Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Supporting Information

NHC-Alcohol Adduct-Mediated Photo-catalytic Deoxygenation to the Synthesis of 6-Phenanthridine Derivatives

Xueji Ma,* Qingyun Wang, Jinge Wu, Liyuan Zhang, Aili Sun and Zhanyong Wang*

School of Pharmacy, Key Laboratory of Nano-carbon Modified Film Technology Engineering of Henan Province, Xinxiang University,Xinxiang 453000, P. R. China.; E-mail: xuejima@zju.edu.cn

Contents

I. General Information and reaction setup

^{1}H NMR spectra were recorded in deuterated solvents on a Bruker 400 (400 MHz) spectrometer and calibrated to the residual solvent peak or tetramethylsilane (δ = 0 ppm). $CDCl_3$ or d_6-DMSO was used as solvent. Multiplicities are abbreviated as follows: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, dd = doublet of doublet, dt = doublet of triplet, br = broad. *J*-values are in Hz. HRMS was measured by a Finnigan MA+ mass spectrometer or a GCT Premier (7000FWHM). Organic solvents used were dried by standard methods when necessary. Commercially obtained reagents were used without further purification. All reactions were monitored by TLC with Huanghai GF_{254} silica gel coated plates. Organocatalysts were synthesized according to the literatures. Flash column chromatography was carried out using 200-300 mesh silica gel at increased pressure.

Representative photos of reaction setup:

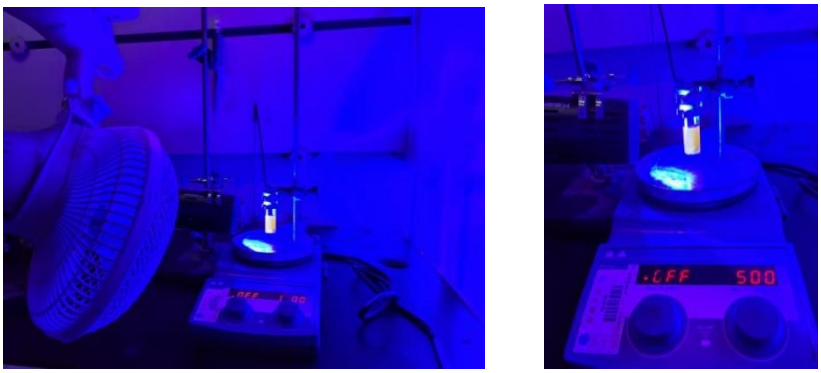


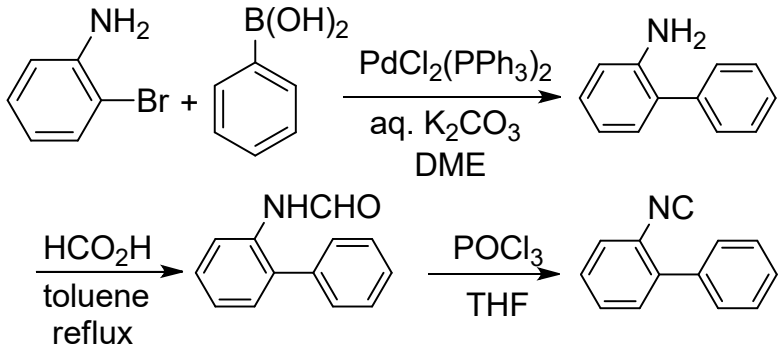
Figure 1. Representative photos of reaction setup:

8 mL glass vial containing a reaction on 0.3 mmol scale under irradiation with 440 nm LED.

II. Experimental Section

1. Synthesis of isonitrile 1:

A typical procedure (synthesis of isonitrile 1) is shown below:[1]

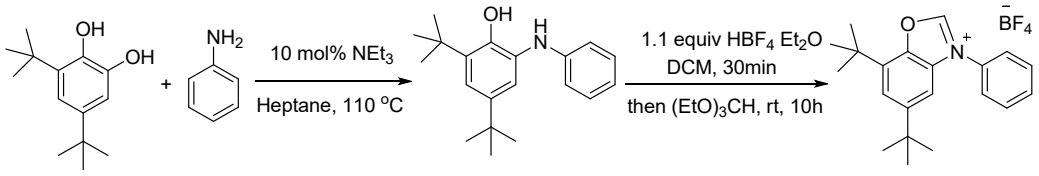


2-Bromo-aniline (1.72 g, 10 mmol, 1.0 equiv), boronic acid (1.34 g, 11.0mmol, 1.1 equiv) and an aqueous solution of K_2CO_3 (2 M, 25 mL) were placed in a three necked flask under N_2. Then, DME (25 mL) was added and the mixture was stirred for 10-30 min. To the stirred mixture, $PdCl_2(PPh_3)_2$ (71.1 mg, 0.1mmol, 0.01 equiv) was added and the mixture was stirred at 80 °C for 6h. The mixture was then cooled to room temperature and diluted with EtOAc. The organic layer was washed with water and dried over anhydrous $MgSO_4$. The solvent was removed under reduced pressure and the residue was purified by flash column chromatography on silica gel by using a 20:1 mixture of pentane/EtOAc as an eluent to provide 2-phenylaniline as white solid (1.44 g, 84%).

A solution of 2-phenylaniline (1.70 g, 10mmol) and formic acid (0.9 mL) in toluene (15mL) is refluxed under N_2 atmosphere. The reaction was monitored by TLC. After the reaction, volatile materials were evaporated under reduced pressure. Crude product was purified by flash column chromatography on silica gel to afford pure 2-phenylformanilide (1.88 g, 95%). A THF solution (20 mL) of 2-phenylformanilide (1.88 g, 9.5 mmol) and NEt_3 (7 mL, 50 mmol) was cooled to 0 °C. Then, $POCl_3$ (1.2 mL, 11 mmol) was added dropwise and the mixture was stirred at 0 °C for 1 h. After the reaction was completed, the mixture was quenched by aqueous saturated Na_2CO_3 solution and stirred for 0.5 h. The mixture was extracted with EtOAc for three times.

The combined organic layer was dried over anhydrous $MgSO_4$. The solvent was removed under reduced pressure and the crude product was purified by flash column chromatography on silica gel (pentane/EtOAc = 50:1) to provide analytical pure isocyanide product as pale oil (1.50 g, 88%).

2. Synthesis of NHCs.

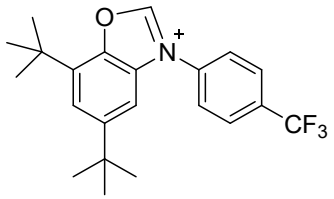


Experimental procedure for benzoxazolium salts and other intermediate synthesis. [2]

Step 1: To a suspension of 3,5-di-*tert*-butylcatechol (66.6 g; 300 mmol; 1.0 equiv) and aniline(28.2 ml, 306 mmol, 1.02 equiv) in n-heptane (200 mL), triethylamine (3.9 ml, 45.0 mmol, 0.1 equiv) was added in one portion under air. The resulting mixture was heated at 120 °C with dean-stark trap under air for 15 h. White solid precipitate out during the reaction. The resulting mixture was cooled down to room temperature and the white solid product precipitate was collected by filtration. The obtained filtrate was stored at -20 °C for overnight. Then the desired product was also collected by filtration. The combined product washed with cold petroleum ether, and air-dried. The product (76.7 g, 258 mmol, 86% yield) was pure enough for next step.

Step 2: Tetrafluoroboric acid diethyl ether complex (26 mL; 190 mmol; 1.05 equiv) was added dropwise to a suspension of 3,5-di-*tert*-butyl-2-hydroxy-*N*-phenylaniline (54.0 g, 181.5 mmol) with 160 mL of dry dichloromethane under nitrogen atmosphere. After 5 min finishing the addition, the suspension became a red homogenous solution. Further stirring at room temperature for additional 25 min, then the solvent was removed. The resulting solid was dissolved in triethyl orthoformate (400 mL) at room temperature, white solid cake precipitate out after several minutes. The suspension was stirred at room temperature for additional 12 hours. The desired product was collected by filtration as a white powder after washed with 50 ml dry

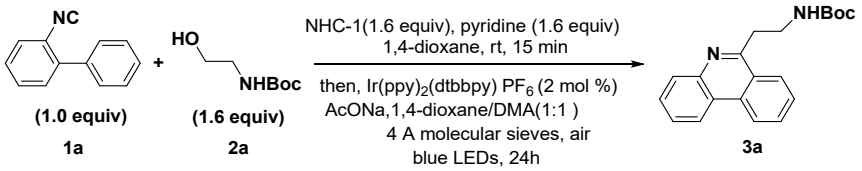
petroleum ether (64.5 g, 163.4 mmol, 90%). ^{1}H-NMR and ^{13}C-NMR data are consistent with literature report. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.21 (s, 1H), 7.81-7.83 (m, 2H), 7.71-7.78 (m, 3H), 7.37 (d, J = 1.2 Hz, 1H), 1.58 (s, 9H), 1.37 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 155.4, 153.8, 146.1, 138.2, 132.3, 131.0, 129.1, 125.2, 125.1, 107.9, 35.9, 35.0, 31.4, 29.8.



p-CF_3-NHC-BF_4 (NHC-5) : 52.9 g a pale yellow solid was obtained following standard NHC synthesis protocol. (53% isolated yield for two steps.) ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.2 (s, 1H), 7.95-8.03 (m, 4H), 7.70 (br, 1H), 7.31 (br, 1H), 1.56 (s, 9H), 1.36 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 156.1, 153.9, 146.1, 138.2, 134.1 (q, J = 32 Hz), 133.0, 129.0, 128.1 (q, J = 3.6 Hz), 126.3, 125.1, 124.5 (q, J = 274 Hz), 107.5, 35.9, 35.0, 31.4, 29.8.

3. General procedure for the synthesis of 3-5

The general procedure is described below using the synthesis of **3a** as example.



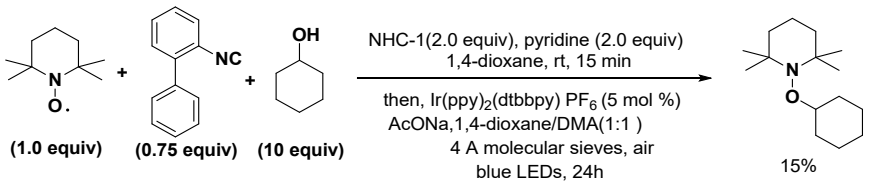
A dry 10 mL vial was charged with *N*-Boc-ethanolamine (**2a**, 78 mg, 0.48 mmol, 1.6 equiv) , NHC-1 (*N*-phenyl benzoxazolium salt, 190 mg, 0.48 mmol, 1.6 equiv) and 1.5 mL 1,4-dioxane. Pyridine (38.5 µl, 0.48 mmol, 1.6 equiv) was added dropwise to the vial at room temperature over the course of 2 min while stirring. The resulting solution stirred for 15 min. A white solid precipitated out during this time. Then the suspension centrifuged to give a clear solution of NHC-alcohol adduct for further use.

Another oven-dried 10mL vial was charged with Ir[ppy]$_2$(dtbbpy)PF_6 (5.5 mg, 0.006 mmol, 0.02 equiv), 2-isocyanobiaryls (**1a**, 54 mg, 0.3 mmol, 1.0 equiv),

AcONa (59 mg, 0.72 mmol, 2.4 equiv), 4A molecular sieve (100mg) and a magnetic stir bar. Dimethylacetamide (DMA, 1.5 mL) was added to this vial to form a yellow solution. Then the solution of NHC-alcohol adduct was transferred into the DMA solution, and the reaction mixture was stirred at 1300 rpm stir rate and irradiated under 440 nm LED (40 W) at 100% light intensity with a cooling fan for 24 hours.

When the reaction is completed, the mixture was diluted with a 0.05 M KH_2PO_4/Na_2HPO_4 aqueous buffer solution (15 mL), water (50mL) and EtOAc (30 mL). The aqueous layer was further extracted with EtOAc three times (25 mL X 3). The combined organic layers were washed with water, brine and dried over anhydrous magnesium sulfate. The solution of EtOAc was concentrated and purified via silica gel column chromatography.

4. Radical trapping experiment

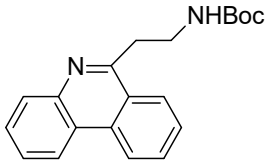


A dry 10 mL vial was charged with NHC-1 (*N*-phenyl benzoxazolium salt, 296 mg, 0.8 mmol, 2.0 equiv), cyclohexanol (401 mg, 4.0 mmol, 10.0 equiv) and 2.0 mL 1,4-dioxane. Pyridine (64.2 µl, 0.80 mmol, 2.0 equiv) was added dropwise to the vial at room temperature over the course of 2 min while stirring. The resulting solution stirred for 15 min. A white solid precipitated out during this time. Then the suspension centrifuged to give a clear solution of NHC-alcohol adduct for further use.

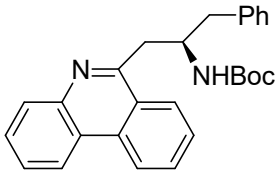
Another oven-dried 10mL vial was charged with $Ir[ppy]_2(dtbbpy)PF_6$ (5.5 mg, 0.02 mmol, 0.05 equiv), TEMPO (2,2,6,6-Tetramethyl-1-piperidinyloxy) (62.4 mg, 0.40 mmol, 1.0 equiv) , 2-isocyanobiaryls (**1a**, 54 mg, 0.3 mmol, 0.75 equiv), AcONa (79 mg, 0.96 mmol, 2.4 equiv), 4A molecular sieve (100mg) and a magnetic stir bar. Dimethylacetamide (DMA, 2.0 mL) was added to this vial to

form a yellow solution. Then the solution of NHC-alcohol adduct was transferred into the DMA solution, and the reaction mixture was stirred at 1300 rpm stir rate and irradiated under 440 nm LED (40 W) at 100% light intensity with a cooling fan for 24 hours. Then the mixture was diluted with a 0.05 M KH_2 PO_4/Na_2HPO_4 aqueous buffer solution (20 mL), water (50mL) and EtOAc (30 mL). The aqueous layer was further extracted with EtOAc three times (25 mL X 3). The combined organic layers were washed with water, brine and dried over anhydrous magnesium sulfate. The solution of EtOAc was concentrated and purified via silica gel column chromatography to give 1-(Cyclohexyloxy)-2,2,6,6-tetramethylpiperidine as light yellow oil (14.3mg, 15%).

5. Compound characterizations.

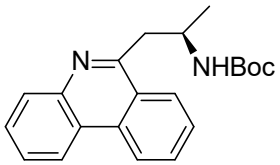


3a; White solid; mp = 108-110°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.53 (d, *J* = 8.4 Hz, 1H), 8.46 (d, *J* = 8.0 Hz, 1H), 8.17 (d, *J* = 8.4 Hz, 1H), 8.08 (d, *J* = 8.0 Hz, 1H), 7.77 (t, *J* = 7.6 Hz, 1H), 7.56-7.70 (m, 3H), 5.59 (br, 1H), 3.84 (t, *J* = 2.4 Hz, 2H), 3.49 (t, *J* = 2.4 Hz, 2H), 1.44 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =159.2, 156.1, 143.4, 132.6, 130.4, 129.7, 128.5, 127.5, 126.5, 125.8, 125.6, 123.6, 122.3, 121.9, 79.0, 38.2, 35.1, 28.5; HRMS (ESI, m/z): calcd. for $C_{20}H_{23}N_2O_2$ (M+H)+: requires 323.1760, found: 323.1762.

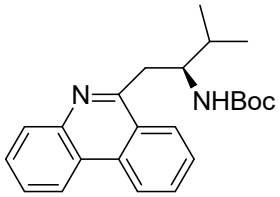


3b; White solid; mp = 152-153°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.63 (d, *J* = 7.6 Hz, 1H), 8.55 (d, *J* = 7.6 Hz, 1H), 8.15 (d, *J* = 7.6 Hz, 1H), 8.06 (d, *J* = 7.6 Hz, 1H), 7.82 (t, *J* = 7.6 Hz, 1H), 7.73 (t, *J* = 7.6 Hz, 1H), 7.62-7.65 (m, 2H), 7.16-7.35 (m, 5H), 5.53 (br, 1H), 4.47-4.50 (m, 1H), 3.45-3.56 (m, 2H), 2.98-3.14 (m, 2H), 1.31 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =158.3, 155.3, 143.3, 132.9, 130.5, 129.7, 128.6,

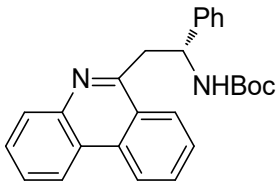
128.5, 127.5, 127.1, 126.7, 126.3, 125.9, 125.5, 123.7, 122.5, 121.9, 79.2, 54.3, 42.0, 28.2; HRMS (ESI, m/z): calcd. for $C_{27}H_{29}N_2O_2$ (M+H)+: requires 413.2229, found: 413.2229.



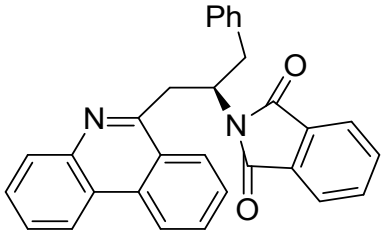
3c; White solid; mp = 98-100°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.65 (d, *J* = 8.0 Hz, 1H), 8.55 (d, *J* = 8.0 Hz, 1H), 8.41 (d, *J* = 8.0 Hz, 1H), 8.13 (d, *J* = 8.0 Hz, 1H), 7.85 (t, *J* = 8.0 Hz, 1H), 7.70-7.75 (m, 2H), 7.64 (t, *J* = 7.6 Hz, 1H), 5.24 (br, 1H), 4.33 (br, 1H), 3.67-3.70 (m, 1H), 3.36-3.42 (m, 1H), 1.35 (s, 9H), 1.27 (d, *J* = 6.4 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =159.2, 155.4, 143.3, 132.9, 130.6, 129.6, 128.6, 127.6, 126.6, 126.5, 125.7, 123.7, 122.4, 121.9, 79.0, 46.5, 42.5, 28.3, 20.8; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}N_2O_2$ (M+H)+: requires 337.1916, found: 337.1916.



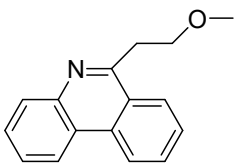
3d; White solid; mp = 139-140°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.64 (d, *J* = 8.0 Hz, 1H), 8.54 (d, *J* = 8.0 Hz, 1H), 8.30 (d, *J* = 8.0 Hz, 1H), 8.10 (d, *J* = 8.0 Hz, 1H), 7.83 (t, *J* = 7.6 Hz, 1H), 7.68-7.74 (m, 2H), 7.61 (t, *J* = 7.6 Hz, 1H), 5.20 (br, 1H), 4.06-4.10 (m, 1H), 3.60-3.65 (m, 1H), 3.35-3.41 (m, 1H), 2.02-2.05 (m, 1H), 1.20 (s, 9H), 1.08 (d, *J* = 6.8 Hz, 3H), 1.00 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =159.3, 155.8, 143.5, 132.9, 130.4, 129.7, 128.4, 127.5, 126.4, 126.1, 125.6, 123.7, 122.5, 121.9, 78.7, 55.5, 38.2, 31.6, 28.2, 19.4, 18.2; HRMS (ESI, m/z): calcd. for $C_{23}H_{29}N_2O_2$ (M+H)+: requires 365.2229, found: 365.2218.



3e; White solid; mp = 143-144°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.61 (d, *J* = 8.4 Hz, 1H), 8.52 (d, *J* = 8.0 Hz, 1H), 8.17 (d, *J* = 8.4 Hz, 1H), 8.12 (d, *J* = 8.0 Hz, 1H), 7.81 (t, *J* = 7.6 Hz, 1H), 7.71 (t, *J* = 7.6 Hz, 1H), 7.61-7.66 (m, 2H), 7.39 (d, *J* = 7.6 Hz, 2H), 7.27 (t, *J* = 7.6 Hz, 2H), 7.19 (d, *J* = 7.6 Hz, 1H), 6.11 (br, 1H), 5.33 (br, 1H), 3.83-3.89 (m, 1H), 3.71 (br, 1H), 1.25 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =158.3, 155.3, 143.3, 132.9, 130.5, 129.7, 128.6, 128.5, 127.5, 127.1, 126.7, 126.3, 125.9, 125.5, 123.7, 122.5, 122.0, 79.2, 54.3, 42.0, 28.2; HRMS (ESI, m/z): calcd. for $C_{26}H_{27}N_2O_2$ (M+H)+: requires 399.2073, found: 399.2077.

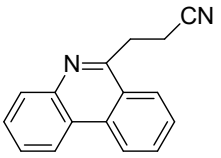


3f; White solid; mp = 133-135°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.59 (d, *J* = 8.0 Hz, 1H), 8.48 (d, *J* = 8.0 Hz, 1H), 8.18 (d, *J* = 8.0 Hz, 1H), 7.89 (d, *J* = 8.0 Hz, 1H), 7.63-7.70 (m, 3H), 7.54-7.61 (m, 4H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.22 (t, *J* = 7.6 Hz, 2H), 7.15 (t, *J* = 7.6 Hz, 2H), 5.41-5.49 (m, 1H), 4.15-4.21 (m, 1H), 3.92-3.97 (m, 1H), 3.52-3.58 (m, 1H), 3.40-3.45 (m, 1H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =168.6, 157.8, 143.5, 138.3, 133.6, 132.7, 131.9, 130.3, 129.8, 129.2, 128.5, 128.4, 127.4, 126.6, 126.4, 125.5, 125.4, 123.5, 122.9, 122.5, 121.8, 51.7, 38.7, 36.4; HRMS (ESI, m/z): calcd. for $C_{30}H_{23}N_2O_2$ (M+H)+: requires 443.1760, found: 443.1763.

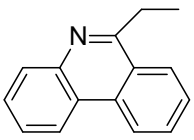


3g; Brown oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.63 (d, *J* = 8.0 Hz, 1H), 8.53 (d, *J* = 8.0 Hz, 1H), 8.29 (d, *J* = 8.0 Hz, 1H), 8.21 (d, *J* = 8.0 Hz, 1H), 7.83 (t, *J* = 7.6 Hz,

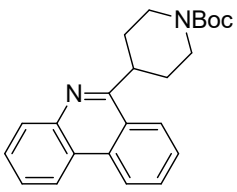
1H), 7.67-7.74 (m, 2H), 7.62 (t, *J* = 7.6 Hz, 1H), 4.03 (t, *J* = 7.2 Hz, 2H), 3.67 (t, *J* = 7.2 Hz, 2H), 3.42 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =159.1, 143.7, 132.8, 130.4, 129.7, 128.6, 127.4, 126.5, 126.3, 125.6, 123.7, 122.4, 121.9, 71.7, 58.9, 35.9; HRMS (ESI, m/z): calcd. for $C_{16}H_{16}NO$ (M+H)+: requires 238.1232, found: 238.1230.



