Supporting information

Heterogeneous Synergistic Catalysis for Promoting Aza-Michael-Henry Tandem Reaction for the Synthesis of Chiral 3-Nitro-1,2-Dihydroquinoline

Zhe An, Lifeng Chen, Yitao Jiang, and Jing He*

Figures and Descriptions:

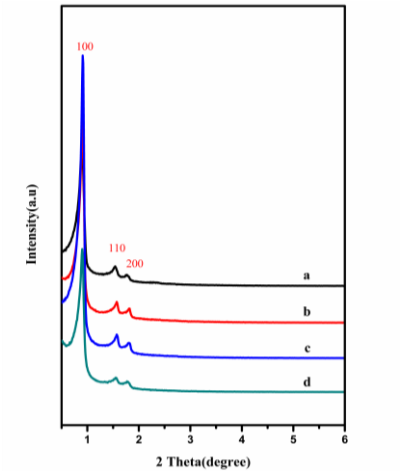


Fig. S1. XRD patterns of (a) SBA-15, (b) SBA-15-SH, (c) SBA-15-PY, and (d) SBA-15-Q.

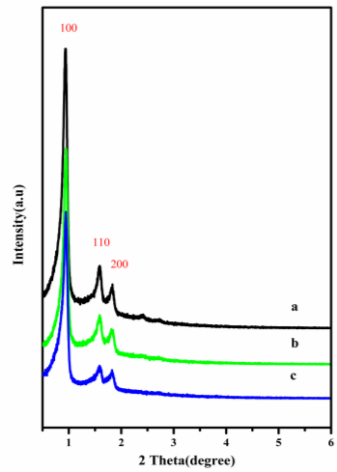


Fig. S2. XRD patterns of (a) SBA-15, (b) SBA-15-Br, and (c) SBA-15-AEP.

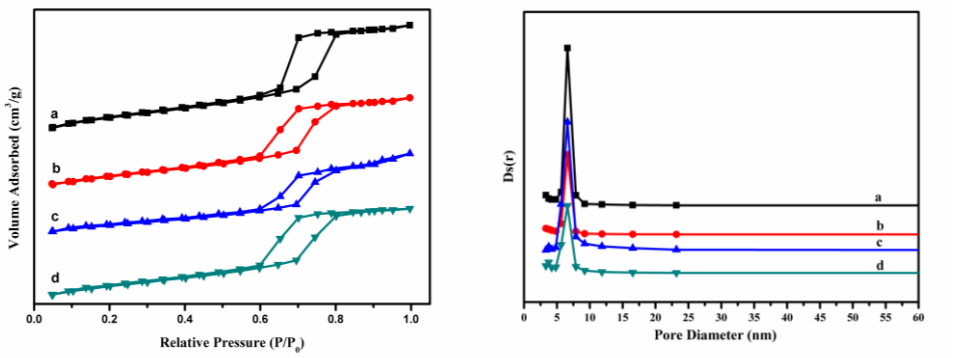


Fig. S3. Nitrogen adsorption-desorption isotherms and the pore size distribution of (a) SBA-15, (b) SBA-15-SH, (c) SBA-15-PY, and (d) SBA-15-Q.

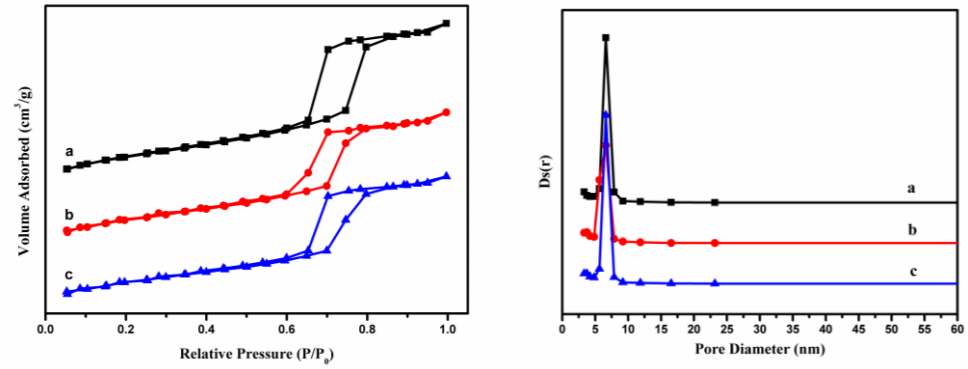


Fig. S4. Nitrogen adsorption-desorption isotherms and the pore size distribution of (a) SBA-15, (b) SBA-15-Br, and (c) SBA-15-AEP.

N_2 adsorption-desorption isotherms for all samples are typical of type IV, and H1-type hysteresis loop with delayed capillary evaporation located at a P/P_0 of about 0.7 is observed, revealing the predominance of well-defined mesopores with uniform size. The pore size shows a narrow distribution with the maximum at 6.5-6.5 nm. Table S1 summarizes the pore sizes along with the BET surface areas and pore volumes. The decreases in surface area and pore volume clearly indicate that the grafted (3-mercaptopropyl)trimethoxysilane/3-bromopropyltrichlorosilane groups and chiral amines are located inside the mesopore channels.

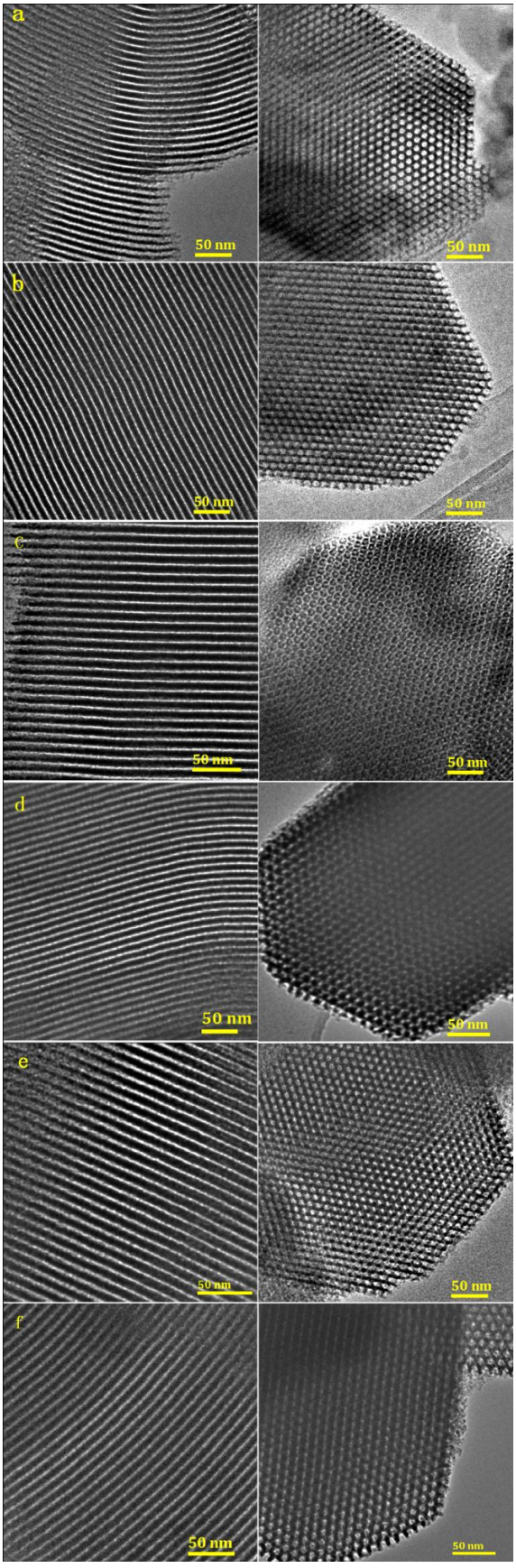


Fig. S5. TEM images of (a) SBA-15, (b) SBA-15-SH, (c) SBA-15-Br, (d) SBA-15-PY, (e) SBA-15-AEP, and (f) SBA-15-Q, perpendicular (left) and parallel (right) to the channels.

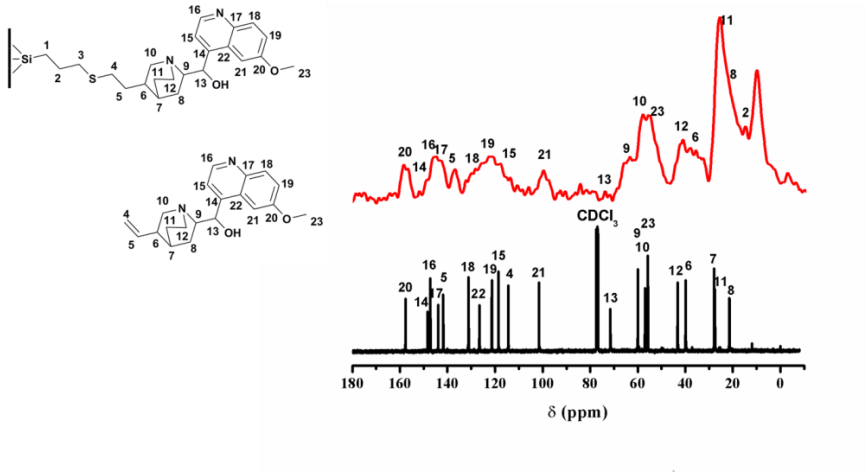


Fig. S6. ^{13}C CP/MAS NMR spectrum of SBA-15-Q and ^{13}C NMR spectrum of quinine.

