Supplementary Information

Carbene-Catalyzed Aerobic Oxidation of Isoquinolinium Salts: Efficient Synthesis of Isoquinolinones

Guanjie Wang,[a] Wanyao Hu,[a] Zhouli Hu,[a] Yuxia Zhang,[a] Wei Yao,[a] Lin Li,[a] Zhenqian Fu, *[,a,b] and Wei Huang*[,a,b]

[a] Key Laboratory of Flexible Electronics (KLOFE) & Institute of Advanced Materials (IAM), Jiangsu National Synergetic Innovation Center for Advanced Materials (SICAM), Nanjing Tech University (NanjingTech), 30 South Puzhu Road, Nanjing, 211816, China.

[b] Shaanxi Institute of Flexible Electronics (SIFE), Northwestern Polytechnical University (NPU), 127 West Youyi Road, Xi'an, 710072, China.

E-mail: iamwhuang@njtech.edu.cn; iamzqfu@njtech.edu.cn

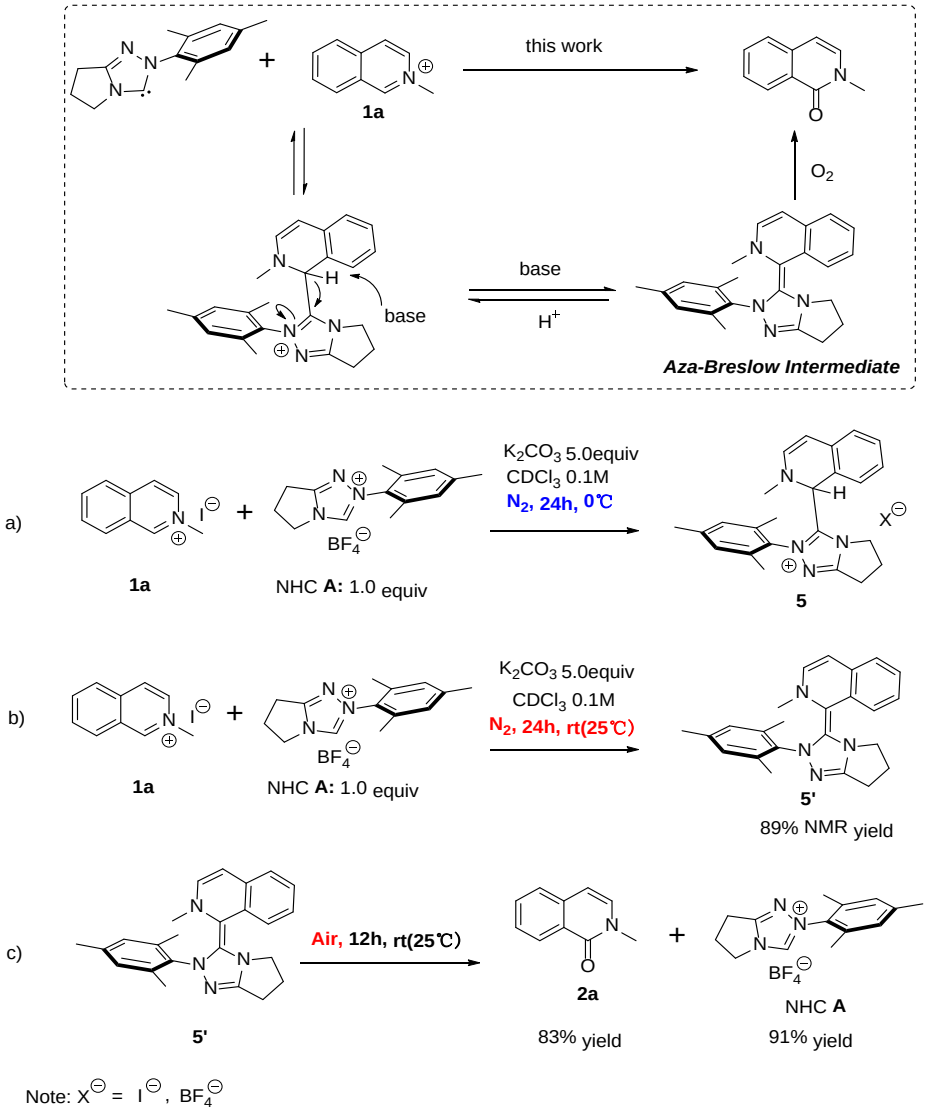
I: General Information

Commercially available materials purchased from Adamas-beta® was used as received. Toluene and DCM was dried over Pure Solv solvent purification system. THF was distilled over sodium. Other solvents were dried over 4Å molecular sieve prior use. Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded on a Bruker (400 MHz) spectrometer. Chemical shifts were recorded in parts per million (ppm, δ) relative to tetramethylsilane (δ 0.00) or chloroform (δ = 7.26, singlet). ^{1}H NMR splitting patterns are designated as singlet (s), doublet (d), triplet (t), quartet (q), dd (doublet of doublets); m (multiplets), and etc. All first-order splitting patterns were assigned on the basis of the appearance of the multiplet. Splitting patterns that could not be easily interpreted are designated as multiplet (m) or broad (br). Carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded on a Bruker (400 MHz) (100 MHz) spectrometer. High resolution mass spectral analysis (HRMS) was performed on a Waters Q–TOF Permier Spectrometer. Analytical thin-layer chromatography (TLC) was carried out on Merck 60 F254 pre-coated silica gel plate (0.2 mm thickness).

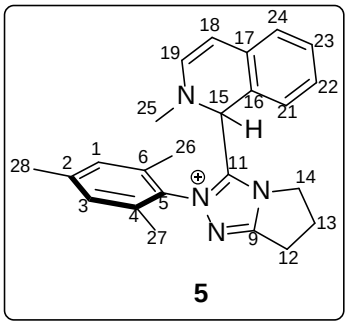
II. Experimental Procedures

a) Mechanism study

In accord with literature precedent on the oxidation of aldehydes with molecular oxygen,[1] it was our expectation that the present carbene-catalyzed aerobic oxidation of isoquinolinium salts proceeds via a aza-breslow intermediate. when the isoquinolinium salts **1a** was treated with 1 equivalent of NHC **A** in presence of K_2CO_3 in $CDCl_3$ under nitrogen atmosphere at room temperature, expected aza-Breslow intermediate **5'** was successfully captured in 89% NMR yield. And its structure was confirmed by ^1H and ^{13}C NMR. Furthermore, when we conduct this reaction at 0℃, we can detect the formation of complex **5** （confirmed by 1H, 13C, 2D NMR） which undergoes deprotonation to give the aza-Breslow intermediate **5'**. Not surprisingly, after the formation of **5'**, the reaction system was exposed to air stirring continued for 12h at room temperature, the aza-Breslow intermediate **5'** was converted to **2a** in 83% yield and regenerated NHC **A** in 91% yield. These results were in accordance with our proposed carbene-catalyzed aerobic oxidation mechanism.

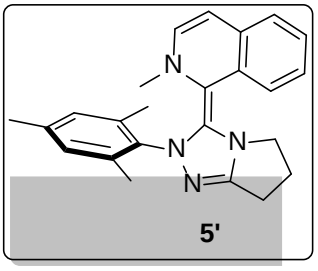


2-mesityl-3-(2-methyl-1,2-dihydroisoquinolin-1-yl)-6,7-dihydro-5H-pyrrolo[2,1-c][1,2,4]triazol-2-ium 5 (Cation is balanced by iodide and tetrafluoroborate ions in solution) We did not succeed in isolating **S13** because of its sensitivity to air and temperature. Instead, we took the reaction solution directly under nitrogen atmosphere for further Characterization. The specific experimental steps are as follows: under nitrogen atmosphere (in glove box), NHC **A** (0.2mmol, 1.0equiv), **1a** (0.2mmol, 1.0equiv) and K_2CO_3 (1.0mmol, 5.0equiv,) were added in an oven-dried Schlenk tube equipped with a magnetic stir bar. After 2 mL(0.1M) degassed $CDCl_3$ were added, the tube was closed with a septum. The reaction mixture was stirred for 24 h at 0℃. Still in a nitrogen atmosphere, the reaction mixture was filtered into a nitrogen filled NMR tube and further characterized as soon as possible. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.15 (td, J = 7.6, 0.8 Hz, 1H, H-21), 7.03 (s, 1H, H-1), 6.92-6.97 (m, 3H, H-3, H-23, H-24), 6.66 (d, J = 7.6 Hz, 1H, H-22), 6.15 (d, J = 7.2 Hz, 1H, H-19), 6.05 (s, 1H, H-15), 5.48 (d, J = 7.2 Hz, 1H, H-18), 4.62-4.69 (m, 1H, H-14a), 4.36-4.42 (m, 1H, H-14b), 3.39-3.46 (m, 1H, H-13a), 3.10-3.15 (m, 1H, H-13b), 3.03 (s, 3H, H-25), 2.97-3.00 (m, 1H, H-12a), 2.76-2.79 (m, 1H, H-12b), 2.36 (s, 3H, H-28), 2.18 (s, 3H, H-26), 1.84 (s, 3H, H-27). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 161.9(C-9), 151.9(C-11), 141.1(C-2), 135.1(C-19), 134.9(C-4), 134.5(C-6), 131.6(C-17), 130.6(C-5), 128.9(C-1, C-3), 128.8(C-21), 126.3(C-22), 125.2(C-24), 122.8(C-23), 117.1(C-16), 99.0(C-18), 57.9(C-15), 50.0(C-14), 42.0(C-25), 25.5(C-12), 21.7(C-13), 20.3(C-28), 17.9(C-26), 17.5(C-27); HRMS(ESI) calcd for $C_{24}H_{27}N_4^+$: 371.2236, Found: 371.2233.



5

(Z)-1-(2-mesityl-2,5,6,7-tetrahydro-3H-pyrrolo[2,1-c][1,2,4]triazol-3-ylidene)-2-methyl-1,2-dihydroisoquinoline 5' Aza-breslow intermediate **5'** is also extremely sensitive to air, and despite some attempts, we are still failing to separate it. However, we used the following method to detect the formation of aza-breslow intermediate **5'** and performed better characterization. Under nitrogen atmosphere (in glove box), NHC **A** (0.2mmol, 1.0equiv), **1a** (0.2mmol, 1.0equiv) and K_2CO_3 (1.0mmol, 5.0equiv,) were added in an oven-dried Schlenk tube equipped with a magnetic stir bar. After 2 mL(0.1M) degassed $CDCl_3$ were added, the tube was closed with a septum. The reaction mixture was stirred for 24 h at room temperature(25℃). Still in a nitrogen atmosphere, the reaction mixture was filtered into a nitrogen filled NMR tube and further characterized. In fact, when we add 1, 3, 5-trimethoxybenzene(0.2mmol, 1.0equiv) as an internal standard to the reaction system, we can obtain **5'** in 89% NMR yield. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.18 (t, J = 7.6 Hz, 1H), 7.02 (s, 1H), 6.92-6.97 (m, 3H), 6.64 (d, J = 7.6 Hz, 1H), 6.15 (d, J = 7.2 Hz, 1H), 5.47 (d, J = 7.2 Hz, 1H), 4.61-4.68 (m, 1H), 4.34-4.41 (m, 1H), 3.38-3.47 (m, 1H), 3.09-3.17 (m, 1H), 3.02 (s, 3H), 2.92-3.00 (m, 1H), 2.71-2.84

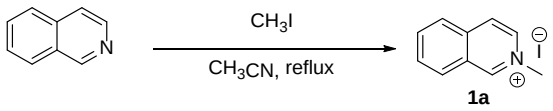


5'

(m, 1H), 2.35 (s, 3H), 2.17 (s, 3H), 1.83 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 163.0, 152.8, 142.1, 136.1, 135.9, 135.4, 132.6, 131.5, 129.9, 129.9, 129.8, 127.3, 126.2, 123.8, 118.1, 99.9, 77.4, 51.0, 43.0, 26.5, 22.7, 21.3, 18.8, 18.5; HRMS(ESI) calcd for $C_{24}H_{28}N_4(M+H)^+$: 371.2236, Found: 371.2261.

In order to further prove the reactivity of aza-breslow intermediate **5'**, after fully forming it according to the above method, we replaced the nitrogen in the reaction system with air and continued to stir for 12 hours. After that, the reaction mixture was concentrated under reduced pressure and separated by flash chromatography to afford **2a** in 83% yield and NHC **A** in 91% yield. NHC **A** were confirmed by ^{1}H NMR spectra comparison with literature data.

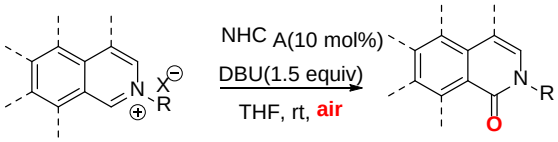
b) General procedure for the preparation of isoquinolinium salts (1a as the example)



1a

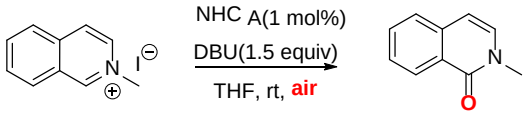
The oven-dried round-bottom flask were charged with CH_3CN (15 mL), quinoline (5mmol, 1.0equiv), CH_3I (10mm ol, 2.0 eq). The reaction mixture was refluxed for 12 hours, and then cooled to room temperature. When ethyl acetate was added to the system, the isoquinoline salt precipitated quickly as a solid, which was filtered and washed with ethyl acetate to give pure product **1a**.

c) General procedure for the catalytic reactions of isoquinolinium salts 1 to synthesize product 2



A 10 mL oven-dried screw-capped test tube with stir bar was charged with isoquinolinium salts 1 (0.20 mmol, 1.0 equiv.) and NHC **A** (6.3 mg, 10 mol%). Then newly distilled solvent THF 2mL and DBU (45μL, 1.5 equiv.) are added sequentially. The mixture was stirred at room temperature for 8-20h until the substrate was consumed completely (monitored by TLC). The mixture was concentrated under vacuum and purified by column chromatography on silica gel (petroleum ether/ethyl acetate) to afford desired product **2**, which was confirmed by ^{1}H NMR, ^{13}C NMR spectra and already reported data.

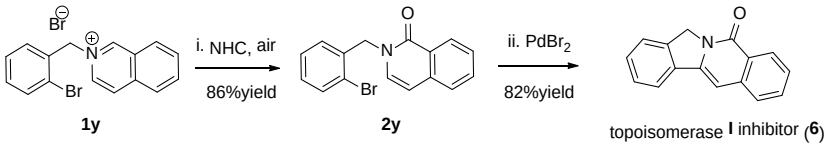
d) Procedure for the scale-up synthesis of product 2a



Isoquinolinium salts **1a** (5.42g, 20 mmol) and NHC **A** (63 mg, 1mol%) were added as a solid to a oven-dried 100mL round-bottomed flask before the fresh distilled THF 30mL was added. DBU (4.5ml, 1.5 equiv) was then slowly added to the system. The resultant reaction mixture was kept stirring at -10℃ for 15 h without sealing so that air could be better involved. Upon completion of the reaction, the mixture was concentrated under vacuum and purified by column chromatography using Petroleum ether/EtOAc (1:1) as eluent to afford the product **2a** as a yellow oil(3.16g, 99% yield).

e) Synthetic application

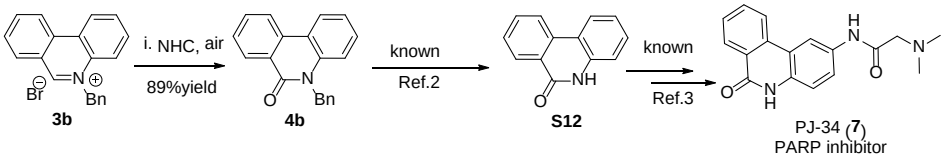
Scheme S1. Synthesis of topoisomerase I inhibitor (6)



Step1: Isoquinolinium salt **1y** (75.8mg, 0.2 mmol) and NHC **A** (12.6mg, 20 mol %) were added to an oven-dried screw-capped test tube before the fresh distilled THF 2mL was added. DBU (45μL, 1.5equiv) was then slowly added to the system. The resultant reaction mixture was kept stirring at -40℃ for 20 h. Upon completion of the reaction, the mixture was concentrated under vacuum and purified by column chromatography using Petroleum ether/EtOAc (5:1) as eluent to afford the product **2y** as a white solid (54.0mg, 86% yield).

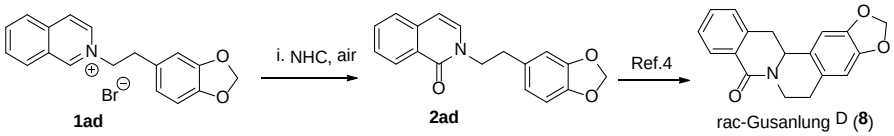
Step2: A dry 10 mL Schlenk tube with stir bar was charged with **2y** (0.20 mmol, 1.0 equiv.), $PdBr_2$ (2.7 mg, 5 mol %), KOAc (39.2 mg, 2.0 equiv). The tube was evacuated, and refilled with nitrogen. Then the mixture was dissolved with 2mL DMA. The mixture was stirred at 90 ℃ for 15 h when the substrate was consumed completely (monitored by TLC). The mixture was concentrated under vacuum and purified by column chromatography on silica gel (Ethyl acetate dichloromethane 1:1) to afford desired product **6** as a yellow solid (38.3 mg, 82% yield)

Scheme S2. Synthesis of PJ-34 (7)



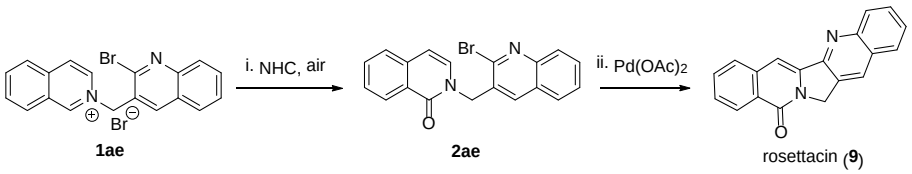
Step1: Phenanthridinium salt **3b** (70.1 mg, 0.2 mmol) and NHC **A** (6.3 mg, 10 mol %) were added to a 10 mL oven-dried screw-capped test tube with stir bar before the fresh distilled THF 2mL was added. DBU (45μL, 1.5 equiv) was then slowly added to the system. The resultant reaction mixture was kept stirring at -10℃ for 15 h. Upon completion of the reaction, the mixture was concentrated under vacuum and purified by column chromatography using Petroleum ether/EtOAc (3:1) as eluent to afford the product **4b** as a white solid (50.8 mg, 89% yield).

Scheme S3.Synthesis of rac-Gusanlung D (8)



Step1: Isoquinolinium salt **1ad** (35.8 mg, 0.1 mmol) and NHC **A** (3.2 mg, 10mol%) were added to a 10 mL oven-dried screw-capped test tube with stir bar before the CH_3CN 2mL was added. DBU (22.5 μL, 1.5 equiv) was then added to the system. The resultant reaction mixture was kept stirring at room temperature for 15 h. Upon completion of the reaction (monitored by TLC), the mixture was concentrated under vacuum and purified by column chromatography using Petroleum ether/EtOAc (3:1) as eluent to afford the product **4b** as a white solid (26.4 mg, 90% yield).

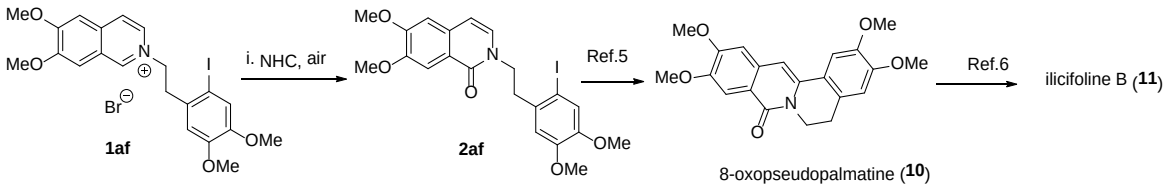
Scheme S4.Synthesis of rosettacin (9)



Step1: Isoquinolinium salt **1ae** (86.0 mg, 0.2 mmol) and NHC **A** (12.6 mg, 20 mol %) were added to an oven-dried screw-capped test tube before the fresh distilled THF 2mL was added. DBU (45 μL, 1.5 equiv) was then slowly added to the system. The resultant reaction mixture was kept stirring at -40 ℃ for 20 h. Upon completion of the reaction, the mixture was concentrated under vacuum and purified by column chromatography using Petroleum ether/EtOAc (3:1) as eluent to afford the product **2ae** as a white solid (53.2 mg, 73% yield).

Step2: A dry 10 mL Schlenk tube with stir bar was charged with **2ae** (0.15 mmol, 1.0 equiv), $Pd(OAc)_2$ (3.4 mg, 10 mol%), KOAc (29.4 mg, 2.0 equiv) and Cy_3P (8.4 mg, 20 mol %). The tube was evacuated, and refilled with nitrogen. Then the mixture was dissolved with 2mL DMF. The mixture was refluxed for 15 h when the substrate was consumed completely (monitored by TLC). The mixture was concentrated under vacuum and purified by column chromatography on silica gel (Ethyl acetate dichloromethane 1:1) to afford desired product **9** as a yellow solid (42.0 mg, 99% yield)

Scheme S5.Synthesis of 8-oxopseudopalmatine (10) and ilicifoline B (11)

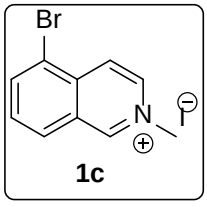


Step1: Isoquinolinium salt **1af** (56.0 mg, 0.1 mmol) and NHC **A** (6.3 mg, 20 mol %) were added to a 10 mL oven-dried screw-capped test tube with stir bar before the DMF 1mL was added. DBU (22.5 μL, 1.5 equiv) was then added to the system. The resultant reaction mixture was kept stirring at room temperature for 18 h. Upon completion of the reaction (monitored by TLC), the mixture was concentrated under vacuum and purified by column chromatography using EtOAc as eluent to afford the product **2af** as oil (37.1 mg, 75% yield).

III. Characterizations of substrates and products, reference

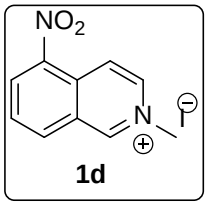
a) Characterization data of substrates

Structrure of known substrates: **1a**,[7] **1b**,[8] **1e**,[9] **1g**,[8] **1i**,[10] **1j**,[11] **1k**,[12] **1l**,[13] **1m**,[14] **1w**,[7] **1y**,[15] **1z**,[7] **1aa**,[16] **1ac**,[17] **3a**,[18] **3b**,[19] **3d**,[19] **3g**[20] were confirmed by ^{1}H NMR spectra comparison with literature data. For substrates not reported before, ^{1}H NMR, ^{13}C NMR characterization and the corresponding spectra are provided.



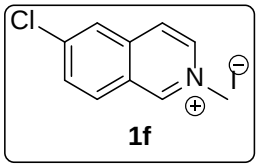
5-bromo-2-methylisoquinolin-2-ium iodide (1c): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.14 (s, 1H), 8.80 (d, J = 6.8 Hz, 1H), 8.56 (t, J = 6.8 Hz, 2H), 8.50 (d, J = 8.0 Hz, 1H), 7.96 (t, J = 8.0 Hz, 1H), 4.51 (s, 3H). ^{13}C NMR (100 MHz,

DMSO-d6) δ = 151.9, 140.6, 138.1, 135.9, 132.5, 130.9, 128.8, 124.7, 121.3, 48.5; HRMS(ESI) calcd for $C_{10}H_9BrN^+$: 221.9913, Found: 221.9911.



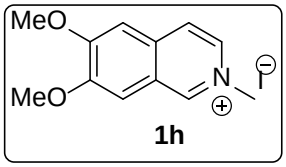
1d

2-methyl-5-nitroisoquinolin-2-ium iodide (1d): brown solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.35 (s, 1H), 9.01 (d, J = 8.0 Hz, 1H), 8.92 (s, 2H), 8.87 (d, J = 8.0 Hz, 1H), 8.24 (t, J = 8.0 Hz, 1H), 4.54 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 152.2, 144.5, 139.1, 137.8, 134.6, 131.1, 129.4, 128.4, 121.7, 48.8; HRMS(ESI) calcd for $C_{10}H_9N_2O_2^+$: 189.0659, Found: 189.0655.



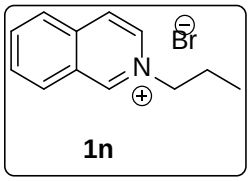
1f

6-chloro-2-methylisoquinolin-2-ium iodide (1f): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.09 (s, 1H), 8.75 (d, J = 6.8 Hz, 1H), 8.46-8.51 (m, 3H), 8.04 (d, J = 8.8 Hz, 1H), 4.47 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 151.1, 142.0, 137.9, 137.5, 132,7, 132.3, 126.6, 126.0, 124.9, 48.6; HRMS(ESI) calcd for $C_{10}H_9ClN^+$: 178.0418, Found: 178.0416.



1h

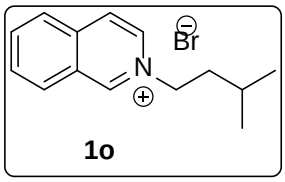
6,7-dimethoxy-2-methylisoquinolin-2-ium iodide (1h): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 9.52 (s, 1H), 8.48 (d, J = 6.4 Hz, 1H), 8.25 (d, J = 6.8 Hz, 1H), 7.73 (s, 2H), 4.37 (s, 3H), 4.03 (s, 3H), 3.97 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 157.7, 152.8, 146.2, 135.3, 134.9, 124.1, 123.5, 107.3, 106.2, 57.4, 56.9, 47.9; HRMS(ESI) calcd for $C_{12}H_{14}NO_2^+$: 204.1019, Found: 204.1017.



1n

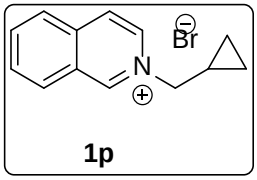
2-propylisoquinolin-2-ium bromide (1n): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.35 (s, 1H), 8.88-8.92 (m, 1H), 8.64 (d, J = 6.8 Hz, 1H), 8.49 (d, J = 8.4 Hz, 1H), 8.36 (d, J = 8.4 Hz, 1H), 8.20-8.25 (m, 1H), 8.02-8.07 (m, 1H), 4.71-4.76 (m, 2H), 1.99-2.08 (m, 2H), 0.87-0.91 (m, 3H); ^{13}C NMR (100 MHz, DMSO-d6) δ =

150.4, 137.4, 137.2, 135.4, 131.6, 130.8, 127.7, 127.6, 126.3, 62.3, 24.5, 10.8; HRMS(ESI) calcd for $C_{12}H_{14}N^+$: 172.1121, Found: 172.1117;



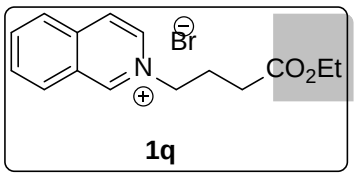
1o

2-isopentylisoquinolin-2-ium bromide (1o): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.37 (s, 1H), 8.93 (d, *J* = 6.8 Hz, 1H), 8.63 (d, *J* = 6.4 Hz, 1H), 8.49 (d, *J* = 8.0 Hz, 1H), 8.35 (d, *J* = 8.4 Hz, 1H), 8.22 (t, *J* = 7.2 Hz, 1H), 8.04 (t, *J* = 8.0 Hz, 1H), 4.79 (t, *J* = 7.6 Hz, 2H), 1.89-1.95 (m, 2H), 1.56-1.66 (m, 1H), 0.93 (s, 3H), 0.92 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.5, 137.4, 137.2, 135.5, 131.6, 130.8, 127.7, 127.7, 126.3, 59.6, 25.7, 22.7; HRMS(ESI) calcd for $C_{14}H_{18}N^+$: 200.1434, Found: 200.1431;



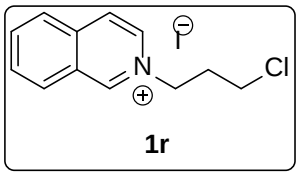
1p

2-(cyclopropylmethyl)isoquinolin-2-ium bromide (1p): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.25 (s, 1H), 8.89 (d, *J* = 6.8 Hz, 1H), 8.63 (d, *J* = 6.8 Hz, 1H), 8.52 (d, *J* = 8.4 Hz, 1H), 8.36 (d, *J* = 8.0 Hz, 1H), 8.25 (t, *J* = 7.2 Hz, 1H), 8.07 (t, *J* = 7.2 Hz, 1H), 4.64 (t, *J* = 7.6 Hz, 2H), 1.50-1.58 (m, 1H), 0.64-0.67 (m, 4H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.0, 137.5, 137.3, 135.3, 131.6, 130.9, 127.8, 127.7, 126.3, 65.0, 12.5, 4.6; HRMS(ESI) calcd for $C_{13}H_{14}N^+$: 184.1121, Found: 184.1117.



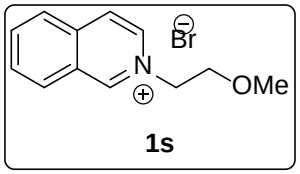
1q

2-(4-ethoxy-4-oxobutyl)isoquinolin-2-ium bromide (1q): yellow oil; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.25 (s, 1H), 8.87 (d, *J* = 6.8 Hz, 1H), 8.62 (d, *J* = 6.8 Hz, 1H), 8.49 (d, *J* = 8.4 Hz, 1H), 8.36 (d, *J* = 8.0 Hz, 1H), 8.24 (t, *J* = 7.2 Hz, 1H), 8.05 (t, *J* = 7.2 Hz, 1H), 4.80 (t, *J* = 7.2 Hz, 2H), 3.93 (q, *J* = 7.2 Hz, 2H), 2.45-2.49 (m, 3H), 2.24-2.32 (m, 2H), 1.08 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 172.4, 150.7, 137.5, 137.3, 135.5, 131.6, 130.9, 127.7, 126.3, 60.6, 60.4, 30.6, 26.3, 14.5; HRMS(ESI) calcd for $C_{15}H_{18}NO_2^+$: 244.1332, Found: 244.1331.



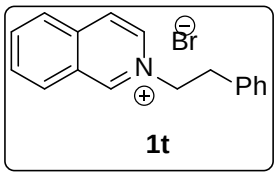
1r

2-(3-chloropropyl)isoquinolin-2-ium iodide (1r): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.18 (s, 1H), 8.83 (d, *J* = 6.8 Hz, 1H), 8.62 (d, *J* = 6.8 Hz, 1H), 8.49 (d, *J* = 8.4 Hz, 1H), 8.35 (d, *J* = 8.0 Hz, 1H), 8.25 (t, *J* = 7.2 Hz, 1H), 8.06 (t, *J* = 7.2 Hz, 1H), 4.87 (t, *J* = 7.2 Hz, 2H), 3.77 (t, *J* = 6.4 Hz, 2H), 2.52-2.57 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.9, 137.5, 137.4, 135.4, 131.7, 130.9, 127.7, 127.7, 126.4, 58.9, 33.3; HRMS(ESI) calcd for $C_{12}H_{13}ClN^{+}$: 206.0731, Found: 206.0727.



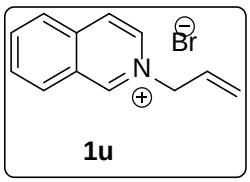
1s

2-(2-methoxyethyl)isoquinolin-2-ium bromide (1s): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.20 (s, 1H), 8.83 (d, *J* = 6.8 Hz, 1H), 8.63 (d, *J* = 6.8 Hz, 1H), 8.52 (d, *J* = 8.0 Hz, 1H), 8.35 (d, *J* = 8.4 Hz, 1H), 8.23 (t, *J* = 7.2 Hz, 1H), 8.04 (t, *J* = 7.6 Hz, 1H), 4.96 (t, *J* = 4.4 Hz, 2H), 3.92 (t, *J* = 4.4 Hz, 2H), 3.24 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.9, 137.5, 137.4, 135.7, 131.7, 130.9, 127.7, 127.4, 126.1, 70.5, 60.6, 58.7; HRMS(ESI) calcd for $C_{12}H_{14}NO^{+}$: 188.1070, Found: 188.1067.



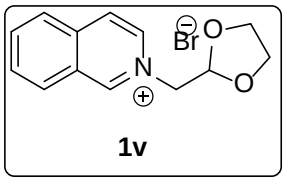
1t

2-phenethylisoquinolin-2-ium bromide (1t): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.13 (s, 1H), 8.84 (d, J = 6.8 Hz, 1H), 8.60 (d, J = 6.8 Hz, 1H), 8.42 (d, J = 8.4 Hz, 1H), 8.33 (d, J = 8.4 Hz, 1H), 8.23 (t, J = 7.2 Hz, 1H), 8.04 (t, J = 7.2 Hz, 1H), 7.19-7.29 (m, 5H), 4.98-5.06 (m, 2H), 3.36-3.39 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.5, 137.4, 137.4, 136.8, 135.4, 131.7, 130.7, 129.4, 129.1, 127.8, 127.5, 127.5, 126.1, 61.8, 36.8; HRMS(ESI) calcd for $C_{17}H_{16}N^{+}$: 234.1277, Found: 234.1275.



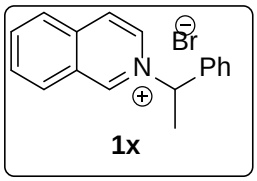
1u

2-allylisoquinolin-2-ium bromide (1u): gray solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.28 (s, 1H), 8.80 (d, *J* = 6.8 Hz, 1H), 8.63 (d, *J* = 6.8 Hz, 1H), 8.52 (d, *J* = 7.6 Hz, 1H), 8.36 (d, *J* = 8.4 Hz, 1H), 8.24 (t, *J* = 7.2 Hz, 1H), 8.05 (t, *J* = 7.2 Hz, 1H), 6.20-6.30 (m, 1H), 5.45-5.53 (m, 4H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.6, 137.5, 137.4, 135.3, 132.1, 131.7, 130.9, 127.8, 127.6, 126.4, 122.7, 62.7; HRMS(ESI) calcd for $C_{12}H_{12}N^{+}$: 170.0964, Found: 170.0961.



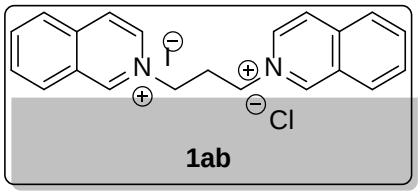
1v

2-((1,3-dioxolan-2-yl)methyl)isoquinolin-2-ium bromide (1v): red solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.09 (s, 1H), 8.72 (d, *J* = 6.8 Hz, 1H), 8.62 (d, *J* = 6.8 Hz, 1H), 8.56 (d, *J* = 8.0 Hz, 1H), 8.37 (d, *J* = 8.0 Hz, 1H), 8.27 (t, *J* = 7.6 Hz, 1H), 8.07 (t, *J* = 7.6 Hz, 1H), 5.47 (t, *J* = 3.2 Hz, 1H), 5.03 (d, *J* = 2.8 Hz, 2H), 3.79-3.83 (m, 2H), 3.64-3.68 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 151.8, 137.7, 137.6, 136.8, 131.7, 131.0, 127.8, 127.2, 125.5, 100.2, 65.4, 61.2; HRMS(ESI) calcd for $C_{13}H_{14}NO_2^+$: 216.1019, Found: 216.1017.



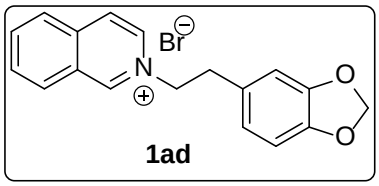
1x

2-(1-phenylethyl)isoquinolin-2-ium bromide (1x): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.60 (s, 1H), 8.92 (d, *J* = 6.8 Hz, 1H), 8.59-8.62 (m, 2H), 8.34 (d, *J* = 8.0 Hz, 1H), 8.23 (t, *J* = 7.2 Hz, 1H), 8.06 (t, *J* = 7.6 Hz, 1H), 7.64 (d, *J* = 6.8 Hz, 2H), 7.35-7.44 (m, 3H), 6.43 (q, *J* = 7.2 Hz, 1H), 2.15 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 149.3, 138.8, 137,7, 137.6, 134.0, 131.7, 131.3, 129.7, 129.6, 127.9, 127.9, 127.7, 126.8, 69.7, 20.3; HRMS(ESI) calcd for $C_{17}H_{16}N^+$: 234.1277, Found: 234.1274.



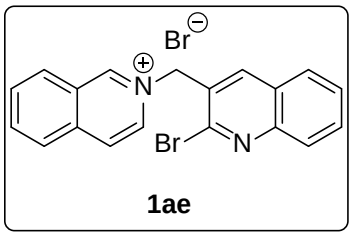
1ab

2,2'-(propane-1,3-diyl)bis(isoquinolin-2-ium) chloride iodide (1ab): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.20 (s, 2H), 8.86 (d, *J* = 7.2 Hz, 2H), 8.65 (d, *J* = 6.8 Hz, 2H), 8.48 (d, *J* = 8.0 Hz, 2H), 8.36 (d, *J* = 8.0 Hz, 2H), 8.26 (t, *J* = 7.6 Hz, 2H), 8.07 (t, *J* = 7.6 Hz, 2H), 4.94 (t, *J* = 7.2 Hz, 4H), 2.88-2.95 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.8, 137.6, 137.5, 135.4, 131.7, 130.9, 127.7, 127.7, 126.4, 58.0, 31.7; HRMS(ESI) calcd for $C_{21}H_{20}N_2^{2+}$: 300.1616, Found: 300.1611.



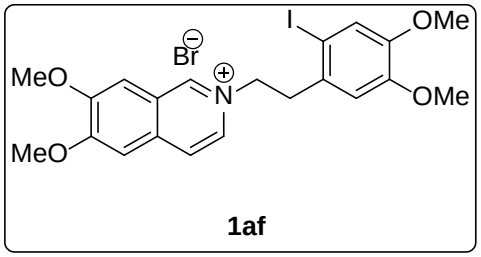
1ad

2-(2-(benzo[d][1,3]dioxol-5-yl)ethyl)isoquinolin-2-ium bromide (1ad): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.07 (s, 1H), 8.79 (d, *J* = 6.8 Hz, 1H), 8.58 (d, *J* = 6.8 Hz, 1H), 8.43 (d, *J* = 8.0 Hz, 1H), 8.33 (d, *J* = 8.4 Hz, 1H), 8.24 (t, *J* = 7.6 Hz, 1H), 8.05 (t, *J* = 8.0 Hz, 1H), 6.94 (s, 1H), 6.75 (d, *J* = 8.0 Hz, 1H), 6.60 (d, *J* = 8.0 Hz, 1H), 5.95 (s, 2H), 4.93 (t, *J* = 7.2 Hz, 2H), 3.28 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 150.4, 147.9, 146.7, 137.4, 137.4, 135.4, 131.7，130.8, 130.4, 127.8, 127.5, 126.1, 122.5, 109.7, 108.7, 101.4, 62.1, 36.5; HRMS(ESI) calcd for $C_{18}H_{16}NO_2^+$: 278.1176, Found: 278.1173.



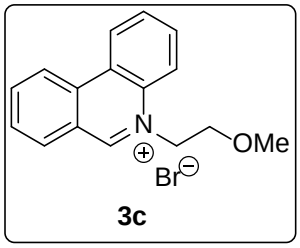
1ae

2-((2-bromoquinolin-3-yl)methyl)isoquinolin-2-ium bromide (1ae): gray solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.33 (s, 1H), 8.96 (d, *J* = 6.8 Hz, 1H), 8.72 (d, *J* = 6.8 Hz, 1H), 8.59 (d, *J* = 8.4 Hz, 1H), 8.50 (s, 1H), 8.45 (t, *J* = 8.0 Hz, 1H), 8.32 (t, *J* = 7.2 Hz, 1H), 8.11 (t, *J* = 7.2 Hz, 1H), 8.04 (t, *J* = 8.4 Hz, 2H), 7.90 (t, *J* = 7.2 Hz, 1H), 7.74 (t, *J* = 6.8 Hz, 1H), 6.31 (s, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 151.5, 147.9, 142.4, 140.6, 137.9, 135.9, 132.3, 131.8, 131.3, 129.0, 128.6, 128.3, 128.2, 127.9, 127.8, 127.2, 126.7, 62.8; HRMS(ESI) calcd for $C_{19}H_{14}BrN_2^+$: 349.0335, Found: 349.0331.



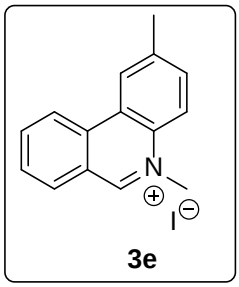
1af

2-(2-iodo-4,5-dimethoxyphenethyl)-6,7-dimethoxyisoquinolin-2-ium bromide (1af): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 9.48 (s, 1H), 8.41 (d, *J* = 6.8 Hz, 1H), 8.25 (d, *J* = 6.8 Hz, 1H), 7.75 (s, 2H), 7.18 (s, 1H), 6.95 (s, 1H), 4.85 (t, *J* = 6.8 Hz, 2H), 4.04 (s, 3H), 3.97 (s, 3H), 3.70 (s, 3H), 3.60 (s, 3H), 3.33 (t, *J* = 6.8 Hz, 2H).^{13}C NMR (100 MHz, DMSO-d6) δ = 158.0, 152.9, 149.6, 148.9, 145.6, 135.8, 134.3, 131.6, 124.3, 123.6, 121.8, 113.9, 107.6, 106.2, 89.4, 60.9, 57.4, 56.9, 56.3, 56.0, 40.8; HRMS(ESI) calcd for $C_{21}H_{23}INO_4^+$: 400.0666, Found: 400.0659.



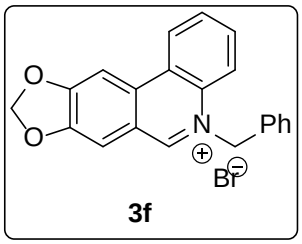
3c

5-(2-methoxyethyl)phenanthridin-5-ium bromide (3c): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.41 (s, 1H), 9.16 (d, *J* = 8.0 Hz, 1H), 9.11 (d, *J* = 8.4 Hz, 1H), 8.71 (d, *J* = 8.4 Hz, 1H), 8.65 (d, *J* = 7.2 Hz, 1H), 8.37 (t, *J* = 8.4 Hz, 1H), 8.06-8.14 (m, 3H), 5.36 (t, *J* = 4.8 Hz, 2H), 3.96 (t, *J* = 4.8 Hz, 2H), 3.23 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 156.4, 138.7, 134.9, 133.6, 133.4, 132.5, 130.9, 130.8, 126.2, 125.5, 123.7, 123.7, 120.7, 69.3, 58.9, 57.7; HRMS(ESI) calcd for $C_{16}H_{16}NO^{+}$: 238.1226, Found: 238.1219.



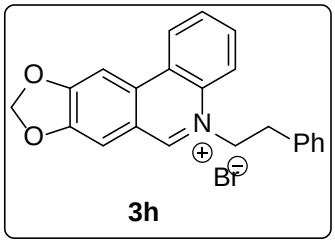
3e

2,5-dimethylphenanthridin-5-ium iodide (3e): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.24 (s, 1H), 9.08 (d, *J* = 8.4 Hz, 1H), 8.96 (s, 1H), 8.53 (d, *J* = 8.0 Hz, 1H), 8.43 (d, *J* = 8.8 Hz, 1H), 8.36 (t, *J* = 7.2 Hz, 1H), 8.09 (t, *J* = 7.2 Hz, 1H), 7.99 (t, *J* = 8.8 Hz, 1H), 4.65 (s, 3H), 2.69 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 155.1, 141.4, 138.0, 134.4, 133.8, 132.9, 132.8, 130.7, 125.8, 124.5, 124.1, 123.6, 120.1, 46.3, 21.6; HRMS(ESI) calcd for $C_{14}H_{12}N^{+}$: 194.0964, Found: 194.0961.



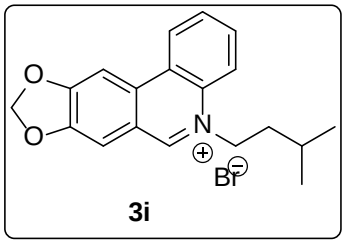
3f

5-benzyl-[1,3]dioxolo[4,5-j]phenanthridin-5-ium bromide (3f): gray solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.24 (s, 1H), 9.04 (d, *J* = 7.6 Hz, 1H), 8.67 (s, 1H), 8.39 (d, *J* = 9.6 Hz, 1H), 7.92-7.99 (m, 3H), 7.31-7.43 (m, 5H), 6.51 (s, 2H), 6.32 (s, 2H). ^{13}C NMR (100 MHz, DMSO-d6) δ = 158.3, 152.7, 150.7, 135.7, 134.5, 133.2, 132.1, 130.0, 129.6, 129.2, 127.6, 126.1, 125.7, 121.1, 120.4, 108.1, 104.9, 101.9, 60.3; HRMS(ESI) calcd for $C_{21}H_{16}NO_2^{+}$: 314.1176, Found: 314.1173.



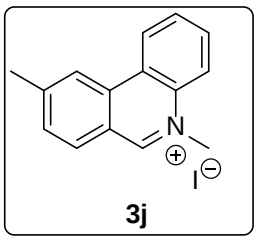
3h

5-phenethyl-[1,3]dioxolo[4,5-j]phenanthridin-5-ium bromide (3h): brown solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 9.83 (s, 1H), 9.00 (d, *J* = 7.6 Hz, 1H), 8.61 (d, *J* = 8.4 Hz, 1H), 8.58 (s, 1H), 8.07 (t, *J* = 7.2 Hz, 1H), 7.98 (t, *J* = 7.6 Hz, 1H), 7.74 (s, 1H), 7.17-7.26 (m, 5H), 6.46 (s, 2H), 5.25 (t, *J* = 7.6 Hz, 2H), 3.34 (t, *J* = 7.6 Hz, 2H).^{13}C NMR (100 MHz, DMSO-d6) δ = 158.0, 151.7, 150.5, 136.9, 135.1, 132.9, 132.3, 130.0, 129.5, 129.1, 127.5, 125.7, 125.7, 120.7, 120.1, 107.5, 104.8, 101.8, 58.3, 35.3; HRMS(ESI) calcd for $C_{22}H_{18}NO_2^+$: 328.1332, Found: 328.1327.



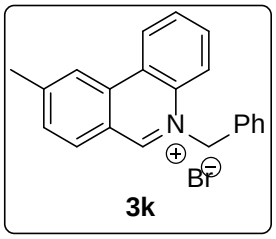
3i

5-isopentyl-[1,3]dioxolo[4,5-j]phenanthridin-5-ium bromide (3j): brown solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.10 (s, 1H), 9.02 (d, *J* = 8.0 Hz, 1H), 8.60 (s, 1H), 8.48 (d, *J* = 8.8 Hz, 1H), 8.09 (t, *J* = 7.6 Hz, 1H), 8.00 (t, *J* = 8.0 Hz, 1H), 7.90 (s, 1H), 6.49 (s, 2H), 5.02 (t, *J* = 7.2 Hz, 2H), 1.81-1.95 (m, 3H), 1.03 (s, 3H), 1.02 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 157.8, 151.6, 150.4, 135.0, 133.0, 132.2, 129.9, 125.9, 125.7, 121.1, 119.9, 107.7, 104.7, 101.7, 56.2, 38.3, 26.1, 22.7. HRMS(ESI) calcd for $C_{19}H_{20}NO_2^+$: 294.1489, Found: 294.1485.



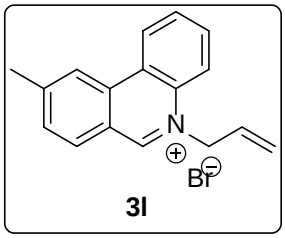
3j

5,9-dimethylphenanthridin-5-ium iodide (3j): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.20 (s, 1H), 9.08 (d, *J* = 8.0 Hz, 1H), 8.92 (s, 1H), 8.48 (d, *J* = 8.8 Hz, 1H), 8.41 (d, *J* = 8.0 Hz, 1H), 8.10-8.14 (m, 1H), 8.04-8.08 (m, 1H), 7.91 (d, *J* = 8.4 Hz, 1H), 4.61 (s, 3H), 2.72 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 155.5, 150.3, 134.7, 134.7, 132.7, 132.5, 132.3, 130.5, 125.4, 125.1, 123.2, 122.1, 120.4, 46.1, 23.1; HRMS(ESI) calcd for $C_{15}H_{14}N^+$: 208.1121, Found: 208.1117.



3k

5-benzyl-9-methylphenanthridin-5-ium bromide (3k): white solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.64 (s, 1H), 9.12-9.15 (m, 1H), 9.00 (s, 1H), 8.55 (d, J = 8.4 Hz, 1H), 8.44-8.48 (m, 1H), 7.96-8.02 (m, 3H), 7.48 (d, J = 6.8 Hz, 2H), 7.31-7.39 (m, 3H), 6.41 (s, 2H), 2.76 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 156.2, 151.2, 135.3, 134.3, 133.7, 133.5, 132.6, 132.3, 130.5, 129.6, 129.2, 127.8, 126.2, 125.5, 123.3, 122.3, 120.8, 60.6, 23.2; HRMS(ESI) calcd for $C_{21}H_{18}N^{+}$: 284.1434, Found: 284.1431.

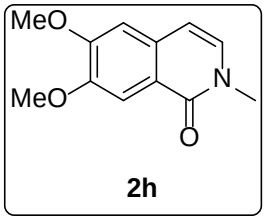


3l

5-allyl-9-methylphenanthridin-5-ium bromide (3l): yellow solid; ^{1}H NMR (400 MHz, DMSO-d6) δ = 10.42 (s, 1H), 9.11 (d, J = 8.0 Hz, 1H), 8.95 (s, 1H), 8.46-8.51 (m, 2H), 8.01-8.10 (m, 2H), 7.91 (d, J = 8.0 Hz, 1H), 6.23-6.32 (m, 1H), 5.77 (d, J = 5.6 Hz, 2H), 5.42-5.49 (m, 2H), 2.72 (s, 3H).^{13}C NMR (100 MHz, DMSO-d6) δ = 155.4, 150.8, 135.0, 133.7, 133.1, 132.5, 132.3, 131.7, 130.5, 125.9, 125.4, 123.3, 122.2, 121.4, 120.7, 59.7, 23.1; HRMS(ESI) calcd for $C_{17}H_{16}N^{+}$: 234.1277, Found: 234.1274.

b) Characterization data of products

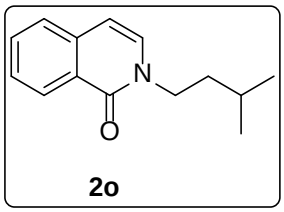
Structrure of known products: **2a**,[21] **2b**,[22] **2c**,[21] **2d**,[21] **2e**,[21] **2f**,[21] **2g**,[21] **2i**,[21] **2j**,[21] **2k**,[23] **2l**,[24] **2m**,[25] **2n**,[21] **2p**,[21] 2q,[21] **2r**,[21] **2v**,[21] **2w**,[21] **2x**,[21] **2y**,[26] **2z**,[21] **2aa**,[26] **2ac**,[21] **4a**,[21] **4b**,[27] **4d**,[27] **4e**,[28] **4f**,[28] **4g**,[28] **4h**,[29] **4i**,[28], **4j**,[30] **4k,**[31] **6**,[32] **9,**[32]were confirmed by ^{1}H NMR spectra comparison with literature data. For substrates not reported before, ^{1}H NMR, ^{13}C NMR characterization and the corresponding spectra are provided.



2h

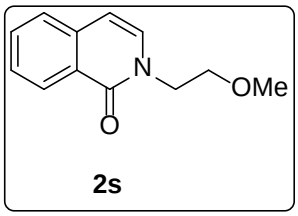
6,7-dimethoxy-2-methylisoquinolin-1(2H)-one(2h): yellow solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.78 (s, 1H), 6.98 (d, J = 7.2 Hz, 1H), 6.84 (s, 1H), 6.39 (d, J = 7.2

Hz, 1H), 3.98 (s, 3H), 3.97 (s, 3H), 3.58 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.0, 153.2, 149.2, 132.6, 131.1, 120.1, 107.5, 105.9, 105.5, 56.2, 56.1, 37.2; HRMS(ESI) calcd for $C_{12}H_{14}NO_3$ $(M+H)^+$: 220.0968, Found: 220.0965.



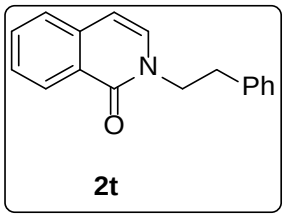
2o

2-isopentylisoquinolin-1(2H)-one (2o): yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.42 (d, J = 8.0 Hz, 1H), 7.59 (t, J = 7.2 Hz, 1H), 7.43-7.49 (m, 2H), 7.04 (d, J = 7.2 Hz, 1H), 6.47 (d, J = 7.2 Hz, 1H), 3.99 (t, J = 6.8 Hz, 2H), 1.62-1.68 (m, 3H), 0.97 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.1, 137.0, 132.0, 131.6, 127.8, 126.7, 126.3, 125.8, 106.0, 47.8, 38.2, 25.9, 22.5; HRMS(ESI) calcd for $C_{14}H_{18}NO$ $(M+H)^+$: 216.1383, Found: 216.1383.



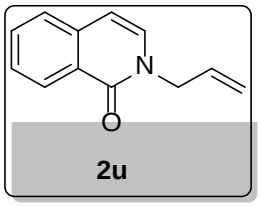
2s

2-(2-methoxyethyl)isoquinolin-1(2H)-one (2s): yellow oli; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.40 (d, J = 8.0 Hz, 1H), 7.59 (t, J = 7.6 Hz, 1H), 7.42-7.49 (m, 2H), 7.13 (d, J = 7.2 Hz, 1H), 6.44 (d, J = 7.2 Hz, 1H), 4.16 (t, J = 4.8 Hz, 2H), 3.69 (t, J = 4.8 Hz, 2H), 3.30 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.2, 137.2, 133.0, 132.1, 127.7, 126.7, 126.1, 125.9, 105.5, 70.8, 59.0, 49.3; HRMS(ESI) calcd for $C_{12}H_{14}NO_2$ $(M+H)^+$: 204.1019, Found: 204.1013.

