Base-Catalysed [3+2] Cycloaddition of Propargylamines and Aldehydes to Substituted Furans

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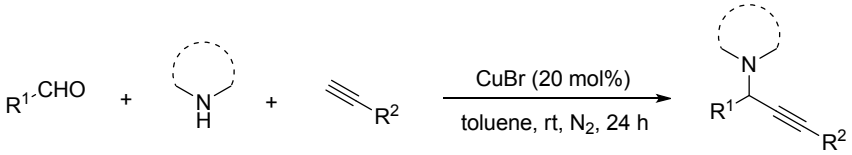
Context

1. General information:

Unless otherwise stated, all commercial materials and solvents were used directly without further purification. ^{1}H NMR spectra were recorded on 400 MHz spectrometers, and ^{13}C NMR spectra were recorded on a 100 MHz spectrometer. Chemical shifts (in ppm) were referenced to tetramethylsilane (δ = 0 ppm) in $CDCl_3$ as an internal standard at room temperature. ^{13}C NMR spectra were obtained by using the same NMR spectrometers and were calibrated with $CDCl_3$ (δ = 77.00 ppm). High-resolution mass spectra (HRMS) were equipped with an ESI source and a TOF detector. Column chromatography was performed on silica gel (70-230 mesh ASTM) using the reported eluents. Thin-layer chromatography (TLC) was carried out on 4×15 cm plates with a layer thickness of 0.2 mm (silica gel 60 F254).

The A3-propargylamines were prepared according to the literatures.[1]



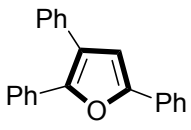
To a 25 mL round-bottom flask equipped with a magnetic stir bar were added amine (1.3 mmol), aldehyde (1.0 mmol), acetylene (1.3 mmol), copper (I) bromide (20 mol%) and toluene (5 mL). The mixture was degassed and backfilled with argon, and then stirred in room temperature for 24 h (monitored by TLC). The resulting reaction mixture was diluted with CH_2Cl_2 (10 mL) and filtered through a thin pad of silica gel. The filter cake was washed with CH_2Cl_2, and the combined filtrate was concentrated in vacuum. The crude product was purified by flash column chromatography on silica gel to afford the corresponding A3-propargylamines **2**.

2. General procedure for synthesis of furans 3:

A mixture of aldehydes **1** (0.25 mmol), propargylamines **2** (0.25 mmol, 1 equiv), and TBAOH (0.05 mmol, 0.2 equiv) in DMSO (1.25 mL) was stirred in room temperature (25 ^{o}C) under air atmosphere for 2 h (monitored by TLC). Then H_2O was added and the resultant was extracted with EtOAc (3 x 10 mL). The combined EtOAc extracts were dried over Na_2SO_4 and concentrated. Then solvent was evaporated and the residue was purified by silica gel flash chromatography (EtOAc/PE=1/100 to EtOAc/PE=1/10) to give furans **3**.

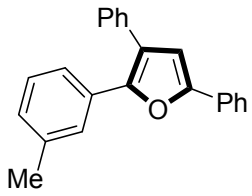
For **3aa** (gram-scale): A mixture of benzaldehyde **1a** (0.53g, 5 mmol), 2-(1,3-diphenylprop-2-yn-1-yl)-1,2,3,4-tetrahydroisoquinoline **2a** (1.62g, 5 mmol, 1 equiv), and TBAOH (1 mmol, 0.2 equiv) in DMSO (12.5 mL) was stirred in room temperature (25 ^{o}C) under air atmosphere for 2 h (monitored by TLC). Then H_2O was added and the resultant was extracted with EtOAc (3 x 20 mL). The combined EtOAc extracts were dried over Na_2SO_4 and concentrated. Then solvent was evaporated and the residue was purified by silicagel flash chromatography (EtOAc/PE=1/100) to give 2,3,5-triphenylfuran **3aa** in a 69% yield (1.02 g).

3. Characterization data for products:



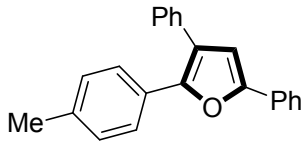
2,3,5-triphenylfuran **3aa**[2]

56.7 mg, 78% yield. White solid. Mp 91-93 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.0 Hz, 2H), 7.60 (d, *J* = 8.1 Hz, 2H), 7.44 (d, *J* = 7.9 Hz, 2H), 7.36 (dd, *J* = 17.8, 7.7 Hz, 4H), 7.32 – 7.19 (m, 5H), 6.77 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.5, 147.9, 134.3, 131.1, 130.5, 128.7, 128.7, 128.6, 128.4, 127.5, 127.5, 127.3, 126.1, 124.5, 123.8, 109.4.



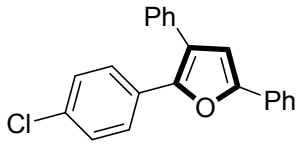
3,5-Diphenyl-2-(m-tolyl)furan **3ba**

57.2 mg, 74% yield. White solid. Mp 60-62 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 7.5 Hz, 2H), 7.46 (d, *J* = 6.8 Hz, 3H), 7.42 – 7.34 (m, 5H), 7.33 – 7.24 (m, 2H), 7.16 (t, *J* = 7.7 Hz, 1H), 7.06 (d, *J* = 7.5 Hz, 1H), 6.80 (s, 1H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.4, 148.1, 138.0, 134.3, 131.0, 130.6, 128.7, 128.7, 128.6, 128.3, 128.2, 127.5, 127.2, 126.8, 124.4, 123.8, 123.4, 109.4, 21.5; HRMS (ESI) m/z calcd for $C_{23}H_{19}O$ (MH+) 311.1430, found 311.1426.



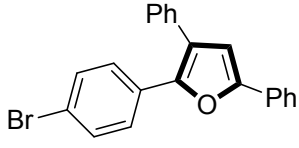
3,5-Diphenyl-2-(p-tolyl)furan **3ca**[3]

48.4 mg, 62% yield. White solid. Mp 108-110 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, *J* = 8.3 Hz, 2H), 7.52 – 7.45 (m, 4H), 7.40 (dd, *J* = 13.6, 7.1 Hz, 4H), 7.31 (dd, *J* = 14.9, 7.6 Hz, 2H), 7.12 (d, *J* = 7.9 Hz, 2H), 6.81 (s, 1H), 2.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.2, 148.2, 137.4, 134.4, 130.6, 129.1, 128.7, 128.7, 128.6, 128.3, 127.4, 127.2, 126.1, 123.8, 123.7, 109.3, 21.3.



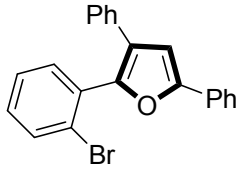
2-(4-Chlorophenyl)-3,5-diphenylfuran **3da**[3]

60.3 mg, 73% yield. White solid. Mp 100-102 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, *J* = 7.3 Hz, 2H), 7.56 (d, *J* = 8.7 Hz, 2H), 7.49 – 7.30 (m, 10H), 6.84 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.8, 146.7, 134.0, 133.1, 130.3, 129.5, 128.8, 128.8, 128.6, 128.6, 127.7, 127.5, 127.2, 125.0, 123.8, 109.6.



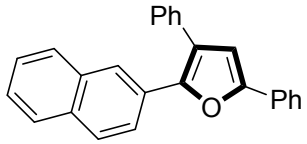
2-(4-Bromophenyl)-3,5-diphenylfuran **3ea**[3]

65.3 mg, 70% yield. White solid. Mp 103-105 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, *J* = 7.4 Hz, 2H), 7.49 – 7.32 (m, 11H), 7.29 (t, *J* = 7.4 Hz, 1H), 6.79 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.9, 146.8, 134.0, 131.6, 130.3, 130.0, 128.8, 128.8, 128.6, 127.7, 127.5, 127.5, 125.2, 123.9, 121.3, 109.6.



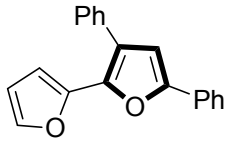
2-(2-Bromophenyl)-3,5-diphenylfuran **3fa**

60.1 mg, 64% yield. White solid. Mp 51-53 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, *J* = 7.8 Hz, 2H), 7.72 (d, *J* = 7.8 Hz, 1H), 7.44 (t, *J* = 7.0 Hz, 3H), 7.36 – 7.24 (m, 8H), 7.01 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.5, 147.2, 133.5, 133.3, 132.8, 132.6, 130.5, 130.2, 128.7, 128.5, 127.7, 127.4, 127.3, 127.0, 125.7, 124.1, 123.9, 106.7; HRMS (ESI) m/z calcd for $C_{22}H_{16}BrO$ (MH+) 375.0379, found 375.0376.



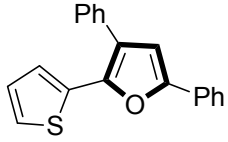
2-(Naphthalen-2-yl)-3,5-diphenylfuran **3ga**

65.5 mg, 76% yield. White solid. Mp 110-112 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.77 (ddd, *J* = 19.6, 10.0, 5.5 Hz, 5H), 7.68 – 7.63 (m, 1H), 7.53 – 7.48 (m, 2H), 7.48 – 7.33 (m, 7H), 7.30 (td, *J* = 7.1, 1.1 Hz, 1H), 6.86 (d, *J* = 1.3 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.8, 148.0, 134.3, 133.4, 132.6, 130.5, 128.8, 128.8, 128.7, 128.5, 128.2, 127.9, 127.6, 127.6, 127.4, 126.3, 126.1, 125.0, 124.9, 124.2, 123.9, 109.6; HRMS (ESI) m/z calcd for $C_{26}H_{19}O$ (MNa+) 369.1250, found 369.1252.



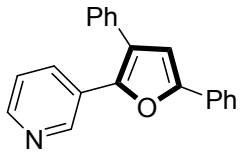
3,5-Diphenyl-2,2'-bifuran **3ha**

60.2 mg, 84% yield. Brown oil. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 – 7.71 (m, 2H), 7.55 (dd, *J* = 5.2, 3.3 Hz, 2H), 7.43 – 7.36 (m, 5H), 7.35 – 7.30 (m, 1H), 7.27 (dd, *J* = 10.5, 4.3 Hz, 1H), 6.81 (s, 1H), 6.63 – 6.50 (m, 1H), 6.42 (dd, *J* = 3.4, 1.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.8, 146.2, 142.0, 140.4, 133.2, 130.2, 128.7, 128.6, 128.4, 127.7, 127.4, 124.6, 123.9, 111.3, 108.6, 107.3; HRMS (ESI) m/z calcd for $C_{20}H_{15}O_2$ (MH+) 287.1067, found 287.1071.



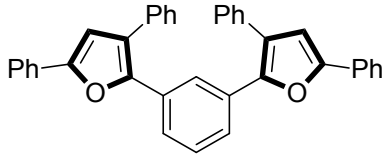
3,5-Diphenyl-2-(thiophen-2-yl)furan **3ia**

54.8 mg, 73% yield. Brown oil. R_f = 0.3 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (d, *J* = 7.4 Hz, 2H), 7.55 – 7.49 (m, 2H), 7.44 – 7.32 (m, 5H), 7.27 (t, *J* = 7.4 Hz, 1H), 7.23 – 7.21 (m, 1H), 7.21 – 7.14 (m, 1H), 6.96 (dd, *J* = 4.9, 3.8 Hz, 1H), 6.77 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.3, 143.9, 133.5, 133.1, 130.2, 128.9, 128.7, 128.6, 127.6, 127.6, 127.3, 124.7, 124.2, 124.0, 123.8, 109.2; HRMS (ESI) m/z calcd for $C_{20}H_{15}OS$ (MH+) 303.0838, found 303.0834.



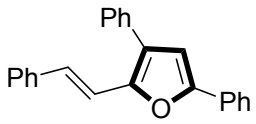
3-(3,5-Diphenylfuran-2-yl)pyridine **3ja**

58.0 mg, 78% yield. White solid. Mp 105-107 °C. R_f = 0.4 (EtOAc/PE = 1:10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.86 (s, 1H), 8.50 – 8.41 (m, 1H), 7.88 – 7.82 (m, 1H), 7.76 (dd, *J* = 8.3, 1.0 Hz, 2H), 7.42 (ddt, *J* = 12.6, 9.6, 4.8 Hz, 6H), 7.37 – 7.29 (m, 2H), 7.21 (dd, *J* = 8.0, 4.8 Hz, 1H), 6.82 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.6, 148.1, 147.1, 144.9, 133.5, 132.7, 130.1, 128.9, 128.8, 128.5, 127.9, 127.8, 127.3, 126.3, 123.9, 123.2, 109.5; HRMS (ESI) m/z calcd for $C_{21}H_{16}NO$ (MH+) 298.1226, found 298.1228.



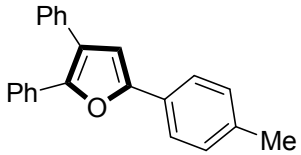
1,3-Bis(3,5-diphenylfuran-2-yl)benzene **3kb**

45.2 mg, 35% yield. Pale yellow solid. Mp 117-119 °C. R_f = 0.3 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.98 (d, *J* = 1.2 Hz, 1H), 7.66 (d, *J* = 7.8 Hz, 4H), 7.49 – 7.43 (m, 6H), 7.43 – 7.32 (m, 10H), 7.28 (t, *J* = 7.3 Hz, 2H), 7.20 (dd, *J* = 12.0, 4.5 Hz, 1H), 6.78 (d, *J* = 1.5 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.5, 147.4, 134.2, 131.3, 130.4, 128.8, 128.7, 128.7, 128.4, 127.5, 127.3, 124.9, 124.9, 123.8, 123.4, 109.6; HRMS (ESI) m/z calcd for $C_{38}H_{27}O_2$ (MH+) 515.2006, found 515.2008.