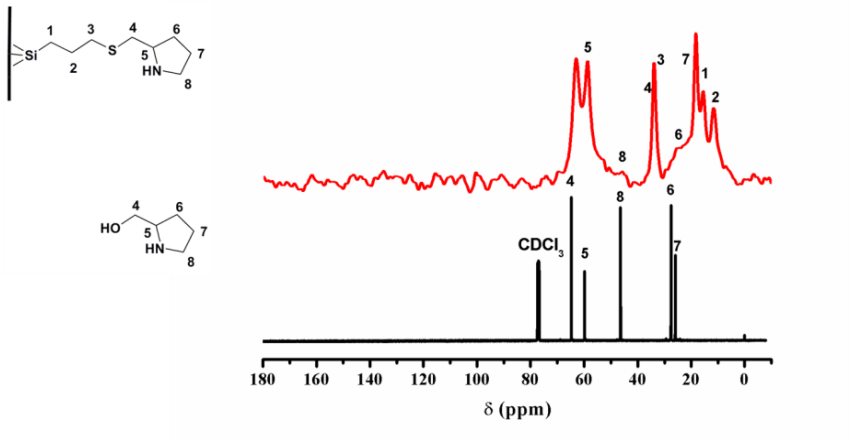


Fig. S7. ^{13}C CP/MAS NMR spectrum of SBA-15-PY and ^{13}C NMR spectrum of (S)-(+)-prolinol.

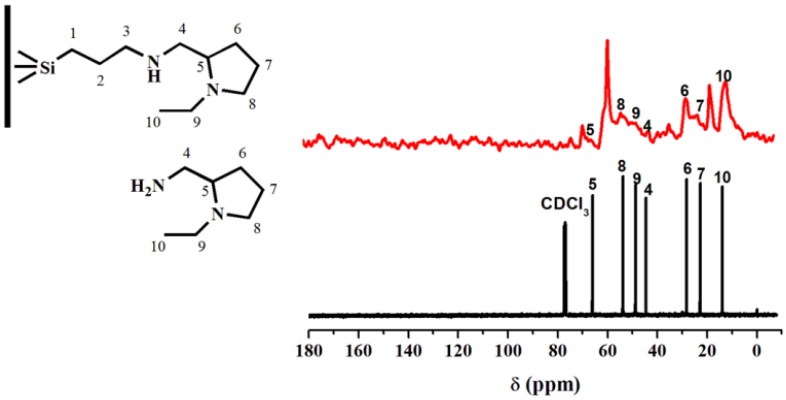


Fig. S8. ^{13}C CP/MAS NMR spectrum of SBA-15-AEP and ^{13}C NMR spectrum of (S)-(-)-2-aminomethyl-1-ethylpyrrolidine.

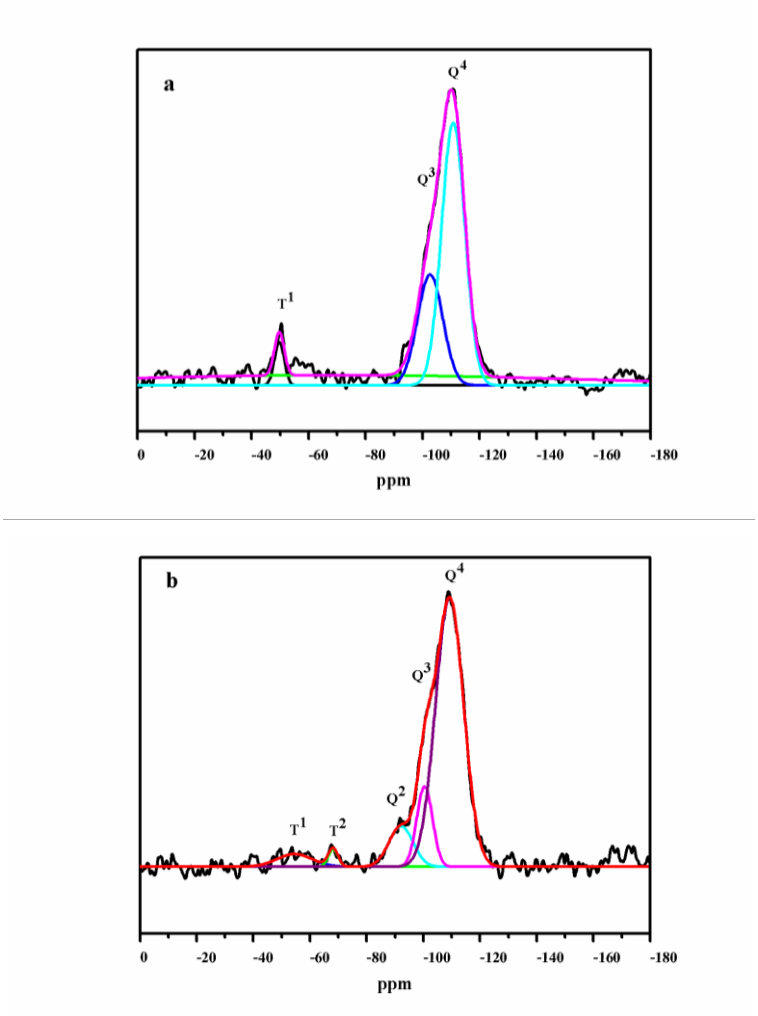


Fig. S9. ^{29}Si MAS NMR spectra of (a) SBA-15-SH and (b) SBA-15-Br.

^{29}Si BD/MAS NMR spectra were recorded for SBA-15-SH/SBA-15-Br. The resonances attributed to the silicon in Q^4 [$Si(SiO)_4$], Q^3 [$Si(SiO)_3OH$], and Q^2 [$Si(SiO)_3(OH)_2$] linkages are observed at -110, -100 and -92 ppm. The silanol density was quantified by curve fitting and deconvolution of ^{29}Si MAS NMR signals according to the reference method [Palkovits, R.; Yang, C. M.; Olejnik, S.; Schüth, F. Active sites on SBA-15 in the Beckmann rearrangement of cyclohexanone oxime to ε-caprolactam, J. Catal. 2006, 243, 93-98.] and the calculated formula is illustrated as follows:

$$\text{Silanol density } (\mu\text{mol g}^{-1}) = \sum W_{Qn} \cdot M_{Qn}$$

Wherein W and M respectively represent the peak area percentage and the molar mass of Q^i (i =2, 3, 4). The results are shown in Table S3. The final silanol density based on the specific surface area of SBA-15-SH/SBA-15-Br is calculated as 4.46 and 8.87μmol/m^2.

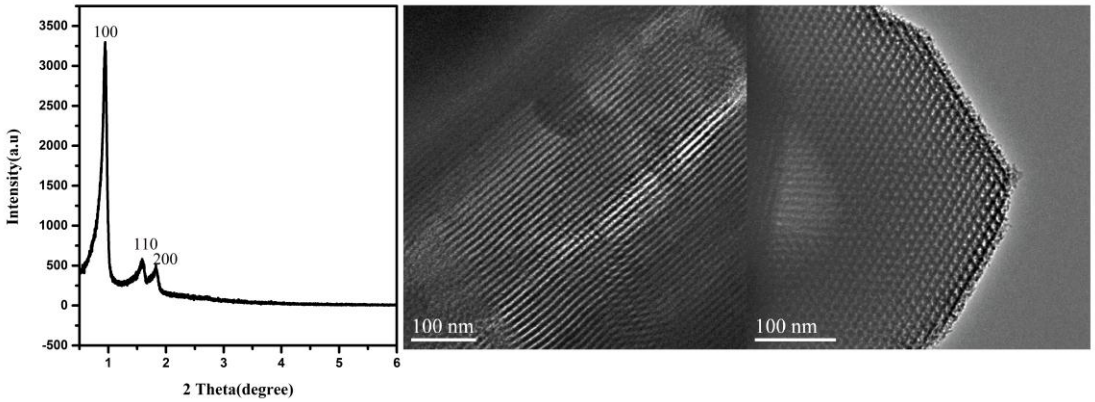


Fig. S10. XRD pattern and TEM images of reused SBA-15-AEP in five runs.

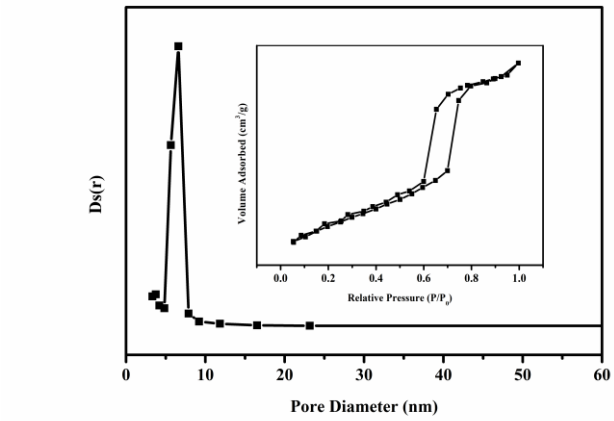


Fig. S11. Nitrogen adsorption-desorption isotherms and the pore size distribution of reused SBA-15-AEP in five runs.

Tables:

Table S1. The specific surface area, pore volume, and pore diameter of mesoporous silica.

Sample	Surface area/ m^2g^{-1}	Pore volume/cm^3g^{-1}	Pore diameter/nm
SBA-15	618	1.043	6.6
SBA-15-SH	549	0.995	6.6
SBA-15-Q	386	0.608	6.5
SBA-15-PY	452	0.727	6.5
SBA-15-Br	539	0.798	6.6
SBA-15-AEP	454	0.783	6.6

Table S2. The density of chiral basic sites and the ratio of silanol to basic sites.

Catalyst	SBA-15-Q	SBA-15-PY	SBA-15-AEP
The content of C, unit mass (mmol/g)	11.69	7.49	6.03
The content of H, unit mass (mmol/g)	20.50	17.70	16.90
The content of S, unit mass (mmol/g)	0.800	0.938	--
The content of N, unit mass (mmol/g)	0.829	0.639	0.629
The content of N, unit area (μmol/m^2)	2.148	1.414	1.385
The density of basic sites (μmol/m^2)[a]	1.074	0.707	0.693
The density of silanol (μmol/m^2)[b]	4.46	4.46	8.87
The molar ratio of silanol to basic sites[c]	4:1	6:1	13:1

[a] The density of basic sites = The content of N (unit area, μmol/m^2)/N atom number in the basic site (2 for SBA-15-Q and SBA-15-AEP; 1 for SBA-15-PY); [b] determined from the ^{29}Si BD-MAS NMR spectra; [c] The molar ratio of silanol to basic sites = The density of silanol (μmol/m^2)/The density of basic sites (μmol/m^2)

Table S3. The molecular weight, molar fractions of Q^i sites and the density of silanols for SBA-15-SH and SBA-15-Br.

