Electronic Supplementary Material (ESI)
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Supporting Information for Microfluidic synthesis of pyrrolidin-2-ones via photoinduced organocatalyzed cyclization of styrene, α-bromoalkyl ester and primary amine†

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Contents

1.General Information

1H/13C NMR spectra were recorded on magnet system 400’54 ascend instrument purchased from Bruker Biospin AG. All chemical shifts are given in parts per million and are measured relative to $CDCl_3$ as an internal standard. ESI-MS spectra were recorded on Agilent Q-TOF 6520. Products were purified by flash chromatogrgraphy on 200-300 mesh silica gel and visualized using a UV lamp (254 nm or 365 nm). All the solvents were used without further purification, unless otherwise state. the other commercial chemicals were used without further purification. All reactions were performed under an inert atmosphere of nitrogend.

General procedure for the synthesis of 4 (4aaa as an example):

An oven-dried 5 mL reaction syringe was charged with styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (1 mmol, 1 equiv), aniline (1 mmol, 1 equiv), PC-B (1 mol %) and Pyridine (1.1 mmol, 1.1 equiv). And add 2 mL Dichloroethane (0.5 M) solution. Pass the solutions through a Quartz tubing (id = 0.5 mm, length =1.0 m) to building the pyrrolidin-2-ones during 20 minutes of residence time under the simulated solar lamp (300W, 220V, wavelength 250nm-780nm). The reaction mixture was diluted with HCl (30, 0.3 M) and extracted by ethyl acetate (30 mL) or dichloromethane (30 mL). The separated organic layers

were dried over by anhydrous Na_2SO_4 and filtered. The filtrate was concentrated under reduced pressure and the residue was chromatographed on silica gel using hexane/ethyl acetate or dichloromethane/methanol to afford the desired product 4aaa (90% yield).

2. Batch and Microfluidic Reactor Device

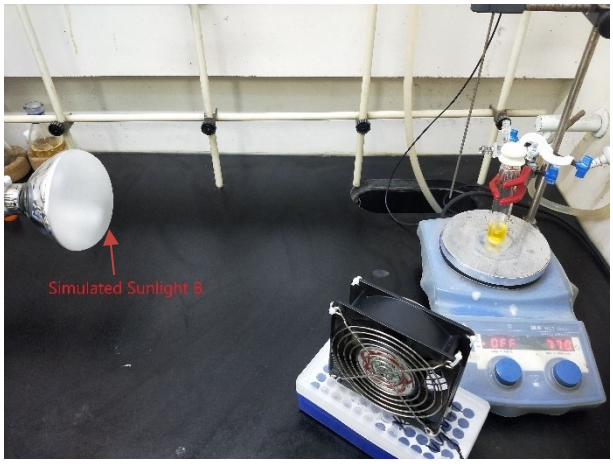


Figure S1. Batch reactor device

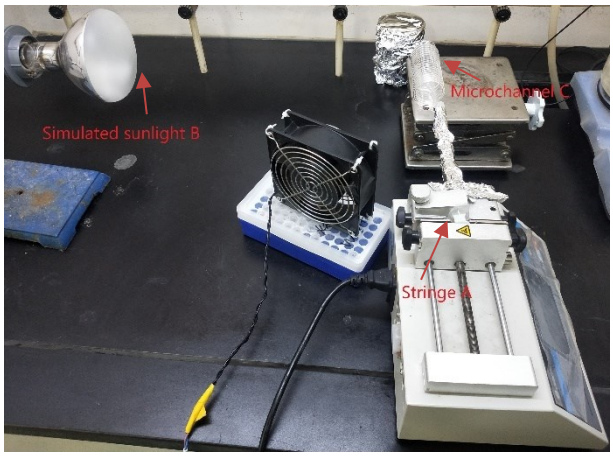
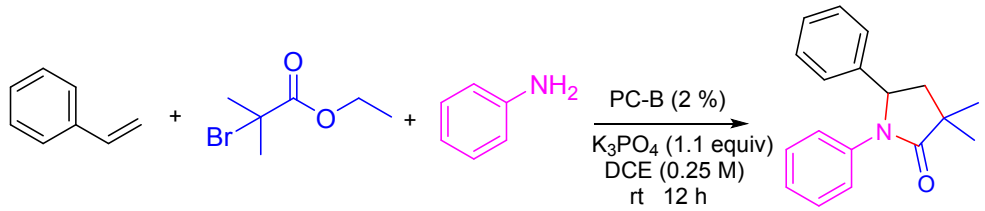


Figure S2. Microfluidic reactor device

Note: The light source is a simulated solar lamp (300W, 220V, wavelength 250nm-780nm).

3. Select Optimization Results

3.1 Table 1. Varying the wavelength of light.[a]



1a 2a 3a 4aaa

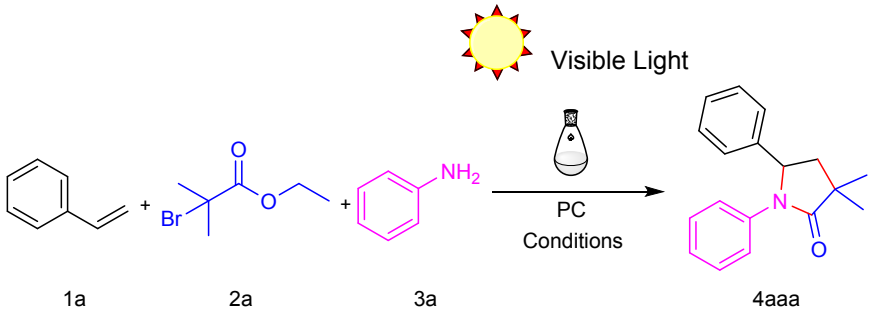
Entry	Wavelength of Light	yield 4aaa[b] (%)
1	360-370 nm	84
2	380-385 nm	73
3	390-398 nm	61
4	420-430 nm	58
5	435-445 nm	45
6[c]	250-780 nm	81

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC-B (2 % equiv), K_3PO_4 (1.1 mmol, 1.1 equiv), and a stir bar. Add 4 mL DCE (0.25 M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature. Unless otherwise specified, the model of all lamps used is 10W, 220V, LED.

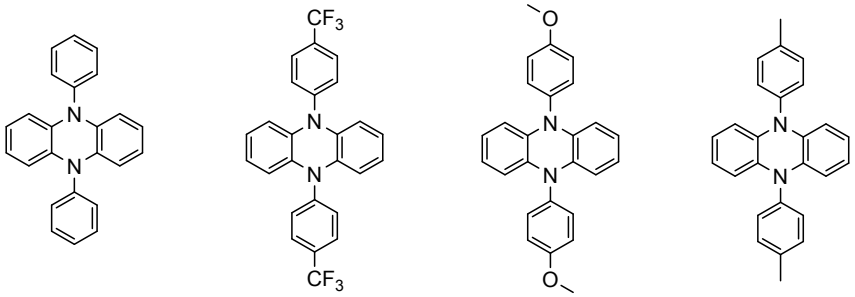
[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

[c] Simulated Sunlight.

3.2 Table 2. Varying the Catalyst.[a]



1a 2a 3a 4aaa



PC-A PC-B PC-C PC-D

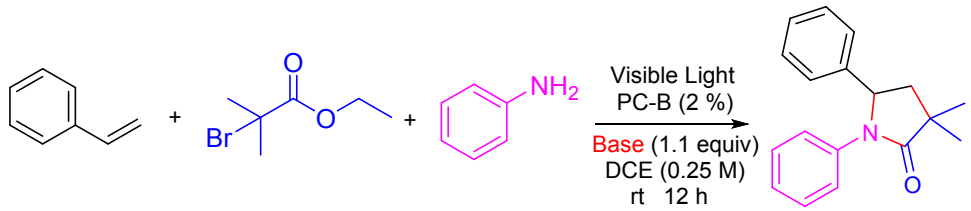
Entry	PC	Base	Solvent	Time	yield 4aaa[b] (%)
1	PC-A	K_3PO_4	DCE	12	75
2	PC-B	K_3PO_4	DCE	12	81
3	PC-C	K_3PO_4	DCE	12	73
4	PC-D	K_3PO_4	DCE	12	71
5	None	K_3PO_4	DCE	12	None
6[c]	PC-B	K_3PO_4	DCE	12	None

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), K_3PO_4 (1.1 mmol, 1.1 equiv), and a stir bar. Add 4 mL DCE (0.25 M) solution.This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature.

[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

[c] No light

3.3 Table 3. Varying the Base.[a]



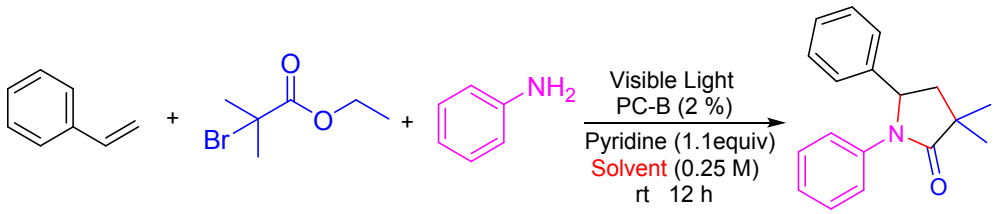
1a 2a 3a 4aaa

Entry	PC	Base	Solvent	Time	yield 4aaa[b] (%)
1	PC-B	K_3PO_4	DCE	12	81
2	PC-B	K_2CO_3	DCE	12	63
3	PC-B	$NaHCO_3$	DCE	12	58
4	PC-B	LiOtBu	DCE	12	67
5	PC-B	Et_3N	DCE	12	None
6	PC-B	DMAP	DCE	12	79
7	PC-B	DBU	DCE	12	32
8	PC-B	Pyridine	DCE	12	84
9	PC-B	None	DCE	12	45

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), Base (1.1 mmol, 1.1 equiv), and a stir bar. Add 4 mL DCE (0.25 M) solution.This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature.

[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.4 Table 4. Varying the Solvent.[a]

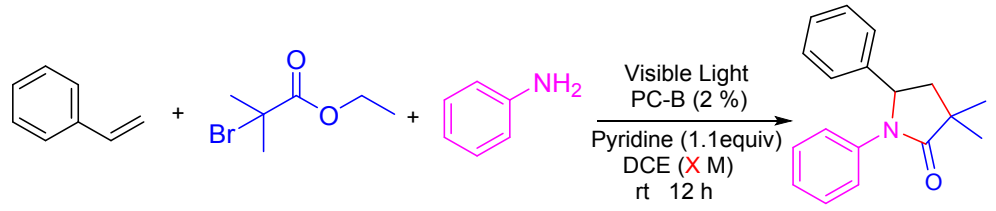


1a 2a 3a 4aaa

Entry	PC	Base	Solvent	Time	yield 4aaa[b] (%)
1	PC-B	Pyridine	DCE	12	84
2	PC-B	Pyridine	MeCN	12	51
3	PC-B	Pyridine	THF	12	45
4	PC-B	Pyridine	DMA	12	23
5	PC-B	Pyridine	DMF	12	31

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), Pyridine (1.1 mmol, 1.1 equiv), and a stir bar. Add X mL (0.25 M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature.
[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.5 Table 5. Concentration.[a]

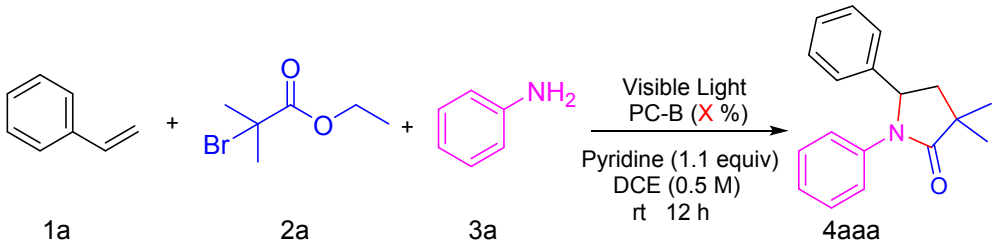


1a 2a 3a 4aaa

Entry	Concentration	yield 4aaa[b] (%)
1	1.0 M	81
2	0.5 M	86
3	0.25 M	84
4	0.10 M	73

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), Pyridine (1.1 mmol, 1.1 equiv), and a stir bar. Add DCE (X M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature.
[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.6 Table 6. Catalyst concentration.[a]

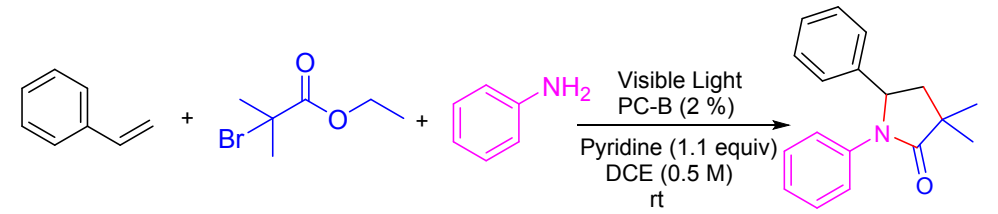


1a 2a 3a 4aaa

Entry	PC (X mol %)	yield 4aaa[b] (%)
1	2	86
2	1	71
3	0.5	65
4	0.1	48
5	0.05	29
6	None	None

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (X % equiv), Pyridine (1.1 mmol, 1.1 equiv), and a stir bar. Add 2 mL DCE (0.5 M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm for 12 h at room temperature.
[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.7 Table 7. Residence time.[a]



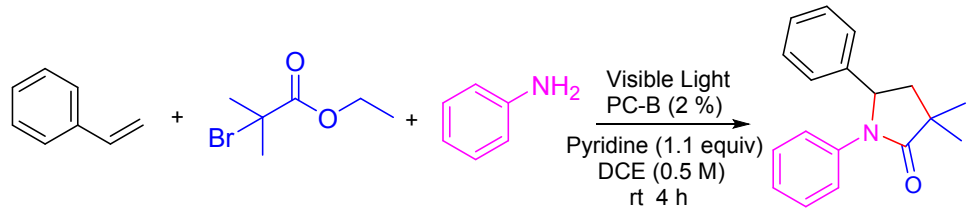
1a 2a 3a 4aaa

Entry	Time(h)	yield 4aaa[b] (%)
1	1	23
2	2	31
3	3	59
4	4	84
5	6	86
6	12	86

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), Pyridine (1.1 mmol, 1.1 equiv), and a stir bar. Add 2 mL DCE (0.5 M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (2 mmol, 2 equiv), aniline (1 mmol, 1 equiv). Cover with a rubber stopper and stir at 660 rpm in room temperature.