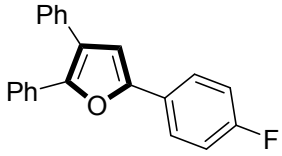
3,5-Diphenyl-2-styrylfuran **3la**

27.8 mg, 35% yield. Colorless oil. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 – 7.75 (m, 2H), 7.48 (ddt, *J* = 15.4, 13.6, 4.8 Hz, 8H), 7.38 – 7.28 (m, 4H), 7.27 – 7.22 (m, 2H), 7.10 (d, *J* = 16.1 Hz, 1H), 6.87 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.9, 148.1, 137.3, 133.5, 130.4, 128.8, 128.8, 128.7, 128.3, 127.9, 127.7, 127.5, 127.2, 126.9, 126.4, 124.0, 115.2, 108.1; HRMS (ESI) m/z calcd for $C_{24}H_{19}O$ (MH+) 323.1430, found 323.1426.



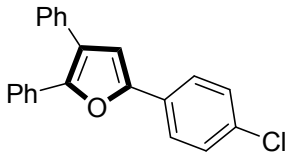
2,3-Diphenyl-5-(p-tolyl)furan **3af**[3]

51.8 mg, 67% yield. White solid. Mp 97-99 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 (d, *J* = 8.0 Hz, 2H), 7.59 (d, *J* = 7.8 Hz, 2H), 7.45 (d, *J* = 7.5 Hz, 2H), 7.36 (t, *J* = 7.4 Hz, 2H), 7.29 (dd, *J* = 15.2, 7.7 Hz, 3H), 7.21 (t, *J* = 8.9 Hz, 3H), 6.74 (s, 1H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.8, 147.5, 137.4, 134.4, 131.2, 129.4, 128.7, 128.6, 128.4, 127.9, 127.3, 127.2, 126.1, 124.5, 123.8, 108.8, 21.3.



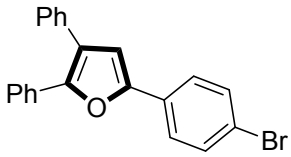
5-(4-Fluorophenyl)-2,3-diphenylfuran **3ag**[3]

65.2 mg, 83% yield. White solid. Mp 85-87 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 – 7.69 (m, 2H), 7.59 (dd, *J* = 8.3, 1.1 Hz, 2H), 7.45 (dd, *J* = 8.1, 1.3 Hz, 2H), 7.40 – 7.24 (m, 6H), 7.10 (dd, *J* = 12.1, 5.4 Hz, 2H), 6.74 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.3 (d, *J* = 247.4 Hz), 151.7, 147.9, 134.2, 131.0, 128.7, 128.7, 128.4, 127.5 (d, *J* = 19.7 Hz), 126.9 (d, *J* = 3.2 Hz), 126.1, 125.6, 125.5, 124.5, 115.8 (d, *J* = 21.9 Hz), 109.1.



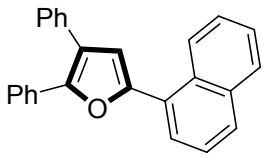
5-(4-Chlorophenyl)-2,3-diphenylfuran **3ah**[3]

75.1 mg, 91% yield. White solid. Mp 98-100 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 – 7.64 (m, 2H), 7.61 – 7.56 (m, 2H), 7.44 (dd, *J* = 8.1, 1.3 Hz, 2H), 7.40 – 7.23 (m, 8H), 6.79 (s, 1H); ^{13}C NMR (100MHz, $CDCl_3$) δ 151.5, 148.2, 134.1, 133.1, 130.9, 129.0, 129.0, 128.7, 128.7, 128.4, 127.7, 127.4, 126.2, 125.0, 124.6, 109.9.



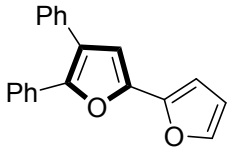
5-(4-Bromophenyl)-2,3-diphenylfuran **3ai**[3]

61.8 mg, 66% yield. White solid. Mp 103-104 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 – 7.55 (m, 4H), 7.50 (d, *J* = 8.6 Hz, 2H), 7.45 – 7.40 (m, 2H), 7.39 – 7.23 (m, 6H), 6.78 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.4, 148.2, 134.0, 131.9, 130.9, 129.4, 128.7, 128.6, 128.4, 127.7, 127.4, 126.1, 125.2, 124.6, 121.2, 110.0.



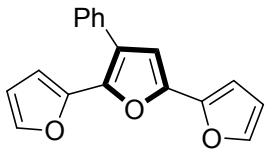
5-(Naphthalen-1-yl)-2,3-diphenylfuran **3aj**

51.9 mg, 60% yield. Colorless oil. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.57 (d, *J* = 8.4 Hz, 1H), 7.94 – 7.83 (m, 3H), 7.66 (d, *J* = 7.3 Hz, 2H), 7.60 – 7.49 (m, 5H), 7.41 (t, *J* = 7.5 Hz, 2H), 7.37 – 7.24 (m, 4H), 6.91 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.2, 148.3, 134.4, 134.0, 131.1, 130.3, 128.8, 128.7, 128.7, 128.6, 128.5, 128.2, 127.5, 127.3, 126.7, 126.2, 126.1, 126.0, 125.5, 125.4, 124.2, 113.7 ; HRMS (ESI) m/z calcd for (MNa+) 369.1250, found 369.1252.



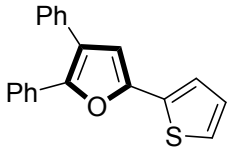
4,5-Diphenyl-2,2'-bifuran **3ak**

45.1 mg, 63% yield. Brown oil. R_f = 0.3 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 – 7.54 (m, 2H), 7.44 (d, *J* = 7.2 Hz, 3H), 7.29 (dddd, *J* = 14.5, 10.6, 7.5, 4.4 Hz, 6H), 6.71 (s, 1H), 6.65 (d, *J* = 3.4 Hz, 1H), 6.50 – 6.44 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.6, 146.3, 145.3, 142.0, 134.0, 130.8, 128.7, 128.7, 128.4, 127.6, 127.4, 126.2, 124.1, 111.5, 109.3, 105.5; HRMS (ESI) m/z calcd for $C_{20}H_{15}O_2$ (MH+) 287.1067, found 287.1063.



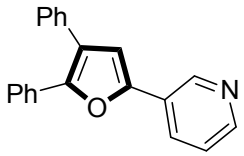
3'-Phenyl-2,2':5',2''-terfuran **3hk**

50.1 mg, 72% yield. Brown oil. R_f = 0.3 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, *J* = 7.1 Hz, 2H), 7.45 – 7.42 (m, 1H), 7.42 – 7.36 (m, 3H), 7.35 – 7.30 (m, 1H), 6.72 (s, 1H), 6.67 (d, *J* = 3.4 Hz, 1H), 6.56 (d, *J* = 3.4 Hz, 1H), 6.50 – 6.46 (m, 1H), 6.45 – 6.38 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.0, 145.9, 145.5, 142.2, 142.1, 140.1, 132.9, 128.6, 128.4, 127.5, 124.3, 111.5, 111.3, 108.6, 107.6, 105.9; HRMS (ESI) m/z calcd for $C_{18}H_{13}O_3$ (MH+) 277.0859, found 277.0855.



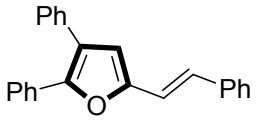
2,3-Diphenyl-5-(thiophen-2-yl)furan **3al**

47.8 mg, 63% yield. Pale yellow solid. Mp 72-74 °C. R_f = 0.3 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 – 7.74 (m, 4H), 7.49 – 7.39 (m, 4H), 7.38 – 7.30 (m, 3H), 7.20 (dd, *J* = 3.5, 1.1 Hz, 1H), 7.11 (dd, *J* = 5.1, 3.5 Hz, 1H), 6.87 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.5, 148.5, 135.5, 130.7, 130.2, 128.7, 128.4, 127.9, 127.7, 127.4, 126.4, 126.0, 125.1, 123.9, 117.5, 109.6; HRMS (ESI) m/z calcd for $C_{20}H_{15}OS$ (MH+) 303.0838, found 303.0840.



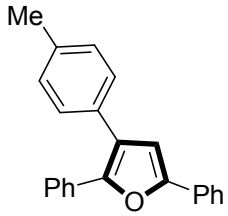
3-(4,5-Diphenylfuran-2-yl)pyridine **3am**

59.6 mg, 80% yield. White solid. Mp 103-104 °C. R_f = 0.4 (EtOAc/PE = 1:10). ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.01 (s, 1H), 8.51 (s, 1H), 7.99 (d, *J* = 7.9 Hz, 1H), 7.59 (d, *J* = 7.5 Hz, 2H), 7.44 (d, *J* = 7.2 Hz, 2H), 7.40 – 7.23 (m, 7H), 6.88 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 149.5, 148.9, 148.2, 145.3, 133.7, 130.6, 130.6, 128.7, 128.6, 128.4, 127.8, 127.4, 126.5, 126.2, 124.5, 123.5, 110.7; HRMS (ESI) m/z calcd for $C_{21}H_{16}NO$ (MH+) 298.1226, found 298.1227.



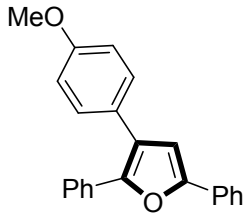
2,3-diphenyl-5-styrylfuran **3an**

18.0 mg, 22% yield. White solid. Mp 93-95 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 – 7.57 (m, 2H), 7.51 (d, *J* = 7.4 Hz, 2H), 7.45 – 7.41 (m, 2H), 7.39 – 7.24 (m, 9H), 7.16 (d, *J* = 16.2 Hz, 1H), 6.93 (d, *J* = 16.2 Hz, 1H), 6.52 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.0, 148.1, 137.0, 134.2, 131.0, 128.7, 128.7, 128.7, 128.4, 127.7, 127.6, 127.5, 127.3, 126.4, 126.2, 124.6, 116.1, 113.1; HRMS (ESI) m/z calcd for $C_{24}H_{19}O$ (MH+) 323.1430, found 323.1432.



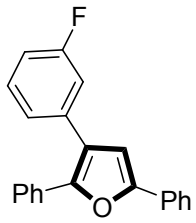
2,5-Diphenyl-3-(p-tolyl)furan **3ao**[4]

46.0 mg, 59% yield. White solid. Mp 126-127 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 – 7.72 (m, 2H), 7.65 – 7.59 (m, 2H), 7.41 – 7.33 (m, 4H), 7.31 – 7.16 (m, 6H), 6.77 (d, *J* = 1.4 Hz, 1H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.4, 147.7, 137.0, 131.3, 131.2, 130.6, 129.4, 128.7, 128.5, 128.3 127.4, 127.4, 126.0, 124.5, 123.8, 109.5, 21.2.



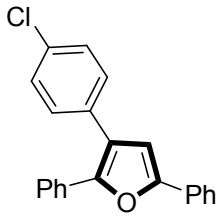
3-(4-Methoxyphenyl)-2,5-diphenylfuran **3ap**[4]

53.2 mg, 65% yield. Colorless oil. R_f = 0.4 (EtOAc/PE = 1:20). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.71 (m, 2H), 7.61 (dd, *J* = 5.3, 3.3 Hz, 2H), 7.42 – 7.35 (m, 4H), 7.32 – 7.20 (m, 4H), 6.95 – 6.88 (m, 2H), 6.76 (s, 1H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.9, 152.4, 147.5, 131.2, 130.6, 129.8, 128.7, 128.4, 127.4, 127.3, 126.6, 126.0, 124.2, 123.8, 114.1, 109.6, 55.2.



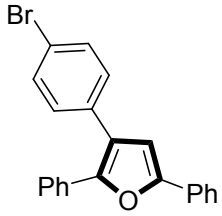
3-(3-Fluorophenyl)-2,5-diphenylfuran **3aq**

65.2 mg, 83% yield. White solid. Mp 79-80 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, *J* = 7.7 Hz, 2H), 7.66 (d, *J* = 7.4 Hz, 2H), 7.47 (t, *J* = 7.5 Hz, 2H), 7.35 (ddd, *J* = 25.7, 12.5, 4.6 Hz, 6H), 7.23 (d, *J* = 9.9 Hz, 1H), 7.07 (t, *J* = 8.3 Hz, 1H), 6.85 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.0 (d, *J* = 245.9 Hz), 152.8, 148.3, 136.5 (d, *J* = 8.2 Hz), 130.7, 130.3, 130.1 (d, *J* = 8.5 Hz), 128.8, 128.5, 127.8, 127.7, 126.3, 124.4 (d, *J* = 2.8 Hz), 123.8, 123.3 (d, *J* = 2.2 Hz), 115.5 (d, *J* = 21.8 Hz), 114.2 (d, *J* = 21.0 Hz), 109.0; HRMS (ESI) m/z calcd for $C_{22}H_{16}FO$ (MH+) 315.1180, found 315.1176.



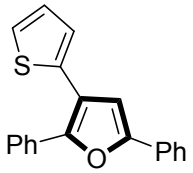
3-(4-Chlorophenyl)-2,5-diphenylfuran **3ar**

50.4 mg, 61% yield. White solid. Mp 117-119 °C. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 (d, *J* = 7.9 Hz, 2H), 7.56 (d, *J* = 7.8 Hz, 2H), 7.32 (dtd, *J* = 23.3, 15.4, 7.8 Hz, 10H), 6.73 (d, *J* = 0.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.7, 148.1, 133.1, 132.7, 130.8, 130.3, 129.9, 128.9, 128.7, 128.5, 127.7, 127.6, 126.2, 123.8, 123.2, 109.0; HRMS (ESI) m/z calcd for $C_{22}H_{16}ClO$ (MH+) 331.0884, found 331.0882.



3-(4-Bromophenyl)-2,5-diphenylfuran **3as**[4]

56.1 mg, 60% yield. White solid. Mp 119-121 °C. R_f = 0.4 (EtOAc/PE = 1:100).^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.67 (d, *J* = 8.1 Hz, 2H), 7.57 (d, *J* = 8.5 Hz, 2H), 7.49 (t, *J* = 7.6 Hz, 2H), 7.44 – 7.31 (m, 6H), 6.83 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.8, 148.0, 133.2, 131.8, 130.7, 130.3, 130.2, 128.7, 128.5, 127.7, 127.6, 126.2, 123.8, 123.2, 121.2, 108.9.



