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Supporting Information

Aryl-to-alkyl radical relay arylation reaction of remote $C(sp^3)$-H bond using 1,4-ficyanobenzene as electrochemical redox-mediator

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Contents

Part 1: General information

The instrument for electrolysis is dual display potentiostat (DJS-292B) (made in China). The electrodes were purchased from Gaoss Union.

Reagents. Unless otherwise noted, all reagents were purchased from commercial suppliers (Leyan.com., *J&K* Scientific, Energy Chemical, Alfa Aesar) without further purification.

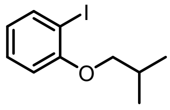
Analytical methods.

All reactions were monitored by thin-layer chromatography (TLC) or GC-MS (SHIMADZU GCMS-QP2020 NX).

NMR spectra were recorded on a Brüker Advance 400 (^{1}H: 400 MHz, ^{13}C:100 MHz, ^{19}F: 376MHz). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet-doublet, m = multiplet, br = broad. ^{1}H NMR and ^{13}C NMR chemical shifts were determined relative to internal standard TMS at δ 0.0 and chloroform at δ 77.16 ppm or DMSO-d$_6$ at δ 39.52 ppm, respectively. All chemical shifts (δ) were reported in ppm and coupling constants (*J*) in Hz.

High-resolution mass spectra were obtained by the electrospray ionization time-of-flight (ESI-TOF) mass spectrometry.

Part 2: Preparation of substrates



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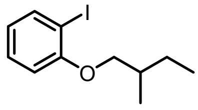

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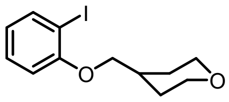

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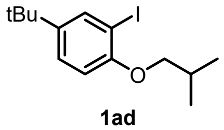

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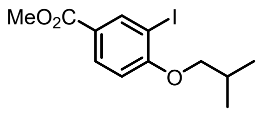

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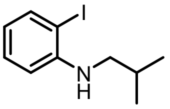

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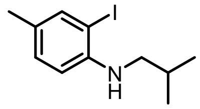

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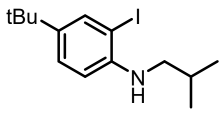

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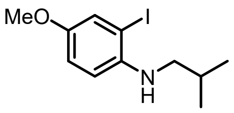

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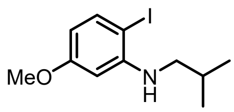

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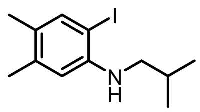

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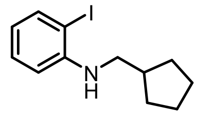

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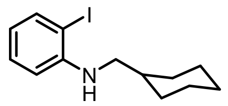

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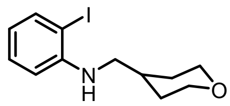

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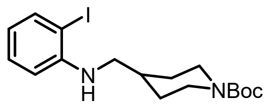

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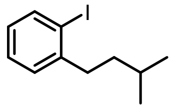

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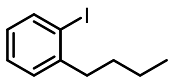

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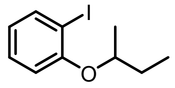

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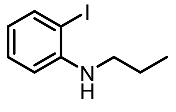

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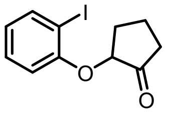

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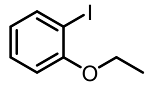

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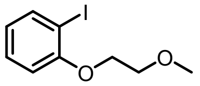

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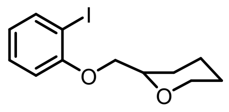

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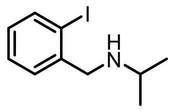

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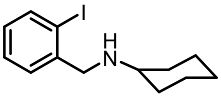

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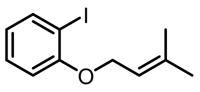
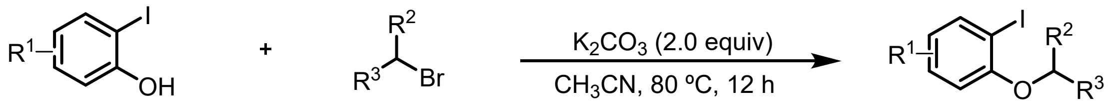


1az

General procedure A for preparation of 1[1]:

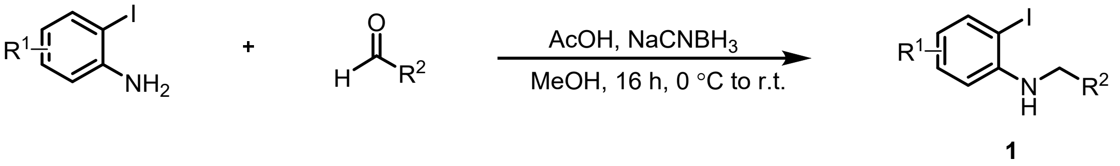


1

An oven-dried round 50 mL bottom flask was charged with 2-iodophenols (10 mmol, 1.0 equiv), K_2CO_3 (20 mmol, 2.0 equiv), CH_3CN (20 mL), and alkyl bromide (15 mmol, 1.5 equiv). The reaction mixture was stirred at 80 °C in an oil bath for 12 h. After rapid filtration of silica gel, the solvent was evaporated by rotary evaporator, and the residue was purified by flash column chromatography on silica gel using EtOAc/petroleum ether as eluent to afford the product **1**.

1aa, **1ab**, **1ac**, **1ad,** **1ae**, **1ar**, **1at**, **1au**, **1av**, **1aw**, and **1az** were prepared by the general procedure A.

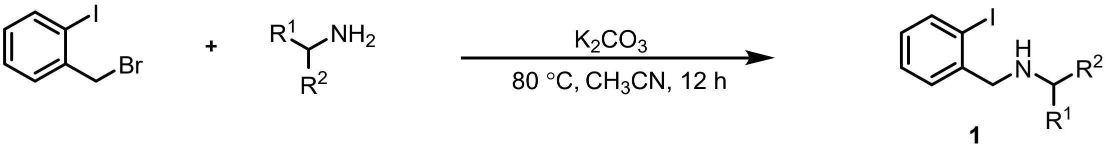
General procedure B for preparation of 1[2]:



In a flame-dried 50 mL round bottom flask, 2-iodoaniline (10 mmol, 1.0 equiv) and the corresponding aldehyde (15 mmol, 1.5 equiv) were dissolved in 20 mL MeOH. Acetic acid (15 mmol, 1.5 equiv) was added, and the reaction was stirred at r.t. for 30 min. Then, the reaction was cooled down to 0 °C and sodium cyanoborohydride (13 mmol, 1.3 equiv) was added in two portions over 30 min. The reaction was allowed to stir from 0 °C to r.t. overnight (or until complete by TLC). The reaction was quenched with a saturated aq solution of sodium bicarbonate (30 mL) and then extracted with Et_2O (3 x 30 mL). The combined organic layers were dried with Na_2SO_4, filtered and the solvent was removed under reduced pressure. The crude was flashed in 5% DCM/petroleum ether to give the compound **1.**

1af, **1ag**, **1ah**, **1ai, 1aj**, **1ak**, **1al**, **1am**, **1an**, **1ao**, and **1as** were prepared by the general procedure B.

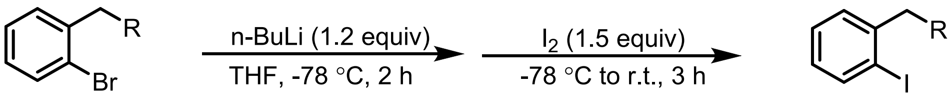
General procedure C for preparation of 1[1]:



An oven-dried round 50 mL bottom flask was charged with 1-(bromomethyl)-2-iodobenzene (10 mmol, 1.0 equiv), K_2CO_3 (20 mmol, 2.0 equiv), CH_3CN (20 mL), and alkyl amine (15 mmol, 1.5 equiv). The reaction mixture was stirred at 80 °C in an oil bath for 12 h. After rapid filtration of silica gel, the solvent was evaporated by rotary evaporator, and the residue was purified by flash column chromatography on silica gel using EtOAc/petroleum ether as eluent to afford the product **1**.

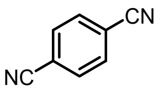
1ax and **1ay** were prepared by the general procedure C.

General procedure D for preparation of 1[3]:



To a solution of bromoaromatics (10 mol, 1.0 equiv) in THF (30 ml) was added dropwise a solution of n-BuLi in hexane (12 mmol, 8.0 ml, 1.5 M) at –78 °C, and the resulting solution was stirred for 1 h at room temperature. Iodine (15 mmol, 1.5 equiv) was added in portions and then the reaction mixture was allowed to warm to room temperature. The reaction was quenched with a saturated aqueous solution of $Na_2S_2O_3$ and extracted with ethyl ether. The combined organic layer was dried over magnesium sulfate, and the crude product was purified by flash column chromatography on silica gel using petroleum ether as eluent to afford the product **1**.

1ap and **1aq** were prepared by the general procedure D.



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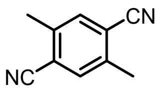

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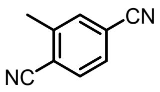

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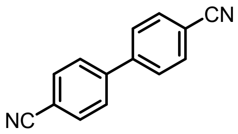

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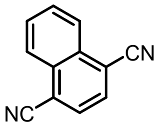

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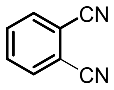

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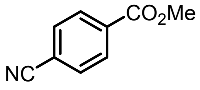

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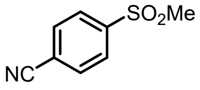

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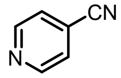
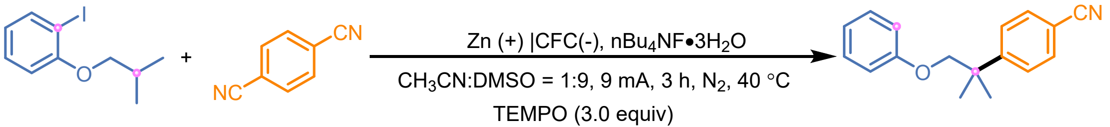


2ai

2aa, **2ab**, **2ac**, **2ad**, **2ae**, **2af**, **2ag**, **2ah**, and **2ai** were purchased from commercial suppliers (Leyan.com.)

Part 3. Mechanistic studies

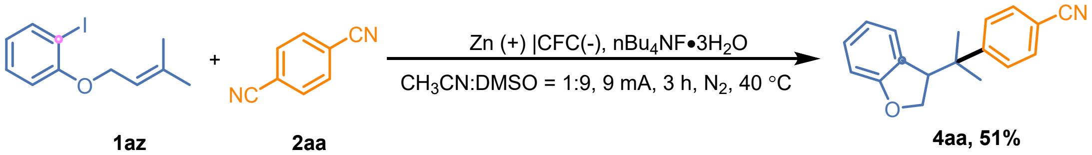
3.1 Radical trapping experiments



1aa **2aa** **3aa, N.D.**

In an oven-dried undivided three-necked bottle (25 mL) equipped with a stir bar, **1aa** (165.6 mg, 0.6 mmol, 2.0 equiv), $nBu_4NF\cdot3H_2O$ (156.9 mg, 0.6 mmol, 2.0 equiv), and TEMPO (140.6 mg, 0.9 mmol, 3.0 equiv) were added. The bottle was equipped with Zn (15 mm×15 mm×1 mm depth in solution) as the anode and carbon fiber cloth (CFC) (15 mm×15 mm×1 mm depth in solution) as the cathode and was then charged with nitrogen. Under the protection of N_2, **2aa** (122.4 mg, 0.3 mmol, 1.0 equiv.), CH_3CN (1.0 mL), and DMSO (9.0 mL) were added via a syringe. The reaction mixture was stirred and electrolyzed at a constant current of 9 mA under 40 °C for 3 h. After completion of the reaction, the product **3aa** was not determined by TLC and GC-MS.

3.2 Radical clock experiments



In an oven-dried undivided three-necked bottle (25 mL) equipped with a stir bar, **1az** (157.8 mg, 0.6 mmol, 2.0 equiv) and $nBu_4NF·3H_2O$ (156.9 mg, 0.6 mmol, 2.0 equiv) were added. The bottle was equipped with Zn (15 mm×15 mm×1 mm depth in solution) as the anode and carbon fiber cloth (CFC) (15 mm×15 mm×1 mm depth in solution) as the cathode and was then charged with nitrogen. Under the protection of N_2, **2aa** (122.4 mg, 0.3 mmol, 1.0 equiv.), CH_3CN (1.0 mL), and DMSO (9.0 mL) were added via a syringe. The reaction mixture was stirred and electrolyzed at a constant current of 9 mA under 40 °C for 3 h. After completion of the reaction, 20 mL water was added, and the mixture was extracted with EtOAc (20 mL×3). The organic layer was washed with saturated brine, dried over anhydrous Na_2SO_4, and filtered, and then the filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PE/EA = 20:1) to give the product as a yellow oil (40.2 mg, 51%).

3.3 Cyclic voltammetry (CV) experiments

Mechanistic experiments for cyclic voltammetry (CV): Cyclic voltammetry experiment was performed in a three-electrode cell connected to an undivided three-necked bottle with stir bar under nitrogen at room temperature. The working electrode was a glass carbon electrode and the counter electrode a platinum wire. The reference was an Ag/AgCl electrode submerged in saturated aqueous KCl solution. After adding 0.2 mmol substrates, and the mixture then charged with nitrogen. Under the protection of N_2, liquid 0.2 mmol substrates were added (if liquid), and anhydrous degassed 10 mL $nBu_4NF·3H_2O$ solution in $CH_3CN/DMSO$ (v/v = 1:9 mL) were injected into the electrochemical cell in all experiments. The scan rate was ranged from 100 mV/s, and voltage range was 0 V ~ -3.0 V.

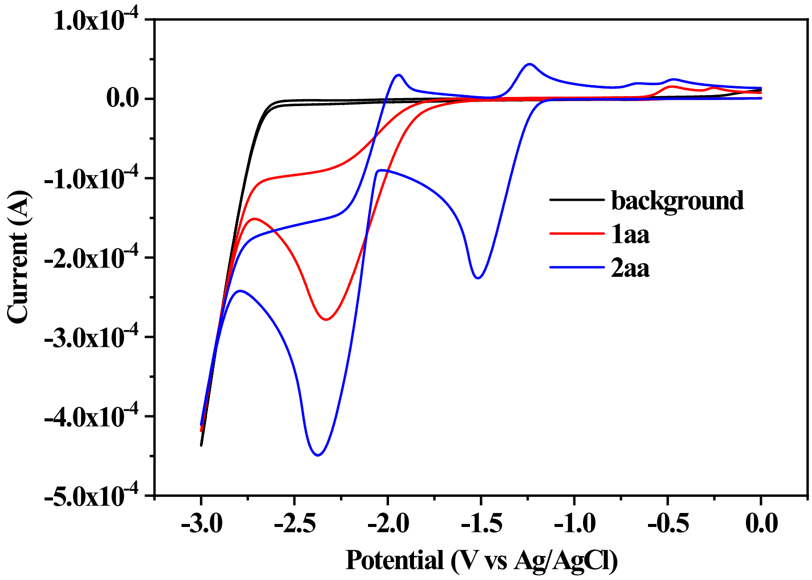


Figure S1. Cyclic voltammetry by using $nBu_4NF\cdot3H_2O$ as electrolyte in CH_3CN/DMSO (v/v = 1:9 mL): A cyclic voltammograms in 0.1 M $nBu_4NF\cdot3H_2O$ solution (in CH_3CN/DMSO, v/v = 1:9 mL) by using glassy carbon as the working electrode, Pt wire as the counter electrode and Ag/AgCl as the reference electrode under N_2 at room temperature. **Black line**: background. **Red line**: **1aa** (0.2 mmol), 1.0 mmol $nBu_4NF\cdot3H_2O$ in CH_3CN/DMSO (v/v = 1:9 mL), the reduction peaks of red line were observed at -2.33 V (*vs* Ag/AgCl). Blue line: **2aa**, (0.2 mmol), 1.0 mmol $nBu_4NF\cdot3H_2O$, CH_3CN/DMSO (v/v = 1:9 mL), the reduction peaks of blue line were observed at -1.52, -2.37 V (*vs* Ag/AgCl).

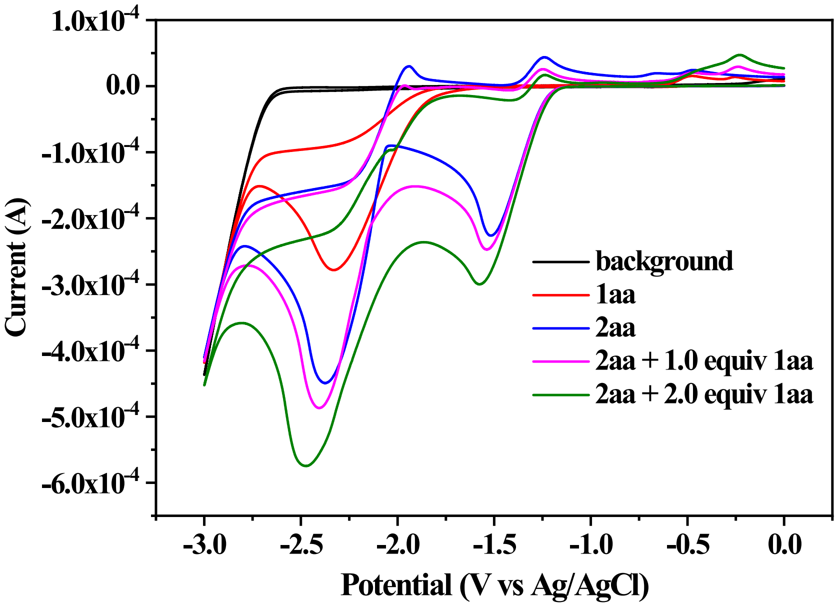
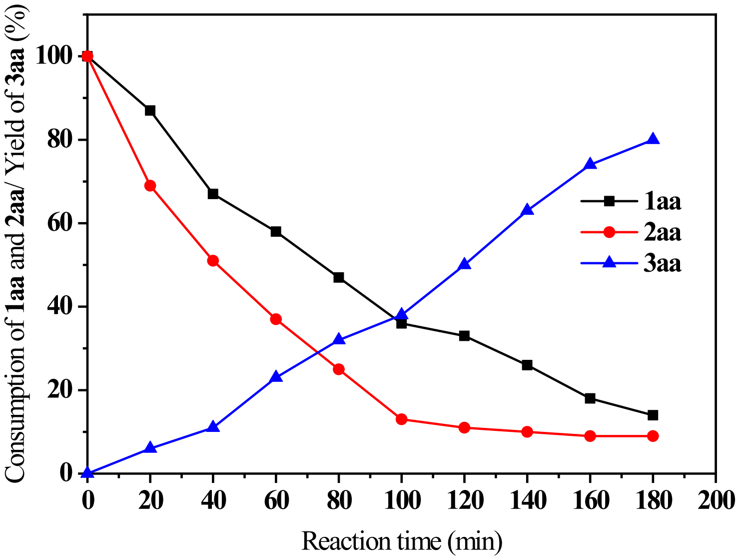


Figure S2. Cyclic voltammetry of **1aa** and **2aa** in CH_3CN/DMSO (v/v = 1:9 mL) by using $nBu_4NF\cdot3H_2O$ (0.1 M) as electrolyte: A cyclic voltammograms in solvent (CH_3CN/DMSO, v/v = 1:9) by using glassy carbon as the working electrode, Pt wire as the counter electrode and Ag/AgCl as the reference electrode under N_2 at room temperature. 10 mL $nBu_4NF\cdot3H_2O$ solution in CH_3CN/DMSO (v/v = 1:9) was poured into the electrochemical cell in all experiments. The scan rate is 20 mV/s. **Black line**: background. **Red line**: **1aa** (0.2 mmol), 10 mL $nBu_4NF\cdot3H_2O$ solution in (CH_3CN/DMSO, v/v = 1:9). **Blue line: 2aa** (0.2 mmol), 10 mL $nBu_4NF\cdot3H_2O$ solution (CH_3CN/DMSO, v/v = 1:9). **Pink line**: **1aa** (0.2 mmol), **2aa** (0.2 mmol), 10 mL $nBu_4NF\cdot3H_2O$ solution (CH_3CN/DMSO, v/v = 1:9). **Green line**: **1aa** (0.4 mmol), **2aa** (0.2 mmol), 10 mL $nBu_4NF\cdot3H_2O$ solution (CH_3CN/DMSO, v/v = 1:9).

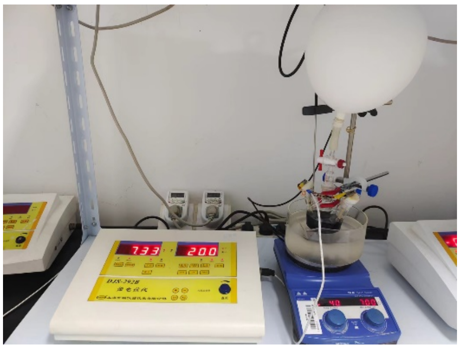
3.4 Kinetic experiments of the standard condition

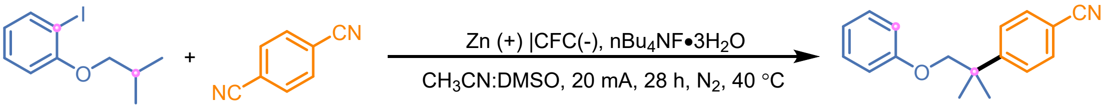
A series of parallel experiments: In an oven-dried undivided three-necked bottle (25 mL) equipped with a stir bar, **1aa** (165.6 mg, 0.6 mmol, 2.0 equiv.) and $nBu_4NF\cdot3H_2O$ (156.9 mg, 0.6 mmol, 2.0 equiv.) were added. The bottle was equipped with Zn (15 mm×15 mm×1 mm depth in solution) as the anode and carbon fiber cloth (CFC) (15 mm×15 mm×1 mm) as the cathode and was then charged with nitrogen. Under the protection of N_2, **2aa** (122.4 mg, 0.3 mmol, 1.0 equiv.), CH_3CN (1.0 mL), and DMSO (9.0 mL) were added via a syringe. The reaction mixture was stirred and electrolyzed at a constant current of 9 mA under 40 °C for corresponding time. After completion of the reaction, 20 mL water was added, and the mixture was extracted with DCM (20 mL×3). The organic layer was washed with saturated brine, dried over anhydrous Na_2SO_4, and filtered, and then the filtrate was concentrated in vacuo. The residue was purified by flash column chromatography. The yield of **3aa** was measured by GC-MS for every 20 minutes (biphenyl as internal standard).



Part 4: Scale-up experiments

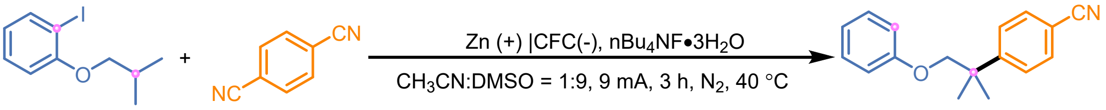
In an oven-dried undivided three-necked bottle (125 mL) equipped with a stir bar, **1aa** (2.76 g, 10.0 mmol, 2.0 equiv.) and $nBu_4NF\cdot3H_2O$ (2.61 mg, 10.0 mmol, 2.0 equiv.) were added. The bottle was equipped with Zn (40 mm×15 mm×1 mm depth in solution) as the anode and carbon fiber cloth (CFC) (40 mm×15 mm×1 mm depth in solution) as the cathode and was then charged with nitrogen. Under the protection of N_2, **2aa** (0.64 g, 5.0 mmol, 1.0 equiv.), CH_3CN (10.0 mL), and DMSO (90.0 mL) was added via a syringe. The reaction mixture was stirred and electrolyzed at a constant current of 20 mA under 40 °C for 28 h. After completion of the reaction, 80 mL water was added, and the mixture was extracted with EtOAc (50 mL×3). The organic layer was washed with saturated brine, dried over anhydrous Na_2SO_4, and filtered, and then the filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PE/EA = 20:1) to give the product as a yellow oil (0.87 g, 69%).





1aa, 10 mmol **2aa, 5 mmol** **3aa, 0.87 g, 69%**

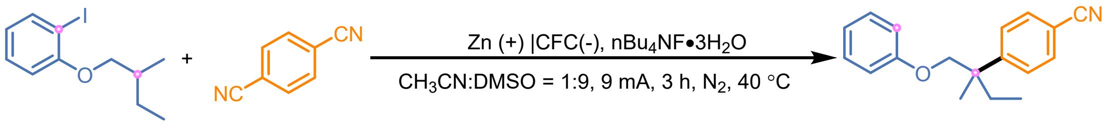
Part 5: Electroreduction-enabled aryl-to-alkyl radical relay arylation reaction of remote C(sp^3)-H bond of 2-iodoalkylarenes



1aa **2aa** **3aa**

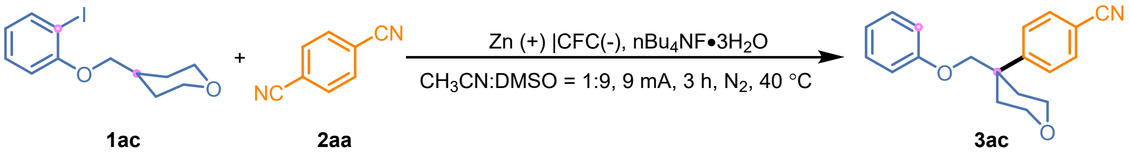
4-(2-methyl-4-phenylbutan-2-yl)benzonitrile (3aa)

General procedure E: In an oven-dried undivided three-necked bottle (25 mL) equipped with a stir bar, **1aa** (165.6 mg, 0.6 mmol, 2.0 equiv.) and nBu$_4$NF·3H$_2$O (156.9 mg, 0.6 mmol, 2.0 equiv.) were added. The bottle was equipped with Zn (15 mm×15 mm×1 mm depth in solution) as the anode and carbon fiber cloth (CFC) (15 mm×15 mm×1 mm) as the cathode and was then charged with nitrogen. Under the protection of N$_2$, **2aa** (122.4 mg, 0.3 mmol, 1.0 equiv.), CH$_3$CN (1.0 mL), and DMSO (9.0 mL) was added via a syringe. The reaction mixture was stirred and electrolyzed at a constant current of 9 mA under 40 °C for 3 h. After completion of the reaction, 20 mL water was added, and the mixture was extracted with EtOAc (20 mL×3). The organic layer was washed with saturated brine, dried over anhydrous Na$_2$SO$_4$, and filtered, and then the filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PE/EA = 20:1) to give the product as a yellow oil (60.4 mg, 80%). ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.48 (d, J = 8.8 Hz, 2H), 7.42 (d, J = 8.4 Hz, 2H), 7.15 (t, J = 8.0 Hz, 2H), 6.83 (t, J = 7.2 Hz, 1H), 6.75 (d, J = 8.4 Hz, 2H), 3.85 (s, 2H), 1.35 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 158.9, 152.6, 132.0, 129.5, 127.1, 121.0, 119.1, 114.6, 110.0, 76.4, 39.5, 25.9. HRMS (ESI) calcd for C$_{17}$H$_{17}$NO [M+Na]$^+$ 274.1202, found: 274.1208.



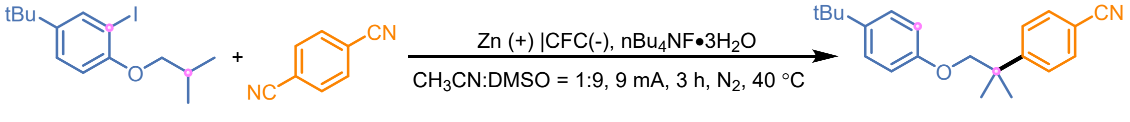
1ab **2aa** **3ab**

Product **3ab** was prepared by the general procedure E as a yellow oil (47.8 mg, 60%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.61 (d, J = 8.4 Hz, 2H), 7.49 (d, J = 8.4 Hz, 2H), 7.26 (d, J = 7.6 Hz, 2H), 6.94 (t, J = 7.2 Hz, 1H), 6.85 (d, J = 7.6 Hz, 2H), 4.04 (d, J = 8.8 Hz, 1H), 3.92 (d, J = 8.8 Hz, 1H), 1.96 – 1.87 (m, 1H), 1.86 – 1.77 (m, 1H), 1.45 (s, 3H), 0.74 (t, J = 7.6 Hz, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 159.0, 151.3, 132.1, 129.6, 127.7, 121.1, 119.1, 114.7, 110.0, 75.5, 43.0, 31.6, 22.2, 8.4. HRMS (ESI) calcd for C$_{18}$H$_{19}$NO [M+Na]$^+$ 288.1359, found: 288.1369.



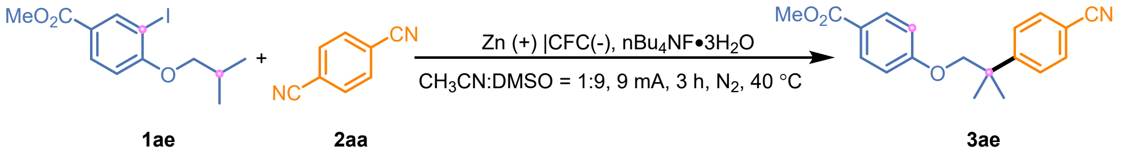
1ac **2aa** **3ac**

Product **3ac** was prepared by the general procedure E as a brown oil (43.9 mg, 50%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.58 (d, J = 8.4 Hz, 2H), 7.46 (d, J = 8.4 Hz, 2H), 7.15 (t, J = 8.0 Hz, 2H), 6.84 (t, J = 7.2 Hz, 1H), 6.70 (d, J = 7.6 Hz, 2H), 3.87 (s, 2H), 3.82 – 3.71 (m, 2H), 3.51 (t, J = 8.8 Hz, 2H), 2.21 – 2.04 (m, 4H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 158.7, 149.3, 132.3, 129.6, 128.2, 121.3, 118.9, 114.6, 110.6, 75.2, 64.1, 41.1, 32.8. HRMS (ESI) calcd for C$_{19}$H$_{19}$NO$_2$ [M+H]$^+$ 294.1489, found: 294.1492.