[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.8 Table 8. Reagent Loadings.[a]



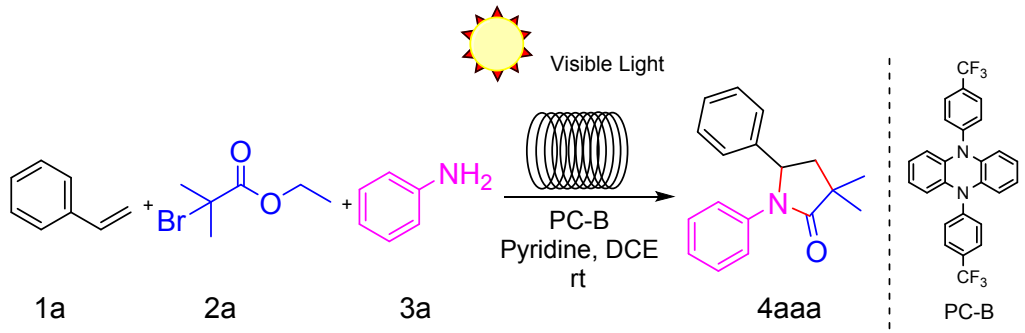
1a 2a 3a 4aaa

Entry	Ethyl 2-bromo-2-methylpropanoate	Aniline	yield 4aaa[b] (%)
1	2	1	84
2	2	3	87
3	2	5	89
4	1	1	63
5	3	1	88
6	5	1	87

[a] In a nitrogen-filled glovebox an oven-dried 10-mL reaction vial was charged with PC (2 % equiv), Pyridine (1.1 mmol, 1.1 equiv), and a stir bar. Add 2 mL DCE (0.5 M) solution. This was followed by styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (1-5 mmol), aniline (1-5 mmol). Cover with a rubber stopper and stir at 660 rpm for 4 h at room temperature.

[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

3.9 Table 9. Reagent Loadings.[a]

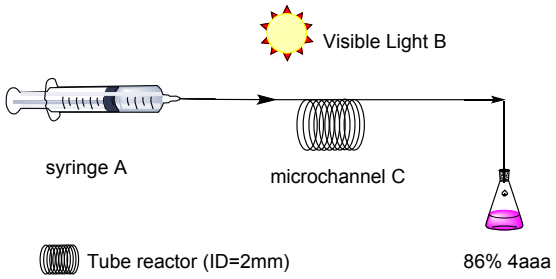


Entry	PC-B (euqiv)	Tube diameter (mm)	Tube length (m)	Flow rate (μL / minute)	Residence time(minute)	yield 4aaa[b] (%)
1	2%	2	1	104.7	30	89
2	1%	2	1	104.7	30	87
3	0.5%	2	1	104.7	30	63
4	0.1%	2	1	104.7	30	48
5	1%	1	1	26.2	30	90
6	1%	0.5	1	6.5	30	93
7	1%	0.5	0.5	3.3	30	68
8	1%	0.5	2	13.1	30	91
9	1%	0.5	1	39.3	5	46
10	1%	0.5	1	19.6	10	72
11	1%	0.5	1	9.8	20	93
12	1%	0.5	1	4.9	40	94

[a] Reaction conditions: Pyridine (1.1 mmol, 1.1 equiv), styrene (1 mmol, 1 equiv), ethyl 2-bromo-2-methylpropanoate (1 mmol, 1 equiv), aniline (1 mmol, 1 equiv) and 2 mL DCE (0.5 M) solution, room temperature.

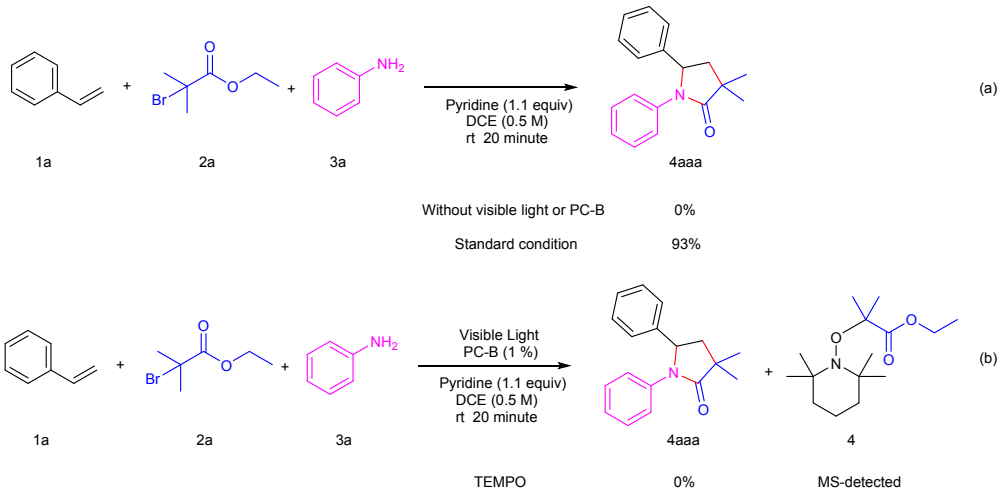
[b] In situ yield determined by NMR analysis (Dibromomethane as an internal standard).

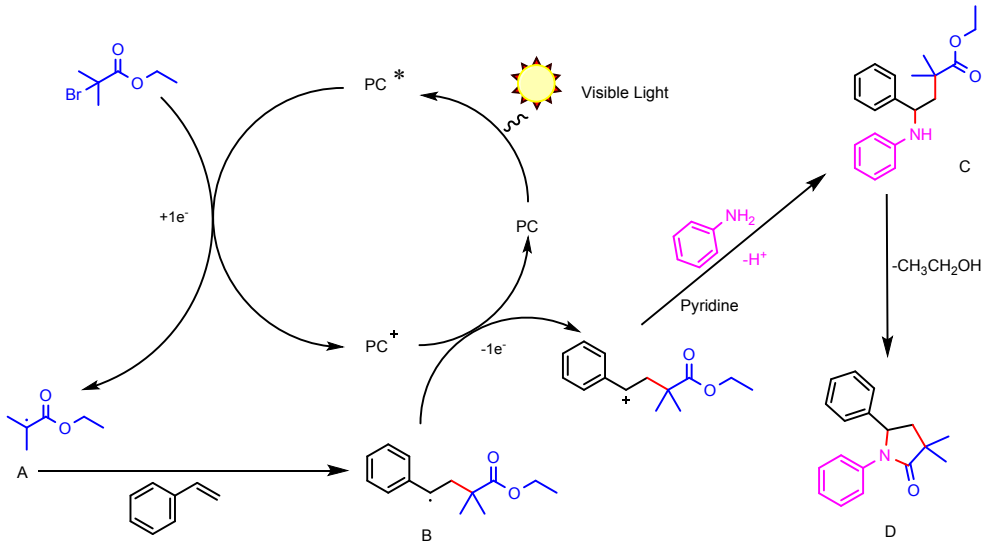
3. 10 A Scale-up Continuous Flow Reaction.[a]



[a] Reaction conditions: 1 (10 mmol), 2 (1 equiv), 3 (1equiv), DCE (20 mL), Pyridine (1.1 equiv), and PC-B (1 % equiv.) at room temperature for 20 minutes. [b] Isolated yield.

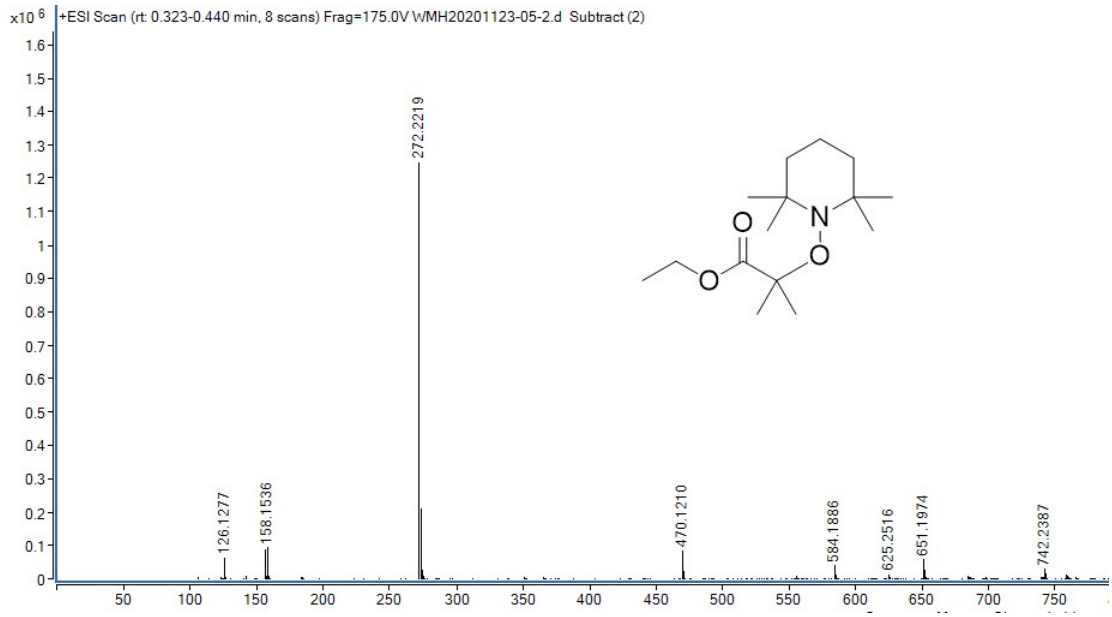
4. Experiments for Mechanistic Studies



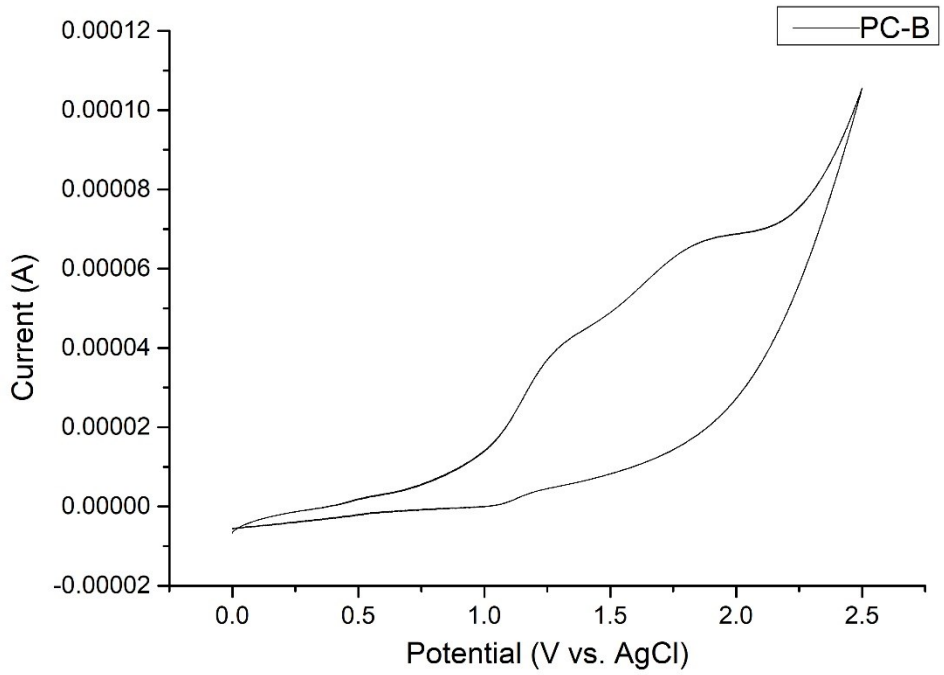


Proposed mechanism.

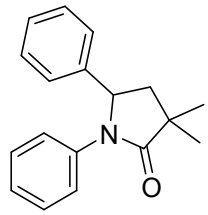
Electrospray Ionization-Time-of-Flight-Mass Spectrometry (ESI-TOF-MS) of some intermediates and byproducts.



Cyclic voltammograms (vs. Ag/AgCl) of catalysts PC-B in DCE.



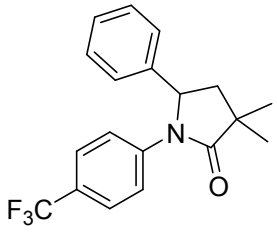
5. Analytical data for isolated compounds



4aaa

3,3-dimethyl-1,5-diphenylpyrrolidin-2-one:

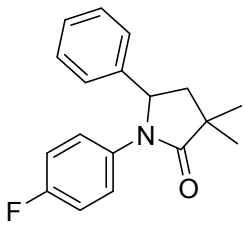
Reddish brown oily (239.5mg, 90% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 – 7.25 (m, 7H), 7.24 – 7.01 (m, 3H), 5.42 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.43 (dd, *J* = 12.7, 6.0 Hz, 1H), 2.04 (d, *J* = 3.8 Hz, 1H), 1.44 (d, *J* = 13.4 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 139.20 , 127.59 , 127.53 , 127.08 , 124.39 , 122.52 , 121.71 , 79.14 , 46.23 , 40.83 , 28.68 , 25.30 , 25.18 .HRMS calcd for C18H19NO [M+H]$^{+}$ 266.1539 found 266.1508.



