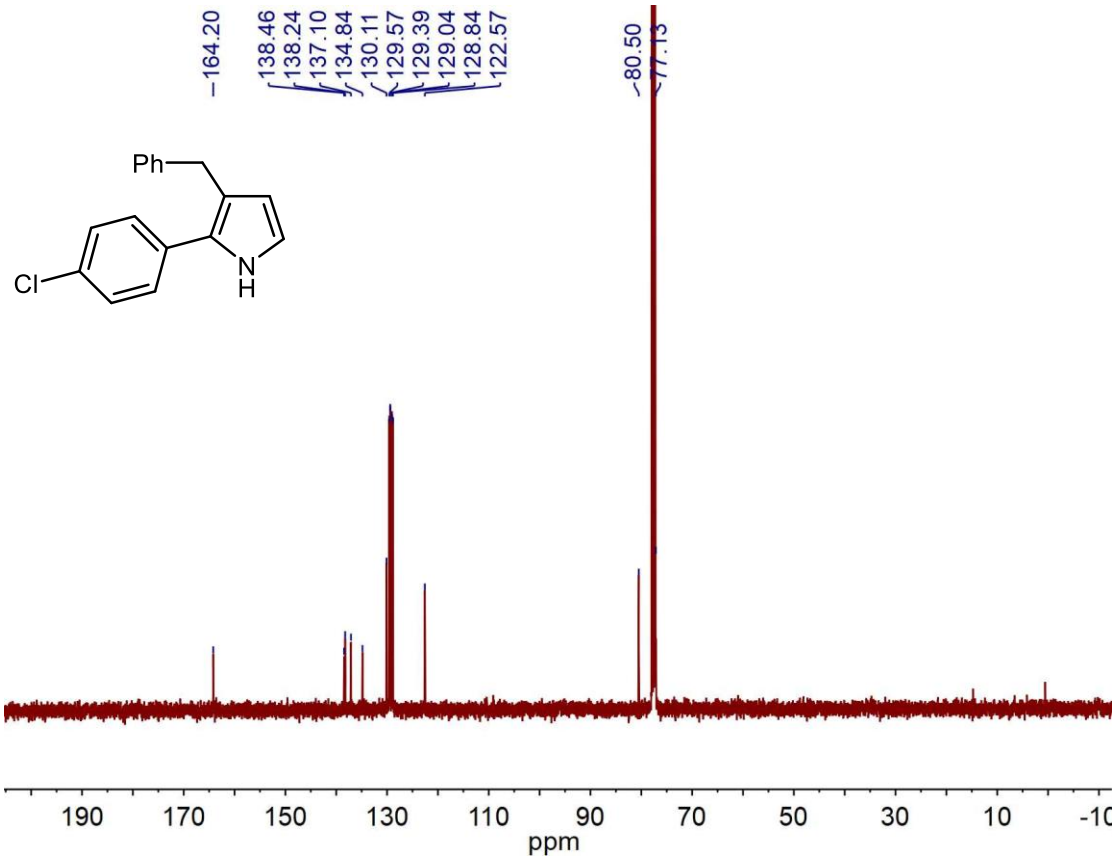




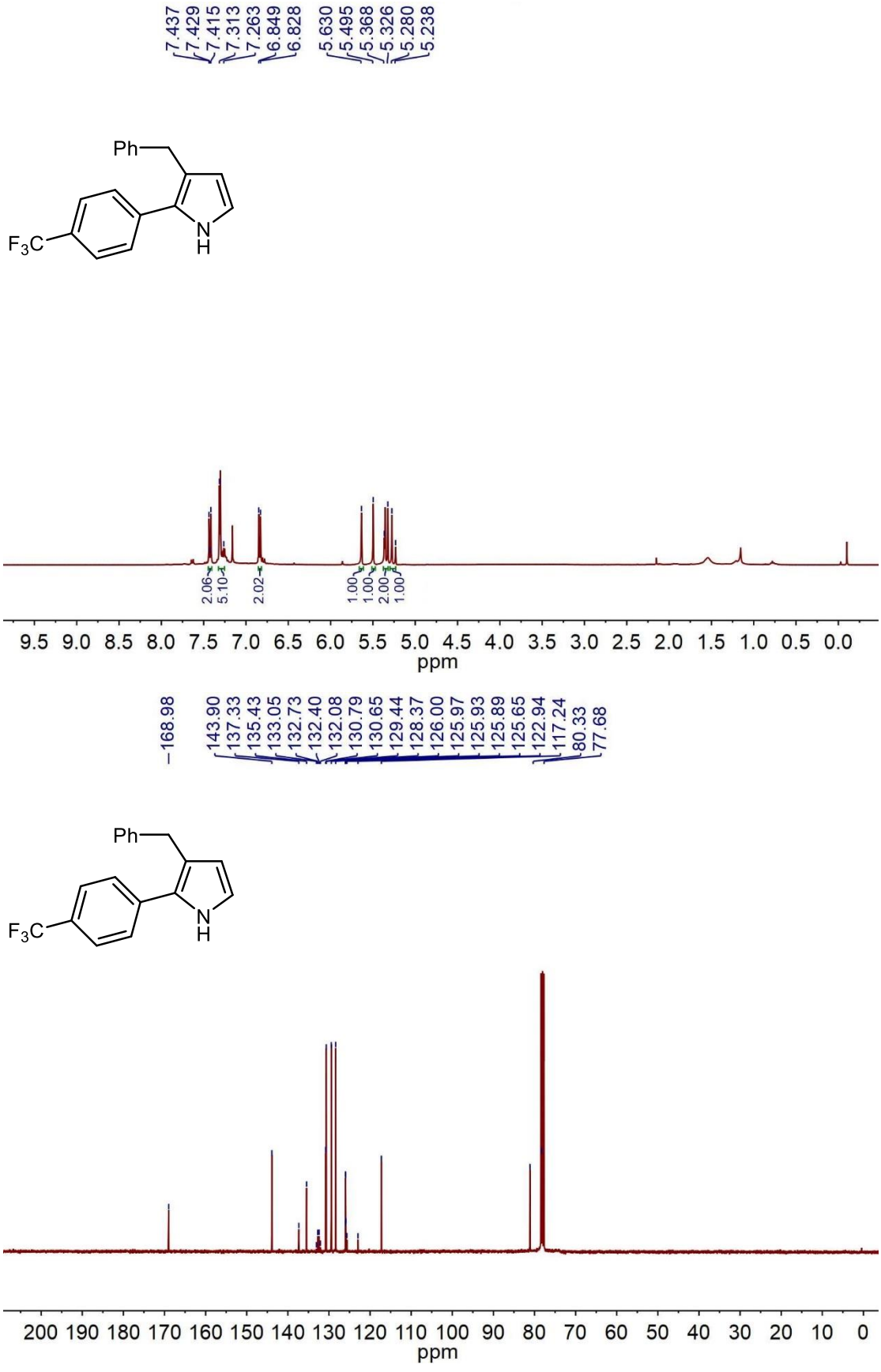


3-Benzyl-2-(4-chlorophenyl)-1*H*-pyrrole (5d)