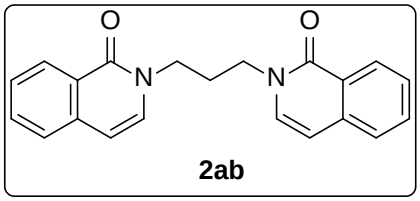


2t

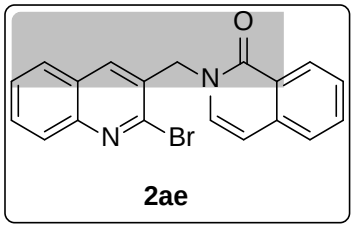
2-phenethylisoquinolin-1(2H)-one (2t): yellow oli; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.47 (d, J = 7.2 Hz, 1H), 7.62 (t, J = 7.6 Hz, 1H), 7.49 (t, J = 7.6 Hz, 2H), 7.19-7.30 (m, 5H), 6.79 (d, J = 7.2 Hz, 1H), 6.36 (d, J = 7.2 Hz, 1H), 4.21 (t, J = 7.2 Hz, 2H), 3.09 (t, J = 7.2 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.1, 138.3, 137.1, 132.1, 132.0, 129.0, 128.7, 127.8, 126.8, 126.7, 126.3, 125.9, 105.7, 51.6, 35.3; HRMS(ESI) calcd for $C_{17}H_{16}NO$ $(M+H)^+$: 250.1226, Found: 250.1221.



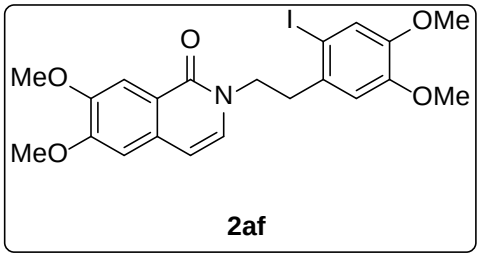
2-allylisoquinolin-1(2H)-one (2u): yellow oli; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.43 (d, *J* = 8.0 Hz, 1H), 7.61 (t, *J* = 7.6 Hz, 1H), 7.44-7.50 (m, 2H), 7.03 (d, *J* = 7.2 Hz, 1H), 6.49 (d, *J* = 7.2 Hz, 1H), 5.91-6.01 (m, 1H), 5.16-5.24 (m, 2H), 4.63 (d, *J* = 5.6 Hz, 2H). ^{13}C NMR (100 MHz, DMSO) δ = 162.0, 137.0, 132.9, 132.2, 131.2, 127.9, 126.8, 126.2, 125.9, 118.0, 106.3, 50.7; HRMS(ESI) calcd for $C_{12}H_{12}NO$ $(M+H)^+$: 186.0913, Found: 186.0907.



2,2'-(propane-1,3-diyl)bis(isoquinolin-1(2H)-one) (2ab): white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.39 (d, *J* = 8.0 Hz, 2H), 7.60 (t, *J* = 7.2 Hz, 2H), 7.43-7.47 (m, 4H), 7.12 (d, *J* = 7.6 Hz, 2H), 6.46 (d, *J* = 7.2 Hz, 2H), 4.08 (t, *J* = 7.2 Hz, 4H), 2.24-2.31 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.3, 137.1, 132.2, 131.6, 127.7, 126.9, 126.1, 126.0, 106.5, 46.9, 29.0; HRMS(ESI) calcd for $C_{21}H_{19}N_2O_2$ $(M+H)^+$: 331.1441, Found: 331.1439.

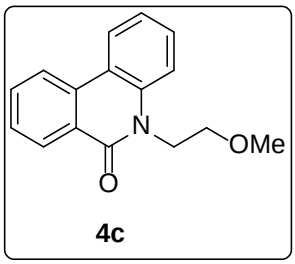


2-((2-bromoquinolin-3-yl)methyl)isoquinolin-1(2H)-one (2ae): white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.48 (d, *J* = 8.0 Hz, 1H), 8.03 (d, *J* = 8.8 Hz, 1H), 7.86 (s, 1H), 7.68-7.72 (m, 3H), 7.50-7.59 (m, 3H), 7.25 (d, *J* = 7.2 Hz, 1H), 6.60 (d, *J* = 7.2 Hz, 1H), 5.44 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.3, 147.7, 142.3, 137.1, 137.0, 132.7, 131.6，130.6, 130.2, 128.3, 128.1, 127.8, 127.4, 127.3, 127.2, 126.2, 107.0, 51.5; HRMS(ESI) calcd for $C_{19}H_{14}BrN_2O$ $(M+H)^+$: 365.0284, Found: 365.0281.



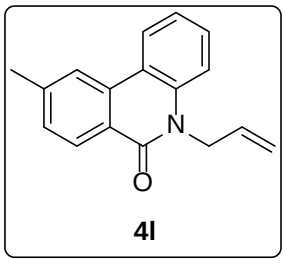
2af

2-(2-iodo-4,5-dimethoxyphenethyl)-6,7-dimethoxyisoquinolin-1(2H)-one (2af): yellow solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.81 (s, 1H), 7.19(s, 1H), 6.82 (s, 1H), 6.73 (d, *J* = 7.2 Hz, 1H), 6.57 (s, 1H), 6.29 (d, *J* = 7.2 Hz, 1H), 4.16 (t, *J* = 7.2 Hz, 2H), 3.99 (s, 3H), 3.96 (s, 3H), 3.82 (s, 3H), 3.57 (s, 3H), 3.14 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 161.6, 153.4, 149.4, 149.2, 148.3, 133.2, 132.6, 130.7, 121.4, 120.0, 113.0, 107.4, 105.9, 105.5, 87.8, 56.1, 56.1, 56.1, 55.7, 49.9, 39.1; HRMS(ESI) calcd for $C_{21}H_{23}INO_5$ $(M+H)^+$: 496.0615, Found: 496.0611.



4c

5-(2-methoxyethyl)phenanthridin-6(5H)-one (4c): white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.53 (d, *J* = 8.0 Hz, 1H), 8.22-8.24 (m, 2H), 7.73 (t, *J* = 7.6 Hz, 1H), 7.49-7.58 (m, 3H), 7.28 (t, *J* = 8.0 Hz, 1H), 4.59 (t, *J* = 6.4 Hz, 2H), 3.78 (t, *J* = 6.4 Hz, 2H), 3.38 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 161.7, 137.6, 133.7, 132.5, 129.5, 128.8, 127.9, 125.4, 123.3, 122.5, 121.6, 119.4, 115.6, 69.8, 59.2, 42.6; HRMS(ESI) calcd for $C_{16}H_{16}NO_2$ $(M+H)^+$: 254.1176, Found: 254.1173.



4l

5-allyl-9-methylphenanthridin-6(5H)-one (4l): white solid; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 8.44 (d, *J* = 8.0 Hz, 1H), 8.24 (d, *J* = 7.2 Hz, 1H), 8.03 (s, 1H), 7.47 (t, *J* = 7.6 Hz, 1H), 7.38 (d, *J* = 7.6 Hz, 1H), 7.33 (d, *J* = 8.4 Hz, 1H), 7.27 (t, *J* = 7.2 Hz, 1H), 5.96-6.05 (m, 1H), 5.12-5.23 (m, 2H), 5.02-5.03 (m, 2H), 2.54 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 161.4, 143.1, 137.4, 133.7, 132.1, 129.4, 129.3, 129.0, 123.2, 123.2, 122.4, 121.7, 119.4, 116.9, 115.8, 45.0, 22.2; HRMS(ESI) calcd for $C_{17}H_{16}NO$ $(M+H)^+$: 250.1226, Found: 250.1222.

c) Reference

[1] (a) Reddy, R. S.; Rosa, J. N.; Veiros, L. F.; Caddick, S.; Gois, P. M. P. *Org. Biomol. Chem.* **2011**, *9*, 3126. (b) Zhao, J.; MückLichtenfeld, C.; Studer, A. *Adv. Synth. Catal.* **2013**, *355*, 1098. (c) Kiran, I. N. C.; Lalwani, K.; Sudalai, A. *RSC Adv*. **2013**, *3*, 1695. (d) Reddi, R. N.; Malekar, P. V.; Sudalai, A. *Tetrahedron Lett*. **2013**, *54*, 2679. (e) Delany, E. G.; Fagan, C.-L.; Gundala, S.; Mari, A.; Broja, T.; Zeitler, K.; Connon, S. J. *Chem. Commun.* **2013**. *49*, 6510. (f) Delany, E. G.; Fagan, C.-L.; Gundala, S.; Zeitler, K.; Connon, S. J. *Chem. Commun*. **2013**, *49*, 6513. (g) Ta, L.; Axelsson, A.; Sundén, H. *Green Chem.* **2016**, *18*, 686. (h) Xie, D.; Shen, D.; Chen, Q.; Zhou, J.; Zeng, X.; Zhong, G. *J. Org. Chem.* **2016**, *81*, 6136. （i）Bortolini, O.; Chiappe, C.; Fogagnolo, M.; Massi, A.; Pomelli, C. S. *J. Org. Chem*. **2017**, *82*, 302.

[2] Bernini, R.; Cacchi, S.; Fabrizi, G.; Fabrizi, G.; Sferrazza, A. *Synthesis* **2008**, 729.

[3] Liang, Z.; Zhang, J.; Liu, Z.; Wang, K.; Zhang, Y. *Tetrahedron* **2013**, *69*, 6519.

[4] Wakchaure, P. B.; Easwar, S.; Argade, N. P. *Synthesis* **2009**, *2009*, 1667.

[5] Chen, A.; Zhao, K.; Zhang, H.; Gan, X.; Lei, M.; Hu, L. *Monatsh. Chem*. **2012**, *143*, 825.

[6] Tohma, H.; Iwata, M.; Maegawa, T.; Kita, Y.; *Tetrahedron Lett*. **2002**, *43*, 9241.

[7] Xu，J. H.; Zheng，S. C.; Zhang，J. W.; Liu，X. Y.; Tan, B. *Angew. Chem. Int. Ed.* **2016**, *55*, 11834.

[8] Neelakantan, H.; Wang, H. Y.; Vance, V.; Hommel, J. D.; McHardy, S. F.; Watowich, S. J. *J. Med. Chem.* **2017**, *60*, 5015.

[9] Tsuji,K.; Nishimura, N.; Duan, X. M.; Okada, S.; Oikawa, H.; Matsuda, H.; Nakanishi, H. *Bull. Chem. Soc. Jpn.* **2005**, *7*8, 180.

[10] Shukla, M. *J. Mol. Struct*. **2017**, *1131*, 275.

[11] Therkelsen, M.; Rasmussen, M. T.; Lindhardt, A. T. *Chem. Commun.* **2015**, *51*, 9651.

[12] Magriz, A.; Gómezbujedo, S.; Álvarez，E.; Fernández，R.; Lassaletta, J. M. *Organometallics*. **2010**, *29*, 5941.

[13] Chen, Y. T.; Jordan, F. *J. Org. Chem*. **1991**, *56*, 5029.

[14] Gromov,S. P.; Fomina, M. V. *Russ. Chem. B*+. **2004**, *53*, 901.

[15] Park, Y.-T.; Joo, C.-H.; Choi, C.-D.; Park, K.-S.; *J. Heterocyclic Chem.* **1991**, *28*, 1083

[16] Chernyshov, I. Y.; Levin, V. V.; Dilman, A. D.; Belyakov, P. A.; Struchkova, M. I.; Tartakovsky, V. A.; *Russ. Chem. B.* **2010**, *59*, 2102.

[17] Kwok, J. C.; Macartney, D. H. *Supramol. Chem.* **2014**, *26*, 182.

[18] Dostal, J.; Potacek, M.; Nechvatal, M.; *Collect. Czech. Chem. C.* **1993**, *58*, 395.

[19] Jhang, Y.; Fan-Chiang, T.; Huang, J.; Hsieh, J. *Org. Lett.* **2016**, *18*, 1154.

[20] Kuwata, Y.; Sonoda, M.; Tanimori, S. *J. Heterocyclic Chem.* **2017**, *54*, 1645.

[21] Jin, Y.; Ou, L.; Yang, H.; Fu, H. *J. Am. Chem. Soc*. **2017**, *139*, 14237.

[22] Hohmann, A. F.; Martin, L. J.; Minder J. L.; Jae-Seok Roe1 , Shi, J.; Steurer, S.; Bader, G.; McConnell, D.; Pearson, M.; Gerstberger, T.; Gottschamel, T.; Thompson, D.; Suzuki, Y.; Koeg, M.; Vakoc, C. R. *Nat. Chem. Biol*. **2016**, *12*, 672.

[23] Huestis, M. P. *J. Org. Chem*. **2016**, *81*, 12545.

[24] Yang, Y.; Zhang, X.; Zeng, W.; Huang, H.; Liang, Y. *RSC Adv*. **2014**, *4*, 6090.

[25] Shaikh, A. C.; Shinde, D. R.; Patil, N. T. *Org. Lett*. **2016**, *18*, 1056.

[26] Luo, W.; Shi, X.; Zhou, W.; Yang, L. *Org. Lett*. **2016**, *18*, 2036.

[27] Lu, C.; Dubrovskiy, A. V.; Larock, R. C. *J. Org. Chem*. **2012**, *77*, 8648.

[28] Feng, M.; Tang, B.; Wang, N.; Xu, H.; Jiang, X. *Angew. Chem. Int. Ed*. **2015**, *54*, 14960

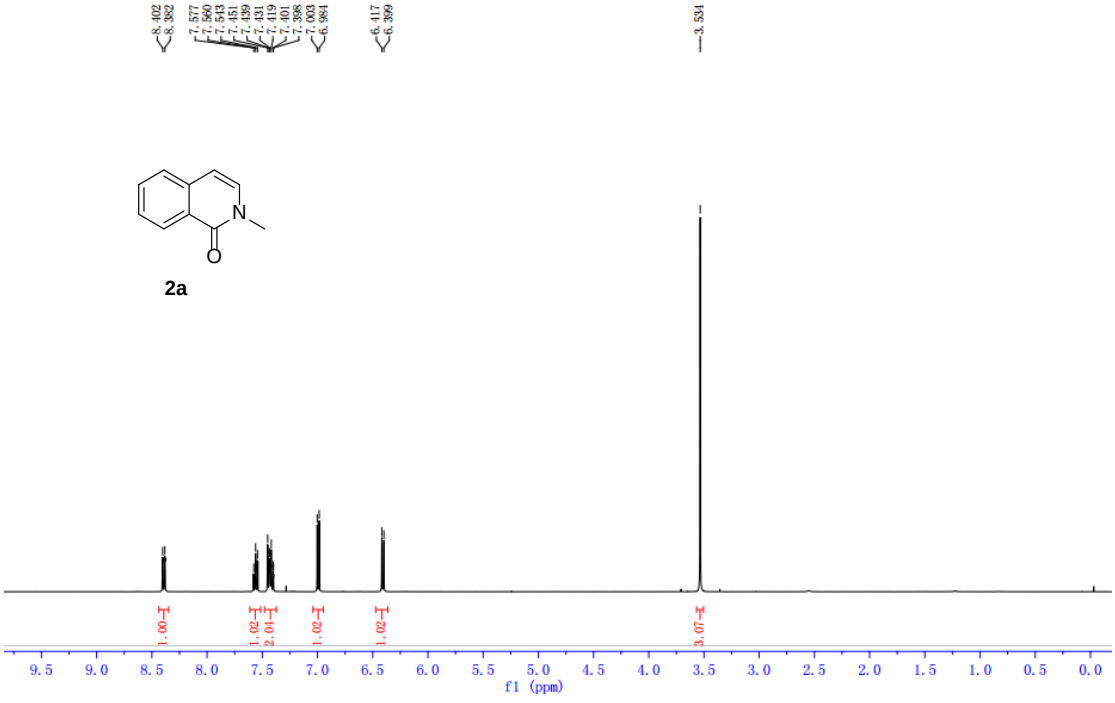
[29] Feng, M.; Tang, B.; Xu, H.; Jiang, X. *Org. Lett*. **2016**, *18*, 4352.

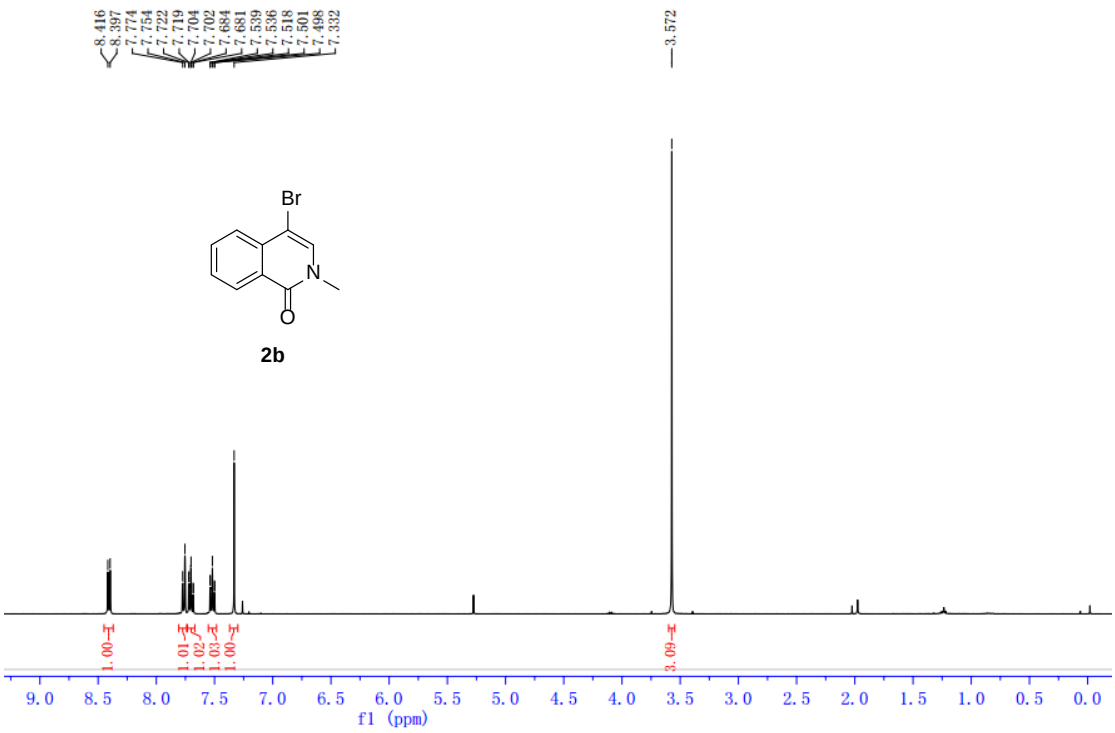
[30] Iwasaki, H.; Eguchi, T.; Tsutsui, N.; Ohno, H.; Tanaka, T. *J. Org. Chem.* **2008**, *73*, 7145.

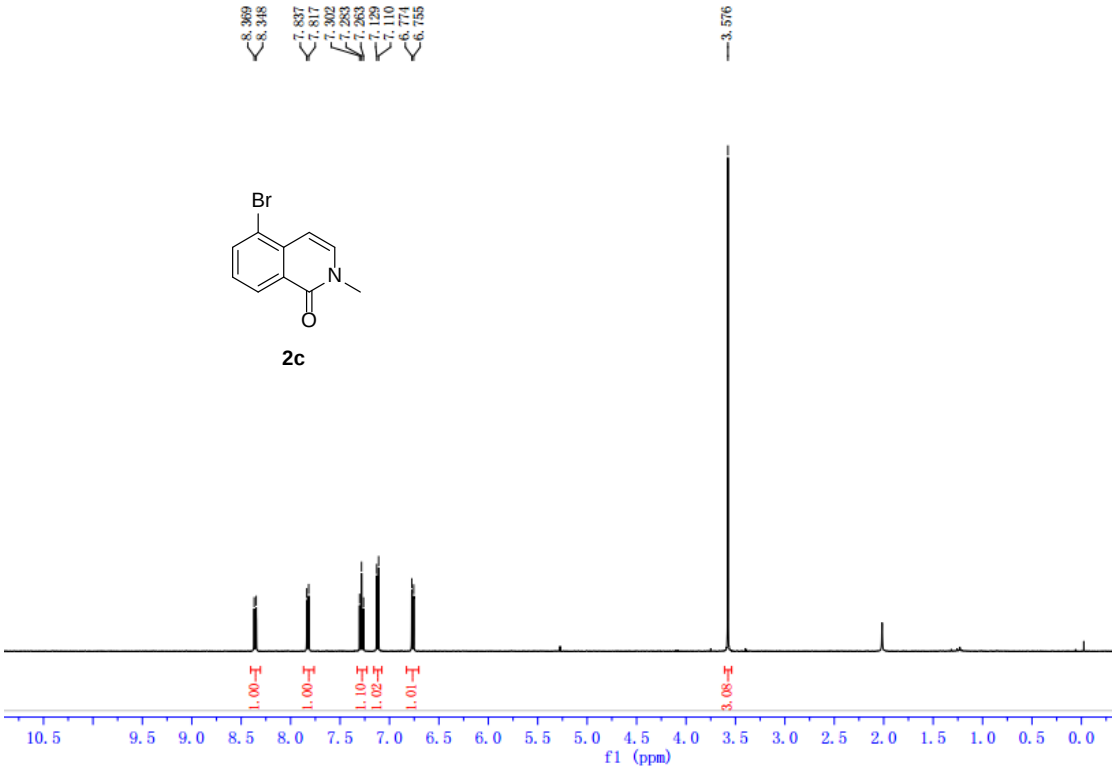
[31] Lu, C.; Dubrovskiy, A. V.; Larock, R. C. *J. Org. Chem.* **2012**, *77*, 8648.

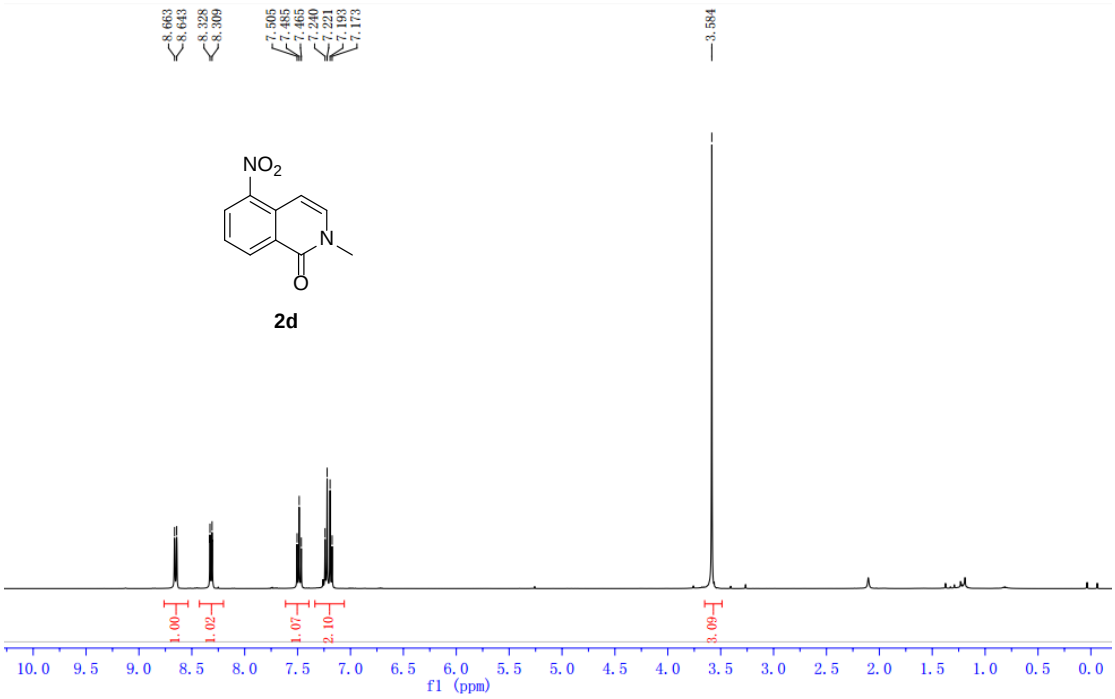
[32] Reddy, C. R.; Mallesh, K. *Org. Lett.* **2018**, *20*, 150.

d) ^{1}H NMR and ^{13}C NMR Spectra

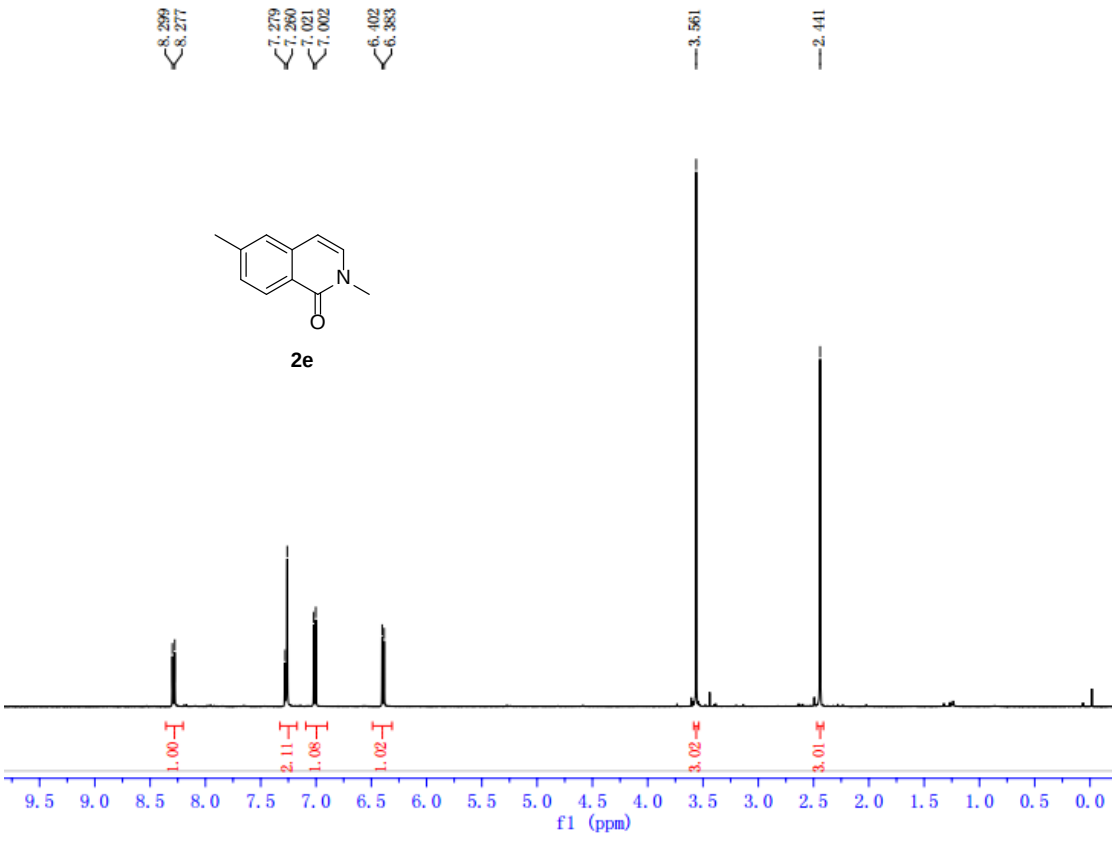



8.416
8.397
7.774
7.754
7.722
7.719
7.704
7.702
7.684
7.681
7.539
7.536
7.518
7.501
7.498
7.332
3.572
Br
N
O
2b
1.00
1.01
1.02
1.03
1.00
3.09
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

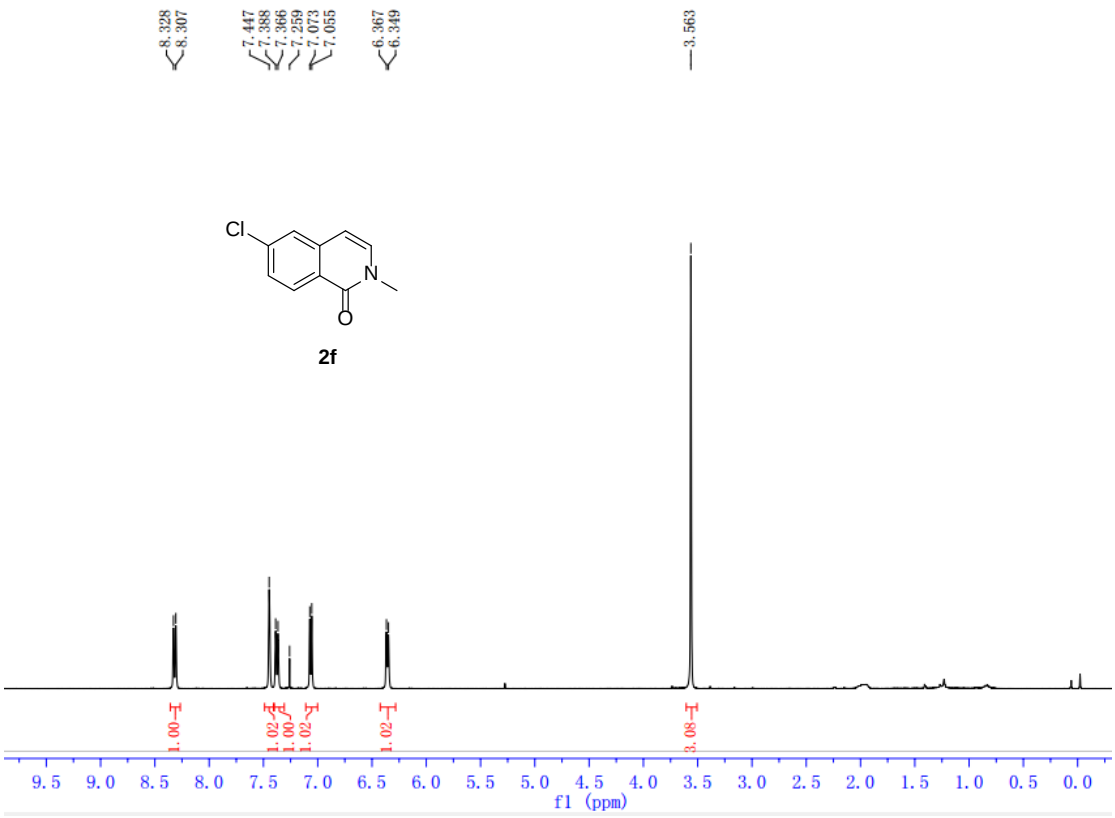

8.369
8.348
7.837
7.817
7.302
7.283
7.263
7.129
7.110
6.774
6.755
3.576
Br
N
O
2c
1.00
1.00
1.10
1.02
1.01
3.08
10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.663
8.643
8.328
8.309
7.505
7.485
7.465
7.240
7.221
7.193
7.173
3.584
NO2
N
O
1.00
1.02
1.07
2.10
3.09
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

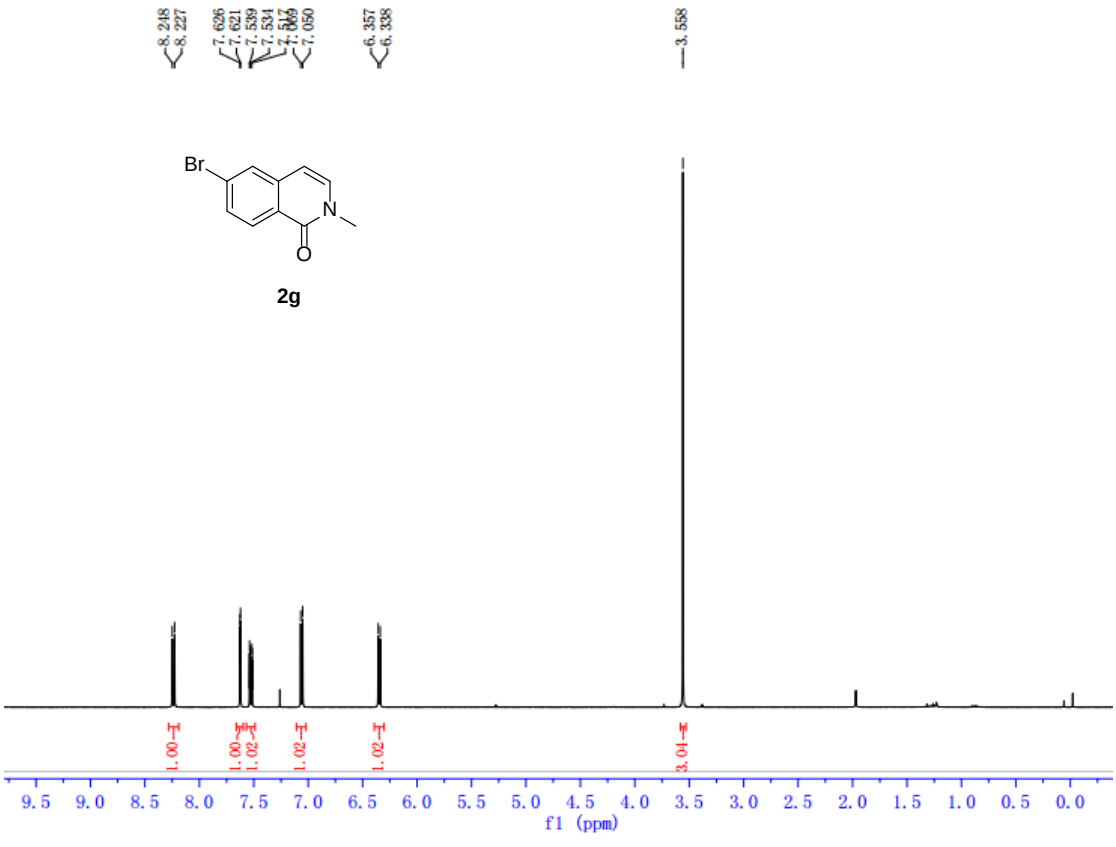
2d


8.299
8.277
7.279
7.260
7.021
7.002
6.402
6.383
3.561
2.441
N
O
1.00
2.11
1.08
1.02
3.02
3.01
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

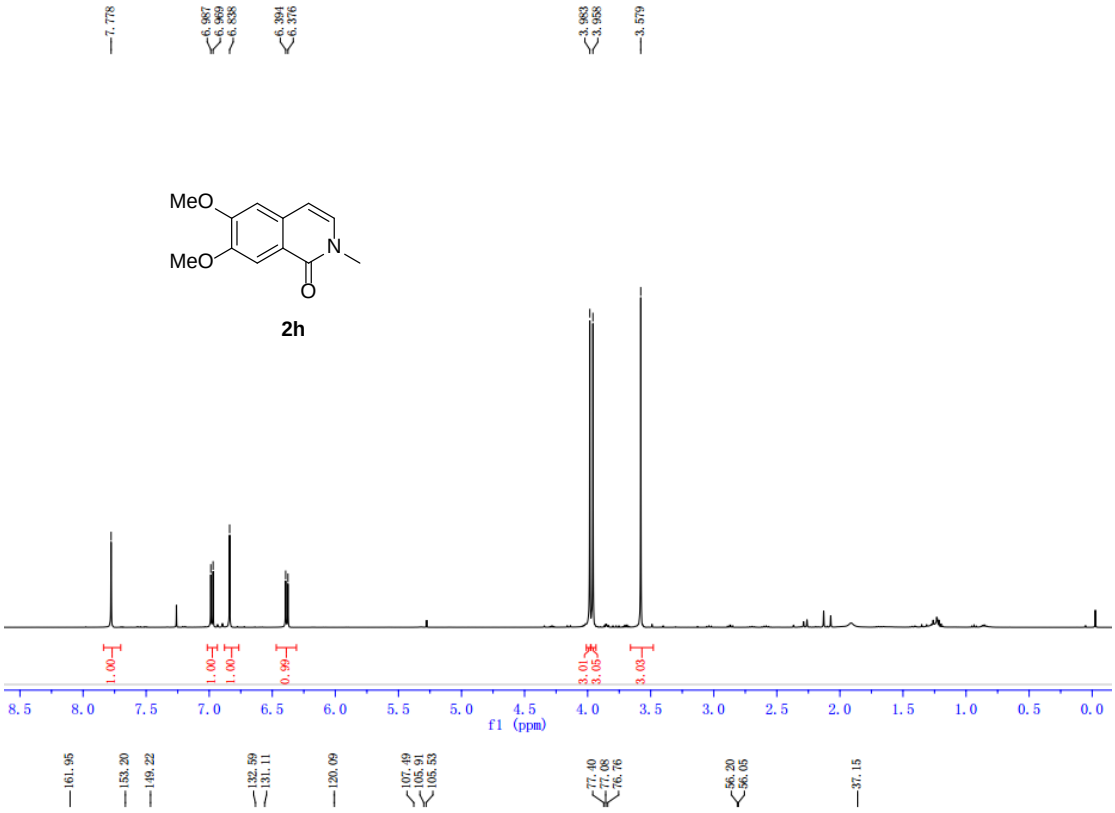
2e

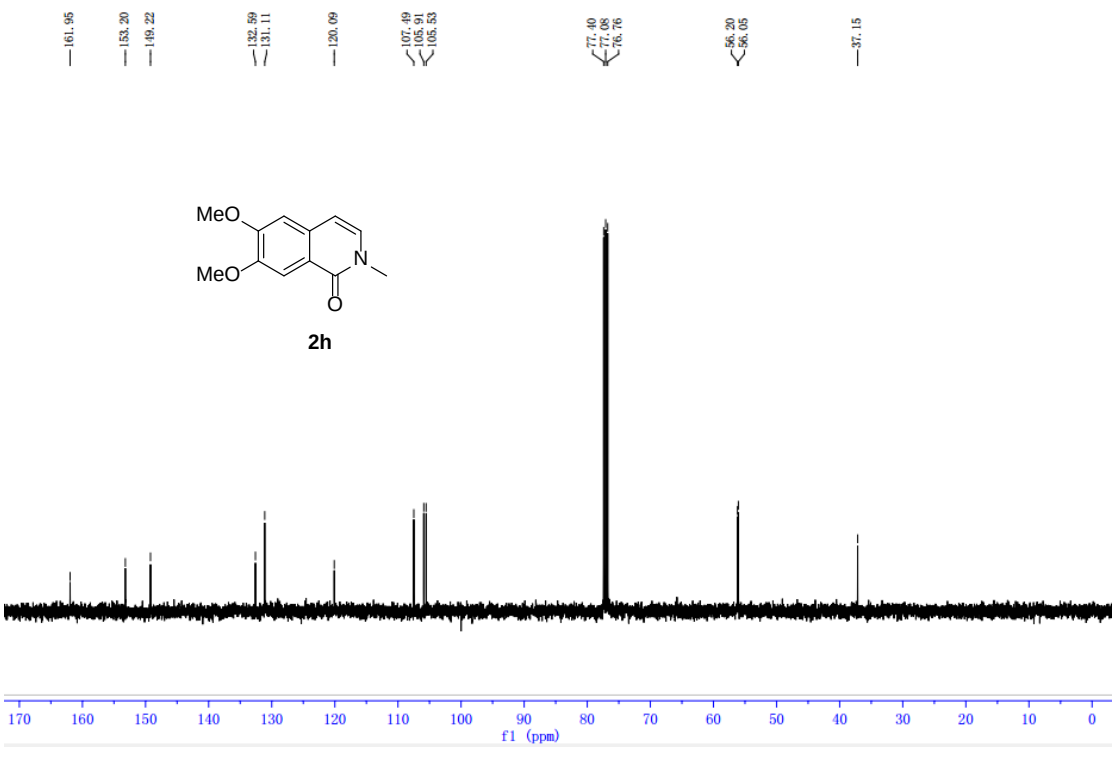

8.328
8.307
7.447
7.388
7.366
7.259
7.073
7.055
6.367
6.349
3.563
Cl
N
O
1.00
1.02
1.00
1.02
1.02
3.08
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

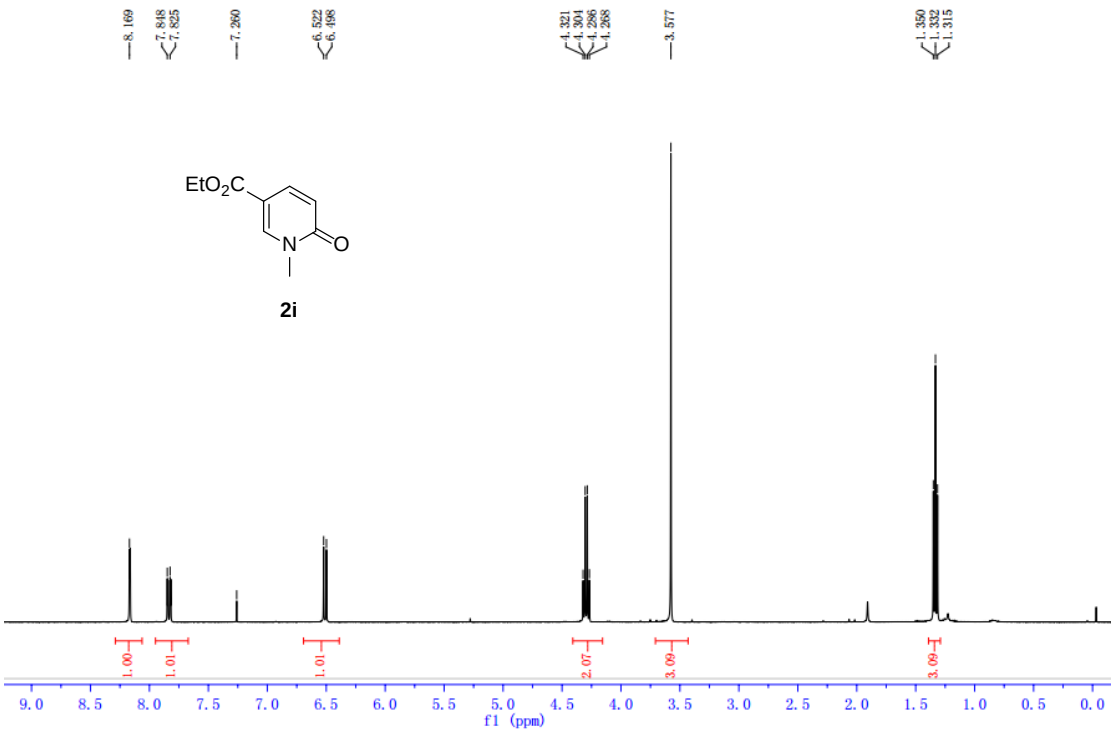
2f


8.248
8.227
7.626
7.621
7.539
7.534
7.050
6.357
6.338
3.558
Br
N
O
1.00
1.00
1.02
1.02
1.02
3.04
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

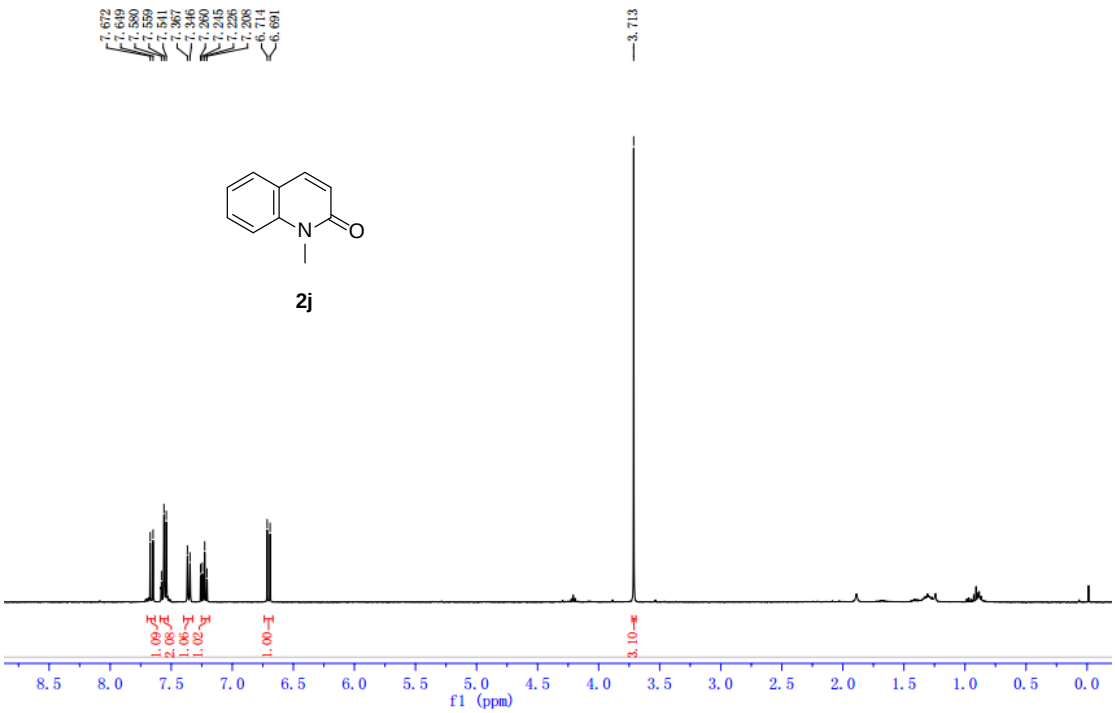
2g


7.778
6.987
6.969
6.838
6.394
6.376
3.983
3.958
3.579
MeO
MeO
N
O
2h
1.00
1.00
1.00
0.99
3.01
3.05
3.03
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

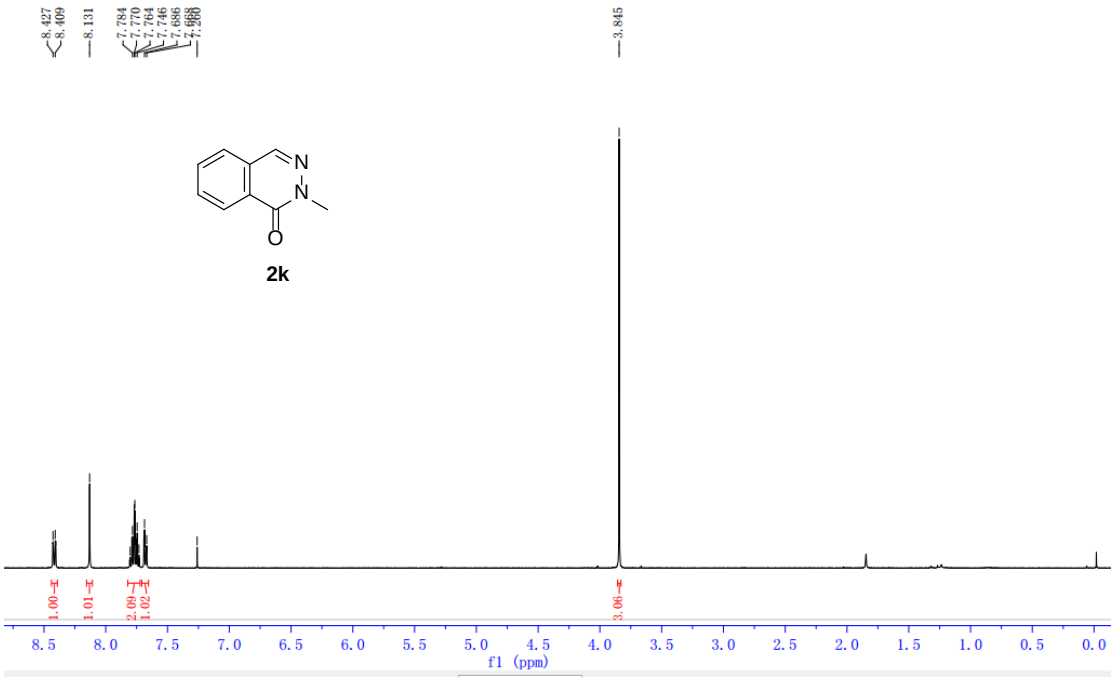

161.95
153.20
149.22
132.59
131.11
120.09
107.49
105.91
105.53
77.40
77.08
76.76
56.20
56.05
37.15
MeO
MeO
N
O
2h
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


8.169
7.848
7.825
7.260
6.522
6.498
4.321
4.304
4.286
4.268
3.577
1.350
1.332
1.315
EtO2C
N
O
1.00
1.01
1.01
2.07
3.09
3.09
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

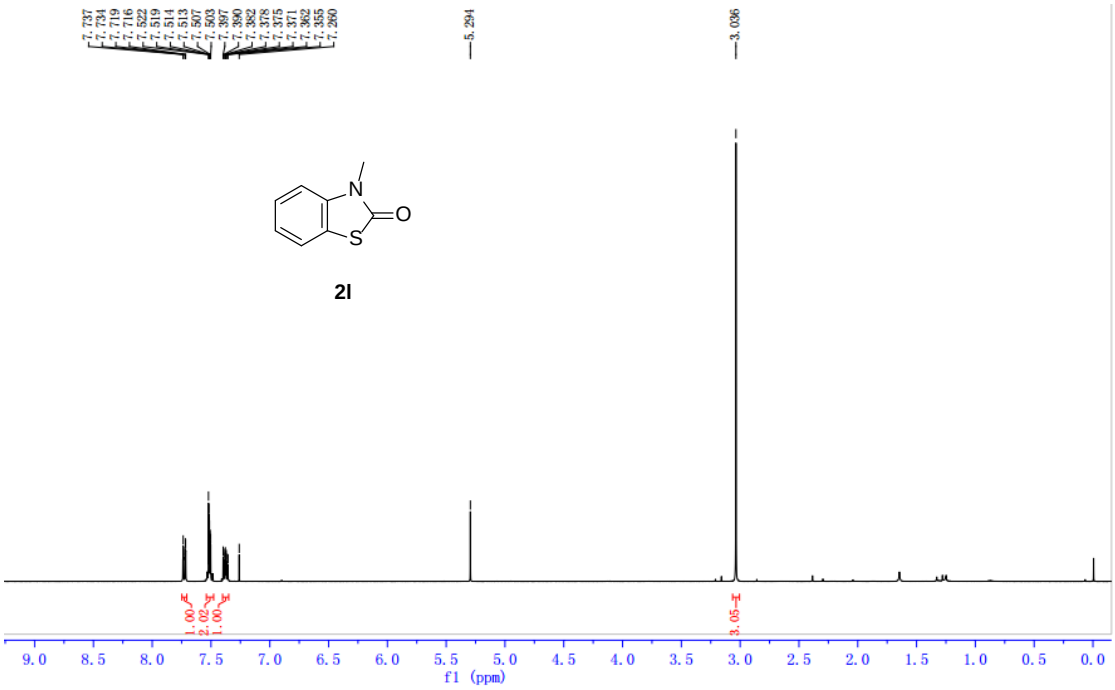
2i


7.672
7.649
7.580
7.559
7.511
7.367
7.346
7.260
7.245
7.226
7.208
6.714
6.691
3.713
N
O
1.09
2.08
1.06
1.02
1.00
3.10
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

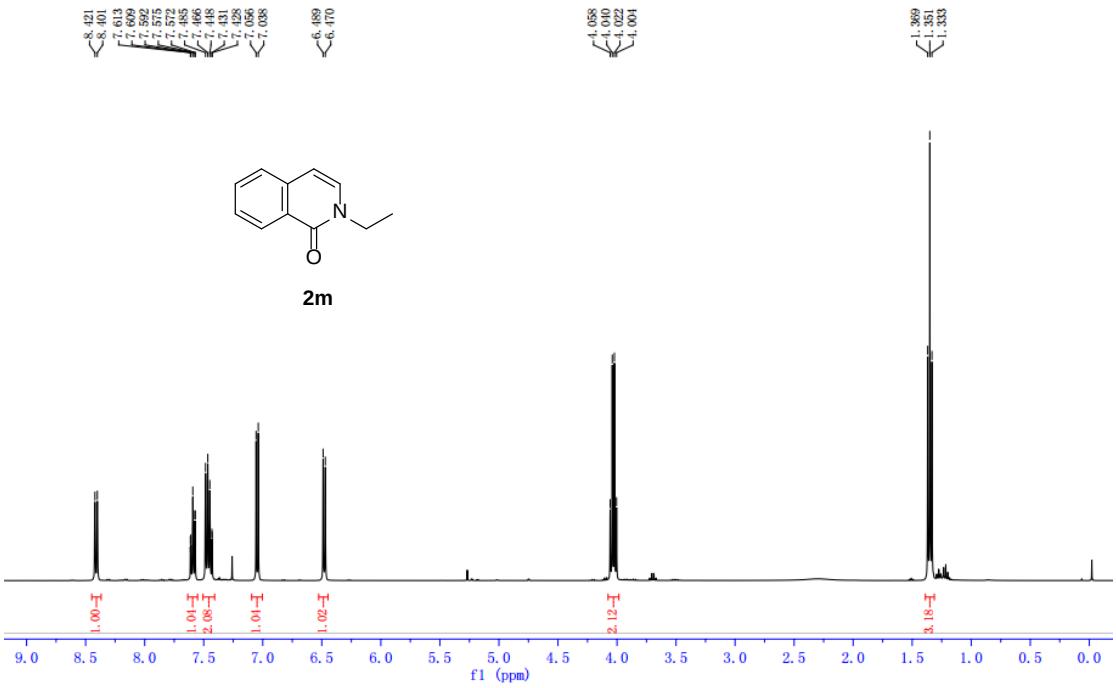
2j


8.427
8.409
8.131
7.784
7.770
7.764
7.746
7.686
3.845
N
N
O
1.00
1.01
2.69
1.02
3.06
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