4aab

3,3-dimethyl-5-phenyl-1-(4-(trifluoromethyl)phenyl)pyrrolidin-2-one:

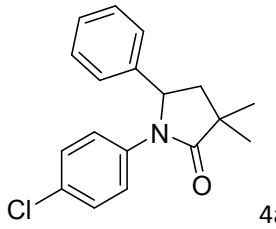
Reddish brown oily (177.1mg, 53% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 (d, *J* = 8.3 Hz, 2H), 7.25 (dd, *J* = 8.1, 6.3 Hz, 2H), 7.20 – 7.14 (m, 3H), 7.07 (d, *J* = 8.2 Hz, 2H), 5.30 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.32 (dd, *J* = 12.7, 6.0 Hz, 1H), 1.94 (dd, *J* = 12.8, 10.2 Hz, 1H), 1.33 (d, *J* = 13.8 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.17 , 149.85 , 138.79 , 127.65 , 127.23 , 124.94 , 124.71 (q, *J* = 3.7 Hz), 124.35 , 121.70 , 111.09 , 79.38 , 45.97 , 40.86 , 25.16 , 25.05 .^{19}F NMR (376 MHz, Chloroform-*d*) δ -61.04. HRMS calcd for C19H18F3NO [M+H]$^{+}$ 334.1413 found 334.1393



4aac

1-(4-fluorophenyl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

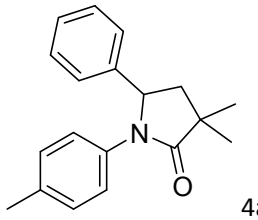
Brown oil(201.7mg, 71% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.43 – 7.31 (m, 6H), 7.21 – 7.15 (m, 2H), 7.04 – 6.96 (m, 2H), 5.45 (dd, *J* = 10.4, 5.9 Hz, 1H), 2.45 (dd, *J* = 12.7, 6.0 Hz, 1H), 2.06 (dd, *J* = 12.7, 10.3 Hz, 1H), 1.46 (d, *J* = 11.5 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.13 , 159.39 , 156.99 , 142.08 , 139.08 , 127.57 , 127.08 , 124.34 , 123.29 (d, *J* = 7.9 Hz), 114.10 , 113.87 , 79.02 , 45.96 , 40.76 , 25.25 , 25.05 .^{19}F NMR (376 MH$_{Z}$, Chloroform-*d*) δ -120.18. HRMS calcd for C18H18FNO [M+H]$^{+}$ 284.1445 found 284.1446.



4aad

1-(4-chlorophenyl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

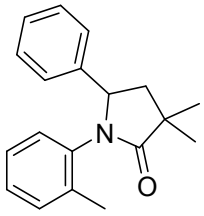
Reddish brown oily (186.1mg, 62% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.45 – 7.21 (m, 7H), 7.08 (d, *J* = 8.2 Hz, 2H), 5.41 (dd, *J* = 10.3, 5.9 Hz, 1H), 2.42 (dd, *J* = 12.7, 5.9 Hz, 1H), 2.12 – 1.95 (m, 1H), 1.42 (d, *J* = 13.3 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.80 , 140.01 , 128.71 , 128.64 , 128.59 , 128.25 , 125.43 , 124.28 , 80.32 , 47.10 , 41.96 , 26.31 , 26.17 . ^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.80 , 145.74 , 140.01 , 128.71 , 128.59 , 128.25 , 125.43 , 124.28 , 80.32 , 47.10 , 41.96 , 26.31 , 26.17 .HRMS calcd for C18H18CLNO $[M+H]^+$ 300.1150 found 300.1129.



4aae

3,3-dimethyl-5-phenyl-1-(p-tolyl)pyrrolidin-2-one:

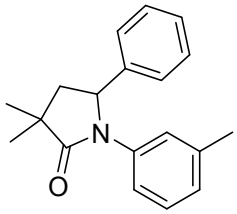
Brown yellow solid (232.5mg, 83% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.38 – 7.27 (m, 5H), 7.15 – 6.97 (m, 4H), 5.39 (dd, *J* = 10.1, 6.0 Hz, 1H), 2.41 (dd, *J* = 12.7, 6.0 Hz, 1H), 2.29 (s, 3H), 2.01 (dd, *J* = 12.6, 10.1 Hz, 1H), 1.42 (d, *J* = 12.1 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.92 , 144.33 , 140.39 , 132.86 , 129.13 , 128.72 , 128.58 , 128.03 , 125.41 , 125.31 , 122.67 , 79.95 , 77.60 , 77.23 , 47.31 , 41.75 , 26.37 , 26.22 , 20.91 . HRMS calcd for C19H21NO $[M+H]^+$ 280.1696 found 280.1689.



4aaf

3,3-dimethyl-5-phenyl-1-(o-tolyl)pyrrolidin-2-one:

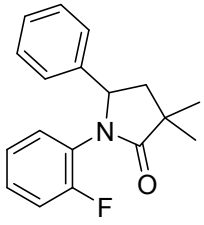
Reddish brown oil(226.9mg, 81% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.35 – 7.25 (m, 4H), 7.23 – 7.09 (m, 3H), 6.97 – 6.90 (m, 2H), 5.36 (dd, *J* = 10.1, 6.0 Hz, 1H), 2.42 (dd, *J* = 12.7, 6.0 Hz, 1H), 2.20 (s, 3H), 2.06 – 2.01 (m, 1H), 1.46 (d, *J* = 13.2 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 166.46 , 139.21 , 128.98 , 128.10 , 127.51 , 127.01 , 125.00 , 124.42 , 122.07 , 120.01 , 78.75 , 46.33 , 40.51 , 25.38 , 25.26 , 16.85 .HRMS calcd for C19H21NO $[M+H]^+$ 280.1693 found 280.1663.



4aag

3,3-dimethyl-5-phenyl-1-(m-tolyl)pyrrolidin-2-one:

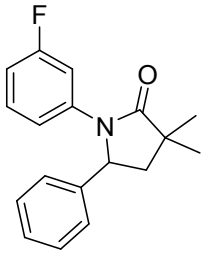
Reddish brown oil(221.3mg, 79% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.36 – 7.33 (m, 2H), 7.29 (t, *J* = 3.1 Hz, 2H), 7.21 – 7.08 (m, 2H), 6.94 (d, *J* = 7.5 Hz, 2H), 6.84 (d, *J* = 7.4 Hz, 1H), 5.39 (dd, *J* = 10.1, 6.0 Hz, 1H), 2.41 (dd, *J* = 12.6, 6.0 Hz, 1H), 2.34 – 2.28 (m, 3H), 2.01 (dd, *J* = 12.5, 10.0 Hz, 1H), 1.42 (d, *J* = 14.9 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.87 , 147.22 , 140.49 , 138.21 , 128.76 , 128.61 , 128.38 , 128.04 , 125.43 , 124.23 , 123.46 , 119.56 , 79.85 , 47.34 , 41.69 , 26.39 , 26.28 , 21.49 .HRMS calcd for C19H21NO $[M+H]^+$ 280.1704 found 280.1693.



4aah

1-(2-fluorophenyl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

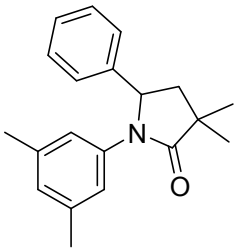
Brown oil (196.1mg, 69% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.40 – 7.31 (m, 5H), 7.13 – 7.01 (m, 4H), 5.44 (dd, *J* = 10.2, 5.9 Hz, 1H), 2.46 (dd, *J* = 12.7, 5.9 Hz, 1H), 2.08 (dd, *J* = 12.8, 10.1 Hz, 1H), 1.49 (d, *J* = 12.6 Hz, 6H). ^{13}C NMR (101 MHz,) δ 170.33 , 155.36 , 152.92 , 140.06 , 135.55 (d, *J* = 13.5 Hz), 128.63 , 128.17 , 125.51 , 124.31 – 124.01 (m), 123.91 (d, *J* = 3.6 Hz), 115.66 (d, *J* = 20.4 Hz), 80.43 , 47.68 , 41.89 , 26.26 , 26.15 .^{19}F NMR (376 MHz, $CDCl_3$) δ -124.80.HRMS calcd for C18H18FNO $[M+H]^+$ 284.1445 found 284.1437.



4aai

5-(3-fluorophenyl)-3,3-dimethyl-1-phenylpyrrolidin-2-one:

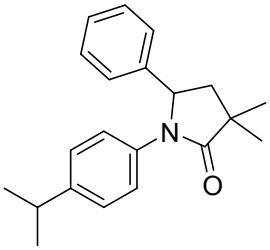
Brown oil(184.7mg, 65% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 – 7.30 (m, 5H), 7.24 (d, *J* = 8.1 Hz, 1H), 6.95 – 6.87 (m, 2H), 6.77 (td, *J* = 8.4, 2.5 Hz, 1H), 5.46 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.46 (dd, *J* = 12.7, 6.0 Hz, 1H), 2.07 (dd, *J* = 12.7, 10.2 Hz, 1H), 1.46 (d, *J* = 15.0 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.75 , 163.17 , 160.74 , 148.10 (d, *J* = 9.5 Hz), 138.96 , 128.45 (d, *J* = 9.4 Hz), 127.62 , 127.14 , 124.35 , 117.61 (d, *J* = 2.8 Hz), 109.01 (dd, *J* = 21.9, 19.5 Hz), 79.23 , 46.01 , 40.83 , 25.22 , 25.08 .^{19}F NMR (376 MH_Z, Chloroform-*d*) δ -113.62.HRMS calcd for C18H18FNO $[M+H]^+$ 284.1445 found 284.1441.



4aaj

1-(3,5-dimethylphenyl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

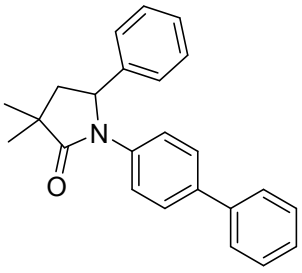
Brown oil(214.8mg, 73% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.32 – 7.25 (m, 5H), 6.75 (s, 2H), 6.66 (s, 1H), 5.36 (dd, *J* = 10.0, 6.0 Hz, 1H), 2.40 – 2.35 (m, 1H), 2.26 (s, 6H), 1.98 (dd, *J* = 12.6, 10.1 Hz, 1H), 1.40 (d, *J* = 14.0 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.71 , 147.24 , 140.64 , 137.99 , 128.62 , 128.04 , 125.45 , 125.22 , 120.39 , 79.81 , 47.37 , 41.67 , 26.46 , 26.33 , 21.46 .HRMS calcd for C20H23NO $[M+H]^+$ 294.1837 found 294.1854.



4aak

1-(4-isopropylphenyl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

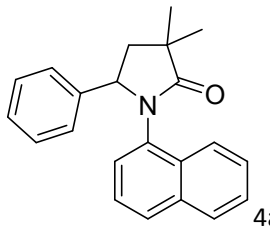
Brown oil (234.2mg, 76% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 – 7.34 (m, 5H), 7.16 (d, *J* = 2.9 Hz, 4H), 5.43 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.89 (p, *J* = 6.9 Hz, 1H), 2.44 (dd, *J* = 12.6, 6.0 Hz, 1H), 2.05 (dd, *J* = 12.7, 10.3 Hz, 1H), 1.46 (d, *J* = 10.1 Hz, 6H), 1.25 (d, *J* = 6.9 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.68 , 144.53 , 143.99 , 140.47 , 129.32 , 128.64 , 128.09 , 127.93 , 126.51 , 125.52 , 122.89 , 116.21 , 79.99 , 59.86 , 49.51 , 47.39 , 41.82 , 33.60 , 27.70 , 26.43 , 26.27 , 24.21 , 24.16 , 24.13 , 24.00 .HRMS calcd for C21H25NO $[M+H]^+$ 308.2009 found 308.2008.



4aal

1-([1,1'-biphenyl]-4-yl)-3,3-dimethyl-5-phenylpyrrolidin-2-one:

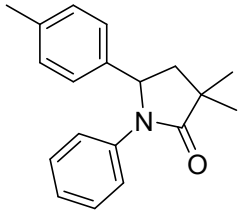
Reddish brown solid(290.9mg, 85% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.54 (dd, *J* = 17.5, 7.8 Hz, 4H), 7.43 – 7.29 (m, 6H), 7.23 (d, *J* = 8.1 Hz, 4H), 5.39 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.39 (dd, *J* = 12.7, 6.1 Hz, 1H), 2.02 (d, *J* = 10.8 Hz, 1H), 1.42 (d, *J* = 9.1 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.34 , 146.60 , 141.19 , 140.35 , 136.35 , 128.89 , 128.74 , 128.21 , 127.34 , 126.91 , 126.81 , 125.53 , 123.40 , 80.18 , 47.29 , 41.94 , 26.46 , 26.32 .HRMS calcd for C24H23NO $[M+H]^+$ 342.1852 found 342.1848.



4aam

3,3-dimethyl-1-(naphthalen-1-yl)-5-phenylpyrrolidin-2-one:

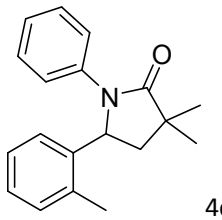
Brown oil (275.1mg, 87% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.15 – 8.08 (m, 1H), 7.86 – 7.82 (m, 1H), 7.59 (d, *J* = 8.2 Hz, 1H), 7.51 – 7.47 (m, 2H), 7.45 – 7.41 (m, 1H), 7.35 – 7.29 (m, 3H), 7.22 (td, *J* = 8.0, 7.4, 1.5 Hz, 3H), 5.45 (dd, *J* = 10.0, 6.0 Hz, 1H), 2.52 (dd, *J* = 12.7, 6.1 Hz, 1H), 2.13 (dd, *J* = 12.7, 10.0 Hz, 1H), 1.62 (d, *J* = 7.8 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 140.07 , 134.19 , 128.58 , 128.09 , 127.91 , 127.87 , 125.82 , 125.77 , 125.36 , 125.20 , 123.64 , 123.54 , 116.98 , 80.38 , 47.41 , 42.20 , 29.74 , 26.57 , 26.43 .HRMS calcd for C22H21NO [M+H]$^{+}$316.1696 found 316.1682.