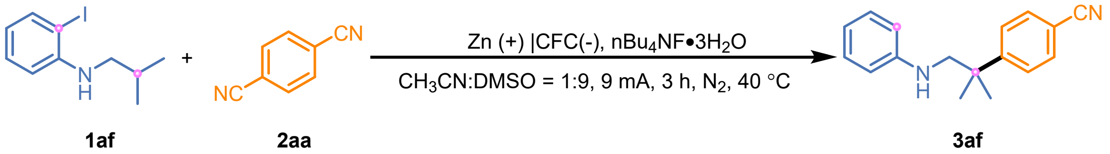


1ad **2aa** **3ad**

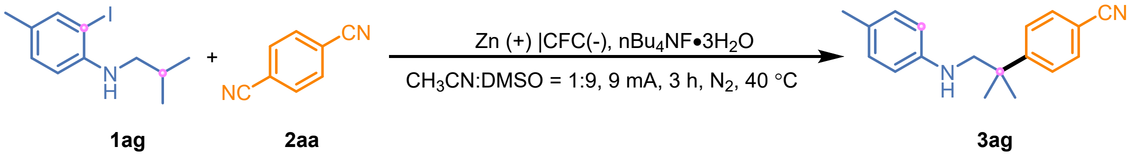
Product **3ad** was prepared by the general procedure E as white solid (65.3 mg, 71%), M.p. = 104 – 106 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 8.4 Hz, 2H), 7.20 (d, *J* = 8.8 Hz, 2H), 6.71 (d, *J* = 8.4 Hz, 2H), 3.86 (s, 2H), 1.38 (s, 6H), 1.21 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.7, 152.8, 143.9, 132.1, 127.2, 126.4, 119.1, 114.1, 110.1, 76.6, 39.6, 34.2, 31.6, 26.0. HRMS (ESI) calcd for $C_{21}H_{25}NO$ $[M+H]^+$ 308.2009, found: 308.2011.



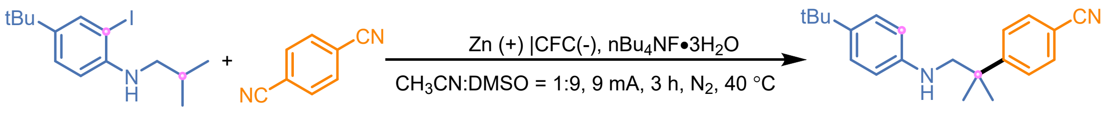
Product **3ae** was prepared by the general procedure E as colorless oil (59.5 mg, 64%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 8.4 Hz, 2H), 7.53 (d, *J* = 8.0 Hz, 2H), 6.86 (d, *J* = 8.4 Hz, 2H), 4.00 (s, 2H), 3.88 (s, 3H), 1.48 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 162.6, 152.2, 132.2, 131.7, 127.1, 123.1, 119.0, 114.2, 110.3, 76.7, 52.0 39.5, 25.9. HRMS (ESI) calcd for $C_{19}H_{19}NO_3$ $[M+H]^+$ 310.1438, found: 310.1434.



Product **3af** was prepared by the general procedure E as brown oil (38.2 mg, 51%); ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.76 (d, *J* = 8.5 Hz, 2H), 7.63 (d, *J* = 8.5 Hz, 2H), 7.00 (dd, *J* = 8.2, 7.5 Hz, 2H), 6.58 (d, *J* = 7.8 Hz, 2H), 6.48 (t, *J* = 7.2 Hz, 1H), 5.21 (t, *J* = 6.0 Hz, 1H), 3.23 (d, *J* = 6.0 Hz, 2H), 1.36 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 153.7, 149.2, 131.9, 128.7, 127.3, 119.0, 115.5, 112.0, 108.6, 54.4, 39.7, 26.5. HRMS (ESI) calcd for $C_{18}H_{18}N_2$ $[M+H]^+$ 251.1543, found: 251.1540.

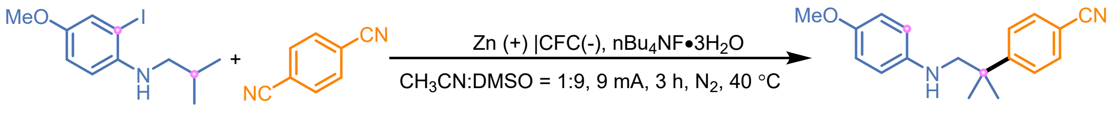


Product **3ag** was prepared by the general procedure E as brown oil (65.9 mg, 83%); ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.75 (d, *J* = 8.4 Hz, 2H), 7.61 (d, *J* = 8.4 Hz, 2H), 6.83 (d, *J* = 8.4 Hz, 2H), 6.49 (d, *J* = 8.4 Hz, 2H), 4.98 (t, *J* = 6.0 Hz, 1H), 3.20 (d, *J* = 6.0 Hz, 2H), 2.12 (s, 3H), 1.35 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 153.8, 146.9, 131.9, 129.1, 127.3, 123.9, 119.0, 112.2, 108.6, 54.8, 39.7, 26.5, 20.0. HRMS (ESI) calcd for $C_{18}H_{20}N_2$ $[M+H]^+$ 265.1699, found: 265.1691.



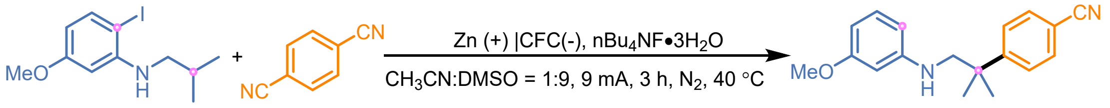
1ah **2aa** **3ah**

Product **3ah** was prepared by the general procedure E as yellow oil (65.5 mg, 71%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.75 (d, *J* = 8.8 Hz, 2H), 7.61 (d, *J* = 8.4 Hz, 2H), 7.03 (d, *J* = 8.4 Hz, 2H), 6.51 (d, *J* = 8.8 Hz, 2H), 4.99 (t, *J* = 6.0 Hz, 1H), 3.21 (d, *J* = 6.4 Hz, 2H), 1.35 (s, 6H), 1.19 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 153.8, 146.8, 137.8, 131.8, 127.3, 125.2, 119.0, 111.8, 108.6, 54.7, 39.7, 33.3, 31.4, 26.5. HRMS (ESI) calcd for $C_{21}H_{26}N_2$ [M+H]$^+$ 307.2169, found: 307.2174.



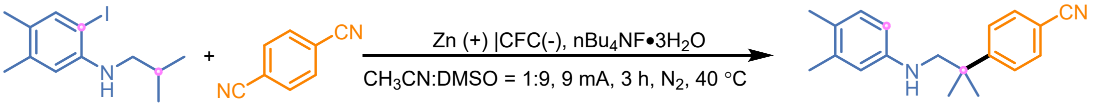
1ai **2aa** **3ai**

Product **3ai** was prepared by the general procedure E as brown oil (64.6 mg, 77%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.75 (d, *J* = 8.4 Hz, 2H), 7.61 (d, *J* = 8.4 Hz, 2H), 6.66 (d, *J* = 8.8 Hz, 2H), 6.54 (d, *J* = 9.2 Hz, 2H), 4.77 (t, *J* = 6.0 Hz, 1H), 3.62 (s, 3H), 3.18 (d, *J* = 6.4 Hz, 2H), 1.36 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 153.9, 150.6, 143.5, 131.9, 127.3, 119.0, 114.4, 113.1, 108.6, 55.5, 55.3, 39.6, 26.5. HRMS (ESI) calcd for $C_{18}H_{20}N_2O$ [M+H]$^+$ 281.1649, found: 281.1639.



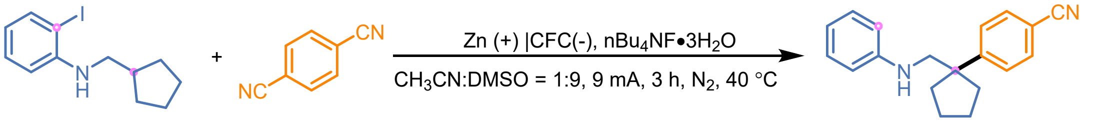
1aj **2aa** **3aj**

Product **3aj** was prepared by the general procedure E as brown oil (54.4 mg, 65%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.76 (d, *J* = 8.8 Hz, 2H), 7.62 (d, *J* = 8.8 Hz, 2H), 6.90 (t, *J* = 8.0 Hz, 1H), 6.18 (dd, *J* = 8.4, 1.6 Hz, 1H), 6.14 (t, *J* = 2.2 Hz, 1H), 6.07 (dd, *J* = 8.0, 1.6 Hz, 1H), 5.24 (t, *J* = 6.0 Hz, 1H), 3.64 (s, 3H), 3.23 (d, *J* = 6.0 Hz, 2H), 1.36 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 160.2, 153.7, 150.5, 131.9, 129.3, 127.3, 119.0, 108.6, 105.0, 101.4, 97.8, 54.6, 54.4, 39.7, 26.5. HRMS (ESI) calcd for $C_{18}H_{20}N_2O$ [M+H]$^+$ 281.1649, found: 281.1640.



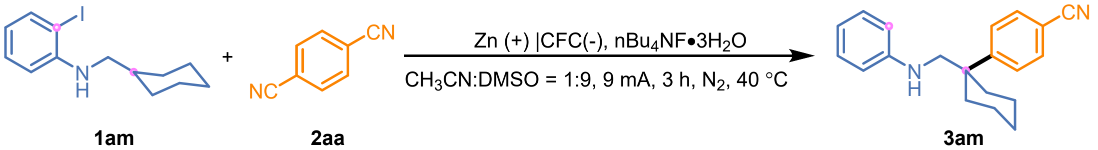
1ak **2aa** **3ak**

Product **3ak** was prepared by the general procedure E as yellow oil (51.8 mg, 62%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.75 (d, *J* = 8.4 Hz, 2H), 7.61 (d, *J* = 8.4 Hz, 2H), 6.76 (d, *J* = 8.4 Hz, 1H), 6.36 (s, 1H), 6.30 (dd, *J* = 8.0, 2.4 Hz, 1H), 4.86 (t, *J* = 6.0 Hz, 1H), 3.19 (d, *J* = 6.4 Hz, 2H), 2.06 (s, 3H), 2.03 (s, 3H), 1.35 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 153.8, 147.2, 135.9, 131.8, 129.6, 127.3, 122.8, 119.0, 113.8, 109.6, 108.5, 54.8, 39.7, 26.5, 19.6, 18.3. HRMS (ESI) calcd for $C_{19}H_{22}N_2$ [M+Na]$^+$ 301.1675, found: 301.1666.



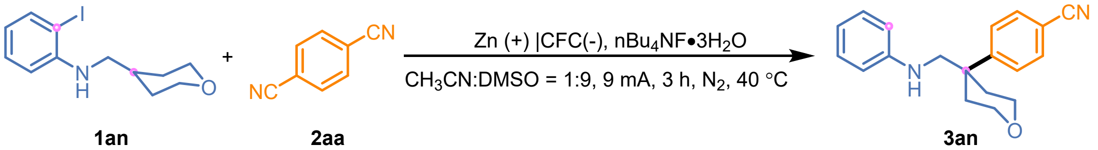
1al **2aa** **3al**

Product **3al** was prepared by the general procedure E as brown oil (41.5 mg, 50%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.72 (d, *J* = 8.4 Hz, 2H), 7.55 (d, *J* = 8.4 Hz, 2H), 6.95 (t, *J* = 7.6 Hz, 2H), 6.47 – 6.40 (m, 3H), 5.13 (t, *J* = 6.0 Hz, 1H), 3.19 (d, *J* = 6.4 Hz, 2H), 2.10 – 2.03 (m, 2H), 1.90 – 1.81 (m, 2H), 1.77 – 1.74 (m, 1H), 1.64 – 1.61 (m, 1H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 153.6, 149.1, 131.7, 128.6, 128.2, 119.0, 115.5, 111.9, 108.4, 52.5, 52.0, 35.5, 23.2. HRMS (ESI) calcd for $C_{19}H_{20}N_2$ [M+Na]$^+$ 299.1518, found: 299.1530.



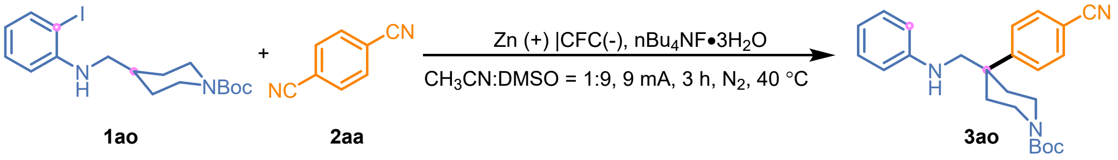
1am **2aa** **3am**

Product **3am** was prepared by the general procedure E as yellow oil (47.1 mg, 54%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.76 (d, *J* = 8.8 Hz, 2H), 7.62 (d, *J* = 8.8 Hz, 2H), 6.94 (t, *J* = 8.0 Hz, 2H), 6.45 (d, *J* = 7.6 Hz, 2H), 6.42 (d, *J* = 7.2 Hz, 1H), 5.16 (t, *J* = 6.4 Hz, 1H), 3.10 (d, *J* = 6.4 Hz, 2H), 2.20 (d, *J* = 14.0 Hz, 2H), 1.68 (t, *J* = 10.8 Hz, 2H), 1.55 (dd, *J* = 9.2, 4.4 Hz, 2H), 1.51 – 1.42 (m, 2H), 1.37 – 1.26 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 151.2, 149.2, 131.9, 128.5, 128.4, 119.0, 1154, 111.9, 108.4, 54.9, 43.9, 32.9, 25.8, 21.8. HRMS (ESI) calcd for $C_{20}H_{22}N_2$ [M+H]$^+$ 291.1856, found: 291.1847.



1an **2aa** **3an**

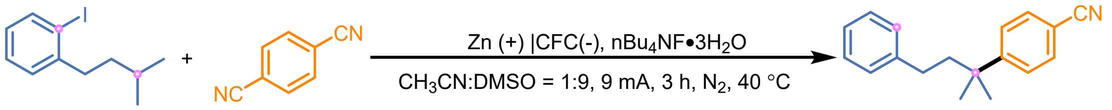
Product **3an** was prepared by the general procedure E as brown oil (44.9 mg, 51%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.78 (d, *J* = 8.4 Hz, 2H), 7.63 (d, *J* = 8.4 Hz, 2H), 6.95 (t, *J* = 8.0 Hz, 2H), 6.45 (t, *J* = 8.4 Hz, 3H), 5.22 (t, *J* = 6.4 Hz, 1H), 3.77 – 3.69 (m, 2H), 3.35 – 3.29 (m, 2H), 3.22 (d, *J* = 6.5 Hz, 2H), 2.15 (d, *J* = 14.4 Hz, 2H), 1.99 – 1.92 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 150.4, 149.1, 132.0, 128.6, 128.5, 118.9, 115.6, 112.0, 108.8, 63.3, 53.7, 41.8, 33.1. HRMS (ESI) calcd for $C_{19}H_{20}N_2O$ [M+H]$^+$ 293.1649, found: 293.1639.



1ao **2aa** **3ao**

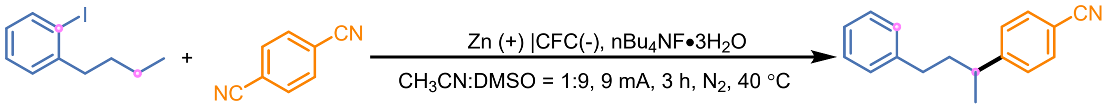
Product **3ao** was prepared by the general procedure E as brown oil (73.5 mg, 63%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.78 (d, *J* = 8.4 Hz, 2H), 7.64 (d, *J* = 8.4 Hz, 2H), 6.95 (t, *J* = 7.6 Hz, 2H), 6.45 (t, *J* = 8.0 Hz, 3H), 5.24 (t, *J* = 6.4 Hz, 1H), 3.66 (d, *J* = 13.6

Hz, 2H), 3.19 (d, *J* = 6.8 Hz, 2H), 2.86 (s, 2H), 2.19 (d, *J* = 14.0 Hz, 2H), 1.88 – 1.76 (m, 2H), 1.37 (s, 9H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 154.0, 149.6, 149.0, 132.1, 128.6, 128.5, 118.9, 115.6, 112.0, 108.9, 78.6, 53.6, 42.6, 32.0, 28.0. HRMS (ESI) calcd for $C_{24}H_{29}N_3O_2$ [M+H]$^+$ 392.2333, found: 392.2337.



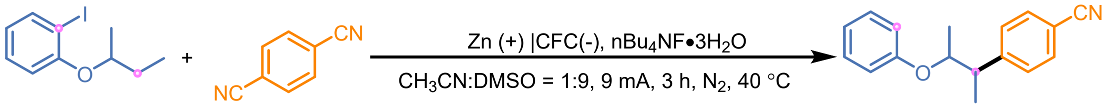
1ap **2aa** **3ap**

Product **3ap** was prepared by the general procedure E as yellow oil (53.6 mg, 72%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.62 (d, *J* = 8.0 Hz, 2H), 7.48 (d, *J* = 8.4 Hz, 2H), 7.24 (t, *J* = 7.2 Hz, 2H), 7.15 (t, *J* = 7.2 Hz, 1H), 7.06 (d, *J* = 7.2 Hz, 2H), 2.36 – 2.29 (m, 2H), 1.97 – 1.90 (m, 2H), 1.39 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 155.0, 142.4, 132.2, 128.5, 128.3, 126.9, 125.9, 119.2, 109.7, 46.4, 38.7, 31.3, 28.7. HRMS (ESI) calcd for $C_{18}H_{19}N$ [M+Na]$^+$ 272.1409, found: 272.1410.



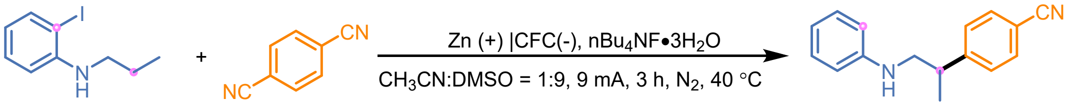
1aq **2aa** **3aq**

Product **3aq** was prepared by the general procedure E as yellow oil (51.0 mg, 66%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.59 (d, *J* = 8.4 Hz, 2H), 7.31 – 7.23 (m, 4H), 7.17 (t, *J* = 7.3 Hz, 1H), 7.10 (d, *J* = 7.2 Hz, 2H), 2.84 – 2.72 (m, 1H), 2.57 – 2.44 (m, 2H), 1.92 (q, *J* = 7.6 Hz, 2H), 1.28 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 153.1, 141.9, 132.5, 128.5, 128.4, 128.1, 126.1, 119.2, 110.1, 39.8, 39.6, 33.9, 22.1. HRMS (ESI) calcd for $C_{17}H_{17}N$ [M+Na]$^+$ 258.1253, found: 258.1261.



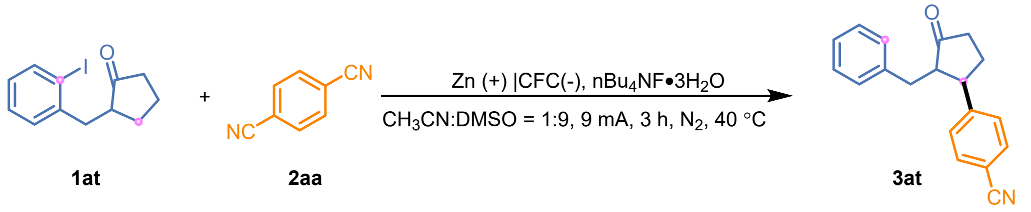
1ar **2aa** **3ar**

Product **3ar** was prepared by the general procedure E as colorless oil (27.5 mg, 40%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.58 (dd, *J* = 8.4, 3.6 Hz, 4H), 7.41 (d, *J* = 8.0 Hz, 2H), 7.36 (d, *J* = 8.4 Hz, 2H), 7.27 – 7.24 (m, 4H), 6.93 (d, *J* = 9.6 Hz, 2H), 6.87 (d, *J* = 8.0 Hz, 2H), 6.81 (d, *J* = 7.6 Hz, 2H), 4.45 (dt, *J* = 12.4, 6.0 Hz, 2H), 3.09 (dt, *J* = 13.6, 6.8 Hz, 2H), 1.41 (d, *J* = 7.2 Hz, 3H), 1.36 (d, *J* = 7.2 Hz, 3H), 1.23 (d, *J* = 6.0 Hz, 3H), 1.14 (d, *J* = 6.4 Hz, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 157.97, 157.95, 149.51, 149.41, 132.2, 132.1, 129.7, 129.6, 129.2, 129.1, 121.13, 121.08, 119.14, 119.05, 116.2, 116.0, 110.5, 110.3, 77.6, 77.4, 45.7, 45.5, 17.5, 17.2, 17.0. HRMS (ESI) calcd for $C_{22}H_{17}NO$ [M+Na]$^+$ 251.1310, found: 251.1310.

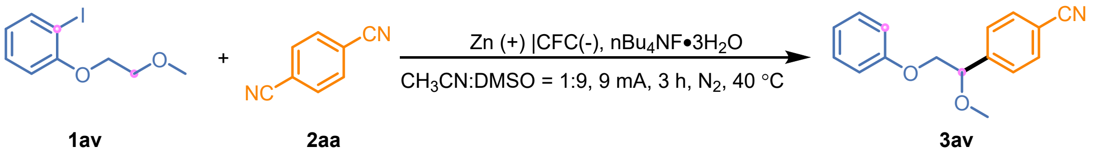


1as **2a** **3as**

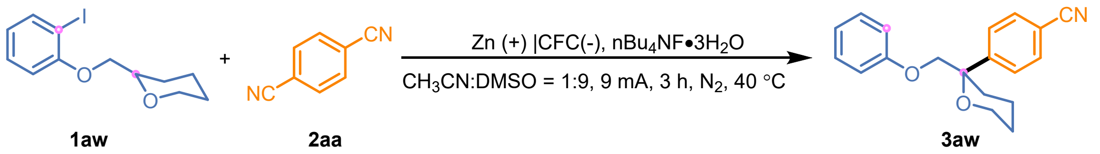
Product **3as** was prepared by the general procedure E as brown oil (29.0 mg, 41%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.76 (d, *J* = 8.4 Hz, 2H), 7.48 (d, *J* = 8.0 Hz, 2H), 7.05 (t, *J* = 8.0 Hz, 2H), 6.56 (d, *J* = 7.6 Hz, 2H), 6.51 (t, *J* = 7.2 Hz, 1H), 5.58 (t, *J* = 5.6 Hz, 1H), 3.24 – 3.07 (m, 3H), 1.27 (d, *J* = 6.8 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 151.3, 148.6, 132.2, 128.8, 128.4, 119.0, 115.6, 112.0, 108.9, 49.6, 38.7, 19.0. ^{13}C NMR (100 MHz, DMSO) δ 151.3, 148.6, 132.2, 128.8, 128.4, 119.0, 115.6, 112.0, 108.9, 49.6, 38.7, 19.0. HRMS (ESI) calcd for $C_{16}H_{16}N_2$ [M+H]$^+$ 237.1386, found: 237.1392.



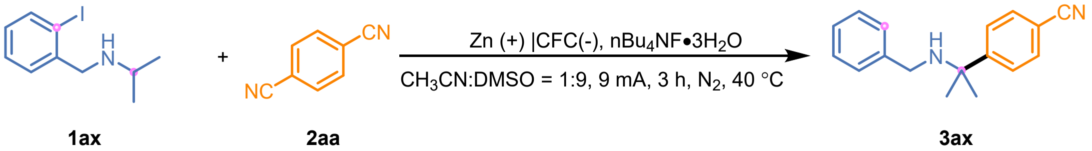
Product **3at** was prepared by the general procedure E as yellow oil (47.9 mg, 58%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.67 (d, *J* = 8.4 Hz, 2H), 7.42 (d, *J* = 8.4 Hz, 2H), 7.13 – 7.03 (m, 3H), 6.94 – 6.89 (m, 2H), 3.03 (td, *J* = 12.0, 6.0 Hz, 1H), 2.93 – 2.86 (m, 1H), 2.80 (dd, *J* = 14.0, 5.6 Hz, 1H), 2.71 (dd, *J* = 14.0, 6.0 Hz, 1H), 2.42 (dd, *J* = 16.4, 8.4 Hz, 1H), 2.20 – 2.09 (m, 2H), 1.89 – 1.80 (m, 1H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 217.3, 149.1, 138.8, 132.1, 129.1, 128.5, 127.9, 125.8, 118.9, 109.0, 55.8, 47.4, 37.6, 33.2, 29.7. HRMS (ESI) calcd for $C_{19}H_{17}NO$ [M+H]$^+$ 276.1383, found: 276.1386.



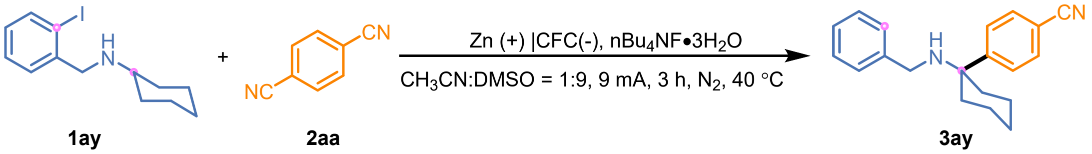
Product **3av** was prepared by the general procedure E as brown oil (53.0 mg,70%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.69 (d, *J* = 8.0 Hz, 2H), 7.53 (d, *J* = 8.0 Hz, 2H), 7.26 (t, *J* = 7.2 Hz, 2H), 6.95 (t, *J* = 7.2 Hz, 1H), 6.87 (d, *J* = 8.0 Hz, 2H), 4.67 – 4.58 (m, 1H), 4.21 – 4.14 (m, 1H), 4.00 (dd, *J* = 9.6, 4.0 Hz, 1H), 3.38 (s, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 158.4, 144.5, 132.5, 129.6, 127.9, 121.4, 118.8, 114.7, 112.2, 81.7, 71.5, 57.7. HRMS (ESI) calcd for $C_{16}H_{15}NO_2$ [M+Na]$^+$ 276.0995, found: 276.0995.



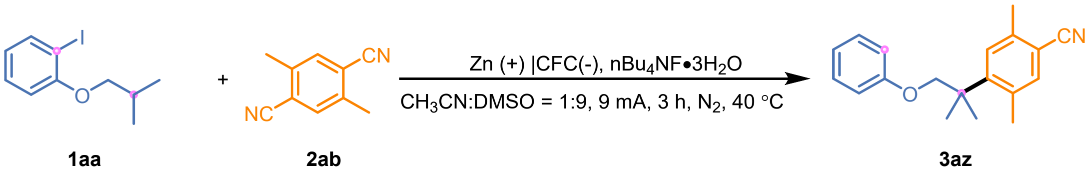
Product **3aw** was prepared by the general procedure E as brown oil (50.2 mg, 57%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.68 (d, *J* = 8.8 Hz, 2H), 7.63 (d, *J* = 8.4 Hz, 2H), 7.24 – 7.17 (m, 2H), 6.90 (t, *J* = 7.2 Hz, 1H), 6.78 (d, *J* = 7.6 Hz, 2H), 3.95 (d, *J* = 9.2 Hz, 1H), 3.84 (d, *J* = 9.2 Hz, 2H), 3.48 (td, *J* = 11.6, 2.4 Hz, 1H), 2.48 – 2.38 (m, 1H), 2.06 (td, *J* = 12.4, 3.6 Hz, 1H), 1.82 – 1.69 (m, 2H), 1.53 – 1.40 (m, 2H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 158.8, 146.9, 132.3, 129.5, 128.4, 121.2, 118.9, 114.8, 111.3, 77.8, 76.1, 63.2, 30.0, 25.9, 19.4. HRMS (ESI) calcd for $C_{19}H_{19}NO_2$ [M+H]$^+$ 294.1489, found: 294.1497.



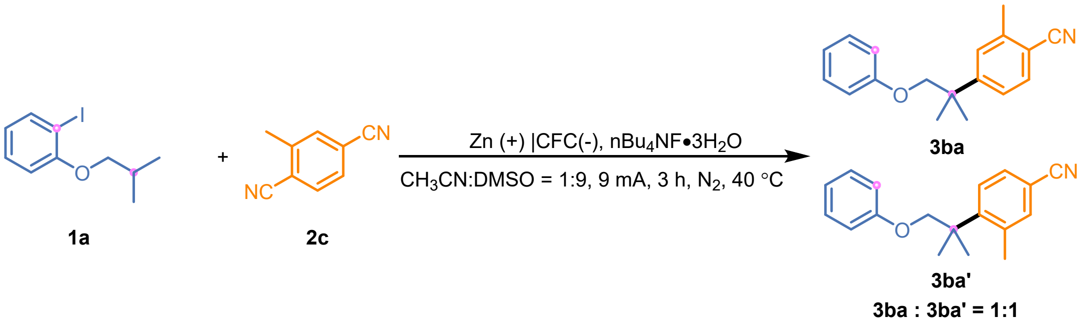
Product **3ax** was prepared by the general procedure E as yellow oil (51.2 mg, 68%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.80 (d, *J* = 8.4 Hz, 2H), 7.75 (d, *J* = 8.8 Hz, 2H), 7.33 – 7.25 (m, 4H), 7.20 (t, *J* = 6.8 Hz, 1H), 3.34 (s, 2H), 2.63 (s, 1H), 1.44 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 154.5, 141.4, 132.0, 128.0, 127.8, 127.1, 126.4, 119.0, 108.9, 56.1, 46.8, 29.0. HRMS (ESI) calcd for $C_{17}H_{18}N_2$ $[M+H]^+$ 251.1543, found: 251.1546.



Product **3ay** was prepared by the general procedure E as brown oil (53.2 mg, 61%); ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.80 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 4.8 Hz, 4H), 7.22 – 7.16 (m, 1H), 3.18 (s, 2H), 1.88 (t, *J* = 6.4 Hz, 2H), 1.82 – 1.68 (m, 4H), 1.59 (d, *J* = 12.3 Hz, 1H), 1.47 – 1.37 (m, 2H), 1.29 – 1.20 (m, 1H). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ 154.2, 141.3, 132.0, 128.0, 127.9, 127.3, 126.4, 119.0, 108.8, 57.5, 45.8, 35.3, 25.4, 21.4. HRMS (ESI) calcd for $C_{20}H_{22}N_2$ $[M+Na]^+$ 313.1675, found: 313.1680.

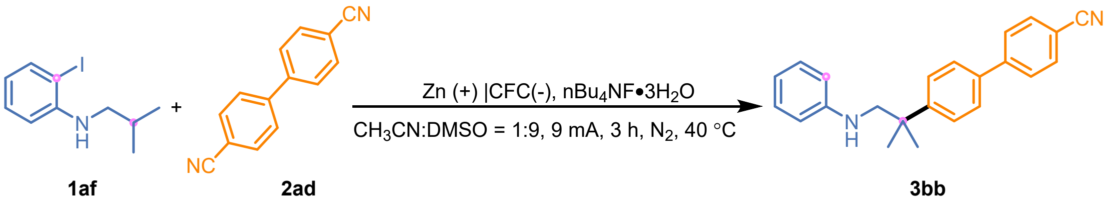


Product **3az** was prepared by the general procedure E as yellow oil (51.0 mg, 61%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.32 (d, *J* = 11.2 Hz, 2H), 7.26 (d, *J* = 8.8 Hz, 2H), 6.95 (t, *J* = 7.6 Hz, 1H), 6.86 (d, *J* = 7.6 Hz, 2H), 4.10 (s, 2H), 2.50 (s, 3H), 2.48 (s, 3H), 1.52 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 159.1, 149.7, 139.1, 136.4, 134.8, 129.7, 129.6, 121.1, 118.4, 114.7, 110.6, 75.7, 40.8, 26.2, 22.8, 20.4. HRMS (ESI) calcd for $C_{19}H_{21}NO$ $[M+H]^+$ 280.1696, found: 280.1704.