3h; White solid; mp = 78-80^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.65 (d, *J* = 8.4 Hz, 1H), 8.55 (d, *J* = 8.0 Hz, 1H), 8.16 (d, *J* = 8.0 Hz, 1H), 8.13 (d, *J* = 8.4 Hz, 1H), 7.86 (t, *J* = 7.6 Hz, 1H), 7.71-7.75 (m, 2H), 7.65 (t, *J* = 7.6 Hz, 1H), 3.73 (t, *J* = 7.6 Hz, 2H), 3.19 (t, *J* = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =156.0, 143.3, 132.8, 130.7, 129.9, 128.8, 127.6, 126.9, 124.9, 123.7, 122.7, 122.0, 120.4, 30.4, 14.5; HRMS (ESI, m/z): calcd. for $C_{16}H_{13}N_2$ (M+H)+: requires 233.1079, found: 233.1074.

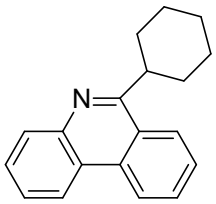


3i; Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.62 (d, *J* = 8.0 Hz, 1H), 8.52 (d, *J* = 8.0 Hz, 1H), 8.24 (d, *J* = 8.0 Hz, 1H), 8.14 (d, *J* = 8.4 Hz, 1H), 7.81 (t, *J* = 7.6 Hz, 1H), 7.62-7.72 (m, 2H), 7.60 (t, *J* = 7.6 Hz, 1H), 3.40 (q, *J* = 7.6 Hz, 2H), 1.50 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =163.4, 143.6, 133.0, 130.4, 129.5, 128.6, 127.3, 126.4, 126.3, 125.0, 123.7, 122.5, 121.9, 29.4, 13.8; HRMS (ESI, m/z): calcd. for $C_{15}H_{14}N$ (M+H)+: requires 208.1121, found: 208.1121.

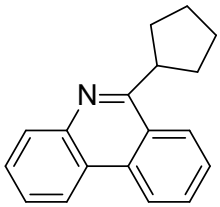


3j; White solid; mp = 159-160 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.66 (d, *J* = 8.0 Hz, 1H), 8.54 (d, *J* = 8.0 Hz, 1H), 8.28 (d, *J* = 8.0 Hz, 1H), 8.11 (d, *J* = 8.0 Hz, 1H), 7.83 (t, *J* = 7.6 Hz, 1H), 7.66-7.71 (m, 2H), 7.62 (t, *J* = 7.6 Hz, 1H), 4.35 (br, 2H),

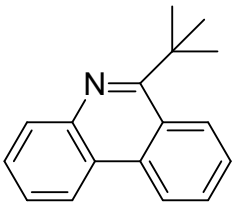
3.71-3.78 (m, 1H), 3.73 (t, *J* = 7.6 Hz, 2H), 3.02 (br, 2H), 2.14 (br, 2H), 2.03 (br, 2H), 1.51 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =163.1, 154.9, 143.7, 133.1, 130.2, 130.0, 128.6, 127.3, 126.5, 125.2, 124.5, 123.4, 122.8, 121.9, 79.4, 40.1, 31.4, 31.2, 28.6; HRMS (ESI, m/z): calcd. for $C_{23}H_{27}N_2O_2$ (M+H)+: requires 363.2073, found: 363.2067.



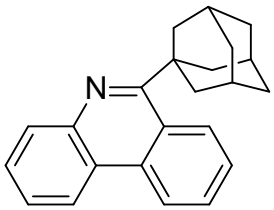
3k; Yellowish oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.63 (d, *J* = 8.4 Hz, 1H), 8.51 (d, *J* = 8.0 Hz, 1H), 8.30 (d, *J* = 8.4 Hz, 1H), 8.13 (d, *J* = 8.4 Hz, 1H), 7.79 (t, *J* = 7.6 Hz, 1H), 7.64-7.70 (m, 2H), 7.58 (t, *J* = 7.6 Hz, 1H), 3.52-3.64 (m, 1H), 2.09-1.82 (m, 7H), 1.52-1.61 (m, 2H), 1.41-1.49 (m, 1H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 165.3, 143.9, 133.1, 133.0, 129.9, 128.4, 127.1, 126.1, 125.6, 124.8, 123.4, 122.6, 121.8, 42.0, 32.3, 26.9, 26.4; HRMS (ESI, m/z): calcd. for $C_{19}H_{20}N$ (M+H)+: requires 262.1590, found: 262.1589.



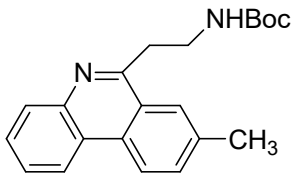
3l; Yellowish oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.63 (d, *J* = 8.4 Hz, 1H), 8.52 (d, *J* = 8.0 Hz, 1H), 8.31 (d, *J* = 8.0 Hz, 1H), 8.11 (d, *J* = 8.8 Hz, 1H), 7.80 (t, *J* = 7.6 Hz, 1H), 7.65-7.71 (m, 2H), 7.59 (t, *J* = 7.6 Hz, 1H), 4.02-4.09 (m, 1H), 2.15-2.59 (m, 4H), 1.91-1.96 (m, 2H), 1.77-1.82 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 164.2, 143.8, 132.9, 130.0, 129.9, 128.4, 127.1, 126.3, 126.1, 125.7, 123.5, 122.4, 121.8, 43.6, 32.2, 26.1; HRMS (ESI, m/z): calcd. for $C_{18}H_{18}N$ (M+H)+: requires 248.1433, found: 248.1431.



3m; Yellowish oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.68 (d, *J* = 8.4 Hz, 1H), 8.62 (d, *J* = 8.4 Hz, 1H), 8.52 (d, *J* = 8.0 Hz, 1H), 8.12 (d, *J* = 8.0 Hz, 1H), 7.77 (t, *J* = 7.6 Hz, 1H), 7.55-7.72 (m, 3H), 1.73(s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 166.7, 143.0, 134.0, 130.3, 129.3, 128.4, 128.3, 126.5, 125.9, 124.3, 123.4, 123.0, 121.6, 40.2, 31.2; HRMS (ESI, m/z): calcd. for $C_{17}H_{18}N$ (M+H)+: requires 236.1434, found: 236.1433.

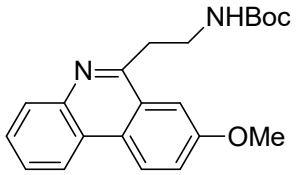


3n; White Solid, mp = 171-173 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.84 (d, *J* = 8.4 Hz, 1H), 8.67 (d, *J* = 8.4 Hz, 1H), 8.50 (d, *J* = 8.4 Hz, 1H), 8.11 (d, *J* = 8.0 Hz, 1H), 7.75 (t, *J* = 7.6 Hz, 1H), 7.68 (t, *J* = 7.6 Hz, 1H), 7.55-7.66 (m, 2H), 2.48 (br, 6H), 2.22 (br, 3H), 1.85-1.96 (m, 6H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 166.0, 143.2, 134.1, 130.3, 129.2, 128.4, 128.0, 126.4, 125.7, 124.5, 123.3, 123.1, 121.6, 43.0, 42.1, 37.3, 29.3; HRMS (ESI, m/z): calcd. for $C_{17}H_{18}N$ (M+H)+: requires 236.1434, found: 236.1433.

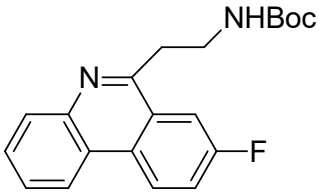


4a; White solid; mp = 157-158°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.47-8.51 (m, 2H), 8.09 (d, *J* = 8.0 Hz, 1H), 7.99 (s, 1H), 7.58-7.69 (m, 3H), 5.58 (br, 1H), 3.85 (d, *J* = 5.6 Hz, 2H), 3.51 (d, *J* = 5.6 Hz, 2H), 2.59 (s, 3H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 159.0, 156.1, 143.1, 137.4, 132.2, 130.5, 129.7, 128.1, 126.5, 125.8, 125.3, 123.8, 122.3, 121.8, 79.0, 38.0, 35.0, 28.5, 21.9; HRMS (ESI, m/z):

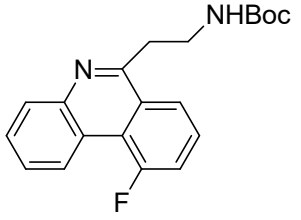
calcd. for $C_{21}H_{25}N_2O_2$ (M+H)+: requires 337.1916, found: 337.1918.



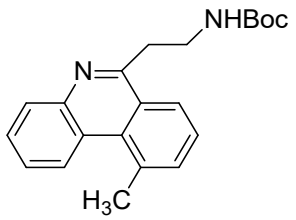
4b; White solid; mp = 149-150°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.52 (d, *J* = 8.8 Hz, 1H), 8.45 (d, *J* = 8.0 Hz, 1H), 8.09 (d, *J* = 7.6 Hz, 1H), 7.65 (d, *J* = 6.8 Hz, 1H), 7.58-7.64 (m, 2H), 7.45 (dd, *J* = 8.8 Hz, 2.4Hz, 1H), 7.58-7.69 (m, 3H), 5.56 (br, 1H), 4.00 (s, 3H), 3.83-3.88 (m, 2H), 3.50 (t, *J* = 6.0 Hz, 2H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 158.9, 158.3, 156.2, 142.6, 129.7, 127.6, 127.0, 126.9, 126.6, 124.1, 123.8, 121.5, 121.2, 105.9, 79.1, 55.6, 38.1, 35.4, 28.5; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}N_2O_3$ (M+H)+: requires 353.1865, found: 353.1864.



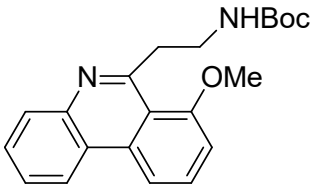
4c; White solid; mp = 146-147°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.61 (dd, *J* = 8.8 Hz, 5.6 Hz, 1H), 8.47 (d, *J* = 8.0 Hz, 1H), 8.11 (d, *J* = 8.0 Hz, 1H), 7.84 (d, *J* = 8.8 Hz, 1H), 7.71 (t, *J* = 7.6 Hz, 1H), 7.64 (d, *J* = 7.6 Hz, 1H), 7.57 (d, *J* = 8.8 Hz, 1H), 5.51 (br, 1H), 3.84-3.88 (m, 2H), 3.47 (t, *J* = 6.0 Hz, 2H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 161.5 (d, *J* = 249.6 Hz), 158.4, 156.1, 143.1, 129.9, 129.3, 128.4, 127.0, 125.0 (d, *J* = 8.5 Hz), 123.2, 121.7,119.8, 119.5, 110.5 (d, *J* = 21.5 Hz), 79.1, 38.0, 35.1, 28.5; HRMS (ESI, m/z): calcd. for $C_{20}H_{22}FN_2O_2$ (M+H)+: requires 341.1665, found: 341.1662.



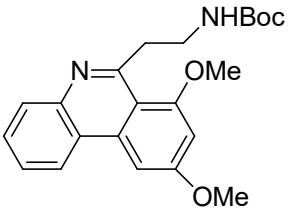
4d; White solid; mp = 103-105°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.94 (d, *J* = 8.0 Hz, 1H), 8.14 (d, *J* = 8.0 Hz, 1H), 8.08 (d, *J* = 8.0 Hz, 1H), 7.75 (t, *J* = 7.6 Hz, 1H), 7.63-7.68 (m, 2H), 7.52-7.57 (m, 1H), 5.51 (br, 1H), 4.01 (s, 3H), 3.84-3.88 (m, 2H), 3.53 (t, *J* = 5.6 Hz, 2H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 160.9 (d, *J* = 255.8 Hz), 158.4, 156.1, 143.8, 129.7, 128.8, 128.0, 127.8 (d, *J* = 8.7 Hz), 127.1 (d, *J* = 16.3 Hz), 126.8, 122.0 (d, *J* = 2.8 Hz), 121.7, 121.3, 117.1(d, *J* = 23.5 Hz), 79.1, 38.0, 35.6, 28.5; HRMS (ESI, m/z): calcd. for $C_{20}H_{22}FN_2O_2$ (M+H)+: requires 341.1665, found: 341.1667.



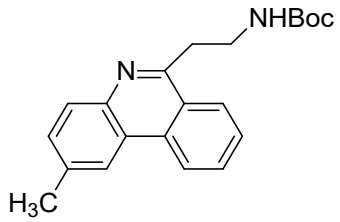
4e; Light brown oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.75 (d, *J* = 8.4 Hz, 1H), 8.15 (d, *J* = 8.0 Hz, 2H), 7.71 (t, *J* = 7.6 Hz, 1H), 7.64 (t, *J* = 7.6 Hz, 1H), 7.55-7.63 (m, 2H), 5.58 (br, 1H), 3.82-3.86 (m, 2H), 3.50-3.55 (m, 2H), 3.09 (s, 3H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 159.5, 156.2, 144.5, 135.6, 134.8, 132.2, 130.0, 127.8, 127.1, 126.9, 126.6, 125.7, 125.1, 124.3, 79.0, 38.3, 35.7, 28.5, 26.9; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}N_2O_2$ (M+H)+: requires 337.1916, found: 337.1918.



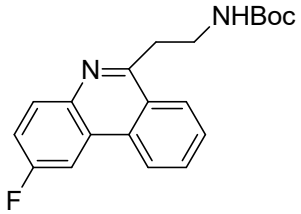
4f; White solid; mp = 154-155°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.46 (t, *J* = 7.2 Hz, 1H), 8.19 (t, *J* = 8.0 Hz, 1H), 8.06 (d, *J* = 8.0 Hz, 1H), 7.67-7.73 (m, 2H), 7.58 (t, *J* = 7.2 Hz, 1H), 7.06 (t, *J* = 7.2 Hz, 1H), 5.58 (br, 1H), 4.01 (s, 3H), 3.76-3.82 (m, 2H), 3.71 (t, *J* = 5.6 Hz, 2H), 1.41 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 159.0, 158.6, 143.2, 135.5, 130.9, 129.5, 128.7, 126.4, 123.0, 122.5, 117.4, 114.5, 108.2, 78.7, 55.6, 41.1, 38.6, 28.5; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}N_2O_3$ (M+H)+: requires 353.1865, found: 353.1860.



4h; White solid; mp = 146-148 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.40 (d, *J* = 8.4 Hz, 1H), 8.03 (d, *J* = 8.0 Hz, 1H), 7.68 (d, *J* = 7.6 Hz, 1H), 7.56 (d, *J* = 7.6 Hz, 1H), 7.54 (s, 1H), 6.67 (s, 1H), 5.57 (br, 1H), 4.03 (s, 3H), 4.00 (s, 3H), 3.76 (t, *J* = 5.6 Hz, 2H), 3.65 (t, *J* = 5.6 Hz, 2H), 1.41 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 161.7, 160.2, 158.6, 156.1, 143.7, 137.1, 129.5, 128.8, 125.9, 122.9, 122.4, 113.0, 991, 95.2, 78.7, 55.7, 55.5, 40.7, 38.7, 28.5; HRMS (ESI, m/z): calcd. for $C_{22}H_{27}N_2O_4$ (M+H)+: requires 383.1965, found: 383.1959.

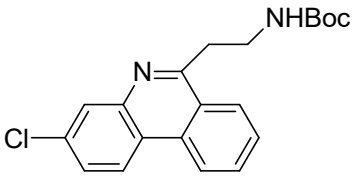


4i; White solid; mp = 143-144 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.54-8.61 (m, 1H), 8.28 (d, *J* = 8.0 Hz, 1H), 8.17-8.20 (m, 1H), 7.99 (t, *J* = 8.0 Hz, 1H), 7.75-7.82 (m, 1H), 7.62-7.69 (m, 3H), 7.52 (t, *J* = 8.0 Hz, 1H), 5.56 (br, 1H), 3.82-3.87 (m, 2H), 3.48-3.53 (m, 2H), 2.60 (s, 3H), 1.43 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 158.2, 156.1, 141.8, 136.4, 132.4, 130.2, 129.5, 127.3, 125.8, 125.7, 125.6, 123.5, 122.3, 121.6, 79.0, 38.3, 35.1, 28.5, 21.9; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}N_2O_2$ (M+H)+: requires 337.1916, found: 337.1917.

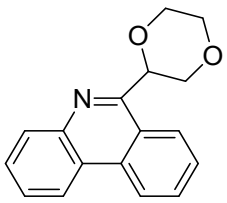


4j; White solid; mp = 128-129^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.48 (d, *J* = 8.0

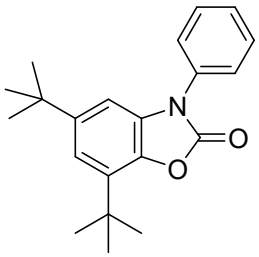
Hz, 1H), 8.25 (d, *J* = 8.4 Hz, 1H), 8.07-8.13 (m, 1H), 8.10 (s, 1H), 7.84 (t, *J* = 8.0 Hz, 1H), 7.73 (t, *J* = 8.0 Hz, 1H), 7.41-7.46 (m, 1H), 5.49 (br, 1H), 3.84 (t, *J* = 5.6 Hz, 2H), 3.52 (t, *J* = 5.6 Hz, 2H), 1.44 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ = 161.1 (d, *J* = 247.2 Hz), 158.5, 156.1, 140.3, 132.1(d, *J* = 4.2 Hz), 131.9 (d, *J* = 9.1 Hz), 130.6, 128.2, 125.9, 125.7, 125.0 (d, *J* = 9.0 Hz), 122.6, 117.3 (d, *J* = 24.2 Hz), 106.9 (d, *J* = 23.3 Hz), 79.1, 38.2, 35.1, 28.5; HRMS (ESI, m/z): calcd. for $C_{20}H_{21}FN_2O_2Na$ (M+Na)+: requires 363.1479, found: 363.1473.



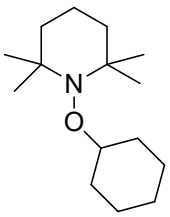
4k; White solid; mp = 148-149^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.55 (d, *J* = 8.4 Hz, 1H), 8.43 (d, *J* = 8.4 Hz, 1H), 8.24 (d, *J* = 8.4 Hz, 1H), 8.09 (s, 1H), 7.84 (t, *J* = 7.6 Hz, 1H), 7.70 (t, *J* = 7.6 Hz, 1H), 7.57 (t, *J* = 8.4 Hz, 1H), 5.49 (br, 1H), 3.85 (t, *J* = 6.0 Hz, 2H), 3.54 (t, *J* = 6.0 Hz, 2H), 1.44 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =160.7, 156.1, 144.1, 134.2, 132.2, 130.9, 129.0, 127.8, 127.1, 126.0, 125.6, 123.3, 122.3, 122.2, 79.1, 37.9, 35.2, 28.5; HRMS (ESI, m/z): calcd. for $C_{20}H_{22}ClN_2$ O_2(M+H)+: requires 357.1370, found: 357.1372.



6-(1,4-dioxan-2-yl)phenanthridine, White solid; mp = 159-161 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.65 (d, *J* = 8.4 Hz, 1H), 8.55 (d, *J* = 8.0 Hz, 1H), 8.43 (d, *J* = 8.4 Hz, 1H), 8.20 (d, *J* = 8.0 Hz, 1H), 7.85 (t, *J* = 7.6 Hz, 1H), 7.64-7.77 (m, 3H), 5.48 (dd, *J* = 7.6Hz, 5.2 Hz, 1H), 4.30-4.33 (m, 2H), 4.10-4.16 (m, 2H), 3.90-3.95 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =156.1, 143.2, 133.3, 130.6, 130.5, 128.6, 127.4, 127.3, 126.1, 124.5, 124.1, 122.5, 121.9, 76.2, 70.1, 67.8, 66.6; HRMS (ESI, m/z): calcd. for $C_{17}H_{15}NO_2Na$(M+ Na)+: requires 288.0995, found: 288.0994.



5; White solid; mp = 110-111°C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.55-7.58 (m, 4H), 7.42-7.49 (m, 1H), 7.14 (s, 1H), 6.91 (s, 1H), 1.48 (s, 9H), 1.30 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =153.7, 147.2, 138.5, 133.8, 133.5, 131.1, 129.9, 128.3, 125.5, 117.4, 104.3, 35.2, 34.4, 31.7, 29.8; HRMS (ESI, m/z): calcd. for $C_{21}H_{25}NO_2Na$(M+ Na)+: requires 346.1778, found: 346.1777.



1-(Cyclohexyloxy)-2,2,6,6-tetramethylpiperidine; Light yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.56-3.61(m, 1H), 2.03-2.05 (m, 2H), 1.63-1.74 (m, 2H), 1.35-1.56 (m, 6H), 1.15-1.26 (m, 6H), 1.12 (s, 12H); ^{13}C NMR (101 MHz, $CDCl_3$): δ =81.8, 59.7, 40.4, 34.6, 33.0, 26.1, 25.2, 20.4, 17.5; HRMS (ESI, m/z): calcd. for $C_{15}H_{30}NO$ (M+ H)+: requires 240.2322, found: 240.2315.

