Electronic Supplementary Information

Activation of DMSO(-d_6) via heterogeneous photo-Fenton-like process with in-situ production of hydroxyl radicals for the C-H (trideutero)methylation of (iso)quinoliniums

Palani Natarajan [a,b,*], Aleyna Başak [a] and Onder Metin [a,c,*]

[a] *Department of Chemistry, College of Sciences, Koç University, 34450, Sarıyer, Istanbul, Türkiye*

[b] *Department of Chemistry & Centre for Advanced Studies in Chemistry, Panjab University, Chandigarh - 160014, India*

[c] *Koç University Surface Science and Technology Center (KUYTAM), 34450, Sarıyer, Istanbul, Türkiye*

pnataraj@pu.ac.in (P. Natarajan), ometin@ku.edu.tr (O. Metin)

TABLE OF CONTENTS

1. General Information

Unless otherwise stated, all reagents and substrates were purchased from commercial sources with the best quality and they were used without further purification. All the reactions were carried out in open vessel using oven-dried Pyrex glassware unless otherwise specified. All reactions are stirred magnetically unless otherwise specified. The progress of the optimization reactions were monitored by gas chromatography. All products were characterized by NMR spectra. Chemical shifts are expressed as δ-value in parts per million (ppm) and were calibrated using the residual protonated solvent as an internal standard. The peak patterns are indicated as follows: s, singlet; d, doublet; t, triplet; m, multiplet and so on. The coupling constants, J, are reported in Hertz (Hz). Photochemical reactions were performed using a Philiphs metal halide lamp provides white light (150 W). Powder X-Ray Diffraction (PXRD) analysis was performed by using Bruker D2 X-ray diffractometer (Cu Kα, 1.54 Å). Transmission electron microscopy (TEM), high angle annular dark field (HAADF), scanning transmission microscopy (STEM) and related energy dispersive spectroscopy (EDS) images were recorded on a Hitachi HT7800 (TEM, 120 kV). Shimadzu 3600 Plus UV-Vis-NIR instrument was used for acquiring the ultraviolet-visible diffuse reflectance spectra (UV-Vis DRS). Photoluminescence (PL) spectra were conducted on Agilent Cary Eclipse PL spectrophotometer with an excitation wavelength of 350 nm.

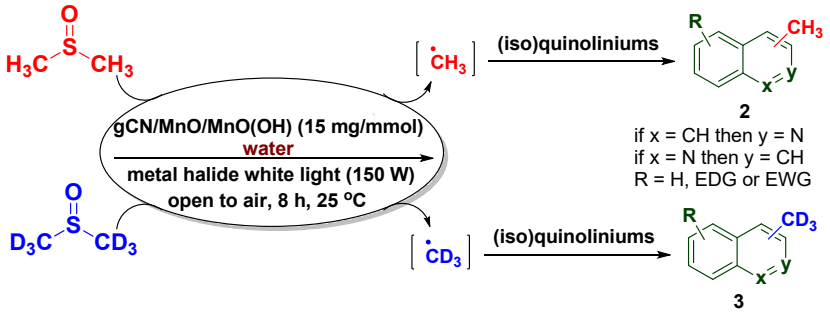
2. Experimental Section

2.1. Synthesis and characterization of gCN/MnO/MnO(OH) catalyst[1]

The gCN/MnO/MnO(OH) heterojunction was synthesized by hydrothermal treatment method.[1a] 1.0 g of as-prepared gCN was dispersed in 70 mL water and then mixed with 1.5 mmol of $Mn(OCOCH_3)_2$ and 2.8 mmol of Na_2SO_4. The resultant mixture was stirred overnight. Later, entire mixture was sonicated in an ultrasonic bath for 3 h and then with continuous sonication drop wise the $KMnO_4$ solution (1.0 mmol) was added to the mixture. Subsequently, this new mixture was further sonicated for 3 h and then transferred into a Teflonlined autoclave reactor and heated at 170 °C for 12 h. Afterwards, the entire material was centrifuged several times with water and then ethanol followed by dried for 3 h in an oven at 80 °C. As very detailed characterization of gCN/MnO/MnO(OH) and its precursors were merely reported by us for the purpose of comparison to another similar kind, such as GCN/MnO/MnO(OH)-PdAg, which

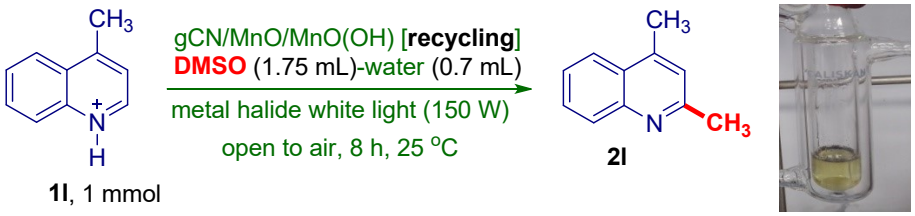
shows good activity in the photocatalytic formic acid dehydrogenation reaction; here described few essential characterization for ready references.[1a]

2.2. General procedure for the (trideutero)methylation of (iso)quinoliniums



An oven-dried jacketed flask (made of Pyrex glass) equipped with a magnetic stir bar was charged with (iso)quinolium trifluoroacetate (**1**, 0.5 mmol). To this, water (350 µl), DMSO (875 µl, added three times with 3 h gap between each addition) and gCN/MnO/MnO(OH) (8 mg) were added. The flask was then water inlet and outlet was given by a side-jacket. Afterwards, mixture was stirred few minutes to mix well and then with constant stirring irradiated using a white-light of metal halide lamp (150 W) at a distance of 2 cm under open air atmosphere at 25 °C. After 8 h of stirring, the reaction mixture was neutralized with aqueous potassium carbonate solution, product was extracted with ethyl acetate and then the ethyl acetate layer was separated and dried over anhydrous Na_2SO_4, filtered and concentrated. The resulting gummy material was passed through a short-pad of silica gel column chromatography using 10-20% ethyl acetate in n-hexane mixture to obtain the desired product. For the synthesis of trideuteromethylated (iso)quinolones, same procedure has been utilized. However, DMSO-d_6 has been utilized in place of DMSO.

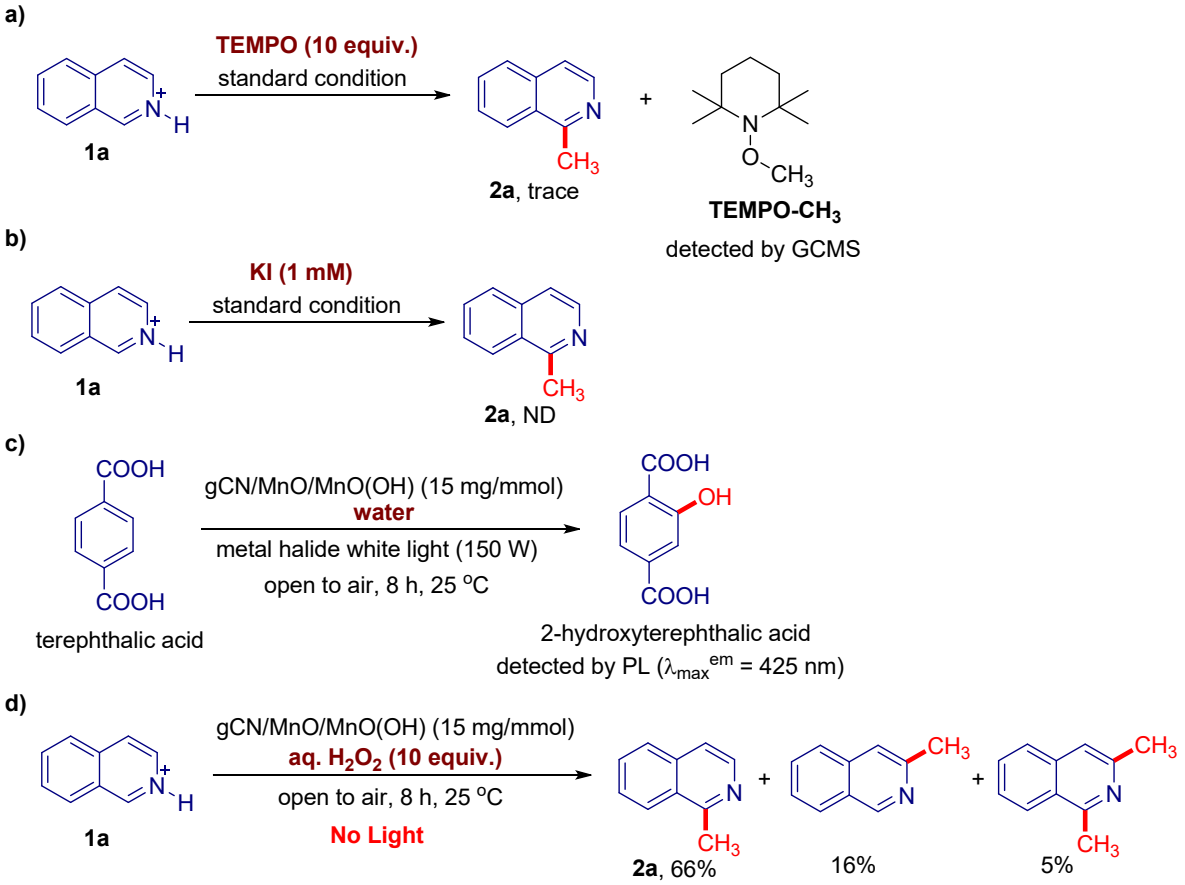
2.3. Procedure for gCN/MnO/MnO(OH) isolation and recycle



After the completion of reaction described above, it was centrifuged and with the help of syringe with a needle; all solution sucked-out and then washed catalyst with ethyl acetate, ethanol and water. Use of sonication is crucial throughout the washing process and recovered catalyst (with

added fresh ethanol) needs sonication for at least 60 minutes after every two cycles in order to achieve a product with about the same yield in subsequent runs. The reusability of the isolated catalyst was investigated by the same procedure described above. The process was repeated up to four times.

2.4. Procedure for control experiments



Reaction with TEMPO: A radical scavenger such as 2,2,6,6-tetramethylpiperidinoxy (TEMPO, 10.0 equiv) was added to the general procedure described in section 2.2. After 8 h, the crude reaction mixture was diluted with ethyl acetate, dried using anhydrous Na_2SO_4, filtered and analyzed by GCMS. GCMS analysis revealed that the formation of 1-methoxy-2,2,6,6-tetramethylpiperidine.

Reaction with KI: A hydroxide-radical quencher such as potassium iodide (KI) was added to the general procedure described in section 2.2. After 8 h, the crude reaction mixture was diluted with ethyl acetate, dried using anhydrous Na_2SO_4, filtered and analyzed by GCMS. GCMS analysis revealed that there was no product **2a**.

Reaction with terephthalic acid: An oven-dried jacketed flask (made of Pyrex glass) equipped with a magnetic stir bar was charged with hydroxide-radical scavenger such as terephthalic acid (0.5 mmol). To this, water (2.0 mL), and gCN/MnO/MnO(OH) (8 mg) were added. The flask was then water inlet and outlet was given by a side-jacket. Afterwards, resultant heterogeneous suspension was stirred and irradiated using a white-light of metal halide lamp (150 W) at a distance of 2 cm under open air atmosphere at 25 ^oC. The reaction mixture was taken out at different time intervals and analyzed by the fluorescence emission measurements. The sample solutions were prepared with a final absorbance of 0.01 at 325 nm, the wavelength employed for excitation and analyzed.

Reaction with H_2O_2: An oven-dried round-bottom flask equipped with a magnetic stir bar was charged with (iso)quinolium trifluoroacetate (**1**, 0.5 mmol). To this, H_2O_2 (5 mmol), DMSO (875 µl, added three times with 3 h gap between each addition) and gCN/MnO/MnO(OH) (8 mg) were added. Afterwards, mixture was stirred under open air atmosphere at 25 ^oC. After 8 h of stirring, the reaction mixture was neutralized with aqueous potassium carbonate solution, product was extracted with ethyl acetate and then the ethyl acetate layer was separated and dried over anhydrous Na_2SO_4, filtered, concentrated and analyzed by GCMS.

Reaction at 40 °C (instead of 25 °C): Under the optimized condition, we did a reaction at an elevated temperature (40 °C). Regrettably, we observed the formation of mixed products like 2-methylated quinoline, 4-methylated quinoline, 7-methylated quinoline, 2,4-dimethylated quinoline, 2,7-dimethylated quinoline, and so on. We believe that at high temperatures, it is feasible to readily produce di- or tri-methylated iso(quinolines) than the mono-methylated quinolines with this catalytic system. It is worthy to mention that the rate of the decomposition of hydrogen peroxide is known to increase approximately 2.2 times for each 10 °C rise over the range of 20-100 °C.[1b]

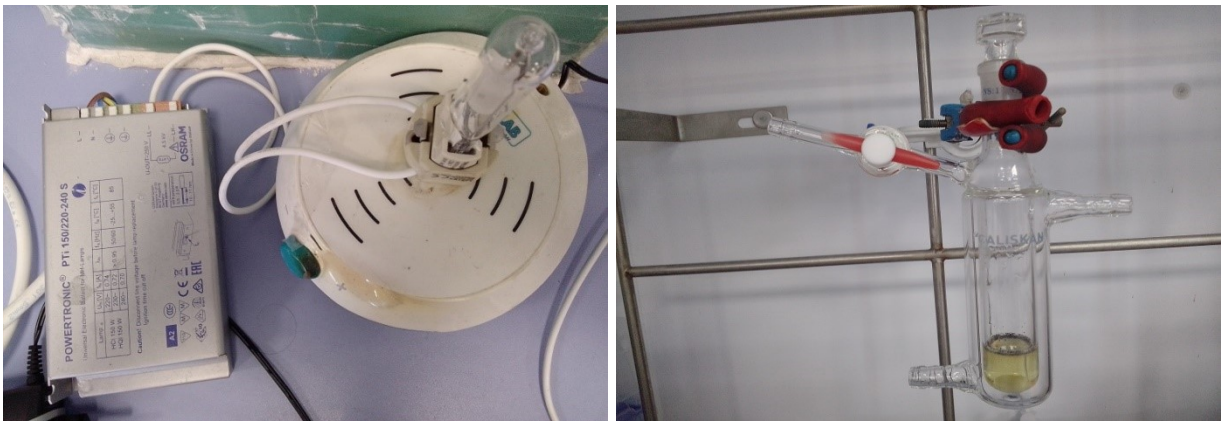


Figure S1. Photographs of parts of a custom made photochemical reactor setup used to perform reactions described in this work. Metal halide lamp with a magnetic stirrer and inbuilt fan (left) and a jacketed flask made of Pyrex glass (right) were used.

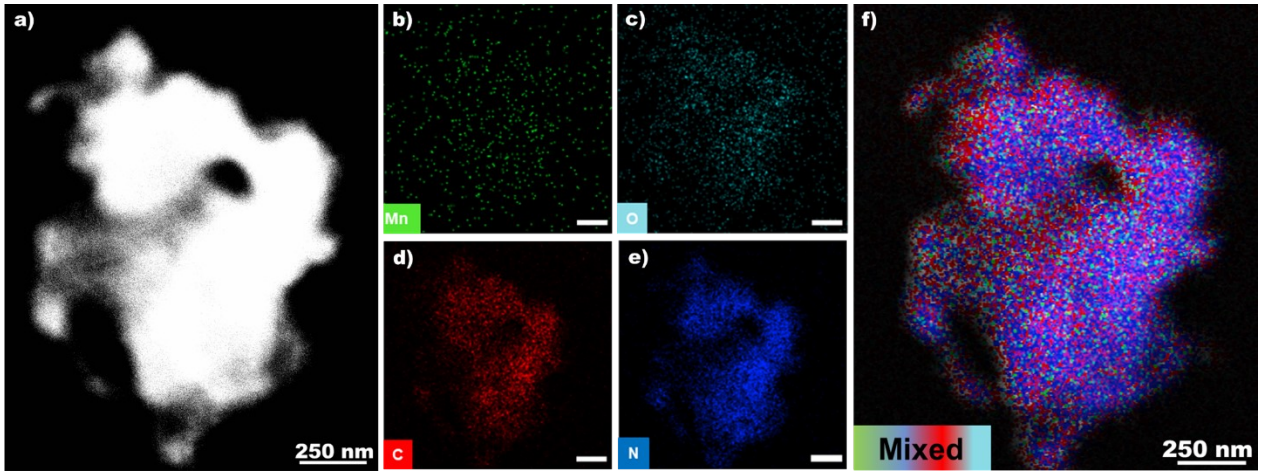
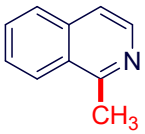


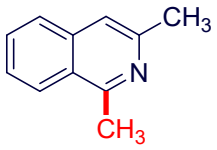
Figure S2. a) HAADF-STEM image and b-f) elemental mapping of gCN/MnO/MnO(OH) after 7th cycle.(all scale bars in figure are 250 nm.)