2,5-Diphenyl-3-(thiophen-2-yl)furan **3at**[5]

54.5 mg, 72% yield. Colorless oil. R_f = 0.4 (EtOAc/PE = 1:100). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 – 7.74 (m, 4H), 7.49 – 7.39 (m, 4H), 7.38 – 7.30 (m, 3H), 7.20 (dd, *J* = 3.5, 1.1 Hz, 1H), 7.11 (dd, *J* = 5.1, 3.5 Hz, 1H), 6.87 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.5, 148.5, 135.5, 130.7, 130.2, 128.7, 128.4, 127.9, 127.7, 127.4, 126.4, 126.0, 125.1, 123.9, 117.5, 109.6.

References:

1. (a) Q.-H. Zheng, W. Meng, G.-J. Jiang and Z.-X. Yu, *Org. Lett.*, 2013, **15**, 5928; (b) Y. Odabachian, S. Tong, Q. Wang, M.-X. Wang and J. Zhu, *Angew. Chem. Int. Ed.*, 2013, **52**, 10878.
2. Dudnik, A. S.; Gevorgyan, V. *Angew. Chem. Int. Ed.*, 2007, **46**, 5195.
3. Y. Wu, Z. Huang, Y. Luo, D. Liu, Y. Deng, H. Yi, J. Lee, C. Pao, J. Chen and A. Lei, *Org. Lett.*, 2017, **19**, 2330.
4. Y. Xia, Y. M. Xia, R. Ge, Z. Liu, Q. Xiao, Y. Zhang and J. B. Wang, *Angew. Chem. Int. Ed.*, 2014, **53**, 3917.
5. K.-W. Chen, S. Syu, Y.-J. Jang and W. Lin, *Org. Biomol. Chem.*, 2011, **9**, 2098.

4. ^{1}H NMR, 13C NMR spectra of products:

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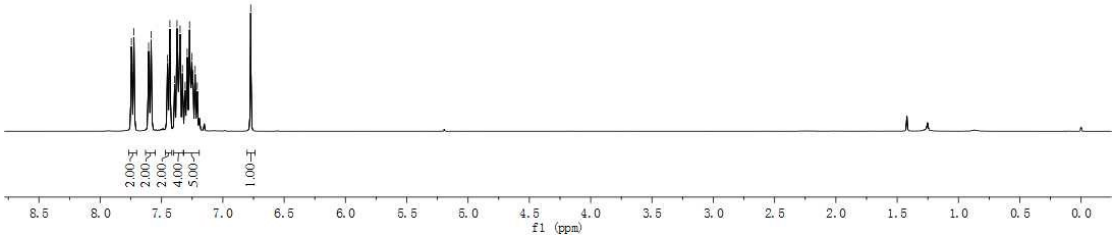

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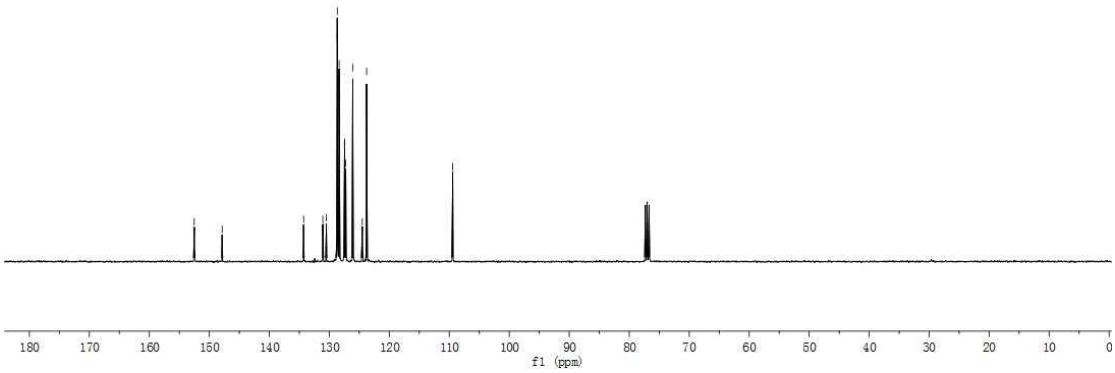


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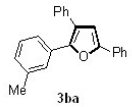
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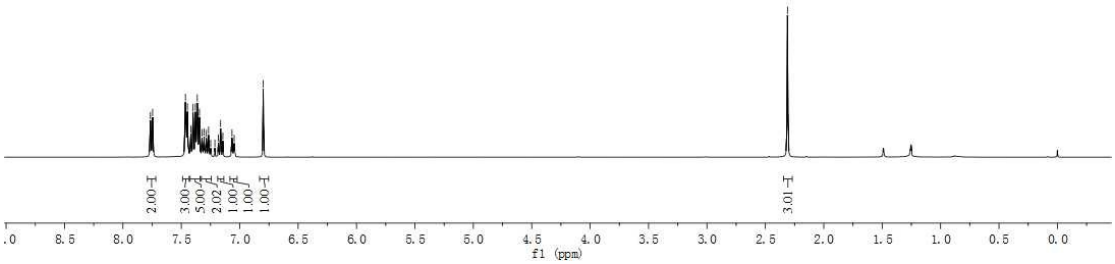
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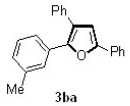
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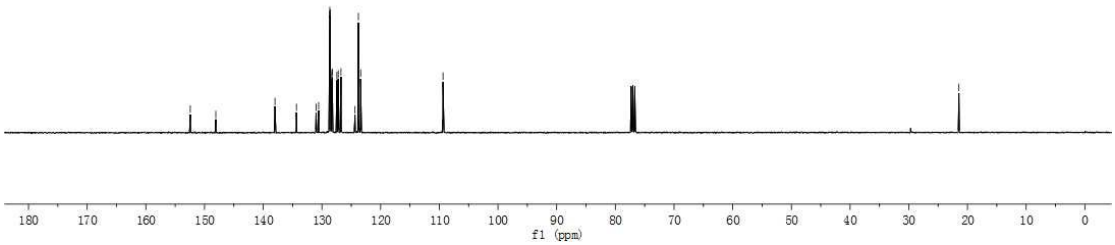
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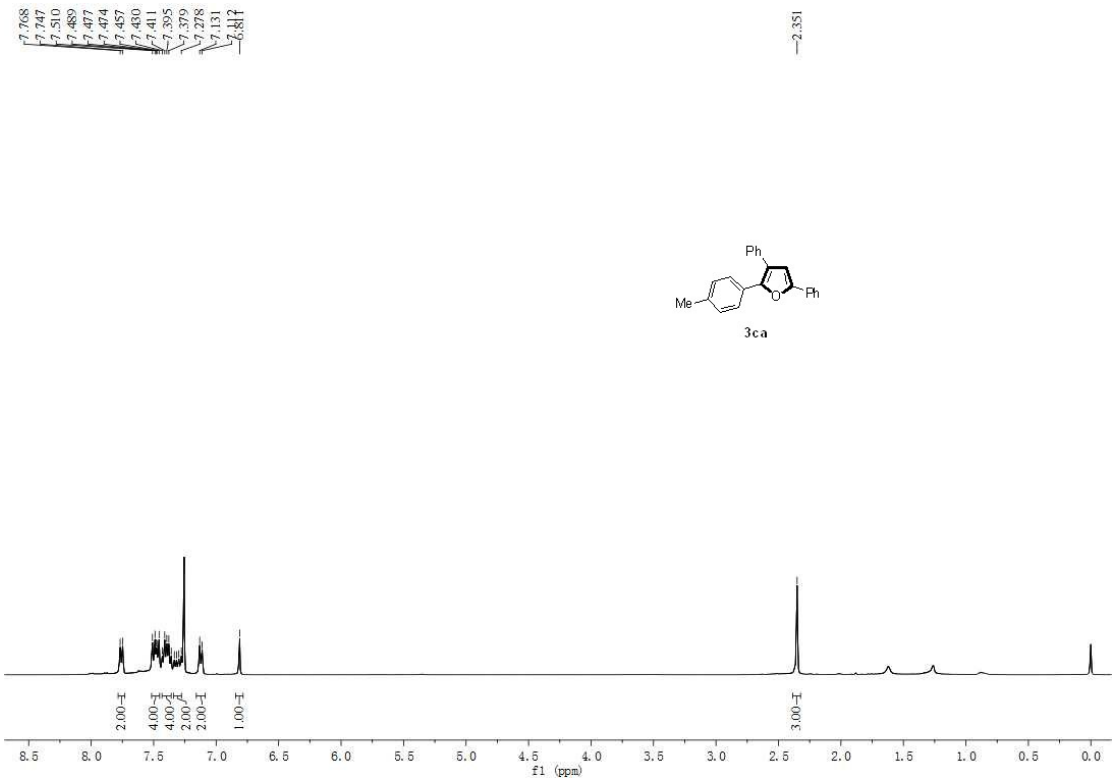
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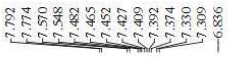
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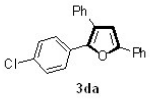
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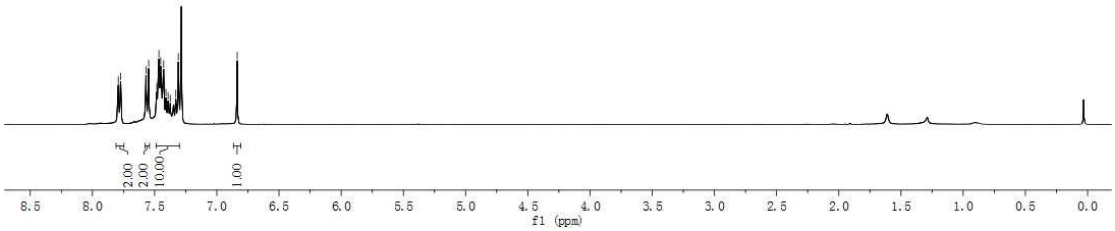
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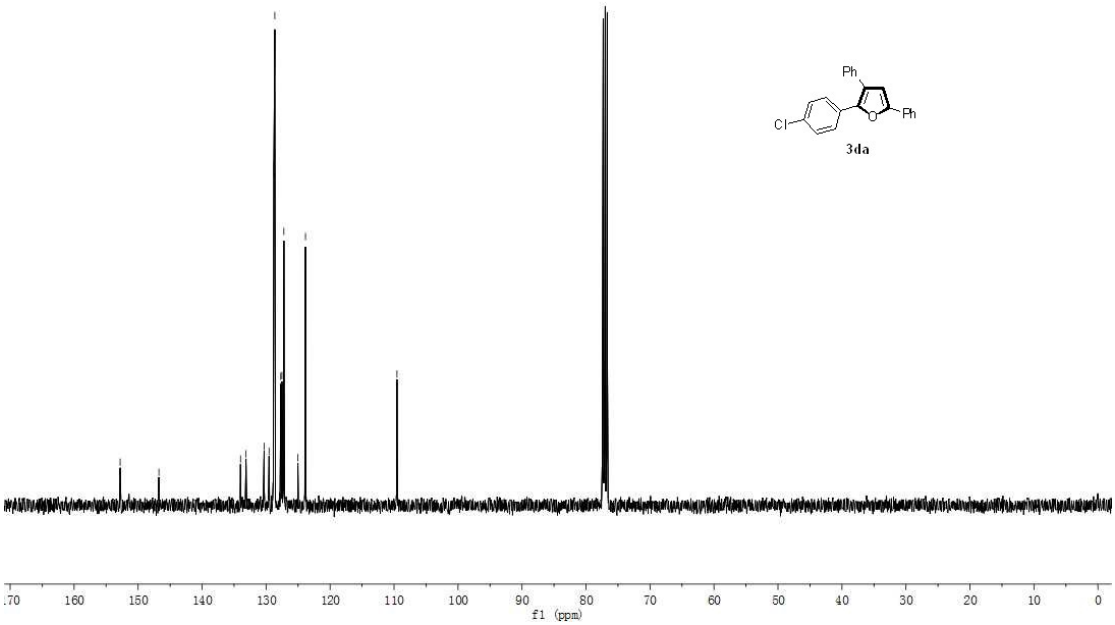
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40
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20
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0
f1 (ppm)

Ph
Cl
O
Ph

3da


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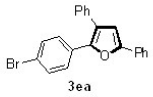
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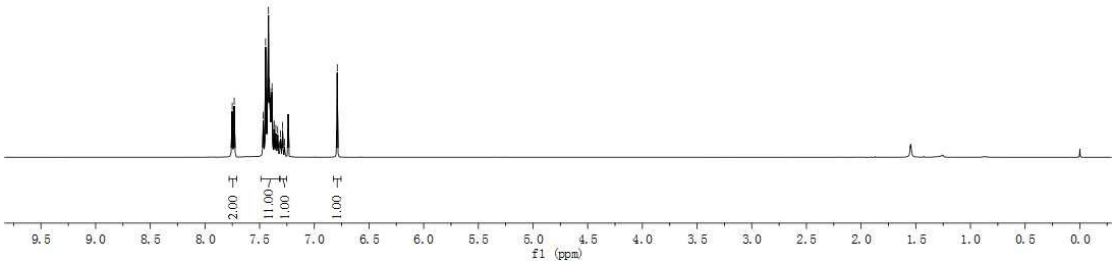
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f1 (ppm)