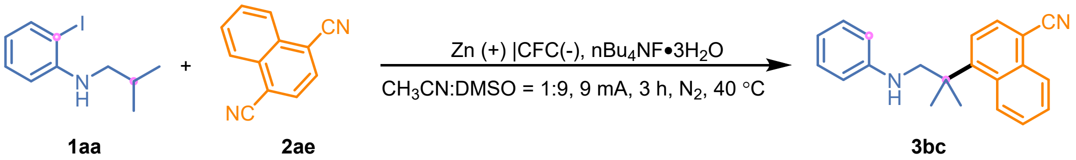


Product **3ba and 3ba’** was prepared by the general procedure E as yellow oil (63.6 mg, 80%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.57 – 7.51 (m, 1H), 7.48 – 7.36 (m, 4H), 7.31 – 7.19 (m, 5H), 6.94 (d, *J* = 5.6 Hz, 2H), 6.85 (d, *J* = 7.6 Hz, 4H), 4.11 (d, *J* = 1.6 Hz, 2H), 3.94 (d, *J* = 2.0 Hz, 2H), 2.54 (d, *J* = 5.2 Hz, 6H), 1.53 (d, *J* = 1.6 Hz, 6H), 1.45

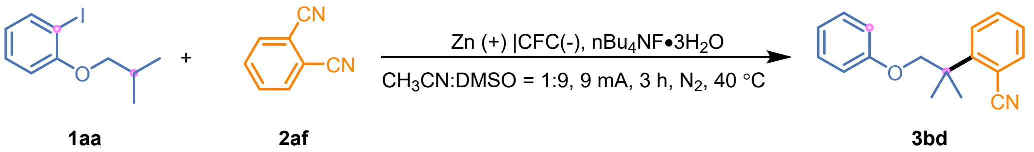
(d, *J* = 1.6 Hz, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 159.0, 158.9, 152.4, 150.0, 141.7, 137.9, 136.1, 132.4, 129.7, 129.6, 129.5, 128.5, 128.3, 124.4, 121.1, 121.0, 119.1, 118.4, 114.68, 114.66, 110.5, 110.2, 76.6, 75.7, 40.9, 39.4, 26.1, 26.0, 23.3, 20.9. HRMS (ESI) calcd for $C_{18}H_{19}NO$ $[M+H]^+$ 266.1540, found: 266.1536.



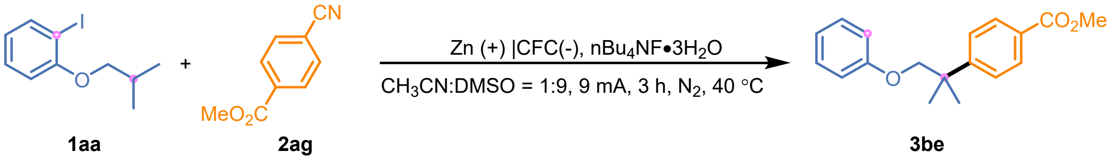
Product **3bb** was prepared by the general procedure E as white solid (50.2 mg, 51%), M.p. = 125 – 126 °C; ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.68 (q, *J* = 8.4 Hz, 4H), 7.55 (s, 4H), 7.25 (d, *J* = 7.6 Hz, 2H), 6.94 (d, *J* = 7.2 Hz, 1H), 6.89 (d, *J* = 8.0 Hz, 2H), 3.98 (s, 2H), 1.50 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 159.3, 147.9, 145.5, 137.0, 132.7, 129.5, 127.7, 127.10, 127.08, 120.9, 119.1, 114.8, 110.8, 77.0, 39.0, 26.2. HRMS (ESI) calcd for $C_{23}H_{21}NO$ $[M+H]^+$ 328.1696, found: 328.1705.



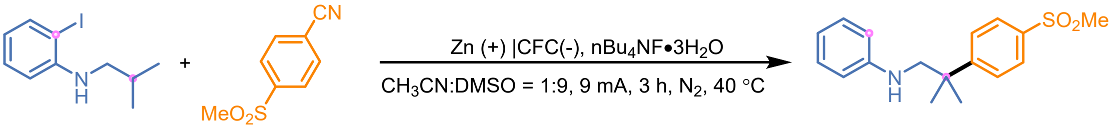
Product **3bc** was prepared by the general procedure E as brown oil (57.7 mg, 64%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.71 (d, *J* = 8.4 Hz, 1H), 8.19 (dd, *J* = 8.0, 1.2 Hz, 1H), 8.10 (d, *J* = 8.0 Hz, 1H), 7.81 – 7.72 (m, 2H), 7.66 (d, *J* = 8.0 Hz, 1H), 6.97 (t, *J* = 7.6 Hz, 2H), 6.55 (d, *J* = 7.6 Hz, 2H), 6.46 (t, *J* = 7.2 Hz, 1H), 5.16 (t, *J* = 5.2 Hz, 1H), 3.66 (d, *J* = 6.0 Hz, 2H), 1.66 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 149.8, 149.1, 132.67, 132.65, 131.0, 128.7, 127.8, 126.8, 125.8, 125.0, 117.9, 115.6, 112.2, 108.3, 53.8, 41.5, 28.1. HRMS (ESI) calcd for $C_{21}H_{20}N_2$ $[M+H]^+$ 301.1699, found: 301.1690.



Product **3bd** was prepared by the general procedure E as yellow oil (31.5 mg, 42%); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.60 (d, *J* = 7.6 Hz, 1H), 7.45 (d, *J* = 4.0 Hz, 2H), 7.23 (dd, *J* = 8.0, 4.0 Hz, 1H), 7.18 (t, *J* = 8.0 Hz, 2H), 6.86 (t, *J* = 7.2 Hz, 1H), 6.80 (d, *J* = 8.0 Hz, 2H), 4.19 (s, 2H), 1.58 (s, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 159.0, 150.0, 135.8, 132.8, 129.6, 128.1, 126.8, 121.1, 120.3, 114.9, 110.9, 75.5, 40.2, 25.7. HRMS (ESI) calcd for $C_{17}H_{17}NO$ $[M+Na]^+$ 274.1202, found: 274.1205.

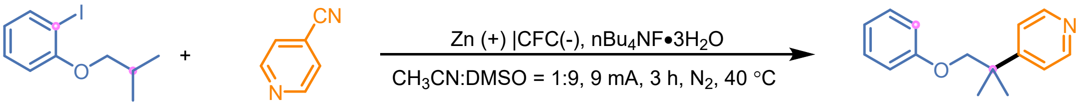


Product **3be** was prepared by the general procedure E as yellow oil (47.0 mg, 55%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, *J* = 8.4 Hz, 2H), 7.43 (d, *J* = 8.4 Hz, 2H), 7.17 (t, *J* = 8.4 Hz, 2H), 6.85 (t, *J* = 7.2 Hz, 1H), 6.78 (d, *J* = 8.0 Hz, 2H), 3.88 (s, 2H), 3.82 (s, 3H), 1.40 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.2, 159.2, 152.5, 129.6, 129.5, 128.1, 126.3, 120.9, 114.7, 52.1, 39.4, 26.1. HRMS (ESI) calcd for $C_{18}H_{20}O_3$ $[M+H]^+$ 285.1485, found: 285.1486.



1af **2ah** **3bf**

Product **3bf** was prepared by the general procedure E as brown oil (47.5 mg, 52%); ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.85 (d, *J* = 8.4 Hz, 2H), 7.70 (d, *J* = 8.4 Hz, 2H), 7.01 (t, *J* = 7.6 Hz, 2H), 6.59 (d, *J* = 7.6 Hz, 2H), 6.48 (t, *J* = 7.2 Hz, 1H), 5.21 (t, *J* = 5.6 Hz, 1H), 3.25 (d, *J* = 6.0 Hz, 2H), 3.17 (s, 3H), 1.38 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 153.9, 149.2, 138.3, 128.6, 127.1, 126.7, 115.5, 112.0, 54.5, 43.6, 39.6, 26.6. HRMS (ESI) calcd for $C_{17}H_{21}NO_2S$ $[M+H]^+$ 304.1366, found: 304.1359.



1aa **2ai** **3bg**

Product **3bg** was prepared by the general procedure E as brown oil (20.4 mg, 30%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.57 (dd, *J* = 4.8, 0.8 Hz, 1H), 7.63 (td, *J* = 8.0, 2.0 Hz, 1H), 7.40 (d, *J* = 8.0 Hz, 1H), 7.25 – 7.21 (m, 2H), 7.13 – 7.09 (m, 1H), 6.94 – 6.84 (m, 4H), 4.14 (s, 2H), 1.49 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.9, 136.3, 129.4, 121.3, 120.7, 120.6, 114.9, 41.7, 25.2. HRMS (ESI) calcd for $C_{15}H_{17}NO$ $[M+H]^+$ 228.1383, found: 228.1391.

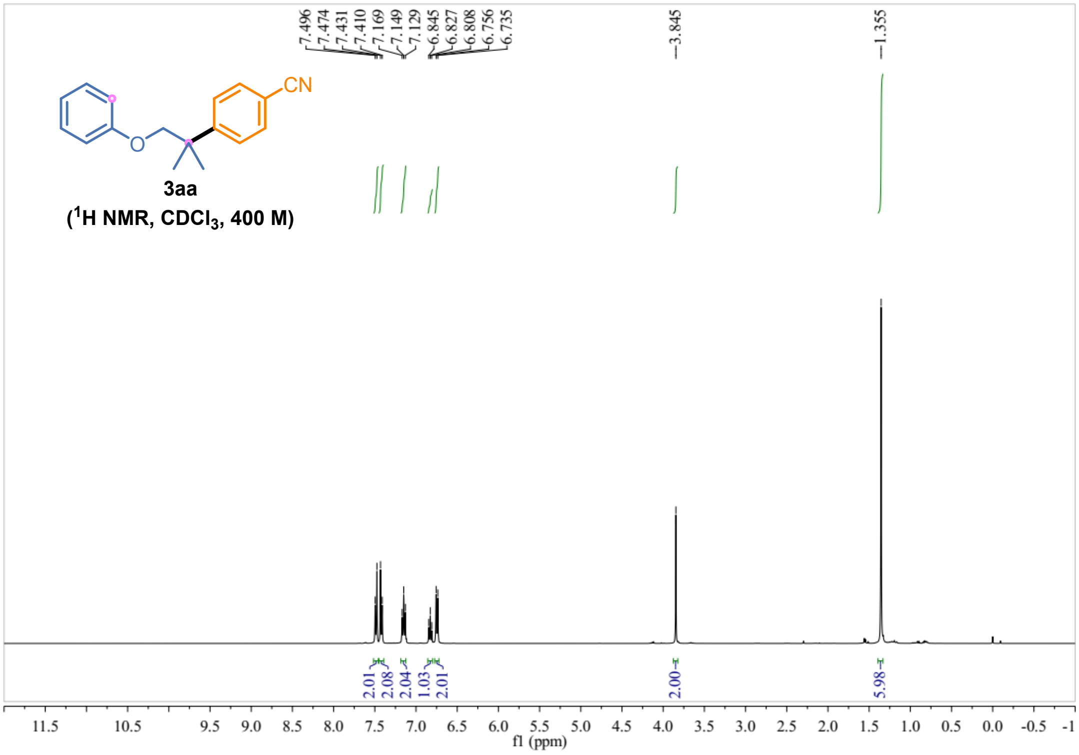
Part 6: References

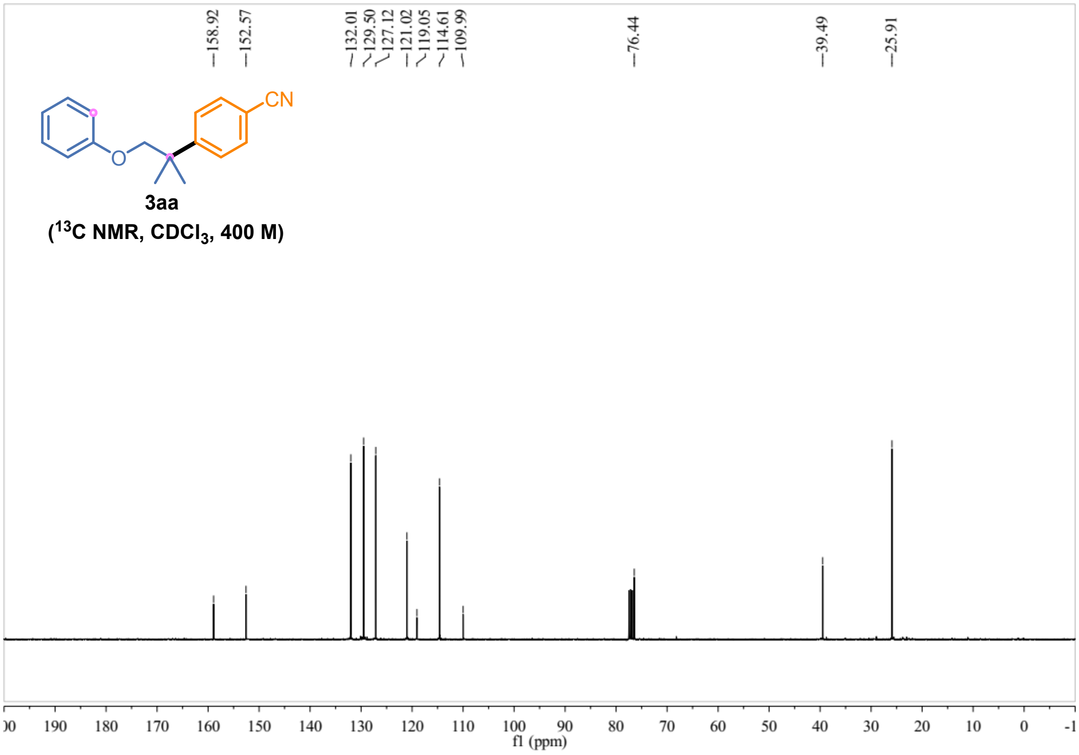
1. A. Y. Koposov, R. R. Karimov, I. M. Geraskin, V. N. Nemykin and V. V. Zhdankin, *J. Org. Chem.*, 2006, **71**, 8452–8458.

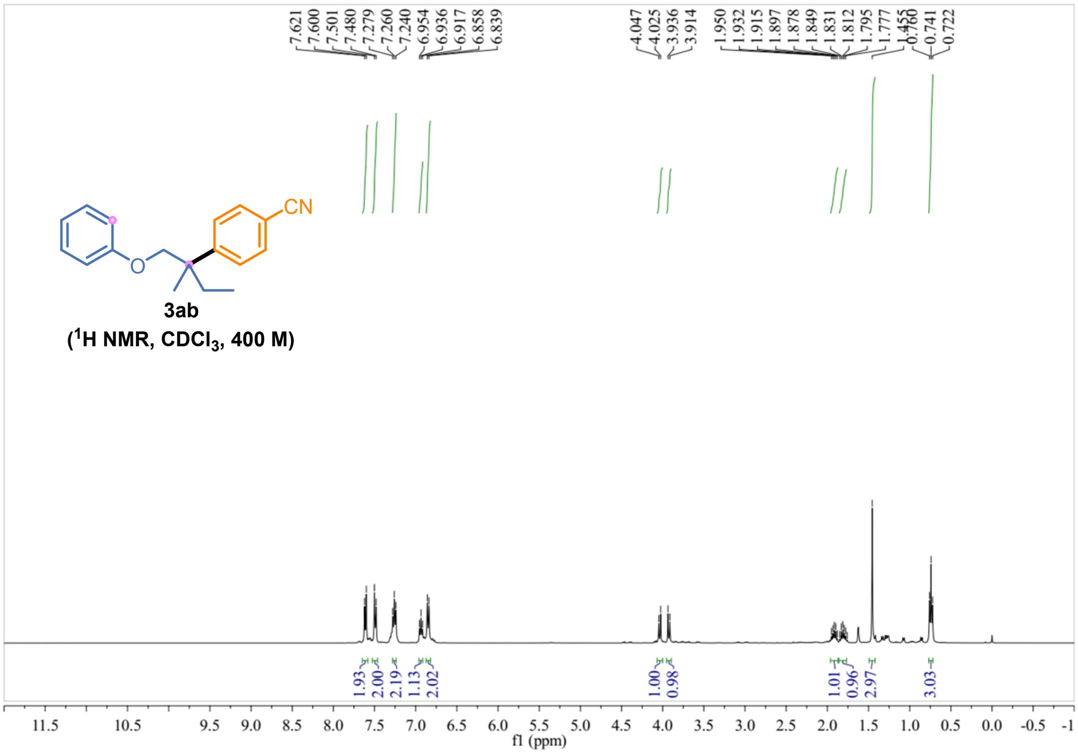
2. A. Whyte, M. E. Olson and M. Lautens, *Org. Lett.*, 2018, **20**, 345–348.

3. B. Zhou, H. Sato, L. Ilies and E. Nakamura, *ACS. Catal.*, 2018, **8**, 8–11.

Part 7: NMR spectra of the products



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7.501
7.480
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7.260
7.240
6.954
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6.917
6.858
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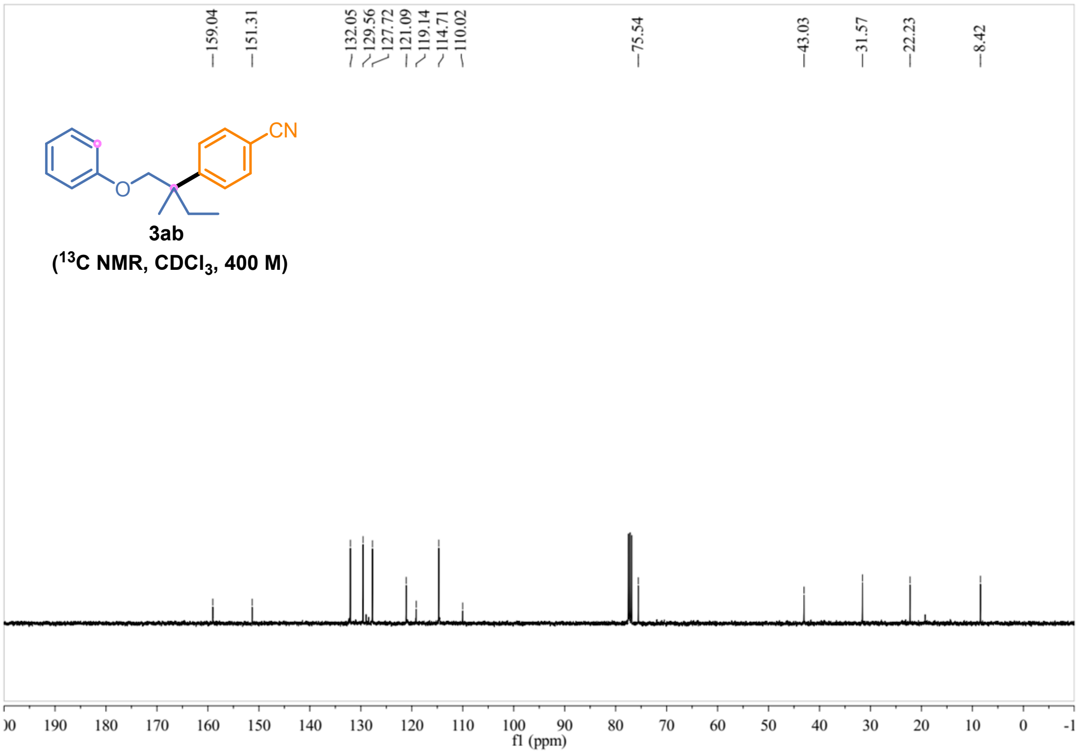
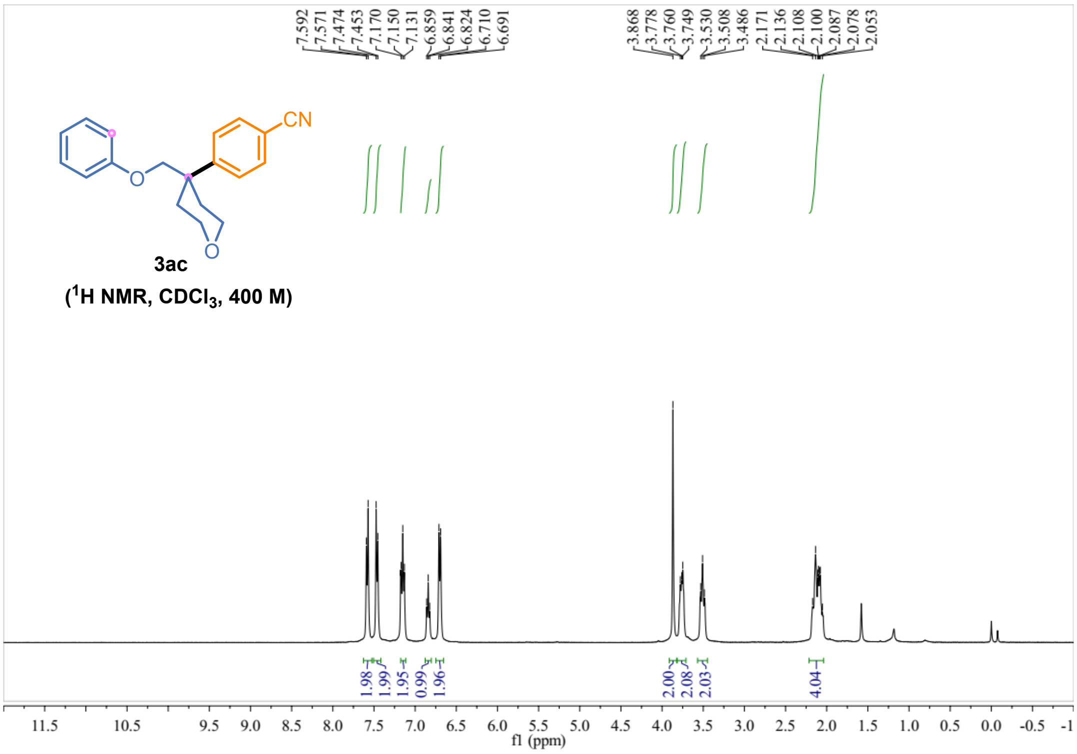
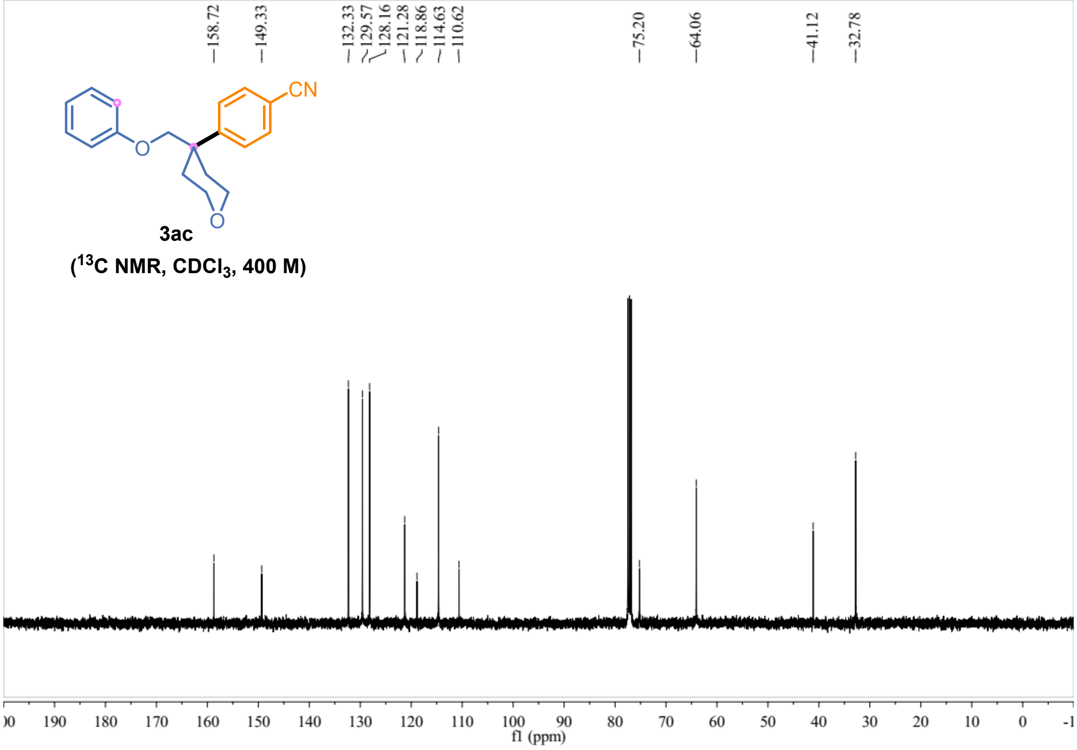
4.047
4.025
3.936
3.914
1.950
1.932
1.915
1.897
1.878
1.849
1.831
1.812
1.795
1.777
1.455
0.760
0.741
0.722
CN
O
3ab
(^{1}H NMR, CDCl$_3$, 400 M)
1.93
2.00
2.19
1.13
2.02
1.00
0.98
1.01
0.96
2.97
3.03
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1
f1 (ppm)

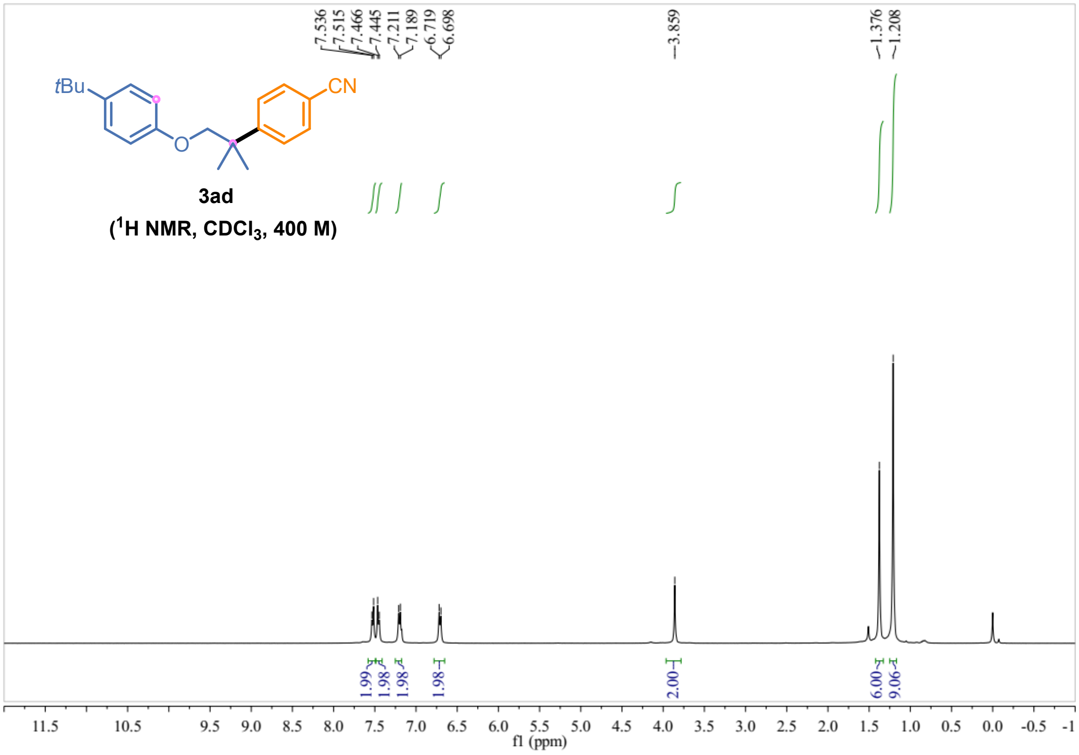

159.04
151.31
132.05
129.56
127.72
121.09
119.14
114.71
110.02
75.54
43.03
31.57
22.23
8.42
CN
O
3ab
(^{13}C NMR, CDCl$_3$, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)


3ac

(^{1}H NMR, CDCl$_3$, 400 M)

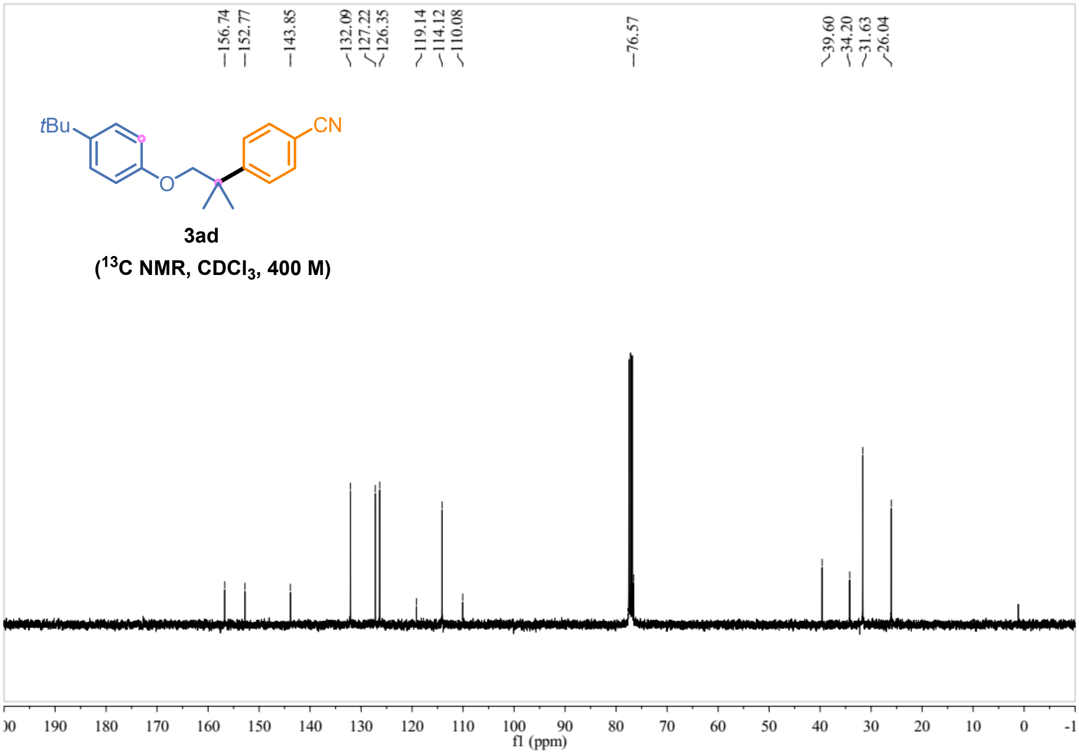

3ac

(^{13}C NMR, CDCl$_3$, 400 M)



