Supporting Information

Nickel-catalyzed direct cross-coupling of heterocyclic phosphonium salt with aryl bromide

Yan-Ying Cui,[a] Wen-Xin Li,[a] Na-Na Ma,[a] Chuanji Shen,[b] Xiaocong Zhou,*[,b] Xue-Qiang Chu,[a] Weidong Rao,[c] Zhi-Liang Shen*[,a]

[a] Technical Institute of Fluorochemistry (TIF), Institute of Advanced Synthesis, School of Chemistry and Molecular Engineering, Nanjing Tech University, Nanjing 211816, China. E-mail: ias_zlshen@njtech.edu.cn.
[b] College of Biological, Chemical Science and Engineering, Jiaxing University, 118 Jiahang Road, Jiaxing 314001, China. E-mail: xczhou@zjxu.edu.cn.
[c] Jiangsu Provincial Key Lab for the Chemistry and Utilization of Agro-Forest Biomass, College of Chemical Engineering, Nanjing Forestry University, Nanjing 210037, China.

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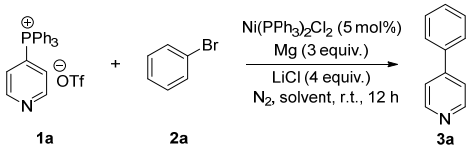
General Information

Commercially available aryl halides were used without further purification. Starting materials **1a-l** were prepared according to reported methods.[1-5] Analytical thin layer chromatography (TLC) was performed using silica gel plate (0.2 mm thickness). Subsequent to elution, plates were visualized using UV radiation (254 nm). Flash chromatography was performed using Merck silica gel (200-300 mesh) for column chromatography with freshly distilled solvents. Columns were typically packed as slurry and equilibrated with the appropriate solvent system prior to use. IR spectra were recorded on a FT-IR spectrophotometer using KBr optics. ^{1}H, ^{19}F, and ^{13}C NMR spectra were recorded in $CDCl_3$ on Jeol 400 MHz spectrometers. Tetramethylsilane (TMS) served as internal standard for ^{1}H and ^{13}C NMR analysis.

Optimization of Reaction Conditions

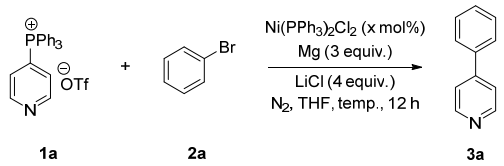
Table S1. Optimization of reaction conditions by using different solvents[a]



Entry	Solvent	Yield[b]
1	**THF**	**50%**
2	DME	38%
3	1,4-dioxane	<5%
4	2-MeTHF	<5%
5	CpOMe	<5%
6	^{t}BuOMe	<5%
7	THP	<5%
8	DMF	<5%

[a] Unless otherwise noted, the reactions were performed at room temperature for 12 h under nitrogen atmosphere by using **1a** (0.5 mmol), **2a** (1.5 mmol), $Ni(PPh_3)_2Cl_2$ (5 mol%, 0.025 mmol), magnesium turnings (1.5 mmol), and LiCl (2 mmol) in solvent (2 mL). [b] Yields were determined by NMR analysis of crude reaction mixture after work-up by using 1,4-dimethoxybenzene as an internal standard.

Table S2. Optimization of reaction conditions by using different catalyst loadings at different temperatures[a]

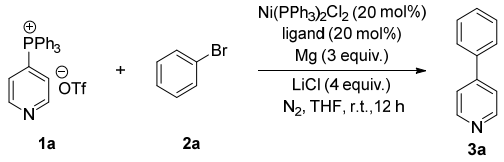


1a 2a 3a

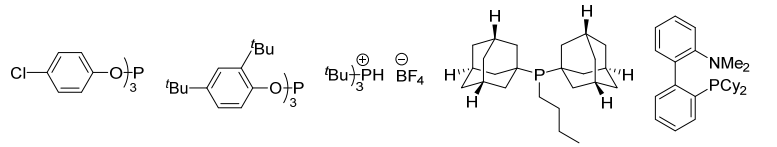
Entry	$Ni(PPh_3)_2Cl_2$ (x mol%)	Temp.	Yield[b]
1	5	0 °C	16%
2	5	r.t.	50%
3	5	60 °C	48%
4	10	r.t.	55%
5	**20**	**r.t.**	**63%**
6	20	r.t.	55%[c]

[a] Unless otherwise noted, the reactions were performed at different temperatures for 12 h under nitrogen atmosphere by using **1a** (0.5 mmol), **2a** (1.5 mmol), $Ni(PPh_3)_2Cl_2$ (x mol%), magnesium turnings (1.5 mmol), and LiCl (2 mmol) in THF (2 mL). [b] Yields were determined by NMR analysis of crude reaction mixture after work-up by using 1,4-dimethoxybenzene as an internal standard. [c] Using 2 equiv. of LiCl.

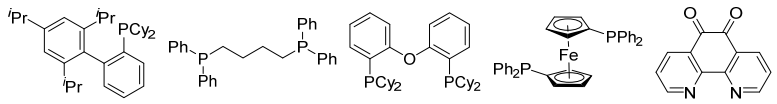
Table S3. Optimization of reaction conditions by using different ligands[a,b]



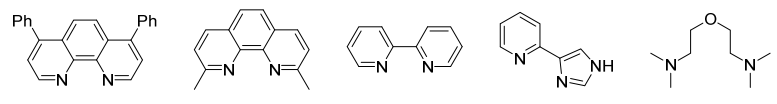
1a 2a 3a



L1, 57% **L2**, 64% TTBP•HBF_4 **L3**, 33% CataCxium **L4**, 58% DavePhos **L5**, 49%



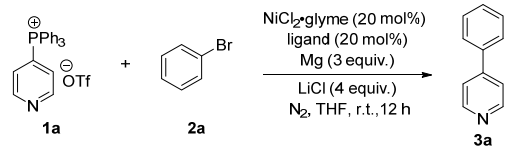
X-Phos **L6**, 49% DPPB **L7**, 26% **L8**,46% DPPF **L9**, 42% **L10**, 77%



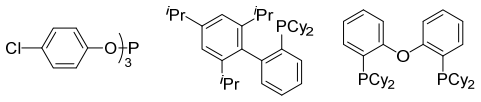
L11, 55% **L12**, 63% **L13**, 62% **L14**, 51% **L15**, 46%

[a] Unless otherwise noted, the reactions were performed at room temperature for 12 h under nitrogen atmosphere by using **1a** (0.5 mmol), **2a** (1.5 mmol), $Ni(PPh_3)_2Cl_2$ (20 mol%, 0.1 mmol), ligand (20 mol%, 0.1 mmol), magnesium turnings (1.5 mmol), and LiCl (2 mmol) in THF (2 mL). [b] Yields were determined by NMR analysis of crude reaction mixture after work-up by using 1,4-dimethoxybenzene as an internal standard.

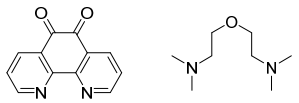
Table S4. Optimization of reaction conditions by using $NiCl_2$·glyme and different ligands[a,b]



1a 2a 3a



L1, 44% X-Phos L6, 51% L8,44%

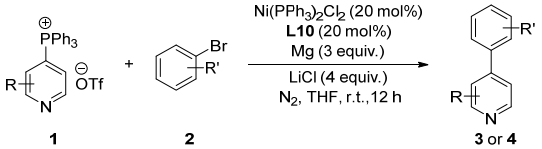


L10, 55% L15, 56%

[a] Unless otherwise noted, the reactions were performed at room temperature for 12 h under nitrogen atmosphere by using **1a** (0.5 mmol), **2a** (1.5 mmol), $NiCl_2$·glyme (20 mol%, 0.1 mmol), ligand (20 mol%, 0.1 mmol), magnesium turnings (1.5 mmol), and LiCl (2 mmol) in THF (2 mL). [b] Yields were determined by NMR analysis of crude reaction mixture after work-up by using 1,4-dimethoxybenzene as an internal standard.

Experimental Procedure

Typical procedures for the cross-coupling reaction of phosphonium salts with aryl bromides (Tables 2-3)



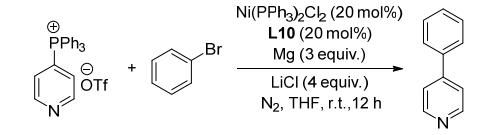
1 2 3 or 4

To an oven-dried seal tube equipped with a magnetic stir bar was added magnesium turnings (36.5 mg, 1.5 mmol) and LiCl (84.7 mg, 2 mmol). Then the mixture was dried under reduced pressure with a heat gun (320 ^{o}C) for 3 min. After cooling to room temperature, dry THF (2 mL) was added and the seal tube was backfilled with nitrogen (x 3). Then phosphonium salt (**1**, 0.5 mmol), $Ni(PPh_3)_2Cl_2$ (65.4 mg, 0.1 mmol), and 1,10-phenanthroline-5,6-dione (**L10**, 21.0 mg, 0.1 mmol) were weighed into the seal tube, followed by the addition of aryl bromide (**2**, 1.5 mmol) by syringe. The reaction mixture was stirred at room temperature for 12 h followed by quenching with saturated NH_4Cl solution (10 mL) and extracting with EtOAc (20 mL x 3). The combined

organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure to afford the crude product, which was further purified through silica gel column chromatography (using EtOAc/petroleum ether as eluents) to yield the product **3-4** as a white solid.

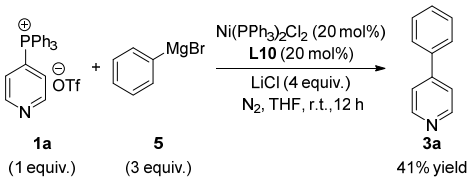
Control Experiments

3 mmol scale reaction



To an oven-dried seal tube equipped with a magnetic stir bar was added magnesium turnings (0.219 g, 9 mmol) and LiCl (0.508 g, 12 mmol). Then the mixture was dried under reduced pressure with a heat gun (320 ^oC) for 3 min. After cooling to room temperature, dry THF (12 mL) was added and the seal tube was backfilled with nitrogen (x 3). Then phosphonium salt (**1a**, 1.468 g, 3 mmol), $Ni(PPh_3)_2Cl_2$ (0.392 g, 0.6 mmol), and 1,10-phenanthroline-5,6-dione (**L10**, 0.126 g, 0.6 mmol) were weighed into the seal tube, followed by the addition of bromobenzene (**2a**, 1.413 g, 9 mmol) by syringe. The reaction mixture was stirred at room temperature for 12 h followed by quenching with saturated NH_4Cl solution (30 mL) and extracting with EtOAc (70 mL x 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure to afford the crude product, which was further purified through silica gel column chromatography (using EtOAc/petroleum ether as eluents) to yield the product **3a** as a white solid (0.297 g, 64%).

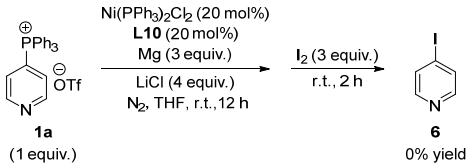
Direct cross-coupling of phosphonium salt 1a with phenylmagnesium bromide 5



To an oven-dried seal tube equipped with a magnetic stir bar was added LiCl (84.7 mg, 2 mmol), then it was dried under reduced pressure with a heat gun (320 ^oC) for 3 min. After cooling to room temperature, the seal tube was backfilled with nitrogen (x 3). Then phosphonium salt (**1a**, 244.7 mg, 0.5 mmol), $Ni(PPh_3)_2Cl_2$ (65.4 mg, 0.1 mmol), and 1,10-phenanthroline-5,6-dione (**L10**, 21.0 mg, 0.1 mmol) were weighed into the seal tube, followed by the addition of Grignard Reagent (**5**, 1.5 mL, 1.5 mmol, 1 M in THF) by syringe. The reaction mixture was stirred at room temperature for 12 h followed by quenching with saturated NH_4Cl solution (10 mL) and extracting with EtOAc (20 mL x 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure to afford the crude product, which was further purified

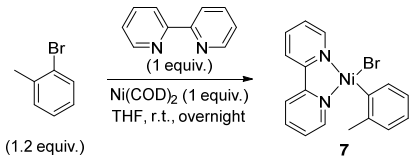
through silica gel column chromatography (using EtOAc/petroleum ether as eluents) to yield the product **3a** as a white solid (0.0321 g, 41% yield).

Treatment of phosphonium salt 1a with magnesium followed by quenching with iodine

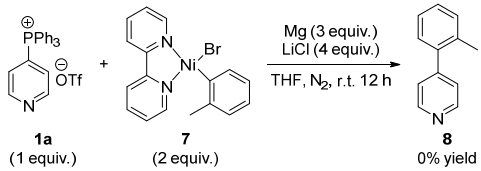


To an oven-dried seal tube equipped with a magnetic stir bar was added magnesium turnings (36.5 mg, 1.5 mmol) and LiCl (84.7 mg, 2 mmol). Then the mixture was dried under reduced pressure with a heat gun (320 ^{o}C) for 3 min. After cooling to room temperature, dry THF (2 mL) was added and the seal tube was backfilled with nitrogen (x 3). Then phosphonium salt (**1a**, 244.7 mg, 0.5 mmol), $Ni(PPh_3)_2Cl_2$ (65.4 mg, 0.1 mmol), and 1,10-phenanthroline-5,6-dione (**L10**, 21.0 mg, 0.1 mmol) were weighed into the seal tube. The reaction mixture was stirred at room temperature for 12 h followed by the addition of I_2 (0.3807 g, 1.5 mmol) and further stirring at room temperature for 2 h before quenching with saturated $Na_2S_2O_5$ solution (10 mL) and extracting with EtOAc (20 mL x 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. TLC analysis against authentic sample showed that no any iodinated product **6** was obtained.

Preparation of arylnickel compound 7 and its cross-coupling with phosphonium salt 1a



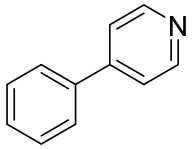
The reaction was performed in an argon-filled glove box.[6] To a flame-dried round-bottomed flask was added bpy (156 mg, 1.0 mmol), $Ni(cod)_2$ (275 mg, 1.0 mmol) and THF (10 mL). After the reaction mixture was stirred at room temperature for overnight, 1-bromo-2-methylbenzene (205 mg, 1.2 mmol) was added and the color changed from dark purple to red. After stirring at room temperature for 4 h, the mixture solution was concentrated under reduced pressure. The solid was washed with dry *n*-pentane for several times and then dried under vacuum for 2 h to give arylnickel compound **7** as a red solid.



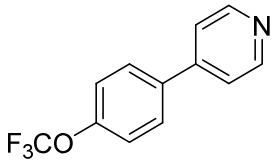
To an oven-dried seal tube equipped with a magnetic stir bar was added magnesium turnings (21.9 mg, 0.9 mmol) and LiCl (50.8 mg, 1.2 mmol). Then the mixture was dried under reduced pressure by a heat gun (320 ^{o}C) for 3 min. After cooling down to room temperature, dry THF (1.5 mL) was added and the seal tube was backfilled with nitrogen (x 3). Then phosphonium salt (**1a**, 0.3 mmol)

was added, followed by the addition of arylnickel compound **7** (23.2 mg, 0.6 mmol). The reaction mixture was stirred at room temperature for 12 h before quenching with saturated NH_4Cl solution (10 mL) and extracting with EtOAc (20 mL x 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Crude NMR and TLC analysis showed that no desired product **8** was formed.

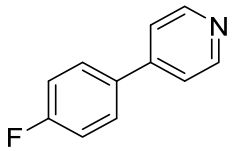
Characterization data of products



4-Phenylpyridine (3a): 57.4 mg. Yield = 74%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.66 (d, *J* = 5.6 Hz, 2H), 7.74-7.58 (m, 2H), 7.57-7.41 (m, 5H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.1, 148.4, 138.0, 129.1, 129.1, 127.0, 121.6 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{11}H_{10}N^+$: 156.0808, found: 156.0809. **FTIR (KBr, neat):** *v* 3058, 2923, 1588, 1483, 1410, 830, 761, 730, 688, 608 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

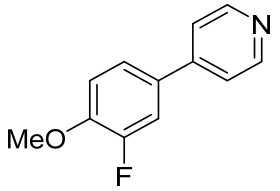


4-(4-(Trifluoromethoxy)phenyl)pyridine (3b): 50.2 mg. Yield = 42%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.67 (dd, *J* = 4.5, 1.6 Hz, 2H), 7.68-7.62 (m, 2H), 7.47 (dt, *J* = 4.5, 1.5 Hz, 2H), 7.36-7.29 (m, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.4, 149.9, 146.9, 136.8, 128.5, 121.5, 121.5, 120.4 (q, *J* = 257.0 Hz) ppm. **^{19}F NMR (376 MHz, $CDCl_3$):** δ -57.86 (s, 3F) ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_9F_3NO^+$: 240.0631, found: 240.0636. **FTIR (KBr, neat):** *v* 3420, 1599, 1489, 1265, 1212, 1167, 807 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

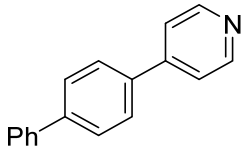


4-(4-Fluorophenyl)pyridine (3c): 46.6 mg. Yield = 54%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.64 (dt, *J* = 4.5, 1.5 Hz, 2H), 7.63-7.56 (m, 2H), 7.46-7.42 (m, 2H), 7.19-7.12 (m, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 163.4 (d, *J* = 247.3 Hz), 150.2, 147.2, 134.1, 128.7 (d, *J* = 8.3 Hz), 121.4, 116.1 (d, *J* = 21.7 Hz) ppm. **^{19}F**

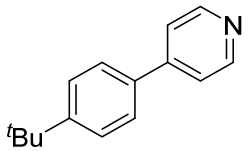
NMR (376 MHz, $CDCl_3$): δ -112.45 (s, 1F) ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{11}H_9FN^+$: 174.0714, found:174.0719. **FTIR (KBr, neat):** *v* 3039, 1607, 1516, 1488, 1220, 1162, 812, 555 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



4-(3-Fluoro-4-methoxyphenyl)pyridine (3d): 57.7 mg. Yield = 57%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.64 (d, *J* = 6.1 Hz, 2H), 7.50-7.46 (m, 2H), 7.41-7.39 (m, 2H), 7.05 (t, *J* = 8.7 Hz, 1H), 3.93 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 152.5 (d, *J* = 245.0 Hz), 149.9, 148.6 (d, *J* = 10.7 Hz), 147.1 (d, *J* = 2.3 Hz), 130.4 (d, *J* = 6.3 Hz), 122.8 (d, *J* = 3.6 Hz), 121.1, 114.5 (d, *J* = 19.2 Hz), 113.6 (d, *J* = 2.5 Hz), 56.2 ppm. **^{19}F NMR (376 MHz, $CDCl_3$):** δ -134.02 (s, 1F) ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{11}FNO^+$: 204.0819, found: 204.0825. **FTIR (KBr, neat):** *v* 3031, 2948, 2848, 1546, 1528, 1495, 1300, 1276, 1138, 805 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

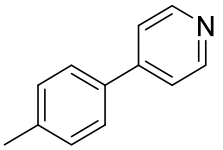


4-([1,1'-Biphenyl]-4-yl)pyridine (3e): 72.8 mg. Yield = 63%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.68 (d, *J* = 4.5 Hz, 2H), 7.72 (s, 4H), 7.65 (dd, *J* = 8.3, 1.2 Hz, 2H), 7.56 (d, *J* = 5.9 Hz, 2H), 7.48 (t, *J* = 7.7 Hz, 2H), 7.42-7.36 (m, 1H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.2, 147.8, 141.9, 140.2, 136.8, 128.9, 127.8, 127.7, 127.3, 127.0, 121.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{17}H_{14}N^+$: 232.1121, found: 232.1126. **FTIR (KBr, neat):** *v* 3024, 2924, 2853, 1603, 1588, 1481, 1404, 816, 765, 700, 690 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

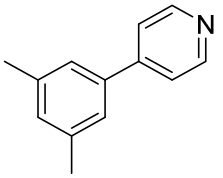


4-(4-(*tert*-Butyl)phenyl)pyridine (3f): 69.7 mg. Yield = 66%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.66-8.61 (m, 2H), 7.61-7.57 (m, 2H), 7.54-7.48 (m, 4H), 1.37 (s, 9H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 152.3, 150.1, 148.0, 135.1, 126.6, 126.0, 121.4, 34.6, 31.2 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{15}H_{18}N^+$: 212.1434, found:

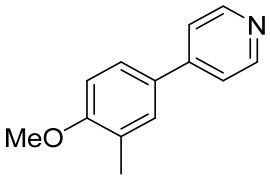
212.1439. **FTIR (KBr, neat):** *v* 3037, 2968, 2869, 1594, 1536, 1475, 1397, 1118, 1032, 811 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



4-(*p*-Tolyl)pyridine (3g): 43.4 mg. Yield = 51%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.67-8.60 (m, 2H), 7.54 (d, *J* = 7.7 Hz, 2H), 7.51-7.46 (m, 2H), 7.29 (d, *J* = 7.7 Hz, 2H), 2.41 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.1, 148.2, 139.2, 135.1, 129.8, 126.8, 121.3, 21.2 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}N^+$: 170.0964, found: 170.0966. **FTIR (KBr, neat):** *v* 3030, 1597, 1541, 1488, 1404, 1235, 1213, 1029, 801, 710 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

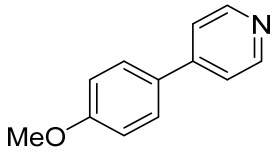


4-(3,5-Dimethylphenyl)pyridine (3h): 48.4 mg. Yield = 53%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.63 (dd, *J* = 4.7, 1.4 Hz, 2H), 7.50-7.45 (m, 2H), 7.24 (s, 2H), 7.08 (s, 1H), 2.39 (s, 6H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.0, 148.5, 138.6, 138.0, 130.6, 124.8, 121.6, 21.3 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{13}H_{14}N^+$: 184.1121, found: 184.1122. **FTIR (KBr, neat):** *v* 3025, 2914, 1617, 1595, 1548, 1402, 1221, 1028, 822, 697, 646 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

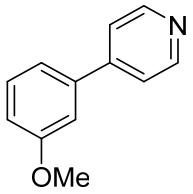


4-(4-Methoxy-3-methylphenyl)pyridine (3i): 44.0 mg. Yield = 44%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.61-8.58 (m, 2H), 7.48-7.44 (m, 4H), 6.91 (d, *J* = 8.4 Hz, 1H), 3.88 (s, 3H), 2.29 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 158.7, 150.0, 148.0, 129.8, 129.1, 127.4, 125.4, 121.0, 110.2, 55.4, 16.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{13}H_{14}NO^+$: 200.1070, found: 200.1071. **FTIR (KBr, neat):** *v* 2966, 2840, 1596, 1488, 1293, 1255, 1226, 1143, 1021, 806 cm^{-1}. The residue obtained was purified by

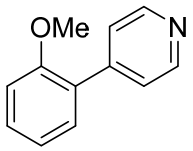
silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



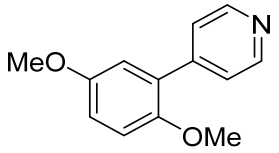
4-(4-Methoxyphenyl)pyridine (3j): 47.7 mg. Yield = 52%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.60 (d, *J* = 5.2 Hz, 2H), 7.62-7.54 (m, 2H), 7.49-7.42 (m, 2H), 7.03-6.95 (m, 2H), 3.85 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 160.5, 150.1, 147.7, 130.3, 128.1, 121.0, 114.5, 55.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}NO^+$: 186.0913, found: 186.0916. **FTIR (KBr, neat):** *v* 2967, 2938, 2842, 1607, 1488, 1287, 1257, 1228, 1035, 809 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



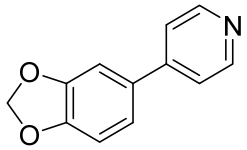
4-(3-Methoxyphenyl)pyridine (3k): 54.8 mg. Yield = 59%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.67-8.62 (m, 2H), 7.50-7.47 (m, 2H), 7.40 (t, *J* = 8.0 Hz, 1H), 7.21 (ddd, *J* = 7.7, 1.6, 0.9 Hz, 1H), 7.17-7.13 (m, 1H), 6.97 (ddd, *J* = 8.3, 2.6, 0.8 Hz, 1H), 3.87 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 160.1, 150.1, 148.2, 139.5, 130.1, 121.7, 119.3, 114.3, 112.7, 55.3 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}NO^+$: 186.0913, found: 186.0917. **FTIR (KBr, neat):** *v* 2959, 2935, 2837, 1596, 1583, 1546, 1477, 1302, 1216, 1032, 796 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



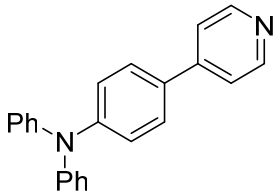
4-(2-Methoxyphenyl)pyridine (3l): 57.0 mg. Yield = 61%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.63-8.60 (m, 2H), 7.48-7.45 (m, 2H), 7.39 (ddd, *J* = 8.3, 7.5, 1.8 Hz, 1H), 7.33 (dd, *J* = 7.6, 1.7 Hz, 1H), 7.05 (td, *J* = 7.5, 1.0 Hz, 1H), 7.00 (d, *J* = 8.3 Hz, 1H), 3.83 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 156.4, 149.4, 146.2, 130.4, 130.1, 127.5, 124.2, 121.0, 111.3, 55.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}NO^+$: 186.0913, found: 186.0917. **FTIR (KBr, neat):** *v* 3015, 2965, 2836, 1590, 1483, 1270, 1233, 1024, 760, 609 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



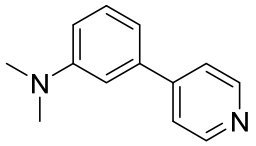
4-(2,5-Dimethoxyphenyl)pyridine (3m): 53.8 mg. Yield = 50%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.62 (d, *J* = 4.0 Hz, 2H), 7.50-7.42 (m, 2H), 6.93-6.89 (m, 3H), 3.80 (s, 3H), 3.76 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 153.8, 150.7, 149.4, 146.1, 128.4, 124.2, 116.2, 114.5, 112.7, 56.1, 55.8 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{13}H_{14}NO_2^+$: 216.1019, found: 216.1023. **FTIR (KBr, neat):** *v* 3010, 2948, 2831, 1596, 1488, 1405, 1232, 1022, 827, 711 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



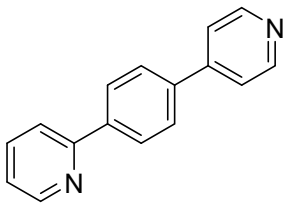
4-(Benzo[*d*][1,3]dioxol-5-yl)pyridine (3n): 49.7 mg. Yield = 50%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.60 (d, *J* = 4.9 Hz, 2H), 7.41 (dt, *J* = 4.5, 1.2 Hz, 2H), 7.15-7.12 (m, 1H), 7.12-7.09 (m, 1H), 6.93-6.89 (m, 1H), 6.02 (d, *J* = 1.1 Hz, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.1, 148.5, 148.5, 147.9, 132.2, 121.2, 120.9, 108.8, 107.2, 101.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{10}NO_2^+$: 200.0706, found: 200.0709. **FTIR (KBr, neat):** *v* 3034, 2891, 1599, 1514, 1418, 1415, 1239, 1015, 924, 802 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



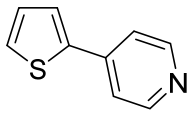
***N,N*-Diphenyl-4-(pyridin-4-yl)aniline (3o):** 99.2 mg. Yield = 62%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.76-8.59 (m, 2H), 7.56-7.48 (m, 4H), 7.32-7.28 (m, 4H), 7.18-7.12 (m, 6H), 7.11-7.06 (m, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** 149.7, 149.2, 148.5, 147.0, 130.1, 129.4, 127.7, 125.0, 123.7, 122.5, 121.1 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{23}H_{19}N_2^+$: 323.1543, found: 323.1548. **FTIR (KBr, neat):** *v* 3033, 2923, 2853, 1590, 1485, 1331, 1279, 809, 753, 696 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