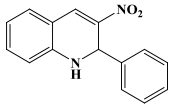
Sample	Q^4 (%)	Q^3 (%)	Q^2 (%)	MW[a] (g/mol)	Content of OH (mmol/g)	Density of OH (μmol/m^2)
SBA-15-SH	69.35	30.65	-	62.75	2.45	4.46
SBA-15-Br	77.17	13.60	9.24	62.89	4.78	8.87

[a] determined as sum of molar weights and fractions of Q^4, Q^3, and Q^2.

Product analysis:

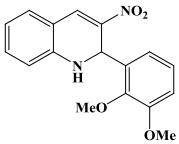
3-nitro-2-phenyl-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ=7.98 (s, 1H), 7.40–7.35 (m, 2H), 7.32–7.28 (m, 3H), 7.20–7.16 (m, 2H), 6.71 (t, *J* = 7.5 Hz, 1H), 6.46 (d, *J* = 8.1 Hz, 1H), 5.99 (s, 1H), 4.70 (s, 1H); ^{13}C NMR (101 MHz, $CDCl_3$): δ= 144.38, 142.16, 134.13, 131.29, 131.26, 130.92, 129.01, 128.85, 128.77, 126.28, 118.65, 114.93, 113.41, 55.51. HRMS (ESI): calcd for $C_{15}H_{12}N_2NaO_2$ $[M]^+$ m/z 275.26; found 275.05.

HPLC analysis of 3-nitro-2-phenyl-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	13.36 min
				16.03 min

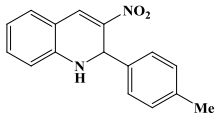
2-(2,3-dimethoxyphenyl)-3-nitro-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ=8.13 (s, 1H), 7.26–7.17 (m, 2H), 7.13–7.06 (m, 1H), 6.94 (m, 1H), 6.74 (dd, *J* = 7.7, 1.3 Hz, 1H), 6.65 (t, *J* = 7.4 Hz, 1H), 6.37 (d, *J* = 8.2 Hz, 1H), 6.34 (s, 1H), 4.99 (s, 1H), 4.00 (s, 3H), 3.87 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ=152.89, 144.96, 144.64, 139.36, 134.33, 133.98, 132.96, 131.17, 124.48, 118.59, 118.44, 115.20, 113.85, 112.48, 60.99, 55.79,49.36. HRMS (ESI): calcd for $C_{17}H_{16}N_2NaO_4$ $[M]^+$ m/z 335.31; found 335.19.

HPLC analysis of 2-(2,3-dimethoxyphenyl)-3-nitro-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	12.35min
				12.81min

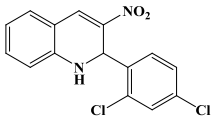
3-nitro-2-p-tolyl-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ= 7.96 (s, 1H), 7.31–7.05 (m, 6H), 6.69 (t, 1H), 6.44 (d, *J* = 8.0 Hz, 1H), 5.94 (s, 1H), 4.68 (s, 1H), 2.30 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ=152.89, 144.96, 144.64, 139.36, 134.33, 133.98, 132.96, 131.17, 124.48, 118.59, 118.44, 115.20, 113.85, 112.48, 60.99, 55.79. HRMS (ESI): calcd for $C_{16}H_{14}N_2NaO_2$ $[M]^+$ m/z 289.28; found 289.20.

HPLC analysis of 3-nitro-2-p-tolyl-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	9.25min
				12.97min

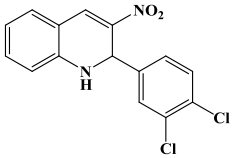
2-(2,4-chlorophenyl)-3-nitro-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ=8.20 (s, 1H), 7.57–7.16 (m, 5H), 6.76 (t, 1H), 6.47 (d, *J* = 8.0 Hz, 1H), 6.46(s, 1H), 4.98 (s, 1H); ^{13}C NMR (101 MHz, $CDCl_3$): δ=143.67, 138.63, 134.98, 134.38, 133.15, 131.96, 131.37, 130.10, 128.69, 127.97, 119.15, 115.06, 114.03, 51.05. HRMS (ESI): calcd for $C_{15}H_{10}Cl_2N_2O_2$ $[M]^+$ m/z 321.02; found 321.23.

HPLC analysis of 2-(2,4-chlorophenyl)-3-nitro-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	9.67min
				19.18min

2-(3,4-chlorophenyl)-3-nitro-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ=8.00 (s, 1H), 7.46 (dd, J = 7.2, 2.2 Hz, 1H), 7.38 (dd, J = 13.1, 7.1 Hz, 1H), 7.19–7.21 (m, 3H), 6.81–6.70 (m, 1H), 6.55–6.42 (m, 1H), 5.98 (s, 1H), 4.71 (s, 1H). ^{13}C NMR (101 MHz, CDCl3): δ=143.81, 142.05, 140.02, 134.87, 135.73, 133.01, 132.19, 130.38, 128.35, 125.66, 119.15, 114.64, 113.51, 54.57. $C_{15}H_{10}Cl_2N_2O_2$ $[M]^+$ m/z 321.02; found 321.26

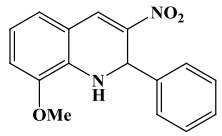
HPLC analysis of 2-(3,4-chlorophenyl)-3-nitro-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	9.79min
				17.25min

8-methoxy-3-nitro-2-phenyl-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ=7.99 (s, 1H), 7.44 – 7.26 (m, 5H), 6.83 (dd, *J* = 7.8, 1.0 Hz, 1H), 6.76 (dd, *J* = 7.9, 0.8 Hz, 1H), 6.63 (t, *J* = 7.9 Hz, 1H), 6.08 (s, 1H), 5.29 (s, 1H), 3.79 (s, 3H) ; ^{13}C NMR (101 MHz, $CDCl_3$): δ=145.45, 142.52, 140.91, 135.00, 131.39, 128.94, 128.62, 126.27, 122.77, 117.39, 114.37, 113.63, 55.59, 55.08.

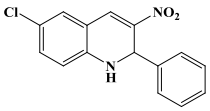
HRMS (ESI): calcd for $C_{16}H_{14}N_2NaO_3[M]^+$ m/z 305.28; found 305.27.

HPLC analysis of 8-methoxy-3-nitro-2-phenyl-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	13.41min
				16.07min

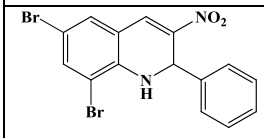
6-chloro-3-nitro-2-phenyl-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 (s, 1H), 7.41–7.28 (m, 6H), 7.12 (dd, J = 8.6, 2.4 Hz, 1H), 6.42 (d, J = 8.6 Hz, 1H), 5.98 (s, 1H), 4.72 (s, 1H); NMR (101 MHz, $CDCl_3$): δ 142.74, 142.08, 141.71, 133.65, 130.05, 129.76, 129.11, 128.99, 126.25, 116.05, 114.66, 55.48. HRMS (ESI): calcd for $C_{15}H_{11}ClN_2NaO_2$ $[M]^+$ m/z 309.70; found 309.50.

HPLC analysis of 6-bromo-3-nitro-2-phenyl-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	10.83min
				17.53min

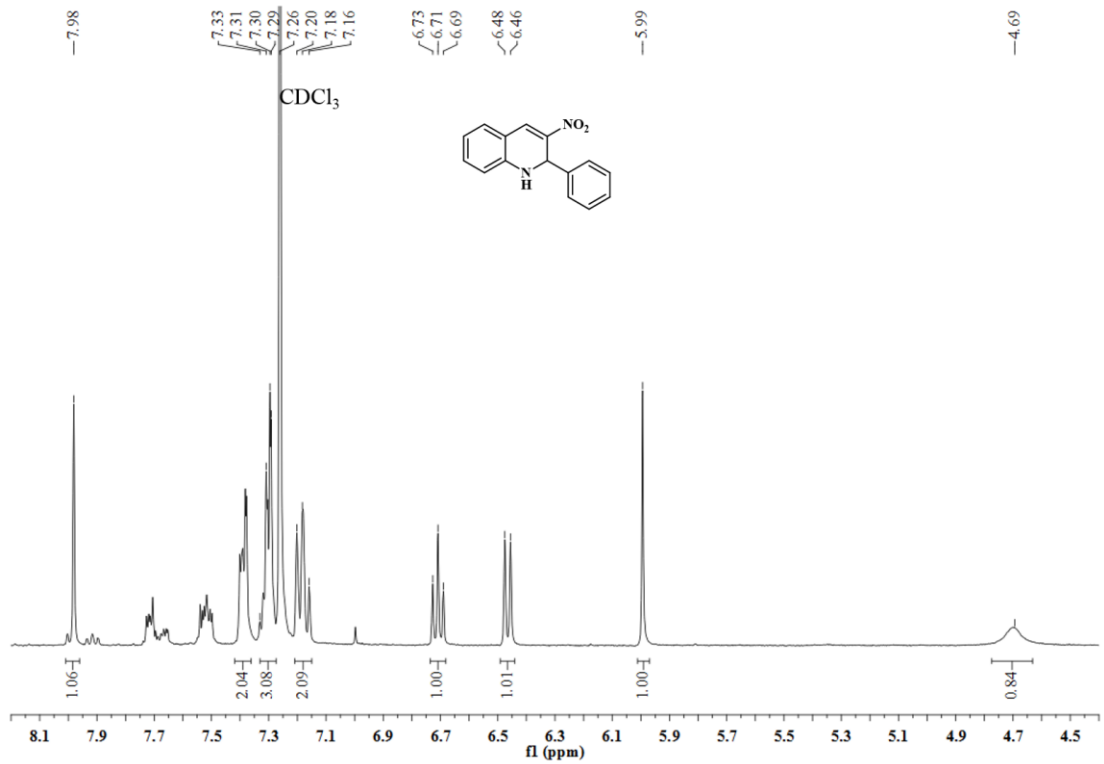
6,8-dibromo-3-nitro-2-phenyl-1,2-dihydroquinoline: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.75 (s, 1H), 7.62 (s, 1H), 7.56 (s, 1H), 7.45–7.31 (m, 6H), 5.63 (s, 1H); ^{13}C NMR (101 MHz, CDCl3): δ 191.98, 139.86, 137.10, 135.10, 134.64, 134.51, 134.16, 131.33, 131.15, 129.96, 128.75, 127.67, 127.02, 59.31, 49.35, 23.44. HRMS (ESI): calcd for $C_{15}H_{11}Br_2N_2NaO_2$ $[M]^+$ m/z 433.05; found 433.27.