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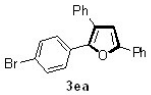
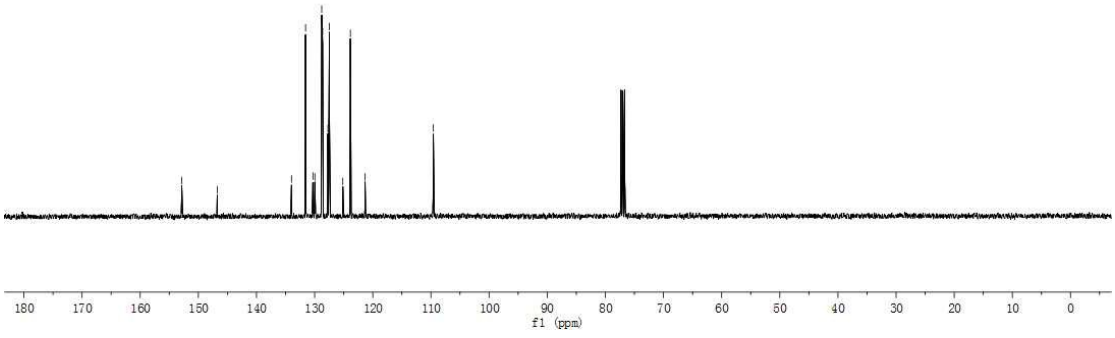
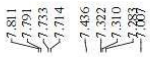
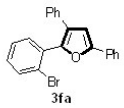
110.382


Ph
Br
O
Ph

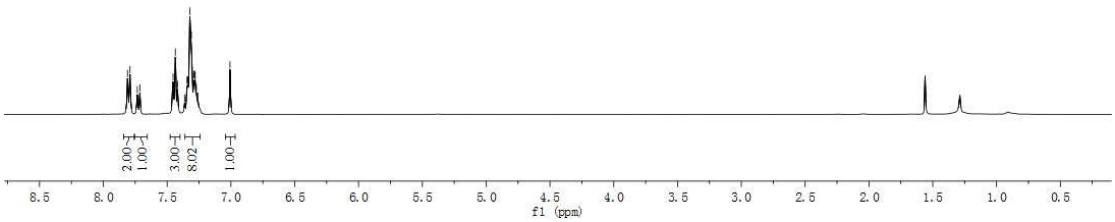
3ea

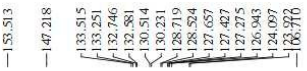

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

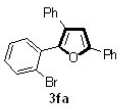

7.811
7.791
7.733
7.714
7.436
7.322
7.310
7.283
7.007


Ph
Ph
Br

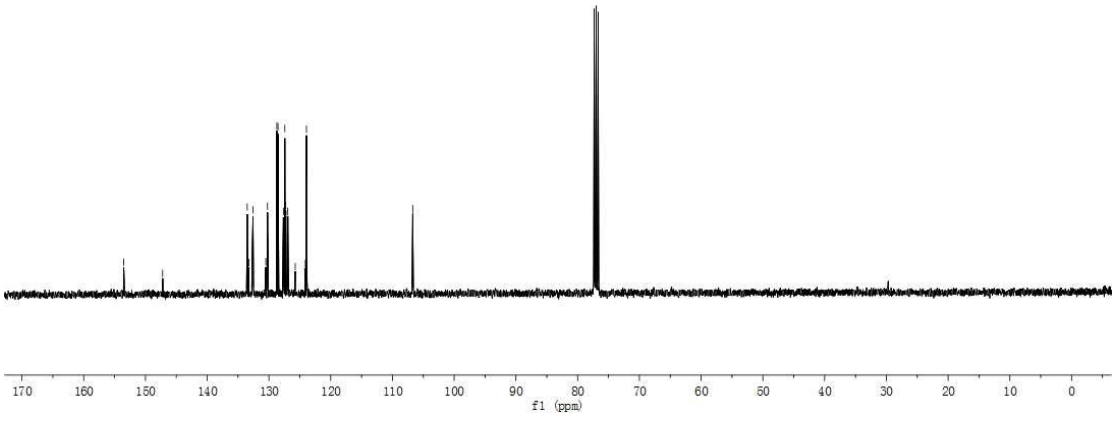
3fa

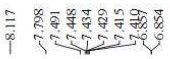

2.00
1.00
3.00
8.02
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

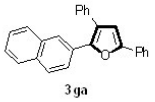

153.513
147.218
133.515
133.251
132.746
132.581
130.514
130.231
128.719
128.524
127.657
127.427
127.275
126.943
124.097
123.922
106.716


Ph
Ph
Br

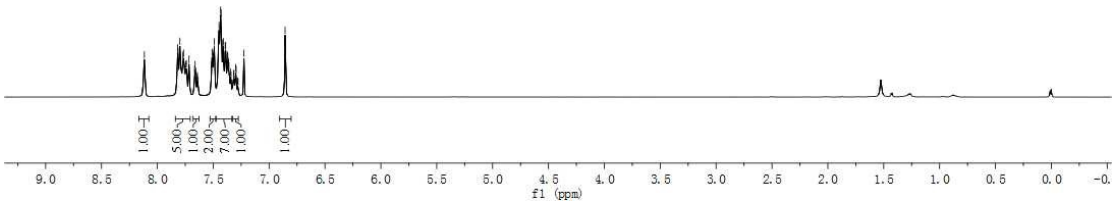
3fa


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

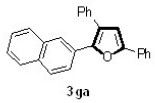

8.117
7.798
7.491
7.448
7.434
7.429
7.415
6.854


Ph
Ph
O

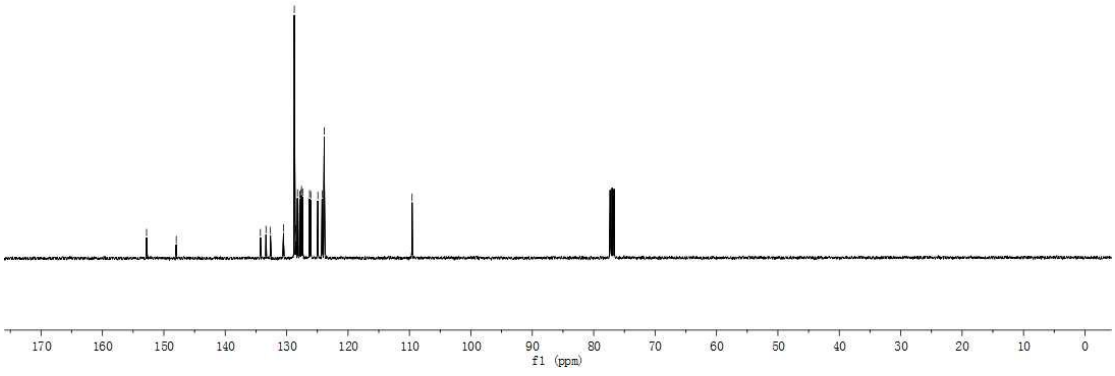
3ga


1.00
5.00
1.00
2.00
7.00
1.00
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

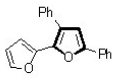

152.811
147.977
130.512
128.755
128.682
128.522
128.233
127.869
127.644
127.584
127.397
126.272
126.076
124.916
124.231
123.877
109.578


Ph
Ph
O

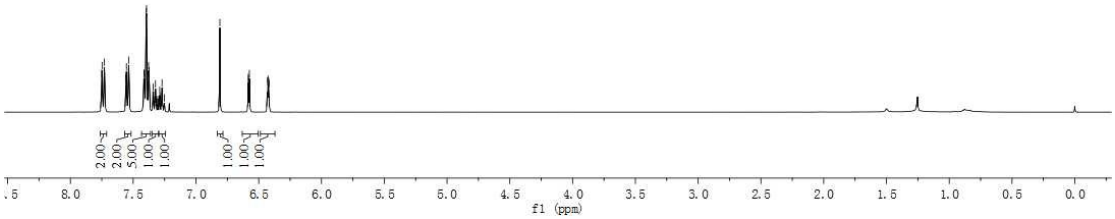
3ga


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

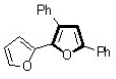

7.751
7.748
7.730
7.554
7.536
7.415
7.411
7.396
7.394
7.377
6.583
6.581
6.574
6.430
6.426
6.422
6.417


Ph
Ph
O

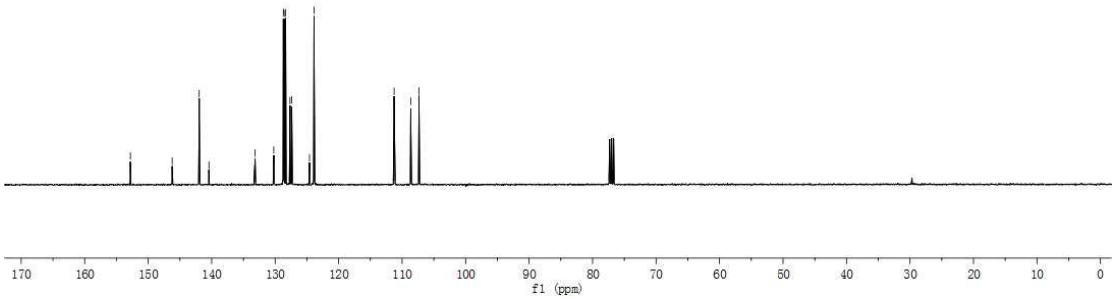
3ha


2.00
2.00
5.00
1.00
1.00
1.00
1.00
1.00
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

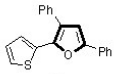

152.797
146.217
141.963
140.432
133.154
130.215
128.707
128.585
128.351
127.665
127.386
124.592
123.882
111.257
108.644
107.341


Ph
Ph
O

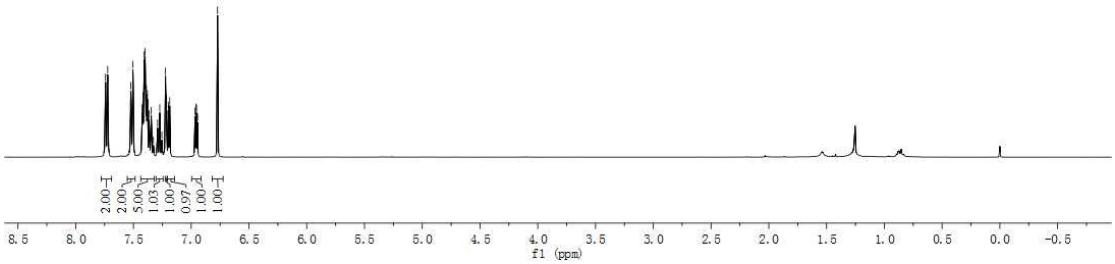
3ha


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

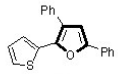

7.742
7.723
7.526
7.522
7.505
7.424
7.418
7.407
7.399
7.388
7.379
7.364
7.351
7.346
7.339
7.327
7.291
7.272
7.254
7.222
7.216
7.215
7.199
7.198
7.186
6.967
6.957
6.955
6.945
6.772


Ph
Ph
S
O

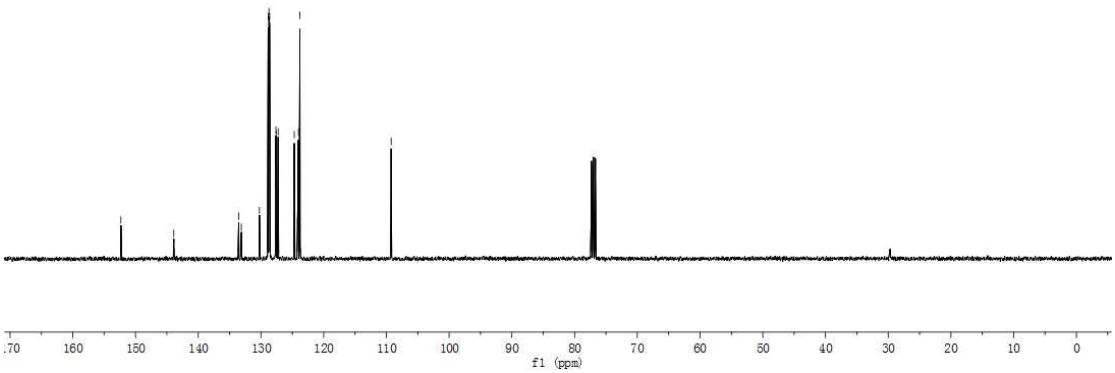
3ia

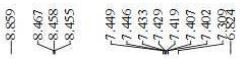

2.00
2.00
5.00
1.03
1.00
0.97
1.00
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

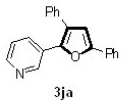

152.329
143.894
133.544
130.243
128.851
128.723
128.612
127.611
127.583
127.256
124.689
124.170
124.025
110.288
110.228


Ph
Ph
S
O

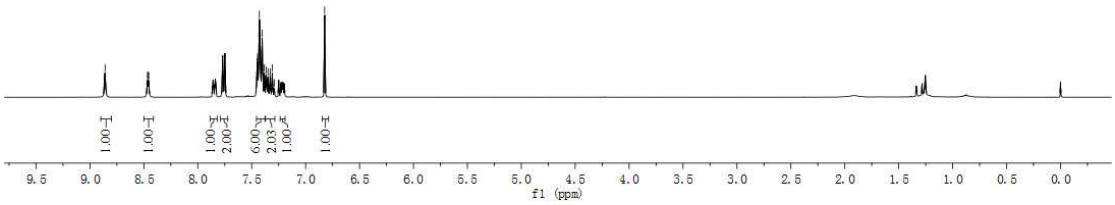
3ia

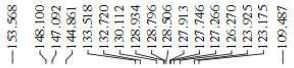

170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

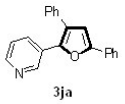

8.859
8.467
8.458
8.455
7.449
7.446
7.433
7.429
7.419
7.407
7.402
7.390
6.824


Ph
Ph
N
O

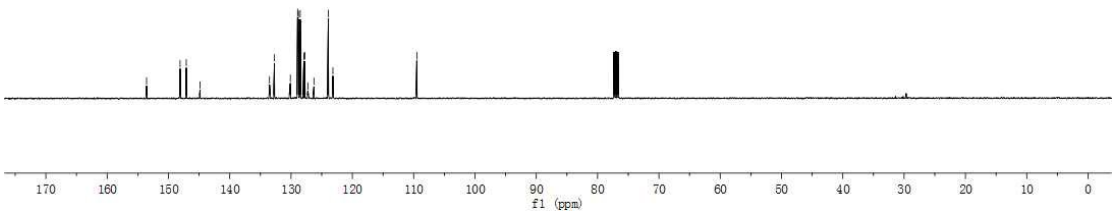
3ja

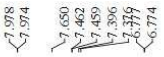

1.00
1.00
1.00
2.00
6.00
2.03
1.00
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