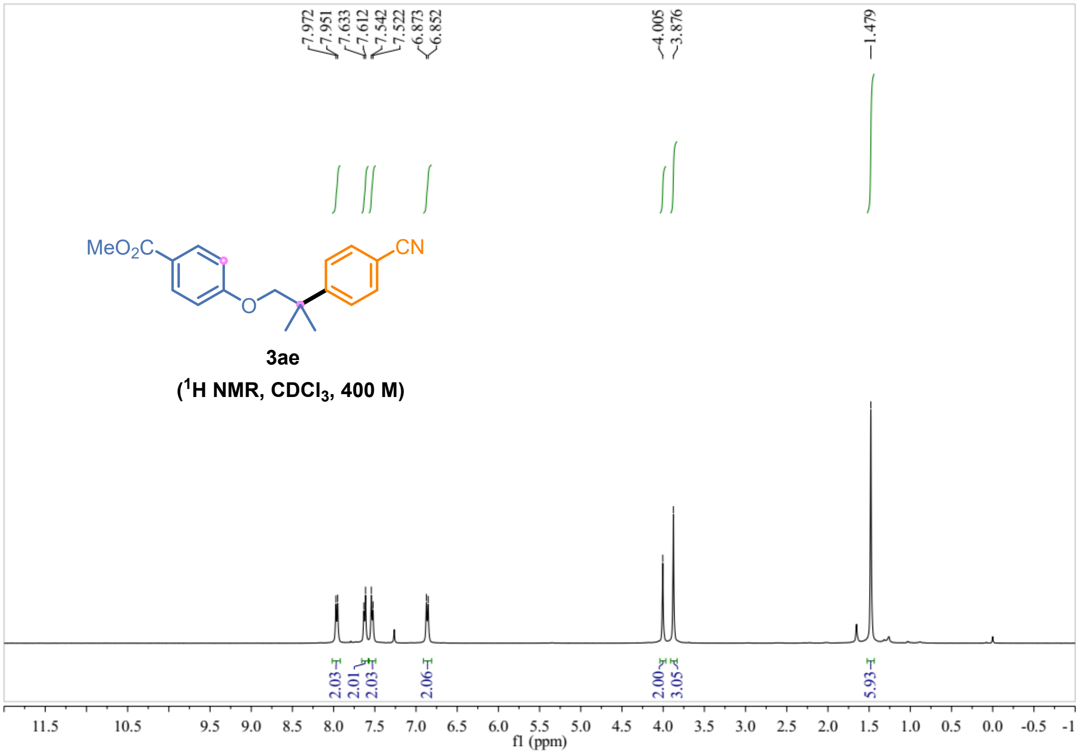
3ad

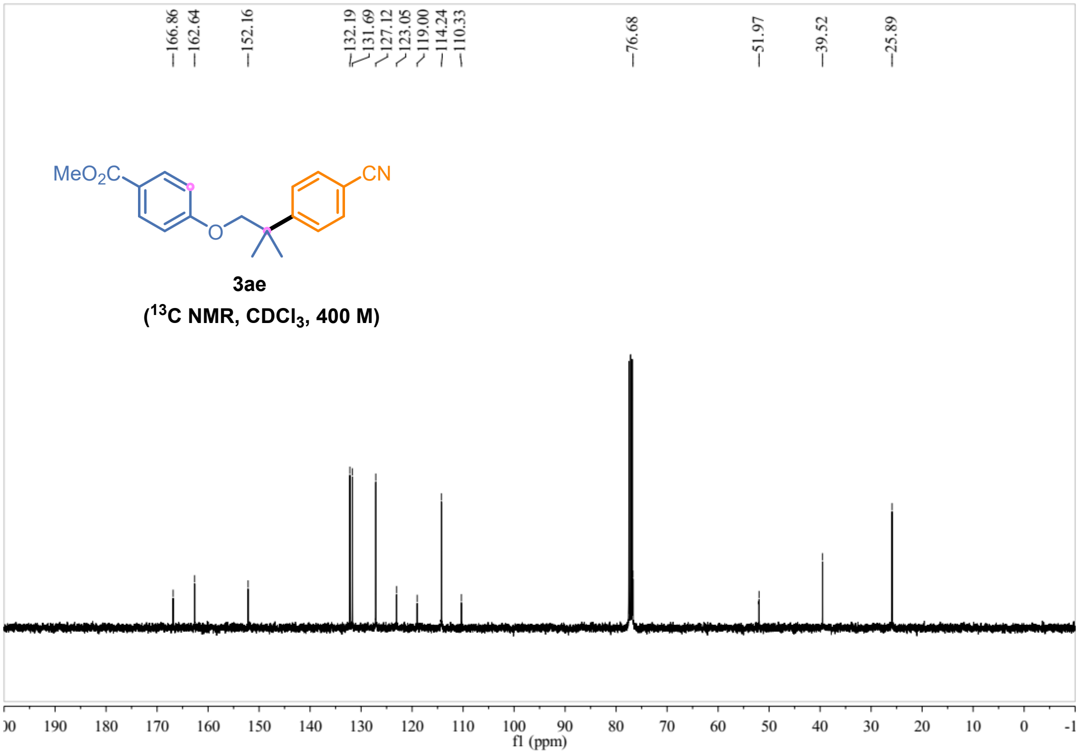
(^{1}H NMR, CDCl$_3$, 400 M)

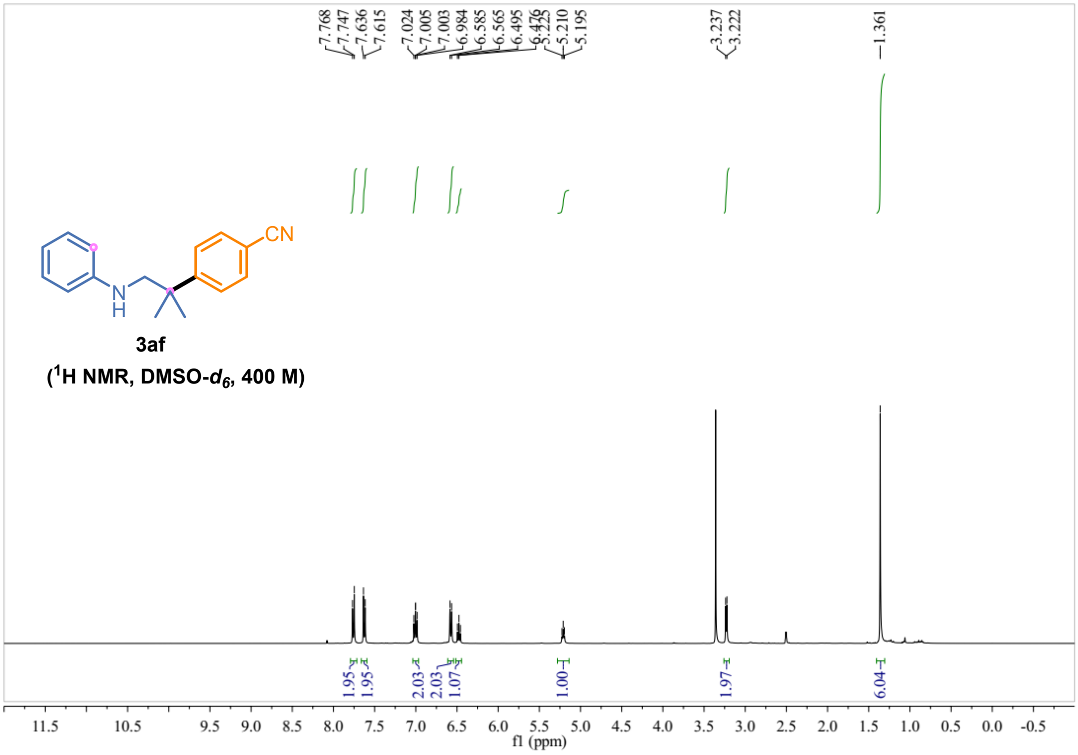


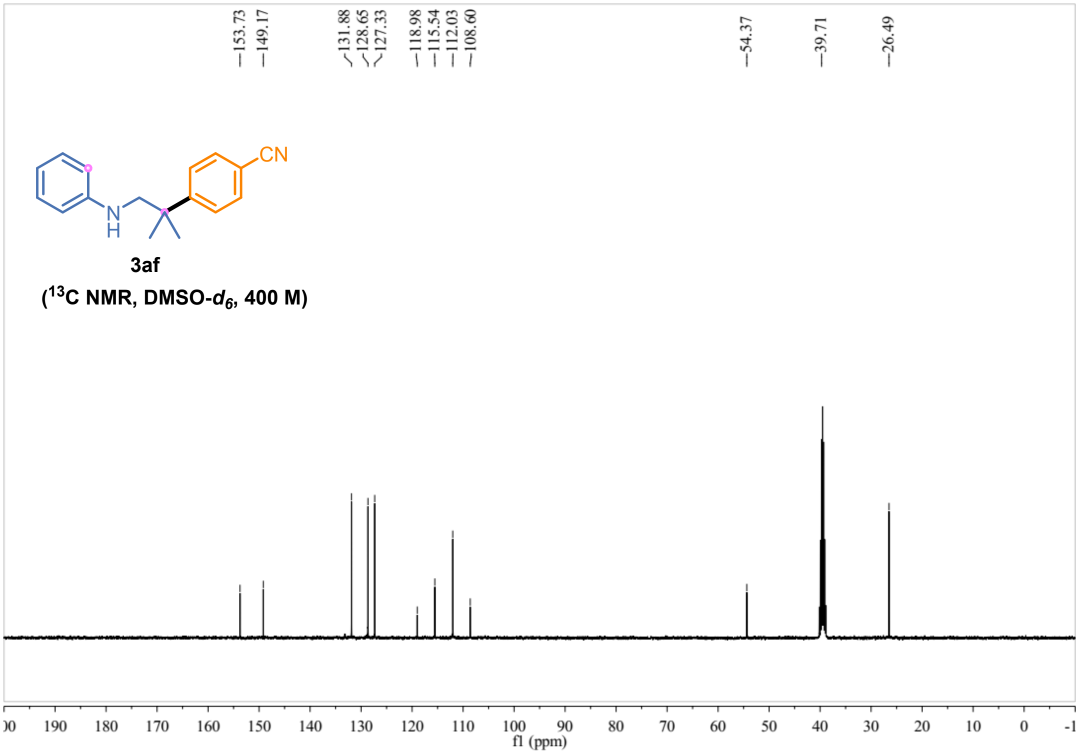
3ad

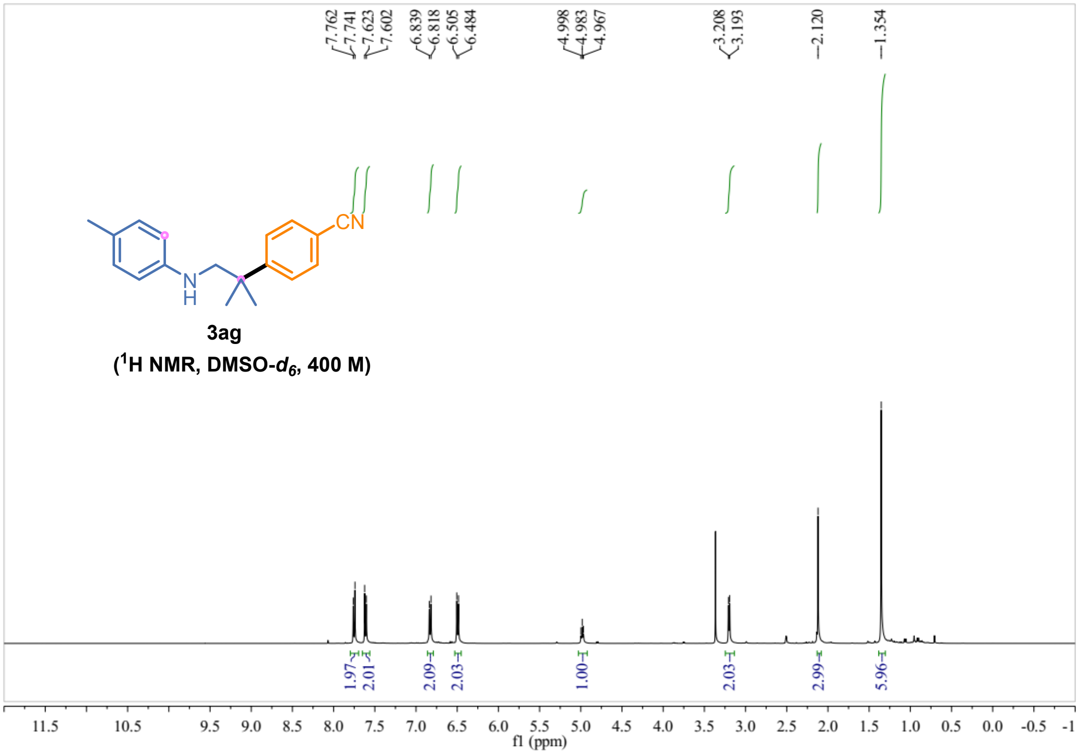
(^{13}C NMR, CDCl$_3$, 400 M)


3ae
(^{1}H NMR, CDCl$_3$, 400 M)


3ae
(^{13}C NMR, CDCl$_3$, 400 M)

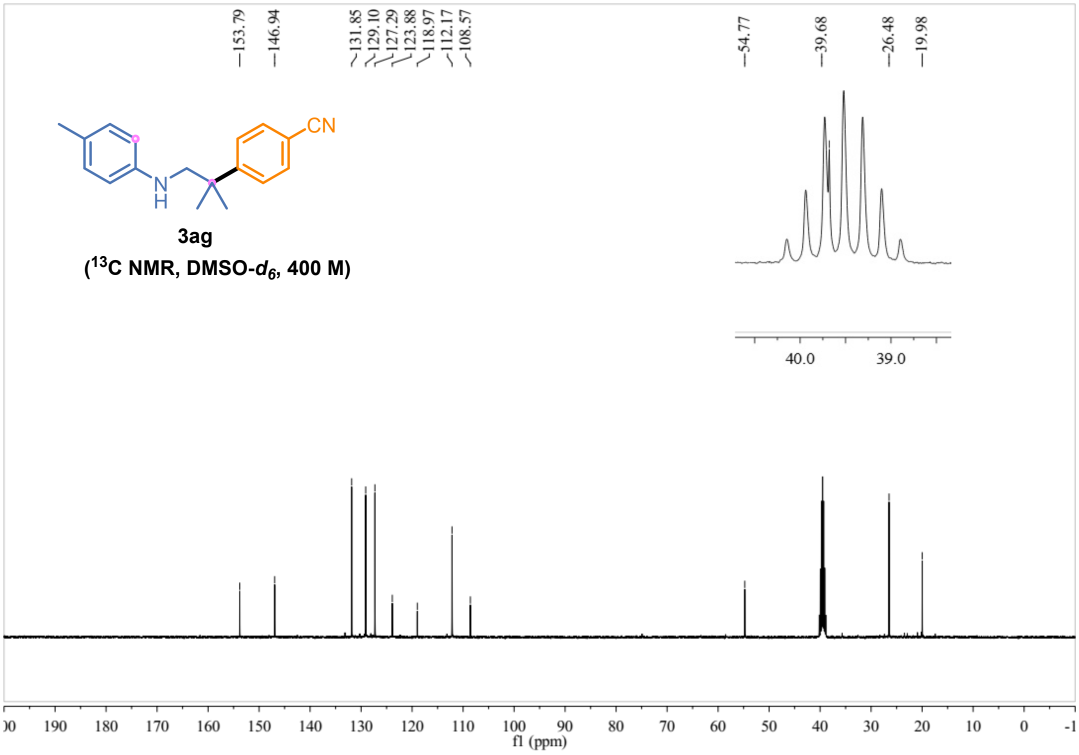

7.768
7.747
7.636
7.615
7.024
7.005
7.003
6.984
6.585
6.565
6.495
6.476
5.225
5.210
5.195
3.237
3.222
1.361
CN
N
H
3af
(^{1}H NMR, DMSO-d_6, 400 M)
1.95
1.95
2.03
2.03
1.07
1.00
1.97
6.04
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


153.73
149.17
131.88
128.65
127.33
118.98
115.54
112.03
108.60
54.37
39.71
26.49
CN
N
H
3af
(^{13}C NMR, DMSO-d_6, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)



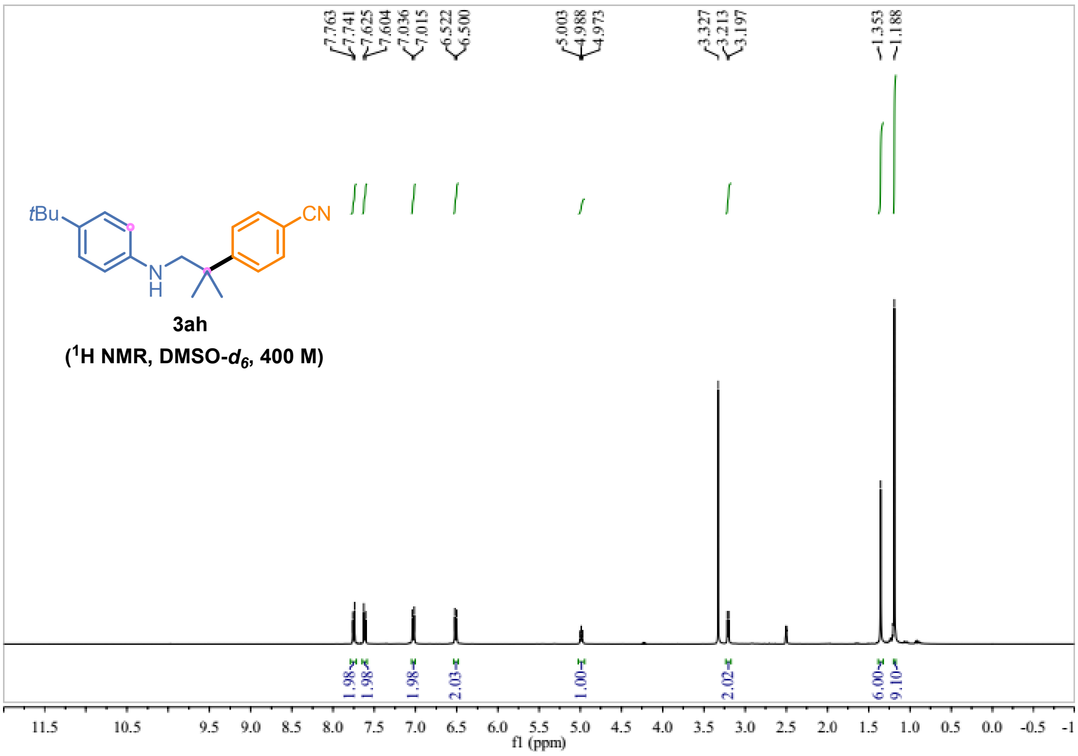
3ag

(^{1}H NMR, DMSO-d_6, 400 M)



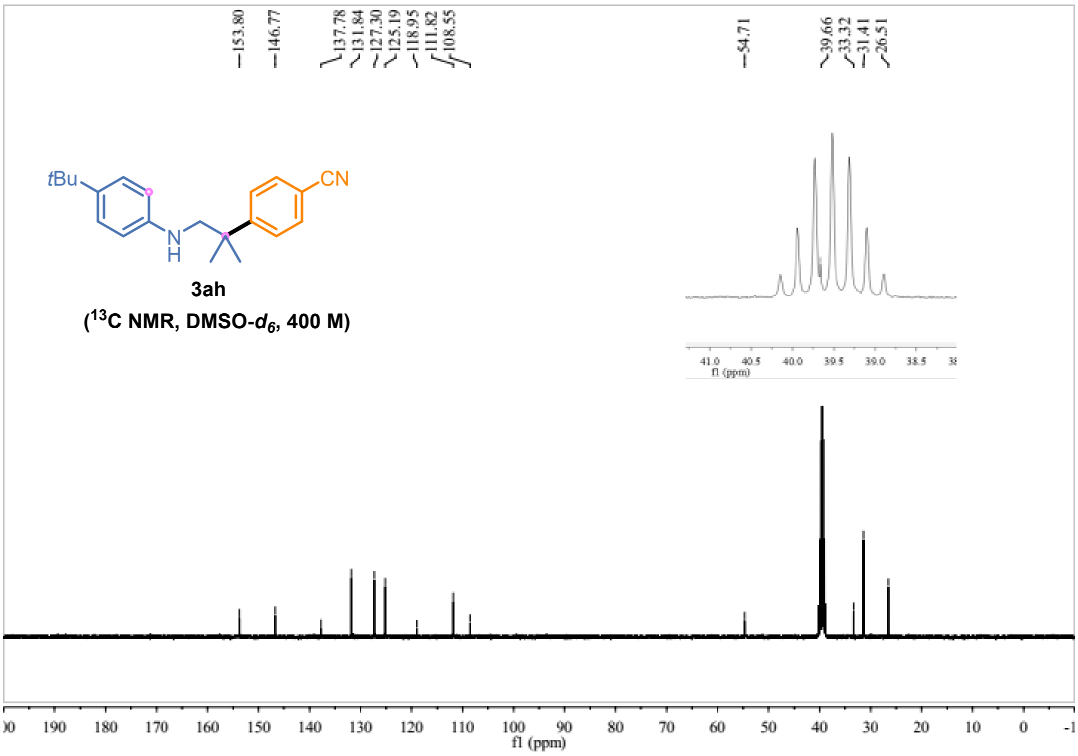
3ag

(^{13}C NMR, DMSO-d_6, 400 M)



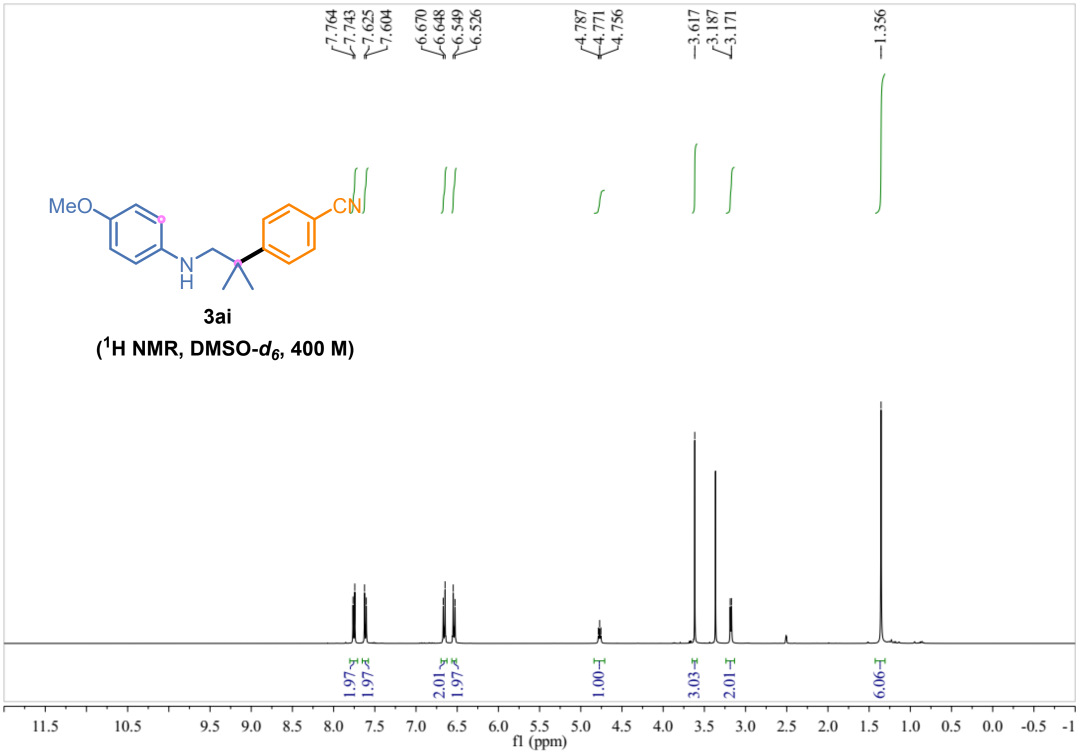
3ah

(^{1}H NMR, DMSO-d_6, 400 M)



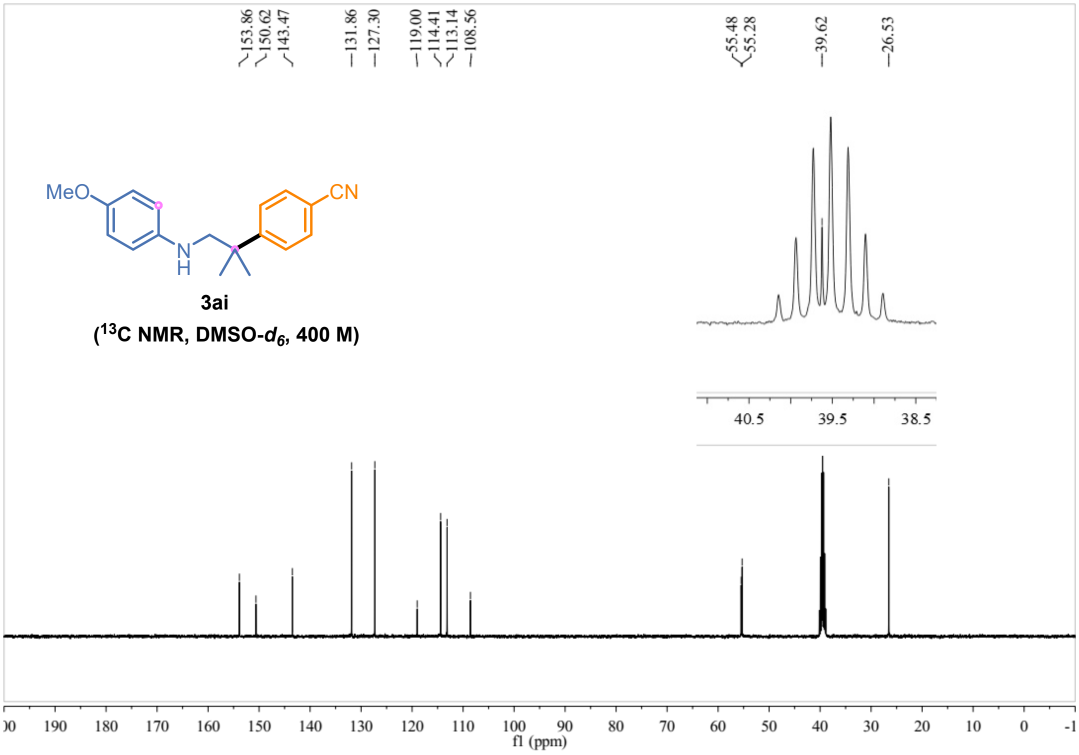
3ah

(^{13}C NMR, DMSO-d_6, 400 M)



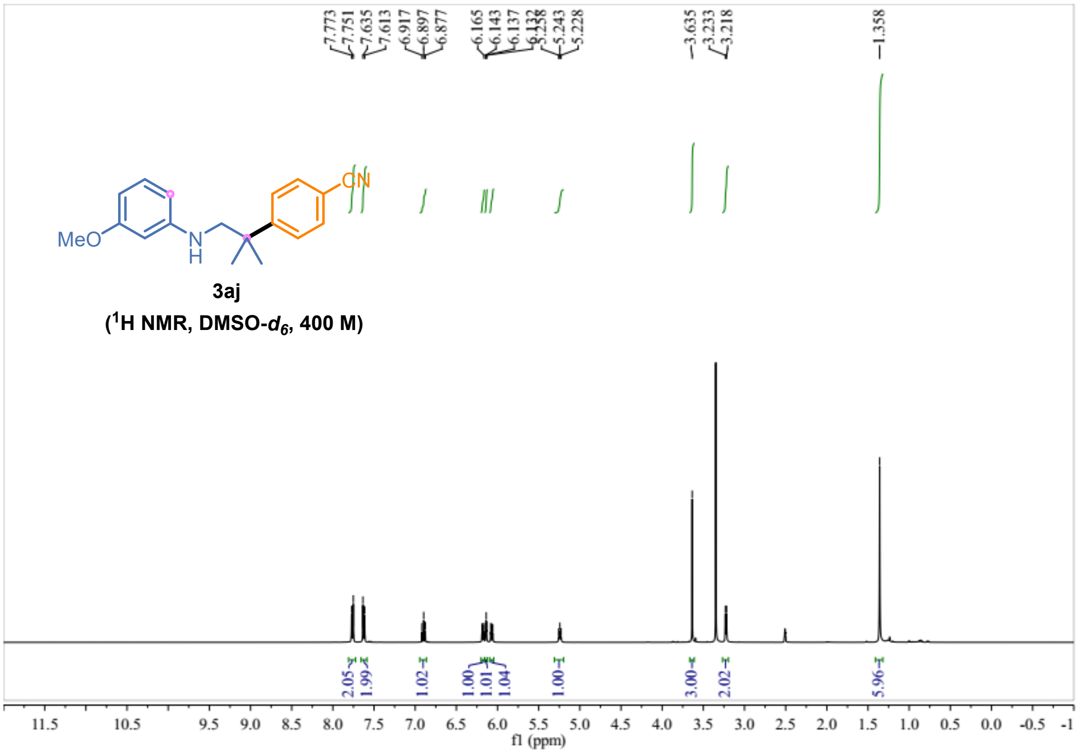
3ai

(^{1}H NMR, DMSO-*d*$_6$, 400 M)



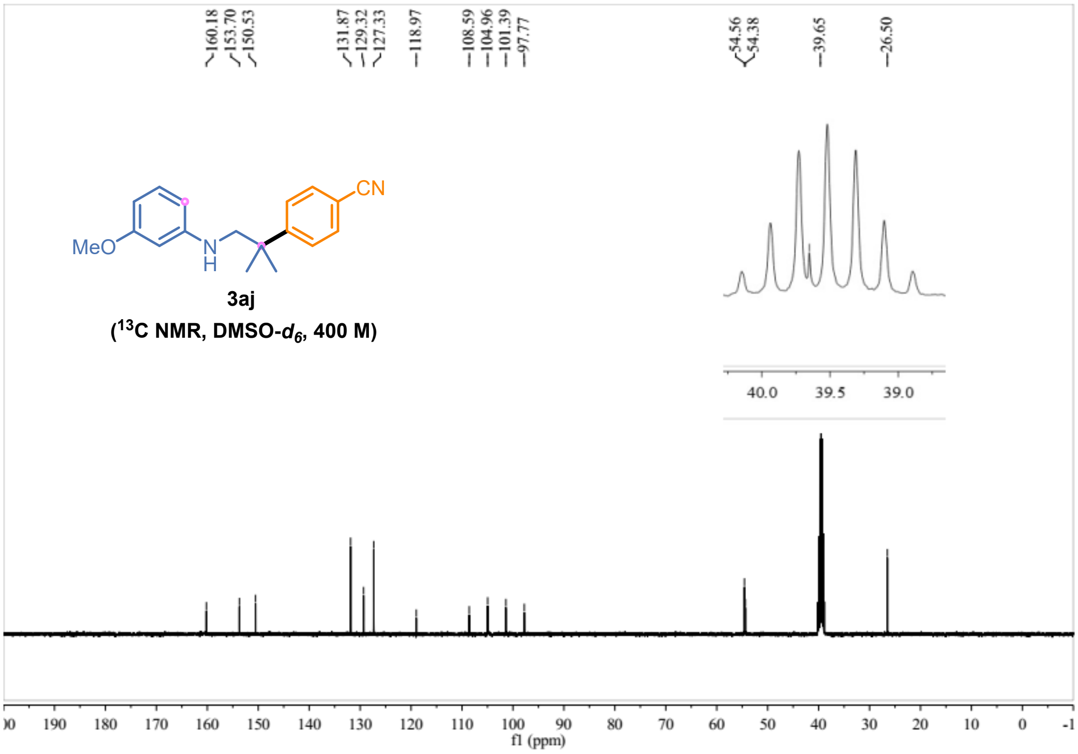
3ai

(^{13}C NMR, DMSO-*d*$_6$, 400 M)