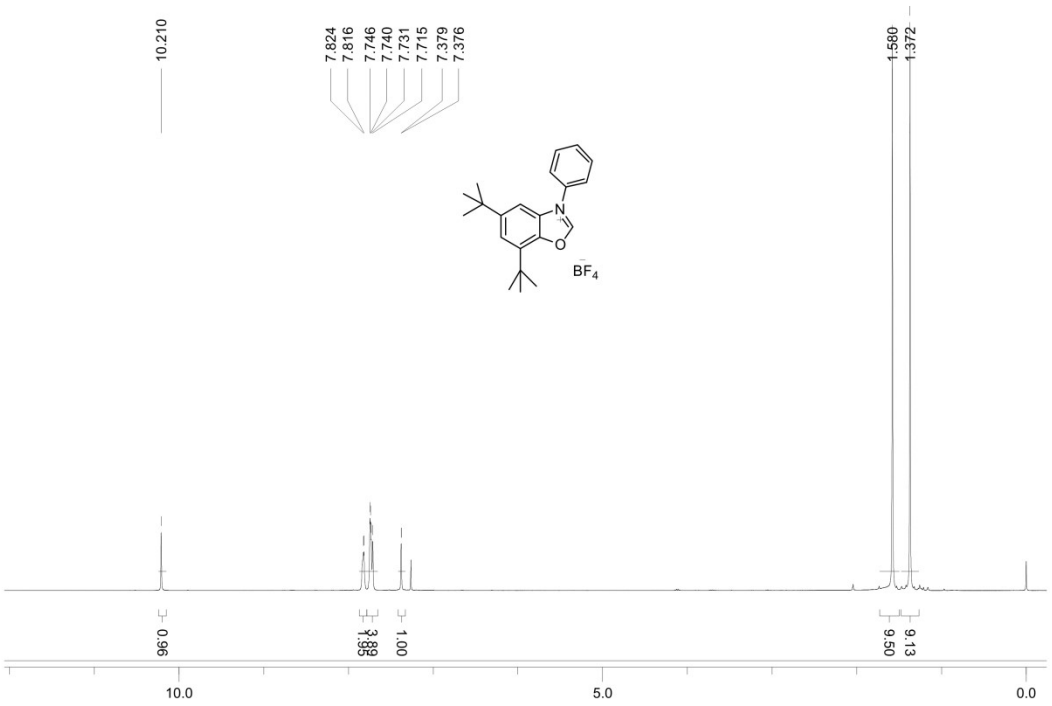
III Reference

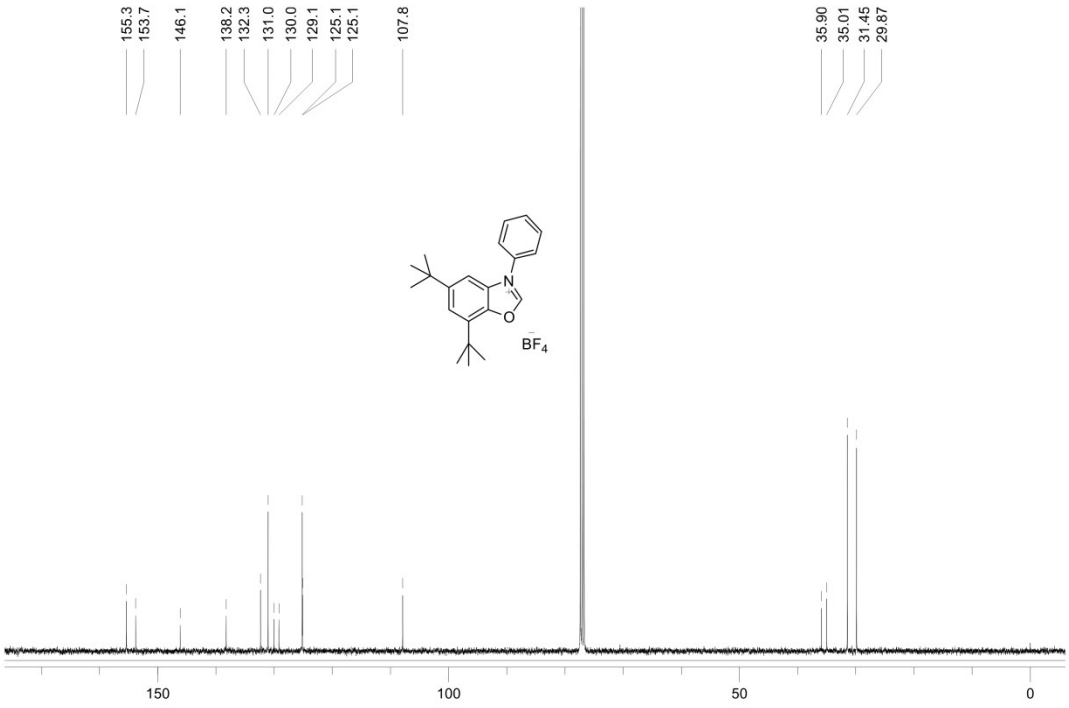
1. Zhang. B, Christian, M. L, Constantin. G. D., Armido. S., *Angew. Chem. Int. Ed.*, 2013, **125**, 10992-10995.

2. Z. Dong, D. W. C. MacMillan., *Nature.,* 2021, **598**, 451–456.

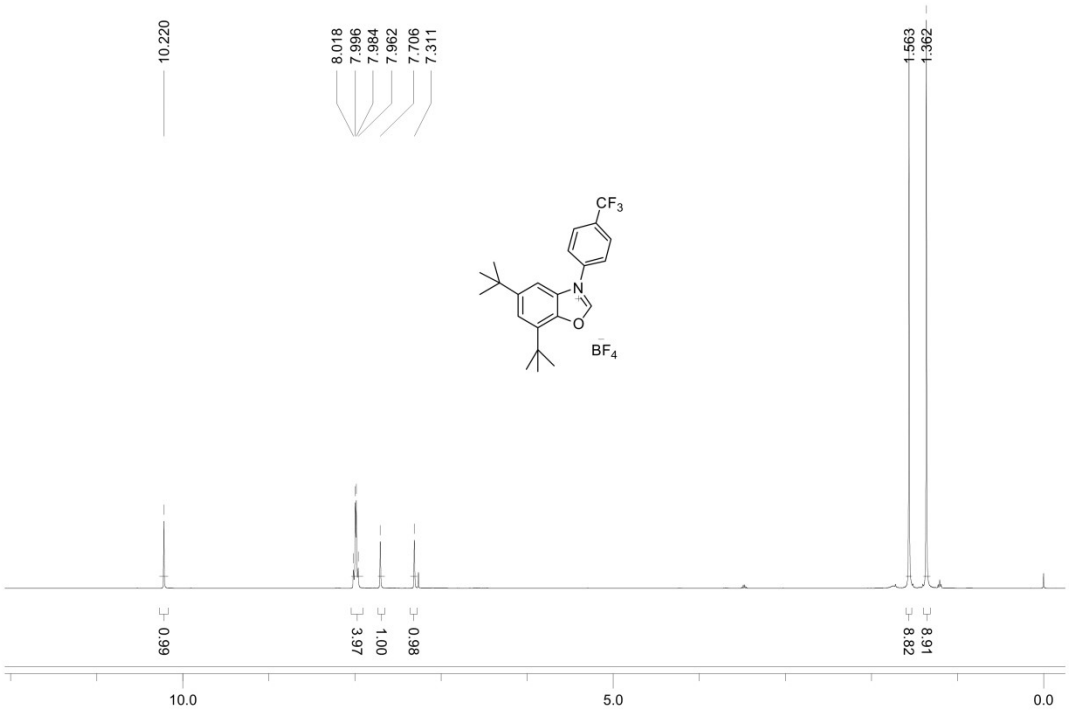
IV NMR Spectrum

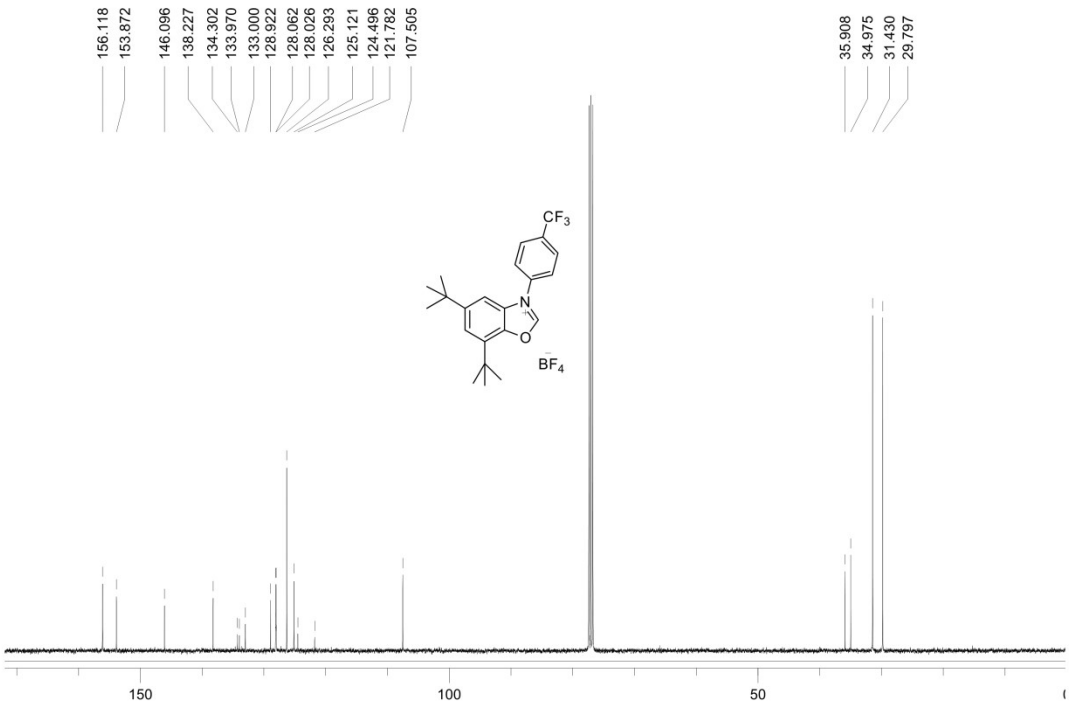
^{1}H NMR and ^{13}C NMR spectrum of **NHC-1**



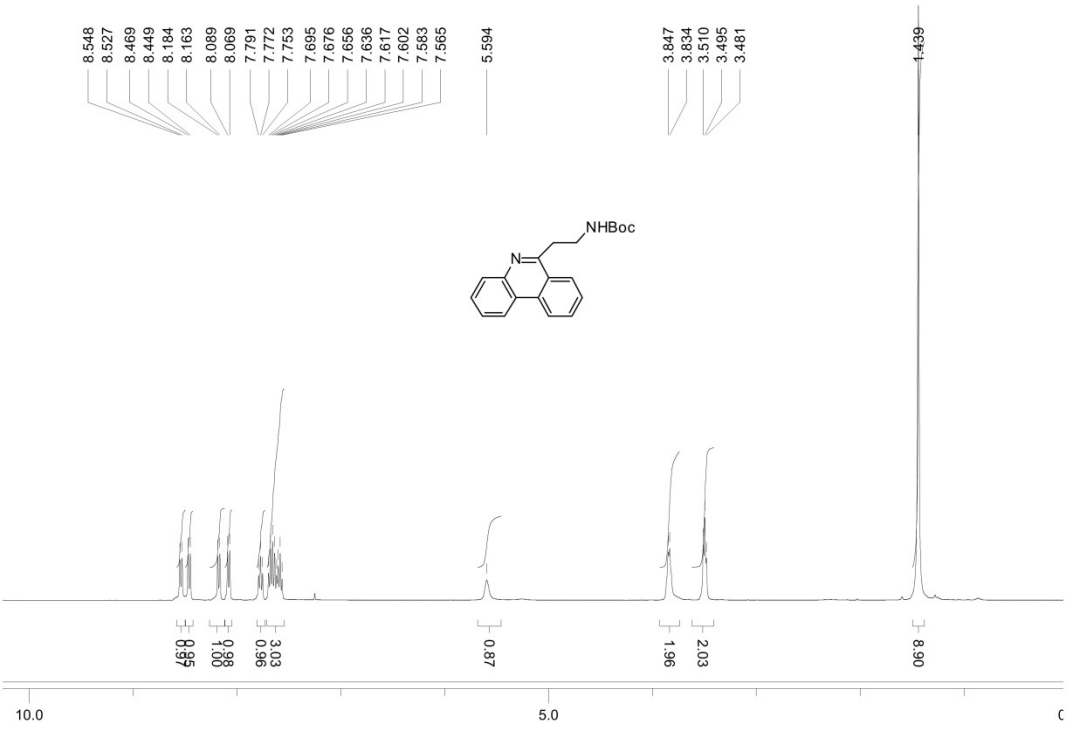


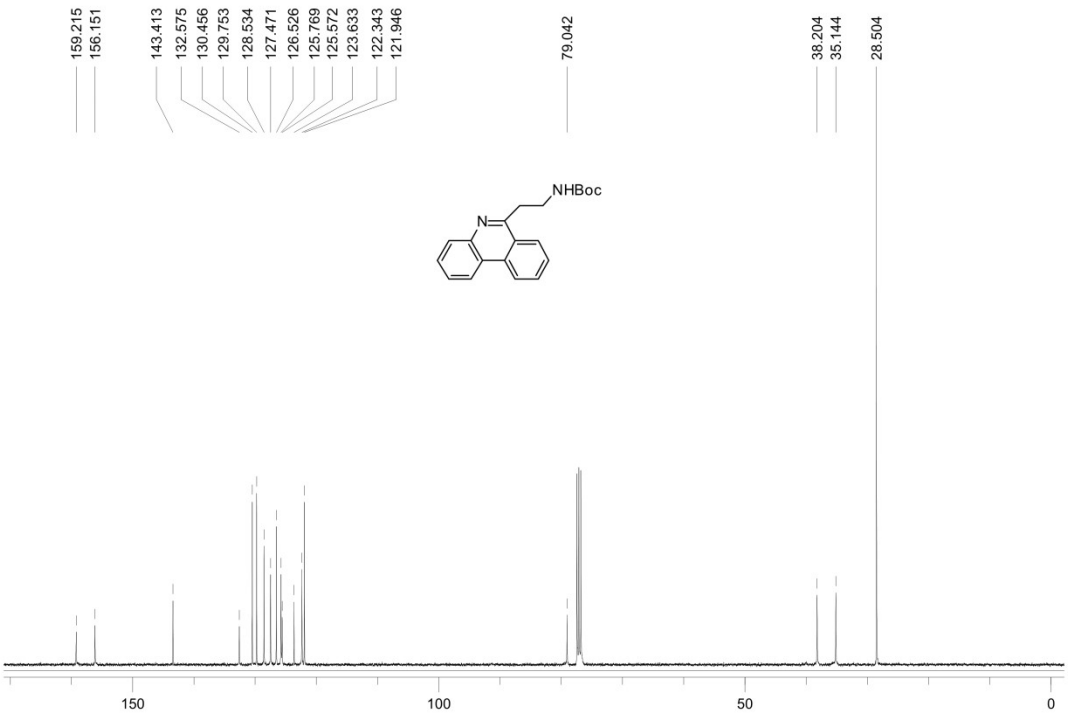
^{1}H NMR and ^{13}C NMR spectrum of **NHC-2**



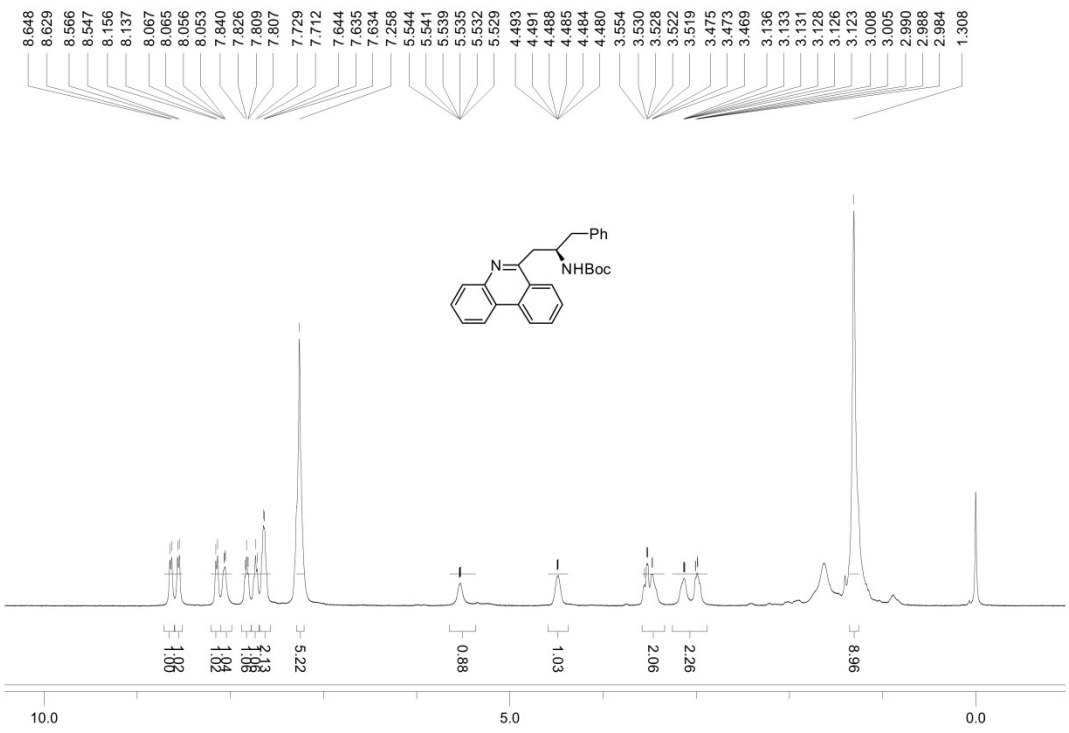


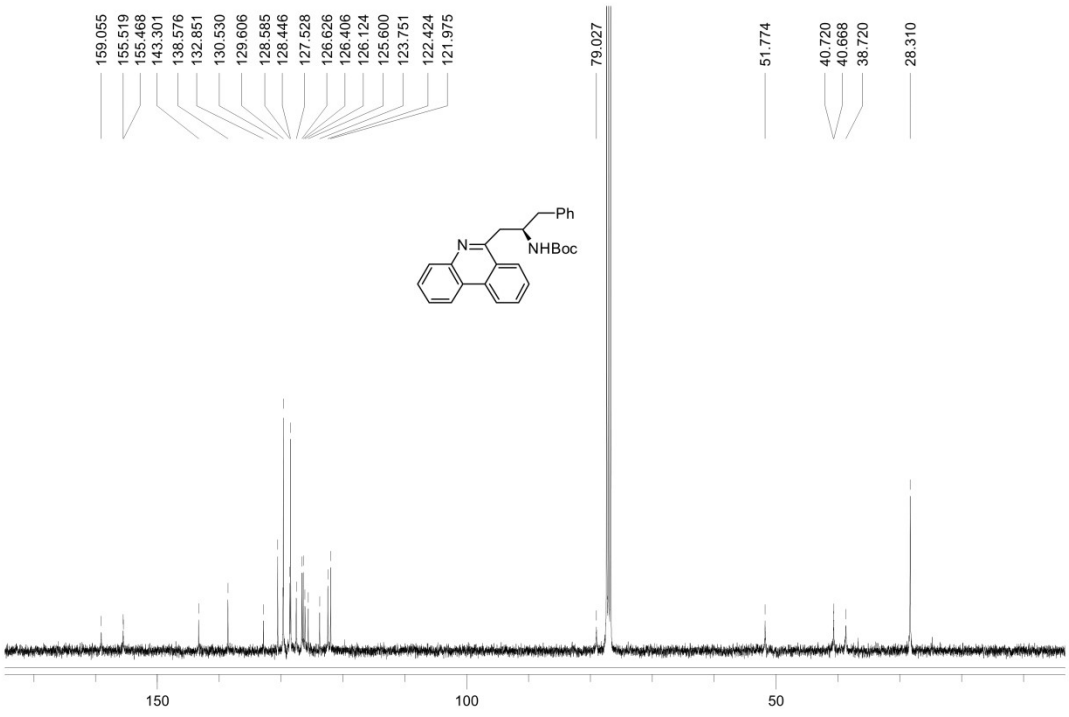
^{1}H NMR and ^{13}C NMR spectrum of **3a**



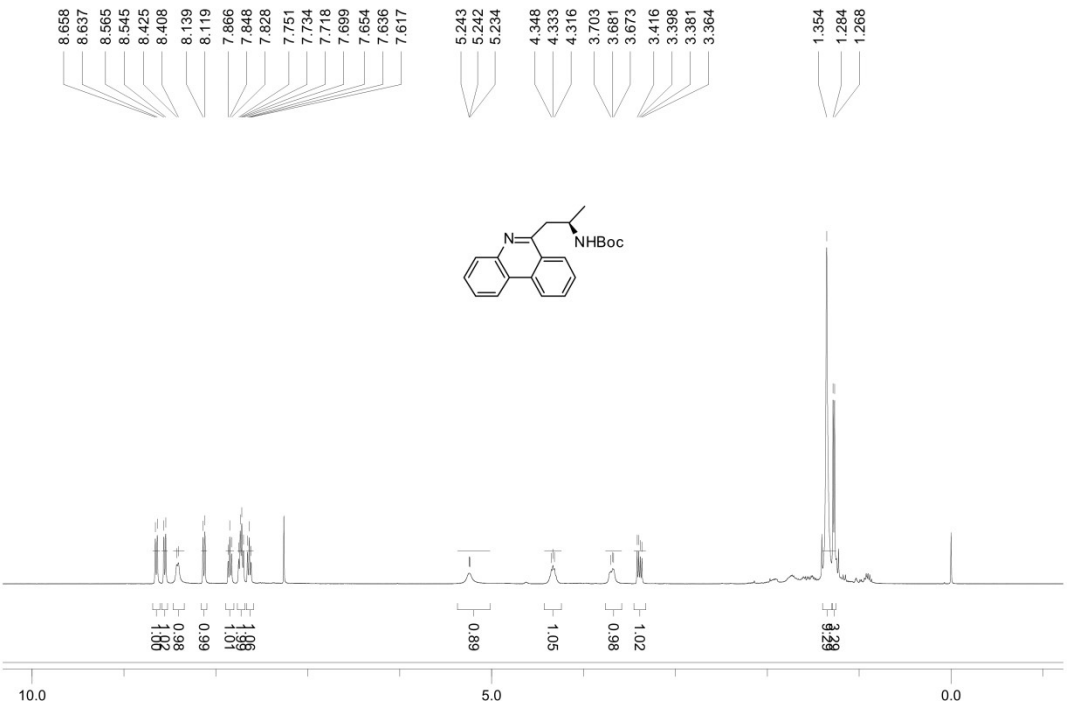


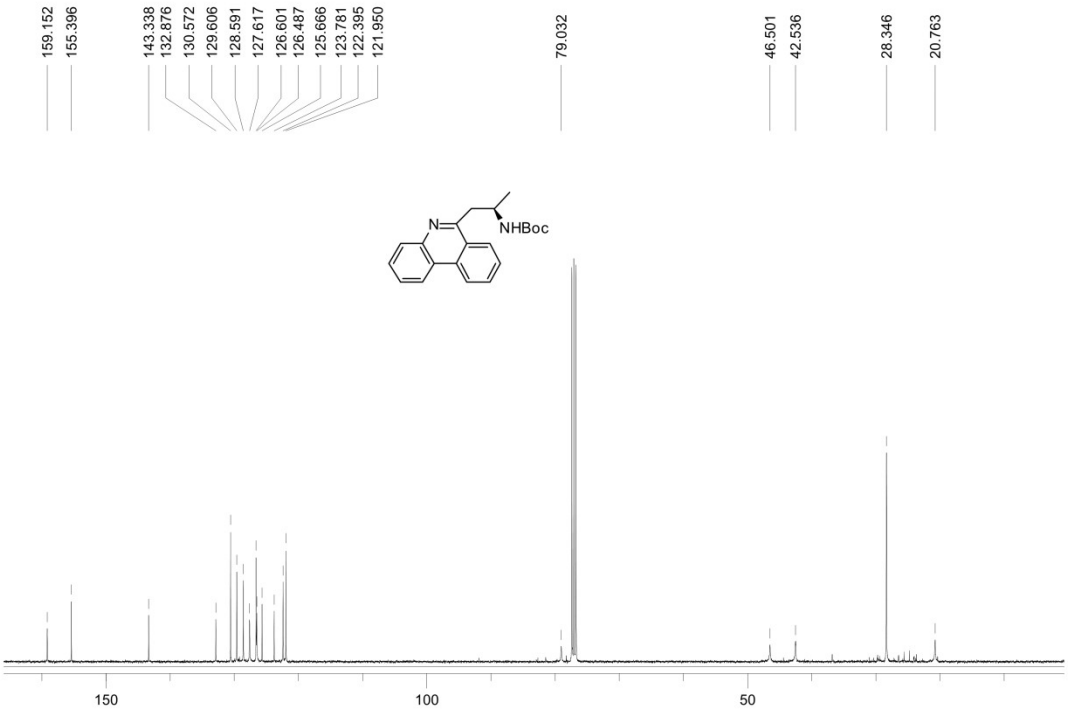
^{1}H NMR and ^{13}C NMR spectrum of **3b**



