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Scope of regioselective Suzuki reactions in the synthesis of arylpyridines and benzylpyridines and subsequent intramolecularcyclizations to azafluorenes and azafluorenones

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Supplementary Information

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General considerations

Unless otherwise noted, all reagents and solvents were purchased from commercial sources and used as received. All reactions were performed in a screw capped vial. The proton (^{1}H) and carbon (^{13}C) NMR spectra were obtained using 400 MHz with Me_4Si as an internal standard and are reported in δ units. Coupling constants (J values) are reported in hertz (Hz). Column chromatography was performed on silica gel (60-120#, 100-200#, and 230-400#). High resolution mass spectra (HRMS) were obtained using electron spray ionization (ESI) and a time-of-flight (TOF) mass analyzer.

General Procedure for the Suzuki Coupling of Bromoheteroarenes with Arylboronic acids (3a-3j)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a bromoheteroarene (bromopyridines) (1 equiv, 0.5 mmol), arylboronic acid (1.2 equiv), $Pd_2(dba)_3$ (1 mol%), X-Phos (2 mol%), and $K_3PO_4.H_2O$ (3 equiv). The tube was evacuated and backfilled with nitrogen. Dioxane (3 mL) and H_2O (1 mL) were added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 100 °C for 16 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8 ~ 3:7) to give the desired product.

General Procedure for the Regioselective Suzuki Coupling of 2,3-Dihalopyridines with 2-Methylphenylboronic acids derivatives (3k-3s)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a bromoheteroarene (e.g. 2,3-dibromopyridine or 3-bromo-2-chloropyridine) (1 equiv, 0.5 mmol), 2-methylphenylboronic acid derivative (1.2 equiv), $Pd_2(dba)_3$ (1 mol%), X-Phos (2 mol%), and $K_3PO_4.H_2O$ (3 equiv). The tube was evacuated and backfilled with nitrogen. 1,4Dioxane (3 mL) and H_2O (1 mL) were added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 100 °C for 16 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8 ~ 3:7) to give the desired product**(3k-3s)**.

Typical Procedure for the synthesis of 3-(Chloromethyl)-2-phenylpyridine (3aa)

In an oven dried 25 mL round bottom flask equipped with a magnetic stirrer bar was charged with a 3-Methyl-2-phenylpyridine **3a** (0.5 mmol), NCS (1.2 equiv), AIBN (5 mol%), and CCl_4 (4 mL). The mixture was refluxed at 90 °C for 12 h. The reaction mixture was allowed to cool to room temperature, neutralized with a saturated solution of Na_2CO_3 (10 mL) and extracted with EtOAc (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

Typical Procedure for the synthesis of 3-(Chloromethyl)-2-phenylpyridine (3ab)

In an oven dried 25 mL round bottom flask equipped with a magnetic stirrer bar was charged with a 3-Methyl-2-phenylpyridine **3a** (0.5 mmol), NBS (1.2 equiv), AIBN (5 mol%), and CCl_4 (4 mL). The mixture was refluxed at 90 °C for 12 h. The reaction mixture was allowed to cool to room temperature, neutralized with a saturated solution of Na_2CO_3 (10 mL) and extracted with EtOAc (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

Typical Procedure for the reduction of Ethyl 2-phenylnicotinate (3i) to (2-Phenylpyridin-3-yl)methanol (3j)

To the solution of ethyl 2-phenylnicotinate **3i**(1 mmol) in THF:MeOH (2:1, 8 mL), $NaBH_4$ (10 equiv) was added portionwise at 0 °C. The mixture was refluxed at 70 °C for 4 h. The solvent was evaporated *in vacuuo.* Water was added (20 mL) and the reaction mixture was extracted with EtOAc (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:6) to give the desired product.

Typical Procedure for the Synthesis of 3-(Chloromethyl)-2-phenylpyridine (3aa) from (2-Phenylpyridin-3-yl)methanol (3j)

To the solution of (2-Phenylpyridin-3-yl)methanol**3j** (0.5 mmol), Et_3N (1.5 equiv) in DCM (4 mL), methane sulphonyl chloride (1.5 equiv) was added drop by drop at 0 °C. The mixture was stirred at rt for 24 h. The reaction mixture was allowed to cool to room temperature, neutralized with a saturated solution of Na_2CO_3 (10 mL) and extracted with DCM (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

Typical Procedure for the Synthesis of 3-(Bromomethyl)-2-phenylpyridine (3ab) from (2-Phenylpyridin-3-yl)methanol (3j)

To the solution of (2-Phenylpyridin-3-yl)methanol**3j** (0.5 mmol) in DCM (4 mL), PBr_3 (1.5 equiv) was added drop by drop at 0 °C. The mixture was stirred at rt for 1 h. The reaction mixture was allowed to cool to room temperature, neutralized with a saturated solution of Na_2CO_3 (10 mL) and extracted with DCM (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

General Procedure for the Regioselective Suzuki Coupling of 2-Halo-3-halomethylpyridine with Arylboronic acids (3t-3x)

A solution of 2-halo-3-halomethylpyridine (0.5 mmol), arylboronic acid (1.2 equiv), $Pd(PPh_3)_4$ (5 mol%), sodium carbonate (2 equiv) in THF:Water (4:1, 3 mL) was heated at 70 ^{o}C for 12 h. The reaction mixture was allowed to cool to room temperature, neutralized with a saturated solution of Na_2CO_3 (10 mL) and extracted with EtOAc (20 mL × 2). The combined organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 1:9 ~ 2:8) to give the desired product.

General Procedure for the Synthesis of 1-Azafluorenes (4a-4e)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a substrate (**3i, 3k, 3m or 3n**, 0.25 mmol), $Pd(OAc)_2$ (5 mol%), PCy_3 (10 mol%) and Na_2CO_3 (1.2 equiv).

The tube was evacuated and backfilled with nitrogen. DMA (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 130 °C for 14 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8 ~ 3:7) to give the desired product.

Typical Procedure for the One-Pot Synthesis of 1-Azafluorene (4a)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a 3-bromo-2-chloro pyridine (0.25 mmol), 2-methylphenylboronic acid (1.2 equiv), $Pd(OAc)_2$ (5 mol%), PCy_3 (10 mol%) and Na_2CO_3 (1.2 equiv). The tube was evacuated and backfilled with nitrogen. DMA (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 130 °C for 24 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 3:7) to give the desired product.

General Procedure for the Synthesis of 4-Azafluorenes (4f-4i)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a substrate (**3o, 3p, 3q, or 3r**, 0.25 mmol), $Pd(OAc)_2$ (5 mol%), X-Phos(10 mol%) and K_2CO_3 (1.2 equiv). The tube was evacuated and backfilled with nitrogen. Toluene (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 110 °C for 3 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

Typical Procedure for the Synthesis of 3-Azafluorene (4j)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a 3-(2-bromophenyl)-4-methylpyridine **3e** (0.25 mmol), $Pd(OAc)_2$ (5 mol%), PCy_3 (10 mol%) and Na_2CO_3 (1.2 equiv). The tube was evacuated and backfilled with nitrogen. DMF (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 130 °C for 24 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 3:7) to give the desired product.

Typical Procedure for the Intramolecular Cyclization of 3-(2 (chloromethyl)phenyl)pyridine (3y)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a 3-(2 (chloromethyl)phenyl)pyridine **3y**(0.25 mmol), $Pd(OAc)_2$ (5 mol%), rac-BINAP(10 mol%) and Cs_2CO_3 (1.2 equiv). The tube was evacuated and backfilled with nitrogen. Toluene (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 110 °C for 16 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 3:7) to give the desired cyclized products.

Typical Procedure for the Synthesis of 4-Azafluorenone (4l)

An oven-dried screw cap vial equipped with a magnetic stirrer bar was charged with a substrate 3-benzyl-2-bromopyridine **3t (**0.25 mmol), $Pd(OAc)_2$ (5 mol%), X-Phos(10 mol%) and K_2CO_3 (1.2 equiv). The tube was evacuated and backfilled with nitrogen. DMF (1mL) was added via a syringe under a flow of nitrogen. The tube was sealed and the mixture was stirred at 130 °C for 3 h. The reaction mixture was allowed to cool to room temperature, and it was neutralized with a saturated solution of $NaHCO_3$ (10 mL) by constant stirring. It was then extracted with EtOAc (20 mL × 2). The organic layers were dried (Na_2SO_4), concentrated under reduced pressure, and purified by column chromatography (100-200# silica, ethyl acetate/hexane = 2:8) to give the desired product.

2. Characterization data

3-*Methyl-2-phenylpyridine* (**3a**)[1]. Yellow oil; yield 89% (75 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.55 (d, *J* = 4.6 Hz, 1H), 7.59 (d, *J* = 7.7 Hz, 1H), 7.54 (d, *J* = 7.9 Hz, 1H), 7.46 (t, *J* = 7.3 Hz, 1H), 7.40 (t, *J* = 7.3 Hz, 1H), 7.20-7.17 (m, 1H), 2.37 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.7, 146.9, 140.6, 138.4, 130.8, 128.9, 128.1, 127.9, 122.0, 20.0; HRMS-ESI m/z calcd for $C_{12}H_{11}N$ $[M+H]^+$ 170.0970, found 170.0978.

2-(2-Chlorophenyl)-3-methylpyridine (**3b**). Colorless oil; yield 81% (41 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.54 (d, *J* = 4.3 Hz, 1H), 7.62 (d, *J* = 7.6 Hz, 1H), 7.50-7.47 (m, 1H), 7.38-7.32 (m, 3H), 7.27-7.25 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.1, 146.7, 139.5, 137.7, 132.7, 132.1, 130.4, 129.4, 129.3, 126.9, 122.9; HRMS-ESI m/z calcd for $C_{12}H_{10}NCl$ $[M+H]^+$204.0580, found 203.0570.

4-Methyl-3-phenylpyridine (**3c**).[2] Brown oil; yield 85% (68 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.45 (d, *J* = 3.2 Hz, 2H), 7.47-7.38 (m, 3H), 7.33 (d, *J* = 7.9 Hz, 2H), 7.22-7.21 (m, 1H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.6, 147.9, 144.8, 137.8, 137.7, 129.4, 129.2, 128.4, 127.7, 125.3, 115.7, 19.8; HRMS-ESI m/z calcd for $C_{12}H_{11}N$ $[M+H]^+$ 170.0970, found 170.0973.

2-(2-Bromophenyl)-3-methylpyridine (**3d**). Yellow oil; yield 77% (95 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.52 (d, *J* = 4.6 Hz, 1H), 7.66 (d, *J* = 7.9 Hz, 1H), 7.60 (d, *J* = 7.7 Hz, 1H), 7.40 (t, *J* = 7.5 Hz, 1H), 7.31-7.23 (m, 3H), 2.15 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.5, 146.6, 141.4, 137.8, 132.6, 131.8, 130.2, 129.5, 127.5, 122.9, 122.5, 18.9; HRMS-ESI m/z calcd for $C_{12}H_{11}NBr$ $[M+H]^+$ 248.0075 and 250.0054 found 248.0068 and 250.0060.

3-(2-Bromophenyl)-4-methylpyridine (**3e**). Colorless oil; yield 79% (98 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56 (d, *J* = 5.0 Hz, 1H), 7.66 (d, *J* = 8.0 Hz, 1H), 7.50 (d, *J* = 7.6 Hz, 1H), 7.39-7.36 (m, 2H), 7.23 (t, *J* = 7.7 Hz, 1H), 7.11 (d, *J* = 4.9 Hz, 1H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.1, 149.1, 147.0, 141.3, 133.2, 131.3, 129.6, 127.4, 125.5, 123.4, 121.8, 21.1; HRMS-ESI m/z calcd for $C_{12}H_{11}BrN$ $[M+H]^+$248.0075 and 250.0054 found 248.0065 and 250.0060.

3-methyl-2-(p-tolyl)pyridine(**3f**). Colorless oil; yield 87% (96 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.43 (d, *J* = 4.0 Hz, 1H), 7.47 (d, *J* = 8.0 Hz, 1H), 7.34 (d, *J* = 8.0 Hz, 2H), 7.17 (d, *J* = 8.0 Hz, 2H), 7.08-7.05 (m, 1H), 2.32 (s, 3H), 2.27 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 158.7, 146.9, 138.4, 137.7, 137.6,130.7, 128.8, 121.8, 21.3, 20.1; HRMS-ESI m/z calcd for $C_{13}H_{14}NO$ $[M+H]^+$184.1126 found 184.1113.

2-(4-fluorophenyl)-3-methylpyridine (**3g**). Colorless oil; yield 83% (92 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.52 (d, *J* = 4.0 Hz, 1H), 7.58 (d, *J* = 4.0 Hz, 1H), 7.52 (dd, *J* = 8.0, 1.7 Hz, 2H), 7.19-7.11 (m, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ*163.7, 157.6, 146.9, 138.6, 136.6, 130.8, 115.1.2, 114.9, 20.0; ^{19}F NMR (150 MHz $CDCl_3$; $CFCl_3$) -113.75 (s), HRMS-ESI m/z calcd for $C_{12}H_{11}FN$ $[M+H]^+$188.0876 found 188.0871.

4-(3-methylpyridin-2-yl)benzonitrile(**3h**). Colorless oil; yield 80% (98 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.56 (d, *J* = 4.0 Hz, 1H), 7.77 (d, *J* = 8.0 Hz, 2H), 7.68-7.63 (m, 3H), 7.28-7.25 (m, 1H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 156.5, 147.3, 145.0, 138.9, 132.0, 130.9, 129.8, 123.0, 118.8, 111.7, 19.8; HRMS-ESI m/z calcd for $C_{13}H_{11}N_2$ $[M+H]^+$195.0922 found 195.920.

Ethyl 2-phenylnicotinate (**3i**).[3] Colorless oil; yield 76% (86 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.12 (dd, *J* = 7.8, 1.7 Hz, 1H), 7.56-7.54 (m, 2H), 7.46-7.44 (m, 3H), 7.38-7.35 (m, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 1.06 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 168.1, 158.8, 151.2, 140.2, 137.8, 128.6, 128.5, 128.1, 127.4, 121.6.HRMS-ESI m/z calcd for $C_{14}H_{16}NO_2$ $[M+H]^+$241.1103 found 241.1100, IR (KBr): 2923, 2853, 1721, 763, 751 cm^{-1}.

(2-Phenylpyridin-3-yl)methanol (**3j**).[3] Colorless oil; yield 71% (65 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.64 (dd, *J* = 4.7, 1.7 Hz, 1H), 7.96 (dd, *J* = 7.7, 1.7 Hz, 1H), 7.57-7.50 (m, 2H), 7.48-7.44 (m, 3H), 7.36-7.33 (m, 1H); 4.73 (d, *J* = 4.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 157.4, 147.7, 139.2, 136.4, 134.4, 128.8, 128.4, 128.2, 122.4, 61.4; HRMS-ESI m/z calcd for $C_{12}H_{11}NO$ $[M+H]^+$ 186.0919 found 186.0919; IR (KBr): 3345, 2955, 2916, 1708 cm^{-1}.

2-Bromo-3-(o-tolyl)pyridine(**3k**). Yellow oil; yield 27% (33 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.65 (dd, *J* = 4.7, 1.7 Hz, 1H), 8.0 (dd, *J* = 8.0, 1.4 Hz, 1H), 7.39-7.26 (m, 4H), 7.20-7.17 (m, 1H), 2.19 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 147.9, 138.5, 136.5, 135.5, 130.2, 130.0, 129.8, 127.5, 124.8, 121.6, 19.9; HRMS-ESI m/z calcd for $C_{12}H_{11}BrN$ $[M+H]^+$248.0075 and 250.0054 found 248.0078 and 250.0058.

2,3-di-o-tolylpyridine (**3k'**). Yellow oil; yield 27% (33 mg); ^1H NMR (400 MHz, $CDCl_3$): *δ* 8.73 (dd, *J* = 4.1, 1.3 Hz, 1H), 7.68 (dd, *J* = 8.0, 1.5 Hz, 1H), 7.37-7.34 (m, 1H), 7.16-7.10 (m, 4H), 7.07-7.05 (m, 1H), 7.00-6.95 (m, 3H), 2.19 (s, 3H), 2.08 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 158.5, 147.9, 139.6, 138.7, 138.5, 136.5, 135.9, 135.5, 130.3, 130.2, 130.0, 129.8, 127.6, 127.5, 125.2, 124.8, 121.6, 20.0, 19.9; HRMS-ESI m/z calcd for $C_{12}H_{11}BrN$ $[M+H]^+$259.1361 found 259.1367.

2-Chloro-3-(o-tolyl)pyridine(**3l**). Colorless oil; yield 80% (81 mg); ^1H NMR (400 MHz, $CDCl_3$): *δ* 8.42 (dd, *J* = 4.5, 1.8 Hz, 1H), 7.59 (dd, *J* = 7.5, 1.8 Hz, 1H), 7.37-7.26 (m, 4H), 7.15 (d, *J* = 7.2 Hz, 1H), 2.16 (s, 3H).^{13}C NMR (100 MHz, $CDCl_3$): δ 150.5, 148.6, 139.6, 136.0, 129.3, 128.6, 125.8, 122.3, 19.8. HRMS-ESI m/z calcd for $C_{12}H_{11}ClN$ $[M+H]^+$ 204.0580 found 204.0593.

Methyl 4-(2-chloropyridin-3-yl)-3-methylbenzoate (**3m**). Colorless oil; yield 68% (88 mg); ^1H NMR (400 MHz, $CDCl_3$): *δ* 8.47 (d, *J* = 4.7 Hz, 1H), 8.01 (s, 1H), 7.96 (d, *J* = 7.9 Hz, 1H), 7.60 (d, *J* = 7.4 Hz, 1H), 7.38-7.35 (m, 1H), 7.24 (d, *J* = 8.0 Hz, 1H), 3.97 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 166.8, 149.1, 141.7, 139.2, 136.6, 136.0, 131.3, 130.3, 129.5, 127.0, 122.3, 52.2, 19.79; HRMS-ESI m/z calcd for $C_{14}H_{13}ClNO_2$ $[M+H]^+$ 262.0635 found 262.0636; IR (KBr): 2981, 2930, 1731, 1705, 1436, 776 cm^{-1}.

2-Chloro-3-(2-methyl-4-(trifluoromethoxy)phenyl)pyridine (**3n**). White solid; yield 84% (120 mg); ^1H NMR (400 MHz, $CDCl_3$): *δ* 8.46 (dd, *J* = 4.7, 1.8 Hz, 1H), 7.59 (dd, *J* = 7.5, 1.8 Hz, 1H), 7.36-7.33 (m, 1H), 7.19-7.13 (m, 3H), 2.17 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 150.5, 149.2, 149.05, 139.6, 138.5, 135.8, 130.7, 122.3, 121.7, 119.2, 118.1, 19.9.; HRMS-ESI m/z calcd for $C_{13}H_{10}ClF_3NO$ $[M+H]^+$ 288.0403 found 288.0411.

N-(4-(2-Chloropyridin-3-yl)-3-methylphenyl)acetamide(**3o**). Yellow solid; yield 76% (98 mg); ^1H NMR (400 MHz, $CDCl_3$): *δ* 8.41 (dd, *J* = 4.6, 1.5 Hz, 1H), 7.76 (s, 1H), 7.57 (dd, *J* = 7.4, 1.5 Hz, 1H), 7.50 (s, 1H), 7.43 (d, *J* = 8.1 Hz, 1H), 7.33-7.30 (m, 1H), 7.08 (d, *J* = 8.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 168.6, 150.7, 148.6, 139.9, 138.1, 137.1, 136.4, 133.2, 129.9, 122.3, 121.2, 117.3, 24.6, 20.0; HRMS-ESI m/z calcd for $C_{14}H_{14}ClN_2O$ $[M+H]^+$ 261.0795 found 261.07805, IR (KBr): 3299, 2926, 1668, 1594, 1533, 1445, 1389, 1315 cm^{-1}.

Methyl 3-(2-chloropyridin-3-yl)-4-methylbenzoate (**3p**). Colorless oil; yield 71% (92 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.46 (dd, J = 4.7, 1.1 Hz, 1H), 8.02 (d, J = 7.9 Hz, 1H), 7.84 (d, J = 1.4 Hz, 1H), 7.60 (dd, J = 7.5, 1.8 Hz, 1H), 7.40-7.34 (m, 2H), 3.92 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.7, 150.4, 149.0, 141.8, 139.6, 137.4, 136.0, 130.5, 130.3, 129.7, 128.0, 122.4, 52.1, 20.0. HRMS-ESI m/z calcd for $C_{14}H_{13}ClNO_2$ $[M+H]^+$ 262.0635 found262.0644; IR (KBr): 2951, 2924, 2853, 1717, 1385, 1256, 1237, 760 cm^{-1}.

2-Chloro-3-(5-methoxy-2-methylphenyl)pyridine(**3q**). Colorless oil; yield 78% (88 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.41 (dd, J = 4.7, 1.9 Hz, 1H), 7.58 (dd, J = 7.5, 1.9 Hz, 1H), 7.32-7.29 (m, 1H), 7.07 (d, J = 8.3 Hz, 1H), 6.86-6.81 (m, 2H), 3.86 (s, 3H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 151.1, 148.4, 140.1, 137.6, 136.7, 130.4, 129.8, 122.2, 115.5, 111.1, 55.2, 20.1. HRMS-ESI m/z calcd for $C_{13}H_{13}ClNO$ $[M+H]^+$ 234.0686 found 234.0699.

2-chloro-2'-methoxy-1,1'-biphenyl (**3r**). Colorless oil; yield 82% (88 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.36 (d, J = 8.1 Hz, 1H), 7.62 (d, J = 8.0 Hz, 1H), 7.41 (t, J = 8.0 Hz, 1H), 7.07 (d, J = 8.3 Hz, 1H), 6.86-6.81 (m, 2H), 3.86 (s, 3H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 151.1, 148.4, 140.1, 137.6, 136.7, 130.4, 129.8, 122.2, 115.5, 111.1, 55.2, 20.1. HRMS-ESI m/z calcd for $C_{13}H_{13}ClNO$ $[M+H]^+$ 234.0686 found 234.0699.

2-bromo-2'-methoxy-1,1'-biphenyl (**3s**). Colorless oil; yield 33% (55 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.63 (d, J = 4.7Hz, 1H), 7.95 (d, J = 8.0 Hz, 1H), 7.43 (t, J = 8.0 Hz, 1H), 7.26 (dd, J = 8.2, 1.8 Hz, 1H), 7.29 (d, J = 8.0 Hz, 1H), 7.04-6.97 (m, 2H),3.76 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ156.6, 151.0, 148.2, 140.3, 134.2, 130.7, 130.1, 126.5, 122.2, 120.5, 111.1, 55.5. HRMS-ESI m/z calcd for $C_{13}H_{12}BrO$ $[M+H]^+$264.0024 and 266.0004 found 264.0071 and 266.00.10.

3-(Chloromethyl)-2-phenylpyridine (**3aa**). Colorless oil; yield 77% (78 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.68 (dd, J = 4.7, 1.2 Hz, 1H), 7.92 (d, J = 7.8 Hz, 1H), 7.63 (d, J = 7.2 Hz, 1H), 7.53-7.47 (m, 3H), 7.37-7.34 (m, 1H), 4.62 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.4, 149.3, 138.9, 138.7, 130.9, 128.8, 128.7, 128.4, 122.7, 43.6; HRMS-ESI m/z calcd for $C_{12}H_{11}ClN$ $[M+H]^+$ 204.0580 found 204.0589.

3-(Bromomethyl)-2-phenylpyridine (**3ab**). Colorless oil; yield 83% (102 mg); ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.67 (dd, J = 4.8, 1.6 Hz, 1H), 8.16 (dd, J = 7.8, 1.5 Hz, 1H), 7.64-7.62 (m, 2H), 7.58-7.53 (m, 4H), 4.68 (s, 2H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 158.1, 149.7, 139.9, 139.5, 131.7, 129.2, 129.0, 128.9, 128.7, 123.5, 32.6; HRMS-ESI m/z calcd for $C_{12}H_{11}BrN$ $[M+H]^+$ 248.0075 and 250.0054 found 248.0083 and 250.0060.

3-Benzyl-2-bromopyridine (**3t**). Viscous oil; yield 72% (89 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.26 (dd, J = 4.6, 1.7 Hz, 1H), 7.40-7.18 (m, 7H), 4.11 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.9, 147.4, 144.6, 138.8, 138.0, 137.9, 129.1, 128.7, 126.7, 122.9, 122.7, 40.9; HRMS-ESI m/z calcd for $C_{12}H_{11}BrN$ $[M+H]^+$ 248.0075 and 250.0054 found 248.0079 and 250.0062.

2-Bromo-3-(2-methylbenzyl)pyridine(**3u**). Colorless oil; yield 68% (89 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.25 (dd, J = 4.6, 2.0 Hz, 1H), 7.25-7.24 (m, 2H), 7.22-7.18 (m, 1H), 7.17-7.15 (m, 1H), 7.13-7.10 (m, 1H), 7.05 (d, J = 7.0 Hz, 1H), 4.06 (s, 2H), 2.22 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.7, 144.7, 138.01, 137.3, 136.7, 136.1, 130.5, 129.9, 127.2, 126.3, 122.9. HRMS-ESI m/z calcd for $C_{13}H_{13}BrN$ $[M+H]^+$ 262.0231 and 264.0211 found 262.0243 and 264.0208.

1-(2-((2-Bromopyridin-3-yl)methyl)phenyl)ethanone(**3v**). Colorless oil; yield 62% (89 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.24 (dd, J = 4.5, 2.0 Hz, 1H), 7.82 (dd, J = 7.6, 1.2 Hz, 1H), 7.47 (td, J = 7.5, 1.4 Hz, 1H), 7.40 (td, J = 7.6, 1.2 Hz, 1H), 7.20-7.13 (m, 3H), 4.36 (s, 2H), 2.60 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 201.2, 147.6, 144.6, 138.5, 138.0, 138.0, 137.7, 132.0, 131.8, 129.9, 126.9, 122.7; HRMS-ESI m/z calcd for $C_{14}H_{13}BrNO$ $[M+H]^+$ 290.0181 and 292.0160 found 290.0184 and 292.0188. IR (KBr): 2955, 2916, 2849, 1672, 1398, 1355, 1238, 1049, 751 cm^{-1}.

1-(4-((2-Bromopyridin-3-yl)methyl)phenyl)ethanone(**3w**). Colorless oil; yield 64% (92 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.29 (dd, J = 4.6, 1.8 Hz, 1H), 7.94 (d, J = 8.2 Hz, 2H), 7.41 (d, J = 7.5, 1.7 Hz, 1H), 7.30 (d, J = 8.2 Hz, 2H), 7.25-7.21 (m, 1H), 4.17 (s, 2H), 2.61 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.6, 148.3, 144.6, 143.6, 138.9, 136.9, 135.7, 129.2, 129.0, 128.8, 123.0, 40.9, 26.6. HRMS-ESI m/z calcd for $C_{14}H_{13}BrNO$ $[M+H]^+$ 290.0181 and 292.0160 found 290.0188 and 292.0167. IR (KBr): 2924, 2853, 1679, 1400, 1356, 1265, 1049, 790 cm^{-1}

3-(4-Fluorobenzyl)-2-(4-fluorophenyl)pyridine(**3x**). Colorless oil; yield 38% (53 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.57 (d, J = 4.6 Hz, 1H), 7.53 (d, J = 7.7 Hz, 1H), 7.43-7.39 (m, 2H), 7.28-

2.23 (m, 1H), 7.11 (d, *J* = 8.6 Hz, 2H), 6.95 (d, *J* = 7.2 Hz, 4H), 4.00 (s, 2H), ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.9, 161.4, 158.1, 147.5, 138.4, 136.2, 130.7, 130.1, 122.5, 115.5, 115.1, 37.7 ^{19}F(150 MHz $CDCl_3$; $CFCl_3$) -113.75 (s), -116.63 (s), HRMS-ESI m/z calcd for $C_{18}H_{15}F_2N$ $[M+H]^+$ 282.1094 found 282.1107.

9H-Indeno[2,1-b]pyridine (**4a**).[4] Yellow solid; yield 87% (36 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.49 (d, *J* = 4.8 Hz, 1H), 8.01 (d, *J* = 7.6 Hz, 1H), 7.79 (d, *J* = 7.2 Hz, 1H), 7.60 (d, *J* = 7.1 Hz, 1H), 7.43-7.35 (m, 2H), 7.28 (d, *J* = 7.6 Hz, 1H), 4.01 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 164.5, 147.5, 141.3, 139.2, 135.1, 127.7, 127.1, 125.3, 121.7, 120.6, 38.7. HRMS-ESI m/z calcd for $C_{12}H_{10}N$ $[M+H]^+$ 168.0813 found 168.0815; IR (KBr): 2923, 2853, 1726, 753 cm^{-1}..

Methyl 9H-indeno[2,1-b]pyridine-6-carboxylate (**4b**). Yellow solid; yield 62% (34 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.55 (dd, *J* = 4.9, 1.1 Hz, 1H), 8.47 (dd, *J* = 0.9 Hz, 1H), 8.10 (dd, *J* = 8.1, 1.4 Hz, 2H), 7.68 (dd, *J* = 7.7 Hz, 1H), 7.36-7.32 (m, 1H), 4.09 (s, 2H), 3.99 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 167.7, 151.0, 141.6, 139.5, 136.2, 135.2, 131.7, 130.9, 128.8, 128.3, 127.5, 124.6, 122.0, 65.5, 52.7; HRMS-ESI m/z calcd for $C_{14}H_{12}NO_2$ $[M+H]^+$ 226.0868 found 226.0880; IR (KBr): 2958, 2954, 2864, 1721, 1276, 1257, 746 cm^{-1}.

6-Methoxy-9H-indeno[2,1-b]pyridine (**4c**). Yellow solid; yield 71% (35 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.40 (dd, *J* = 4.9, 1.4 Hz, 1H), 7.88 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.66 (d, *J* = 8.4 Hz, 1H), 7.24-7.21 (m, 1H), 7.14 (d, *J* = 2.0 Hz, 1H), 6.95 (dd, *J* = 8.4, 2.2 Hz, 1H), 3.97 (s, 2H), 3.87 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 164.0, 159.8, 146.2, 143.2, 135.1, 132.1, 126.0, 121.6, 121.5, 113.5, 110.6, 55.5, 38.8. HRMS-ESI m/z calcdfor : $C_{13}H_{12}NO$ $[M+H]^+$ 198.0919 found 198.0925.

3-(2-Methyl-4-(trifluoromethoxy)phenyl)pyridine (**4e**). Colorless oil; yield 42% (26 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.63 (dd, *J* = 4.8, 1.4 Hz, 1H), 8.58 (d, *J* = 1.7 Hz, 1H), 7.63 (dt, *J* = 7.8, 1.9 Hz, 1H), 7.39-7.36 (m, 1H), 7.23 (d, *J* = 8.2 Hz, 1H), 7.16-7.12 (m, 2H), 2.28 (s, 3H); HRMS-ESI m/z calcd for $C_{13}H_9F_3NO$ $[M+H]^+$ 254.0793 found 254.0802.

5H-Indeno[1,2-b]pyridine (**4f**). Yellow solid; yield 87% (35 mg); ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.62 (dd, *J* = 4.3, 0.6 Hz, 1H), 8.13 (d, *J* = 7.0, Hz, 1H), 7.85 (d, *J* = 7.5 Hz, 1H), 7.61 (d, *J* = 7.3 Hz, 1H), 7.51-7.43 (m, 2H), 7.23-7.20 (m, 1H), 3.91 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): *δ*

160.4, 148.2, 143.6, 132.4, 128.7, 127.3, 125.2, 121.1, 120.9, 34.5. HRMS-ESI m/z calcd for $C_{12}H_{10}N$ $[M+H]^+$ 168.0813 found 168.0821.

6-Methyl-5H-indeno[1,2-b]pyridine (**4g**). Yellow solid; yield 54% (24 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.60 (d, J = 4.7 Hz, 1H), 7.98 (d, J = 7.5 Hz, 1H), 7.85 (d, J = 7.5 Hz, 1H), 7.41 (d, J = 7.5 Hz, 1H), 7.26 (d, J = 7.7 Hz, 1H), 7.22-7.19 (m, 1H), 3.78 (s, 2H), 2.46 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.7, 148.1, 142.4, 140.4, 136.6, 134.3, 132.4, 129.6, 127.7, 121.0, 118.4, 33.4, 18.5. HRMS-ESI m/z calcd for $C_{13}H_{12}N$ $[M+H]^+$ 182.0970 found 182.0977. IR (KBr): 2926, 2854, 736 cm^{-1}

1-(5H-Indeno[1,2-b]pyridin-6-yl)ethanone (**4h**). Yellow solid; yield 74% (38 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.62 (dd, J = 4.8, 0.6 Hz, 1H), 8.34 (d, J = 7.5 Hz, 1H), 7.99 (dd, J = 7.7, 0.7 Hz, 1H), 7.90 (dd, J = 7.5, 0.5 Hz, 1H), 7.62 (t, J = 7.7 Hz, 1H), 7.28-7.24 (m, 1H), 4.27 (s, 2H), 2.72 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 199.2, 158.9, 148.2, 144.5, 142.4, 137.6, 133.5, 132.5, 130.1, 127.7, 125.2, 121.7, 60.3, 36.6. HRMS-ESI m/z calcd for $C_{14}H_{12}NO$ $[M+H]^+$ 210.0919 found 210.0925; IR (KBr): 2923, 2853, 1680, 1356, 1257, 782 cm^{-1}.