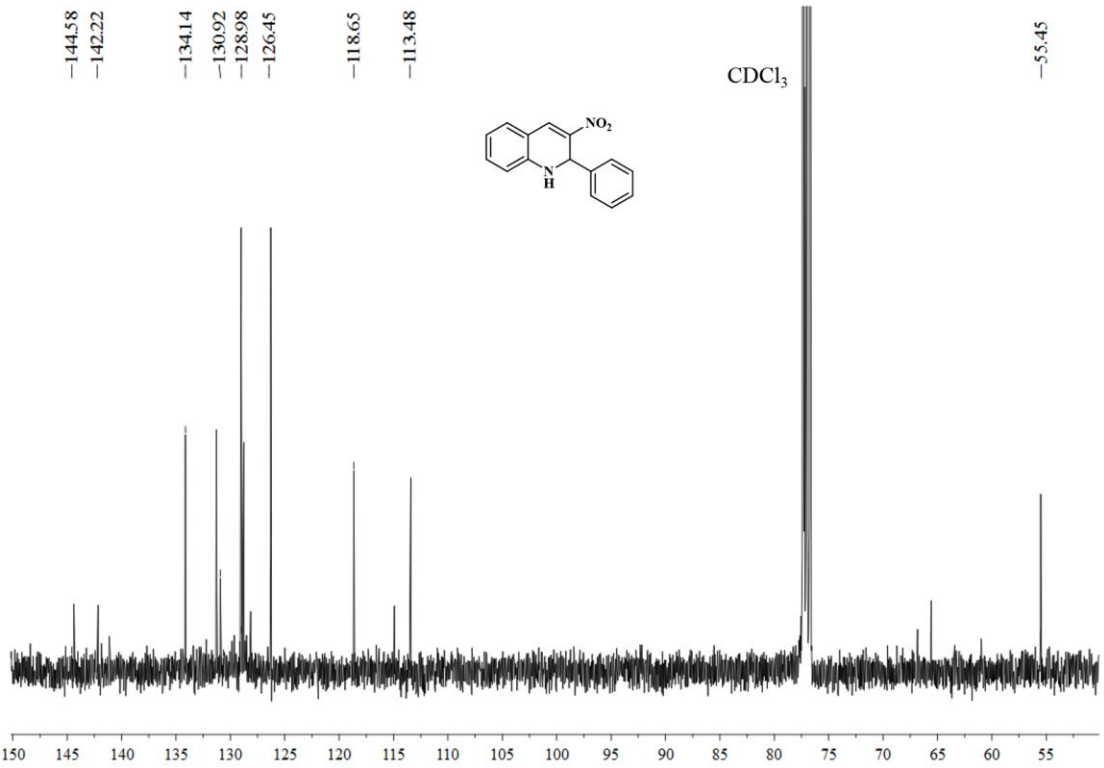
HPLC analysis of 6-bromo-3-nitro-2-phenyl-1,2-dihydroquinoline

Structure	Column	Eluent	Flow rate	Retention time
	CHIRALPAK OD-H	Hexane: 2-PrOH = 85: 15	1.0 mL/min	8.97min
				10.87min

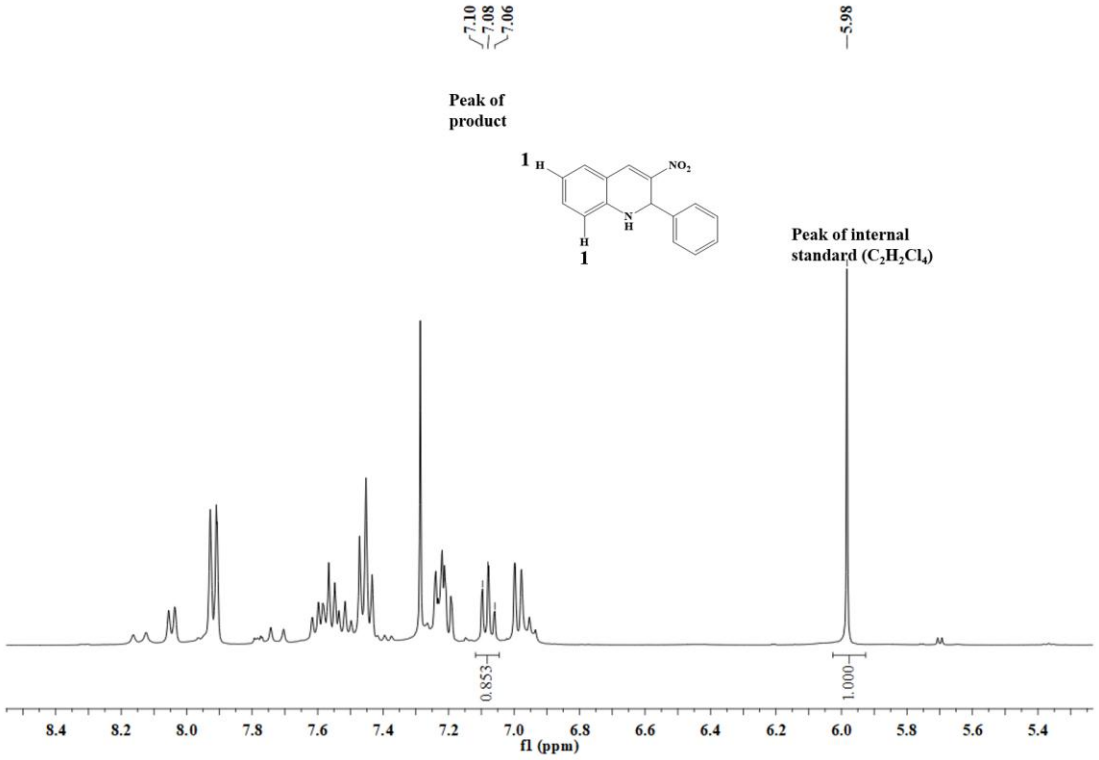
Appendix

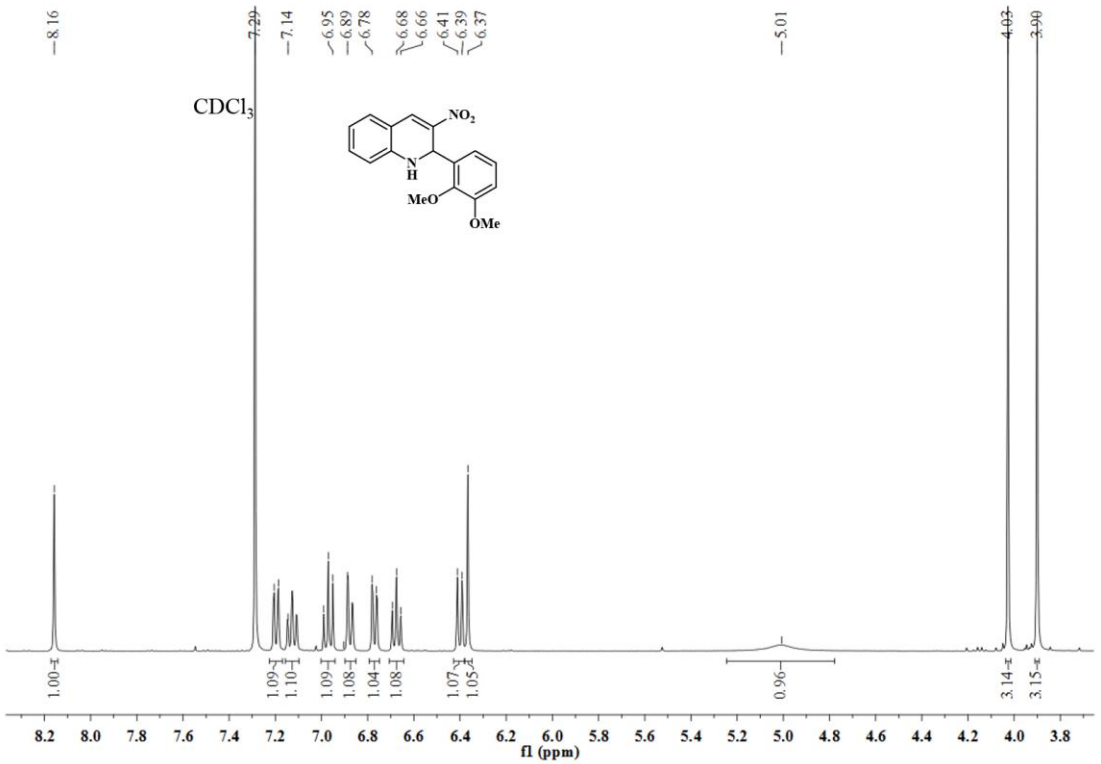
^{1}H/^{13}C NMR spectra





For yield calculation:

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7.29
7.14
6.95
6.89
6.78
6.68
6.66
6.41
6.39
6.37
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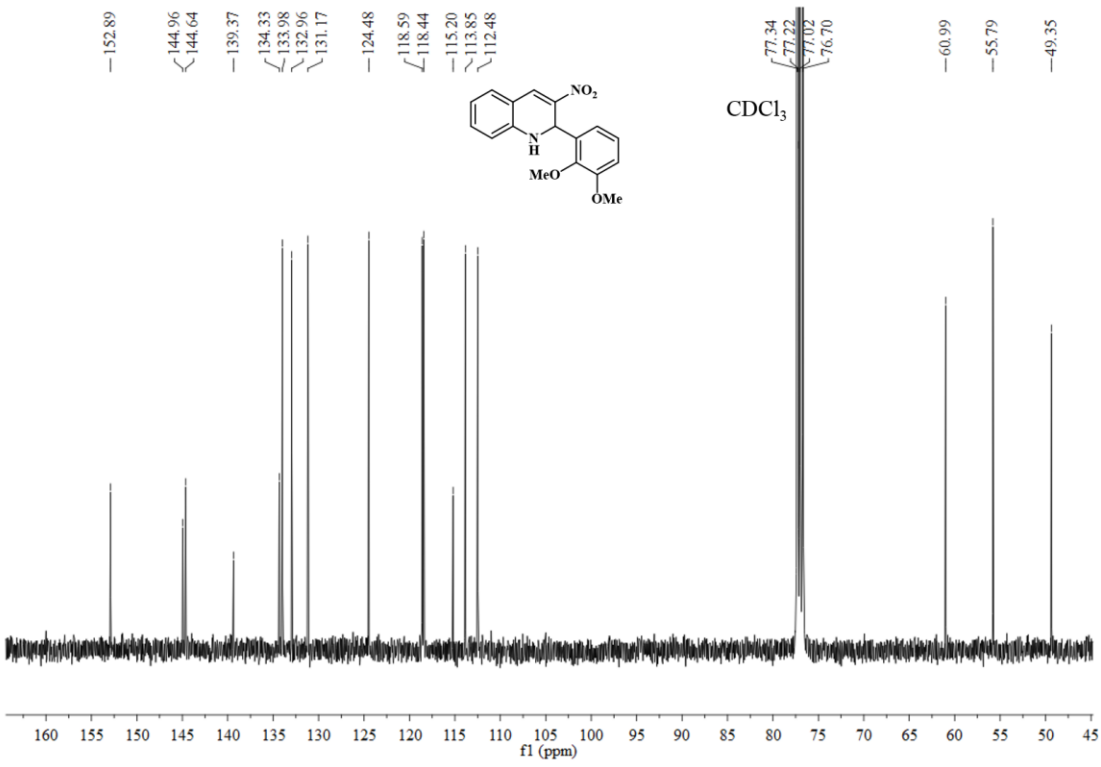
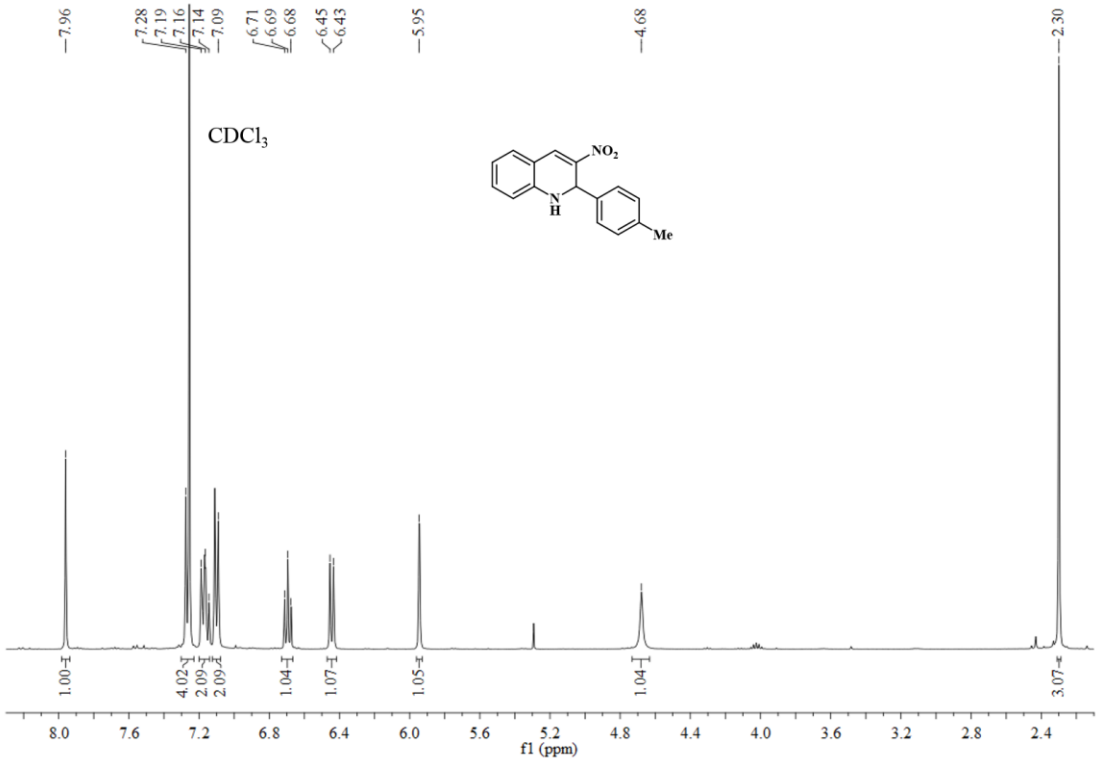
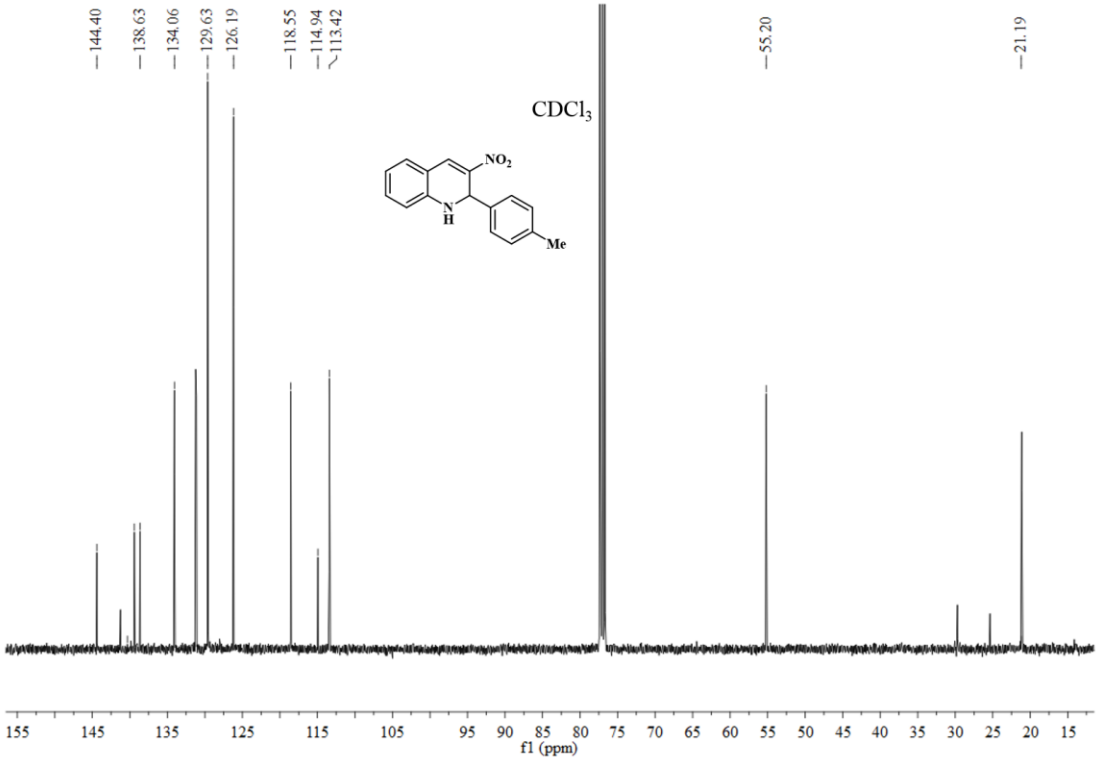
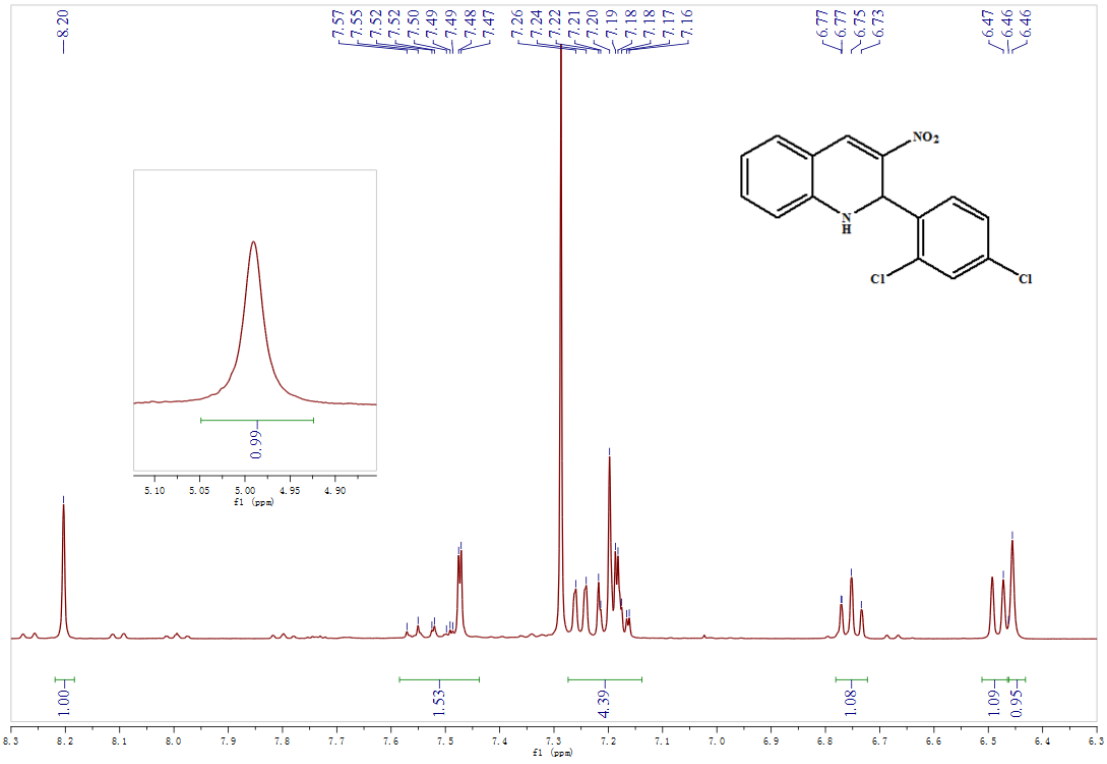
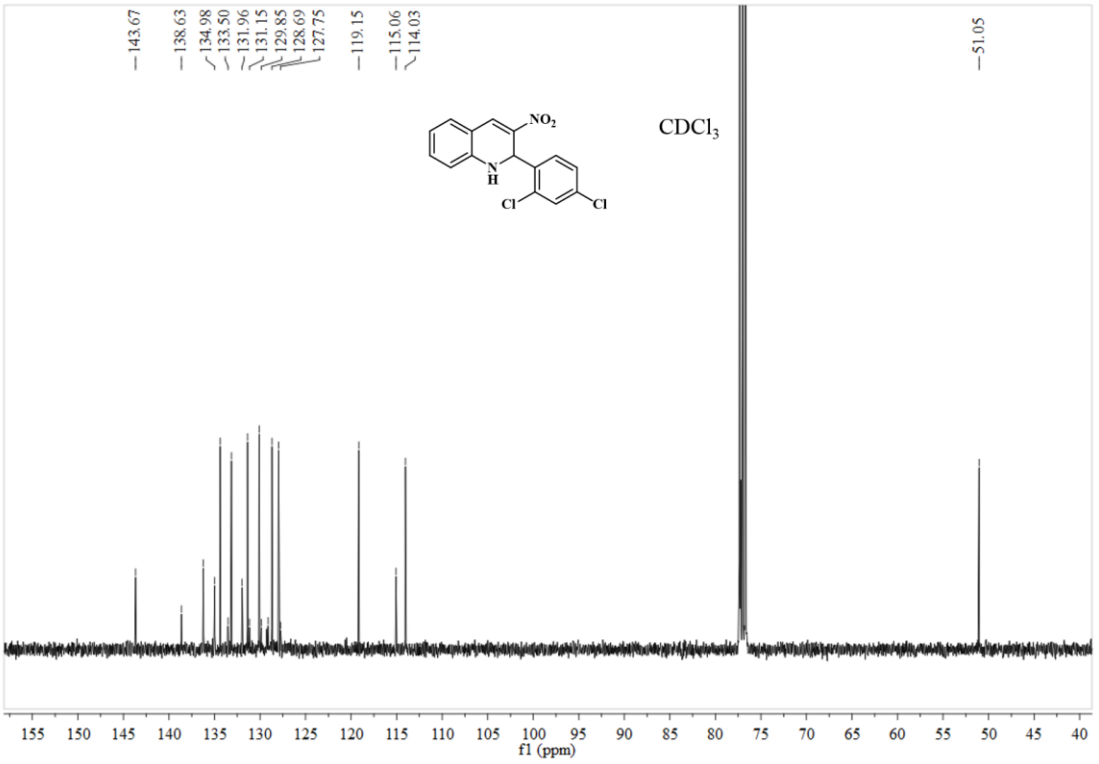
4.03
3.90
CDCl3
NO2
N
H
MeO
OMe
1.00
1.09
1.10
1.09
1.08
1.04
1.08
1.07
1.05
0.96
3.14
3.15
8.2 8.0 7.8 7.6 7.4 7.2 7.0 6.8 6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8
f1 (ppm)