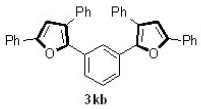

153.568
148.100
147.092
144.861
133.518
132.720
130.112
128.934
128.796
128.506
127.913
127.746
127.266
126.270
123.925
123.175
109.487


Ph
Ph
N
O

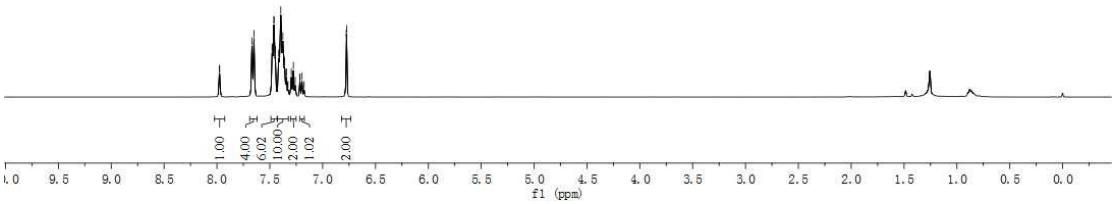
3ja


170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

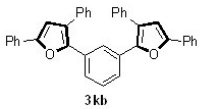

7.978
7.974
7.650
7.462
7.459
7.396
7.376
6.774


Ph
Ph
Ph
Ph
O
O

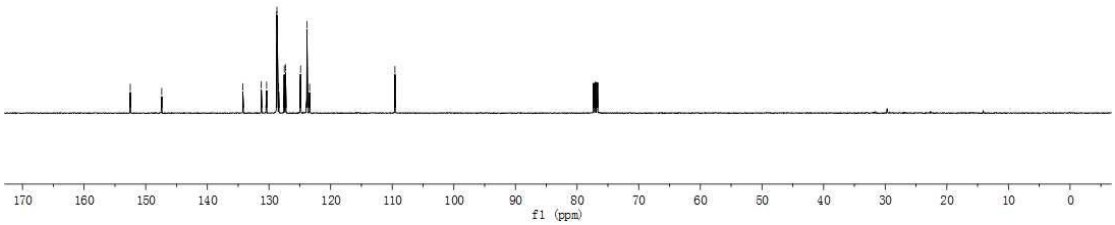
3kb

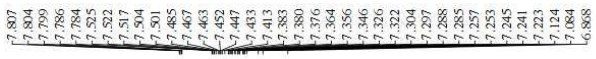

1.00
4.00
6.02
10.00
2.00
1.02
2.00
f1 (ppm)

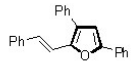

152.513
147.405
134.243
131.248
130.388
128.758
128.705
128.657
128.433
127.519
127.324
124.904
124.874
123.843
123.401
109.559


Ph
Ph
Ph
Ph
O
O

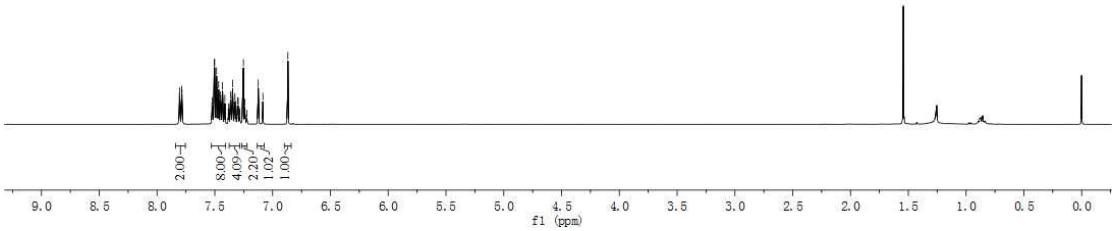
3kb

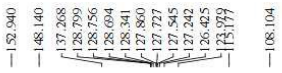

f1 (ppm)

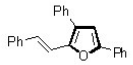

7.807
7.804
7.799
7.786
7.784
7.525
7.522
7.517
7.504
7.501
7.485
7.467
7.463
7.452
7.447
7.433
7.413
7.383
7.380
7.376
7.364
7.356
7.346
7.326
7.322
7.304
7.297
7.288
7.285
7.257
7.253
7.245
7.241
7.223
7.124
7.084
6.868


Ph
Ph
O
Ph

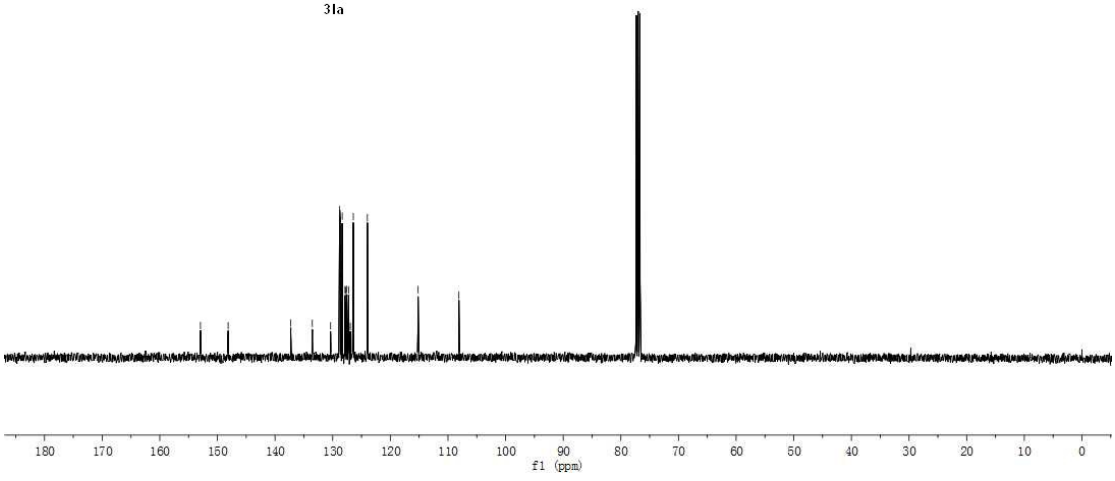
3la

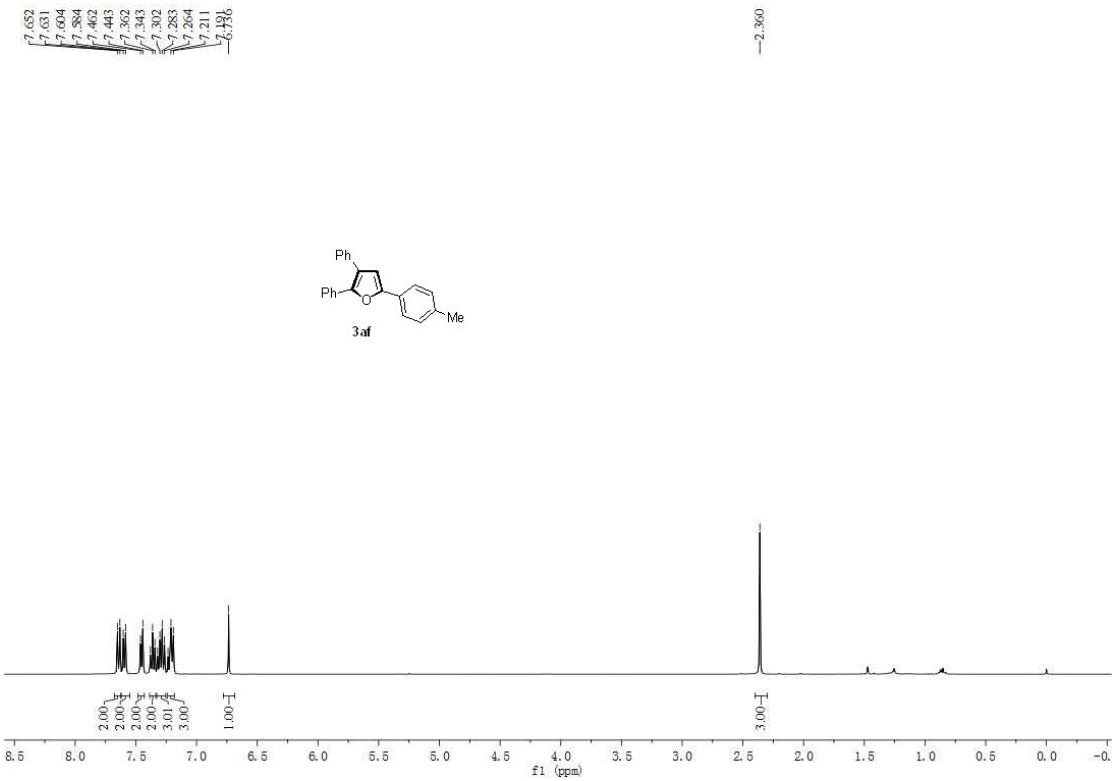

2.00
8.00
4.09
2.20
1.02
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

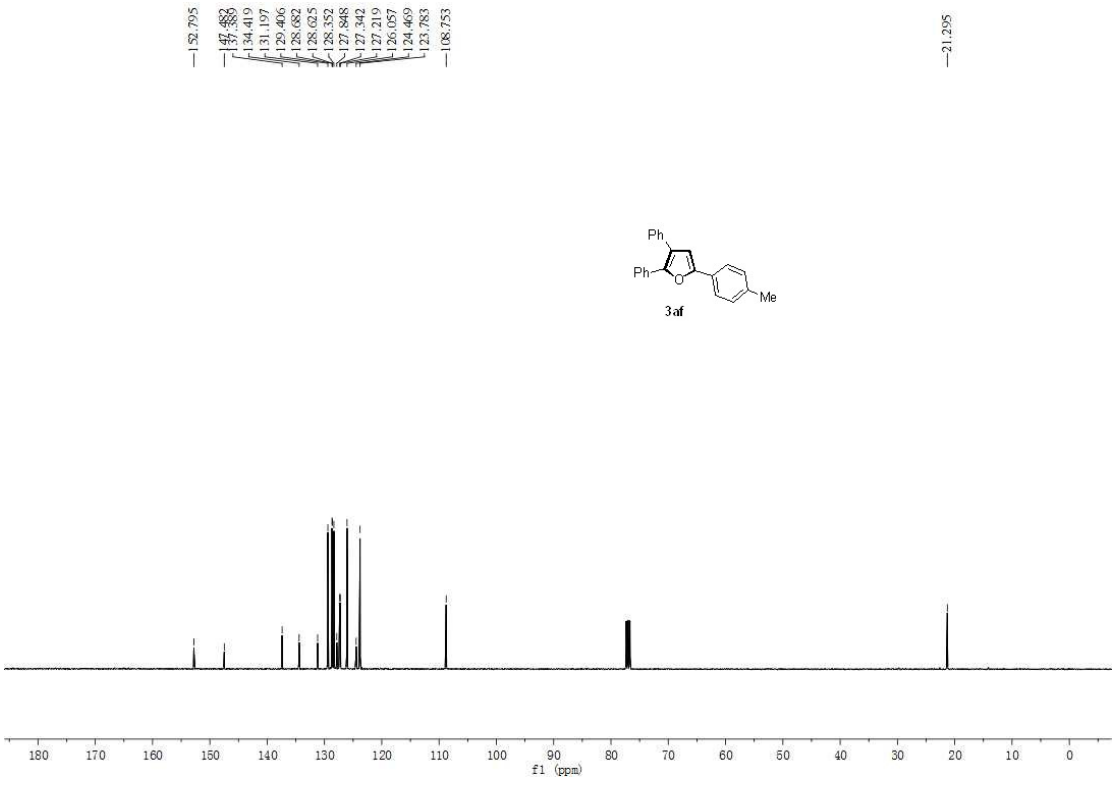

152.940
148.140
137.268
128.799
128.756
128.694
128.341
127.860
127.727
127.545
127.242
126.425
113.979
113.177
108.104


Ph
Ph
O
Ph

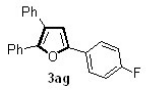
3la


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

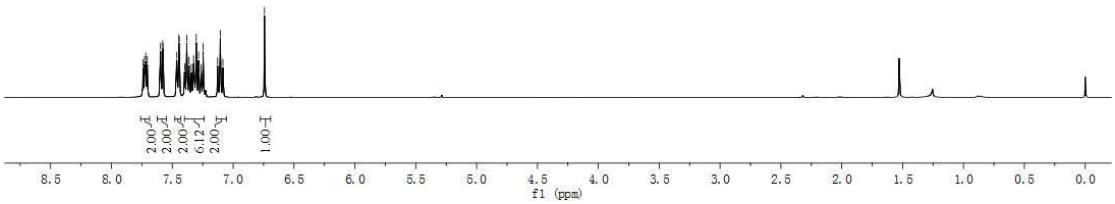

7.652
7.631
7.604
7.584
7.462
7.443
7.362
7.343
7.302
7.283
7.264
7.211
7.191
6.756
2.360
Ph
Ph
Me
3af
2.00
2.00
2.00
3.01
3.00
1.00
3.00
f1 (ppm)


152.795
147.482
137.380
134.419
131.197
129.406
128.682
128.625
128.352
127.848
127.342
127.219
126.057
124.469
123.783
108.753
21.295
Ph
Ph
Me
3af
f1 (ppm)

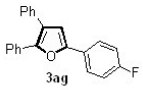

7.727
7.718
7.600
7.596
7.578
7.576
7.463
7.445
7.443
7.381
7.325
7.303
7.284
7.247