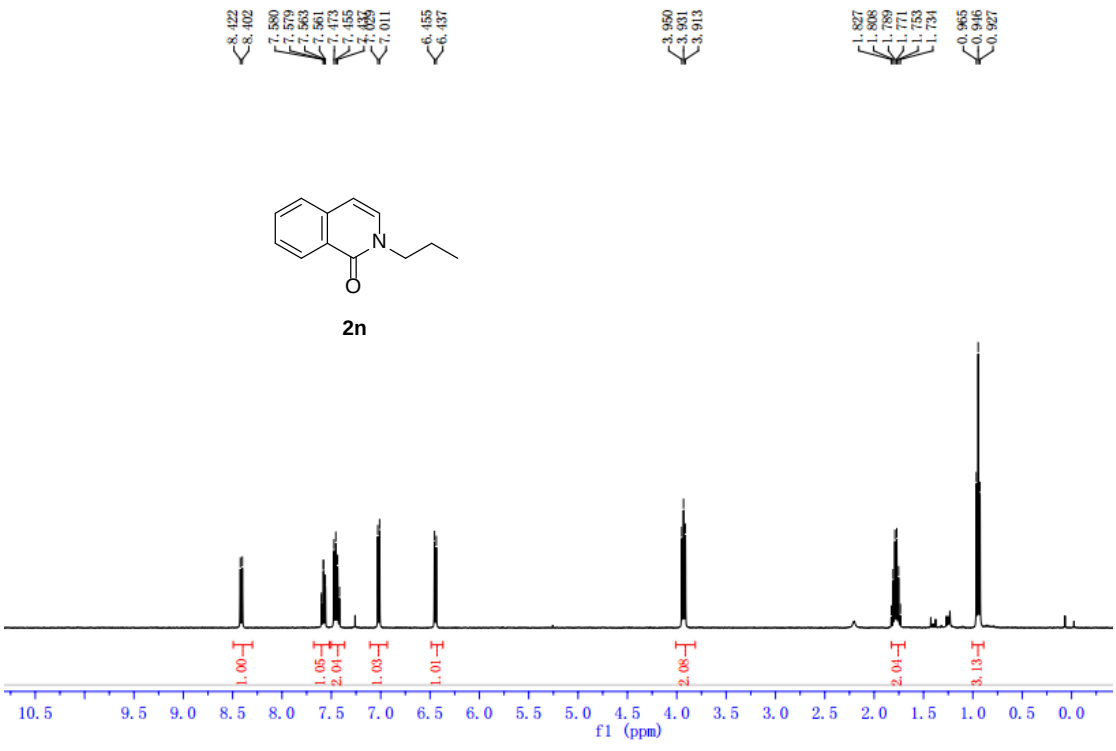
2k


7.737
7.734
7.719
7.716
7.522
7.519
7.514
7.513
7.507
7.503
7.397
7.390
7.382
7.378
7.375
7.371
7.362
7.355
7.260
5.294
3.036
N
O
S
1.00
2.02
1.00
3.05
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

2l

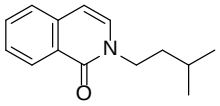

8.421
8.401
7.613
7.609
7.592
7.575
7.572
7.565
7.466
7.448
7.431
7.428
7.056
7.038
6.489
6.470
4.058
4.040
4.022
4.004
1.369
1.351
1.333
N
O
1.00
1.01
2.08
1.01
1.02
2.12
3.18
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

2m

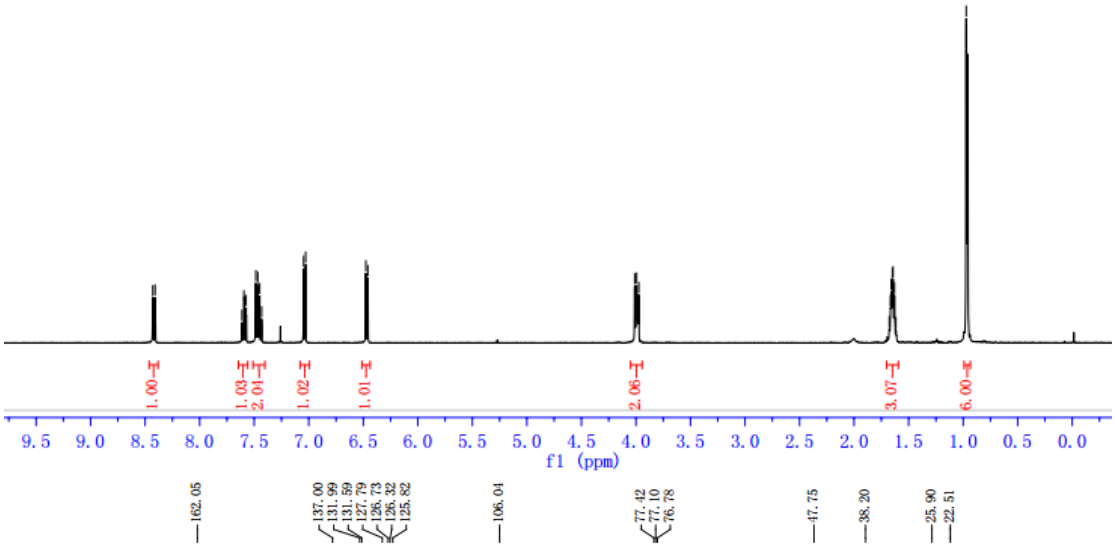

8.422
8.402
7.580
7.579
7.563
7.561
7.473
7.455
7.437
7.029
7.011
6.455
6.437
3.950
3.931
3.913
1.827
1.808
1.789
1.771
1.753
1.734
0.965
0.946
0.927
N
O
1.00
1.05
2.01
1.03
1.01
2.08
2.04
3.13
10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

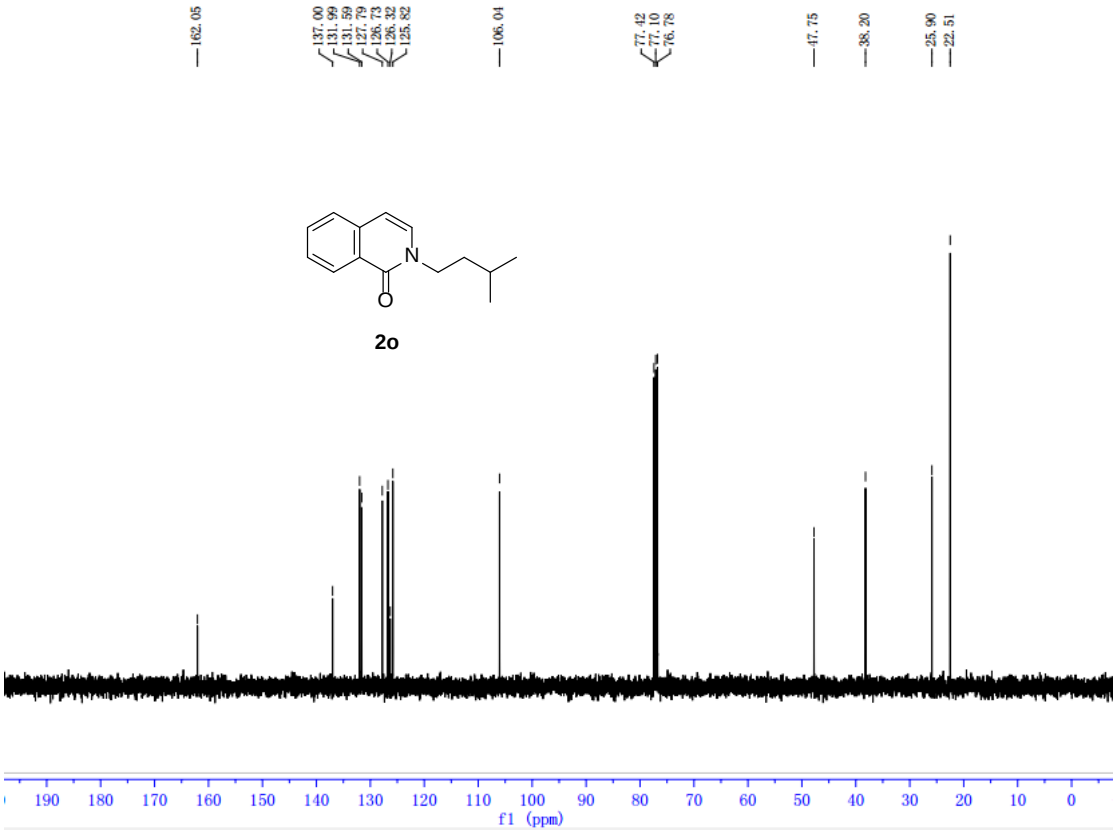
2n


8.429
8.409
7.612
7.594
7.575
7.485
7.467
7.450
7.432
7.047
7.029
6.476
6.458
4.011
3.994
3.974
1.677
1.665
1.660
1.649
1.643
1.630
1.617
0.972


N
O

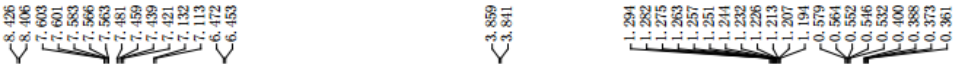
2o

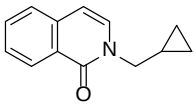

1.00
1.03
2.01
1.02
1.01
2.06
3.07
6.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


162.05
137.00
131.99
131.59
127.79
126.73
126.32
125.82
106.04
77.42
77.10
76.78
47.75
38.20
25.90
22.51
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

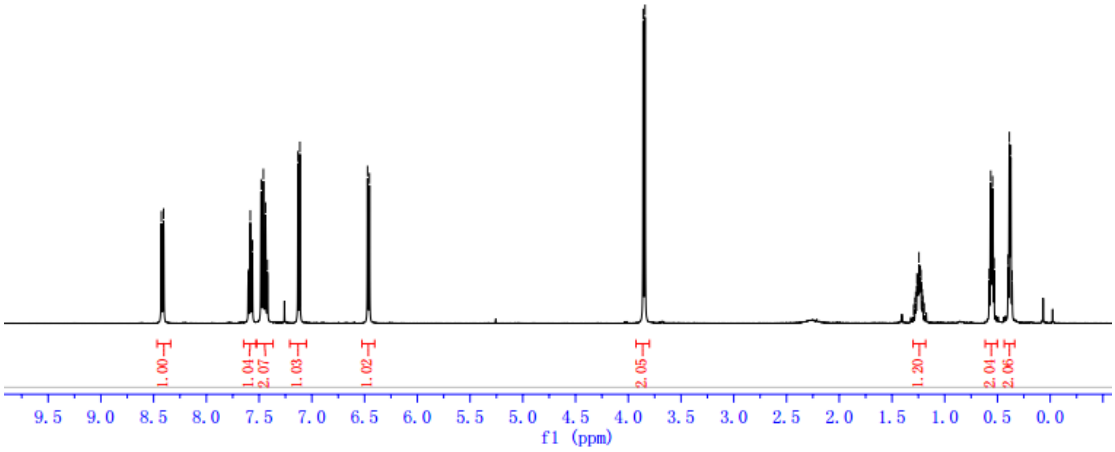
N
O

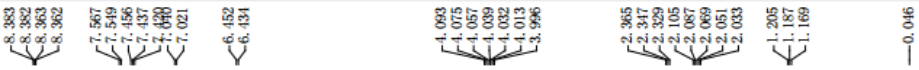
2o

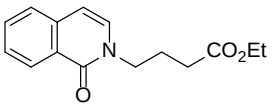




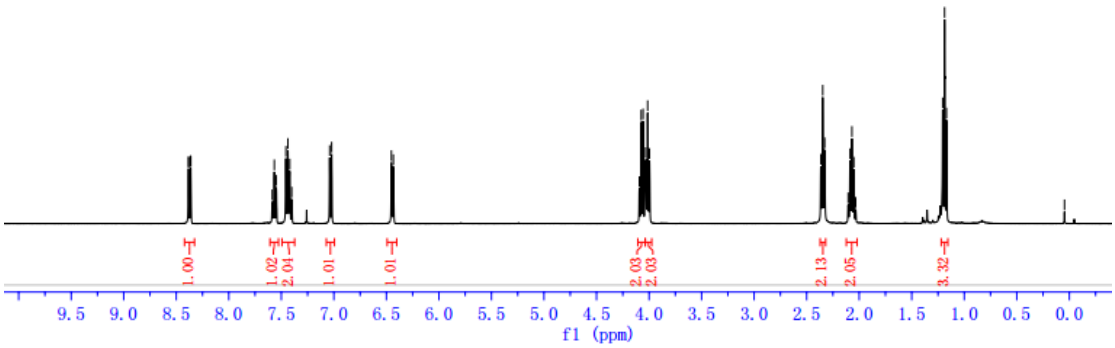
2p

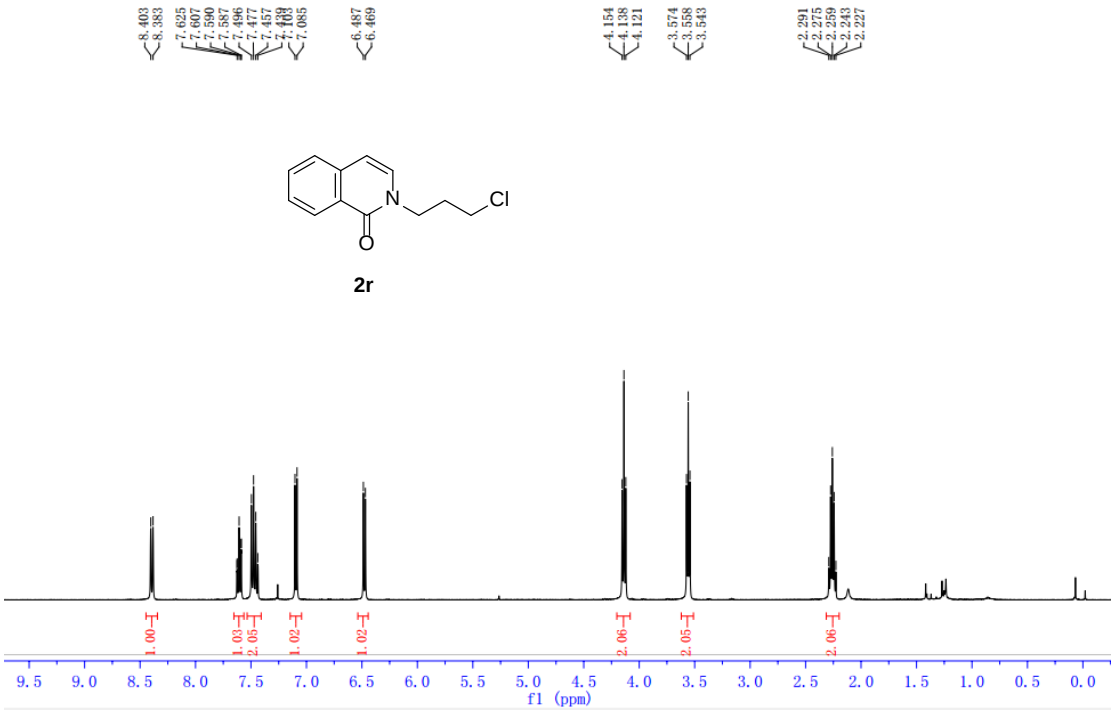




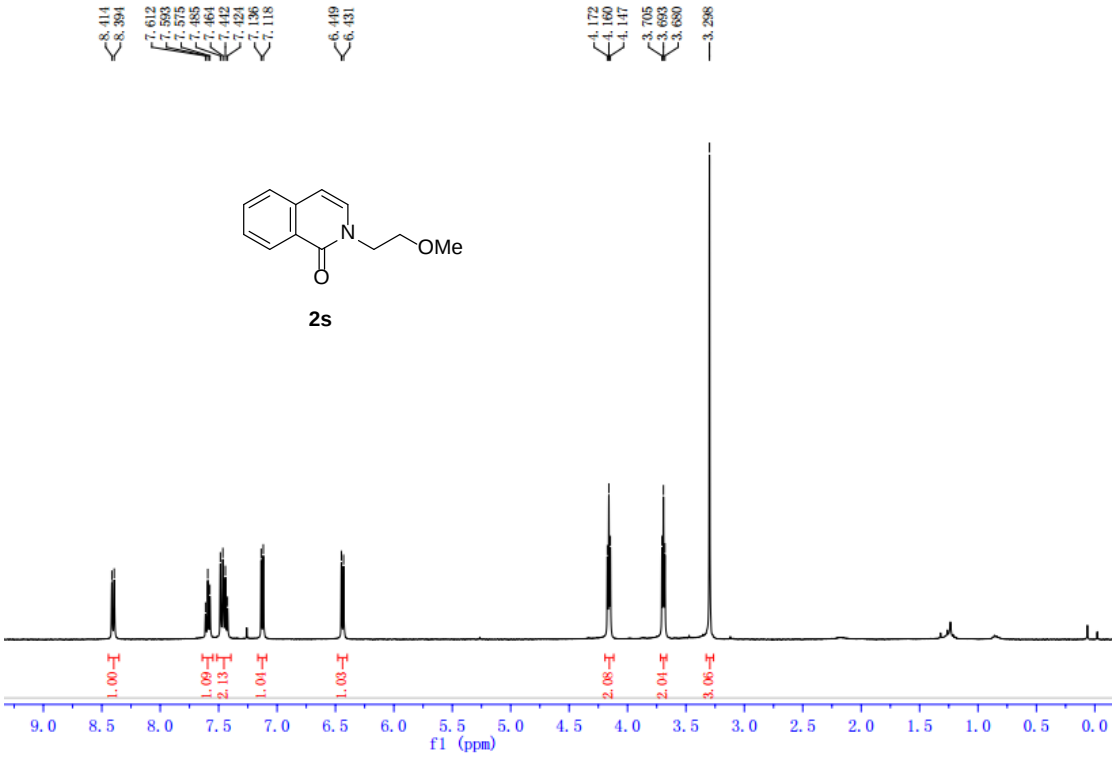


2q

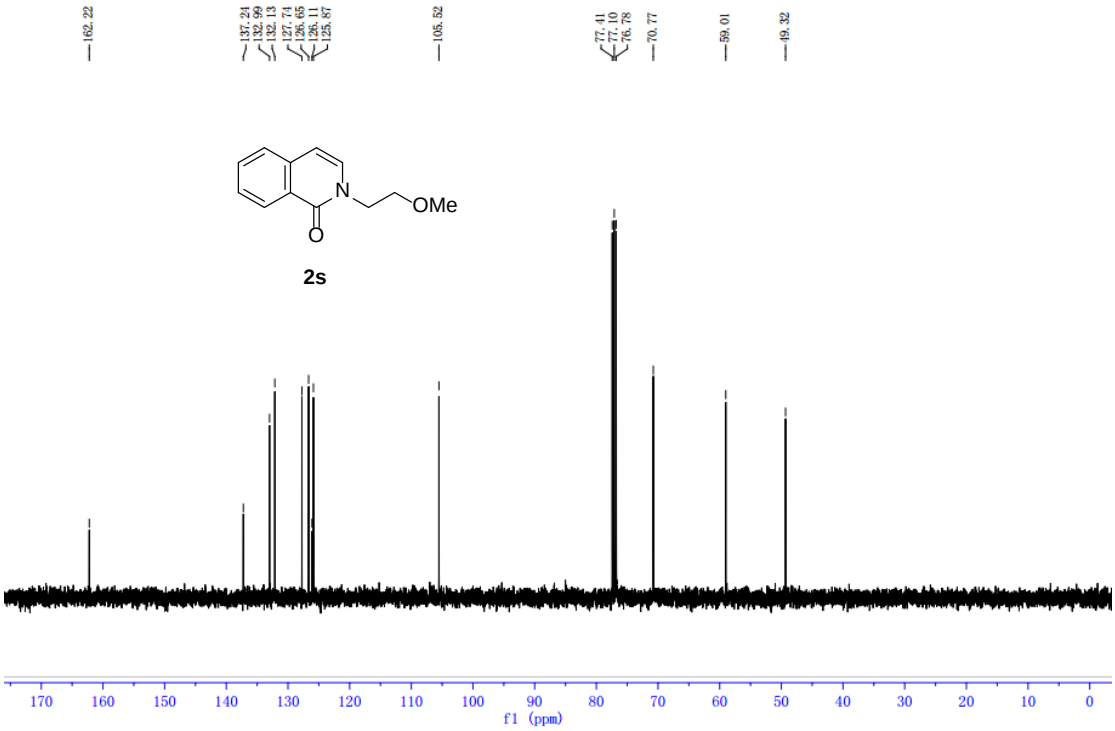



8.403
8.383
7.625
7.607
7.590
7.587
7.496
7.477
7.457
7.439
7.103
7.085
6.487
6.469
4.154
4.138
4.121
3.574
3.558
3.543
2.291
2.275
2.259
2.243
2.227
N
Cl
O
1.00
1.03
2.05
1.02
1.02
2.06
2.05
2.06
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

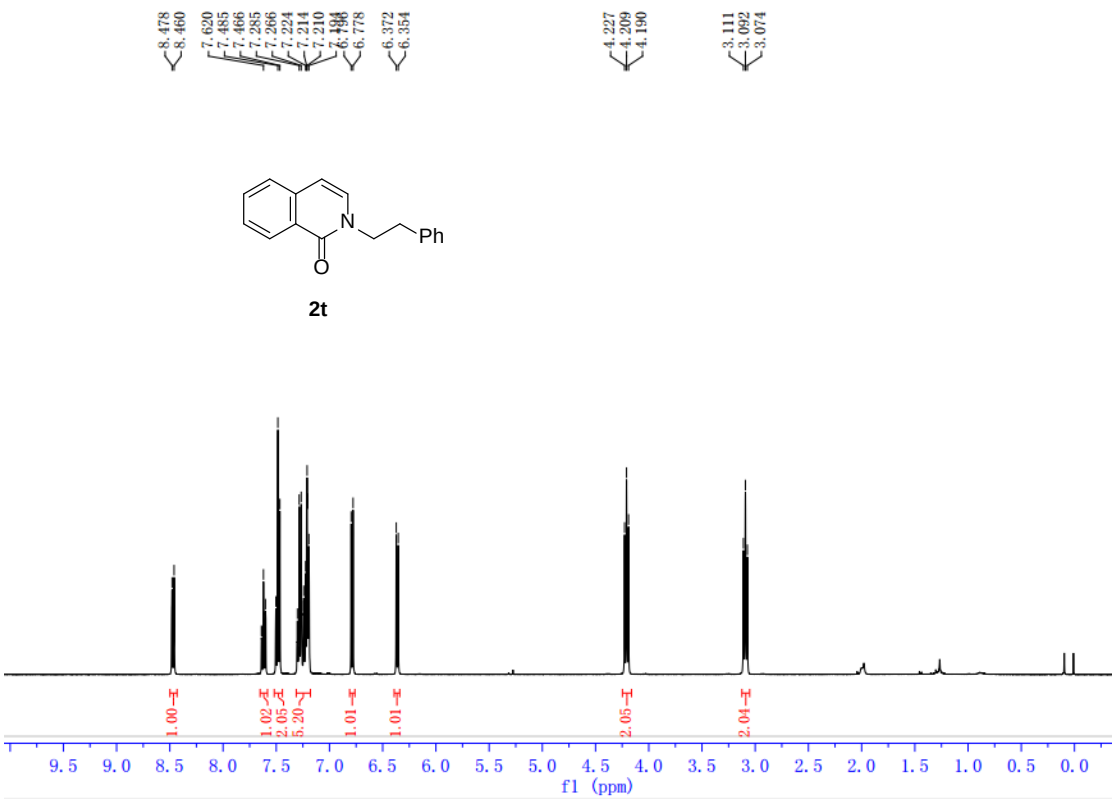
2r


8.414
8.394
7.612
7.593
7.575
7.485
7.464
7.442
7.424
7.136
7.118
6.449
6.431
4.172
4.160
4.147
3.705
3.693
3.680
3.298
N
OMe
O
1.00
1.09
2.13
1.01
1.03
2.08
2.01
3.06
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

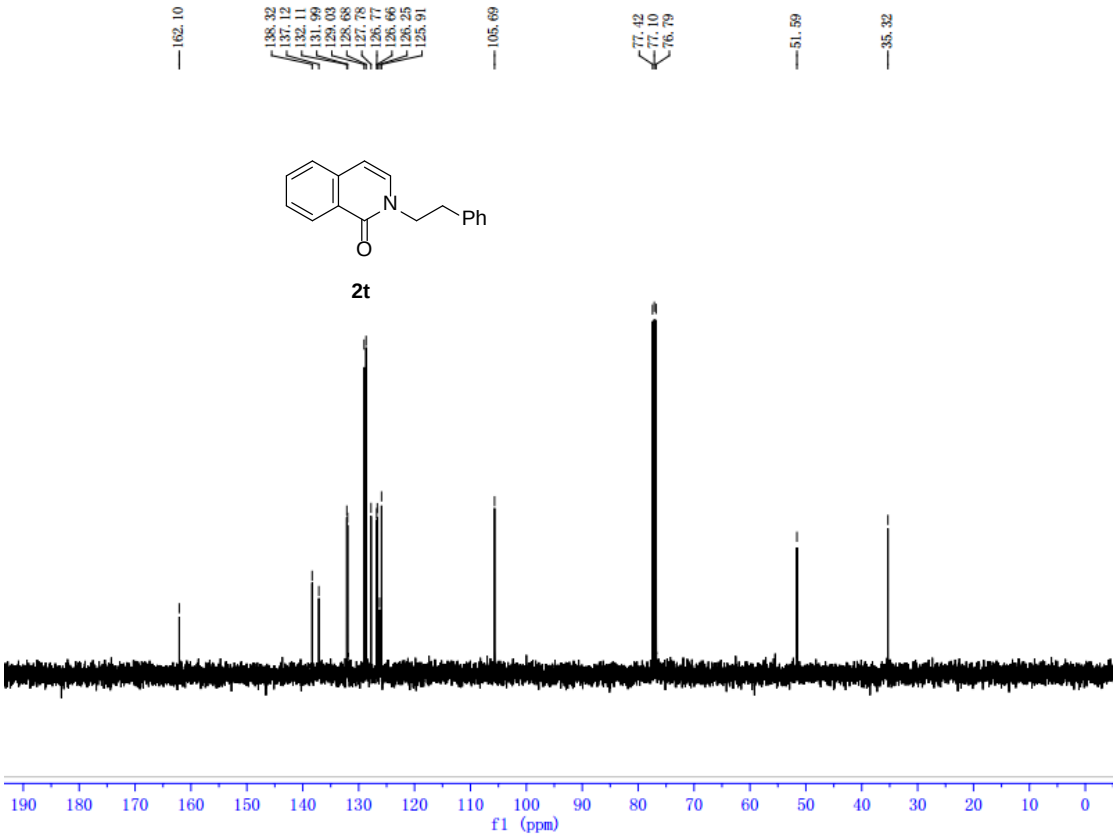
2s


162.22
137.24
132.99
132.13
127.74
126.65
126.11
125.87
105.52
77.41
77.10
76.78
70.77
59.01
49.32
N
OMe
O
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

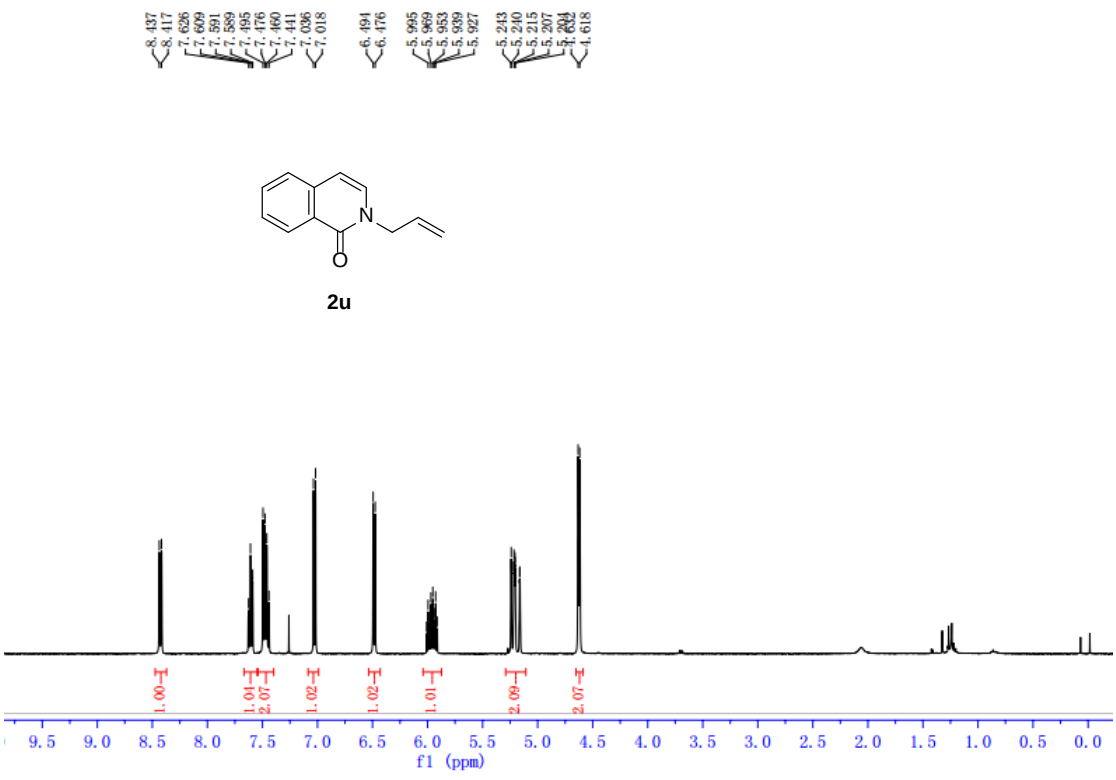
2s


8.478
8.460
7.620
7.485
7.466
7.285
7.266
7.224
7.214
7.210
6.778
6.372
6.354
4.227
4.209
4.190
3.111
3.092
3.074
N
Ph
O
1.00
1.02
2.05
5.20
1.01
1.01
2.05
2.04
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

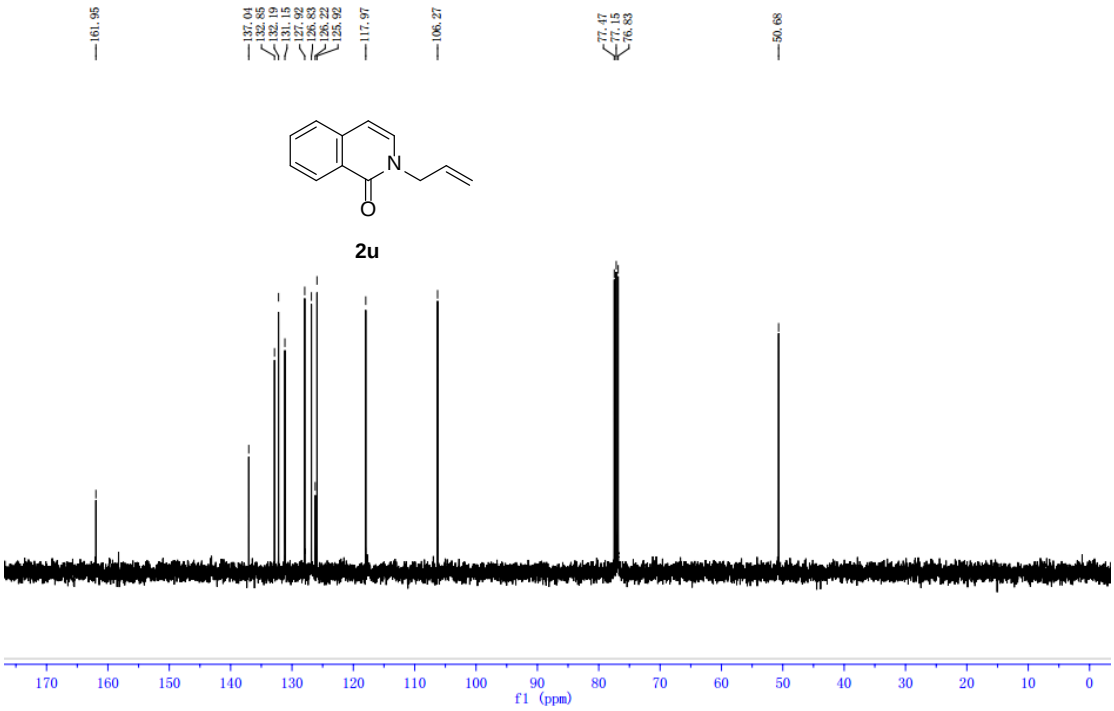
2t


162.10
138.32
137.12
132.11
131.99
129.03
128.68
127.78
126.77
126.66
126.25
125.91
105.69
77.42
77.10
76.79
51.59
35.32
N
Ph
O
f1 (ppm)

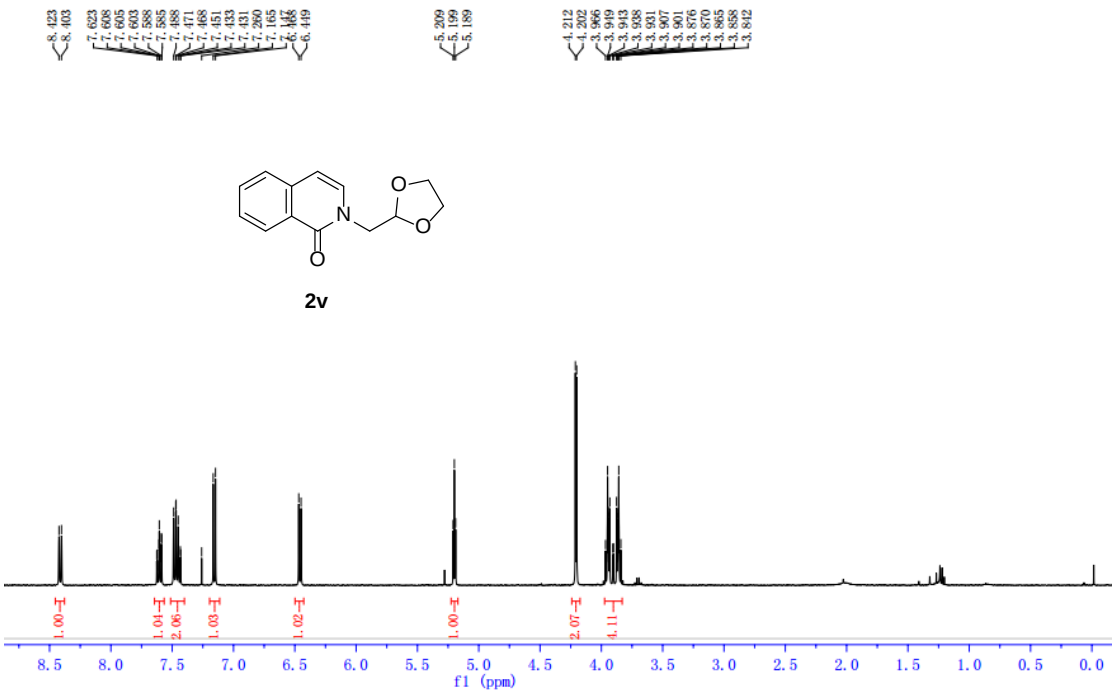
2t


8.437
8.417
7.626
7.609
7.591
7.589
7.495
7.476
7.460
7.441
7.036
7.018
6.494
6.476
5.995
5.969
5.953
5.939
5.927
5.243
5.240
5.215
5.207
4.618
N
O
1.00
1.04
2.07
1.02
1.02
1.01
2.09
2.07
f1 (ppm)

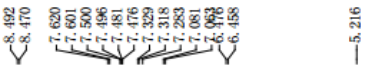
2u

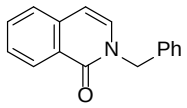

161.95
137.04
132.85
132.19
131.15
127.92
126.83
126.22
125.92
117.97
106.27
77.47
77.15
76.83
50.68
N
O
f1 (ppm)

2u

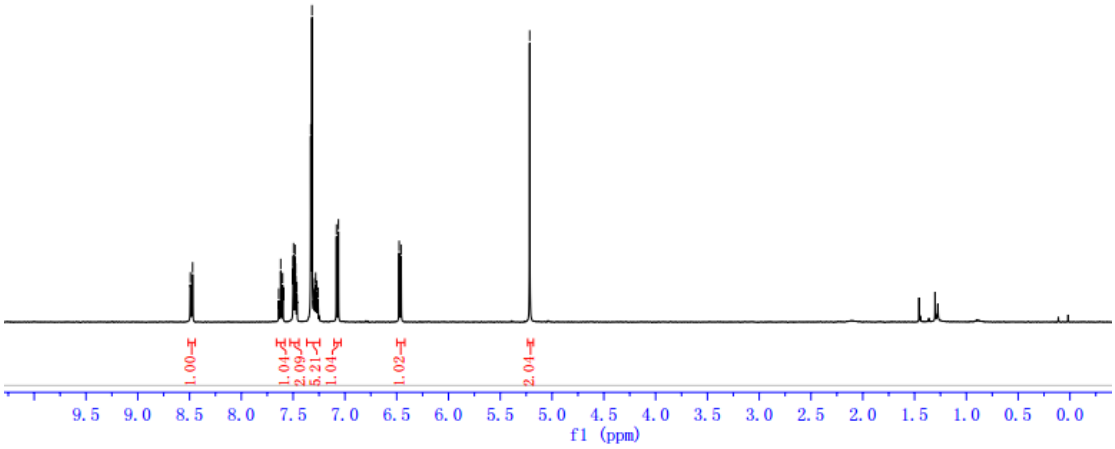

8.423
8.403
7.623
7.608
7.605
7.603
7.588
7.585
7.488
7.471
7.468
7.451
7.433
7.431
7.260
7.165
6.449
5.209
5.199
5.189
4.212
4.202
3.966
3.949
3.943
3.938
3.931
3.907
3.901
3.876
3.870
3.865
3.858
3.842
N
O
O
1.00
1.04
2.06
1.03
1.02
1.00
2.07
4.11
f1 (ppm)

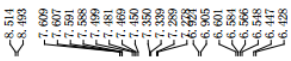
2v

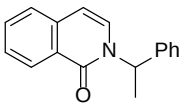

8.492
8.470
7.620
7.601
7.500
7.496
7.481
7.476
7.329
7.318
7.283
7.061
6.458
5.216


N
Ph
O

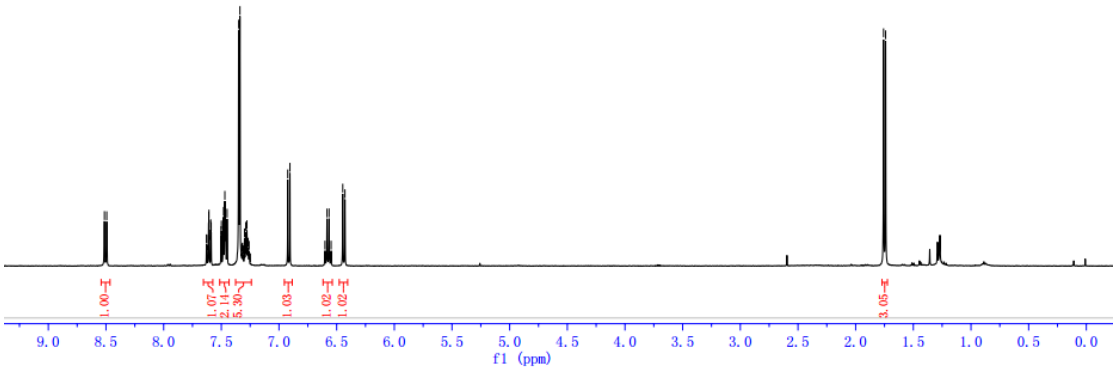
2w

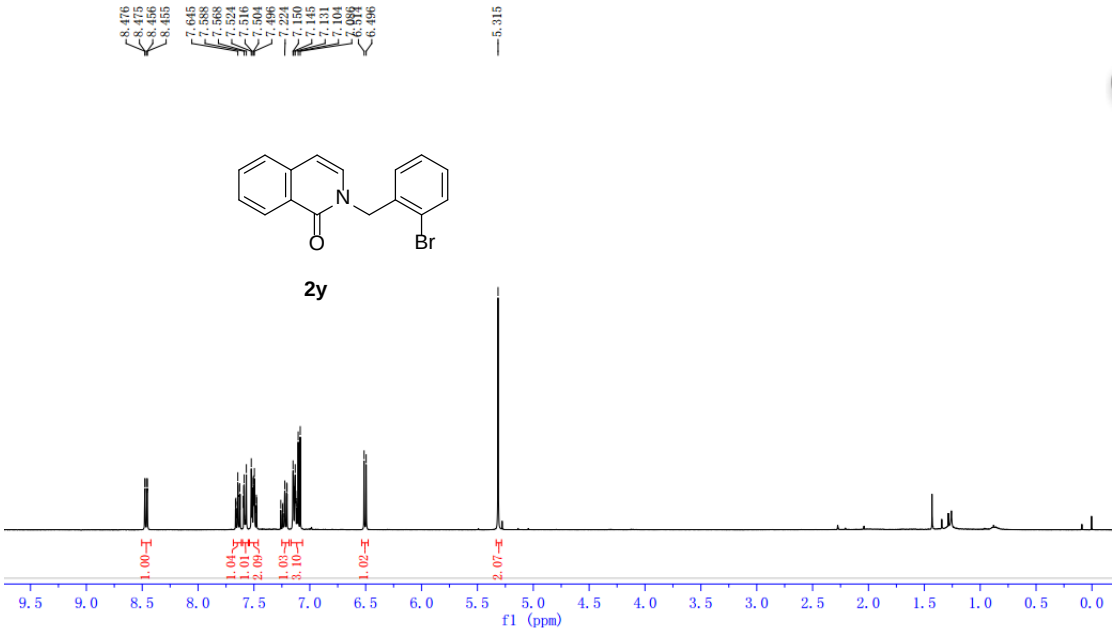

1.00
1.04
2.09
5.21
1.04
1.02
2.04
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.514
8.493
7.609
7.607
7.591
7.588
7.469
7.461
7.450
7.350
7.339
7.289
6.905
6.601
6.584
6.566
6.548
6.447
6.428
1.758
1.740

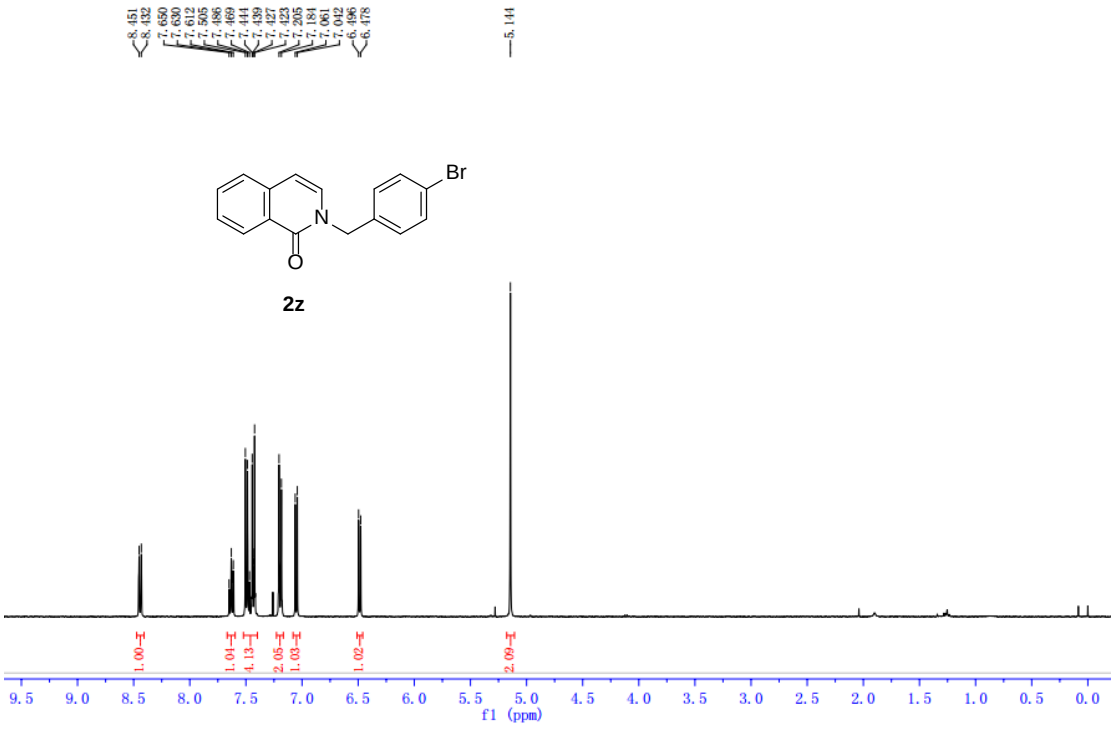

N
Ph
O

2x

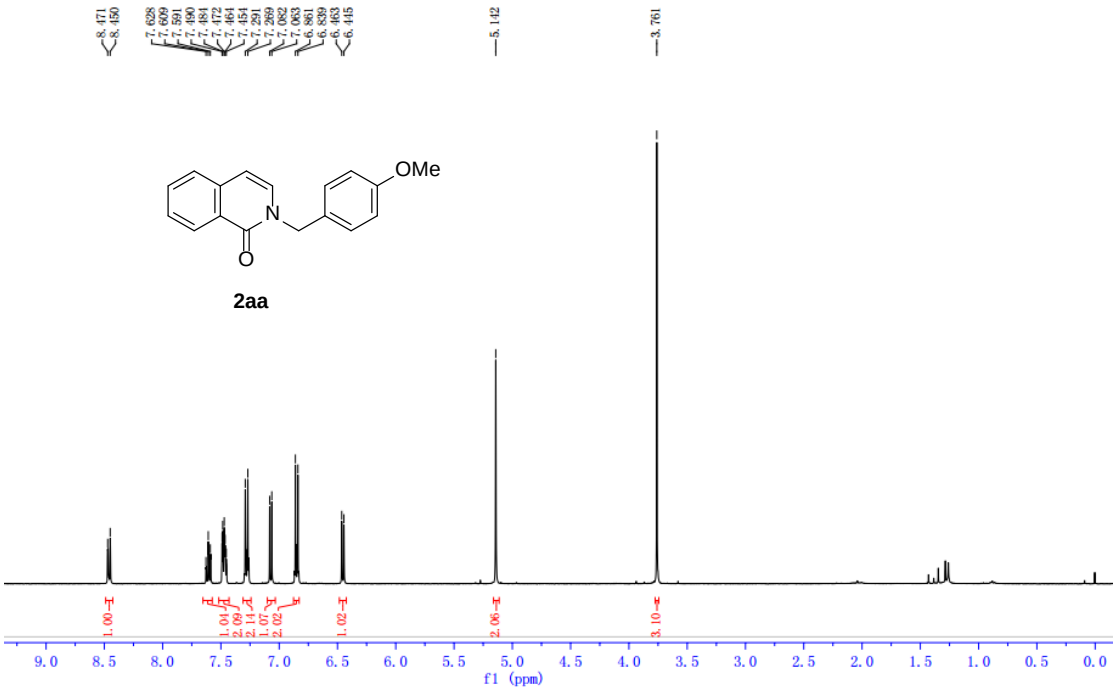

1.00
1.07
2.14
5.30
1.03
1.02
1.02
3.05
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.476
8.475
8.456
8.455
7.645
7.588
7.568
7.524
7.516
7.504
7.496
7.224
7.150
7.145
7.131
7.104
7.098
6.514
6.496
5.315
N
O
Br
1.00
1.04
1.01
2.69
1.03
3.10
1.02
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 0.5 0.0
f1 (ppm)

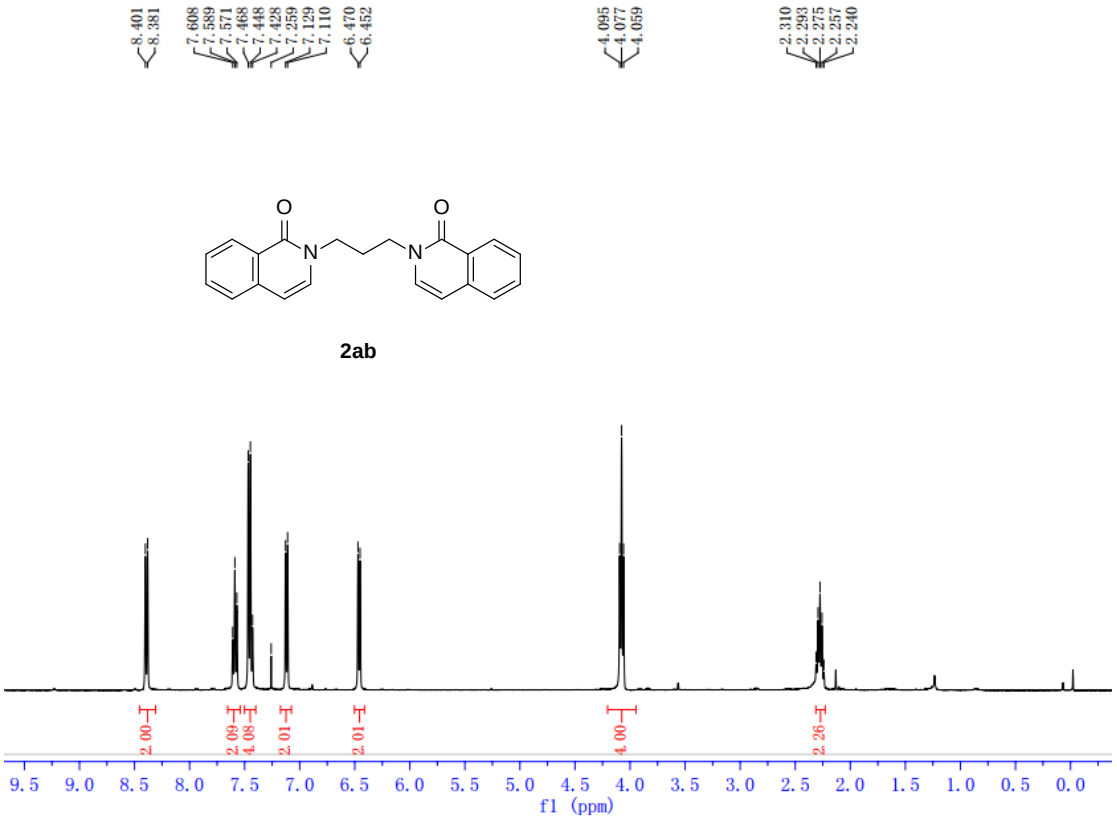
2y


8.451
8.432
7.650
7.630
7.612
7.505
7.486
7.469
7.444
7.439
7.427
7.423
7.295
7.184
7.061
7.042
6.496
6.478
5.144
Br
N
O
1.00
1.04
4.13
2.05
1.03
1.02
2.09
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

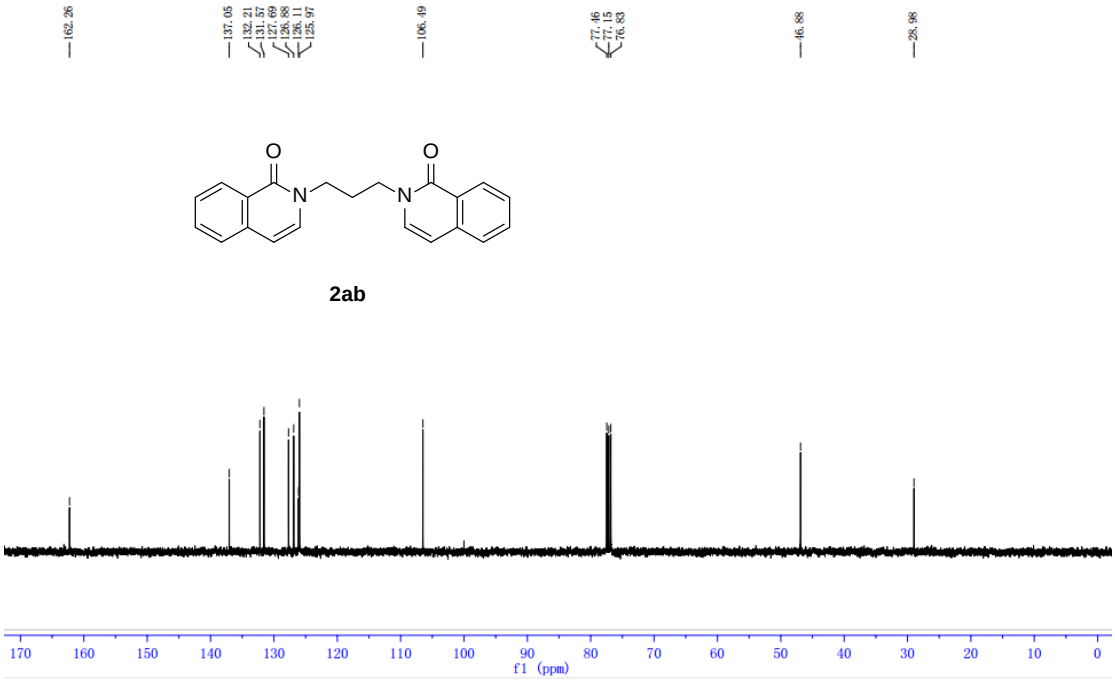
2z


8.471
8.450
7.628
7.609
7.591
7.490
7.481
7.472
7.464
7.454
7.291
7.269
7.082
7.063
6.861
6.839
6.463
6.445
5.142
3.761
OMe
N
O
1.00
1.01
2.09
2.14
1.07
2.02
1.02
2.06
3.10
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