4baa

3,3-dimethyl-1-phenyl-5-(p-tolyl)pyrrolidin-2-one:

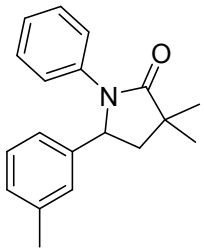
Yellow solid (218.5mg, 78% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.28 – 7.23 (m, 2H), 7.19 – 7.11 (m, 6H), 7.01 (tt, *J* = 7.2, 1.3 Hz, 1H), 5.35 (dd, *J* = 10.2, 5.9 Hz, 1H), 2.39 – 2.35 (m, 1H), 2.32 (s, 3H), 2.00 (dd, *J* = 12.7, 10.2 Hz, 1H), 1.42 (d, *J* = 8.6 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.22 , 147.29 , 137.93 , 137.29 , 129.42 , 129.31 , 128.56 , 125.57, 125.46 , 123.45 , 122.84 , 80.06 , 47.28 , 41.83 , 26.42 , 26.26 , 21.20 .HRMS calcd for C19H21NO [M+H]$^{+}$ 280.1685 found 280.1696.



4caa

3,3-dimethyl-1-phenyl-5-(o-tolyl)pyrrolidin-2-one:

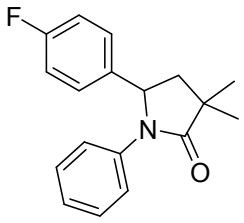
Reddish brown oil (201.7mg, 72% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.40 (d, *J* = 2.8 Hz, 1H), 7.38 – 7.24 (m, 2H), 7.24 – 7.00 (m, 6H), 5.62 (d, *J* = 3.2 Hz, 1H), 2.52 – 2.48 (m, 1H), 2.33 (s, 3H), 1.99 (d, *J* = 3.2 Hz, 1H), 1.34 (d, *J* = 28.3 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 181.86 , 137.71 , 134.20 , 130.66 , 128.58 , 128.06 , 126.51 , 124.37 , 122.72 , 75.43 , 44.78 , 40.64 , 25.20 , 24.54 , 19.10 .HRMS calcd for C19H21NO [M+H]$^{+}$ 280.1696 found 280.1697.



4daa

3,3-dimethyl-1-phenyl-5-(m-tolyl)pyrrolidin-2-one:

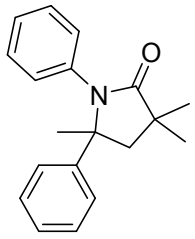
Reddish brown oil (198.9mg, 71% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.33 – 7.22 (m, 3H), 7.22 – 7.00 (m, 6H), 5.41 (dd, *J* = 9.9, 6.2 Hz, 1H), 2.46 (dd, *J* = 12.8, 6.3 Hz, 1H), 2.36 (s, 3H), 2.06 (d, *J* = 2.9 Hz, 1H), 1.33 (d, *J* = 21.4 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 181.75 , 139.40 , 138.49 , 129.05 , 128.85 , 128.59 , 128.52 , 126.16 , 125.93 , 122.77 , 122.51 , 122.37 , 77.66 , 77.25 , 47.20 , 46.08 , 40.76 , 26.33 , 26.17 , 24.94 , 24.20 , 21.41 . HRMS calcd for C19H21NO [M+H]$^{+}$ 280.1696 found 280.1696.



4eaa

5-(4-fluorophenyl)-3,3-dimethyl-1-phenylpyrrolidin-2-one:

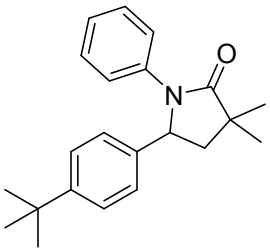
Reddish brown oil (190.4mg, 67% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.27 – 7.22 (m, 1H), 7.22 – 7.17 (m, 3H), 7.09 – 7.01 (m, 2H), 7.01 – 6.93 (m, 3H), 5.32 (dd, *J* = 10.6, 5.9 Hz, 1H), 2.35 (dd, *J* = 12.7, 6.0 Hz, 1H), 1.93 (dd, *J* = 12.7, 10.2 Hz, 1H), 1.38 (d, *J* = 9.1 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 166.68 , 146.16 , 135.00 (d, *J* = 3.4 Hz), 127.51 , 126.19 (d, *J* = 8.1 Hz), 122.42 , 121.60 , 114.76 – 114.46 (m), 114.35 , 78.26 , 46.17 , 40.67 , 25.28 , 25.10 .^{19}F NMR (376 MHz, Chloroform-*d*) δ -113.52 . HRMS calcd for C20H21NO3 [M+H]$^{+}$ 284.1445 found 284.1448.



4faa

3,3,5-trimethyl-1,5-diphenylpyrrolidin-2-one:

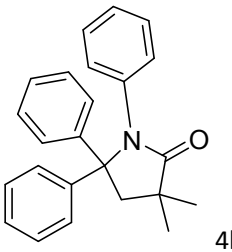
Reddish brown oil (238.1mg, 85% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.38 – 7.29 (m, 6H), 7.26 – 7.16 (m, 3H), 7.10 – 7.03 (m, 1H), 2.54 – 2.49 (m, 1H), 2.29 (d, *J* = 2.3 Hz, 1H), 1.63 (d, *J* = 27.9 Hz, 3H), 1.37 (d, *J* = 46.3 Hz, 3H), 0.99 (d, *J* = 37.2 Hz, 3H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 168.25 , 147.76 , 145.95 , 129.28 , 128.68 , 128.63 , 128.54 , 127.41 , 127.10 , 124.10 , 124.03 , 123.35 , 122.76 , 85.87 , 83.50 , 51.44 , 50.65 , 41.89 , 40.88 , 32.10 , 32.01 , 28.59 , 27.84 , 26.75 , 25.94 .HRMS calcd for C19H21NO [M+H]$^{+}$ 280.1696 found 280.1696.



4gaa

5-(4-(tert-butyl)phenyl)-3,3-dimethyl-1-phenylpyrrolidin-2-one:

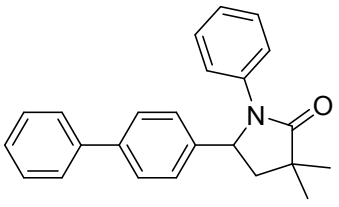
Reddish brown oil (225.6mg, 70% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 – 7.37 (m, 3H), 7.34 – 7.01 (m, 6H), 5.43 (d, *J* = 3.9 Hz, 1H), 2.48 – 2.43 (m, 1H), 2.09 (d, *J* = 2.9 Hz, 1H), 1.32 (s, 9H), 1.31 (d, *J* = 1.3 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 181.82 , 151.49 , 136.35 , 128.56 , 125.66 , 125.56 , 125.38 , 125.24 , 122.83 , 77.67 , 45.95 , 40.85 , 34.64 , 34.01 , 31.34 , 25.00 , 24.24 . HRMS calcd for C22H27NO $[M+H]^+$ 322.2165 found 322.2190.



4haa

3,3-dimethyl-1,5,5-triphenylpyrrolidin-2-one:

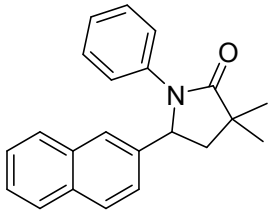
Brown yellow solid (328.5mg, 96% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.46 – 7.43 (m, 1H), 7.38 – 7.33 (m, 6H), 7.31 – 7.24 (m, 5H), 7.17 (d, *J* = 7.0 Hz, 2H), 7.10 (t, *J* = 7.5 Hz, 1H), 2.86 (s, 2H), 1.22 (s, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.45 , 147.56 , 145.42 , 144.80 , 128.72 , 128.61 , 127.67 , 127.38 , 125.06 , 123.56 , 122.80 , 88.47 , 50.97 , 49.97 , 41.71 , 40.68 , 27.75 , 25.88 .HRMS calcd for C24H23NO $[M+H]^+$ 342.1852 found 342.1855.



4iaa

5-([1,1'-biphenyl]-4-yl)-3,3-dimethyl-1-phenylpyrrolidin-2-one:

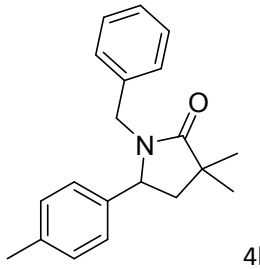
Brown yellow solid (280.6mg, 82% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.58 – 7.53 (m, 4H), 7.40 (t, *J* = 7.5 Hz, 2H), 7.31 (dd, *J* = 15.4, 8.2 Hz, 4H), 7.24 – 7.07 (m, 3H), 7.02 (tt, *J* = 7.2, 1.3 Hz, 1H), 5.40 (dd, *J* = 10.2, 6.0 Hz, 1H), 2.40 (dd, *J* = 12.6, 6.0 Hz, 1H), 2.03 (dd, *J* = 12.6, 10.2 Hz, 1H), 1.43 (d, *J* = 7.3 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 167.94 , 147.16 , 140.97 , 140.49 , 139.21 , 129.20 , 128.77 , 128.52 , 127.40 , 127.28 , 127.01 , 125.88 , 123.43 , 122.72 , 114.99 , 79.72 , 47.10 , 41.72 , 26.33 , 26.16 . HRMS calcd for C24H23NO $[M+H]^+$ 342.1852 found 342.1853.



4jaa

3,3-dimethyl-5-(naphthalen-2-yl)-1-phenylpyrrolidin-2-one:

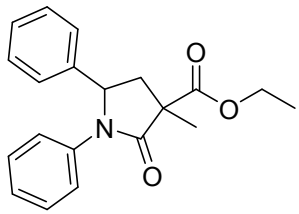
Brown yellow solid (271.9mg, 86% yield);^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.93 – 7.72 (m, 6H), 7.51 – 7.46 (m, 3H), 7.41 – 7.27 (m, 2H), 7.23 – 7.03 (m, 1H), 5.59 (dd, *J* = 9.9, 6.3 Hz, 1H), 2.52 (dd, *J* = 12.9, 6.3 Hz, 1H), 2.16 – 2.10 (m, 1H), 1.35 (d, *J* = 27.4 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 181.85 , 136.84 , 133.17 , 133.12 , 129.00 , 128.79 , 128.67 , 128.06 , 127.80 , 127.77 , 126.61 , 126.43 , 124.40 , 122.95 , 122.85 , 119.82 , 77.80 , 46.03 , 40.85 , 25.39 , 25.04 , 24.33 .HRMS calcd for C22H21NO $[M+H]^+$ 316.1696 found 316.1695.



4bab

1-benzyl-3,3-dimethyl-5-(p-tolyl)pyrrolidin-2-one:

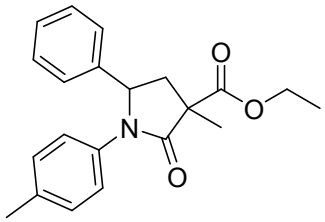
Yellow oil(179.5mg, 61% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.32 (dd, *J* = 18.8, 7.1 Hz, 3H), 7.17 (dtd, *J* = 11.9, 8.2, 2.9 Hz, 6H), 5.31 (dd, *J* = 10.3, 5.8 Hz, 1H), 4.60 – 4.50 (m, 2H), 2.33 (s, 3H), 2.32 – 2.27 (m, 1H), 1.92 (dd, *J* = 12.6, 10.3 Hz, 1H), 1.34 (d, *J* = 7.9 Hz, 6H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 169.01 , 141.37 , 137.89 , 137.66 , 129.44 , 129.33 , 128.23 , 127.60 , 126.25 , 125.62 , 125.49 , 79.20 , 77.74 , 50.85 , 47.82 , 41.16 , 26.43 , 26.27 , 21.24 .HRMS calcd for C20H23NO $[M+H]^+$ 294.1852 found 294.1867.



4aba

ethyl 3-methyl-2-oxo-1,5-diphenylpyrrolidine-3-carboxylate:

Reddish brown oil (171.8mg, 53% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.41 – 7.26 (m, 7H), 7.15 (d, *J* = 7.8 Hz, 2H), 7.05 (t, *J* = 7.3 Hz, 1H), 5.57 (dd, *J* = 10.3, 5.9 Hz, 1H), 4.35 – 4.26 (m, 2H), 3.01 (dd, *J* = 13.2, 6.0 Hz, 1H), 2.05 (dd, *J* = 13.2, 10.3 Hz, 1H), 1.67 (s, 3H), 1.35 (t, *J* = 7.1 Hz, 3H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 172.36 , 162.07 , 146.65 , 139.60 , 128.72 , 128.57 , 128.38 , 125.51 , 123.87 , 122.73 , 81.27 , 78.98 , 77.25 , 61.96 , 52.73 , 44.83 , 22.23 , 14.23 . HRMS calcd for C20H21NO3 $[M+H]^+$ 324.1594 found 324.1599.