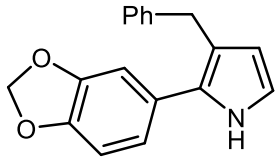


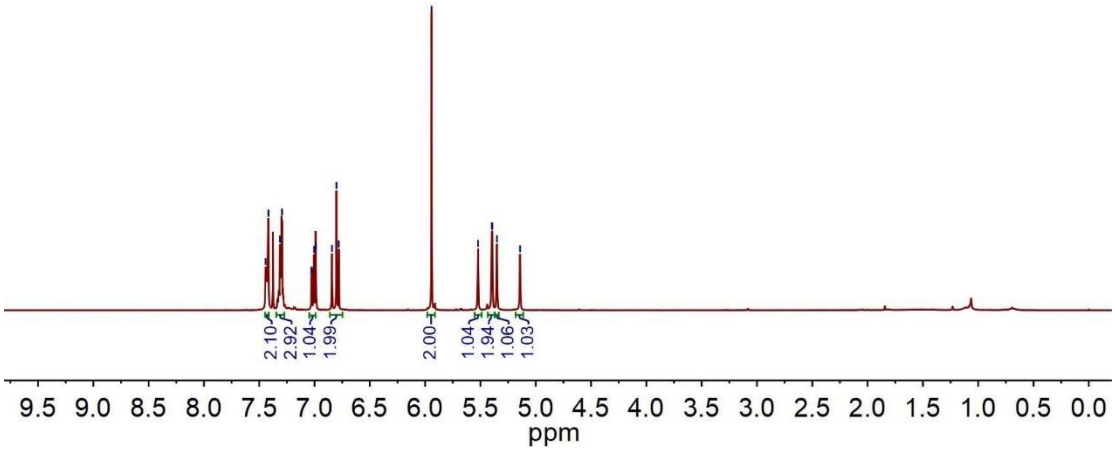


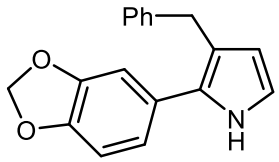
3-Benzyl-2-(4-(trifluoromethyl)phenyl)-1*H*-pyrrole (5e)

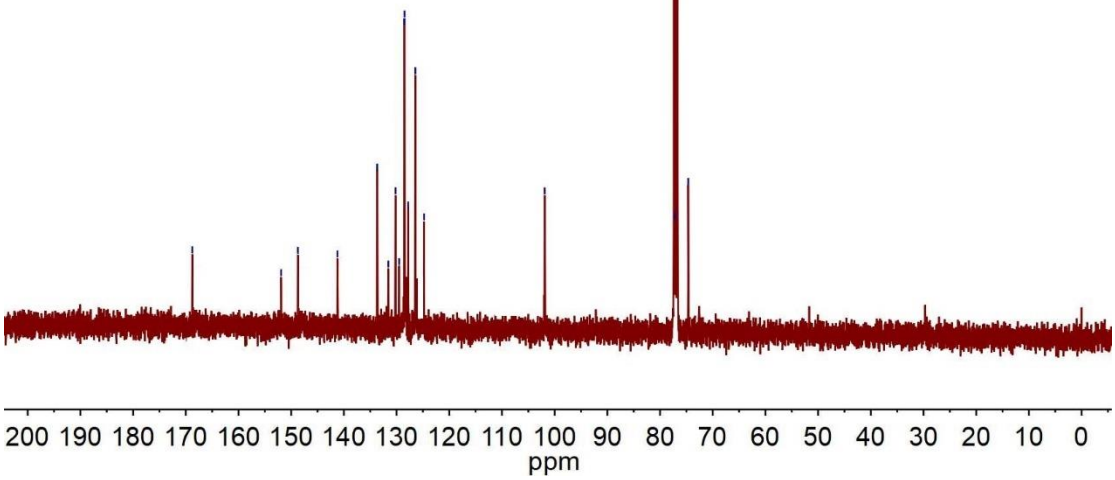


2-(Benzo[d][1,3]dioxol-5-yl)-3-benzyl-1*H*-pyrrole (5f)