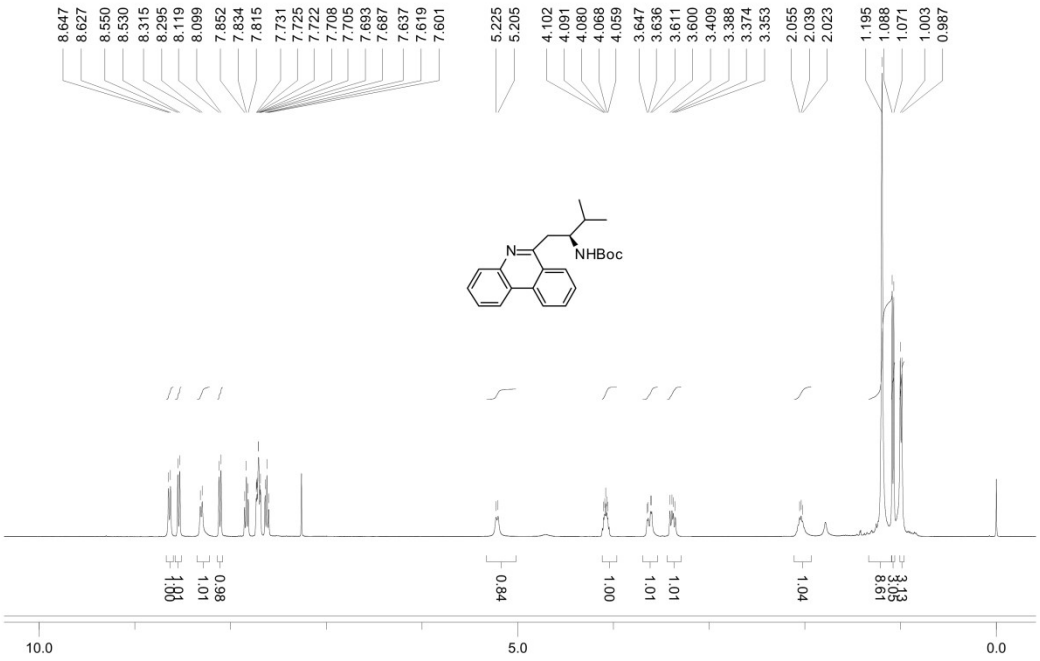


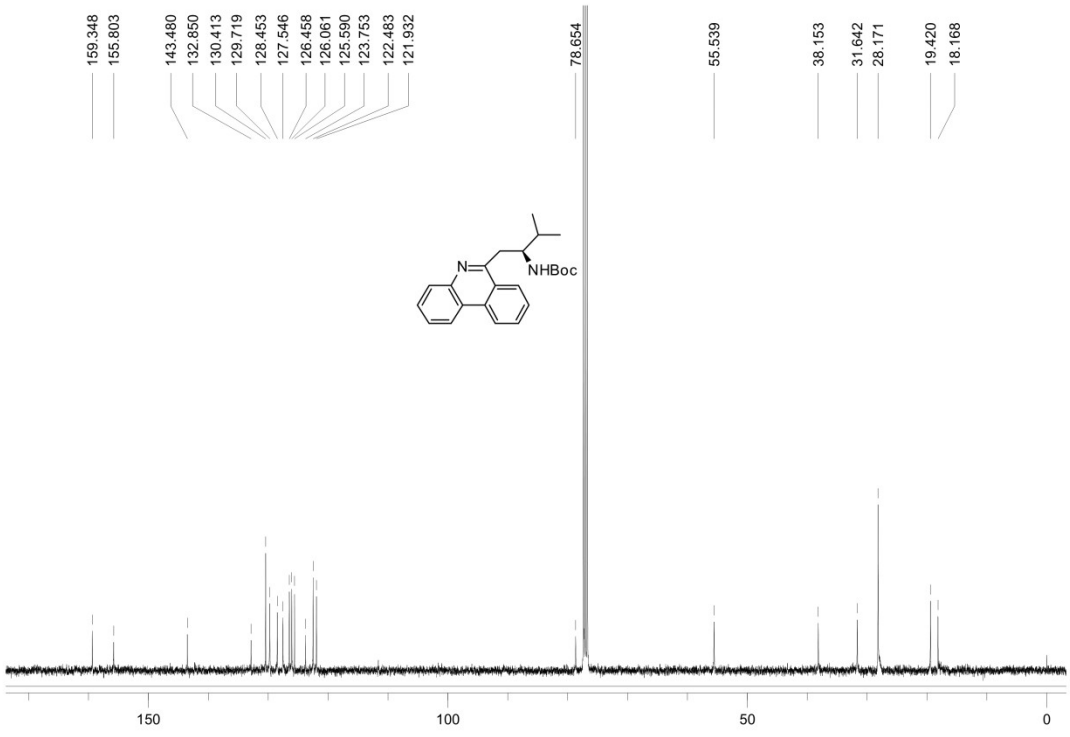
^{1}H NMR and ^{13}C NMR spectrum of **3c**



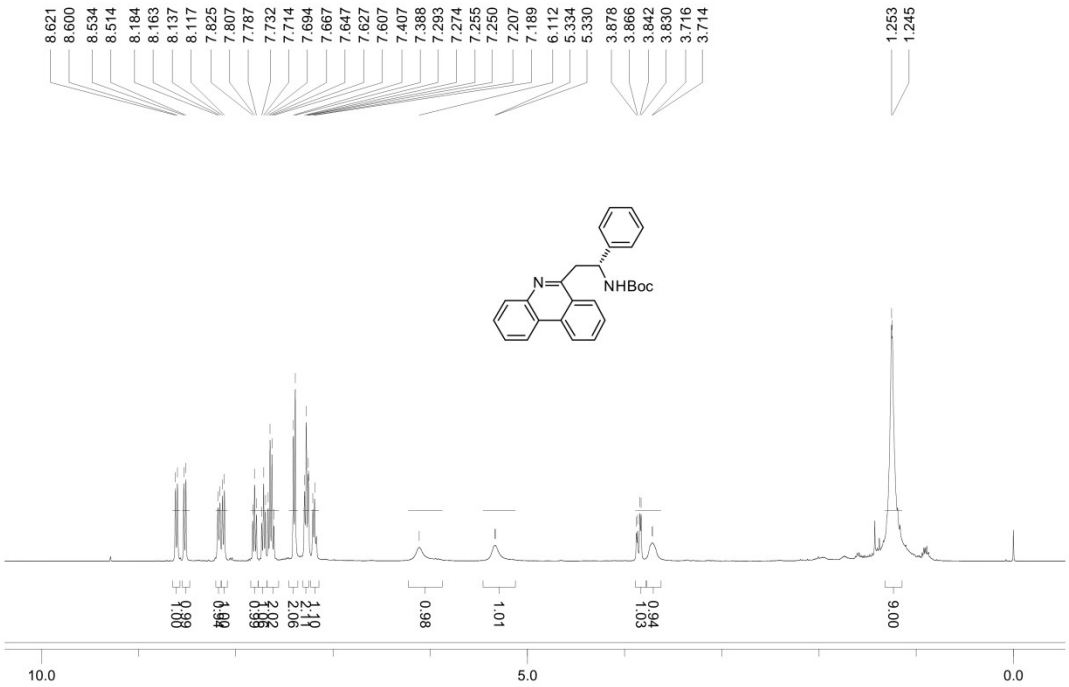


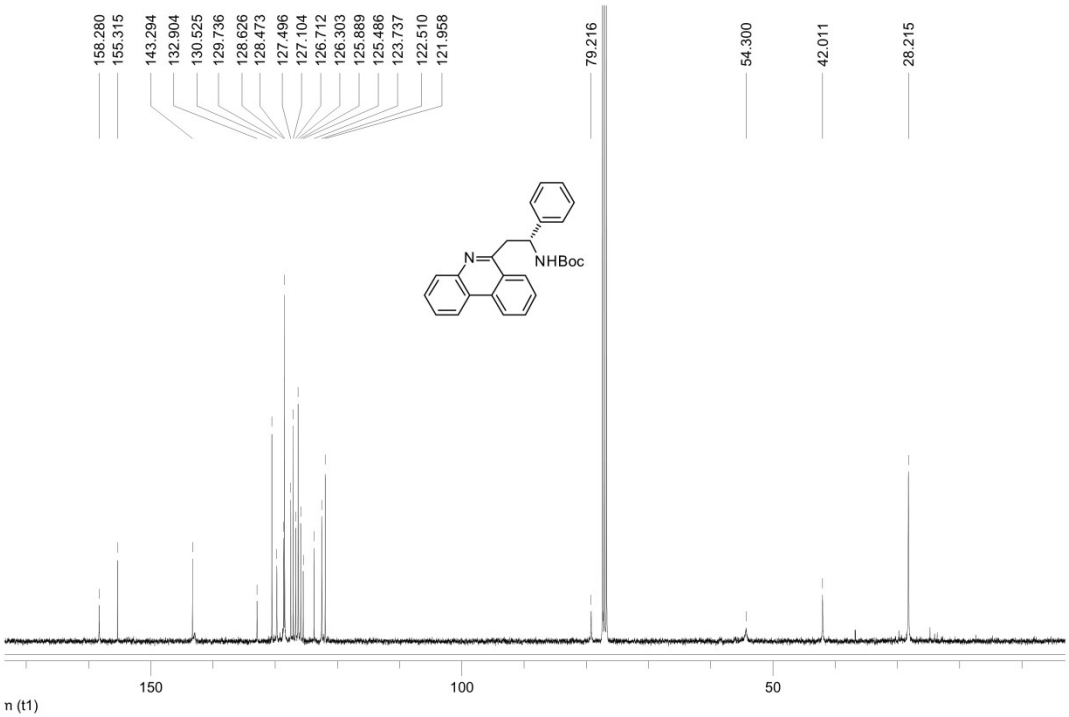
^{1}H NMR and ^{13}C NMR spectrum of **3d**



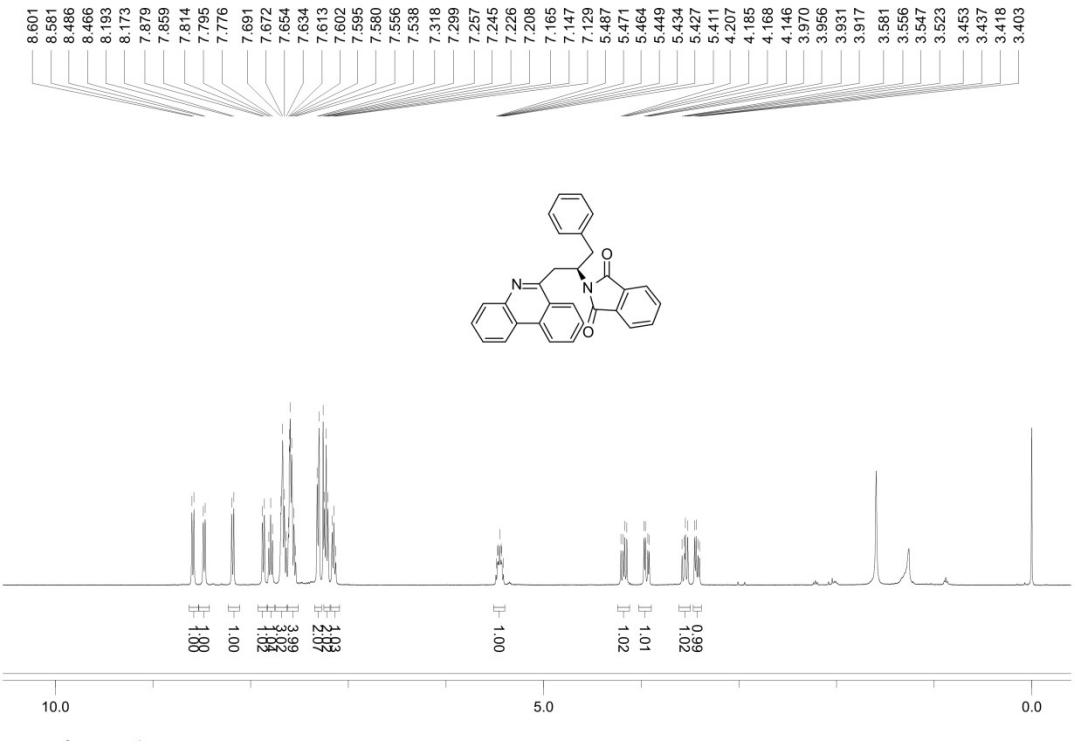


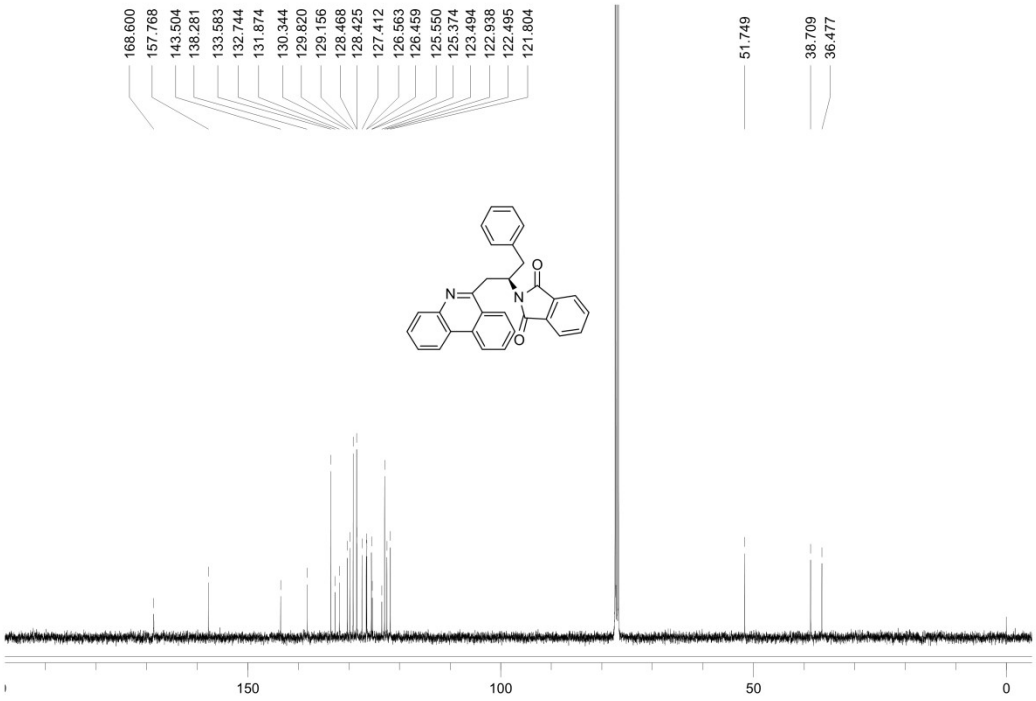
^{1}H NMR and ^{13}C NMR spectrum of **3e**



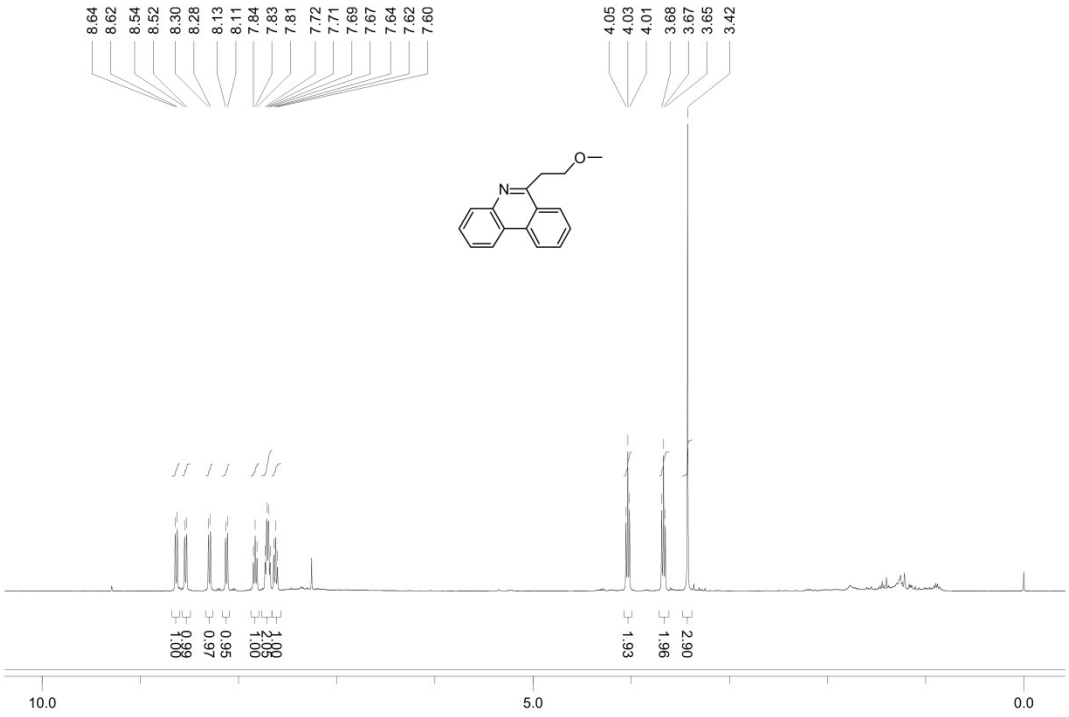


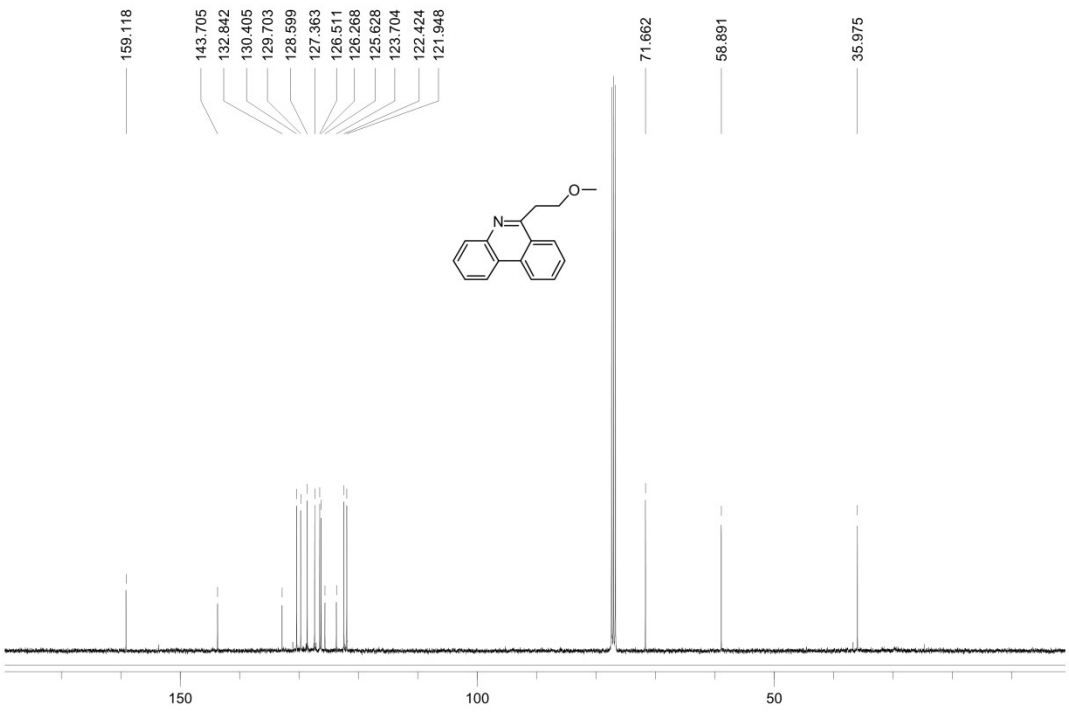
^{1}H NMR and ^{13}C NMR spectrum of **3f**



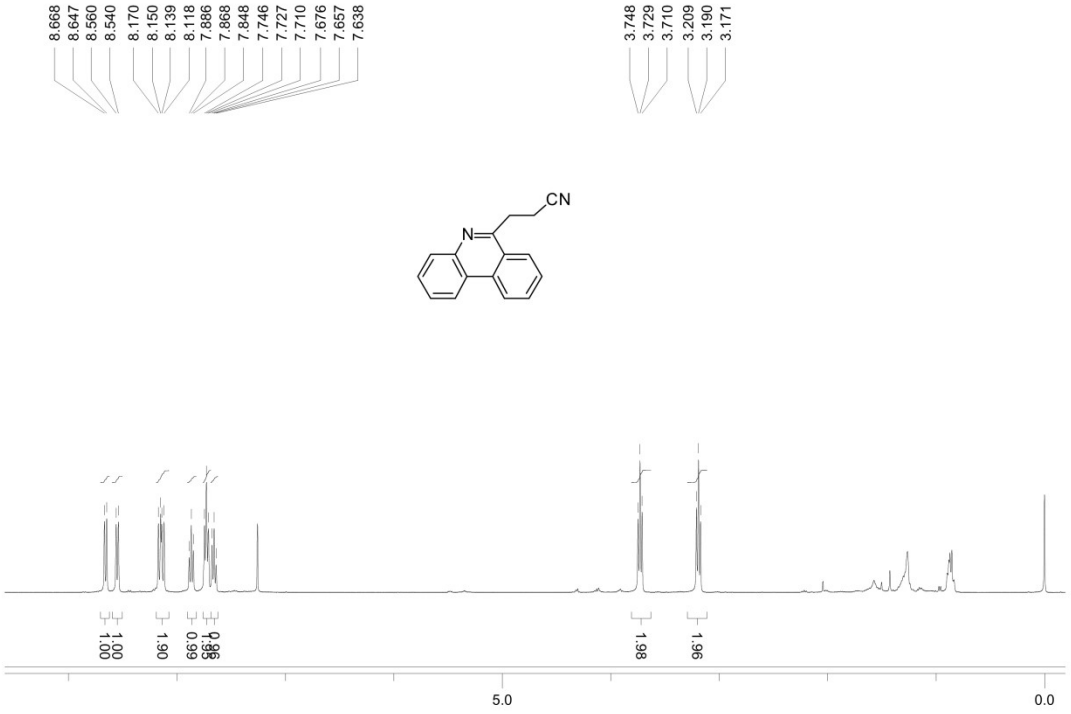


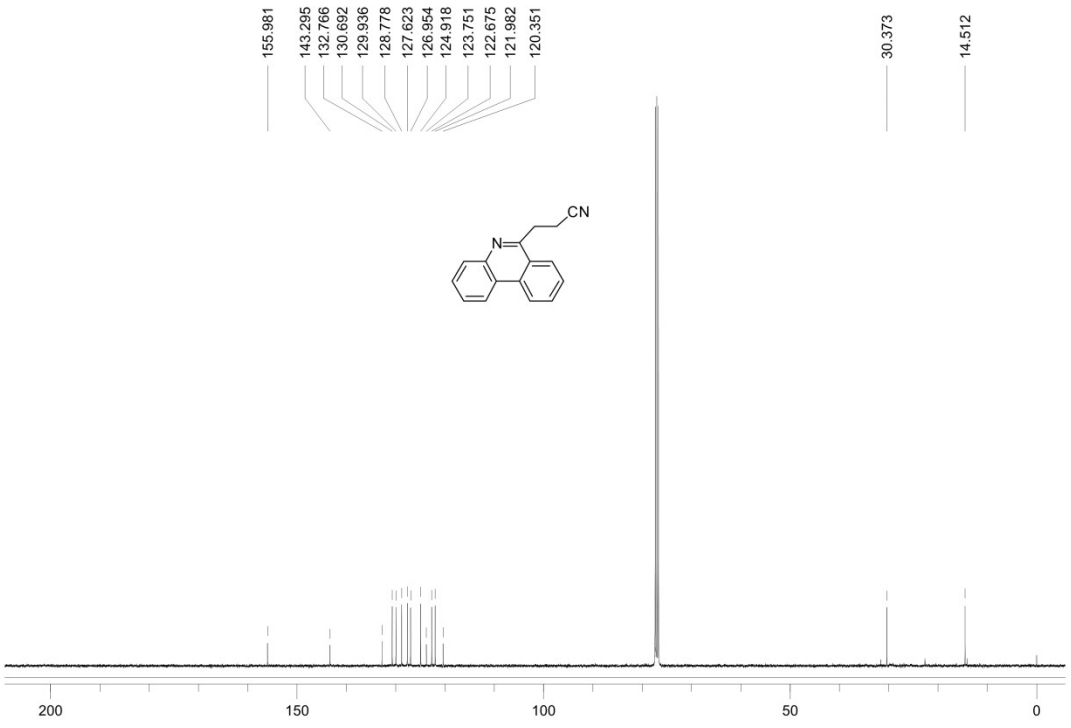
^{1}H NMR and ^{13}C NMR spectrum of **3g**