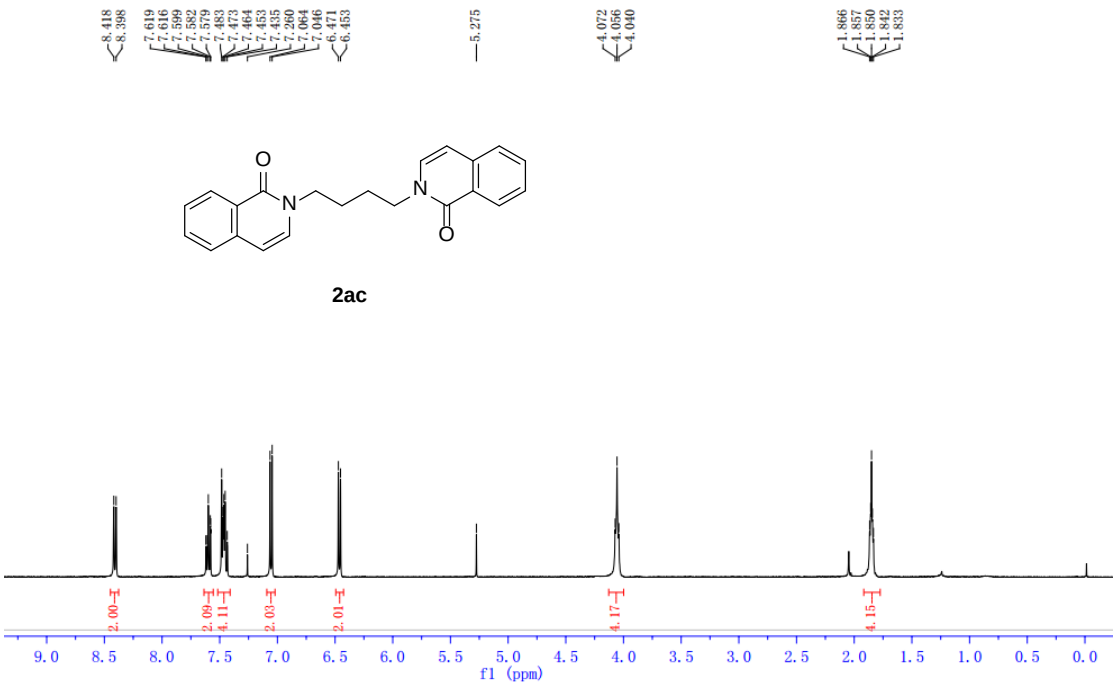
2aa


8.401
8.381
7.608
7.589
7.571
7.468
7.448
7.428
7.259
7.129
7.110
6.470
6.452
4.095
4.077
4.059
2.310
2.293
2.275
2.257
2.240
O
N
O
N
2.00
2.09
4.08
2.01
2.01
4.00
2.26
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

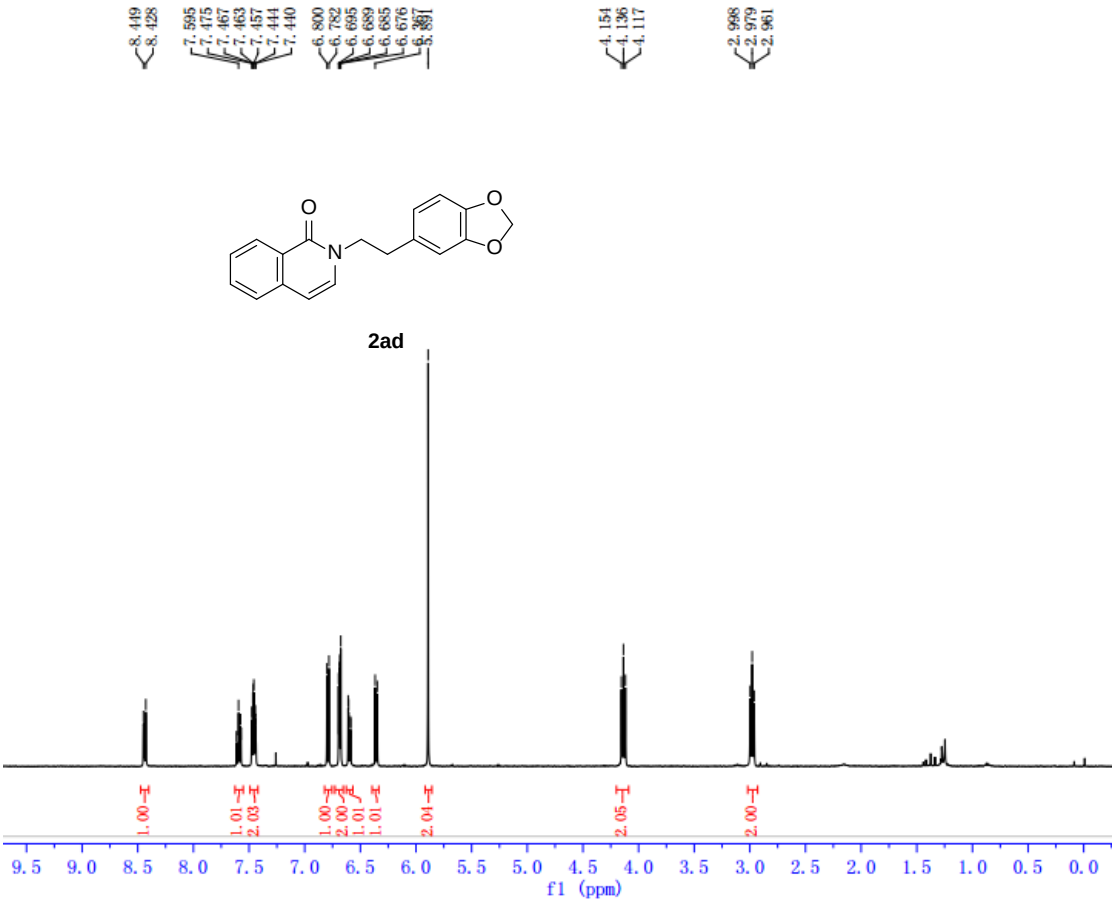
2ab

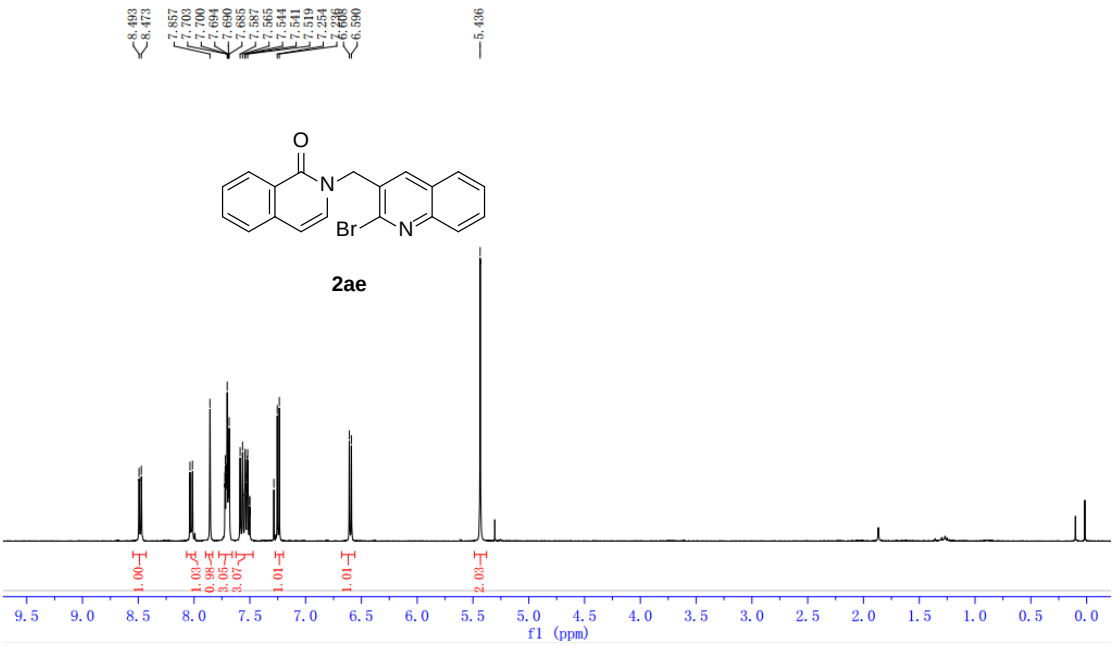

162.26
137.05
132.21
131.57
127.69
126.88
126.11
125.97
106.49
77.46
77.15
76.83
46.88
28.98
O
O
N
N
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

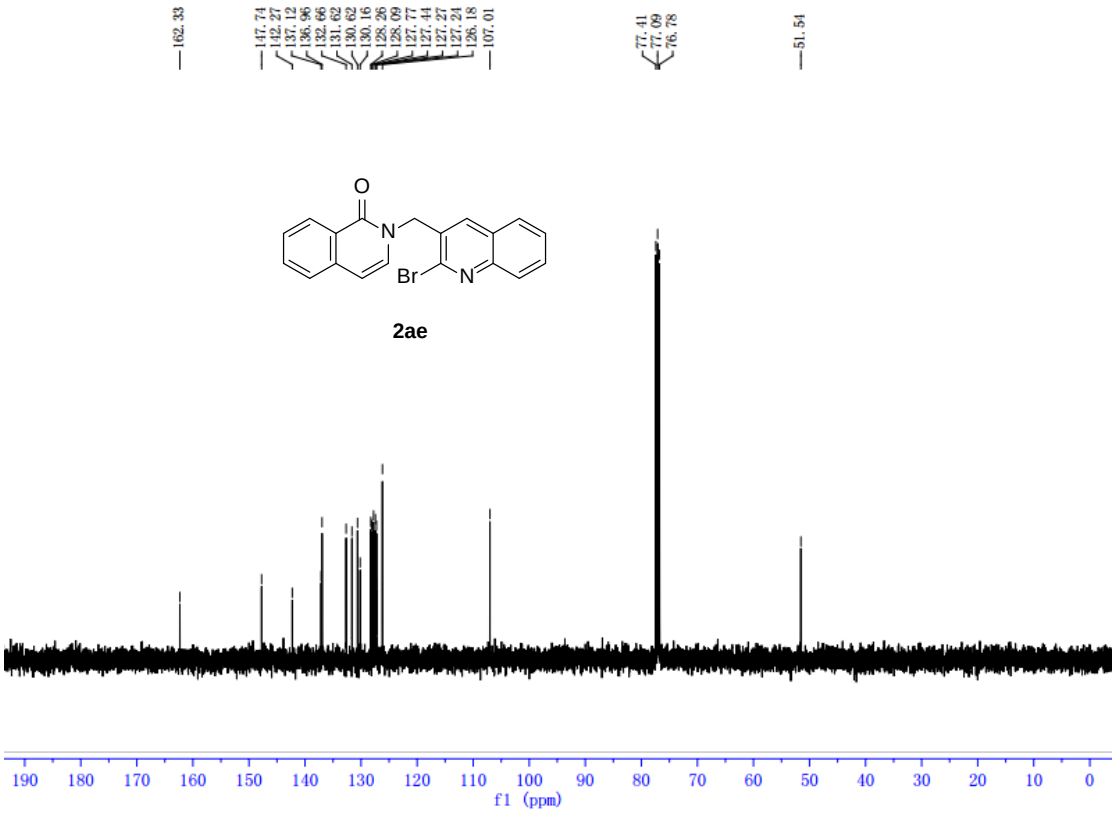
2ab


8.418
8.398
7.619
7.616
7.599
7.582
7.579
7.483
7.473
7.464
7.453
7.435
7.260
7.064
7.046
6.471
6.453
5.275
4.072
4.056
4.040
1.866
1.857
1.850
1.842
1.833
O
N
N
O
2.00
2.09
4.11
2.03
2.01
4.17
4.15
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

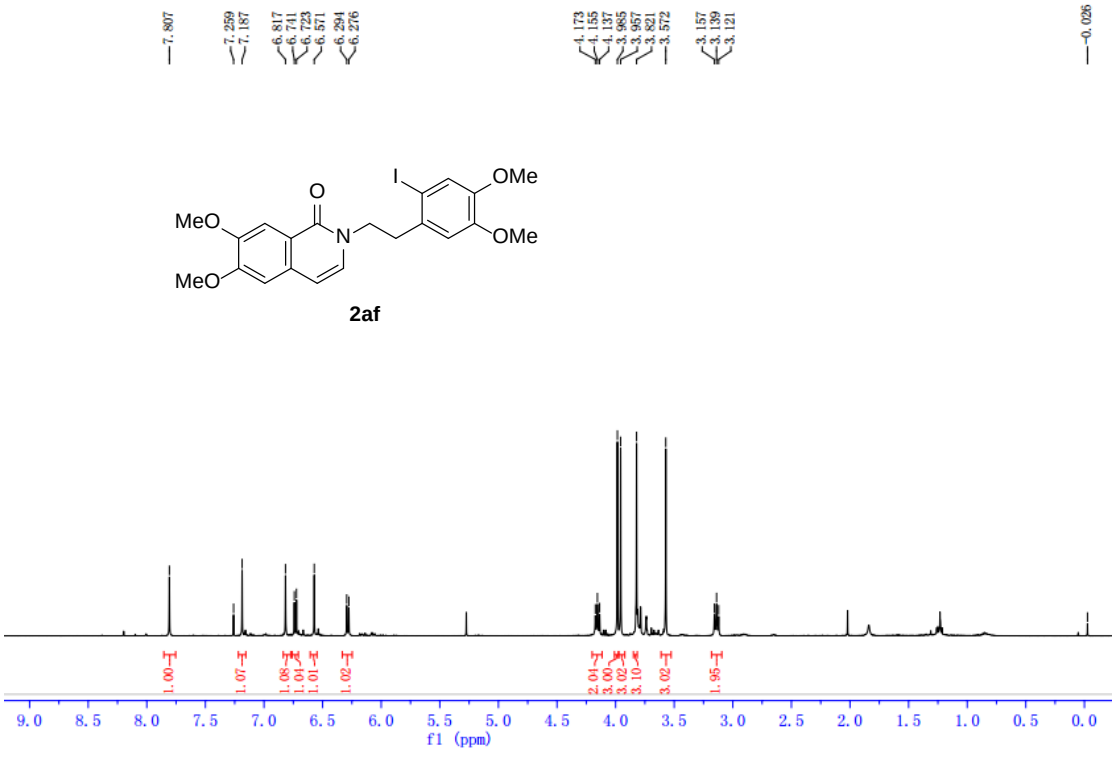
2ac


8.449
8.428
7.595
7.475
7.467
7.463
7.457
7.444
7.440
6.800
6.782
6.695
6.689
6.685
6.676
6.367
5.891
4.154
4.136
4.117
2.968
2.979
2.961
O
N
O
O
2ad
1.00
1.01
2.03
1.00
2.00
1.01
1.01
2.04
2.05
2.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

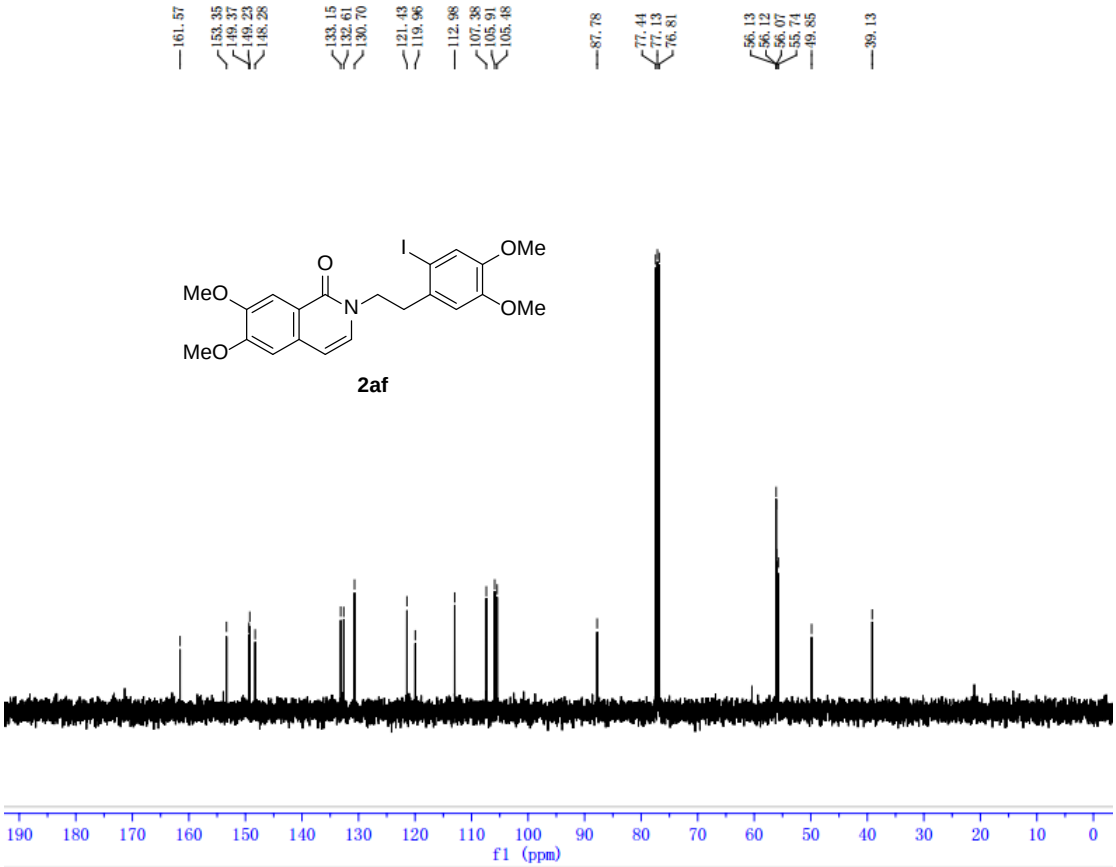

8.493
8.473
7.857
7.703
7.700
7.694
7.690
7.685
7.587
7.565
7.544
7.541
7.519
7.254
6.608
6.590
5.436
O
N
Br
N
2ae
1.00
1.03
0.98
3.05
3.07
1.01
1.01
2.03
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

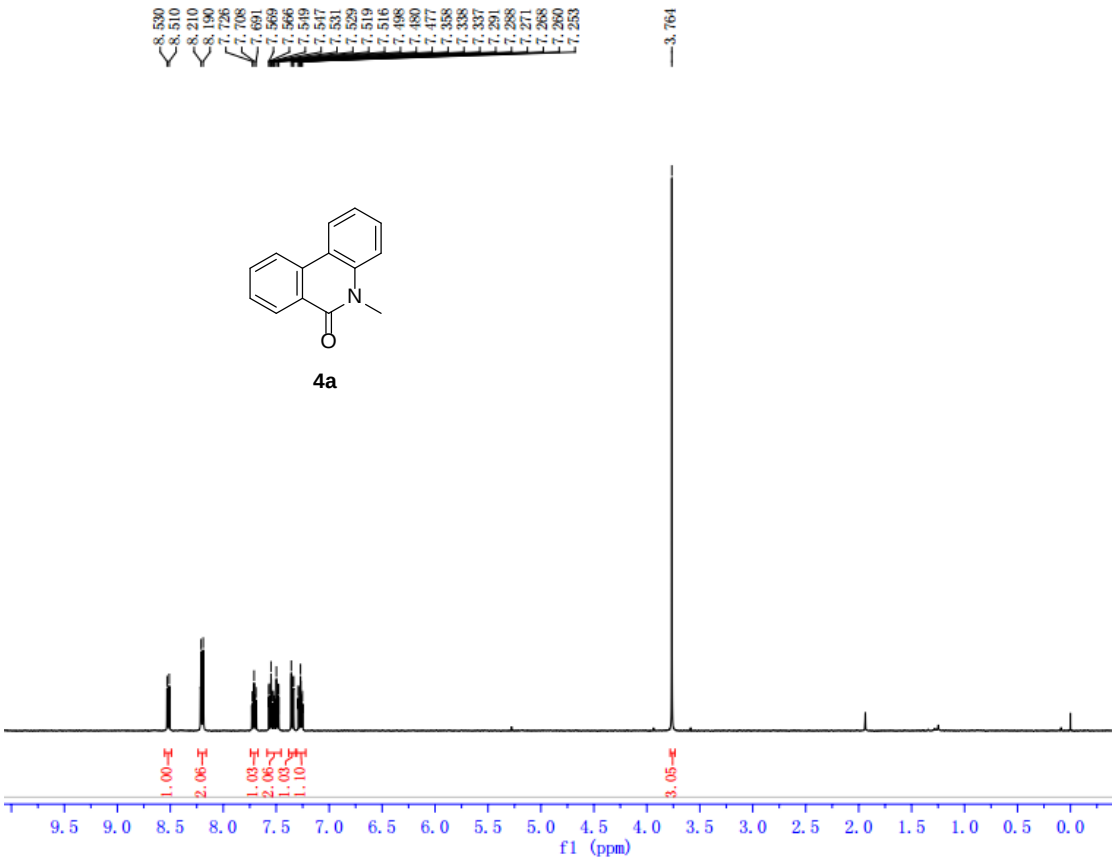

162.33
147.74
142.27
137.12
136.96
132.66
131.62
130.62
130.16
128.26
128.09
127.77
127.44
127.27
127.24
126.18
107.01
77.41
77.09
76.78
51.54
O
N
Br
N
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

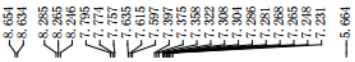
2ae

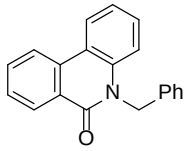

7.807
7.259
7.187
6.817
6.741
6.723
6.571
6.294
6.276
4.173
4.155
4.137
3.985
3.957
3.821
3.572
3.157
3.139
3.121
0.026
O
I
OMe
MeO
N
OMe
MeO
1.00
1.07
1.08
1.04
1.01
1.02
2.04
3.00
3.02
3.10
3.02
1.95
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

2af

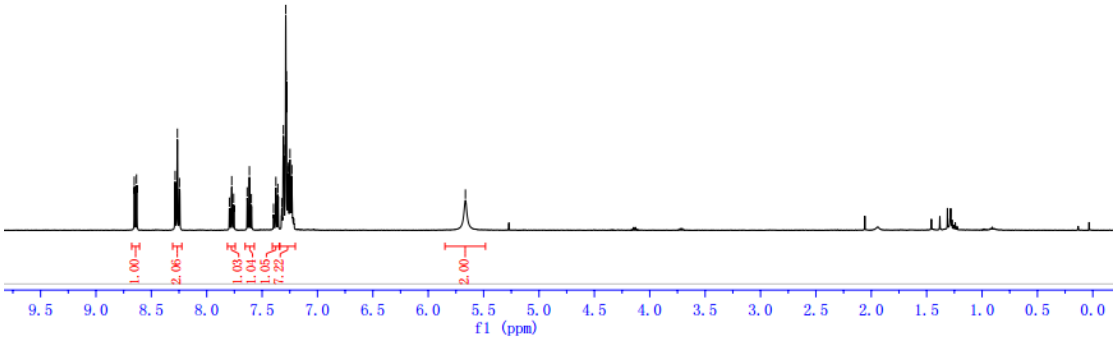

161.57
153.35
149.37
149.23
148.28
133.15
132.61
130.70
121.43
119.96
112.98
107.38
105.91
105.48
87.78
77.44
77.13
76.81
56.13
56.12
56.07
55.74
49.85
39.13
I
OMe
O
MeO
N
OMe
MeO
2af
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

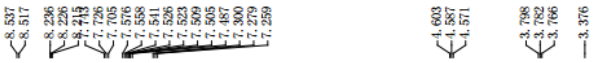

8.530
8.510
8.210
8.190
7.726
7.708
7.691
7.569
7.566
7.549
7.547
7.531
7.529
7.519
7.516
7.498
7.480
7.477
7.358
7.338
7.337
7.291
7.288
7.271
7.268
7.260
7.253
3.764
N
O
4a
1.00
2.06
1.03
2.06
1.03
1.10
3.05
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

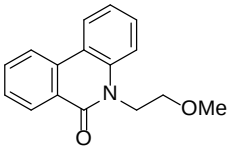

8.654
8.634
8.285
8.265
8.246
7.795
7.774
7.757
7.635
7.615
7.597
7.397
7.375
7.358
7.322
7.308
7.304
7.296
7.281
7.268
7.265
7.218
7.231
5.664


N
Ph
O

4b

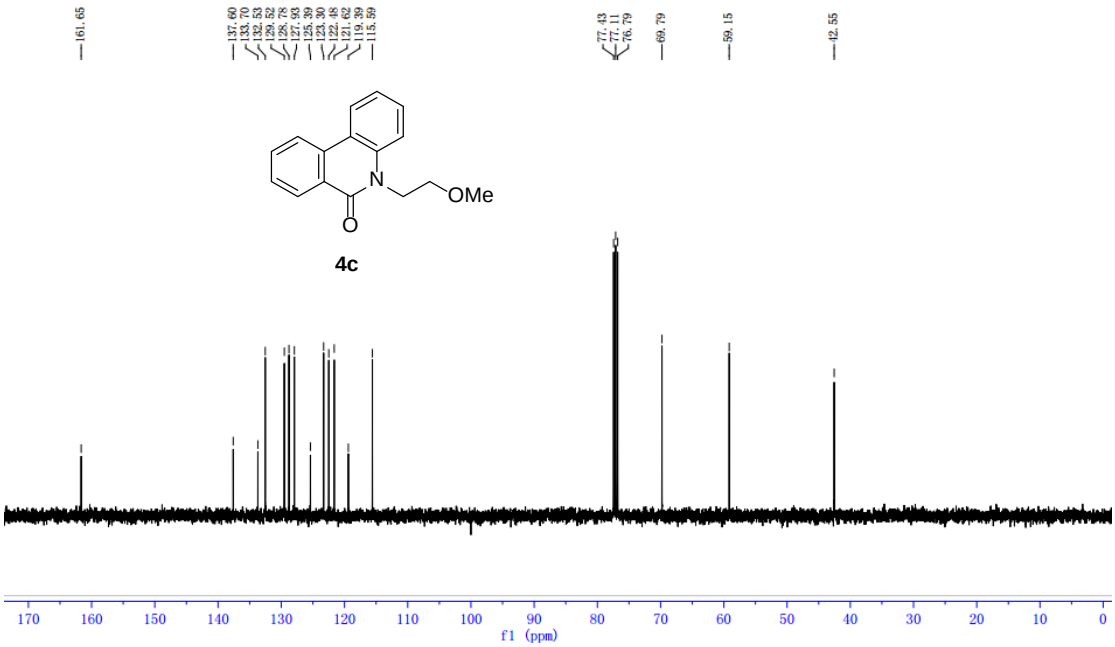

1.00
2.06
1.03
1.04
1.05
7.22
2.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.537
8.517
8.236
8.226
8.215
7.743
7.726
7.705
7.576
7.558
7.541
7.526
7.523
7.509
7.505
7.487
7.300
7.279
7.259
4.603
4.587
4.571
3.798
3.782
3.766
3.376

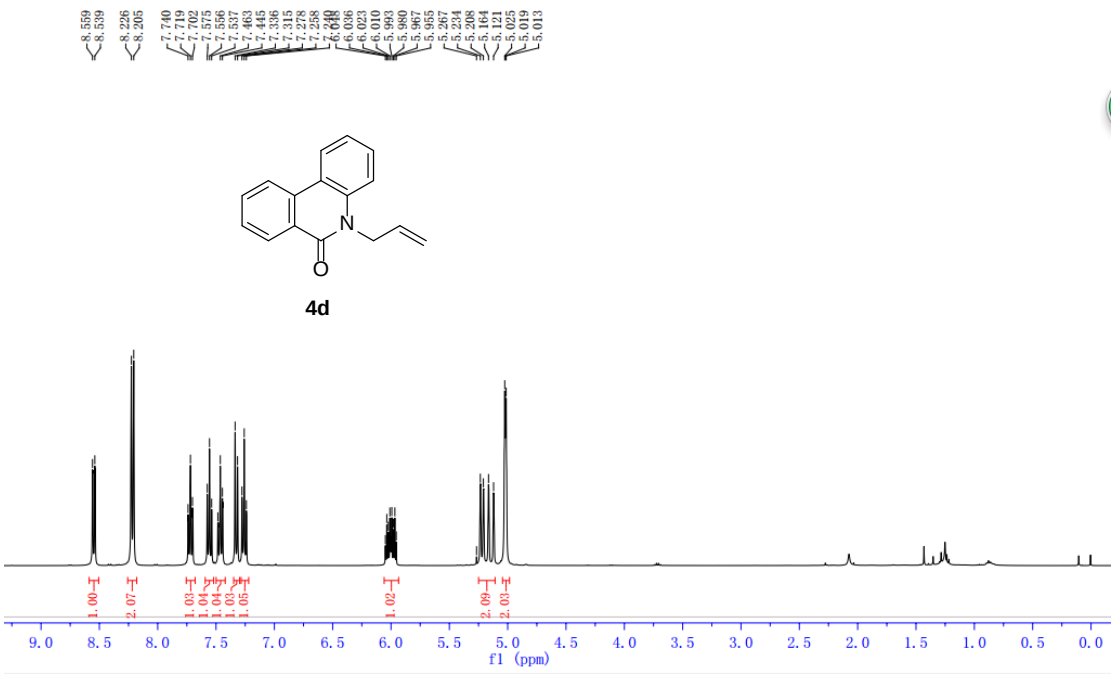

N
OMe
O

4c

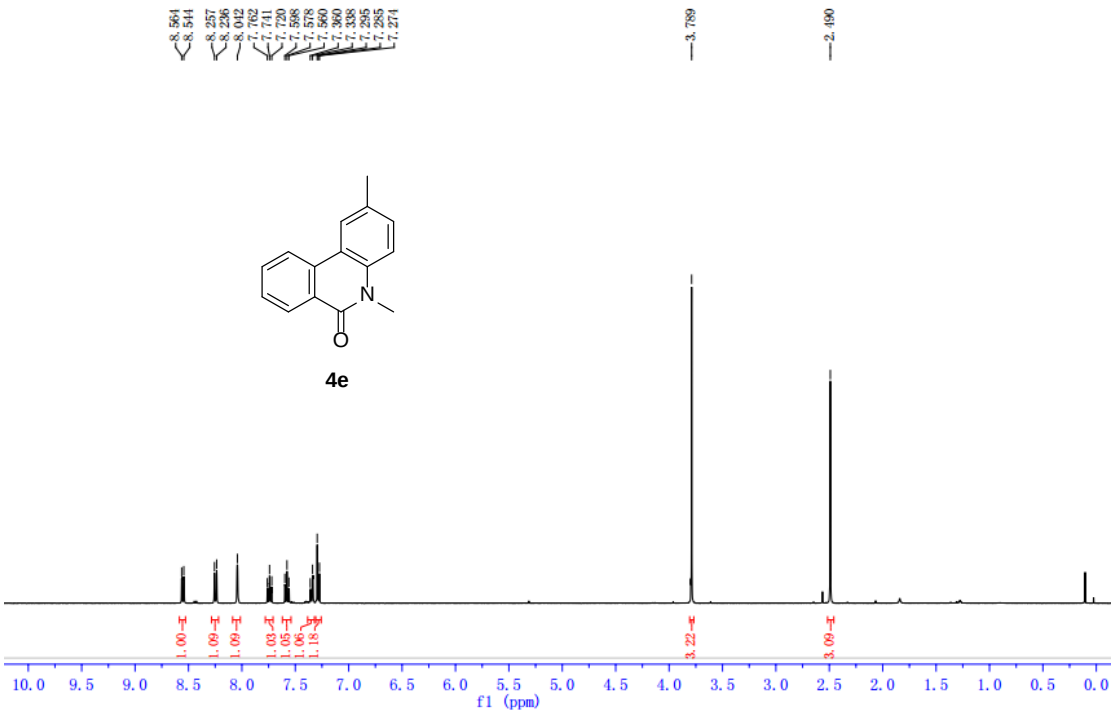
1.00
2.07
1.07
3.15
1.11
2.09
2.09
3.08
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


161.65
137.60
133.70
132.53
129.52
126.78
125.93
125.30
123.30
122.48
121.62
119.39
115.59
77.43
77.11
76.79
69.79
59.15
42.55
N
OMe
O
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

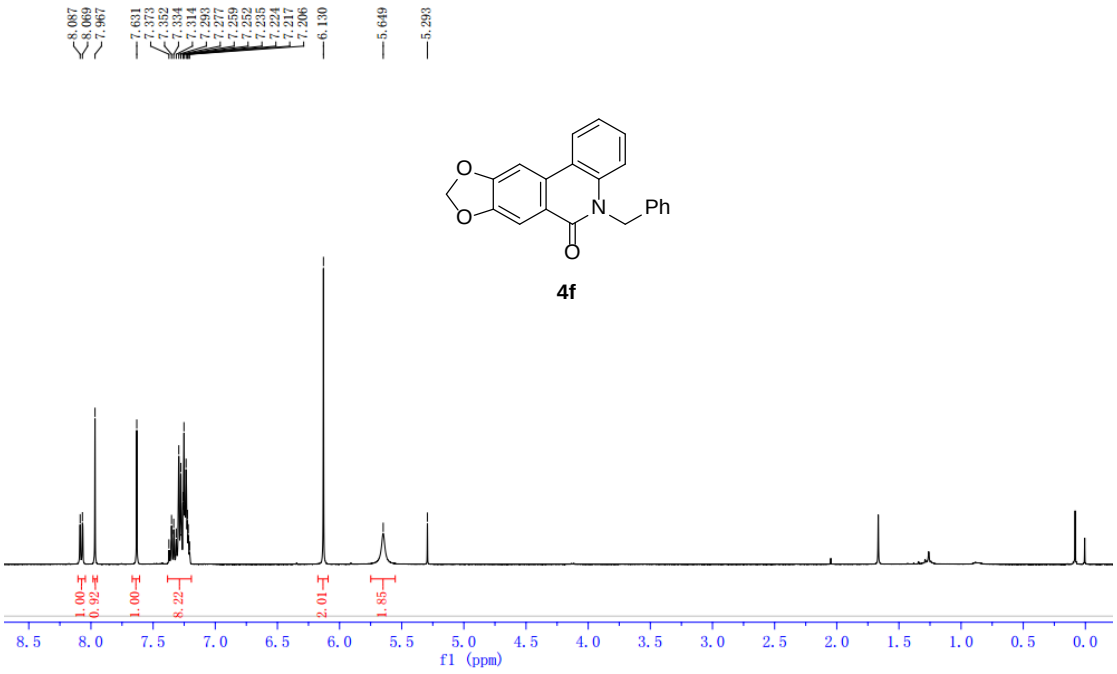
4c


8.559
8.539
8.226
8.205
7.740
7.719
7.702
7.575
7.556
7.537
7.463
7.445
7.336
7.315
7.278
7.258
6.036
6.023
6.010
5.993
5.980
5.967
5.955
5.267
5.234
5.208
5.164
5.121
5.025
5.019
5.013
N
O
1.00
2.07
1.03
1.04
1.04
1.03
1.05
1.02
2.09
2.03
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

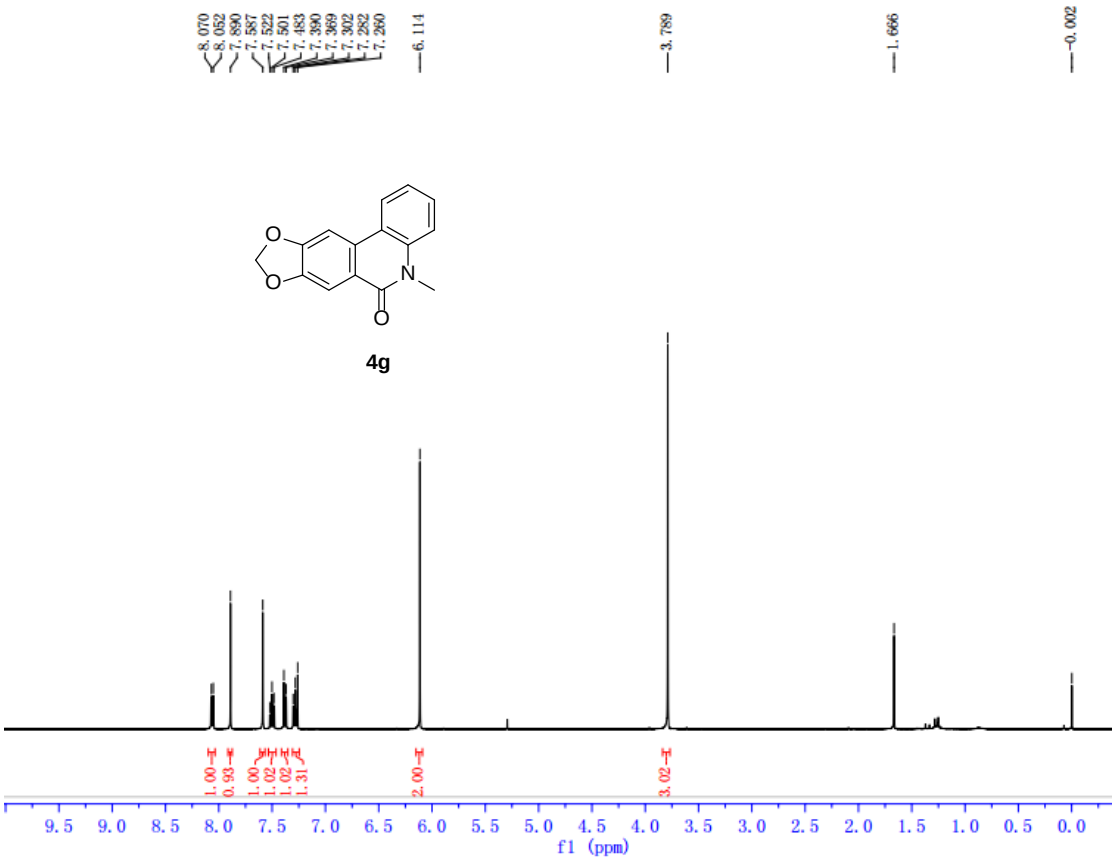
4d

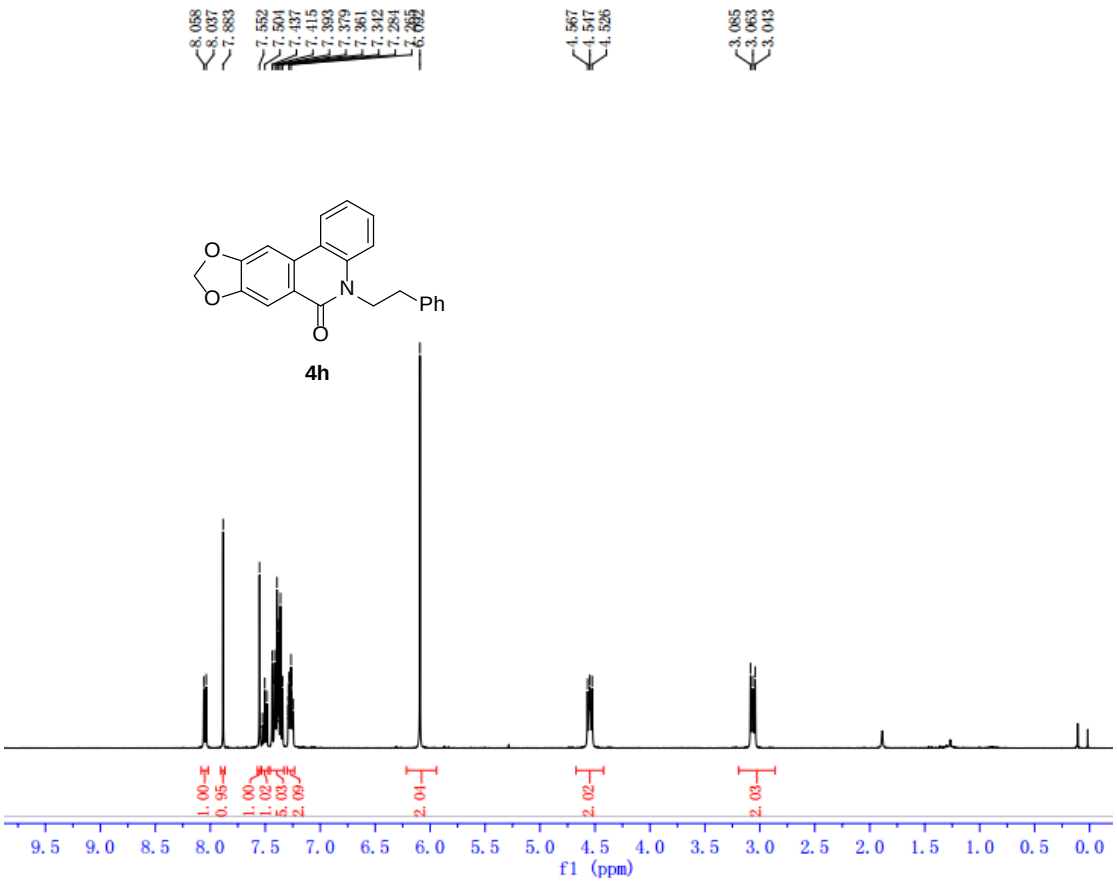

8.564
8.544
8.257
8.236
8.042
7.762
7.741
7.720
7.598
7.578
7.560
7.360
7.338
7.295
7.285
7.274
3.789
2.490
N
O
1.00
1.09
1.09
1.03
1.05
1.06
1.18
3.22
3.09
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

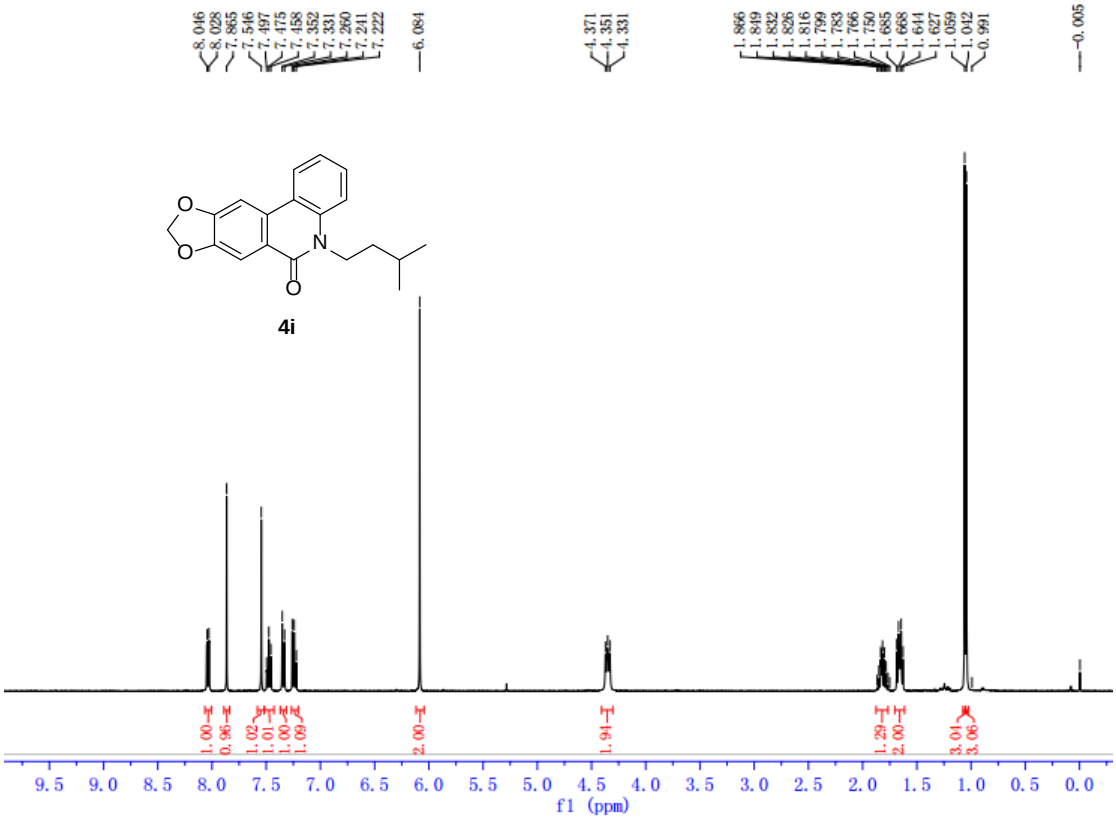
4e

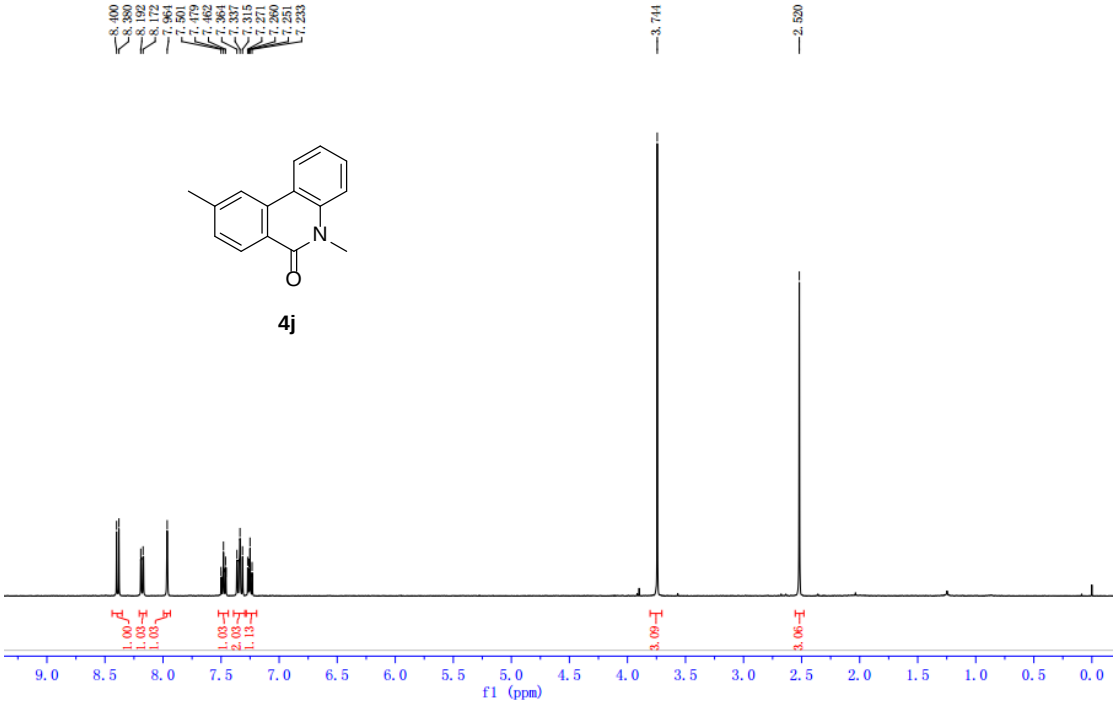

8.087
8.069
7.967
7.631
7.373
7.352
7.334
7.314
7.293
7.277
7.259
7.252
7.235
7.224
7.217
7.206
6.130
5.649
5.293
O
O
N
Ph
O
1.00
0.92
1.00
8.22
2.01
1.85
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

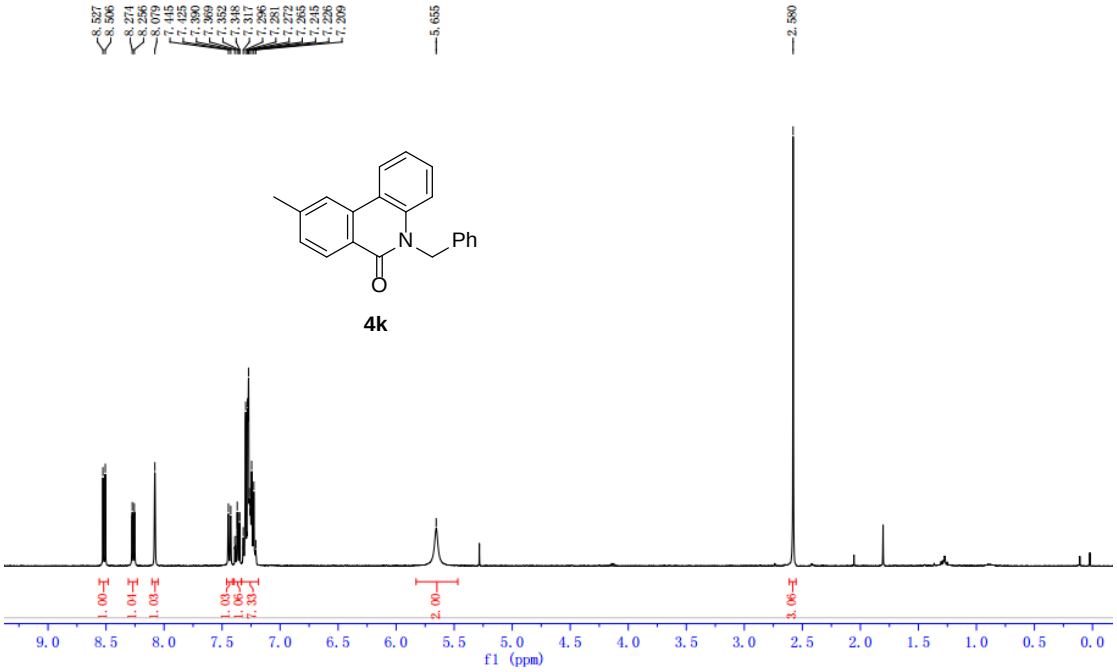
4f


8.070
8.052
7.890
7.587
7.522
7.501
7.483
7.390
7.369
7.302
7.282
7.260
6.114
3.789
1.666
0.002
O
O
N
O
4g
1.00
0.93
1.00
1.02
1.02
1.31
2.00
3.02
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

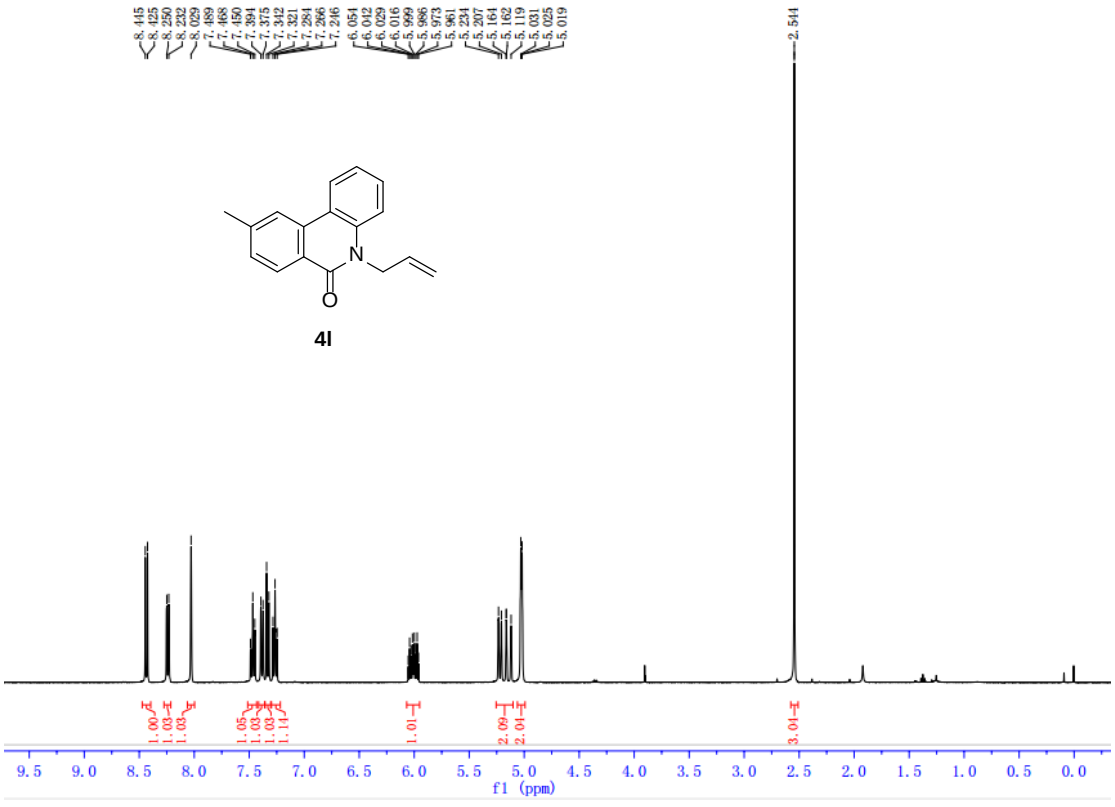

8.058
8.037
7.883
7.552
7.504
7.437
7.415
7.393
7.379
7.361
7.342
7.291
4.567
4.547
4.526
3.065
3.063
3.043
O
O
N
Ph
O
4h
1.00
0.95
1.00
1.02
5.03
2.09
2.04
2.02
2.03
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.046
8.028
7.865
7.546
7.497
7.475
7.458
7.352
7.331
7.260
7.241
7.222
6.084
4.371
4.351
4.331
1.866
1.849
1.832
1.826
1.816
1.799
1.783
1.766
1.750
1.685
1.668
1.644
1.627
1.059
1.042
0.991
0.005
O
O
N
O
4i
1.00
0.96
1.02
1.01
1.00
1.09
2.00
1.94
1.29
2.00
3.04
3.06
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

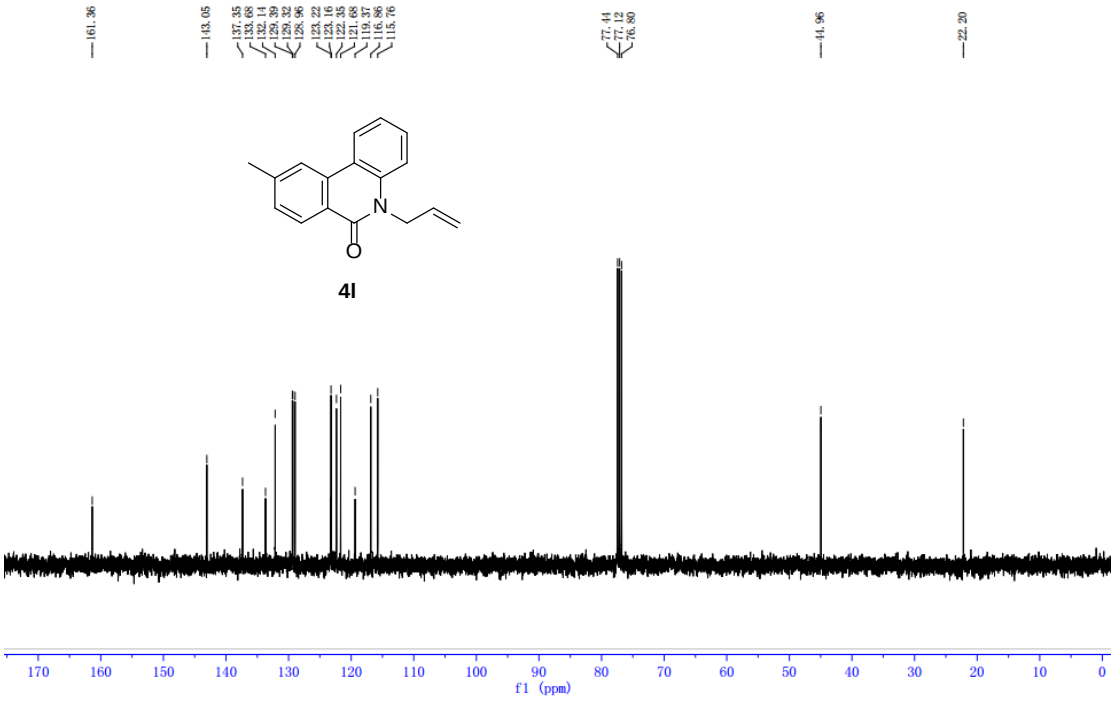

8.400
8.390
8.192
8.172
7.964
7.501
7.479
7.462
7.364
7.337
7.315
7.271
7.260
7.251
7.233
3.744
2.520
N
O
4j
1.00
1.03
1.03
1.03
2.03
1.13
3.09
3.06
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