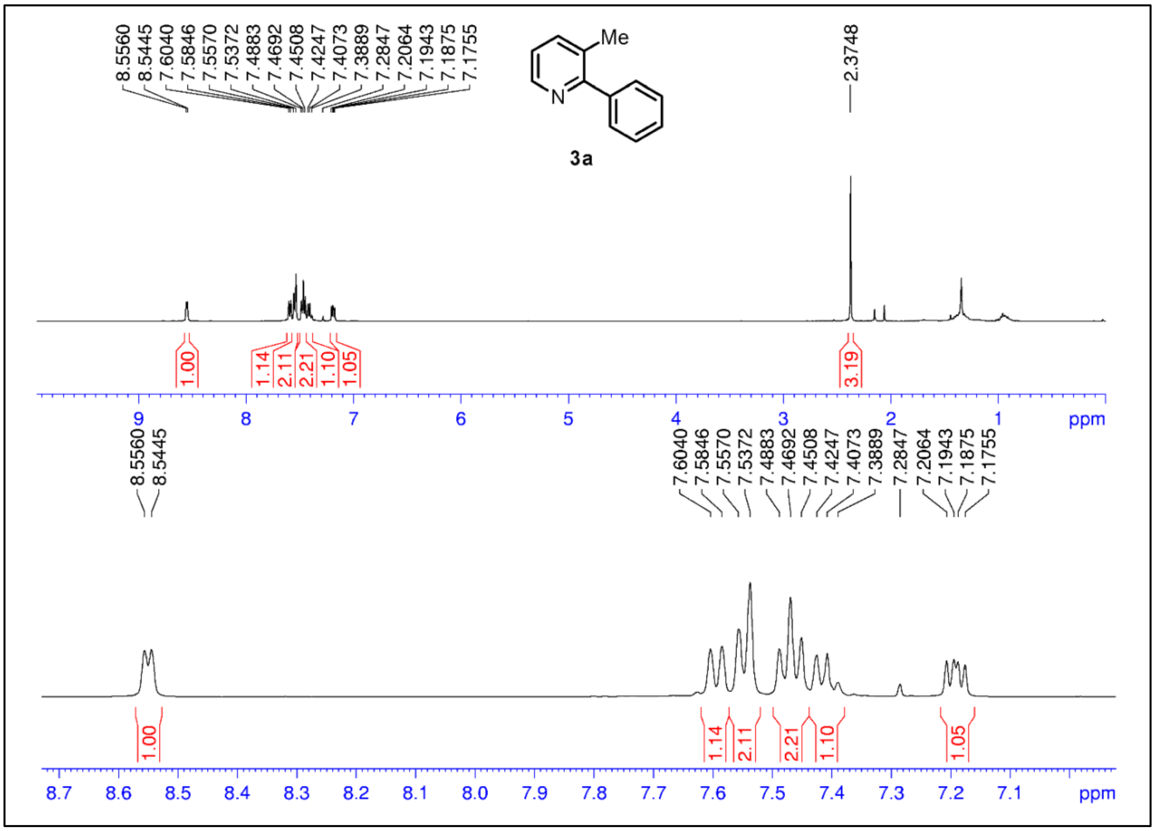
1-(5H-Indeno[1,2-b]pyridin-8-yl)ethanone (**4i**). Yellow solid; yield 51% (26 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.68-8.65 (m, 2H), 8.11 (dd, J = 7.9, 1.6 Hz, 1H), 7.88 (d, J = 7.5 Hz, 1H), 7.69 (d, J = 8.0 Hz, 1H), 7.29-7.26 (m, 1H), 3.97 (s, 2H), 2.73 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.6, 139.4, 136.9, 135.2, 132.7, 131.8, 128.4, 125.4, 121.8, 121.2, 118.3, 34.8, 26.9; HRMS-ESI m/z calcd for $C_{14}H_{12}NO$ $[M+H]^+$ 210.0919 found 210.0928. IR (KBr): 2955, 2918, 2851, 1709, 1685, 1377, 783 cm^{-1}.

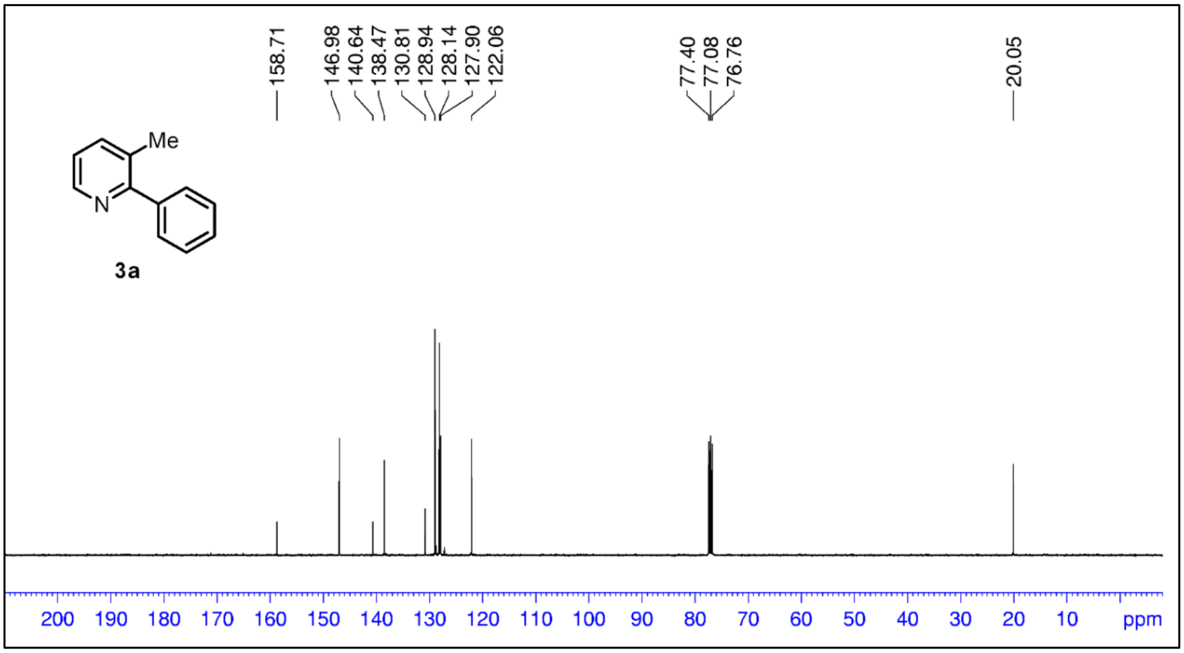
5H-indeno[1,2-c]pyridin-5-one(**4j**). Yellow solid; yield 42% (19 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.90 (s, 1H), 8.70 (d, J = 4.6 Hz, 1H), 7.74 (d, J = 7.4 Hz, 1H), 7.65 (d, J = 7.5 Hz, 1H), 7.57 (td, J = 7.5, 0.9 Hz, 1H), 7.51 (dd, J = 4.6, 0.9 Hz, 1H), 7.38 (td, J = 7.4, 0.7 Hz, 1H). IR (KBr): 2921, 2851, 1715, 739 cm^{-1}.

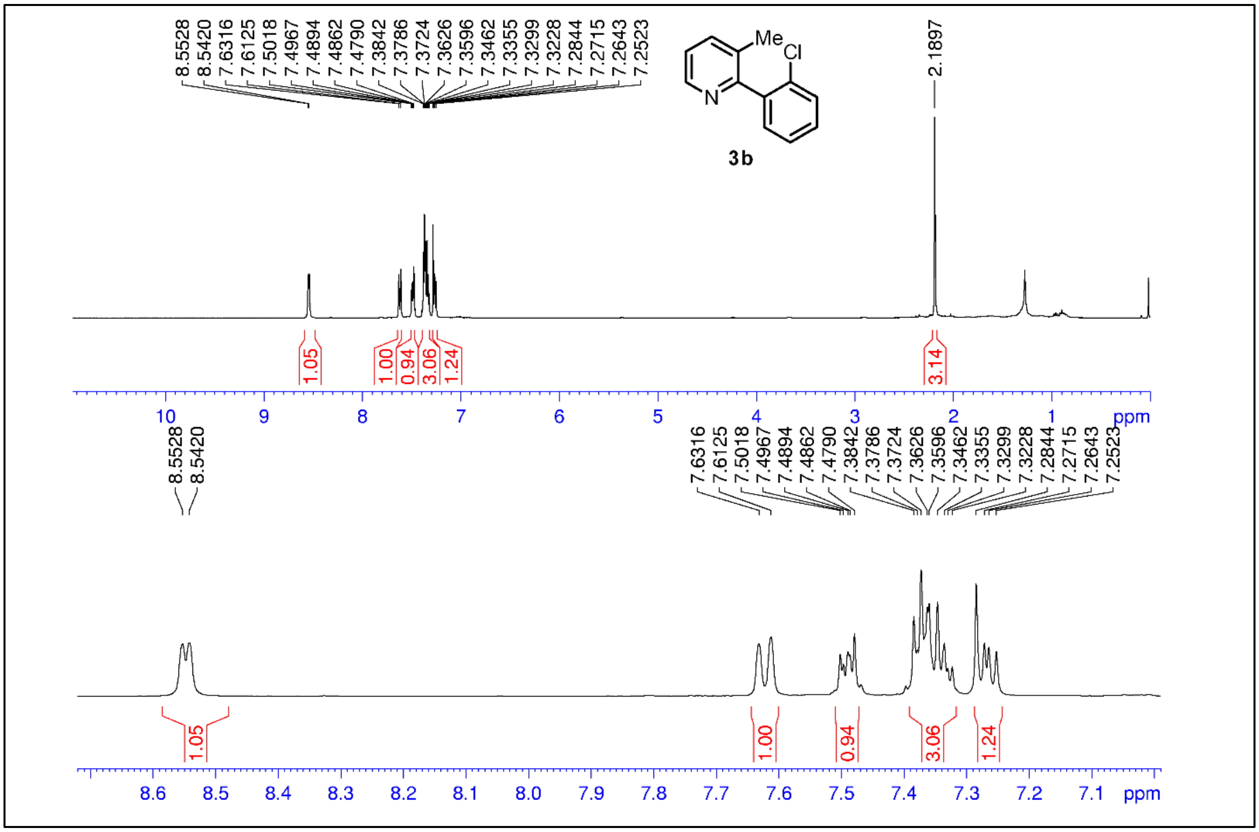
9H-indeno[2,1-b]pyridin-9-one **(4k)**[5]. Yellow solid; yield 13% (6 mg); ^1H NMR (400 MHz, $CDCl_3$): δ 8.60 (d, J = 4.6 Hz, 1H), 7.87 (dd, J = 7.6, 1.0 Hz, 1H), 7.74 (d, J = 7.4 Hz, 1H), 7.57-7.55 (m, 2H), 7.41-7.33 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.6, 153.1, 150.3, 141.6, 140.0, 135.5, 132.3, 130.0, 127.8, 127.1, 124.8, 121.1. IR (KBr): 2920, 2851, 1719, 758 cm^{-1}.

5H-Indeno[1,2-b]pyridin-5-one (**4l**). Yellow solid; yield 84% (38 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.64 (dd, *J* = 5.1, 1.6 Hz, 1H), 7.92 (dd, *J* = 7.4, 1.6 Hz, 1H), 7.89 (d, *J* = 7.4 Hz, 1H), 7.76 (d, *J* = 7.4 Hz, 1H), 7.64 (td, *J* = 7.5, 1.0 Hz, 1H), 7.47 (dd, *J* = 7.4, 0.8 Hz, 1H), 7.26-7.22 (m, 1H).); HRMS-ESI m/z calcd for $C_{12}H_7NO$ $[M+H]^+$ 182.0606 found 182.0606. IR (KBr): 2923, 2853, 1713, 743 cm^{-1}.

3. Copies of ^{1}H and ^{13}C NMR spectra



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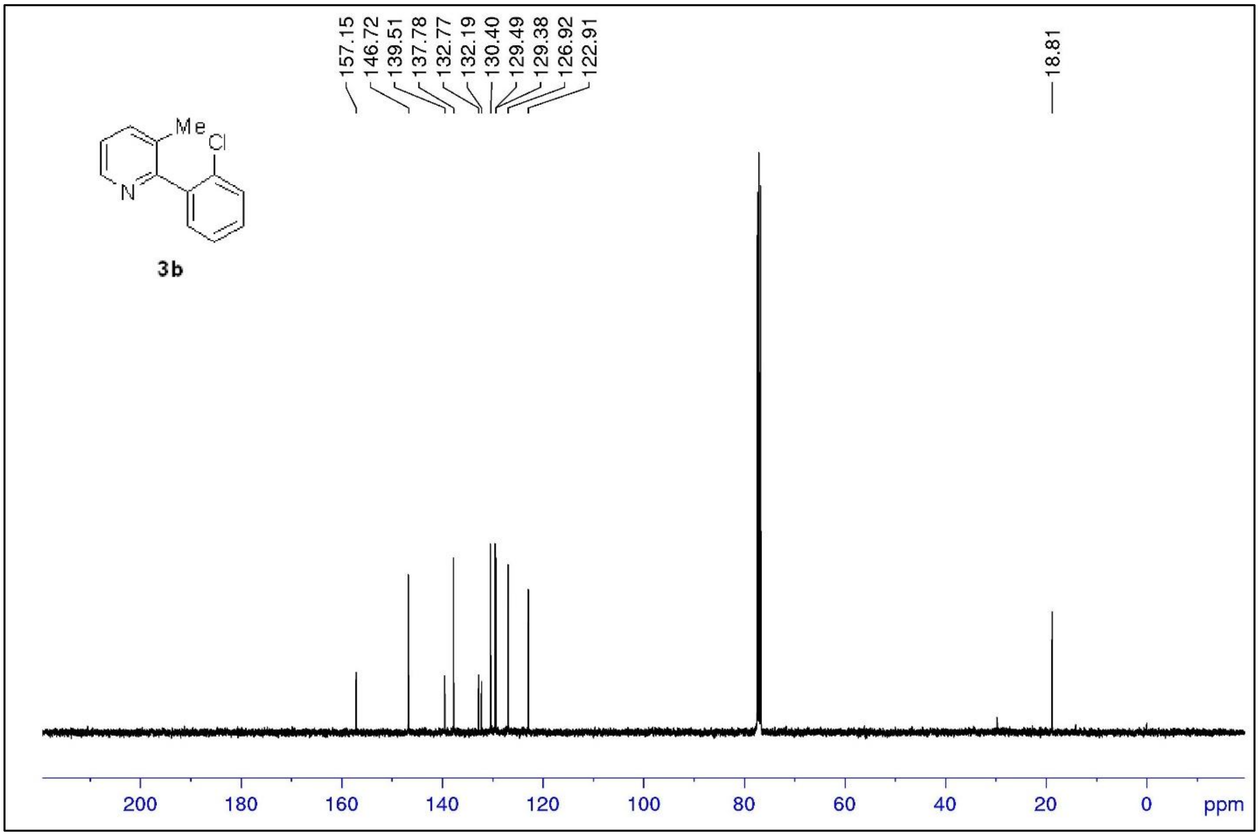
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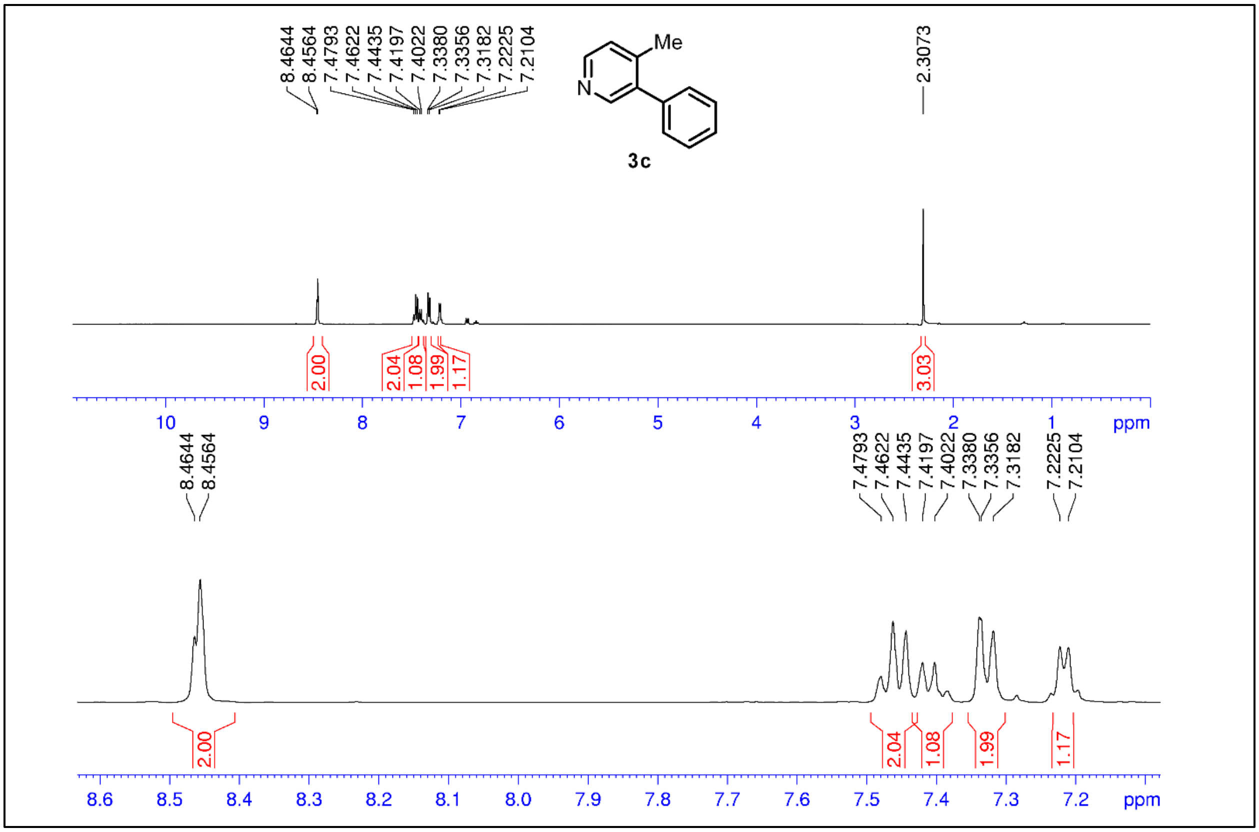
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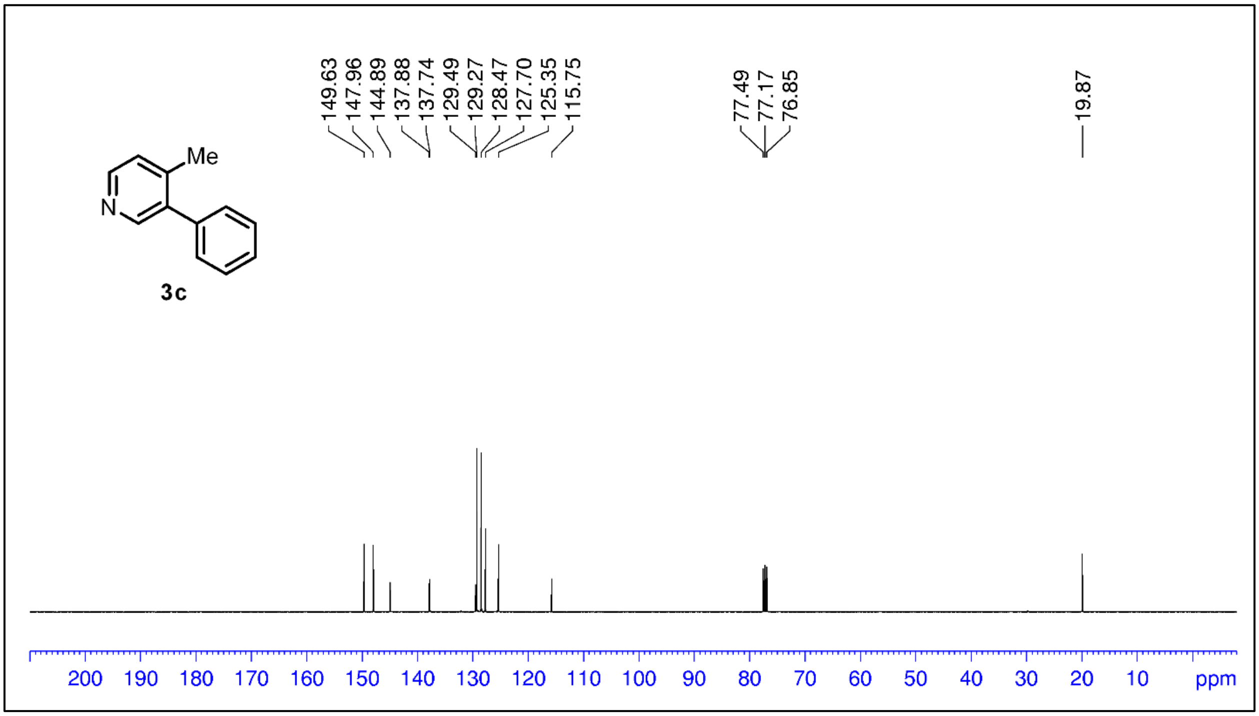
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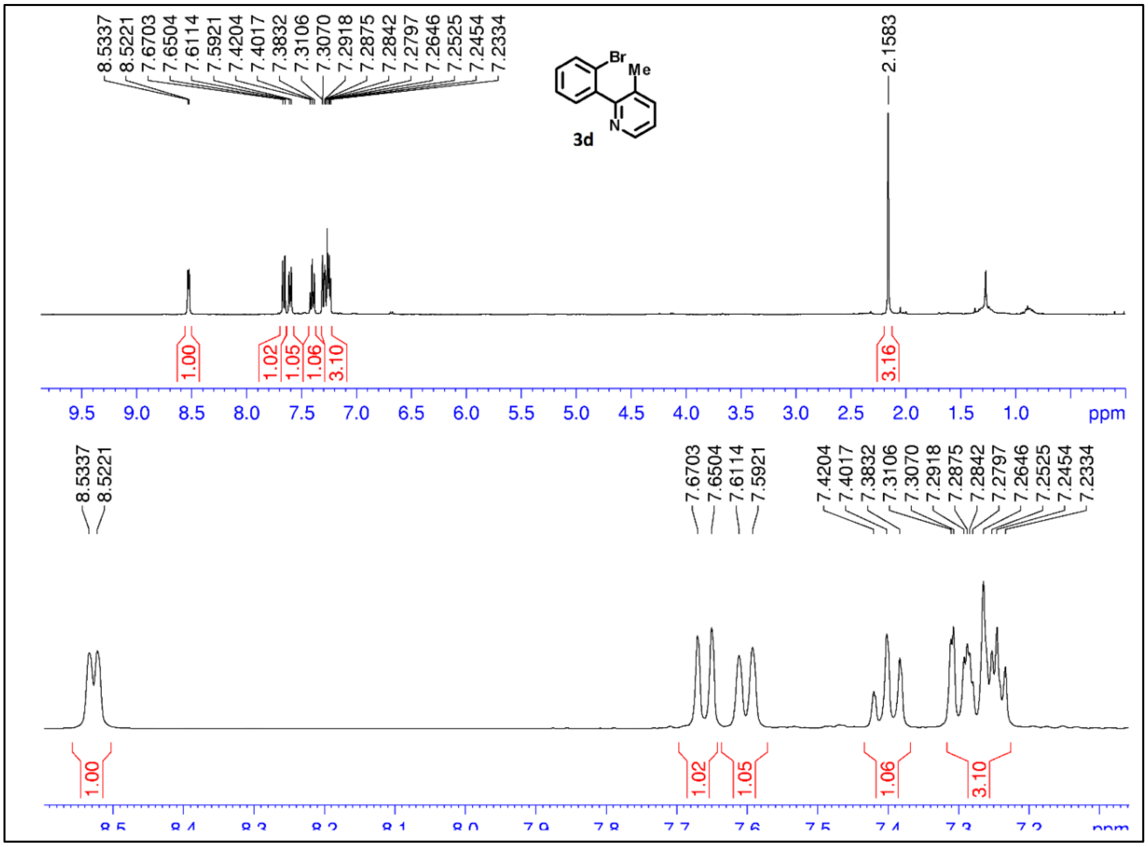
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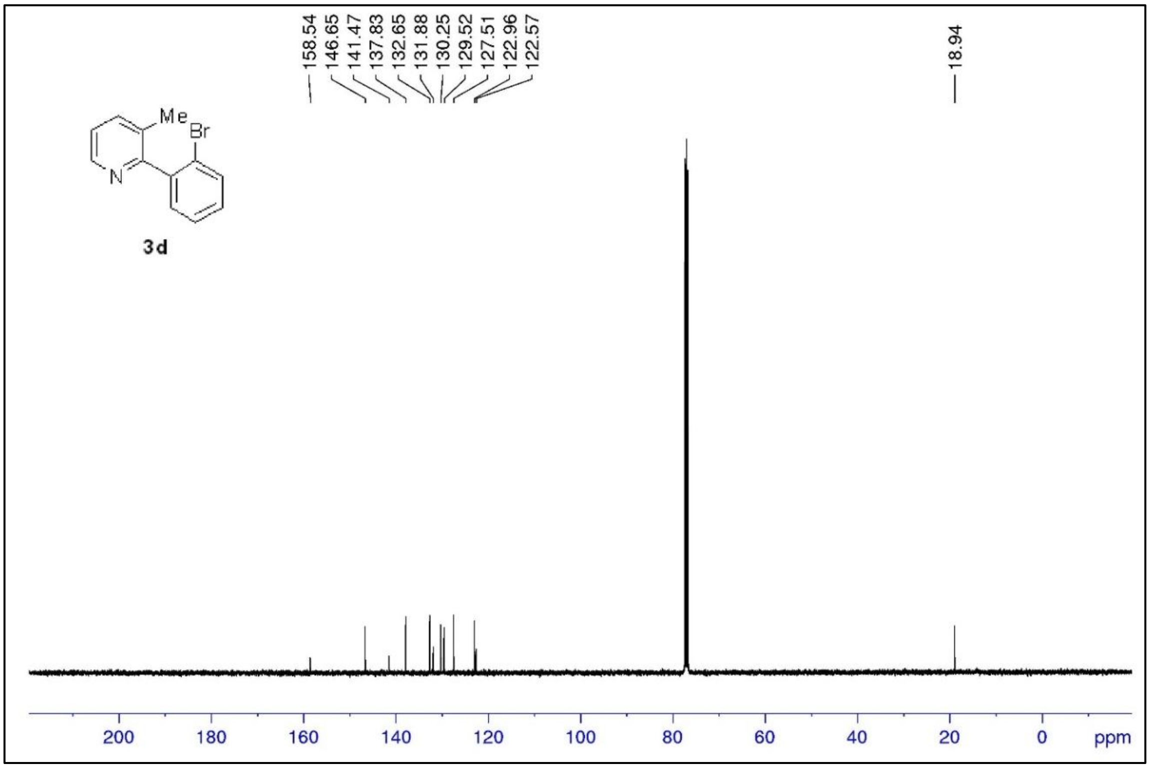
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130.25
129.52
127.51
122.96
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Me
Br
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40
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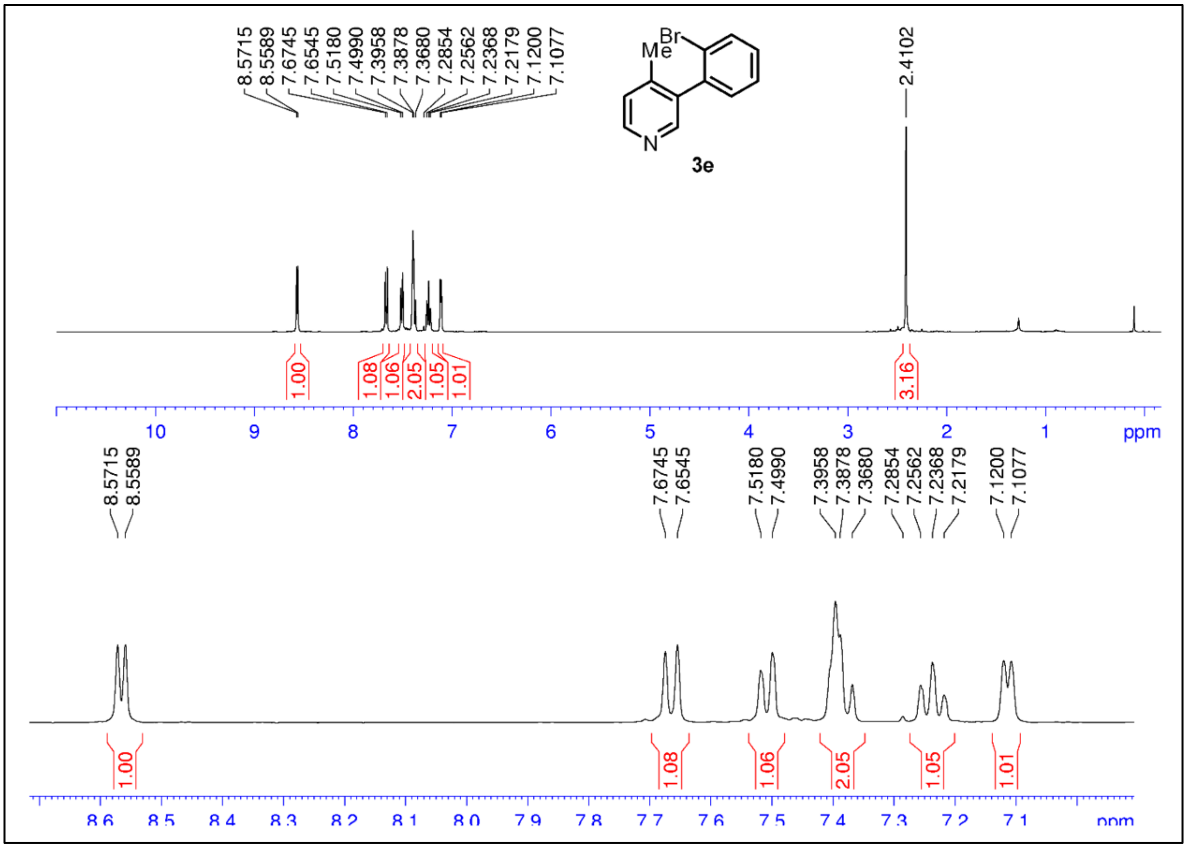
0
ppm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7.3958
7.3878
7.3680
7.2854
7.2562
7.2368
7.2179
7.1200
7.1077
2.4102
Me
Br
N
3e
1.00
1.08
1.06
2.05
1.05
1.01
3.16
10
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
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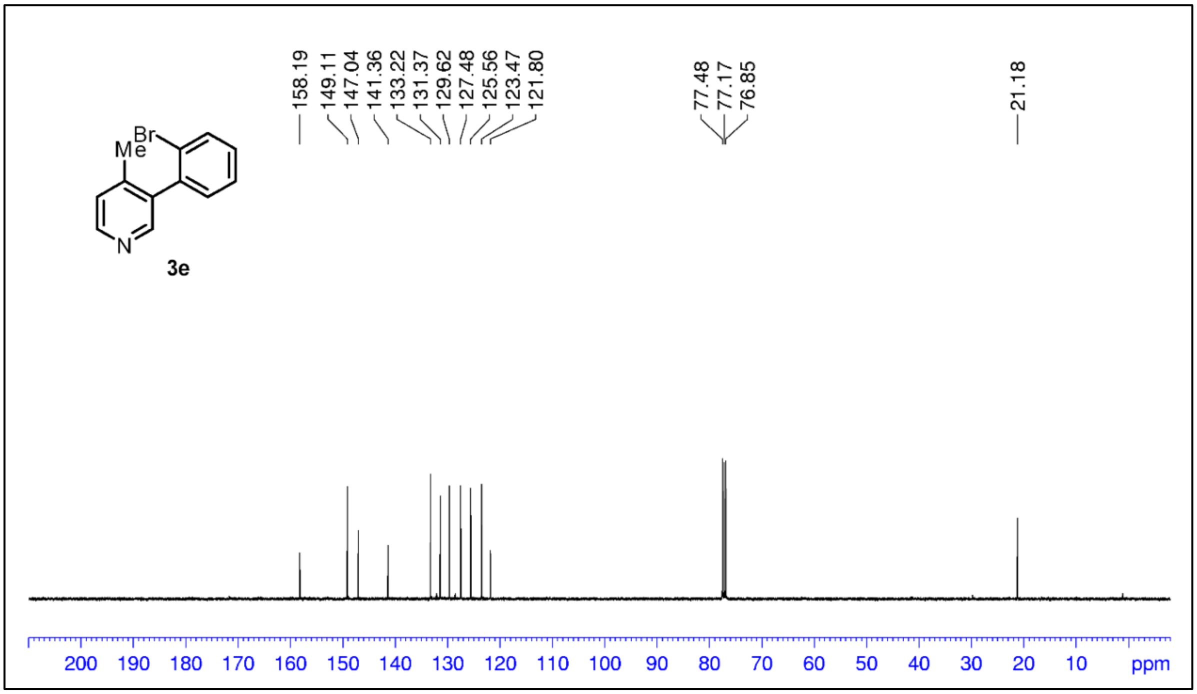
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm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147.04
141.36
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131.37
129.62
127.48
125.56
123.47
121.80
77.48
77.17
76.85
21.18
Me
Br
N
3e
200
190
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150
140
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110
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70
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30
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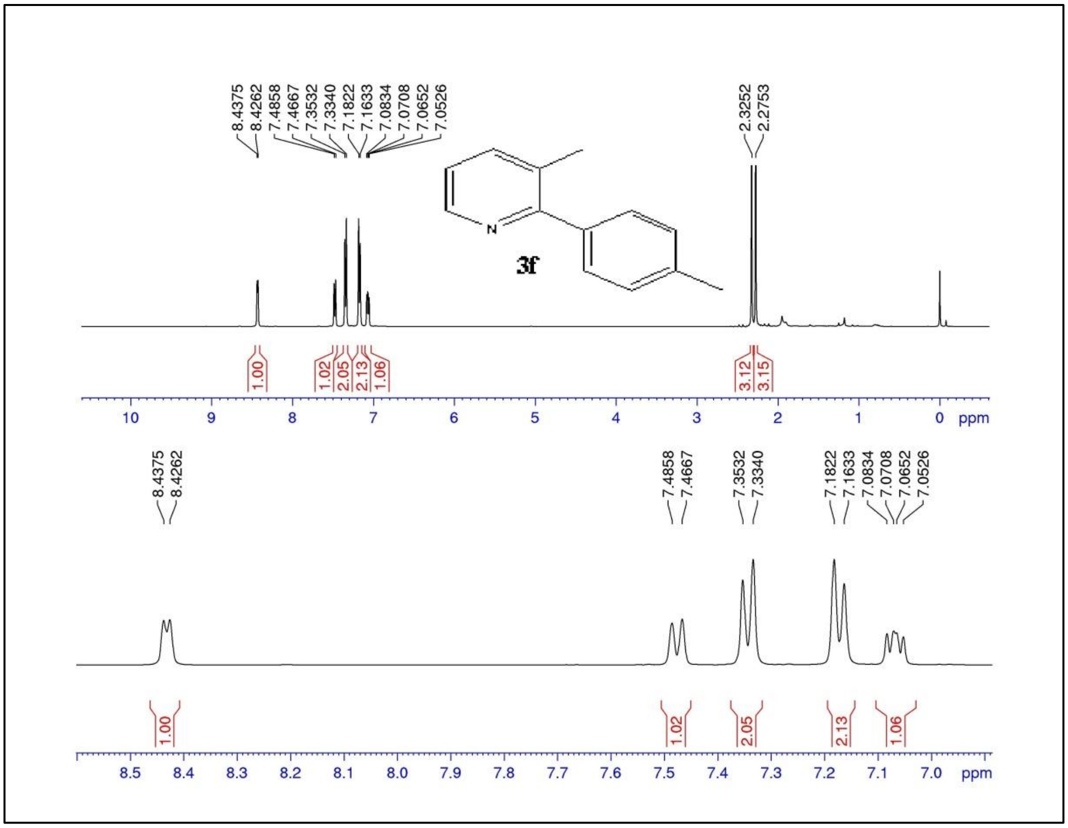
ppm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8.4262
7.4858
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7.1822
7.1633
7.0834
7.0708
7.0652
7.0526
2.3252
2.2753
N
3f
1.00
1.02
2.05
2.13
1.06
3.12
3.15
10 9 8 7 6 5 4 3 2 1 0 ppm
8.4375
8.4262
7.4858
7.4667
7.3532
7.3340
7.1822
7.1633
7.0834
7.0708
7.0652
7.0526
1.00
1.02
2.05
2.13
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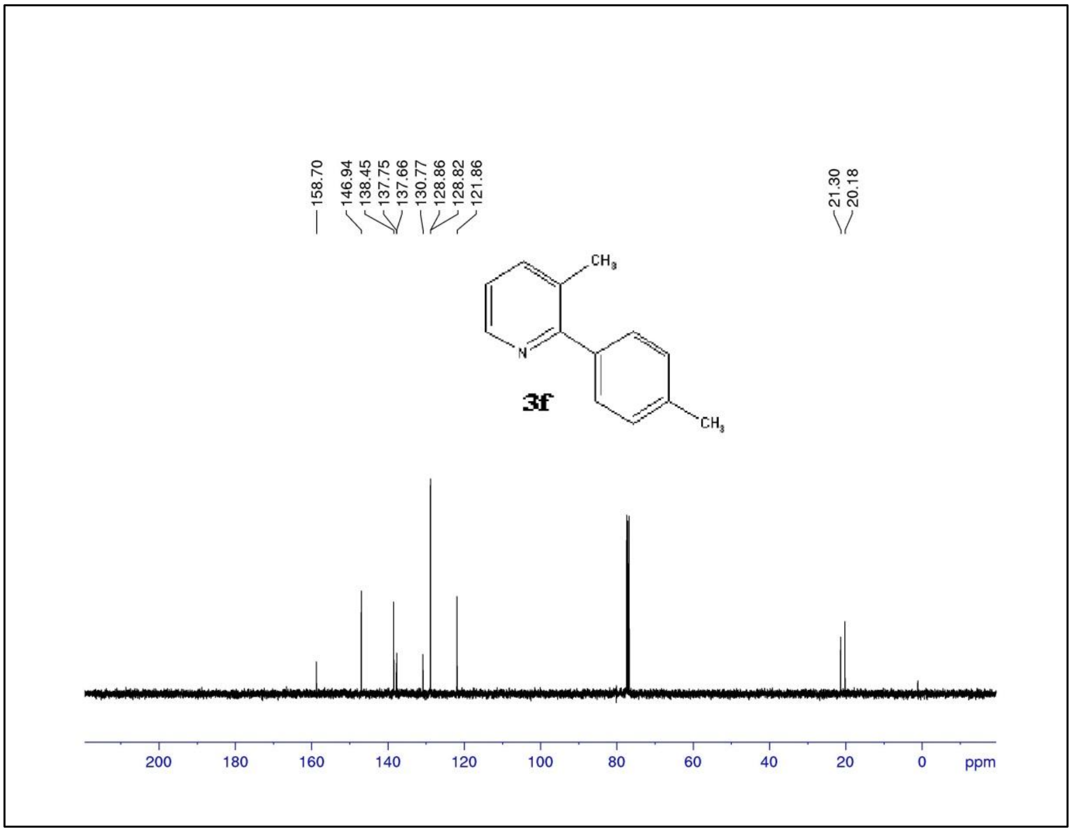
8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 ppm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128.82
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20.18
CH3
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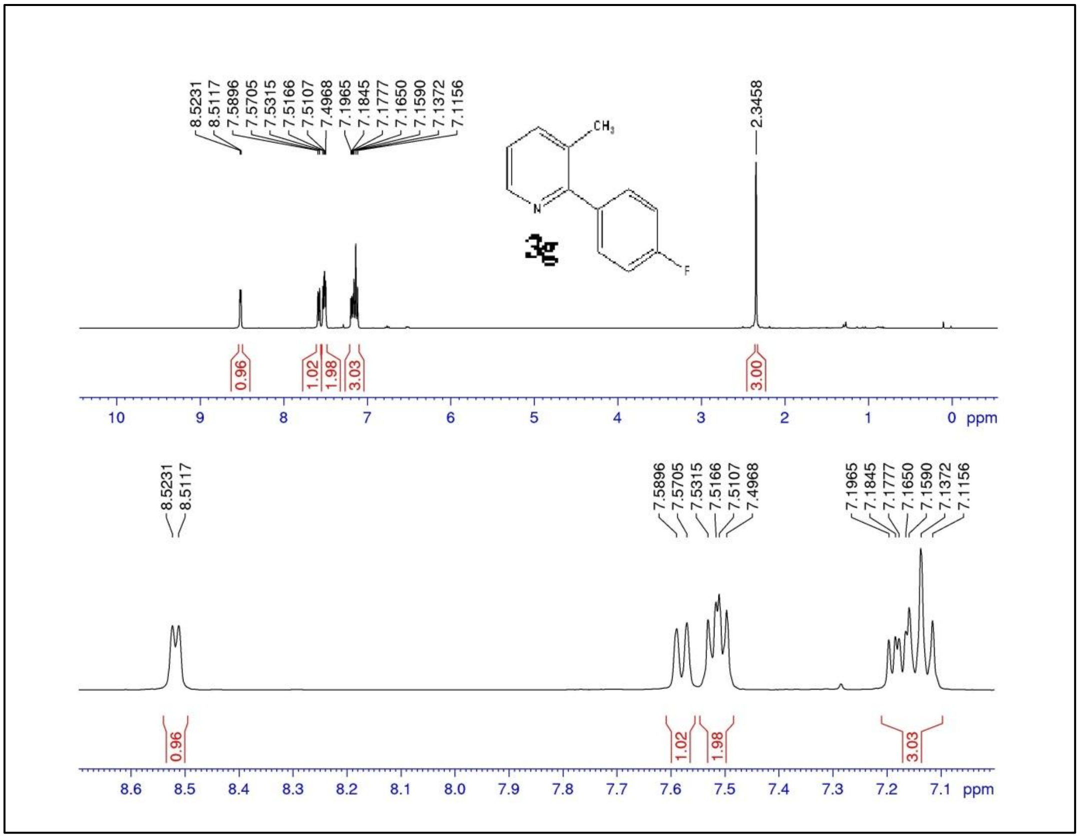
3f
CH3
200 180 160 140 120 100 80 60 40 20 0 ppm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8.5117
7.5896
7.5705
7.5315
7.5166
7.5107
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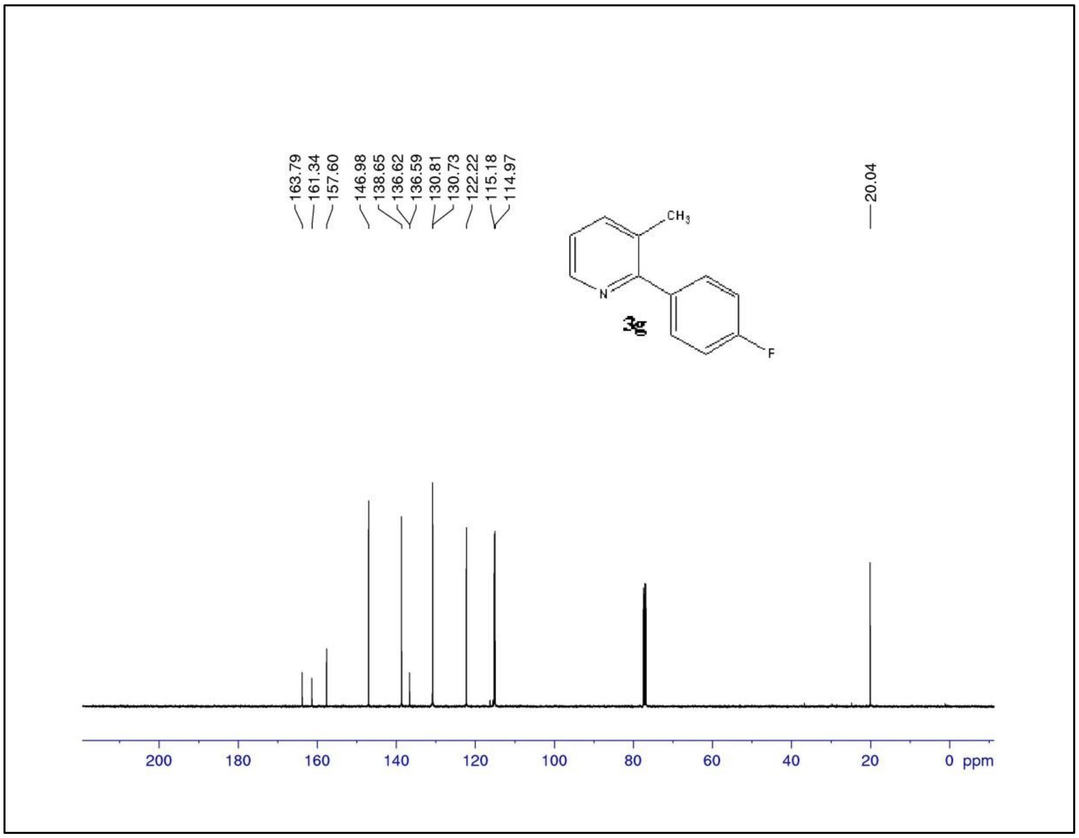
7.1965
7.1845
7.1777
7.1650
7.1590
7.1372
7.1156
2.3458
CH3
N
F
3g
0.96
1.02
1.98
3.03
3.00
10
9
8
7
6
5
4
3
2
1
0 ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1 ppm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161.34
157.60
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138.65
136.62
136.59
130.81
130.73
122.22
115.18
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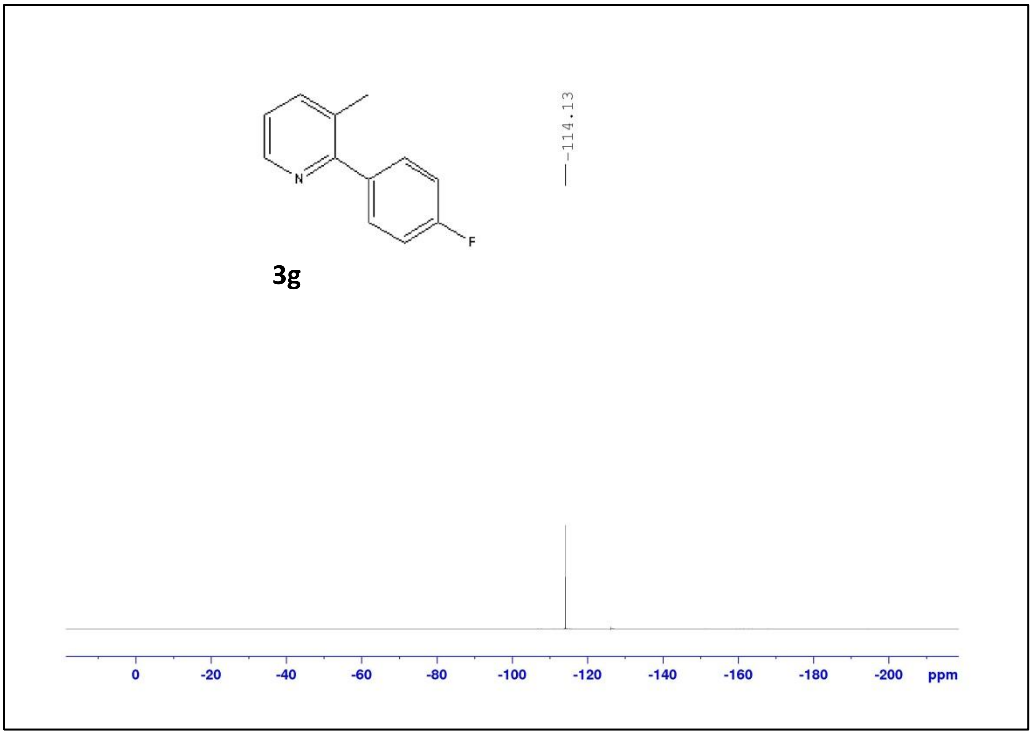
20.04
CH3
N
F
3g
200
180
160
140
120
100
80
60
40
20
0 ppm