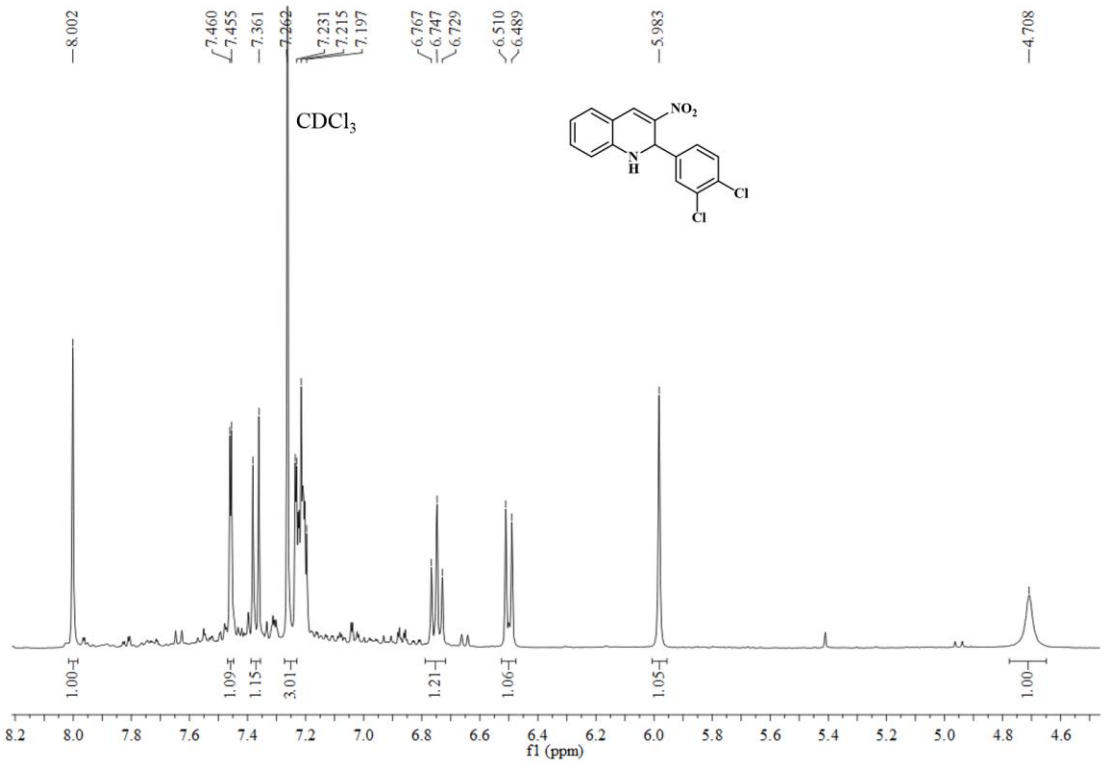

152.89
144.96
144.64
139.37
134.33
133.98
132.96
131.17
124.48
118.59
118.44
115.20
113.85
112.48
77.34
77.22
77.02
76.70
60.99
55.79
49.35
CDCl3
NO2
N
H
MeO
OMe
160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45
f1 (ppm)

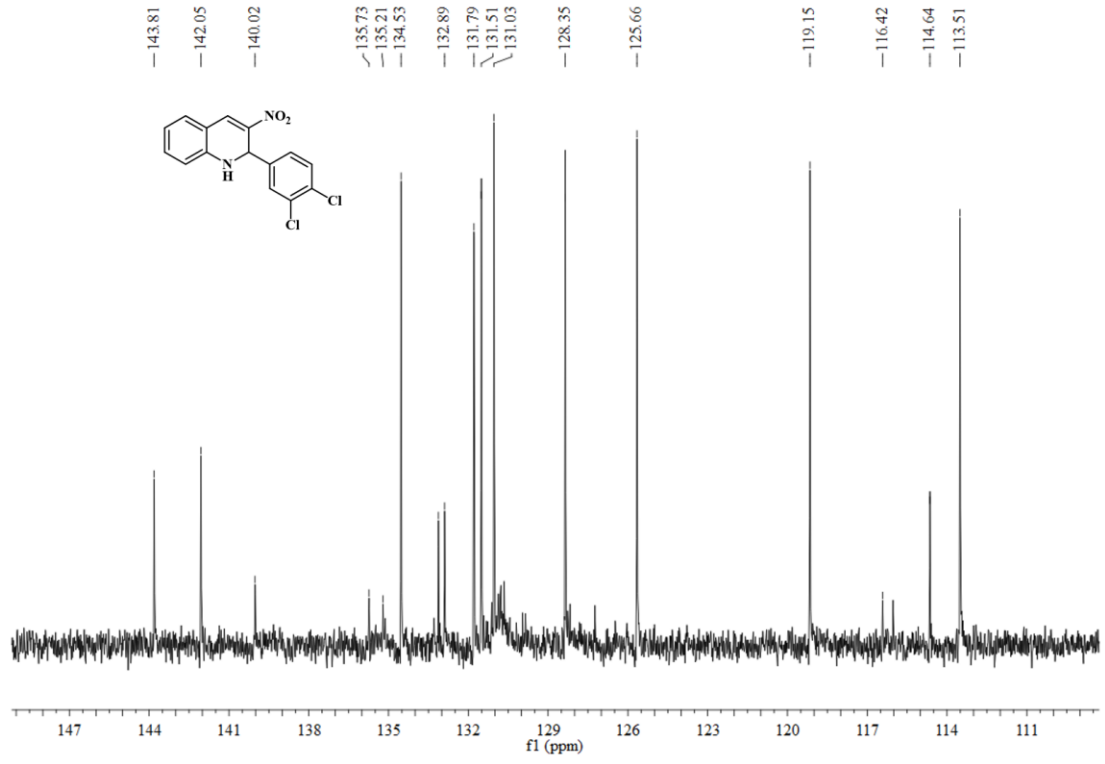

7.96
7.28
7.19
7.16
7.14
7.09
6.71
6.69
6.68
6.45
6.43
5.95
4.68
2.30
CDCl3
NO2
N
H
Me
1.00
4.02
2.09
2.09
1.04
1.07
1.05
1.04
3.07
8.0
7.6
7.2
6.8
6.4
6.0
5.6
5.2
4.8
4.4
4.0
3.6
3.2
2.8
2.4
f1 (ppm)