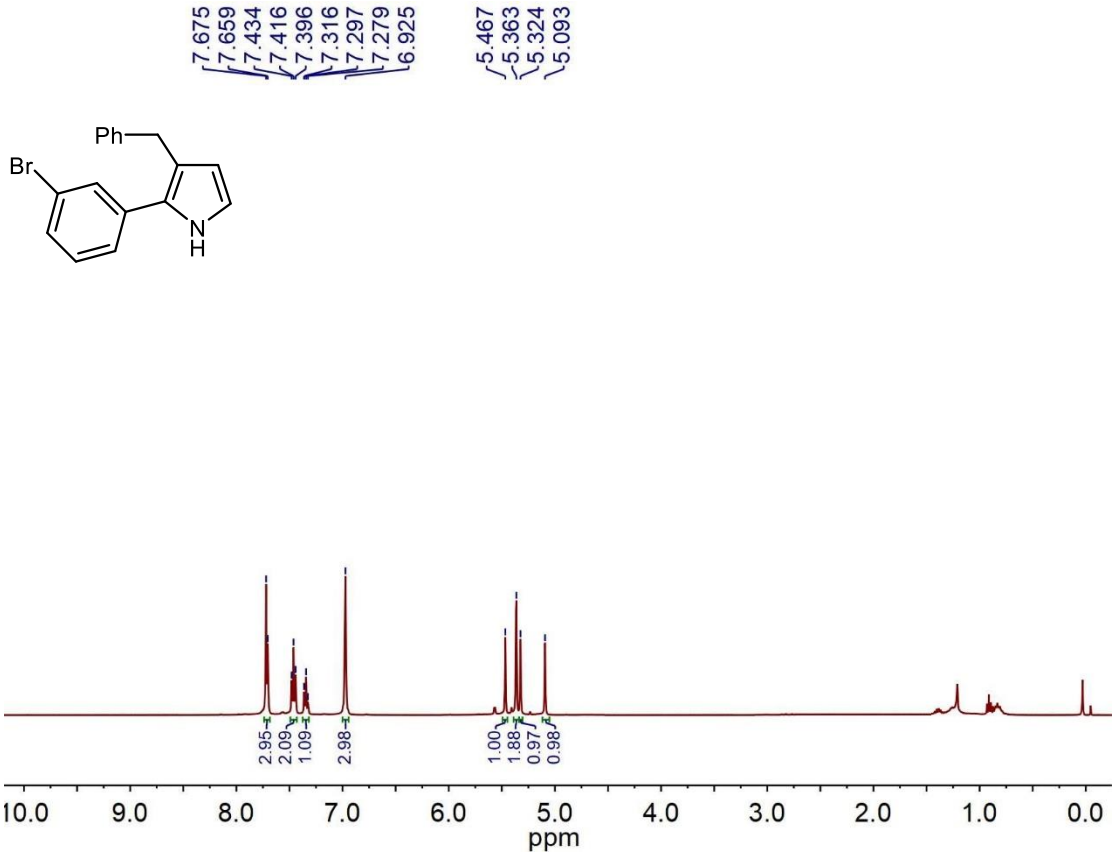


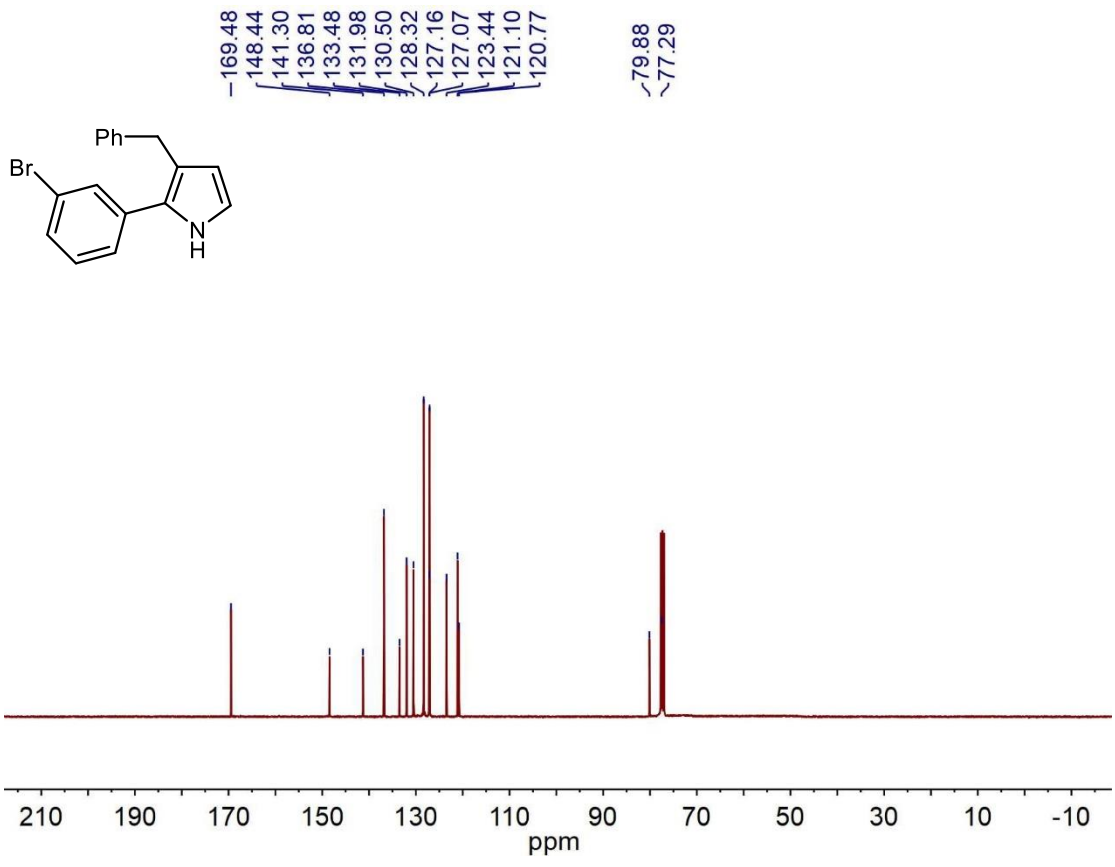




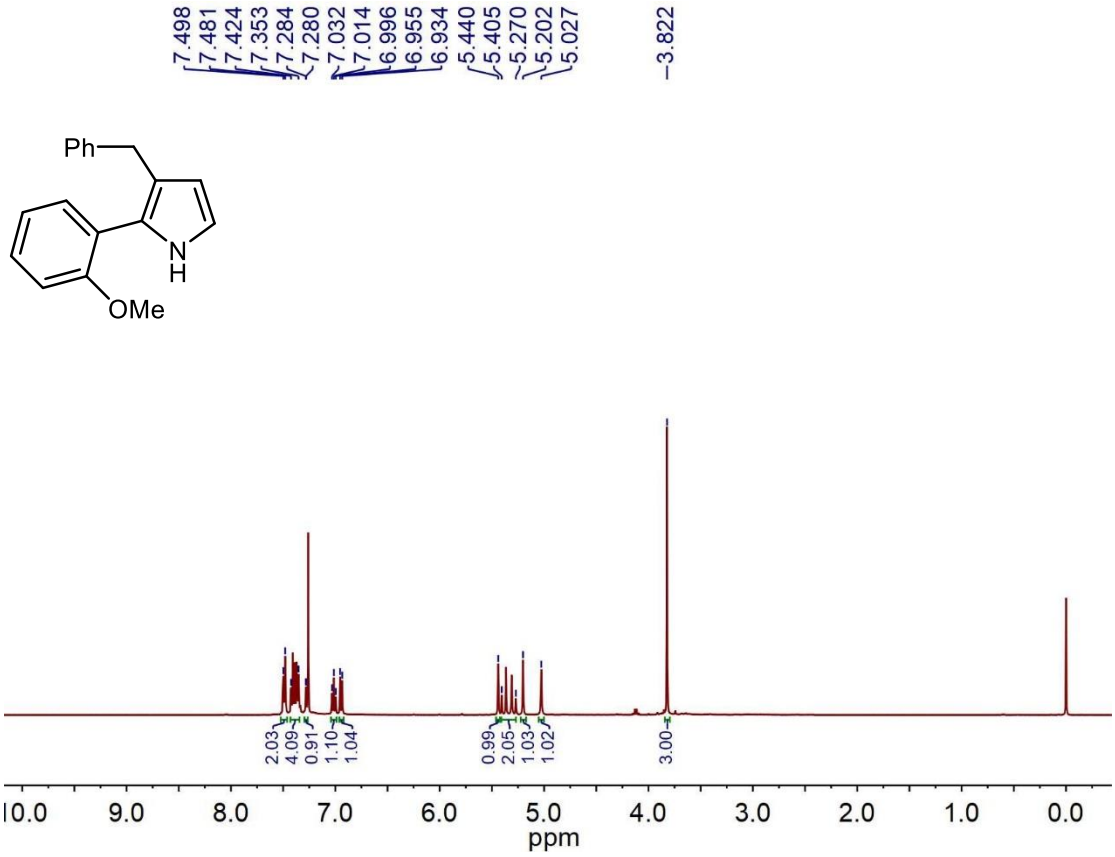


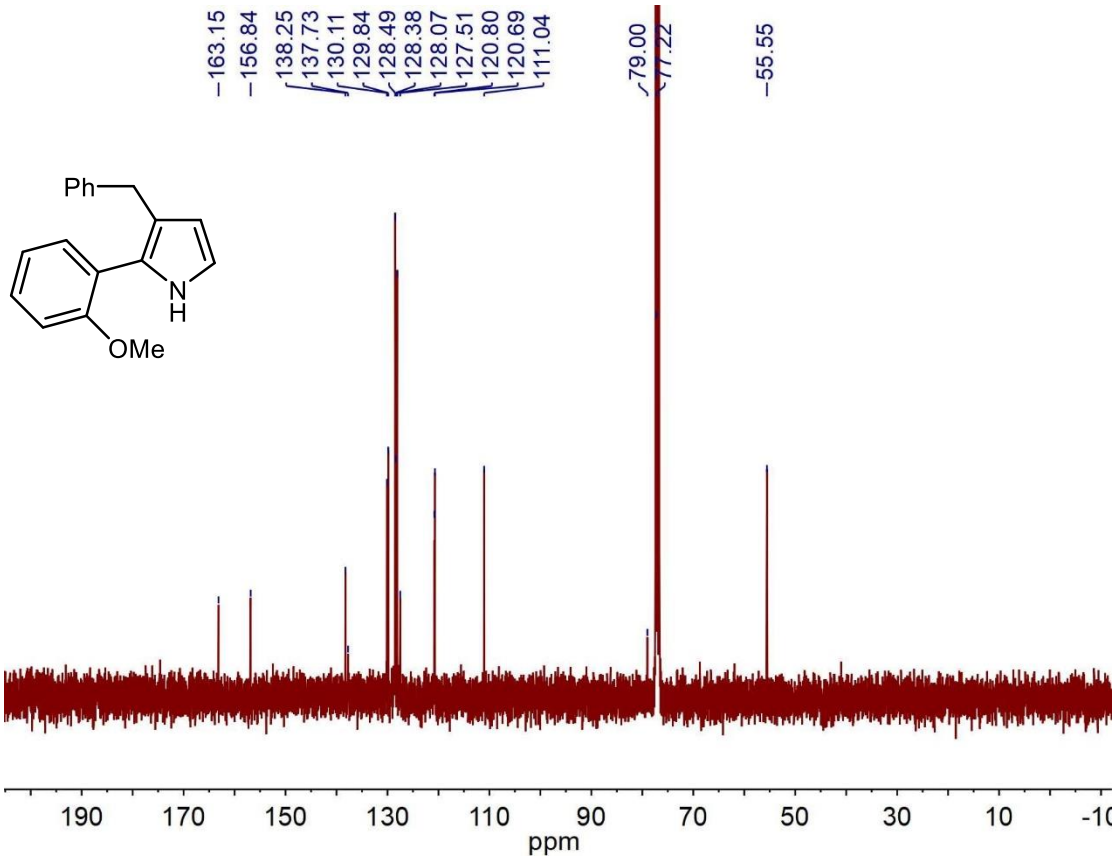
3-Benzyl-2-(3-bromophenyl)-1*H*-pyrrole (5g)