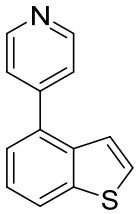
***N,N*-Dimethyl-3-(pyridin-4-yl)aniline (3p):** 57.3 mg. Yield = 58%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.65 (d, *J* = 5.2 Hz, 2H), 7.52 (d, *J* = 5.2 Hz, 2H), 7.34 (t, *J* = 7.9 Hz, 1H), 7.00-6.94 (m, 1H), 6.94-6.90 (m, 1H), 6.84-6.79 (m, 1H), 3.01 (s, 3H), 3.01 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.9, 149.9, 149.6, 138.9, 129.7, 121.9, 115.1, 113.1, 110.7, 40.5 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{13}H_{15}N_2^+$: 199.1230, found: 199.1235. **FTIR (KBr, neat):** *v* 3024, 2892, 2809, 1594, 1546, 1400, 1235, 989, 776, 698 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



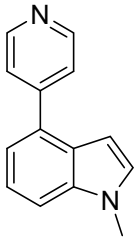
2-(4-(Pyridin-4-yl)phenyl)pyridine (3q): 81.5 mg. Yield = 70%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.65 (d, *J* = 4.8 Hz, 1H), 8.63-8.58 (m, 2H), 8.11-7.99 (m, 2H), 7.77-7.63 (m, 4H), 7.54-7.43 (m, 2H), 7.20 (q, *J* = 4.3 Hz, 1H) ppm.**^{13}C NMR (100 MHz, $CDCl_3$):** δ 156.4, 150.3, 149.8, 147.7, 140.0, 138.4, 136.8, 127.6, 127.3, 122.5, 121.5, 120.6 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{16}H_{13}N_2^+$: 233.1073, found: 233.1078. **FTIR (KBr, neat):** *v* 3036, 1591, 1563, 1540, 1464, 1434, 1405, 819, 719, 713 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



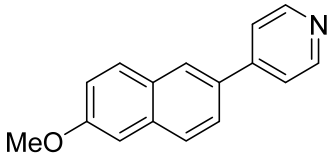
4-(Thiophen-2-yl)pyridine (3r): 51.0 mg. Yield = 64%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.57 (d, *J* = 5.0 Hz, 2H), 7.53-7.42 (m, 3H), 7.42-7.36 (m, 1H), 7.11 (ddd, *J* = 5.0, 3.7, 0.6 Hz, 1H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.3, 141.3, 141.0, 128.4, 127.1, 125.3, 119.8 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_9H_8NS^+$: 162.0372, found: 162.0373. **FTIR (KBr, neat):** *v* 3050, 1597, 1546, 1422, 1221, 990, 812, 729, 710, 695 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



4-(Benzo[*b*]thiophen-4-yl)pyridine (3s): 55.6 mg. Yield = 53%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.83 (d, *J* = 6.1 Hz, 2H), 8.00 (dt, *J* = 7.9, 1.0 Hz, 1H), 7.80-7.76 (m, 2H), 7.59 (d, *J* = 5.8 Hz, 1H), 7.47 (t, *J* = 7.6 Hz, 1H), 7.43 (dd, *J* = 4.9, 1.0 Hz, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 149.8, 148.7, 140.7, 137.2, 134.7, 129.1, 127.4, 126.9, 124.6, 124.3, 123.8, 122.9, 122.3 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{13}H_{10}NS^+$: 212.0528, found: 212.0534. **FTIR (KBr, neat):** *v* 3446, 1597, 1541, 1400, 1204, 824, 786, 760, 699, 647 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

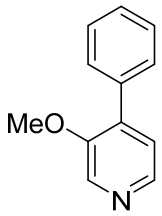


1-Methyl-4-(pyridin-4-yl)-1*H*-indole (3t): 35.1 mg. Yield = 36%. **^{1}H NMR (400 MHz, $CDCl_3$):** 8.65-8.59 (m, 2H), 7.94 (d, *J* = 1.4 Hz, 1H), 7.65-7.60 (m, 2H), 7.53 (dd, *J* = 8.6, 1.8 Hz, 1H), 7.42 (d, J = 8.6 Hz, 1H), 7.13 (d, *J* = 3.1 Hz, 1H), 6.58 (dd, *J* = 3.1, 0.8 Hz, 1H), 3.84 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.5, 149.0, 137.2, 130.1, 129.0, 128.9, 121.8, 120.6, 119.8, 109.9, 101.7, 33.0 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{14}H_{13}N_2^+$: 209.1073, found: 209.1069. **FTIR (KBr, neat):** *v* 3551, 3415, 1636, 1615, 1593, 1250, 1024, 796, 618 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

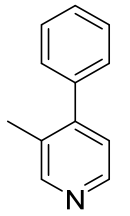


4-(6-Methoxynaphthalen-2-yl)pyridine (3u): 75.8 mg. Yield = 64%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.68 (d, *J* = 4.9 Hz, 2H), 8.06 (s, 1H), 7.84 (t, *J* = 9.4 Hz, 2H), 7.72 (dd, *J* = 8.5, 1.8 Hz, 1H), 7.62 (d, *J* = 5.9 Hz, 2H), 7.24-7.16 (m, 2H), 3.95 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 158.4, 150.2, 148.3, 134.7, 133.0, 130.0, 128.9, 127.7, 126.2, 125.0, 121.6, 119.6, 105.5, 55.4 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{16}H_{14}NO^+$: 236.1070, found: 236.1073. **FTIR (KBr, neat):** *v* 2924, 2853, 1625, 1590, 1495, 1257, 1208, 1023, 834, 801 cm^{-1}. The residue obtained was

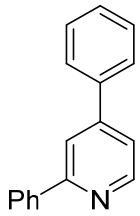
purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



3-Methoxy-4-phenylpyridine (4b): 62.5 mg. Yield = 67%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.37 (s, 1H), 8.31 (d, *J* = 4.8 Hz, 1H), 7.57 (dd, *J* = 8.2, 1.3 Hz, 2H), 7.48-7.36 (m, 3H), 7.25 (d, *J* = 4.8 Hz, 1H), 3.90 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 152.5, 142.9, 137.5, 135.6, 134.3, 129.1, 128.2, 128.2, 124.4, 56.2 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}NO^+$: 186.0913, found: 186.0916. **FTIR (KBr, neat):** *v* 3058, 2925, 2841, 1505, 1479, 1410, 1280, 1015, 747, 698 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 20:1).

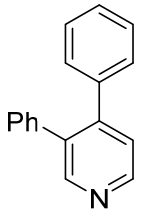


3-Methyl-4-phenylpyridine (4c): 32.6 mg. Yield = 39%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.55 (s, 1H), 8.51 (d, *J* = 5.1 Hz, 1H), 7.48-7.39 (m, 3H), 7.35-7.29 (m, 2H), 7.21 (d, *J* = 5.1 Hz, 1H), 2.29 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.9, 149.7, 147.1, 138.8, 130.0, 128.5, 128.4, 128.1, 124.2, 17.2 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{12}N^+$: 170.0964, found: 170.0968. **FTIR (KBr, neat):** *v* 3398, 3028, 2925, 1591, 1478, 1443, 1404, 743, 770, 702 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

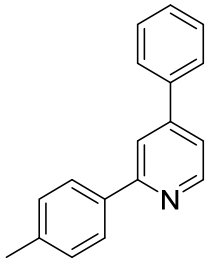


2,4-Diphenylpyridine (4d): 82.0 mg. Yield = 71%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.80-8.72 (m, 1H), 8.13-8.04 (m, 2H), 7.98-7.91 (m, 1H), 7.74-7.66 (m, 2H), 7.57-7.41 (m, 7H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 158.0, 150.0, 149.2, 139.4, 138.4, 129.0, 129.0, 128.7, 127.0, 127.0, 120.2, 118.7 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{17}H_{14}N^+$: 232.1121, found: 232.1126. **FTIR (KBr, neat):** *v* 3056,

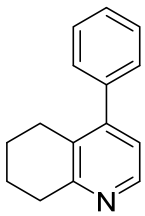
1593, 1578, 1541, 1470, 1443, 1387, 762, 733, 694 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



3,4-Diphenylpyridine (4e): 95.6 mg. Yield = 83%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.65-8.63 (m, 1H), 8.61 (d, *J* = 5.1 Hz, 1H), 7.32 (dd, *J* = 5.1, 0.6 Hz, 1H), 7.27-7.21 (m, 6H), 7.17-7.11 (m, 4H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.9, 148.6, 147.6, 138.5, 137.6, 135.6, 129.7, 129.2, 128.1, 127.7, 127.2, 124.5 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{17}H_{14}N^+$: 232.1121, found: 232.1126. **FTIR (KBr, neat):** *v* 3056, 3021, 1584, 1472, 1443, 1399, 832, 762, 749, 700 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

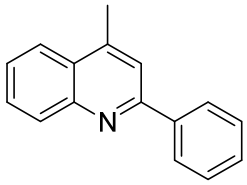


4-Phenyl-2-(*p*-tolyl)pyridine (4f): 77.8 mg. Yield = 63%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.73 (d, *J* = 5.2 Hz, 1H), 7.98 (d, *J* = 8.2 Hz, 2H), 7.93-7.90 (m, 1H), 7.72-7.67 (m, 2H), 7.54-7.40 (m, 4H), 7.32 (d, *J* = 8.1 Hz, 2H), 2.43 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 158.0, 149.9, 149.1, 139.0, 138.6, 136.6, 129.4, 129.4, 129.0, 127.0, 126.8, 119.9, 118.4, 21.2 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{18}H_{16}N^+$: 246.1277, found: 246.1283. **FTIR (KBr, neat):** *v* 3028, 2920, 1594, 1541, 1468, 1384, 1183, 820, 760, 695 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).

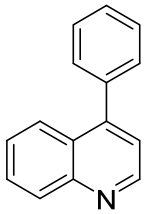


4-Phenyl-5,6,7,8-tetrahydroquinoline (4g): 84.3 mg. Yield = 81%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.39 (d, *J* = 4.9 Hz, 1H), 7.47-7.34 (m, 3H), 7.28 (dt, *J* = 6.9, 1.2 Hz,

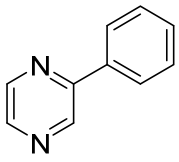
2H), 6.96 (d, J = 4.9 Hz, 1H), 3.01 (t, J = 6.5 Hz, 2H), 2.63 (t, J = 6.3 Hz, 2H), 1.94-1.87 (m, 2H), 1.75-1.69 (m, 2H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 157.5, 149.5, 146.4, 139.3, 129.8, 128.4, 128.2, 127.7, 121.9, 32.9, 27.3, 22.9, 22.9 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{15}H_{16}N^+$: 210.1277, found: 210.1283. **FTIR (KBr, neat):** ν 3054, 2929, 2854, 1579, 1546, 1437, 1402, 865, 764, 702 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



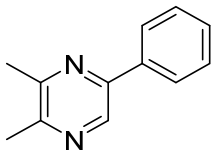
4-Methyl-2-phenylquinoline (4h): 92.7 mg. Yield = 84%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.25-8.21 (m, 1H), 8.20-8.16 (m, 2H), 7.97 (dd, J = 8.3, 1.1 Hz, 1H), 7.73 (ddd, J = 8.4, 6.8, 1.4 Hz, 1H), 7.71-7.69 (m, 1H), 7.57-7.52 (m, 3H), 7.50-7.45 (m, 1H), 2.73 (d, J = 0.8 Hz, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 156.9, 148.0, 144.7, 139.7, 130.2, 129.2, 129.1, 128.7, 127.4, 127.1, 125.9, 123.5, 119.6, 18.9 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{16}H_{14}N^+$: 220.1121, found: 220.1126. **FTIR (KBr, neat):** ν 3059, 2920, 1597, 1550, 1495, 1450, 1348, 769, 755, 693 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 20:1).



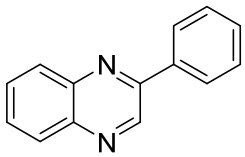
4-Phenylquinoline (4i): 58.6 mg. Yield = 57%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.94 (d, J = 4.4 Hz, 1H), 8.21-8.17 (m, 1H), 7.92 (dd, J = 8.5, 1.2 Hz, 1H), 7.72 (ddd, J = 8.4, 6.8, 1.4 Hz, 1H), 7.57-7.45 (m, 6H), 7.32 (d, J = 4.4 Hz, 1H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 149.9, 148.6, 148.4, 137.9, 129.8, 129.5, 129.2, 128.5, 128.3, 126.7, 126.5, 125.8, 121.3 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{15}H_{12}N^+$: 206.0964, found: 206.0964. **FTIR (KBr, neat):** ν 3058, 2923, 1583, 1574, 1507, 1490, 1444, 1390, 769, 695 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



2-Phenylpyrazine (4j): 33.2 mg. Yield = 43%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 9.03 (d, *J* = 1.4 Hz, 1H), 8.67-8.58 (m, 1H), 8.50 (d, *J* = 2.5 Hz, 1H), 8.06-7.97 (m, 2H), 7.56-7.42 (m, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 152.8, 144.1, 142.9, 142.2, 136.3, 129.9, 129.0, 126.9 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{10}H_9N_2^+$: 157.0760, found: 157.0766. **FTIR (KBr, neat):** *v* 3050, 1474, 1447, 1405, 1148, 1082, 1019, 772, 744, 692 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 5:1).



2,3-Dimethyl-5-phenylpyrazine (4k): 73.2 mg. Yield = 79%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 8.69 (s, 1H), 7.97 (d, *J* = 7.5 Hz, 2H), 7.51-7.37 (m, 3H), 2.59 (s, 3H), 2.55 (s, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 151.6, 150.4, 149.3, 138.1, 136.7, 129.1, 128.8, 126.5, 22.2, 21.7 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{12}H_{13}N_2^+$: 185.1073, found:185.1079. **FTIR (KBr, neat):** *v* 3050, 2982, 1462, 1446, 1386, 1178, 1167, 776, 743, 689 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 10:1).



2-Phenylquinoxaline (4l): 48.0 mg. Yield = 47%. **^{1}H NMR (400 MHz, $CDCl_3$):** δ 9.33 (s, 1H), 8.23-8.09 (m, 4H), 7.82-7.71 (m, 2H), 7.61-7.48 (m, 3H) ppm. **^{13}C NMR (100 MHz, $CDCl_3$):** δ 151.8, 143.3, 142.3, 141.5, 136.7, 130.3, 130.2, 129.6, 129.5, 129.1, 129.1, 127.5 ppm. **HRMS (ESI, m/z):** $[M+H]^+$, calcd. for $C_{14}H_{11}N_2^+$: 207.0917, found: 207.0922. **FTIR (KBr, neat):** *v* 3059, 2923, 2853, 1548, 1488, 1316, 957, 772, 761, 689 cm^{-1}. The residue obtained was purified by silica gel column chromatography using petroleum ether/ethyl acetate as eluent (petroleum ether/EtOAc = 10:1).

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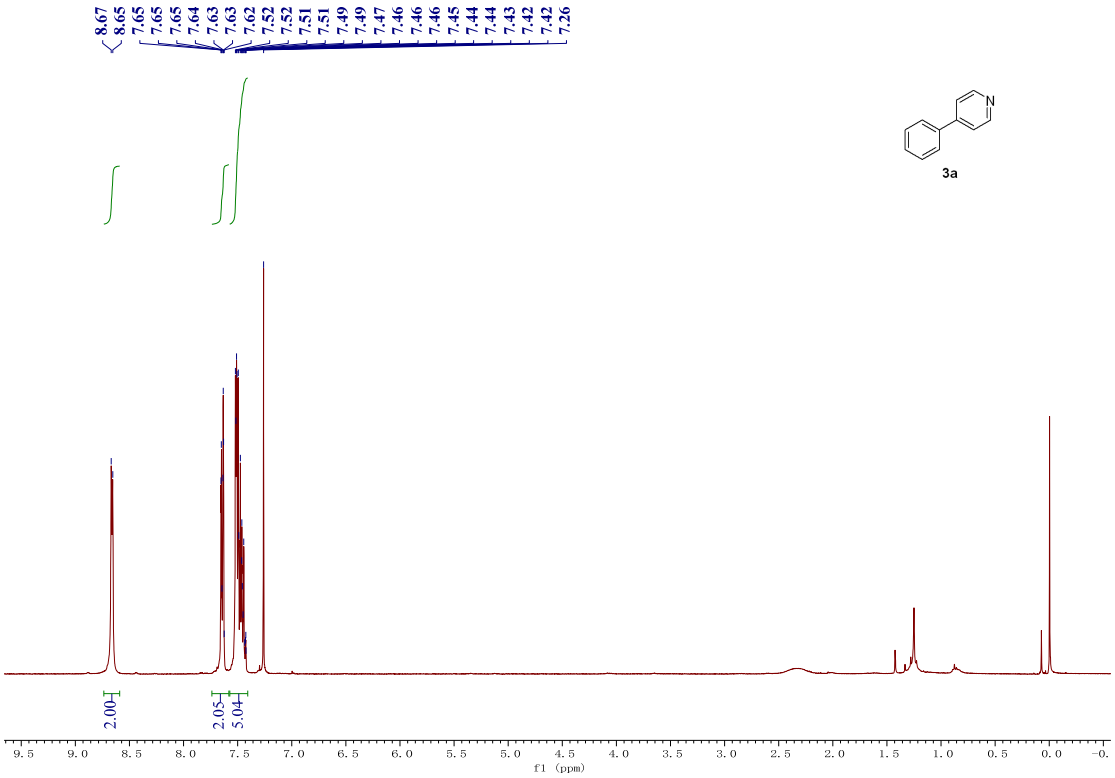
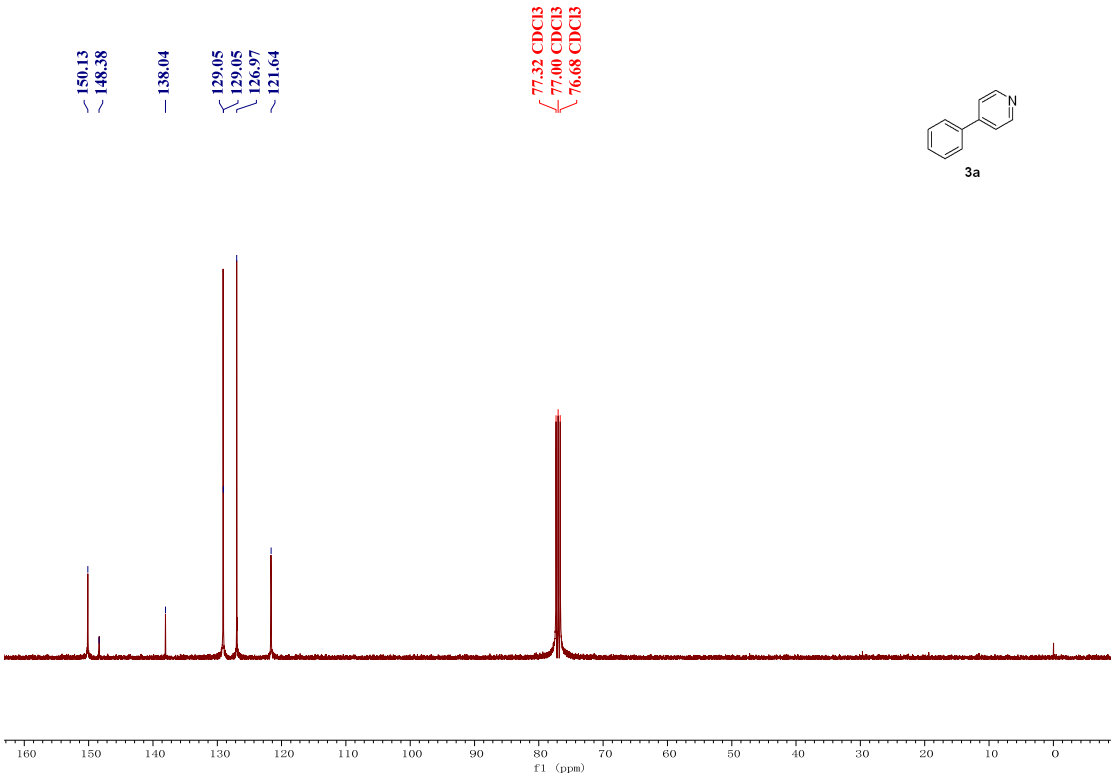
^{1}H, ^{19}F, and ^{13}C NMR spectra of products

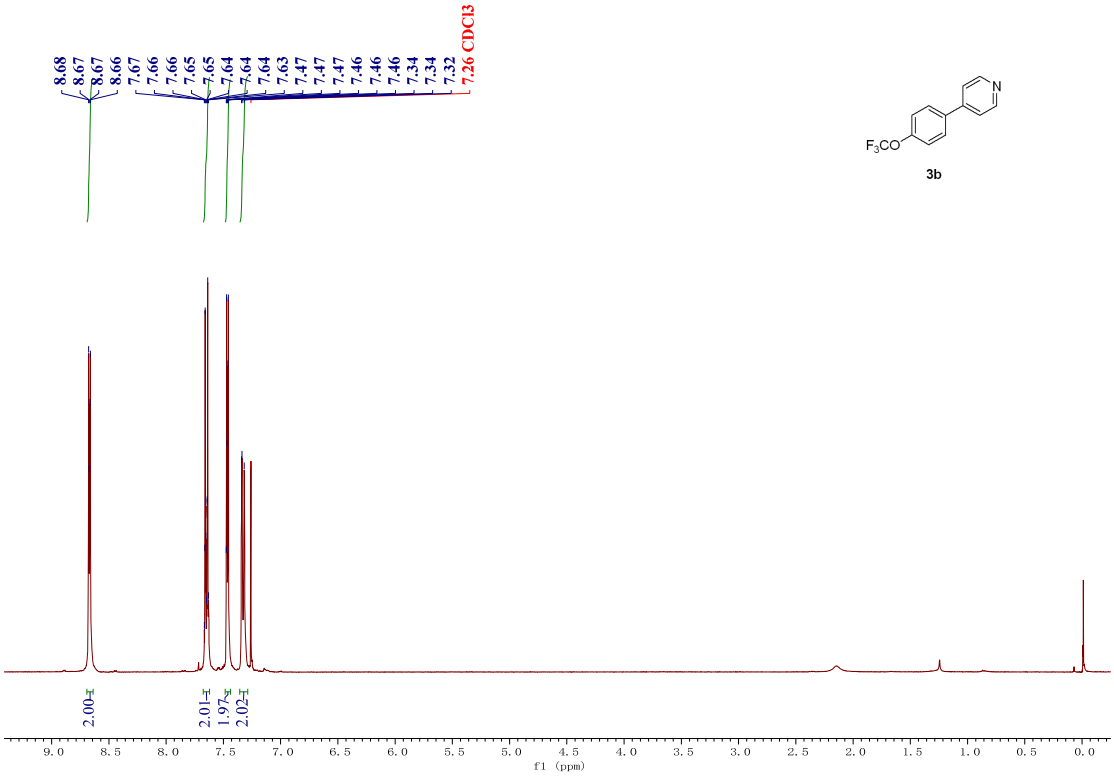
^{1}H NMR spectrum of 3a (400 MHz, $CDCl_3$)



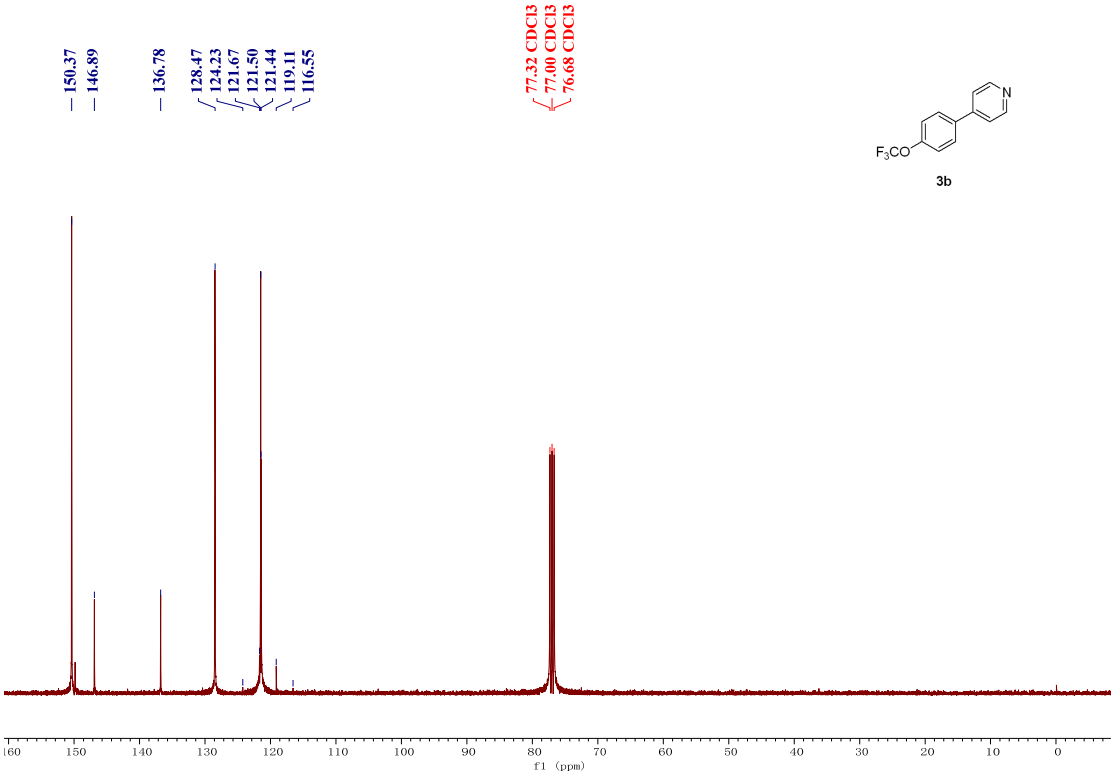
^{13}C NMR spectrum of 3a (100 MHz, $CDCl_3$)



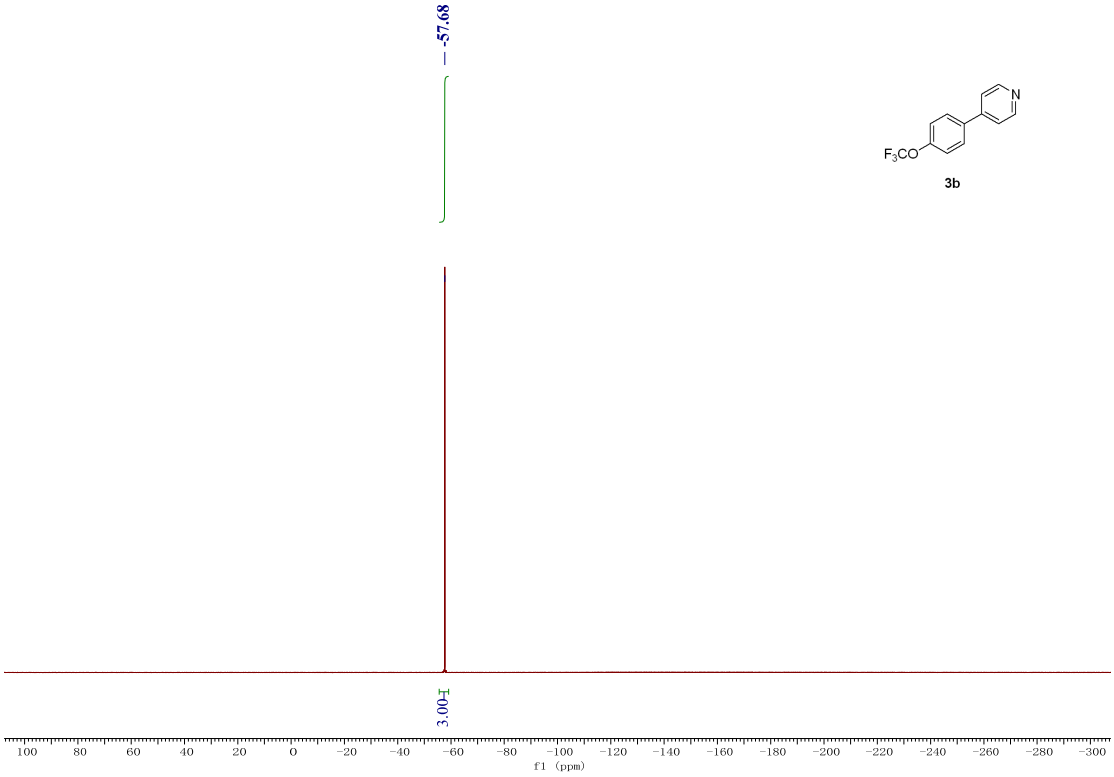
^{1}H NMR spectrum of 3b (400 MHz, $CDCl_3$)