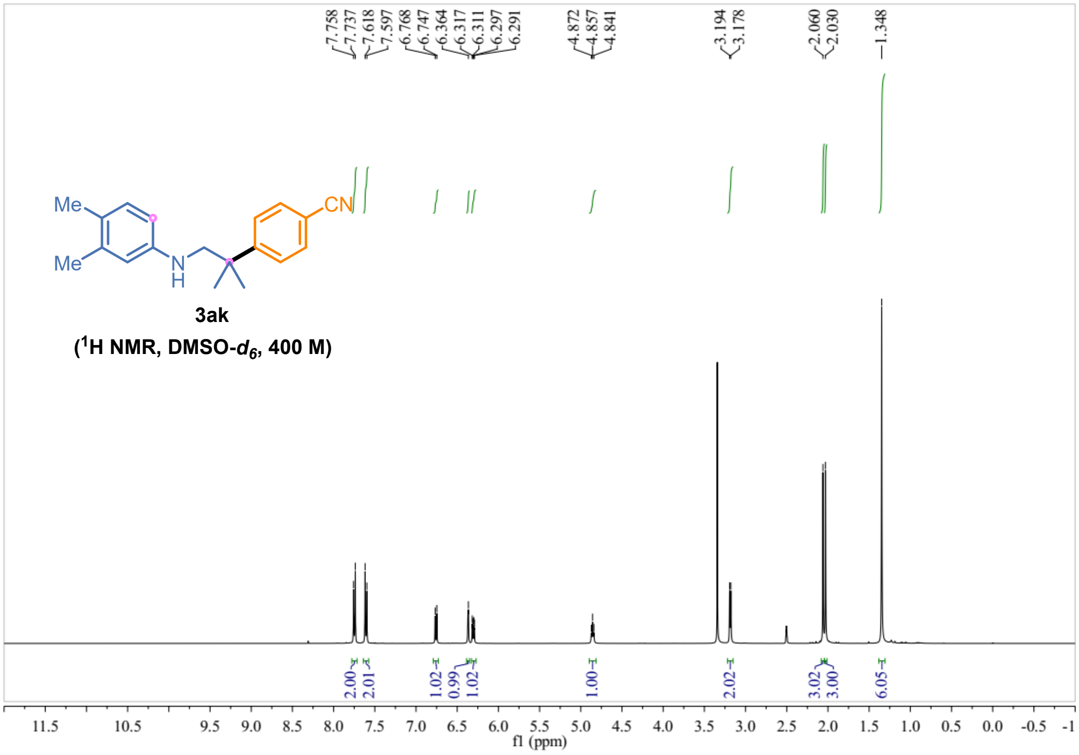
3aj

(^{1}H NMR, DMSO-d_6, 400 M)



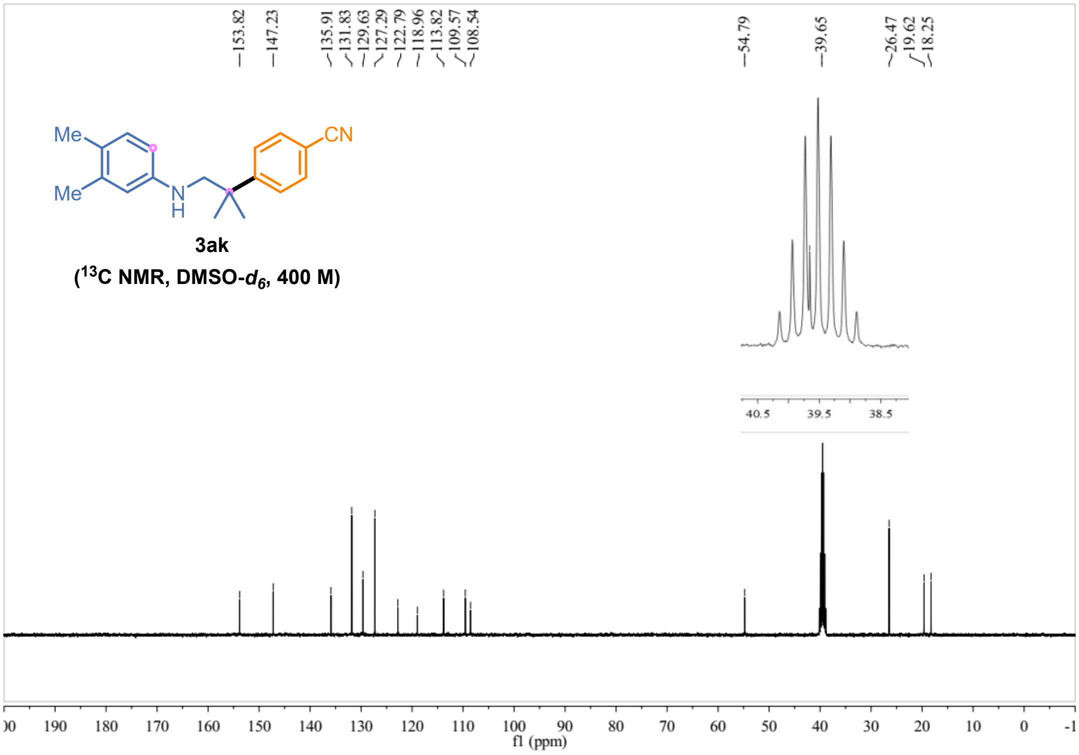
3aj

(^{13}C NMR, DMSO-d_6, 400 M)



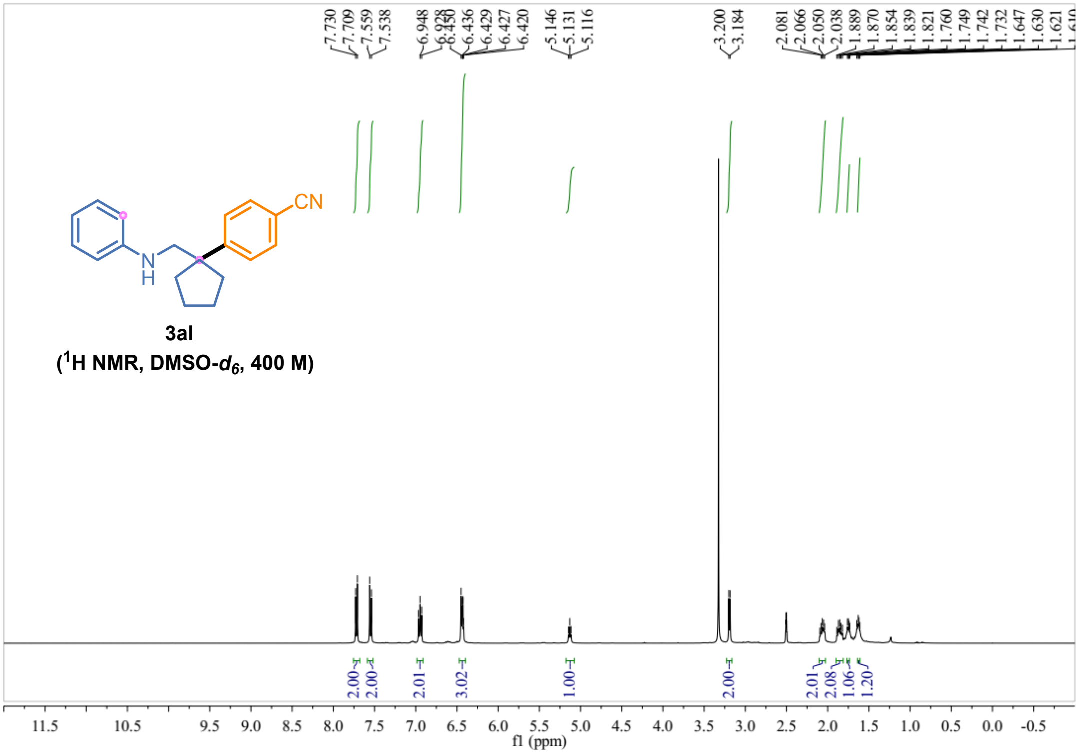
3ak

(^{1}H NMR, DMSO-*d*$_6$, 400 M)



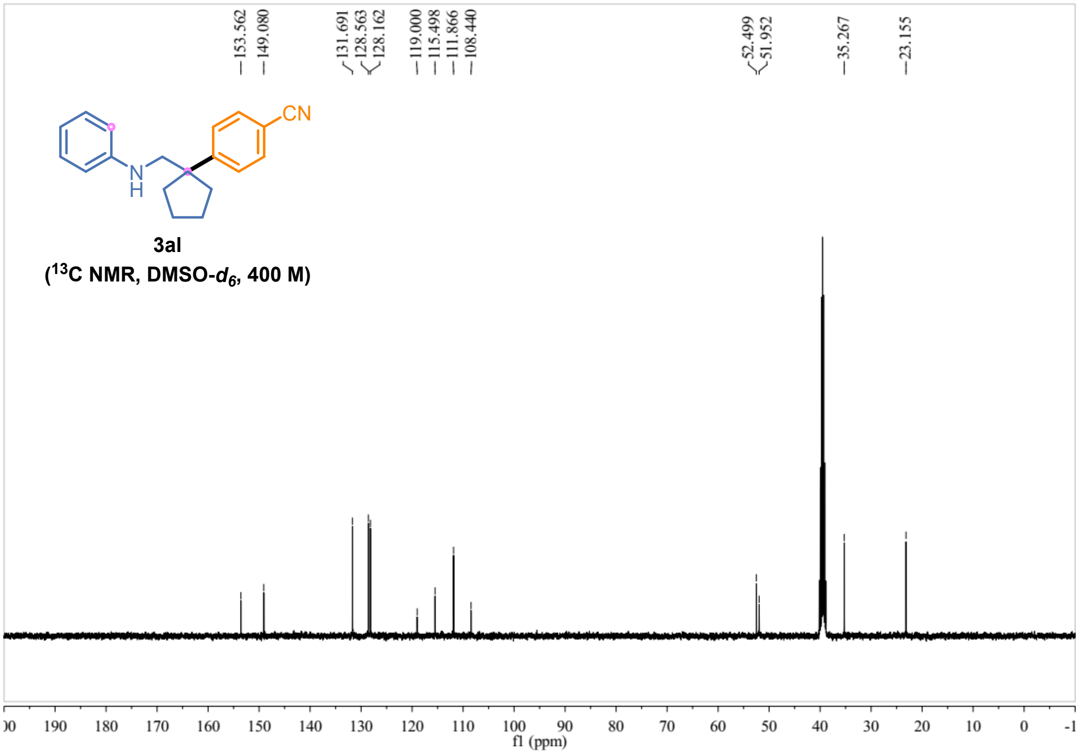
3ak

(^{13}C NMR, DMSO-*d*$_6$, 400 M)



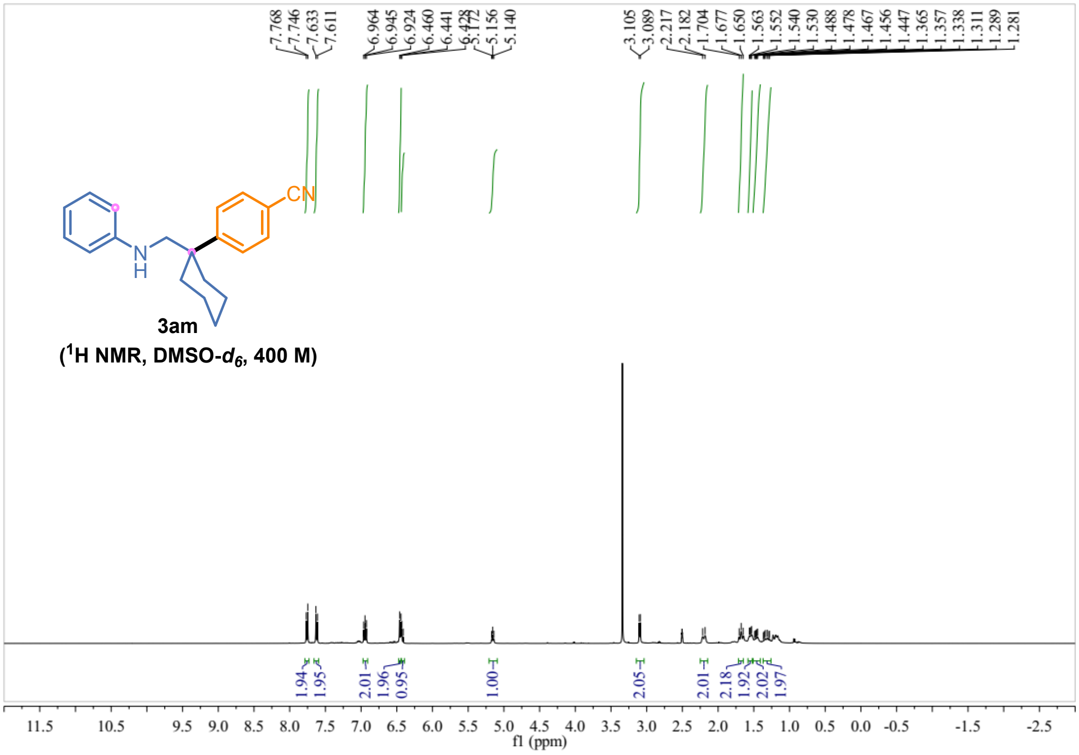
3al

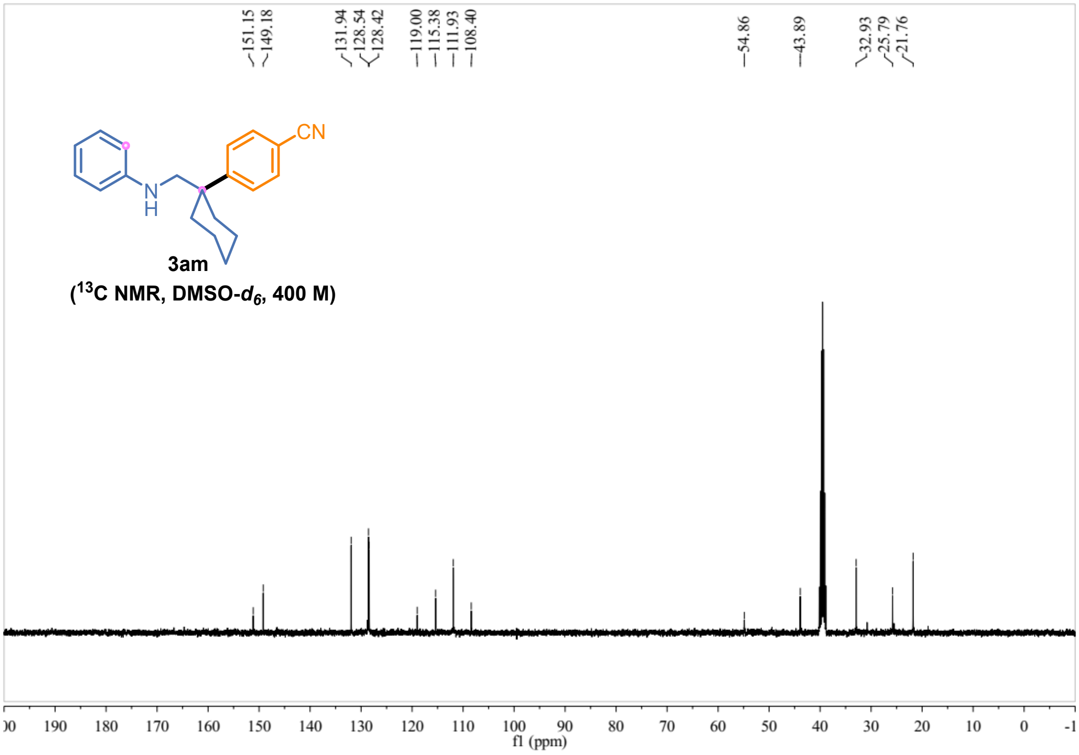
(^{1}H NMR, DMSO-*d*$_6$, 400 M)

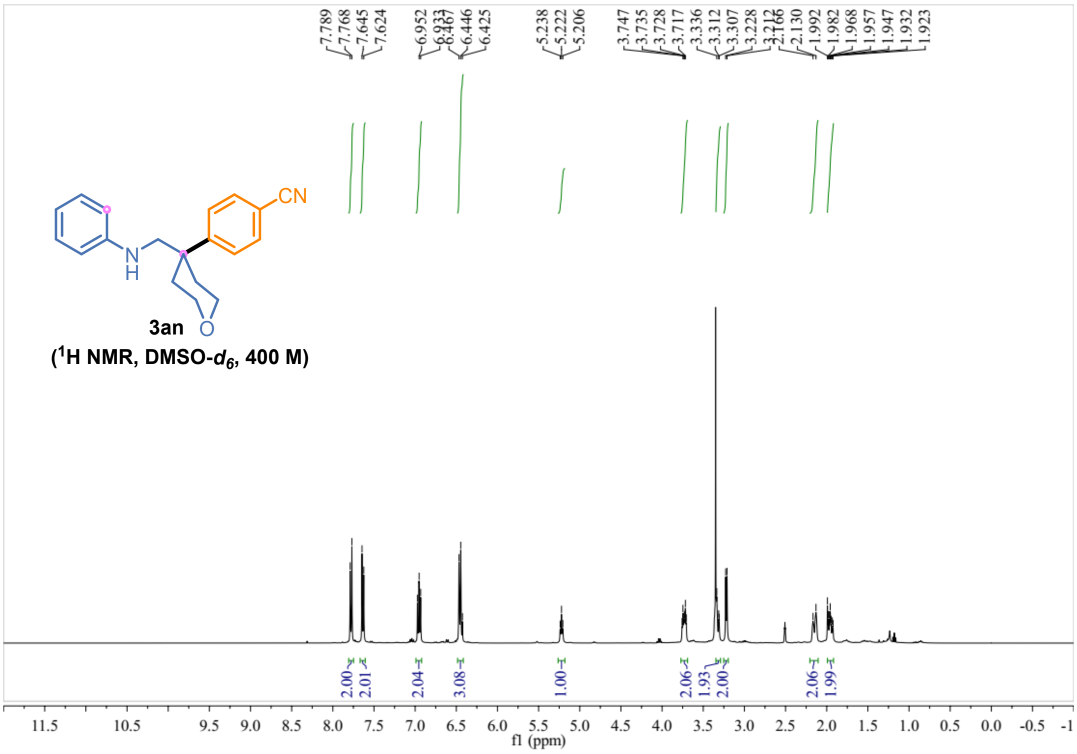


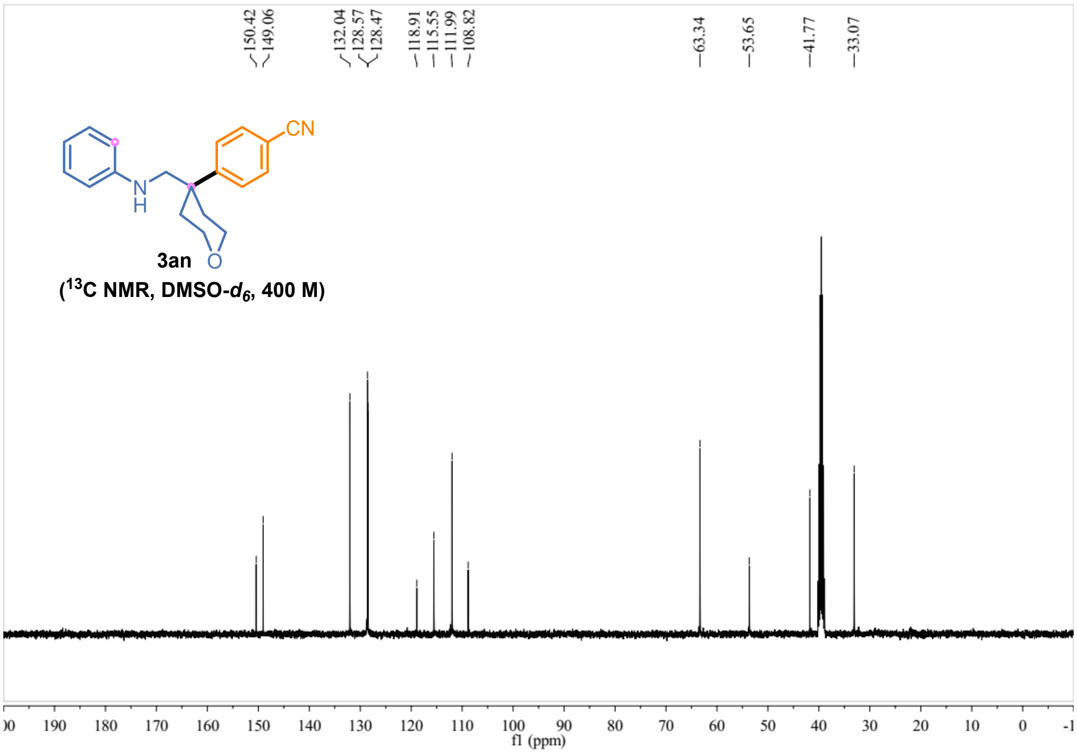
3al

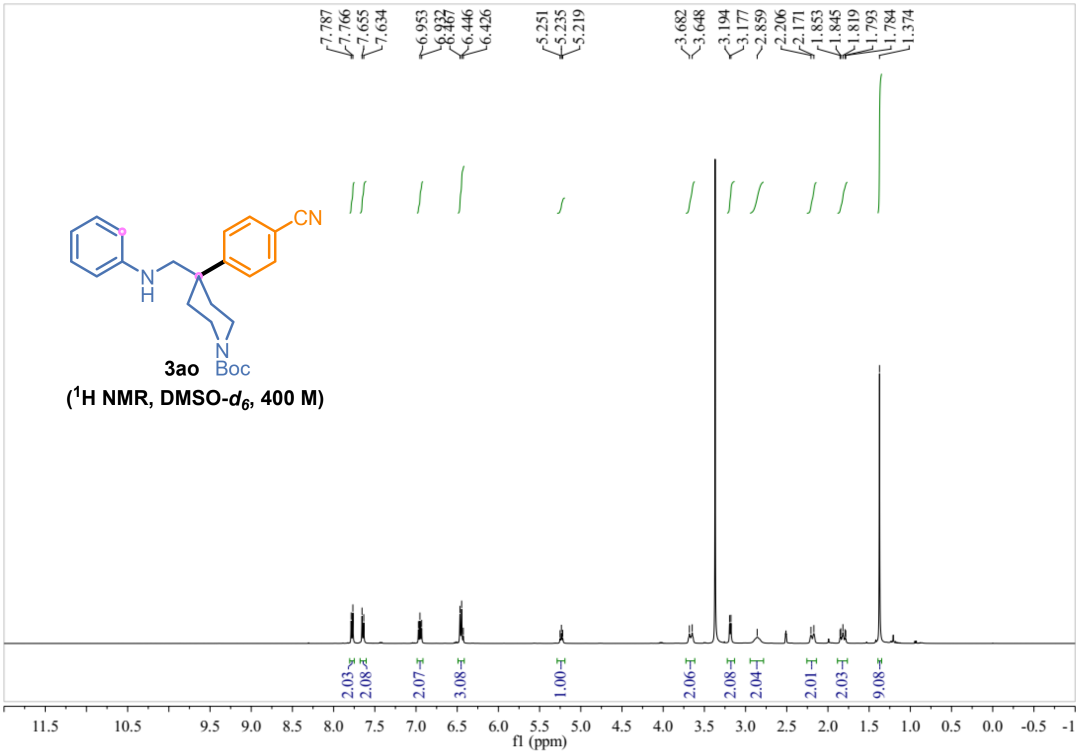
(^{13}C NMR, DMSO-*d*$_6$, 400 M)

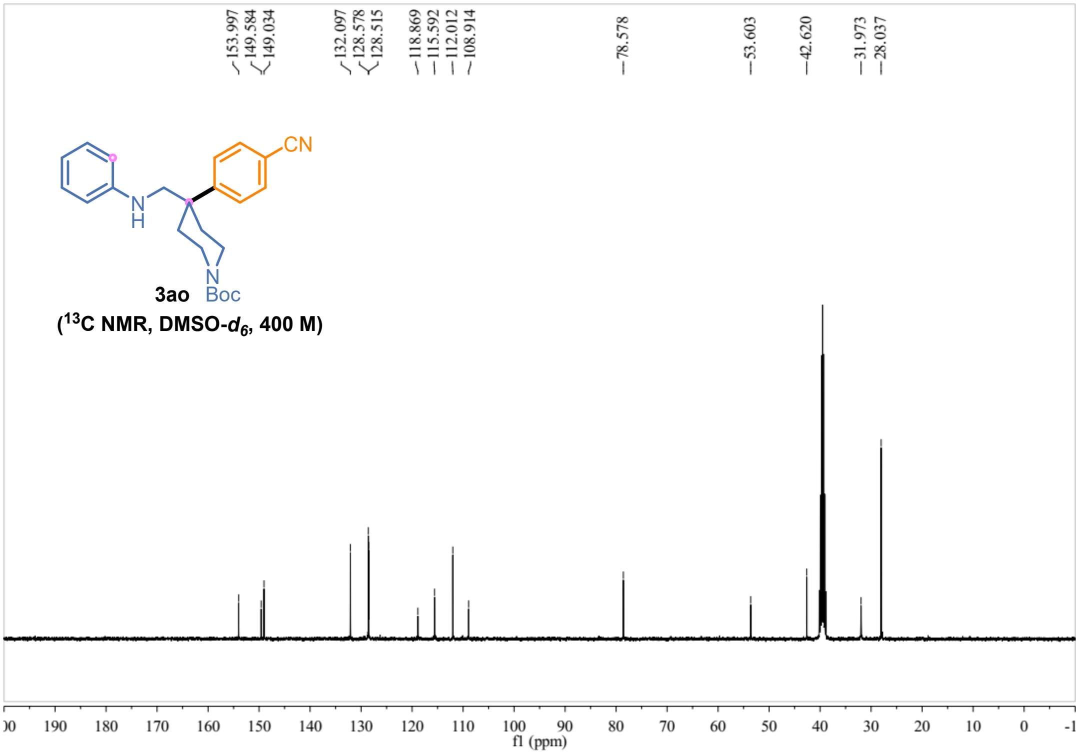

7.768
7.746
7.633
7.611
6.964
6.945
6.924
6.460
6.441
6.428
5.172
5.156
5.140
3.105
3.089
2.217
2.182
1.704
1.677
1.650
1.563
1.552
1.540
1.530
1.488
1.478
1.467
1.456
1.447
1.365
1.357
1.338
1.311
1.289
1.281
CN
N
H
3am
(^{1}H NMR, DMSO-d_6, 400 M)
1.94
1.95
2.01
1.96
0.95
1.00
2.05
2.01
2.18
1.92
2.02
1.97
11.5
10.5
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
-1.5
-2.5
f1 (ppm)

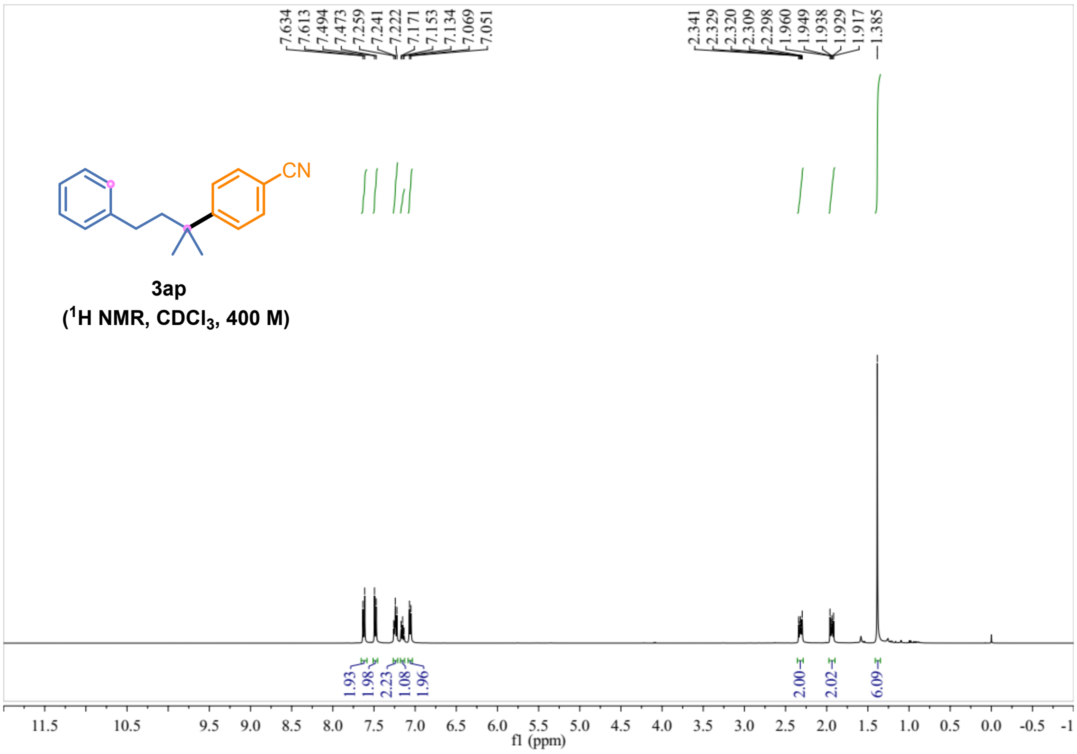

151.15
149.18
131.94
128.54
128.42
119.00
115.38
111.93
108.40
54.86
43.89
32.93
25.79
21.76
CN
N
H
3am
(^{13}C NMR, DMSO-d_6, 400 M)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