3g

F
N
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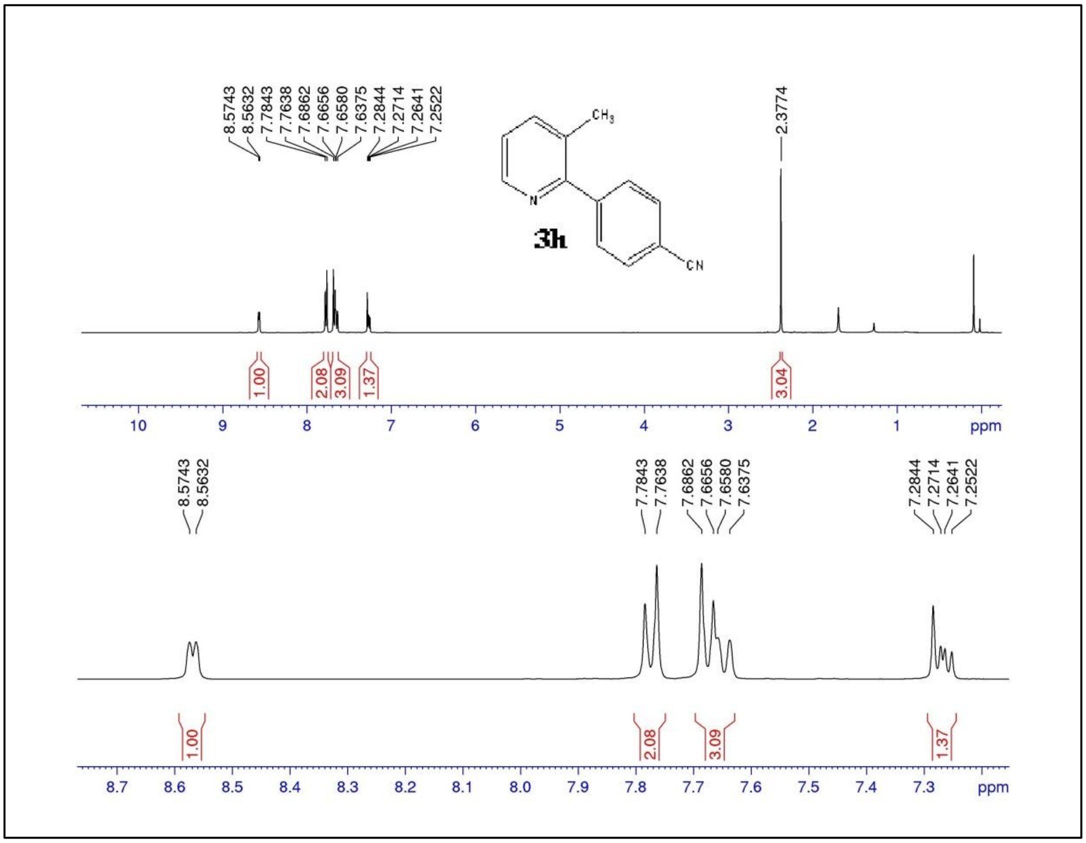
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm


3h

CH3
N
CN
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7.7638
7.6862
7.6656
7.6580
7.6375
7.2844
7.2714
7.2641
7.2522
2.3774
1.00
2.08
3.09
1.37
3.04
10
9
8
7
6
5
4
3
2
1
ppm
8.7
8.6
8.5
8.4
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8.1
8.0
7.9
7.8
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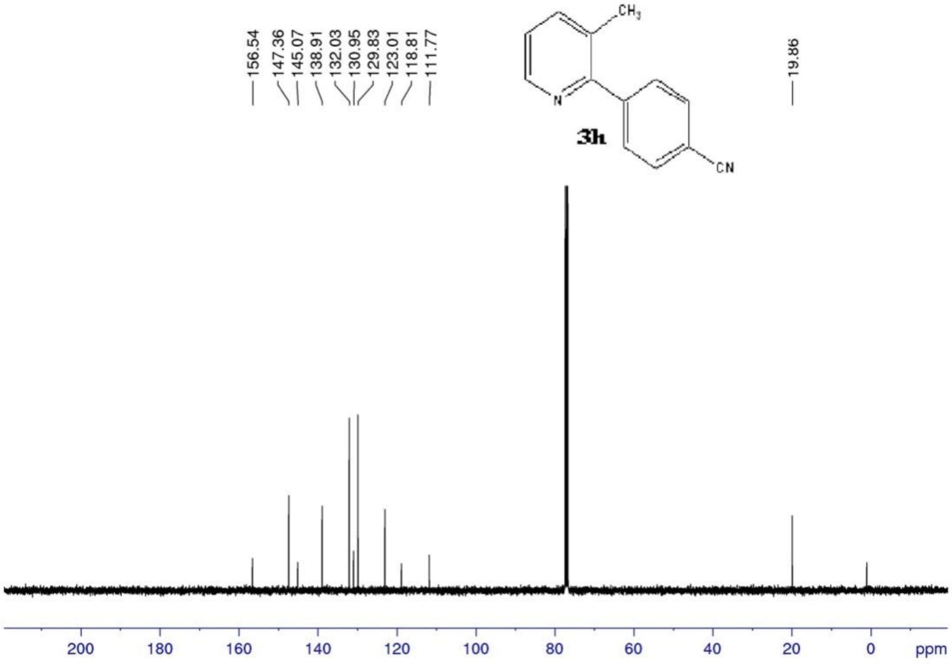
7.6
7.5
7.4
7.3
ppm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147.36
145.07
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130.95
129.83
123.01
118.81
111.77
19.86
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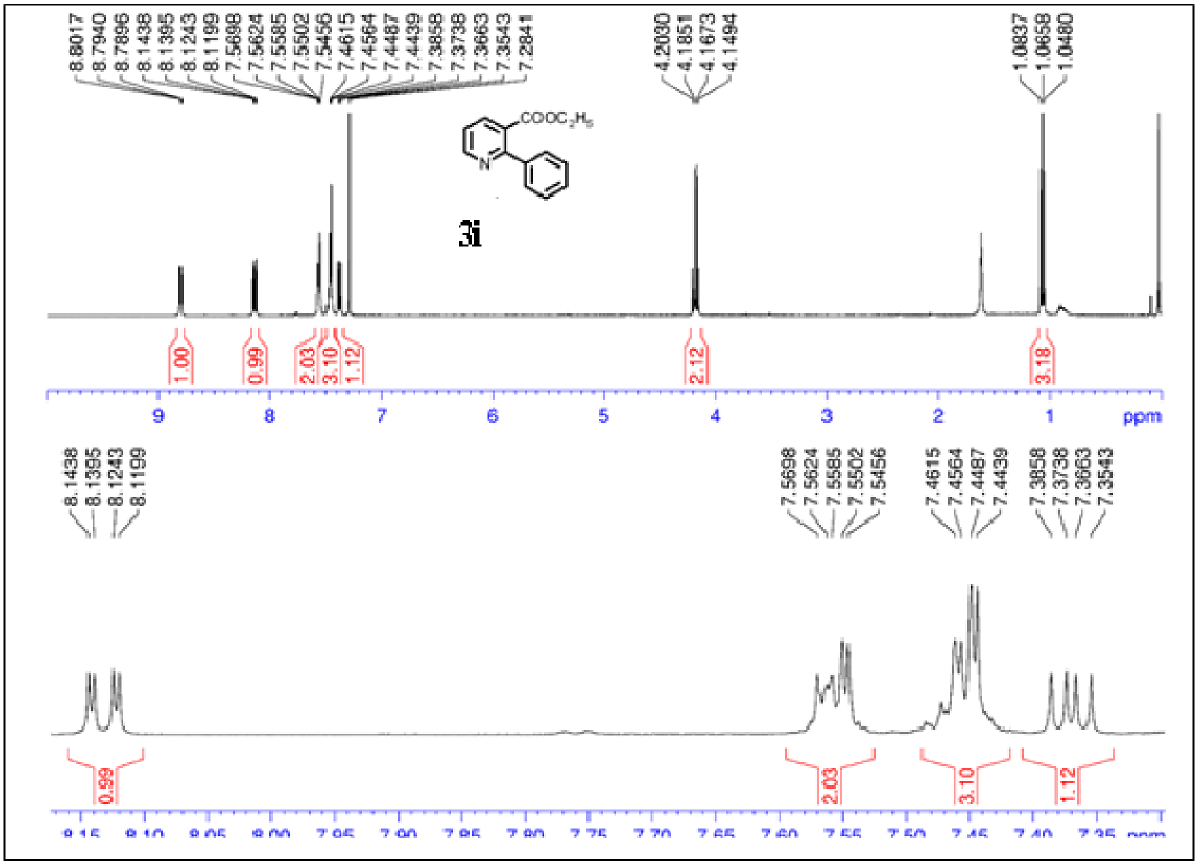
N
CN
3h
200
180
160
140
120
100
80
60
40
20
0
ppm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8.7896
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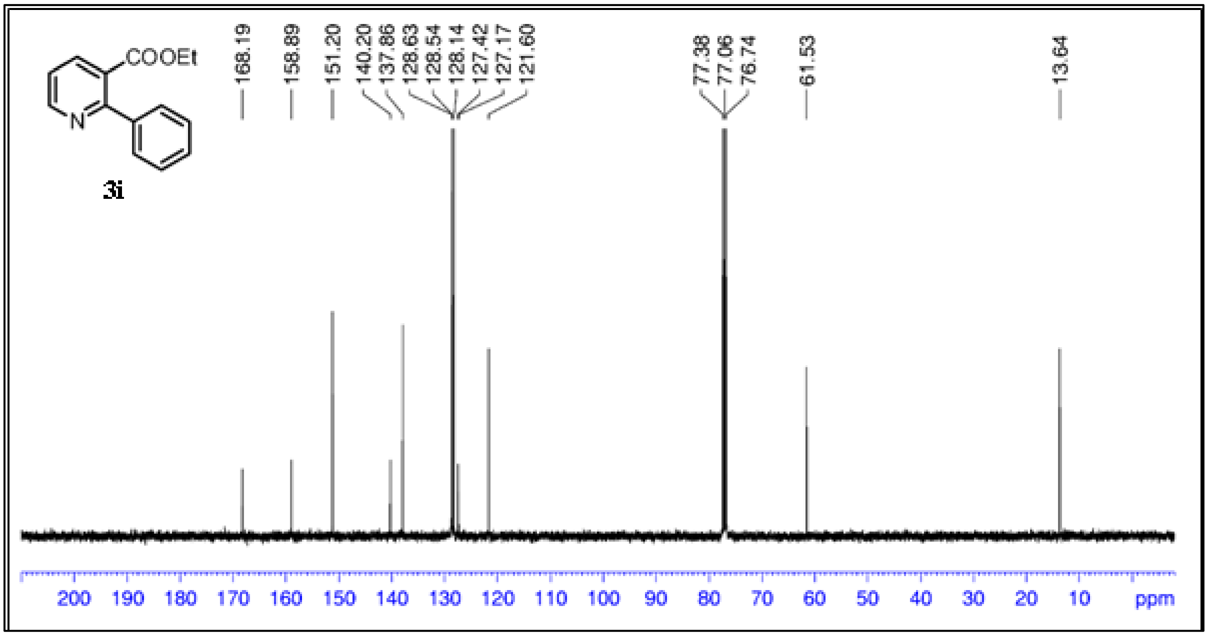
8.1395
8.1243
8.1199
7.5698
7.5624
7.5585
7.5502
7.5456
7.4615
7.4564
7.4487
7.4439
7.3858
7.3738
7.3663
7.3543
7.2841
4.2030
4.1851
4.1673
4.1494
1.0837
1.0658
1.0480
COOC$_2$H$_5$
N
3i
1.00
0.99
2.03
3.10
1.12
2.12
3.18
9
8
7
6
5
4
3
2
1
ppm
8.1438
8.1395
8.1243
8.1199
7.5698
7.5624
7.5585
7.5502
7.5456
7.4615
7.4564
7.4487
7.4439
7.3858
7.3738
7.3663
7.3543
0.99
2.03
3.10
1.12
8.15
8.10
8.05
8.00
7.95
7.90
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
ppm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151.20
140.20
137.86
128.63
128.54
128.14
127.42
127.17
121.60
77.38
77.06
76.74
61.53
13.64
200
190
180
170
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150
140
130
120
110
100
90
80
70
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50
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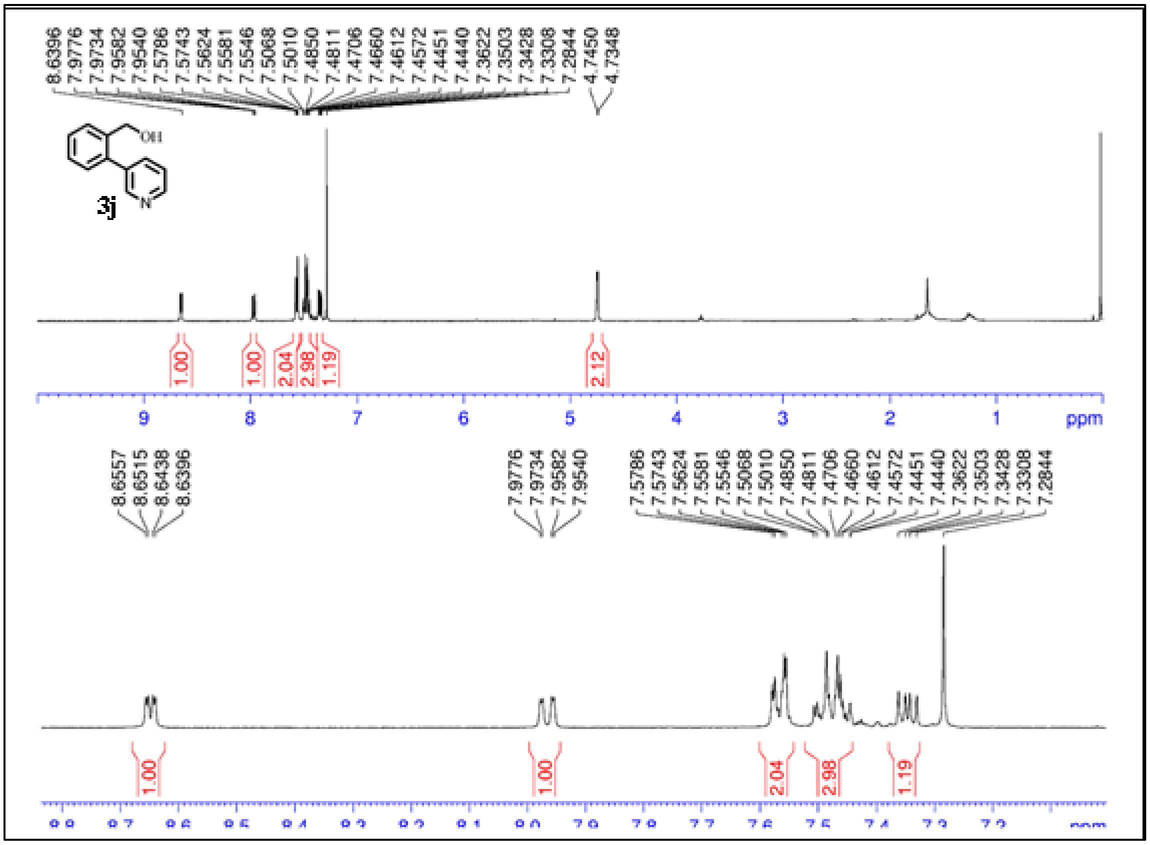
30
20
10
ppm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N
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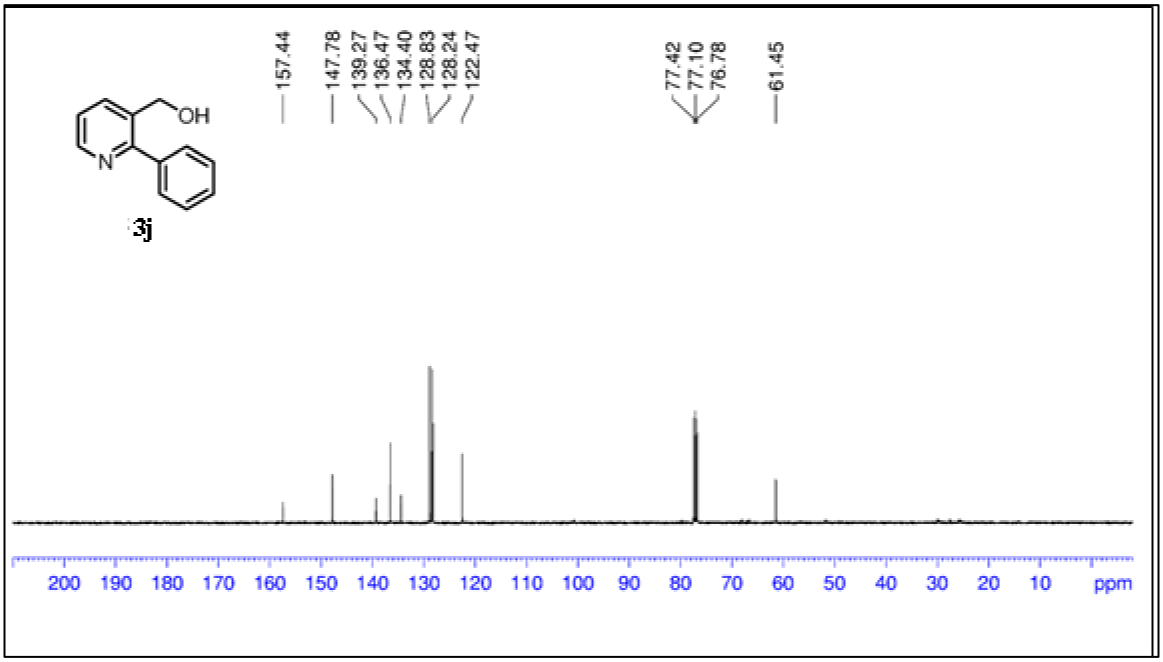
7.9582
7.9540
7.5786
7.5743
7.5624
7.5581
7.5546
7.5068
7.5010
7.4850
7.4811
7.4706
7.4660
7.4612
7.4572
7.4451
7.4440
7.3622
7.3503
7.3428
7.3308
7.2844
4.7450
4.7348
1.00
1.00
2.04
2.98
1.19
2.12
9
8
7
6
5
4
3
2
1
ppm
8.6557
8.6515
8.6438
8.6396
7.9776
7.9734
7.9582
7.9540
7.5786
7.5743
7.5624
7.5581
7.5546
7.5068
7.5010
7.4850
7.4811
7.4706
7.4660
7.4612
7.4572
7.4451
7.4440
7.3622
7.3503
7.3428
7.3308
7.2844
1.00
1.00
2.04
2.98
1.19