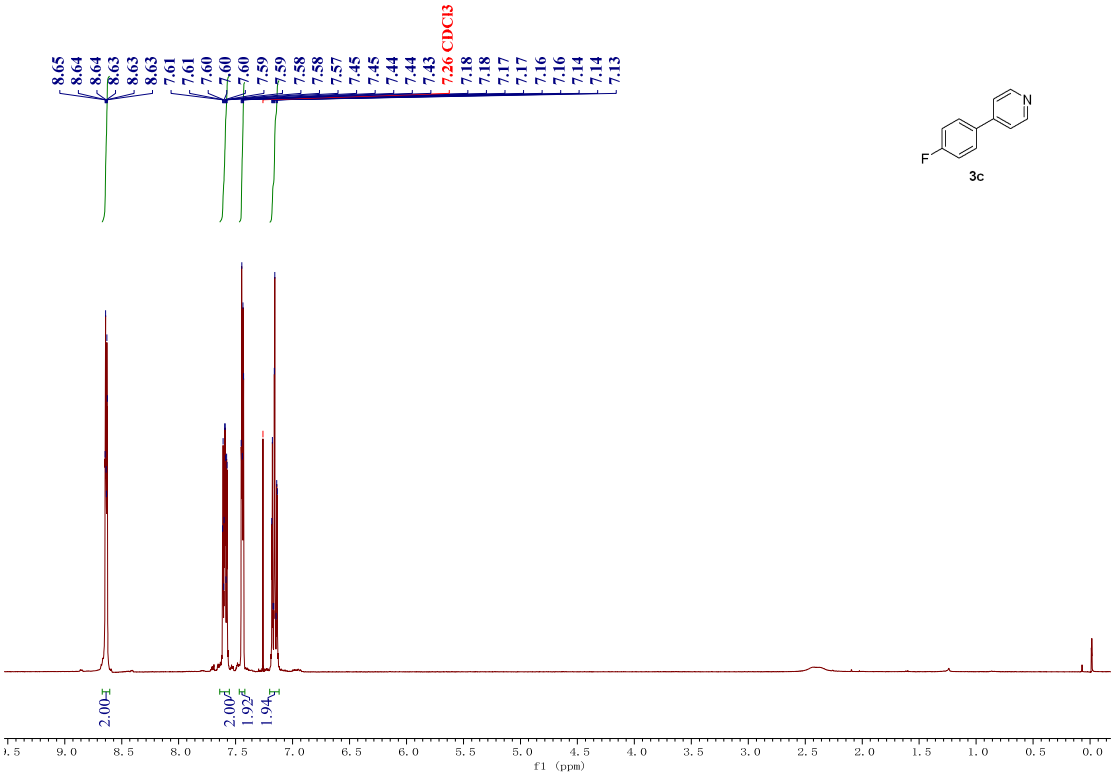
^{13}C NMR spectrum of 3b (100 MHz, $CDCl_3$)



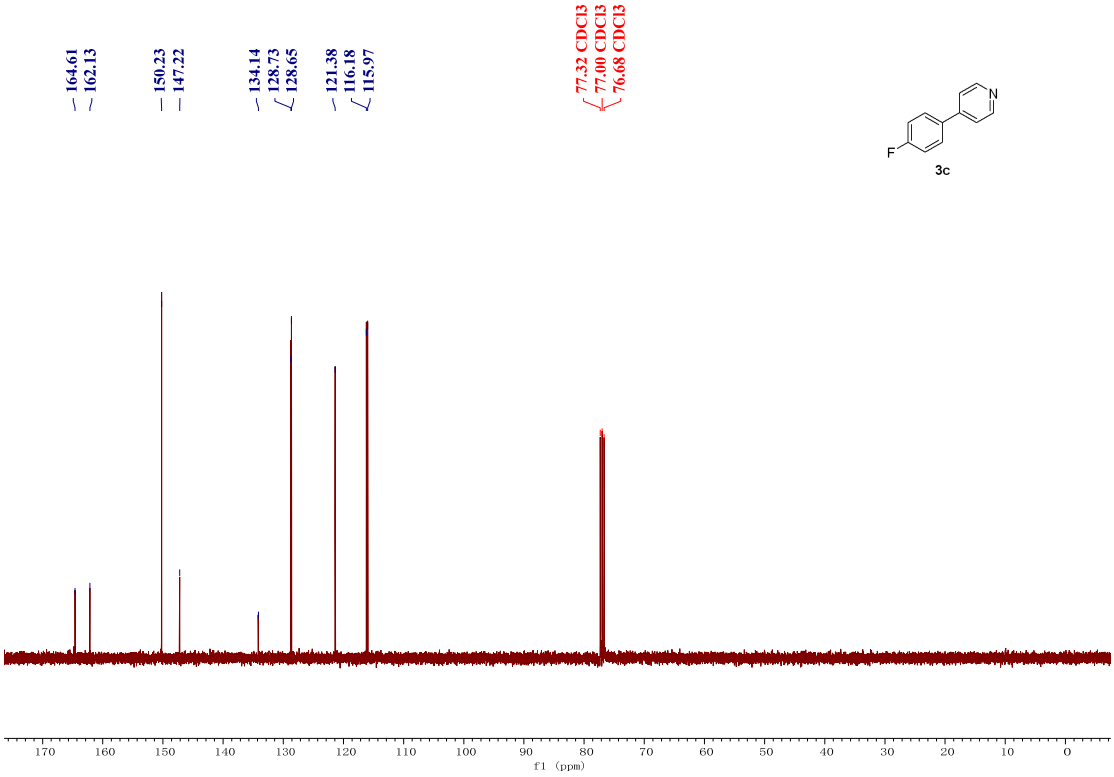
^{19}F NMR spectrum of 3b (376 MHz, $CDCl_3$)



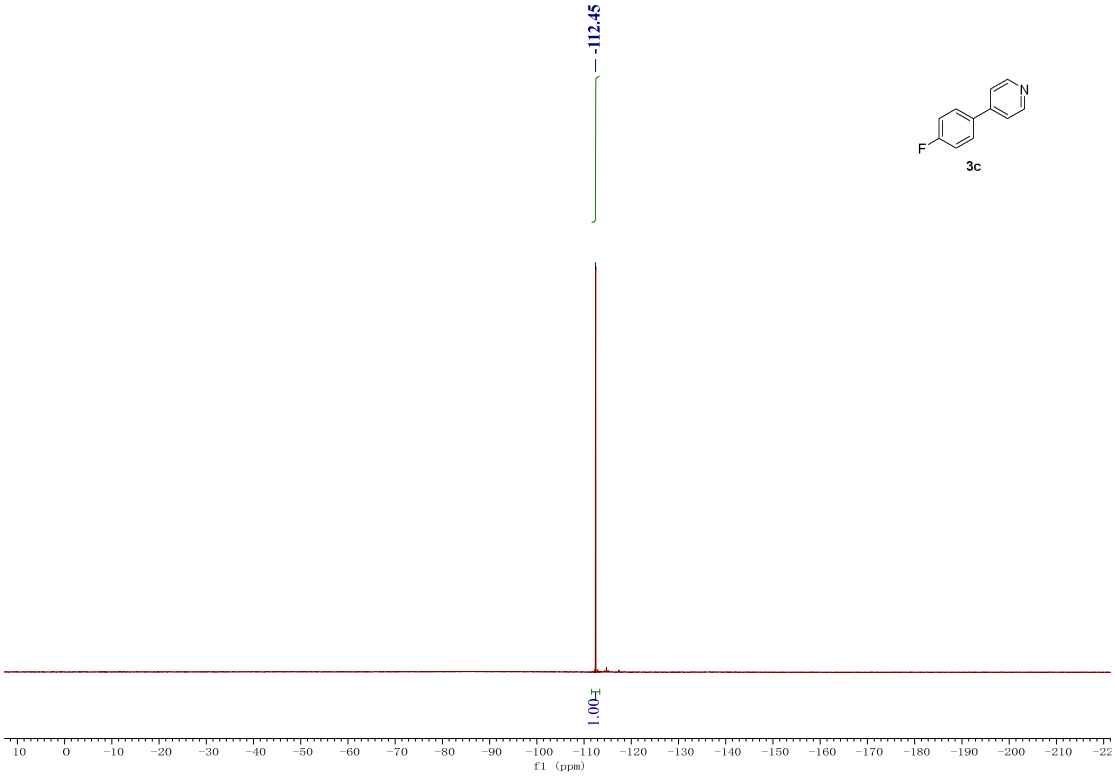
^{1}H NMR spectrum of 3c (400 MHz, $CDCl_3$)



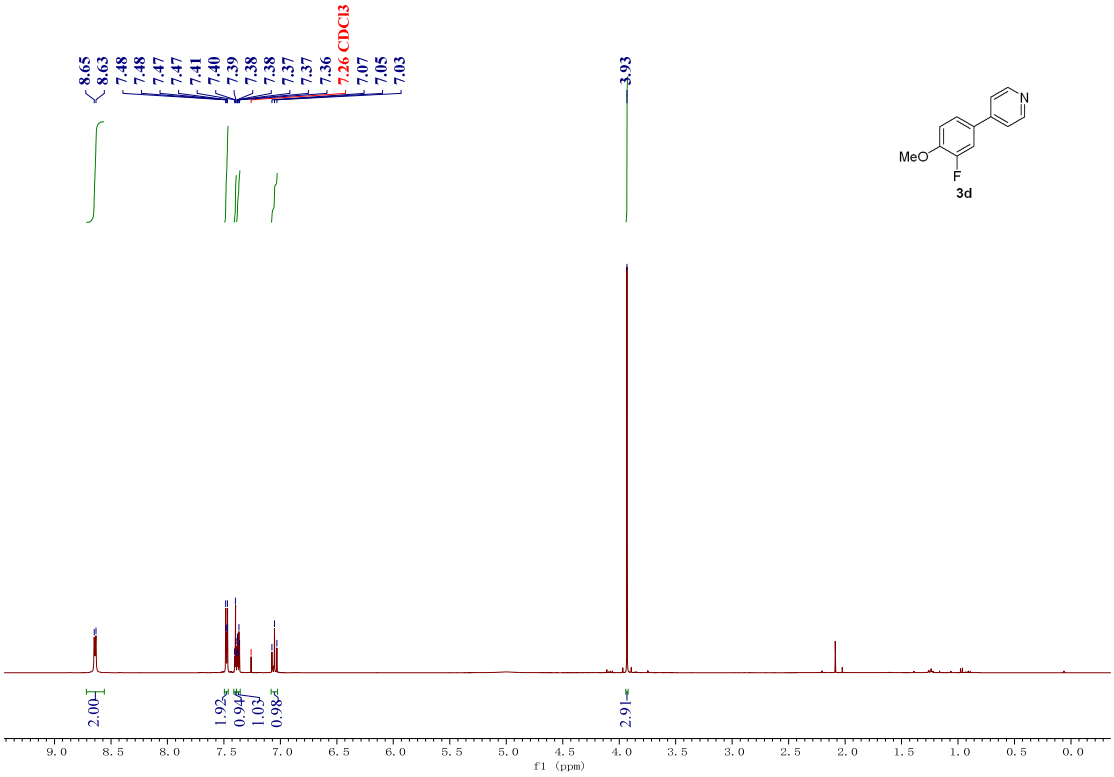
^{13}C NMR spectrum of 3c (100 MHz, $CDCl_3$)



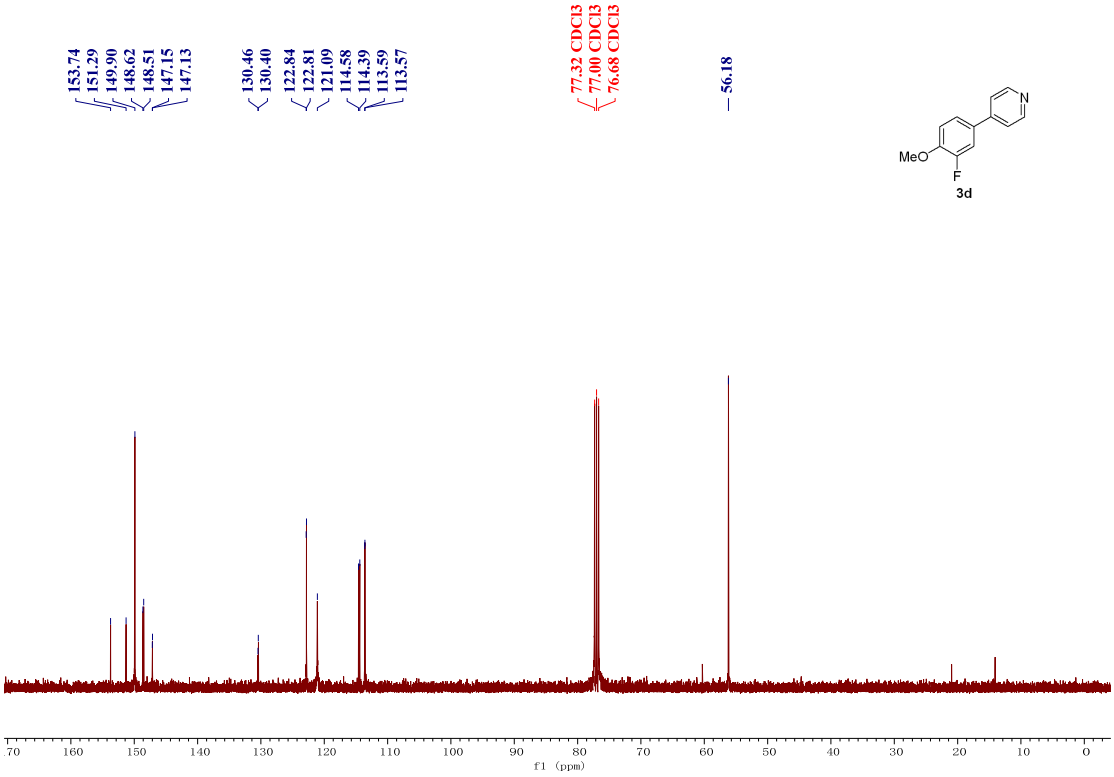
^{19}F NMR spectrum of 3c (376 MHz, $CDCl_3$)



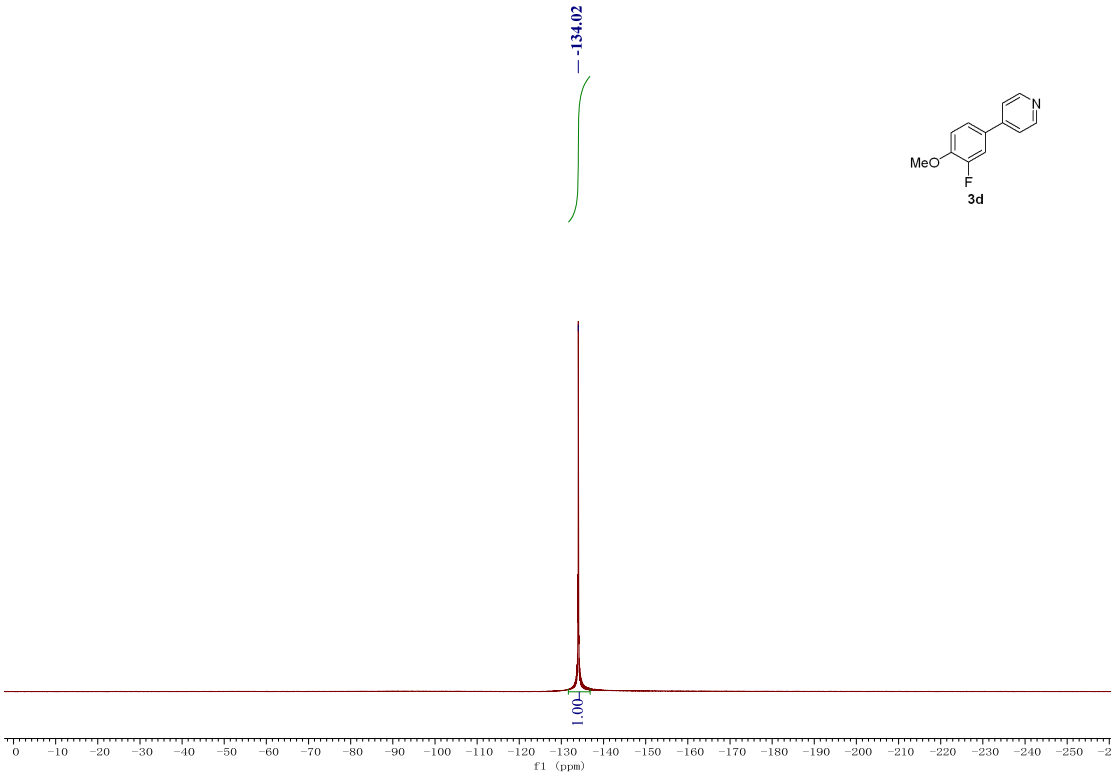
^{1}H NMR spectrum of 3d (400 MHz, $CDCl_3$)



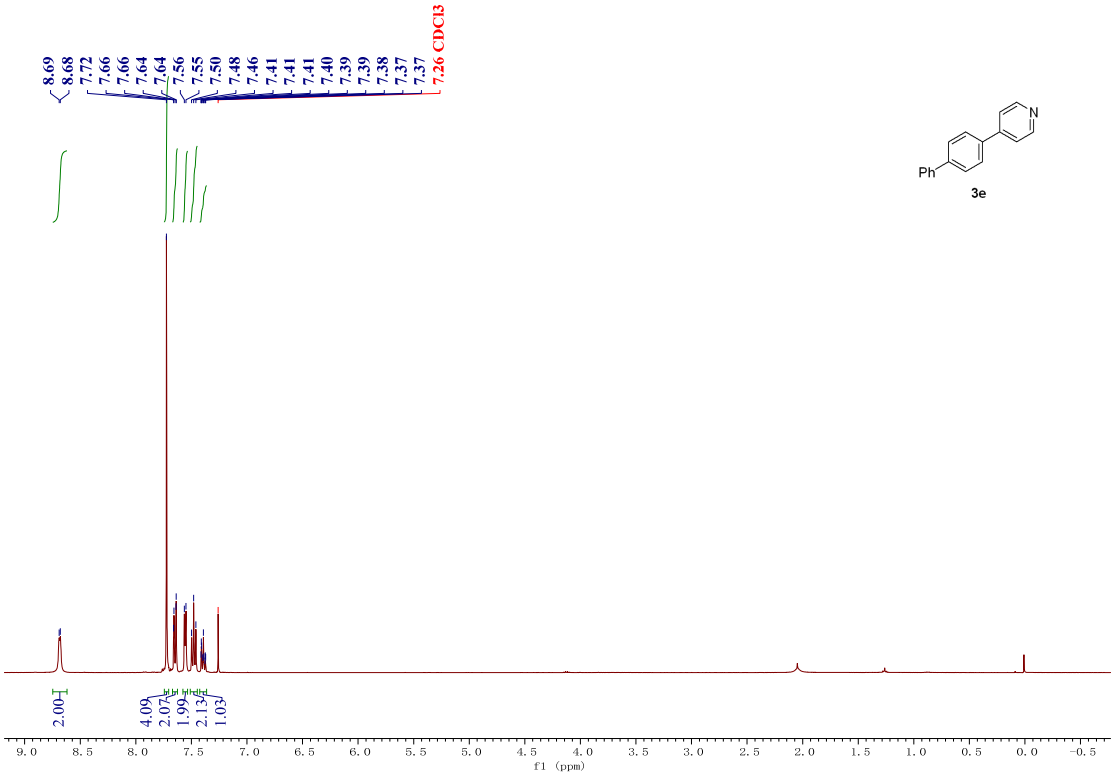
^{13}C NMR spectrum of 3d (100 MHz, $CDCl_3$)



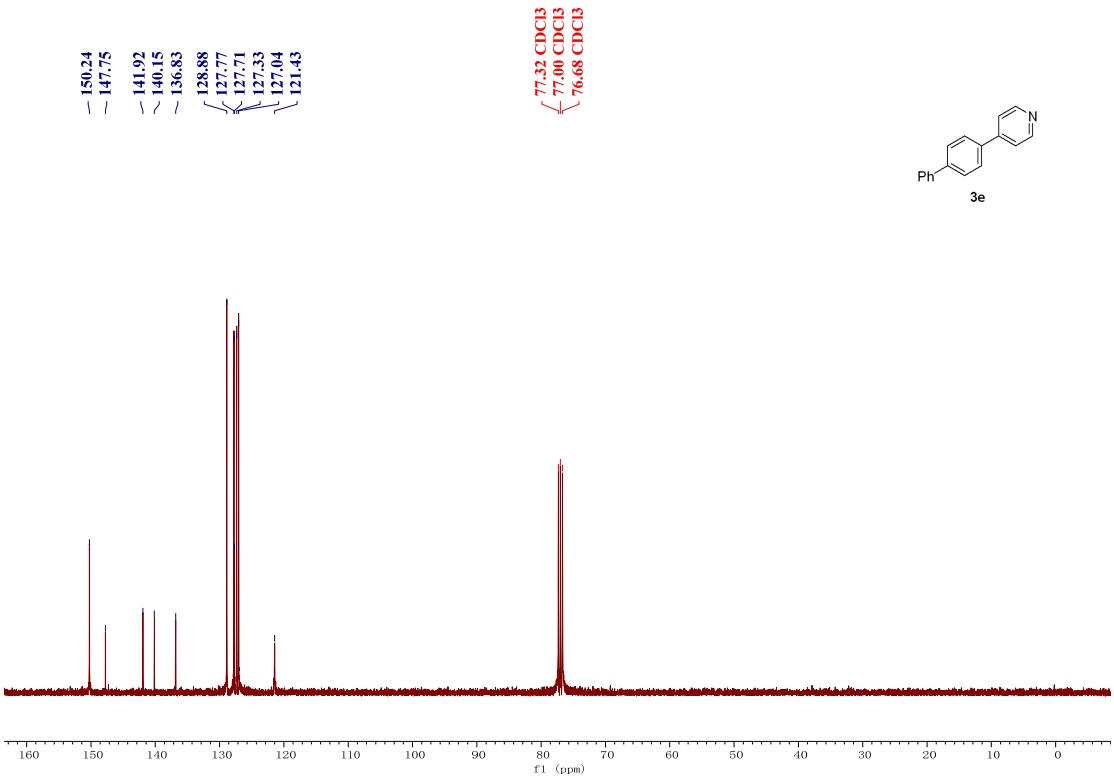
^{19}F NMR spectrum of 3d (376 MHz, $CDCl_3$)



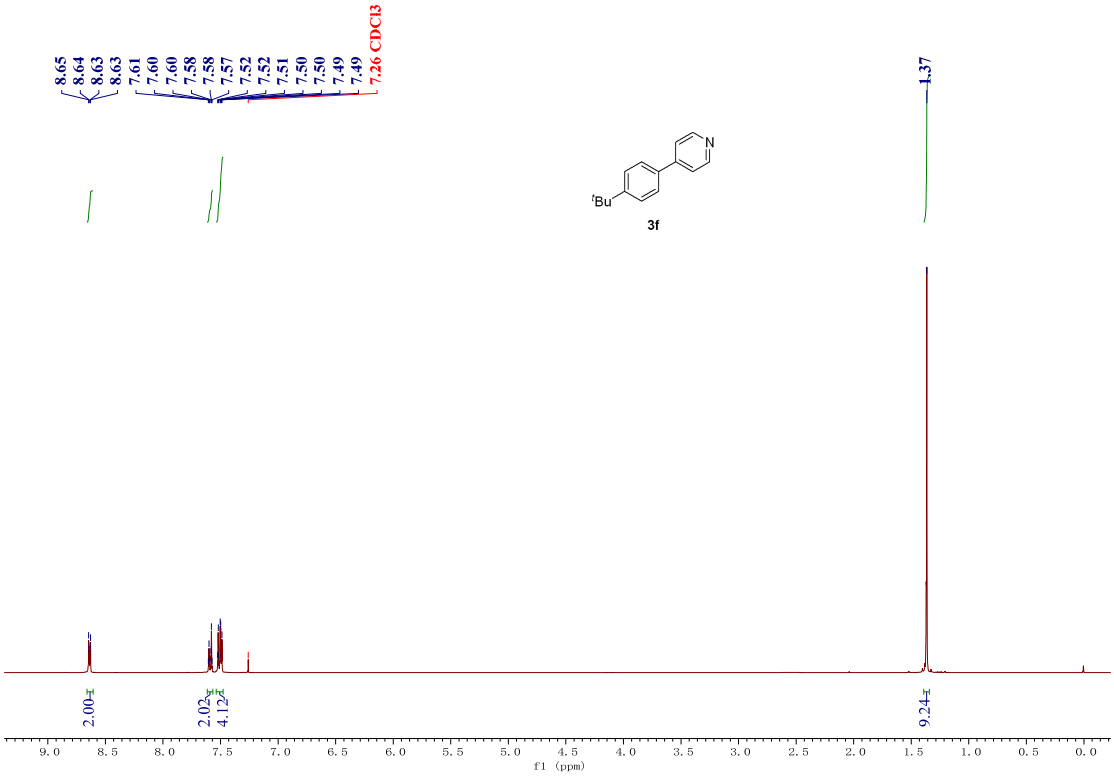
^{1}H NMR spectrum of 3e (400 MHz, $CDCl_3$)



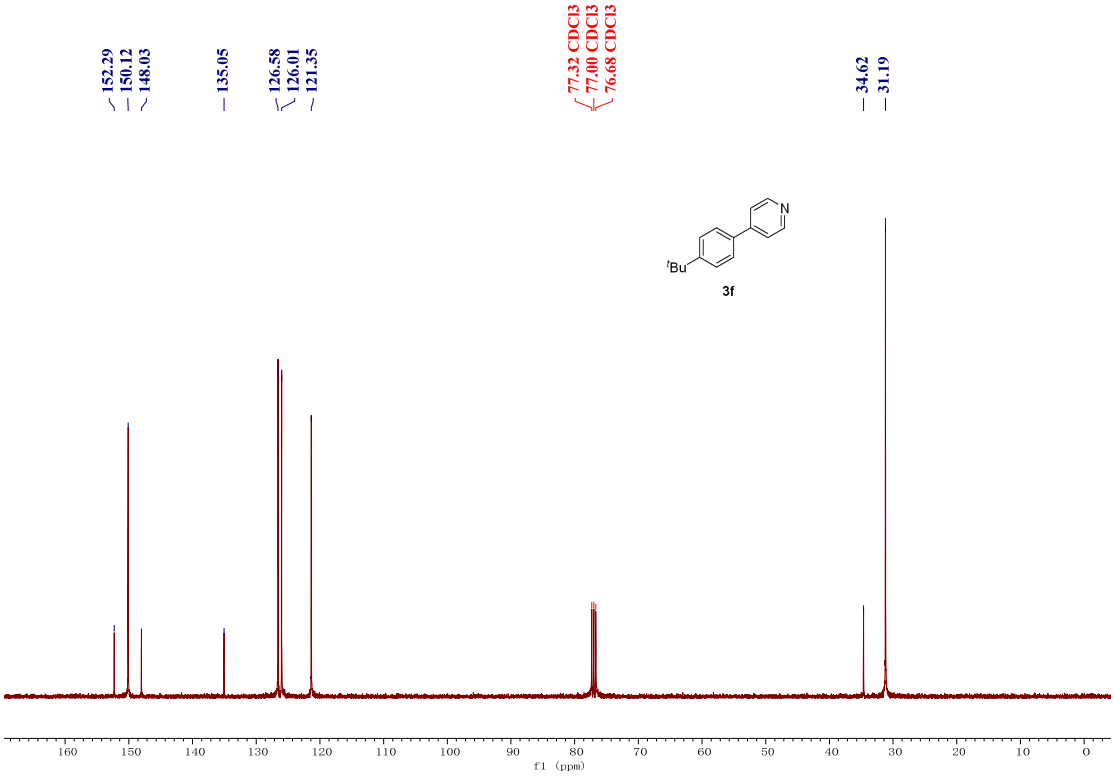
^{13}C NMR spectrum of 3e (100 MHz, $CDCl_3$)