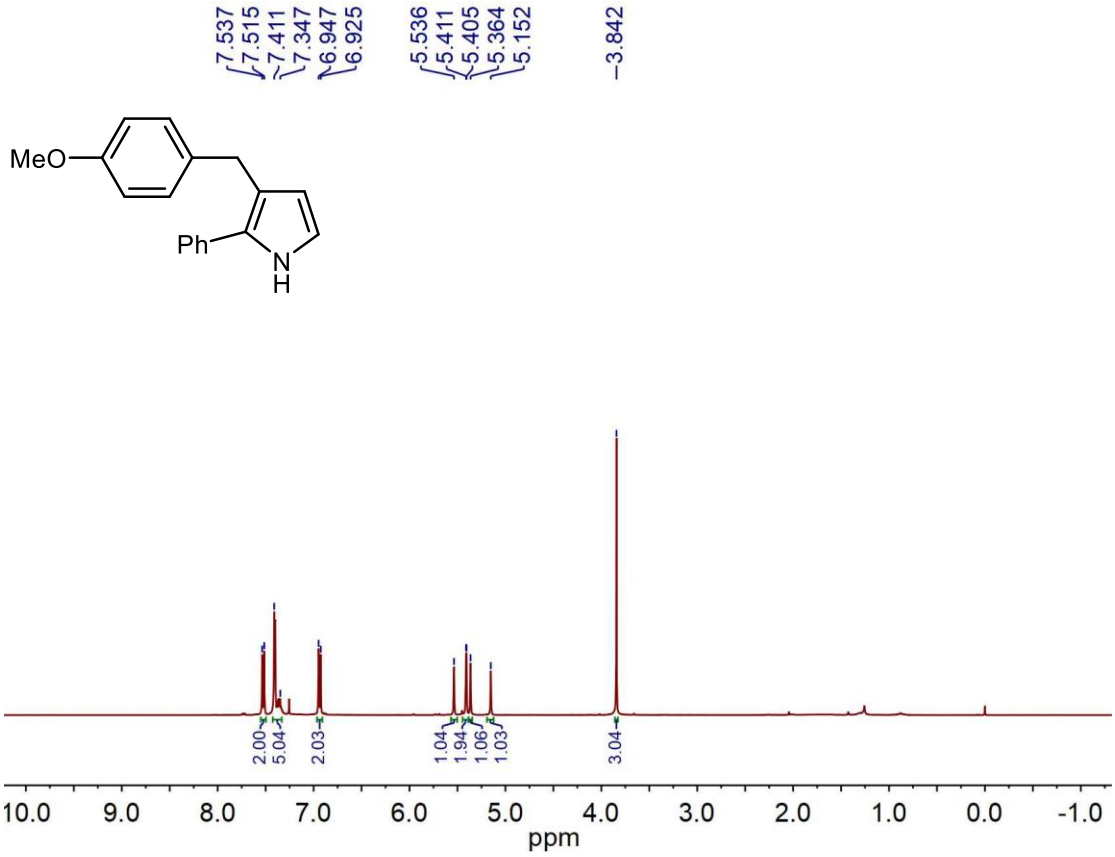


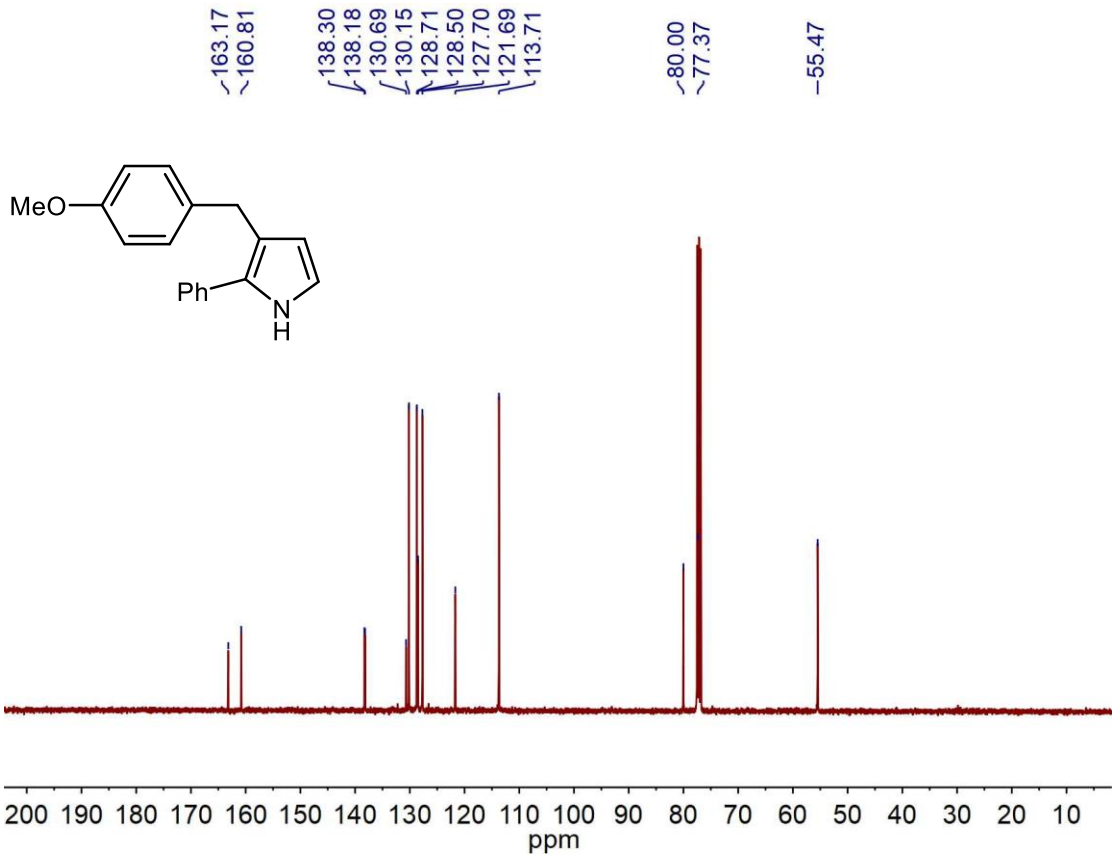
3-Benzyl-2-(2-methoxyphenyl)-1*H*-pyrrole (5h)



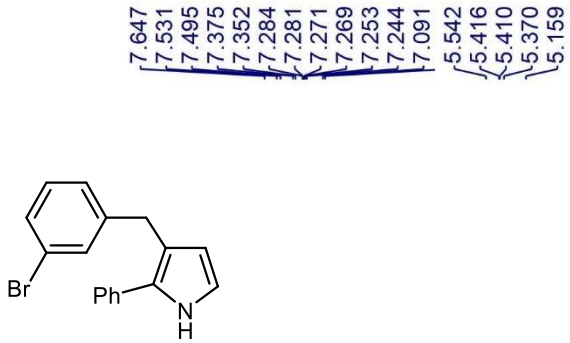


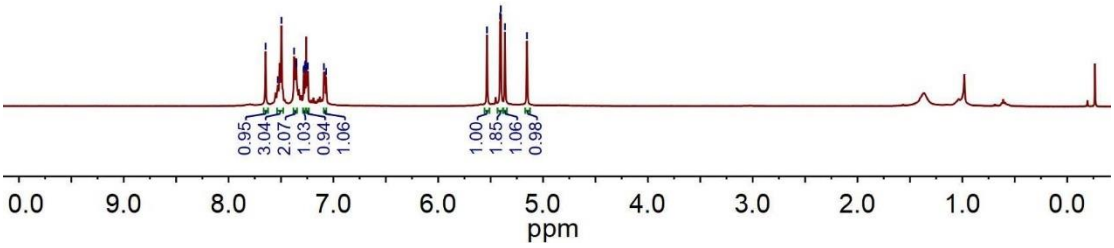
3-(4-Methoxybenzyl)-2-phenyl-1*H*-pyrrole (5i)