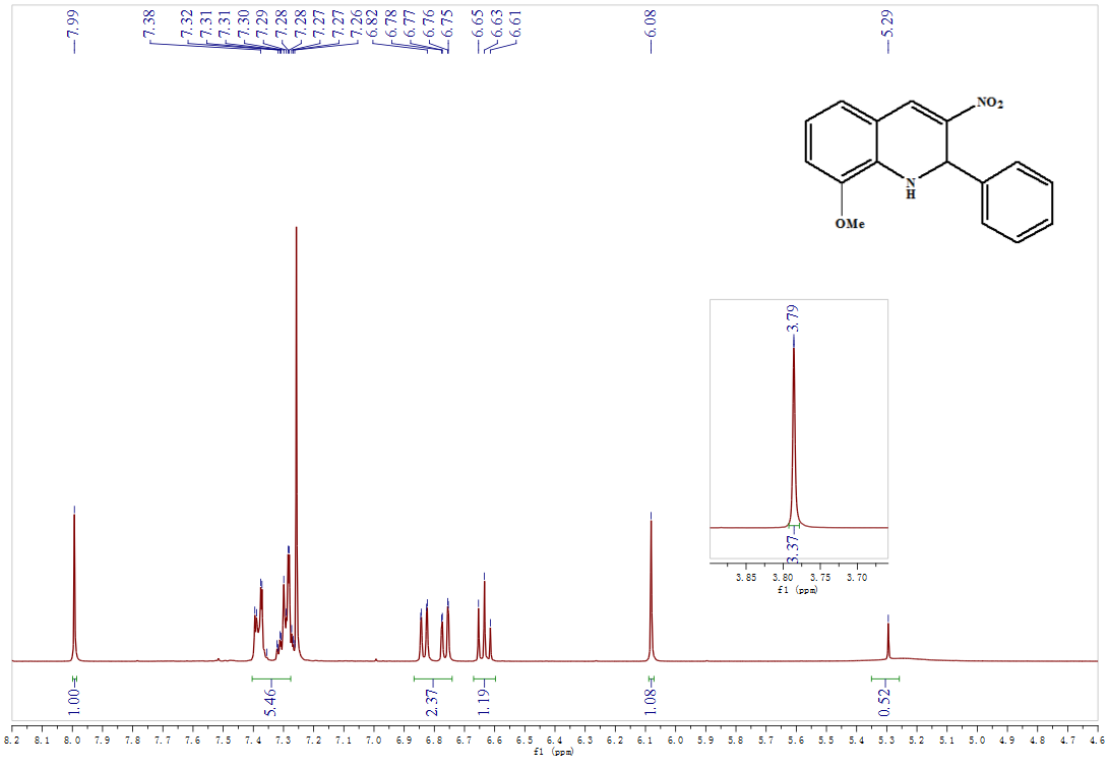

144.40
138.63
134.06
129.63
126.19
118.55
114.94
113.42
55.20
21.19
CDCl3
NO2
N
H
Me
155
145
135
125
115
105
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
f1 (ppm)

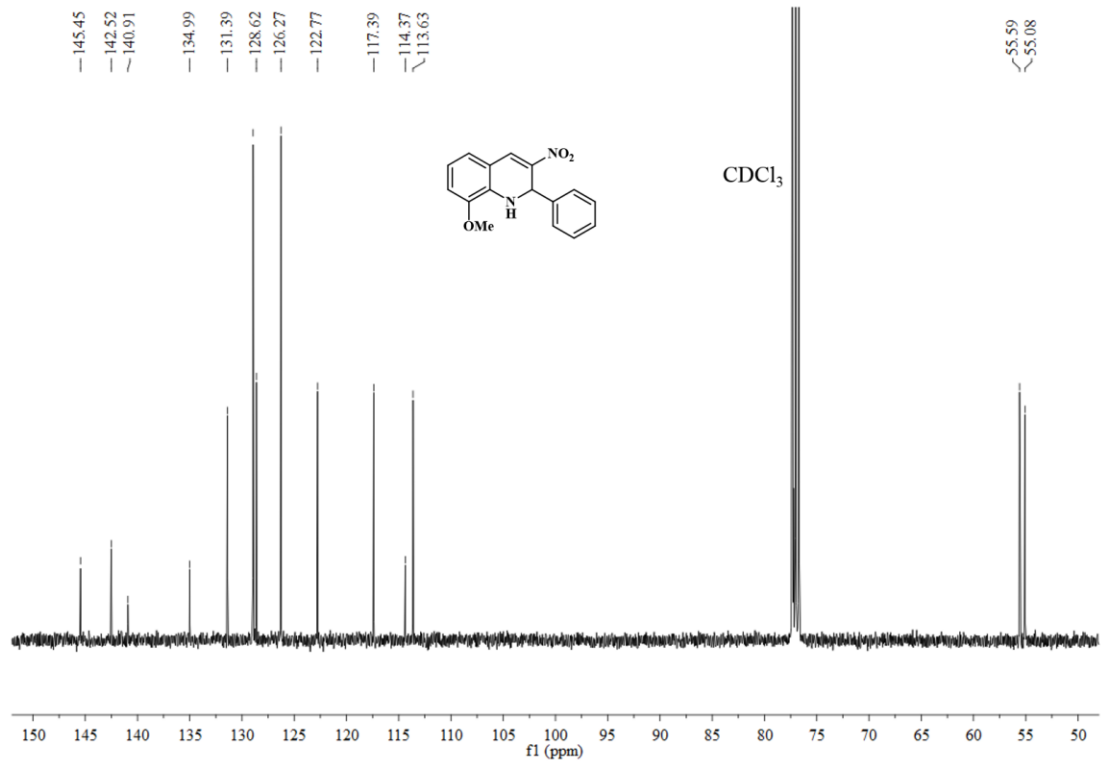

8.20
7.57
7.55
7.52
7.52
7.50
7.49
7.49
7.48
7.47
7.26
7.24
7.22
7.21
7.20
7.19
7.18
7.18
7.17
7.16
6.77
6.77
6.75
6.73
6.47
6.46
6.46
NO2
N
H
Cl
Cl
0.99
1.00
1.53
4.39
1.08
1.09
0.95
f1 (ppm)

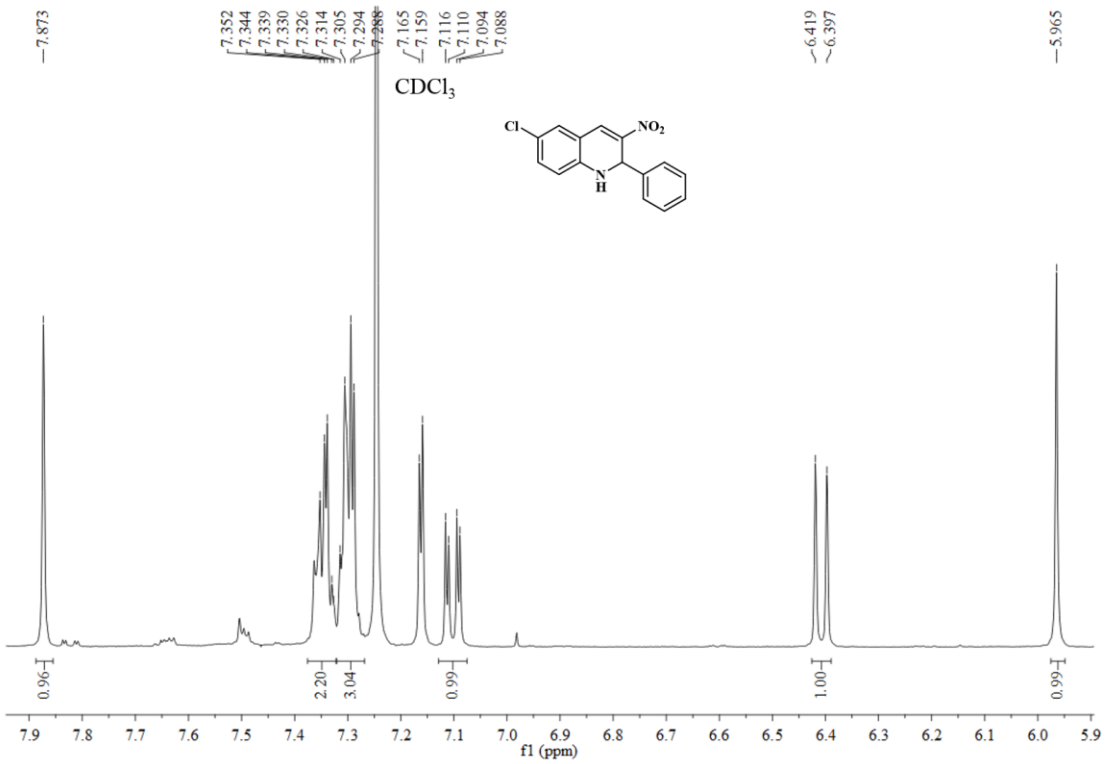

143.67
138.63
134.98
133.50
131.96
131.15
129.85
128.69
127.75
119.15
115.06
114.03
51.05
NO2
N
H
Cl
Cl
CDCl3
f1 (ppm)