OH
N
3j
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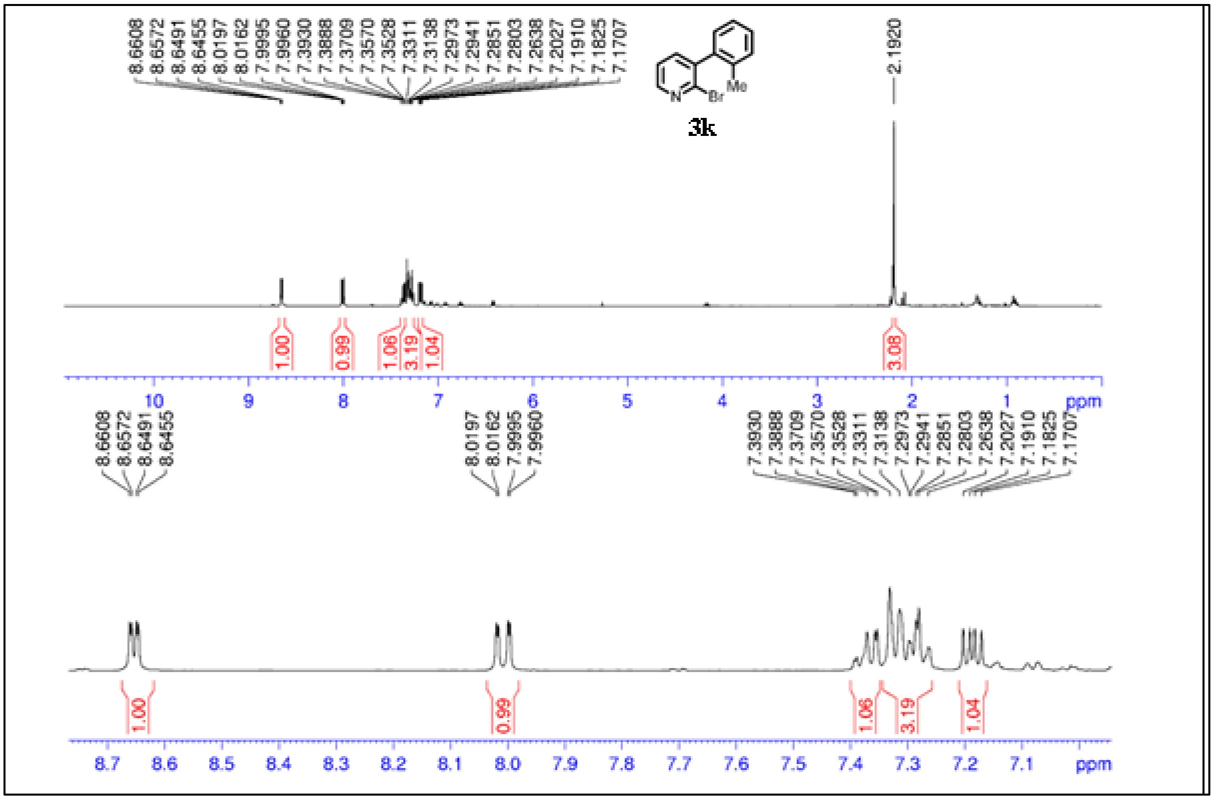
139.27
136.47
134.40
128.83
128.24
122.47
77.42
77.10
76.78
61.45
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm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8.6572
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8.6455
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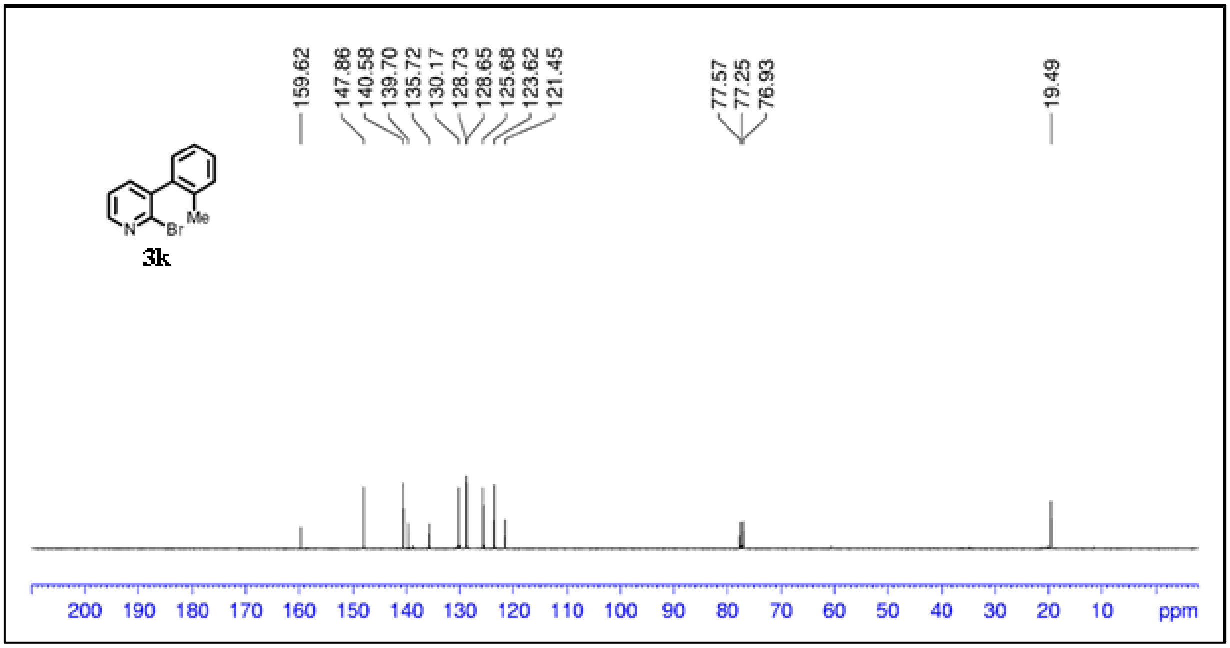
8.0162
7.9995
7.9960
7.3930
7.3888
7.3709
7.3570
7.3528
7.3311
7.3138
7.2973
7.2941
7.2851
7.2803
7.2638
7.2027
7.1910
7.1825
7.1707
2.1920
N
Br
Me
3k
1.00
0.99
1.06
3.19
1.04
3.08
10
9
8
7
6
5
4
3
2
1
ppm
8.6608
8.6572
8.6491
8.6455
8.0197
8.0162
7.9995
7.9960
7.3930
7.3888
7.3709
7.3570
7.3528
7.3311
7.3138
7.2973
7.2941
7.2851
7.2803
7.2638
7.2027
7.1910
7.1825
7.1707
1.00
0.99
1.06
3.19
1.04
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm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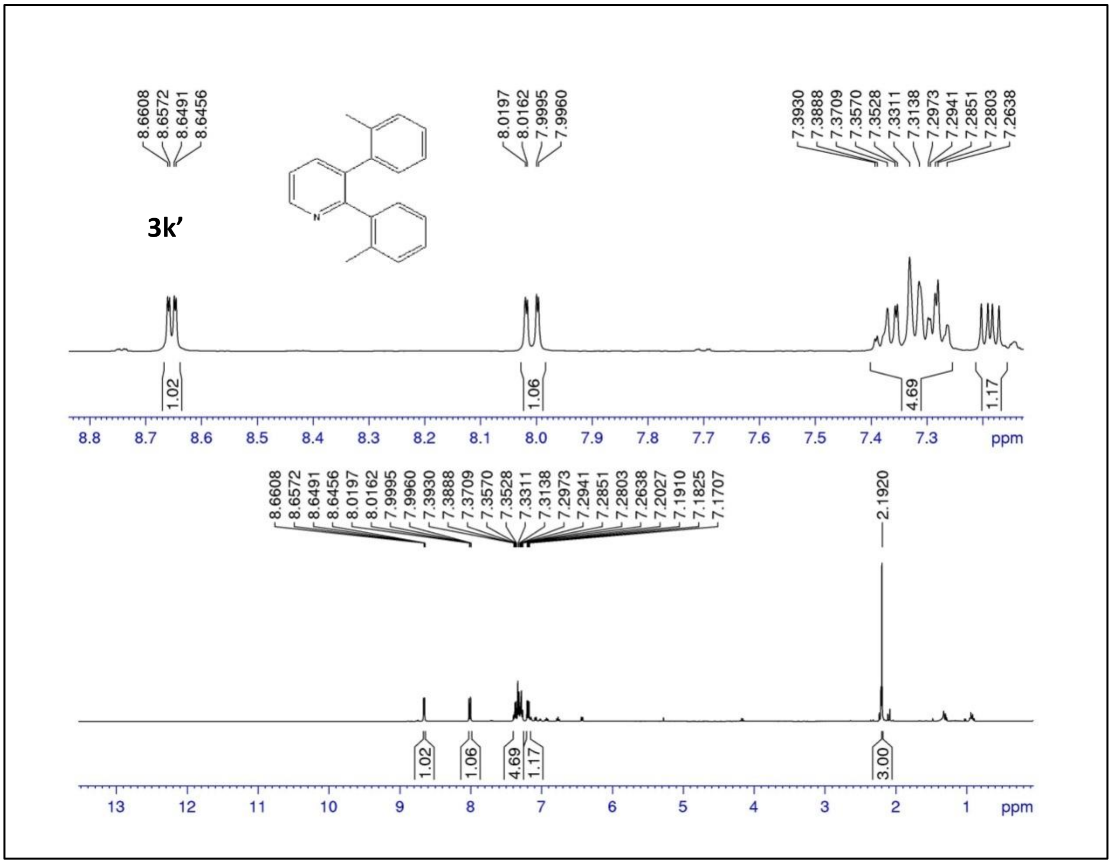
130.17
128.73
128.65
125.68
123.62
121.45
77.57
77.25
76.93
19.49
N
Br
Me
3k
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm


3k’

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8.6572
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8.6456
8.0197
8.0162
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7.9960
7.3930
7.3888
7.3709
7.3570
7.3528
7.3311
7.3138
7.2973
7.2941
7.2851
7.2803
7.2638
N
1.02
1.06
4.69
1.17
8.8 8.7 8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 ppm
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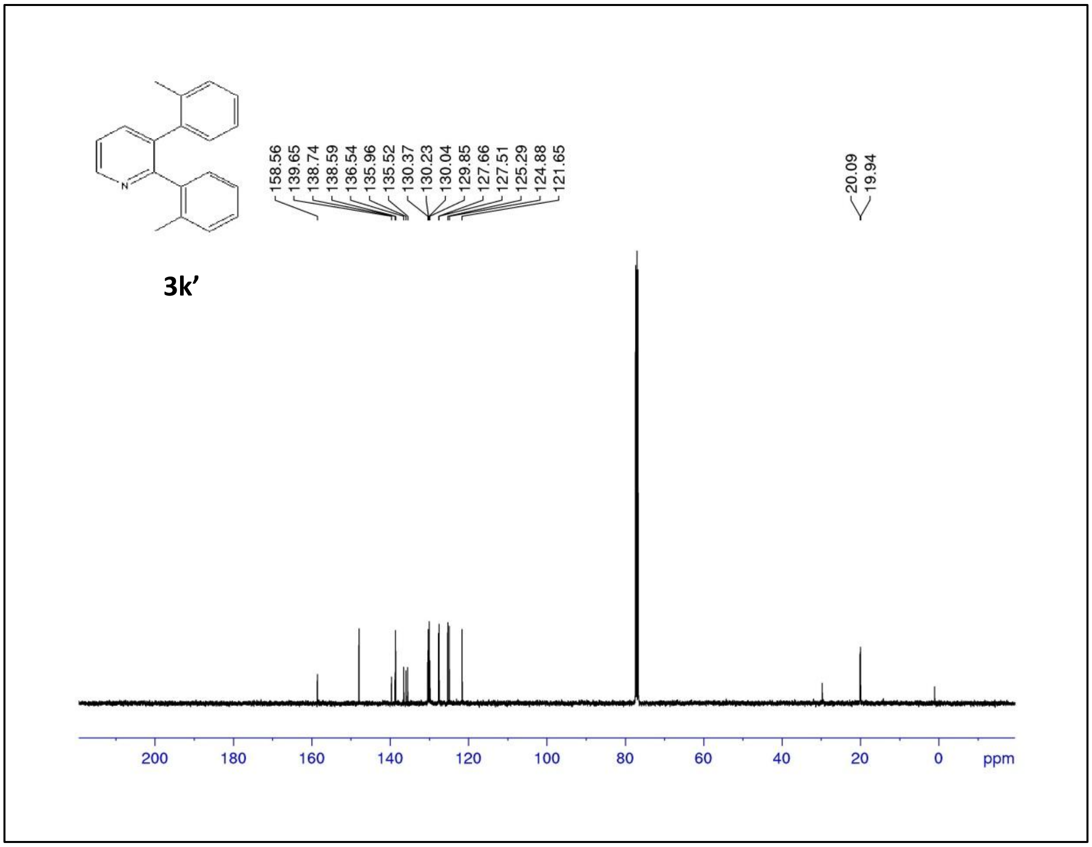
8.6572
8.6491
8.6456
8.0197
8.0162
7.9995
7.9960
7.3930
7.3888
7.3709
7.3570
7.3528
7.3311
7.3138
7.2973
7.2941
7.2851
7.2803
7.2638
7.2027
7.1910
7.1825
7.1707
2.1920
1.02
1.06
4.69
1.17
3.00
13 12 11 10 9 8 7 6 5 4 3 2 1 ppm


N
3k’
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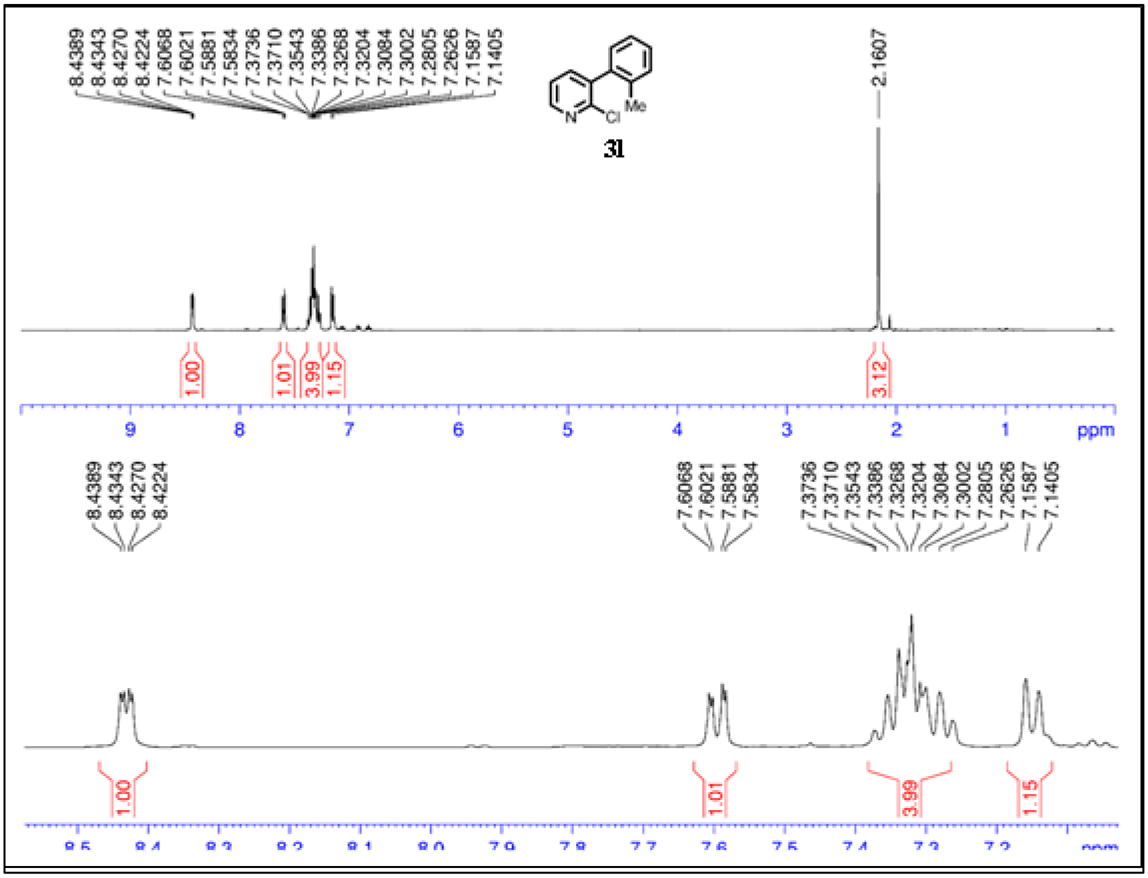
135.96
135.52
130.37
130.23
130.04
129.85
127.66
127.51
125.29
124.88
121.65
20.09
19.94
200
180
160
140
120
100
80
60
40
20
0
ppm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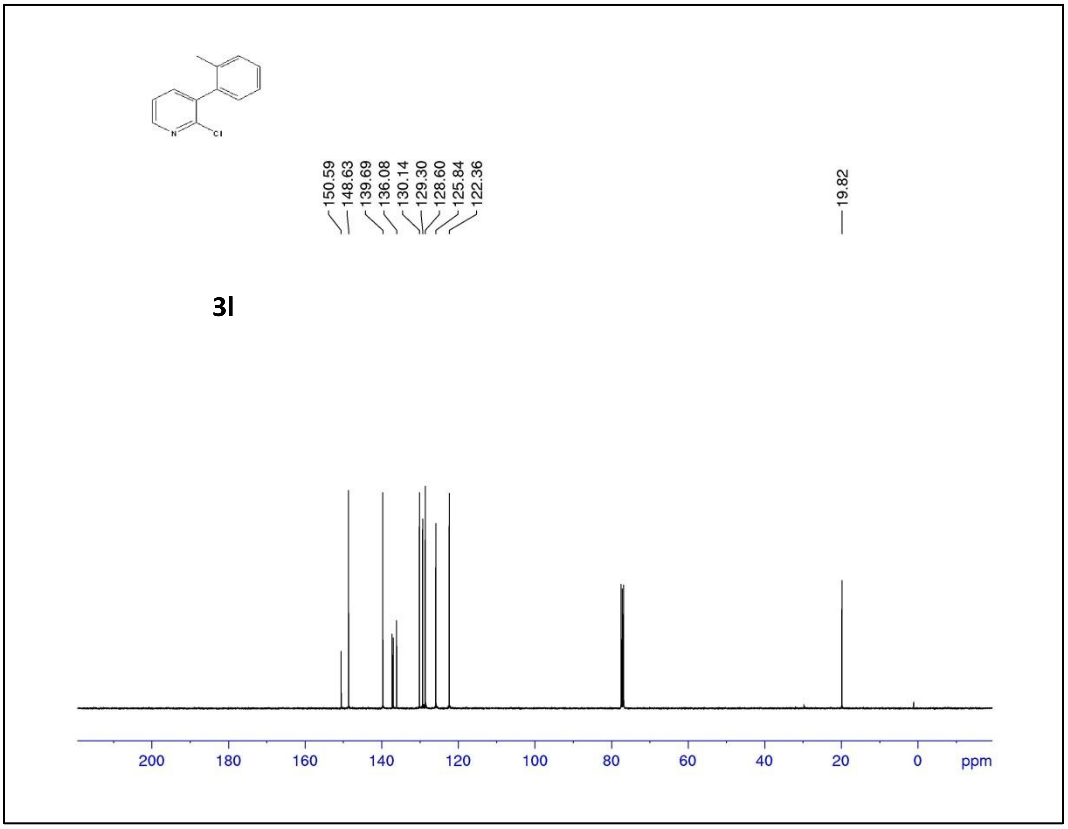
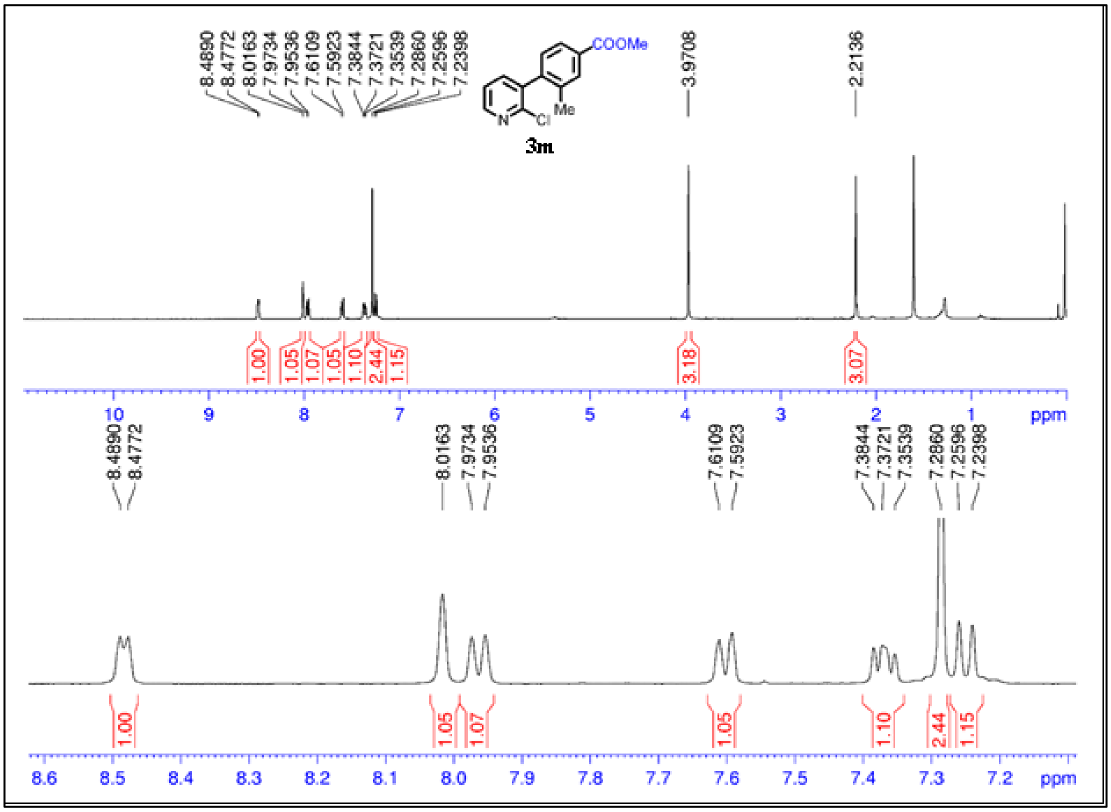
7.3736
7.3710
7.3543
7.3386
7.3268
7.3204
7.3084
7.3002
7.2805
7.2626
7.1587
7.1405
2.1607
N
Cl
Me
31
1.00
1.01
3.99
1.15
3.12
9
8
7
6
5
4
3
2
1
ppm
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm


3l

150.59
148.63
139.69
136.08
130.14
129.30
128.60
125.84
122.36
19.82
N
Cl
200
180
160
140
120
100
80
60
40
20
0
ppm


3m

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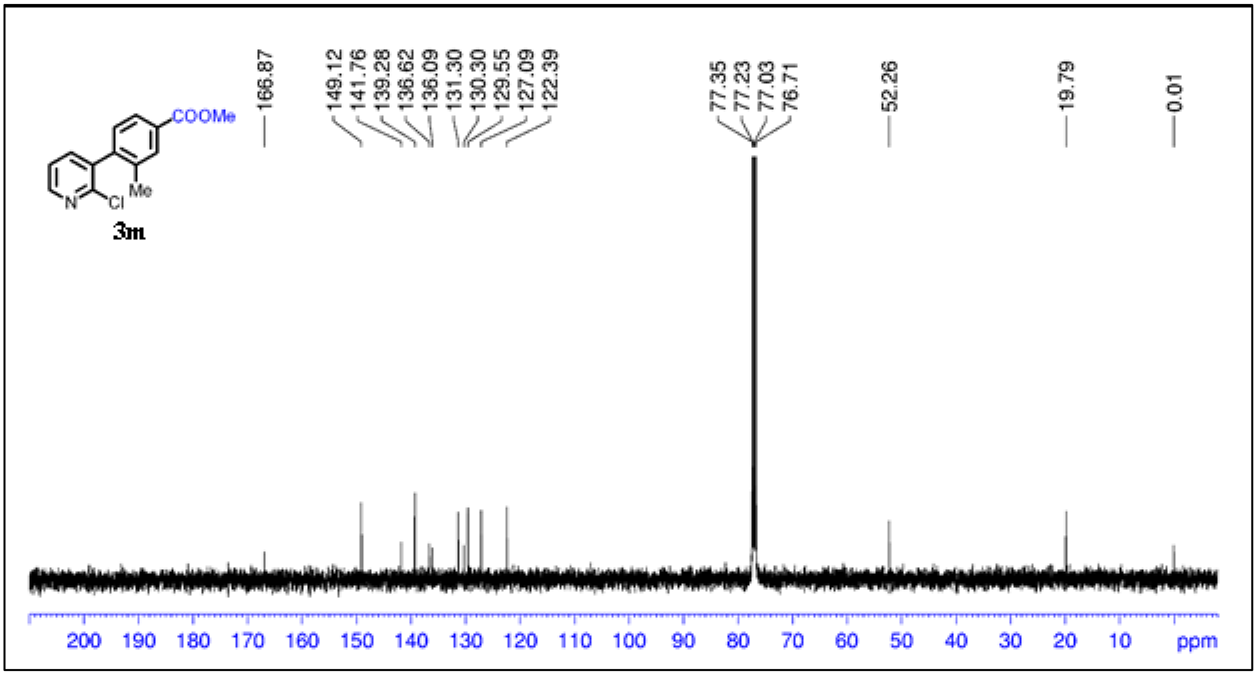
7.9536
7.6109
7.5923
7.3844
7.3721
7.3539
7.2860
7.2596
7.2398
COOMe
Me
N
Cl
3.9708
2.2136
1.00
1.05
1.07
1.05
1.10
2.44
1.15
3.18
3.07
10
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm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COOMe
Me
N
Cl
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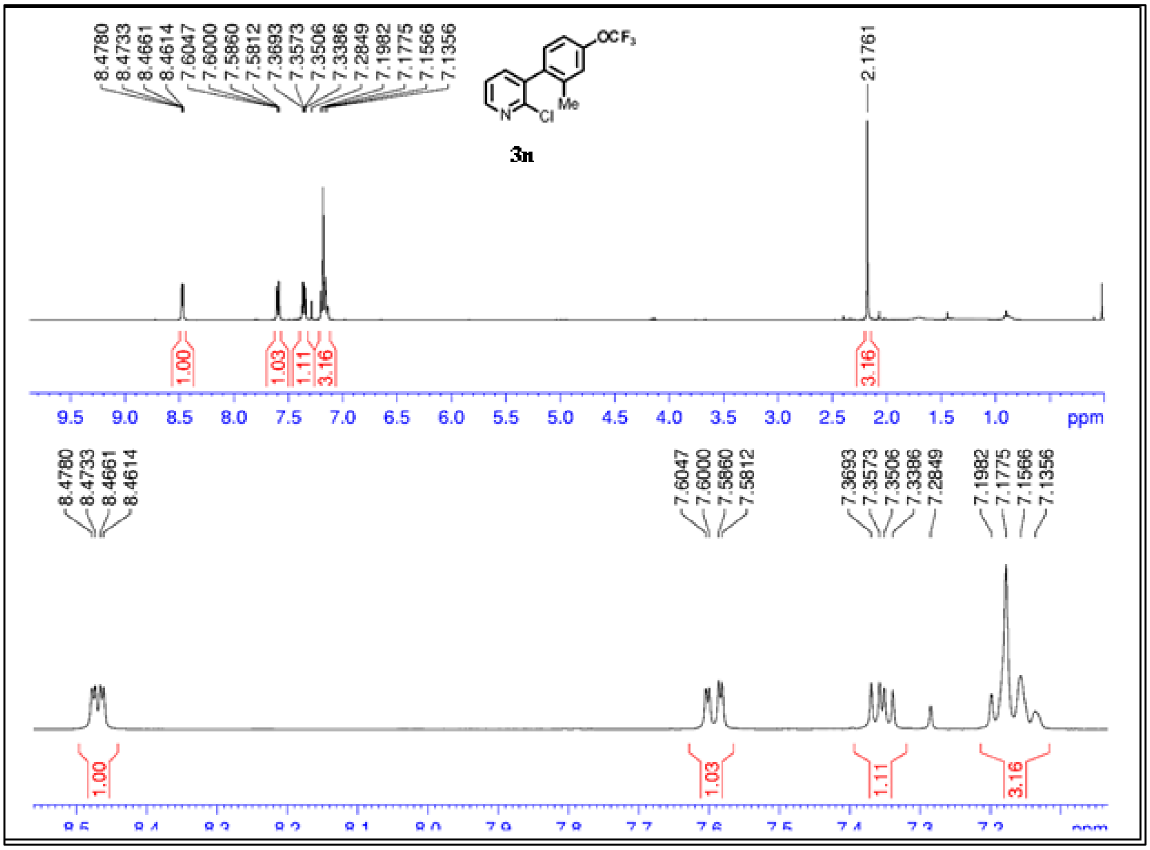
136.09
131.30
130.30
129.55
127.09
122.39
77.35
77.23
77.03
76.71
52.26
19.79
0.01
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm


3n
OCF3
Me
N
Cl
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8.4614
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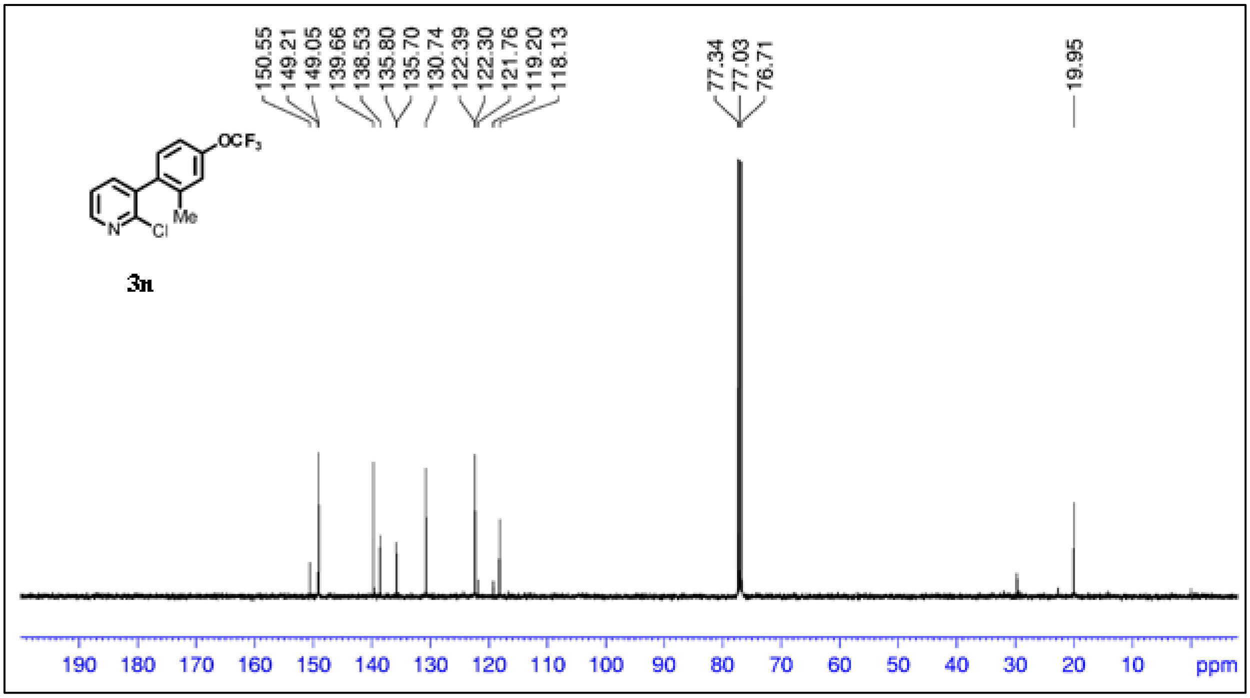
7.6000
7.5860
7.5812
7.3693
7.3573
7.3506
7.3386
7.2849
7.1982
7.1775
7.1566
7.1356
2.1761
1.00
1.03
1.11
3.16
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 ppm
8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 ppm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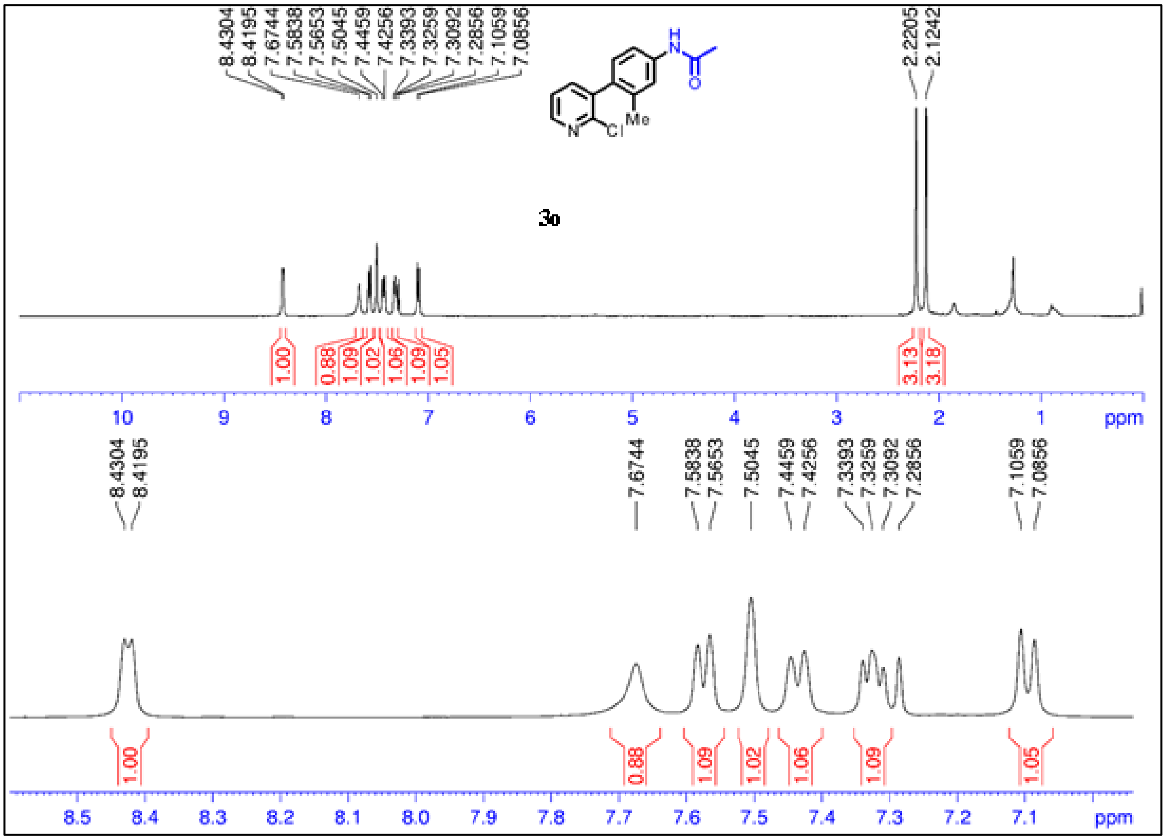
135.80
135.70
130.74
122.39
122.30
121.76
119.20
118.13
77.34
77.03
76.71
19.95
OCF₃
N
Cl
Me
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

3n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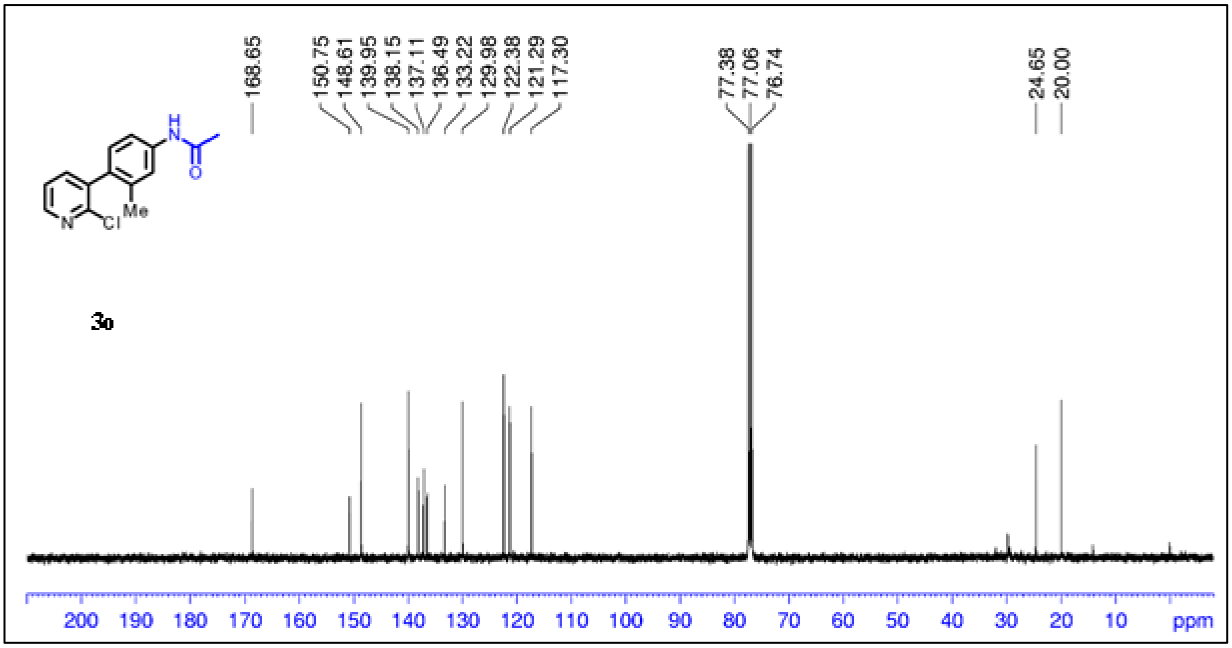
8.4195
7.6744
7.5838
7.5653
7.5045
7.4459
7.4256
7.3393
7.3259
7.3092
7.2856
7.1059
7.0856
2.2205
2.1242
H
N
O
N
Cl
Me
1.00
0.88
1.09
1.02
1.06
1.09
1.05
3.13
3.18
10
9
8
7
6
5
4
3
2
1
ppm
8.4304
8.4195
7.6744
7.5838
7.5653
7.5045
7.4459
7.4256
7.3393
7.3259
7.3092
7.2856
7.1059
7.0856
1.00
0.88
1.09
1.02
1.06
1.09
1.05
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm

3o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77.06
76.74
24.65
20.00
H
N
O
N
Cl
Me
3o
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30
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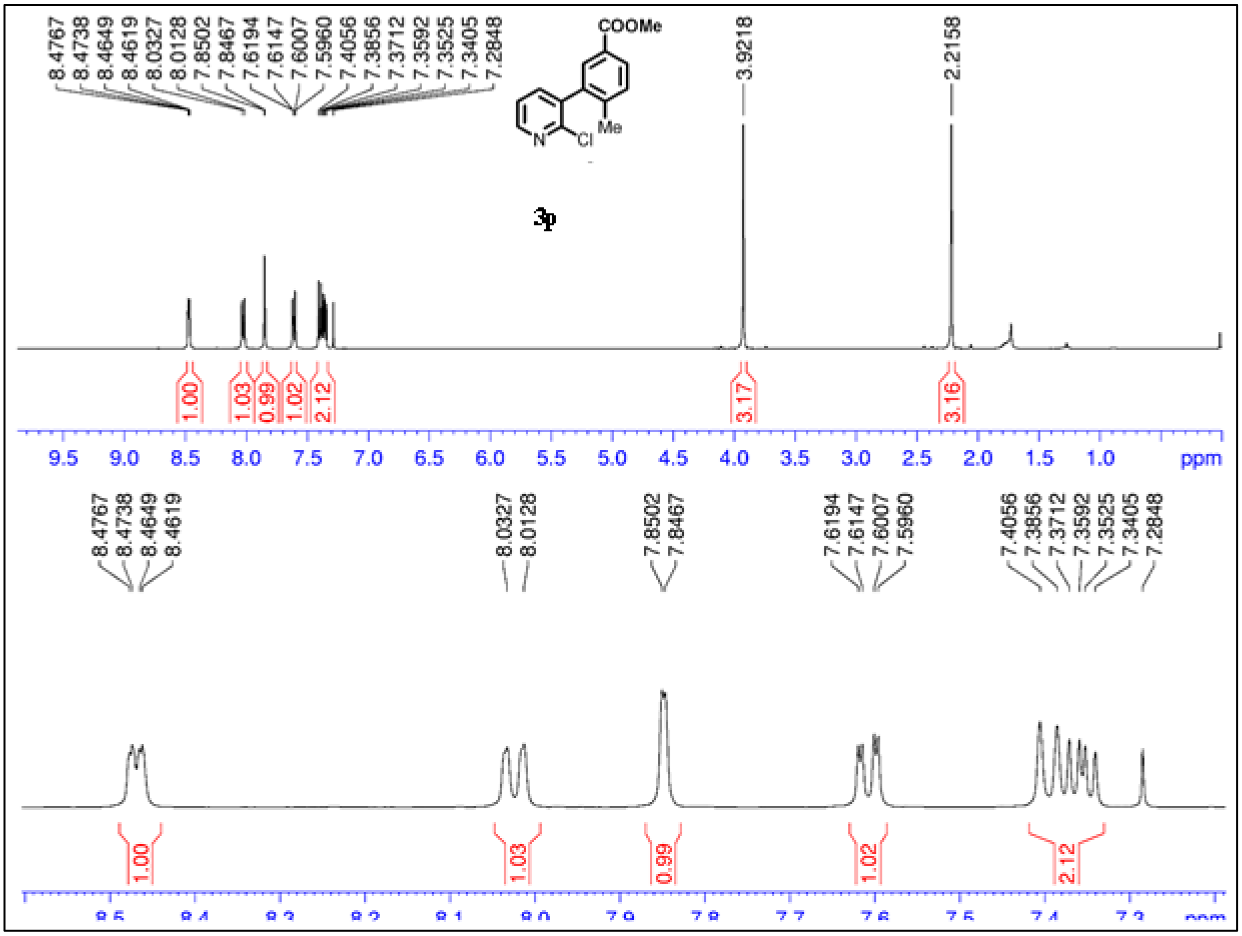
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7.5960
7.4056
7.3856
7.3712
7.3592
7.3525
7.3405
7.2848
COOMe
Me
N
Cl
3p
3.9218
2.2158
1.00
1.03
0.99
1.02
2.12
3.17
3.16
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm
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8.1
8.0
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7.6
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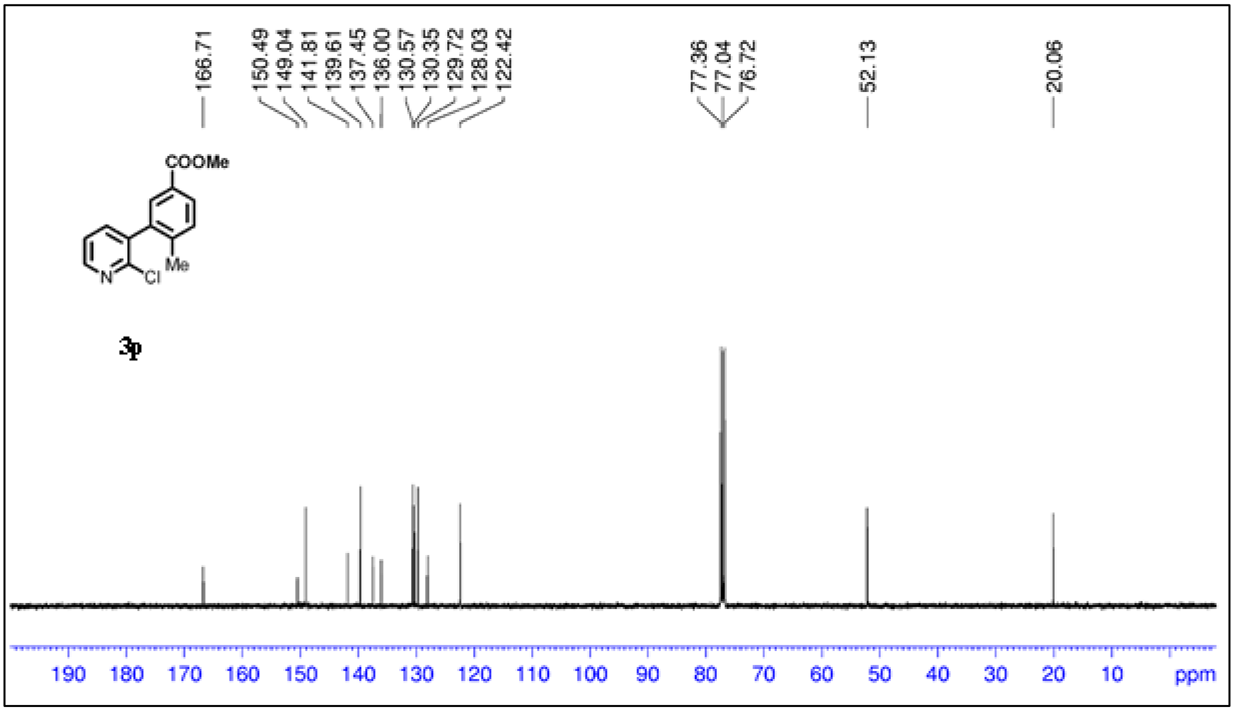
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77.04
76.72
52.13
20.06
COOMe
Me
N
Cl
3p
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150
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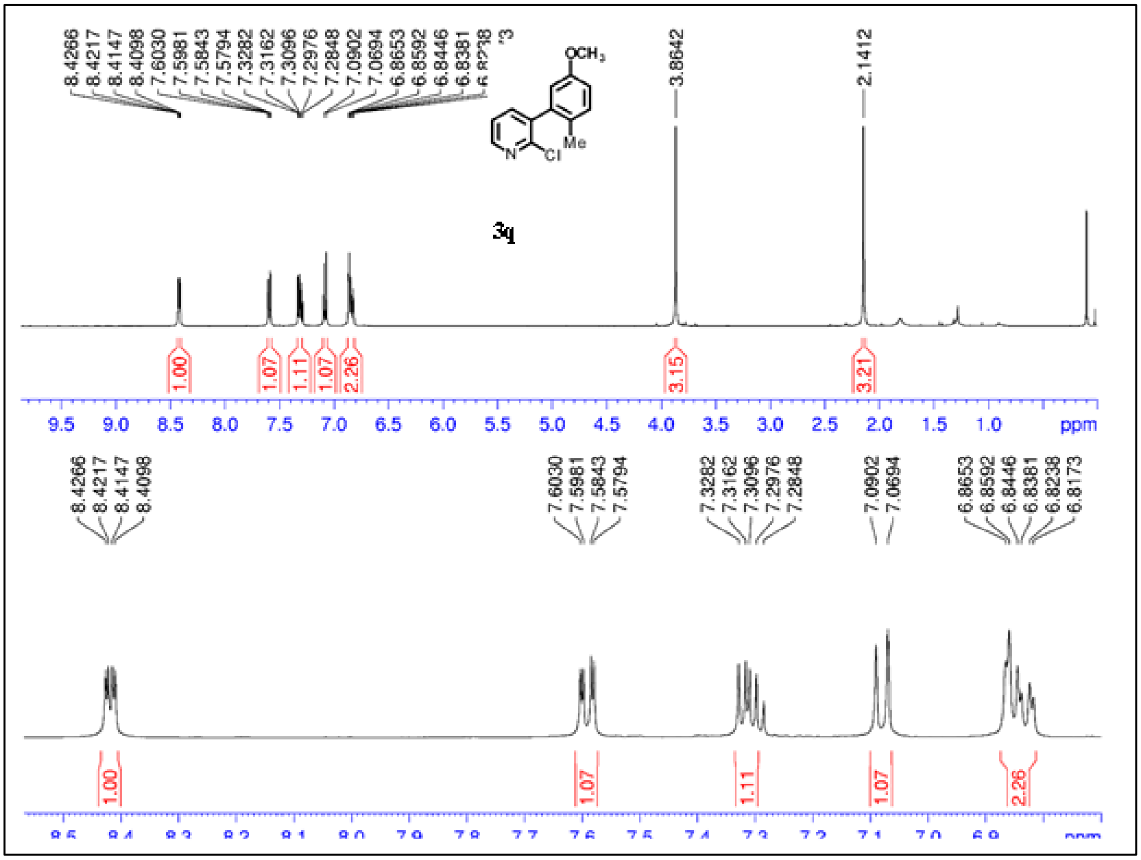
ppm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7.2976
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7.0694
6.8653
6.8592
6.8446
6.8381
6.8238
3.8642
2.1412
OCH3
Me
N
Cl
3q
1.00
1.07
1.11
1.07
2.26
3.15
3.21
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 ppm
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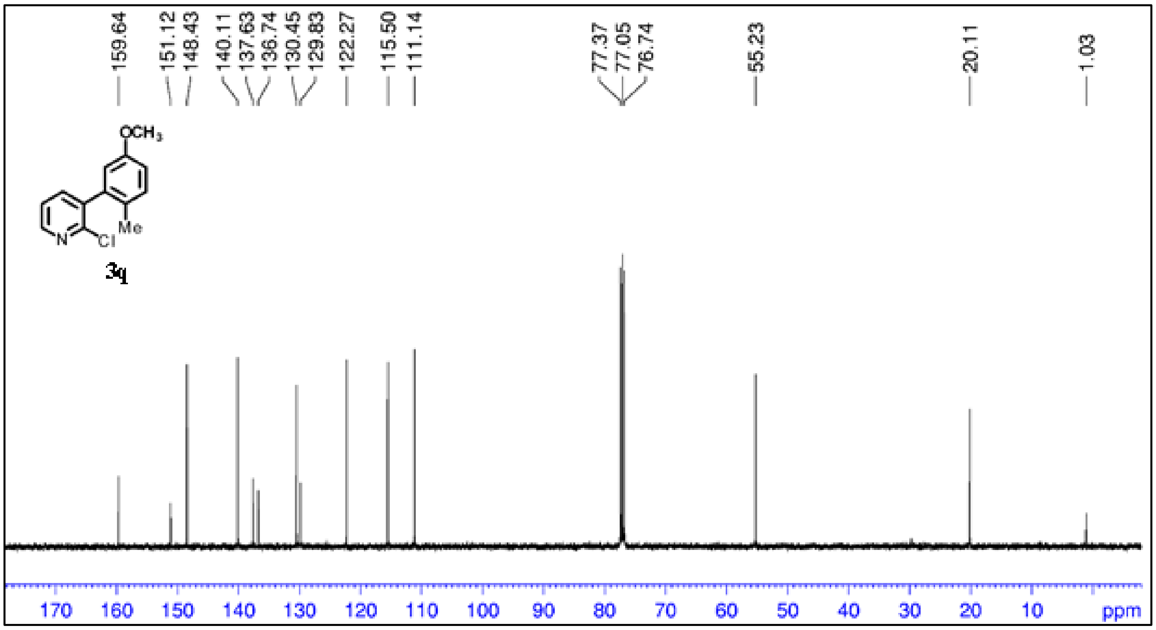
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129.83
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115.50
111.14
77.37
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1.03
OCH3
Me
N
Cl
3q
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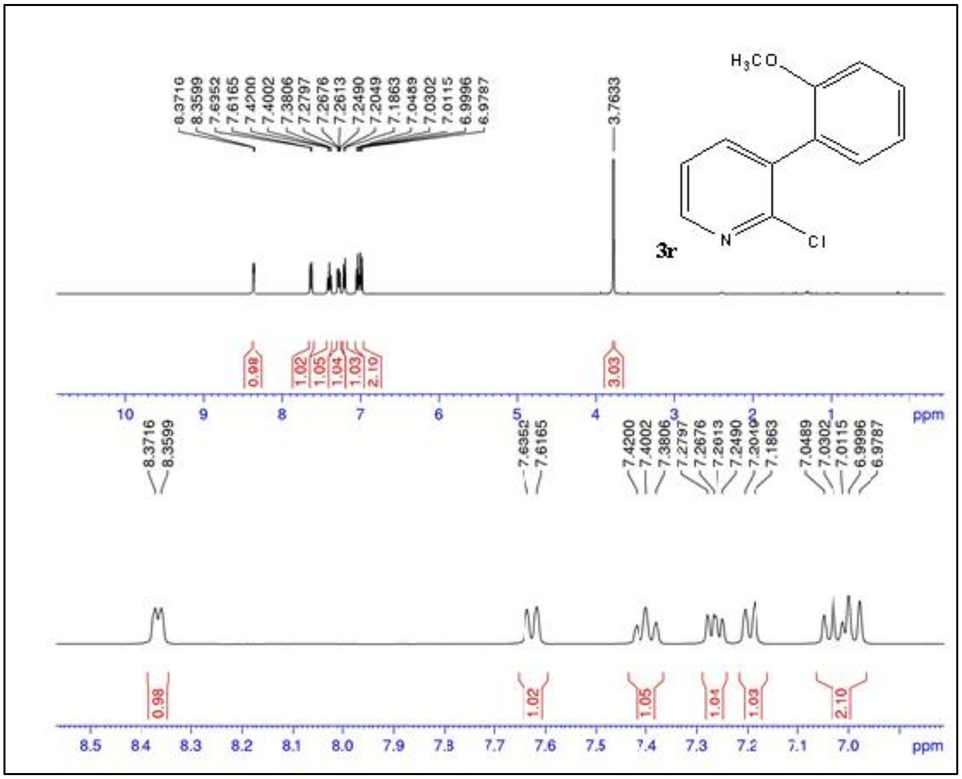
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7.2613
7.2490
7.2049
7.1863
7.0489
7.0302
7.0115
6.9996
6.9787
3.7633
H3CO
N
Cl
3r
0.98
1.02
1.05
1.04
1.03
2.10
3.03
10
9
8
7
6
5
4
3
2
1
ppm
8.5
8.4
8.3
8.2
8.1
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7.8
7.7
7.6
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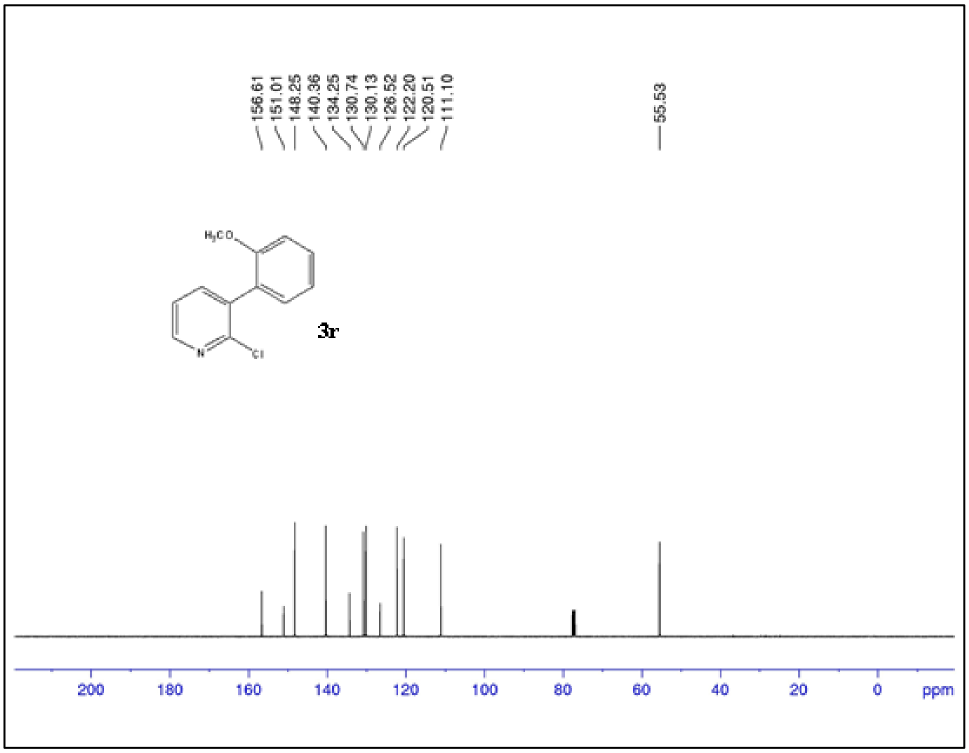
7.3
7.2
7.1
7.0
ppm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126.52
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120.51
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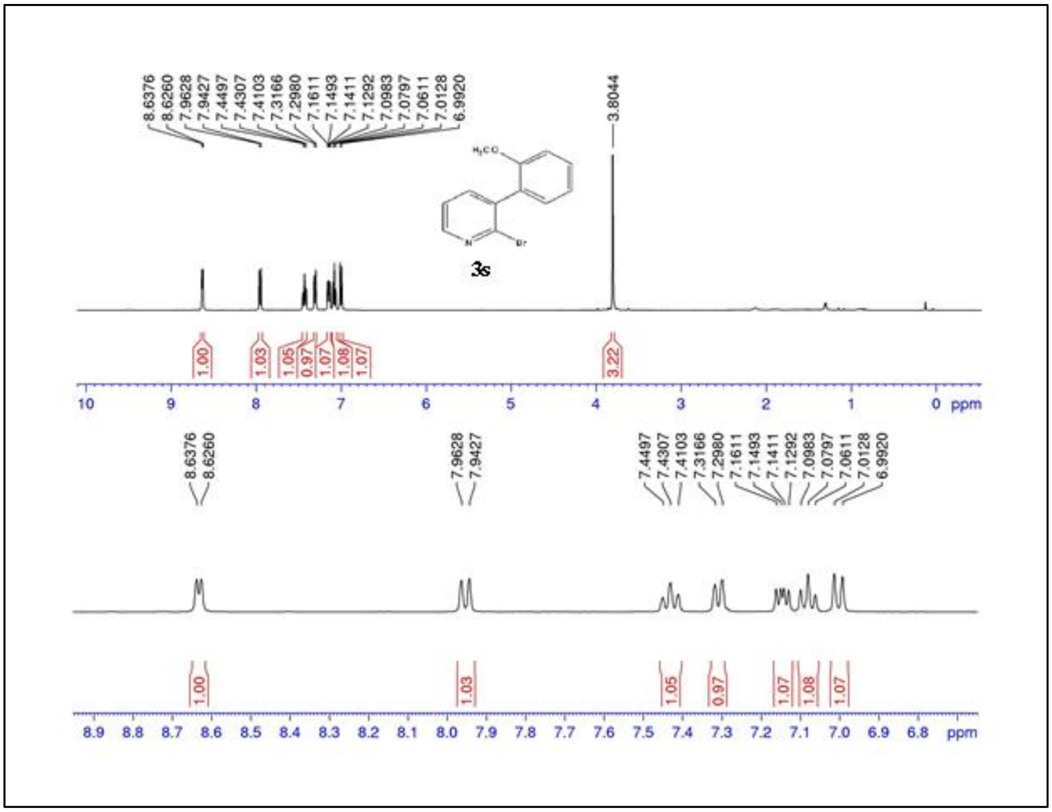
N
Cl
3r
200
180
160
140
120
100
80
60
40
20
0
ppm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7.4103
7.3166
7.2980
7.1611
7.1493
7.1411
7.1292
7.0983
7.0797
7.0611
7.0128
6.9920
3.8044
H3CO
N
Br
3s
1.00
1.03
1.05
0.97
1.07
1.08
1.07
3.22
10
9
8
7
6
5
4
3
2
1
0
ppm
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
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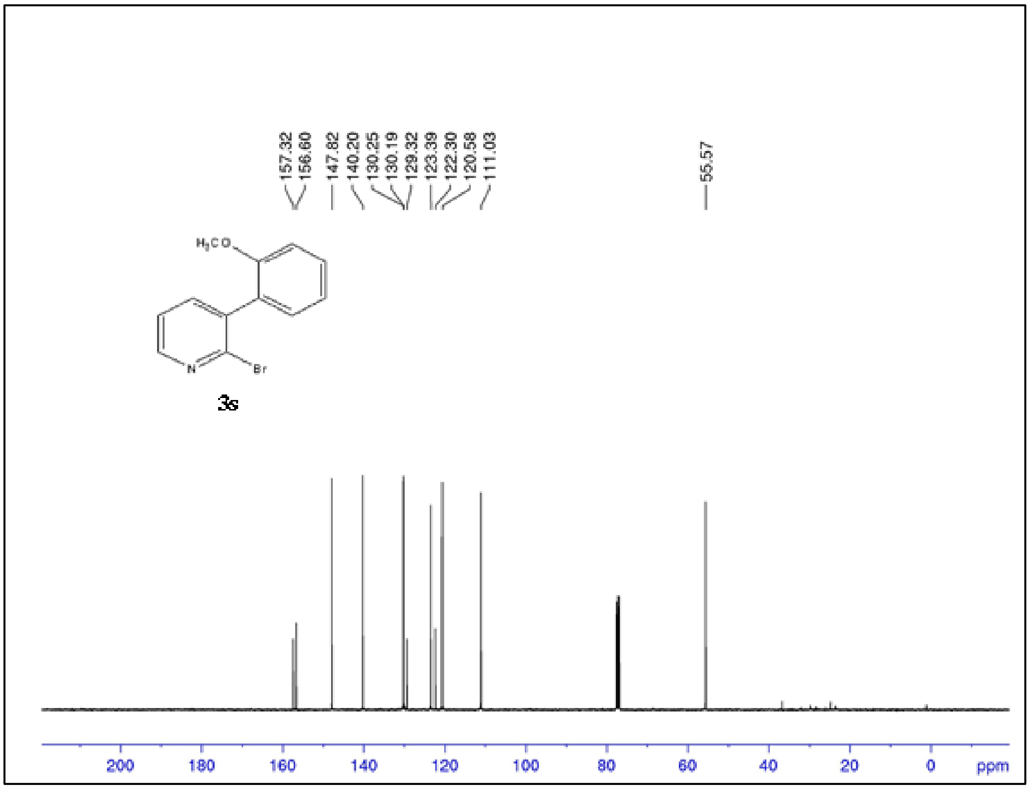
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
6.8
ppm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130.19
129.32
123.39
122.30
120.58
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N
Br
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200
180
160
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120
100
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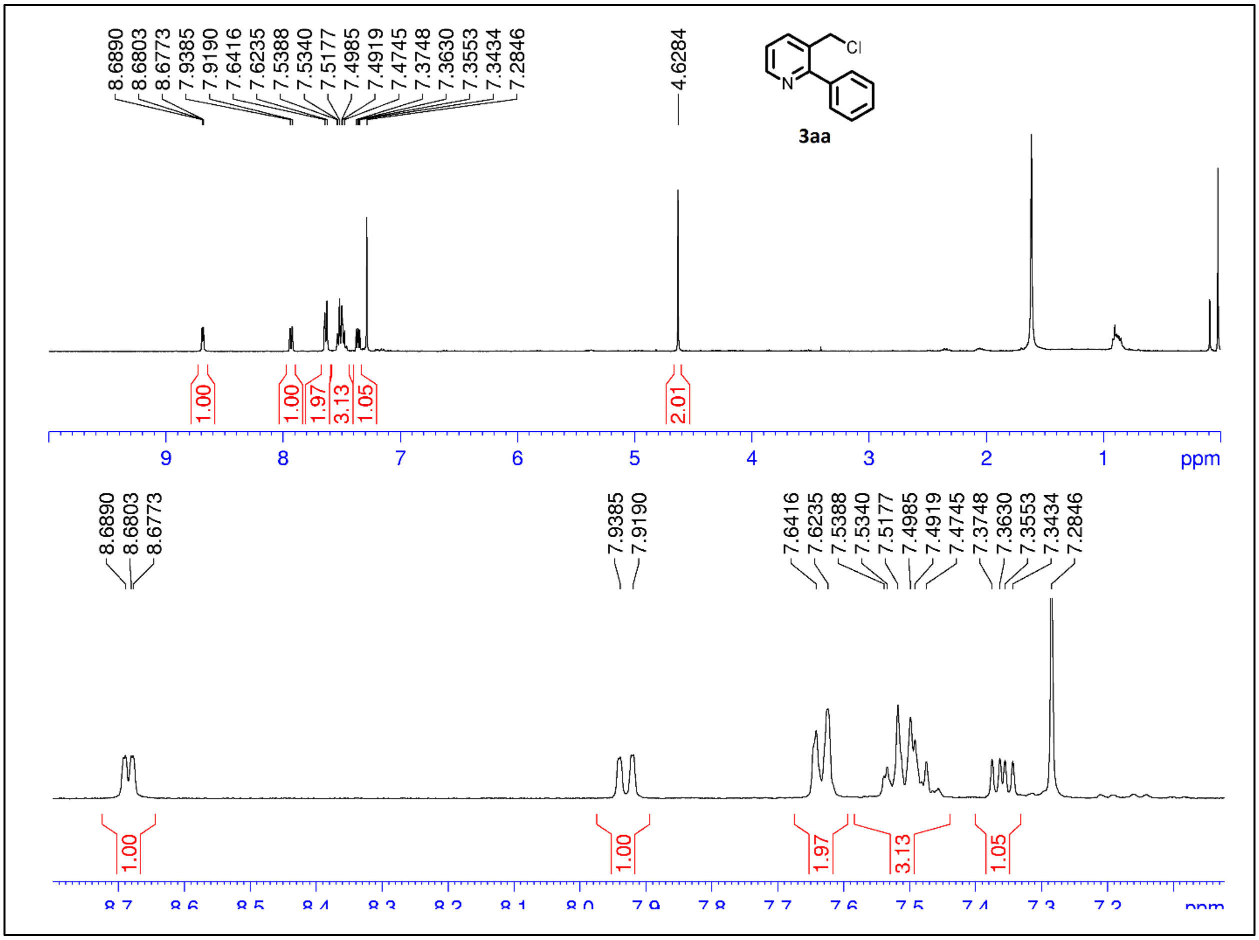
20
0
ppm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7.4985
7.4919
7.4745
7.3748
7.3630
7.3553
7.3434
7.2846
4.6284
Cl
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1.00
1.97
3.13
1.05
2.01
9
8
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1.00
1.97
3.13
1.05
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8.5
8.4
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7.2
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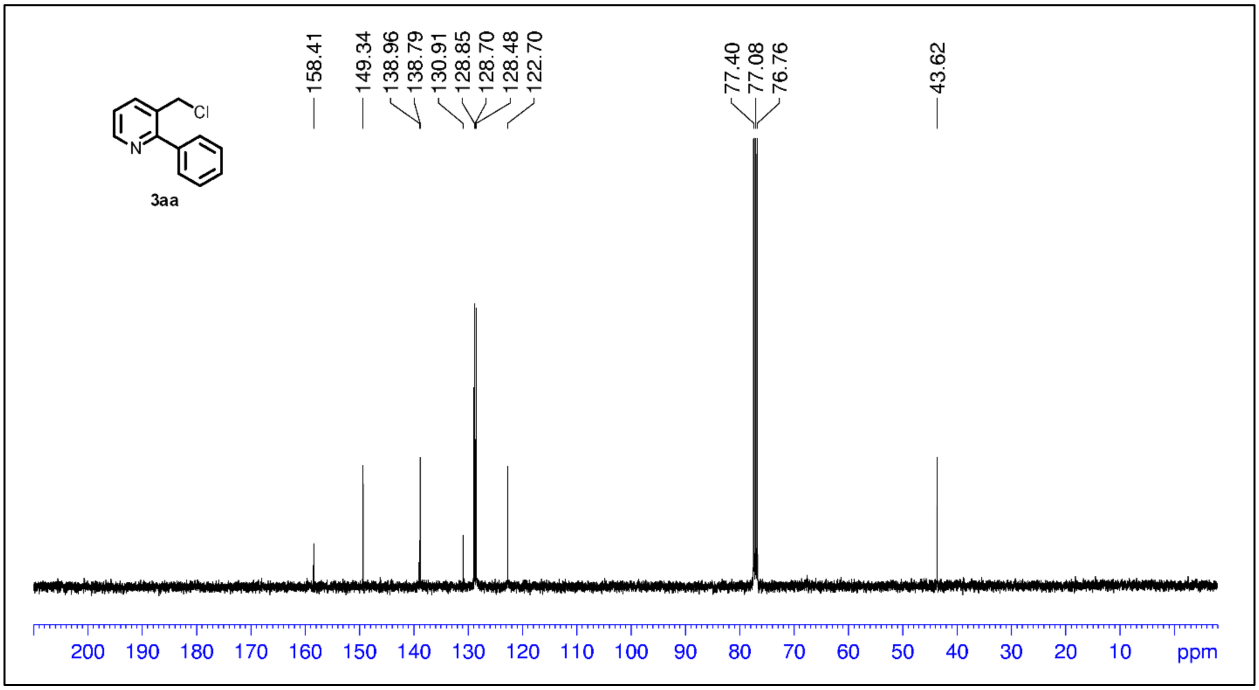
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76.76
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Cl
N
3aa
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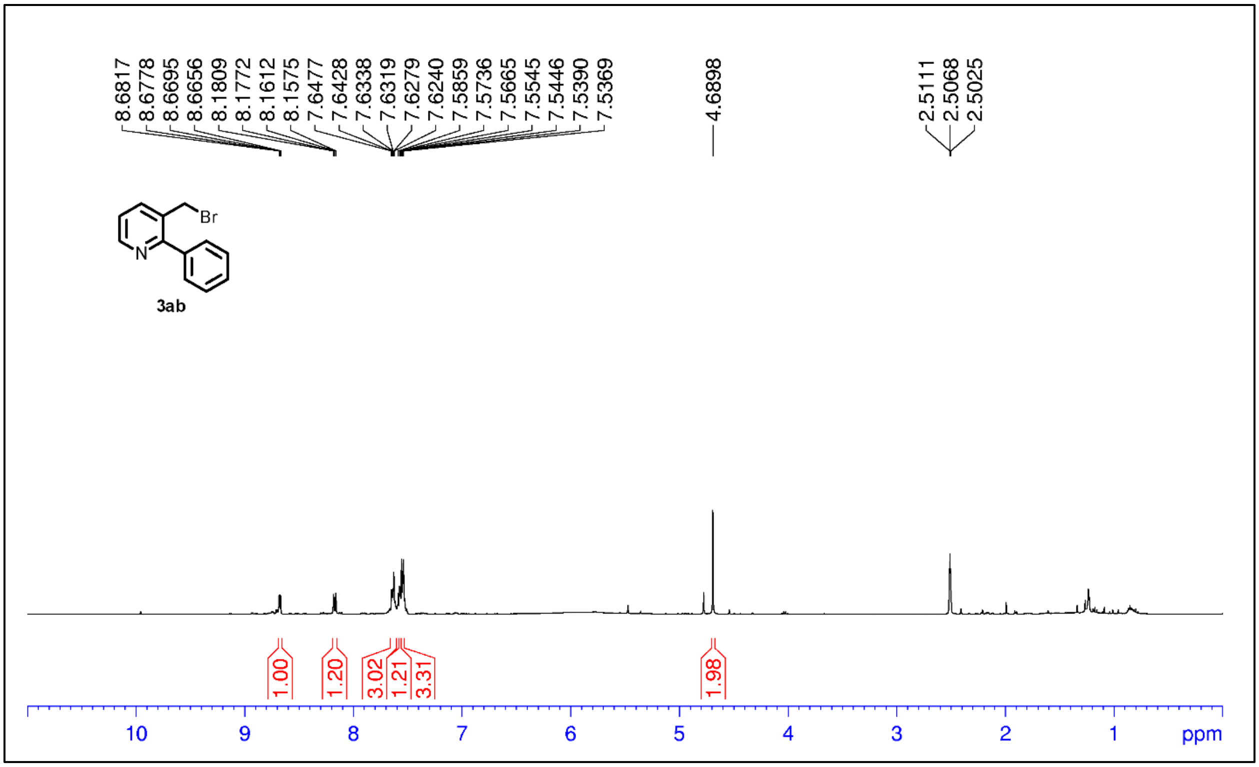
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7.6319
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7.5665
7.5545
7.5446
7.5390
7.5369
4.6898
2.5111
2.5068
2.5025
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7
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3
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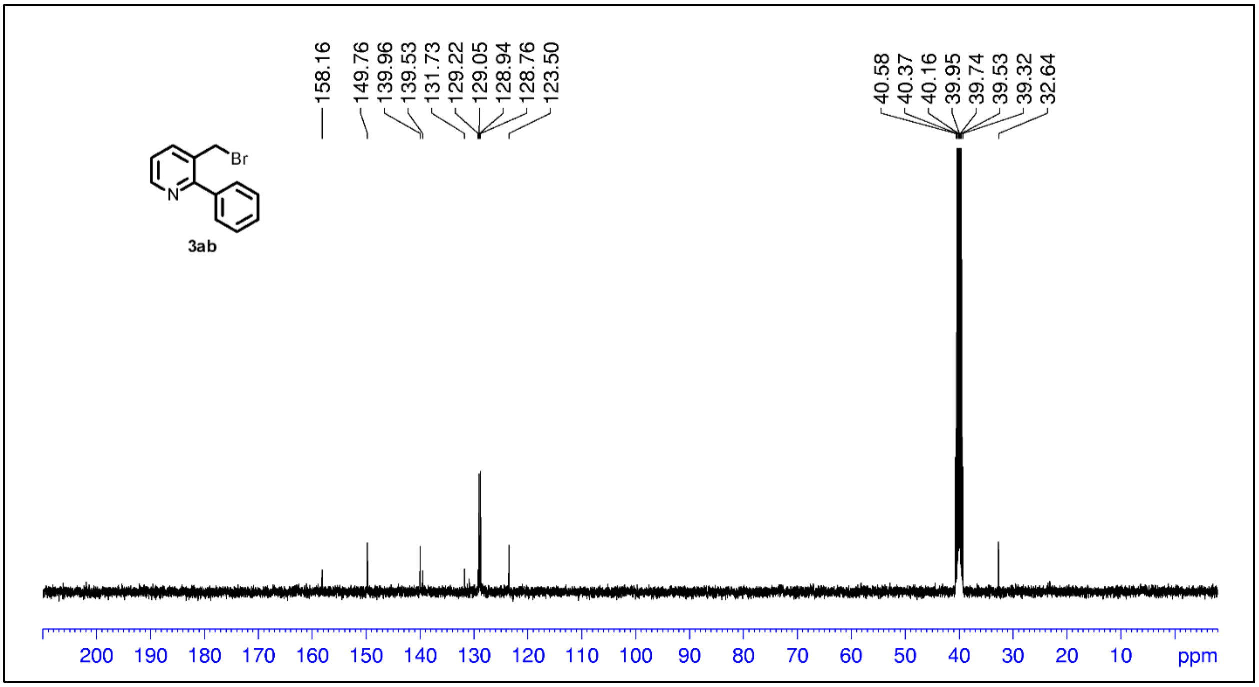
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123.50
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40.16
39.95
39.74
39.53
39.32
32.64
Br
N
3ab
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150
140
130
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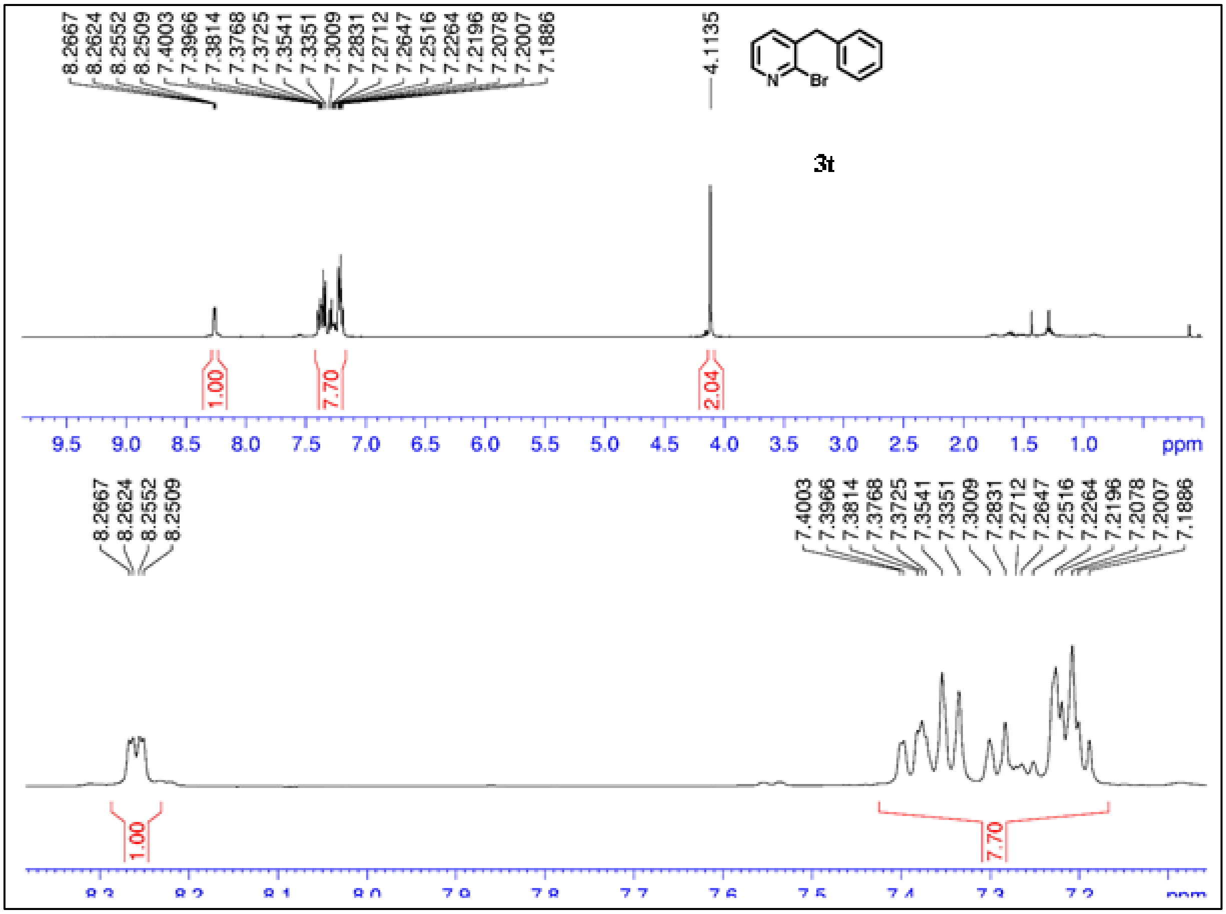
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7.3351
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7.2264
7.2196
7.2078
7.2007
7.1886
4.1135
N
Br
3t
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2.04
9.5
9.0
8.5
8.0
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7.0
6.5
6.0
5.5
5.0
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4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm
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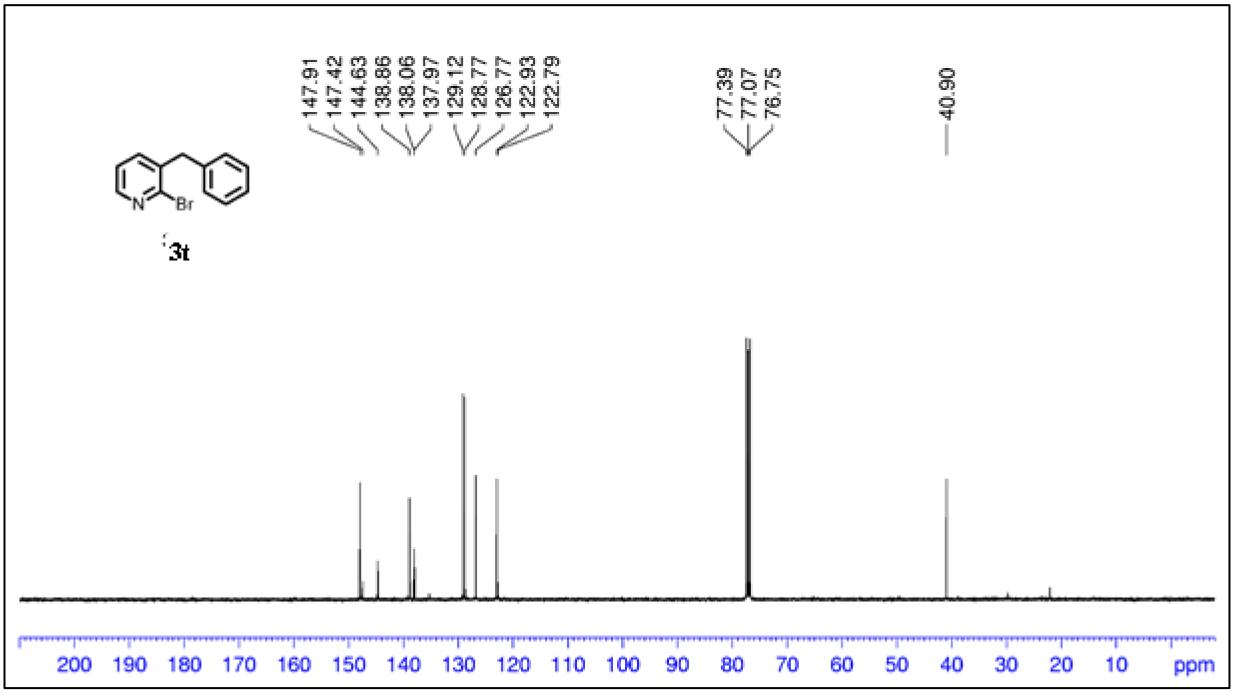
ppm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122.79
77.39
77.07
76.75
40.90
N
Br
3t
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150
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120
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100
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70
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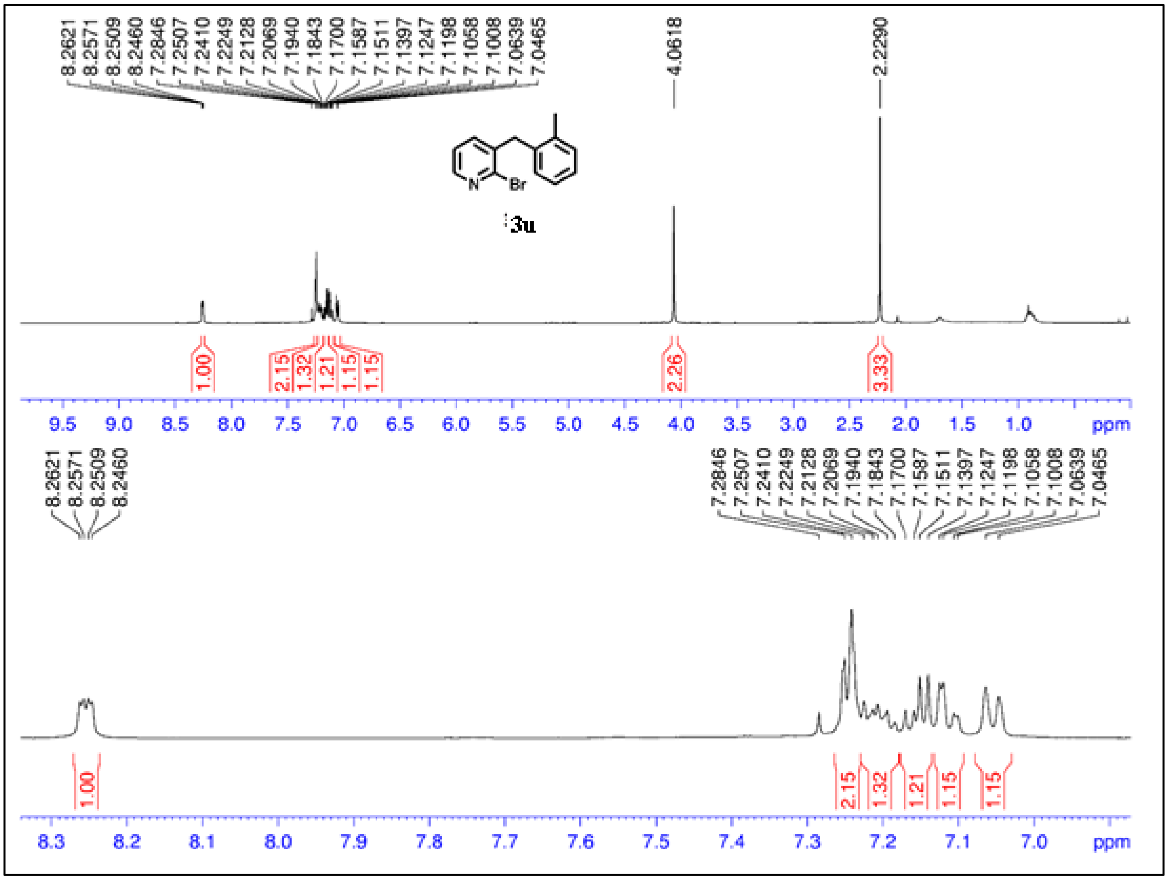
ppm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7.1700
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7.1511
7.1397
7.1247
7.1198
7.1058
7.1008
7.0639
7.0465
4.0618
2.2290
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Br
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1.15
1.15
2.26
3.33
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9.0
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8.0
7.5
7.0
6.5
6.0
5.5
5.0
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4.0
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3.0
2.5
2.0
1.5
1.0
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8.2
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7.1
7.0
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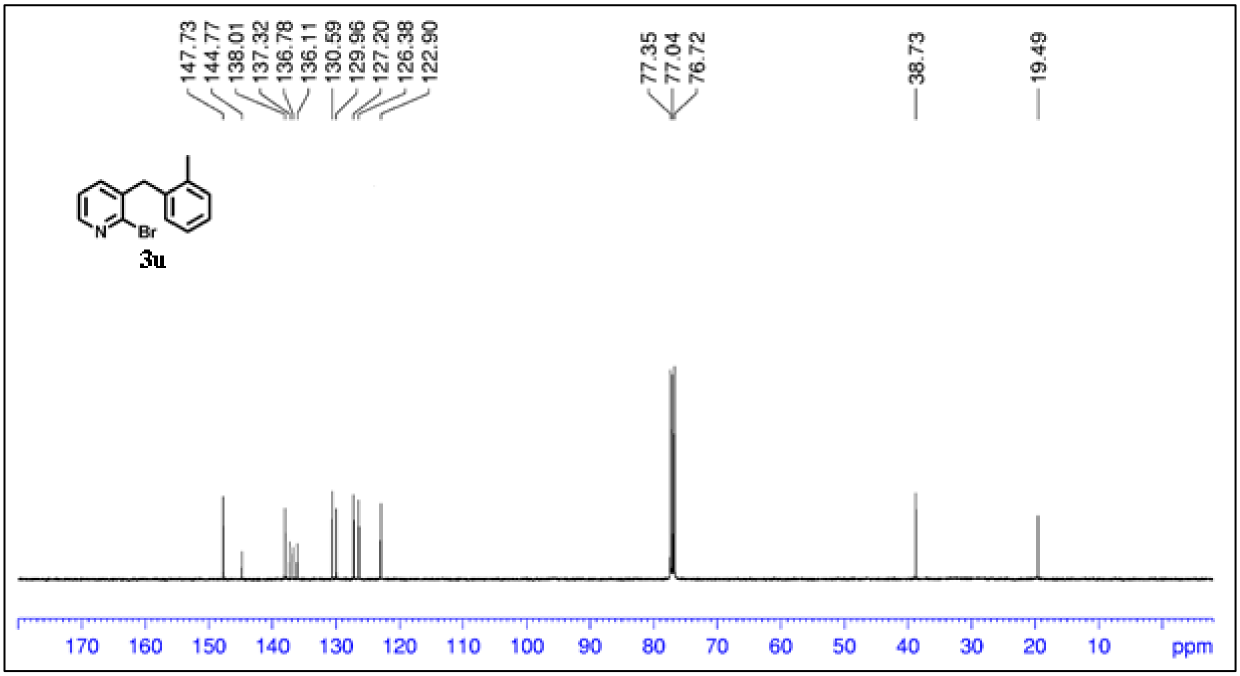
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77.35
77.04
76.72
38.73
19.49
N
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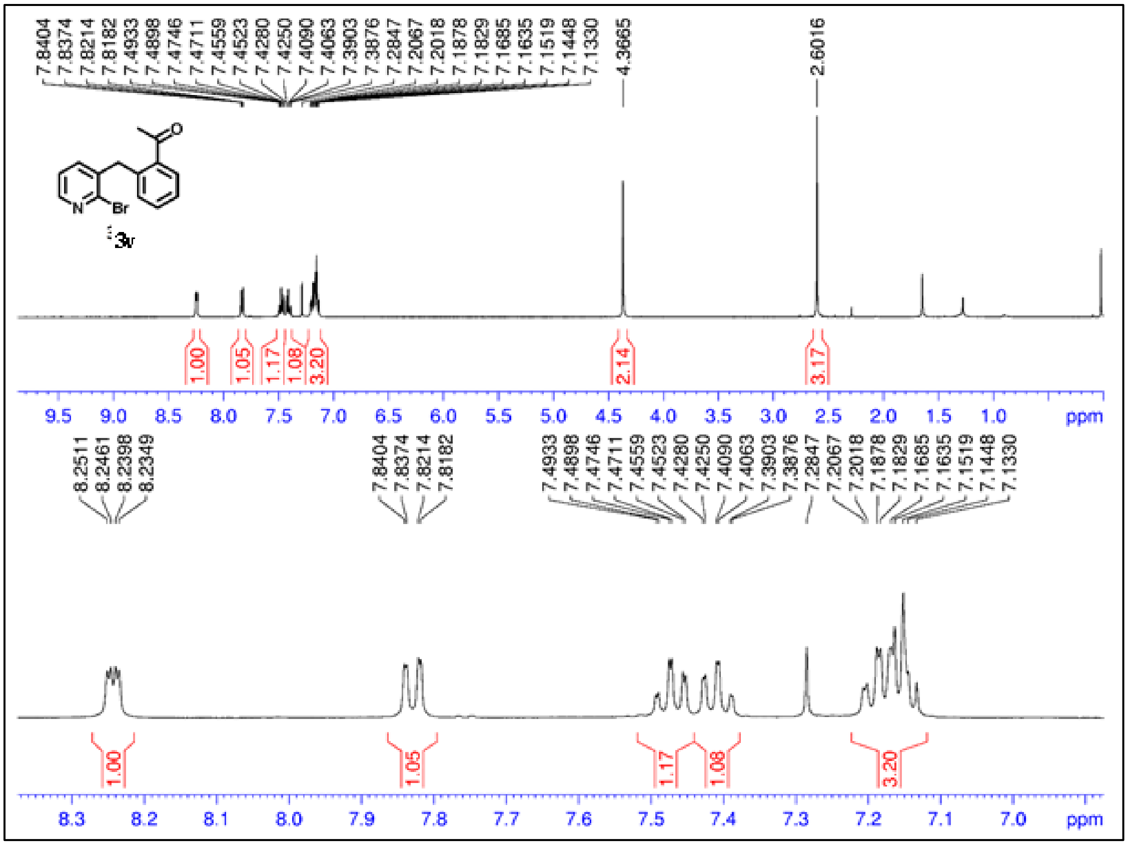
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7.4090
7.4063
7.3903
7.3876
7.2847
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7.2018
7.1878
7.1829
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7.1330
4.3665
2.6016
O
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Br
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1.17
1.08
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2.14
3.17
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8.0
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6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm
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7.7
7.6
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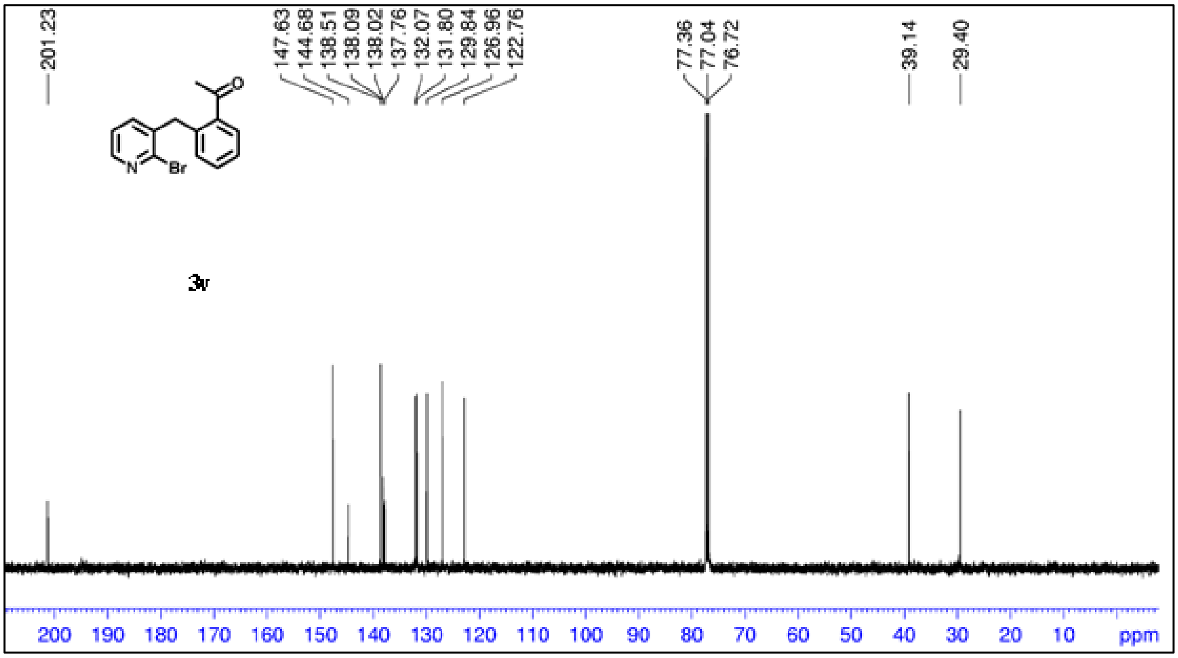
7.3
7.2
7.1
7.0
ppm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129.84
126.96
122.76
77.36
77.04
76.72
39.14
29.40
O
N
Br
3v
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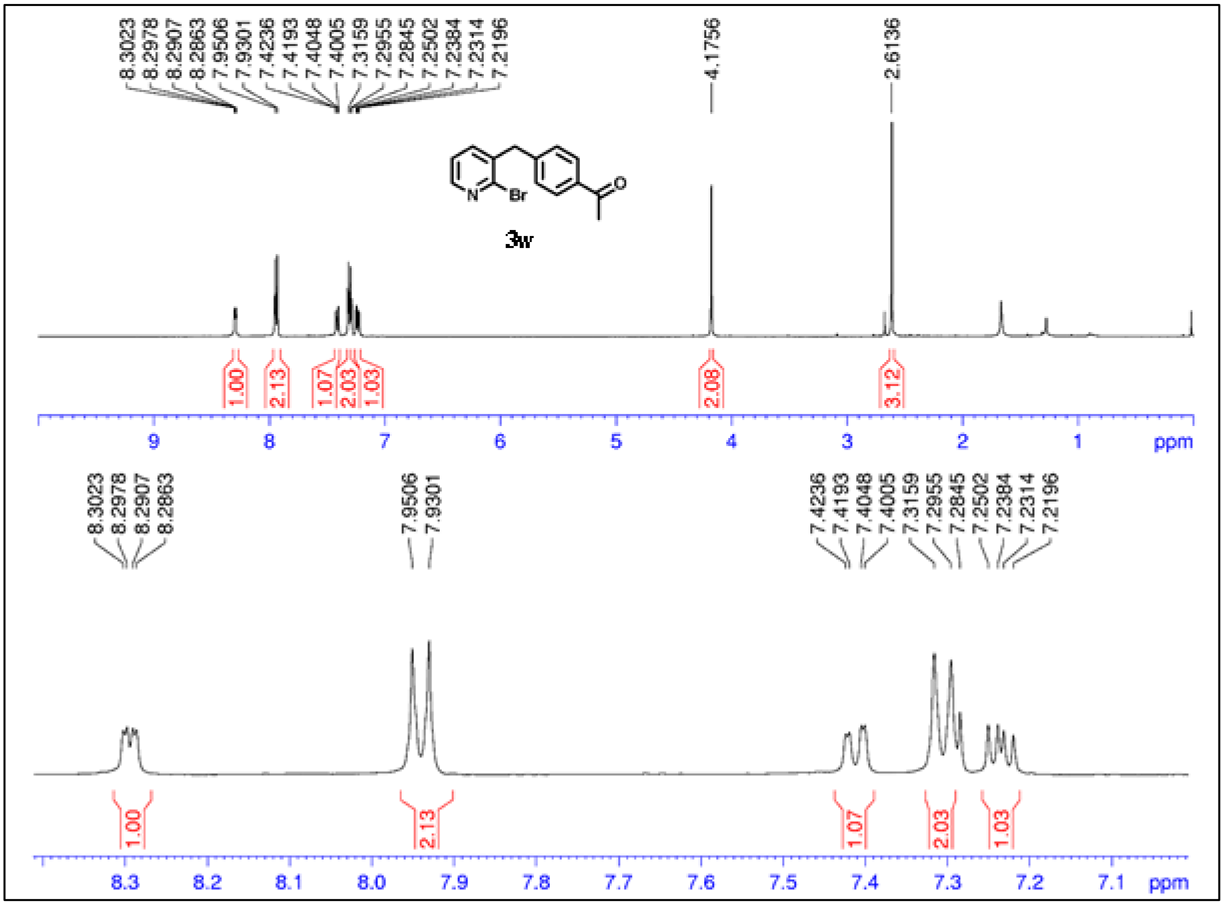
20
10
ppm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7.2955
7.2845
7.2502
7.2384
7.2314
7.2196
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2.6136
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2.03
1.03
2.08
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8
7
6
5
4
3
2
1
ppm
8.3
8.2
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7.7
7.6
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7.4
7.3
7.2
7.1
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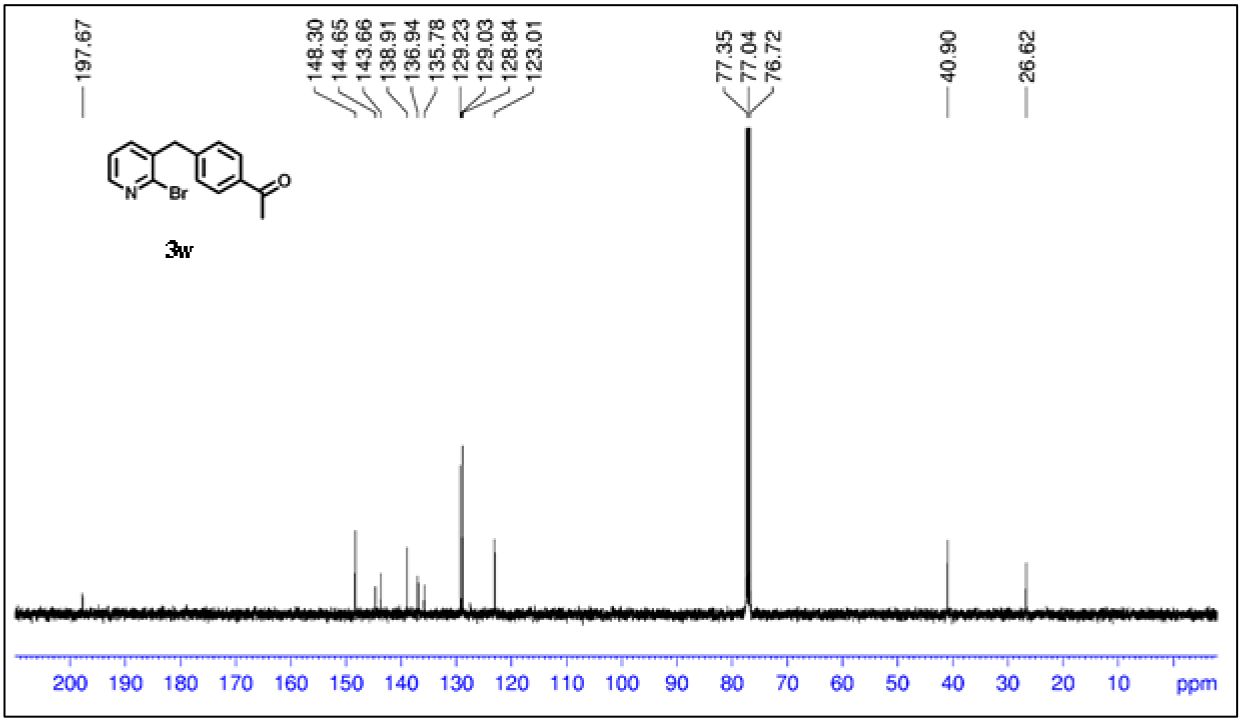
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77.35
77.04
76.72
40.90
26.62
N
Br
O
3w
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140
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20
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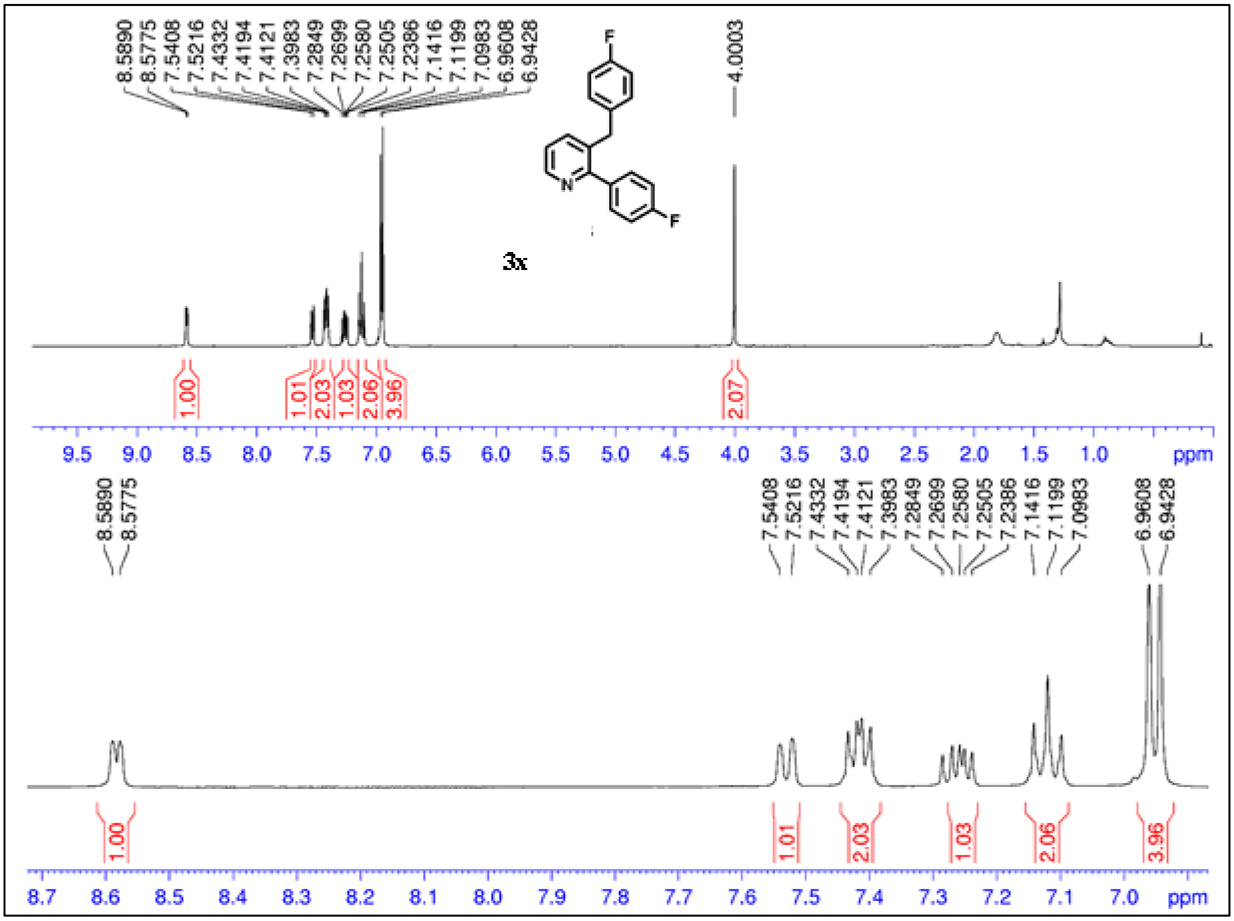
ppm