2.5. Experimental characterization data for products



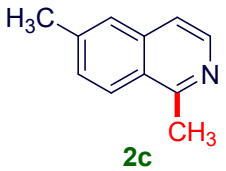
2a

1-Methylisoquinoline (**2a**): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (57 mg, 79% yield). R_f (ethyl acetate): 0.55. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 5.8 Hz, 1H), 8.13 (d, J = 8.2 Hz, 1H), 7.81 (d, J = 8.0 Hz, 1H), 7.65 (dd, J = 8.0, 6.8 Hz, 1H), 7.58 (dd, J = 8.0, 6.8 Hz, 1H), 7.52 (d, J = 5.6 Hz, 1H), 2.98 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 141.8, 136.1, 130.1, 127.6, 127.3, 127.1, 125.6, 119.4, 22.4. Spectra data are consistent with those reported in the literature.[2]



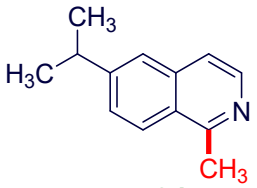
2b

1,3-Dimethylisoquinoline (2b): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (57 mg, 72% yield). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 8.4 Hz, 1H), 7.69 (d, J = 8.2 Hz, 1H), 7.61 (dd, J = 8.2, 6.6 Hz, 1H), 7.49 (dd, J = 8.2, 6.6 Hz, 1H), 7.32 (s, 1H), 2.94 (s, 3H), 2.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.1, 150.2, 136.6, 129.7, 126.6, 126.0, 125.7, 125.5, 117.1, 24.2, 22.3. Spectra data are consistent with those reported in the literature.[2]



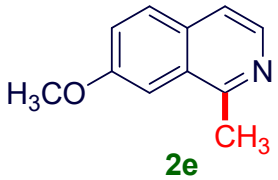
2c

1,6-Dimethylisoquinoline (2c): Synthesized according to the general procedure described in section 2.2. Yellow oil (59 mg, 74% yield). R_f (ethyl acetate): 0.51. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (d, J = 5.8 Hz, 1H), 7.96 (d, J = 8.6 Hz, 1H), 7.53 (s, 1H), 7.39-7.37 (m, 2H), 2.91 (s, 3H), 2.50 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.1, 141.7, 140.1, 136.1, 129.2, 126.0, 125.8, 125.4, 118.6, 22.2, 21.8. Spectra data are consistent with those reported in the literature.[3]



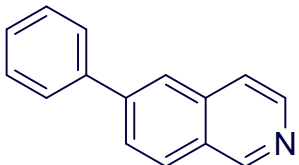
2d

6-Isopropyl-1-methylisoquinoline (2d): Synthesized according to the general procedure described in section 2.2. Colorless oil (36 mg, 39% yield). R_f (ethyl acetate): 0.49. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (d, J = 6.0 Hz, 1H), 7.96 (d, J = 8.6 Hz, 1H), 7.48 (s, 1H), 7.37-7.33 (m, 2H), 2.93-2.88 (m, 4H), 1.24 (d, J = 7.1 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.2, 145.6, 140.0, 136.2, 130.1, 126.0, 125.9, 125.4, 118.7, 37.8, 22.3, 21.5. HRMS (ESI) m/z calculated for $C_{13}H_{16}N$ [$(M+H)^+$] 186.1284, found 186.1291.



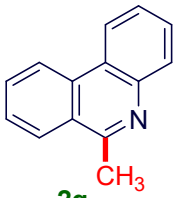
2e

7-Methoxy-1-methylisoquinoline (2e): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (59 mg, 68% yield). R_f (ethyl acetate): 0.42. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (d, J = 6.2 Hz, 1H), 7.96 (d, J = 8.8 Hz, 1H), 7.92 (d, J = 6.2 Hz, 1H), 7.69 (dd, J = 8.8, 2.4 Hz, 1H), 7.44 (d, J = 2.4 Hz, 1H), 3.98 (s, 3H), 2.90 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.8, 155.9, 133.7, 129.9, 129.0, 128.8, 128.7, 122.6, 104.4, 55.9, 22.4. Spectra data are consistent with those reported in the literature.[4]



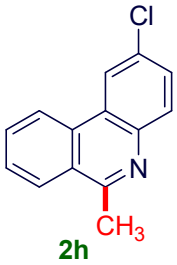
2f

1-Methyl-6-phenylisoquinoline (2f): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (84 mg, 76% yield, m. p. 62-63 °C). R_f (ethyl acetate): 0.40. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.41 (m, 1H), 8.14 (d, J = 7.8 Hz, 1H), 7.95 (s, 1H), 7.80 (d, J = 7.8 Hz, 1H), 7.72-7.69 (m, 2H), 7.53-7.44 (m, 4H), 2.96 (s, 3H). ^{13}C **NMR** (100 MHz, $CDCl_3$) δ 158.5, 142.4, 142.1, 140.0, 136.1, 128.9, 128.0, 127.4, 126.6, 126.4, 126.1, 124.6, 119.4, 22.3. Spectra data are consistent with those reported in the literature.[3]



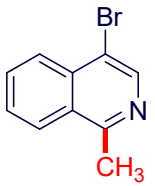
2g

6-Methylphenanthridine (2g): Synthesized according to the general procedure described in section 2.2. Colorless solid (68 mg, 70% yield, m. p. 70-71 °C). R_f (ethyl acetate): 0.36. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.58 (d, J = 8.0 Hz, 1H), 8.50 (d, J = 8.0 Hz, 1H), 8.16 (d, J = 8.2 Hz, 1H), 8.10 (d, J = 8.0 Hz, 1H), 7.82 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H), 7.71 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H), 7.66 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H), 7.61 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H), 3.02 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.8, 143.7, 132.4, 130.4, 129.3, 128.4, 127.2, 126.4, 126.2, 125.8, 123.6, 122.2, 121.8, 23.4. Spectra data are consistent with those reported in the literature.[5]



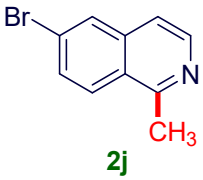
2h

2-Chloro-6-methylphenanthridine (2h): Synthesized according to the general procedure described in section 2.2. Colorless solid (83 mg, 73% yield, m. p. 103-104 °C). R_f (ethyl acetate): 0.37. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.49 (d, J = 8.4 Hz, 1H), 8.43 (d, J = 1.2 Hz, 1H), 8.20 (d, J = 7.8 Hz, 1H), 8.01 (d, J = 8.8 Hz, 1H), 7.83 (t, J = 8.4 Hz, 1H), 7.73-7.70 (m, 1H), 7.62 (dd, J = 8.4, 2.2 Hz, 1H), 3.01 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.0, 142.1, 132.2, 131.5, 130.8, 130.7, 129.1, 127.9, 126.5, 126.1, 124.8, 122.3, 121.7, 23.3. Spectra data are consistent with those reported in the literature.[5]



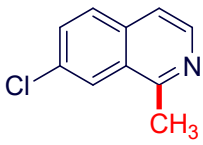
2i

4-Bromo-1-methylisoquinoline (2i): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (87 mg, 78% yield, m. p. 87-89 °C). R_f (ethyl acetate): 0.52. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.57 (s, 1H), 8.18 (d, J = 8.4 Hz, 1H), 8.10 (d, J = 8.4 Hz, 1H), 7.81 (t, J = 7.6 Hz, 1H), 7.67 (t, J = 7.6 Hz, 1H), 2.93 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.3, 143.4, 134.7, 131.4, 128.9, 128.2, 126.8, 126.2, 118.0, 22.3. HRMS (ESI) m/z calculated for $C_{10}H_9BrN$ [$(M+H)^+$] 221.9920, found 221.9916.



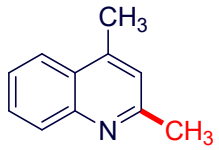
2j

6-Bromo-1-methylisoquinoline (2j): Synthesized according to the general procedure described in section 2.2. Pale yellow semi-solid (91 mg, 82% yield). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J = 5.8 Hz, 1H), 7.97-7.92 (m, 2H), 7.64 (dd, J = 9.0, 1.8 Hz, 1H), 7.39 (d, J = 5.7 Hz, 1H), 2.92 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.8, 142.8, 137.0, 130.5, 129.3, 127.4, 125.8, 124.6, 118.3, 22.3. Spectra data are consistent with those reported in the literature.[4]



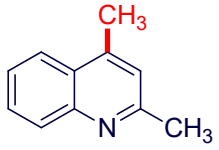
2k

7-Chloro-1-methylisoquinoline (2k): Synthesized according to the general procedure described in section 2.2. Yellow oil (67 mg, 75% yield). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.32 (d, J = 5.8 Hz, 1H), 7.88 (s, 1H), 7.67 (d, J = 8.4 Hz, 1H), 7.52 (d, J = 8.4 Hz, 1H), 7.35 (d, J = 5.8 Hz, 1H), 2.95 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.8, 140.9, 136.8, 133.9, 132.0, 127.5, 126.9, 124.4, 119.0, 22.6. HRMS (ESI) m/z calculated for $C_{10}H_9ClN$ [$(M+H)^+$] 178.0427, found 178.0431.



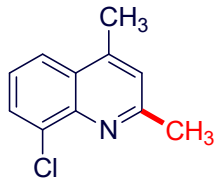
2l

2,4-Dimethylquinoline (2l): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (64 mg, 81% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.53. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, J = 8.2 Hz, 1H), 7.96 (dd, J = 8.2, 0.8 Hz, 1H), 7.67 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.52 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.16 (s, 1H), 2.72 (s, 3H), 2.69 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 147.6, 144.2, 129.1, 129.0, 126.6, 125.4, 123.5, 122.7, 25.2, 18.5. Spectra data are consistent with those reported in the literature.[6]



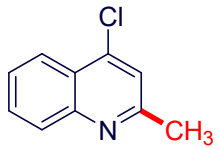
2m

2,4-Dimethylquinoline (2m): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (66 mg, 83% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.53. Spectral data are in accordance with those of **2l** described above.[6]



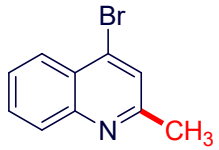
2o

8-Chloro-2,4-dimethylquinoline (2o): Synthesized according to the general procedure described in section 2.2. Colorless solid (79 mg, 82% yield, m. p. 71-73°C). R_f (n-hexane:ethyl acetate; 1:1): 0.52. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, J = 9.0 Hz, 1H), 7.77 (d, J = 7.4 Hz, 1H), 7.39 (t, J = 7.8 Hz, 1H), 7.17 (s, 1H), 2.75 (s, 3H), 2.64 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 144.6, 144.1, 133.4, 129.3, 128.0, 125.1, 123.7, 122.8, 25.7, 19.1. Spectra data are consistent with those reported in the literature.[6]



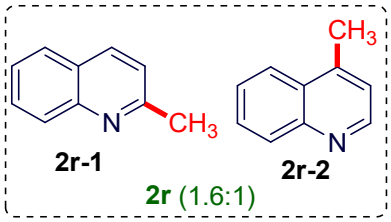
2p

4-Chloro-2-methylquinoline (2p): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (75 mg, 84% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.55. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (d, J = 8.4 Hz, 1H), 8.06 (d, J = 8.4 Hz, 1H), 7.73 (ddd, J = 8.4, 7.0, 1.2 Hz, 1H), 7.59 (ddd, J = 8.4, 7.0, 1.2 Hz, 1H), 7.40 (s, 1H), 2.74 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.9, 148.5, 142.8, 130.6, 128.9, 127.0, 124.9, 124.0, 122.2, 25.1. Spectra data are consistent with those reported in the literature.[6]



2q

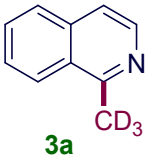
4-Bromo-2-methylquinoline (2q): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (89 mg, 80% yield, m. p. 89-90 °C). R_f (n-hexane:ethyl acetate; 1:1): 0.55. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33 (s, 1H), 8.01 (d, J = 8.2 Hz, 1H), 7.70 (t, J = 7.8 Hz, 2H), 7.52 (dd, J = 7.8, 1.2 Hz, 1H), 2.87 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 157.6, 146.4, 138.5, 129.7, 128.8, 128.0, 126.7, 126.5, 118.9, 25.8. Spectra data are consistent with those reported in the literature.[7]



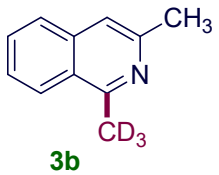
Synthesized according to the general procedure described in section 2.2 and obtained as a mixture with 1.6:1 ratio of 2-methylquinoline (2r-1) and 4-methylquinolin (2r-2).

2-Methylquinoline (2r-1): Colorless oil (34 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (d, J = 9.0 Hz, 1H), 8.02 (d, J = 7.8 Hz, 1H), 7.76 (d, J = 8.0 Hz, 1H), 7.68 (t, J = 7.8 Hz, 1H), 7.49 (t, J = 7.4 Hz, 1H), 7.29 (d, J = 8.4 Hz, 1H), 2.76 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 159.1, 147.8, 136.1, 129.3, 128.6, 127.5, 126.4, 125.6, 122.1, 25.4. Spectra data are consistent with those reported in the literature.[2]

4-Methylquinoline (2r-2): Colorless oil (21 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.77 (d, J = 4.4 Hz, 1H), 8.12 (d, J = 8.4 Hz, 1H), 8.01 (d, J = 8.2 Hz, 1H), 7.71 (dd, J = 8.4, 6.8 Hz, 1H), 7.57 (dd, J = 8.2, 6.8 Hz, 1H), 7.24 (d, J = 4.4 Hz, 1H), 2.73 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 150.1, 148.0, 144.3, 130.0, 129.1, 128.4, 126.3, 123.8, 121.9, 18.8. Spectra data are consistent with those reported in the literature.[2]

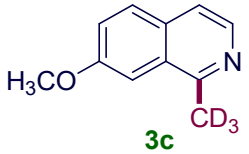


1-Trideuteromethylisoquinoline (3a): Synthesized according to the general procedure described in section 2.2. Colorless oil (57 mg, 77% yield). R_f (ethyl acetate): 0.55. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, J = 6.0 Hz, 1H), 8.11 (d, J = 8.2 Hz, 1H), 7.81 (d, J = 8.2 Hz, 1H), 7.67 (dd, J = 8.2, 6.8 Hz, 1H), 7.59 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.50 (d, J = 6.0 Hz, 1H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 158.7, 141.6, 136.1, 130.2, 127.6, 127.3, 127.1, 125.8, 119.5, 22.2-21.9 (m). Spectra data are consistent with those reported in the literature.[8]



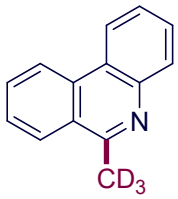
3b

1-Trideuteromethyl-3-methylisoquinoline (3b): Synthesized according to the general procedure described in section 2.2. Pale yellow semi-solid (59 mg, 73% yield). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (d, J = 8.4 Hz, 1H), 7.69 (d, J = 8.2 Hz, 1H), 7.62 (dd, J = 8.2, 6.6 Hz, 1H), 7.49 (dd, J = 8.2, 6.6 Hz, 1H), 7.33 (s, 1H), 2.65 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 158.1, 150.3, 136.7, 129.9, 126.7, 126.1, 125.7, 125.6, 117.3, 24.3, 22.2-21.8 (m). Spectra data are consistent with those reported in the literature.[8]



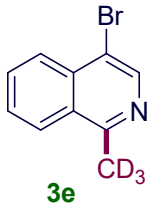
3c

1-Trideuteromethyl-7-methoxyisoquinoline (3c): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (62 mg, 70% yield). R_f (ethyl acetate): 0.42. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29 (d, J = 6.4 Hz, 1H), 7.97 (d, J = 8.8 Hz, 1H), 7.93 (d, J = 6.4 Hz, 1H), 7.70 (dd, J = 8.8, 2.4 Hz, 1H), 7.43 (d, J = 2.4 Hz, 1H), 4.01 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.9, 155.7, 133.6, 129.8, 129.1, 128.9, 128.8, 122.8, 104.2, 56.1, 22.4-22.0 (m). Spectra data are consistent with those reported in the literature.[6]



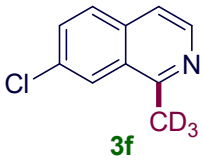
3d

6-Trideuteromethylphenanthridine (3d): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (71 mg, 72% yield, m. p. 69-70 °C). R_f (ethyl acetate): 0.36. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.60 (d, J = 8.2 Hz, 1H), 8.52 (d, J = 8.0 Hz, 1H), 8.20 (d, J = 8.2 Hz, 1H), 8.10 (d, J = 8.2 Hz, 1H), 7.82 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H), 7.71-7.65 (m, 2H), 7.62 (ddd, J = 8.2, 7.0, 1.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.8, 143.8, 132.5, 130.4, 129.4, 128.5, 127.3, 126.5, 126.3, 125.9, 123.7, 122.3, 121.8, 22.9-22.5 (m). Spectra data are consistent with those reported in the literature.[5]



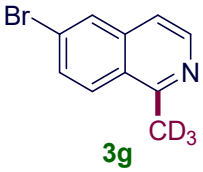
3e

4-Bromo-1-trideuteromethylisoquinoline (3e): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (84 mg, 75% yield, m. p. 87-89 °C). R_f (ethyl acetate): 0.52. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.58 (s, 1H), 8.17 (d, J = 8.4 Hz, 1H), 8.11 (d, J = 8.4 Hz, 1H), 7.80 (t, J = 7.6 Hz, 1H), 7.67 (t, J = 7.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.2, 143.5, 134.7, 131.4, 128.8, 128.2, 126.7, 126.2, 118.01, 22.6-22.3 (m). Spectra data are consistent with those reported in the literature.[8]



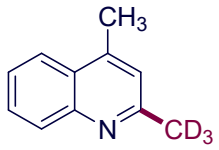
3f

7-Chloro-1-trideuteromethylisoquinoline (3f): Synthesized according to the general procedure described in section 2.2. Yellow oil (64 mg, 71% yield). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.32 (d, J = 5.8 Hz, 1H), 7.87 (s, 1H), 7.67 (d, J = 8.4 Hz, 1H), 7.52 (d, J = 8.4 Hz, 1H), 7.35 (d, J = 5.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.8, 140.9, 136.8, 134.0, 132.1, 127.5, 126.9, 124.4, 119.1, 22.3-22.0 (m). HRMS (ESI) m/z calculated for $C_{10}H_6D_3ClN$ [$(M+H)^+$] 181.0616, found 181.0611.