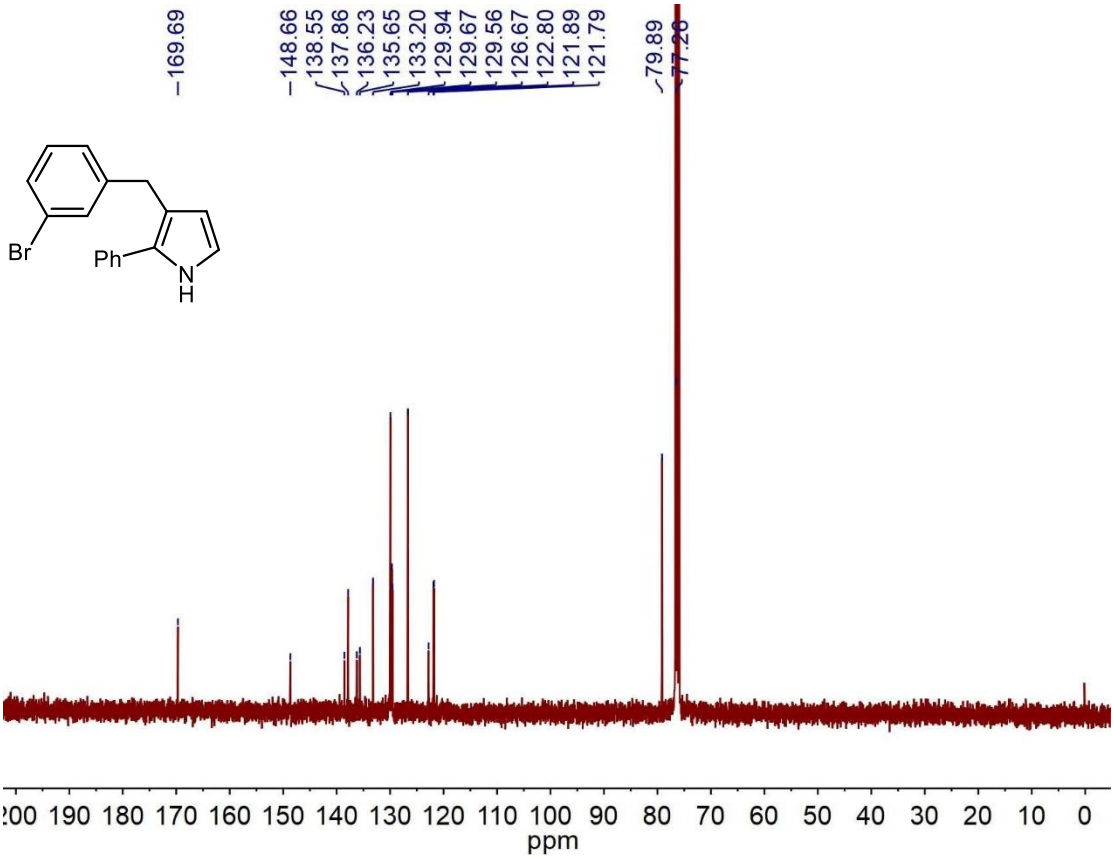




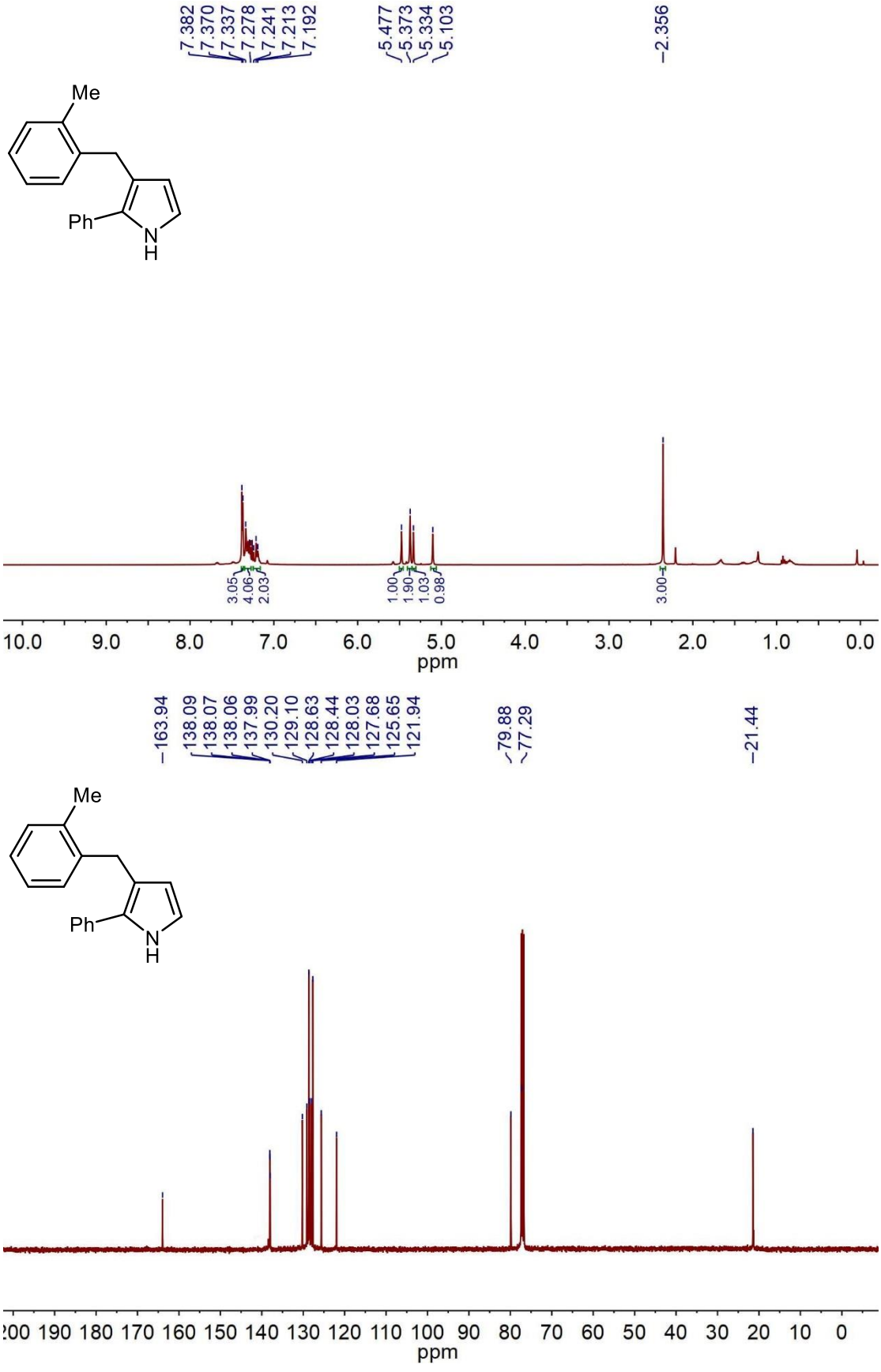
3-(3-Bromobenzyl)-2-phenyl-1*H*-pyrrole (5j)



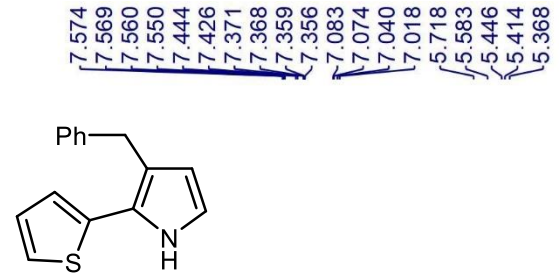


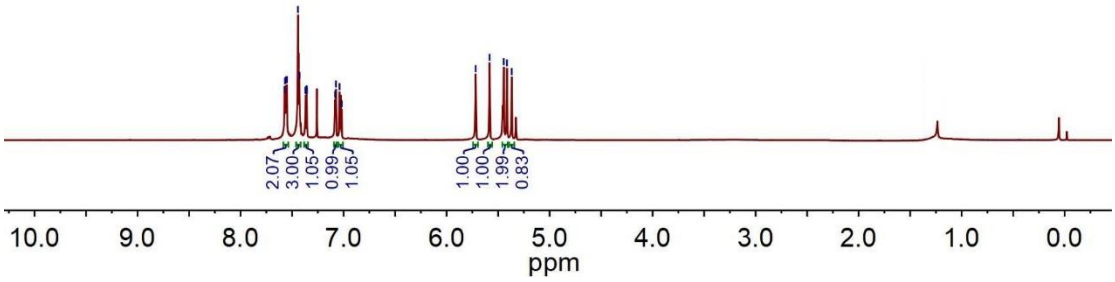


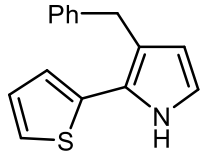
3-(2-Methylbenzyl)-2-phenyl-1*H*-pyrrole (5k)