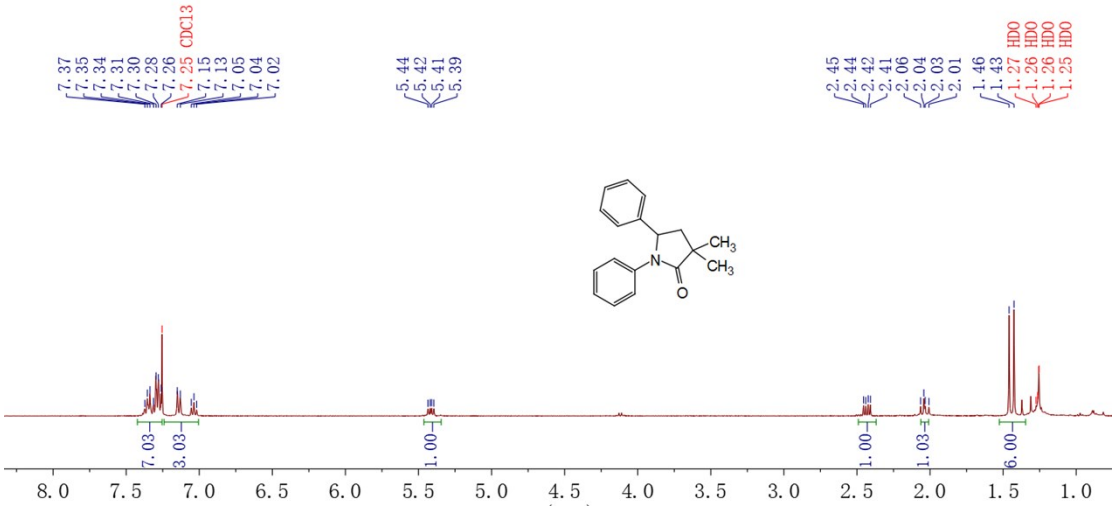
4abb

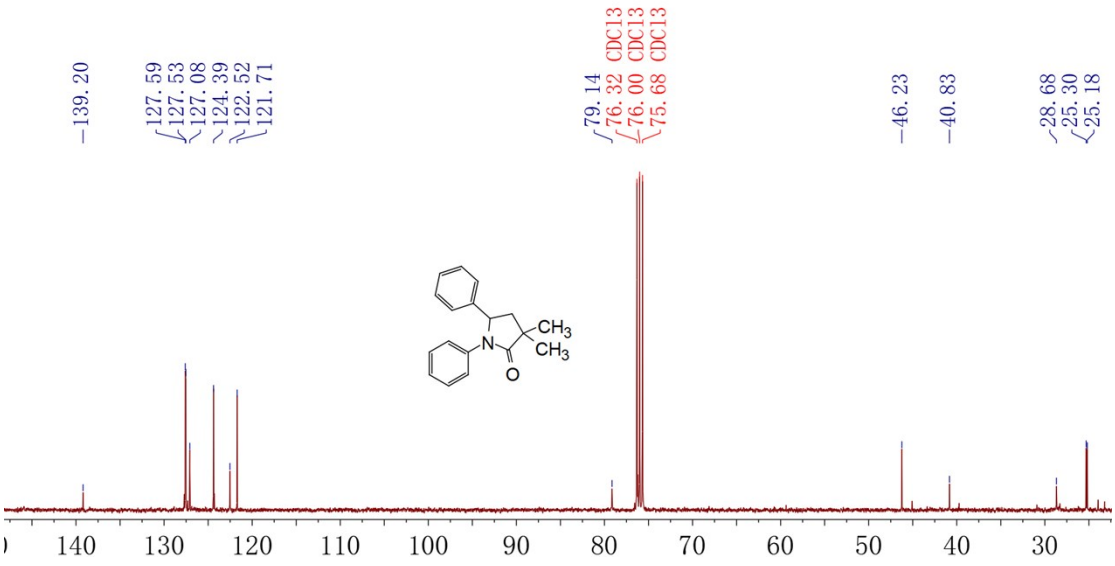
ethyl 3-methyl-2-oxo-5-phenyl-1-(p-tolyl)pyrrolidine-3-carboxylate:

Brown oil (142.1mg, 42% yield); ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.42 – 7.24 (m, 6H), 7.09 (s, 3H), 5.56 (dd, *J* = 10.3, 5.1 Hz, 1H), 4.33 – 4.26 (m, 2H), 2.99 (dd, *J* = 13.2, 6.0 Hz, 1H), 2.29 (s, 3H), 2.04 (dd, *J* = 13.2, 10.3 Hz, 1H), 1.62 (d, *J* = 38.0 Hz, 3H), 1.36 – 1.31 (m, 3H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 172.38 , 143.82 , 139.69 , 138.64, 133.40 , 129.17 , 128.87 , 128.71 , 128.36 , 125.54 , 125.44 , 122.78 , 81.30 , 78.98 , 61.93 , 52.76 , 44.86 , 43.90 , 22.26 , 20.97 , 14.23 .HRMS calcd for C21H23NO3 $[M+H]^{+}$ 338.1751 found 338.1755.