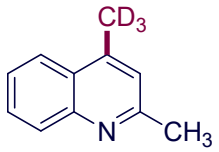
3g

6-Bromo-1-trideuteromethylisoquinoline (3g): Synthesized according to the general procedure described in section 2.2. Off-white solid (88 mg, 78% yield, m. p. 88-89 °C). R_f (ethyl acetate): 0.50. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.40 (d, J = 5.8 Hz, 1H), 7.99-7.93 (m, 2H), 7.66 (dd, J = 9.0, 1.8 Hz, 1H), 7.40 (d, J = 5.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.9, 142.9, 137.2, 130.6, 129.4, 127.6, 125.9, 124.7, 118.4, 22.3-22.0 (m). Spectra data are consistent with those reported in the literature.[6]



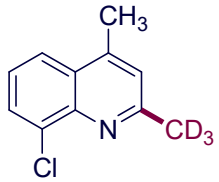
3h

2-**Trideuteromethyl-4-methylquinoline (3h)**: Synthesized according to the general procedure described in section 2.2. Pale yellow oil (62 mg, 77% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.53. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 8.2 Hz, 1H), 7.95 (d, J = 8.2 Hz, 1H), 7.67 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.51 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.14 (s, 1H), 2.68 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.7, 147.6, 144.4, 129.2, 129.1, 126.7, 125.5, 123.6, 122.9, 25.1-24.5 (m), 18.6. Spectra data are consistent with those reported in the literature.[8]



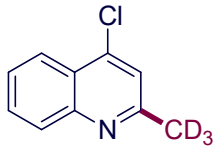
3i

4-**Trideuteromethyl-2-methylquinoline (3i)**: Synthesized according to the general procedure described in section 2.2. Colorless oil (60 mg, 74% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.52. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, J = 8.2 Hz, 1H), 7.94 (d, J = 8.2 Hz, 1H), 7.68 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.49 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.14 (s, 1H), 2.70 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.6, 147.7, 144.2, 129.2, 129.0, 126.6, 125.4, 123.5, 122.7, 25.2, 18.4-18.0 (m). Spectra data are consistent with those reported in the literature.[8]



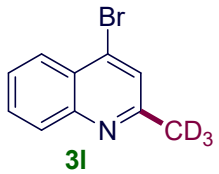
3j

8-Chloro-2-trideuteromethyl-4-methylquinoline (3j): Synthesized according to the general procedure described in section 2.2. Pale yellow solid (74 mg, 76% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.52. ^{1}H NMR (300 MHz, $CDCl_3$) δ ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, J = 9.0 Hz, 1H), 7.78 (d, J = 7.4 Hz, 1H), 7.38 (t, J = 7.8 Hz, 1H), 7.19 (s, 1H), 2.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 144.7, 144.2, 133.3, 129.3, 128.1, 125.2, 123.7, 122.7, 25.4-25.0 (m), 19.0. HRMS (ESI) m/z calculated for $C_{11}H_8D_3ClN$ [$(M+H)^+$] 195.0771, found 195.0769.



3k

4-Chloro-2-trideuteromethylquinoline (3k): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (72 mg, 79% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.55. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.18 (d, J = 8.4 Hz, 1H), 8.06 (d, J = 8.4 Hz, 1H), 7.74 (ddd, J = 8.4, 7.0, 1.2 Hz, 1H), 7.58 (ddd, J = 8.4, 7.0, 1.2 Hz, 1H), 7.41 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.8, 148.5, 142.9, 130.6, 128.9, 126.9, 124.9, 124.0, 122.1, 25.2-24.8 (m). HRMS (ESI) m/z calculated for $C_{10}H_6D_3ClN$ [$(M+H)^+$] 181.0613, found 181.0619.



3l

4-Bromo-2-trideuteromethylquinoline (3l): Synthesized according to the general procedure described in section 2.2. Pale yellow oil (89 mg, 79% yield). R_f (n-hexane:ethyl acetate; 1:1): 0.54. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.34 (s, 1H), 8.01 (d, J = 8.2 Hz, 1H), 7.71 (t, J = 7.8 Hz, 2H), 7.51 (dd, J = 7.8, 1.2 Hz, 1H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 157.8, 146.4, 138.5, 129.7, 128.7, 128.0, 126.7, 126.5, 118.9, 25.7-25.2 (m). HRMS (ESI) m/z calculated for $C_{10}H_6D_3BrN$ [$(M+H)^+$] 225.0109, found 225.0111.

References

1. (a) O. Altan, E. Altintas, S. Alemdar, and O. Metin, *Chem. Eng. J.*, 2022, **441**, 136047. (b) H. Targhan, P. Evans, K. Bahrami, *J. Ind. Eng. Chem.* 2021, **104**, 295-332.
2. J. Jin, and D. W. C. MacMillan, *Nature*, 2015, **525**, 87-90.
3. H. Chu, S. Sun, J.-T. Yu and J. Cheng, *Chem. Commun*., 2015, **51**, 13327-13329.
4. N. J. Webb, S. A. Raw, S. P. Marsden, *Tetrahedron* 2018, **74**, 5200-5205.
5. R. Zhang, X. Shi, Q. Yan, Z. Li, Z. Wang, H. Yu, X. Wang, J. Qi, and M. Jiang, *RSC Adv.,* 2017, 7, 38830-38833.
6. R. A. Garza-Sanchez, T. Patra, A. Tlahuext-Aca, F. Strieth-Kalthoff, and F. Glorius, *Chem. Eur. J*. 2018, **24**, 10064-10068.

7 D. Wang, Y. Wang, J. Zhao, L. Li, L. Miao, D. Wang, H. Sun, and P. Yu, *Tetrahedron* 2016, **72**, 5762-5768.

8. R. Caporaso, S. Manna, S. Zinken, A. R. Kochnev, E. R. Lukyanenko, A. V. Kurkind, and A. P. Antonchick, *Chem. Commun.*, 2016, **52**, 12486-12489.

Copies of NMR Spectra of products

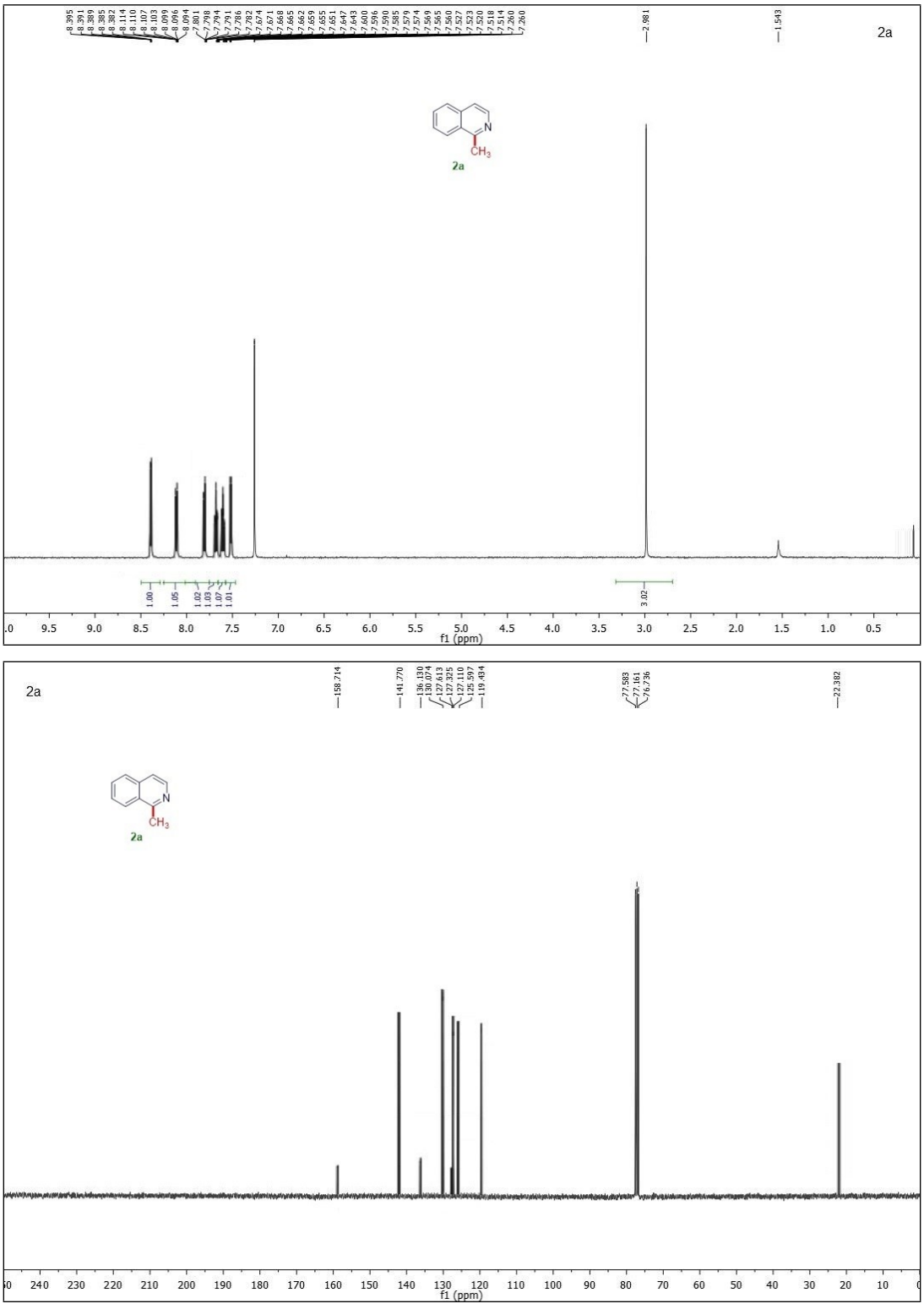


Figure S3. ^{1}H (top) and ^{13}C (bottom) spectra of **2a** in $CDCl_3$.

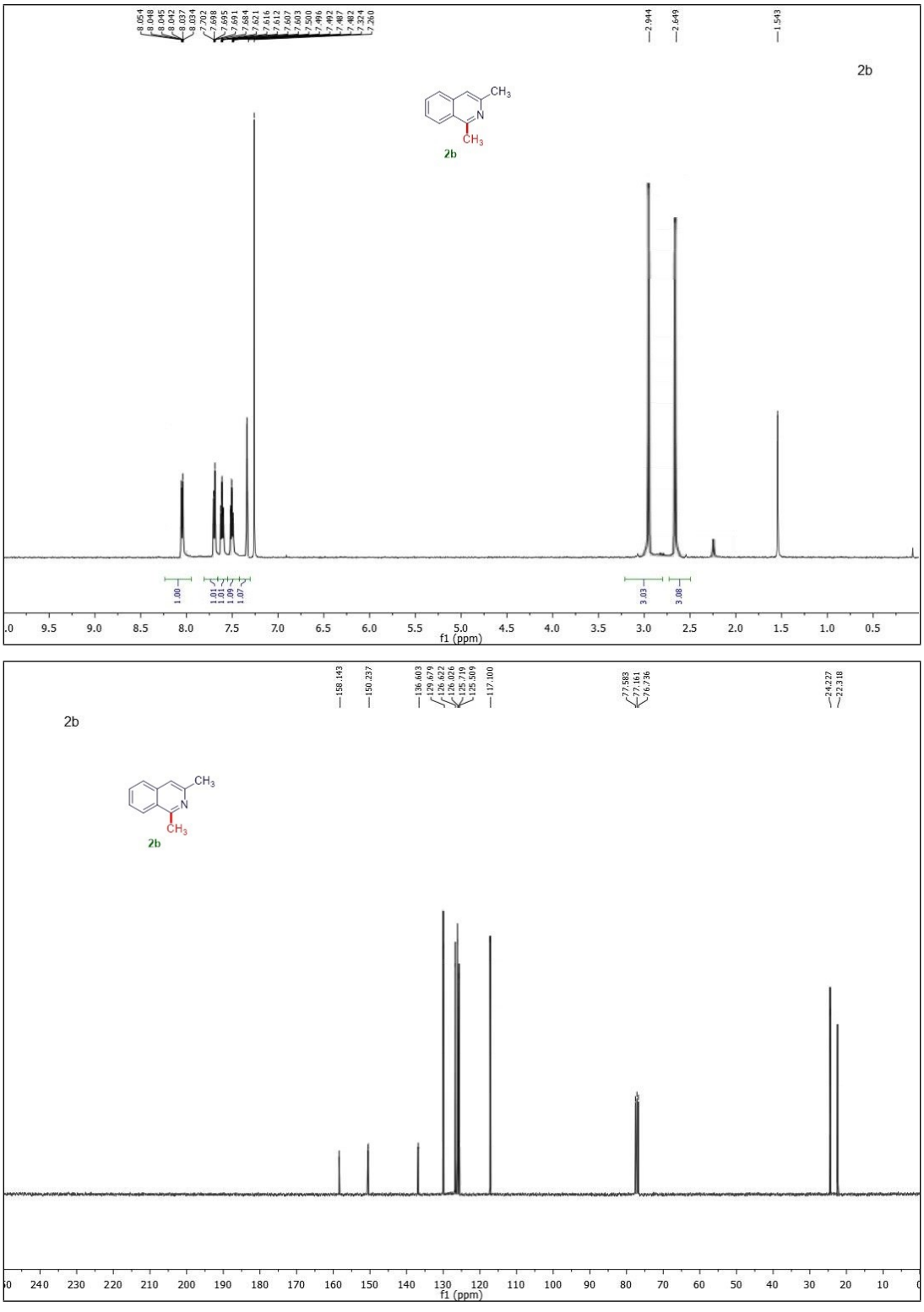


Figure S4. ^{1}H (top) and ^{13}C (bottom) spectra of **2b** in $CDCl_3$.