Ph
Ph
O
F

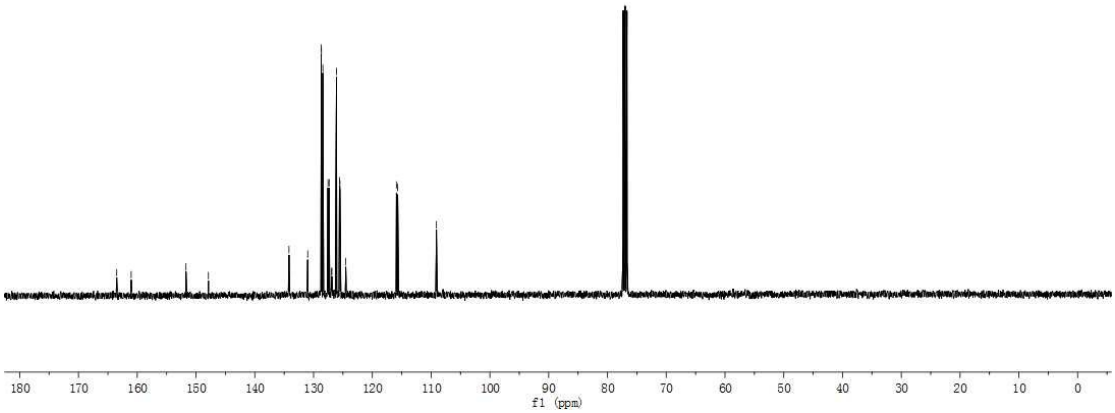
3ag


2.00
2.00
2.00
6.12
2.00
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

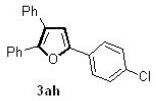

163.493
161.034
151.707
147.895
134.181
130.993
128.685
128.661
128.411
127.543
127.347
126.103
125.922
125.901
115.683
109.095


Ph
Ph
O
F

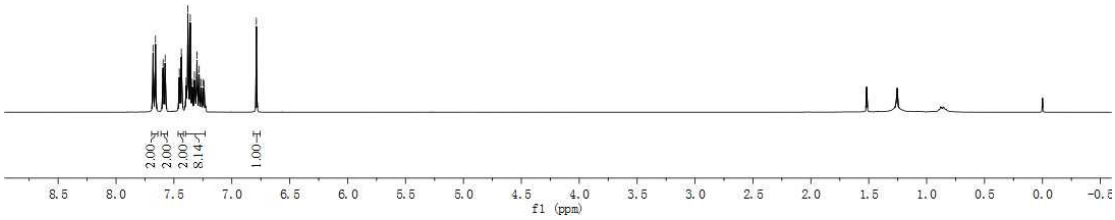
3ag


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

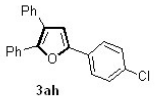

7.681
7.659
7.597
7.594
7.576
7.457
7.453
7.436
7.434
7.394
7.380
7.359
7.323
7.301


Ph
Ph
O
Cl

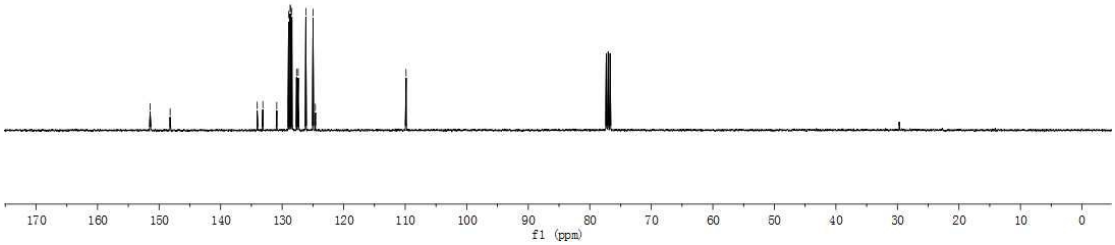
3ah


2.00
2.00
2.00
8.14
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

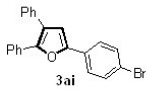

151.459
148.206
134.056
133.133
130.880
129.009
128.952
128.695
128.650
128.422
127.657
127.392
126.151
124.980
124.593
109.862


Ph
Ph
O
Cl

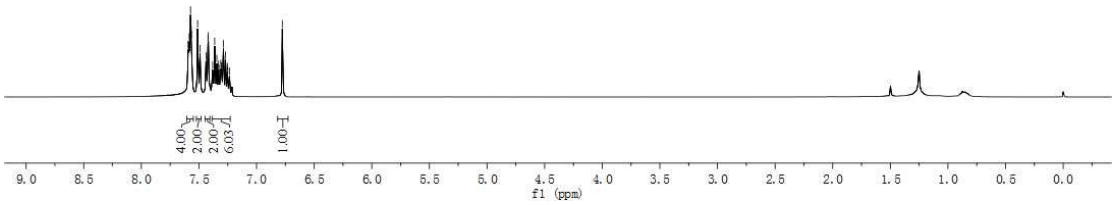
3ah

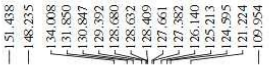

170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

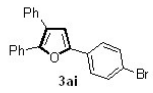

7.594
7.588
7.584
7.573
7.567
7.564
7.512
7.490
7.439
7.421
7.419
7.363
7.345
7.310
7.288
6.776


Ph
Ph
O
Br

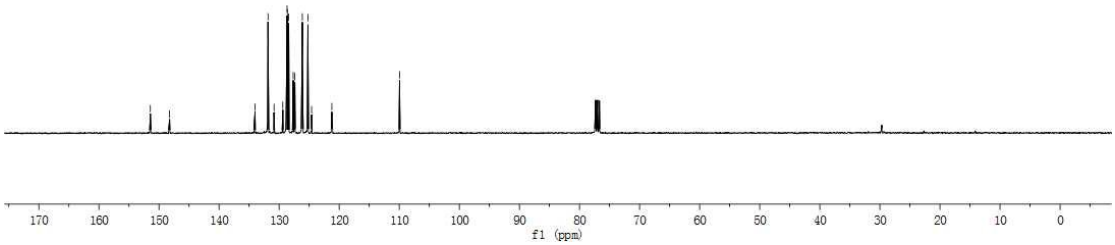
3ai


4.00
2.00
2.00
6.03
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

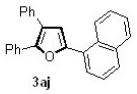

151.438
148.235
134.008
131.850
130.847
129.392
128.680
128.632
128.409
127.661
127.382
126.140
125.213
124.595
121.224
109.954


Ph
Ph
O
Br

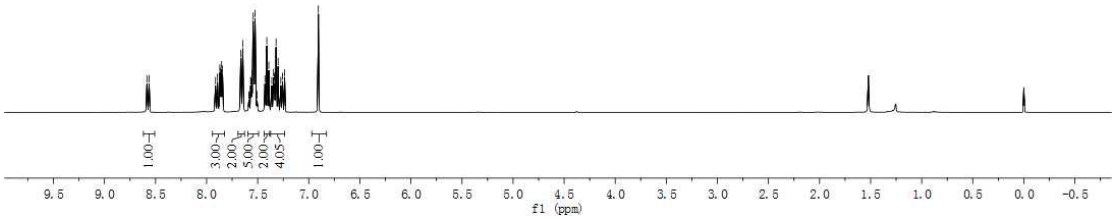
3ai


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

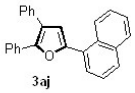

8.584
8.563
7.853
7.664
7.646
7.544
7.540
7.525
7.411
7.320
7.300
6.808


Ph
Ph
O

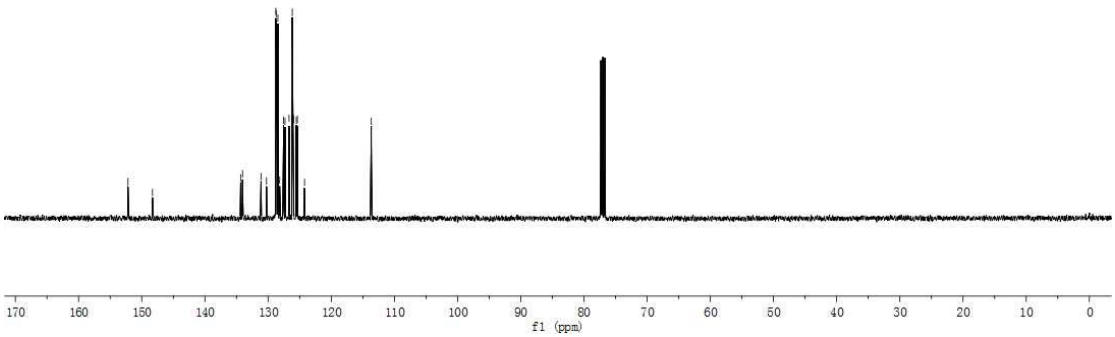
3aj


1.00
3.00
2.00
5.00
2.00
4.05
1.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

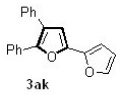

152.180
148.298
128.780
128.715
128.671
128.605
128.446
127.543
126.680
126.169
126.060
125.975
125.530
125.361
113.668


Ph
Ph
O

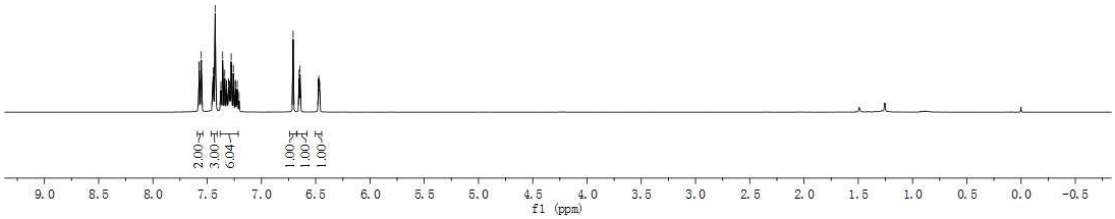
3aj


170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

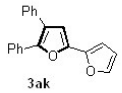

7.574
7.573
7.555
7.445
7.426
7.358
7.338
7.322
7.321
7.303
7.297
7.295
7.279
7.259
7.240
7.223
6.708
6.653
6.644
6.476
6.474
6.472
6.468
6.466
6.464


Ph
Ph
O
O

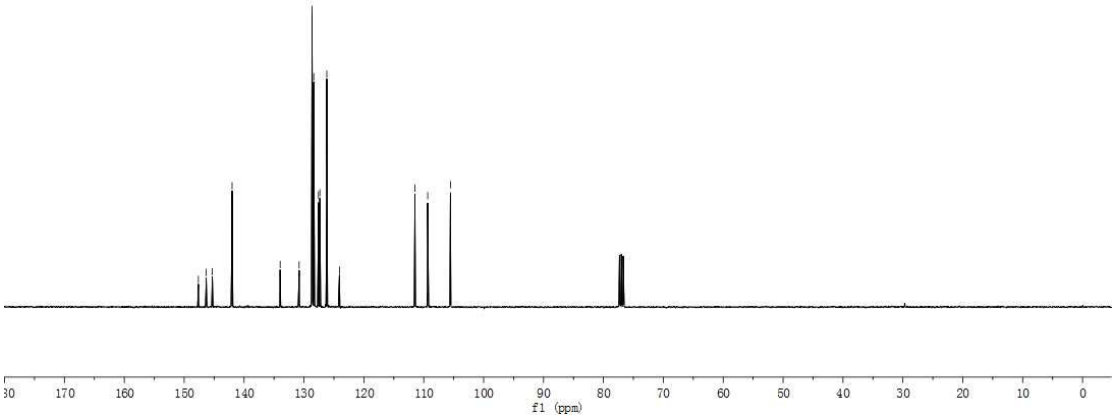
3ak

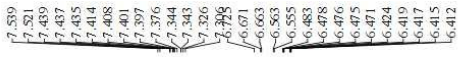

2.00
3.00
6.04
1.00
1.00
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

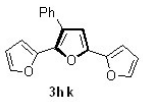

147.636
146.321
145.299
142.004
133.975
130.809
128.660
128.653
128.369
127.579
127.345
126.189
124.078
111.474
109.340
105.545


Ph
Ph
O
O

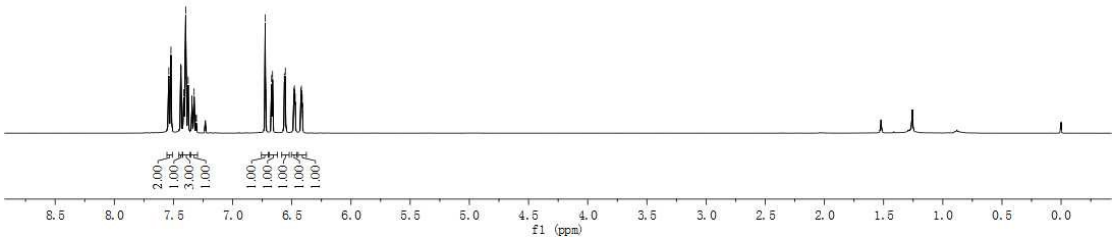
3ak

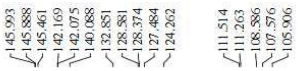

170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

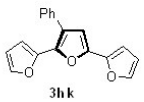

7.539
7.521
7.439
7.437
7.435
7.414
7.408
7.401
7.397
7.376
7.344
7.343
7.326
6.671
6.663
6.563
6.555
6.483
6.478
6.476
6.475
6.471
6.424
6.419
6.417
6.415
6.412


Ph
O
O
O

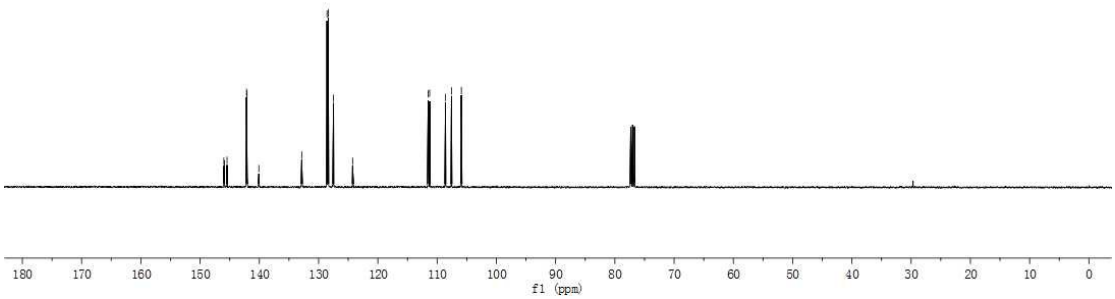
3hk


2.00
1.00
3.00
1.00
1.00
1.00
1.00
1.00
1.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