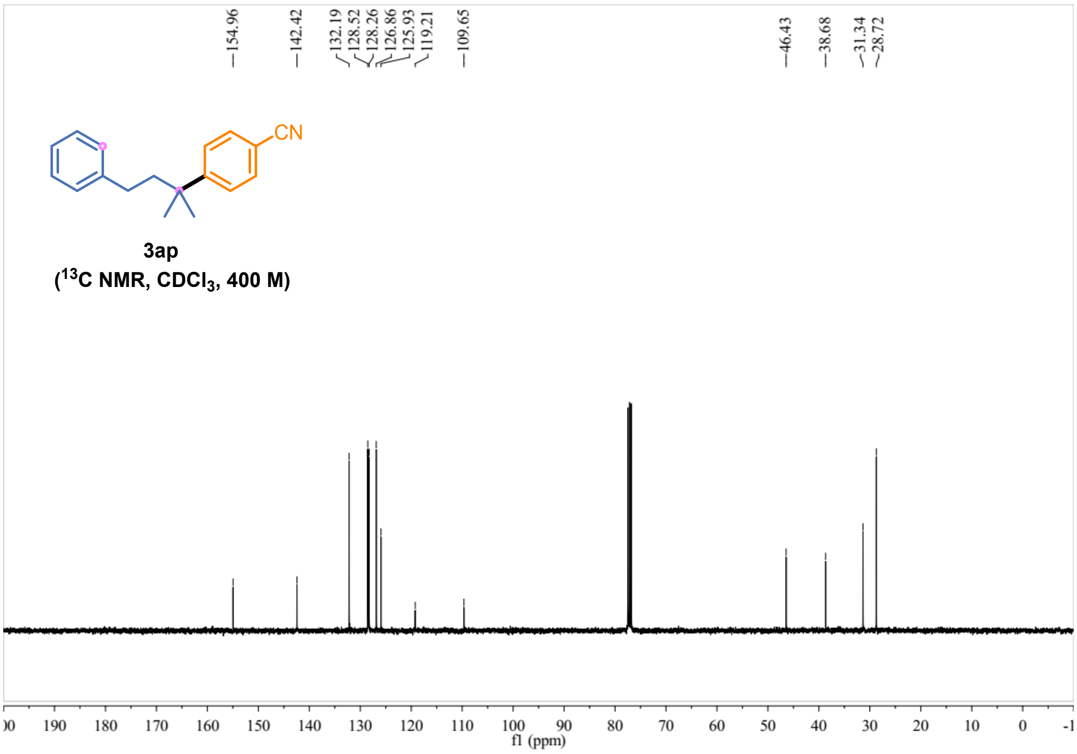

7.789
7.768
7.645
7.624
6.952
6.933
6.467
6.446
6.425
5.238
5.222
5.206
3.747
3.735
3.728
3.717
3.336
3.312
3.307
3.228
3.212
2.166
2.130
1.992
1.982
1.968
1.957
1.947
1.932
1.923
CN
N
H
O
3an
(^{1}H NMR, DMSO-d_6, 400 M)
2.00
2.01
2.04
3.08
1.00
2.06
1.93
2.00
2.06
1.99
11.5
10.5
9.5
9.0
8.5
8.0
7.5
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
-1
f1 (ppm)

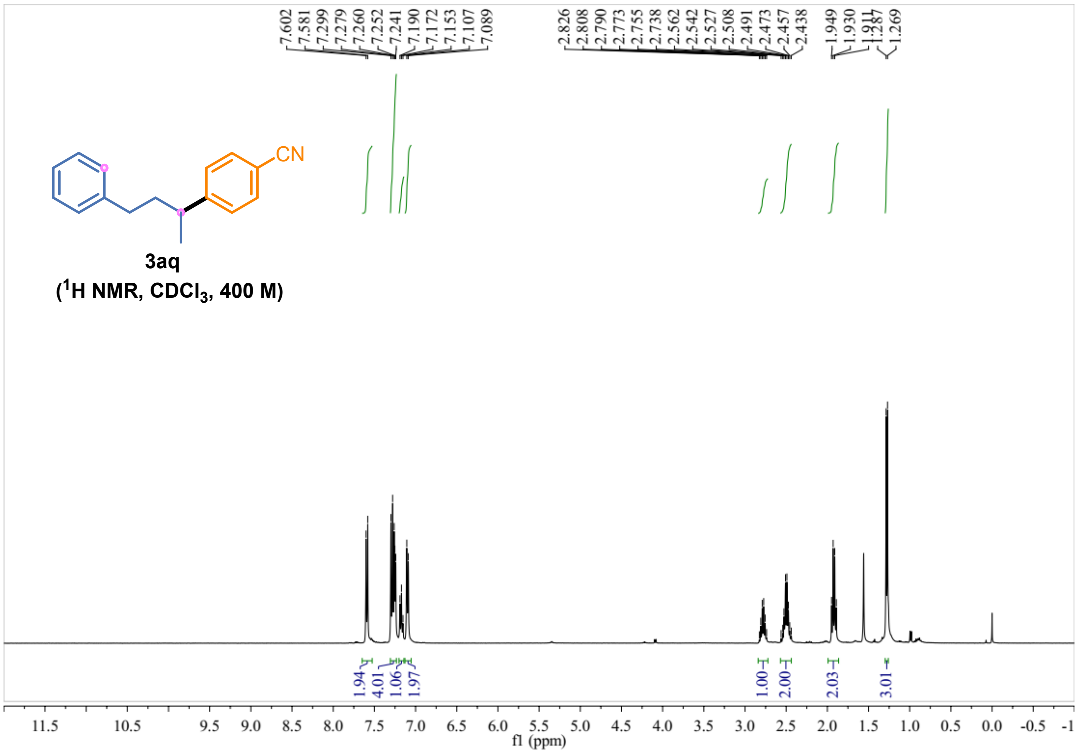

150.42
149.06
132.04
128.57
128.47
118.91
115.55
111.99
108.82
63.34
53.65
41.77
33.07
CN
N
H
O
3an
(^{13}C NMR, DMSO-d_6, 400 M)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

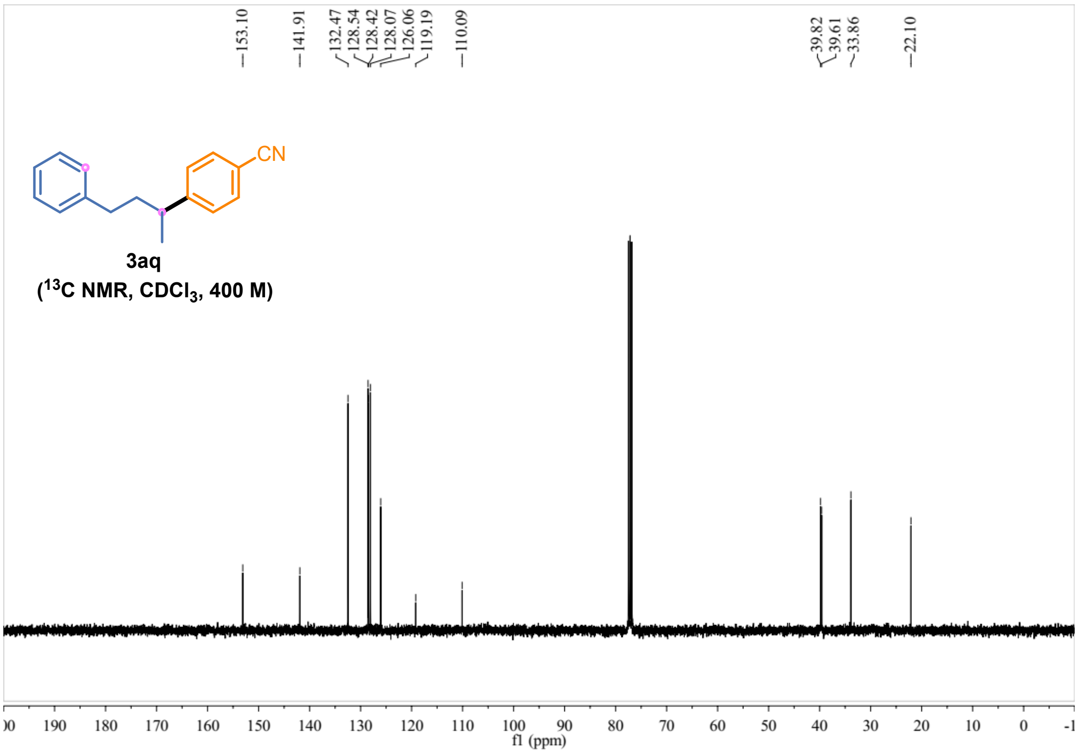

7.787
7.766
7.655
7.634
6.953
6.932
6.467
6.446
6.426
5.251
5.235
5.219
3.682
3.648
3.194
3.177
2.859
2.206
2.171
1.853
1.845
1.819
1.793
1.784
1.374
CN
N
H
N
Boc
3ao
(¹H NMR, DMSO-d6, 400 M)
2.03
2.08
2.07
3.08
1.00
2.06
2.08
2.04
2.01
2.03
9.08
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1
f1 (ppm)

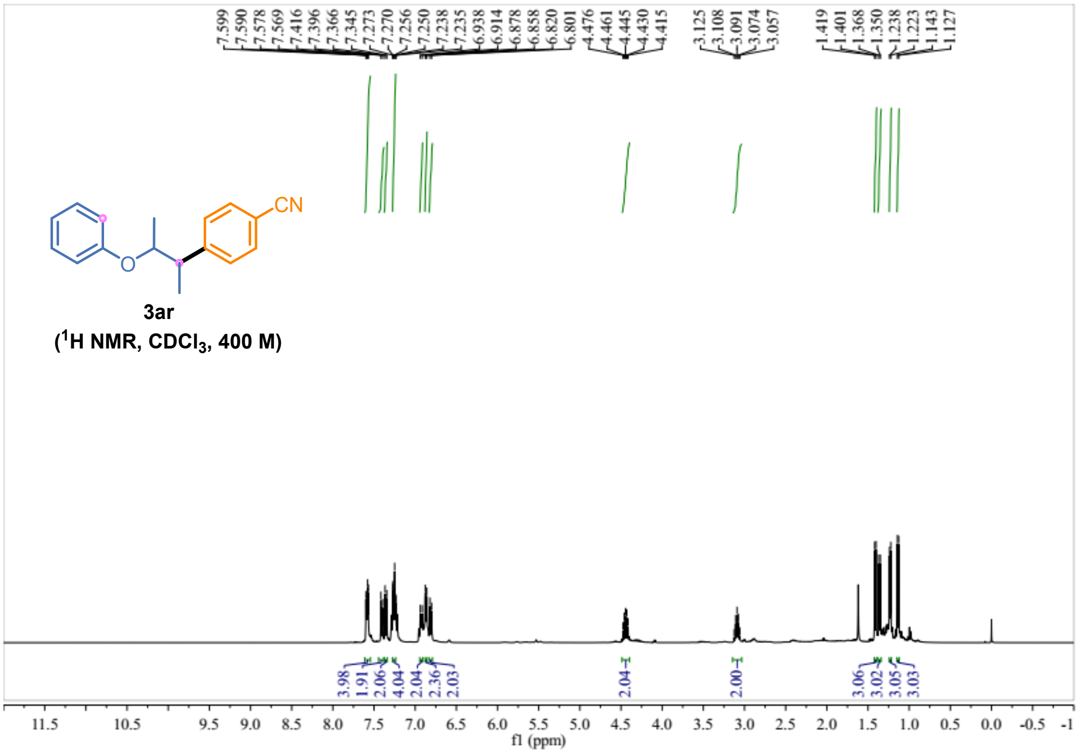

153.997
149.584
149.034
132.097
128.578
128.515
118.869
115.592
112.012
108.914
78.578
53.603
42.620
31.973
28.037
CN
N
H
N
Boc
3ao
(¹³C NMR, DMSO-d6, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)


7.634
7.613
7.494
7.473
7.259
7.241
7.222
7.171
7.153
7.134
7.069
7.051
2.341
2.329
2.320
2.309
2.298
1.960
1.949
1.938
1.929
1.917
1.385
CN
3ap
(^{1}H NMR, CDCl$_3$, 400 M)
1.93
1.98
2.23
1.08
1.96
2.00
2.02
6.09
11.5
10.5
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
-1
f1 (ppm)


154.96
142.42
132.19
128.52
128.26
126.86
125.93
119.21
109.65
46.43
38.68
31.34
28.72
CN
3ap
(^{13}C NMR, CDCl$_3$, 400 M)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

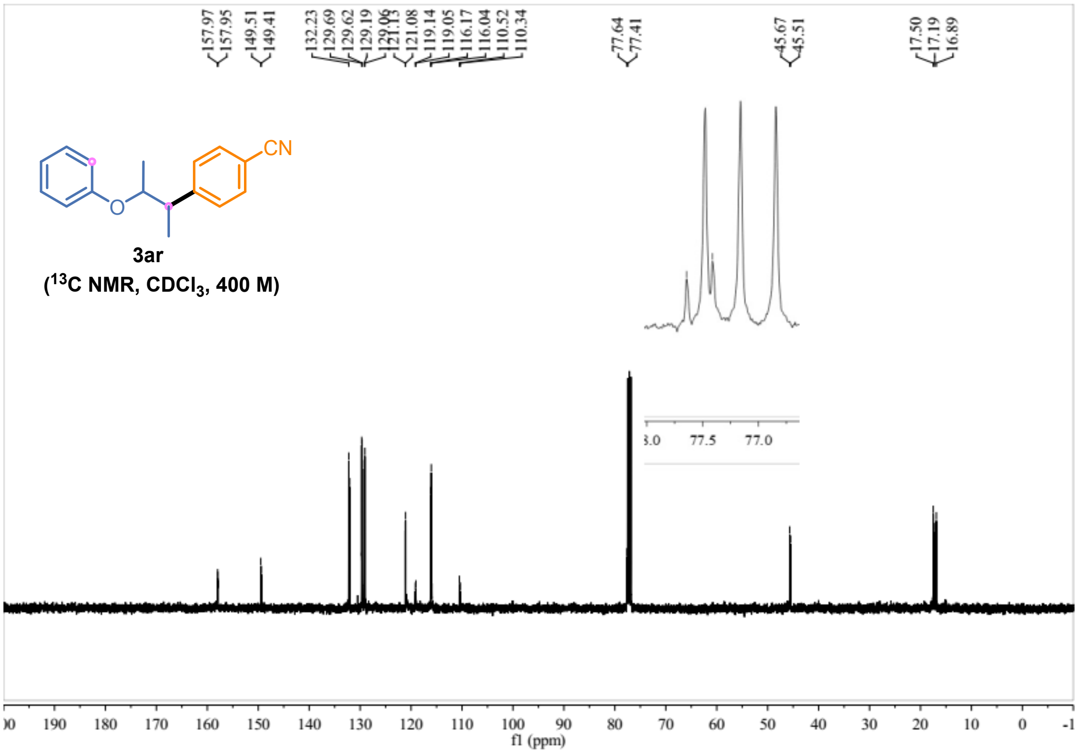

7.602
7.581
7.299
7.279
7.260
7.252
7.241
7.190
7.172
7.153
7.107
7.089
2.826
2.808
2.790
2.773
2.755
2.738
2.562
2.542
2.527
2.508
2.491
2.473
2.457
2.438
1.949
1.930
1.911
1.287
1.269
CN
3aq
(^{1}H NMR, CDCl$_3$, 400 M)
1.94
4.01
1.06
1.97
1.00
2.00
2.03
3.01
11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 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 -1
f1 (ppm)


153.10
141.91
132.47
128.54
128.42
128.07
126.06
119.19
110.09
39.82
39.61
33.86
22.10
CN
3aq
(^{13}C NMR, CDCl$_3$, 400 M)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)



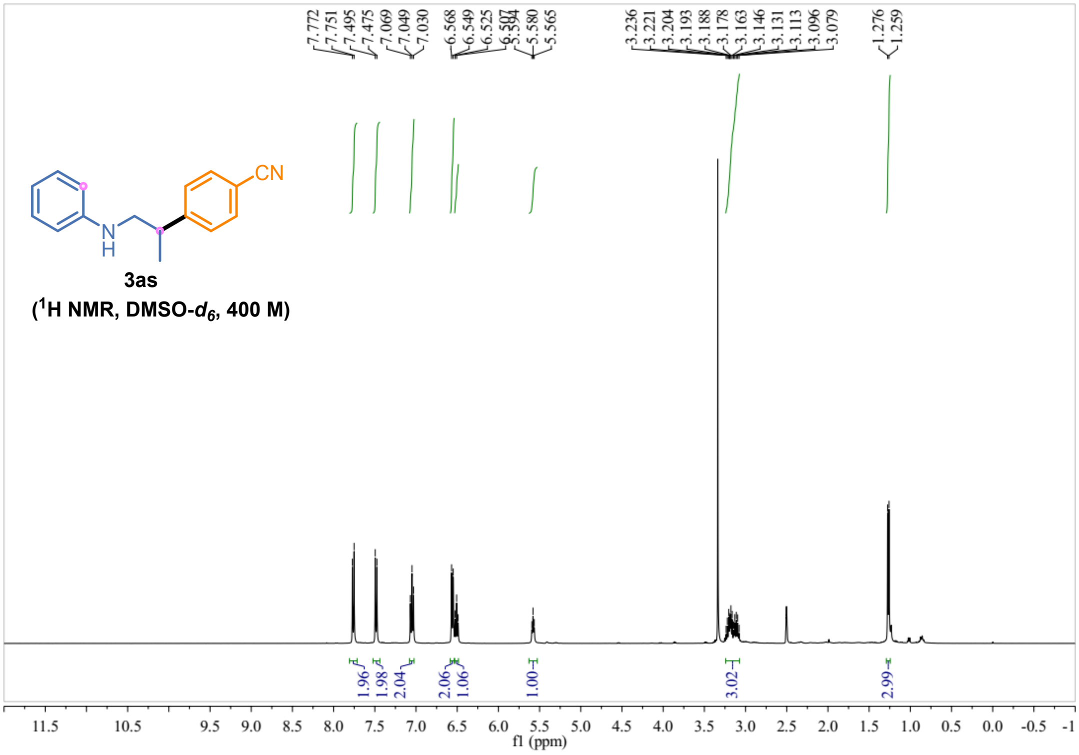
3ar

(^{1}H NMR, CDCl$_3$, 400 M)



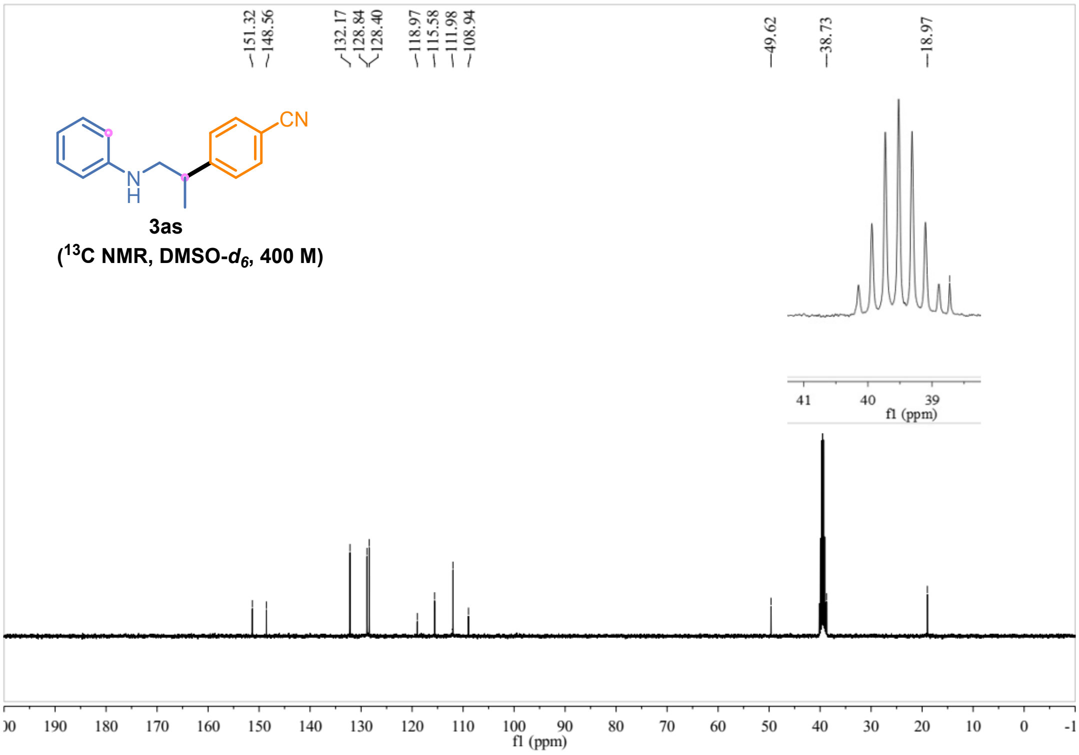
3ar

(^{13}C NMR, CDCl$_3$, 400 M)



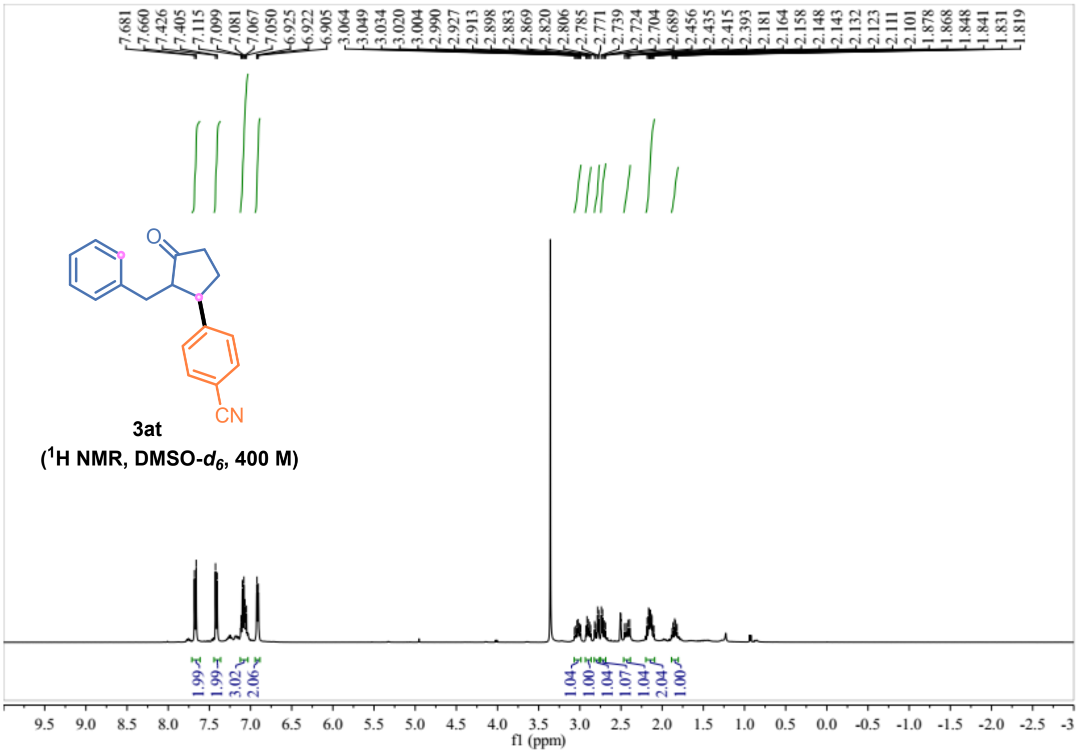
3as

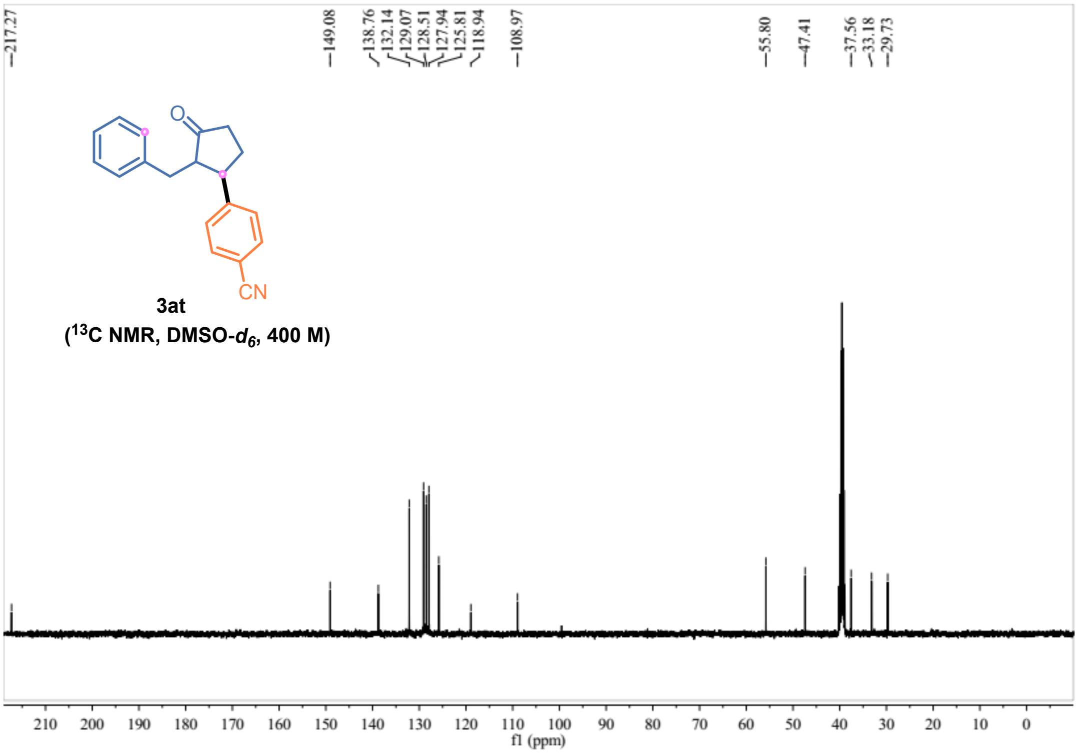
(^{1}H NMR, DMSO-d_6, 400 M)

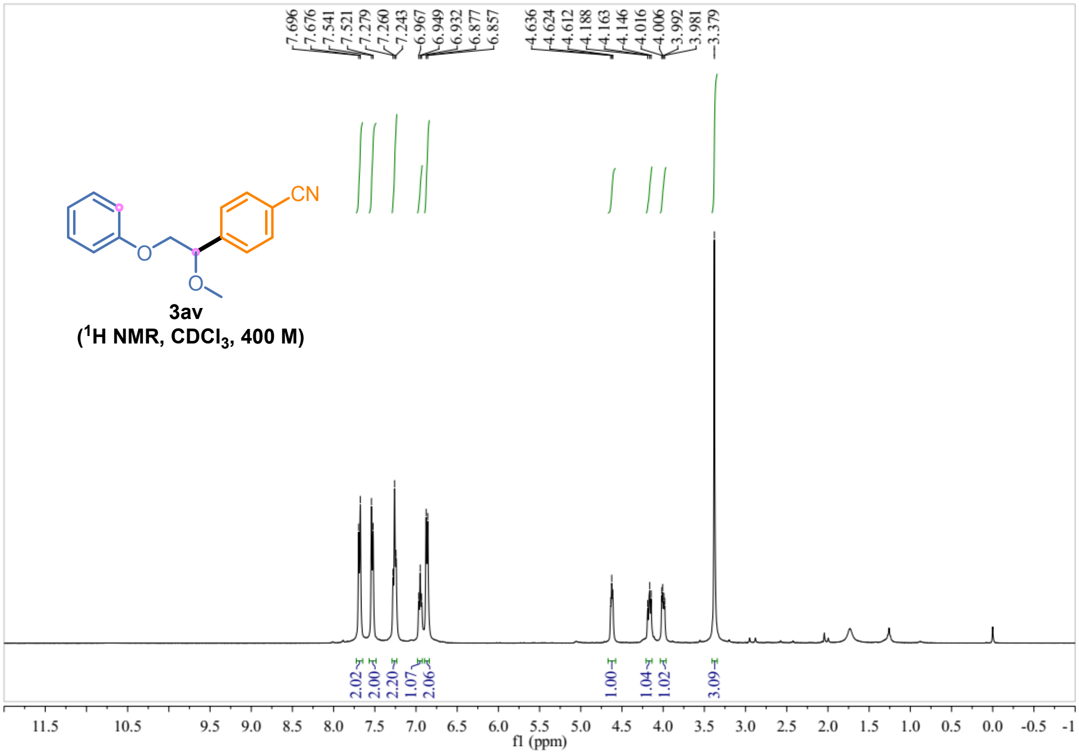


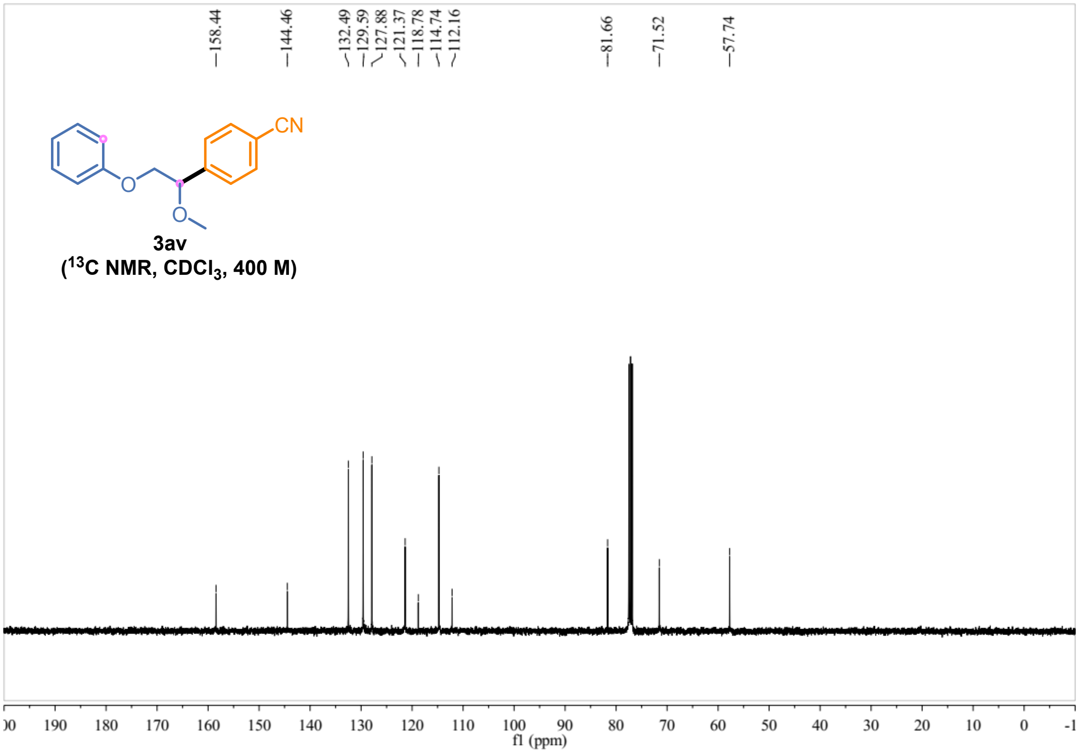
3as

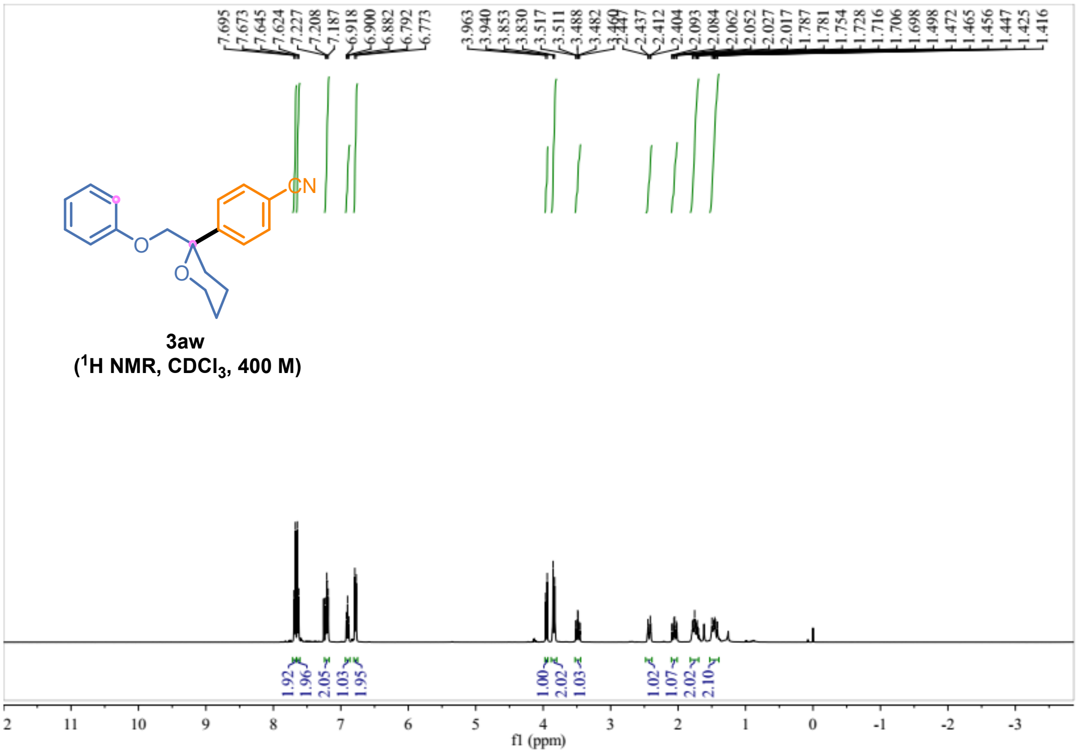
(^{13}C NMR, DMSO-d_6, 400 M)