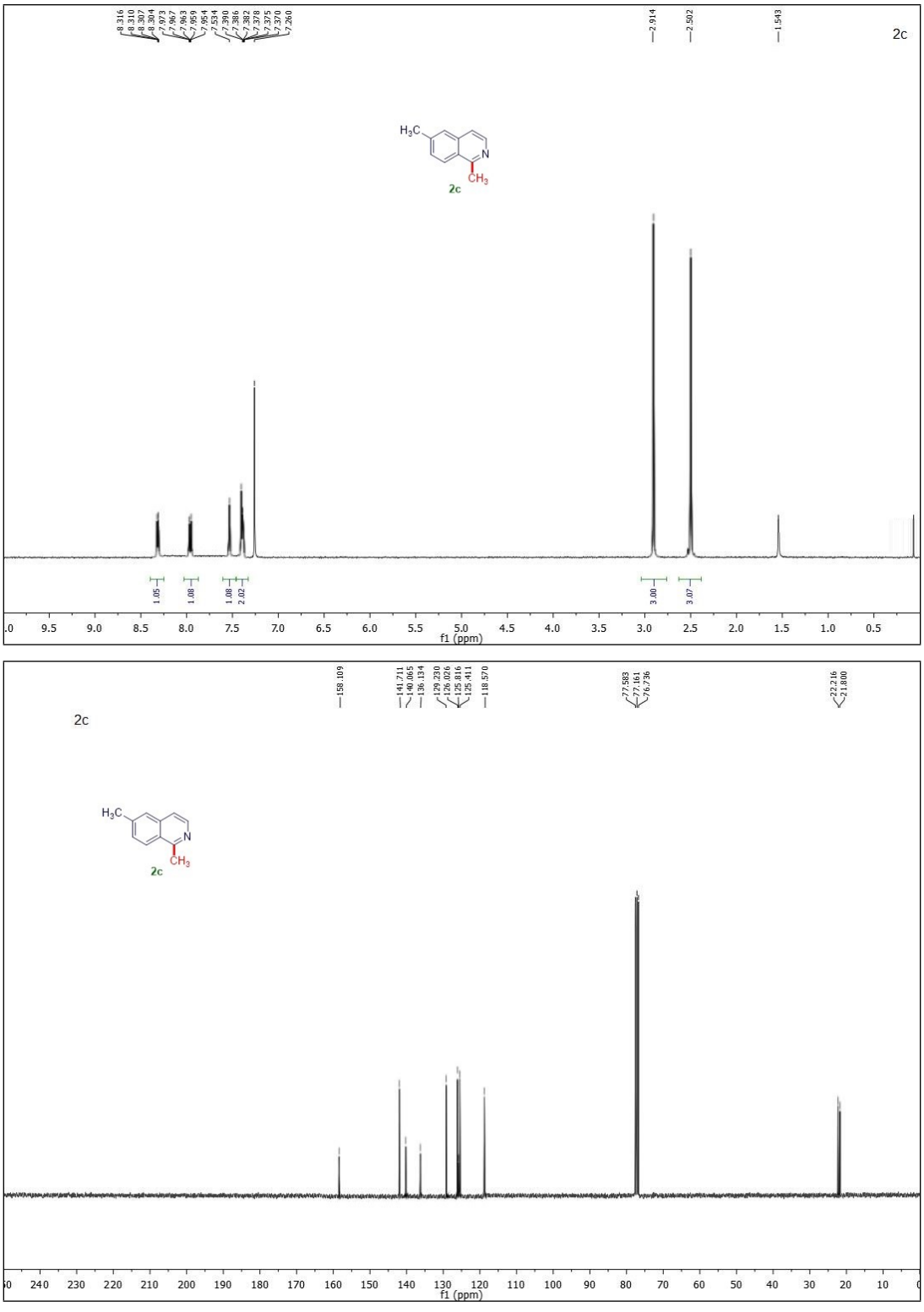


Figure S5. ^{I}H (top) and ^{13}C (bottom) spectra of **2c** in $CDCl_3$.

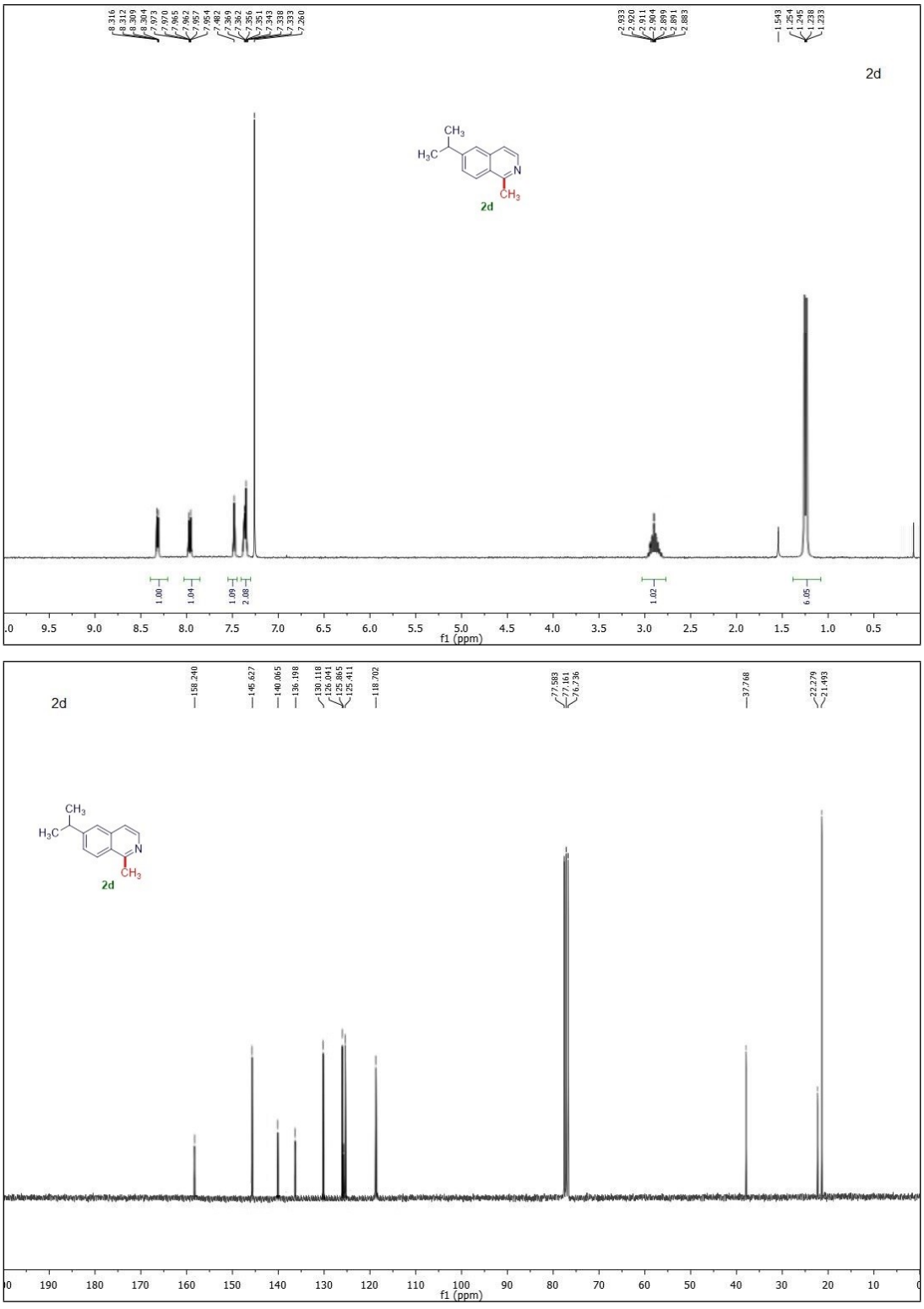


Figure S6. ^{1}H (top) and ^{13}C (bottom) spectra of **2d** in $CDCl_3$.

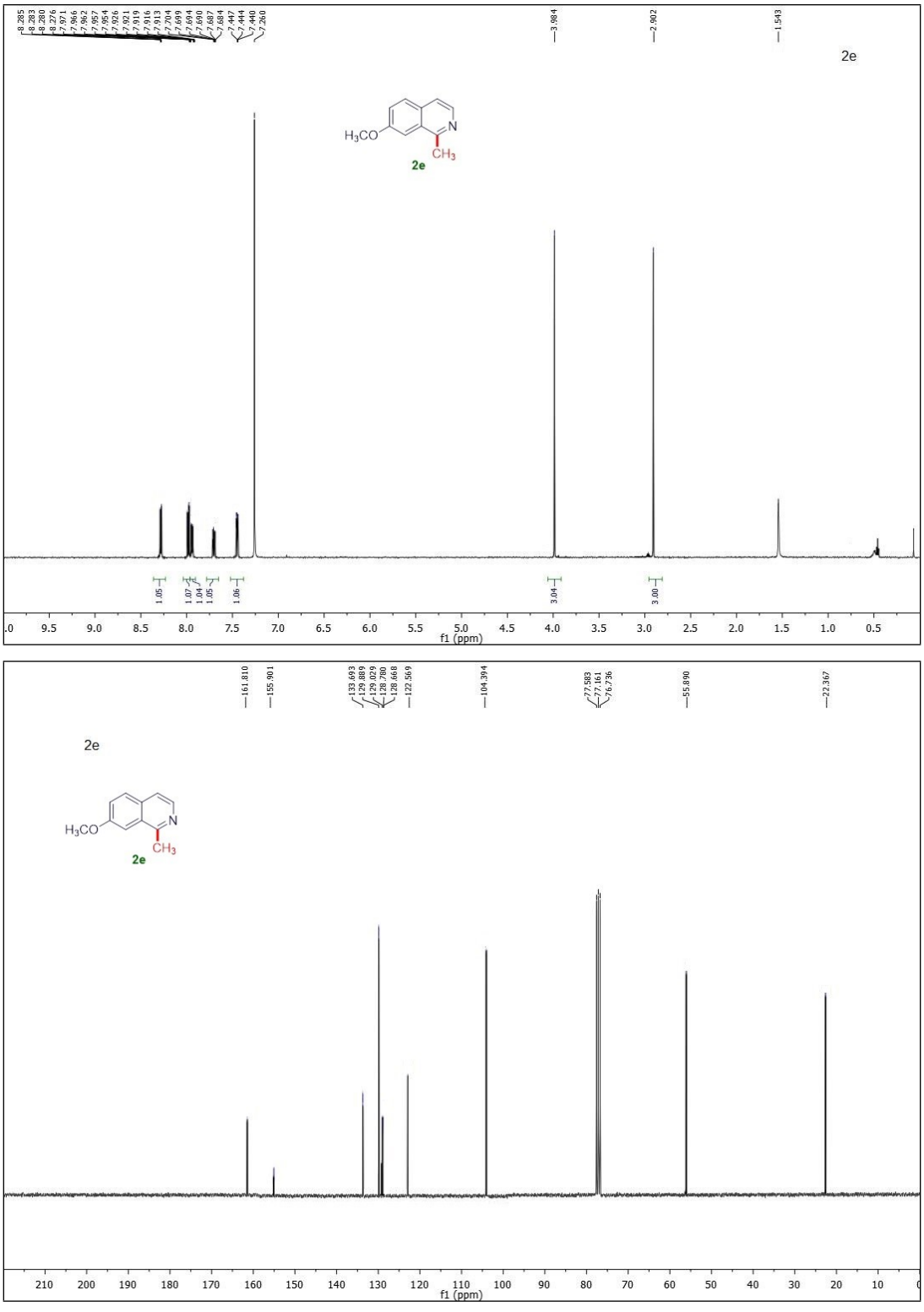


Figure S7. ^{1}H (top) and ^{13}C (bottom) spectra of **2e** in $CDCl_3$.

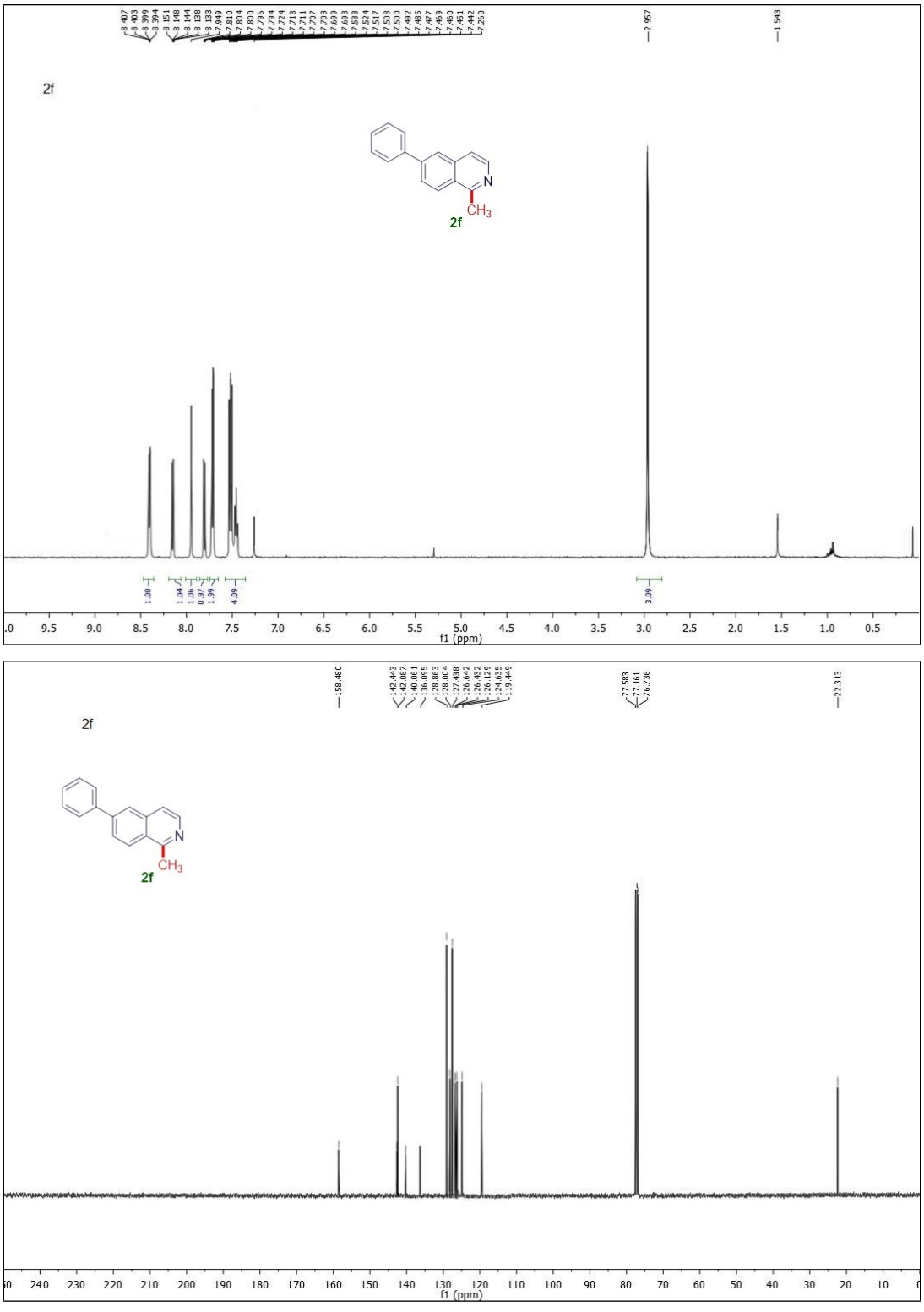


Figure S8. ^{1}H (top) and ^{13}C (bottom) spectra of **2f** in $CDCl_3$.

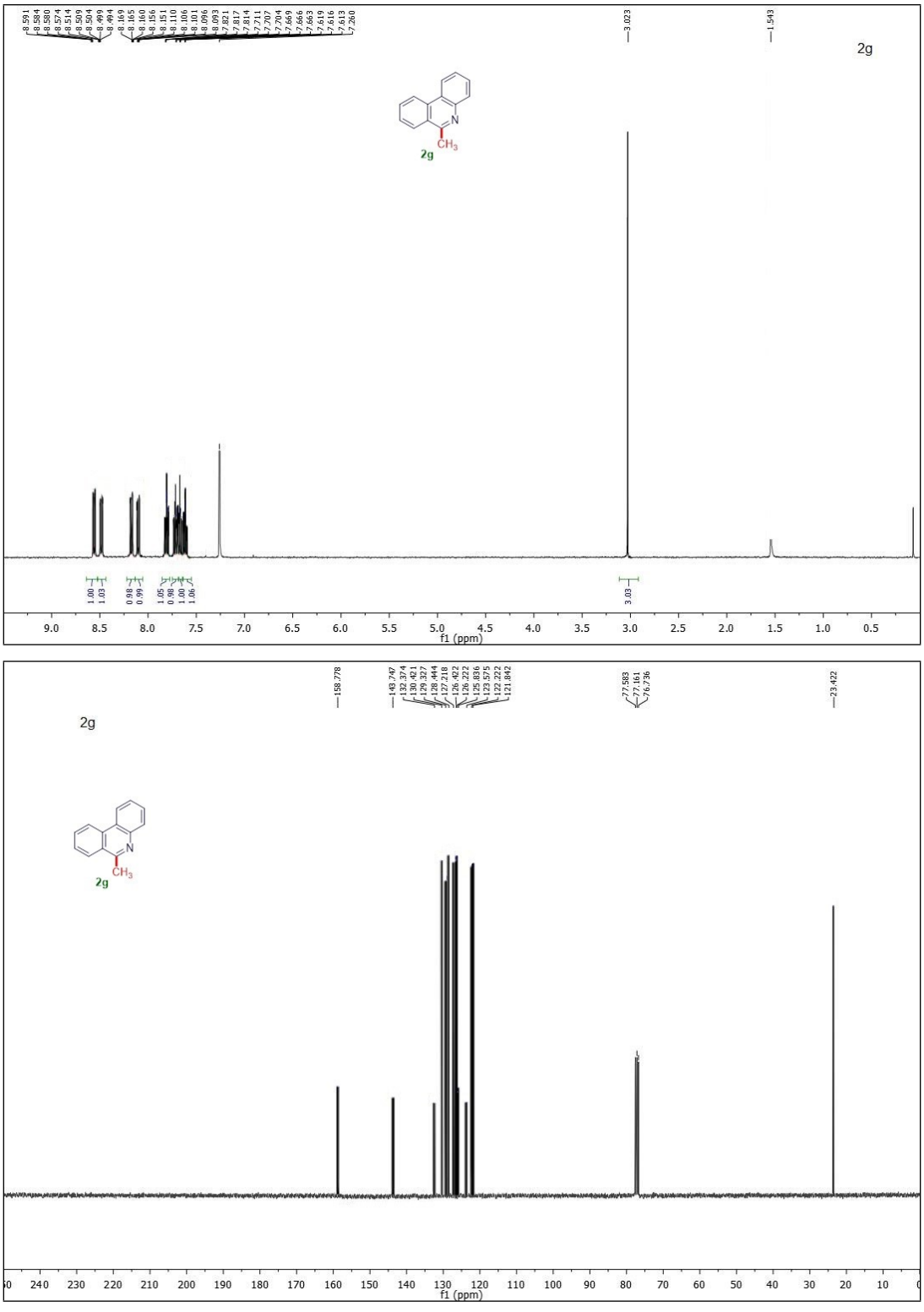


Figure S9. ^{1}H (top) and ^{13}C (bottom) spectra of **2g** in $CDCl_3$.