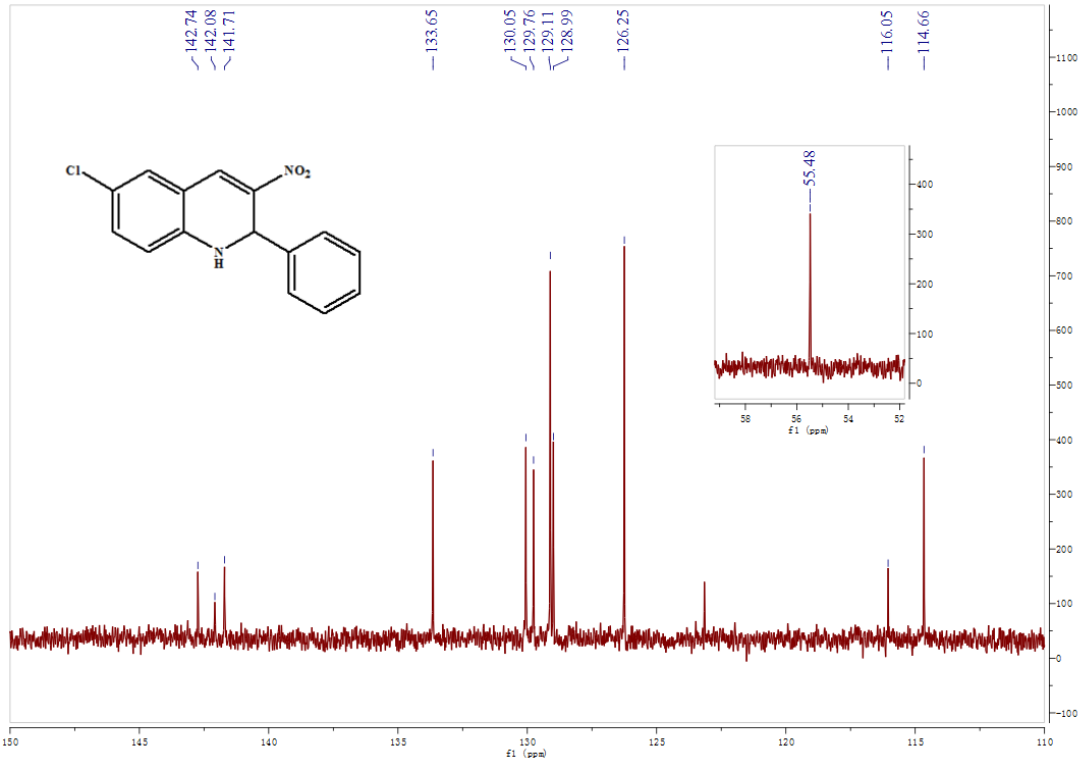

8.002
7.460
7.455
7.361
7.262
7.231
7.215
7.197
6.767
6.747
6.729
6.510
6.489
5.983
4.708
CDCl3
NO2
N
H
Cl
Cl
1.00
1.09
1.15
3.01
1.21
1.06
1.05
1.00
8.2 8.0 7.8 7.6 7.4 7.2 7.0 6.8 6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6
f1 (ppm)

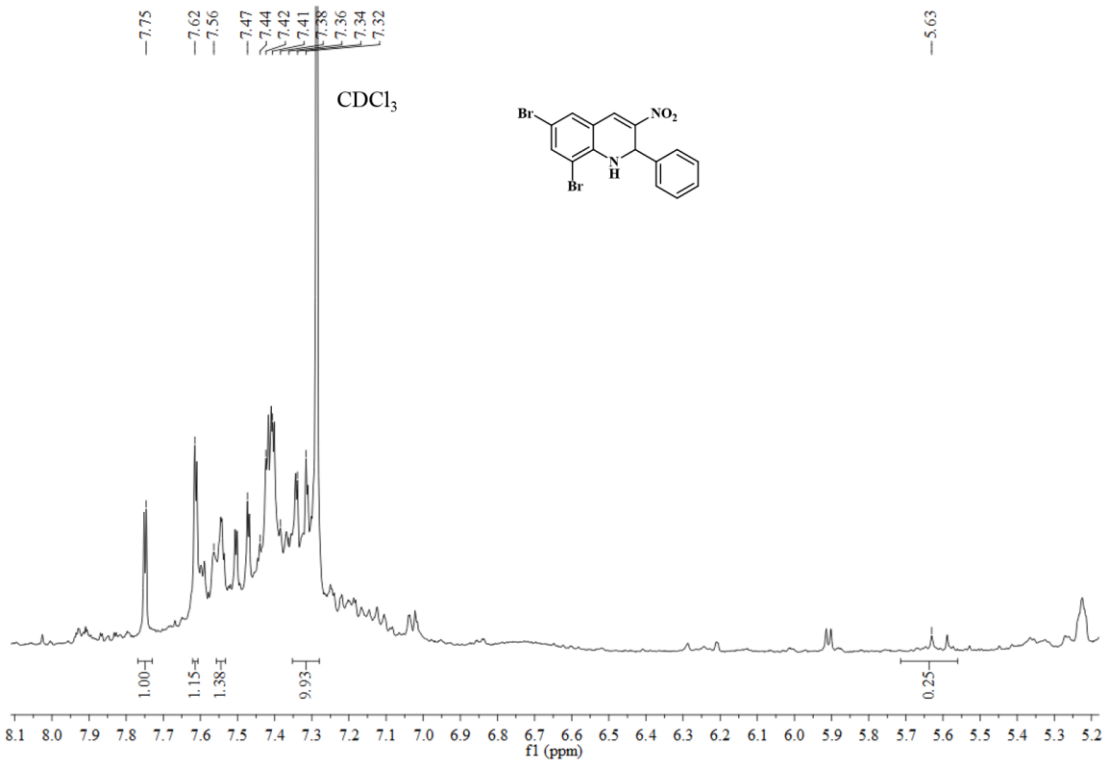

143.81
142.05
140.02
135.73
135.21
134.53
132.89
131.79
131.51
131.03
128.35
125.66
119.15
116.42
114.64
113.51
NO2
N
H
Cl
Cl
147 144 141 138 135 132 129 126 123 120 117 114 111
f1 (ppm)

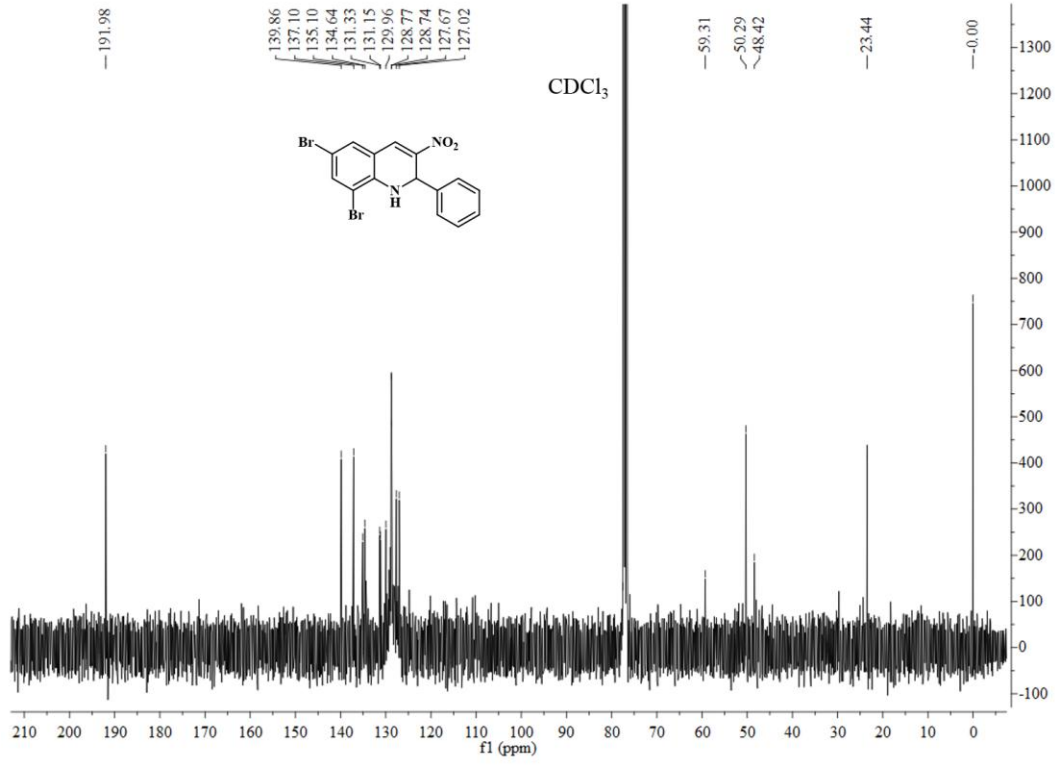

7.99
7.38
7.32
7.31
7.31
7.30
7.29
7.28
7.28
7.27
7.27
7.26
6.82
6.78
6.77
6.76
6.75
6.65
6.63
6.61
6.08
5.29
NO2
N
H
OMe
3.79
3.37
1.00
5.46
2.37
1.19
1.08
0.52
f1 (ppm)


145.45
142.52
140.91
134.99
131.39
128.62
126.27
122.77
117.39
114.37
113.63
55.59
55.08
NO2
N
H
OMe
CDCl3
f1 (ppm)


7.873
7.352
7.344
7.339
7.330
7.326
7.314
7.305
7.294
7.288
7.165
7.159
7.116
7.110
7.094
7.088
6.419
6.397
5.965
CDCl3
Cl
NO2
N
H
0.96
2.20
3.04
0.99
1.00
0.99
f1 (ppm)


142.74
142.08
141.71
133.65
130.05
129.76
129.11
128.99
126.25
116.05
114.66
55.48
Cl
NO2
N
H
f1 (ppm)


7.75
7.62
7.56
7.47
7.44
7.42
7.41
7.38
7.36
7.34
7.32
5.63
CDCl3
Br
NO2
N
H
Br
1.00
1.15
1.38
9.93
0.25
8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9 6.8 6.7 6.6 6.5 6.4 6.3 6.2 6.1 6.0 5.9 5.8 5.7 5.6 5.5 5.4 5.3 5.2
f1 (ppm)


191.98
139.86
137.10
135.10
134.64
131.33
131.15
129.96
128.77
128.74
127.67
127.02
59.31
50.29
48.42
23.44
0.00
CDCl3
Br
NO2
N
H
Br
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)