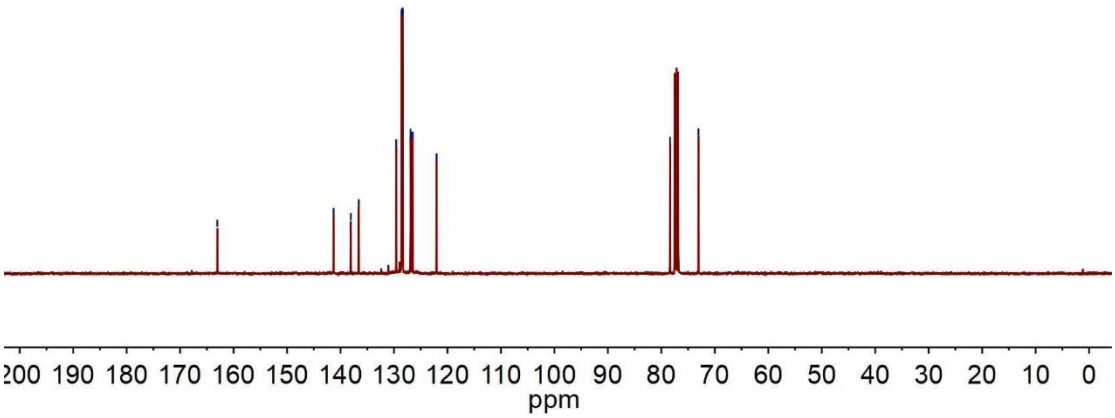


3-Benzyl-2-(thiophen-2-yl)-1*H*-pyrrole (5l)

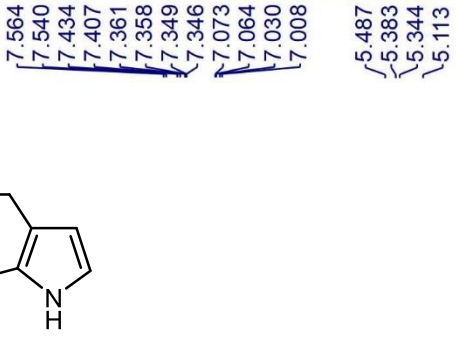


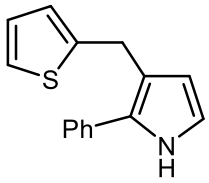


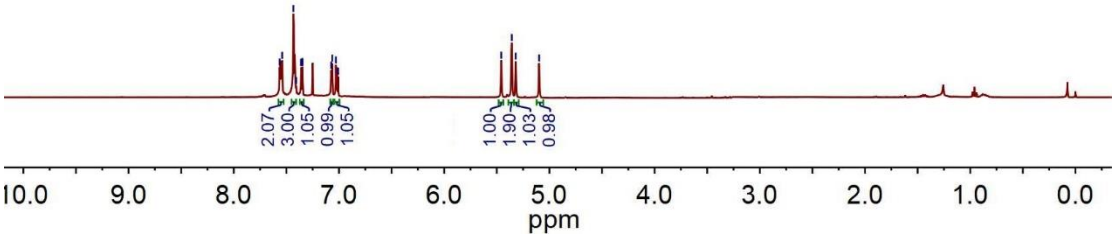


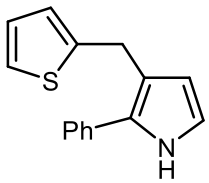


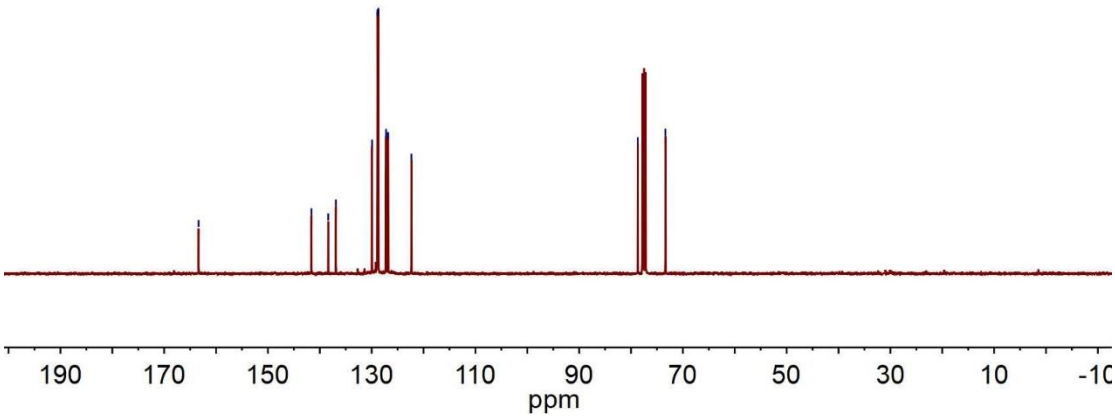
2-Phenyl-3-(thiophen-2-ylmethyl)-1*H*-pyrrole (5m)



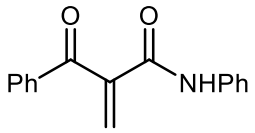


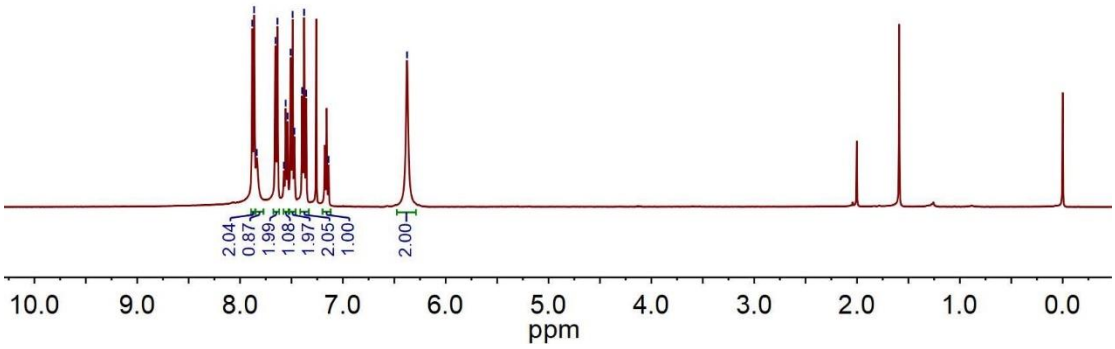


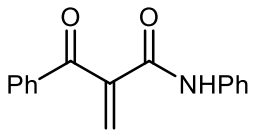


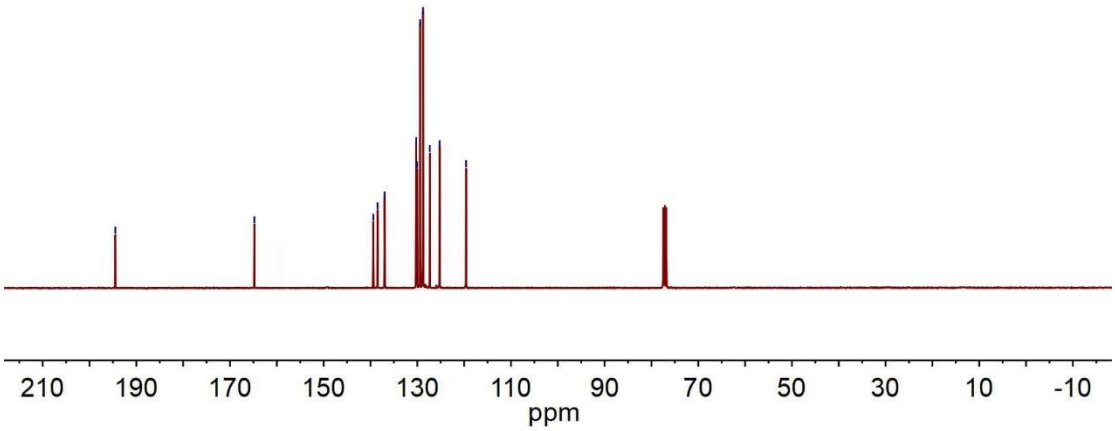


2-Benzoyl-*N*-phenylacrylamide (2a')