3x

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7.2386
7.1416
7.1199
7.0983
6.9608
6.9428
4.0003
F
N
F
1.00
1.01
2.03
1.03
2.06
3.96
2.07
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 ppm
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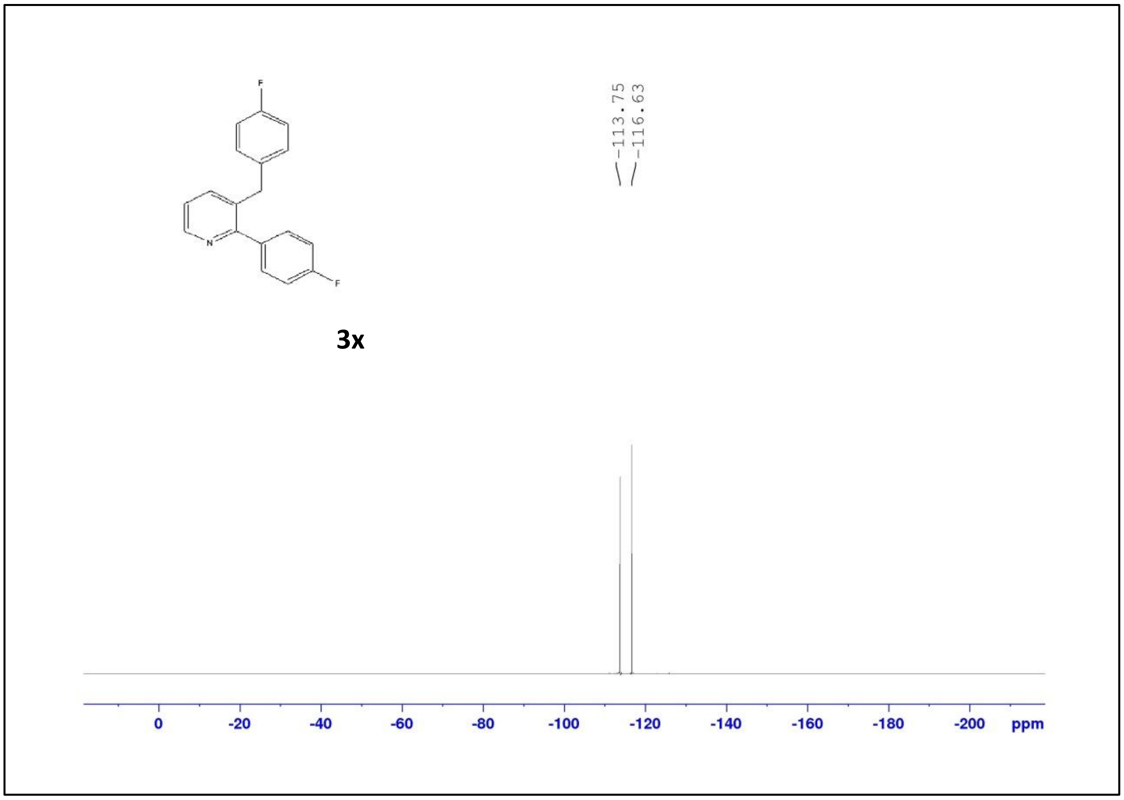
3x

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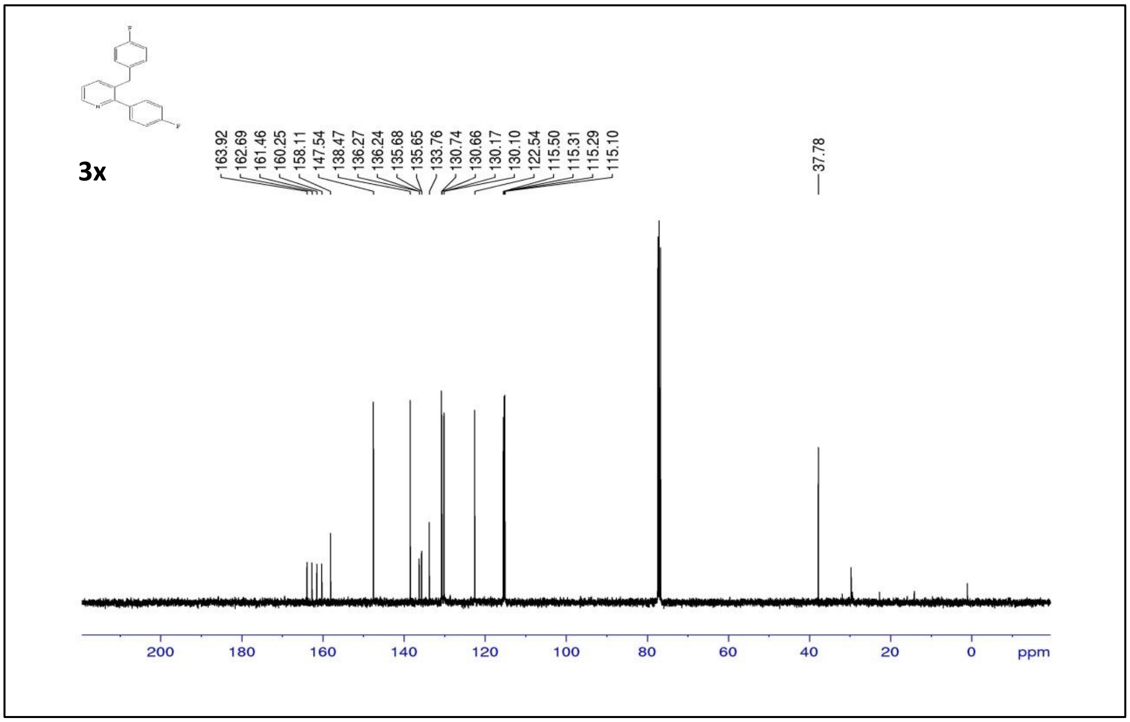
-40
-60
-80
-100
-120
-140
-160
-180
-200
ppm