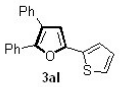

145.993
145.888
145.461
142.169
142.075
140.088
132.851
128.581
128.374
127.484
124.262
111.514
111.263
108.586
107.576
105.906


Ph
O
O
O

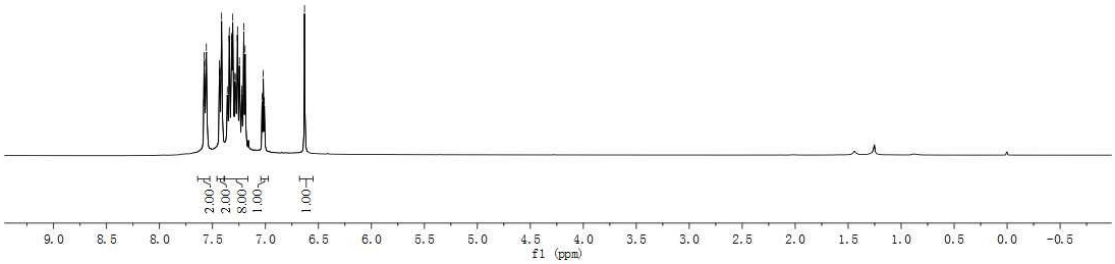
3hk

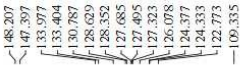

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

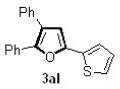

7.579
7.574
7.558
7.434
7.431
7.430
7.414
7.343
7.341
7.321
7.319
7.312
7.308
7.266
7.264
7.246
7.205
7.192
6.631


Ph
Ph
O
S

3al


2.00
2.00
8.00
1.00
1.00
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

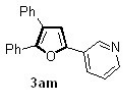

148.207
147.397
133.977
133.404
130.787
128.629
128.352
127.685
127.495
127.323
126.078
124.377
124.333
122.773
109.335


Ph
Ph
O
S

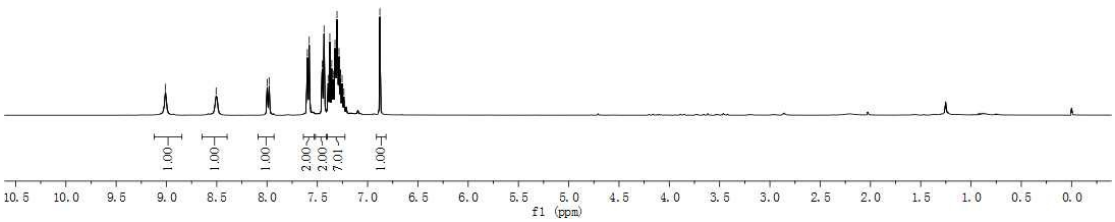
3al

90 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

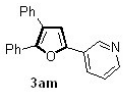

9.009
8.506
7.998
7.978
7.580
7.433
7.375
7.324
7.304
6.898


Ph
Ph
O
N

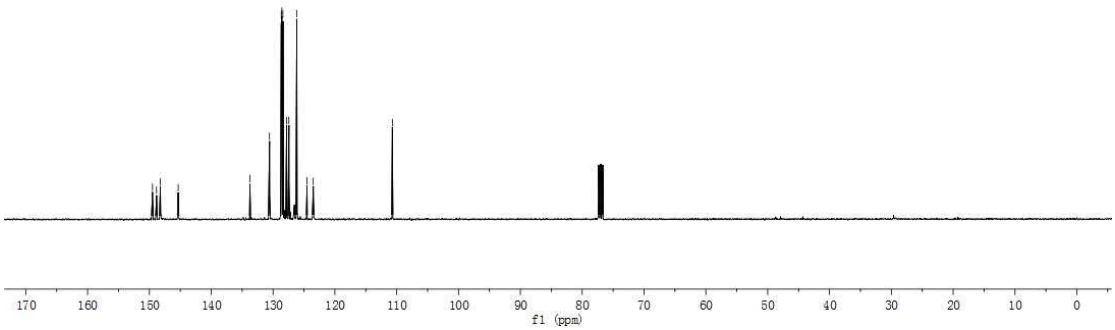
3am


1.00
1.00
1.00
2.00
2.00
7.01
1.00
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

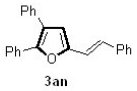

149.506
148.845
148.226
145.340
133.738
130.603
130.575
128.673
128.380
128.406
127.811
127.443
126.159
124.507
123.498
110.706


Ph
Ph
O
N

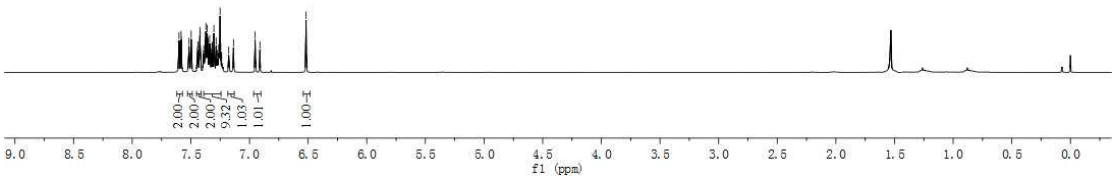
3am


170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

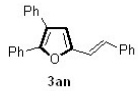

7.604
7.601
7.583
7.580
7.516
7.497
7.423
7.420
7.378
7.372
7.360
7.354
7.340
7.303
7.284
7.251
7.137
6.578
6.578


Ph
Ph
O
Ph

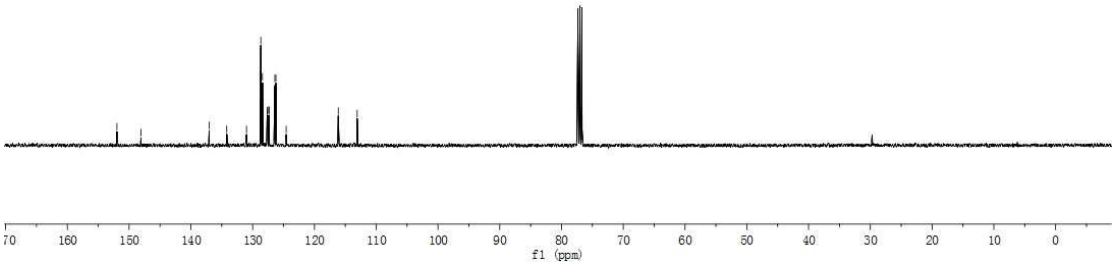
3an

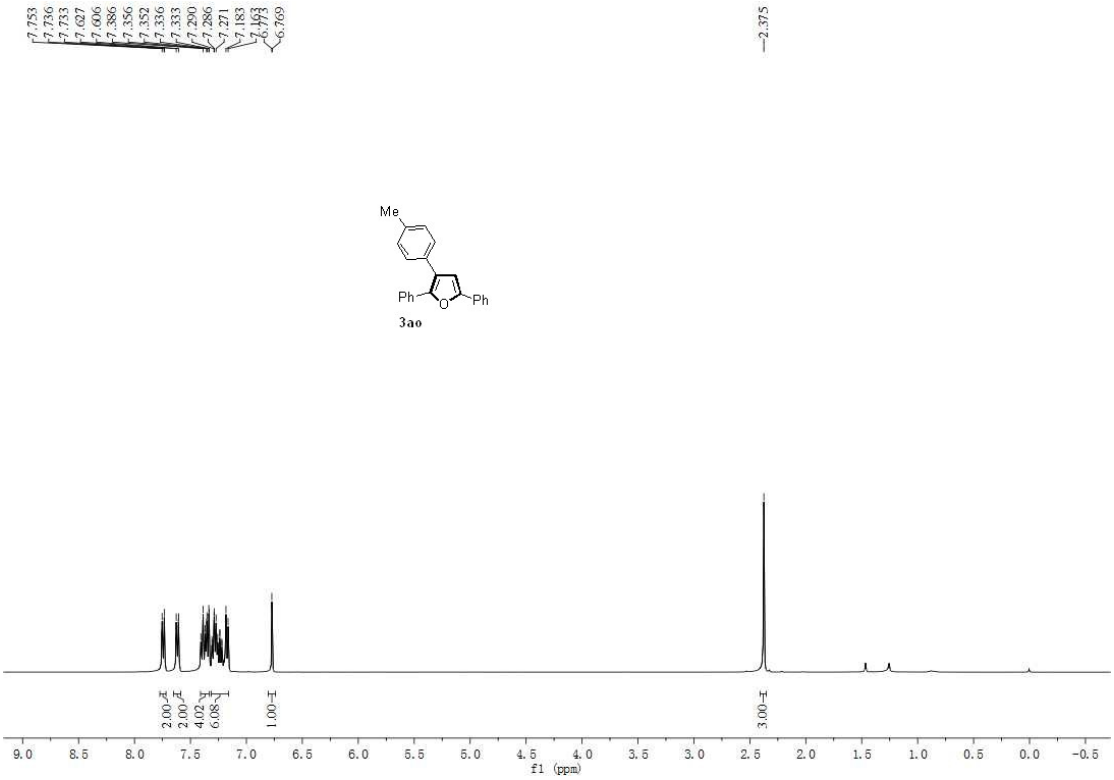

2.00
2.00
2.00
9.32
1.03
1.01
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

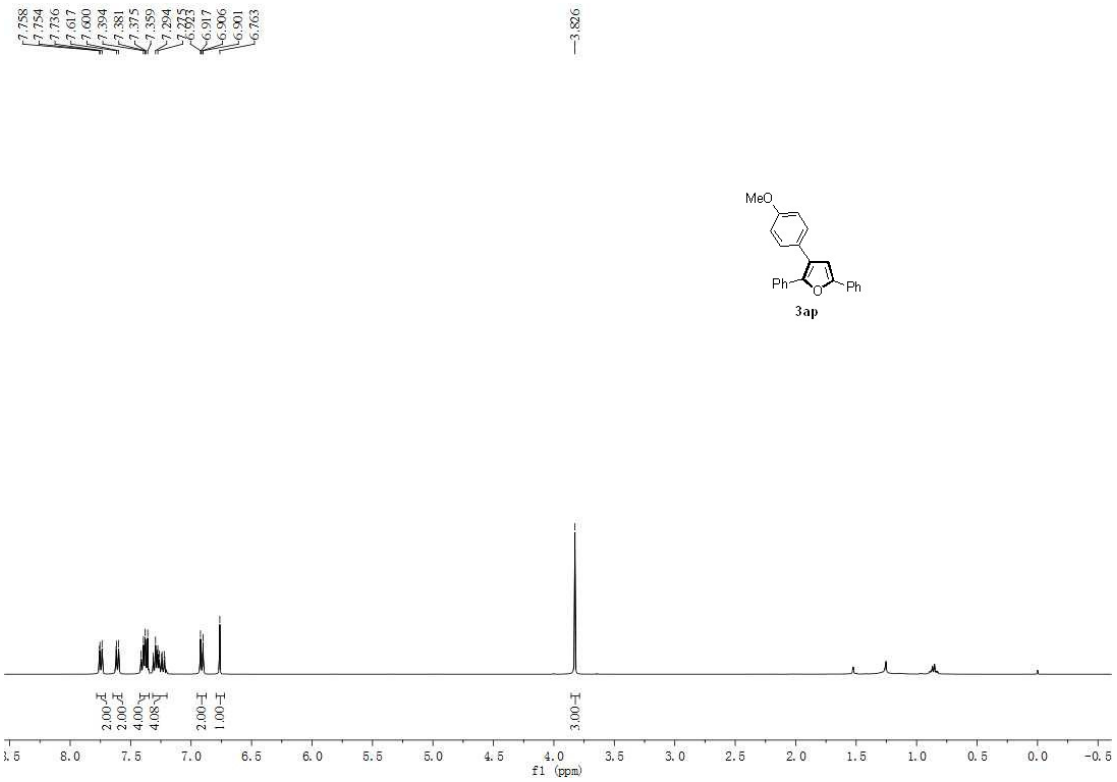

151.974
148.067
137.037
134.190
128.740
128.678
128.410
127.658
127.609
127.537
127.318
126.405
113.078