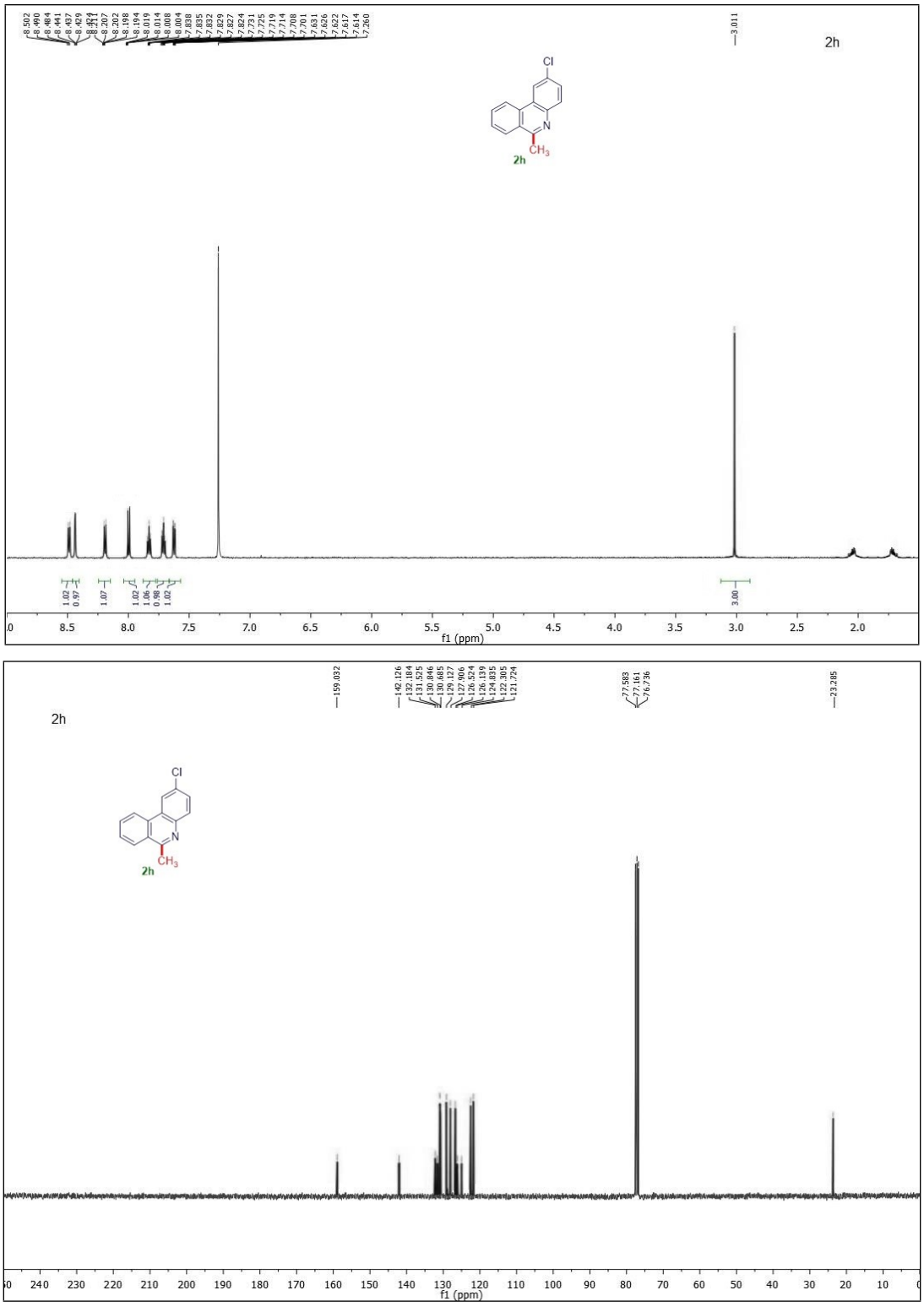


Figure S10. ^{1}H (top) and ^{13}C (bottom) spectra of **2h** in $CDCl_3$.

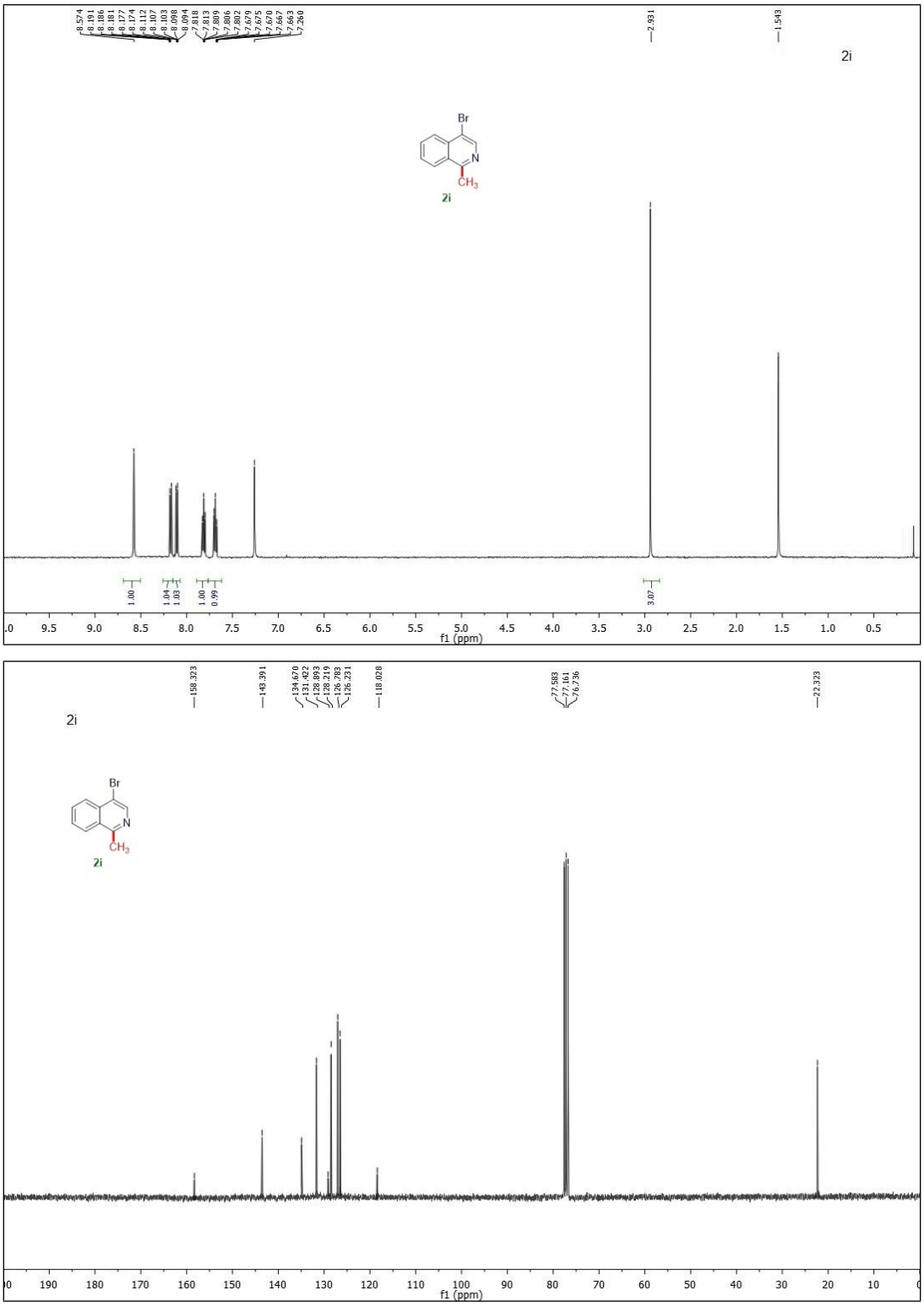


Figure S11. ^{I}H (top) and ^{13}C (bottom) spectra of **2i** in $CDCl_3$.

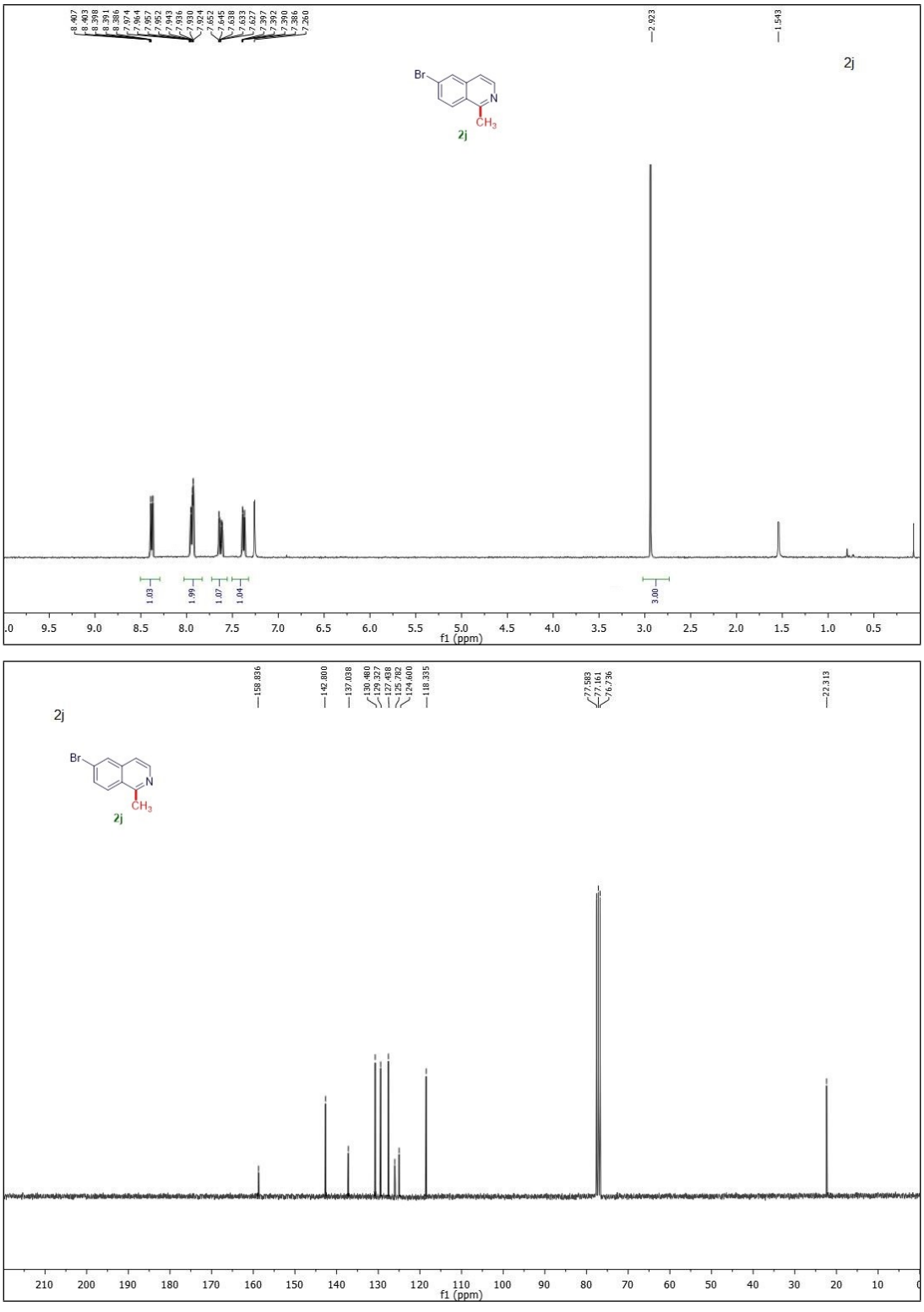


Figure S12. ^{1}H (top) and ^{13}C (bottom) spectra of **2j** in $CDCl_3$.

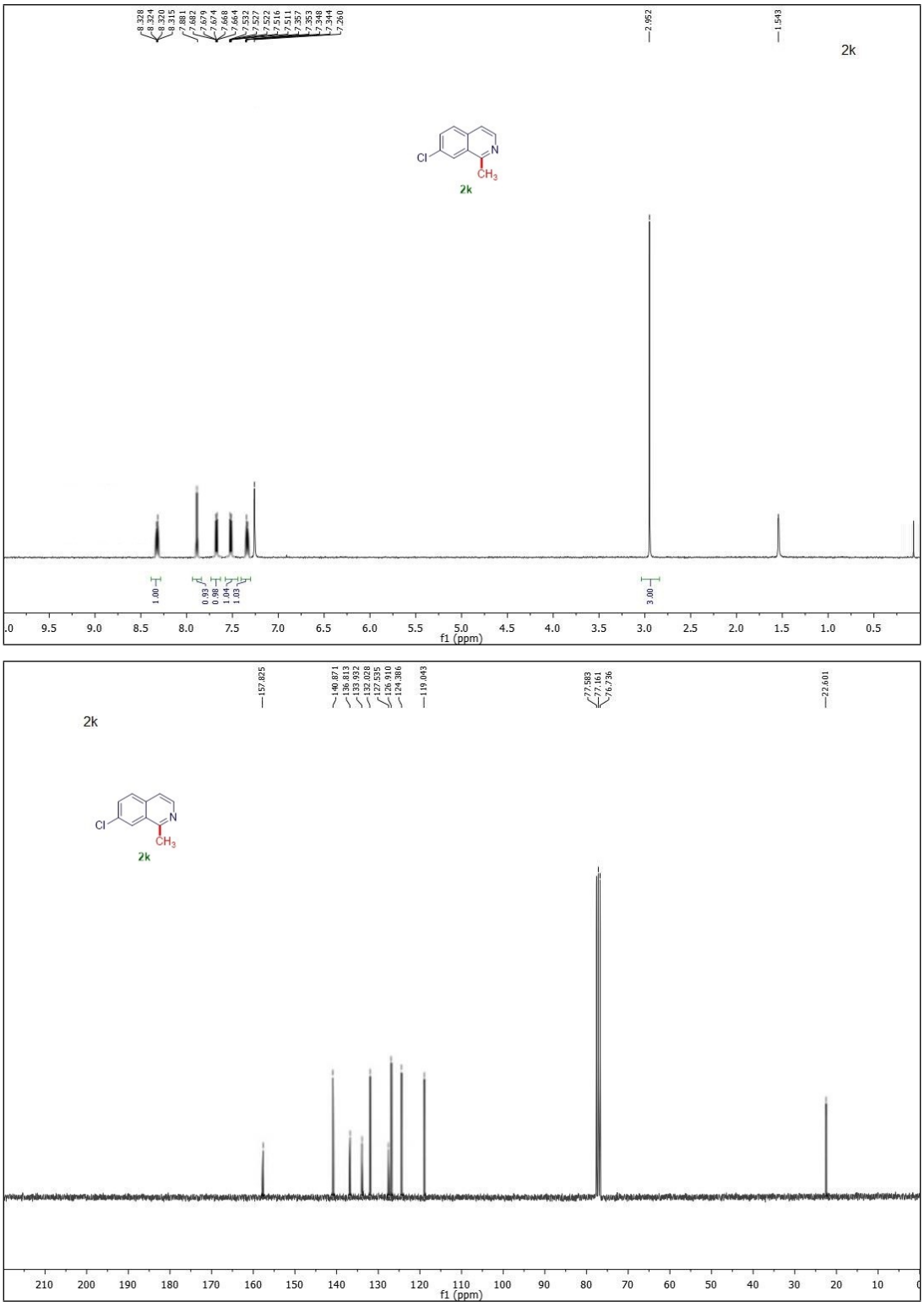


Figure S13. ^{1}H (top) and ^{13}C (bottom) spectra of **2k** in $CDCl_3$.