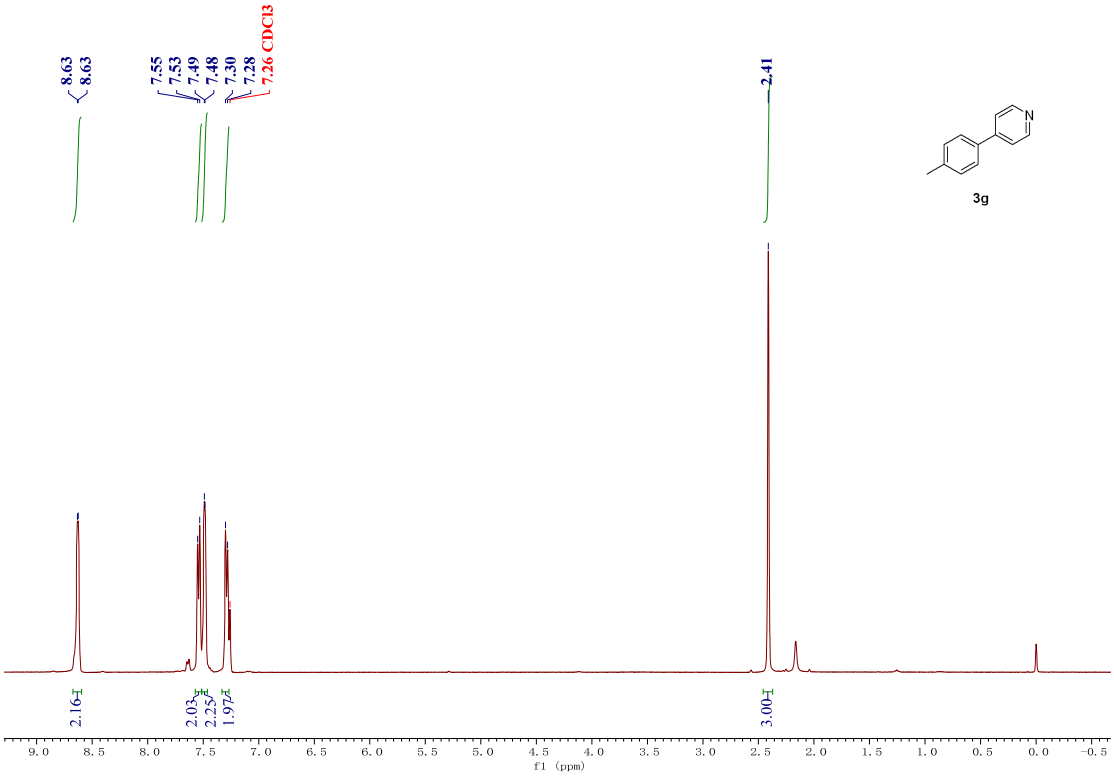
^{1}H NMR spectrum of 3f (400 MHz, $CDCl_3$)



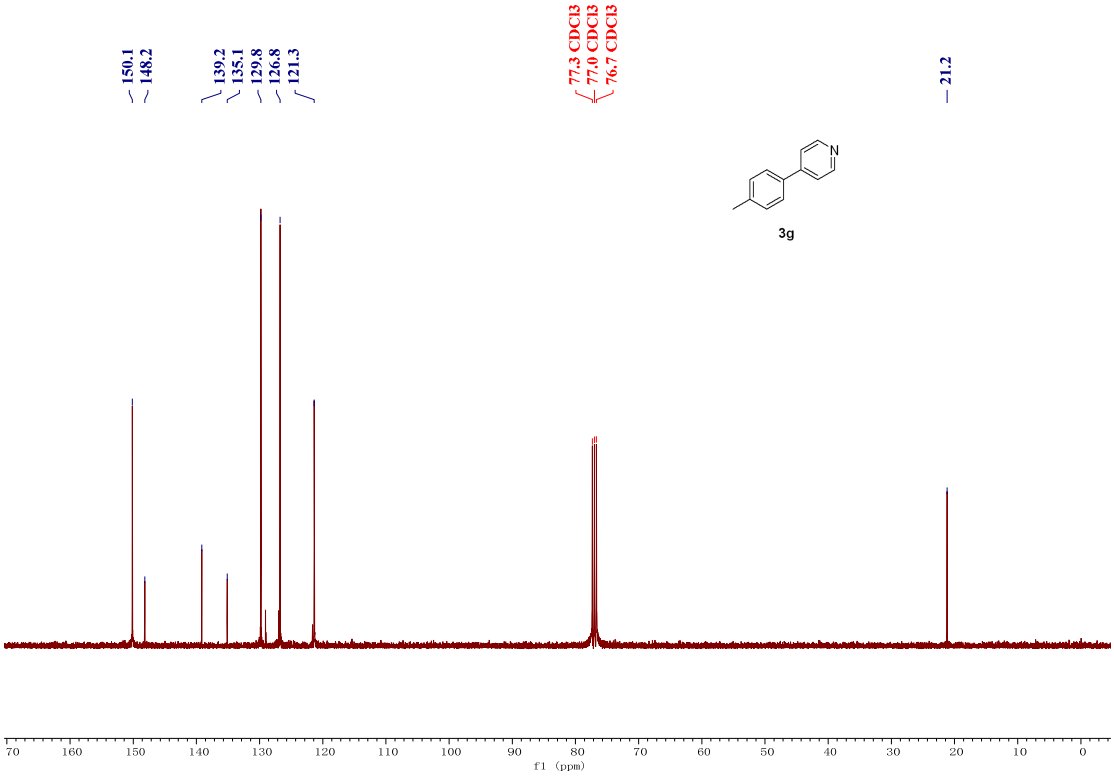
^{13}C NMR spectrum of 3f (100 MHz, $CDCl_3$)



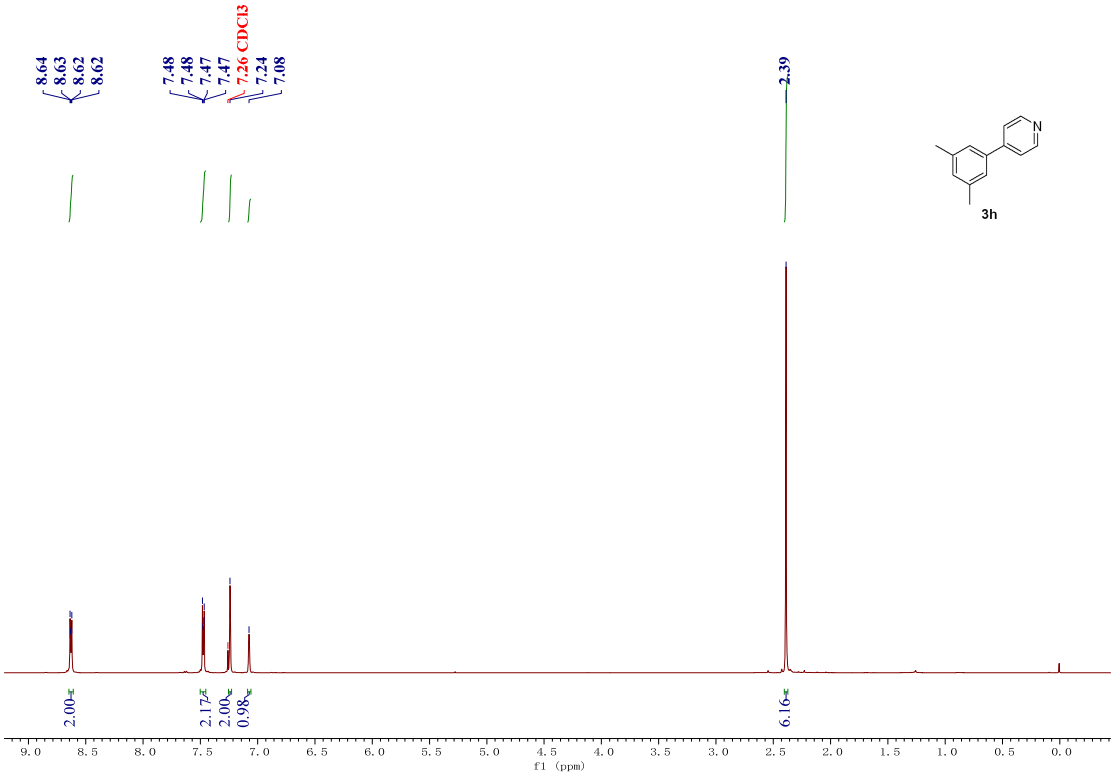
^{1}H NMR spectrum of 3g (400 MHz, $CDCl_3$)



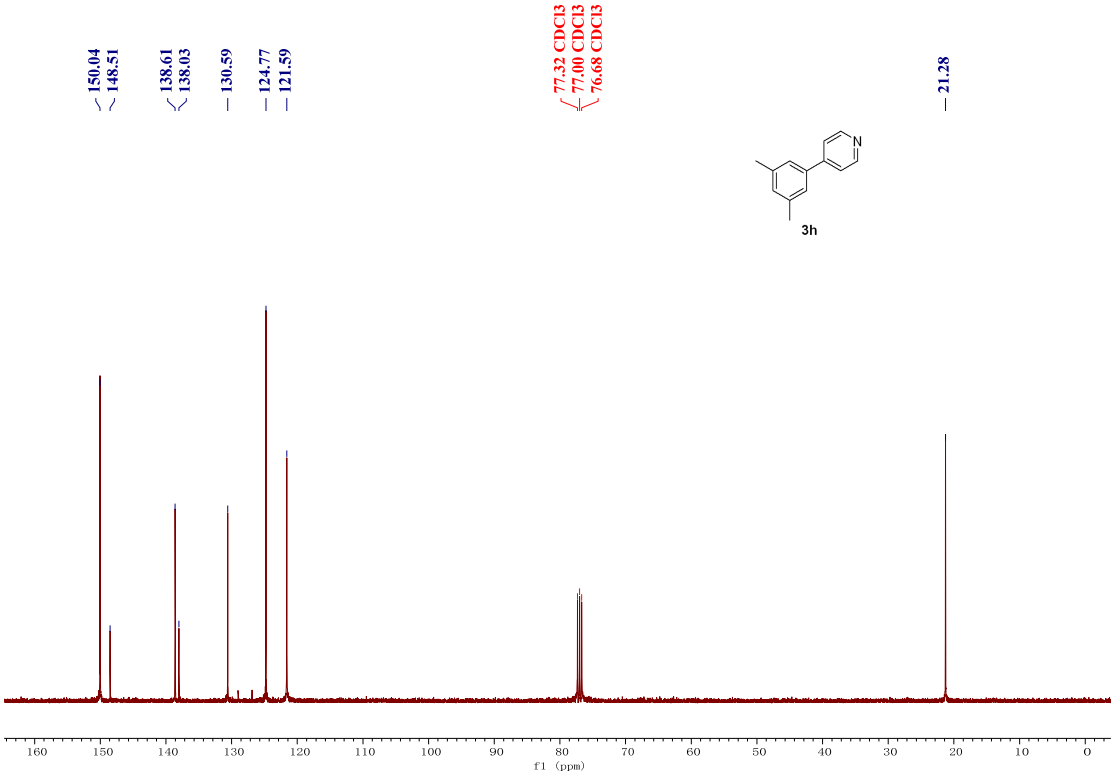
^{13}C NMR spectrum of 3g (100 MHz, $CDCl_3$)



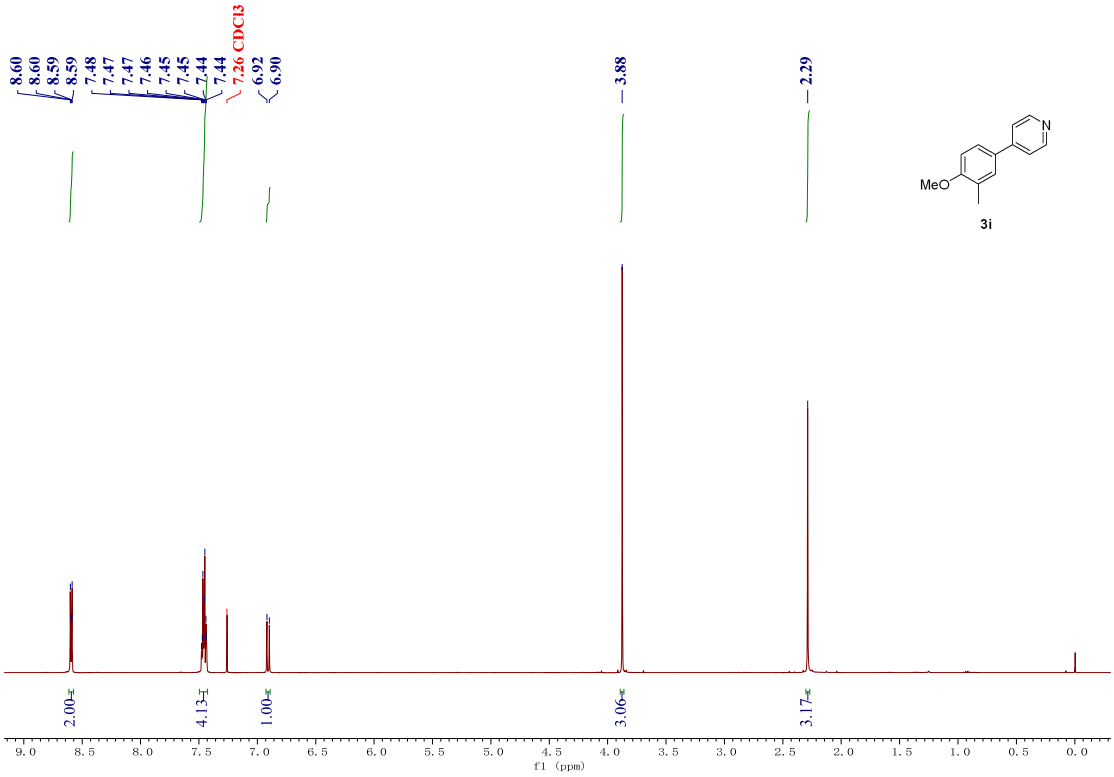
^{1}H NMR spectrum of 3h (400 MHz, $CDCl_3$)



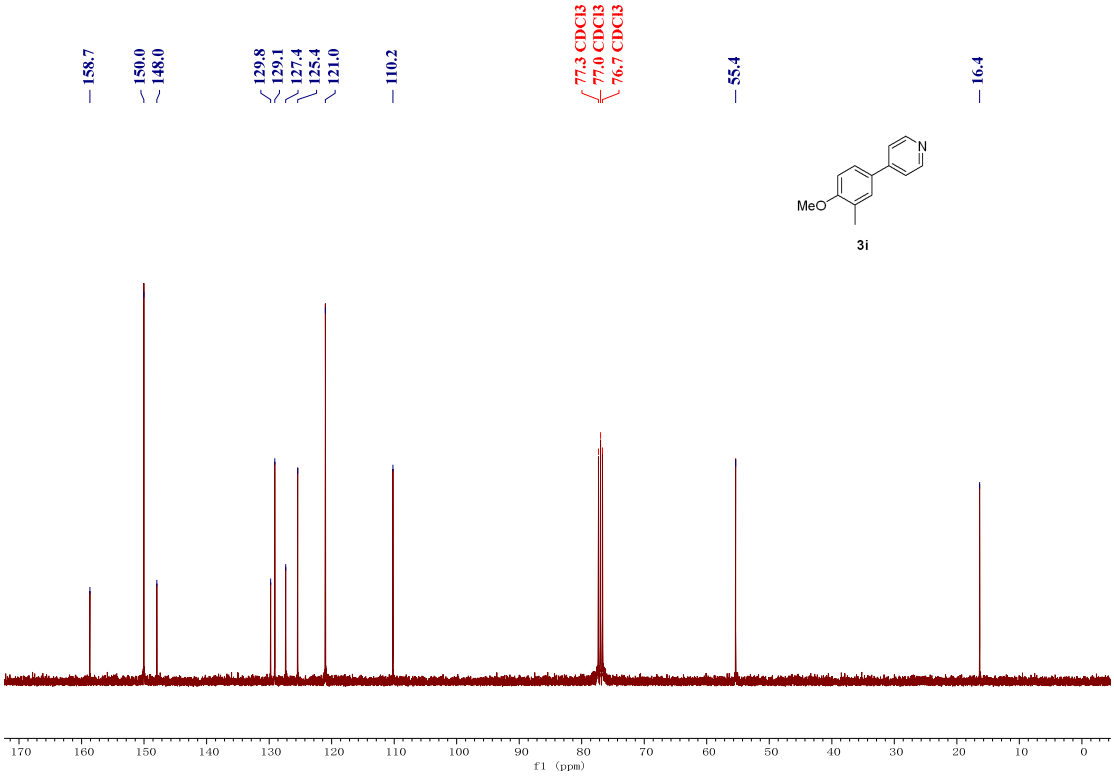
^{13}C NMR spectrum of 3h (100 MHz, $CDCl_3$)



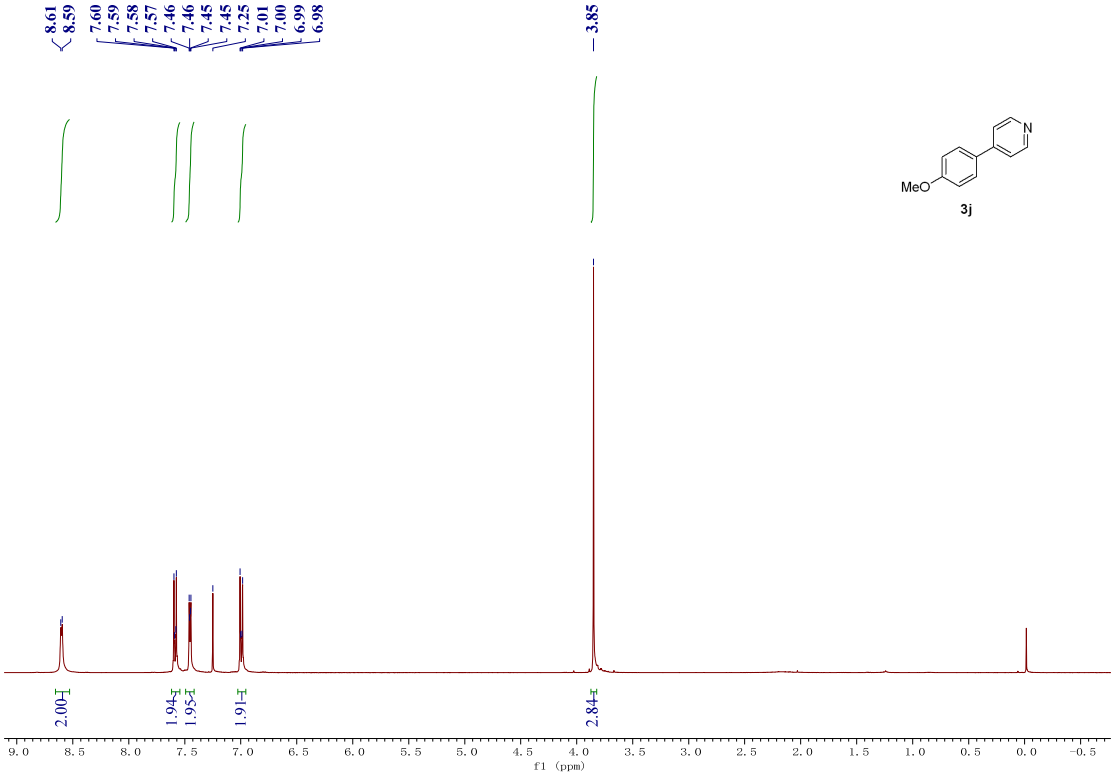
^{1}H NMR spectrum of 3i (400 MHz, $CDCl_3$)



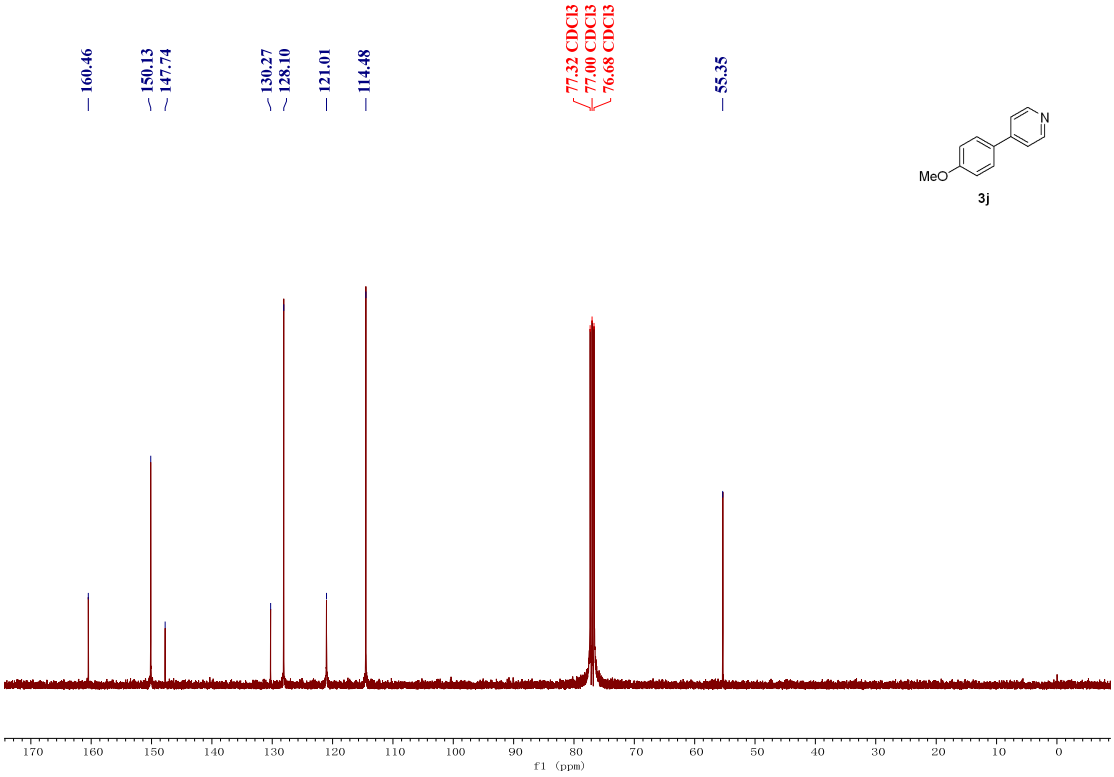
^{13}C NMR spectrum of 3i (100 MHz, $CDCl_3$)



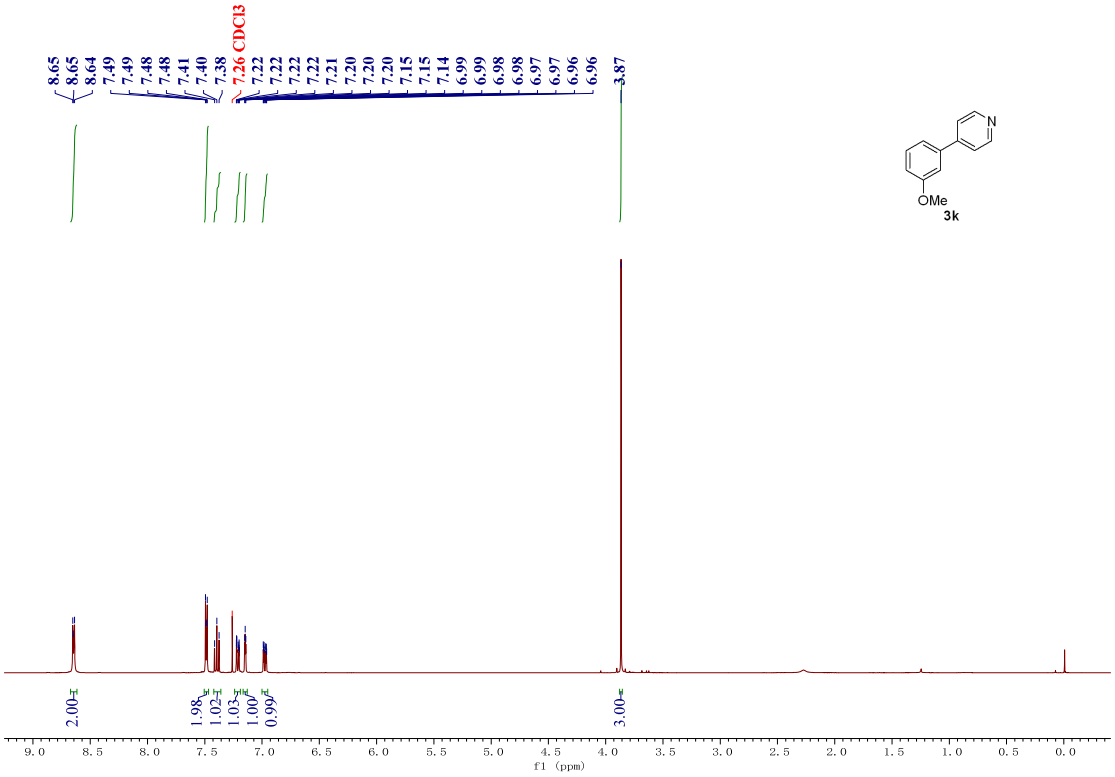
^{1}H NMR spectrum of 3j (400 MHz, $CDCl_3$)



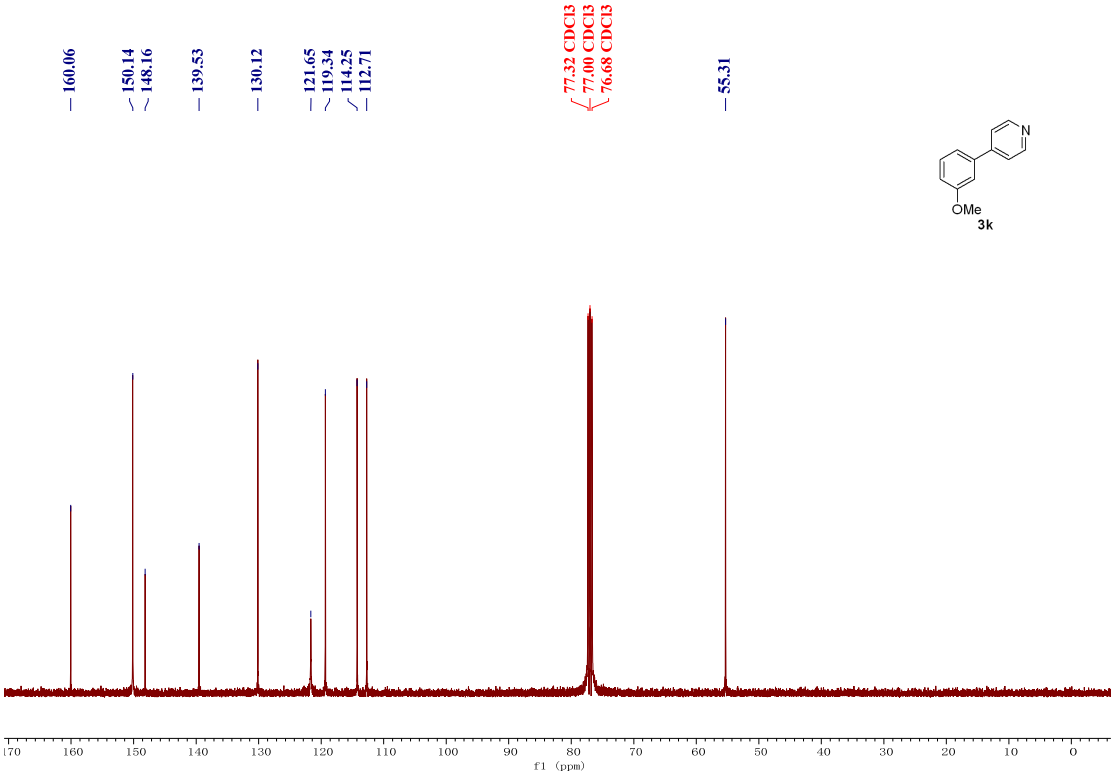
^{13}C NMR spectrum of 3j (100 MHz, $CDCl_3$)