8.527
8.506
8.274
8.256
8.079
7.445
7.425
7.390
7.369
7.352
7.348
7.317
7.296
7.281
7.272
7.265
7.245
7.226
7.209
5.655
2.580
N
Ph
O
1.00
1.01
1.03
1.03
1.06
7.33
2.00
3.06
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

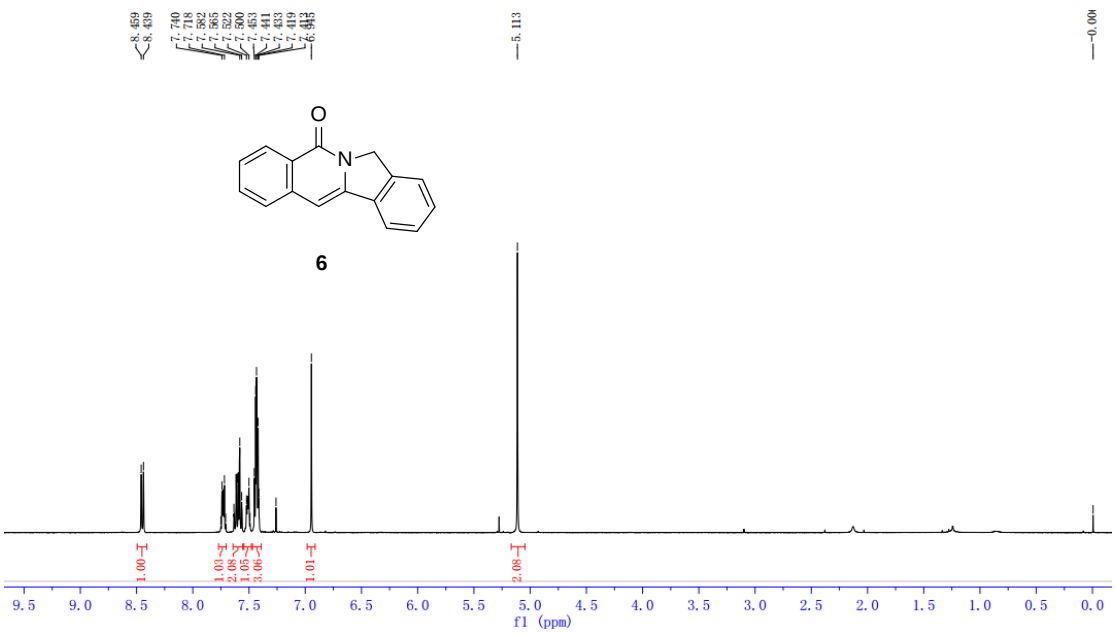
4k


8.445
8.425
8.250
8.232
8.029
7.489
7.468
7.450
7.394
7.375
7.342
7.321
7.284
7.266
7.246
6.054
6.042
6.029
6.016
5.999
5.986
5.973
5.961
5.234
5.207
5.164
5.162
5.119
5.031
5.025
5.019
2.544
N
O
1.00
1.03
1.03
1.05
1.03
1.03
1.14
1.01
2.09
2.01
3.01
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

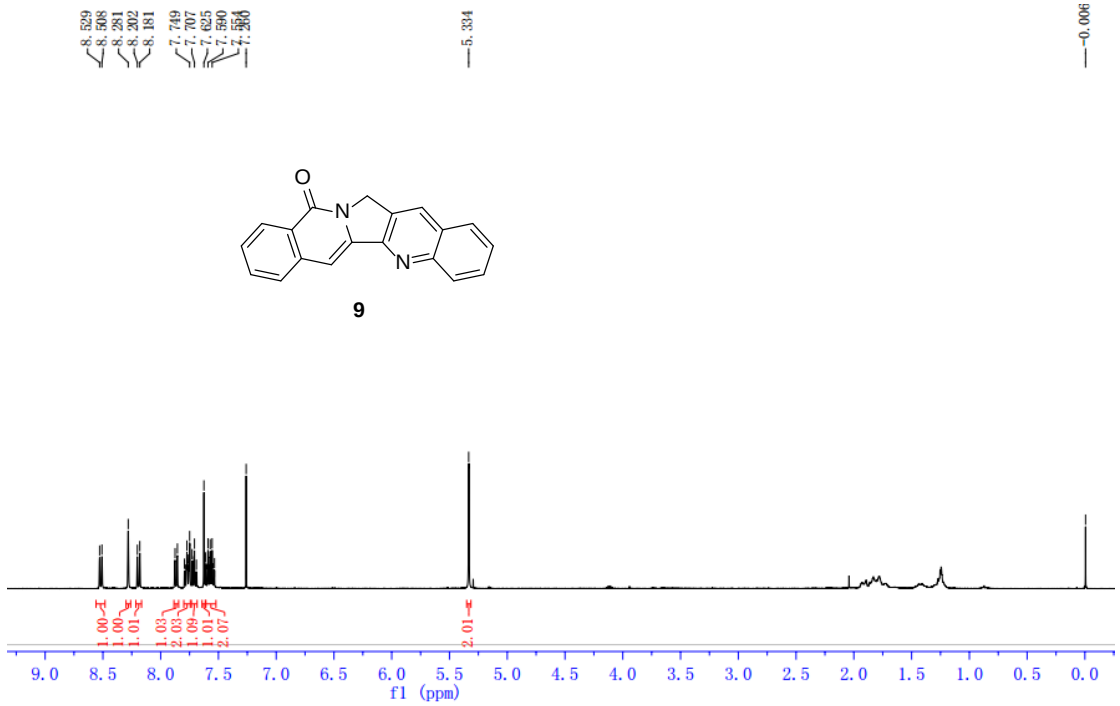
4l

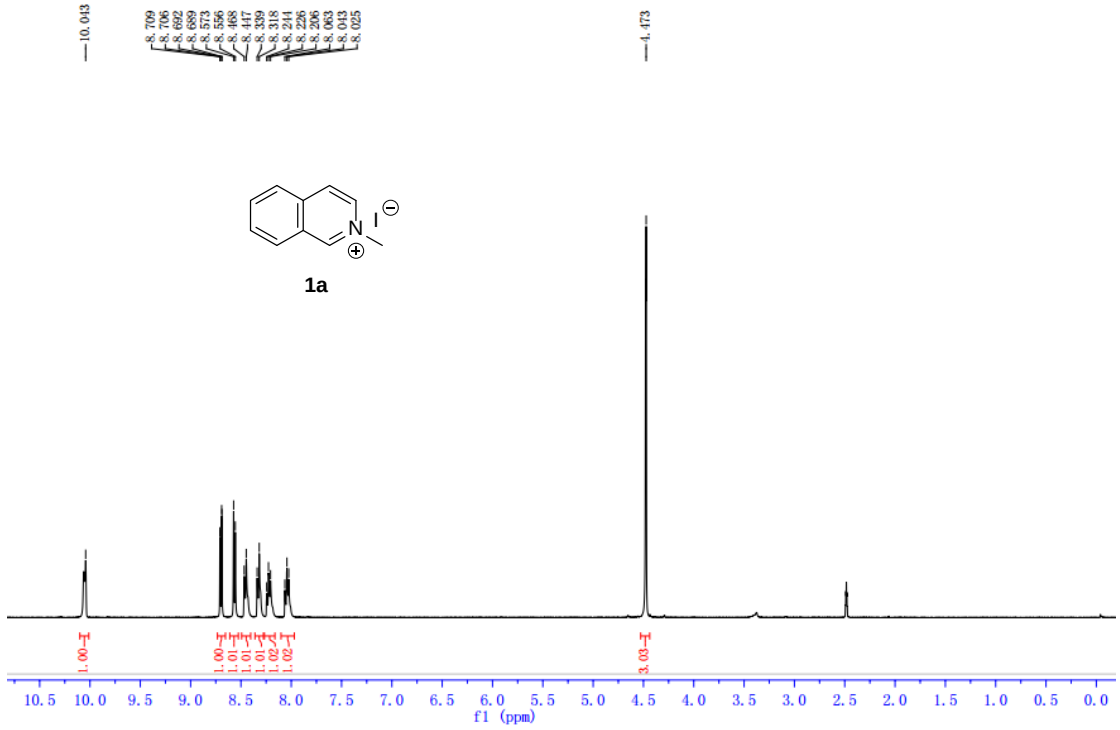

161.36
143.05
137.35
133.68
132.14
129.39
129.32
128.96
123.22
123.16
122.35
121.68
119.57
116.86
115.76
77.44
77.12
76.80
44.96
22.20
O
N
f1 (ppm)

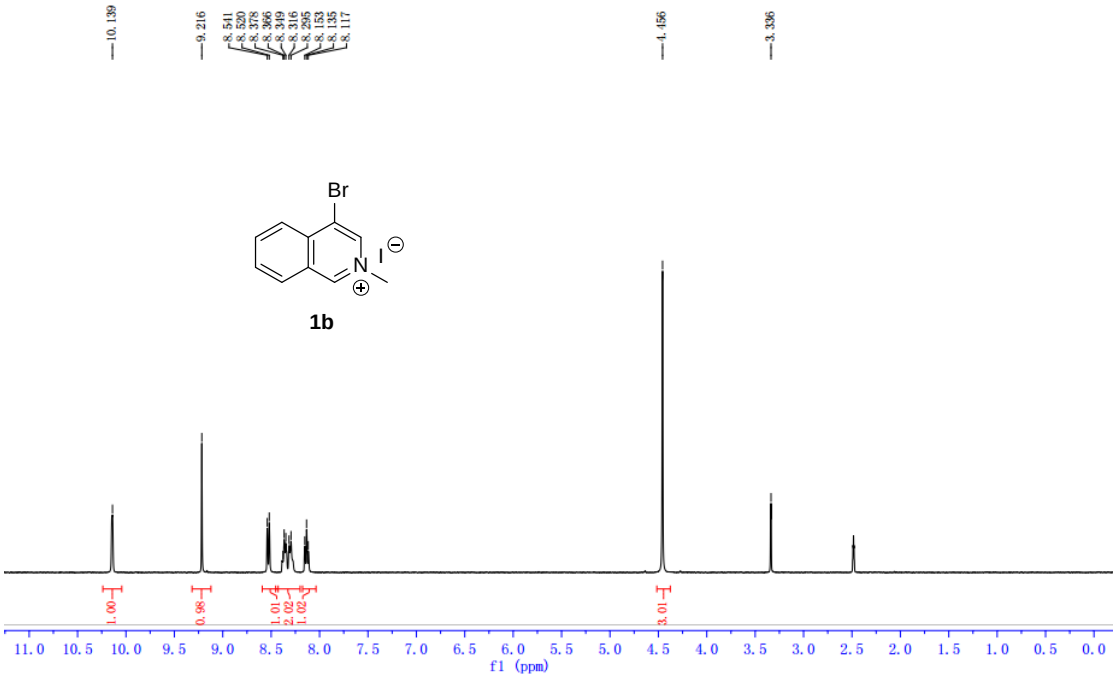
4l

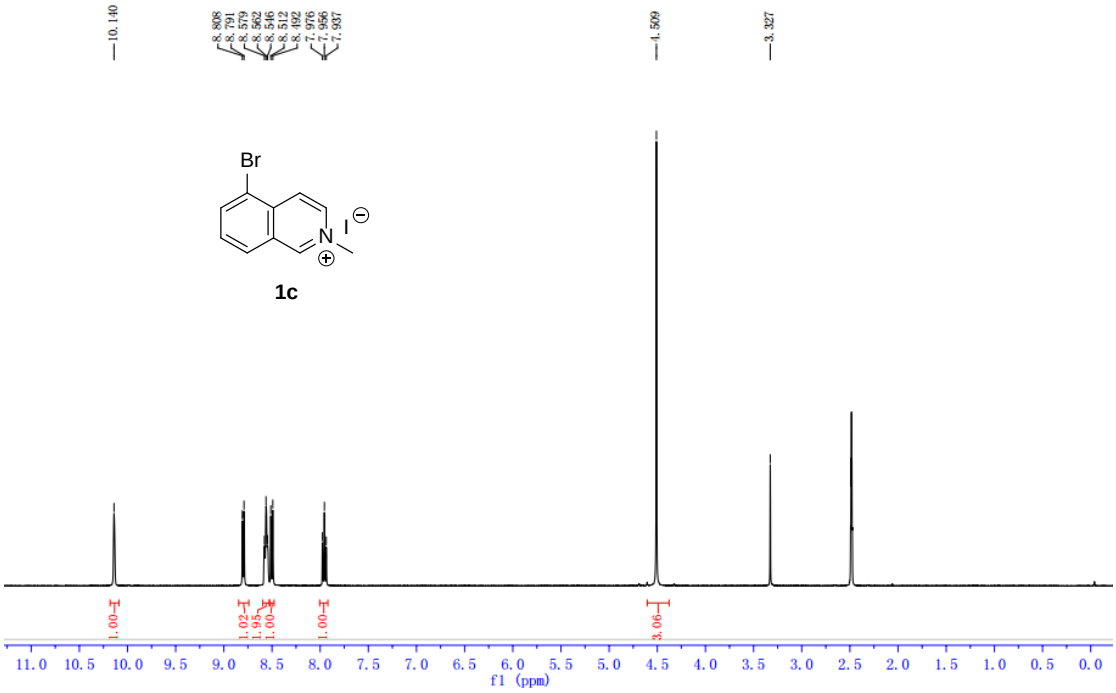

8.459
8.439
7.740
7.718
7.582
7.565
7.522
7.500
7.490
7.441
7.433
7.419
5.113
0.000
O
N
1.00
1.03
2.08
1.05
3.06
1.01
2.08
f1 (ppm)

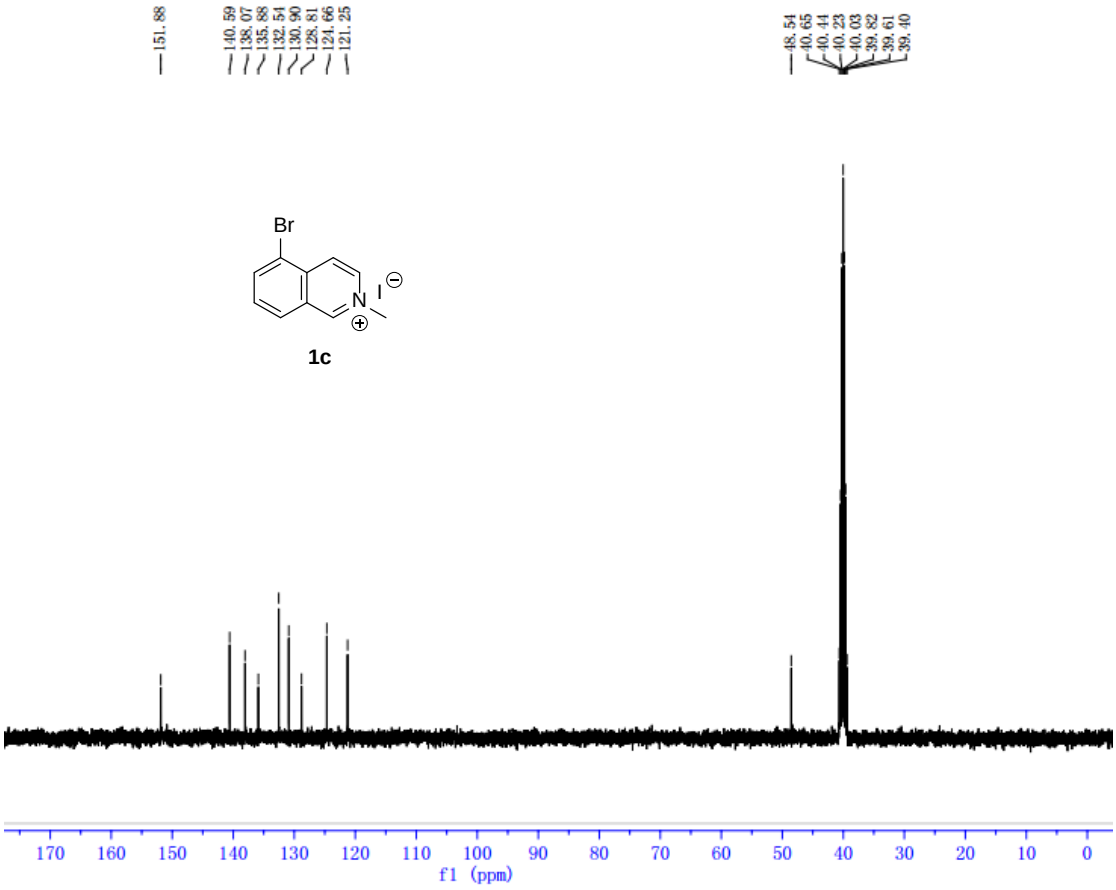
6

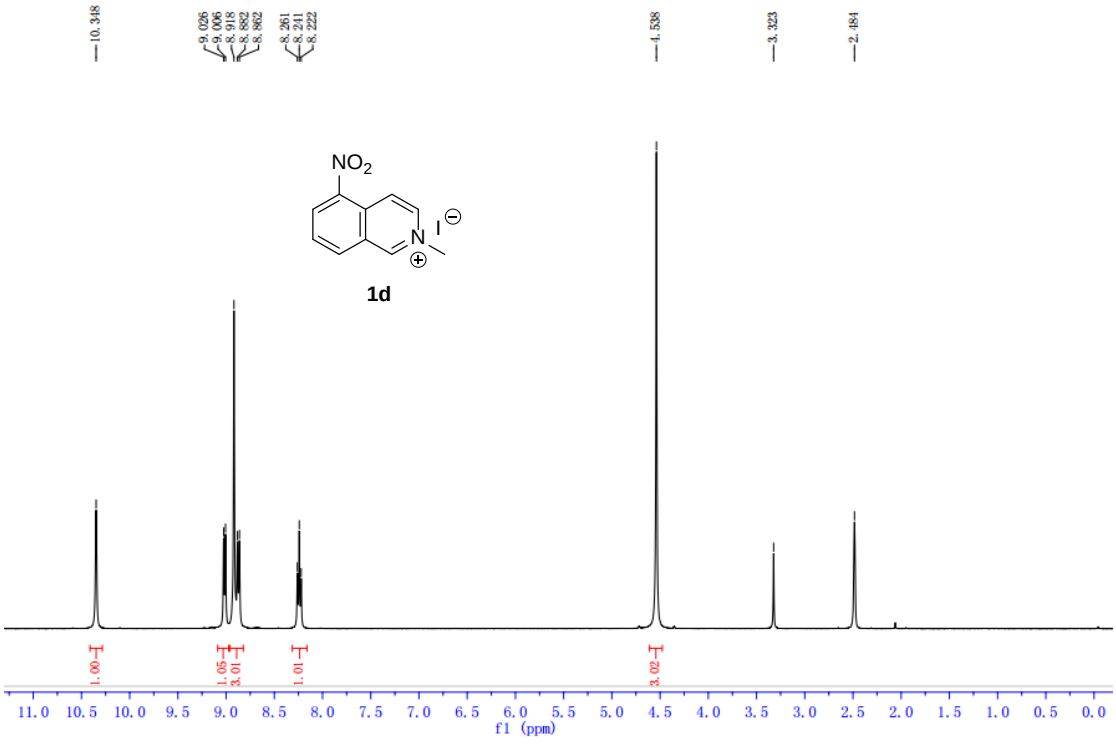

8.529
8.508
8.291
8.202
8.181
7.749
7.707
7.625
7.590
5.334
0.006
O
N
N
9
1.00
1.00
1.01
1.03
2.03
1.09
1.01
2.07
2.01
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

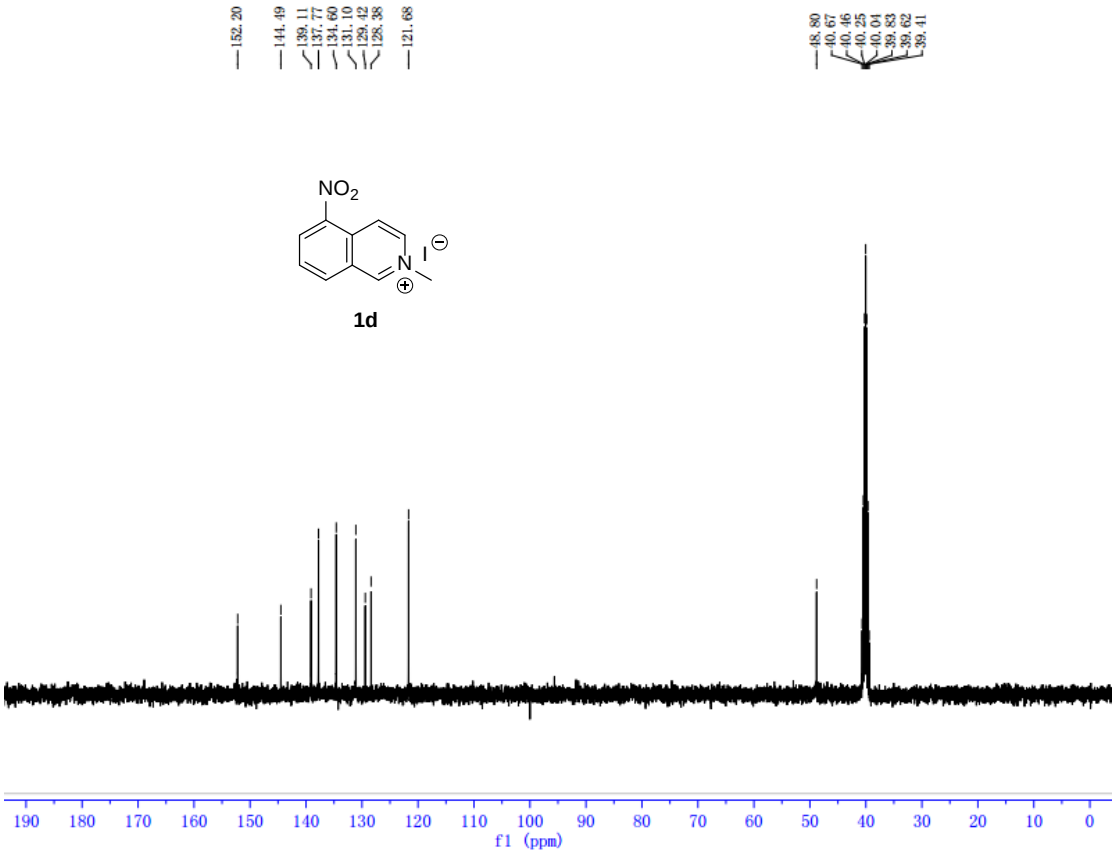

10.043
8.709
8.706
8.692
8.689
8.573
8.556
8.468
8.447
8.339
8.318
8.241
8.226
8.206
8.063
8.043
8.025
4.473
N
I
1a
1.00
1.00
1.01
1.01
1.01
1.02
1.02
3.03
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

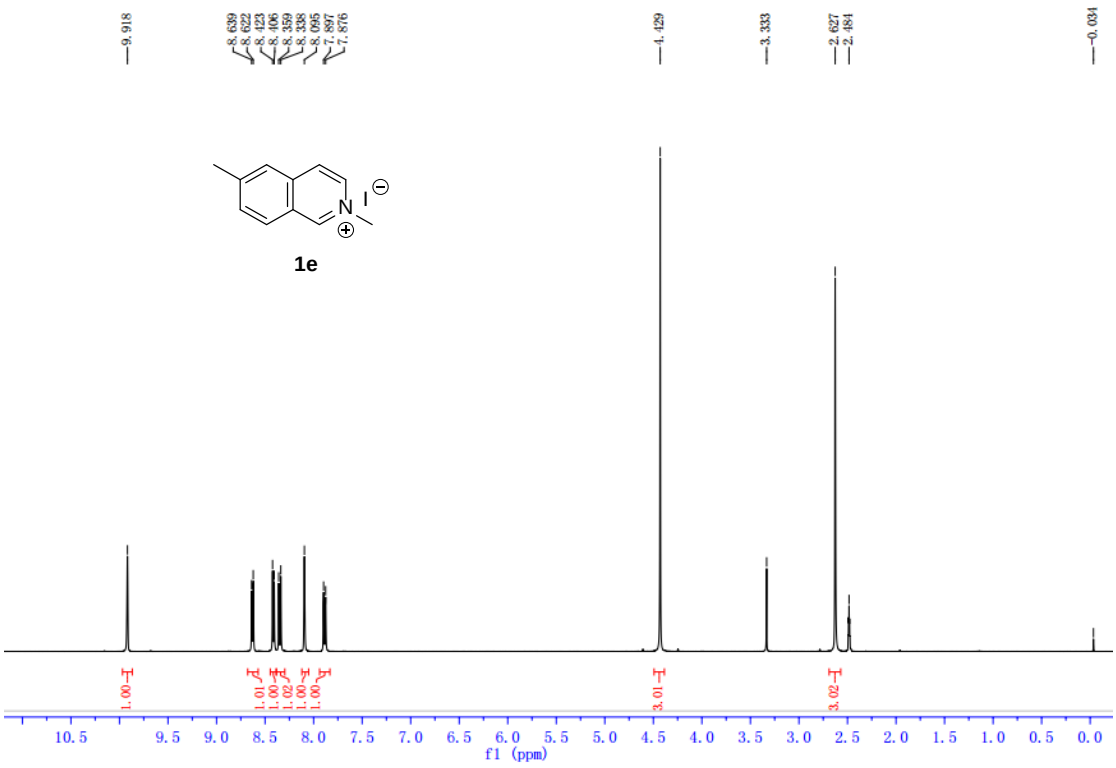

10.139
9.216
8.541
8.520
8.378
8.366
8.349
8.316
8.295
8.153
8.135
8.117
4.456
3.336
Br
N
I
1b
1.00
0.98
1.01
2.02
1.02
3.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

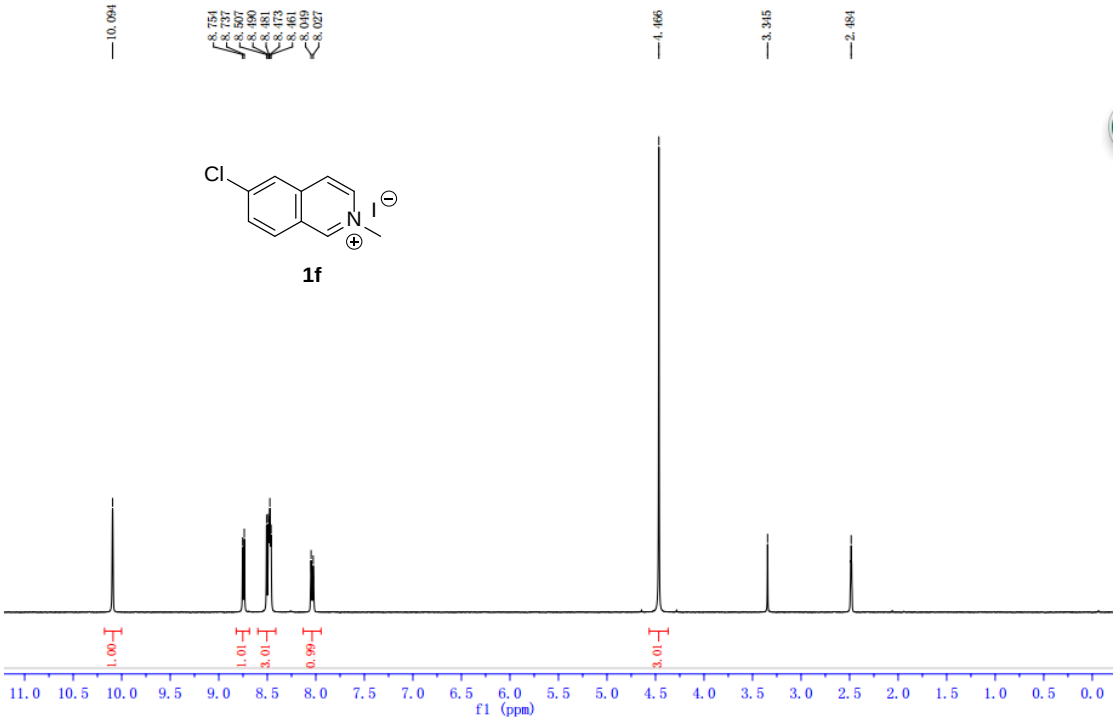

10.140
8.808
8.791
8.579
8.562
8.546
8.512
8.492
7.976
7.956
7.937
4.509
3.327
Br
N
I
1c
1.00
1.02
1.95
1.00
1.00
3.06
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

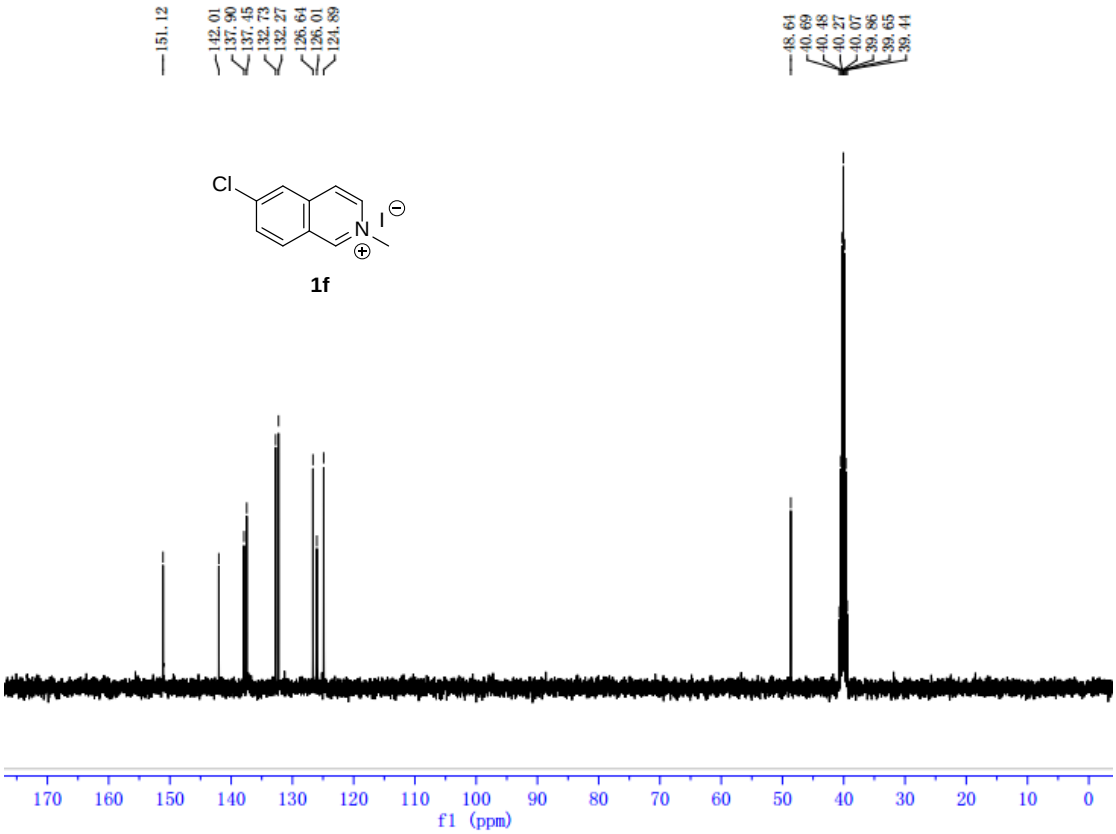

151.88
140.59
138.07
135.88
132.54
130.90
126.81
124.66
121.25
48.54
40.65
40.44
40.23
40.03
39.82
39.61
39.40
Br
N
I
1c
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

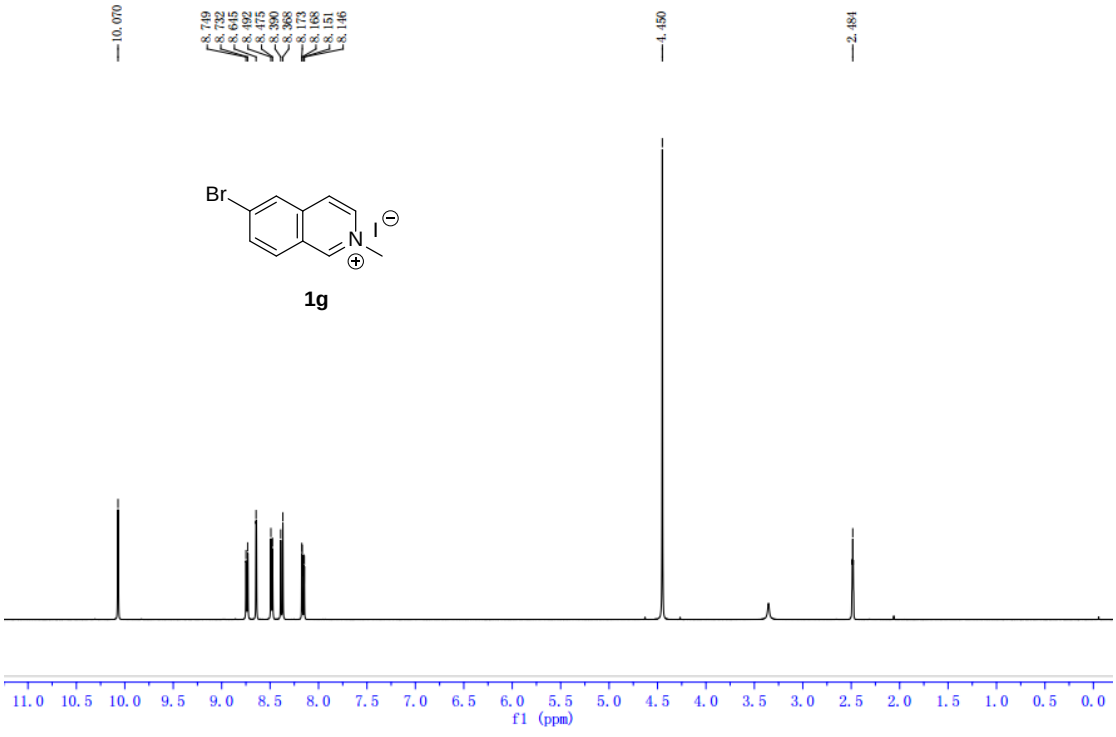

10.348
9.026
9.006
8.918
8.882
8.862
8.261
8.211
8.222
4.538
3.323
2.484
NO2
N
I
1d
1.00
1.05
3.01
1.01
3.02
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


152.20
144.49
139.11
137.77
134.60
131.10
129.42
128.38
121.68
48.80
40.67
40.46
40.25
40.04
39.83
39.62
39.41
NO2
N
I
1d
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

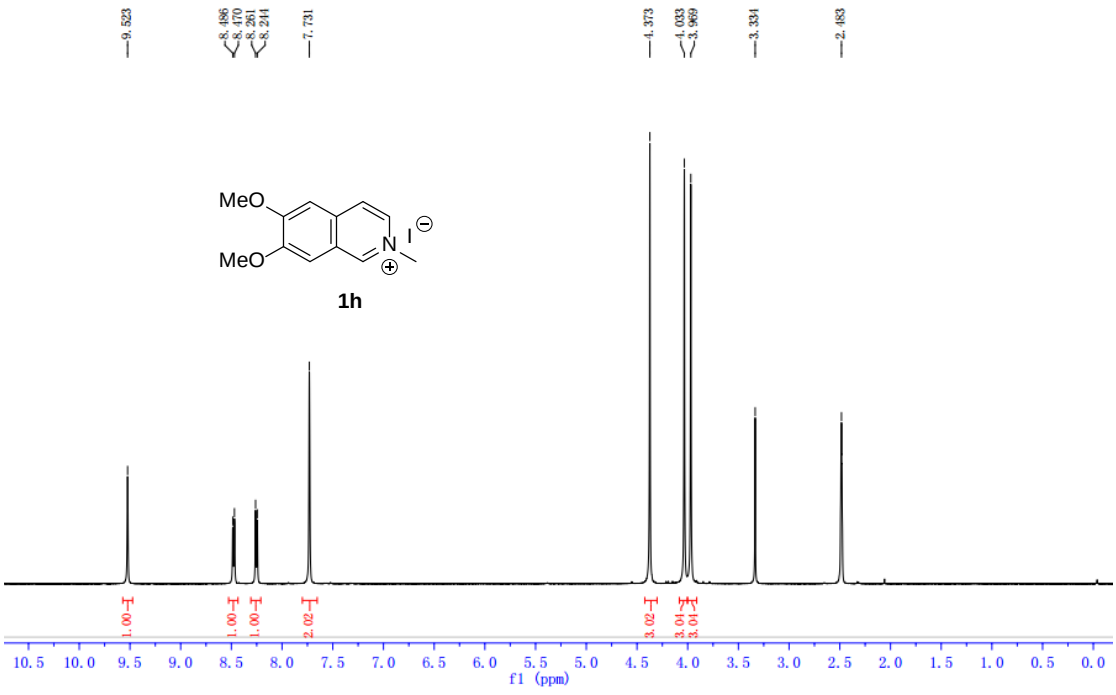

9.918
8.639
8.622
8.423
8.406
8.359
8.338
8.095
7.897
7.876
4.429
3.333
2.627
2.484
-0.034
N
I
1e
1.00
1.01
1.00
1.02
1.00
1.00
3.01
3.02
10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


10.094
8.754
8.737
8.507
8.490
8.481
8.473
8.461
8.049
8.027
1.466
3.345
2.484
Cl
N
I
1f
1.00
1.01
3.01
0.99
3.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

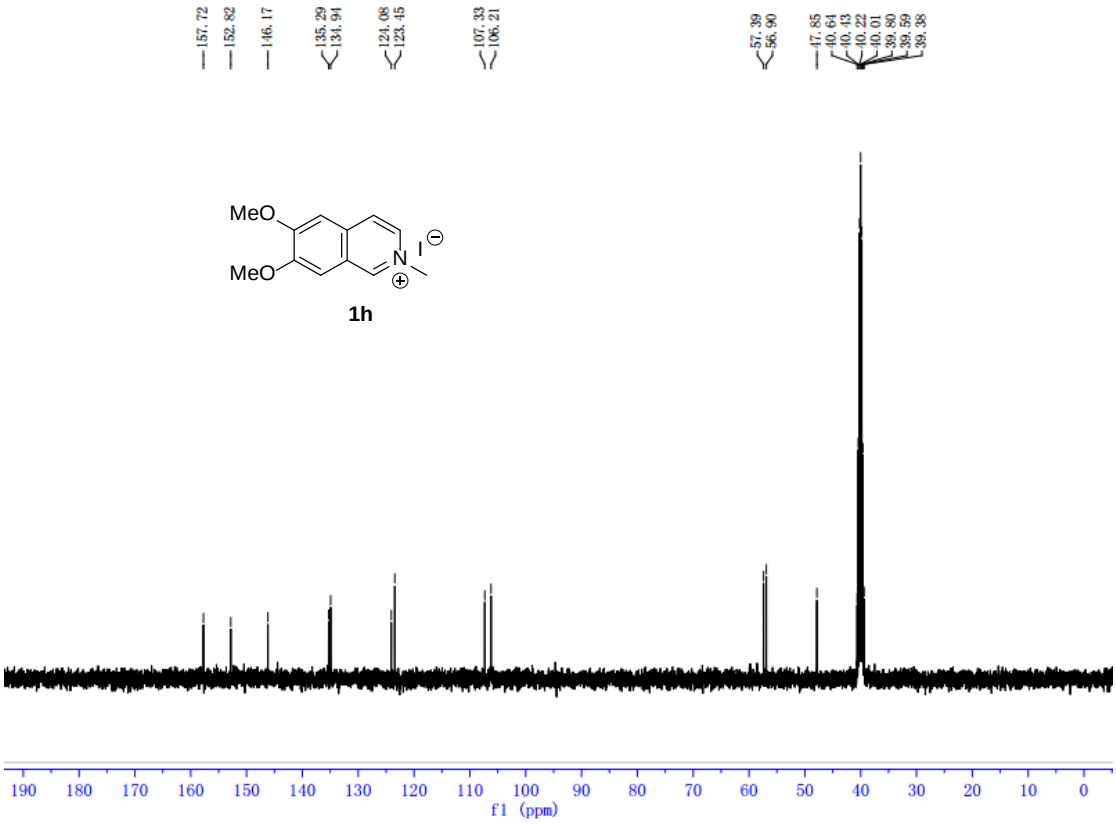

151.12
142.01
137.90
137.45
132.73
132.27
126.64
126.01
124.89
48.61
40.69
40.48
40.27
40.07
39.86
39.65
39.44
Cl
N
I
1f
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

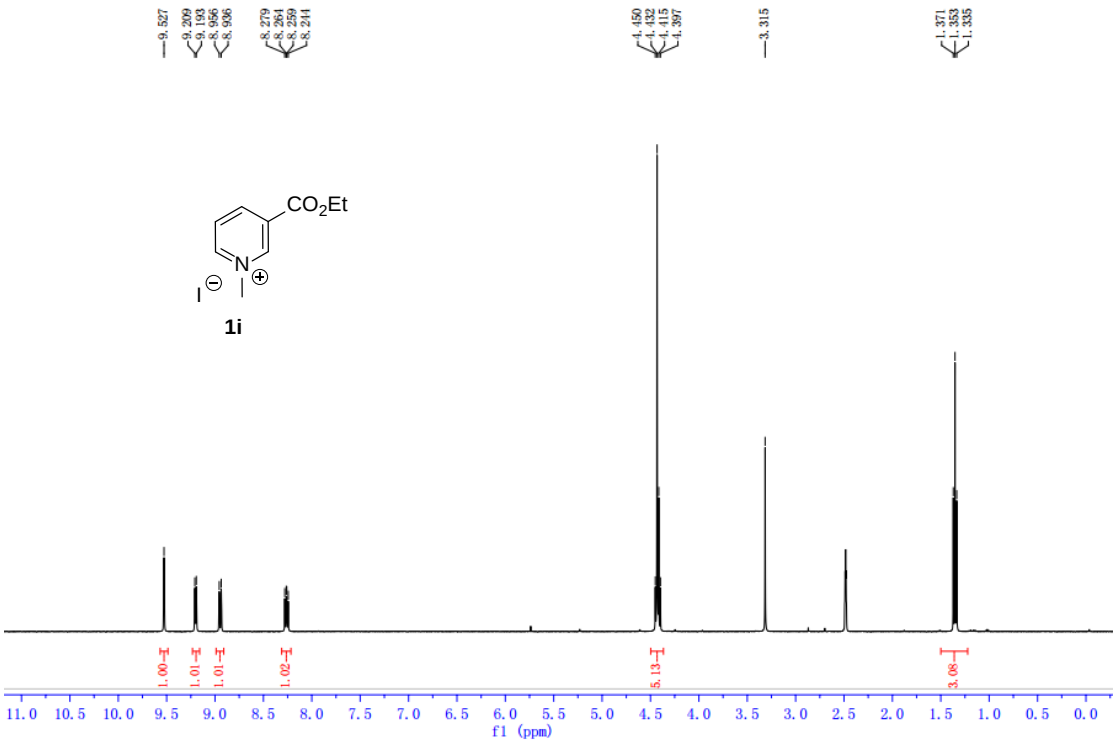

10.070
8.749
8.732
8.645
8.492
8.475
8.390
8.368
8.173
8.168
8.151
8.146
4.450
2.484
Br
N
I
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

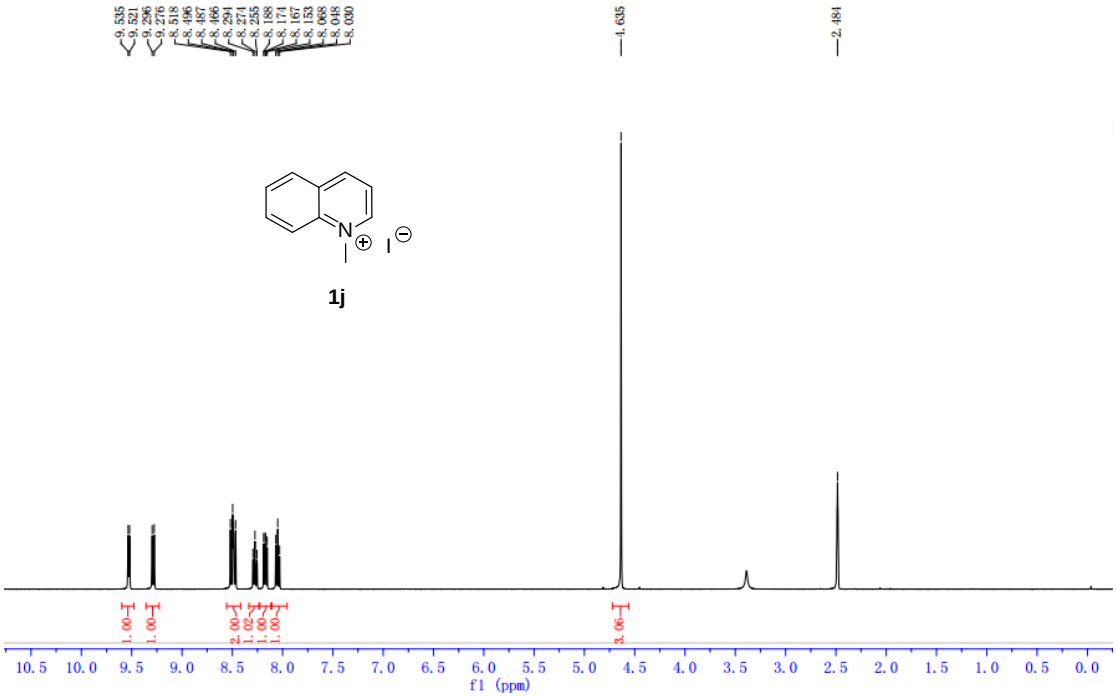
1g

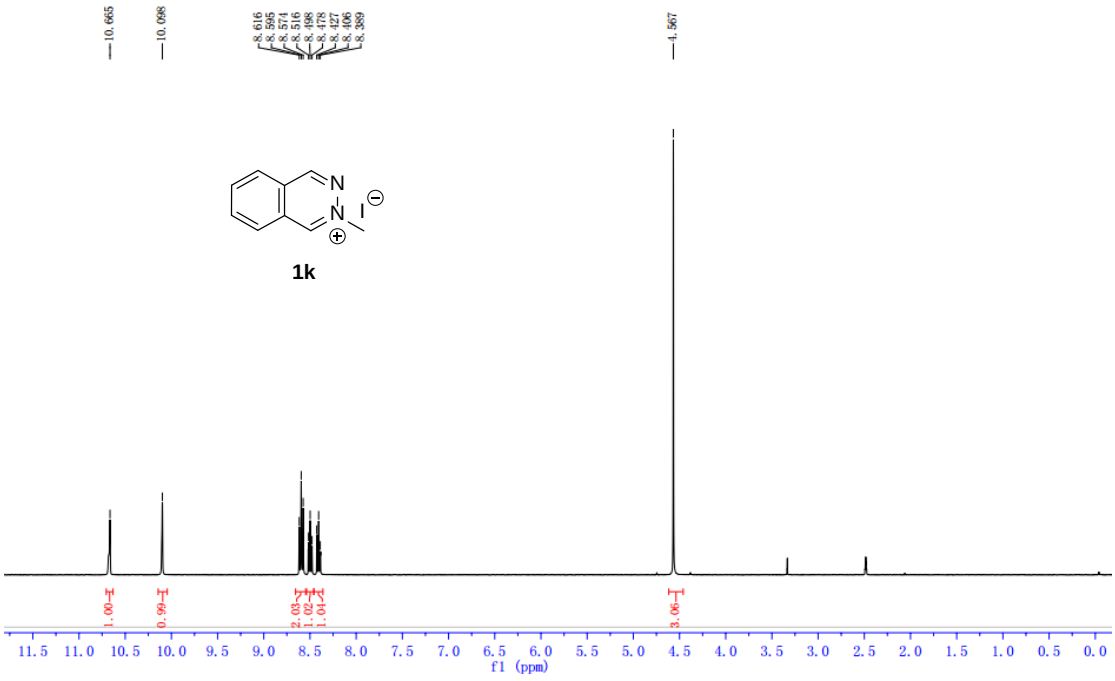

9.523
8.486
8.470
8.261
8.244
7.731
4.373
4.033
3.969
3.334
2.483
MeO
MeO
N
I
1.00
1.00
1.00
2.02
3.02
3.01
3.01
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

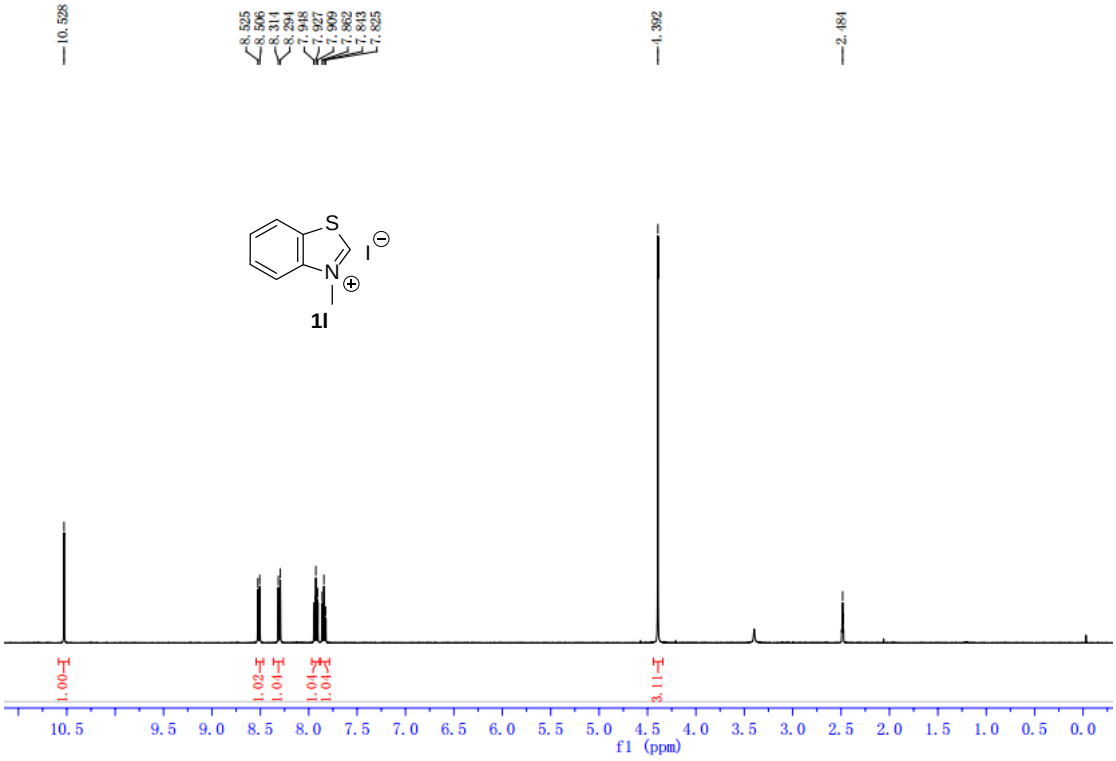
1h


157.72
152.82
146.17
135.29
134.94
124.08
123.45
107.33
106.21
57.39
56.90
47.85
40.64
40.43
40.22
40.01
39.80
39.59
39.38
MeO
MeO
N
I
1h
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

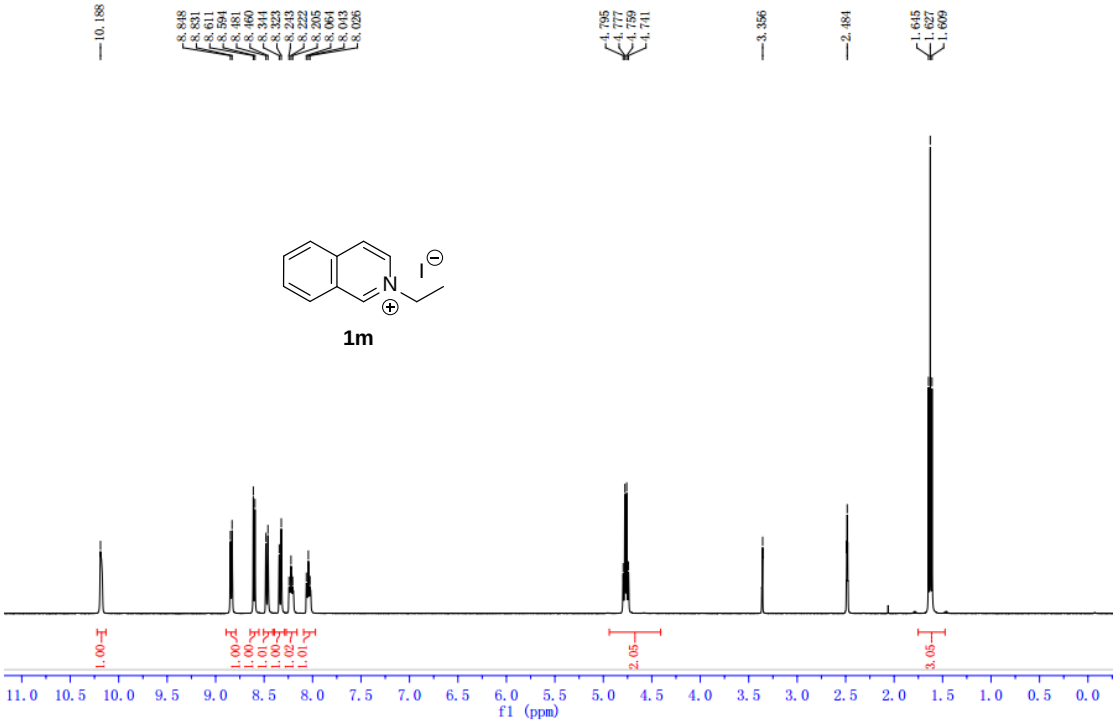

9.527
9.209
9.193
8.996
8.936
8.279
8.264
8.259
8.244
4.450
4.432
4.415
4.397
3.315
1.371
1.353
1.335
CO2Et
N
I
1i
1.00
1.01
1.01
1.02
5.13
3.08
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