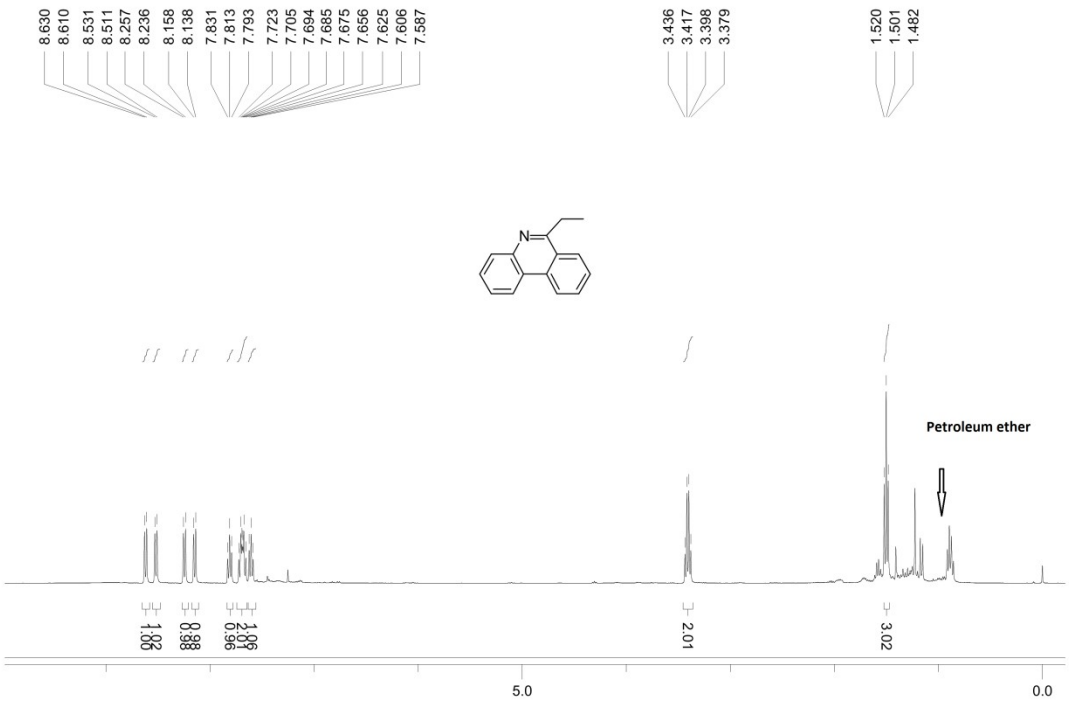


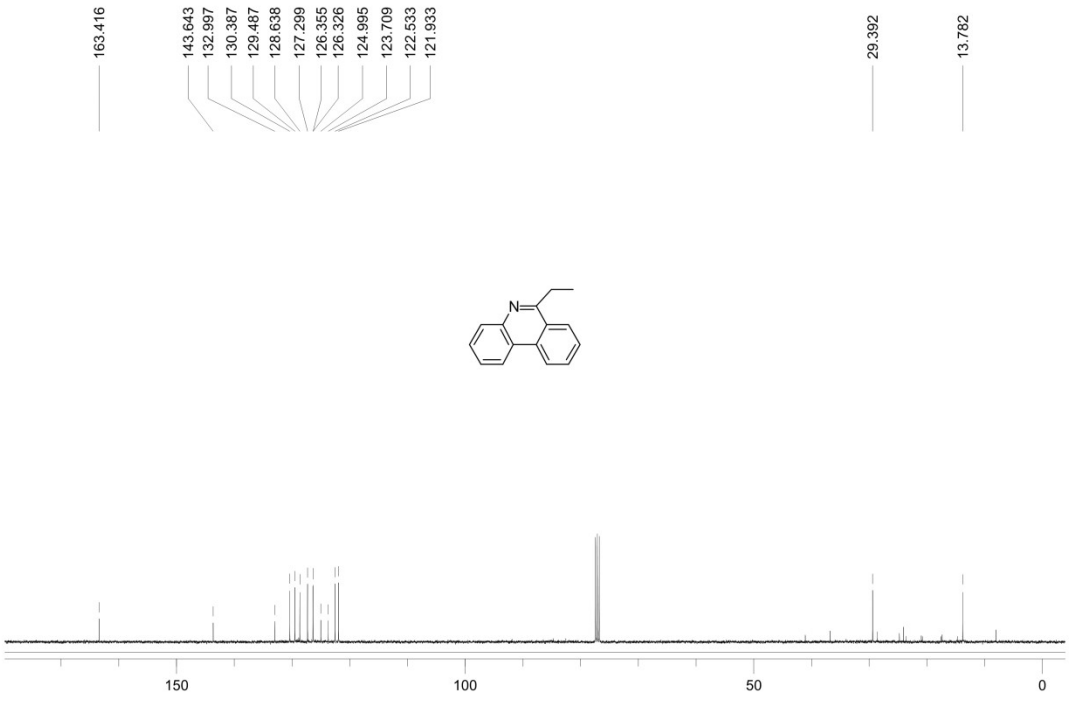
^{1}H NMR and ^{13}C NMR spectrum of **3h**



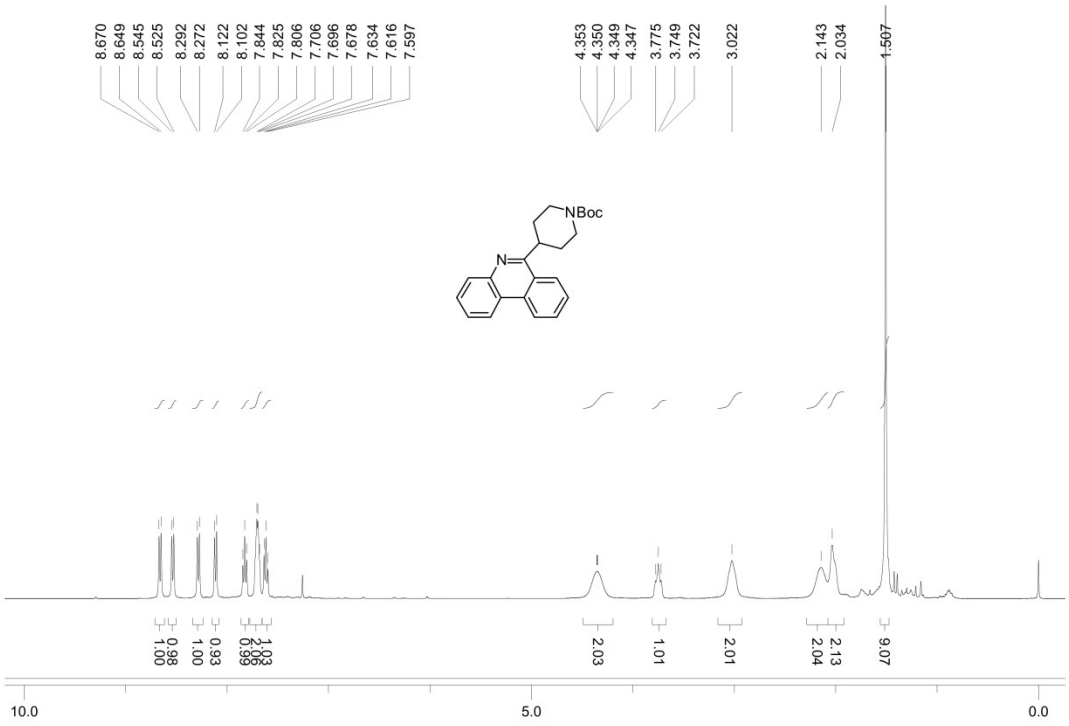


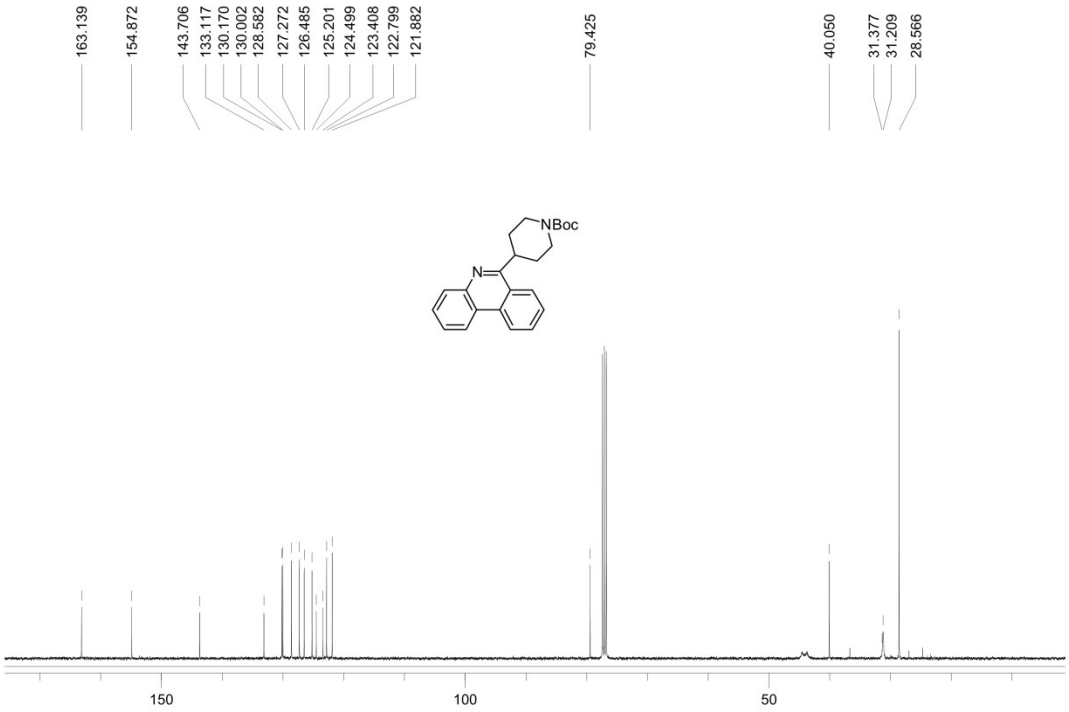
^{1}H NMR and ^{13}C NMR spectrum of **3i**



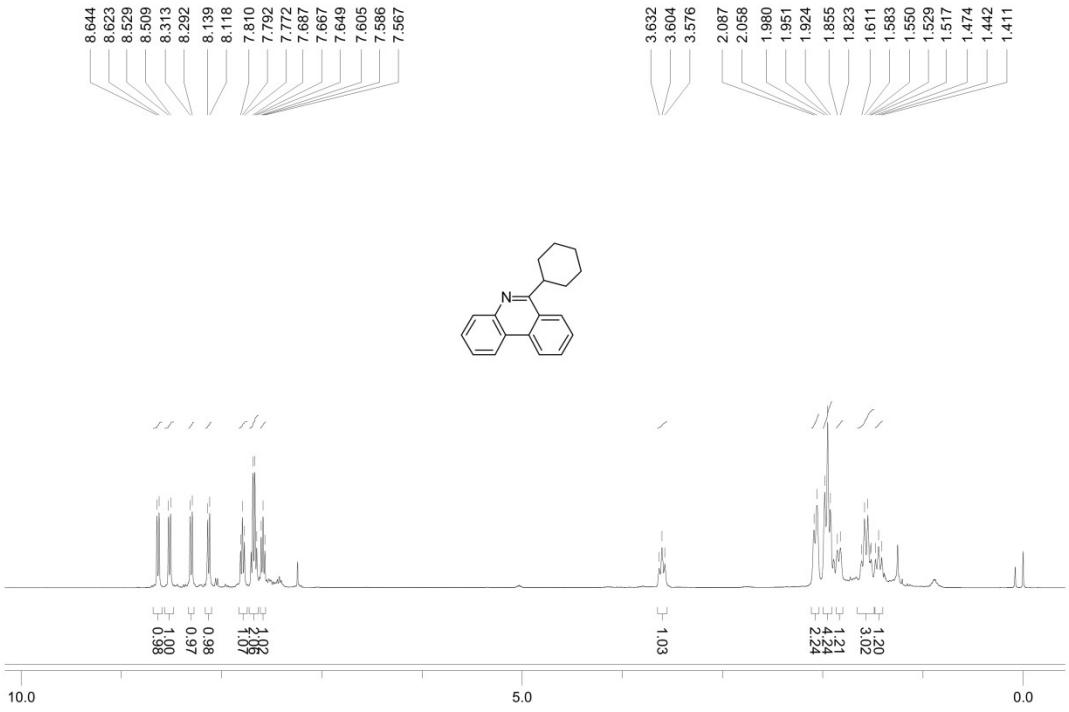


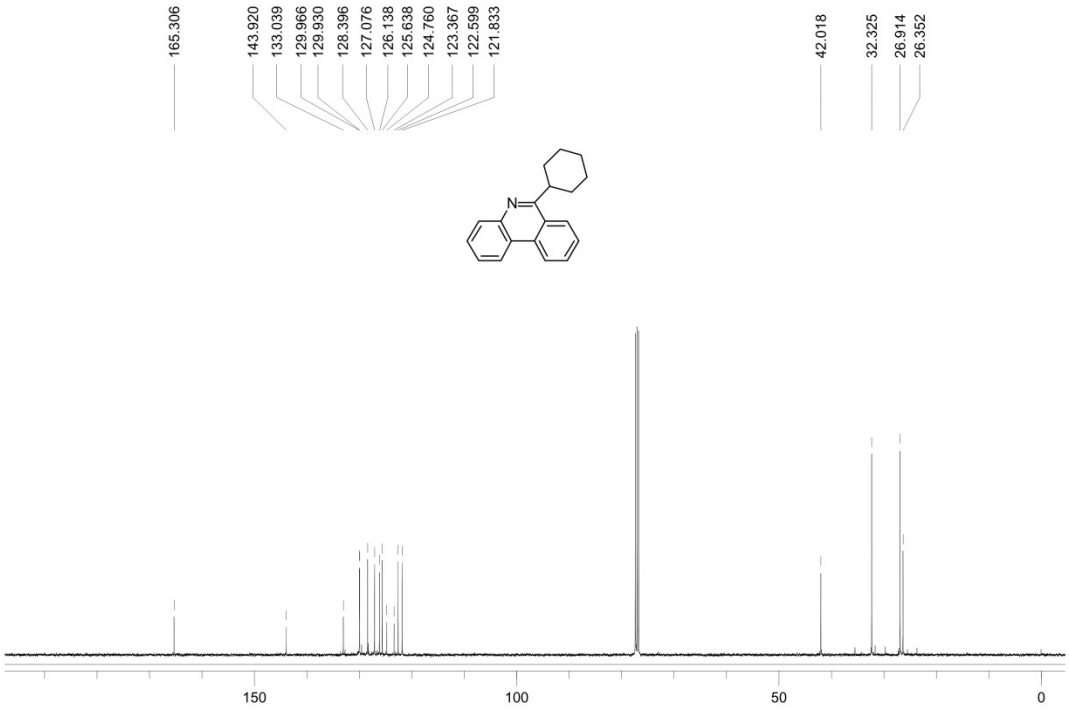
^{1}H NMR and ^{13}C NMR spectrum of **3j**



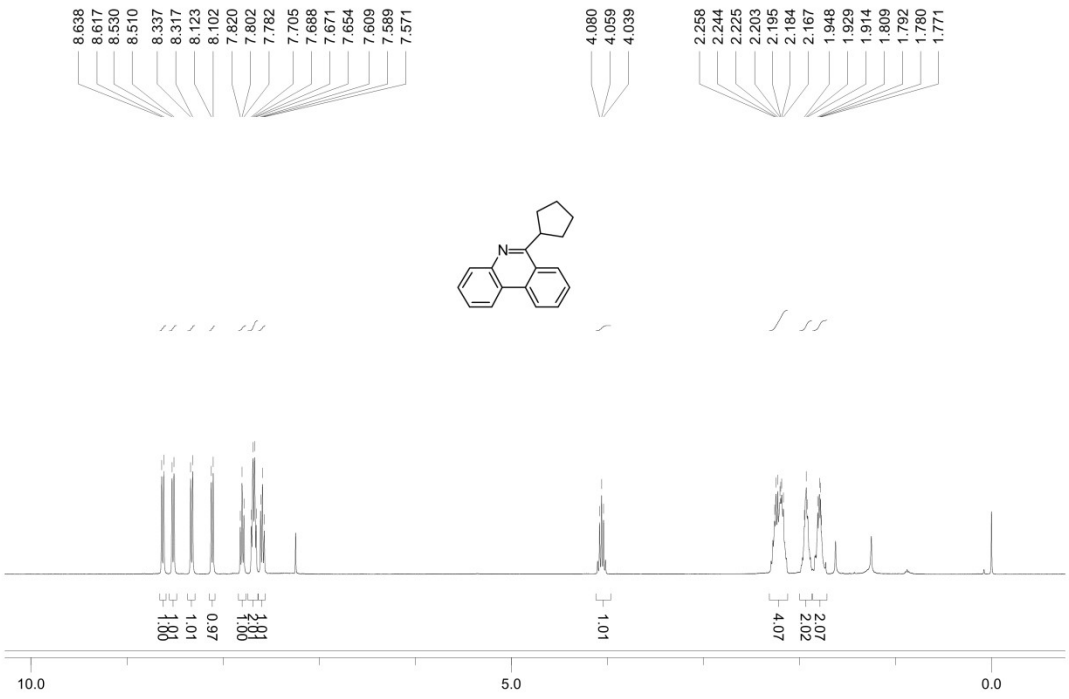


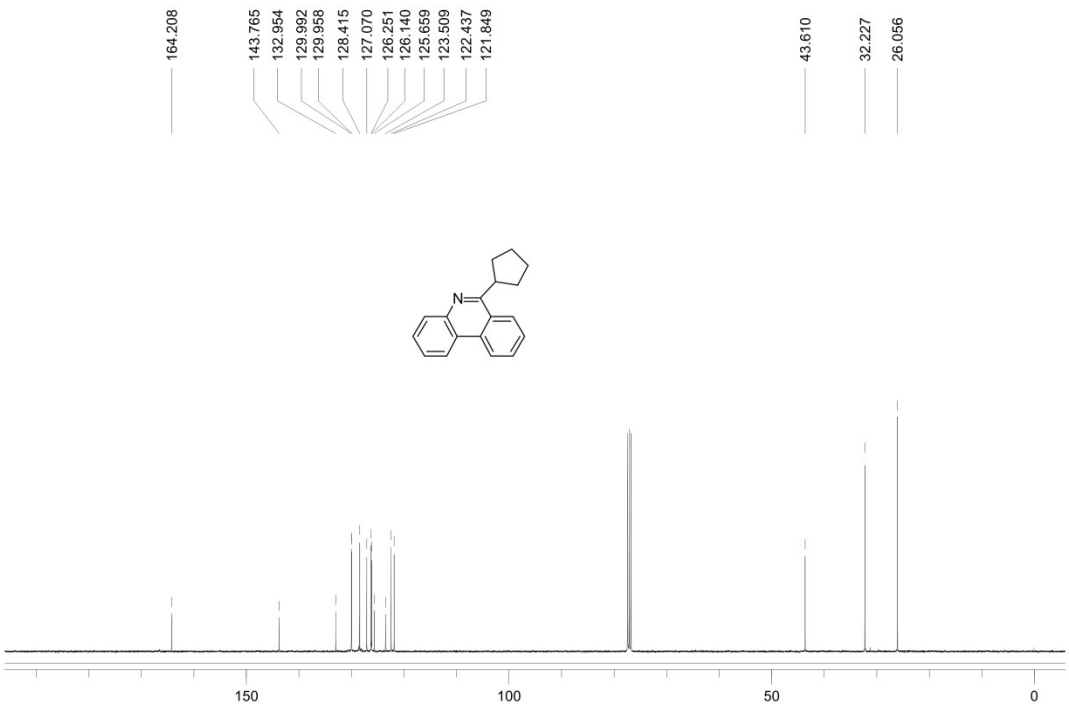
^{1}H NMR and ^{13}C NMR spectrum of **3k**