3x

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158.11
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138.47
136.27
136.24
135.68
135.65
133.76
130.74
130.66
130.17
130.10
122.54
115.50
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115.29
115.10
37.78
200
180
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120
100
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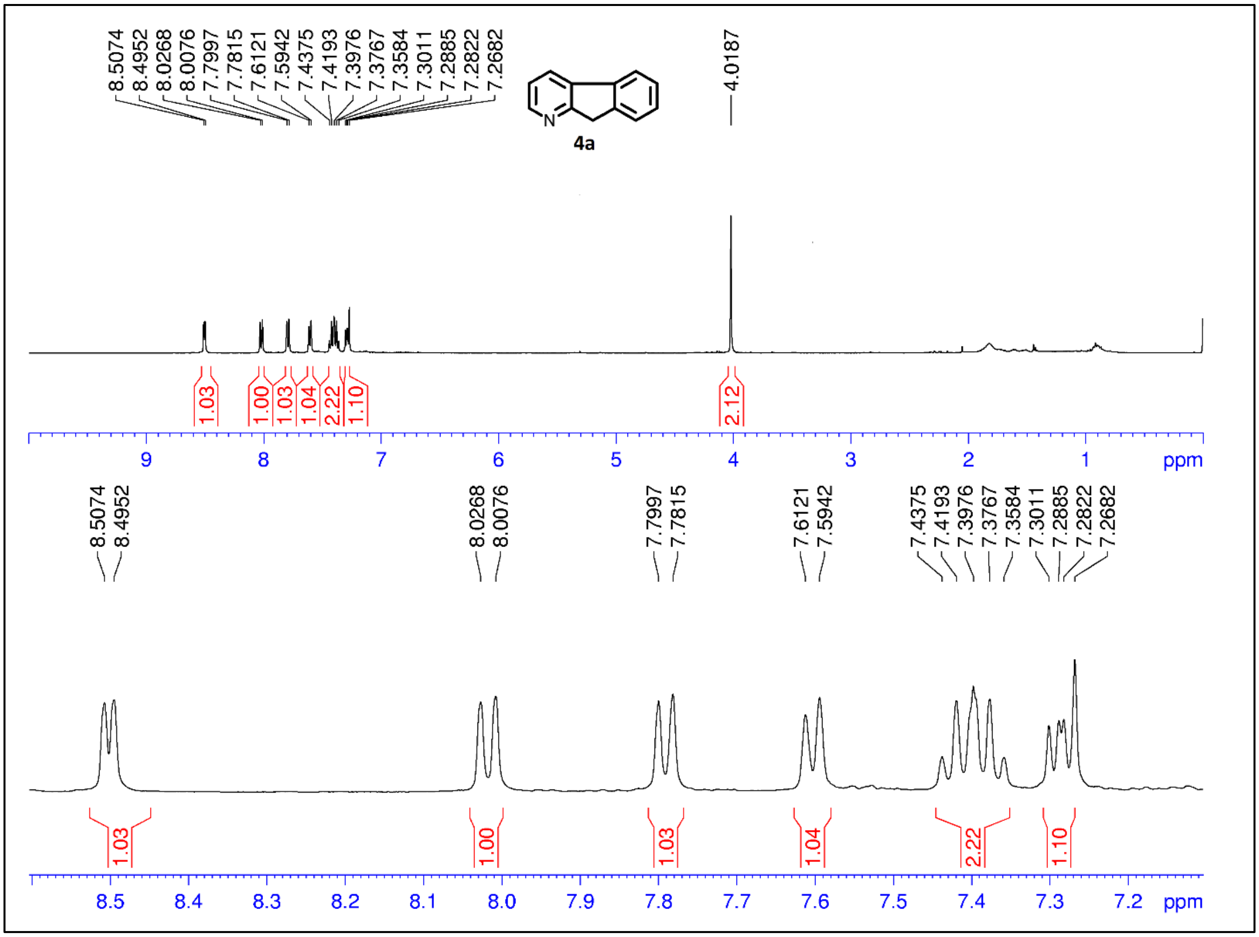
40
20
0
ppm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7.2822
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1.04
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2.12
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8
7
6
5
4
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2
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ppm
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8.4
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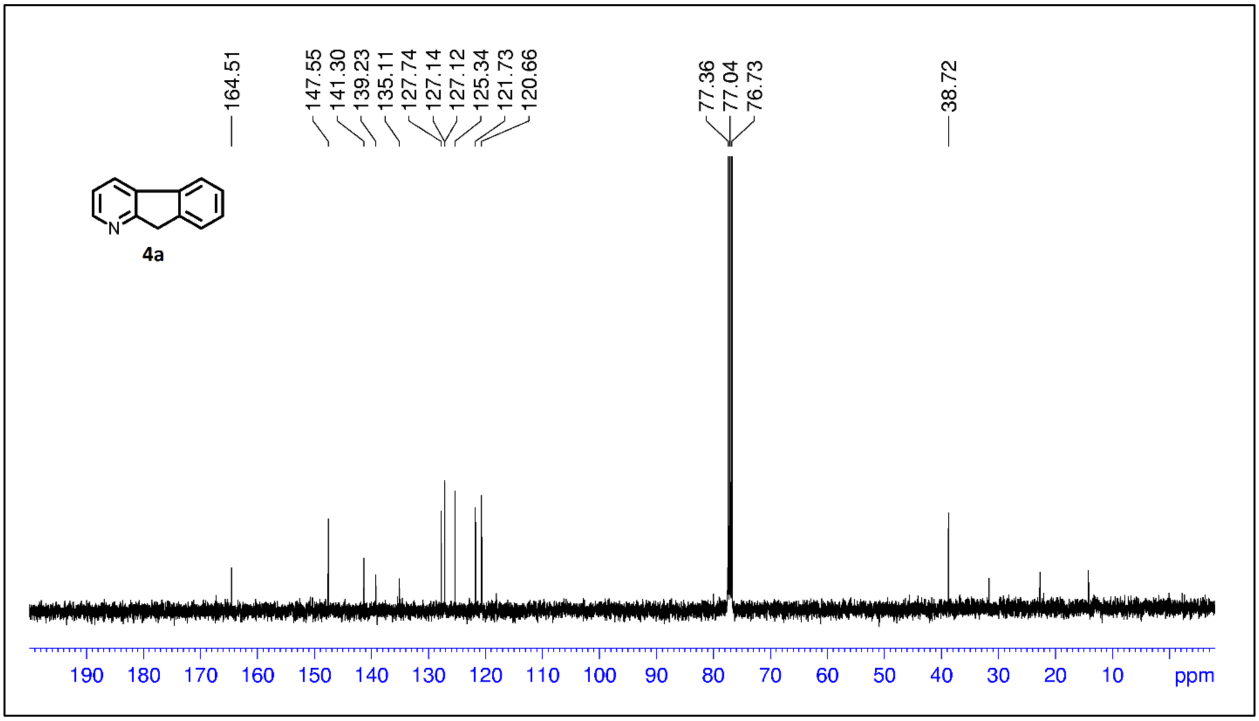
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm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147.55
141.30
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135.11
127.74
127.14
127.12
125.34
121.73
120.66
77.36
77.04
76.73
38.72
N
4a
190
180
170
160
150
140
130
120
110
100
90
80
70
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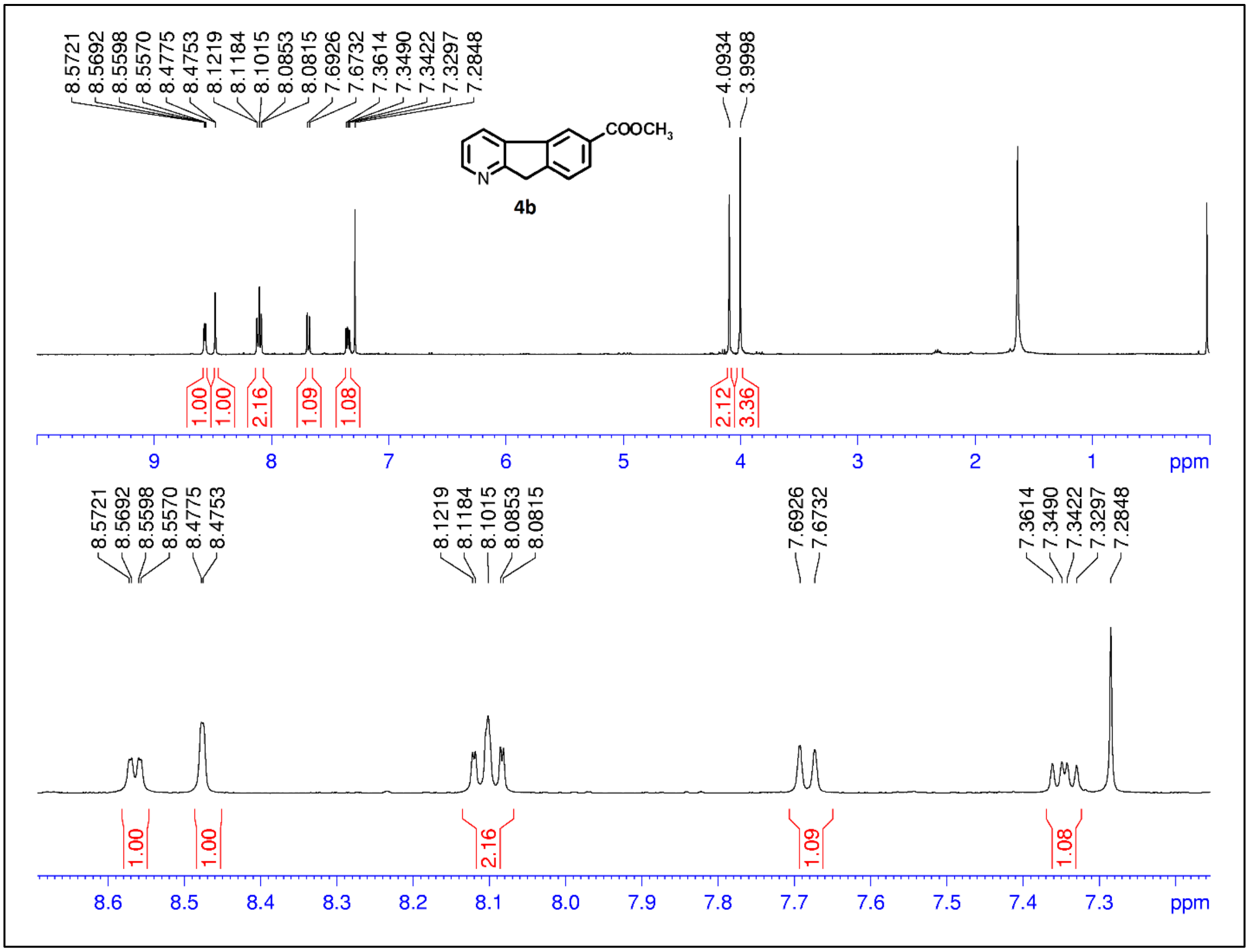
50
40
30
20
10
ppm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8.1219
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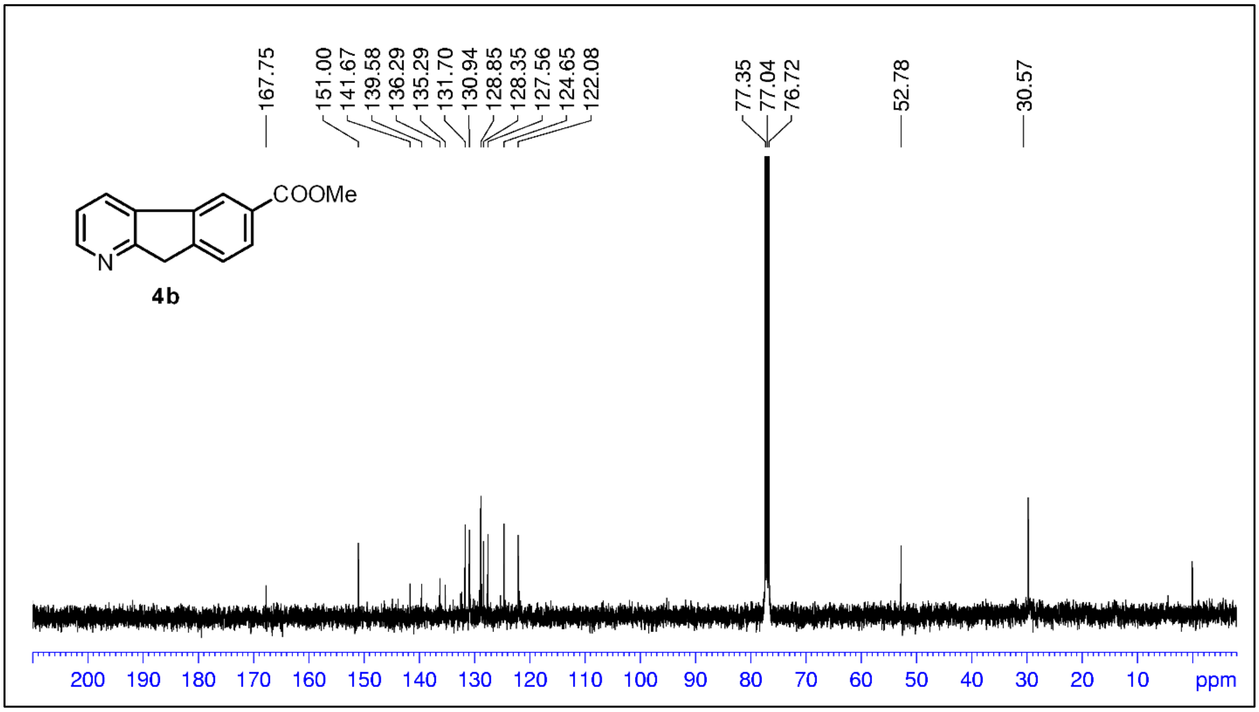
8.1015
8.0853
8.0815
7.6926
7.6732
7.3614
7.3490
7.3422
7.3297
7.2848
4.0934
3.9998
COOCH$_3$
N
4b
1.00
1.00
2.16
1.09
1.08
2.12
3.36
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
ppm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151.00
141.67
139.58
136.29
135.29
131.70
130.94
128.85
128.35
127.56
124.65
122.08
77.35
77.04
76.72
52.78
30.57
COOMe
N
4b
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
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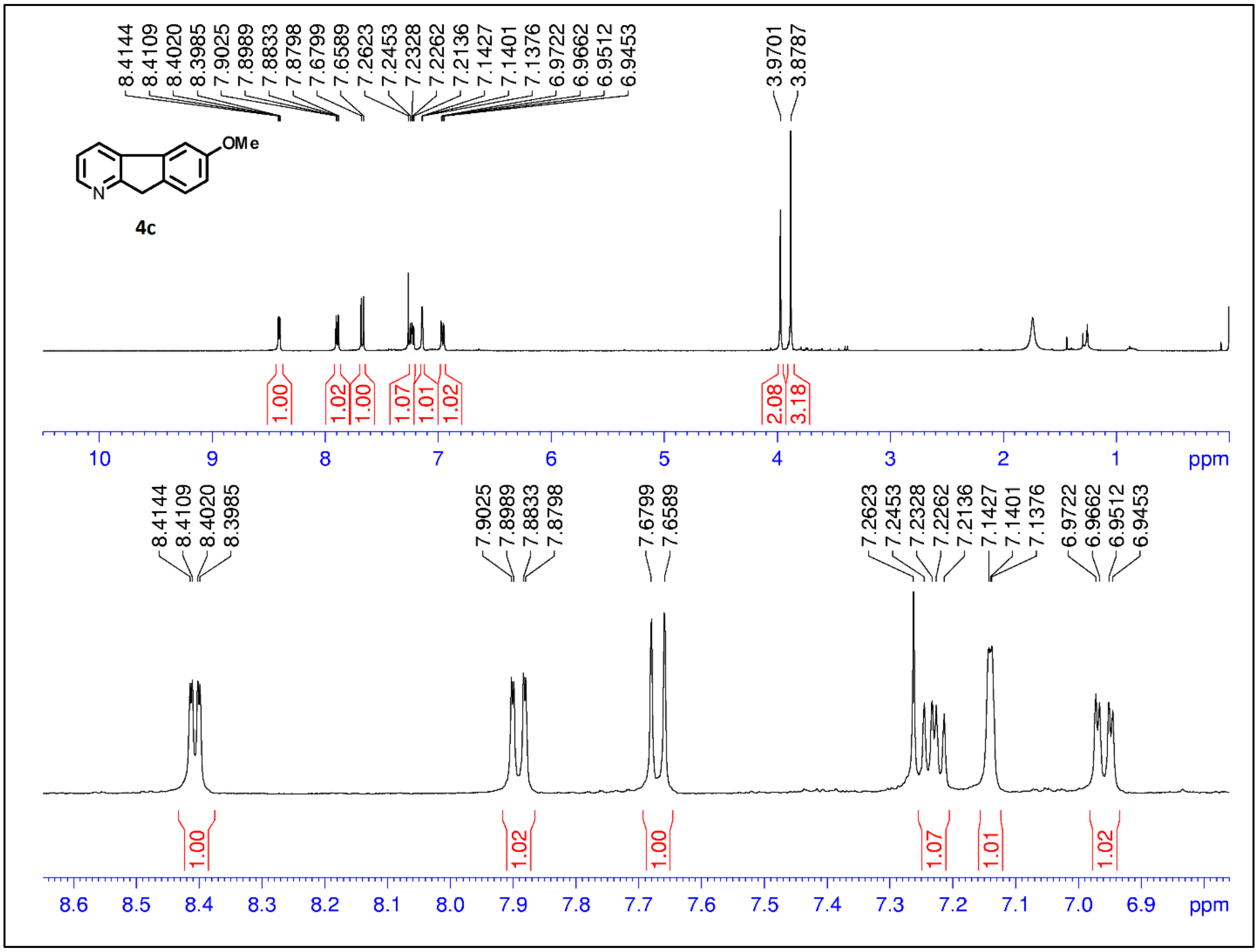
10
ppm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8.4109
8.4020
8.3985
7.9025
7.8989
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7.6799
7.6589
7.2623
7.2453
7.2328
7.2262
7.2136
7.1427
7.1401
7.1376
6.9722
6.9662
6.9512
6.9453
3.9701
3.8787
OMe
N
4c
1.00
1.02
1.00
1.07
1.01
1.02
2.08
3.18
10
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
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7.7
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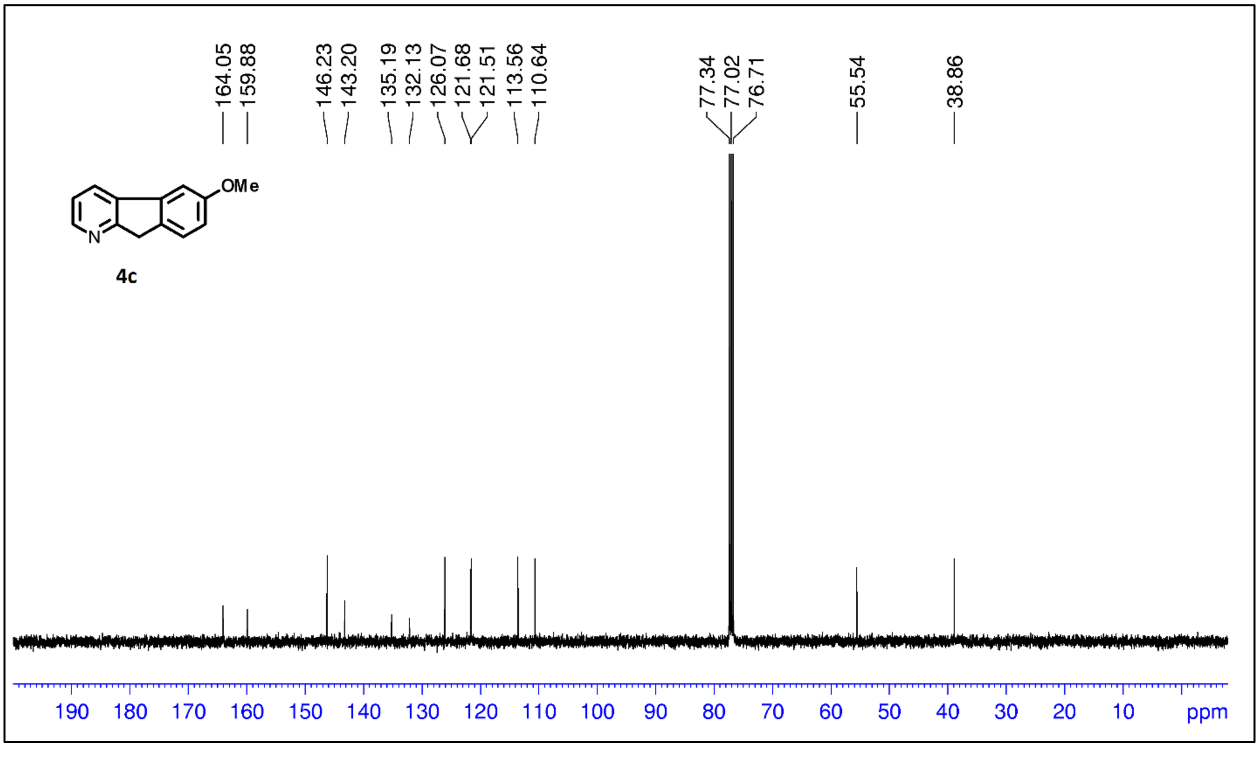
7.3
7.2
7.1
7.0
6.9
ppm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159.88
146.23
143.20
135.19
132.13
126.07
121.68
121.51
113.56
110.64
77.34
77.02
76.71
55.54
38.86
OMe
N
4c
190
180
170
160
150
140
130
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110
100
90
80
70
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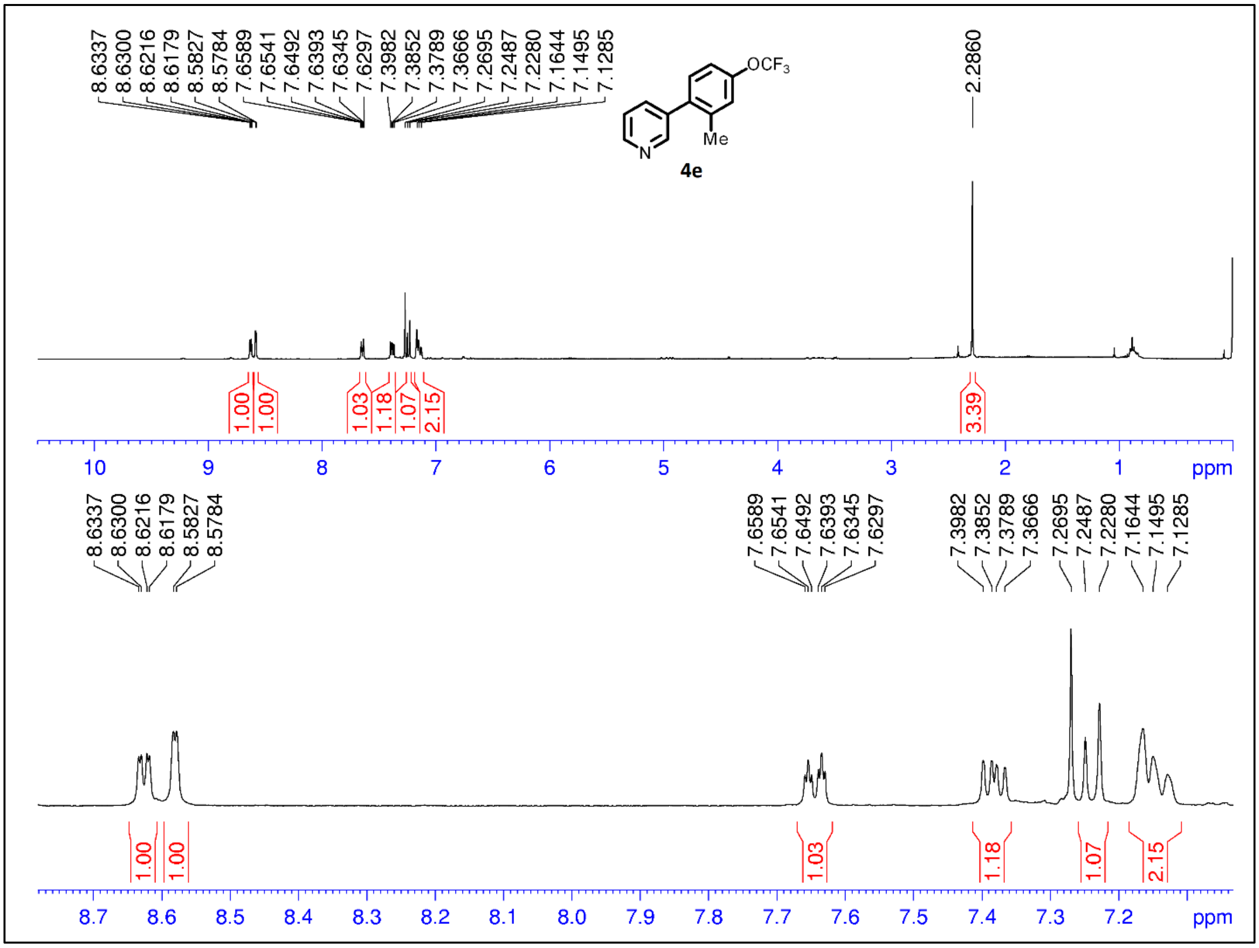
50
40
30
20
10
ppm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8.5784
7.6589
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7.6492
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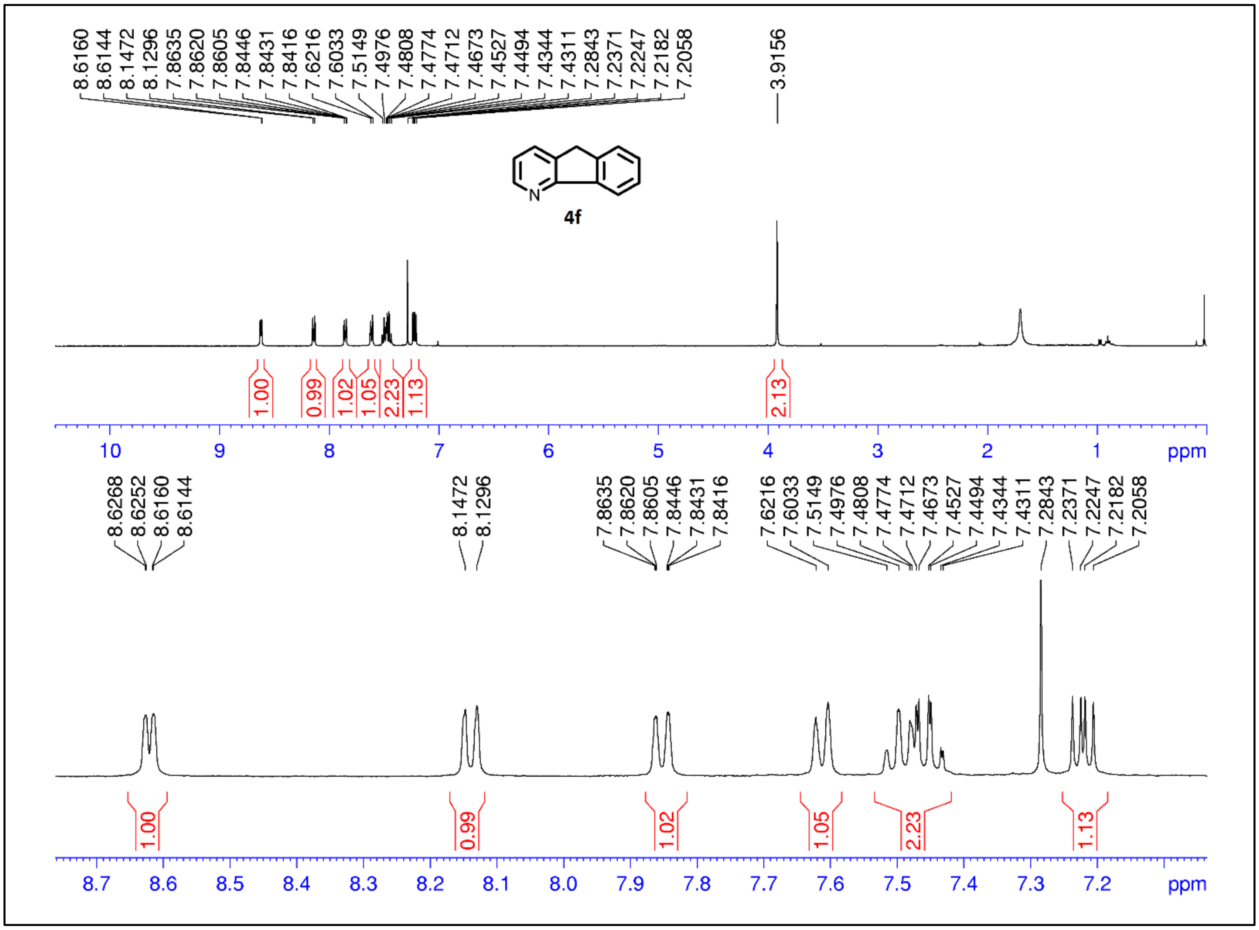
7.6345
7.6297
7.3982
7.3852
7.3789
7.3666
7.2695
7.2487
7.2280
7.1644
7.1495
7.1285
2.2860
OCF$_3$
Me
N
1.00
1.00
1.03
1.18
1.07
2.15
3.39
10
9
8
7
6
5
4
3
2
1
ppm
1.00
1.00
1.03
1.18
1.07
2.15
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm

4e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8.1472
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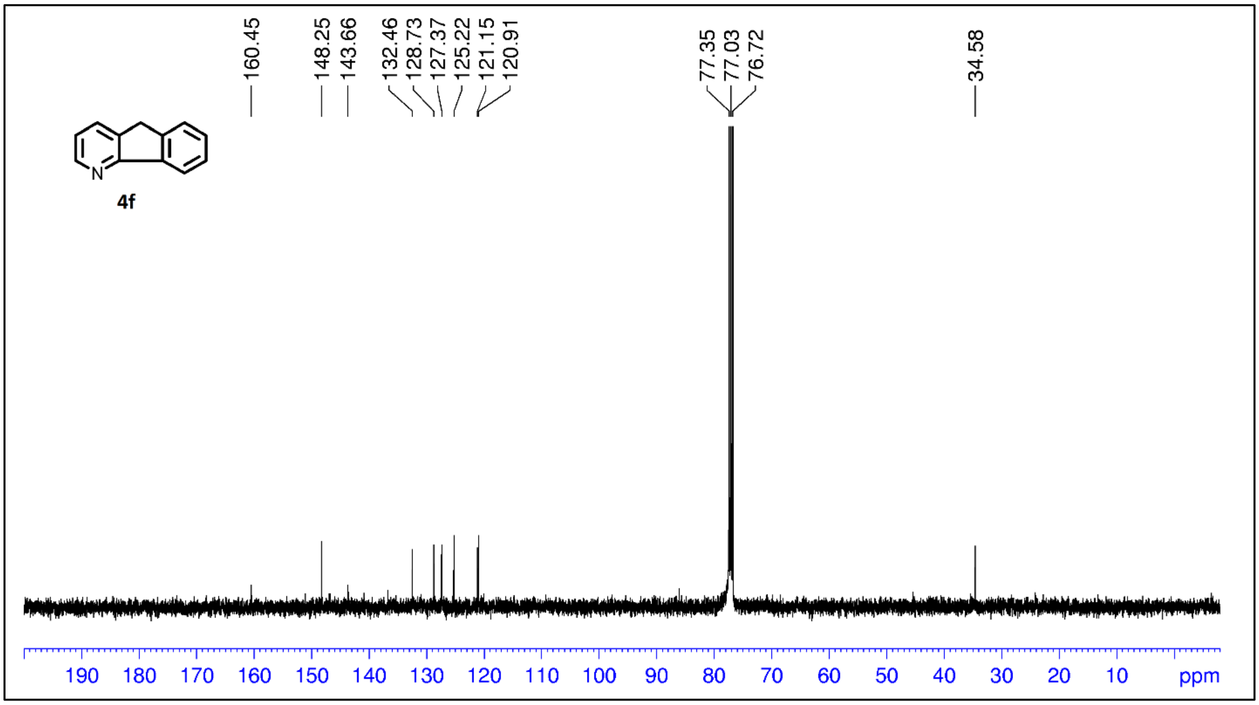
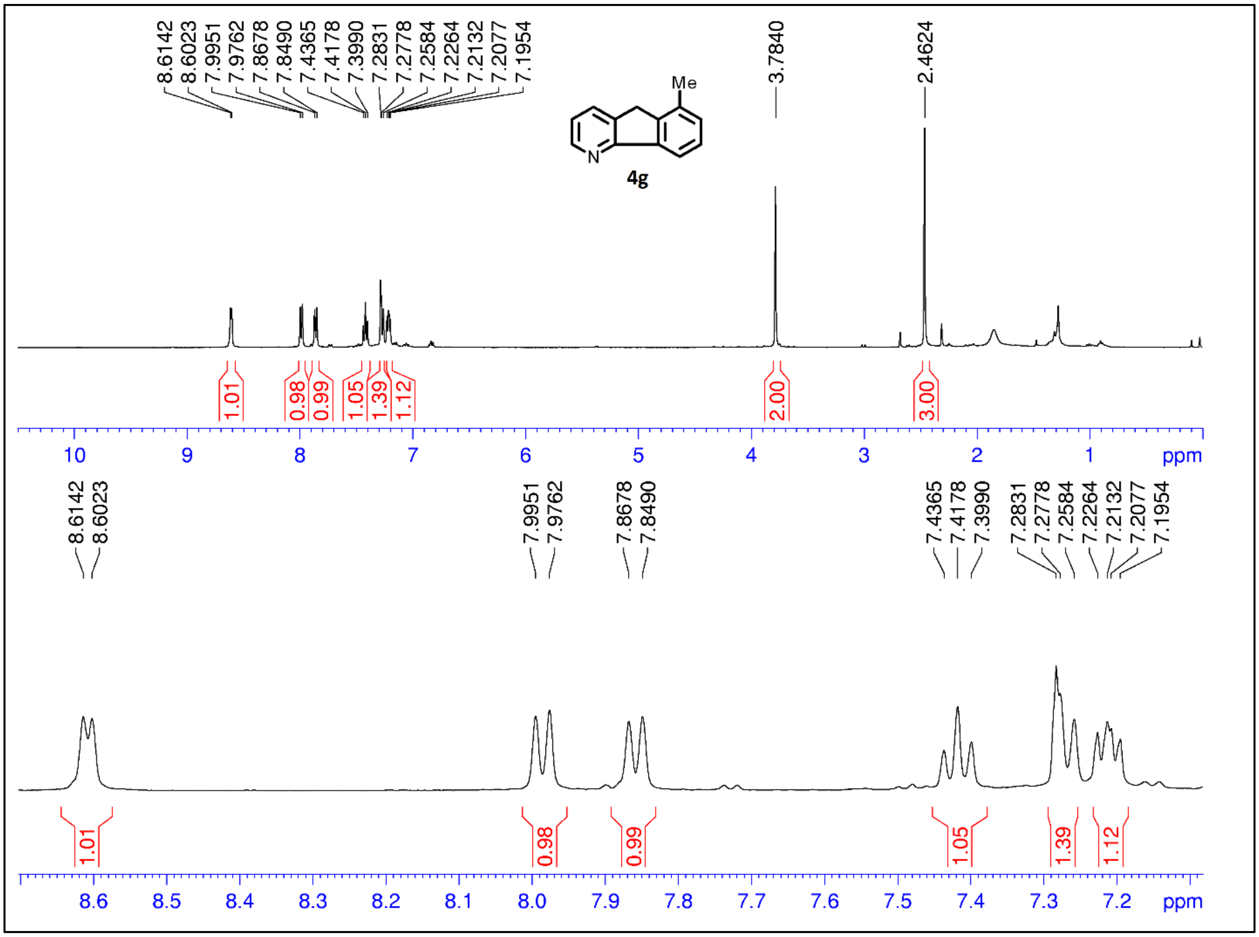
7.8620
7.8605
7.8446
7.8431
7.8416
7.6216
7.6033
7.5149
7.4976
7.4808
7.4774
7.4712
7.4673
7.4527
7.4494
7.4344
7.4311
7.2843
7.2371
7.2247
7.2182
7.2058
3.9156
N
4f
1.00
0.99
1.02
1.05
2.23
1.13
2.13
10
9
8
7
6
5
4
3
2
1
ppm
8.6268
8.6252
8.6160
8.6144
8.1472
8.1296
7.8635
7.8620
7.8605
7.8446
7.8431
7.8416
7.6216
7.6033
7.5149
7.4976
7.4808
7.4774
7.4712
7.4673
7.4527
7.4494
7.4344
7.4311
7.2843
7.2371
7.2247
7.2182
7.2058
1.00
0.99
1.02
1.05
2.23
1.13
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm