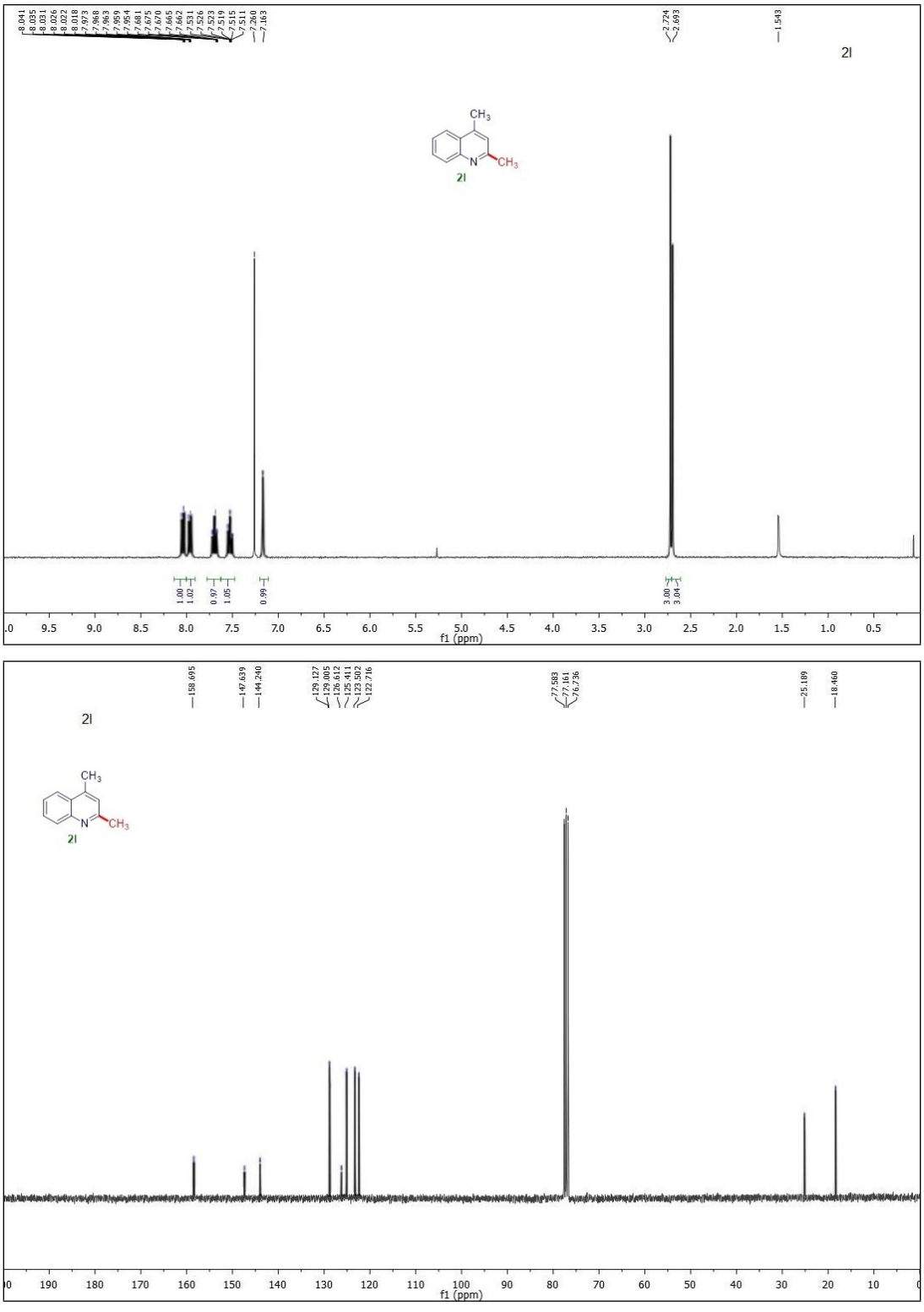


Figure S14. ^{1}H (top) and ^{13}C (bottom) spectra of **2l** in $CDCl_3$.

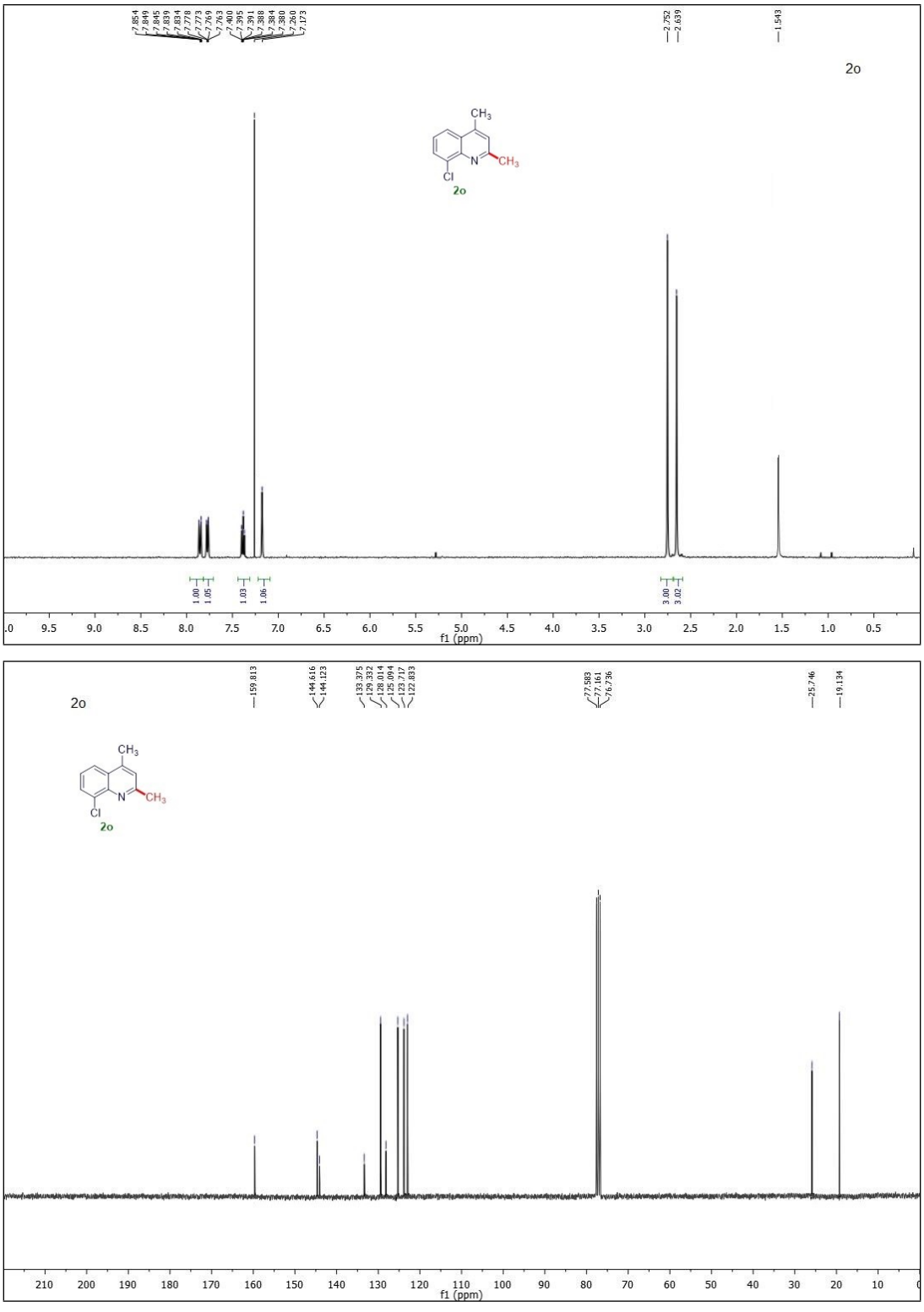


Figure S15. ^{1}H (top) and ^{13}C (bottom) spectra of **2o** in $CDCl_3$.

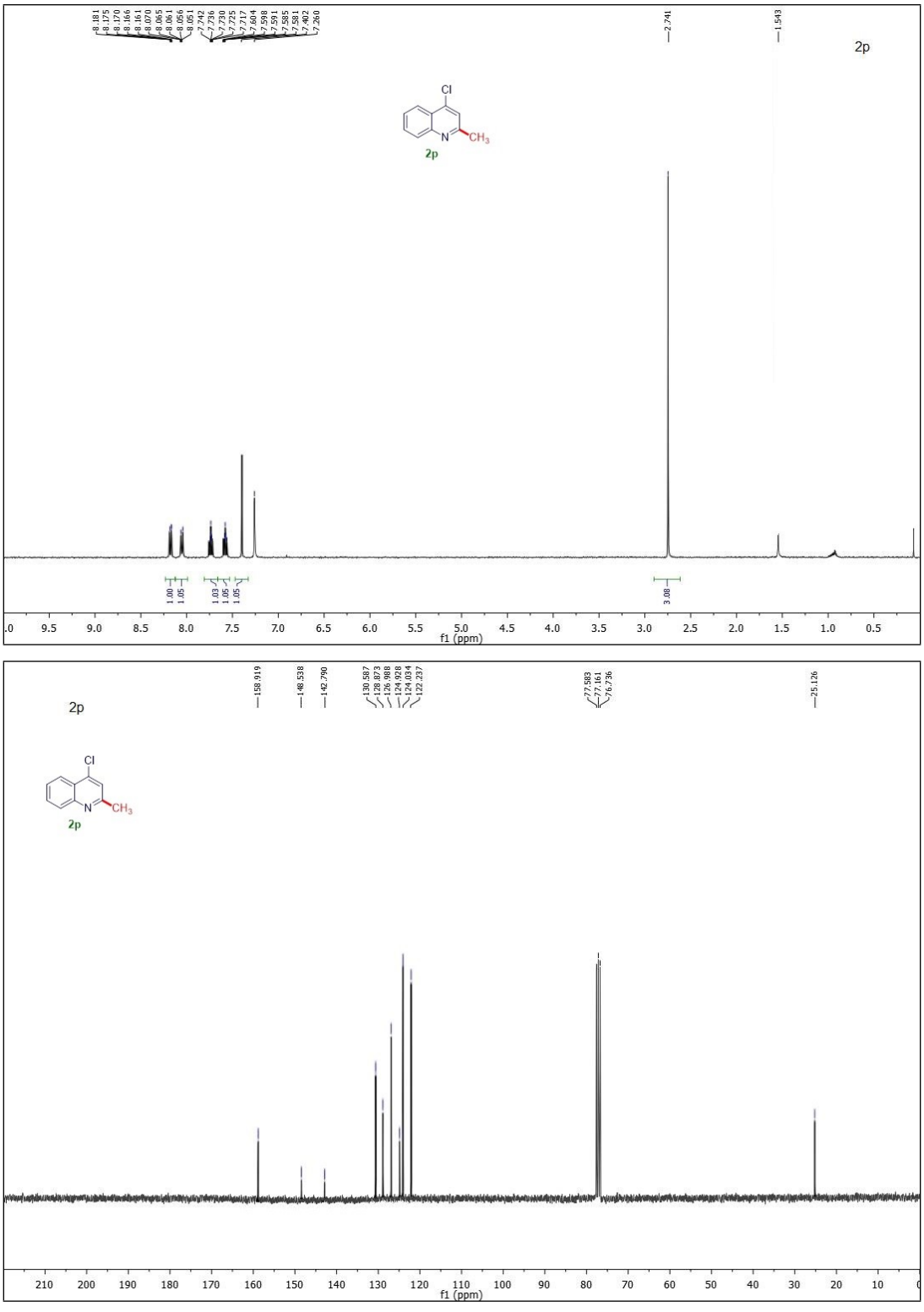


Figure S16. ^{1}H (top) and ^{13}C (bottom) spectra of **2p** in $CDCl_3$.

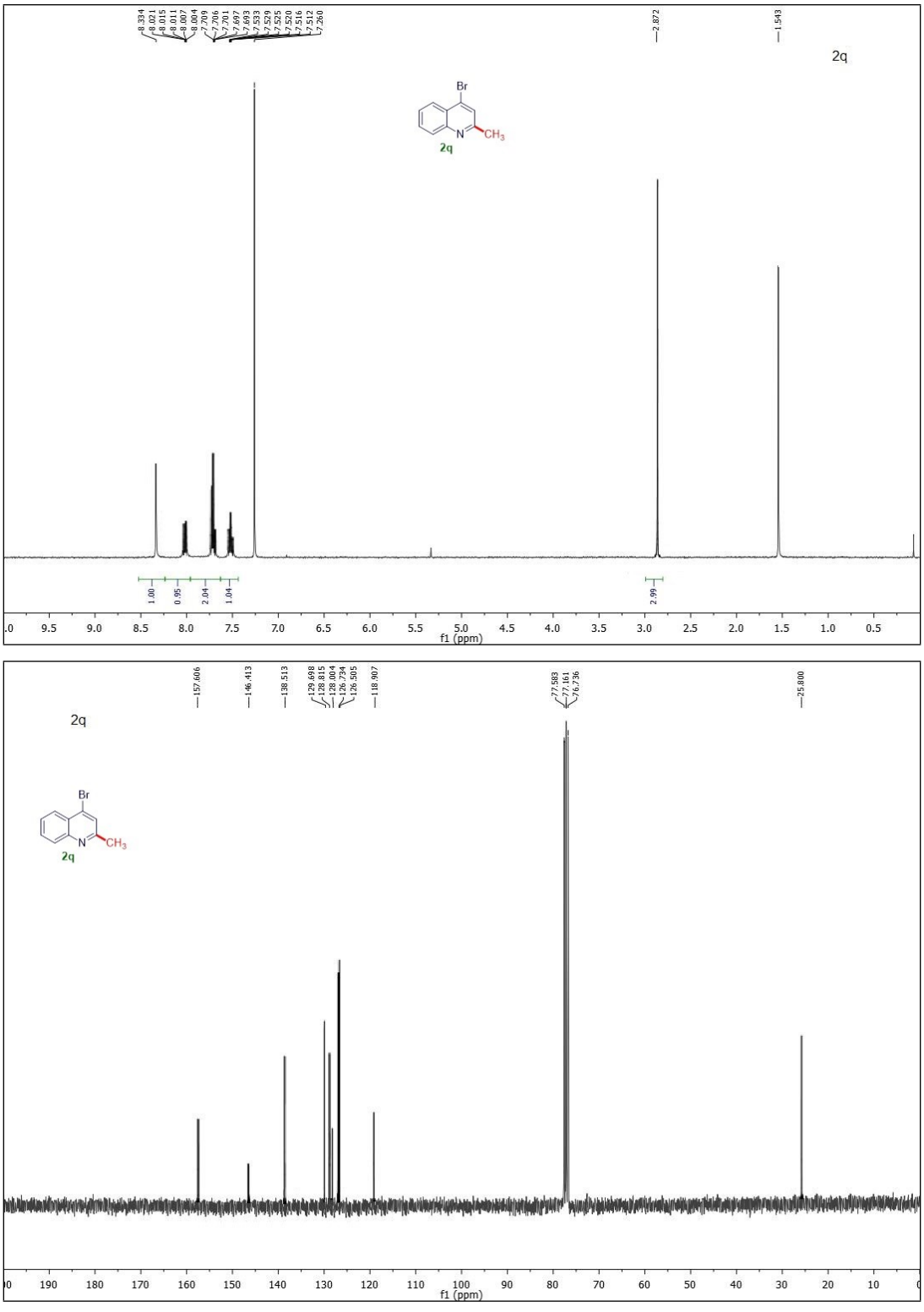


Figure S17. ^{1}H (top) and ^{13}C (bottom) spectra of **2q** in $CDCl_3$.