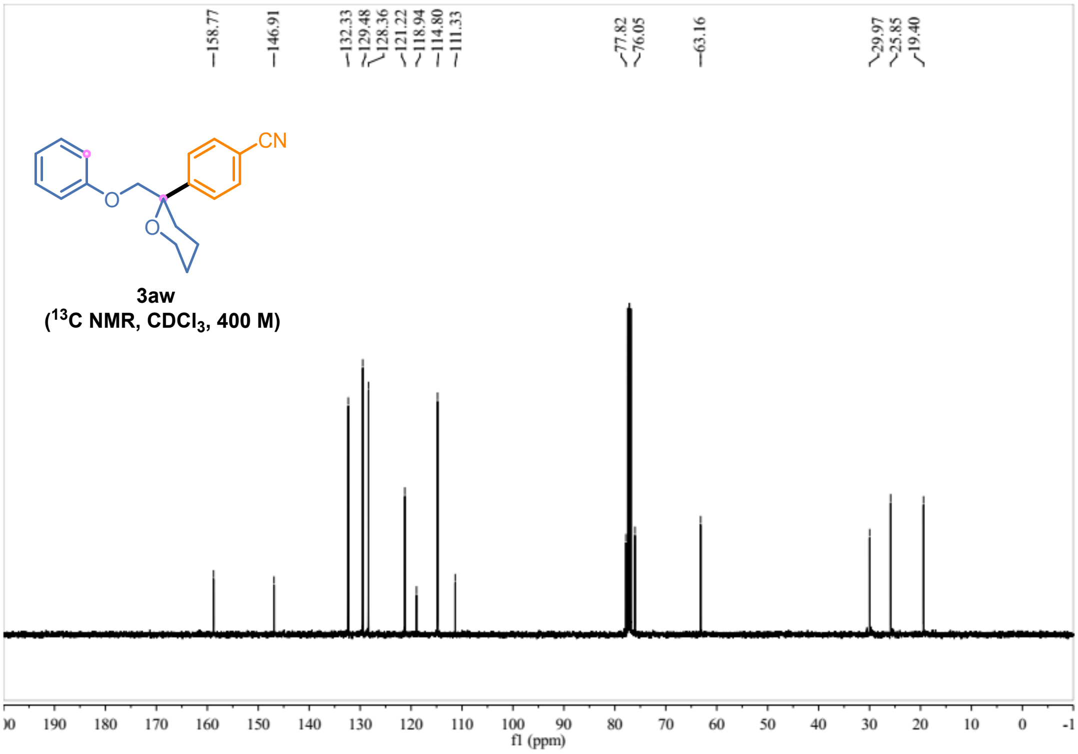

7.681
7.660
7.426
7.405
7.115
7.099
7.081
7.067
7.050
6.925
6.922
6.905
3.064
3.049
3.034
3.020
3.004
2.990
2.927
2.913
2.898
2.883
2.869
2.820
2.806
2.785
2.771
2.739
2.724
2.704
2.689
2.456
2.435
2.415
2.393
2.181
2.164
2.158
2.148
2.143
2.132
2.123
2.111
2.101
1.878
1.868
1.848
1.841
1.831
1.819
O
CN
3at
(^{1}H NMR, DMSO-d_6, 400 M)
1.99
1.99
3.02
2.06
1.04
1.00
1.04
1.07
1.04
2.04
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
-1.0
-1.5
-2.0
-2.5
-3
f1 (ppm)

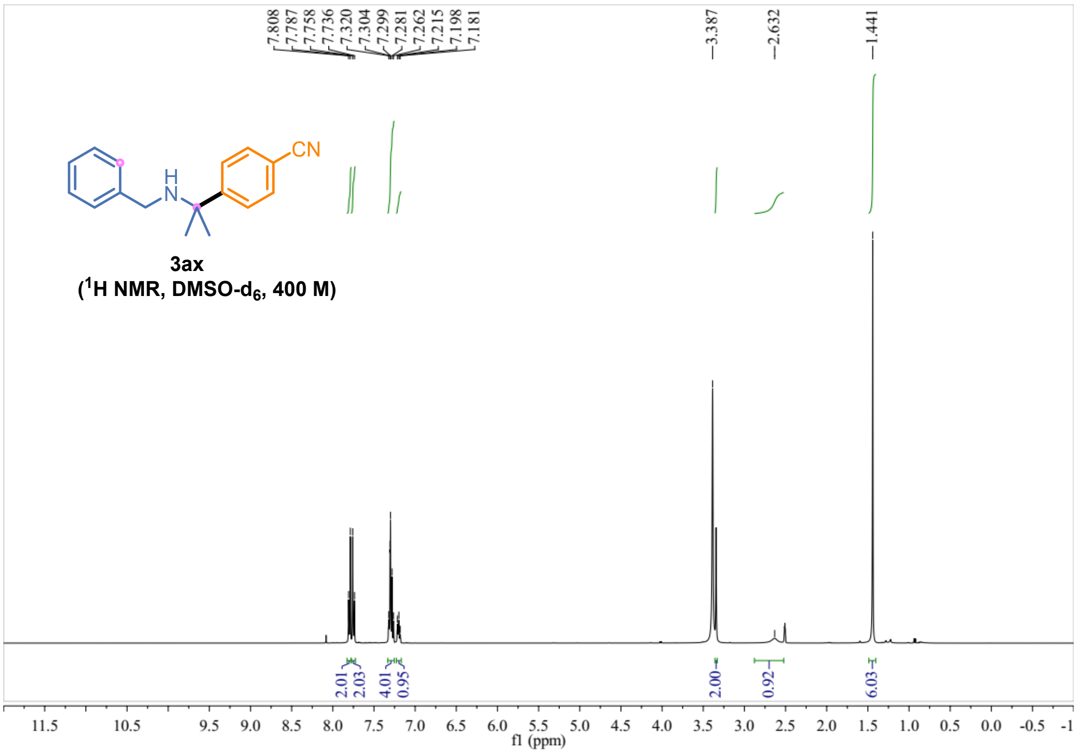

217.27
149.08
138.76
132.14
129.07
128.51
127.94
125.81
118.94
108.97
55.80
47.41
37.56
33.18
29.73
O
CN
3at
(^{13}C NMR, DMSO-d_6, 400 M)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.696
7.676
7.541
7.521
7.279
7.260
7.243
6.967
6.949
6.932
6.877
6.857
4.636
4.624
4.612
4.188
4.163
4.146
4.016
4.006
3.992
3.981
3.379
CN
O
O
3av
(^{1}H NMR, CDCl$_3$, 400 M)
2.02
2.00
2.20
1.07
2.06
1.00
1.04
1.02
3.09
11.5
10.5
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
-1
f1 (ppm)


158.44
144.46
132.49
129.59
127.88
121.37
118.78
114.74
112.16
81.66
71.52
57.74
CN
O
O
3av
(^{13}C NMR, CDCl$_3$, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

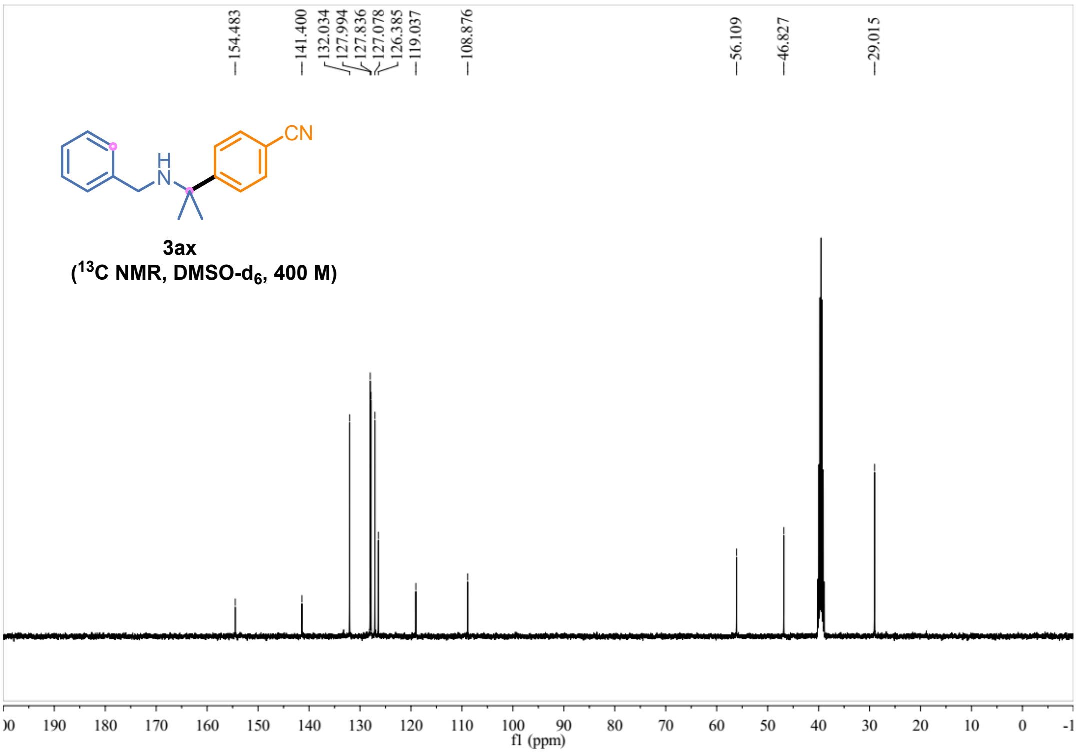

7.695
7.673
7.645
7.624
7.227
7.208
7.187
6.918
6.900
6.882
6.792
6.773
3.963
3.940
3.853
3.830
3.517
3.511
3.488
3.482
3.460
2.447
2.437
2.412
2.404
2.093
2.084
2.062
2.052
2.027
2.017
1.787
1.781
1.754
1.728
1.716
1.706
1.698
1.498
1.472
1.465
1.456
1.447
1.425
1.416
CN
O
O
3aw
(^{1}H NMR, CDCl$_3$, 400 M)
1.92
1.96
2.05
1.03
1.95
1.00
2.02
1.03
1.02
1.07
2.02
2.10
2
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
f1 (ppm)


158.77
146.91
132.33
129.48
128.36
121.22
118.94
114.80
111.33
77.82
76.05
63.16
29.97
25.85
19.40
CN
O
O
3aw
(^{13}C NMR, CDCl$_3$, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)



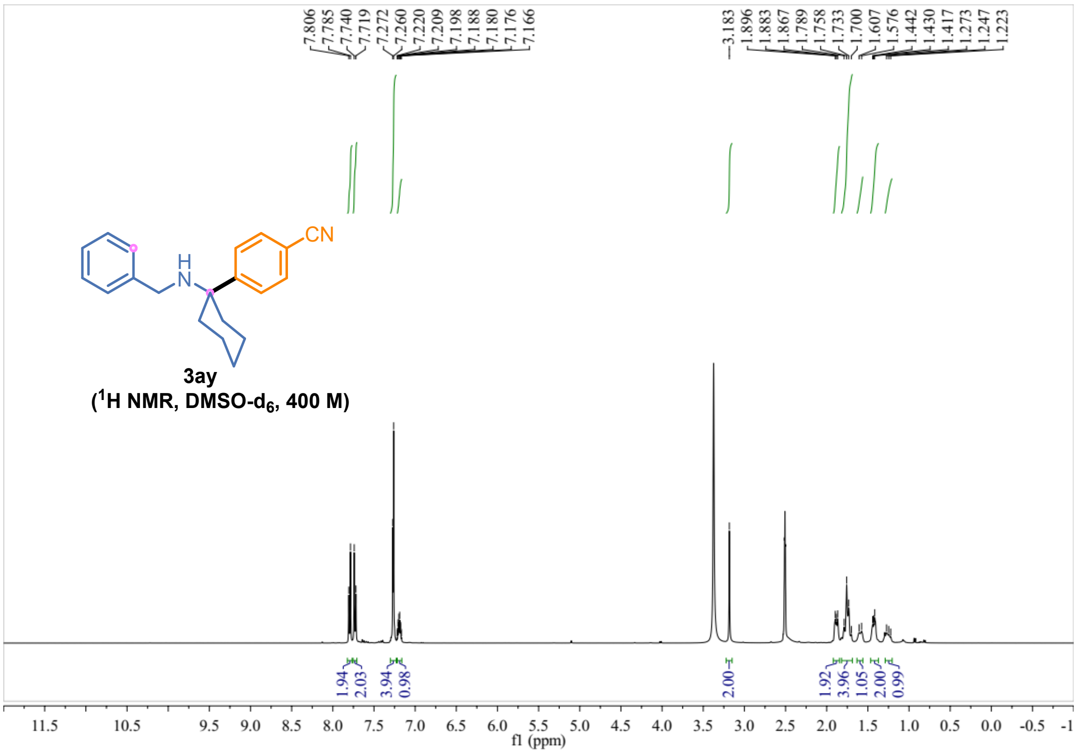
3ax

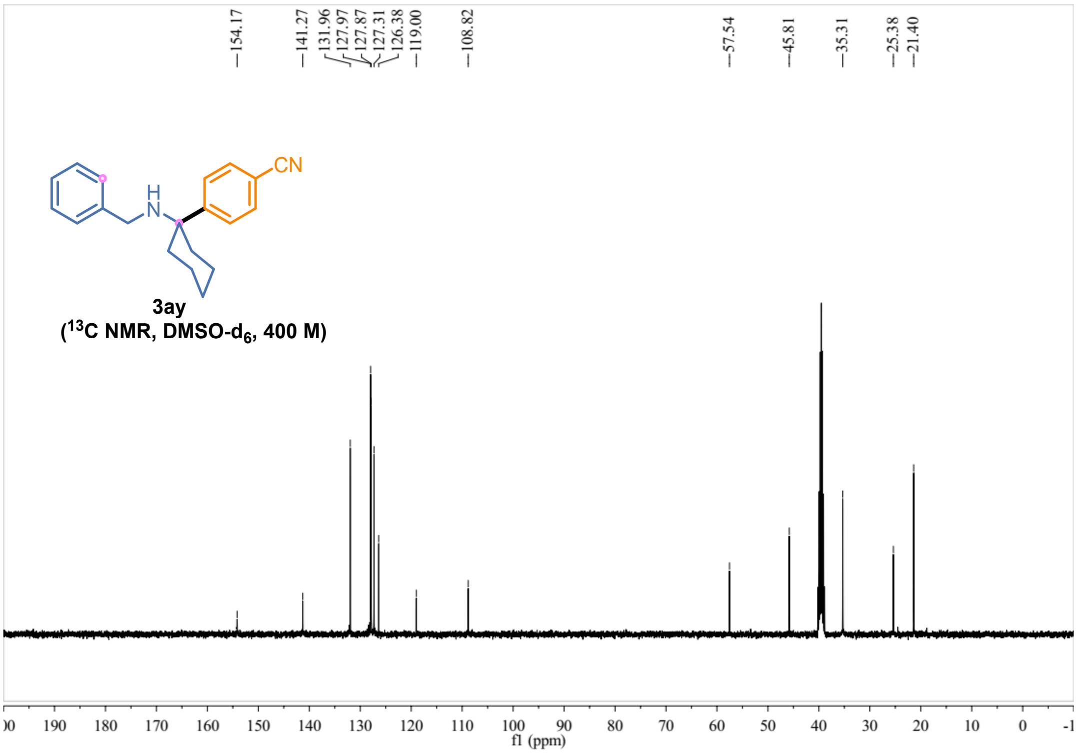
(^{1}H NMR, DMSO-d_6, 400 M)

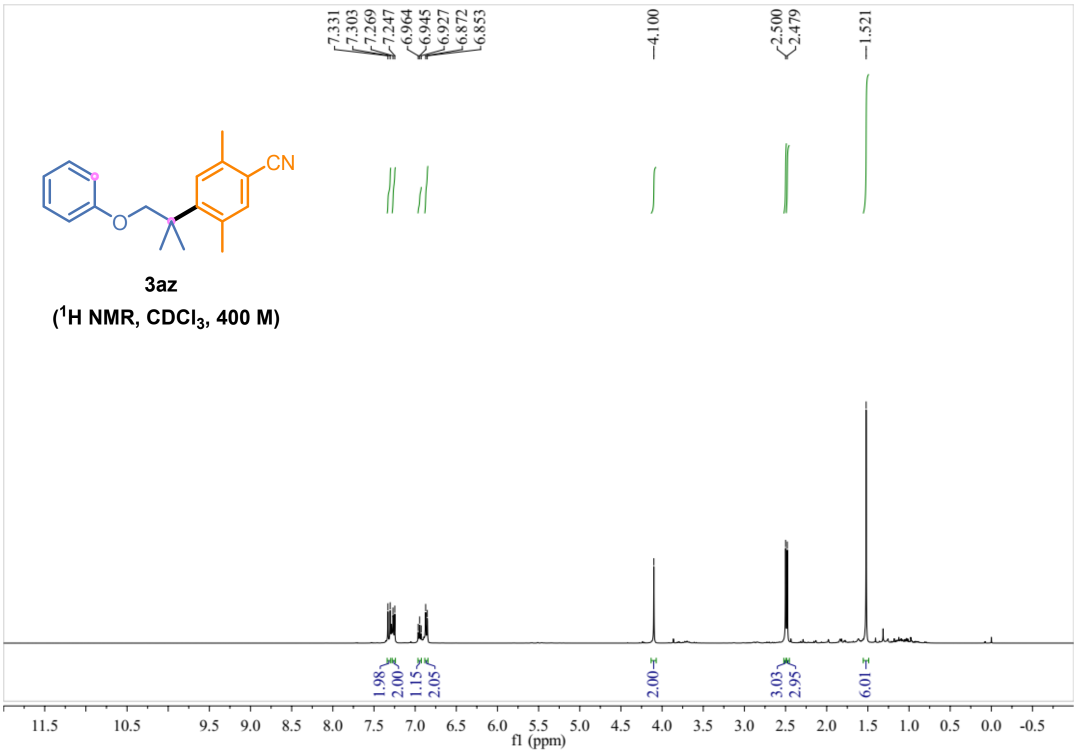


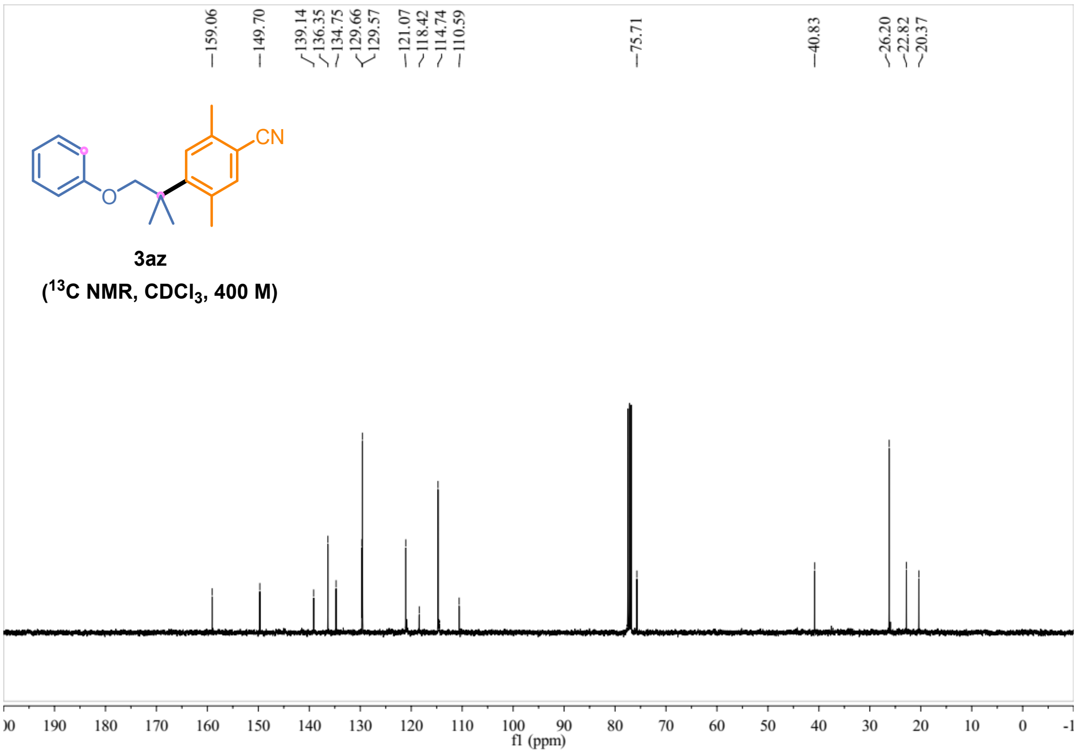
3ax

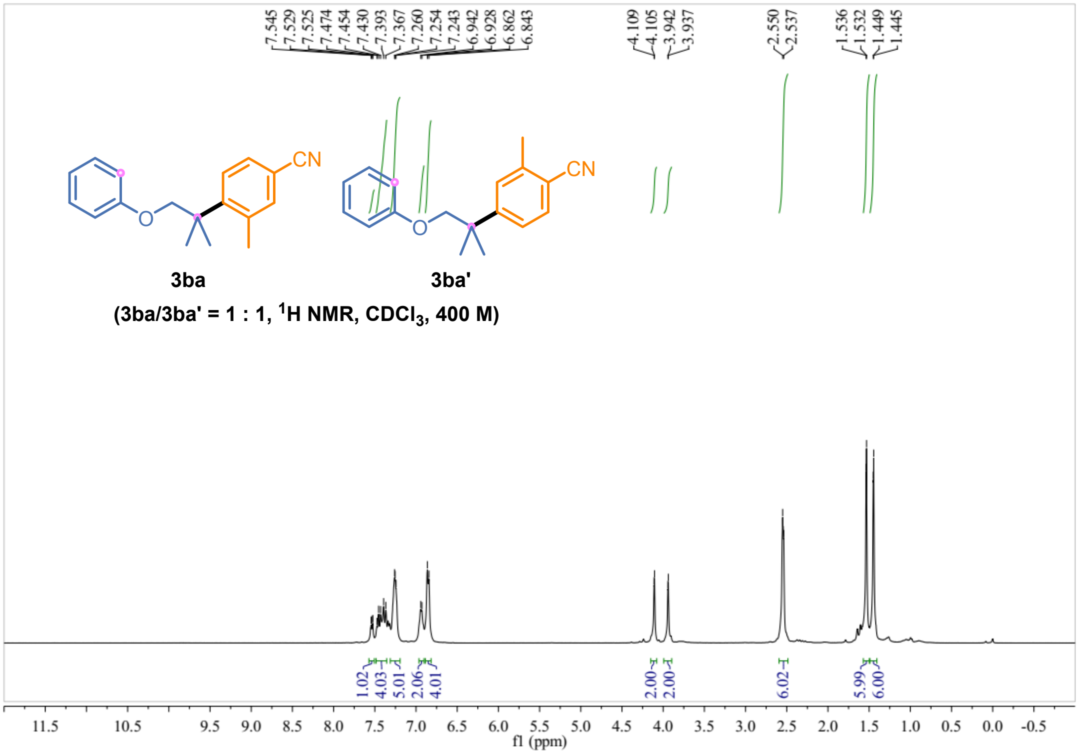
(^{13}C NMR, DMSO-d_6, 400 M)


7.806
7.785
7.740
7.719
7.272
7.260
7.220
7.209
7.198
7.188
7.180
7.176
7.166
3.183
1.896
1.883
1.867
1.789
1.758
1.733
1.700
1.607
1.576
1.442
1.430
1.417
1.273
1.247
1.223
CN
H
N
3ay
(^{1}H NMR, DMSO-d_6, 400 M)
1.94
2.03
3.94
0.98
2.00
1.92
3.96
1.05
2.00
0.99
11.5
10.5
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
-1
f1 (ppm)


154.17
141.27
131.96
127.97
127.87
127.31
126.38
119.00
108.82
57.54
45.81
35.31
25.38
21.40
CN
H
N
3ay
(^{13}C NMR, DMSO-d_6, 400 M)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

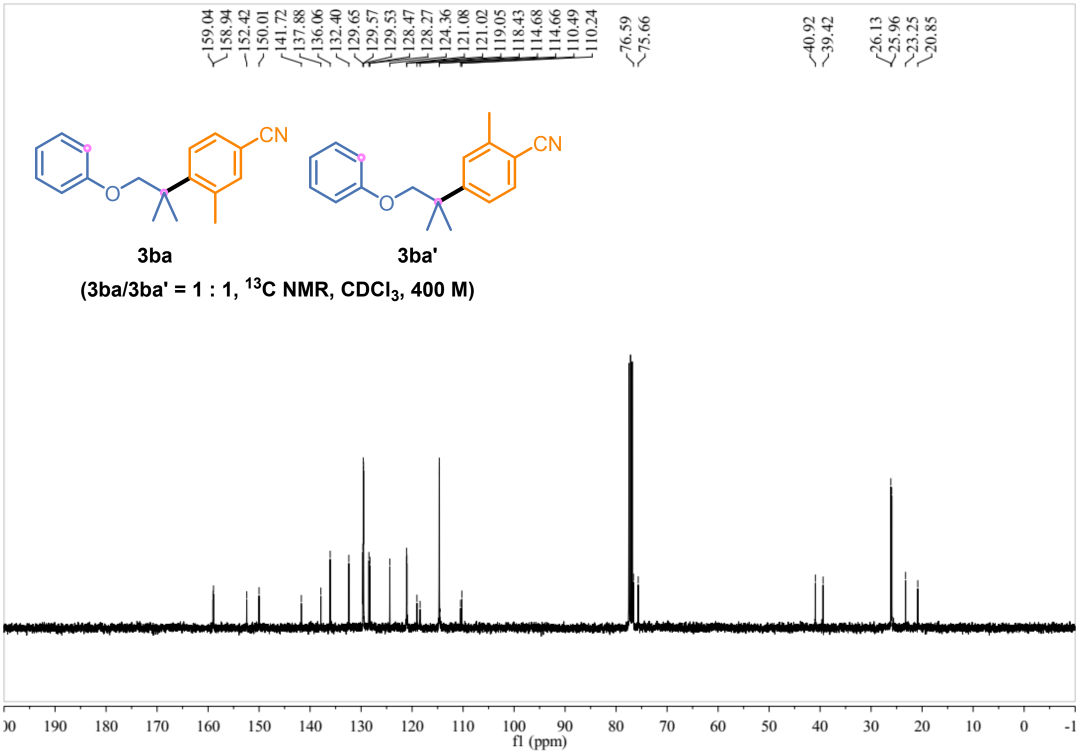

7.331
7.303
7.269
7.247
6.964
6.945
6.927
6.872
6.853
4.100
2.500
2.479
1.521
CN
O
3az
(¹H NMR, CDCl₃, 400 M)
1.98
2.00
1.15
2.05
2.00
3.03
2.95
6.01
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


159.06
149.70
139.14
136.35
134.75
129.66
129.57
121.07
118.42
114.74
110.59
75.71
40.83
26.20
22.82
20.37
CN
O
3az
(¹³C NMR, CDCl₃, 400 M)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)



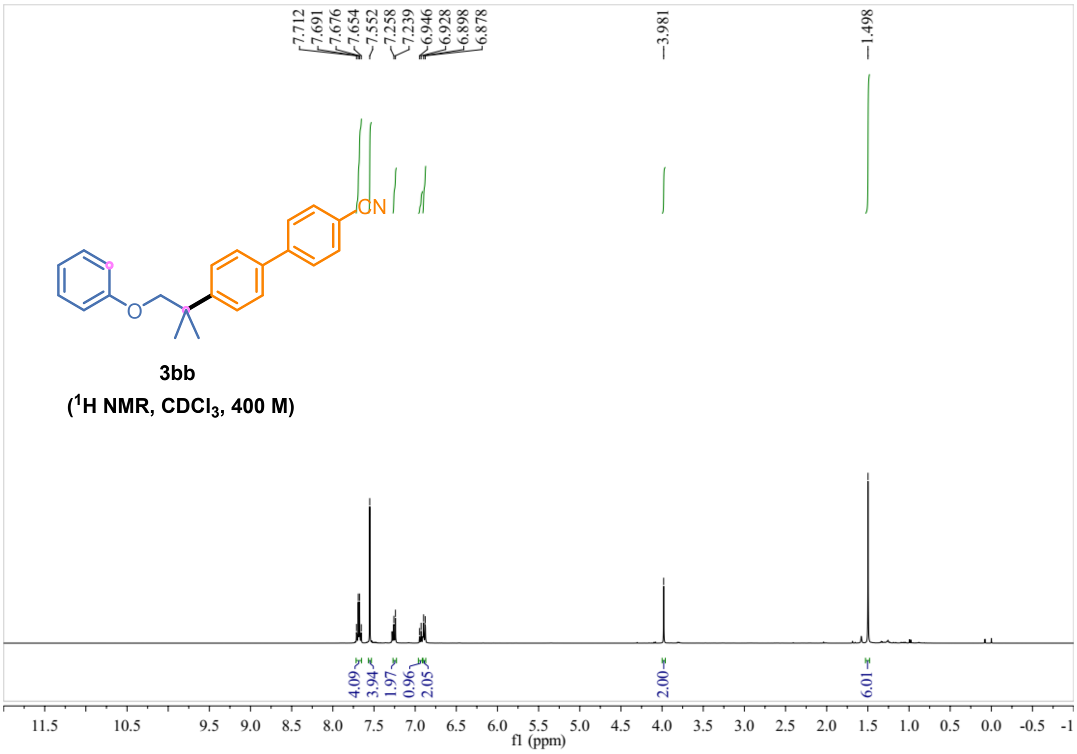
3ba **3ba'**

(3ba/3ba' = 1 : 1, ^{1}H NMR, CDCl$_3$, 400 M)