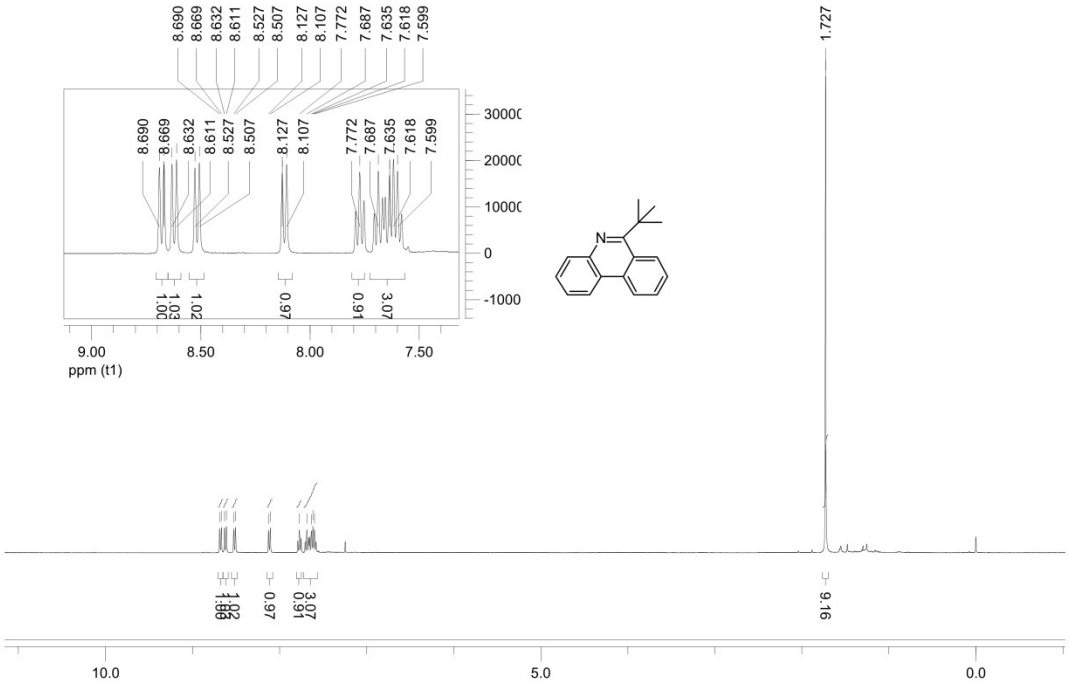


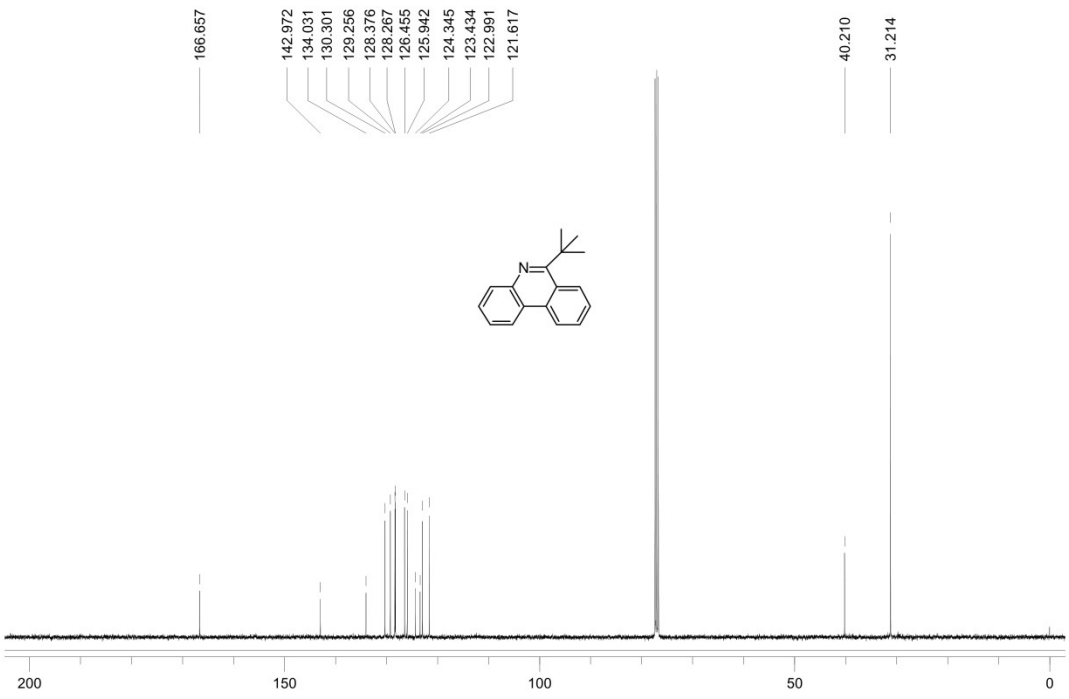
^{1}H NMR and ^{13}C NMR spectrum of **3l**



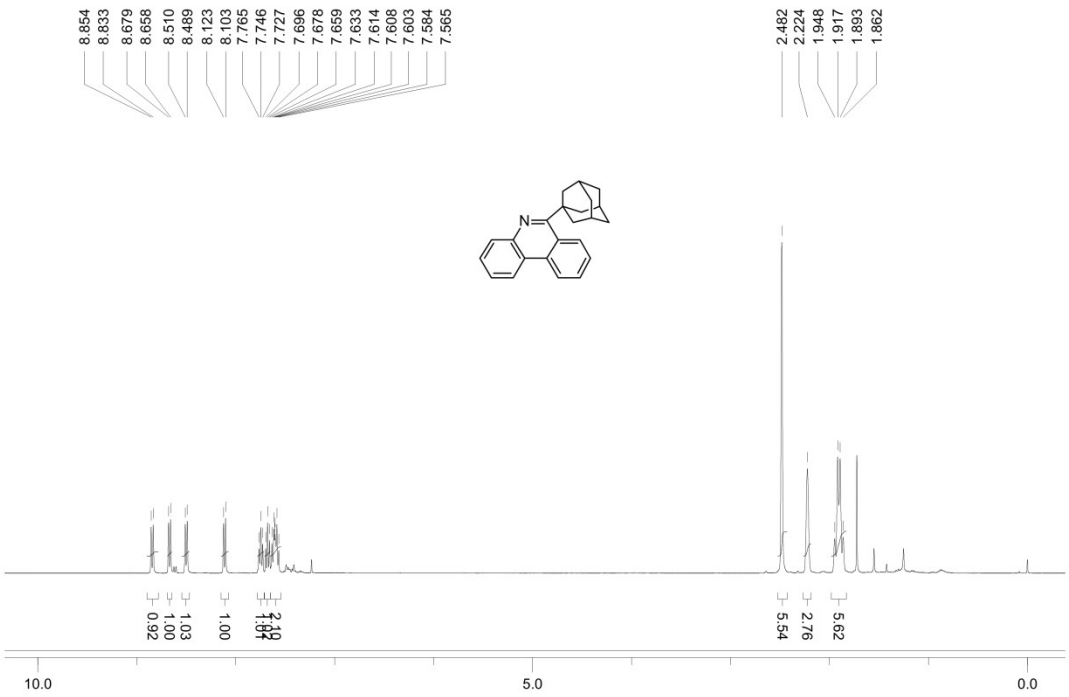


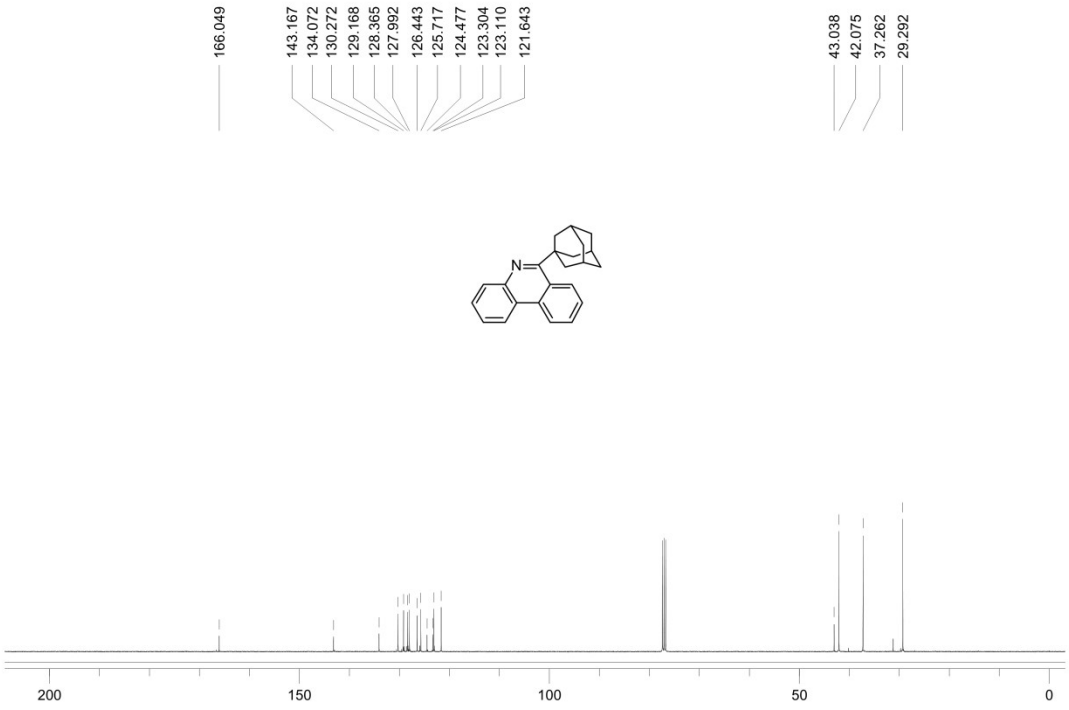
^{1}H NMR and ^{13}C NMR spectrum of **3m**



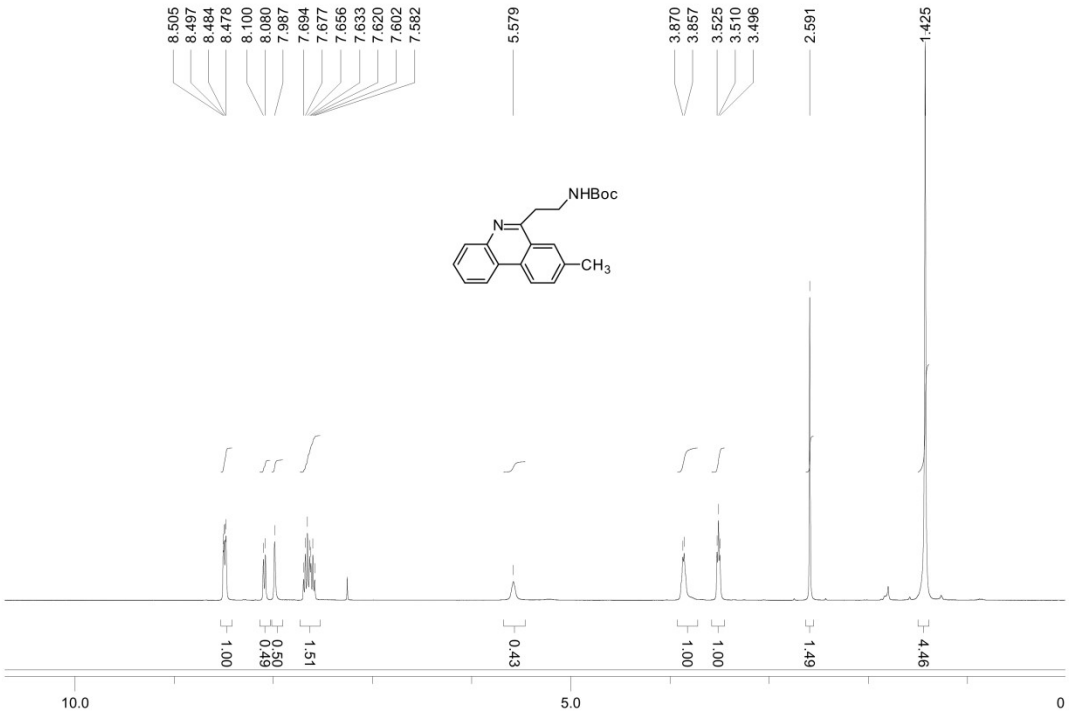


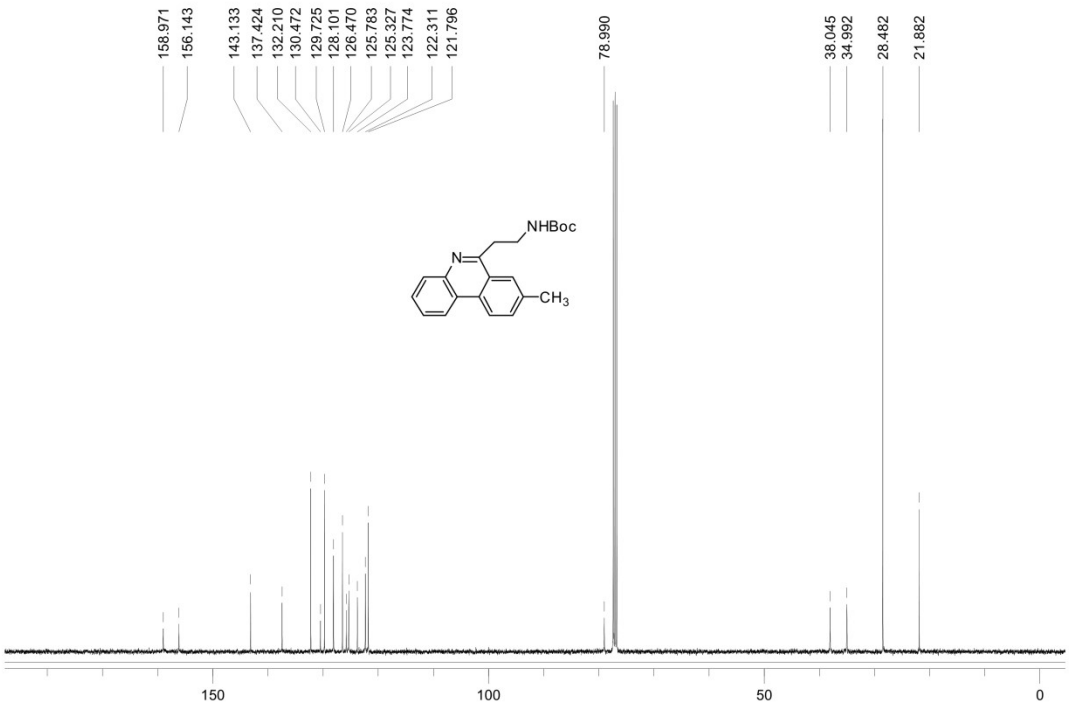
^{1}H NMR and ^{13}C NMR spectrum of **3n**



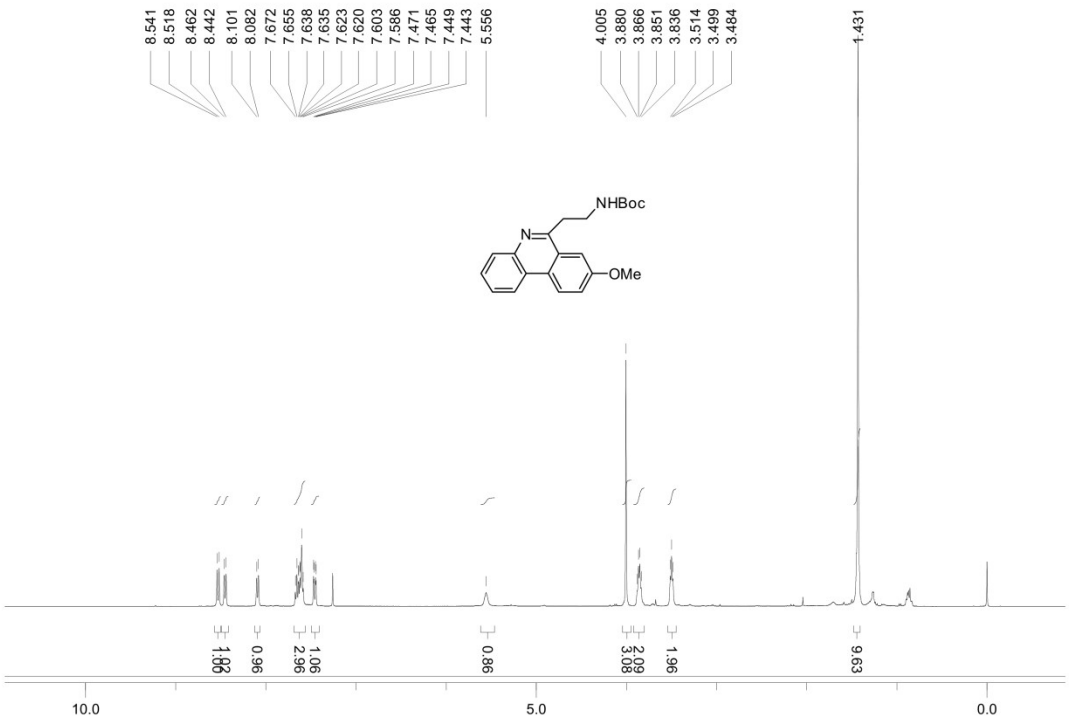


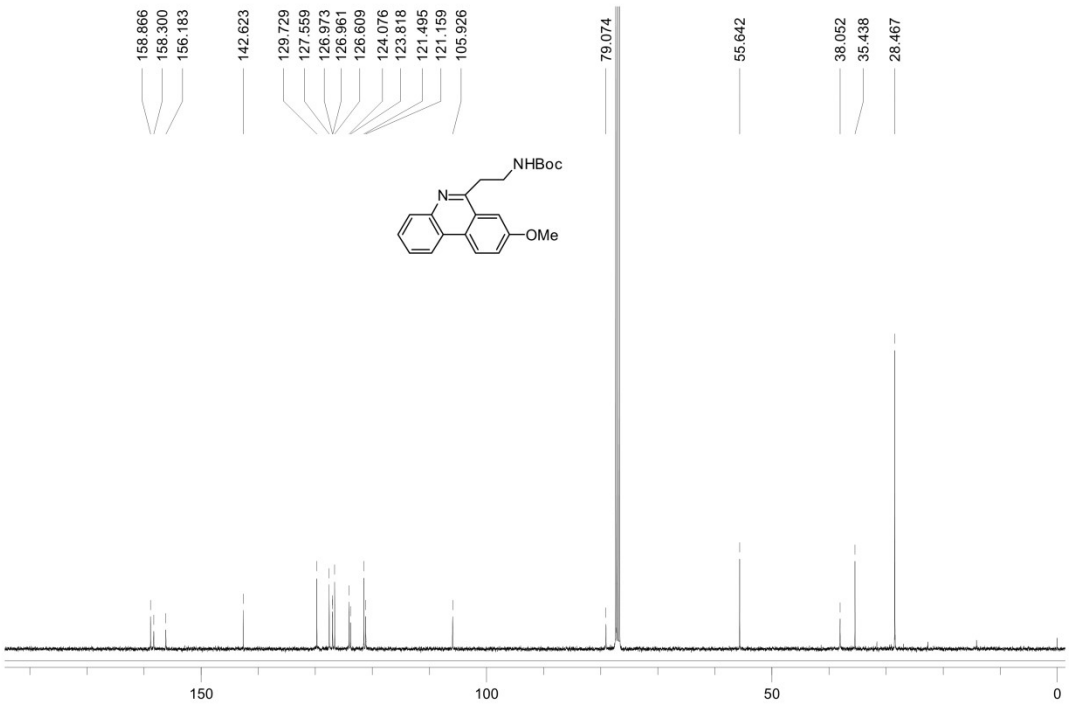
^{1}H NMR and ^{13}C NMR spectrum of **4a**



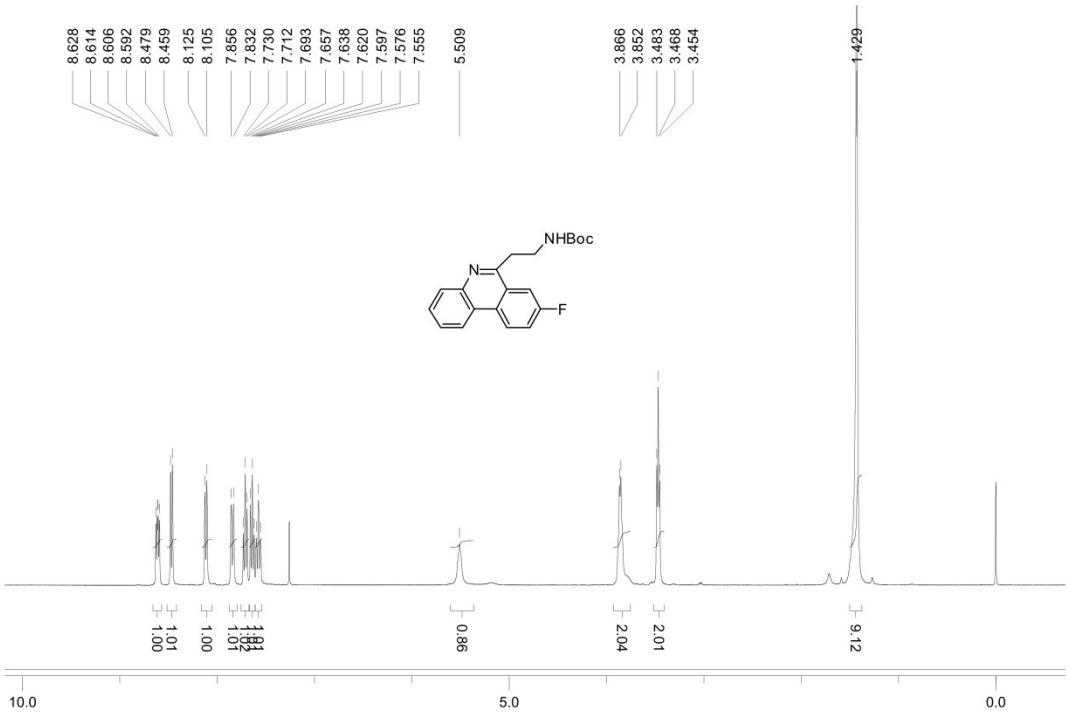


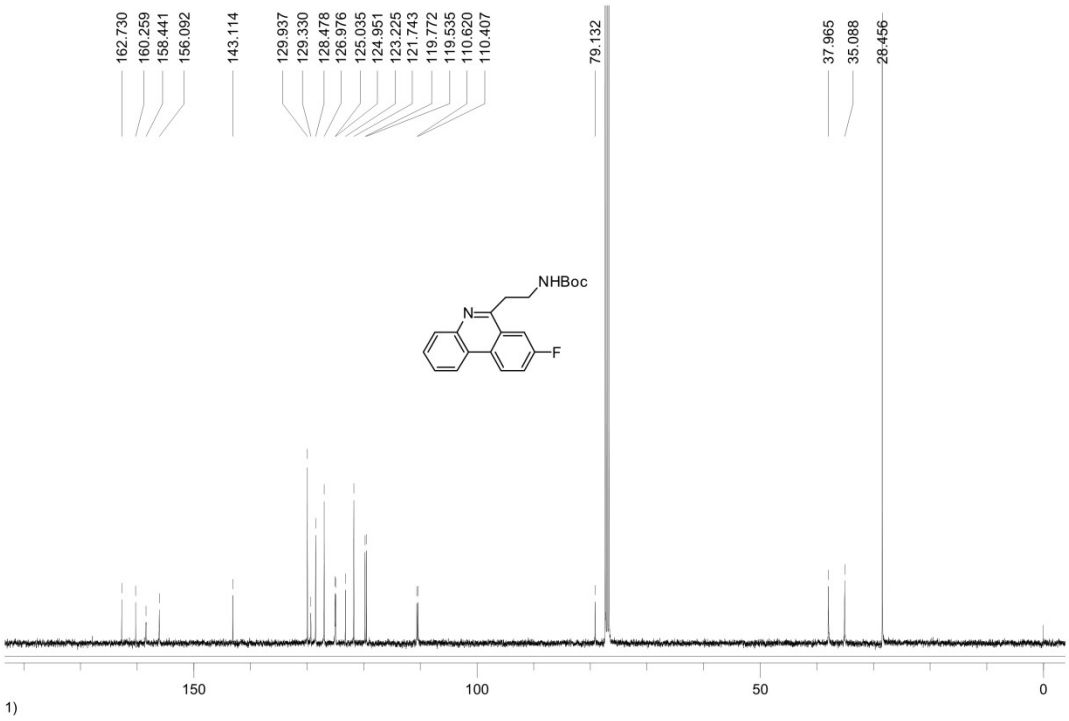
^{1}H NMR and ^{13}C NMR spectrum of **4b**