6. ^{1}H NMR and ^{13}C NMR spectra

4aaa





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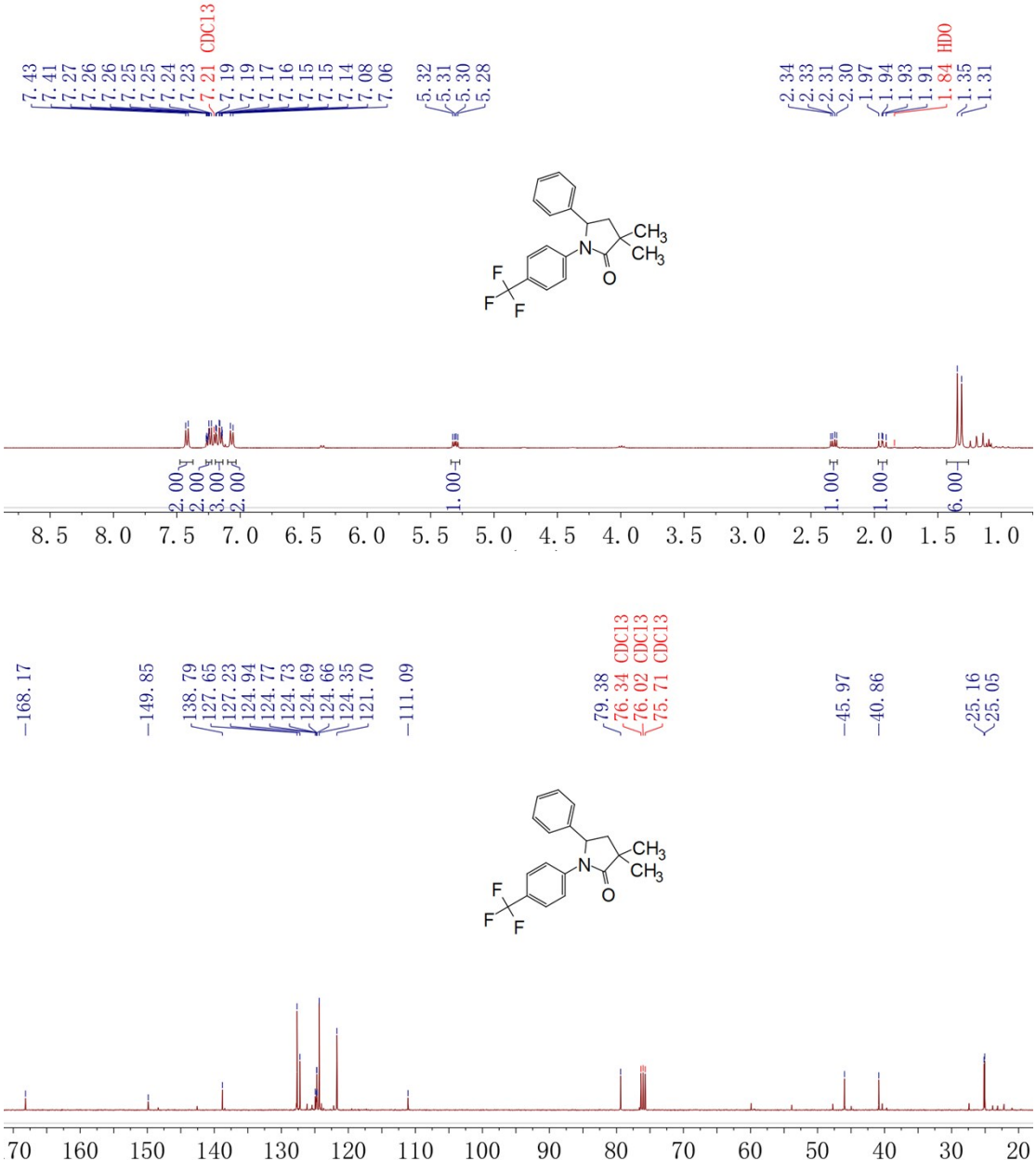
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7.15
7.15
7.14
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1.91
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O
F
F
F
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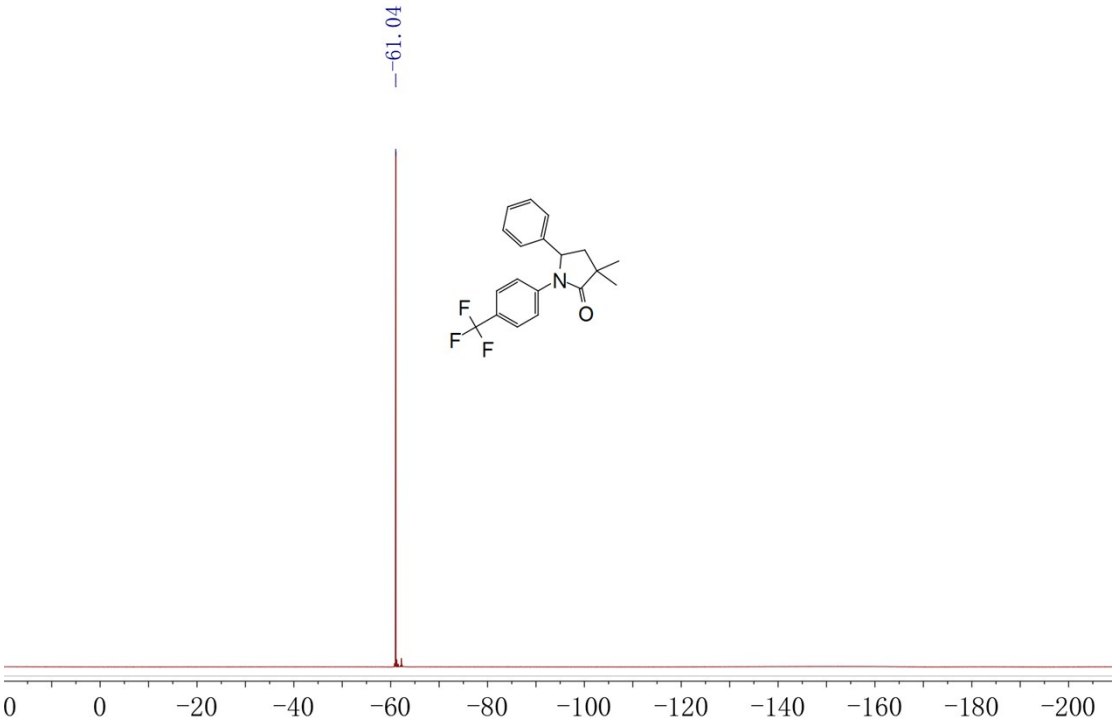
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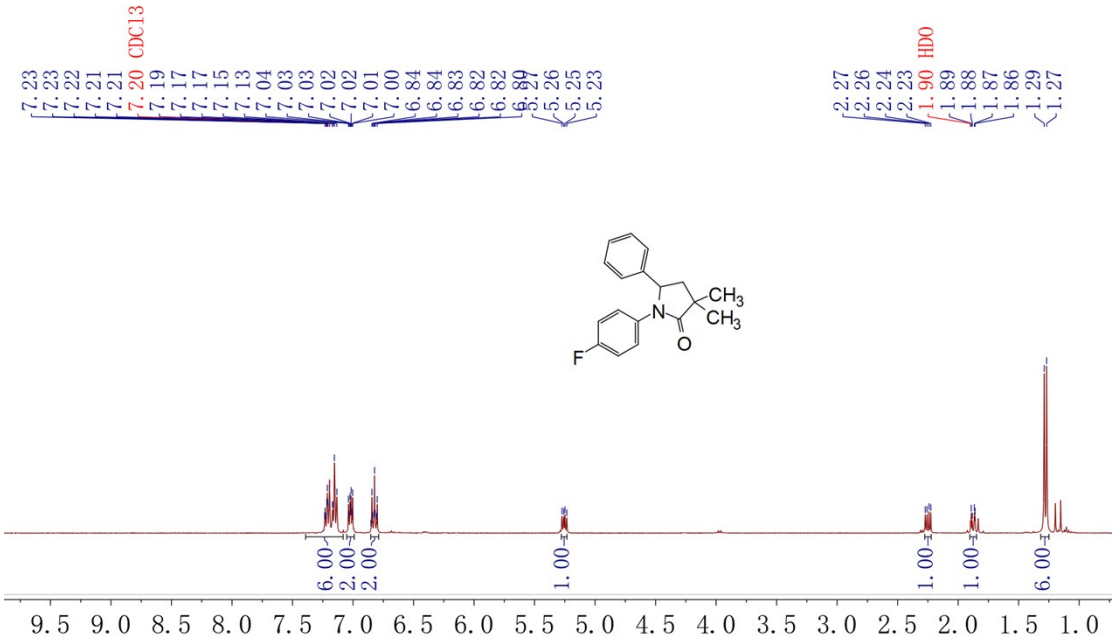
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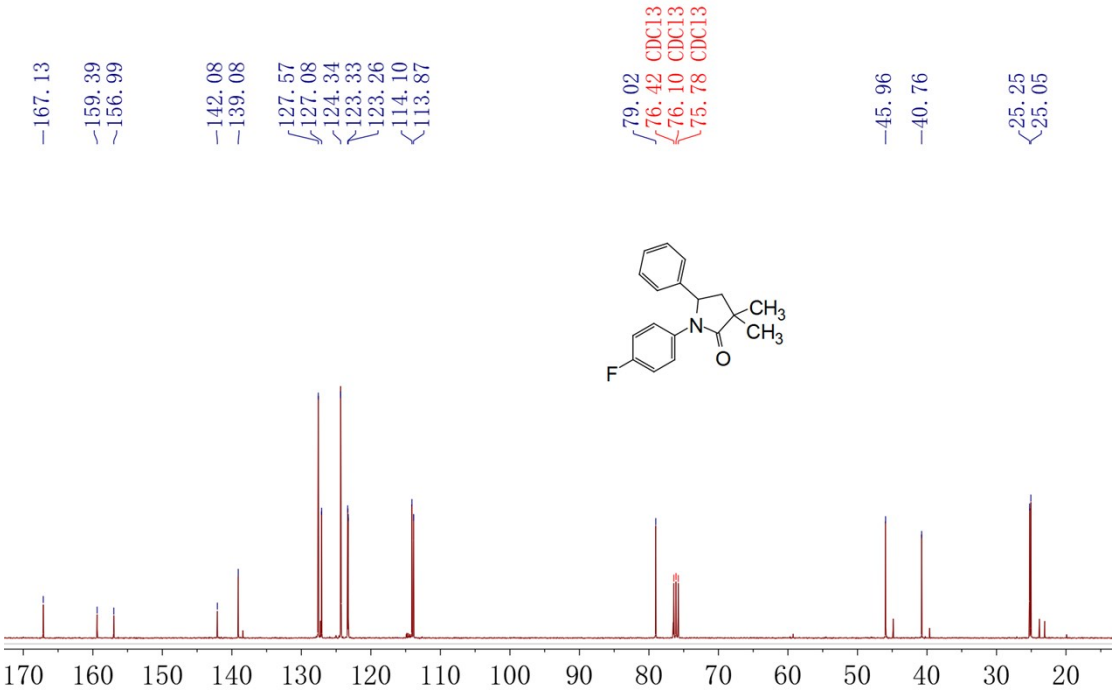
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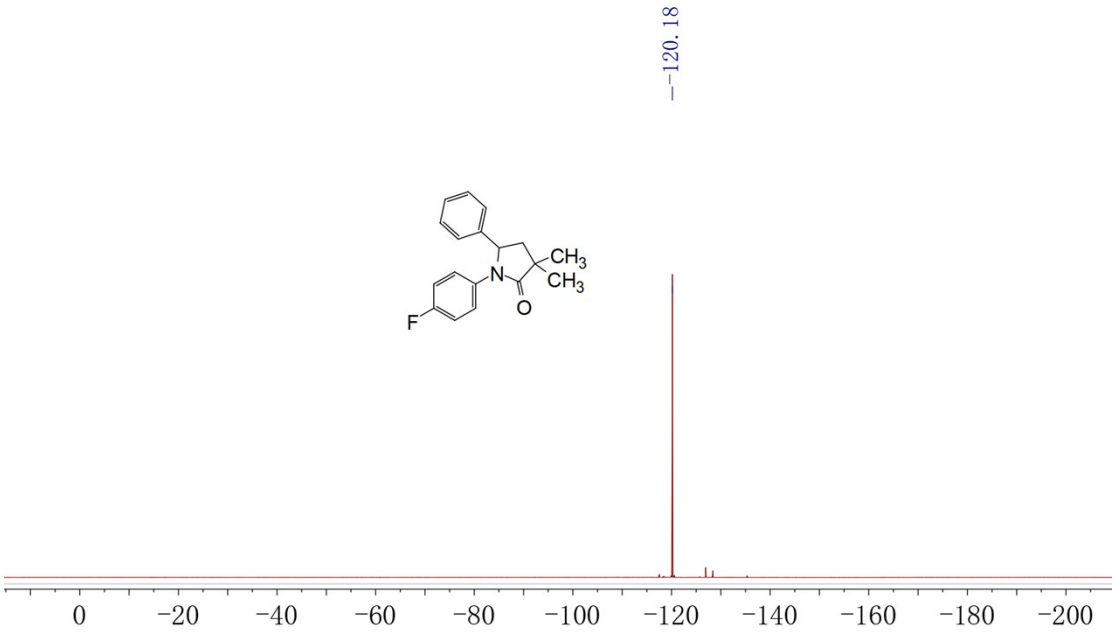