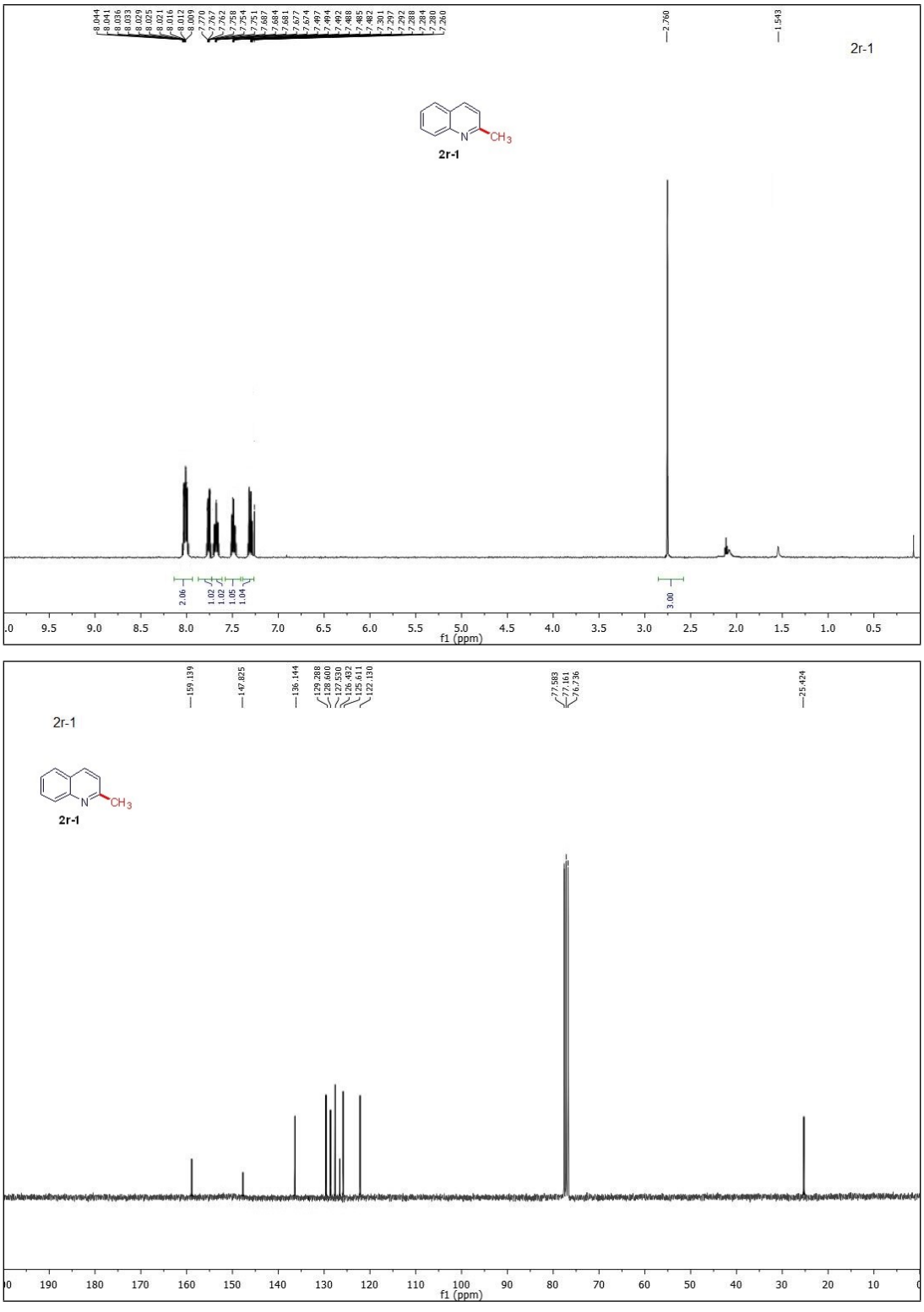


Figure S18. ^{1}H (top) and ^{13}C (bottom) spectra of **2r-1** in $CDCl_3$.

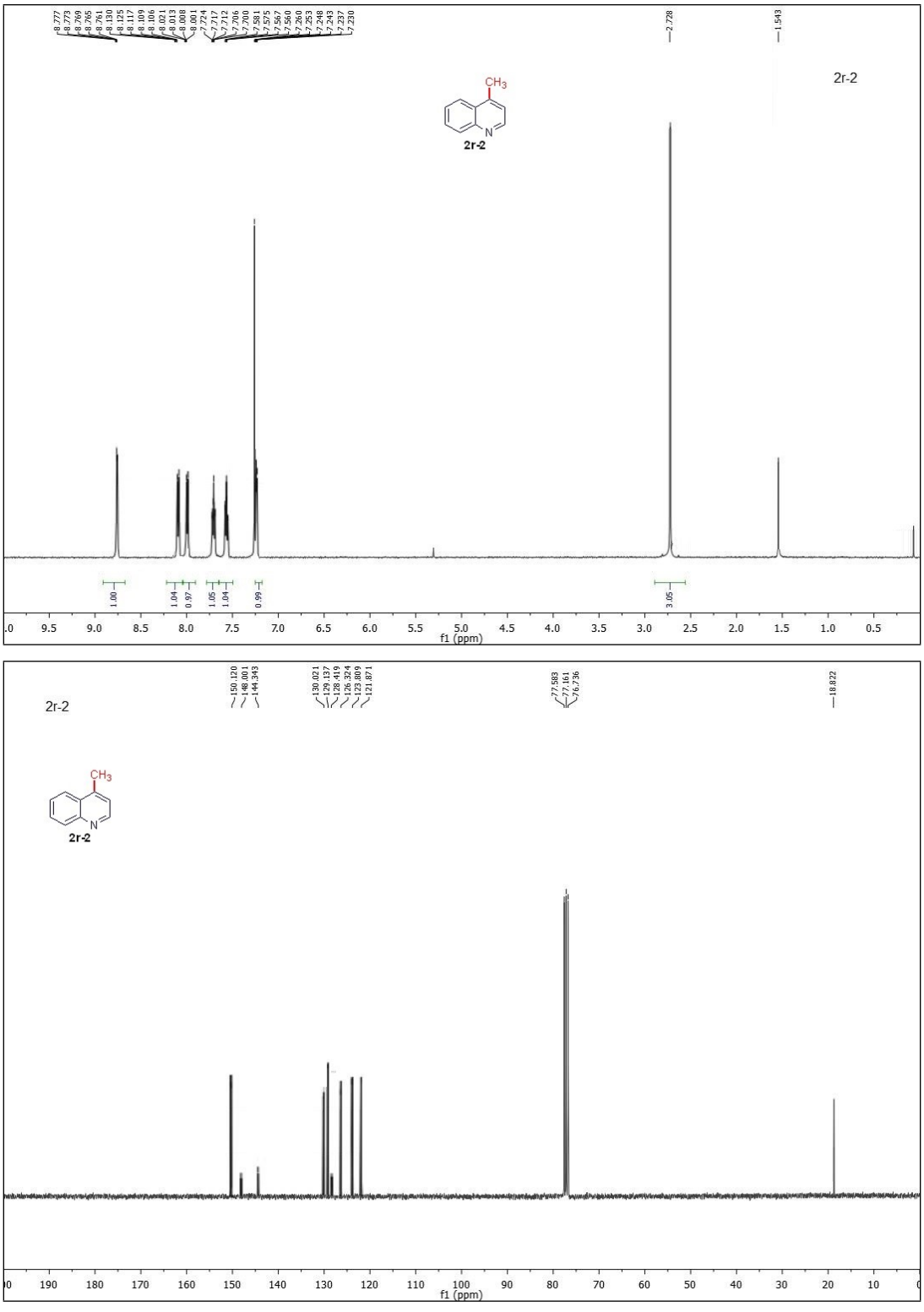


Figure S19. ^{1}H (top) and ^{13}C (bottom) spectra of **2r-2** in $CDCl_3$.

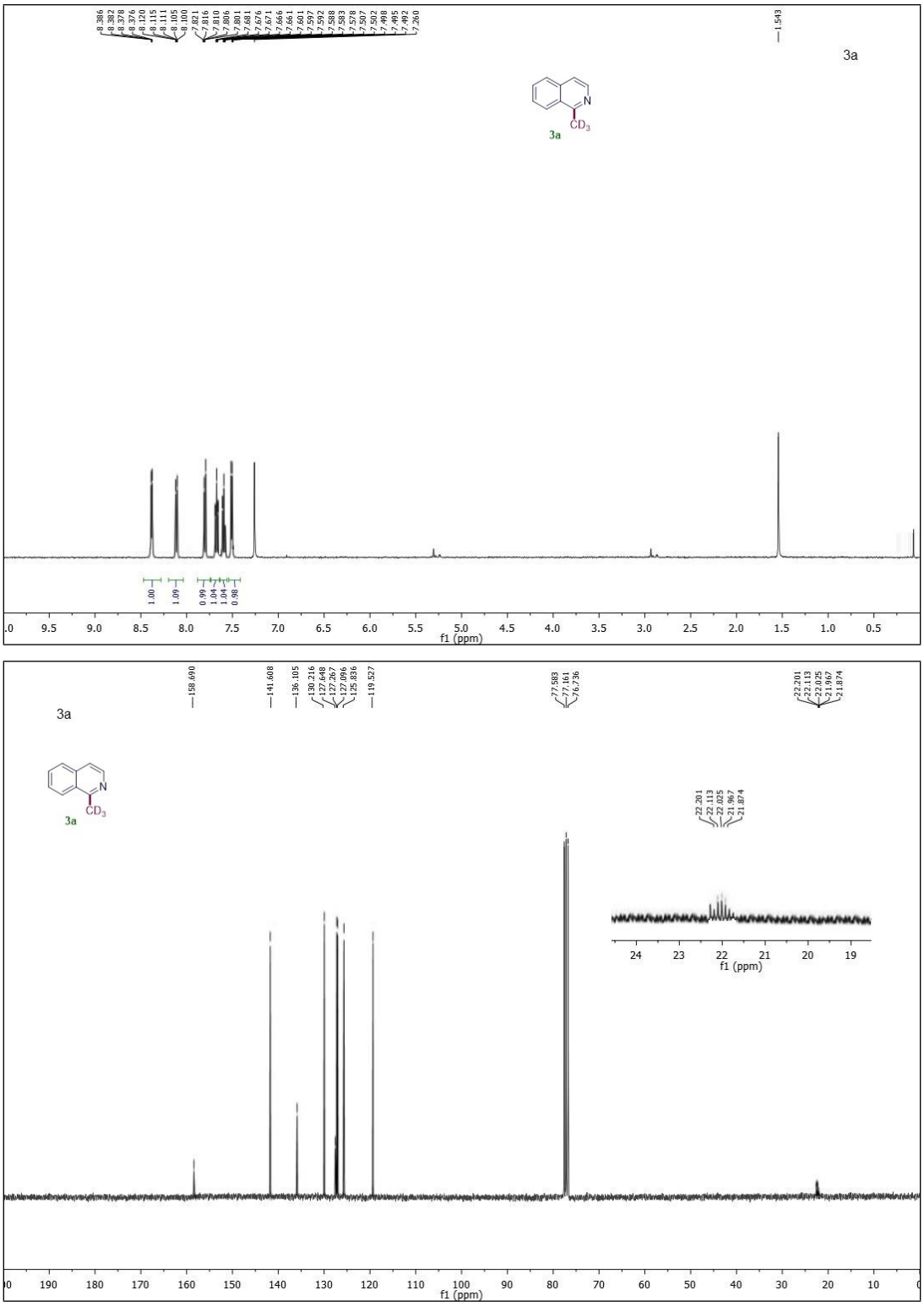


Figure S20. ^{1}H (top) and ^{13}C (bottom) spectra of **3a** in $CDCl_3$.

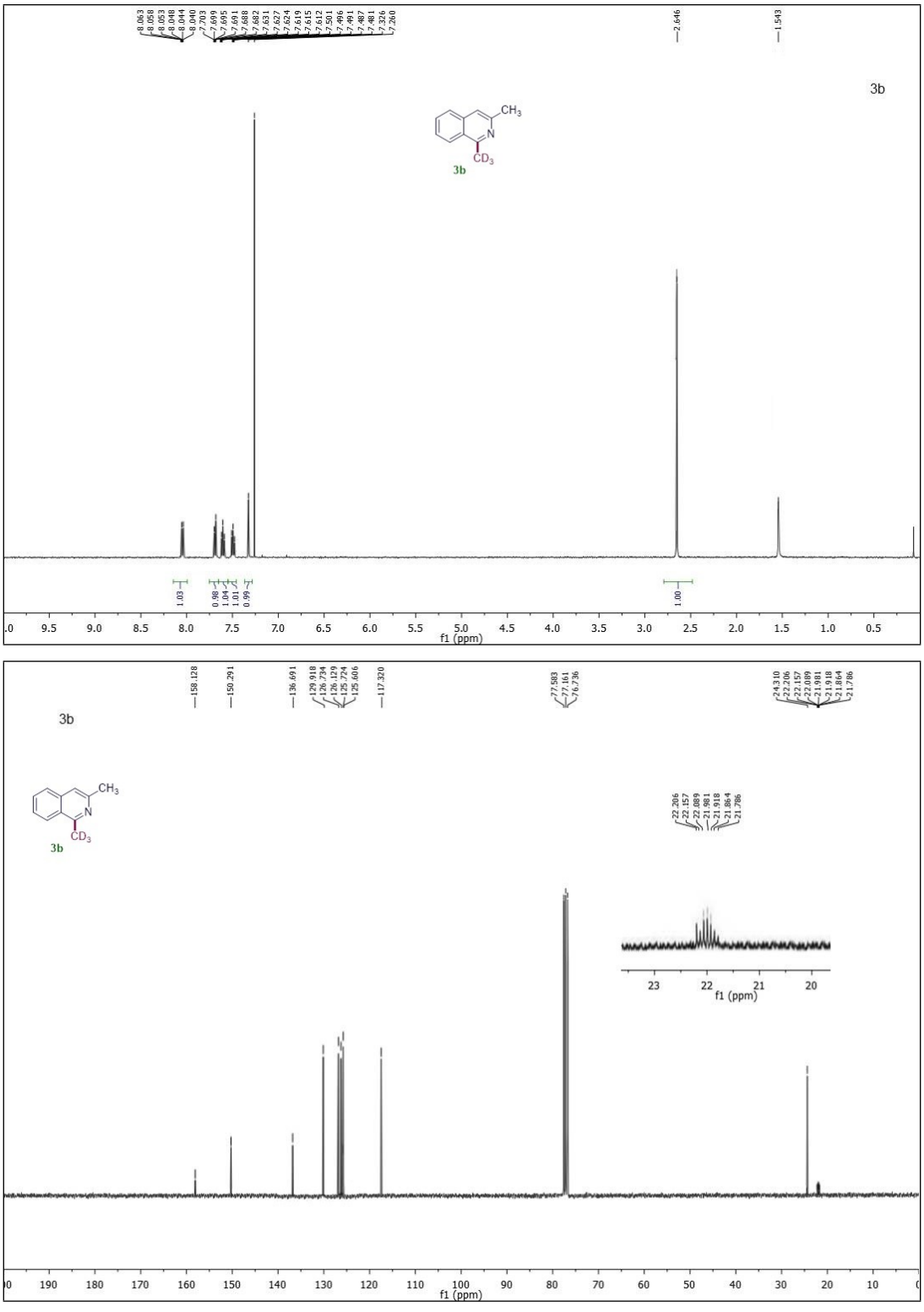


Figure S21. ^{1}H (top) and ^{13}C (bottom) spectra of **3b** in $CDCl_3$.

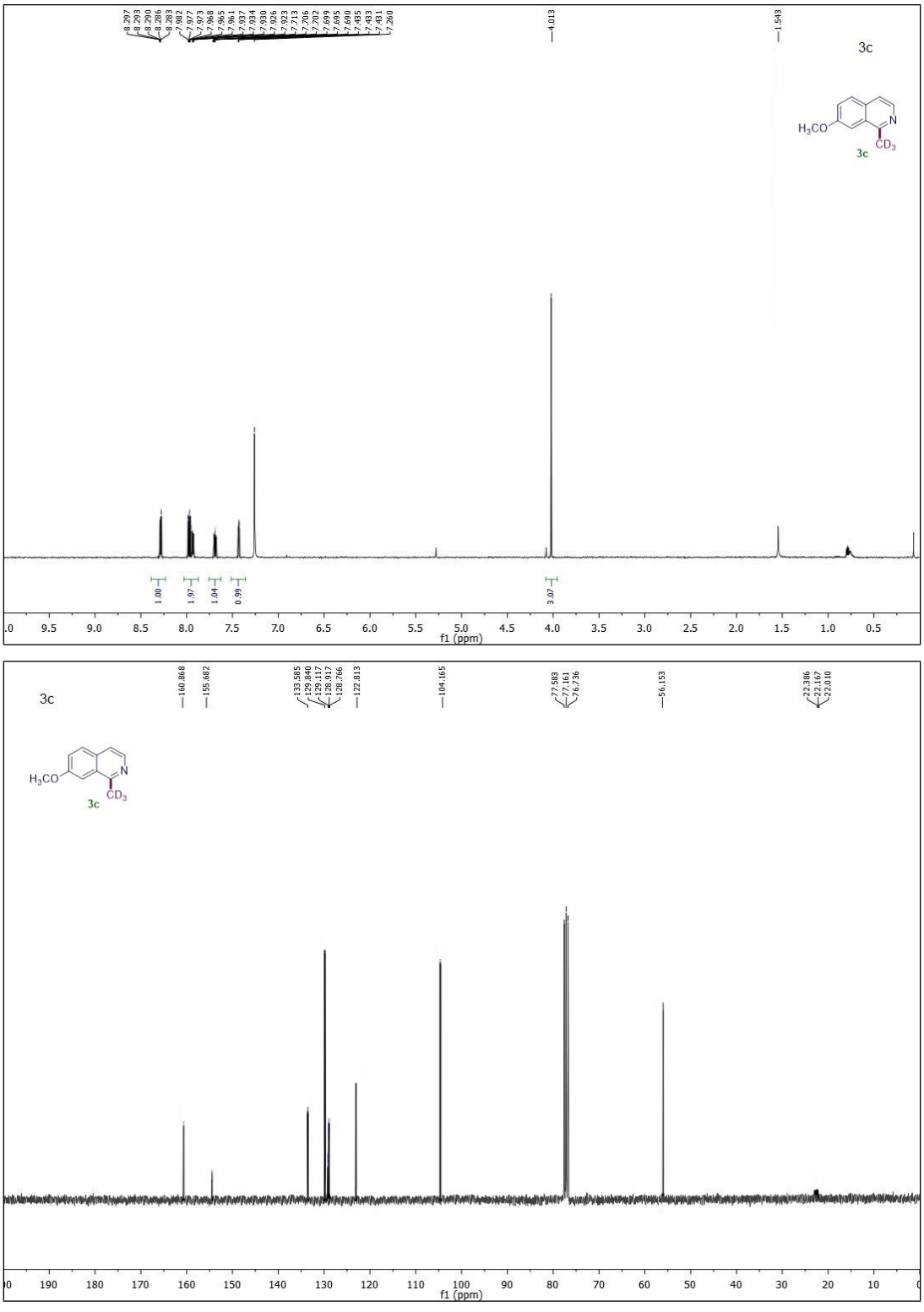


Figure S22. ^{1}H (top) and ^{13}C (bottom) spectra of **3c** in $CDCl_3$.