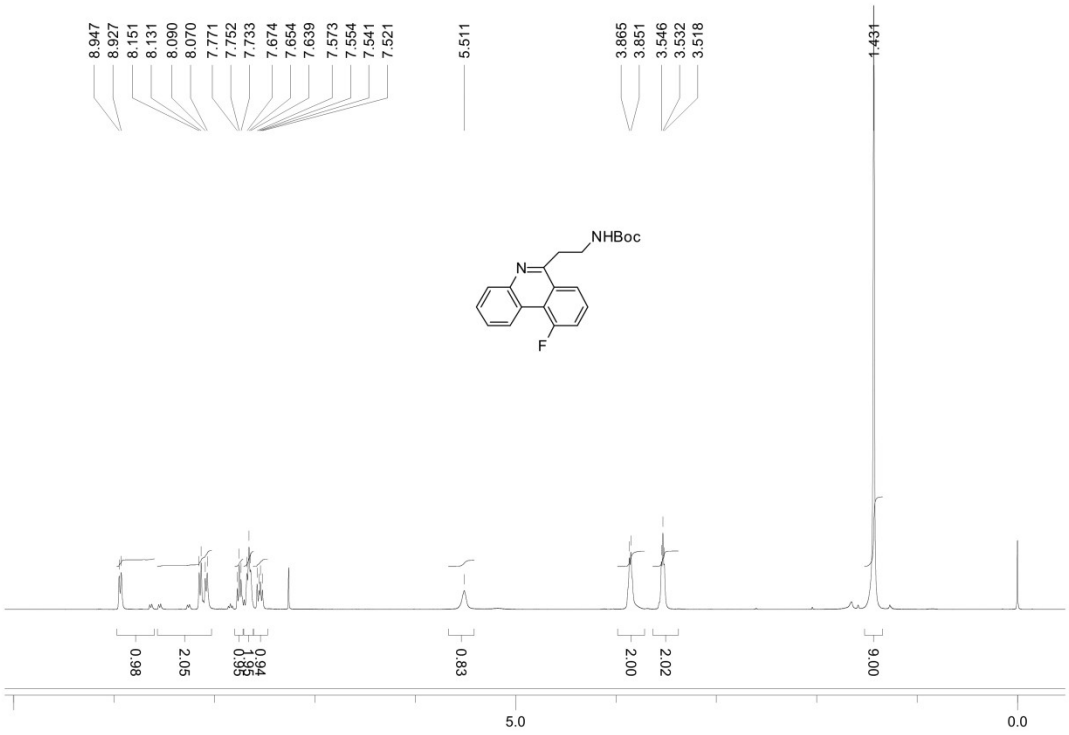


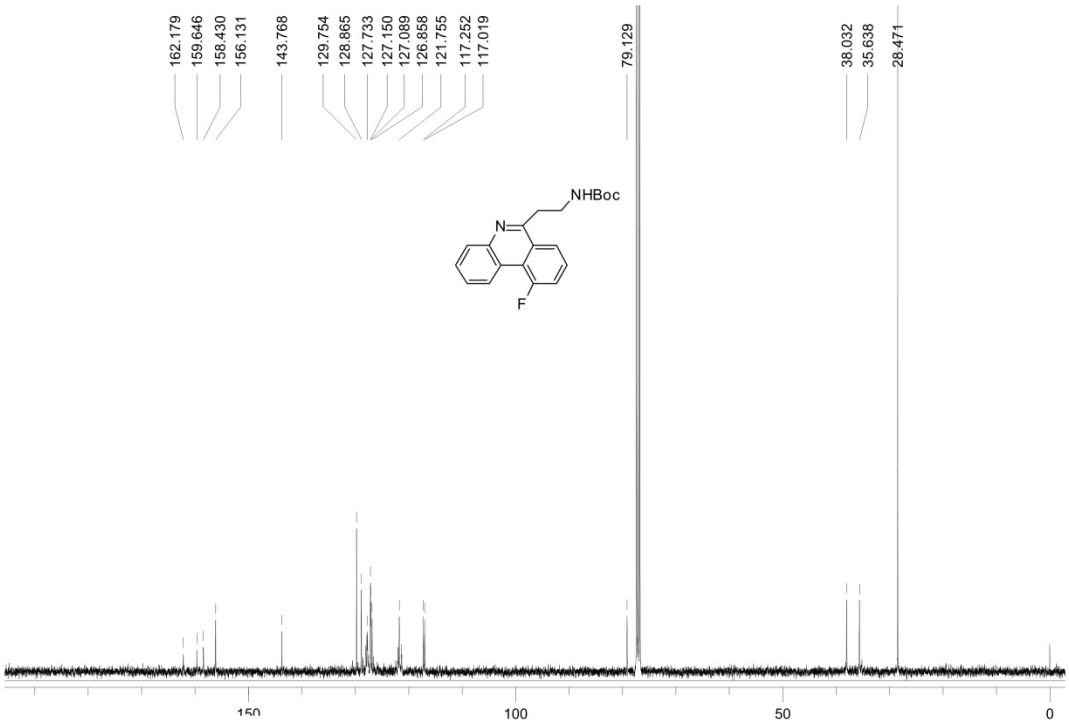
^{1}H NMR and ^{13}C NMR spectrum of **4c**



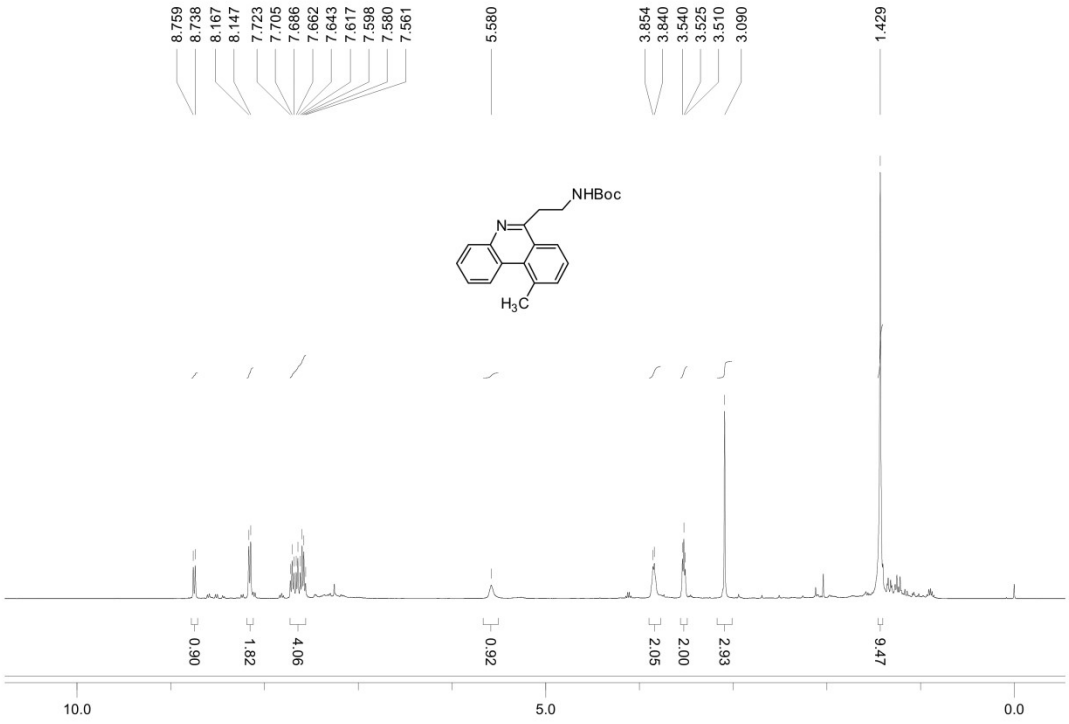


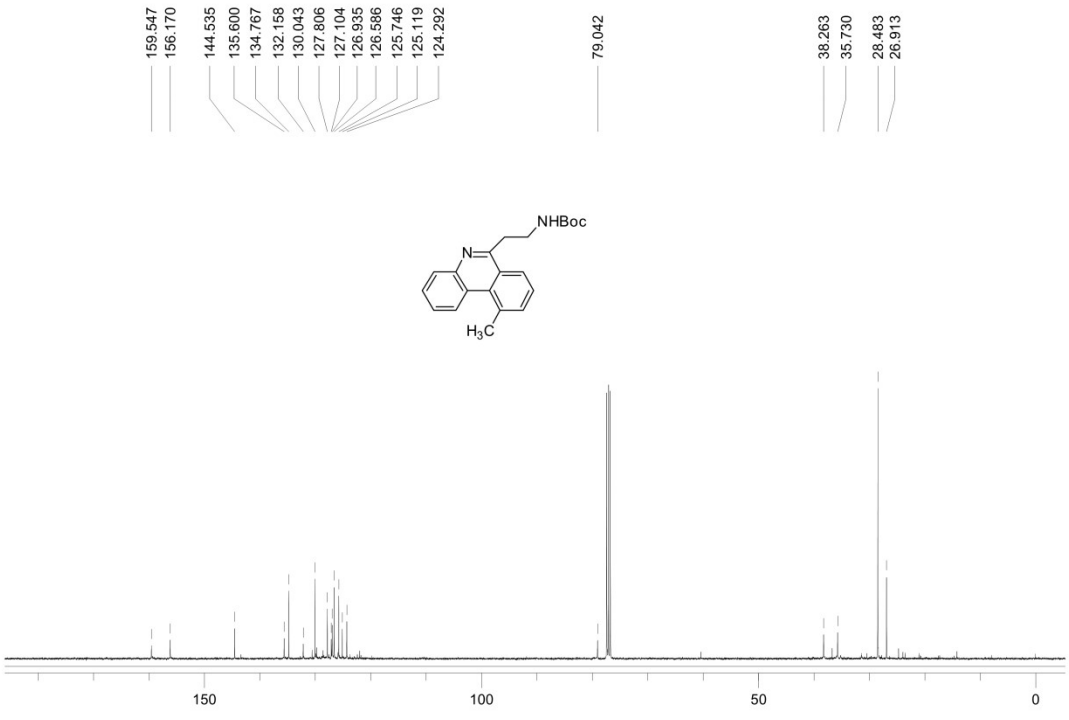
^{1}H NMR and ^{13}C NMR spectrum of **4d**



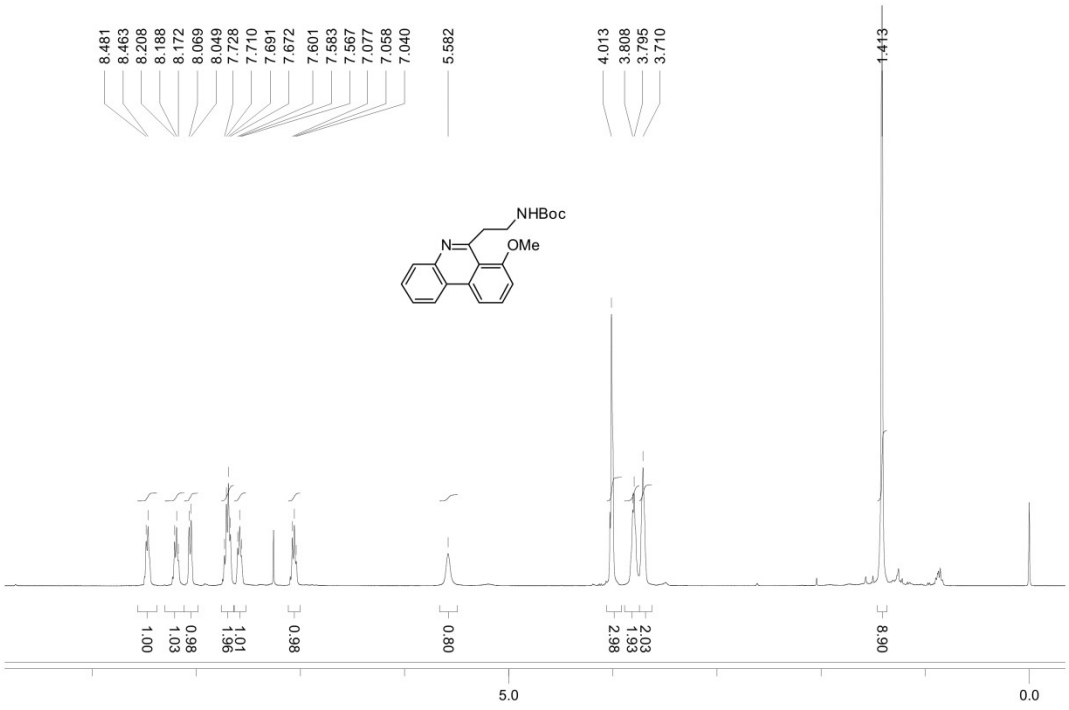


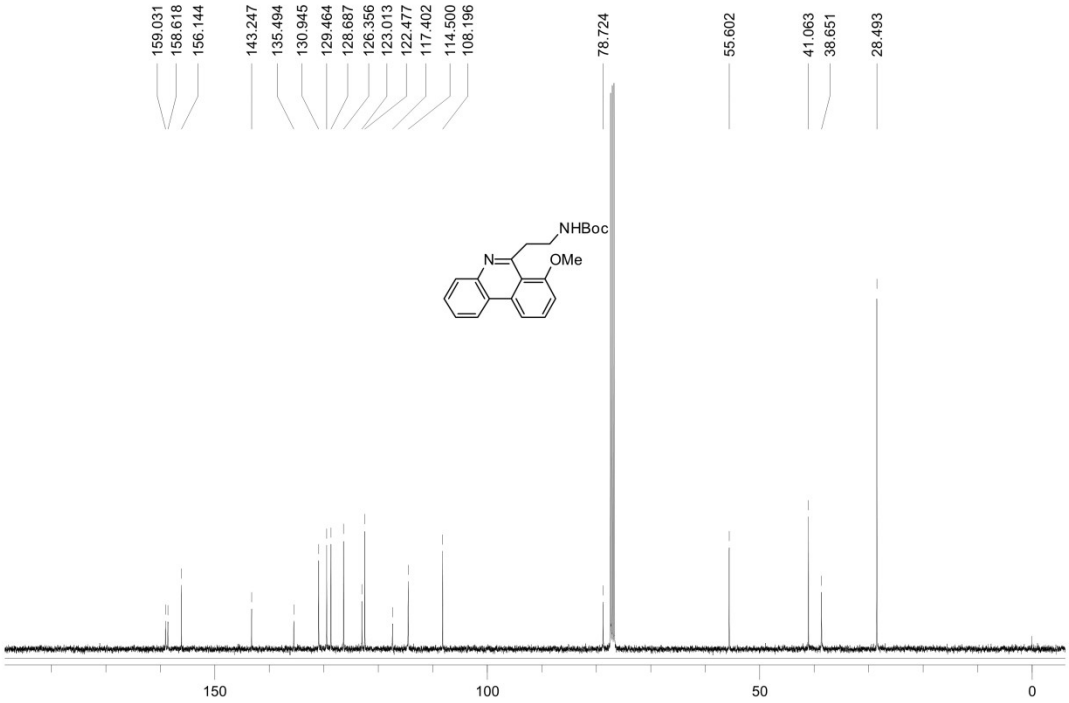
^{1}H NMR and ^{13}C NMR spectrum of **4e**



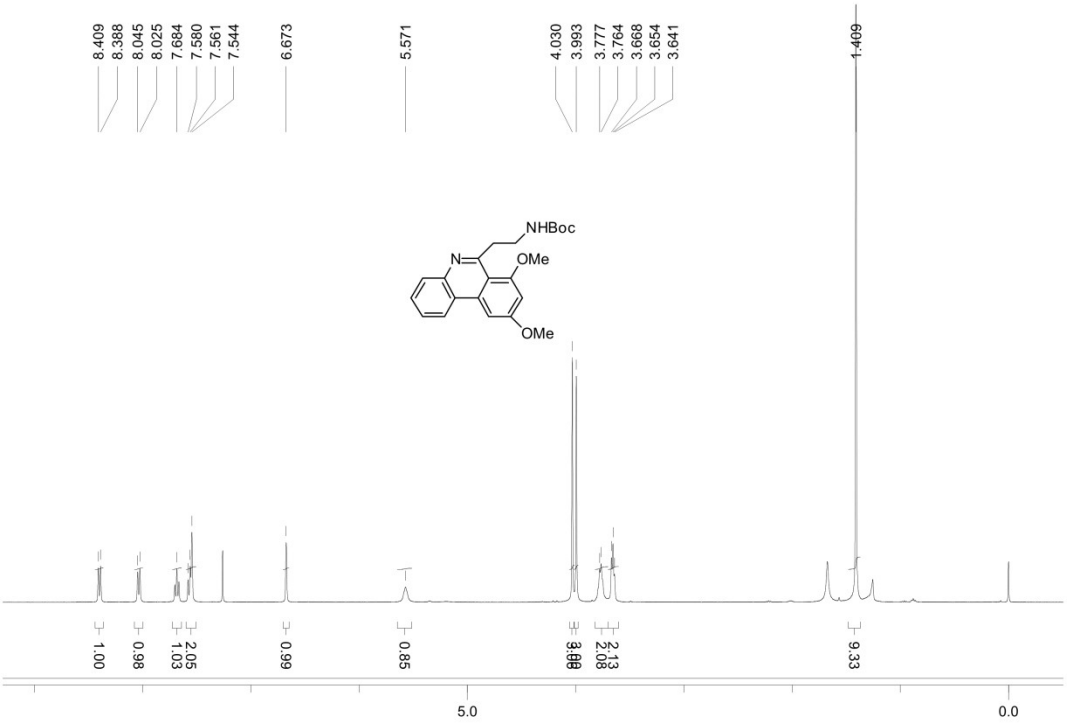


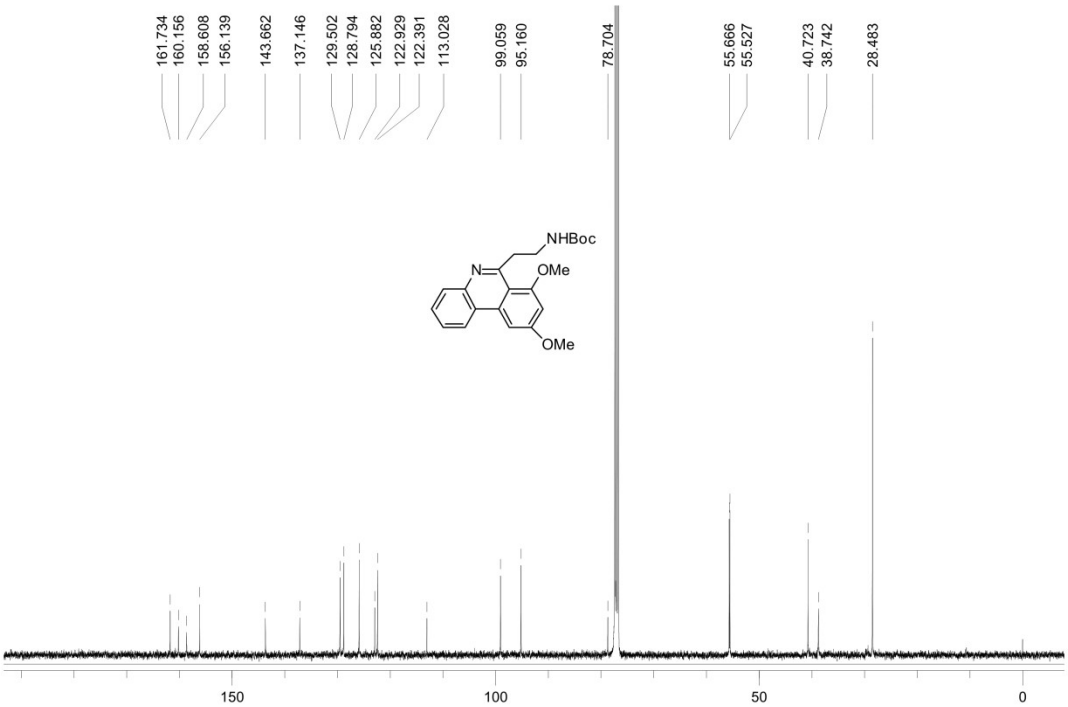
^{1}H NMR and ^{13}C NMR spectrum of **4f**