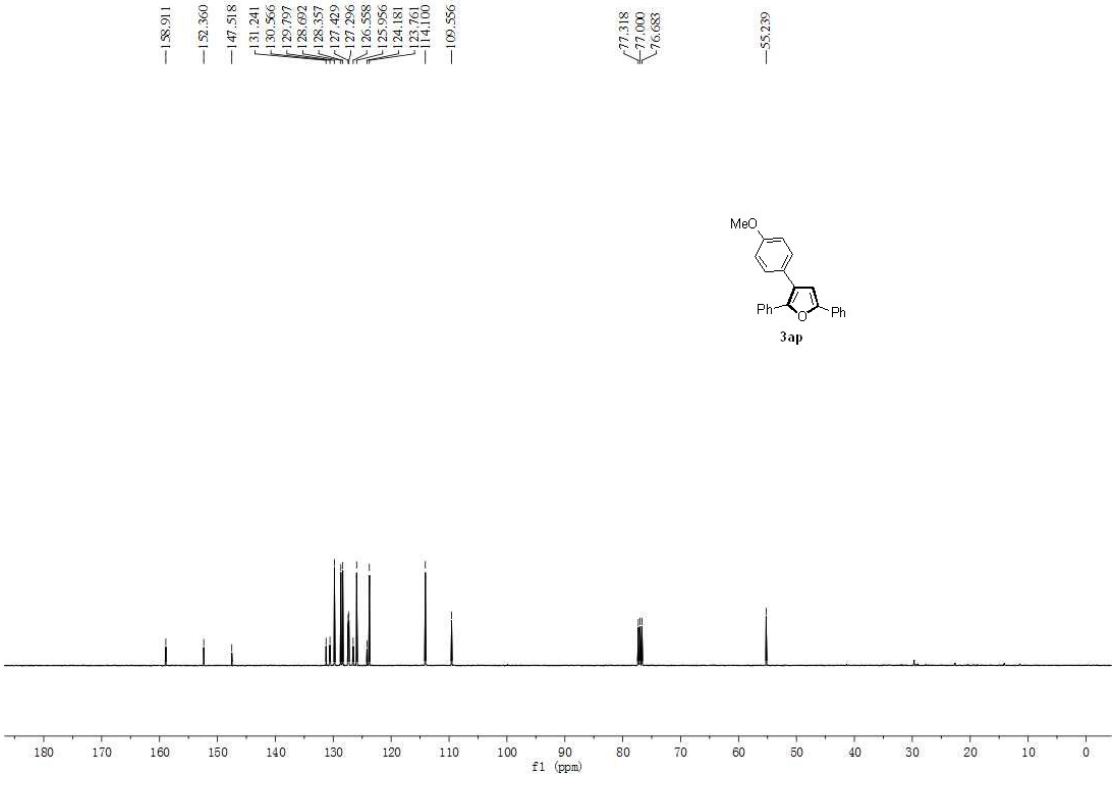

Ph
Ph
O
Ph

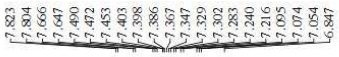
3an

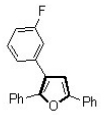

70
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.753
7.736
7.733
7.627
7.606
7.386
7.356
7.352
7.336
7.333
7.290
7.286
7.271
7.183
6.769
2.375
Me
Ph
Ph
O
3ao
2.00
2.00
4.02
6.08
1.00
3.00
f1 (ppm)
152.411
147.671
136.980
130.556
129.355
128.685
128.514
128.337
127.430
127.350
126.038
109.559
21.223
Me
Ph
Ph
O
3ao
f1 (ppm)

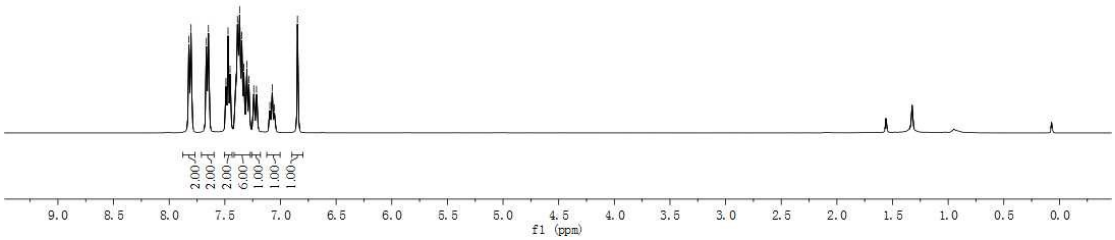

7.758
7.754
7.736
7.617
7.600
7.394
7.381
7.375
7.359
7.294
7.275
6.923
6.917
6.906
6.901
6.763
3.826
MeO
Ph
Ph
O
3ap
2.00
2.00
4.00
4.08
2.00
1.00
3.00
f1 (ppm)

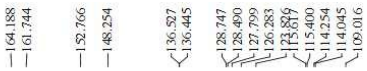

158.911
152.360
147.518
131.241
130.566
129.797
128.692
128.357
127.429
127.296
126.558
125.956
124.181
123.761
114.100
109.556
77.318
77.000
76.683
55.239
MeO
Ph
Ph
O
3ap
f1 (ppm)

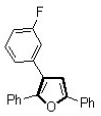

7.823
7.804
7.666
7.647
7.490
7.472
7.453
7.403
7.398
7.386
7.367
7.347
7.329
7.302
7.283
7.240
7.216
7.095
7.074
7.054
6.847


F
Ph
O
Ph

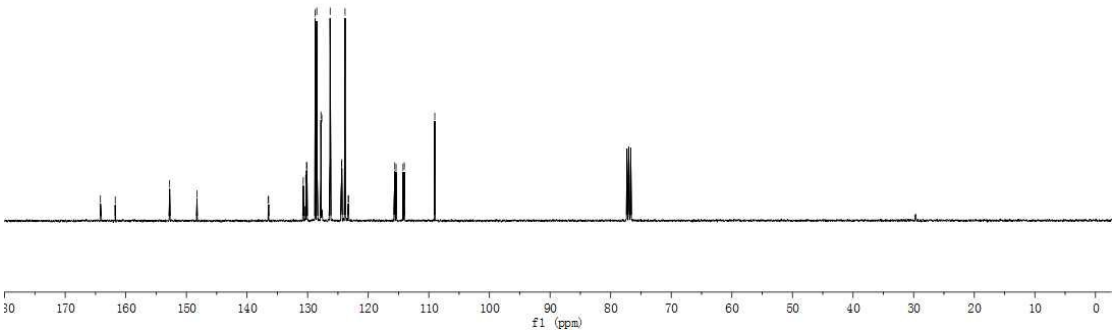
3aq


2.00
2.00
2.00
6.00
1.00
1.00
1.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

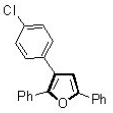

164.188
161.744
152.766
148.254
136.527
136.445
128.747
128.490
127.799
126.283
123.826
115.617
115.400
114.254
114.045
109.016


F
Ph
O
Ph

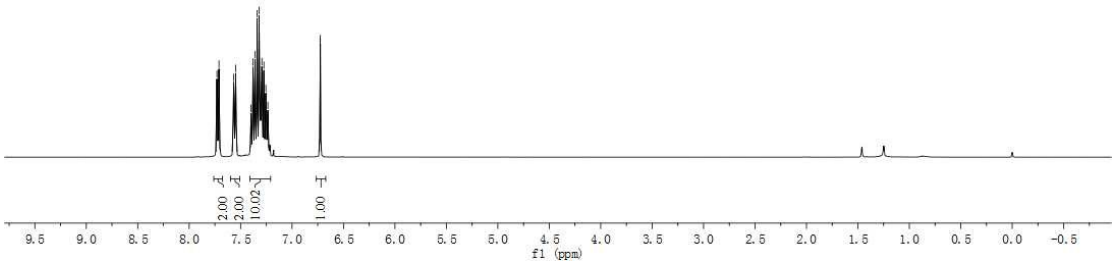
3aq


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

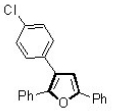

7.730
7.710
7.567
7.548
7.399
7.379
7.360
7.339
7.320
7.293
7.274
7.254
7.235
6.727
6.725


Cl
Ph
O
Ph

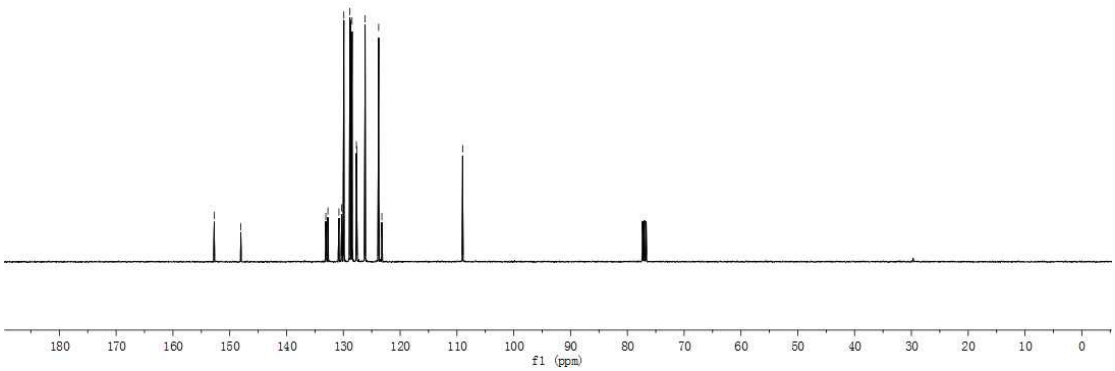
3ar


2.00
2.00
10.02
1.00
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

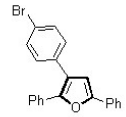

152.738
148.045
133.089
132.716
130.777
130.292
129.918
128.854
128.715
128.466
127.703
127.622
126.167
123.788
123.223
109.002


Cl
Ph
O
Ph

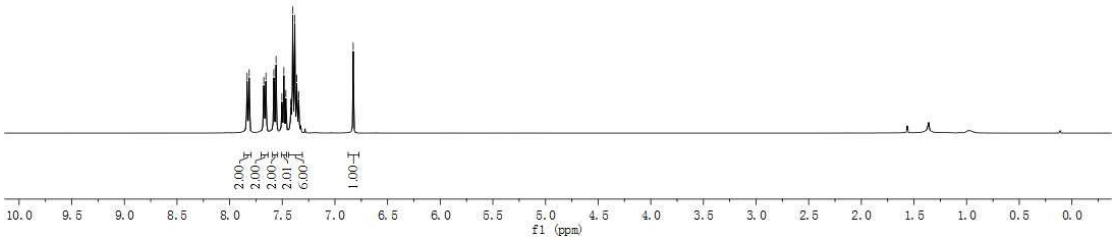
3ar


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

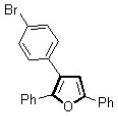

7.834
7.814
7.676
7.656
7.580
7.559
7.504
7.485
7.466
7.419
7.416
7.401
7.381
7.362
7.343
6.826


Br
Ph
O
Ph

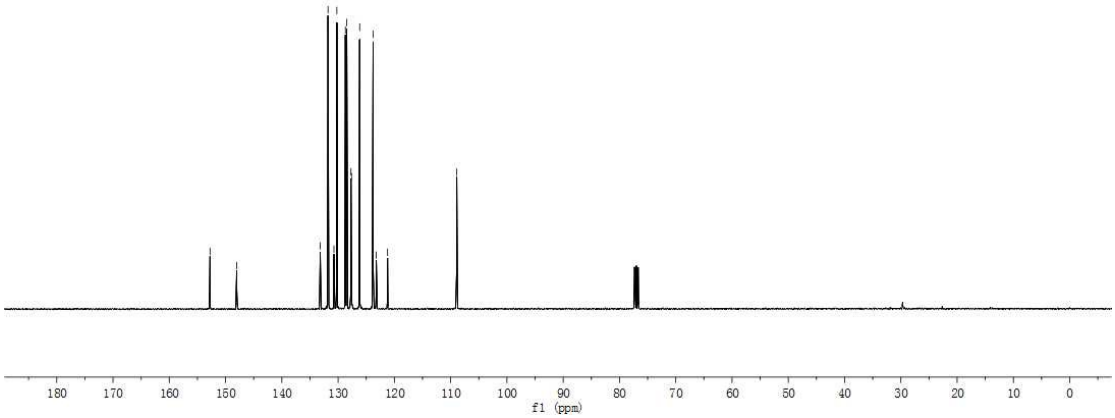
3as


2.00
2.00
2.00
2.01
6.00
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

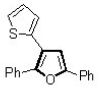

152.757
148.015
133.172
131.791
130.741
130.256
130.222
128.704
128.464
127.717
127.620
126.168
123.781
123.209
121.210
108.911


Br
Ph
O
Ph

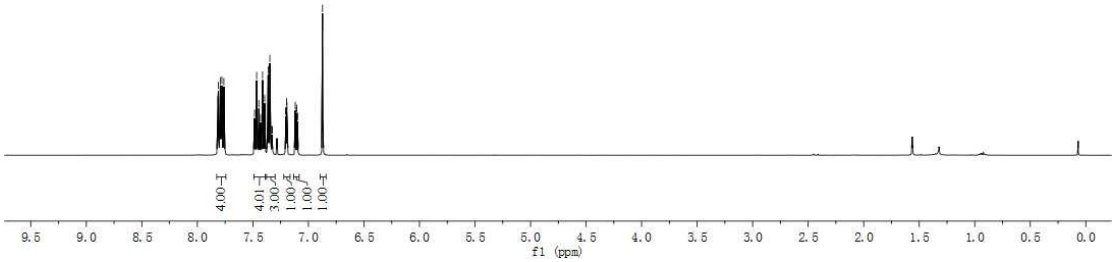
3as


180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

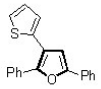

7.815
7.812
7.807
7.794
7.792
7.783
7.779
7.774
7.765
7.761
7.759
7.485
7.481
7.466
7.446
7.434
7.430
7.426
7.413
7.409
7.397
7.394
7.363
7.361
7.350
7.347
7.340
7.328
7.326
7.205
7.202
7.196
7.193
7.118
7.110
7.106
7.097
6.873


S
Ph
O
Ph

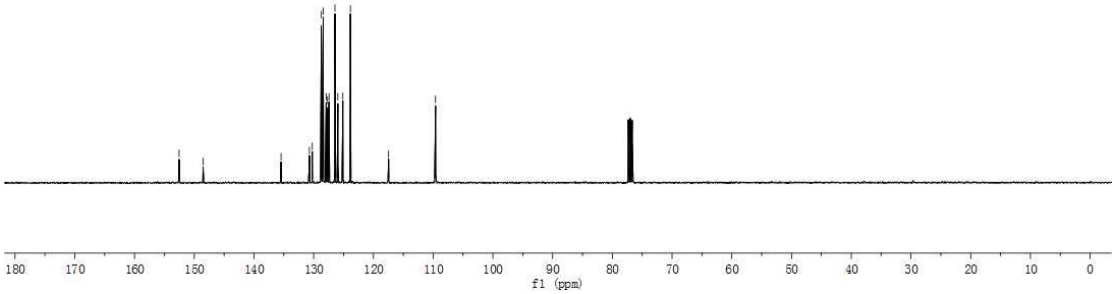
3at


4.00
4.01
3.00
1.00
1.00
1.00
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


152.540
148.513
130.238
128.720
128.413
127.908
127.674
127.427
126.435
125.960
125.124
109.602


S
Ph
O
Ph

3at


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)