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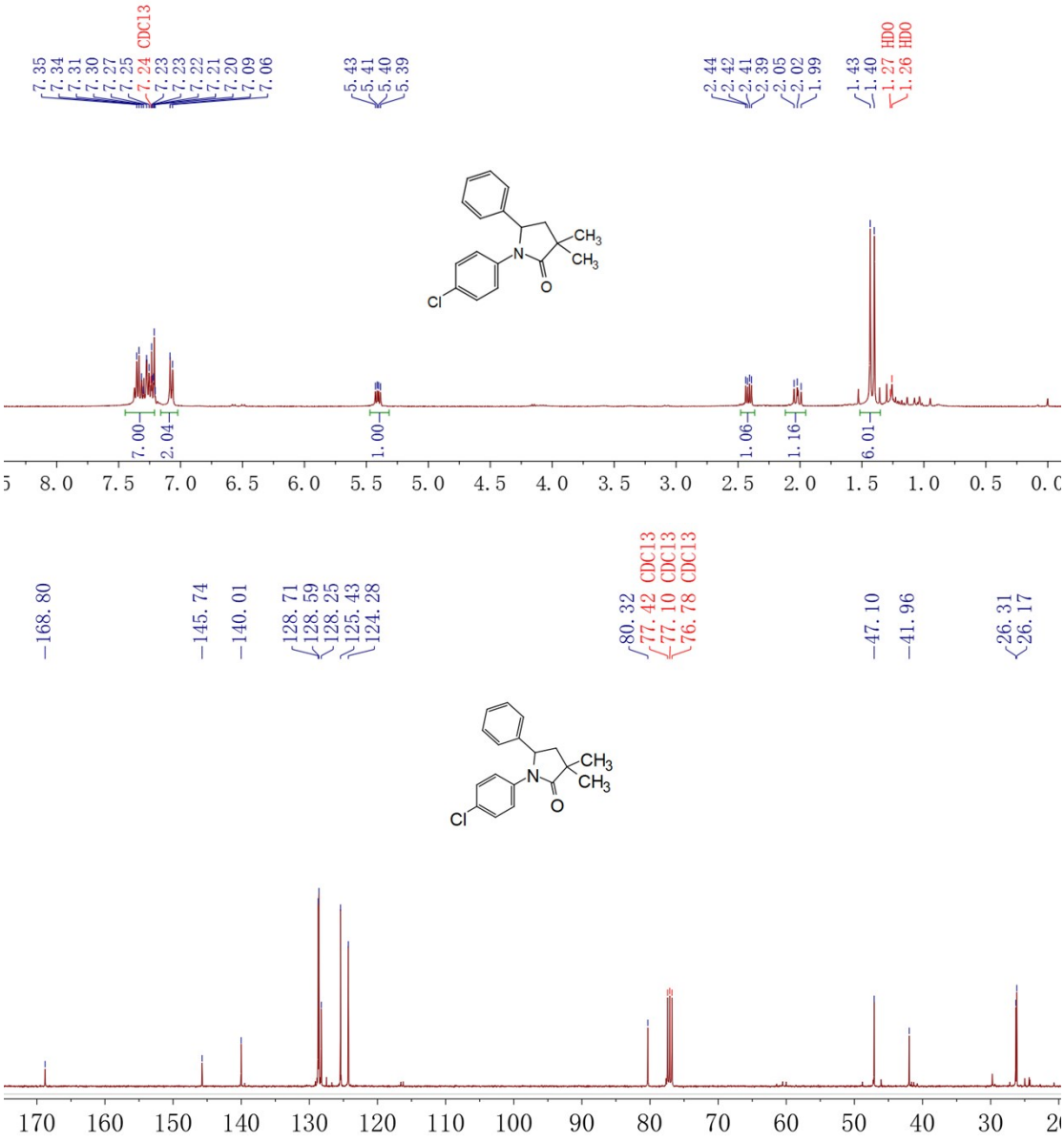
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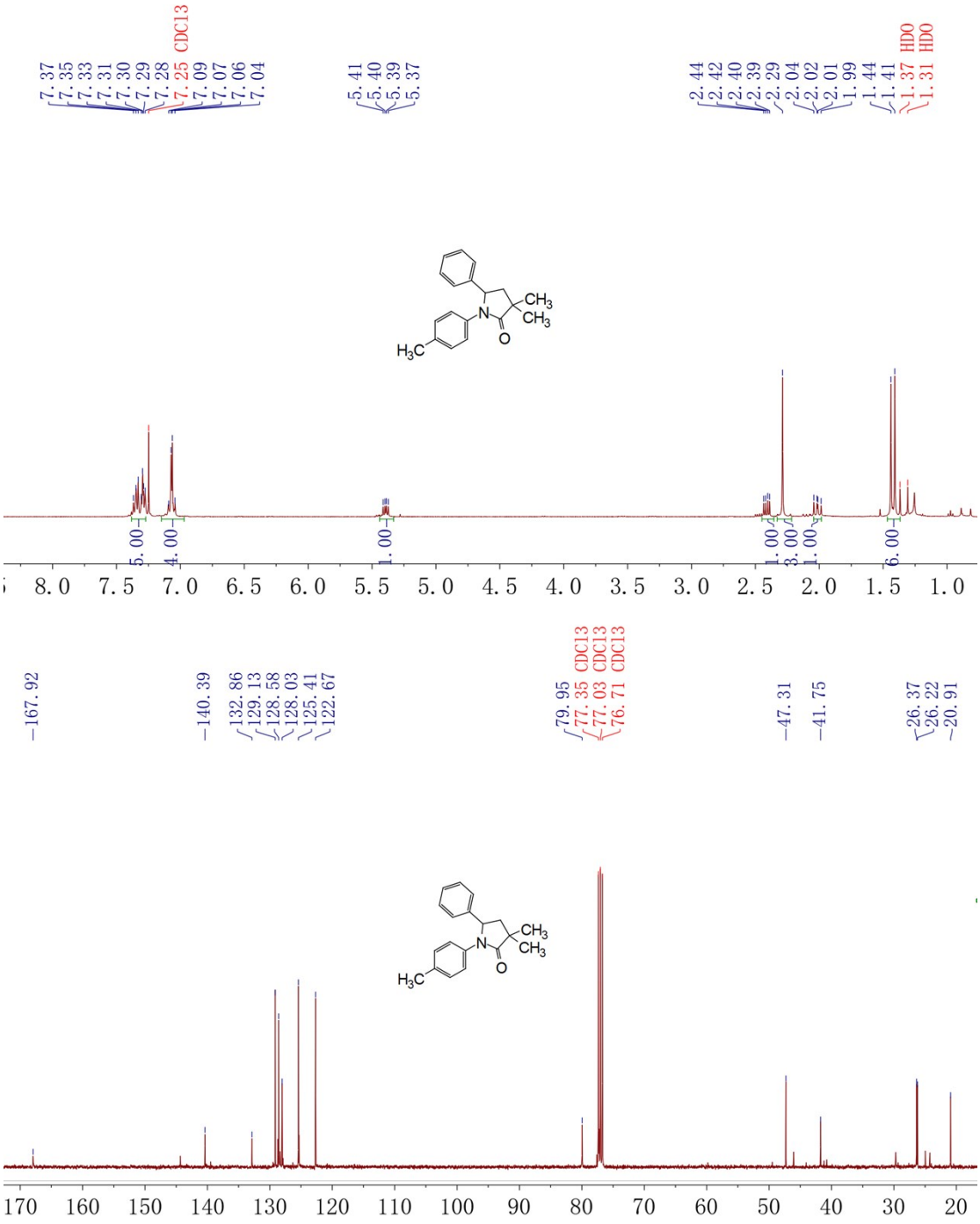
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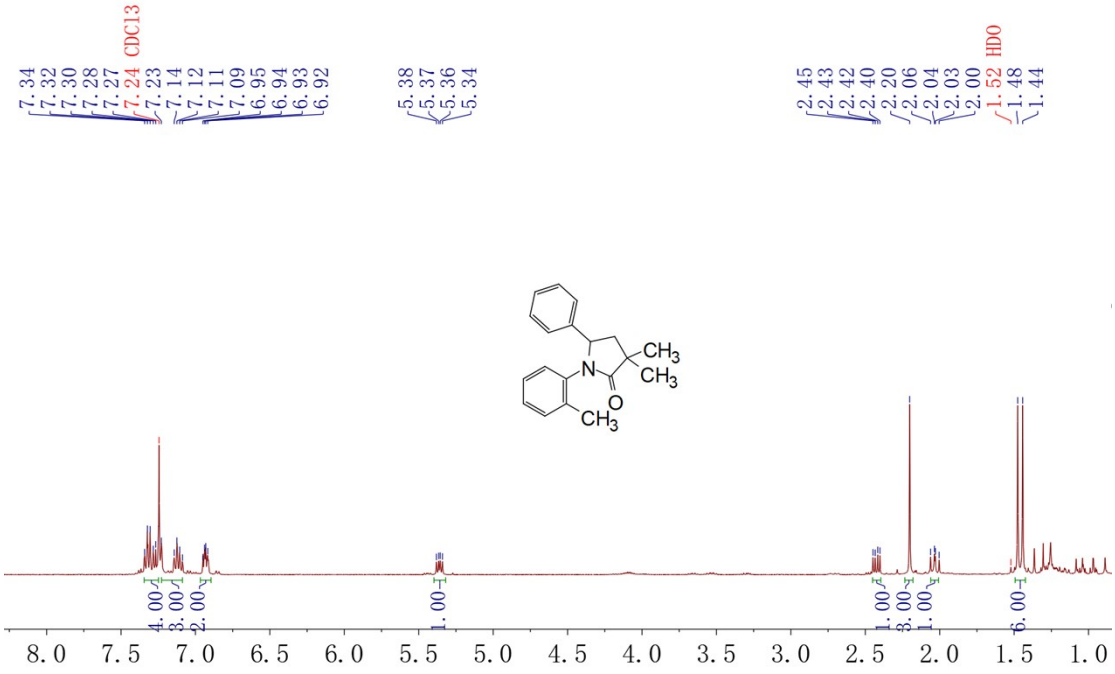
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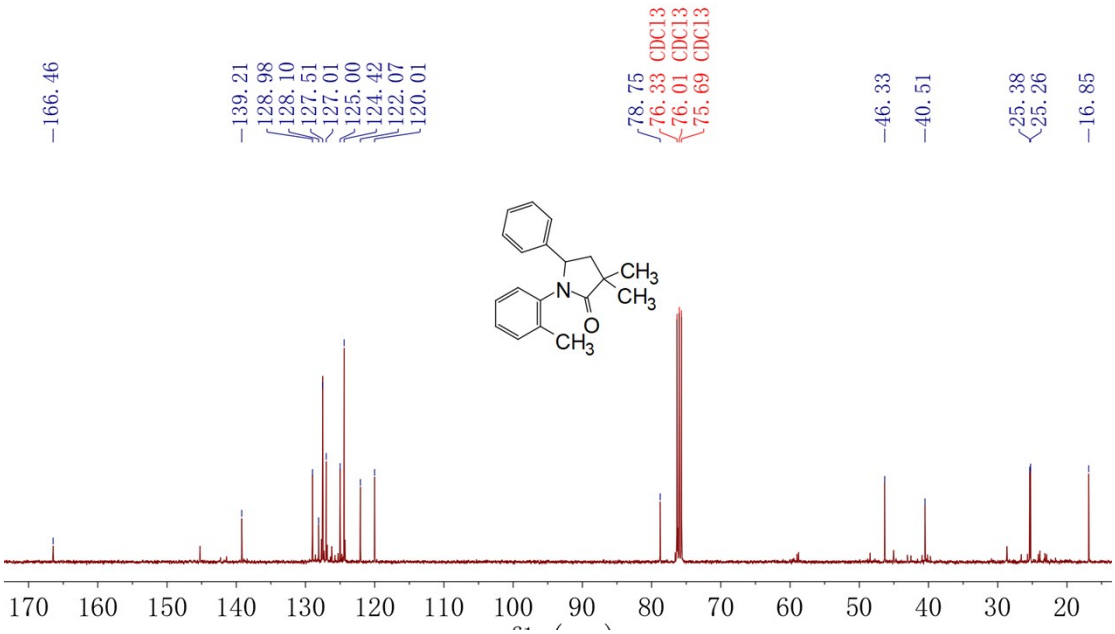
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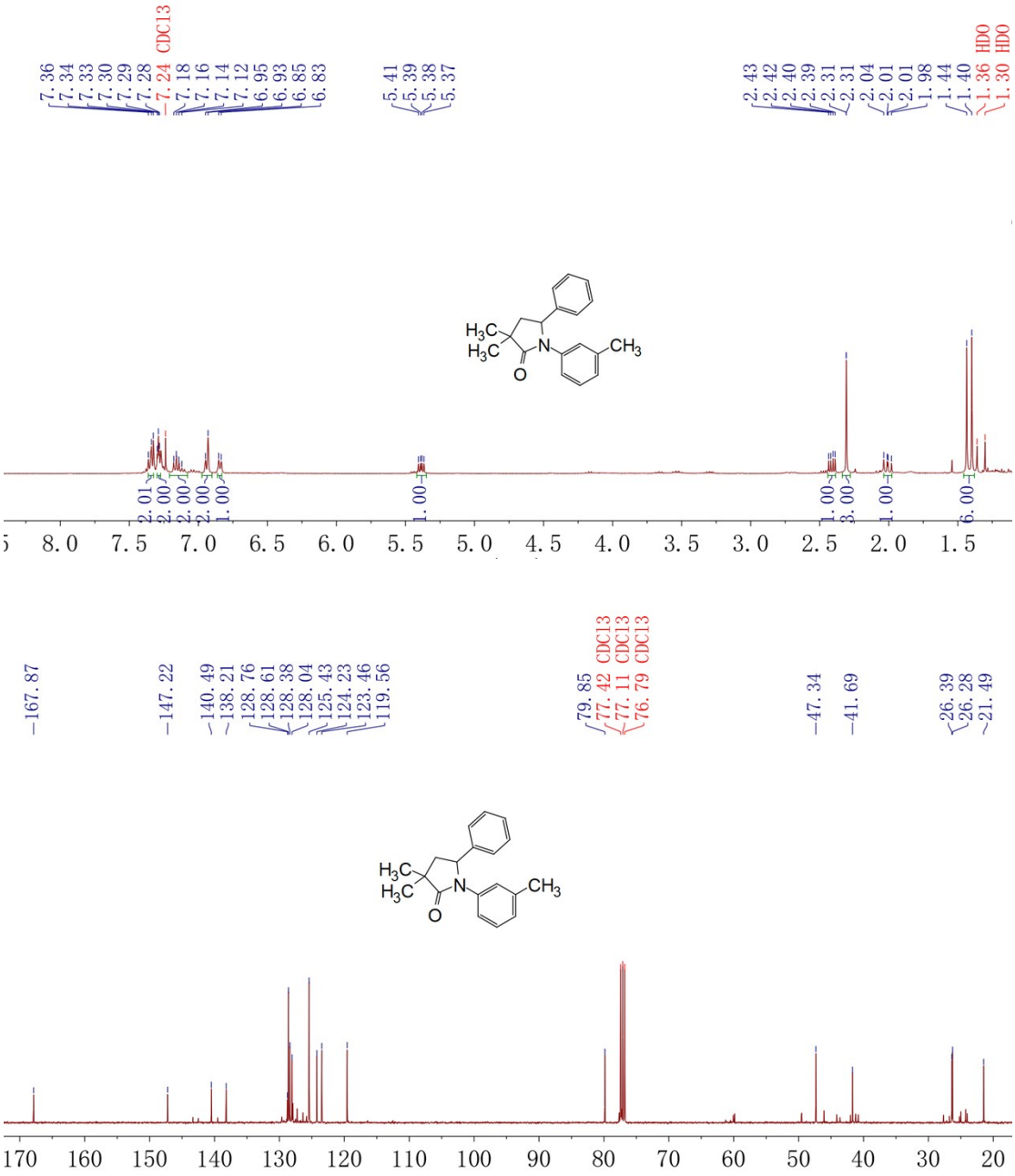
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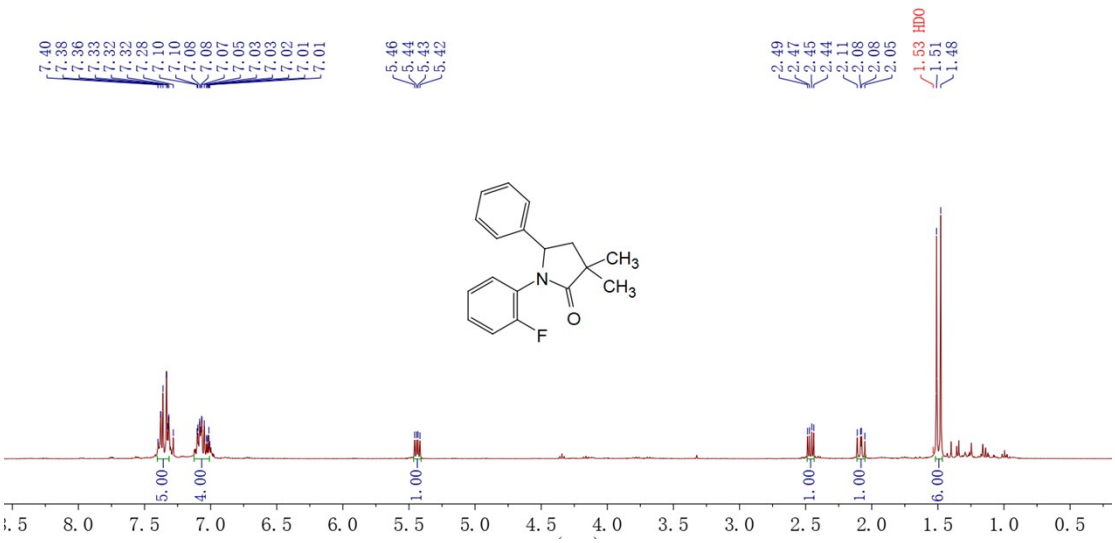
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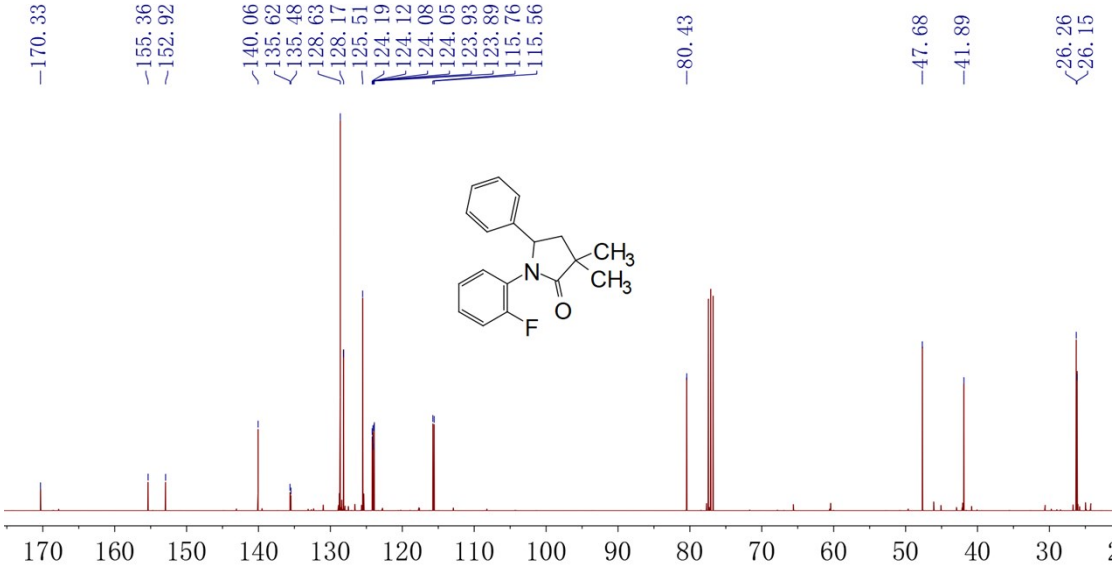