9.535
9.521
9.296
9.276
8.518
8.496
8.487
8.466
8.294
8.271
8.255
8.198
8.171
8.167
8.153
8.068
8.048
8.030
4.635
2.484
1j
1.00
1.00
2.00
1.02
1.00
1.00
3.06
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

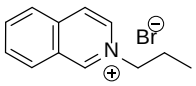

10.665
10.098
8.616
8.595
8.571
8.516
8.498
8.478
8.427
8.406
8.389
4.567
1k
1.00
0.99
2.03
1.02
1.04
3.06
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


10.528
8.525
8.506
8.314
8.294
7.948
7.927
7.909
7.862
7.813
7.825
4.392
2.484
1.00
1.02
1.04
1.01
1.01
3.11
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

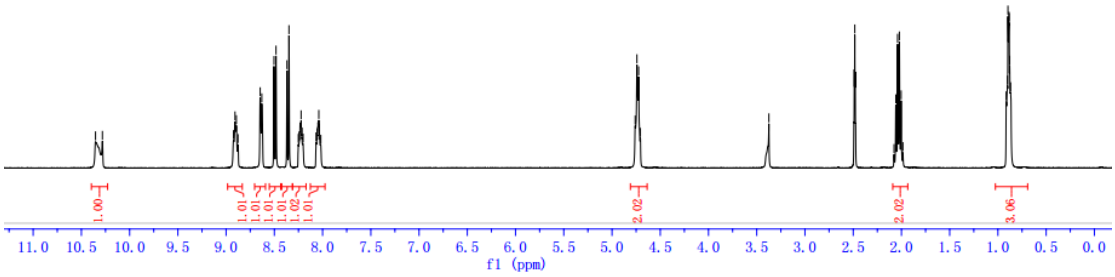
1l

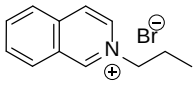

10.188
8.848
8.831
8.611
8.594
8.481
8.460
8.344
8.323
8.243
8.222
8.205
8.064
8.043
8.026
4.795
4.777
4.759
4.741
3.356
2.484
1.645
1.627
1.609
1.00
1.00
1.01
1.00
1.02
1.01
2.05
3.05
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

1m

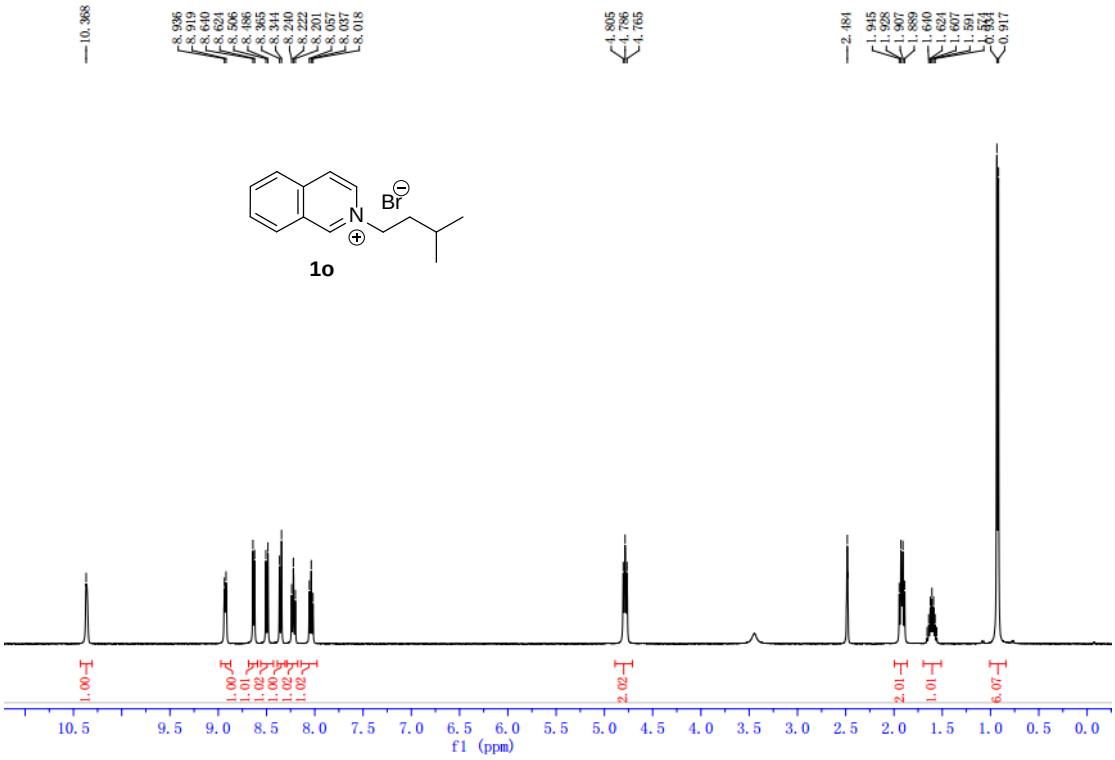


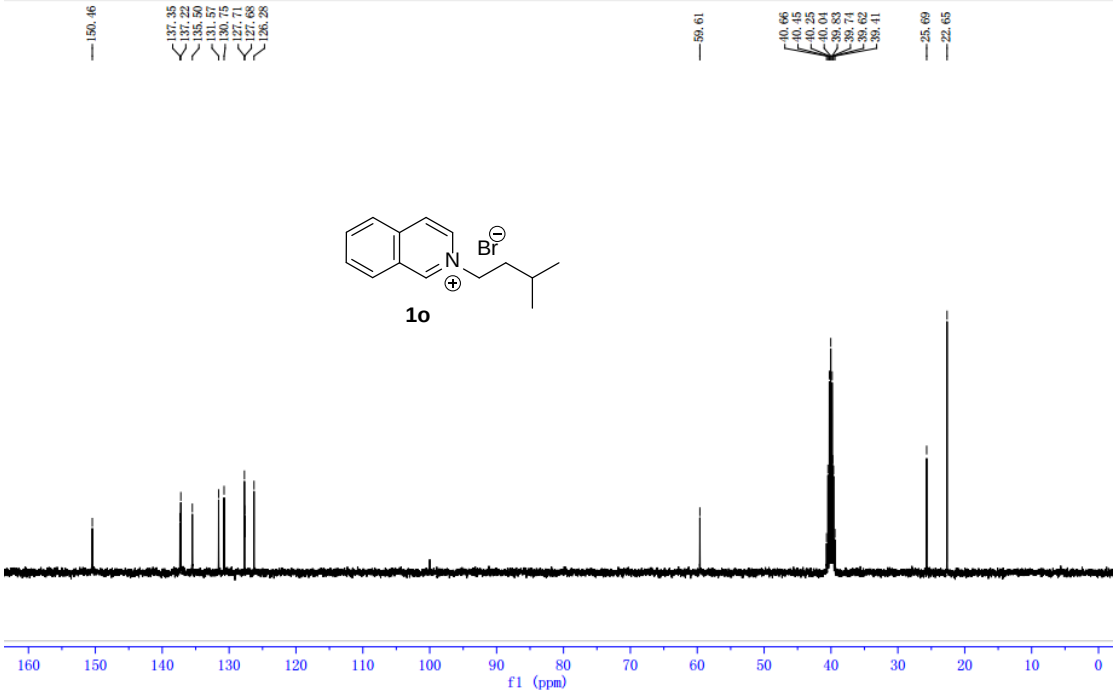
1n

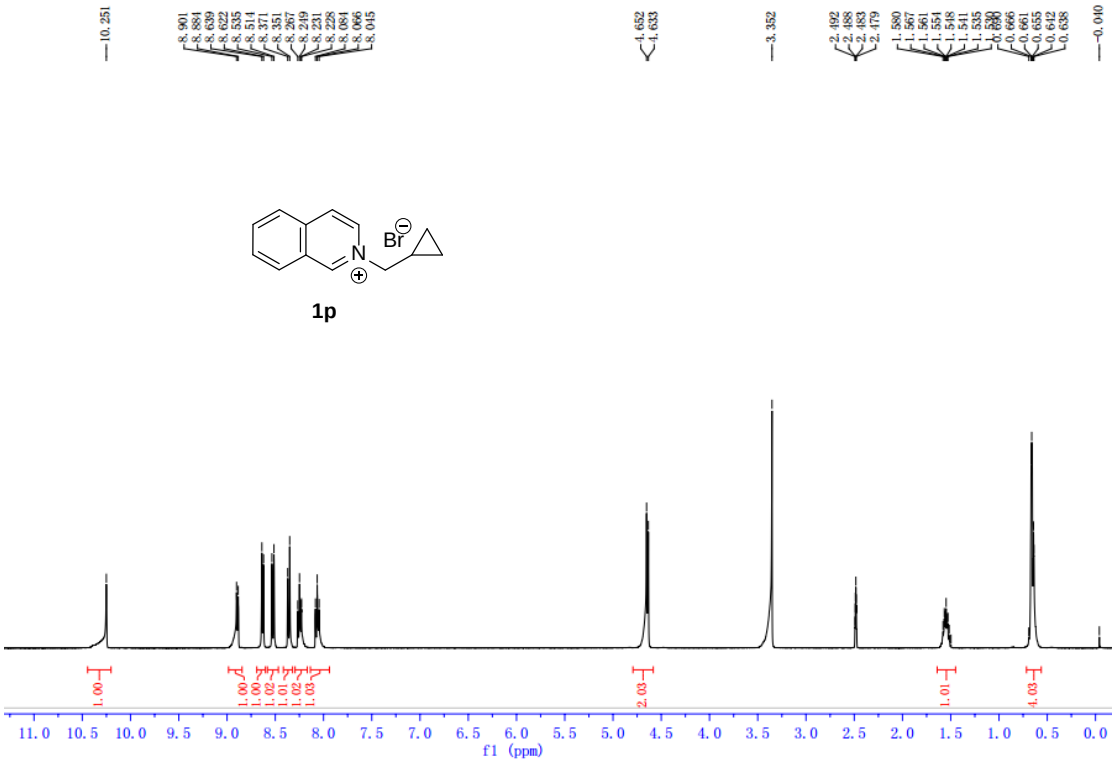




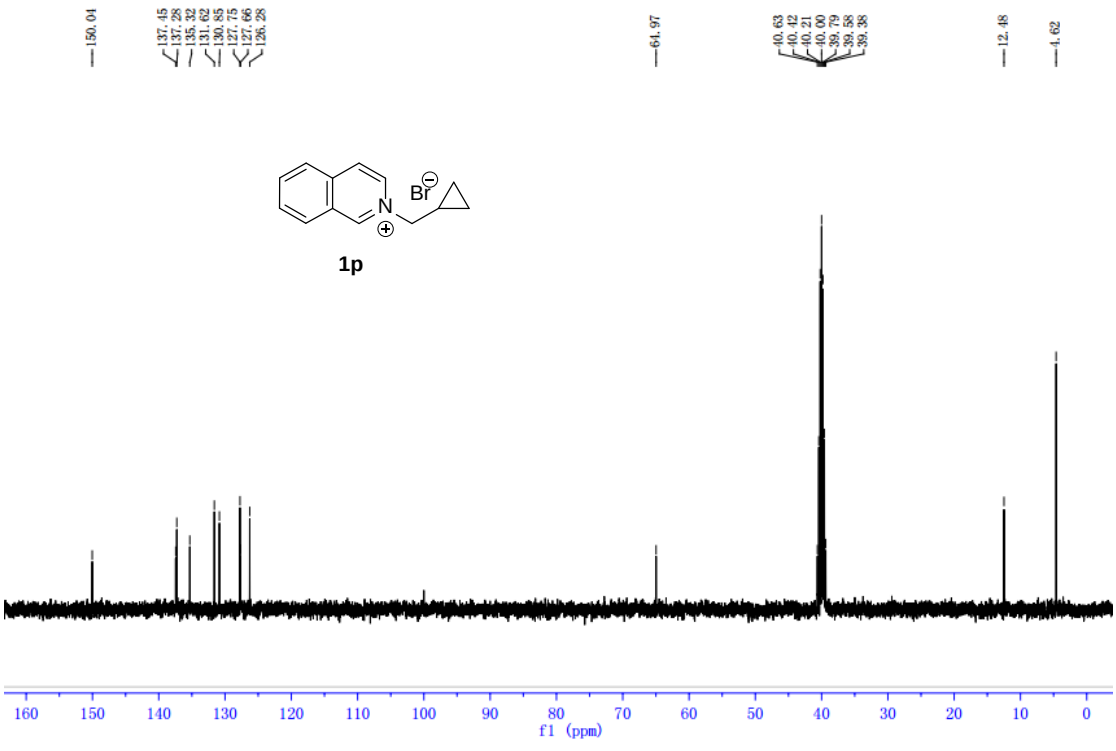
1n


10.368
8.936
8.919
8.640
8.624
8.506
8.486
8.365
8.344
8.240
8.222
8.201
8.057
8.037
8.018
4.805
4.786
4.765
2.484
1.945
1.928
1.907
1.889
1.640
1.624
1.607
1.591
0.934
0.917
Br
N
1o
1.00
1.00
1.01
1.02
1.00
1.02
1.02
2.02
2.01
1.01
6.07
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

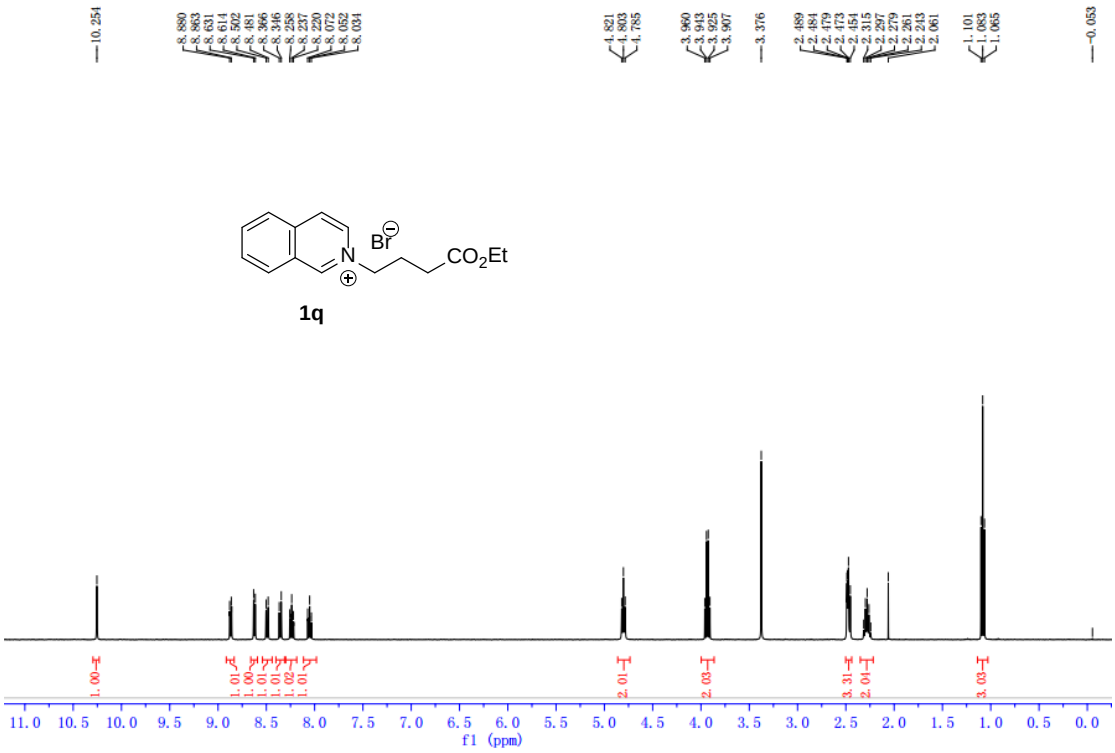

150.46
137.35
137.22
135.59
131.57
130.75
127.71
127.68
126.28
59.61
40.66
40.45
40.25
40.04
39.83
39.71
39.62
39.41
25.69
22.65
Br
N
1o
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


10.251
8.901
8.894
8.639
8.622
8.535
8.514
8.371
8.351
8.267
8.249
8.231
8.228
8.084
8.066
8.045
4.652
4.633
3.352
2.492
2.488
2.483
2.479
1.580
1.567
1.561
1.554
1.548
1.541
1.535
0.666
0.661
0.655
0.642
0.638
0.040
Br
N
1.00
1.00
1.00
1.02
1.01
1.02
1.03
2.03
1.01
4.03
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

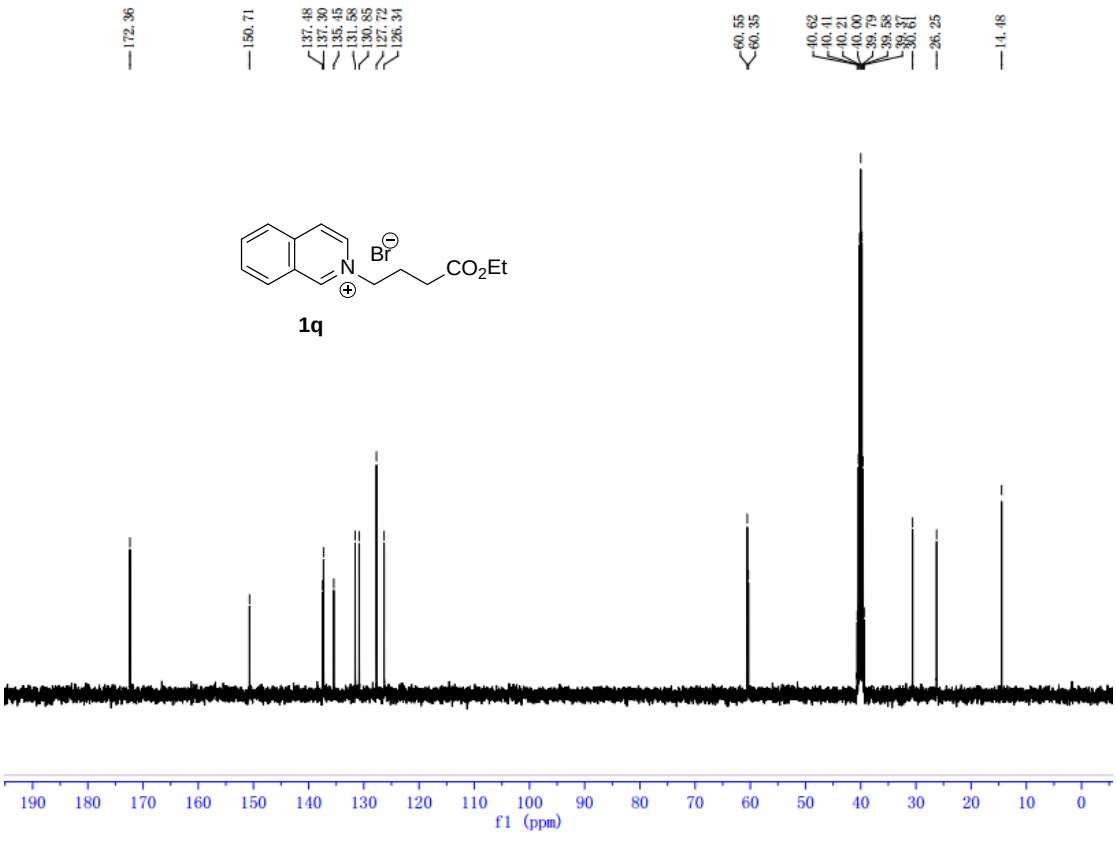
1p


150.04
137.45
137.28
135.32
131.62
130.85
127.75
127.66
126.28
64.97
40.63
40.42
40.21
40.00
39.79
39.58
39.38
12.48
4.62
Br
N
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1p

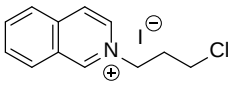

10.254
8.890
8.883
8.631
8.614
8.502
8.481
8.366
8.346
8.258
8.237
8.220
8.072
8.052
8.034
4.821
4.803
4.785
3.960
3.943
3.925
3.907
3.376
2.489
2.484
2.479
2.473
2.454
2.315
2.297
2.279
2.261
2.243
2.061
1.101
1.083
1.065
0.053
Br
N
CO2Et
1.00
1.01
1.00
1.01
1.01
1.02
1.01
2.01
2.03
3.31
2.04
3.03
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

1q

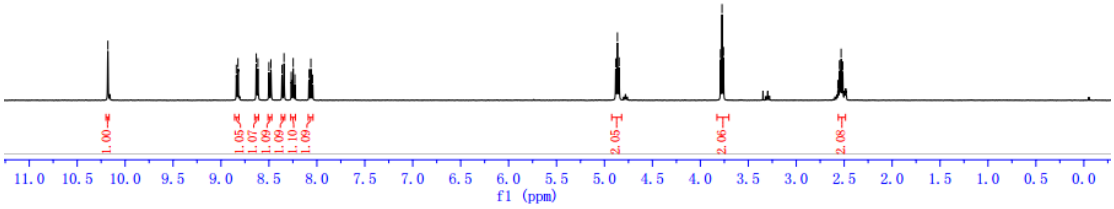

172.36
150.71
137.48
137.30
135.45
131.58
130.85
127.72
126.34
60.55
60.35
40.62
40.41
40.21
40.00
39.79
39.58
39.37
39.16
26.25
14.48
Br
N
CO2Et
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

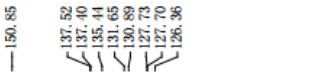
1q

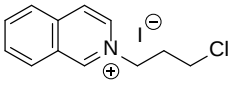

10.180
8.840
8.823
8.632
8.615
8.490
8.479
8.363
8.343
8.267
8.247
8.229
8.081
8.063
8.045
1.883
1.865
1.847
3.790
3.774
3.758
2.566
2.559
2.549
2.532
2.515


I
N
Cl

1r

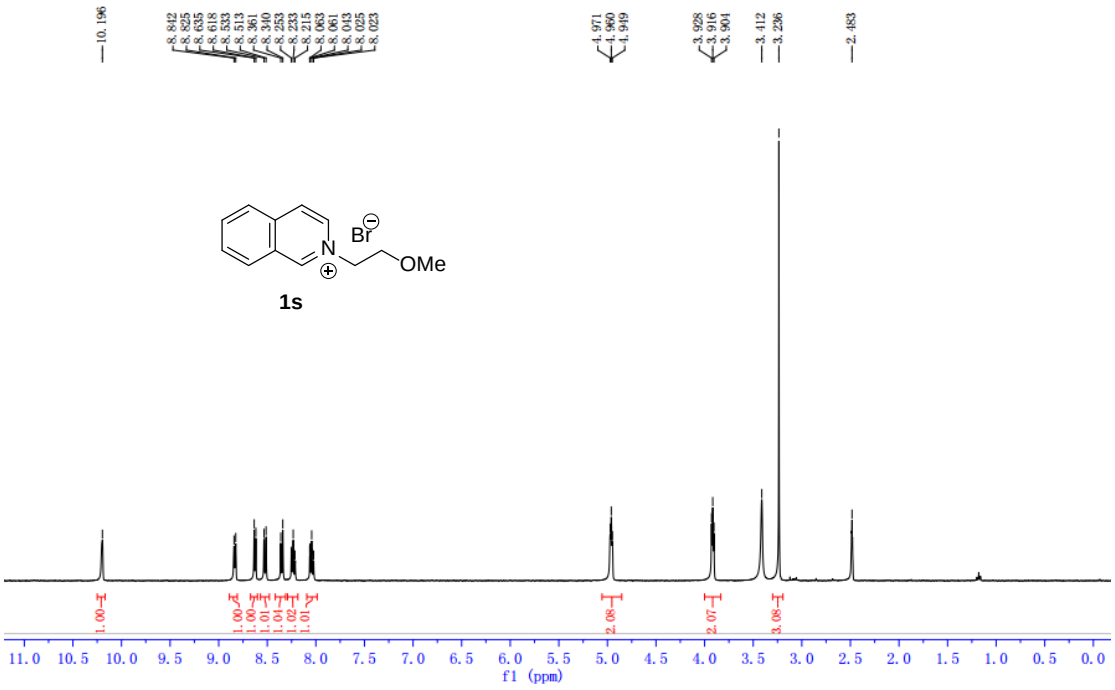

1.00
1.05
1.07
1.09
1.09
1.09
1.10
1.09
2.05
2.06
2.08
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


150.85
137.52
137.40
135.44
131.65
130.89
127.73
127.70
126.36
58.94
42.31
40.68
40.48
40.27
40.06
39.85
39.64
39.43
33.27

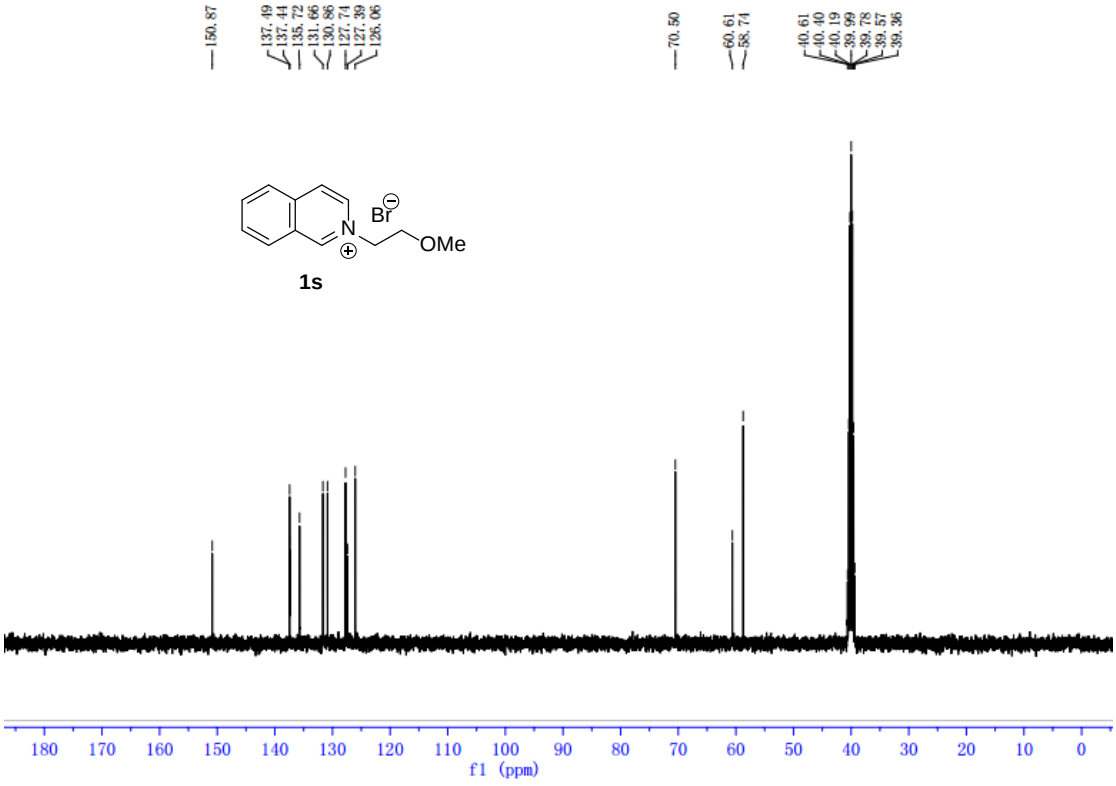

I
N
Cl

1r

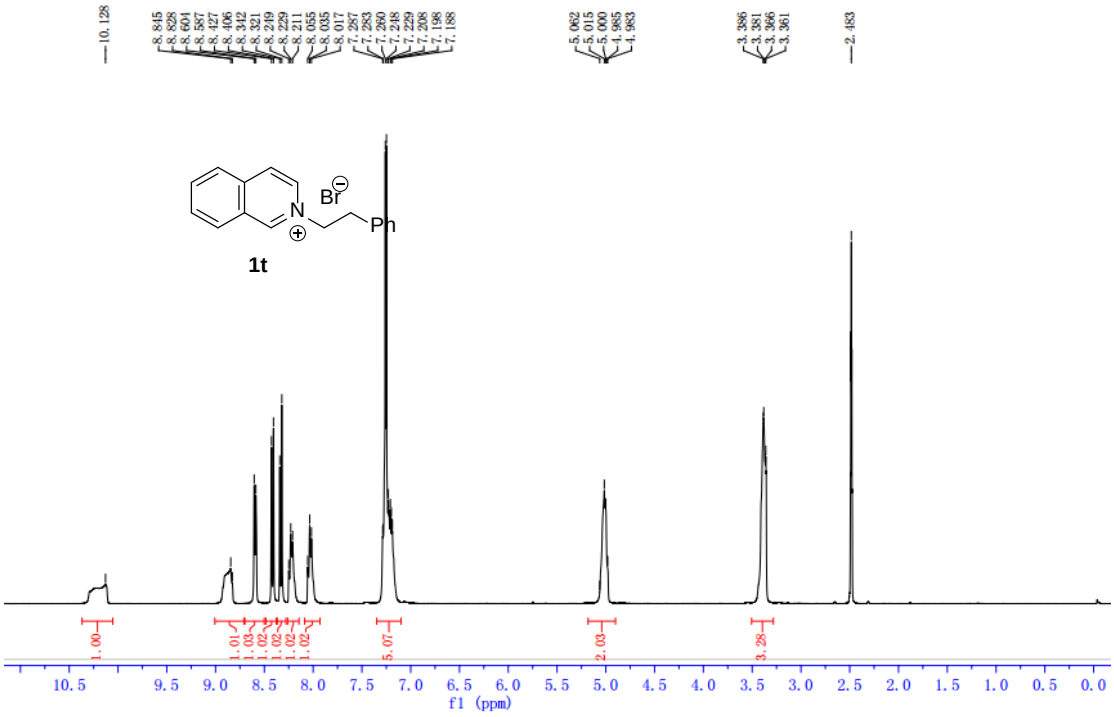
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

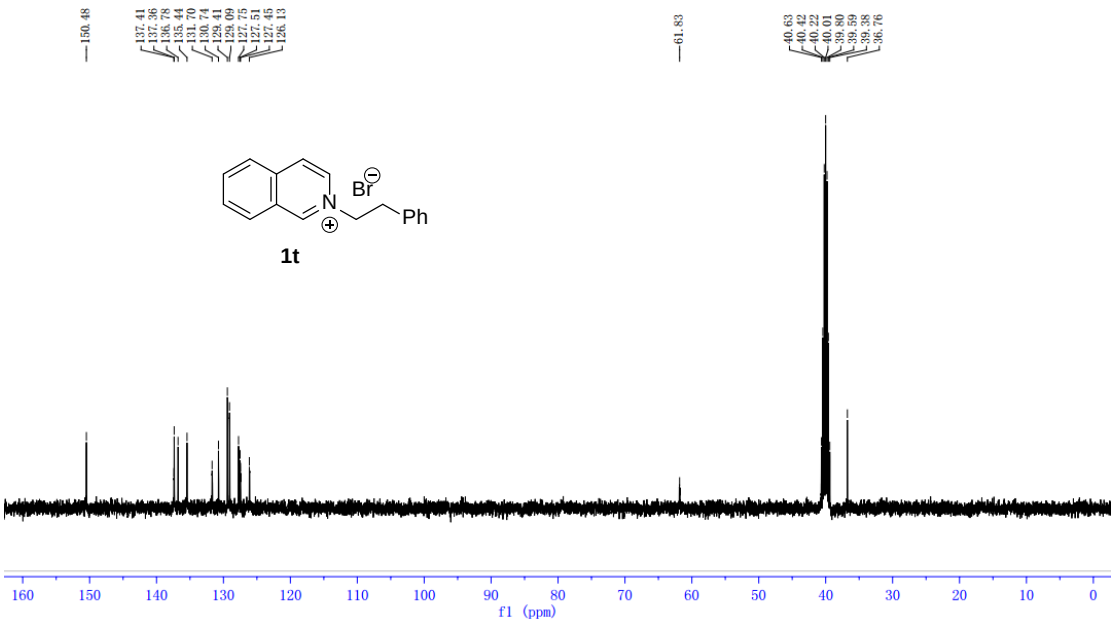

10.196
8.842
8.825
8.635
8.618
8.513
8.361
8.340
8.253
8.233
8.215
8.063
8.061
8.043
8.025
8.023
1.971
1.960
1.949
3.928
3.916
3.904
3.412
3.296
2.483
Br
N
OMe
1.00
1.00
1.00
1.01
1.04
1.02
1.01
2.08
2.07
3.08
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

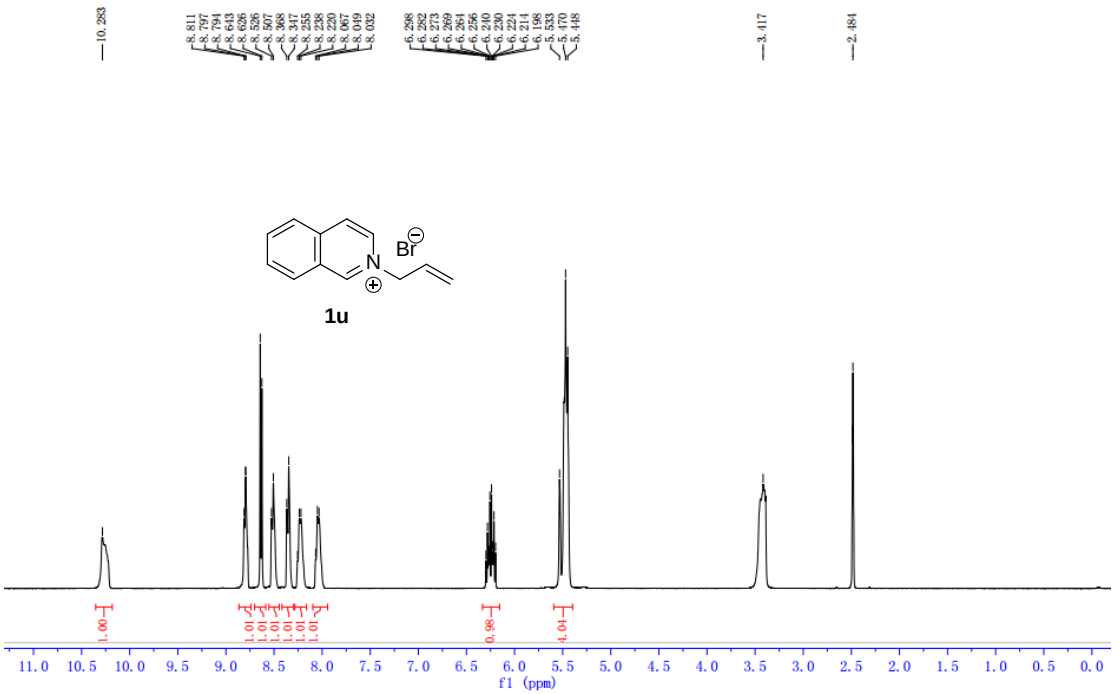
1s

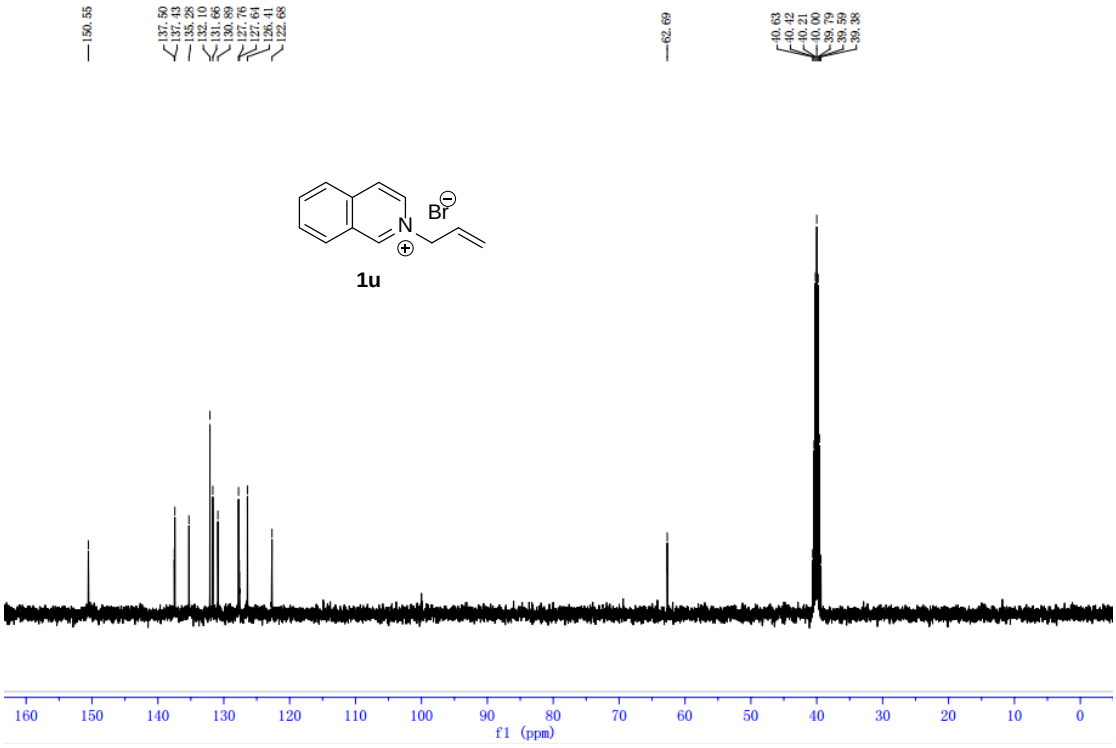

150.87
137.49
137.44
135.72
131.66
130.86
127.74
127.39
126.06
70.50
60.61
58.74
40.61
40.40
40.19
39.99
39.78
39.57
39.36
Br
N
OMe
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

1s

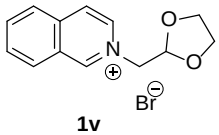

10.128
8.845
8.826
8.601
8.587
8.427
8.406
8.342
8.321
8.249
8.229
8.211
8.055
8.035
8.017
7.297
7.293
7.290
7.218
7.229
7.208
7.198
7.188
5.062
5.015
5.000
4.985
4.963
3.396
3.381
3.366
3.361
2.483
Br
N
Ph
1t
1.00
1.01
1.03
1.02
1.02
1.02
1.02
5.07
2.03
3.28
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


160.48
137.41
137.36
136.78
135.44
131.70
130.74
128.41
128.09
127.75
127.51
127.45
126.13
61.83
40.63
40.42
40.22
40.01
39.80
39.59
39.38
36.76
Br
N
Ph
1t
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

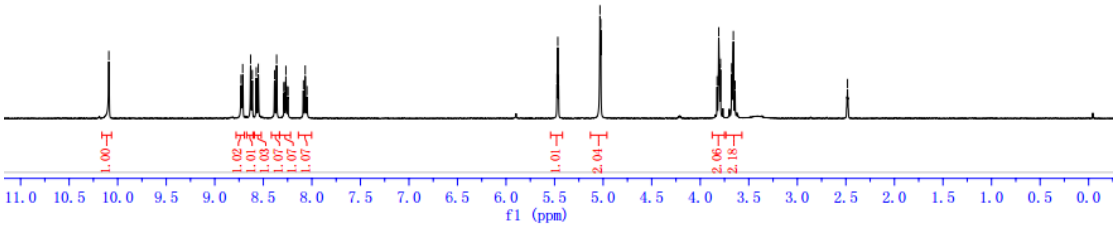

10.283
8.811
8.797
8.794
8.643
8.626
8.577
8.567
8.347
8.255
8.238
8.220
8.067
8.049
8.032
6.298
6.292
6.273
6.269
6.261
6.256
6.240
6.230
6.224
6.211
6.198
5.533
5.470
5.448
3.417
2.484
Br
N
1u
1.00
1.01
1.01
1.01
1.01
1.01
1.01
1.01
0.98
4.04
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


150.55
137.50
137.43
135.28
132.10
131.66
130.89
127.76
127.64
126.41
122.68
62.69
40.63
40.42
40.21
40.00
39.79
39.59
39.38
Br
N
1u
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

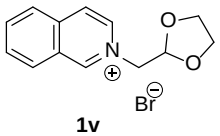

10.091
8.729
8.712
8.631
8.614
8.572
8.552
8.383
8.363
8.287
8.265
8.267
8.249
8.247
8.087
8.069
8.050
5.475
5.467
5.459
5.032
5.025
3.826
3.809
3.800
3.792
3.676
3.668
3.659
3.641
2.484


O
N
O
Br

1v

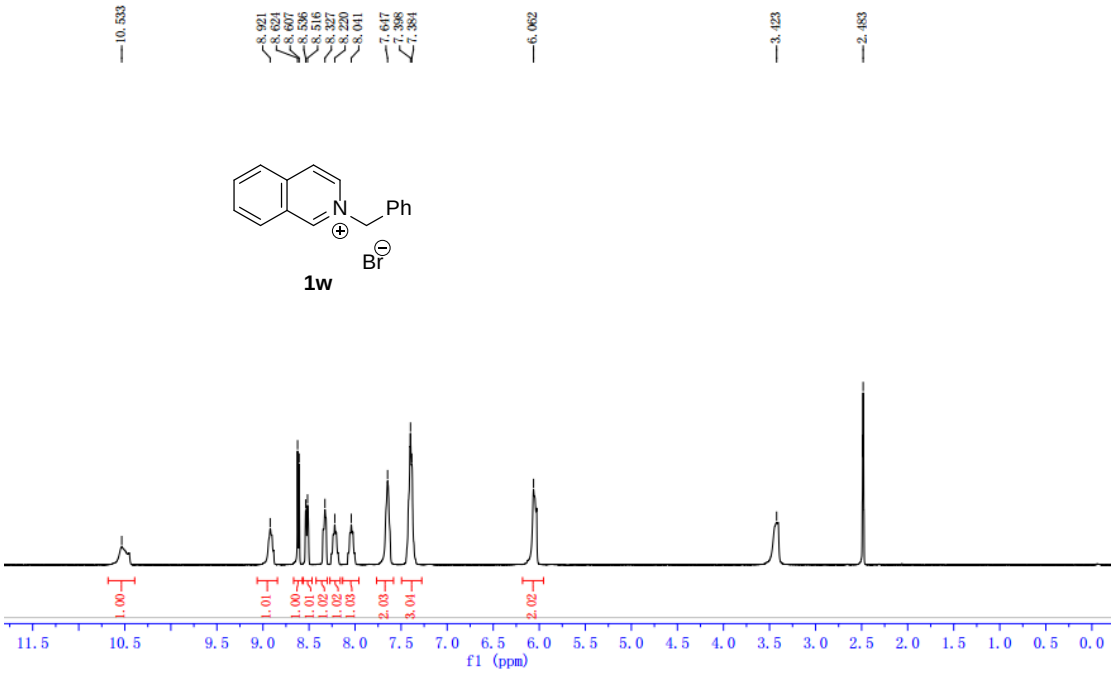

1.00
1.02
1.01
1.03
1.07
1.07
1.07
1.01
2.04
2.06
2.18
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


151.80
137.73
137.63
136.84
131.74
131.03
127.78
127.22
125.54
100.22
65.40
61.16
40.63
40.42
40.21
40.00
39.79
39.59
39.38

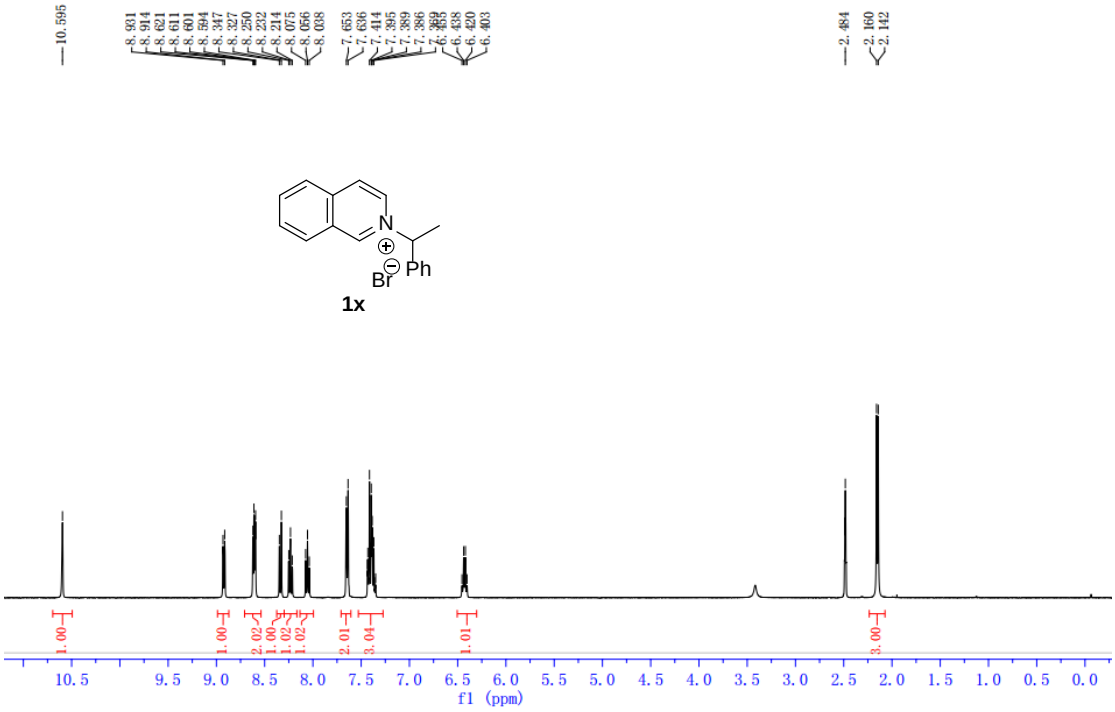

O
N
O
Br

1v

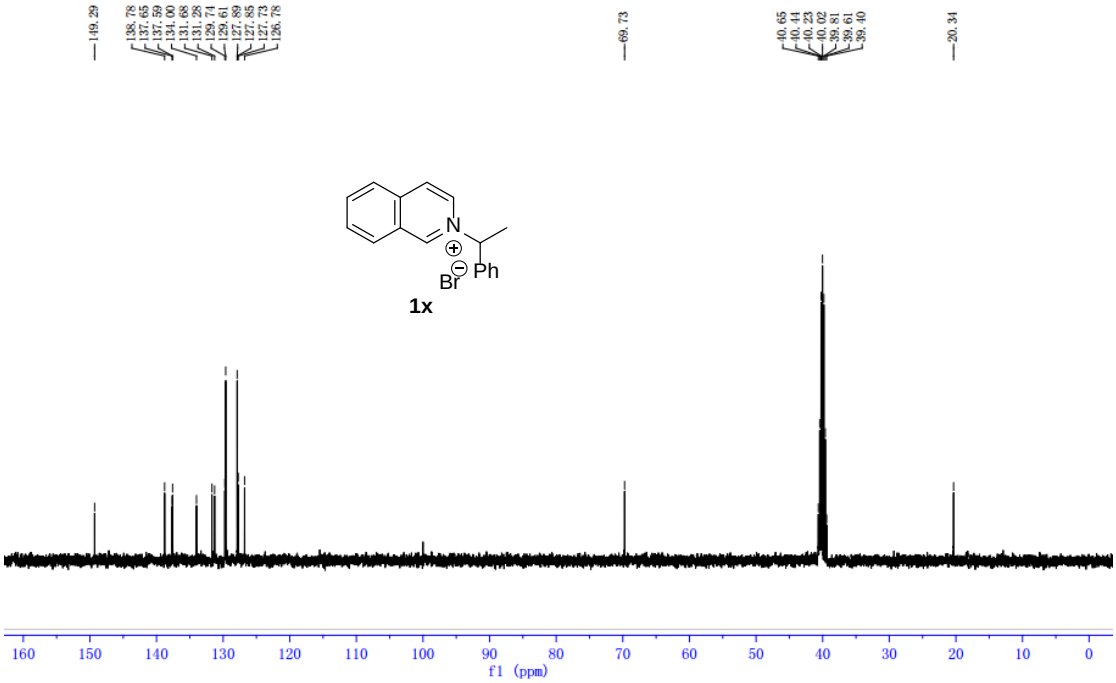
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


10.533
8.921
8.624
8.607
8.536
8.516
8.327
8.220
8.041
7.647
7.398
7.384
6.062
3.423
2.483
N
Ph
Br
1.00
1.01
1.00
1.01
1.02
1.02
1.03
2.03
3.04
2.02
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

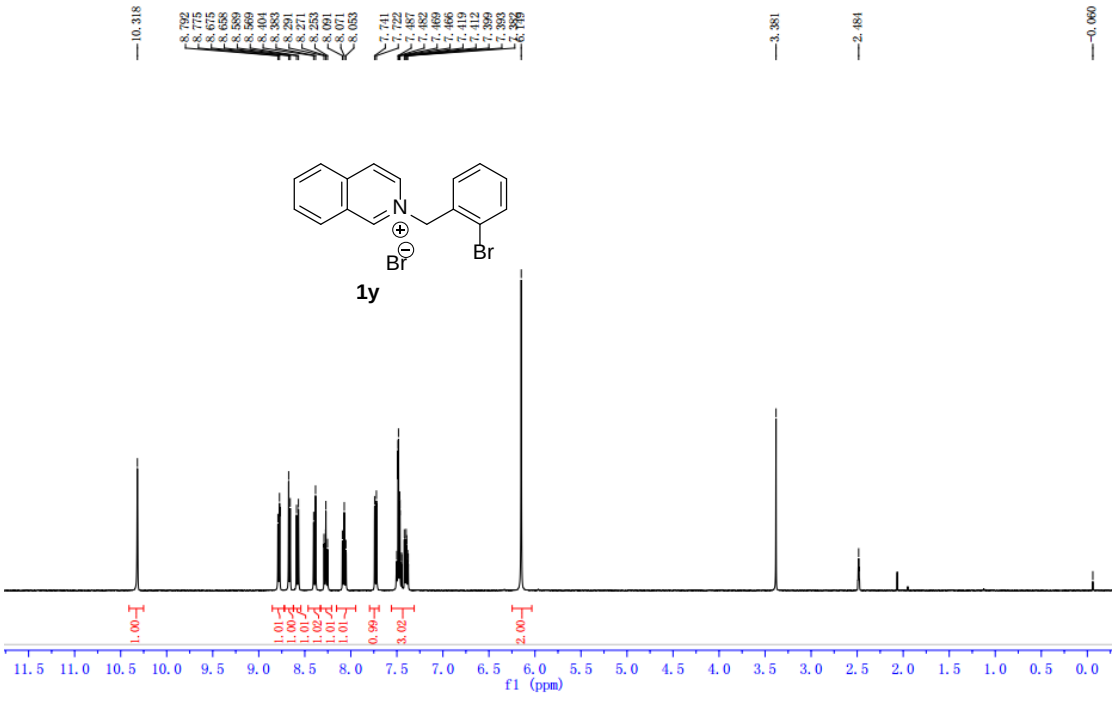
1w


10.595
8.931
8.914
8.621
8.611
8.601
8.594
8.347
8.327
8.250
8.232
8.214
8.075
8.056
8.038
7.653
7.636
7.414
7.395
7.389
7.386
7.369
6.438
6.420
6.403
2.494
2.160
2.142
N
Ph
Br
1.00
1.00
2.02
1.00
1.02
1.02
2.01
3.04
1.01
3.00
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