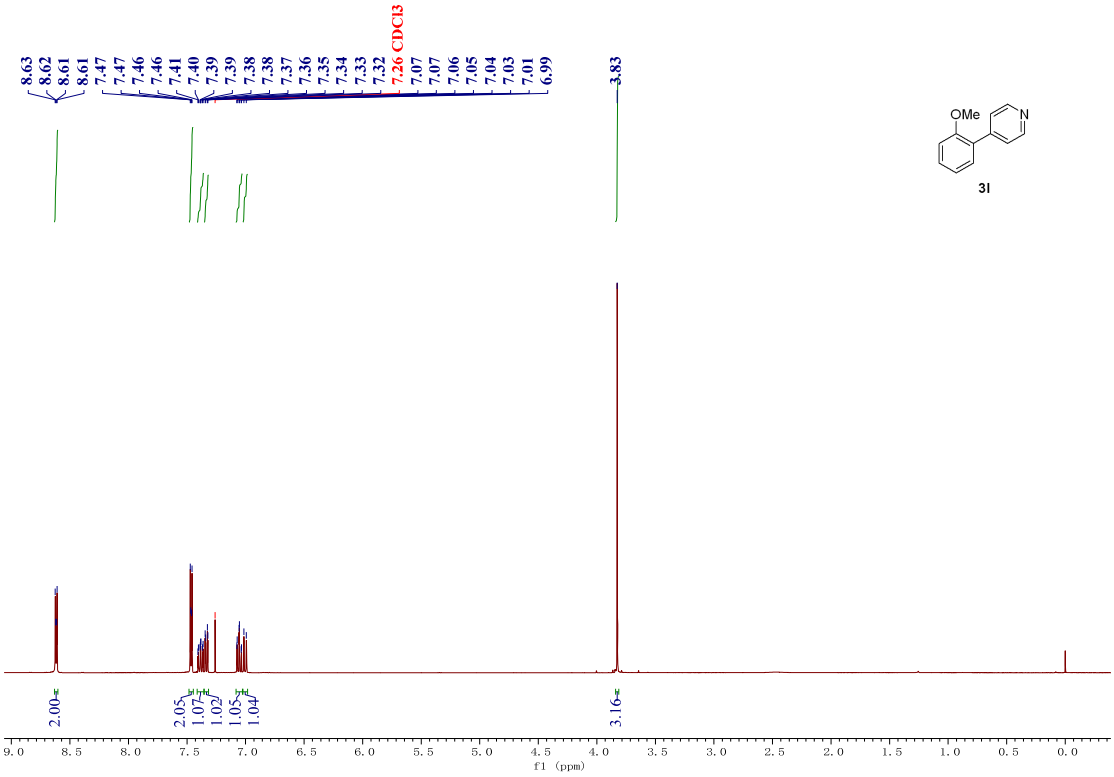
^{1}H NMR spectrum of 3k (400 MHz, $CDCl_3$)



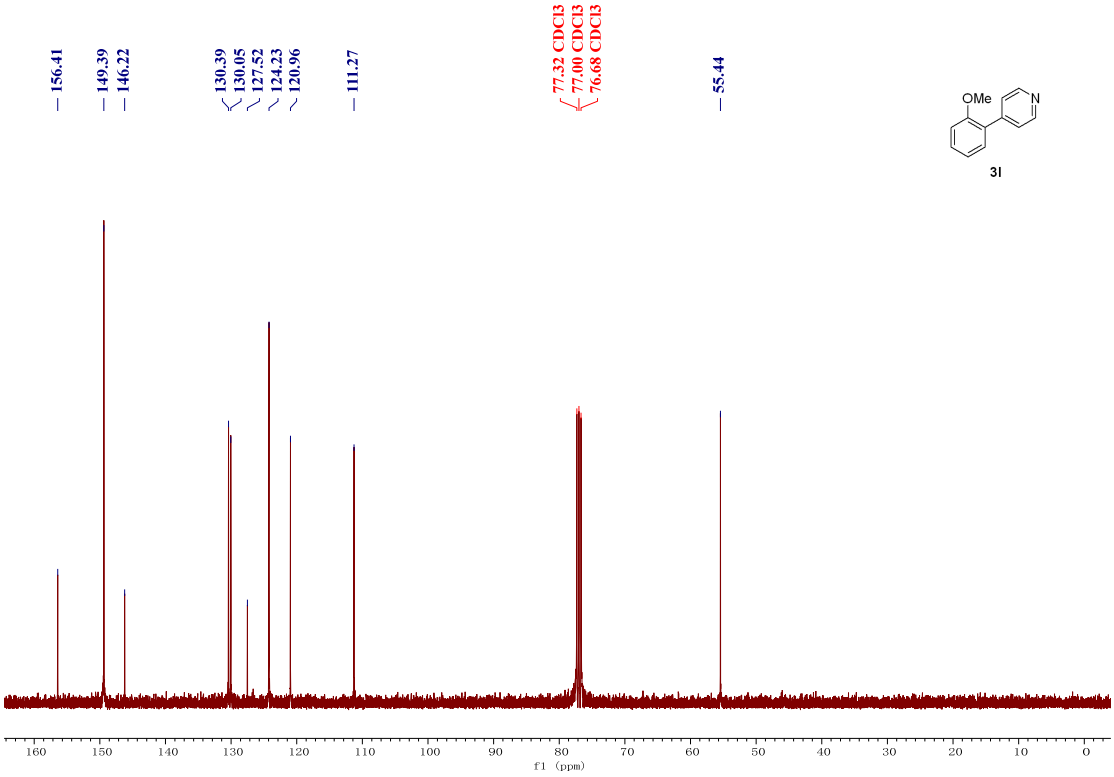
^{13}C NMR spectrum of 3k (100 MHz, $CDCl_3$)



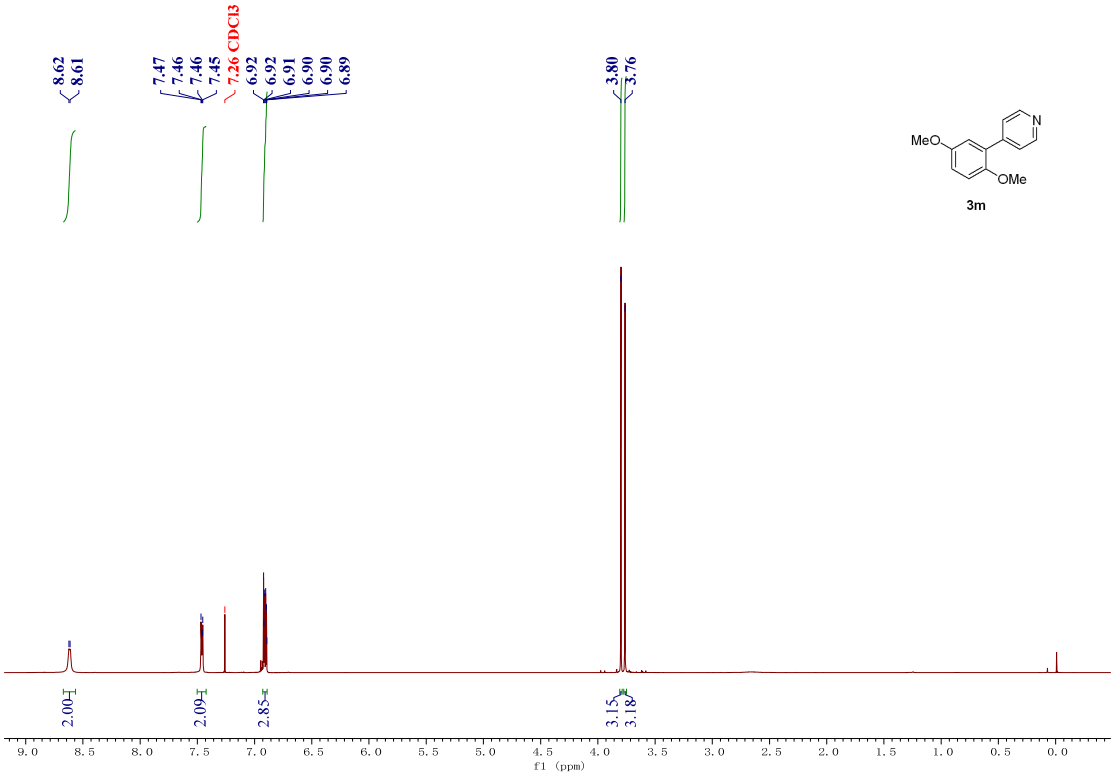
^{1}H NMR spectrum of 3l (400 MHz, $CDCl_3$)



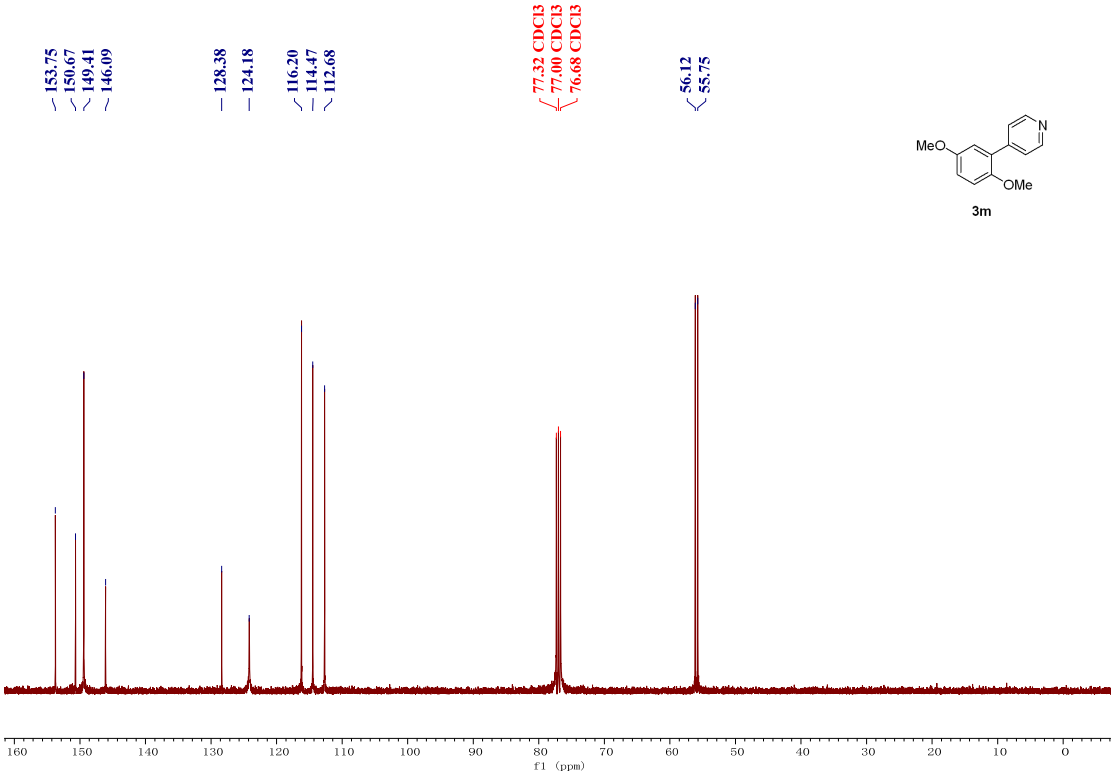
^{13}C NMR spectrum of 3l (100 MHz, $CDCl_3$)



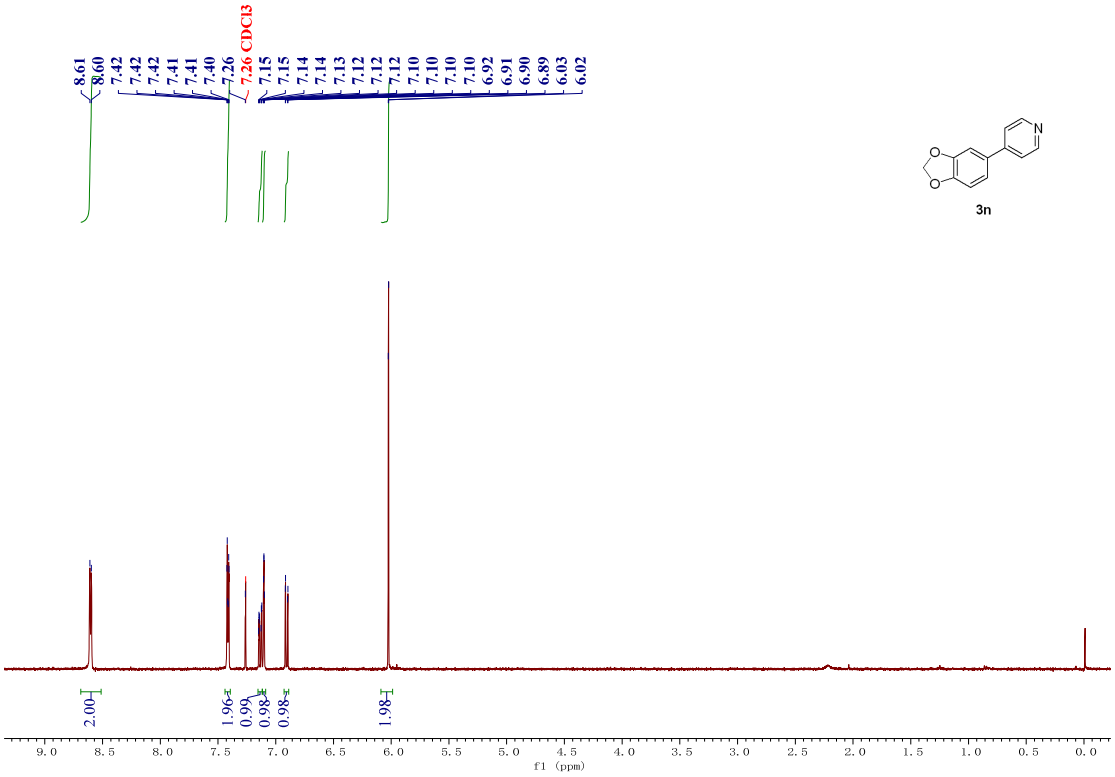
^{1}H NMR spectrum of 3m (400 MHz, $CDCl_3$)



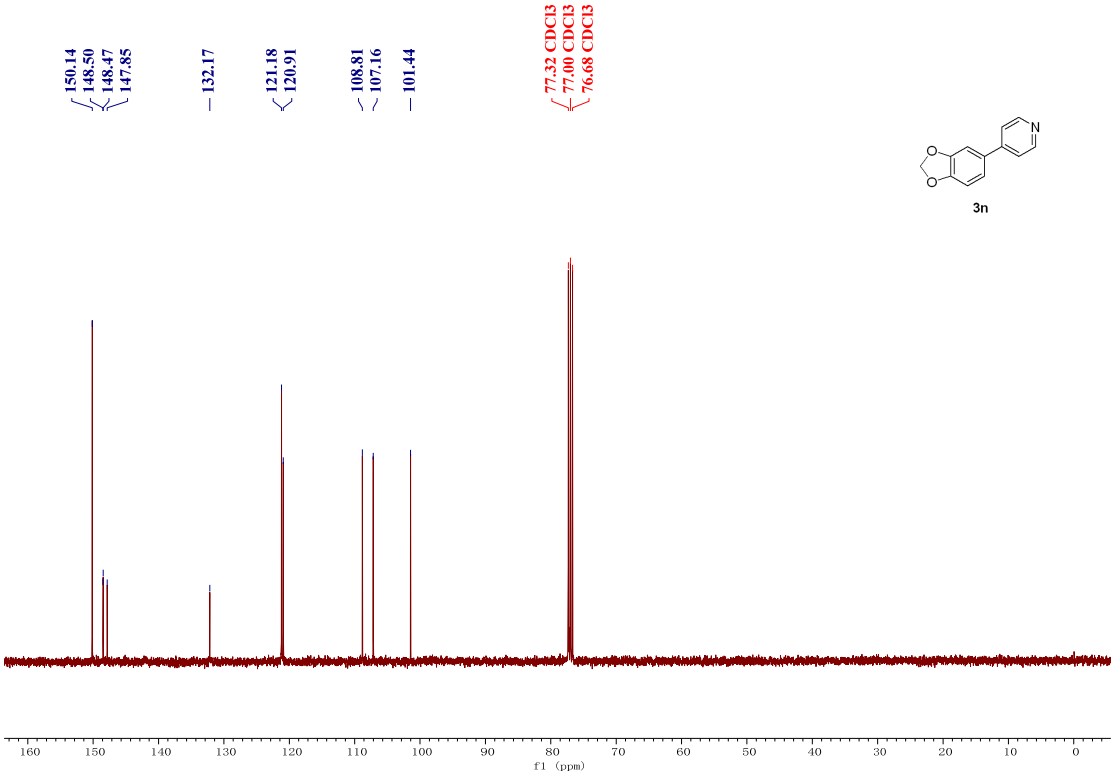
^{13}C NMR spectrum of 3m (100 MHz, $CDCl_3$)



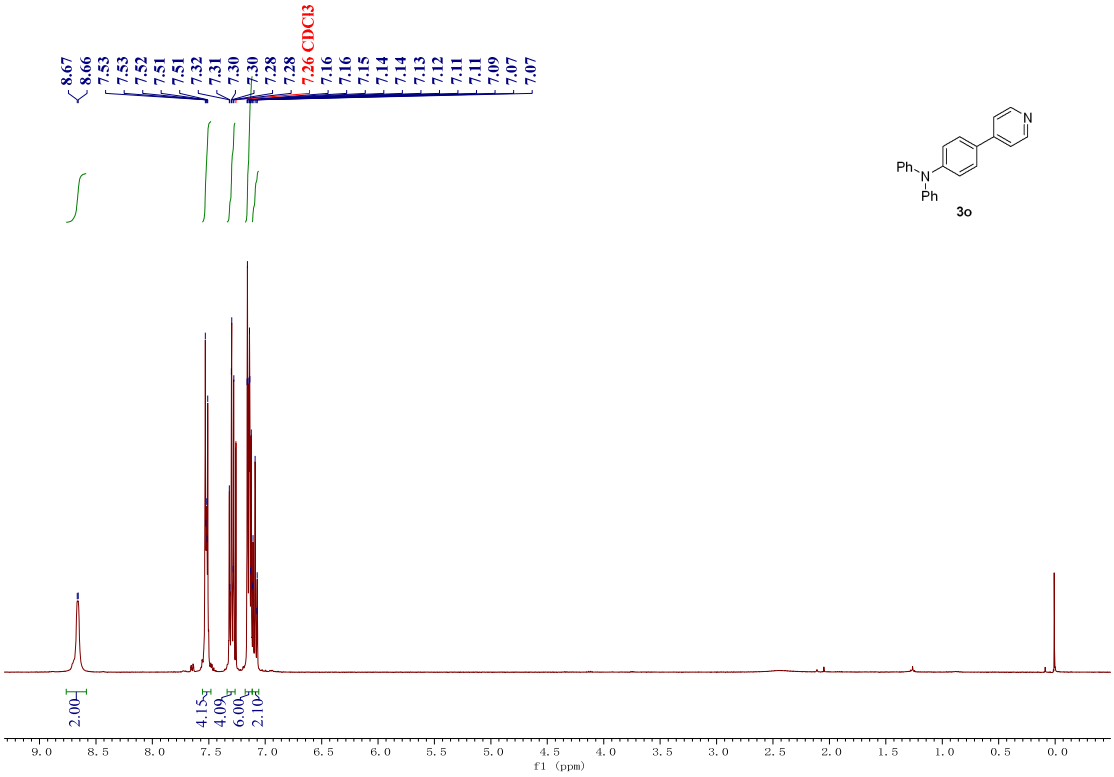
^{1}H NMR spectrum of 3n (400 MHz, $CDCl_3$)



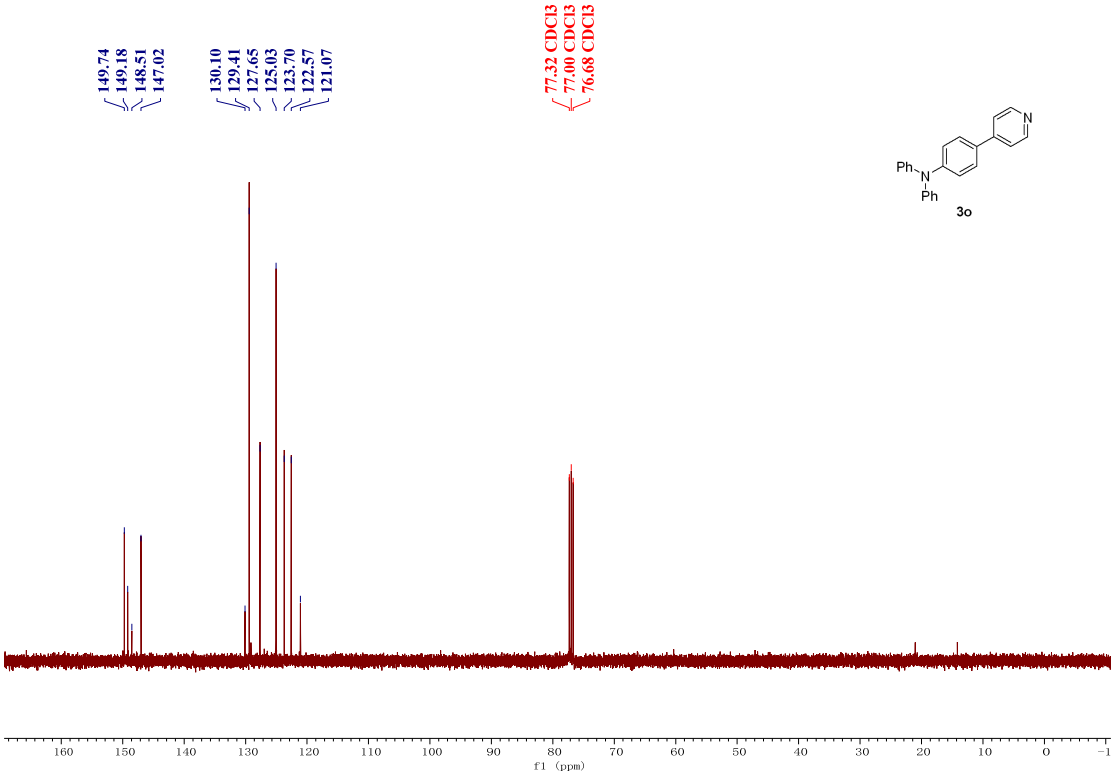
^{13}C NMR spectrum of 3n (100 MHz, $CDCl_3$)



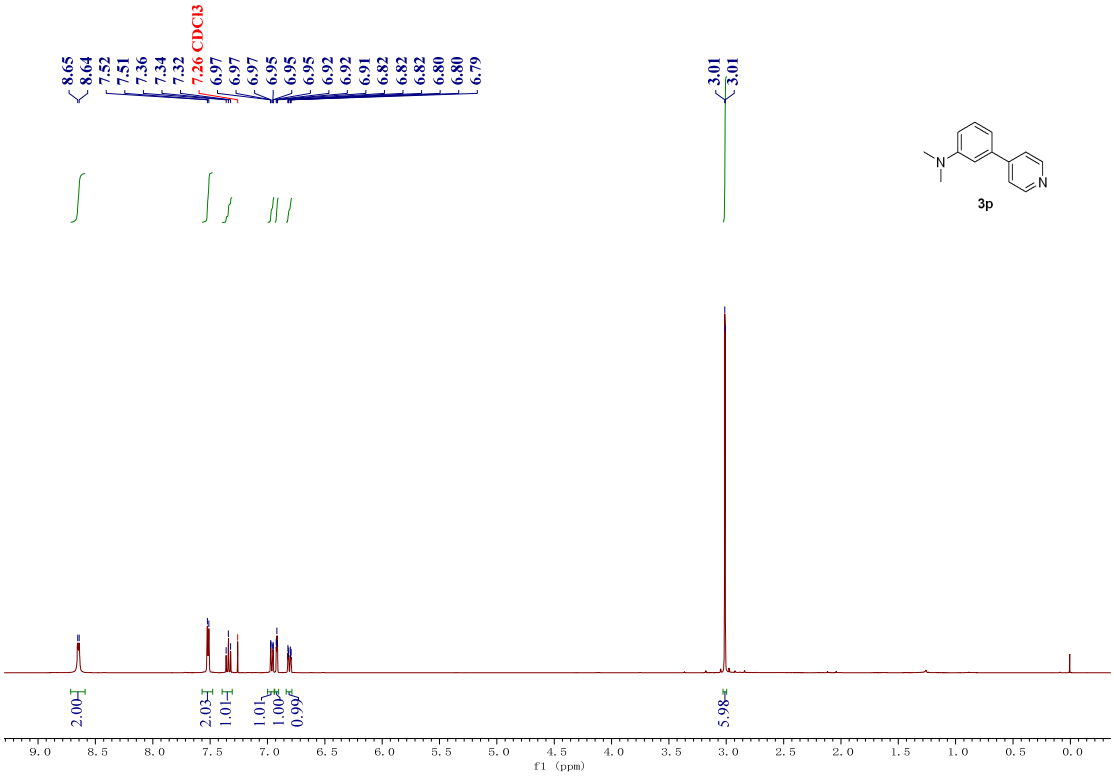
^{1}H NMR spectrum of 3o (400 MHz, $CDCl_3$)



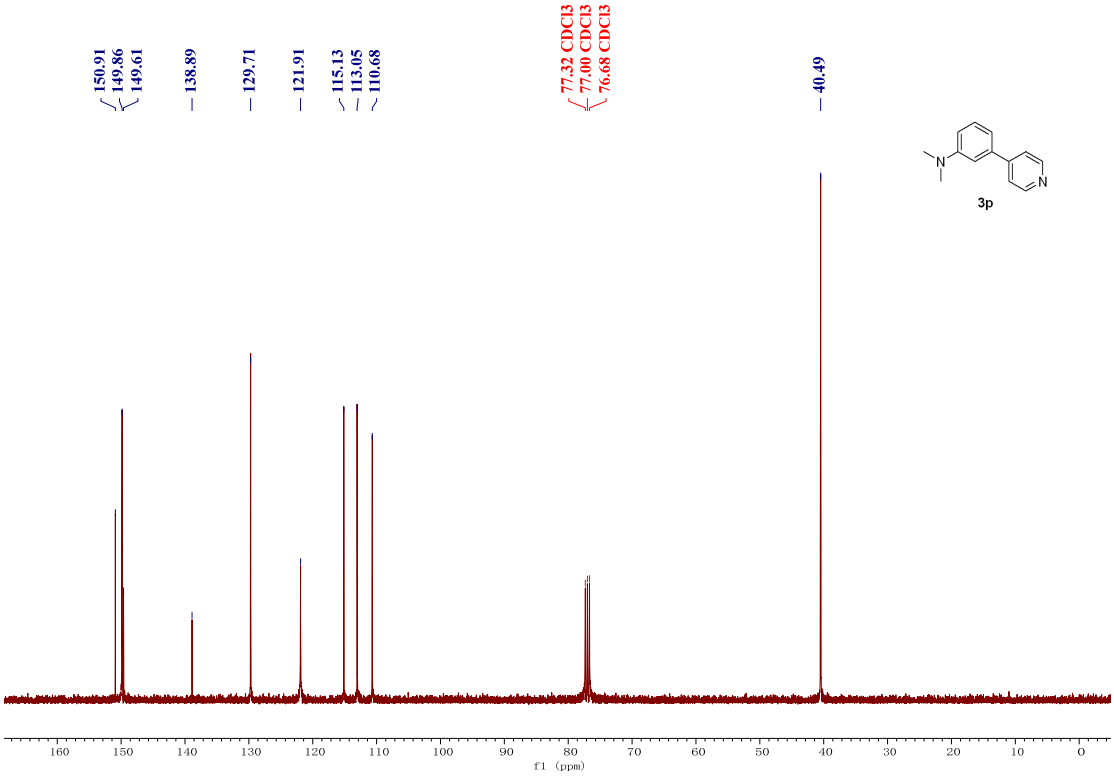
^{13}C NMR spectrum of 3o (100 MHz, $CDCl_3$)



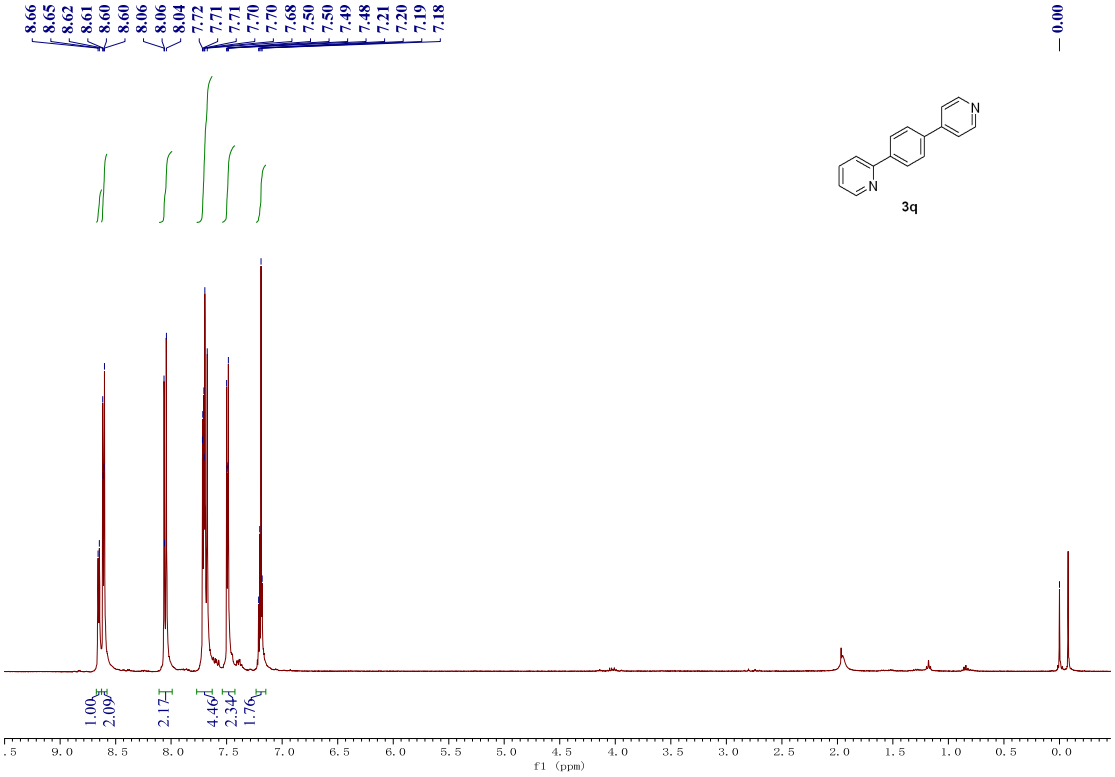
^{1}H NMR spectrum of 3p (400 MHz, $CDCl_3$)