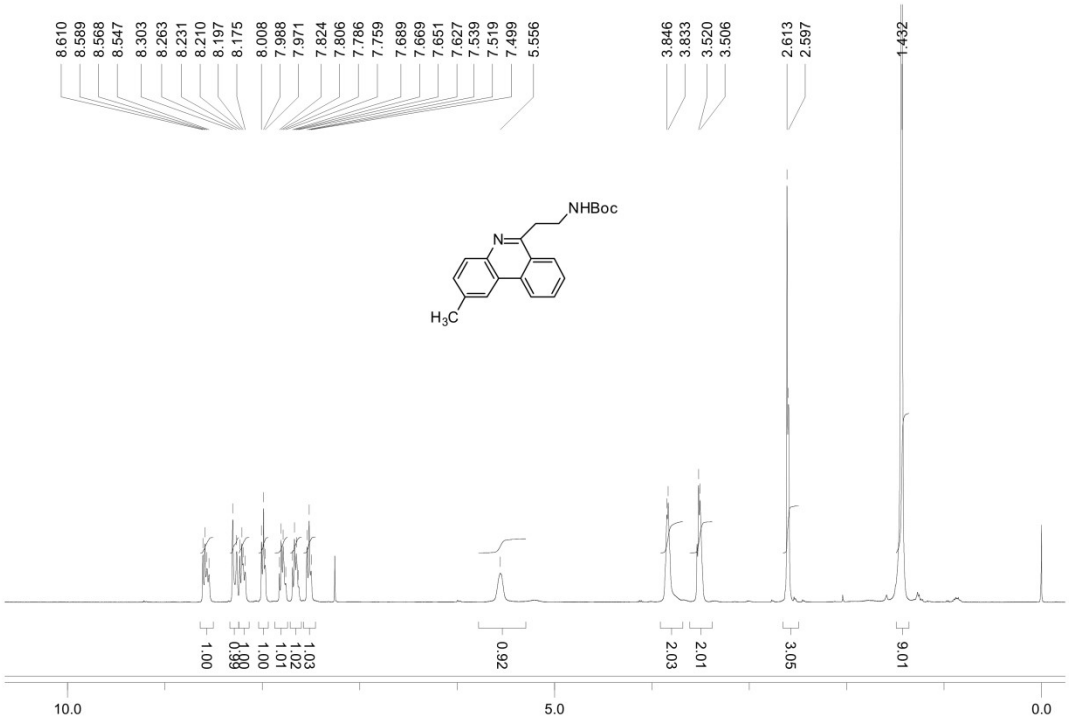


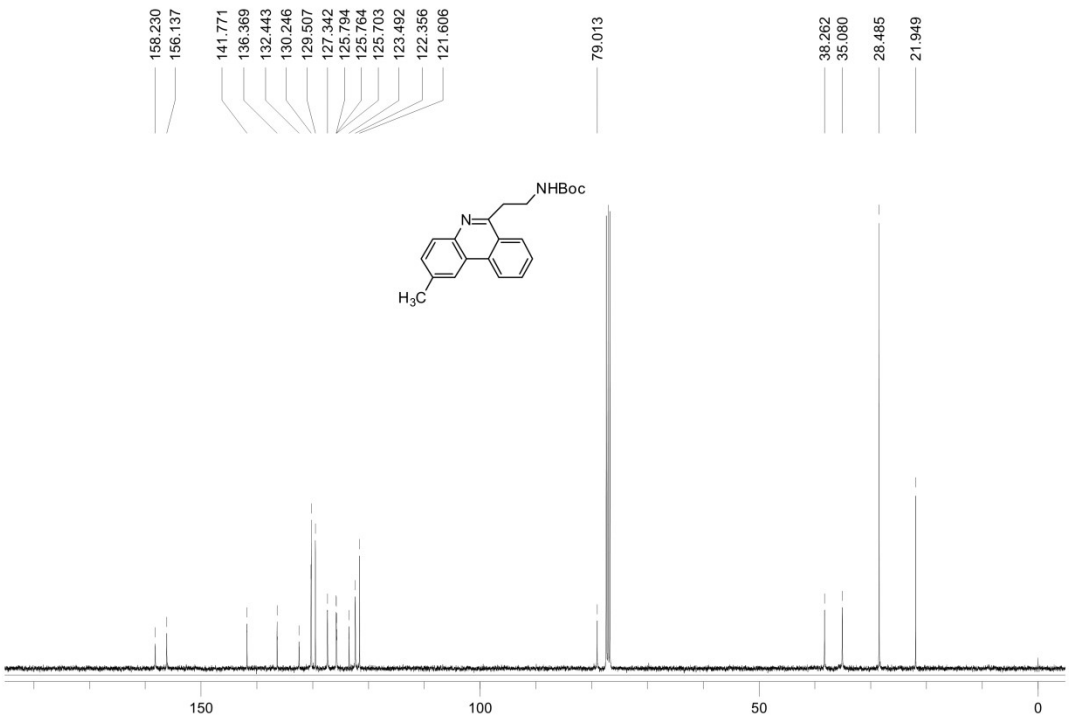
^{1}H NMR and ^{13}C NMR spectrum of **4h**



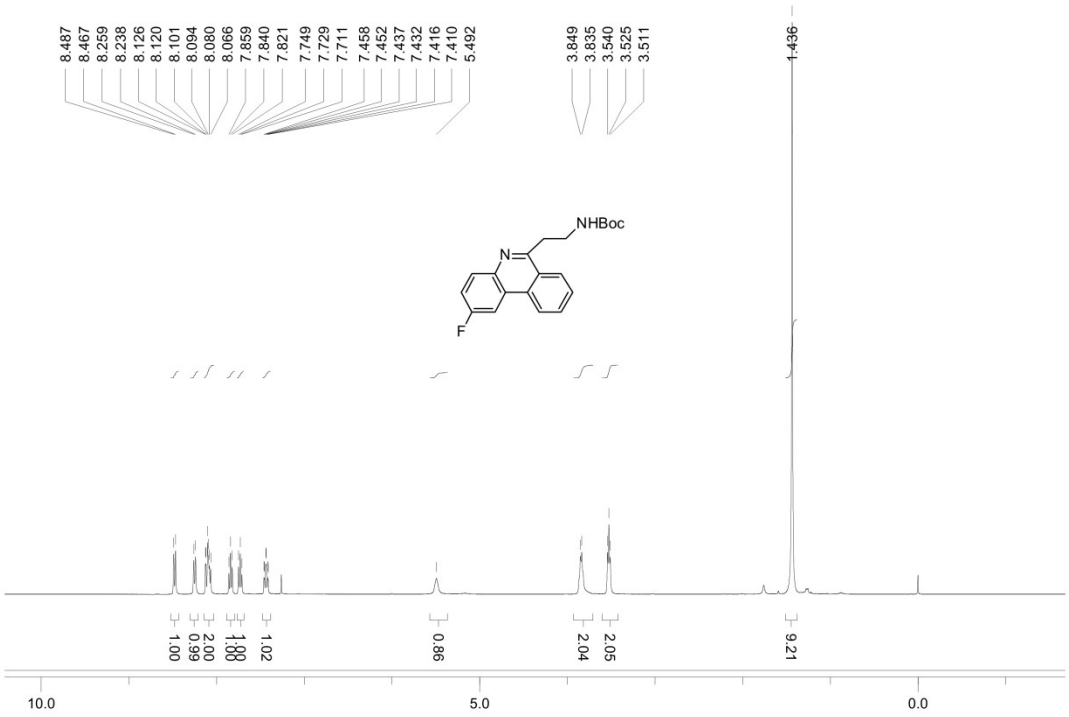


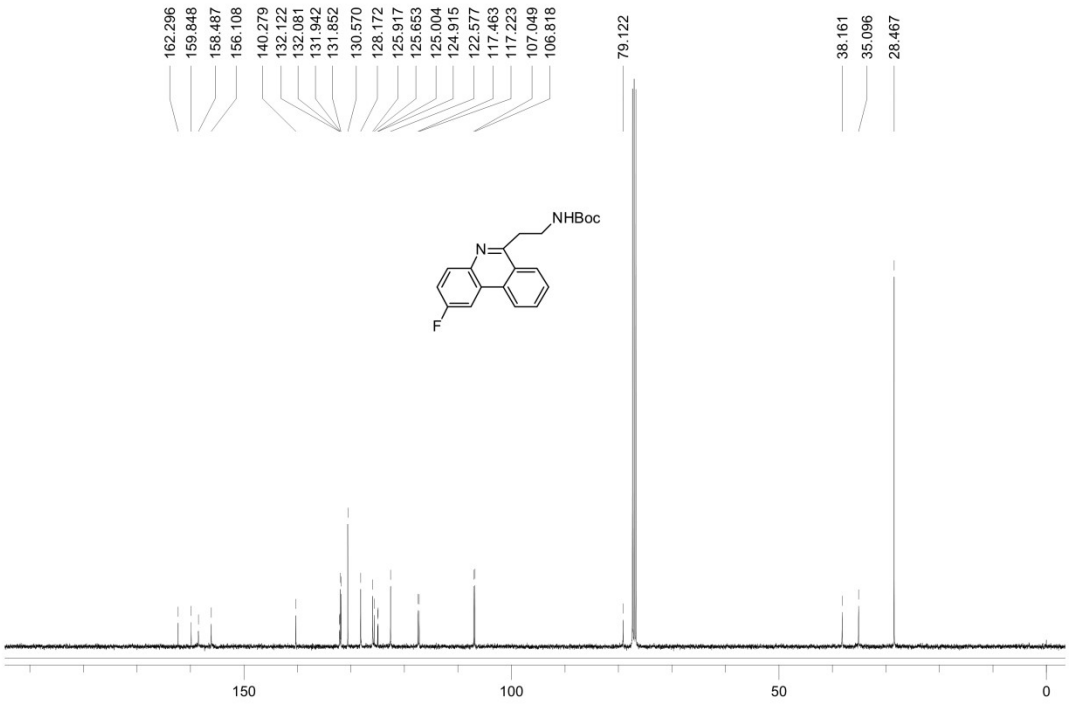
^{1}H NMR and ^{13}C NMR spectrum of **4i**



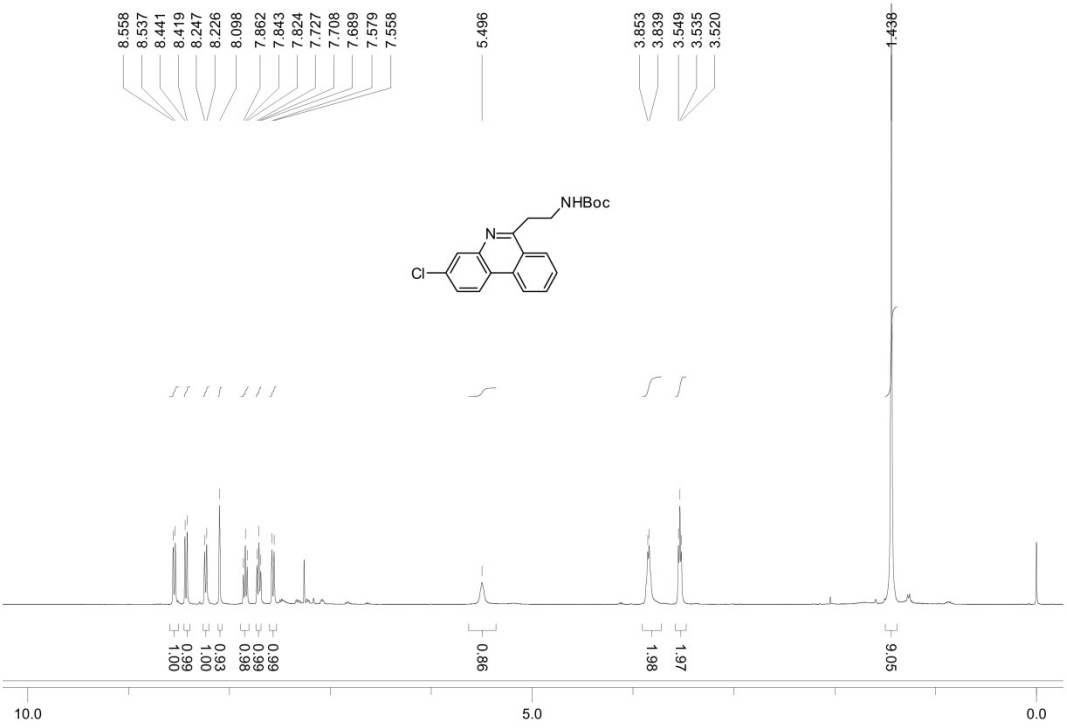


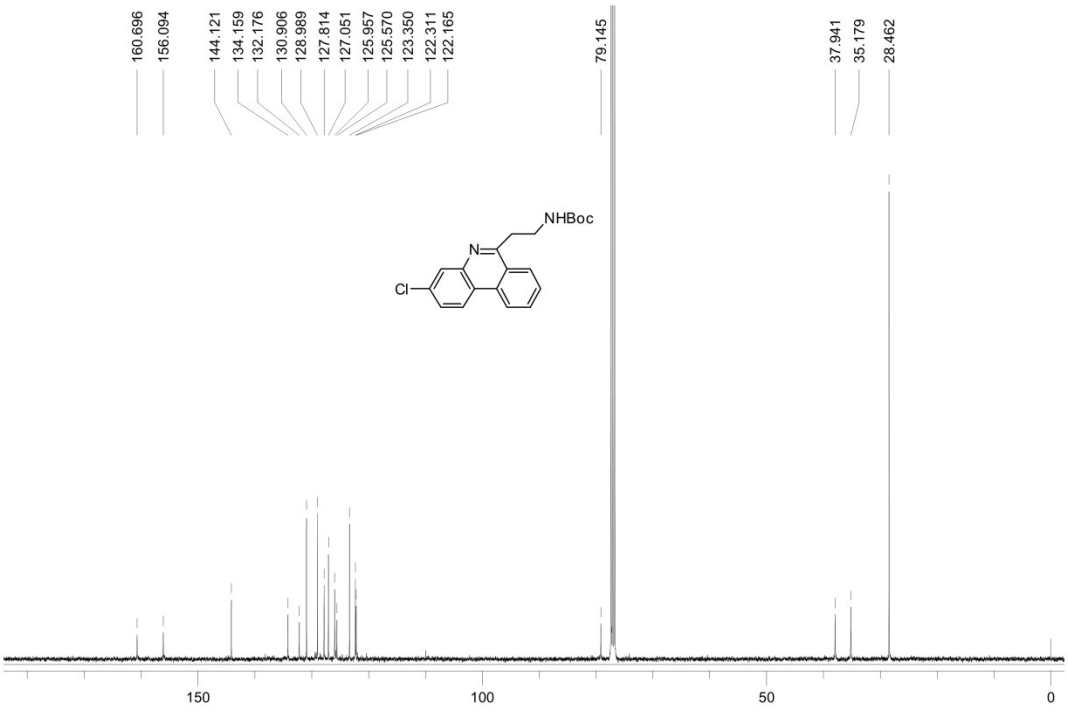
^{1}H NMR and ^{13}C NMR spectrum of **4j**



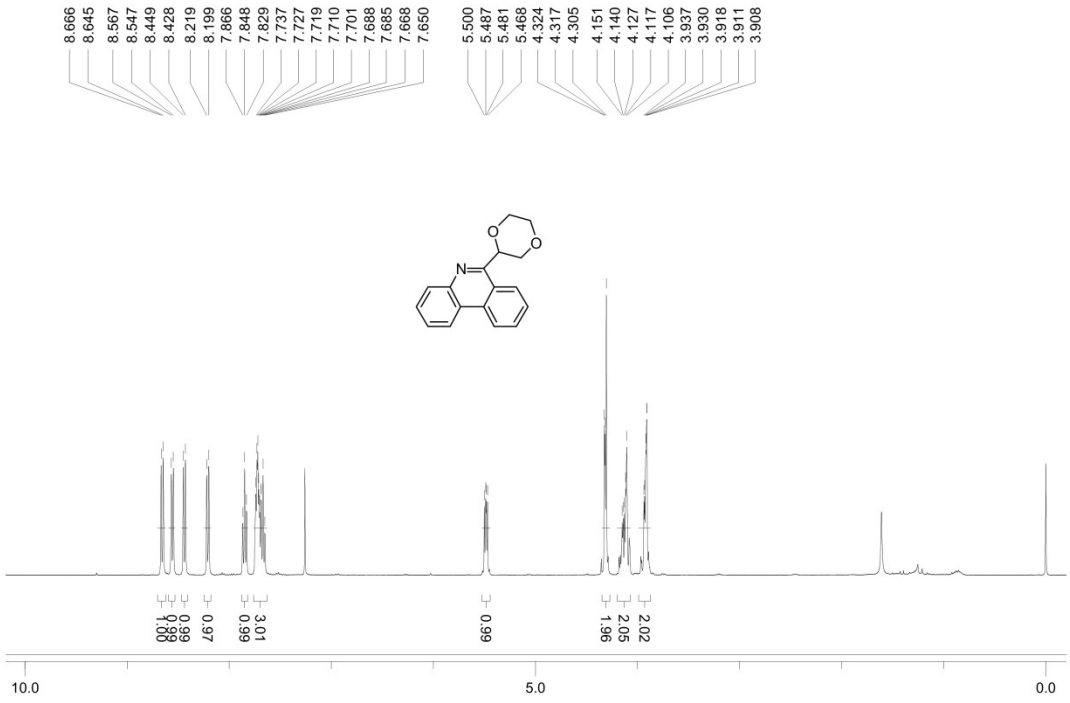


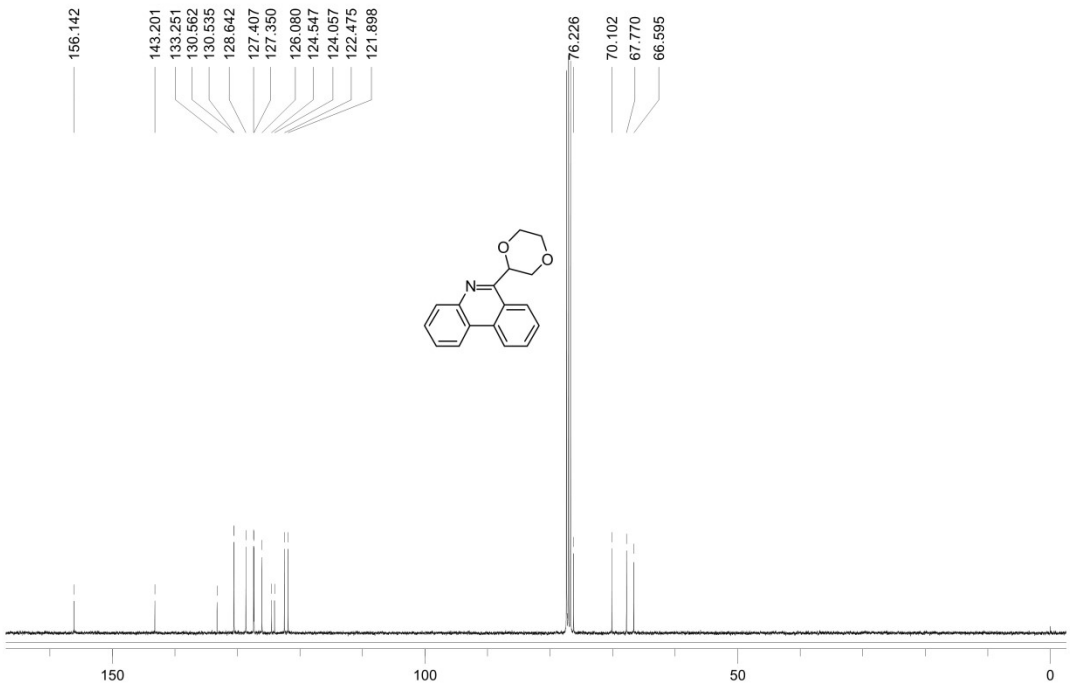
^{1}H NMR and ^{13}C NMR spectrum of **4k**



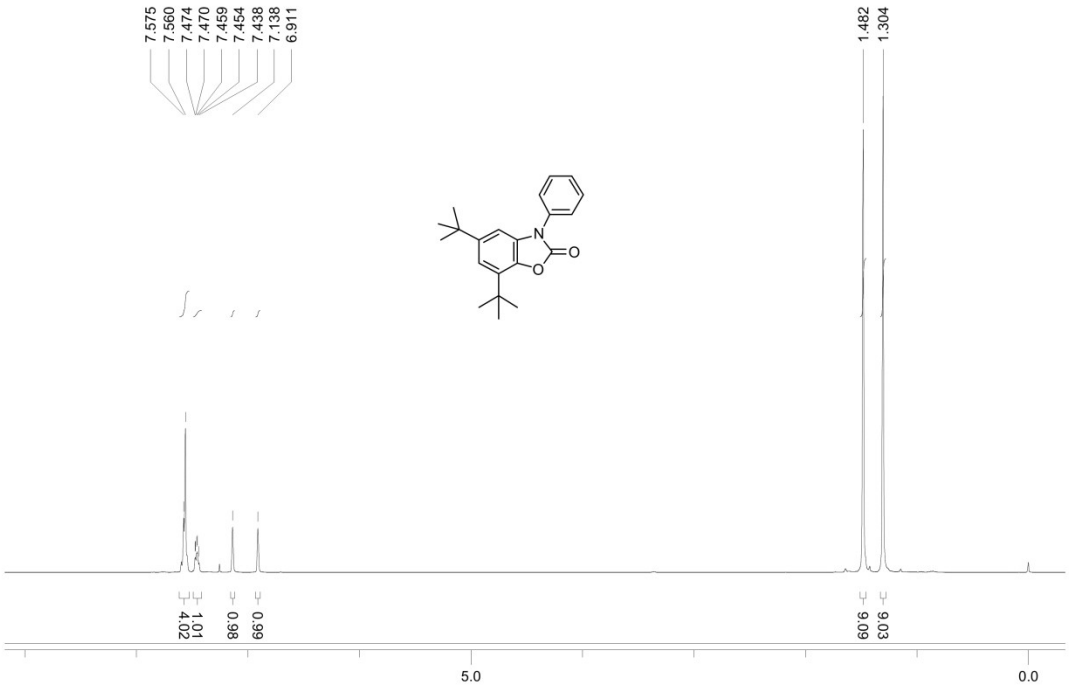


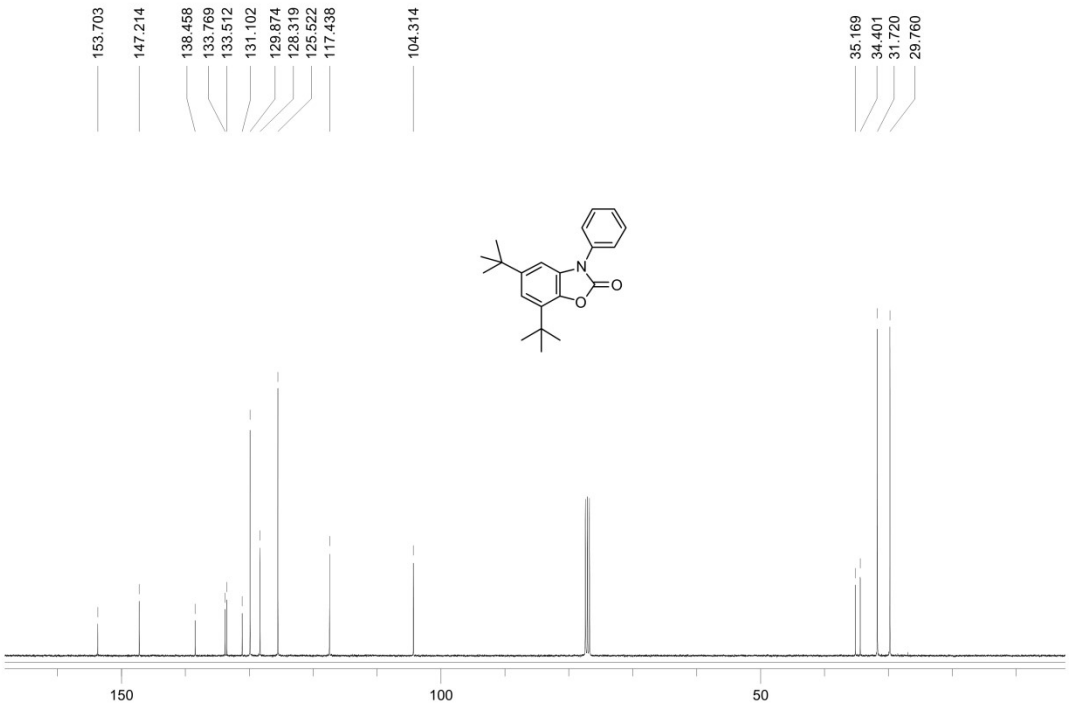
^{1}H NMR and ^{13}C NMR spectrum of **6-(1,4-dioxan-2-yl)phenanthridine**





^{1}H NMR and ^{13}C NMR spectrum of **5**





^{1}H NMR and ^{13}C NMR spectrum of 1-(Cyclohexyloxy)-2,2,6,6-tetramethylpiperidine