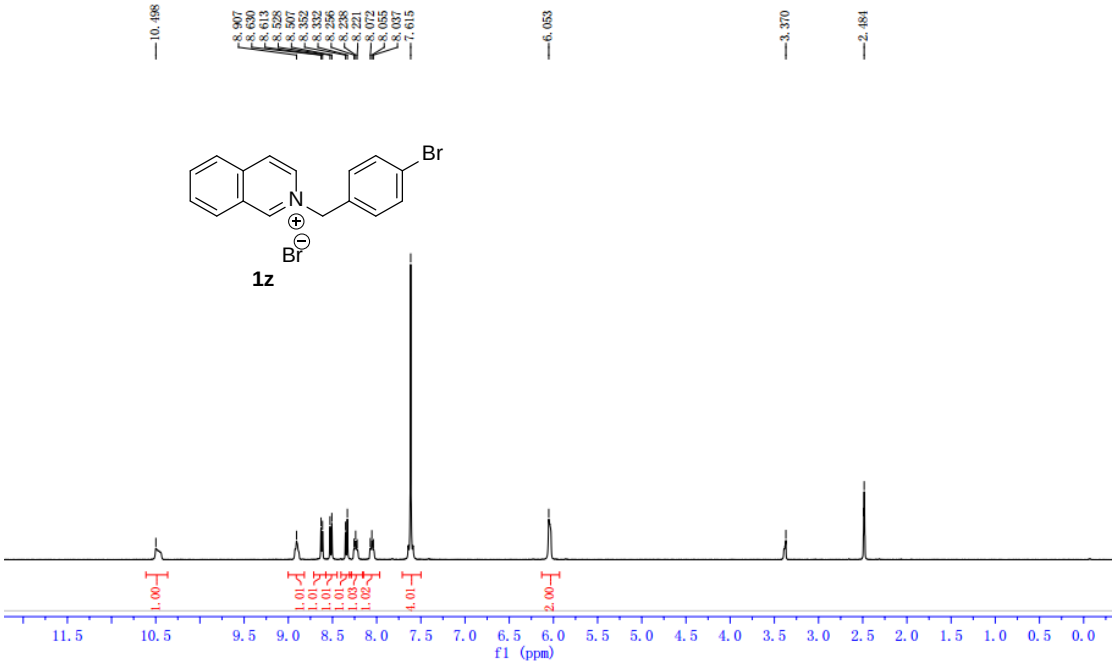
1x

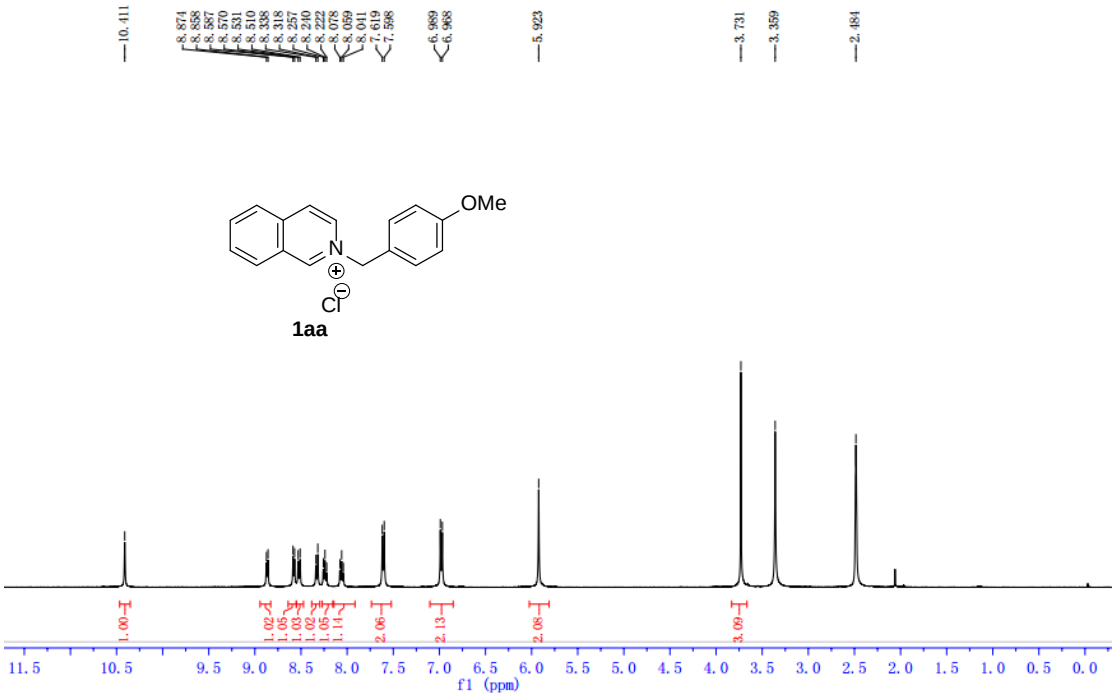

149.29
138.78
137.65
137.59
134.60
131.68
131.28
129.74
129.61
127.89
127.85
127.73
126.78
69.73
40.65
40.44
40.23
40.02
39.81
39.61
39.40
20.34
N
Br
Ph
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

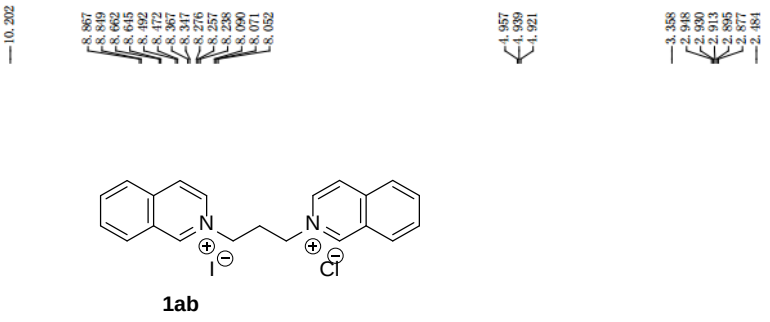
1x


10.318
8.792
8.775
8.675
8.658
8.589
8.569
8.404
8.383
8.291
8.271
8.253
8.091
8.071
8.053
7.741
7.722
7.487
7.482
7.469
7.466
7.419
7.412
7.399
7.393
7.382
7.379
3.381
2.484
0.060
N
Br
Br
1.00
1.01
1.00
1.01
1.02
1.01
1.01
0.99
3.02
2.00
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

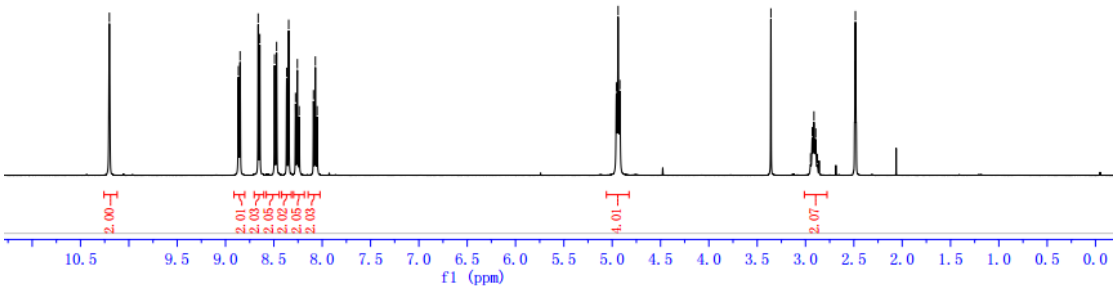
1y

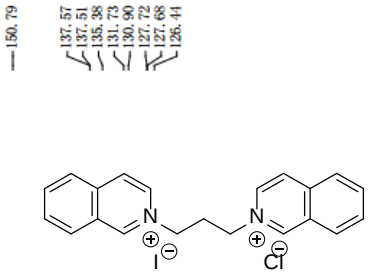

10.498
8.907
8.630
8.613
8.528
8.507
8.352
8.332
8.256
8.238
8.221
8.072
8.055
8.037
7.615
6.053
3.370
2.484
Br
N
Br
1z
1.00
1.01
1.01
1.01
1.01
1.03
1.02
4.01
2.00
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


10.411
8.874
8.858
8.587
8.570
8.531
8.510
8.338
8.318
8.257
8.240
8.222
8.078
8.059
8.041
7.619
7.598
6.989
6.968
5.923
3.731
3.359
2.484
OMe
N
Cl
1aa
1.00
1.02
1.03
1.03
1.05
1.11
2.06
2.13
2.08
3.09
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

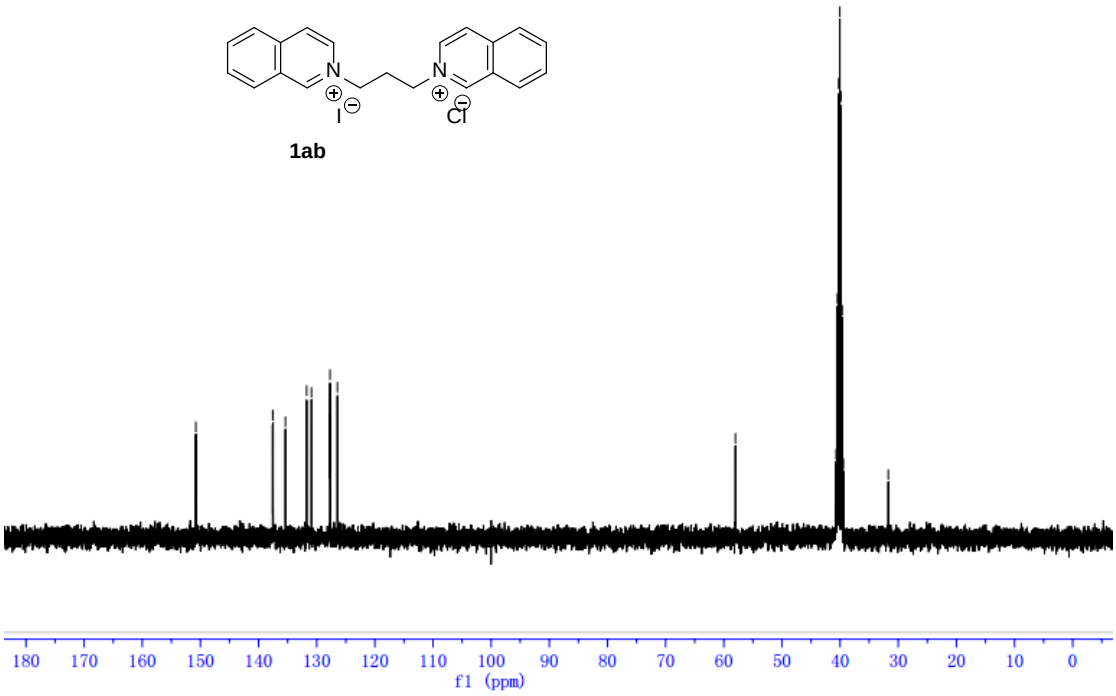

10.202
8.867
8.849
8.662
8.645
8.492
8.472
8.367
8.347
8.276
8.257
8.238
8.090
8.071
8.052
4.957
4.939
4.921
3.358
2.948
2.930
2.913
2.895
2.877
2.481
N
N
I
Cl

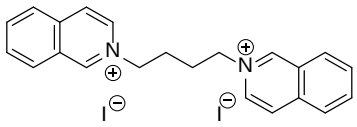
1ab


2.00
2.01
2.03
2.05
2.02
2.05
2.03
4.01
2.07
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

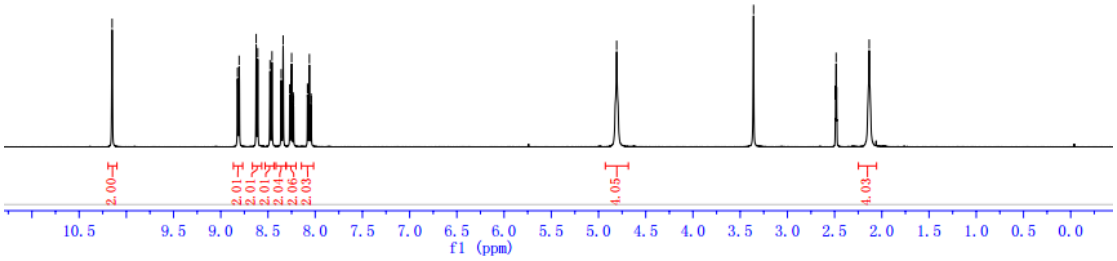

150.79
137.57
137.51
135.38
131.73
130.90
127.72
127.68
126.44
57.99
40.68
40.46
40.26
40.05
39.84
39.63
39.42
31.71
N
N
I
Cl

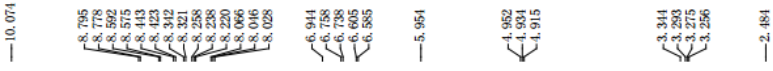
1ab

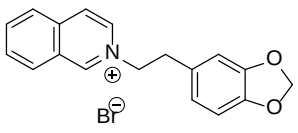

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)



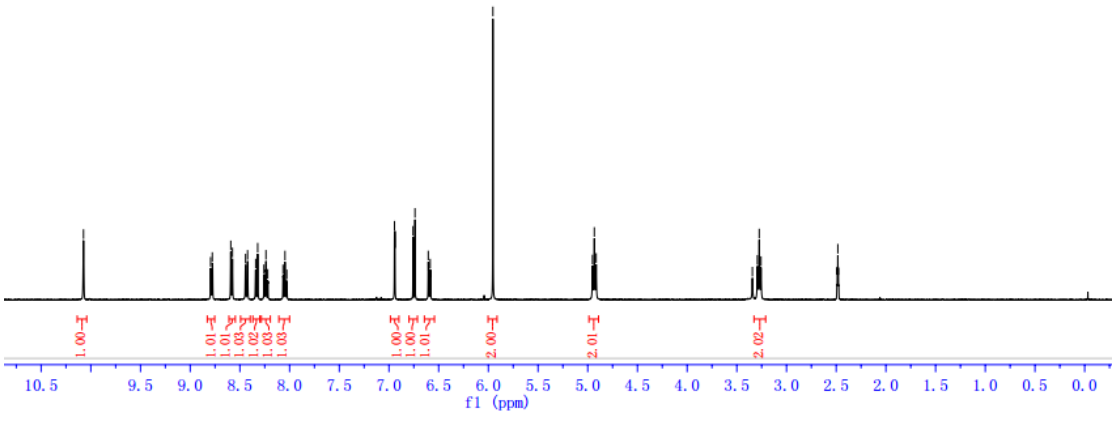
1ac

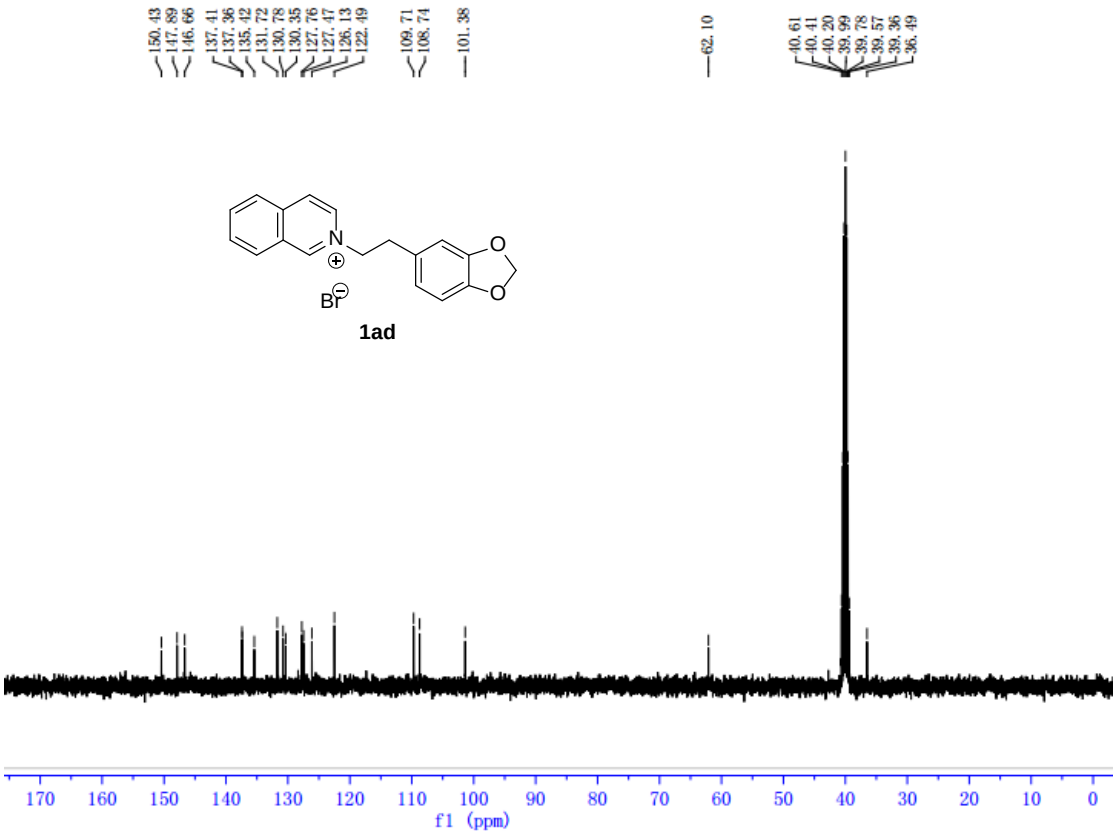




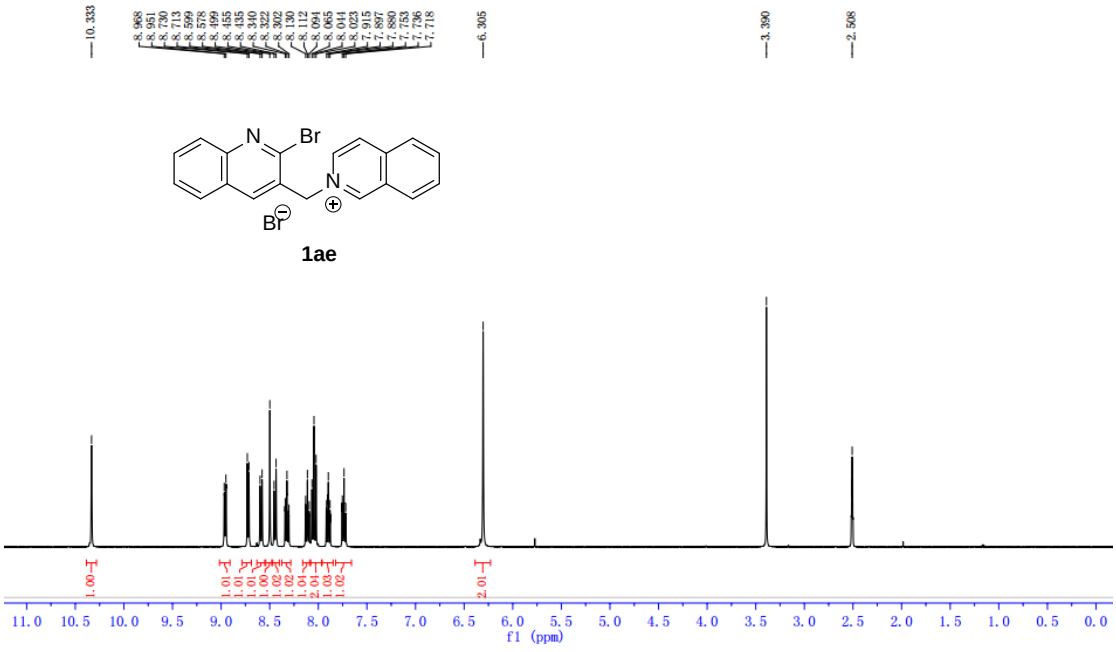


1ad

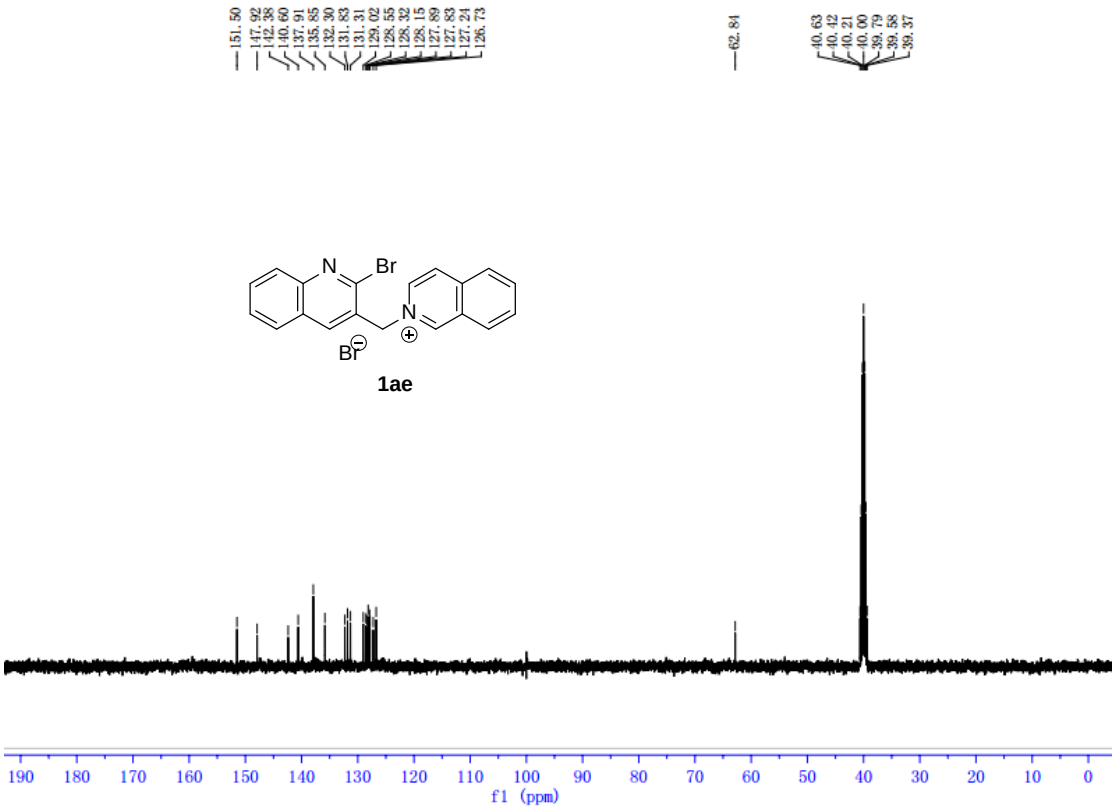


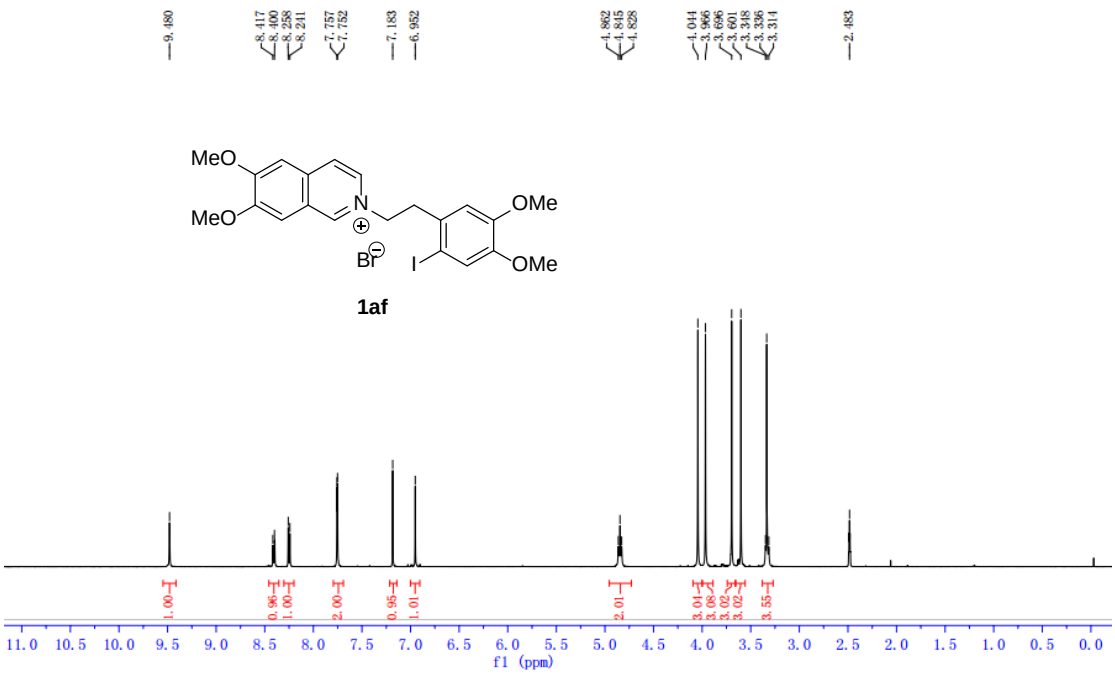

150.43
147.89
146.66
137.41
137.36
135.42
131.72
130.78
130.35
127.76
127.47
126.13
122.49
109.71
108.74
101.38
62.10
40.61
40.41
40.20
39.99
39.78
39.57
39.36
39.49
N
O
O
Br
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

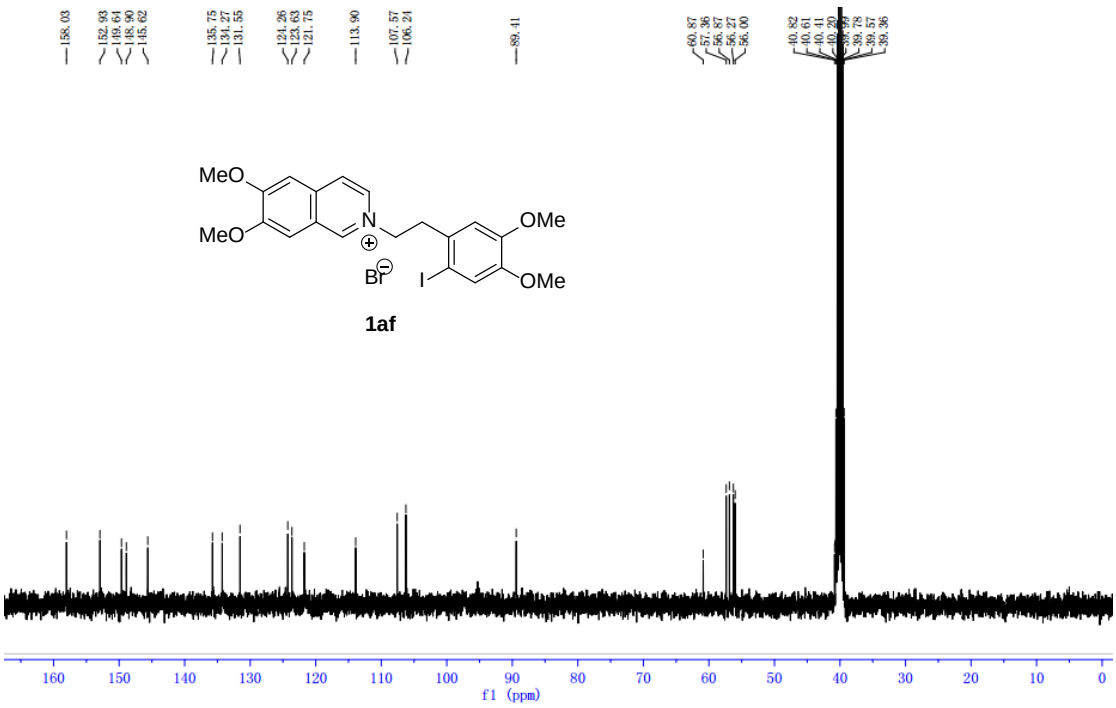
1ad


10.333
8.968
8.951
8.730
8.713
8.599
8.578
8.499
8.455
8.435
8.340
8.322
8.302
8.130
8.112
8.094
8.065
8.044
8.023
7.915
7.897
7.880
7.753
7.736
7.718
6.305
3.390
2.508
N
Br
N
Br
1.00
2.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

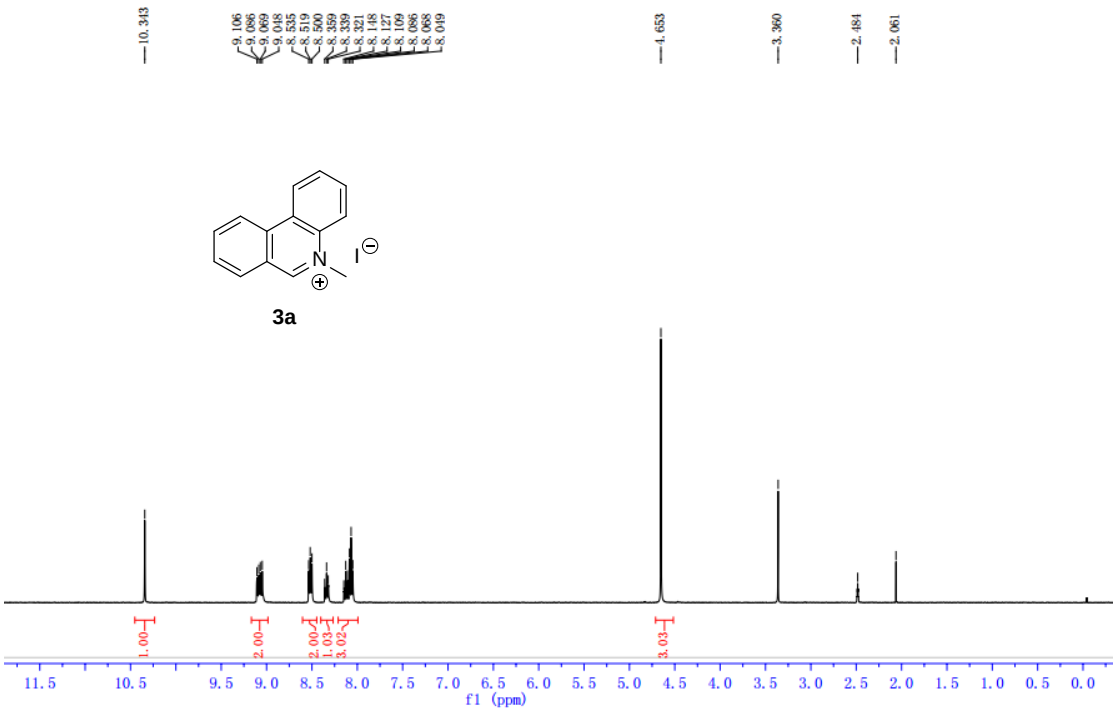
1ae


151.50
147.92
142.38
140.60
137.91
135.85
132.30
131.83
131.31
129.02
128.55
128.32
128.15
127.89
127.83
127.24
126.73
62.84
40.63
40.42
40.21
40.00
39.79
39.58
39.37
N
Br
N
Br
1ae
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

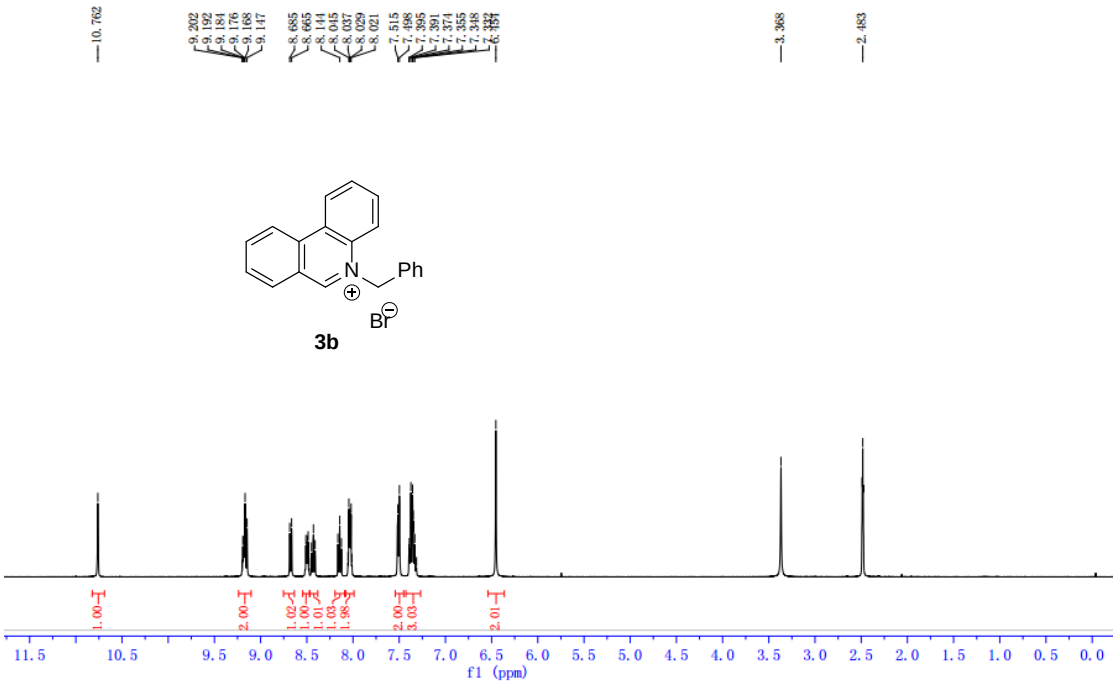

9.480
8.417
8.400
8.258
8.241
7.757
7.752
7.183
6.952
4.862
4.845
4.828
4.044
3.966
3.696
3.691
3.348
3.336
3.314
2.483
MeO
MeO
N
OMe
OMe
Br
I
1af
1.00
0.96
1.00
2.00
0.95
1.01
2.01
3.01
3.08
3.02
3.02
3.55
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


158.03
152.93
149.61
148.90
145.62
135.75
134.27
131.55
124.26
123.63
121.75
113.90
107.57
106.21
89.41
60.87
57.36
56.87
56.27
56.00
40.82
40.61
40.41
40.20
39.99
39.78
39.57
39.36
MeO
MeO
N
OMe
OMe
Br
I
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

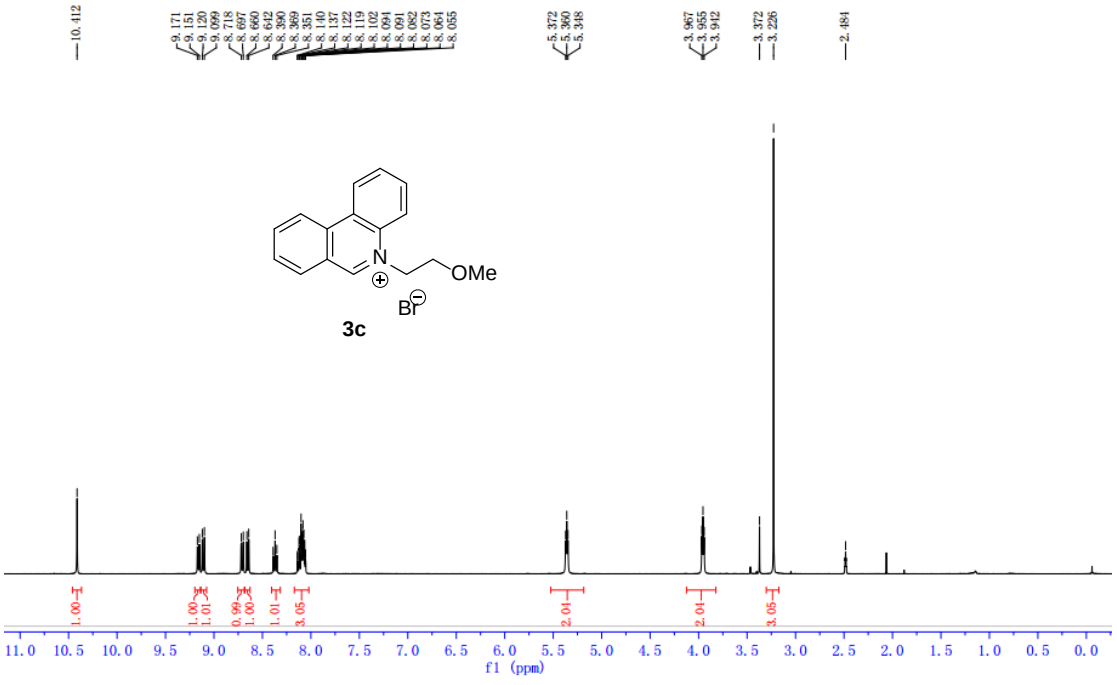
1af


10.343
9.106
9.096
9.069
9.048
8.535
8.519
8.500
8.359
8.339
8.321
8.148
8.127
8.109
8.086
8.068
8.049
4.653
3.360
2.484
2.061
N
I
1.00
2.00
2.00
1.03
3.02
3.03
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

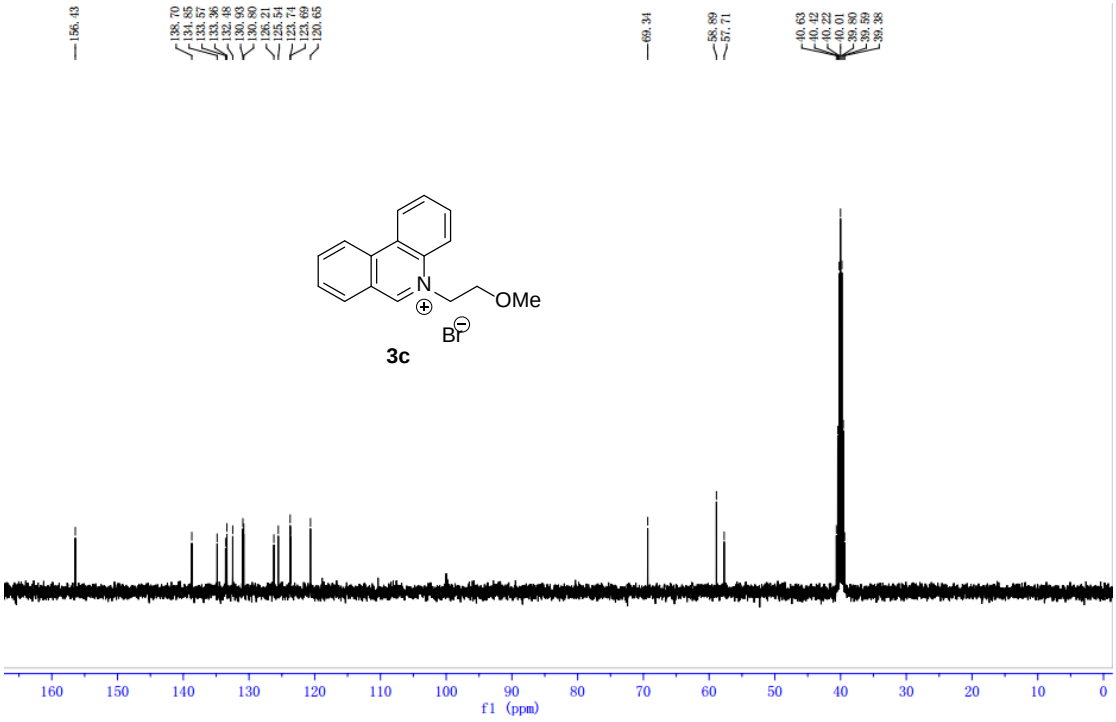
3a

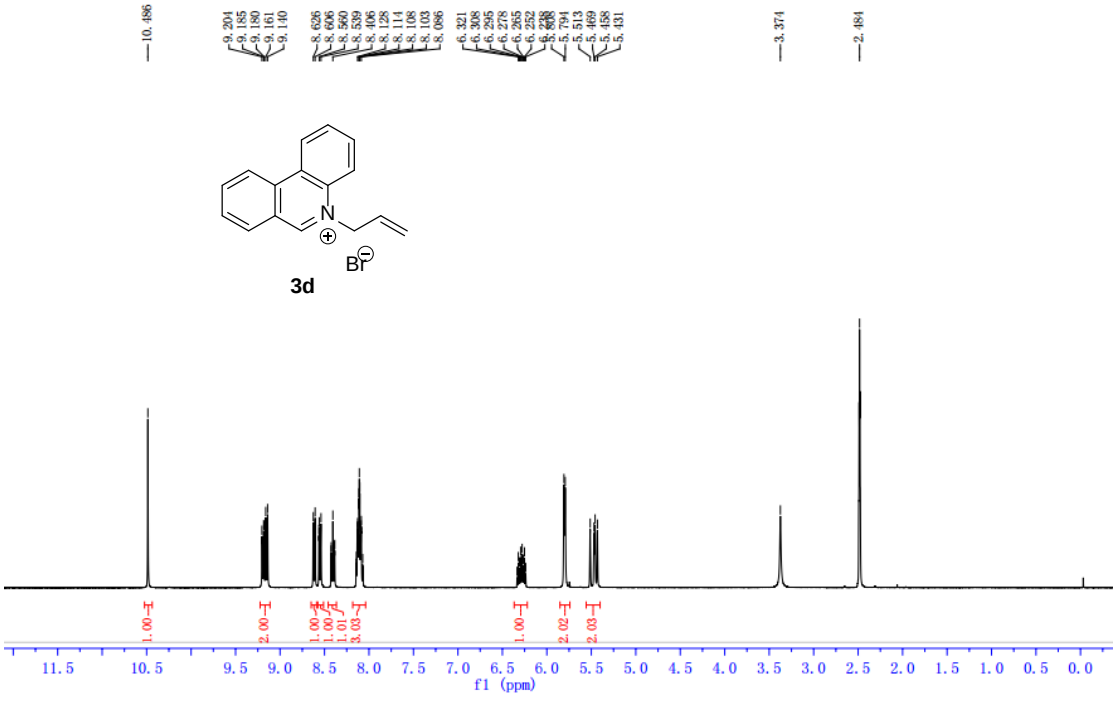

10.762
9.202
9.192
9.184
9.176
9.168
9.147
8.685
8.665
8.144
8.045
8.037
8.029
8.021
7.515
7.498
7.395
7.391
7.374
7.355
7.348
7.332
6.451
3.368
2.483
N
Ph
Br
1.00
2.00
1.02
1.00
1.01
1.03
1.98
2.00
3.03
2.01
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

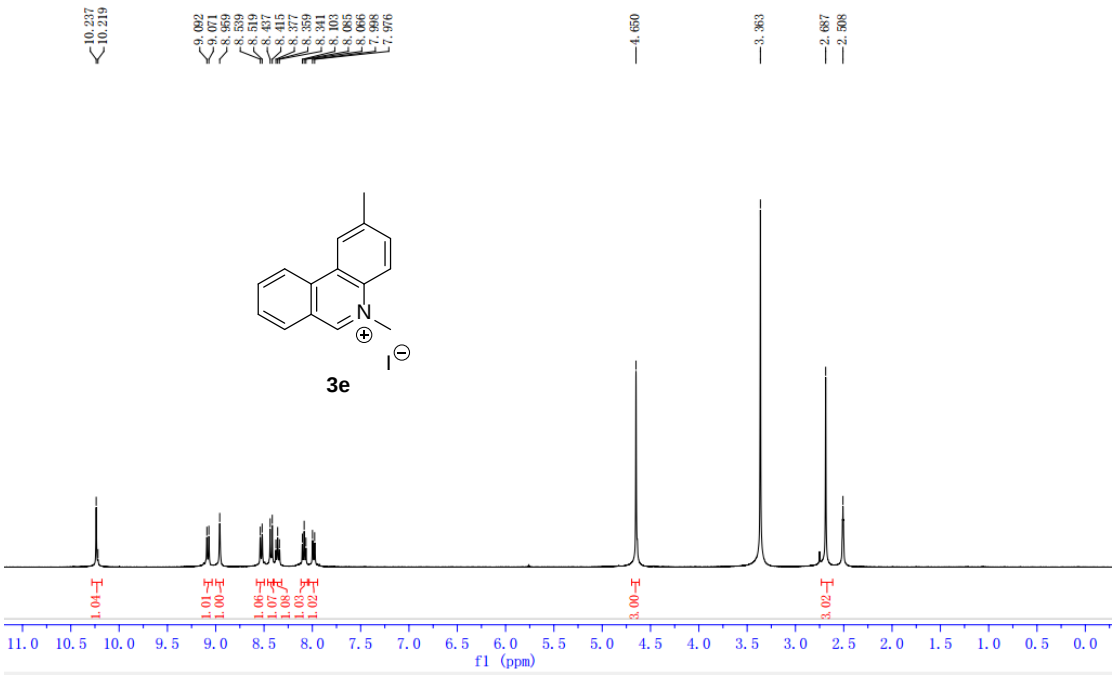
3b

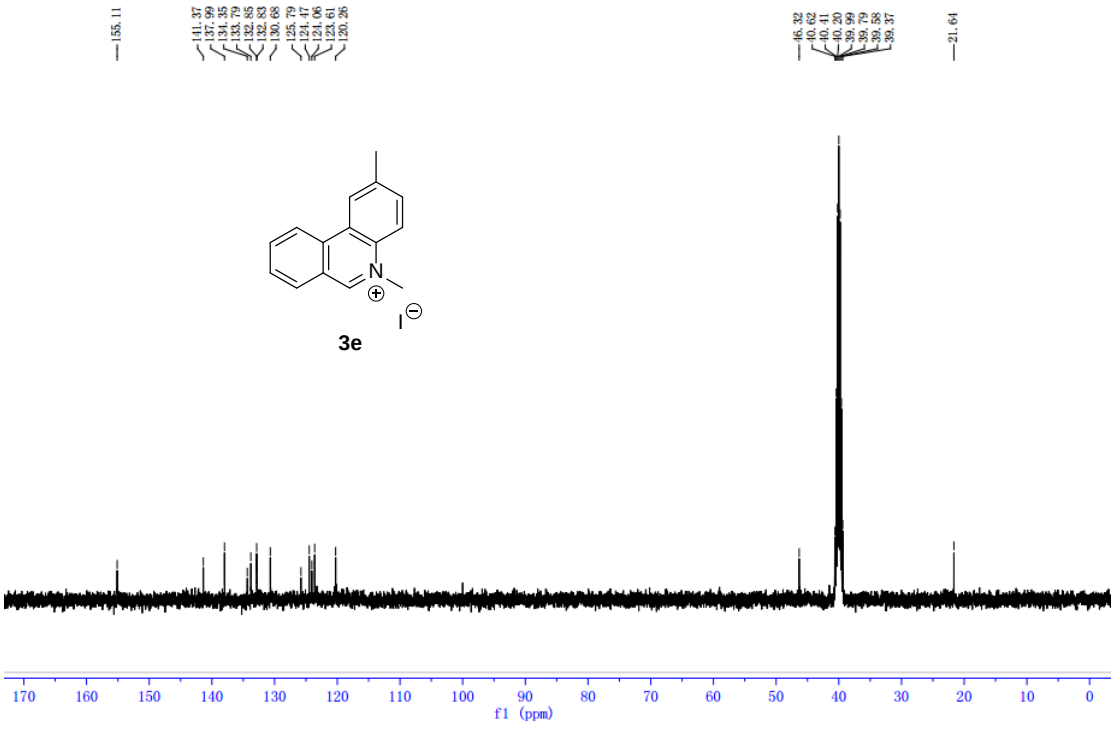

10.412
9.171
9.151
9.120
9.099
8.718
8.697
8.660
8.652
8.369
8.351
8.140
8.137
8.122
8.119
8.102
8.094
8.091
8.082
8.073
8.064
8.055
5.372
5.360
5.348
3.967
3.955
3.942
3.372
3.226
2.484
N
OMe
Br
1.00
1.00
1.01
0.99
1.00
1.01
3.05
2.01
2.01
3.05
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

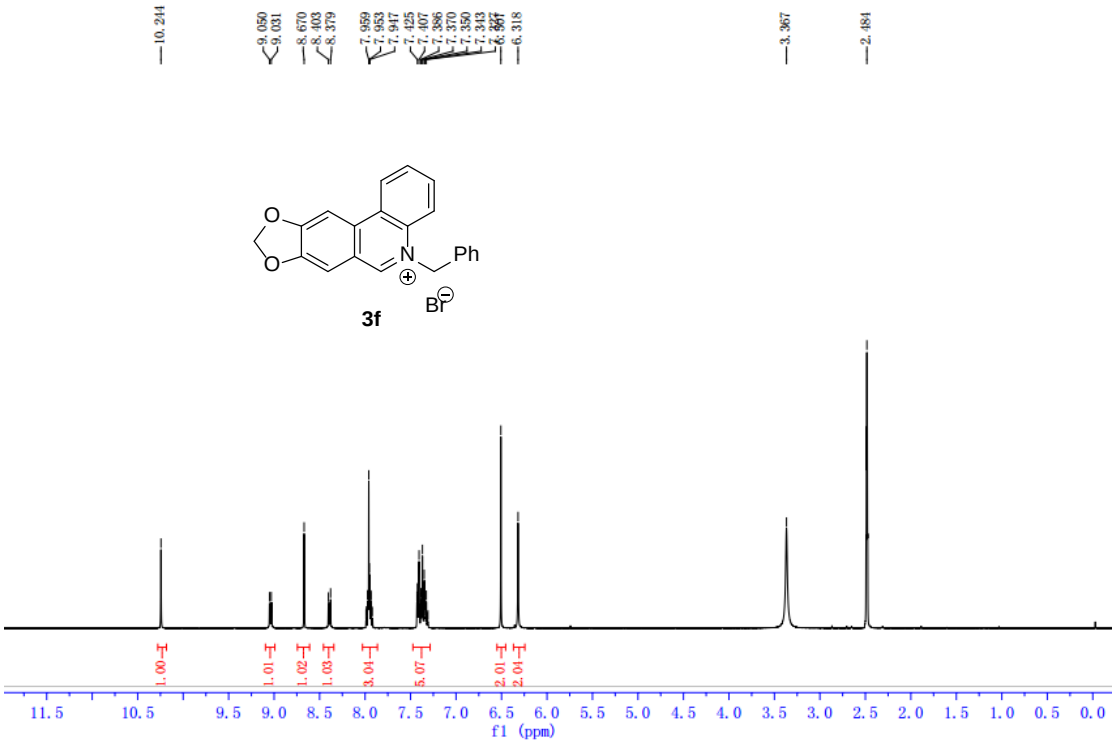
3c


156.43
138.70
134.85
133.57
133.36
132.48
130.93
130.80
126.21
125.54
123.74
123.69
120.65
69.34
58.89
57.71
40.63
40.42
40.22
40.01
39.80
39.59
39.38
OMe
Br
3c
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

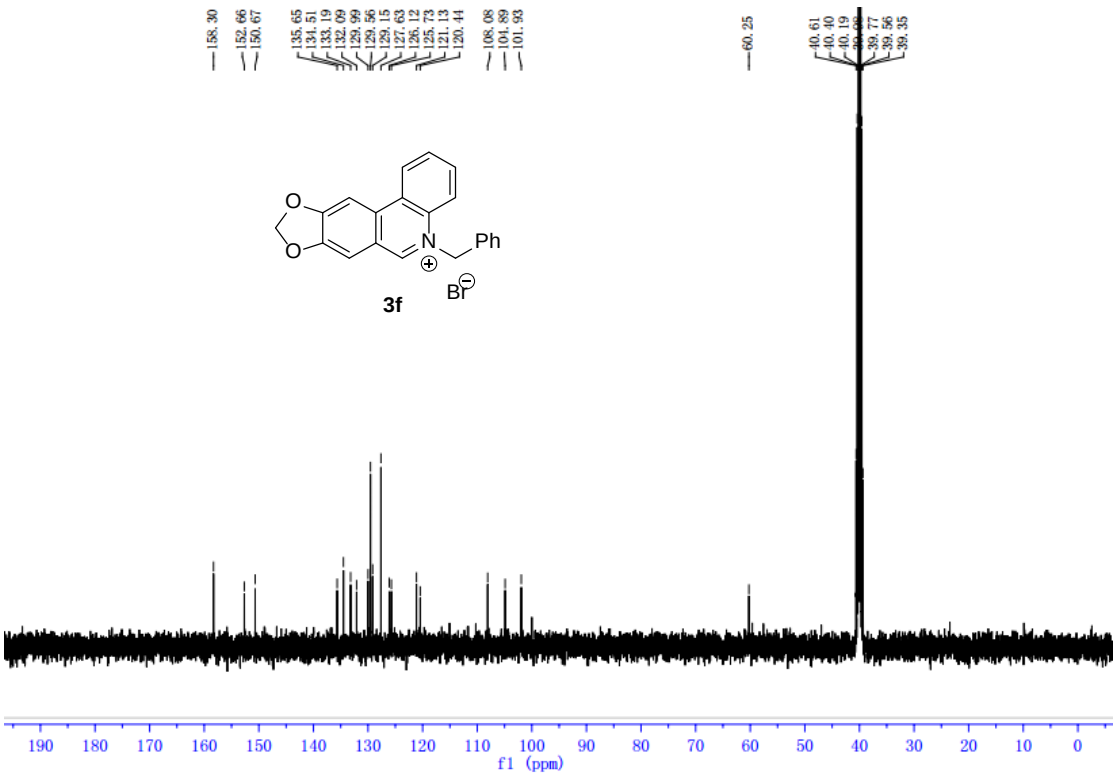

10.486
9.204
9.185
9.180
9.161
9.140
8.626
8.606
8.560
8.539
8.406
8.128
8.114
8.108
8.103
8.086
6.321
6.308
6.295
6.278
6.265
6.252
5.794
5.513
5.469
5.458
5.431
3.374
2.484
N
Br
3d
1.00
2.00
1.00
1.00
1.01
3.03
1.00
2.02
2.03
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


10.237
10.219
9.092
9.071
8.959
8.539
8.519
8.437
8.415
8.377
8.359
8.341
8.103
8.085
8.066
7.998
7.976
4.650
3.363
2.687
2.508
N
I
3e
1.04
1.01
1.00
1.06
1.07
1.08
1.03
1.02
3.00
3.02
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

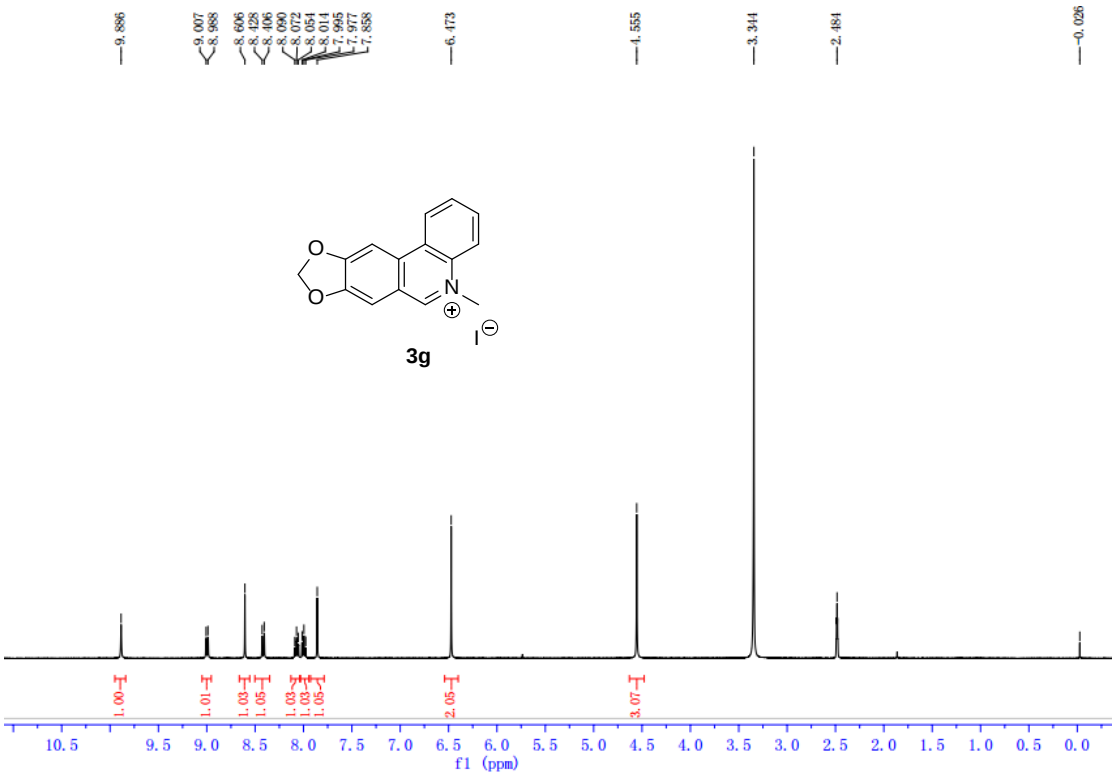

155.11
141.37
137.99
134.35
133.79
132.85
132.83
130.68
125.79
124.47
124.06
123.61
120.26
46.32
40.62
40.41
40.20
39.99
39.79
39.58
39.37
21.64
N
I
3e
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