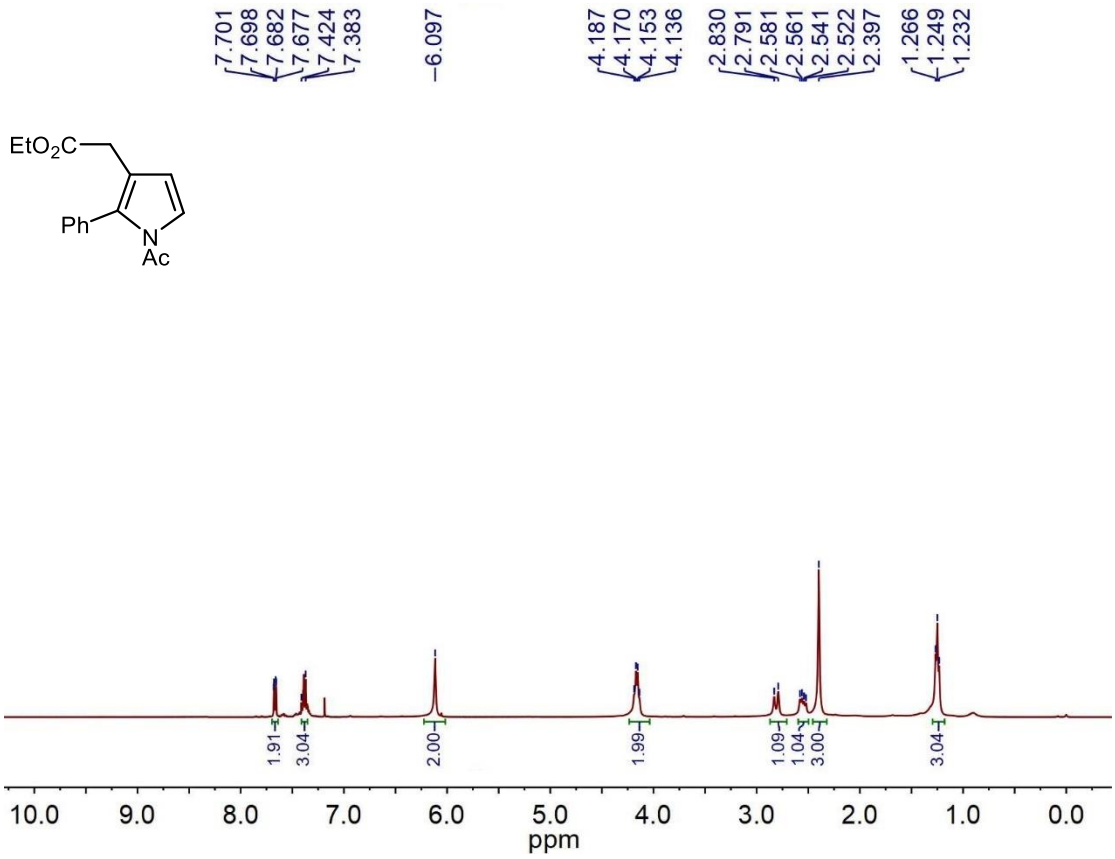


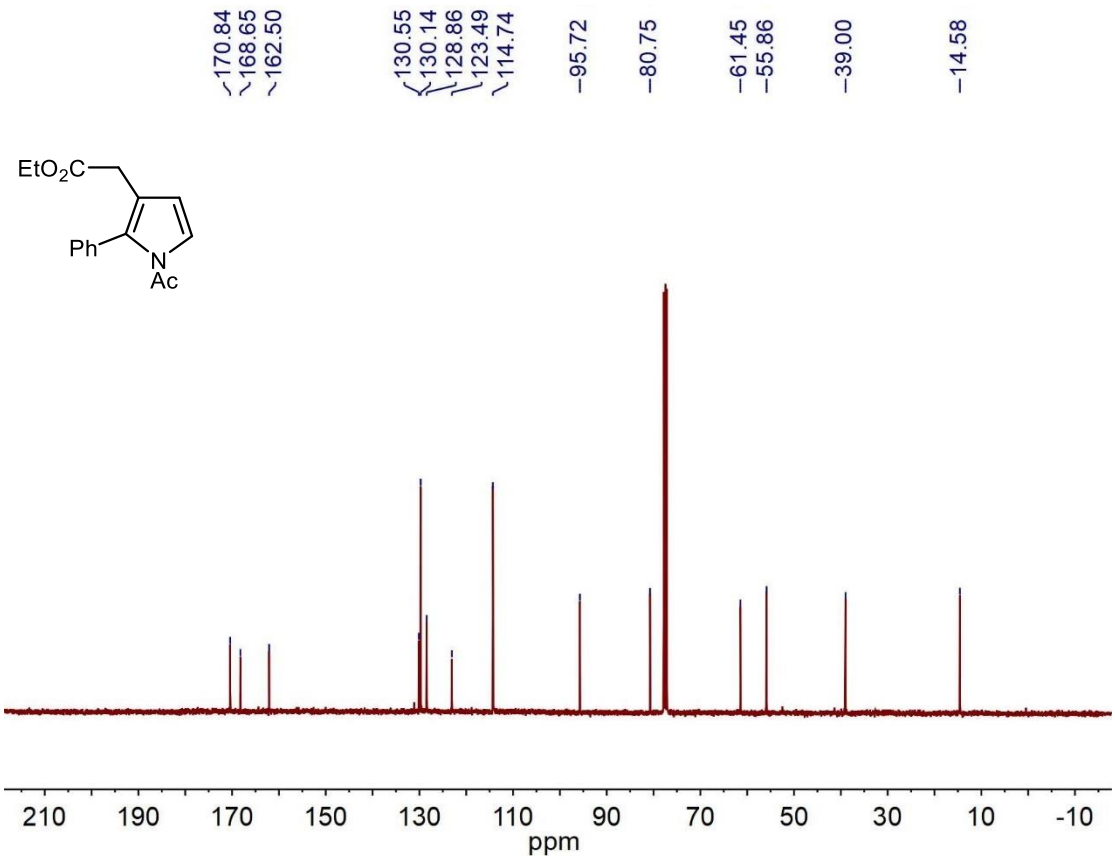




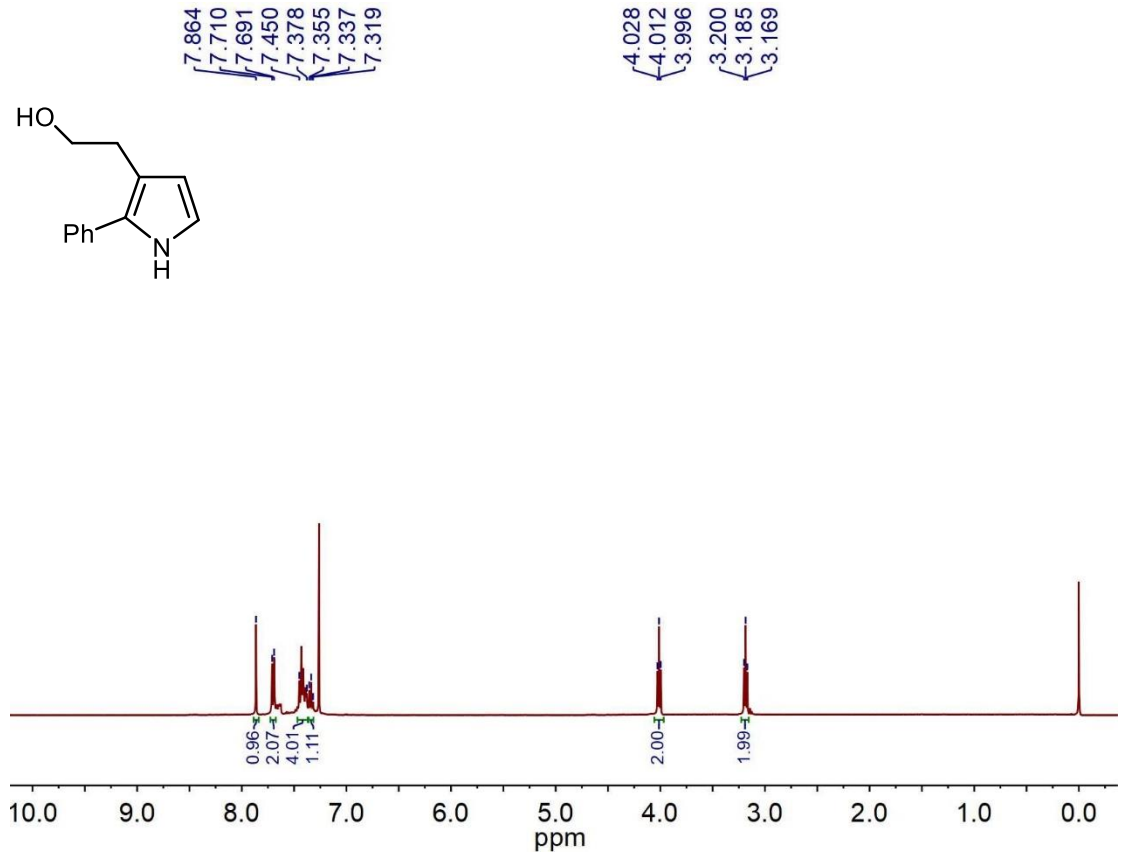


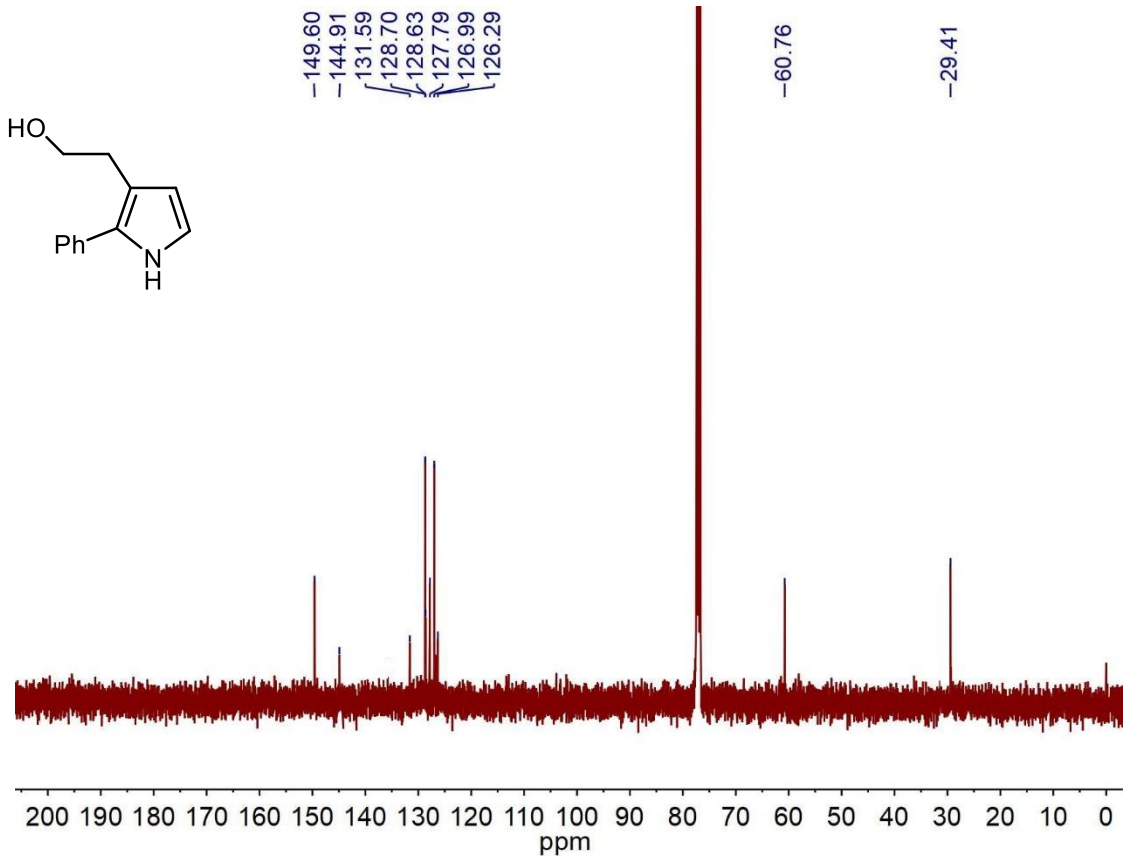
Ethyl 2-(1-acetyl-2-phenyl-1*H*-pyrrol-3-yl)acetate (6)



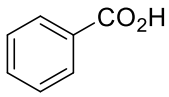