160.45
148.25
143.66
132.46
128.73
127.37
125.22
121.15
120.91
77.35
77.03
76.72
34.58
N
4f
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm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7.4365
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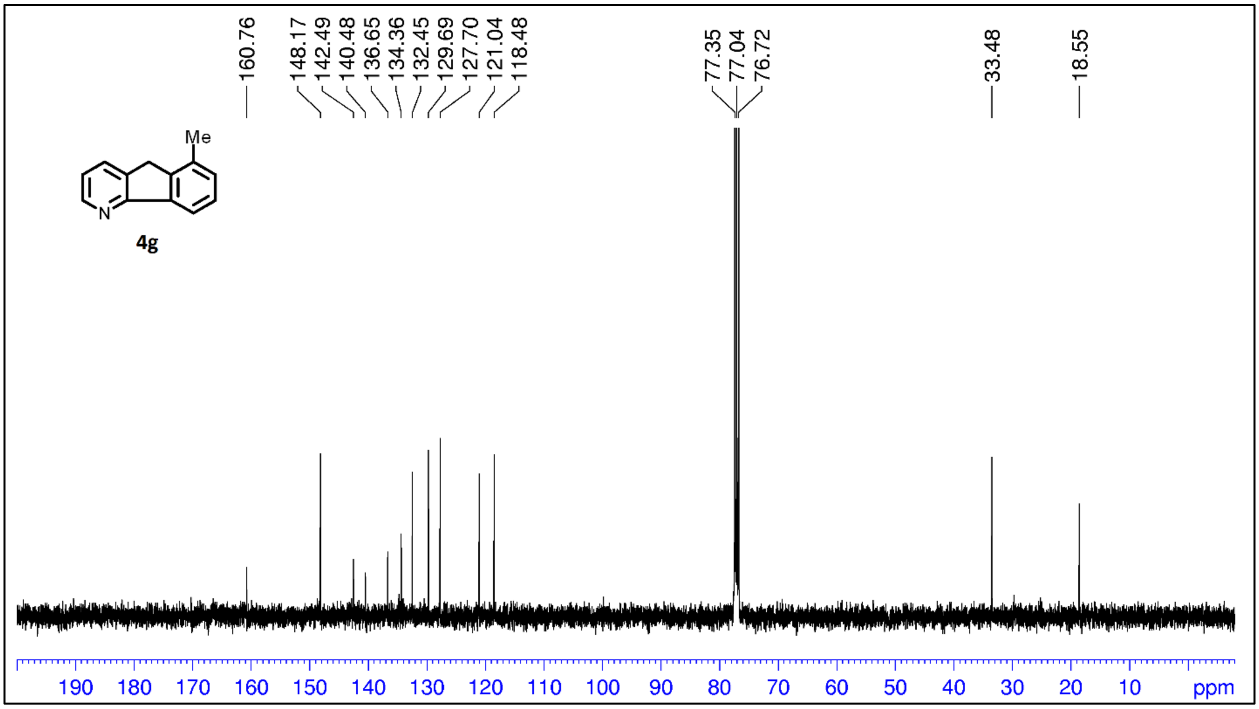
7.3990
7.2831
7.2778
7.2584
7.2264
7.2132
7.2077
7.1954
3.7840
2.4624
Me
N
4g
1.01
0.98
0.99
1.05
1.39
1.12
2.00
3.00
10
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm


160.76
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142.49
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136.65
134.36
132.45
129.69
127.70
121.04
118.48
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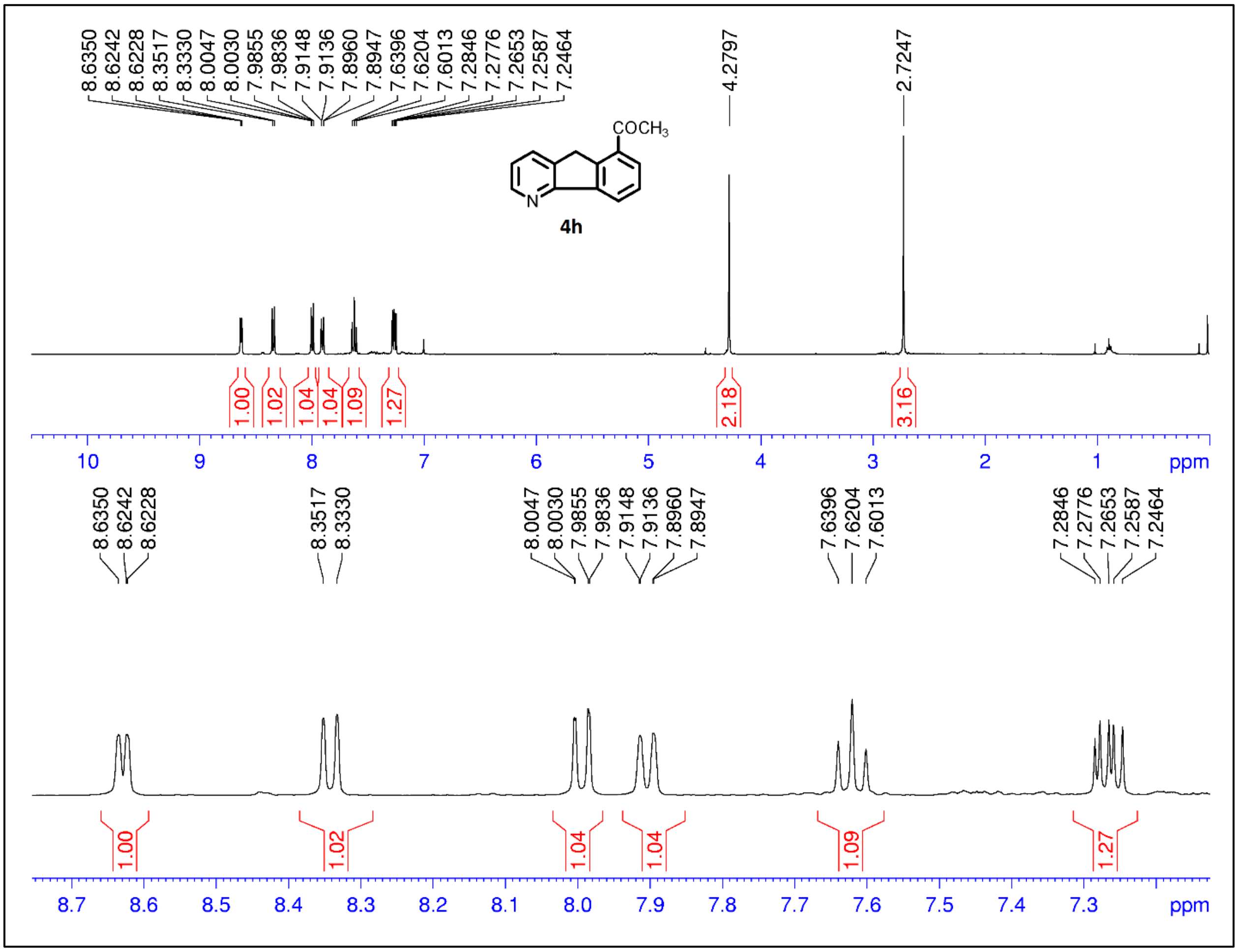
77.04
76.72
33.48
18.55
Me
N
4g
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm


8.6350
8.6242
8.6228
8.3517
8.3330
8.0047
8.0030
7.9855
7.9836
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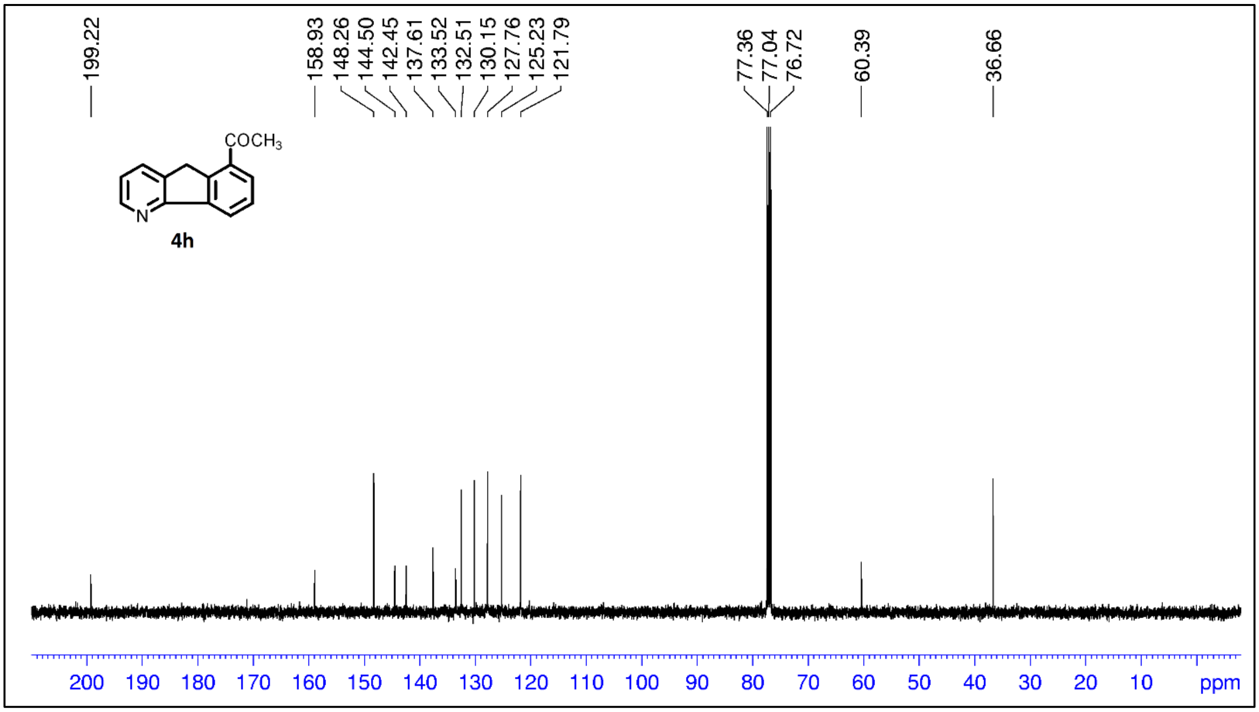
7.9136
7.8960
7.8947
7.6396
7.6204
7.6013
7.2846
7.2776
7.2653
7.2587
7.2464
4.2797
2.7247
COCH3
N
4h
1.00
1.02
1.04
1.04
1.09
1.27
2.18
3.16
10 9 8 7 6 5 4 3 2 1 ppm
8.7 8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 ppm


4h
199.22
158.93
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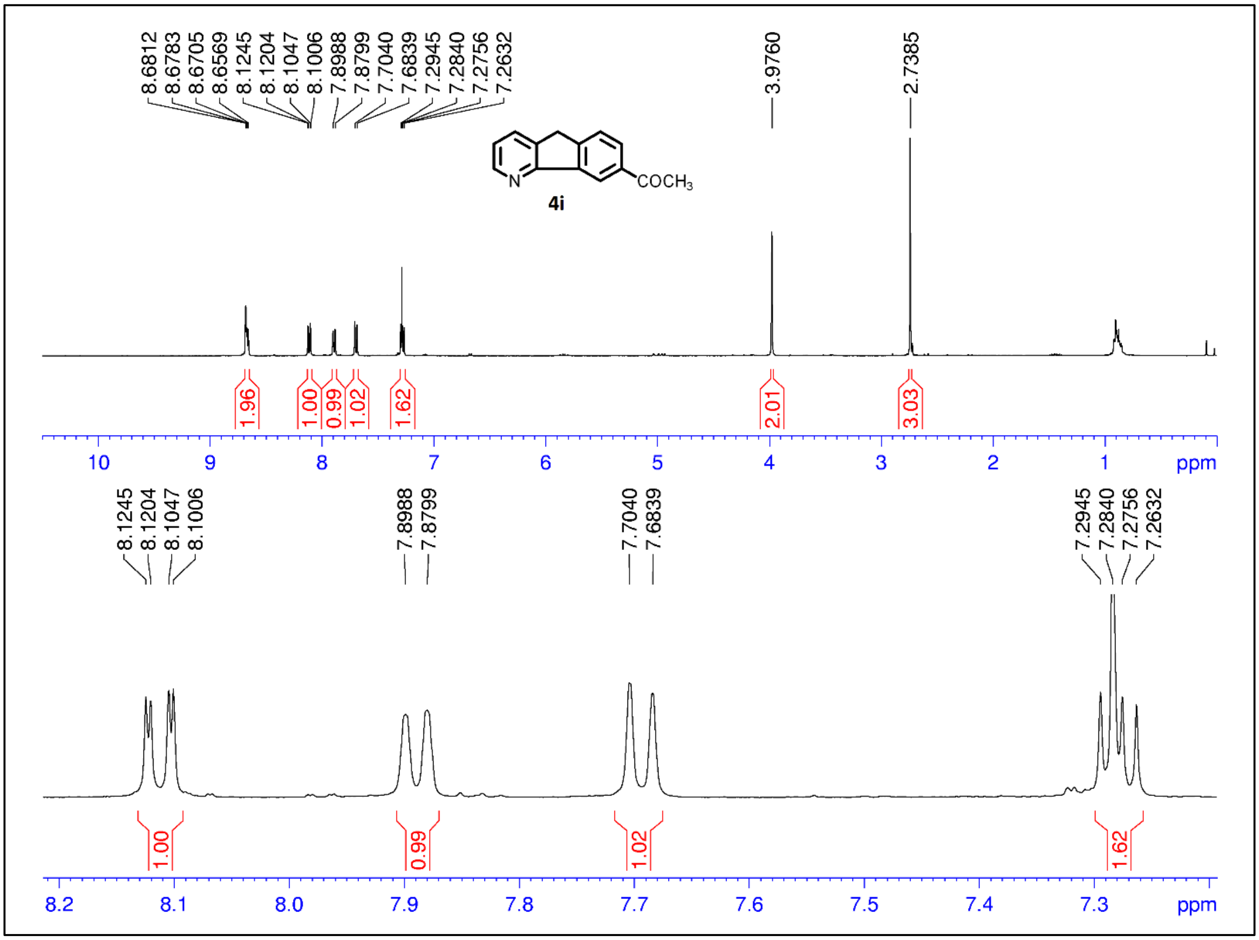
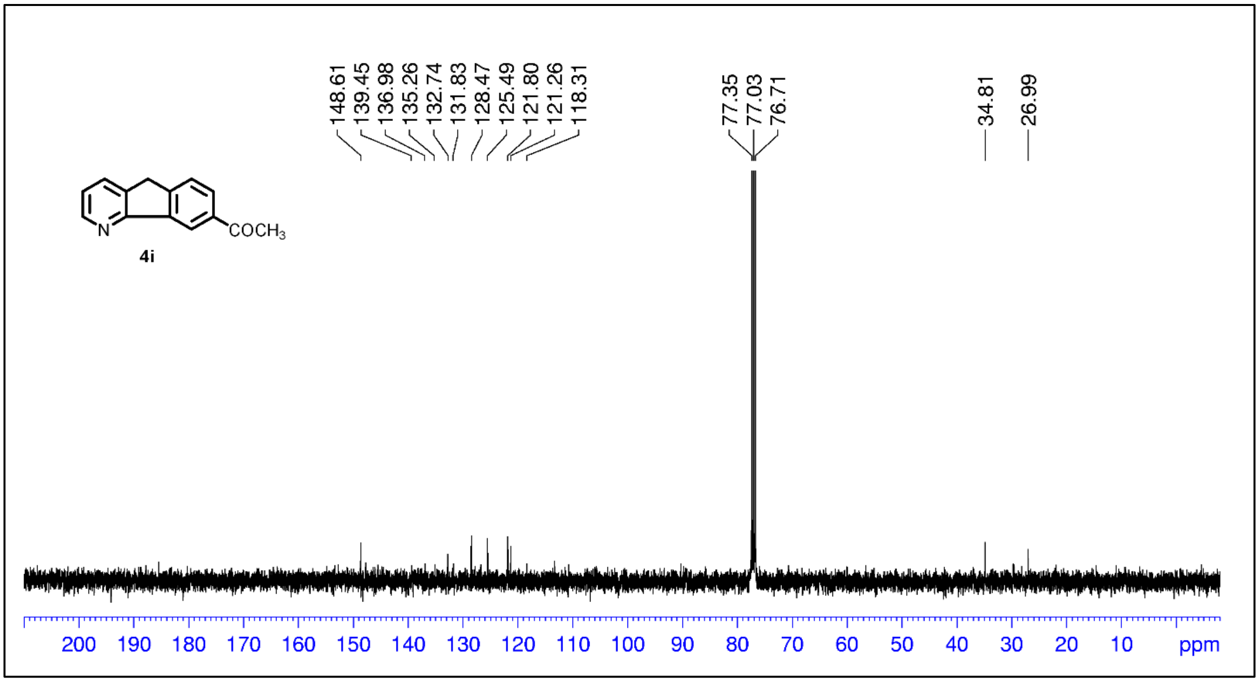
144.50
142.45
137.61
133.52
132.51
130.15
127.76
125.23
121.79
77.36
77.04
76.72
60.39
36.66
COCH3
N
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm


4i
8.6812
8.6783
8.6705
8.6569
8.1245
8.1204
8.1047
8.1006
7.8988
7.8799
7.7040
7.6839
7.2945
7.2840
7.2756
7.2632
3.9760
2.7385
COCH3
N
1.96
1.00
0.99
1.02
1.62
2.01
3.03
10 9 8 7 6 5 4 3 2 1 ppm
8.1245
8.1204
8.1047
8.1006
7.8988
7.8799
7.7040
7.6839
7.2945
7.2840
7.2756
7.2632
1.00
0.99
1.02
1.62
8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 ppm


148.61
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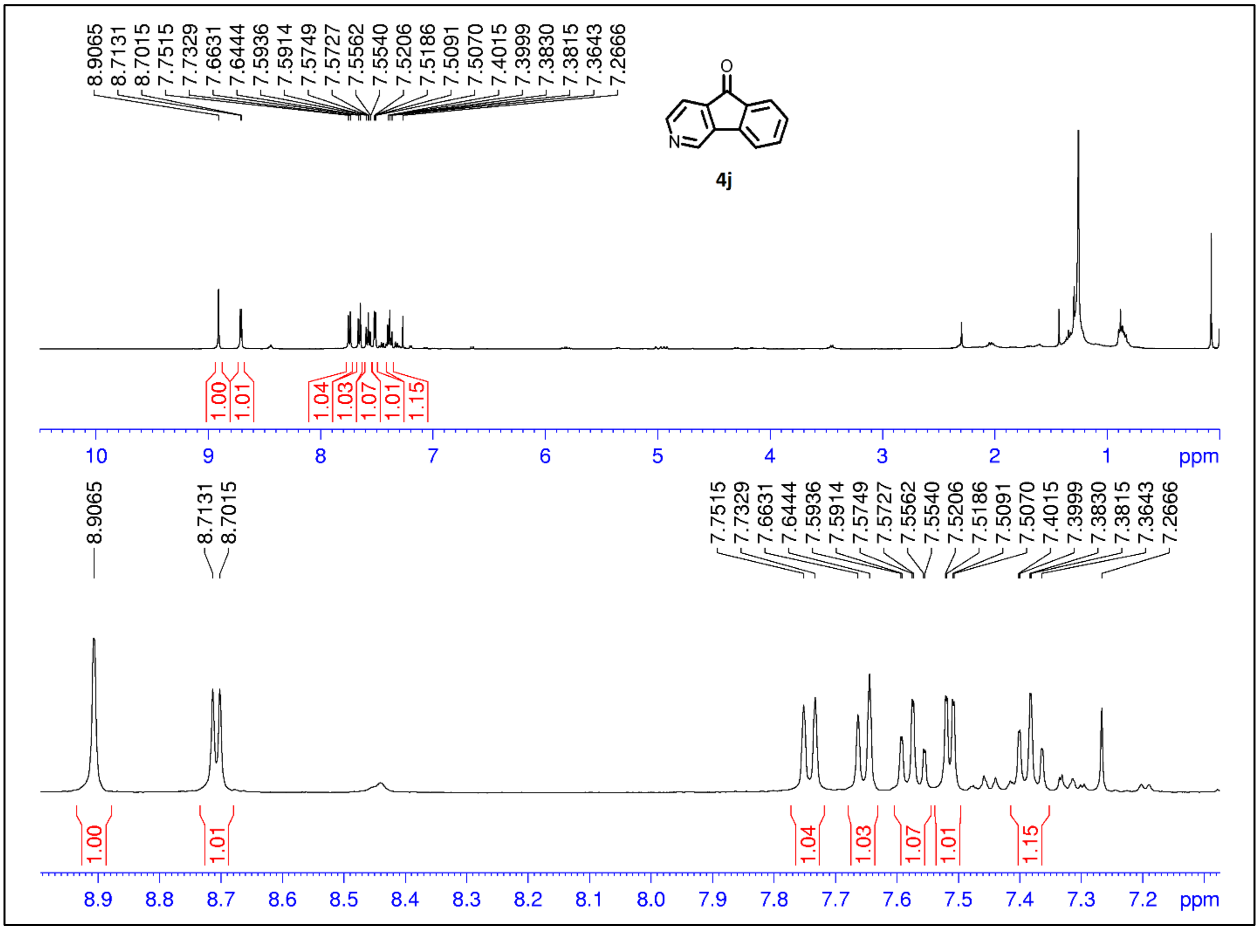
136.98
135.26
132.74
131.83
128.47
125.49
121.80
121.26
118.31
77.35
77.03
76.71
34.81
26.99
N
COCH$_3$
4i
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm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7.5914
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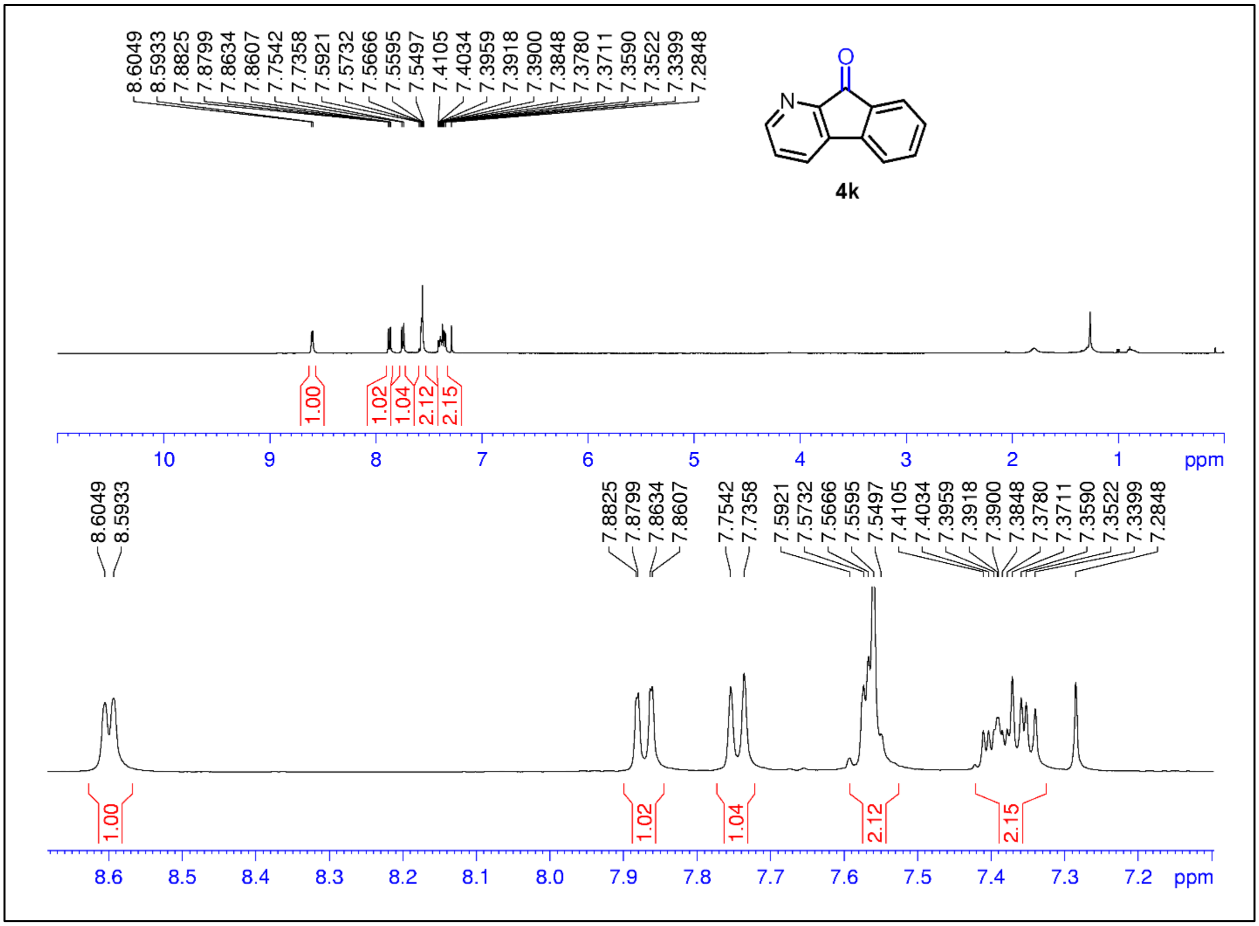
7.5727
7.5562
7.5540
7.5206
7.5186
7.5091
7.5070
7.4015
7.3999
7.3830
7.3815
7.3643
7.2666
O
N
4j
1.00
1.01
1.04
1.03
1.07
1.01
1.15
10 9 8 7 6 5 4 3 2 1 ppm
8.9065
8.7131
8.7015
7.7515
7.7329
7.6631
7.6444
7.5936
7.5914
7.5749
7.5727
7.5562
7.5540
7.5206
7.5186
7.5091
7.5070
7.4015
7.3999
7.3830
7.3815
7.3643
7.2666
1.00
1.01
1.04
1.03
1.07
1.01
1.15
8.9 8.8 8.7 8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 ppm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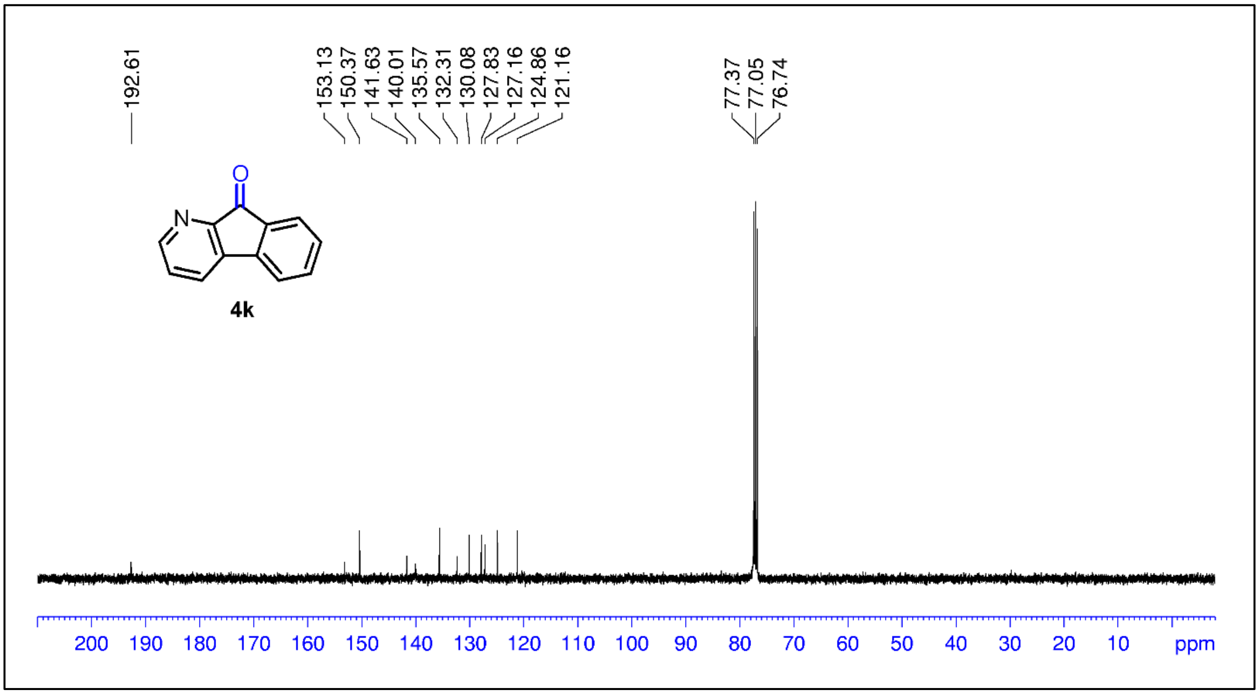
7.7542
7.7358
7.5921
7.5732
7.5666
7.5595
7.5497
7.4105
7.4034
7.3959
7.3918
7.3900
7.3848
7.3780
7.3711
7.3590
7.3522
7.3399
7.2848
O
N
1.00
1.02
1.04
2.12
2.15
10
9
8
7
6
5
4
3
2
1
ppm
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm

4k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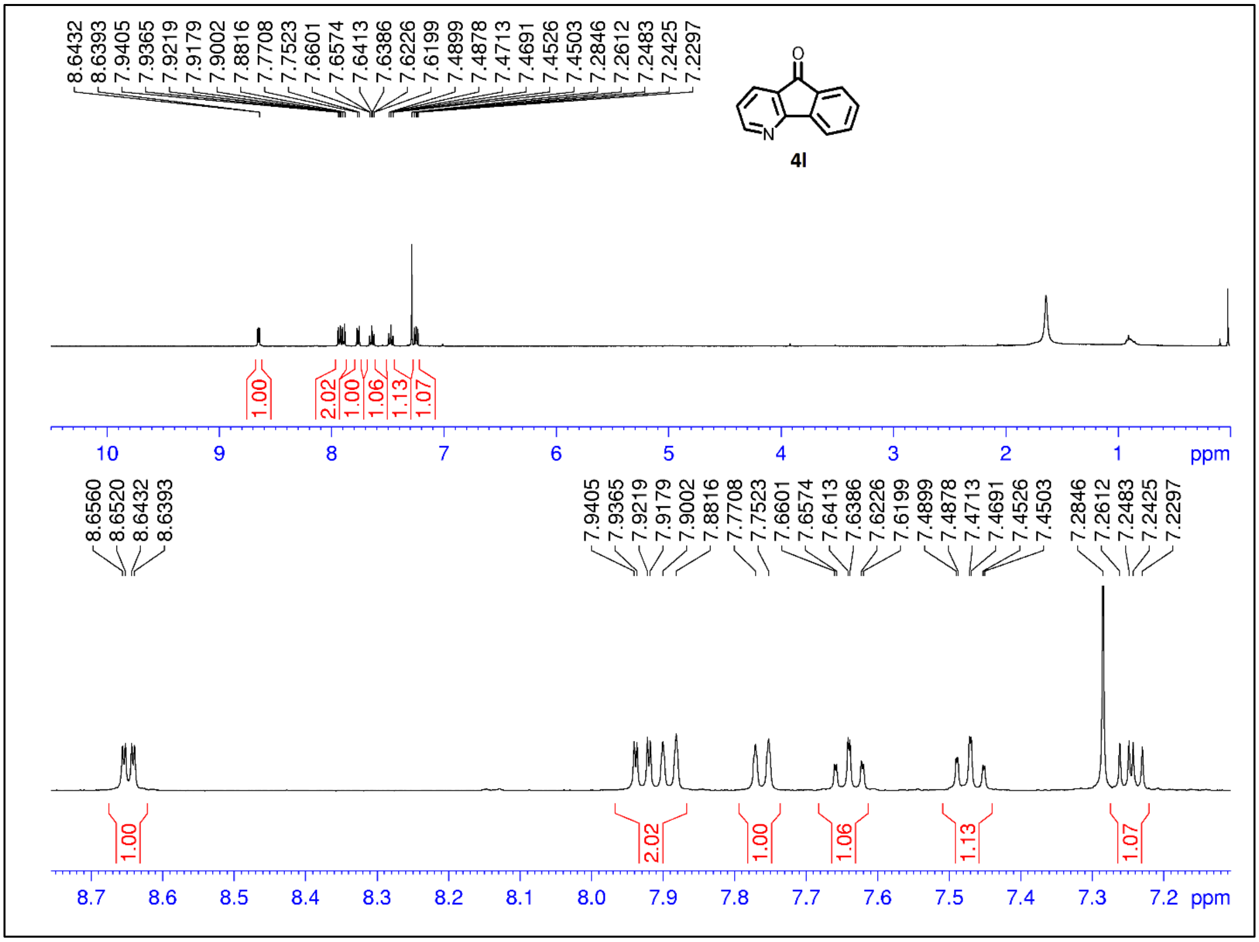
150.37
141.63
140.01
135.57
132.31
130.08
127.83
127.16
124.86
121.16
77.37
77.05
76.74
O
N
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

4k



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2. L. Wang, X. Cui, J. Li, Y. Wu, Z. Zhu, Y. Wu, *Eur. J. Org. Chem.*, 2012, 595.
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