10.244
9.050
9.031
8.670
8.403
8.379
7.959
7.953
7.947
7.425
7.407
7.386
7.370
7.350
7.343
6.318
3.367
2.484
O
O
N
Ph
Br
1.00
1.01
1.02
1.03
3.04
5.07
2.01
2.04
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

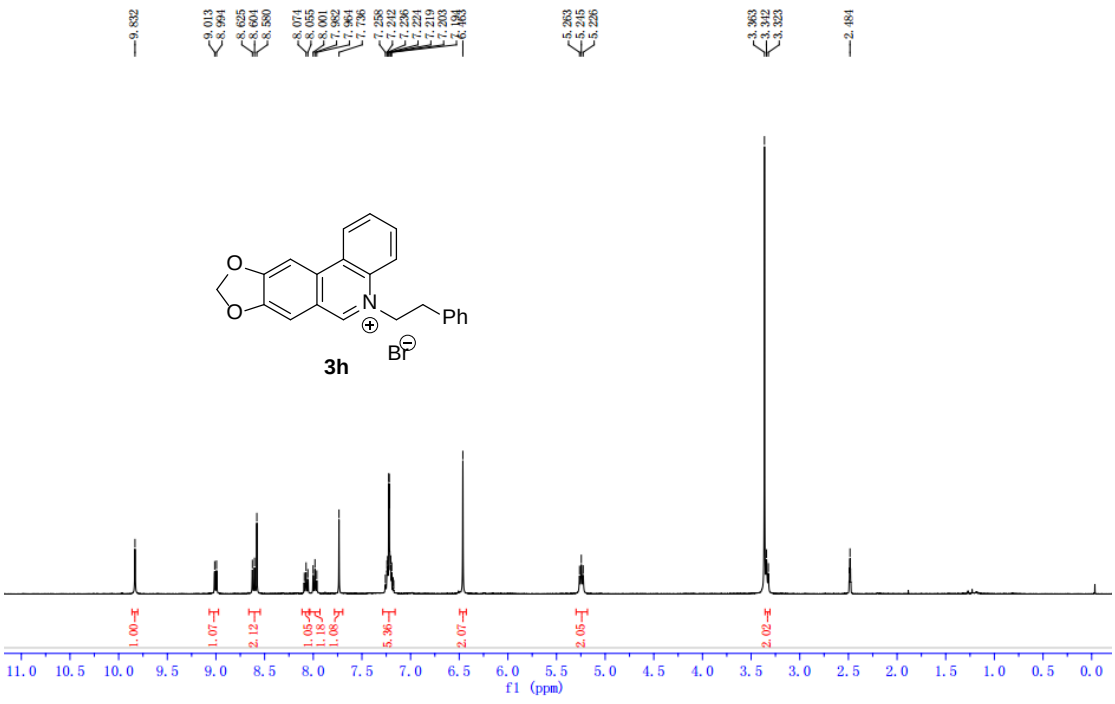
3f


158.30
152.66
150.67
135.65
134.51
133.19
132.09
129.99
129.56
129.15
127.63
126.12
125.73
121.13
120.44
108.08
104.89
101.93
60.25
40.61
40.40
40.19
39.77
39.56
39.35
O
O
N
Ph
Br
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

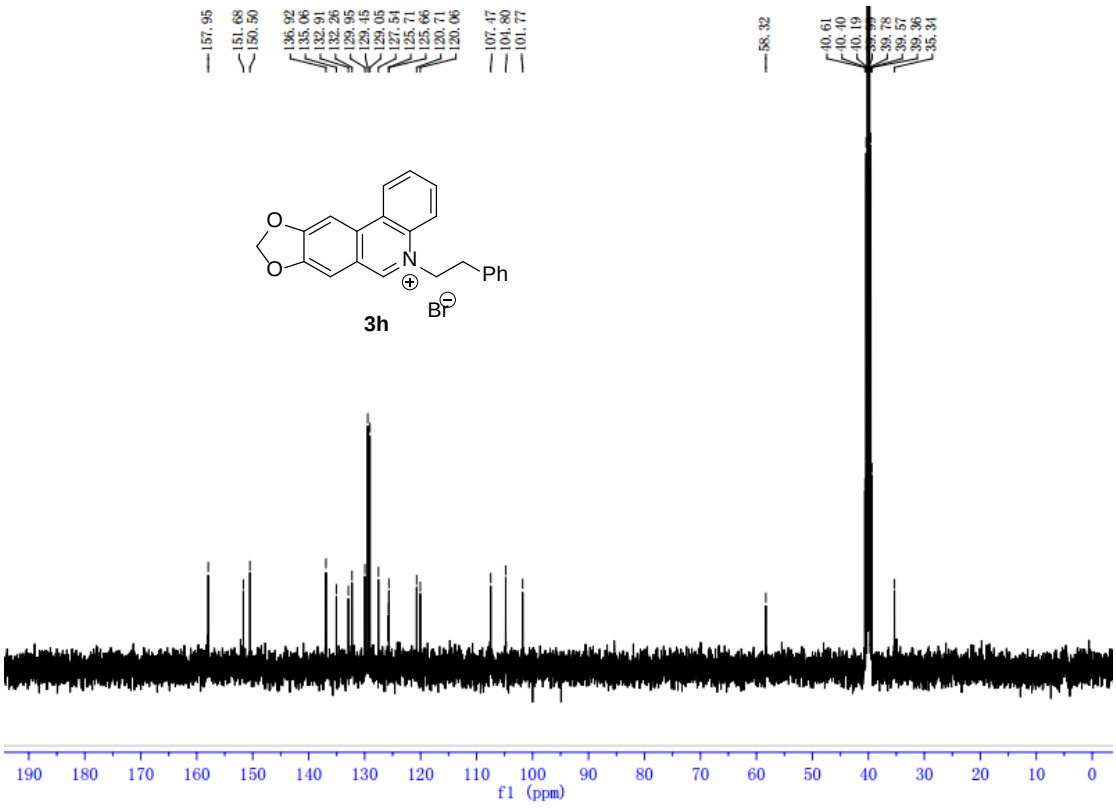
3f

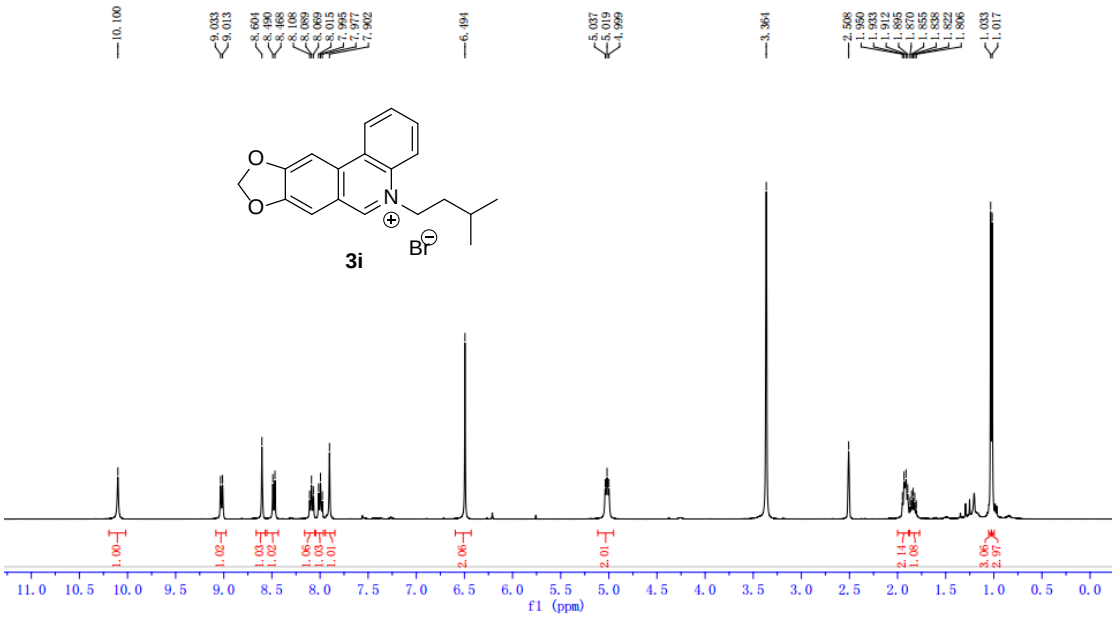

9.886
9.007
8.988
8.606
8.428
8.406
8.090
8.072
8.054
8.014
7.945
7.977
7.838
6.473
4.555
3.344
2.484
0.026
O
O
N
I
1.00
1.01
1.03
1.05
1.03
1.03
1.05
2.05
3.07
10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

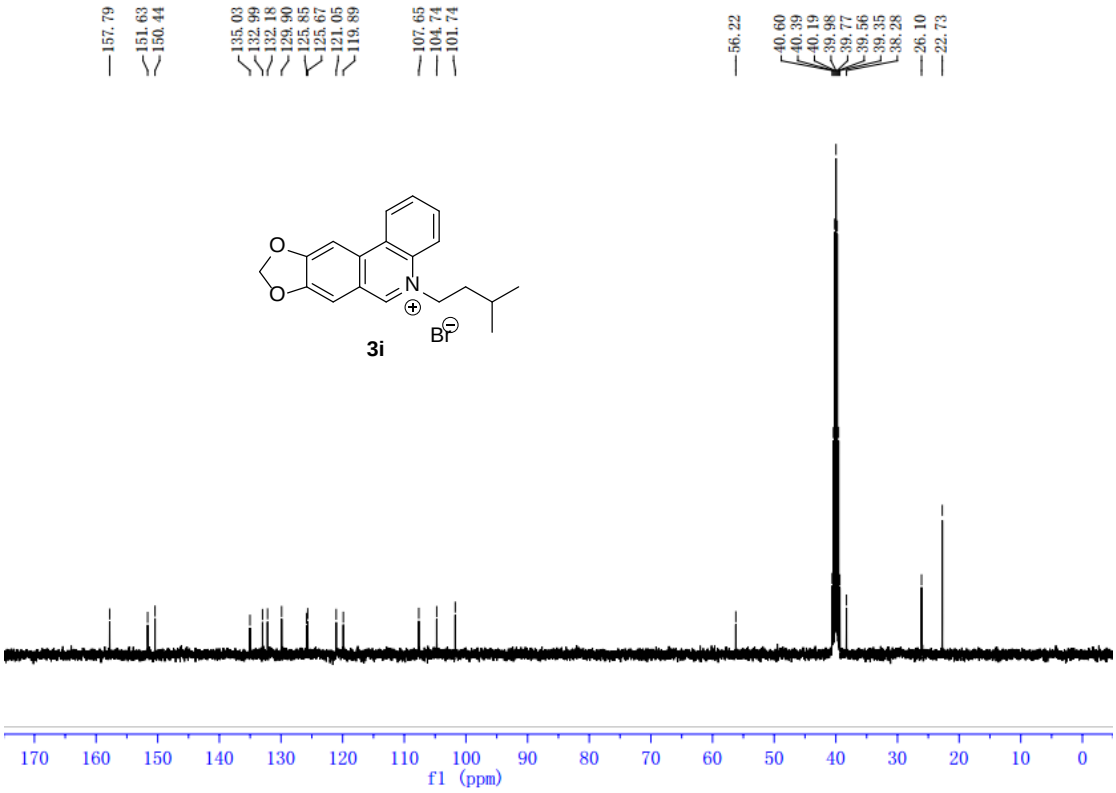
3g

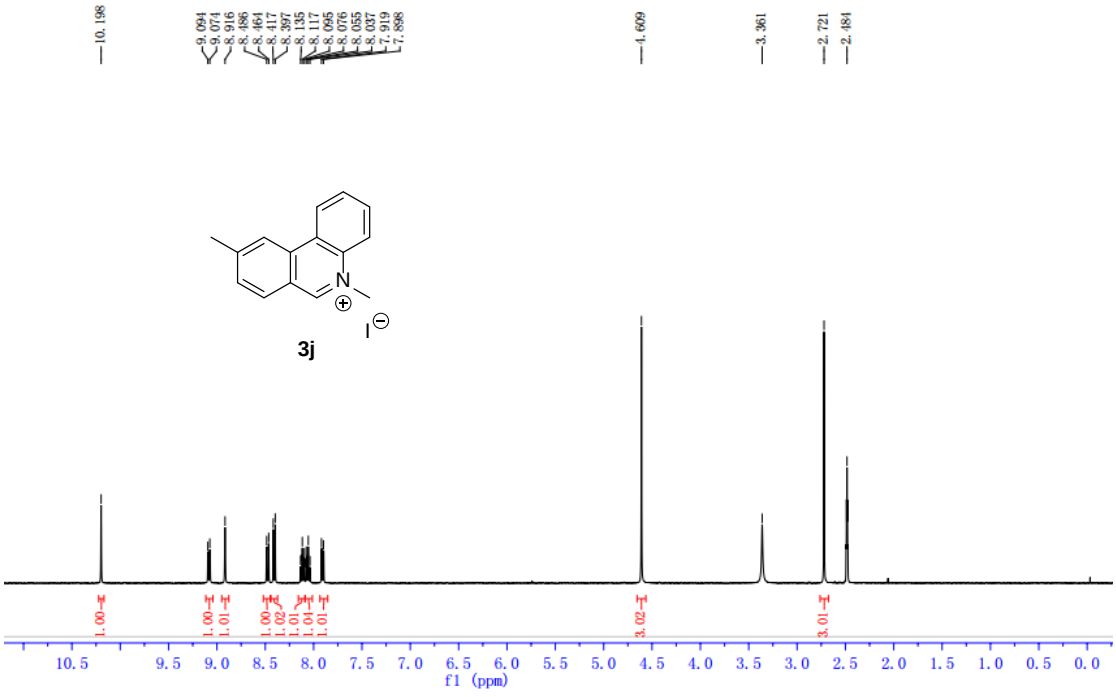

9.832
9.013
8.994
8.635
8.621
8.580
8.071
8.045
8.001
7.982
7.961
7.736
7.258
7.212
7.236
7.221
7.219
7.203
5.263
5.245
5.226
3.363
3.342
3.323
2.484
O
O
N
Ph
Br
1.00
1.07
2.12
1.05
1.18
1.06
5.36
2.07
2.05
2.02
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

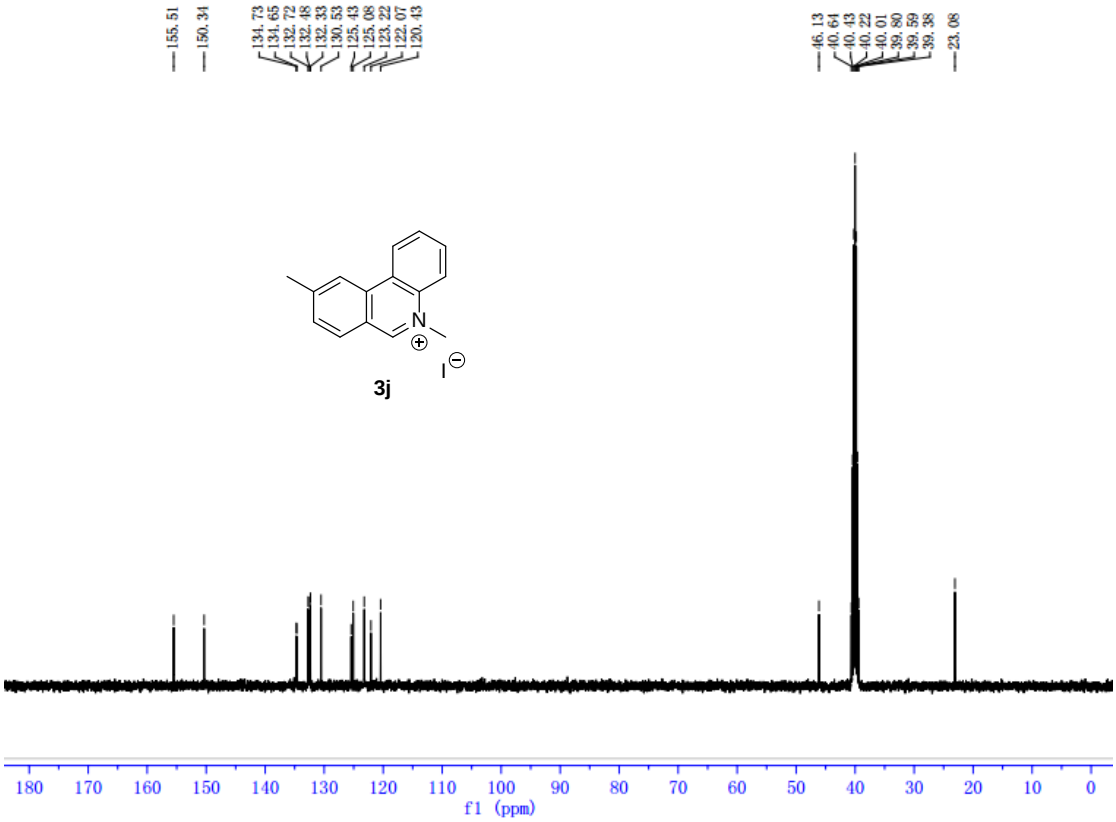
3h


157.95
151.68
150.50
136.92
135.06
132.91
132.26
129.95
129.45
129.05
127.54
125.71
125.66
120.71
120.06
107.47
104.80
101.77
58.32
40.61
40.40
40.19
39.78
39.57
39.36
35.34
O
O
N
Ph
Br
3h
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

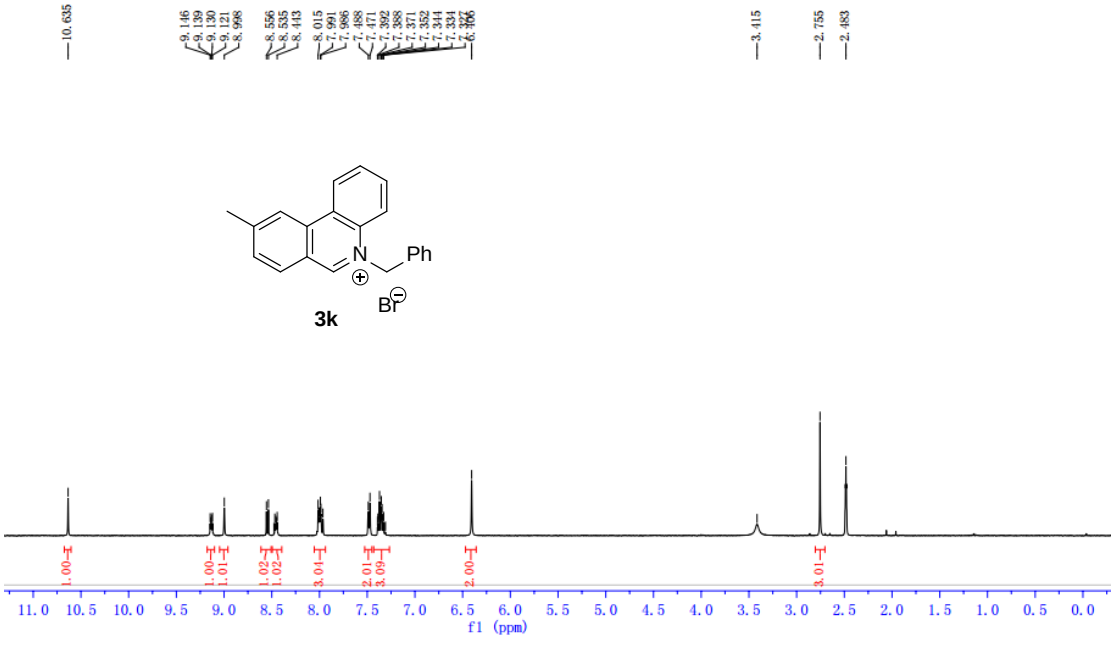

10.100
9.033
9.013
8.604
8.490
8.488
8.108
8.089
8.069
8.015
7.995
7.977
7.902
6.494
5.037
5.019
4.999
3.364
2.508
1.950
1.933
1.912
1.895
1.870
1.855
1.838
1.822
1.806
1.033
1.017
O
O
N
Br
3i
1.00
1.02
1.03
1.02
1.05
1.03
1.10
2.06
2.01
2.11
1.08
3.05
2.97
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


157.79
151.63
150.44
135.03
132.99
132.18
129.90
125.85
125.67
121.05
119.89
107.65
104.74
101.74
56.22
40.60
40.39
40.19
39.98
39.77
39.56
39.35
38.28
26.10
22.73
O
O
N
Br
3i
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

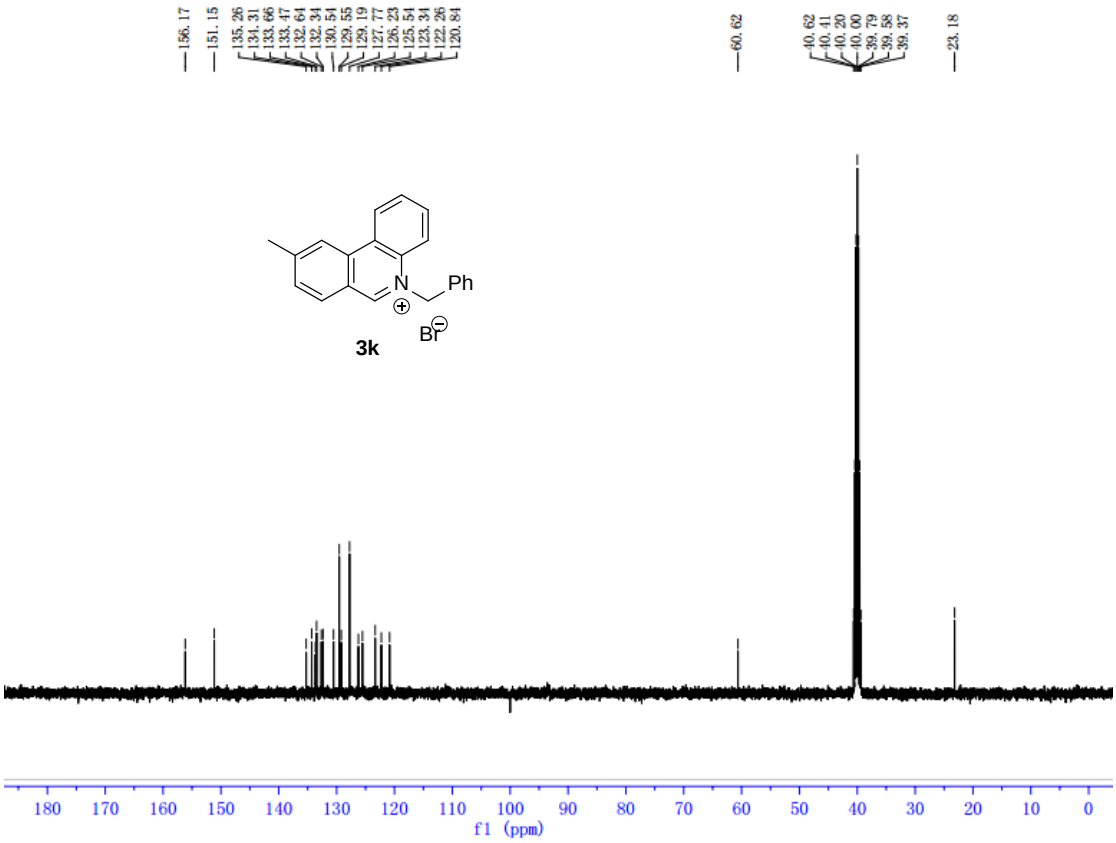

10.198
9.094
9.074
8.916
8.486
8.464
8.417
8.397
8.135
8.117
8.095
8.076
8.055
8.037
7.919
7.898
4.609
3.361
2.721
2.484
N
I
3j
1.00
1.00
1.01
1.00
1.02
1.01
1.04
1.01
1.01
3.02
3.01
10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

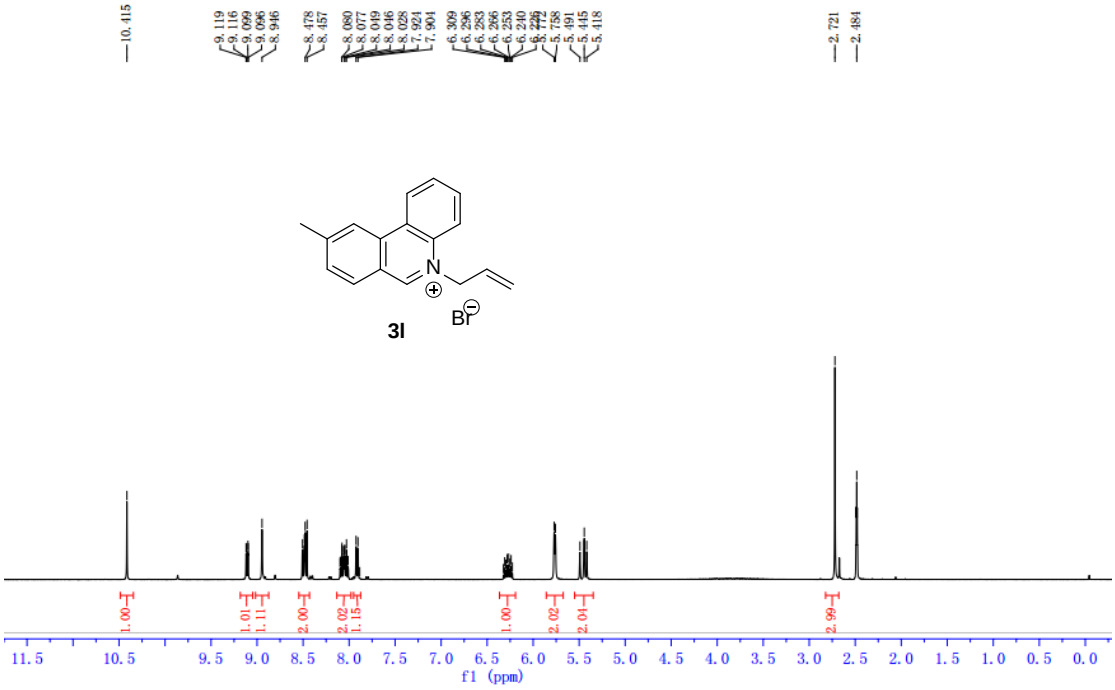

155.51
150.34
134.73
134.65
132.72
132.48
132.33
130.53
125.43
125.06
123.22
122.07
120.43
46.13
40.64
40.43
40.22
40.01
39.80
39.59
39.38
23.06
N
I
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

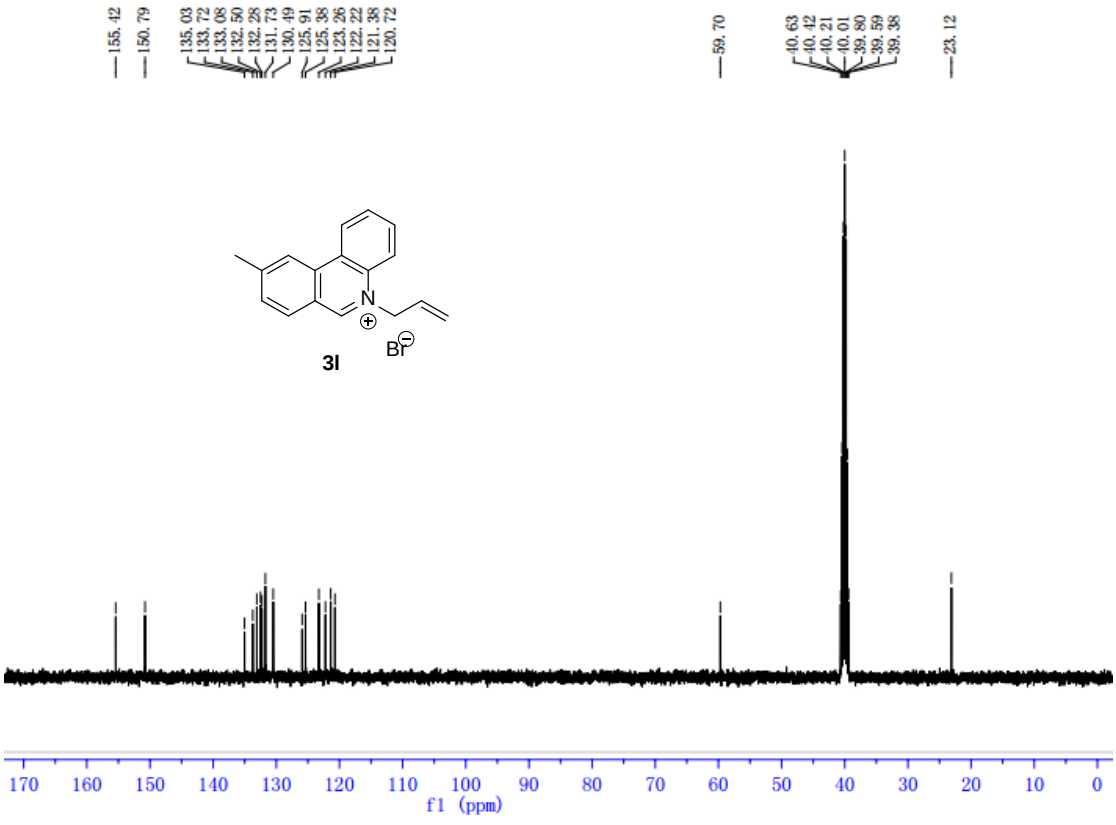
3j


10.635
9.146
9.139
9.130
9.121
8.998
8.556
8.535
8.443
8.015
7.991
7.986
7.488
7.471
7.392
7.388
7.371
7.352
7.344
7.334
7.327
7.306
3.415
2.755
2.483
N
Ph
Br
1.00
1.00
1.01
1.02
1.02
3.04
2.01
3.09
2.00
3.01
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

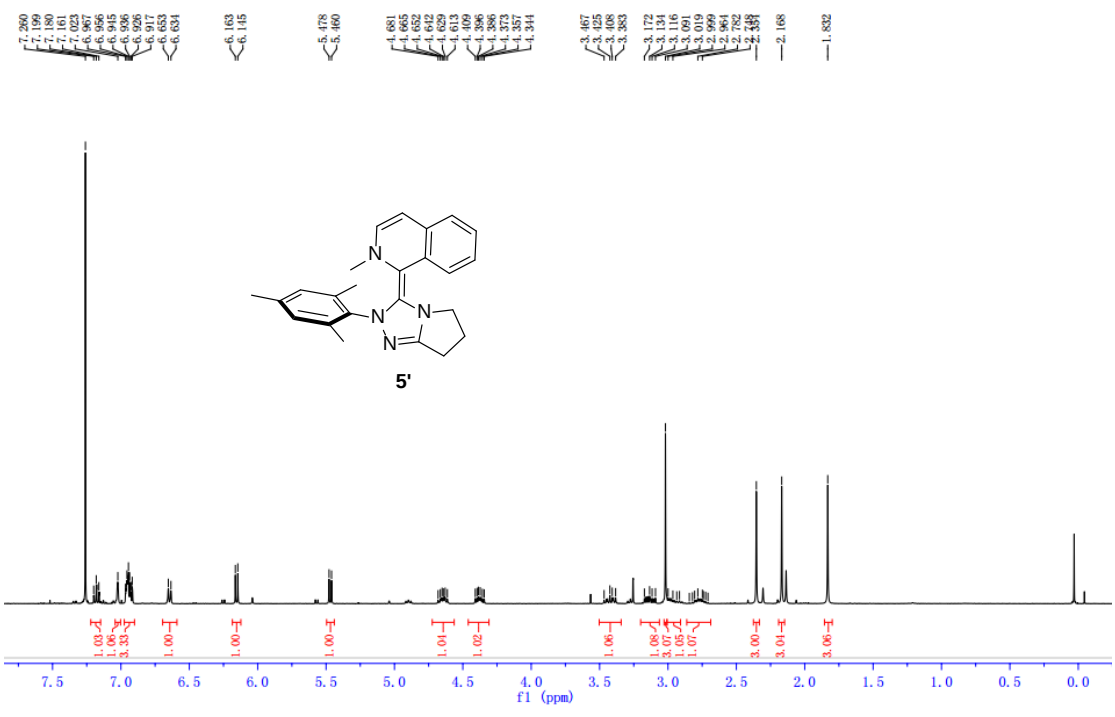
3k


156.17
151.15
135.26
134.31
133.66
133.47
132.64
132.34
130.54
129.55
129.19
127.77
126.23
125.54
123.34
122.26
120.84
60.62
40.62
40.41
40.20
40.00
39.79
39.58
39.37
23.18
N
Ph
Br
3k
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

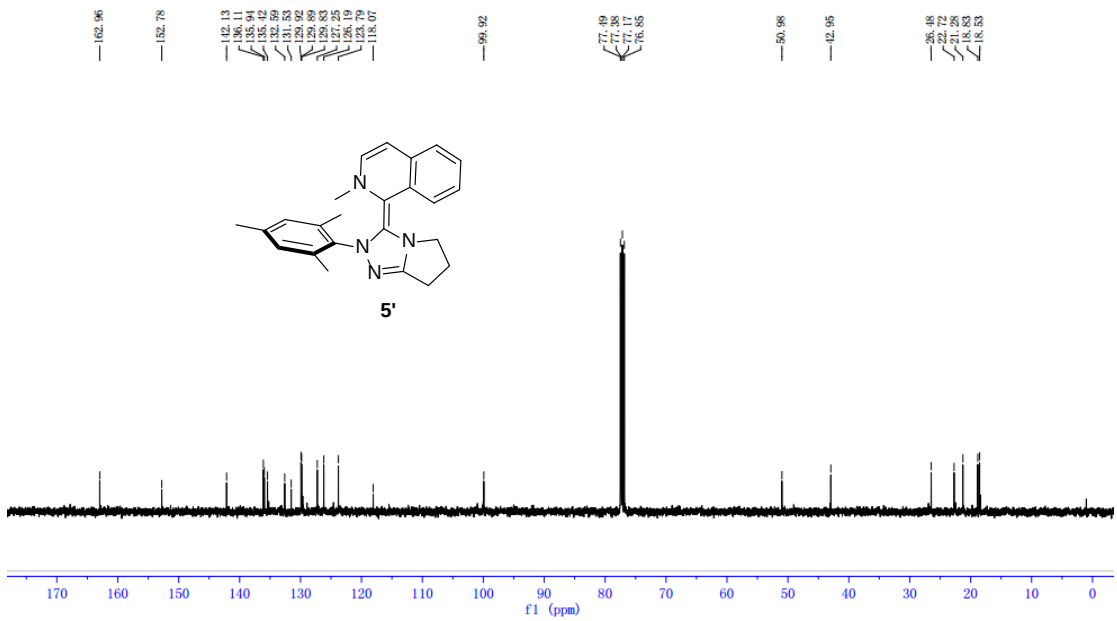

10.415
9.119
9.116
9.099
9.096
8.946
8.478
8.457
8.080
8.077
8.049
8.046
8.028
7.924
7.904
6.309
6.296
6.293
6.286
6.253
6.240
5.758
5.491
5.445
5.418
2.721
2.484
N
Br
3l
1.00
1.01
1.11
2.00
2.02
1.15
1.00
2.02
2.04
2.99
11.5 10.5 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

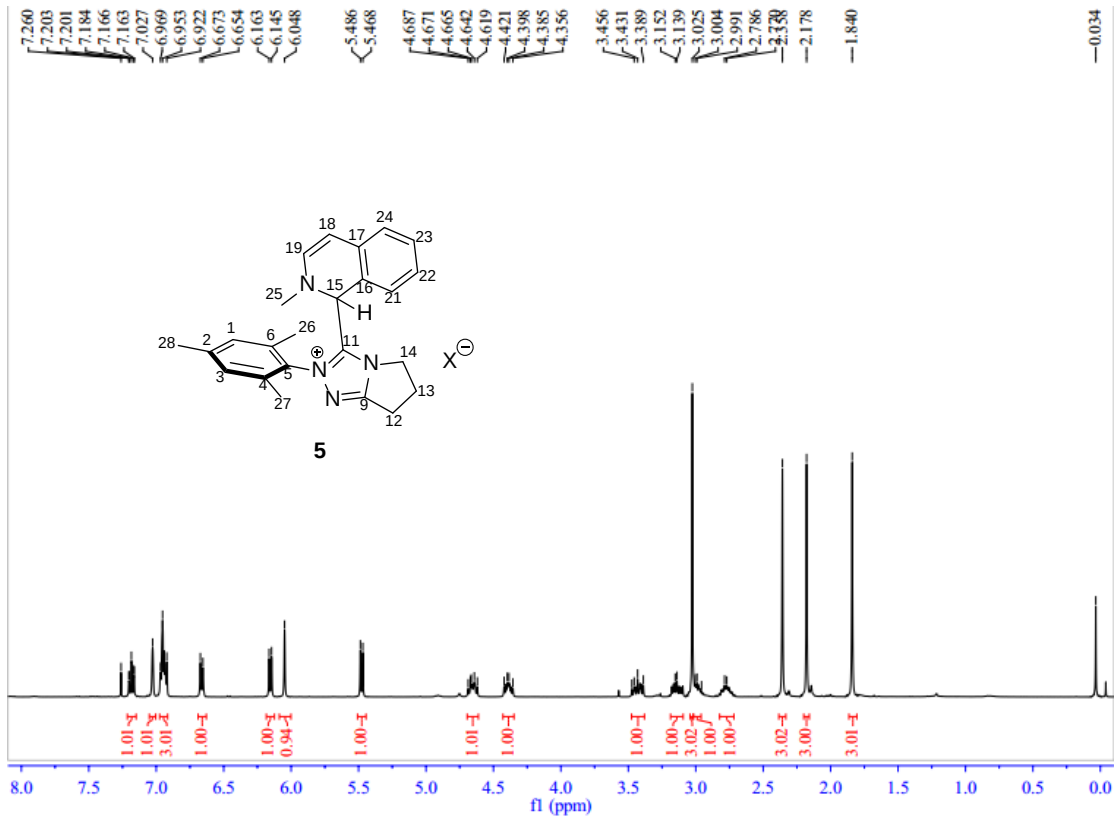

155.42
150.79
135.03
133.72
133.08
132.50
132.28
131.73
130.49
125.91
125.38
123.26
122.22
121.38
120.72
59.70
40.63
40.42
40.21
40.01
39.80
39.59
39.38
23.12
N
Br
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

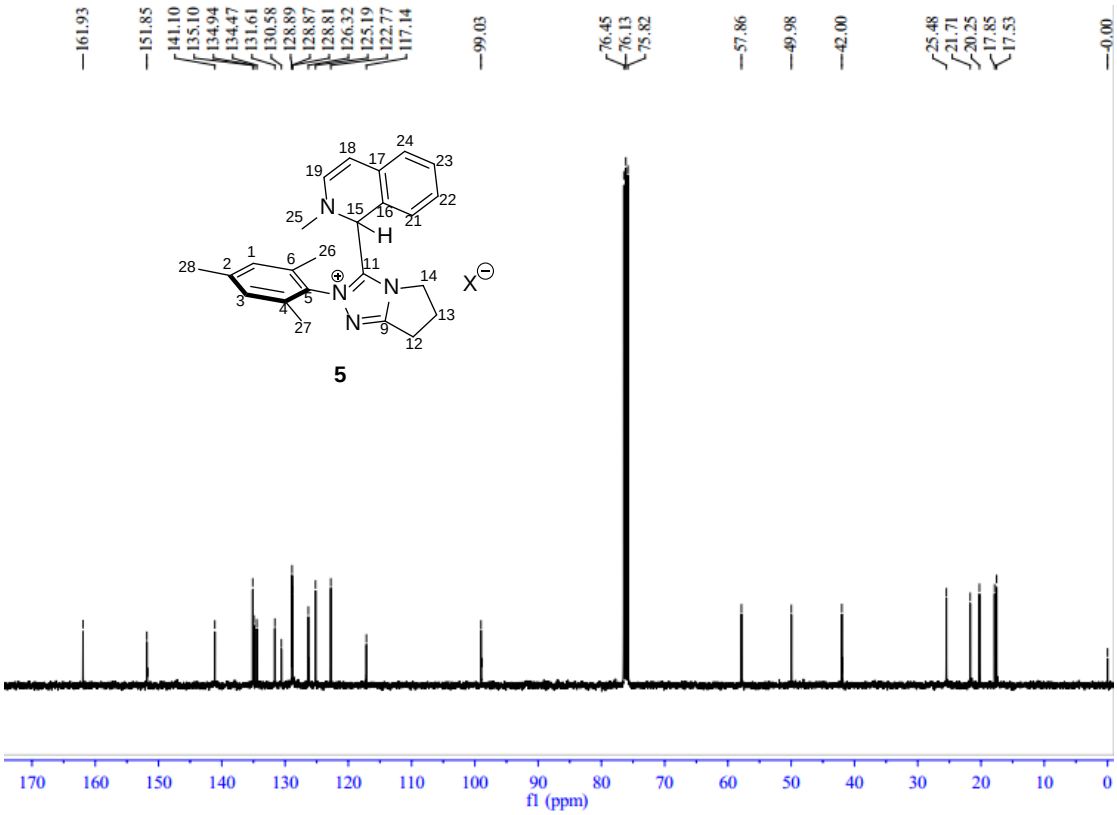
3l


7.260
7.199
7.180
7.161
7.023
6.967
6.945
6.936
6.926
6.917
6.653
6.634
6.163
6.145
5.478
5.460
4.681
4.665
4.652
4.642
4.629
4.613
4.409
4.396
4.386
4.373
4.357
4.344
3.467
3.425
3.408
3.383
3.172
3.134
3.116
3.091
3.019
2.999
2.961
2.782
2.168
1.832
N
N
N
N
1.03
1.06
3.33
1.00
1.00
1.00
1.04
1.02
1.06
1.08
3.07
1.05
1.07
3.00
3.04
3.06
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

5'


162.96
152.78
142.13
136.11
135.94
135.42
132.89
131.53
129.92
129.88
129.83
127.25
126.19
123.79
118.07
99.92
77.49
77.38
77.17
76.85
50.98
42.95
26.48
22.72
21.26
18.83
18.53
N
N
N
N
5'
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

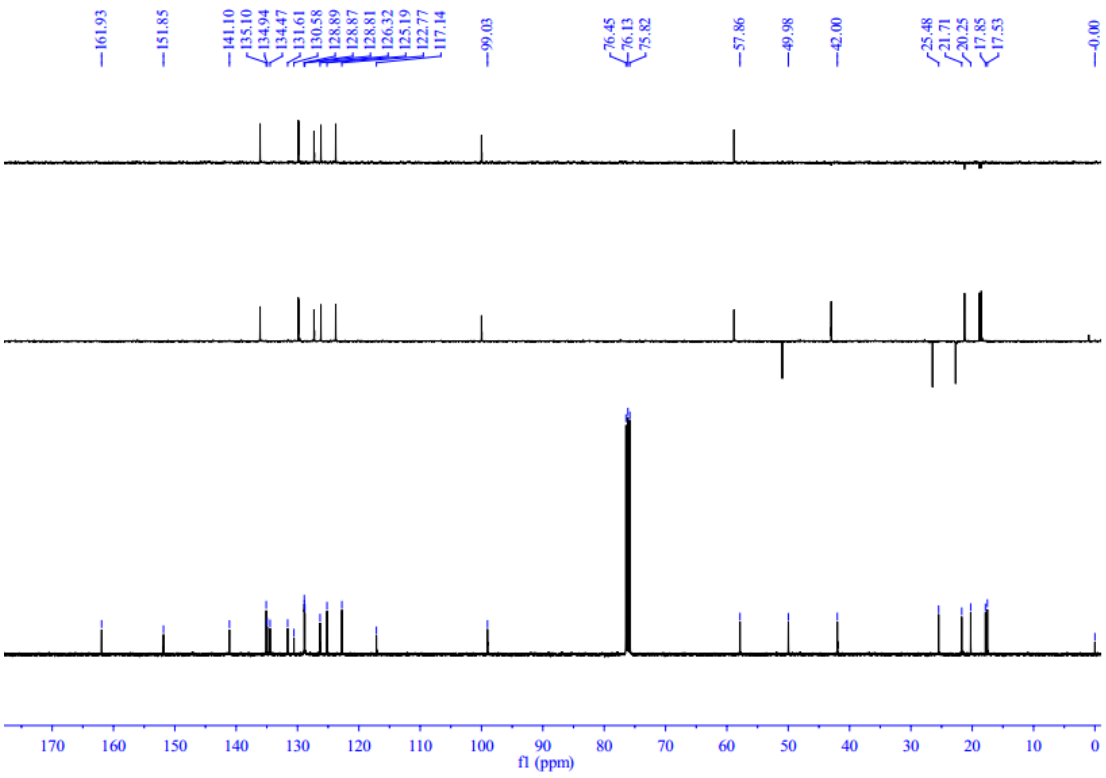

7.260
7.203
7.201
7.184
7.166
7.163
7.027
6.969
6.953
6.922
6.673
6.654
6.163
6.145
6.048
5.486
5.468
4.687
4.671
4.665
4.642
4.619
4.421
4.398
4.385
4.356
3.456
3.431
3.389
3.152
3.139
3.025
3.004
2.991
2.786
2.730
2.338
2.178
1.840
0.034
18
17
24
23
19
22
N
15
16
21
25
H
1
6
26
28
2
11
N
14
X
3
4
5
N
13
27
9
12
5
1.01
1.01
3.01
1.00
1.00
0.94
1.00
1.01
1.00
1.00
1.00
3.02
1.00
1.00
3.02
3.00
3.01
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



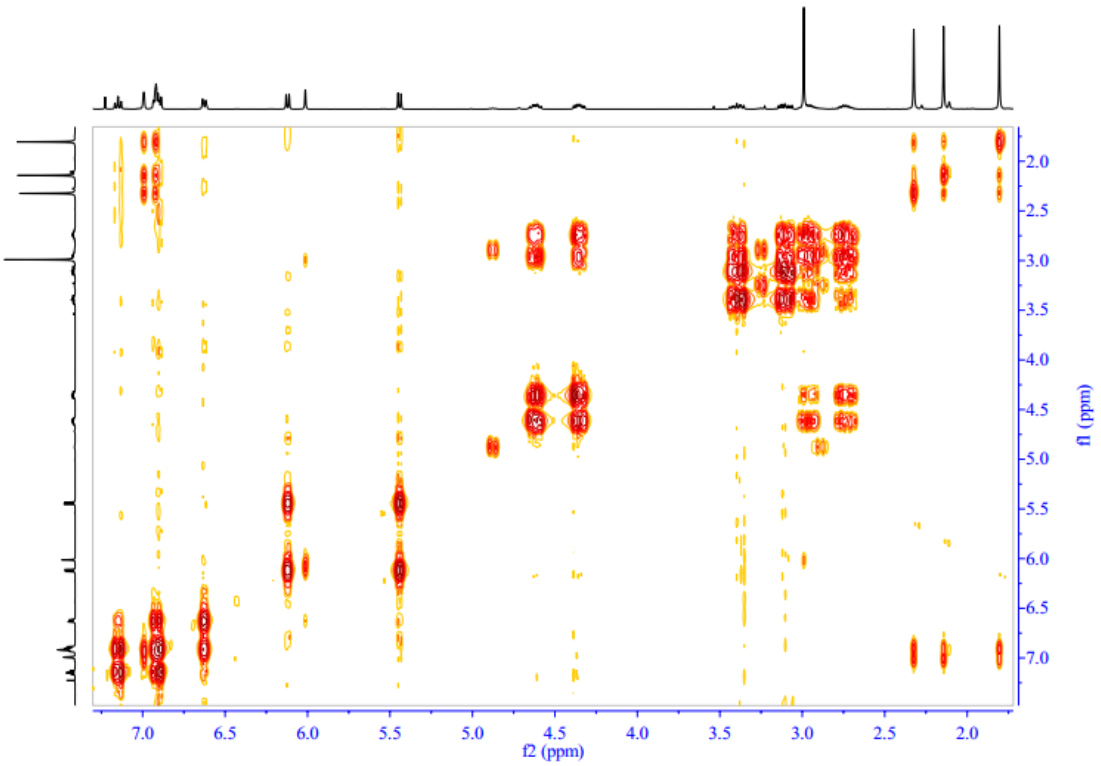
5

e) 2D NMR of intermediate 5

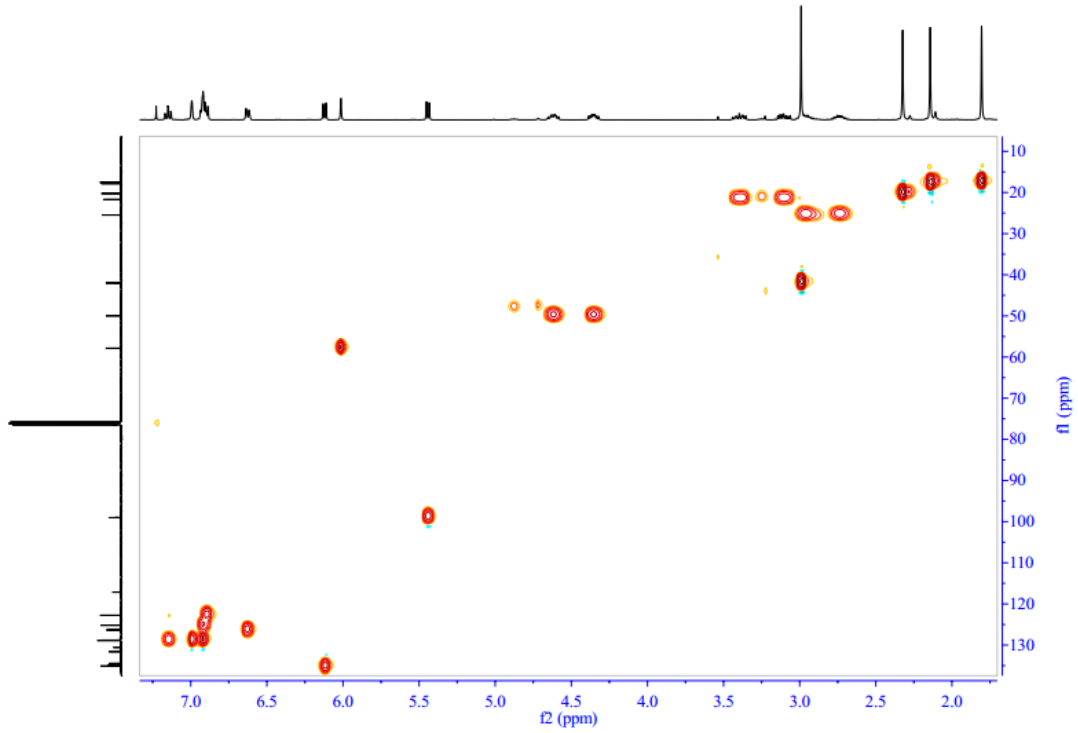
5



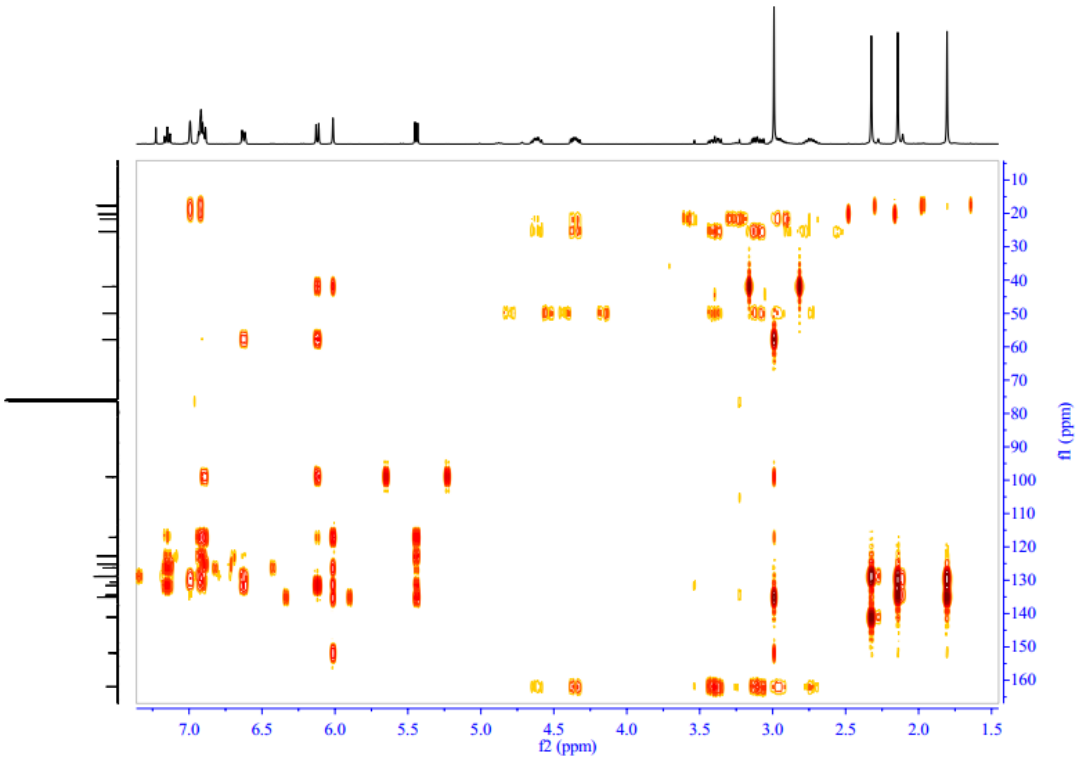
DEPT spectrum of **5**



COSY spectrum of **5**



HSQC spectrum of **5**



HMBC spectrum of **5**