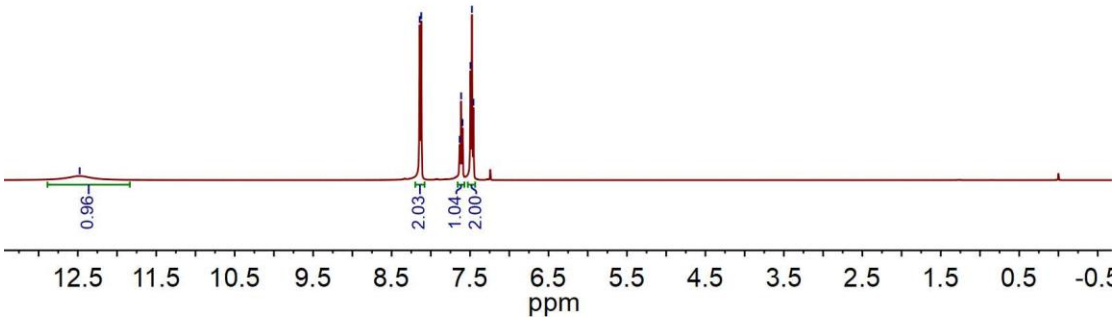
2-(2-Phenyl-1*H*-pyrrol-3-yl)ethan-1-ol (7)

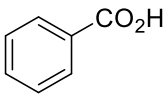


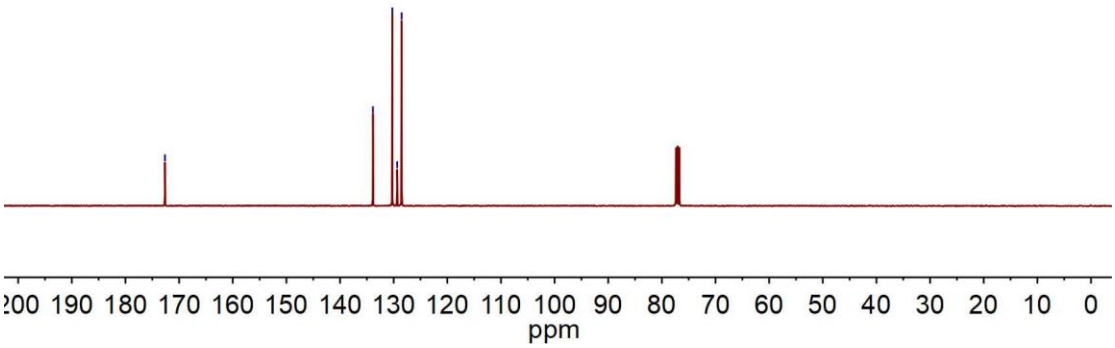


Benzoic acid









HRMS (ESI-TOF) analysis of the reaction mixture