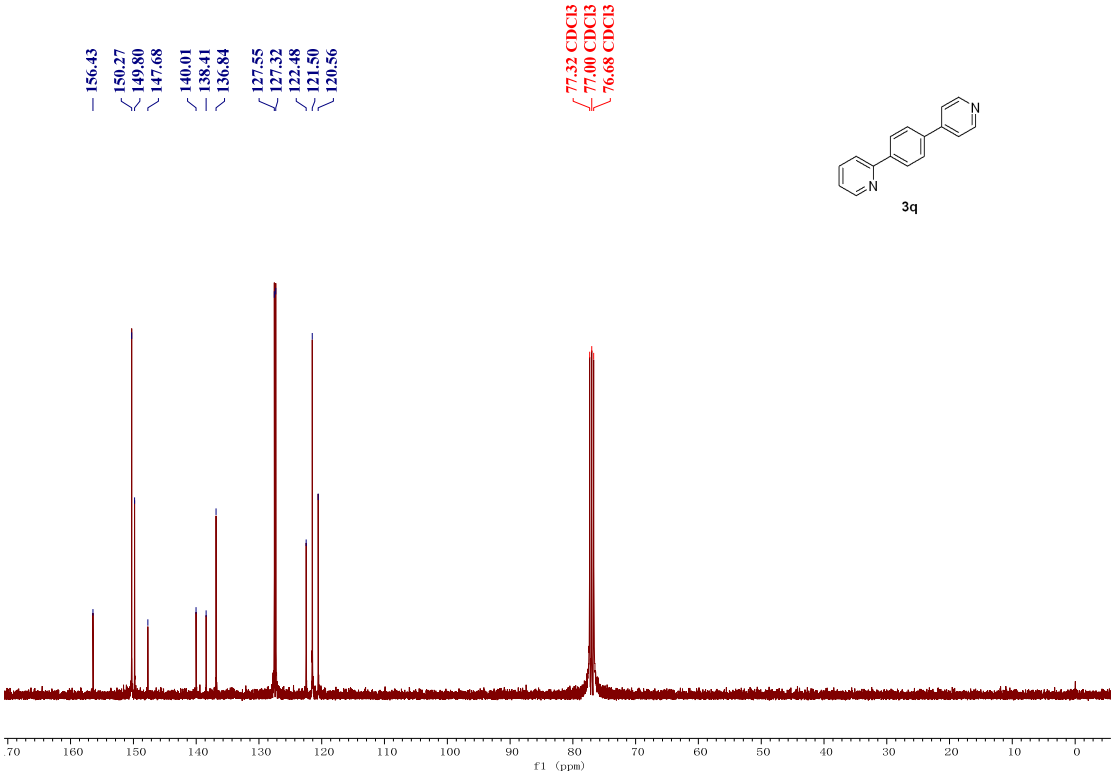
^{13}C NMR spectrum of 3p (100 MHz, $CDCl_3$)



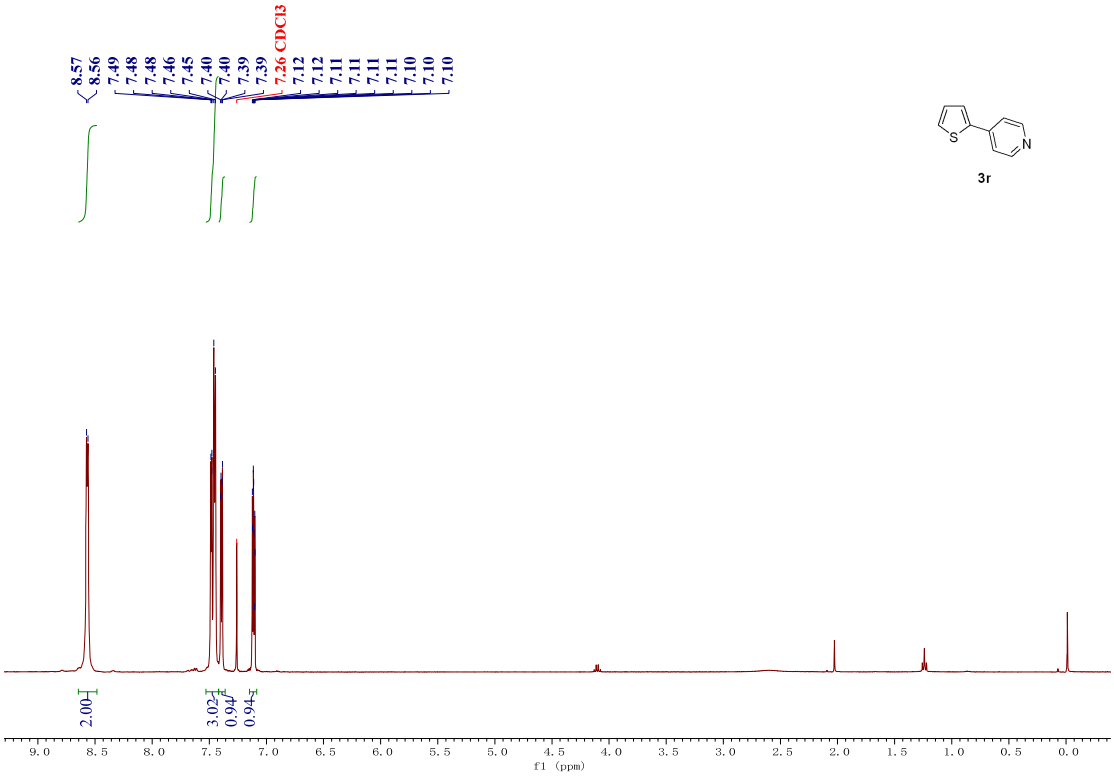
^{1}H NMR spectrum of 3q (400 MHz, $CDCl_3$)



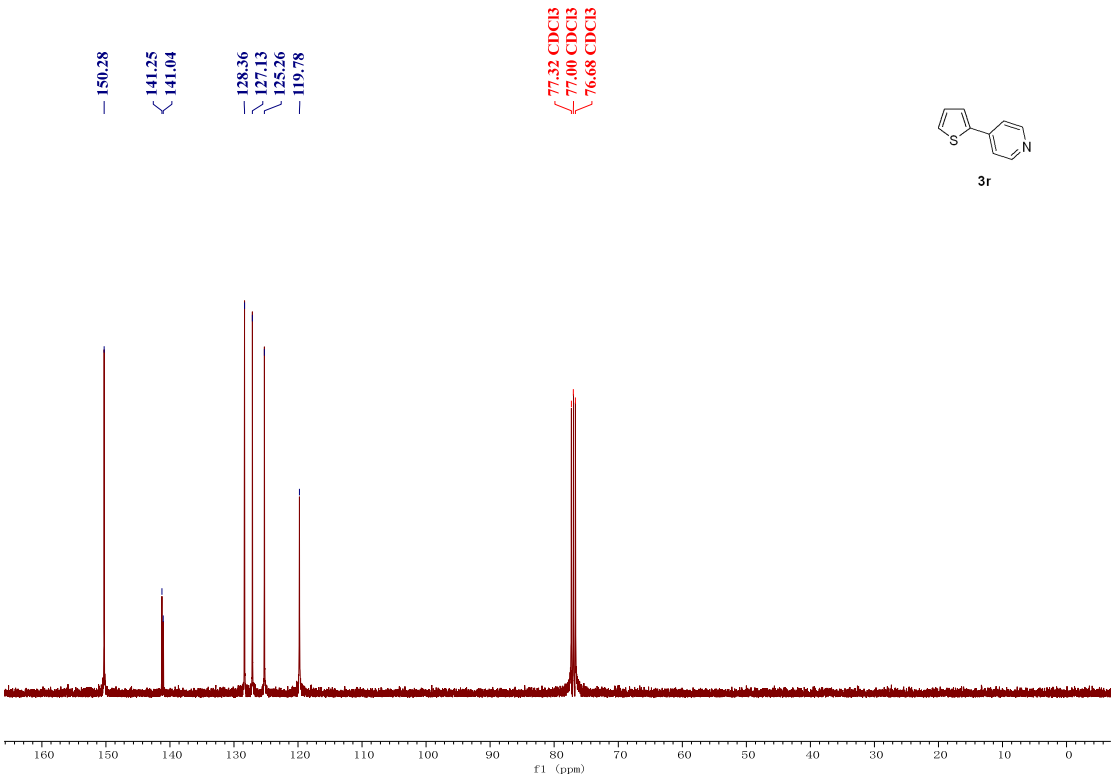
^{13}C NMR spectrum of 3q (100 MHz, $CDCl_3$)



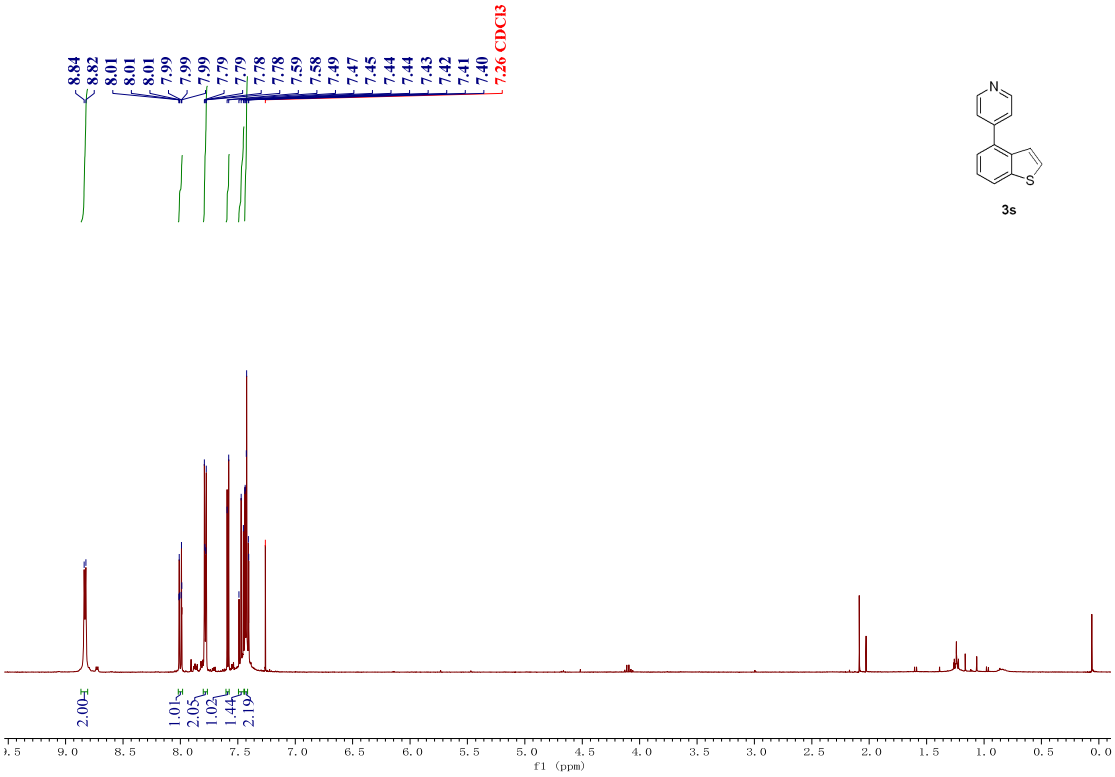
^{1}H NMR spectrum of 3r (400 MHz, $CDCl_3$)



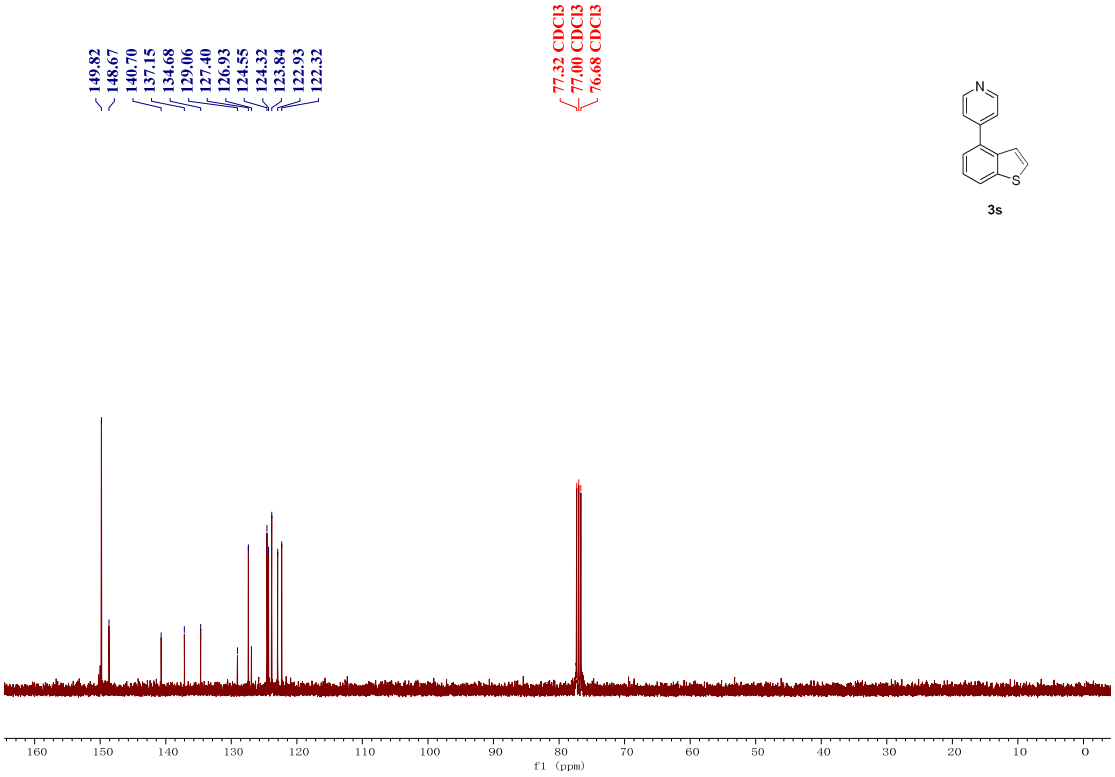
^{13}C NMR spectrum of 3r (100 MHz, $CDCl_3$)



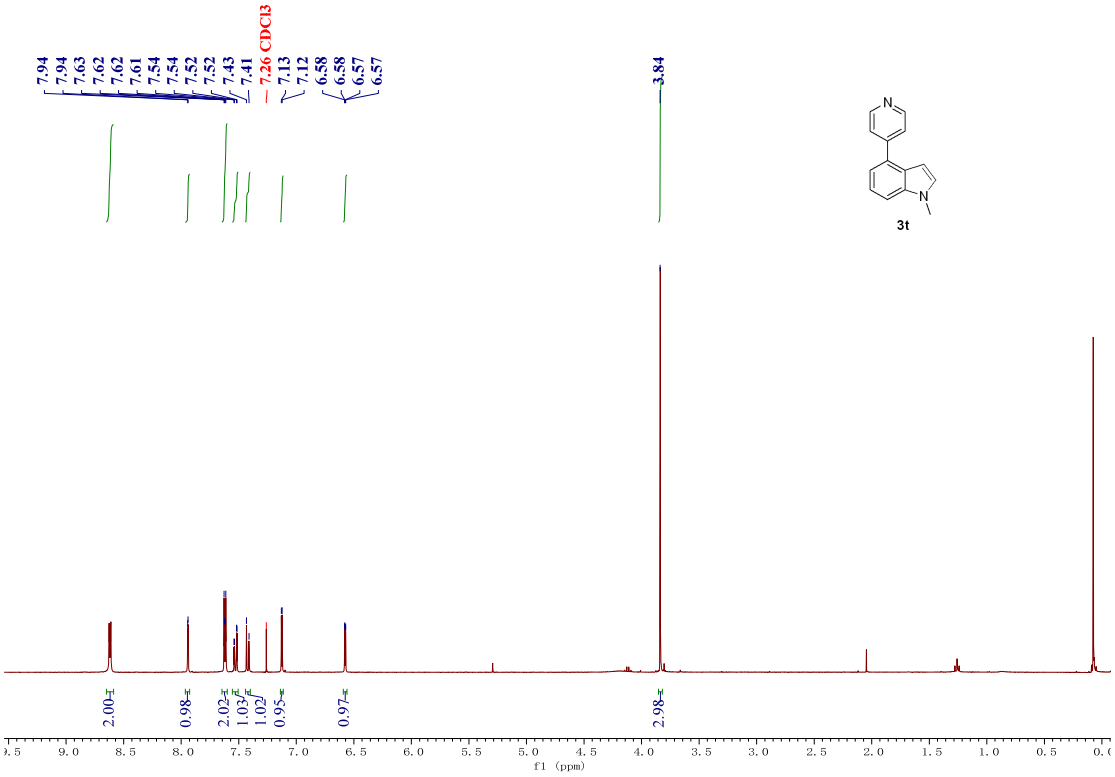
^{1}H NMR spectrum of 3s (400 MHz, $CDCl_3$)



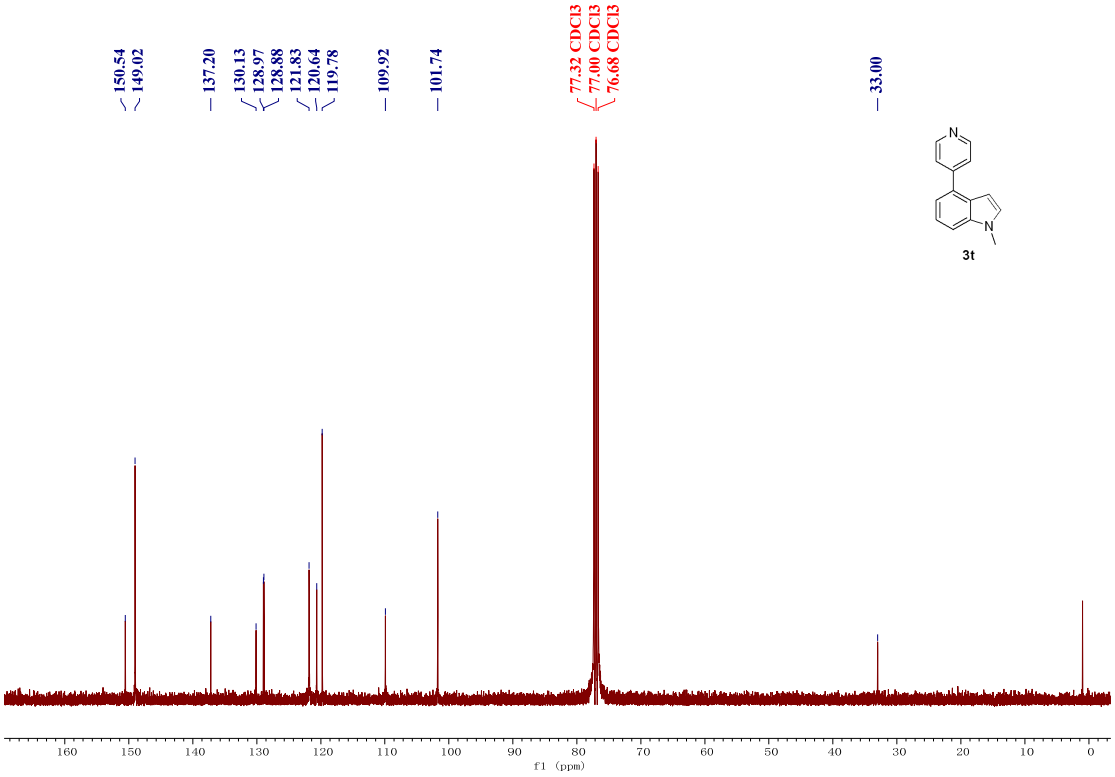
^{13}C NMR spectrum of 3s (100 MHz, $CDCl_3$)



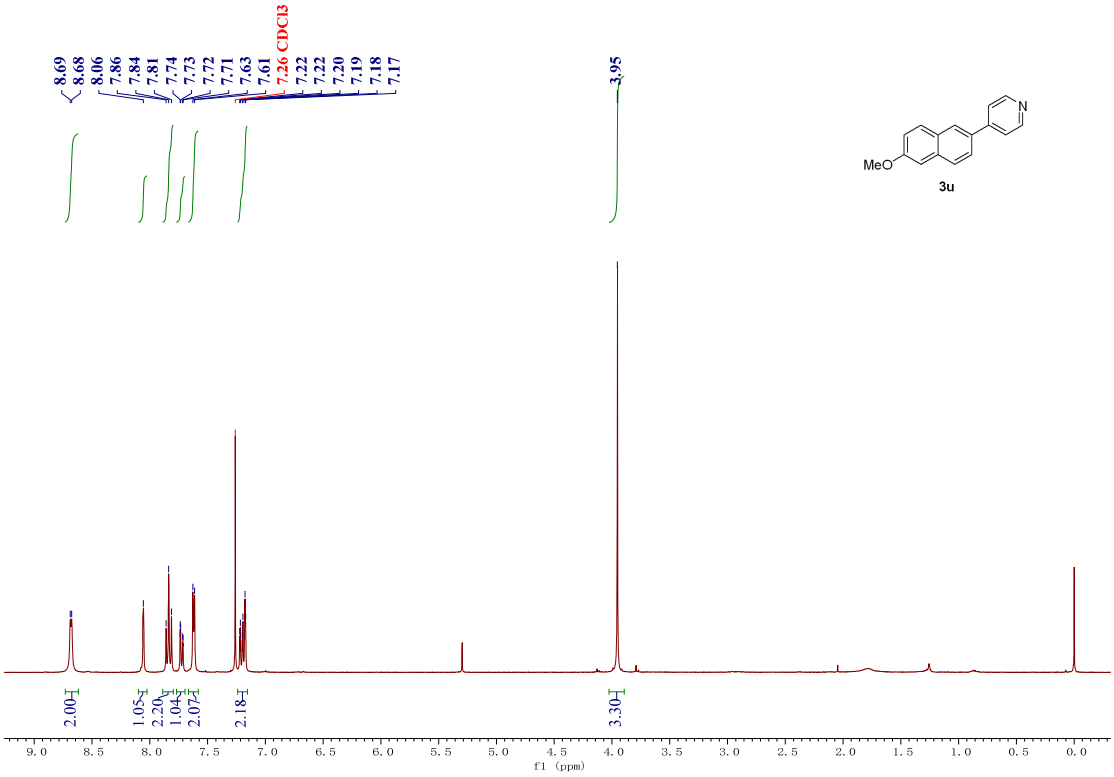
^{1}H NMR spectrum of 3t (400 MHz, $CDCl_3$)



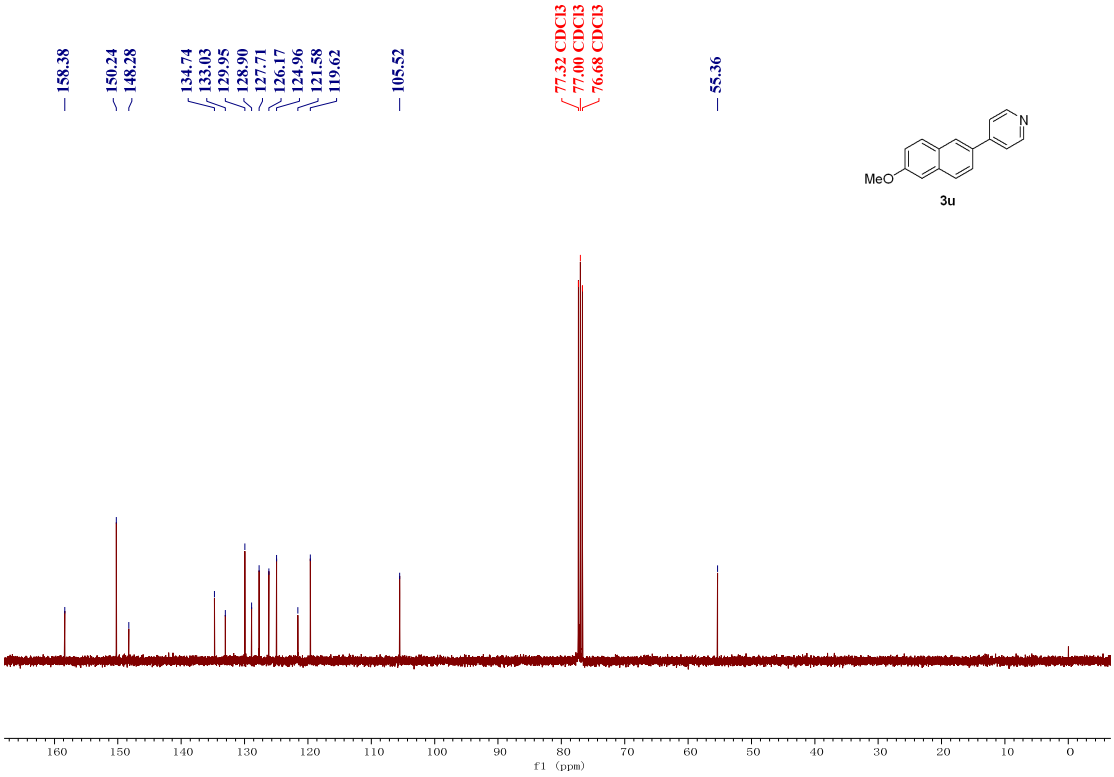
^{13}C NMR spectrum of 3t (100 MHz, $CDCl_3$)



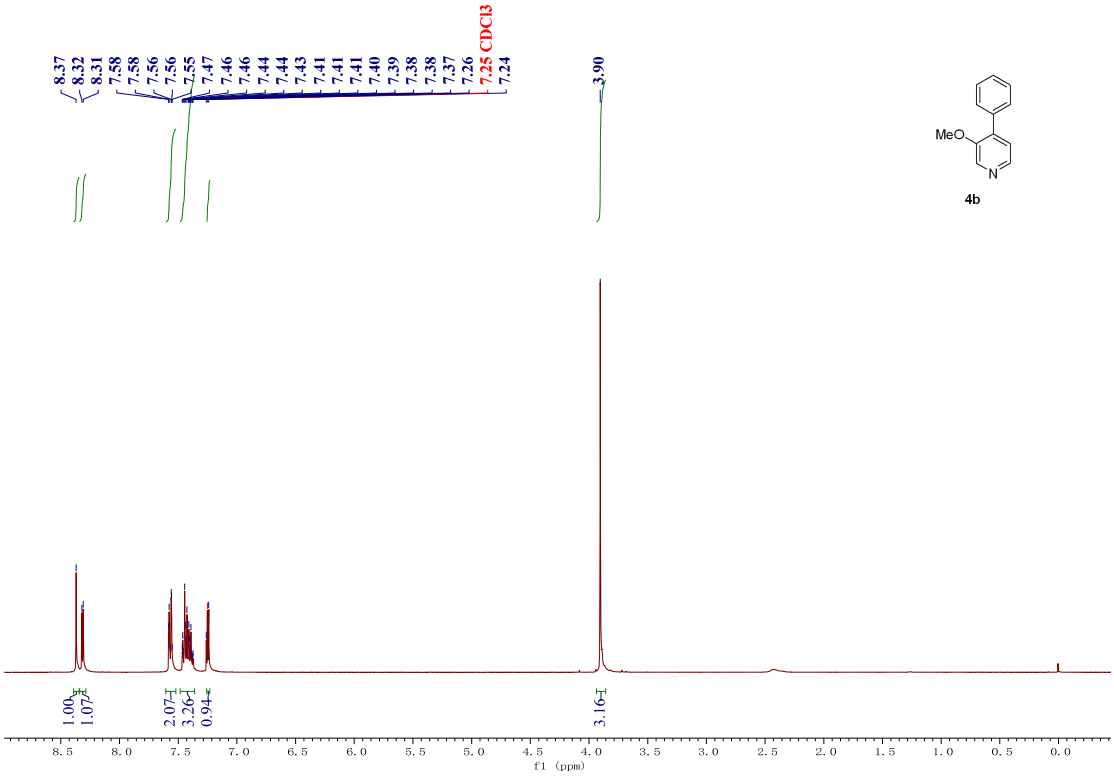
^{1}H NMR spectrum of 3u (400 MHz, $CDCl_3$)