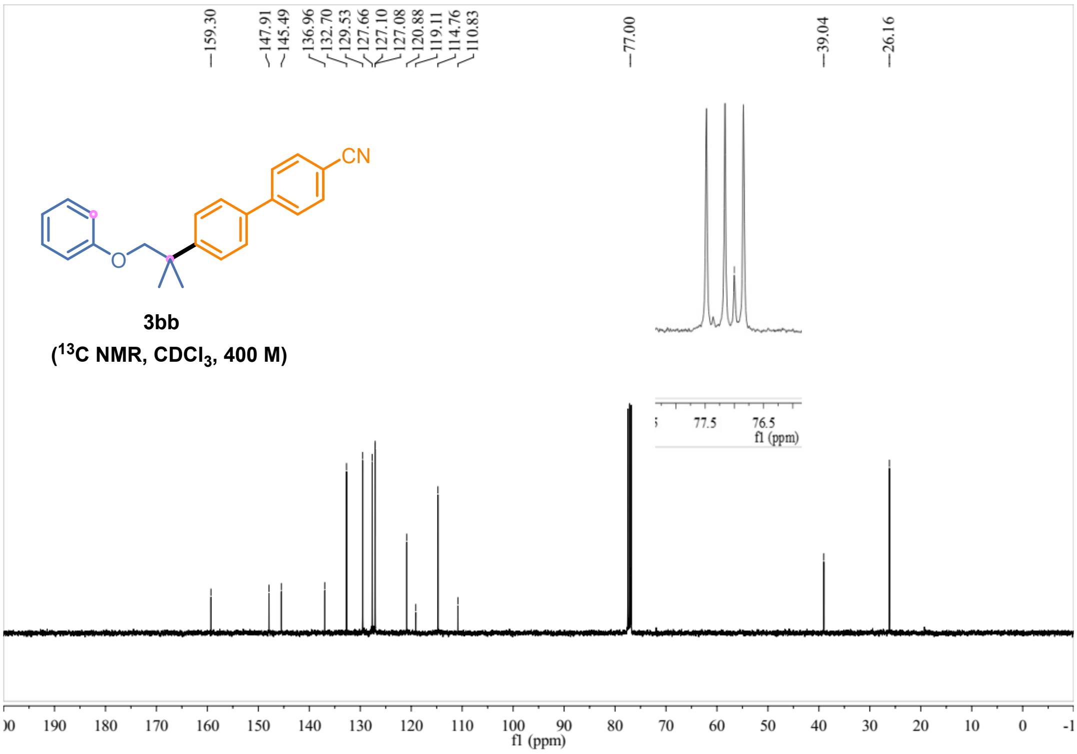


3ba **3ba'**

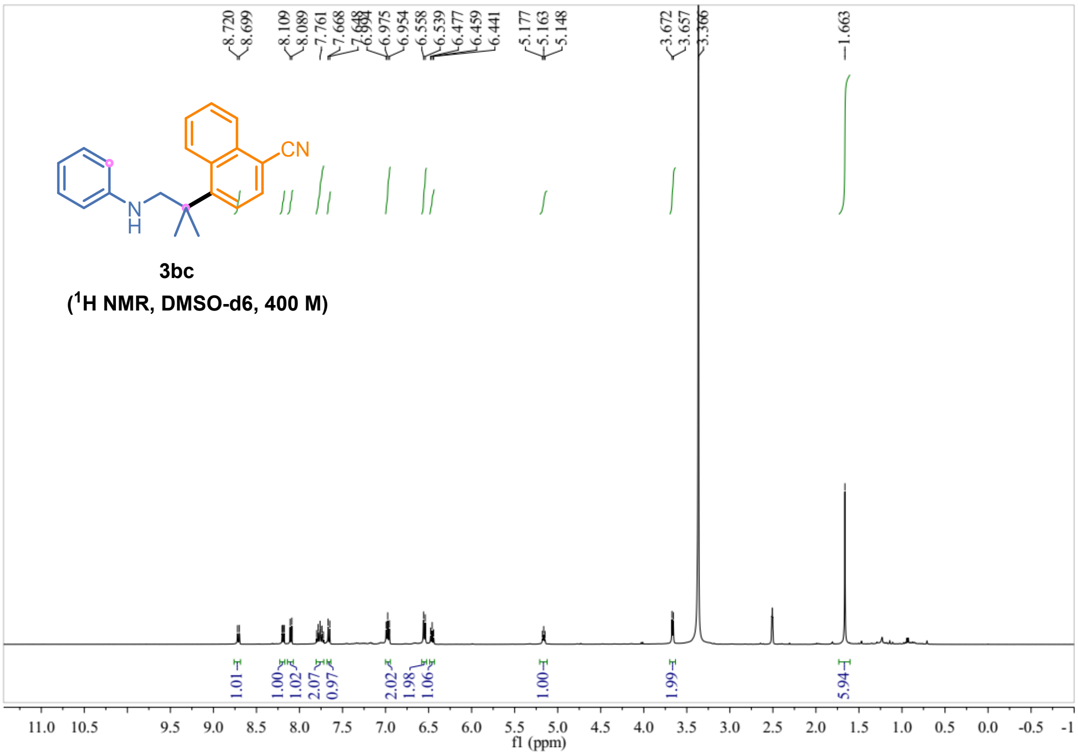
(3ba/3ba' = 1 : 1, ^{13}C NMR, CDCl$_3$, 400 M)

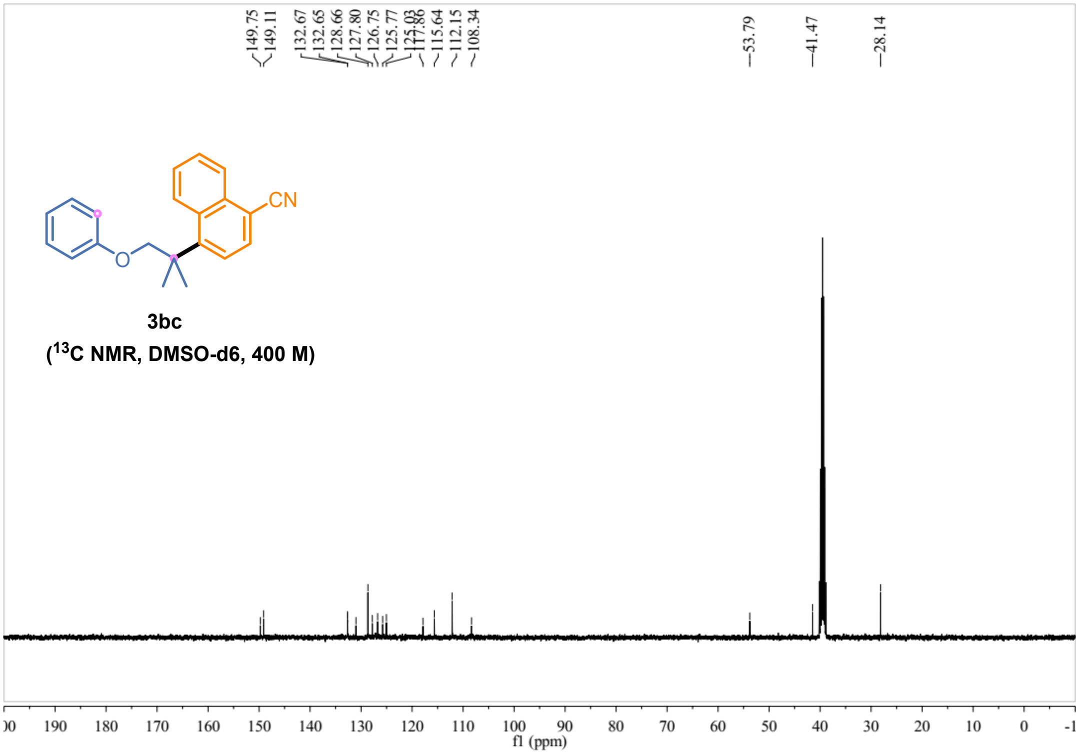

3bb

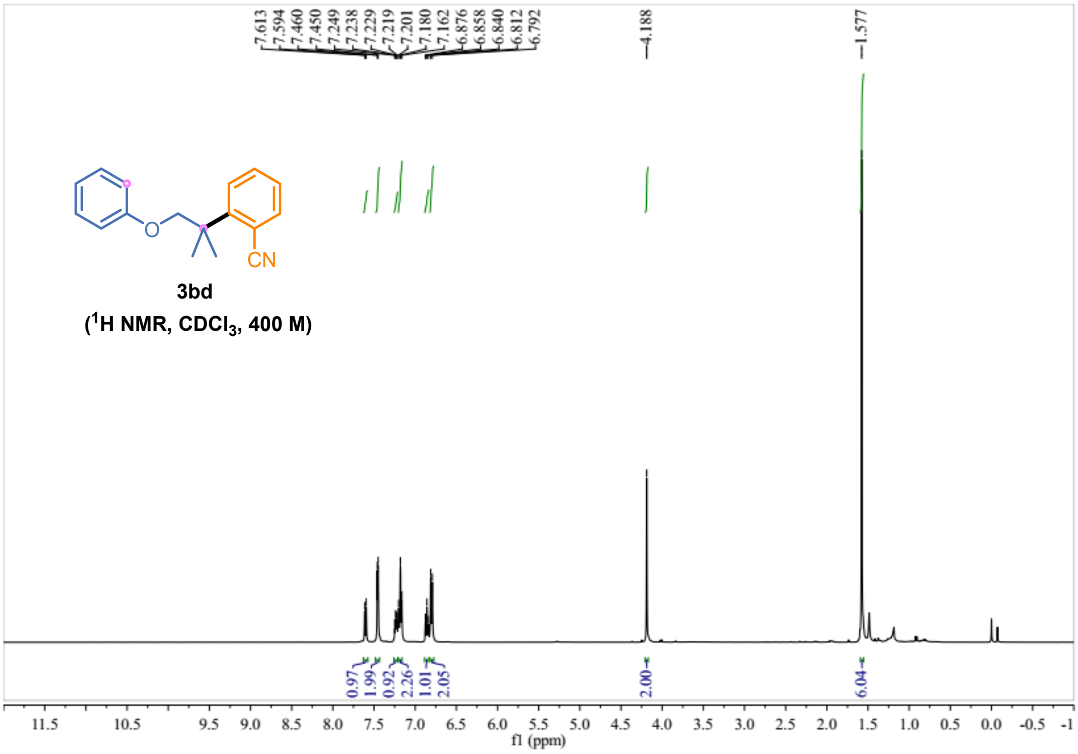
(^{1}H NMR, CDCl$_3$, 400 M)

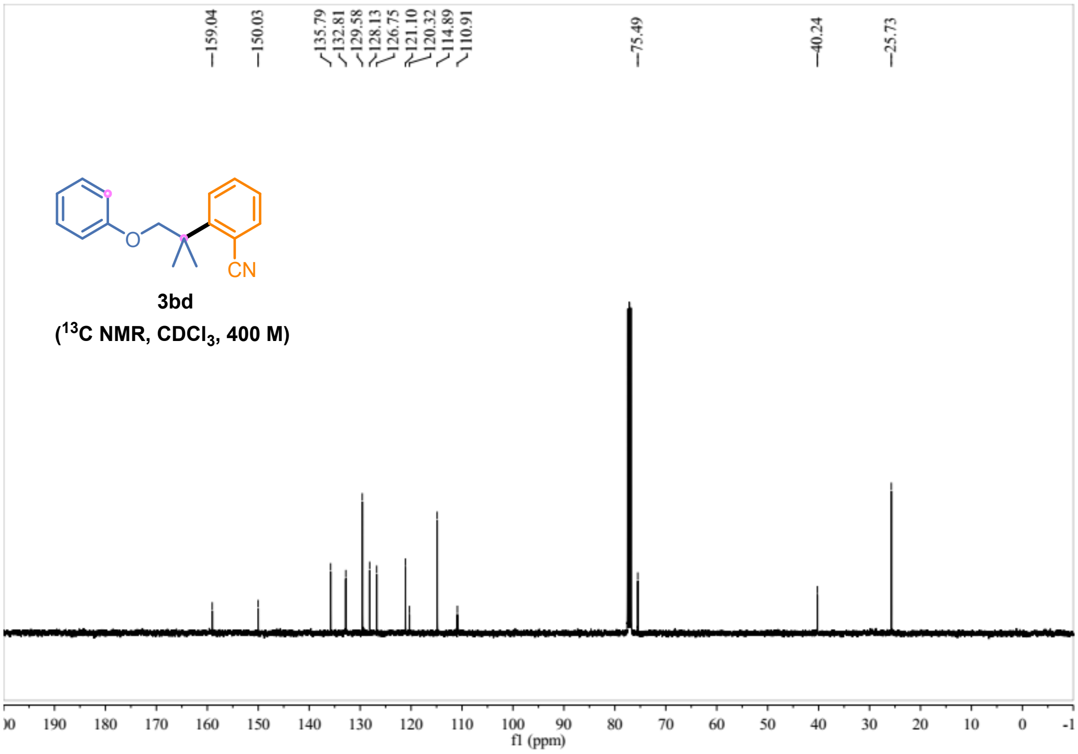

3bb

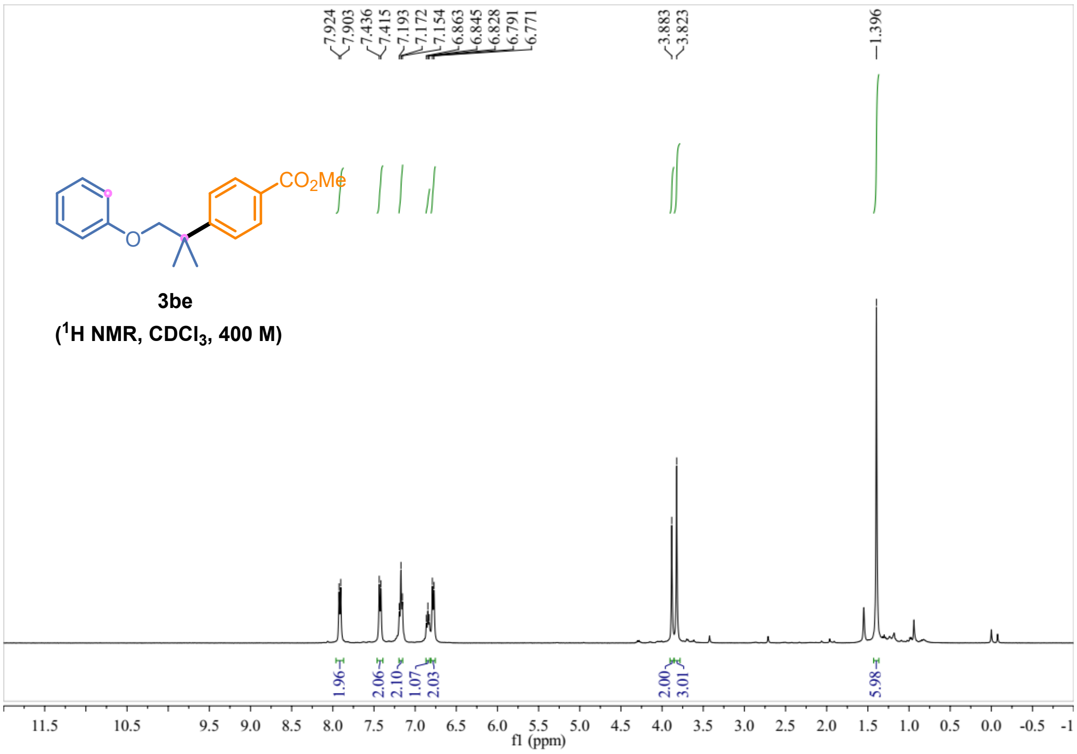
(^{13}C NMR, CDCl$_3$, 400 M)


8.720
8.699
8.109
8.089
7.761
7.668
7.648
6.994
6.975
6.954
6.558
6.539
6.477
6.459
6.441
5.177
5.163
5.148
3.672
3.657
3.366
1.663
CN
N
H
3bc
(^{1}H NMR, DMSO-d6, 400 M)
1.01
1.00
1.02
2.07
0.97
2.02
1.98
1.06
1.00
1.99
5.94
11.0 10.5 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 -1
f1 (ppm)

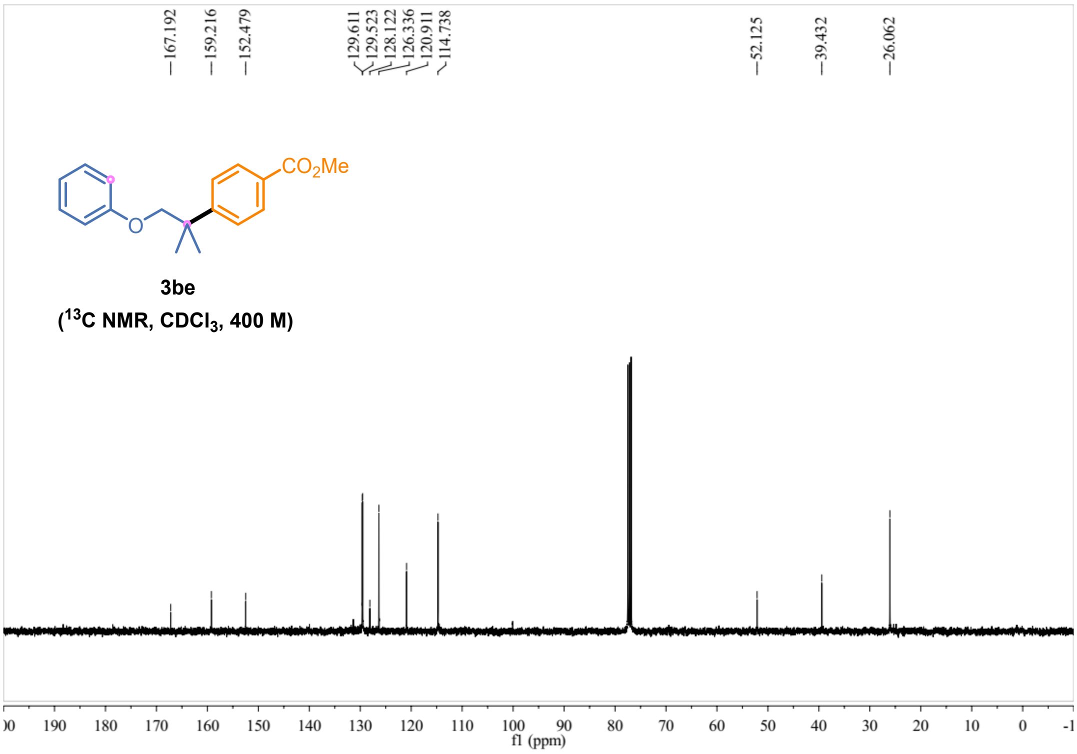

149.75
149.11
132.67
132.65
128.66
127.80
126.75
125.77
125.03
117.86
115.64
112.15
108.34
53.79
41.47
28.14
CN
O
3bc
(^{13}C NMR, DMSO-d6, 400 M)
00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


7.613
7.594
7.460
7.450
7.249
7.238
7.229
7.219
7.201
7.180
7.162
6.876
6.858
6.840
6.812
6.792
4.188
1.577
O
CN
3bd
(^{1}H NMR, CDCl$_3$, 400 M)
0.97
1.99
0.92
2.26
1.01
2.05
2.00
6.04
11.5
10.5
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
-1
f1 (ppm)

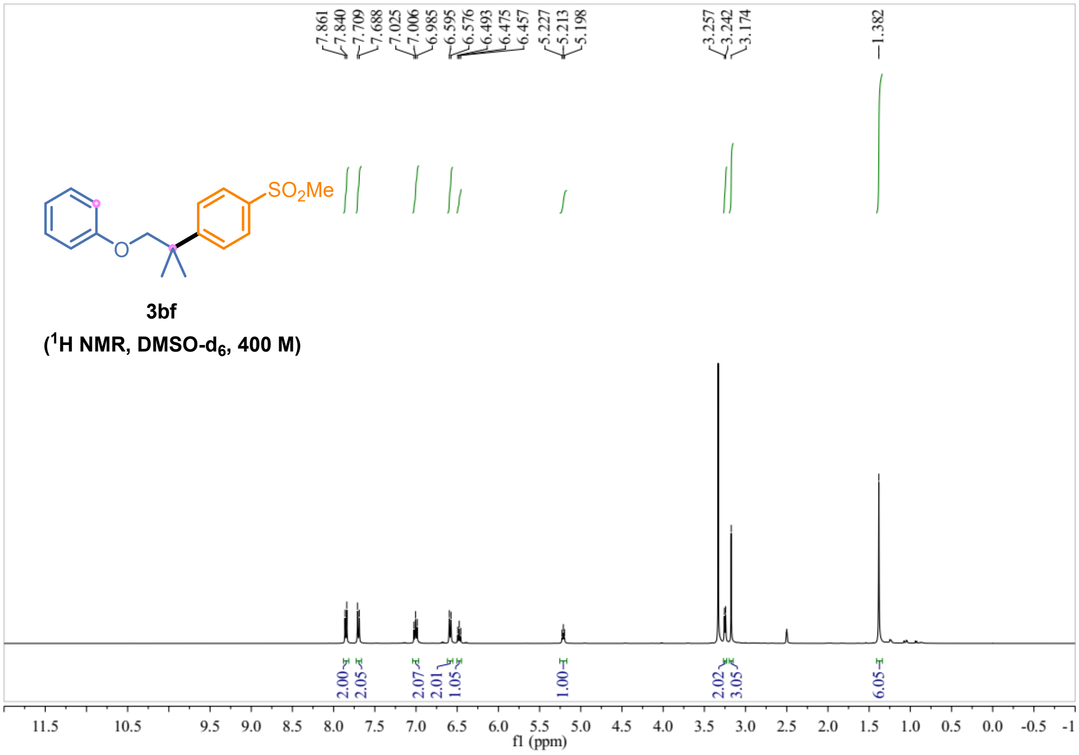

159.04
150.03
135.79
132.81
129.58
128.13
126.75
121.10
120.32
114.89
110.91
75.49
40.24
25.73
O
CN
3bd
(^{13}C NMR, CDCl$_3$, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)

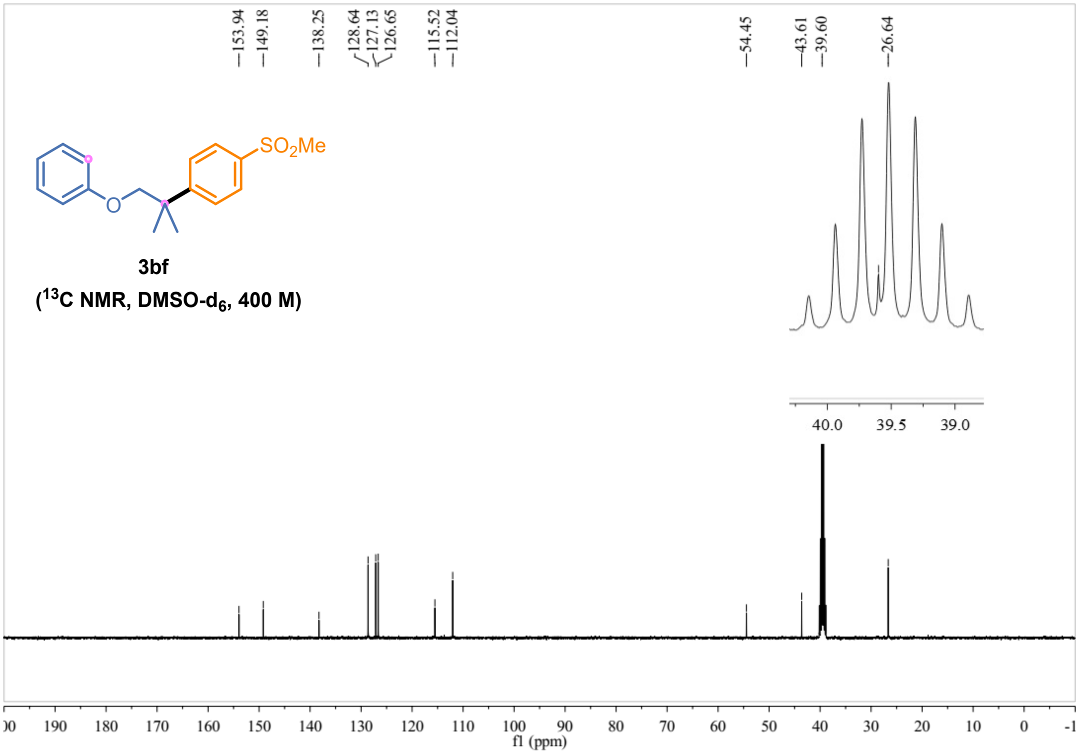

3be

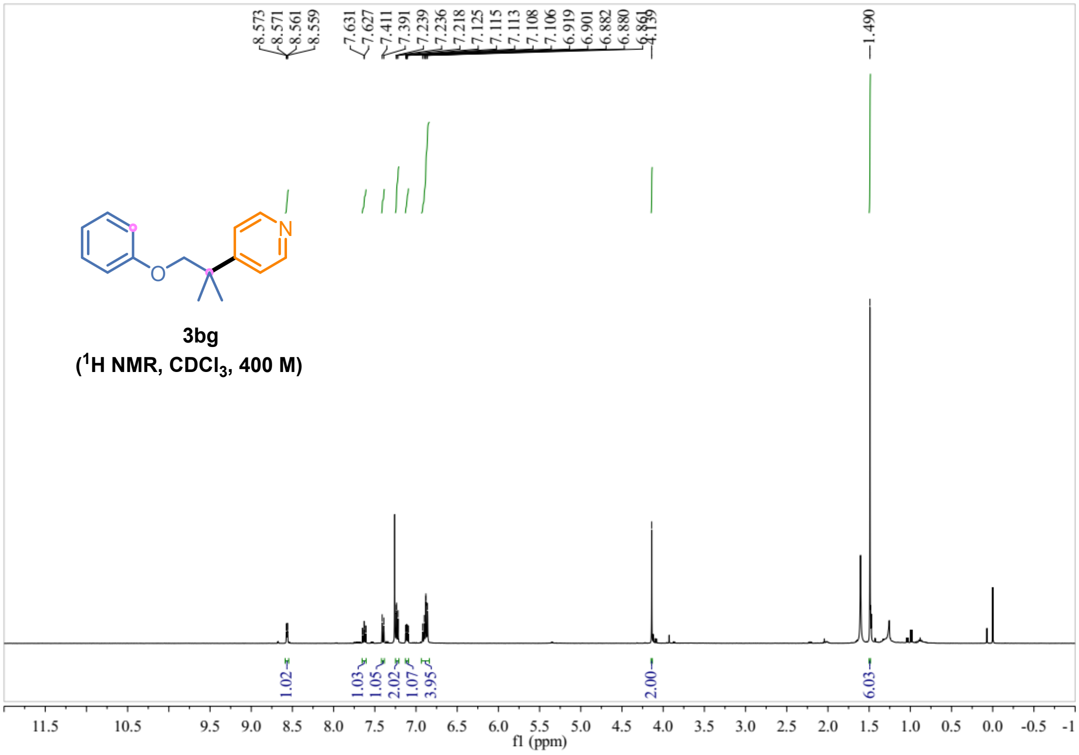
(^{1}H NMR, $CDCl_3$, 400 M)

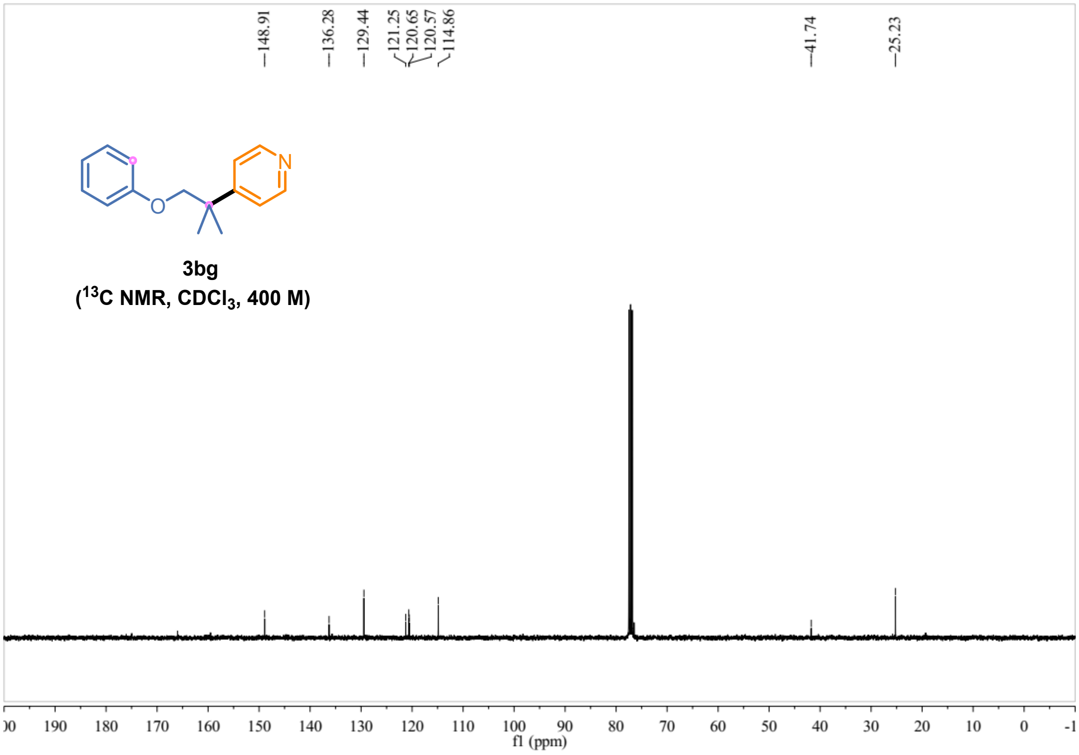

3be

(^{13}C NMR, $CDCl_3$, 400 M)


7.861
7.840
7.709
7.688
7.025
7.006
6.985
6.595
6.576
6.493
6.475
6.457
5.227
5.213
5.198
3.257
3.242
3.174
1.382
SO$_2$Me
O
3bf
(^{1}H NMR, DMSO-d$_6$, 400 M)
2.00
2.05
2.07
2.01
1.05
1.00
2.02
3.05
6.05
11.5
10.5
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
-1
f1 (ppm)


153.94
149.18
138.25
128.64
127.13
126.65
115.52
112.04
54.45
43.61
39.60
26.64
SO$_2$Me
O
3bf
(^{13}C NMR, DMSO-d$_6$, 400 M)
40.0
39.5
39.0
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)


8.573
8.571
8.561
8.559
7.631
7.627
7.411
7.391
7.239
7.236
7.218
7.125
7.115
7.113
7.108
7.106
6.919
6.901
6.882
6.880
6.861
4.139
1.490
O
N
3bg
(^{1}H NMR, CDCl$_3$, 400 M)
1.02
1.03
1.05
2.02
1.07
3.95
2.00
6.03
11.5
10.5
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
-1
f1 (ppm)


148.91
136.28
129.44
121.25
120.65
120.57
114.86
41.74
25.23
O
N
3bg
(^{13}C NMR, CDCl$_3$, 400 M)
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)