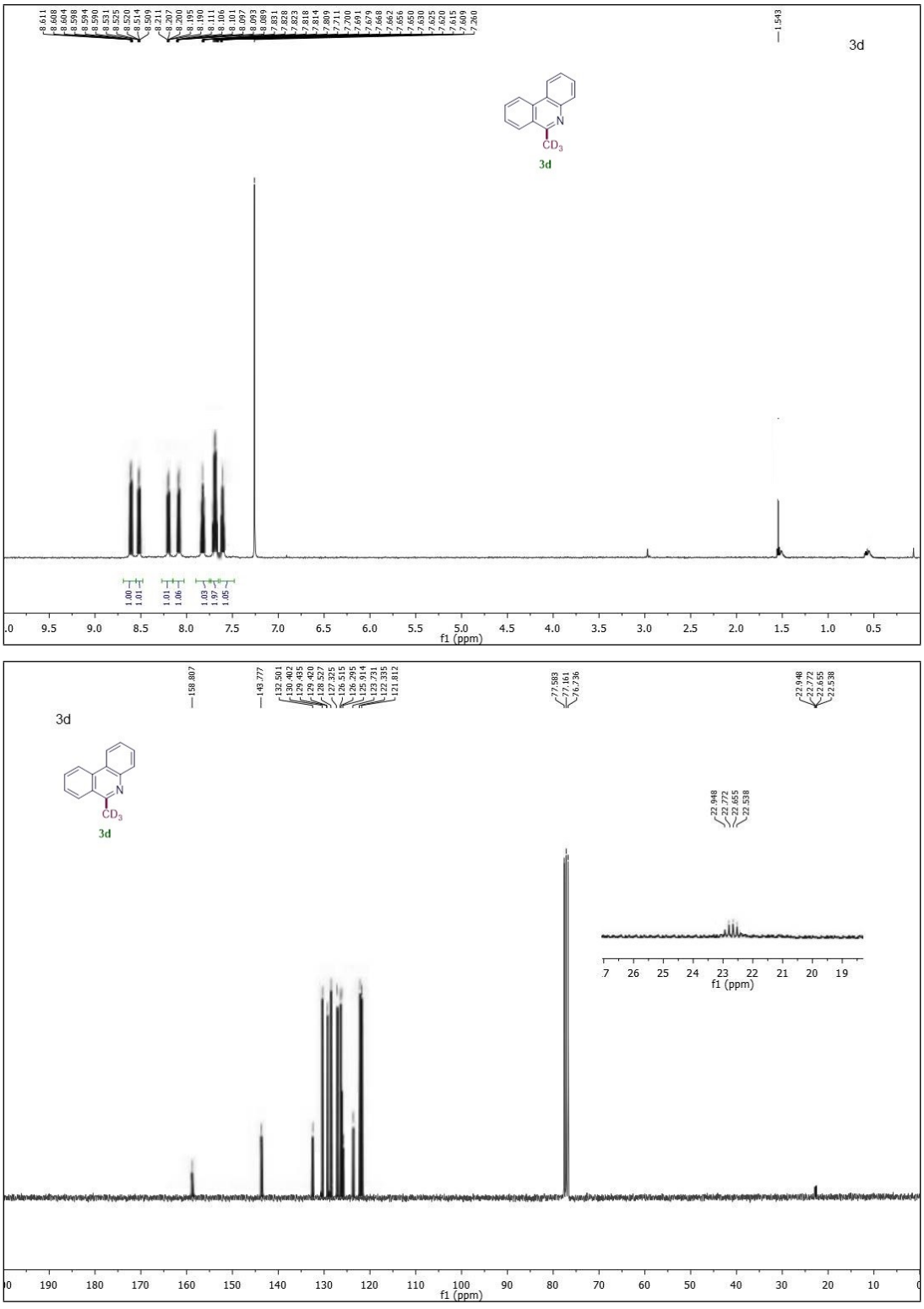


Figure S23. ^{1}H (top) and ^{13}C (bottom) spectra of **3d** in $CDCl_3$.

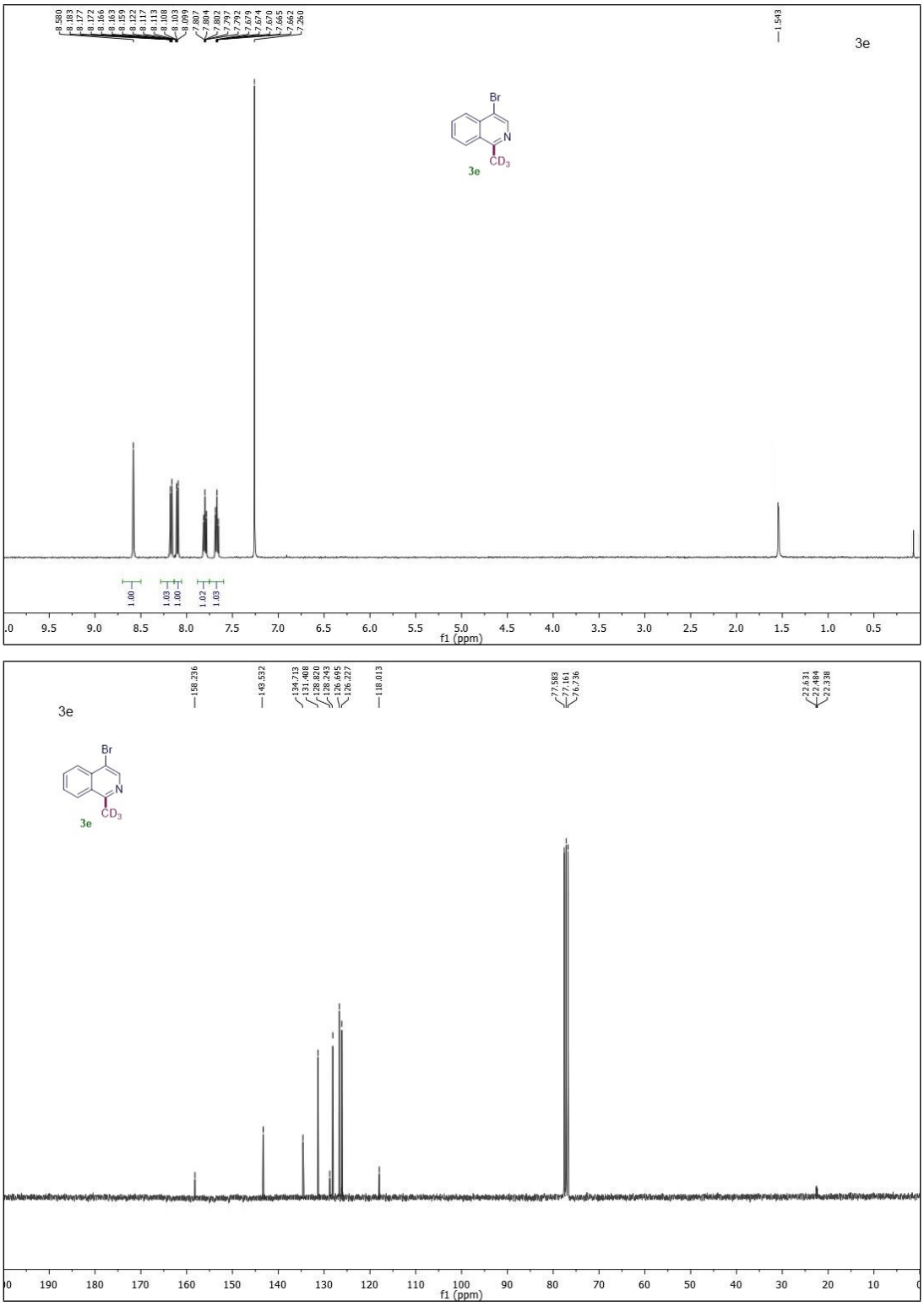


Figure S24. ^{1}H (top) and ^{13}C (bottom) spectra of **3e** in $CDCl_3$.

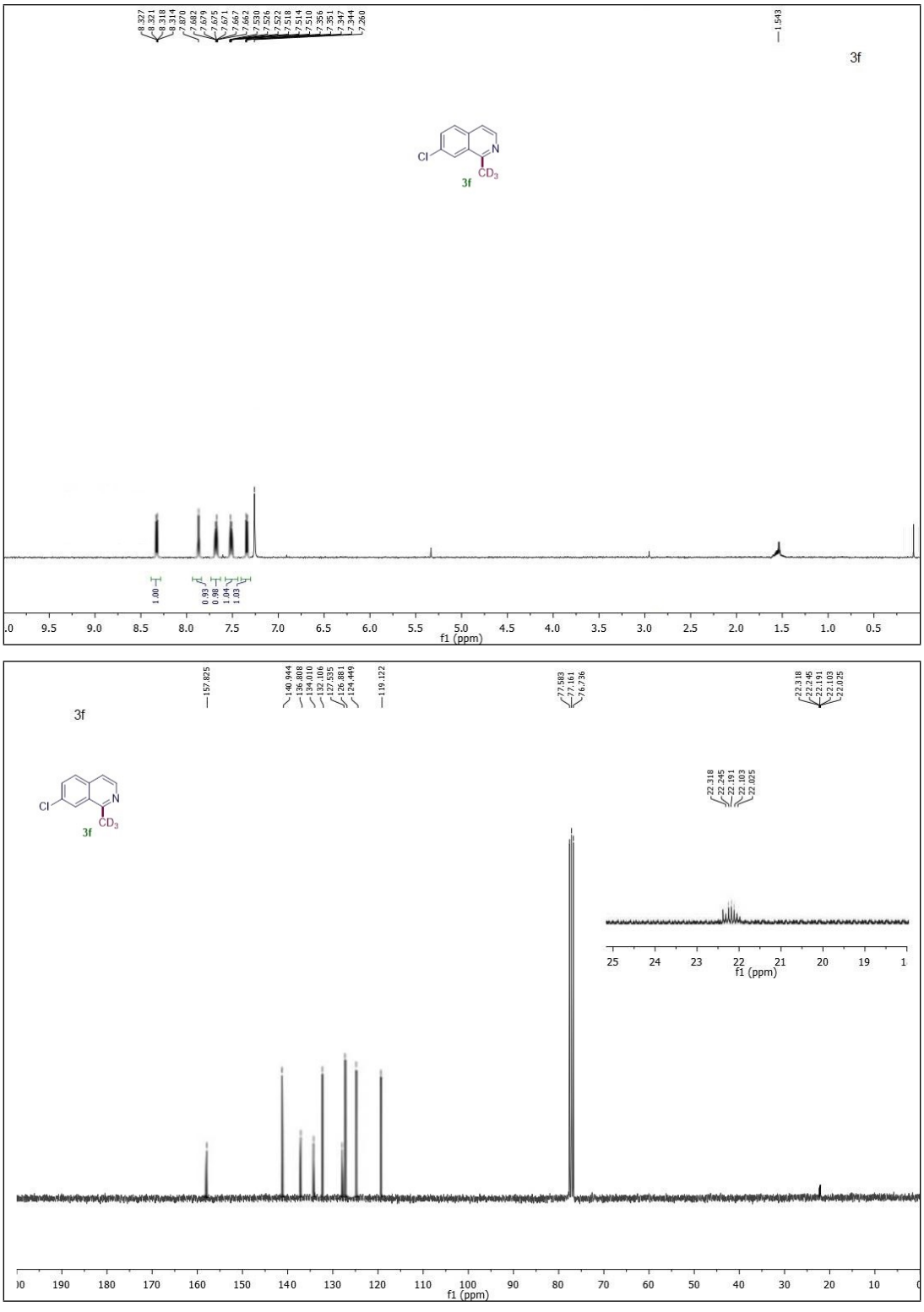


Figure S25. ^{1}H (top) and ^{13}C (bottom) spectra of **3f** in $CDCl_3$.

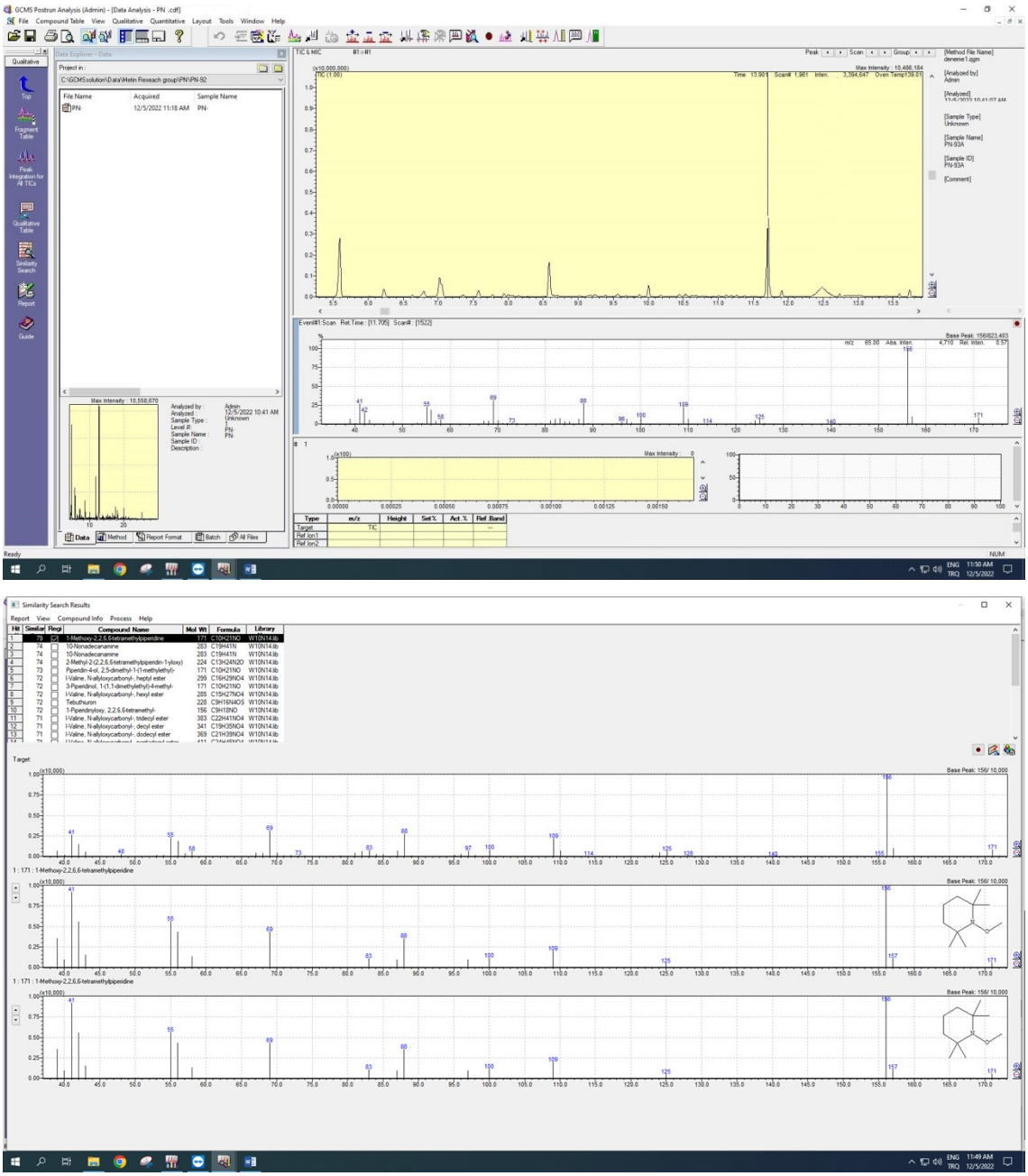


Figure S26. A typical GCMS spectra (top) and literature search result (bottom) of TEMPO-CH_3 (m/z = 171) adduct detected in the TEMPO radical trap experiment.