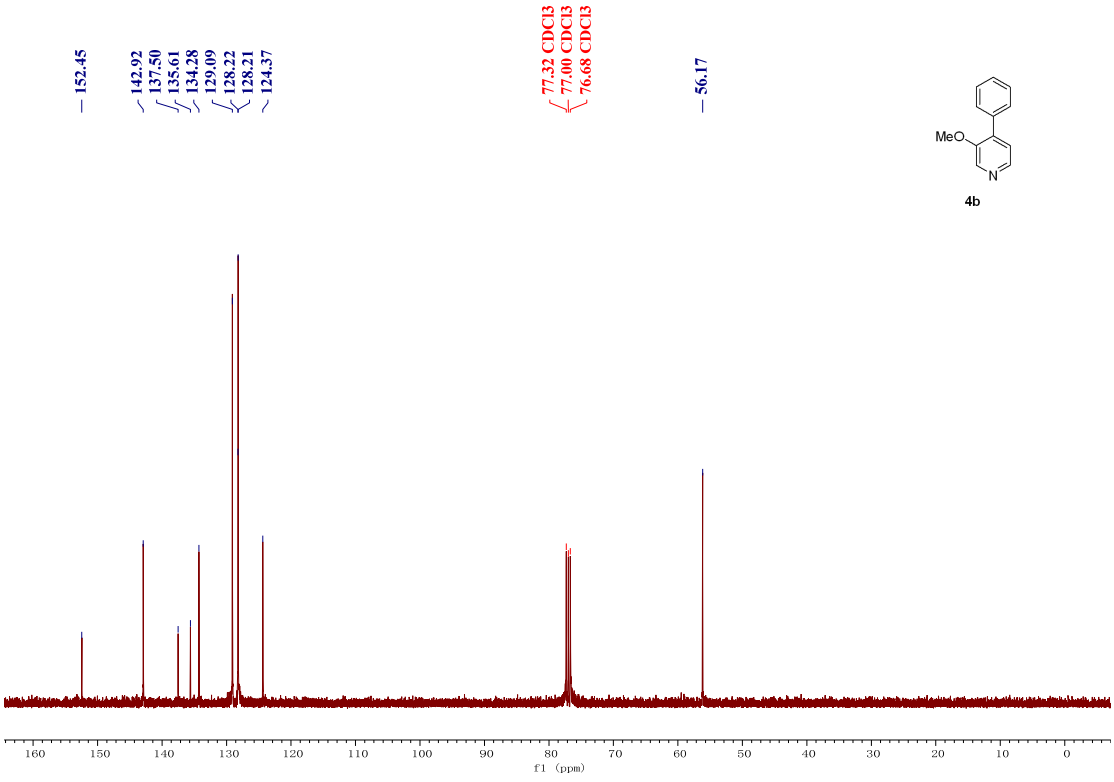
^{13}C NMR spectrum of 3u (100 MHz, $CDCl_3$)



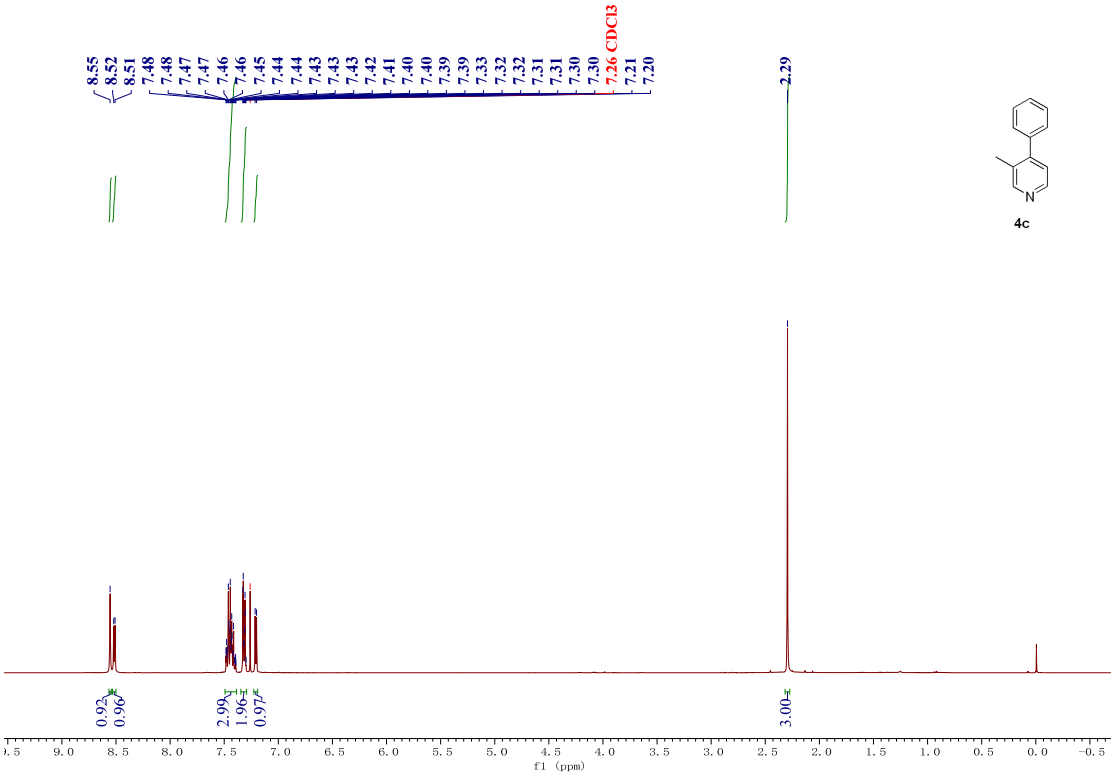
^{1}H NMR spectrum of 4b (400 MHz, $CDCl_3$)



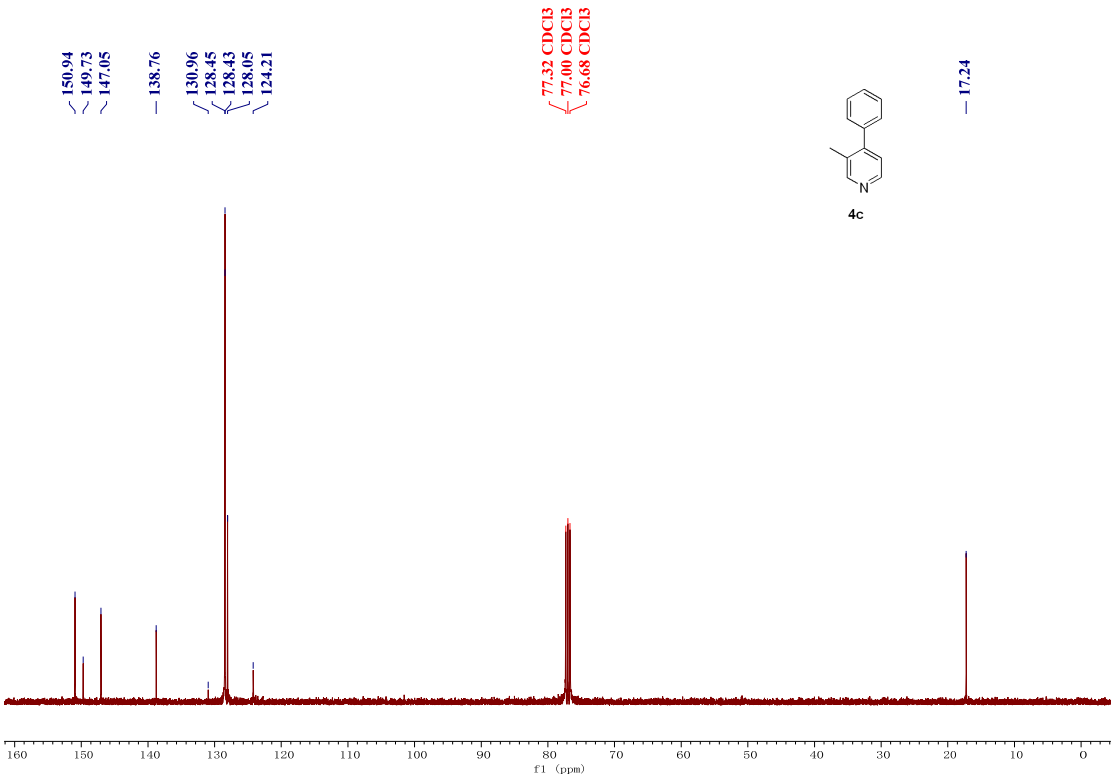
^{13}C NMR spectrum of 4b (100 MHz, $CDCl_3$)



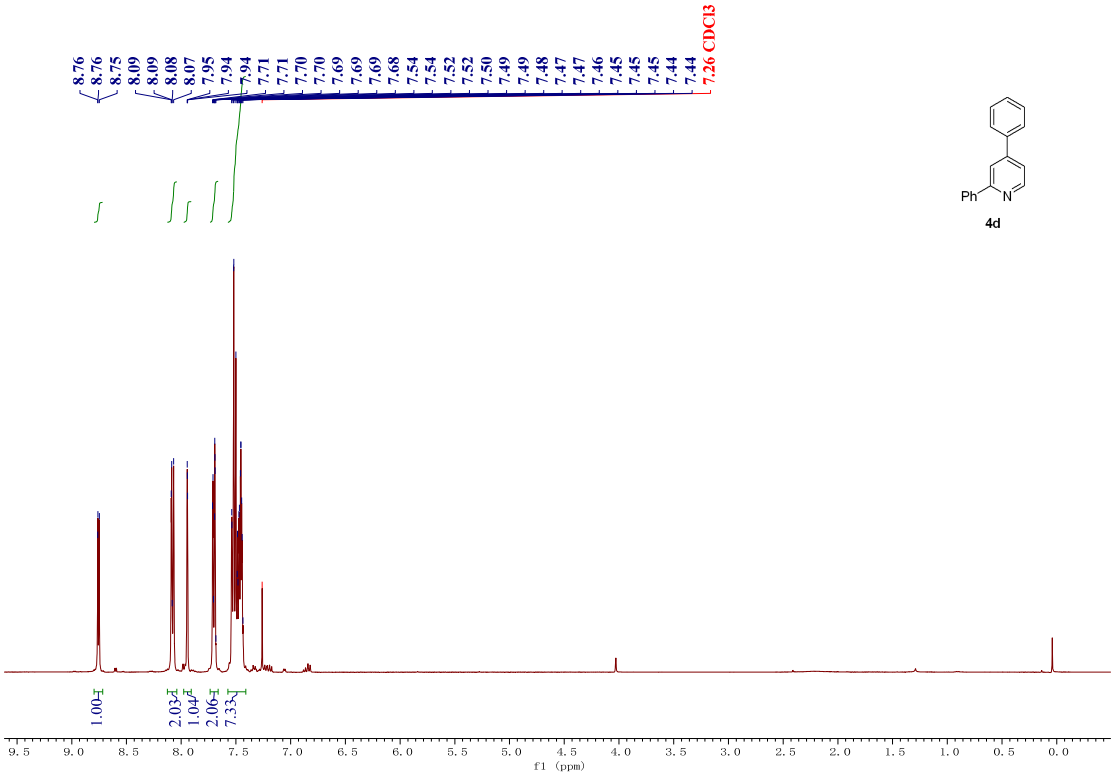
^{1}H NMR spectrum of 4c (400 MHz, $CDCl_3$)



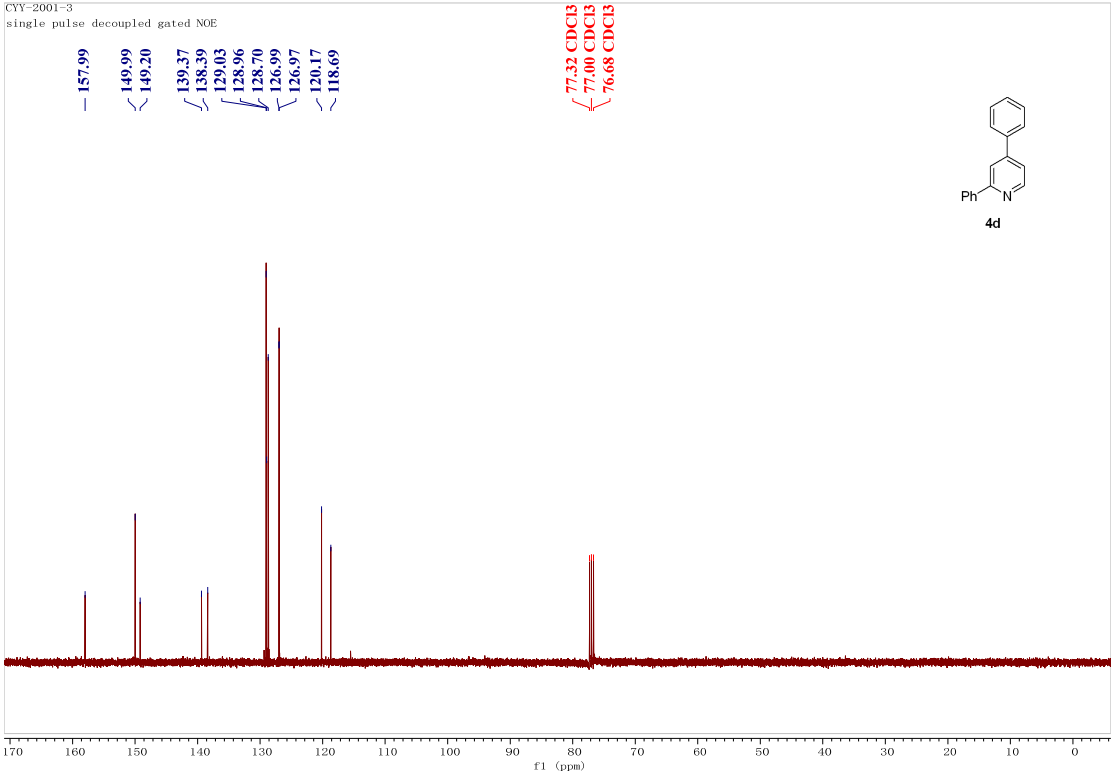
^{13}C NMR spectrum of 4c (100 MHz, $CDCl_3$)



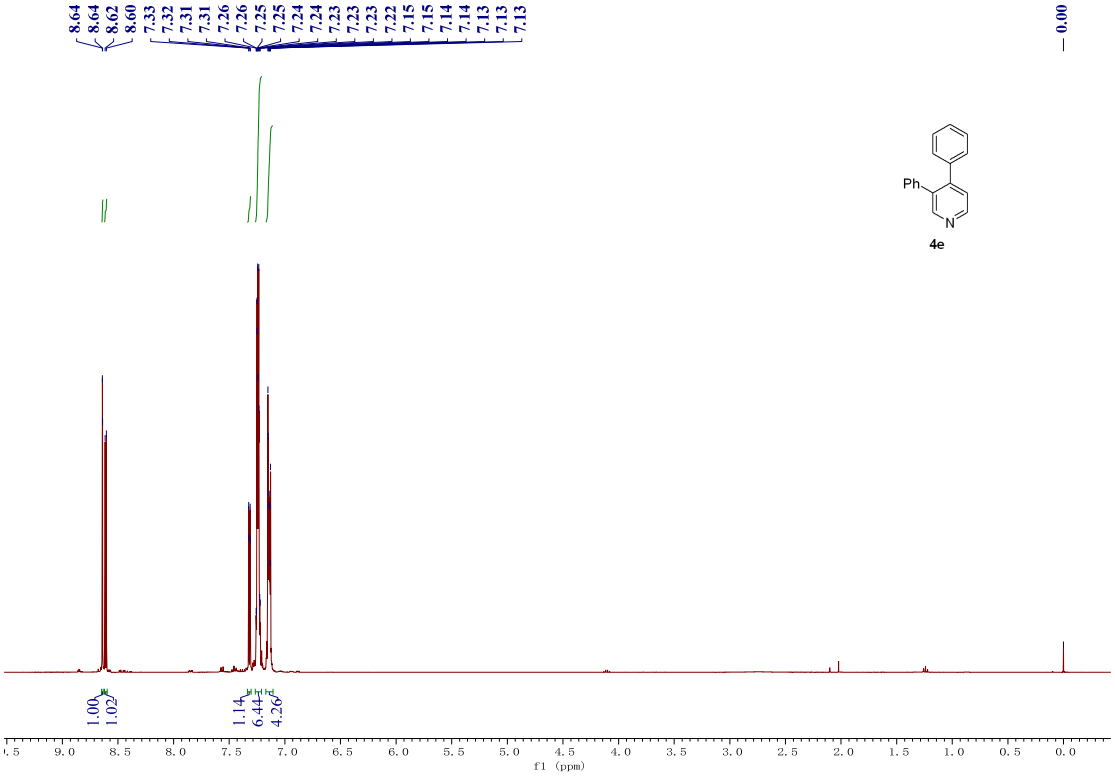
^{1}H NMR spectrum of 4d (400 MHz, $CDCl_3$)



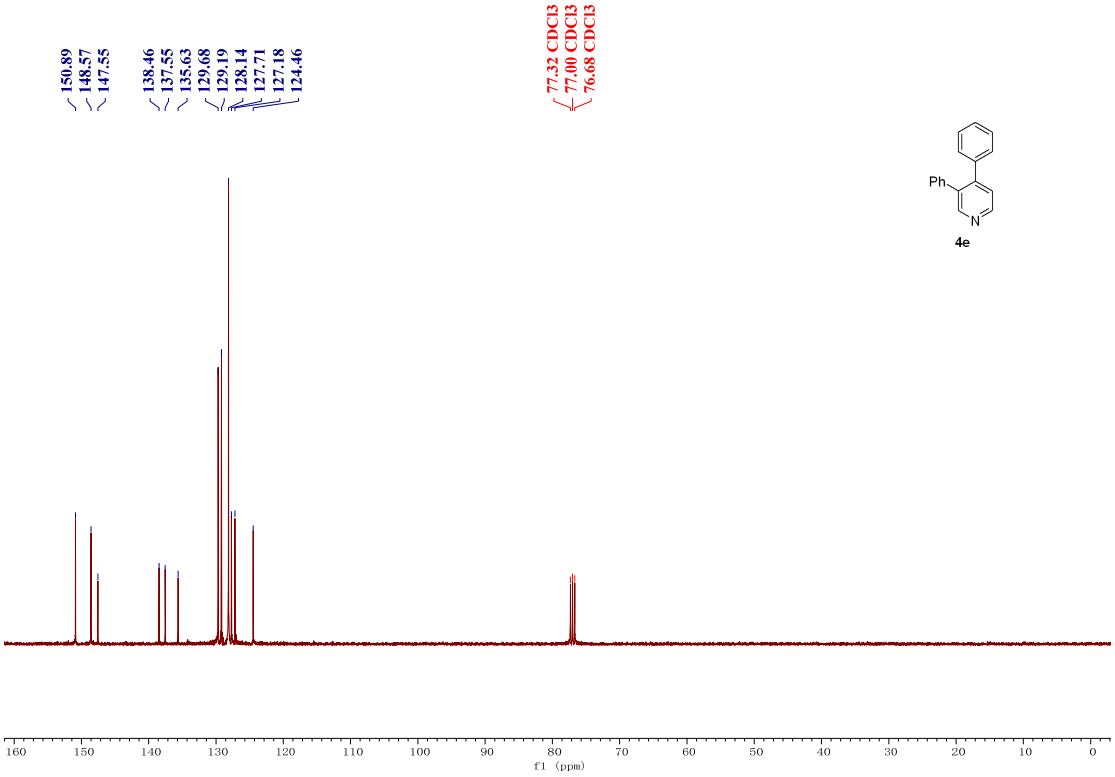
^{13}C NMR spectrum of 4d (100 MHz, $CDCl_3$)



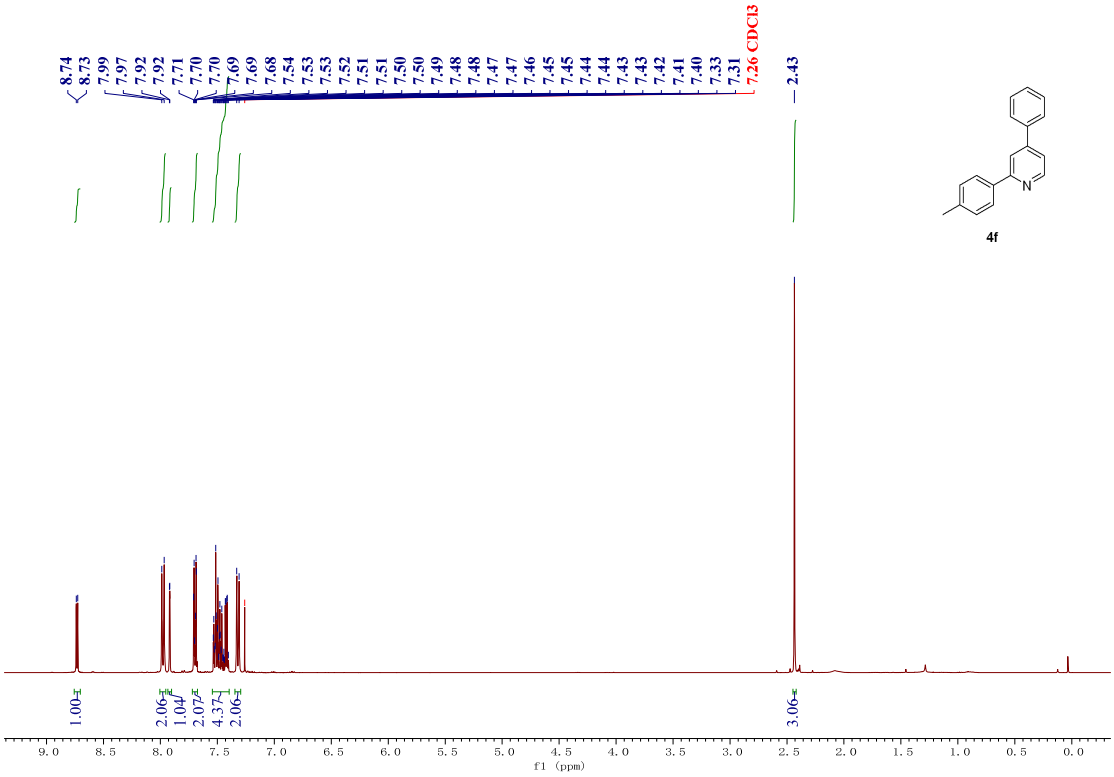
^{1}H NMR spectrum of 4e (400 MHz, $CDCl_3$)



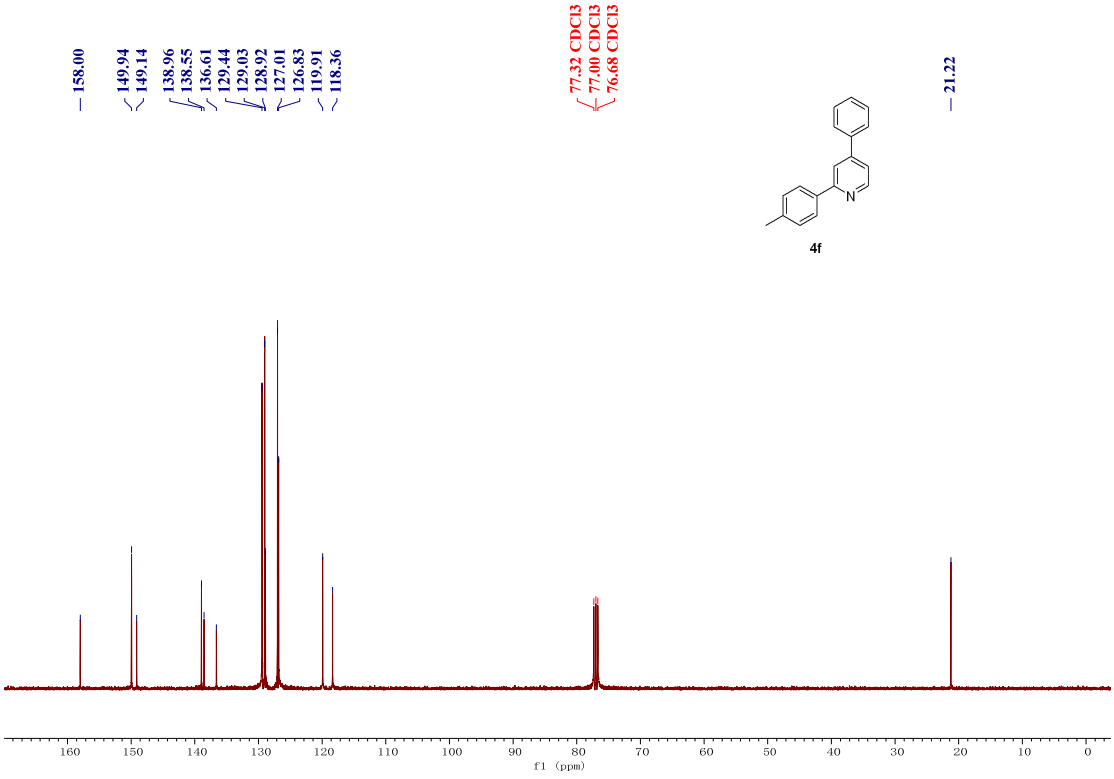
^{13}C NMR spectrum of 4e (100 MHz, $CDCl_3$)



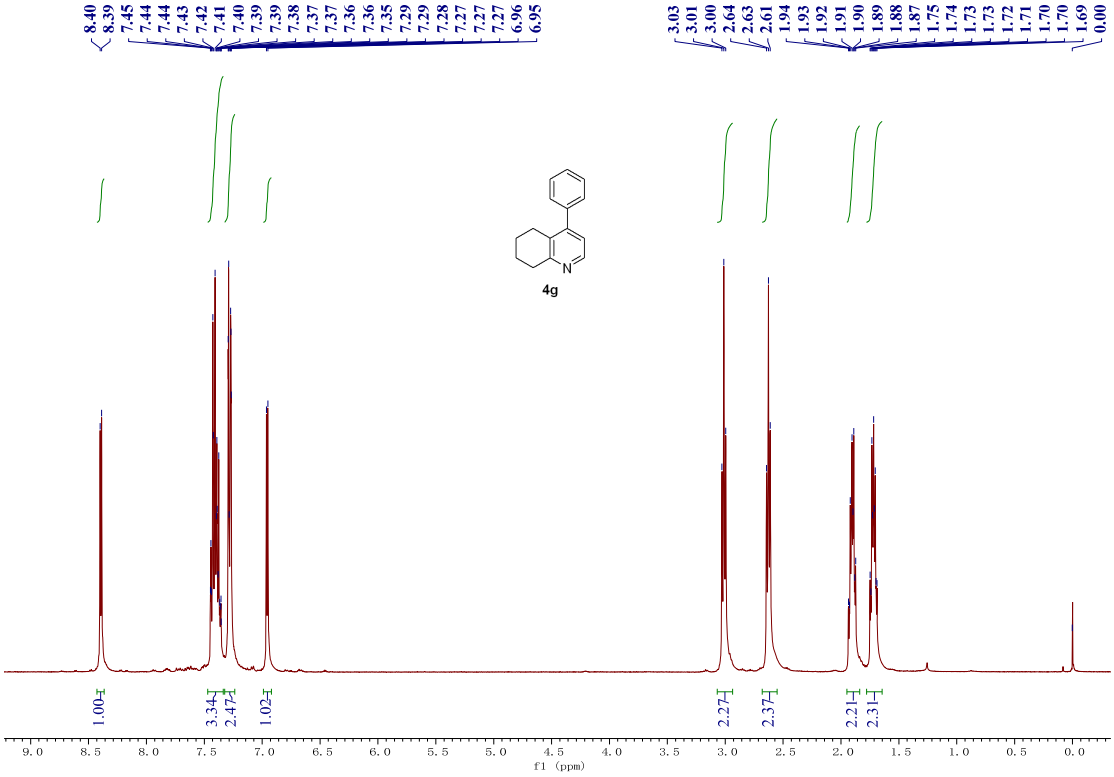
^{1}H NMR spectrum of 4f (400 MHz, $CDCl_3$)



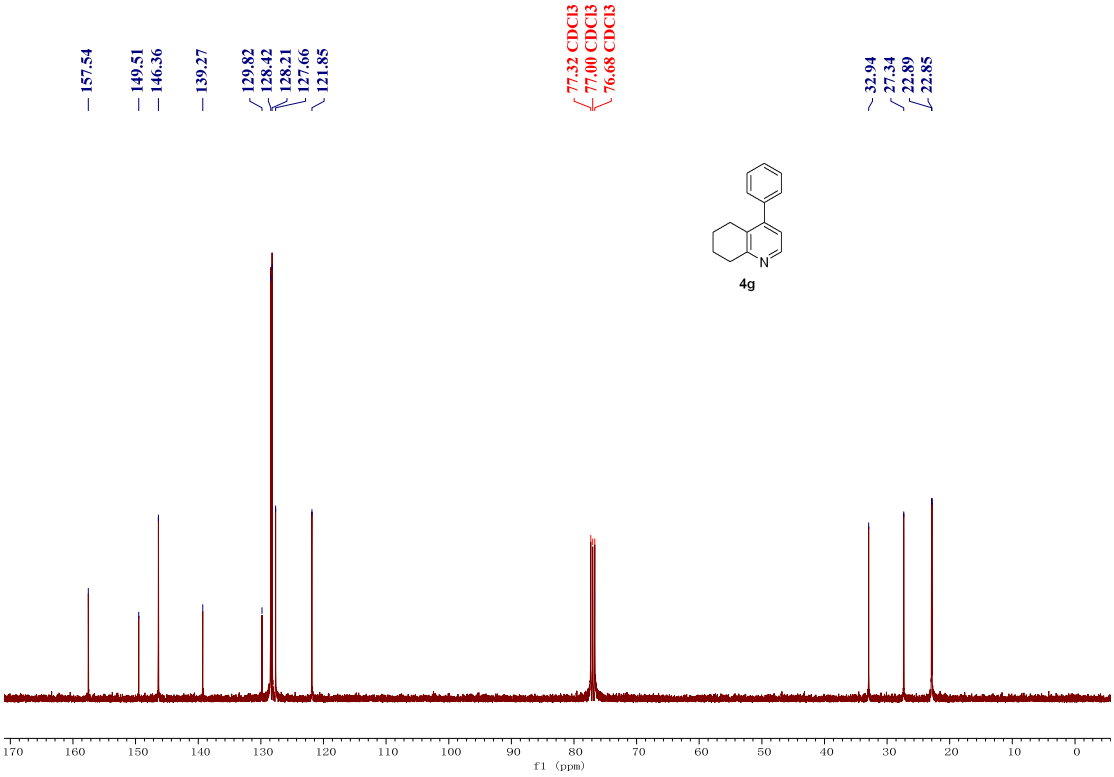
^{13}C NMR spectrum of 4f (100 MHz, $CDCl_3$)



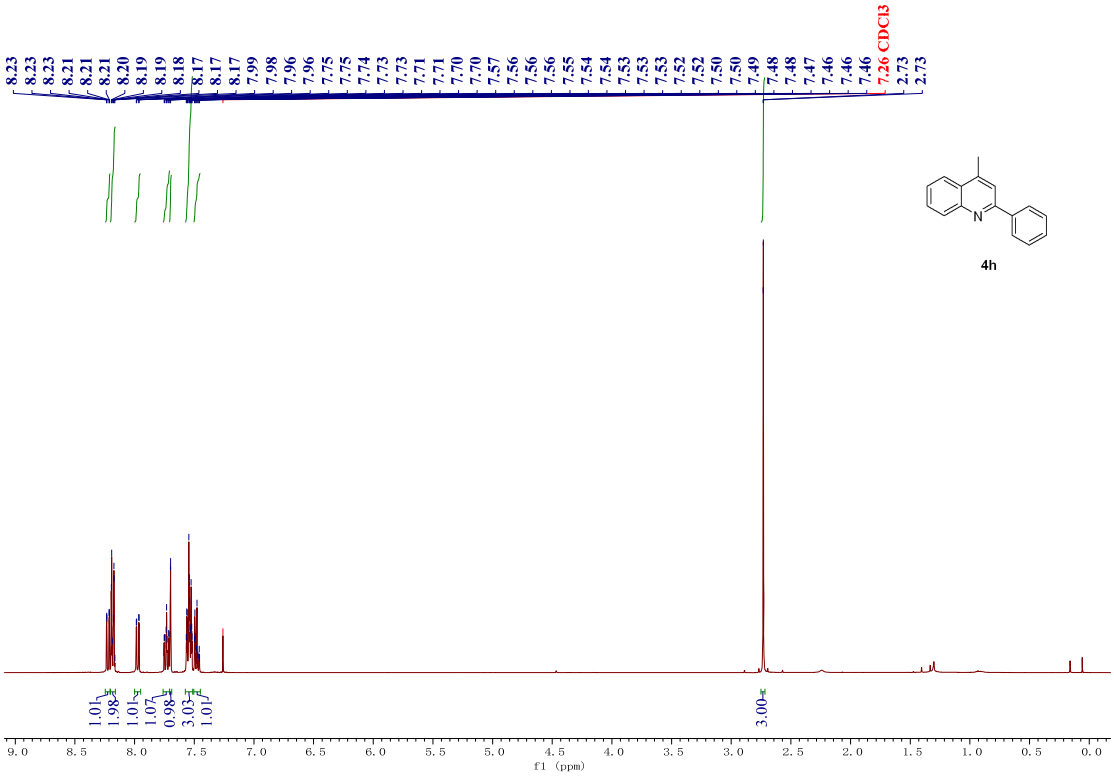
^{1}H NMR spectrum of 4g (400 MHz, $CDCl_3$)



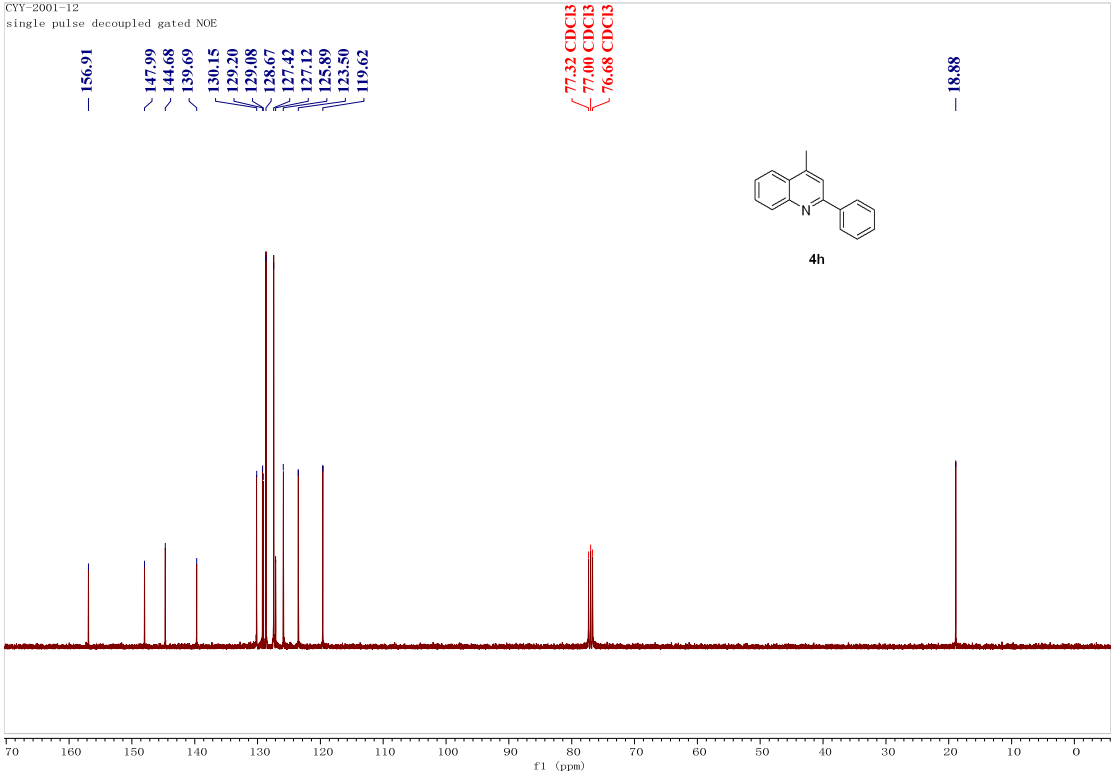
^{13}C NMR spectrum of 4g (100 MHz, $CDCl_3$)



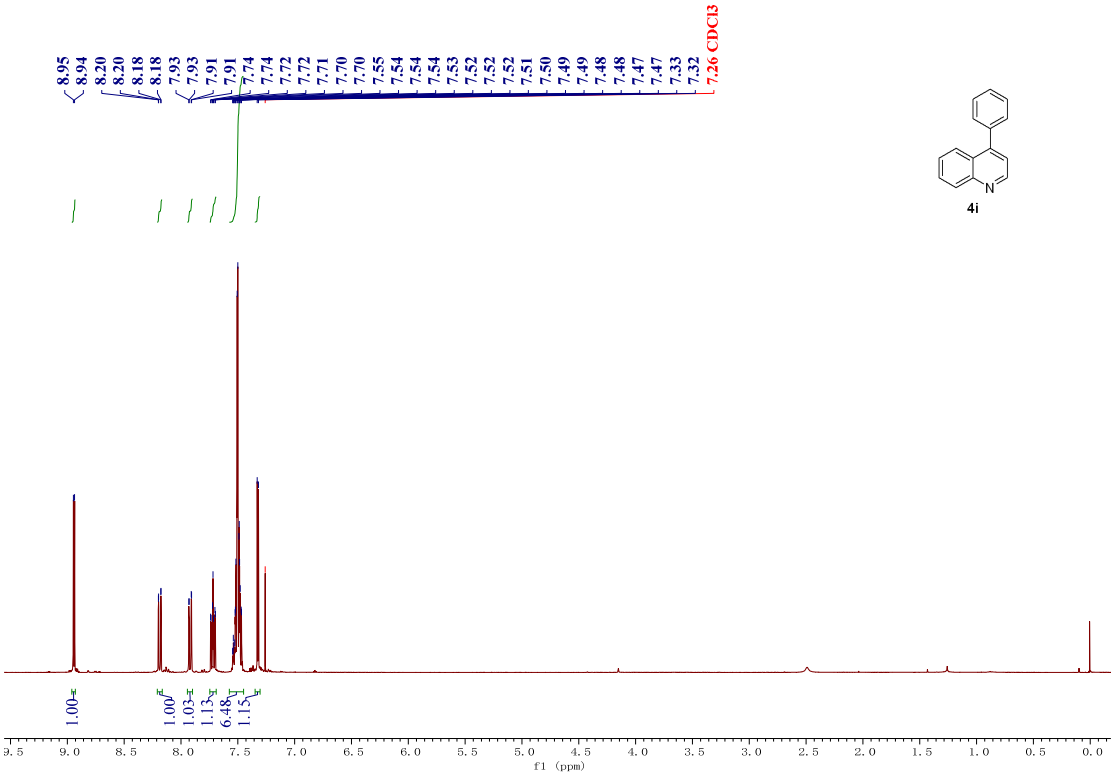
^{1}H NMR spectrum of 4h (400 MHz, $CDCl_3$)



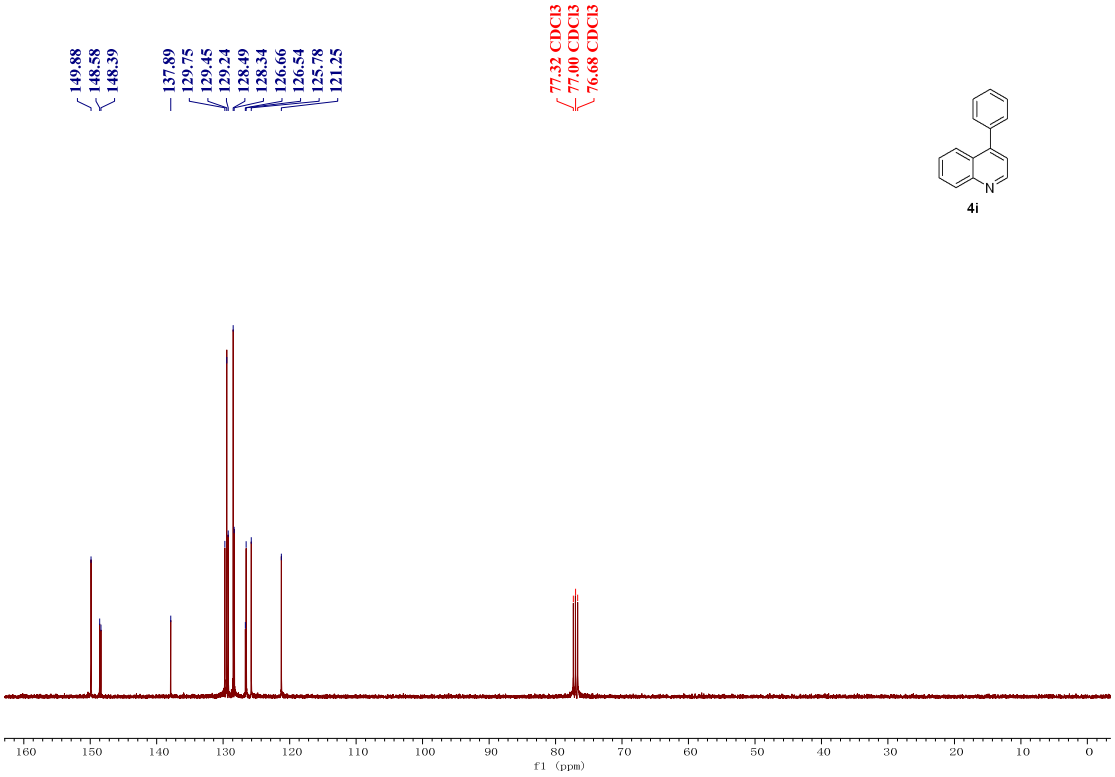
^{13}C NMR spectrum of 4h (100 MHz, $CDCl_3$)



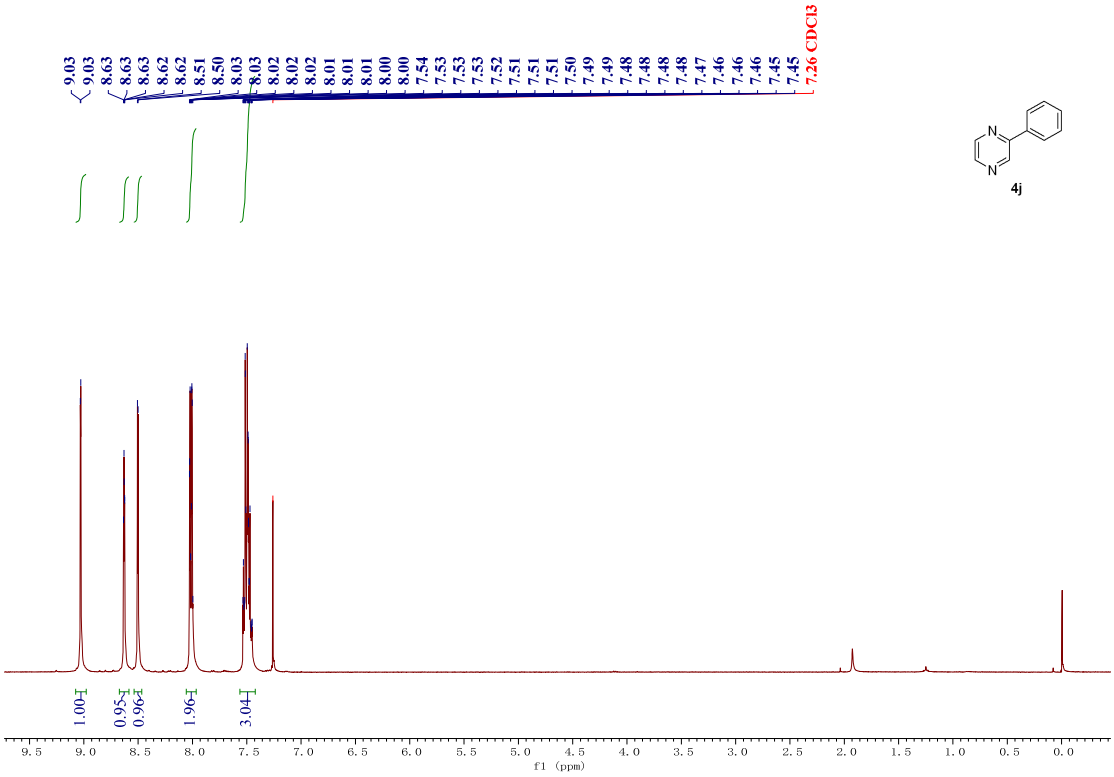
^{1}H NMR spectrum of 4i (400 MHz, $CDCl_3$)



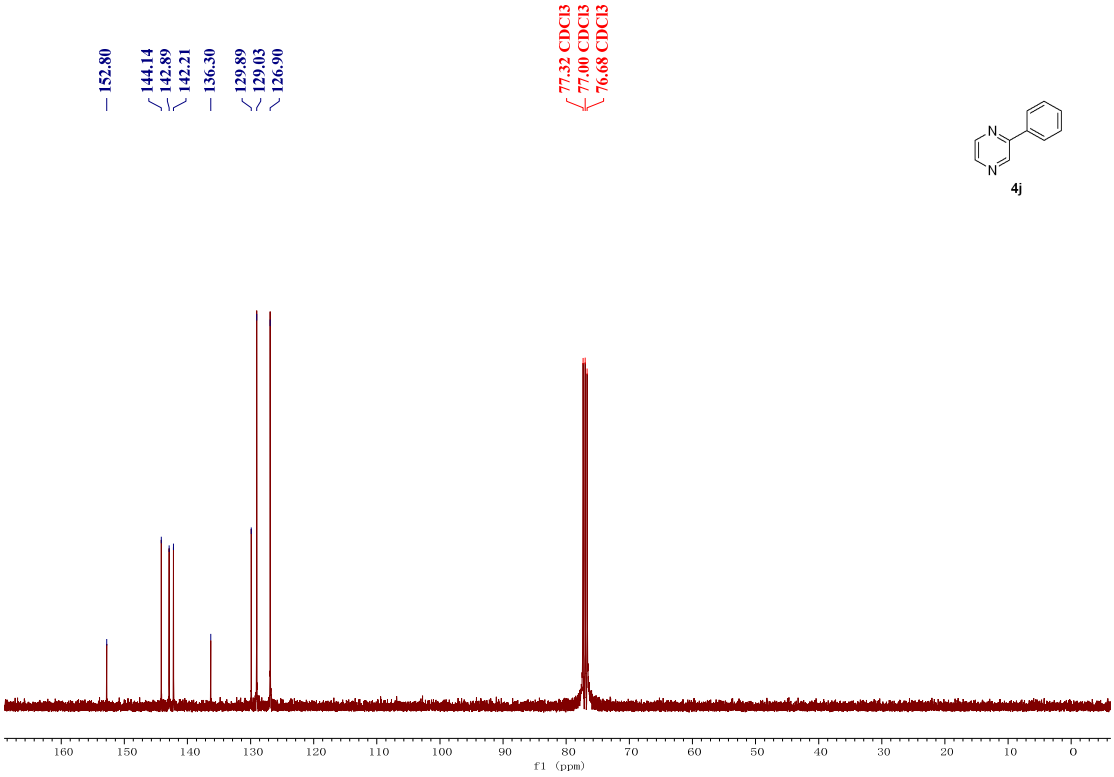
^{13}C NMR spectrum of 4i (100 MHz, $CDCl_3$)



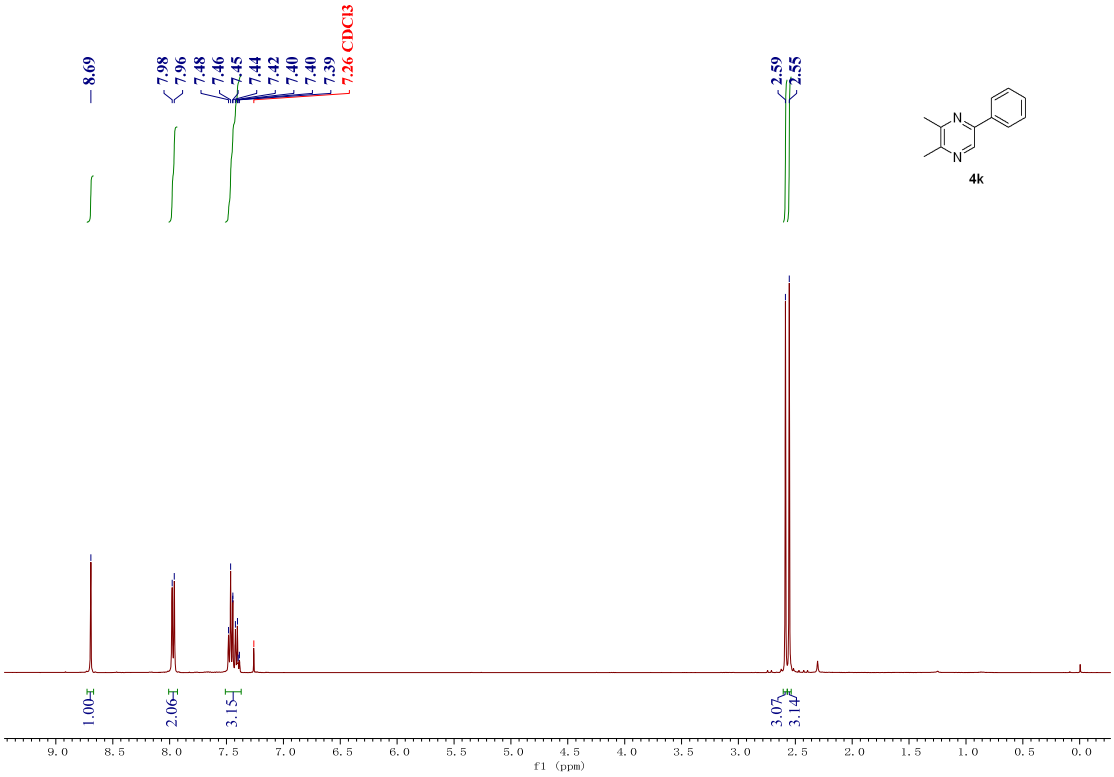
^{1}H NMR spectrum of 4j (400 MHz, $CDCl_3$)



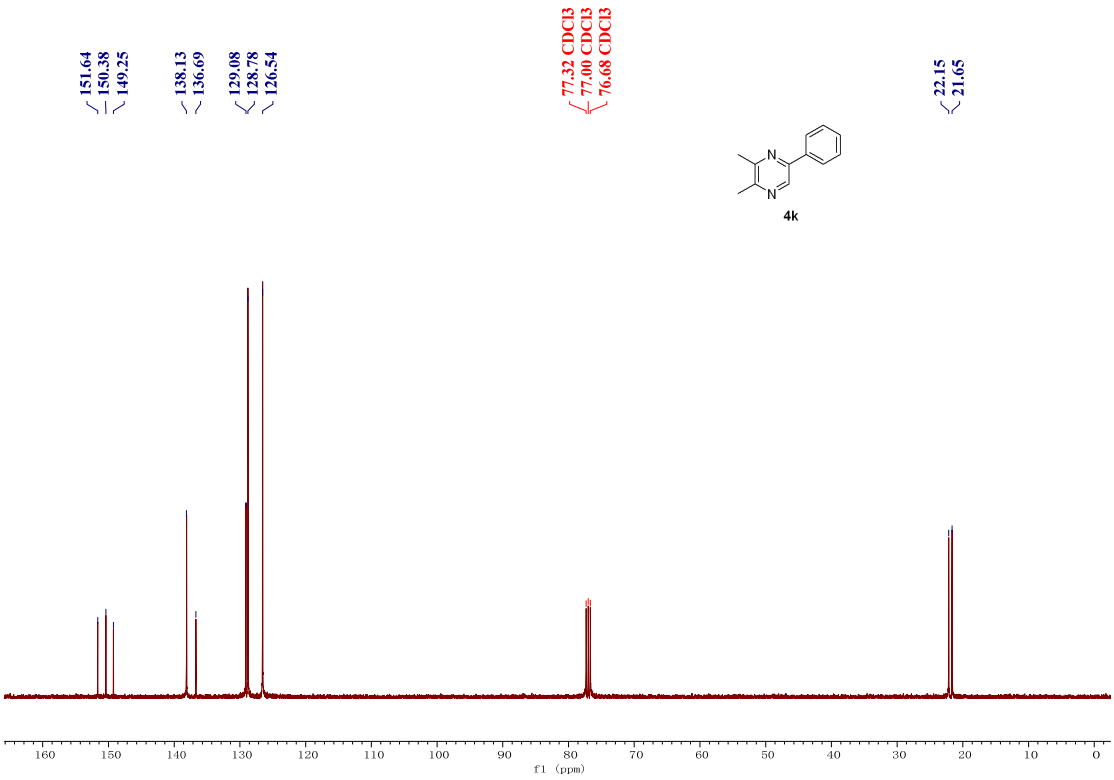
^{13}C NMR spectrum of 4j (100 MHz, $CDCl_3$)



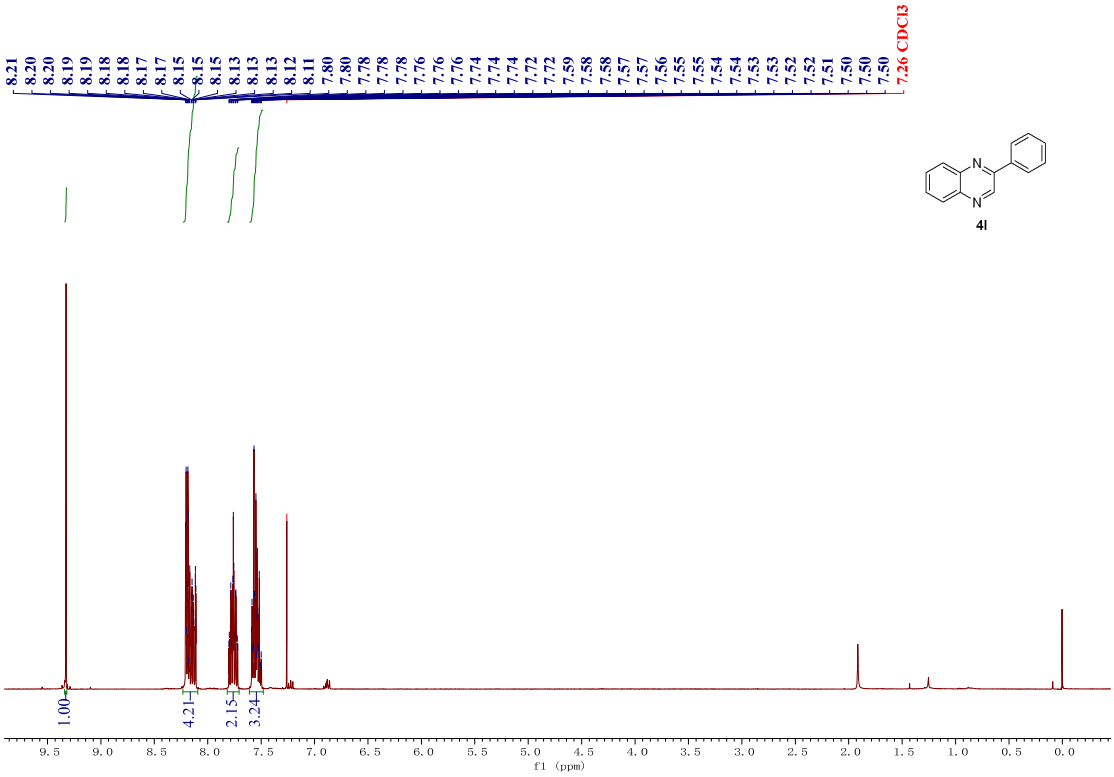
^{1}H NMR spectrum of 4k (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of 4k (100 MHz, $CDCl_3$)



^{1}H NMR spectrum of 4l (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of 4l (100 MHz, $CDCl_3$)