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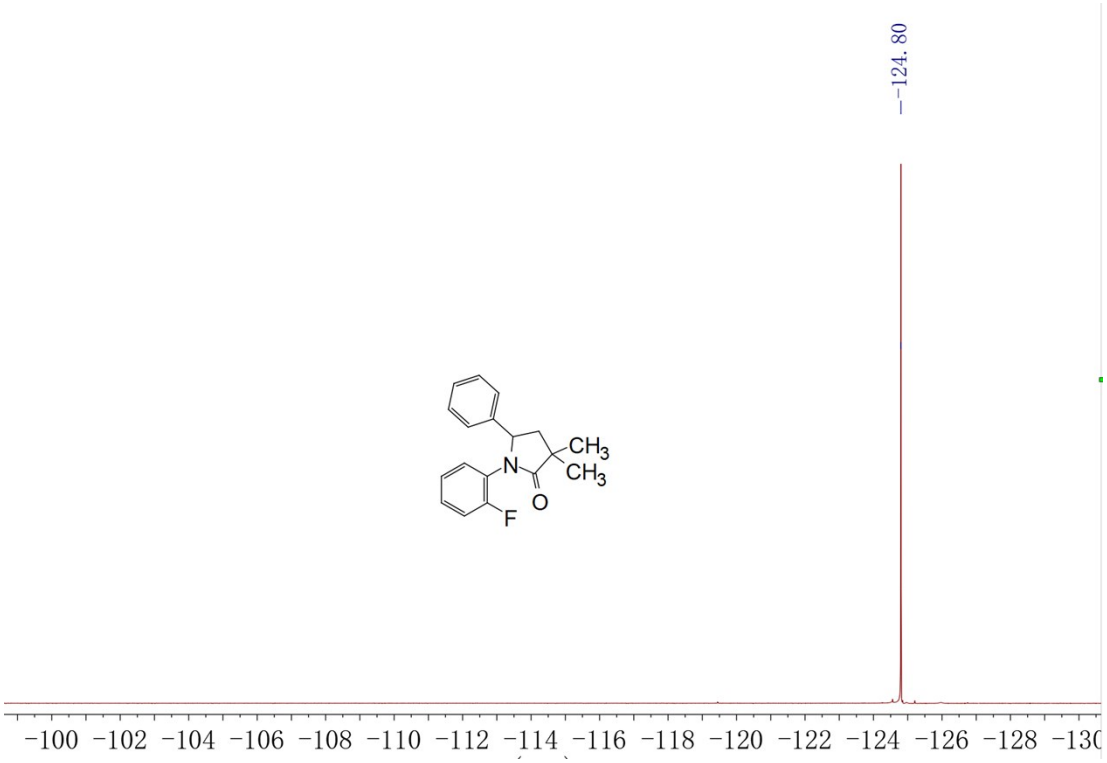
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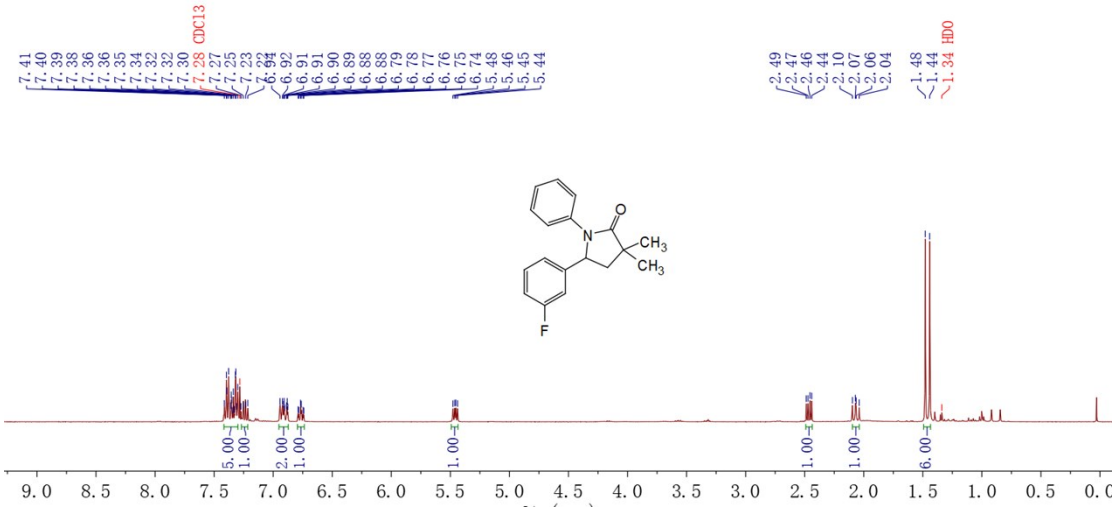
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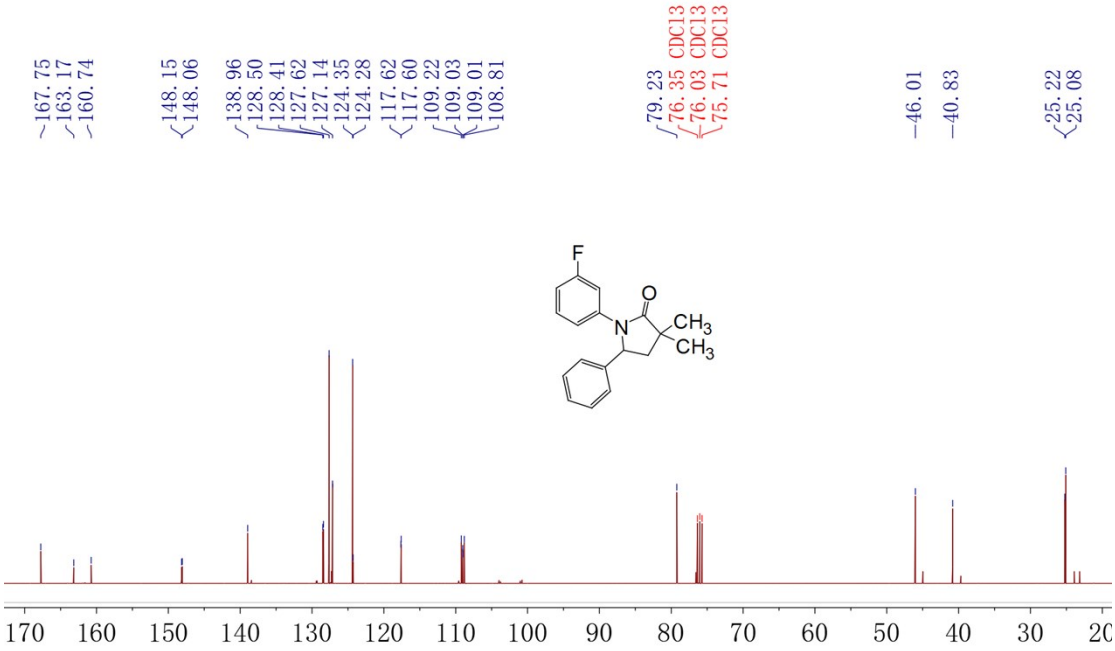
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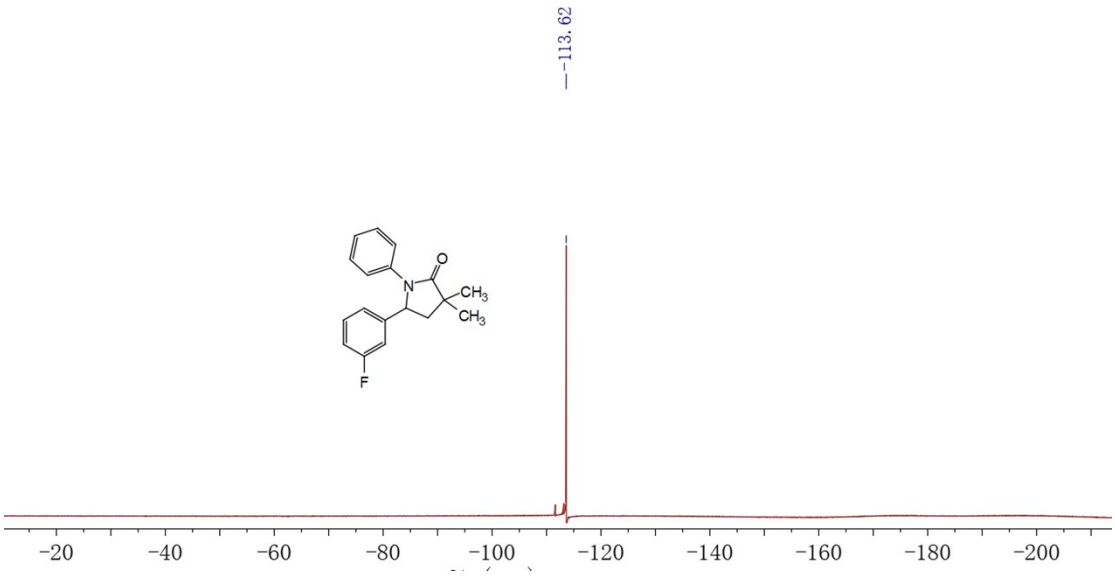
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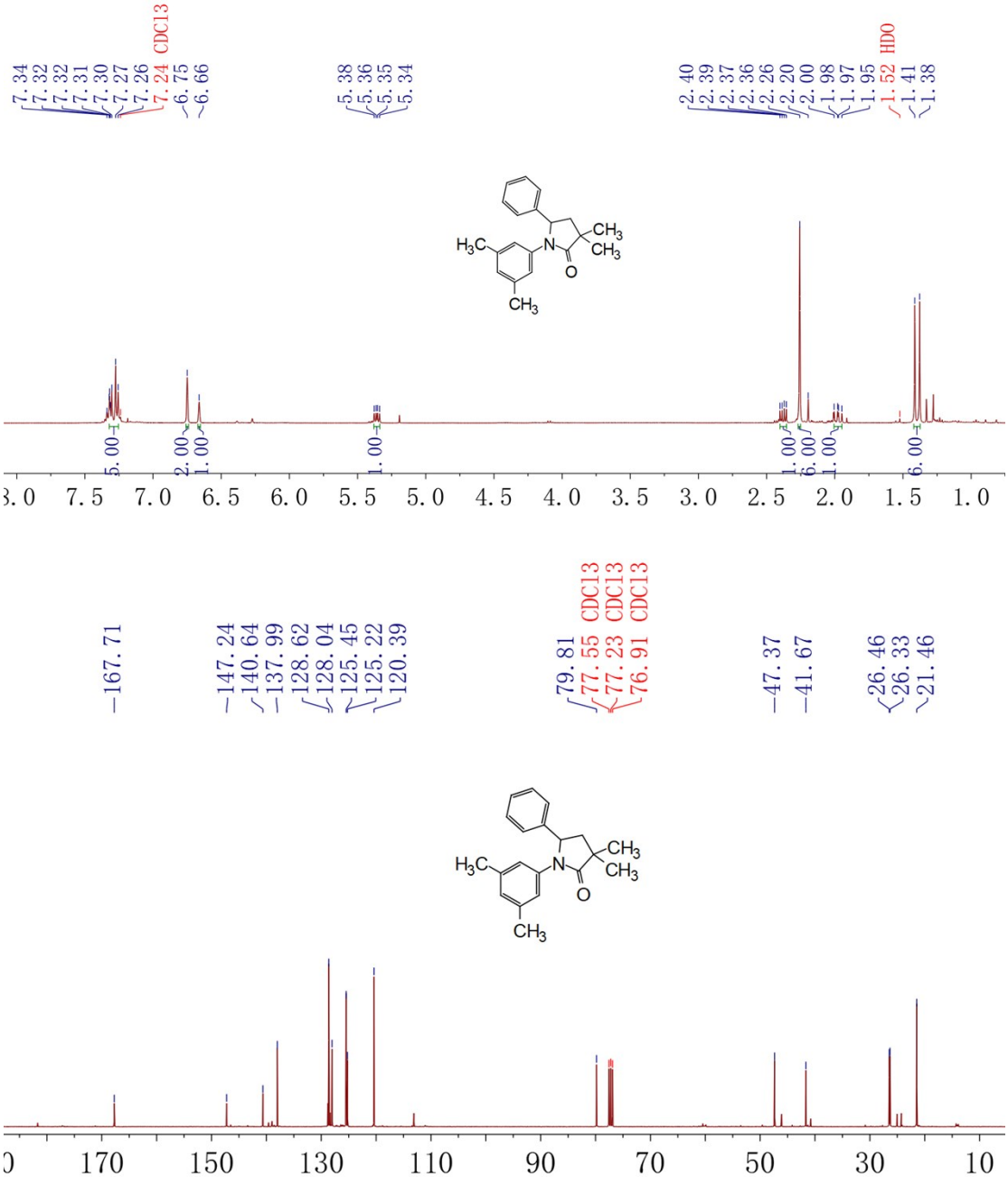
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1.00
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CH3
CH3
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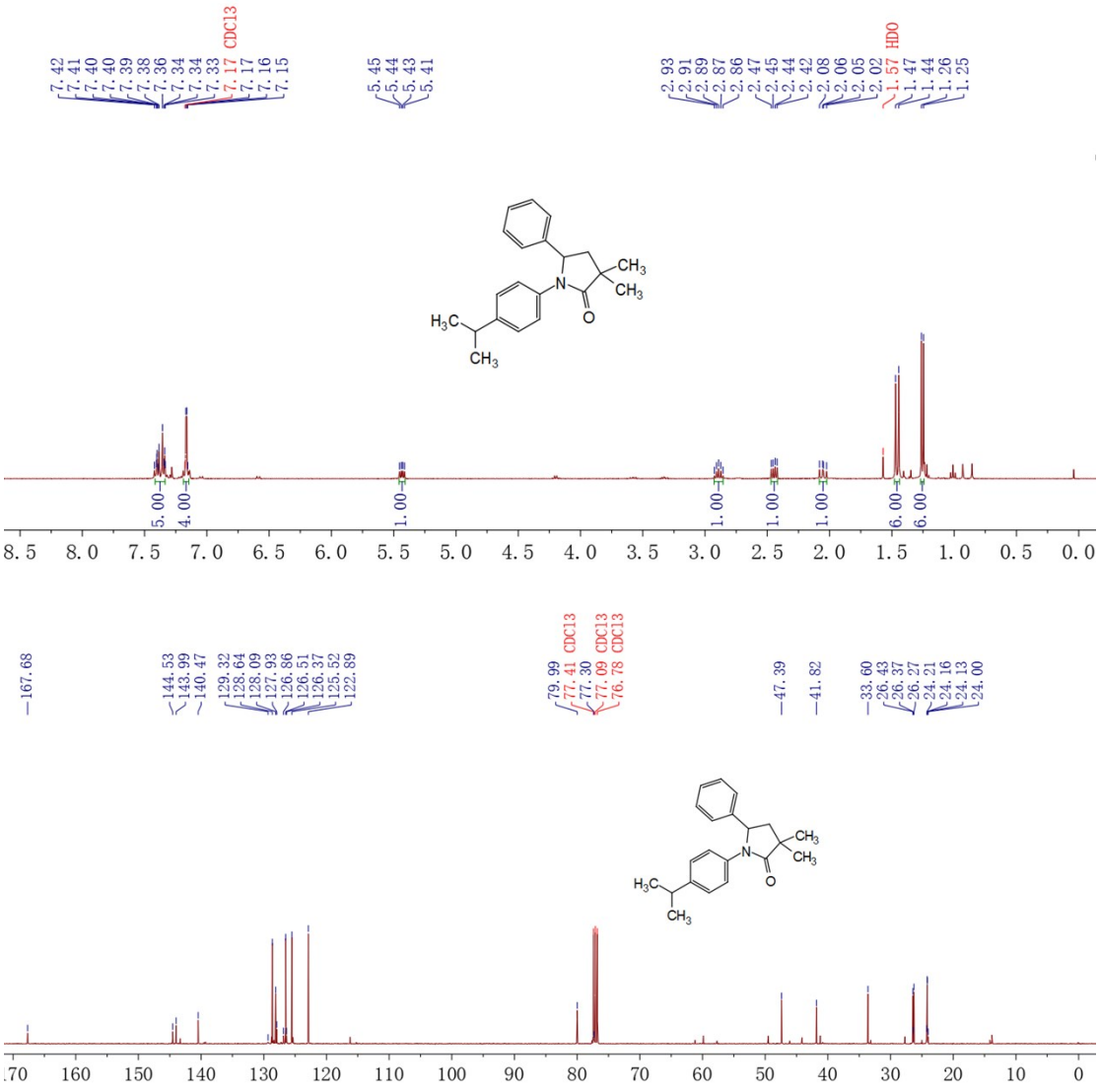
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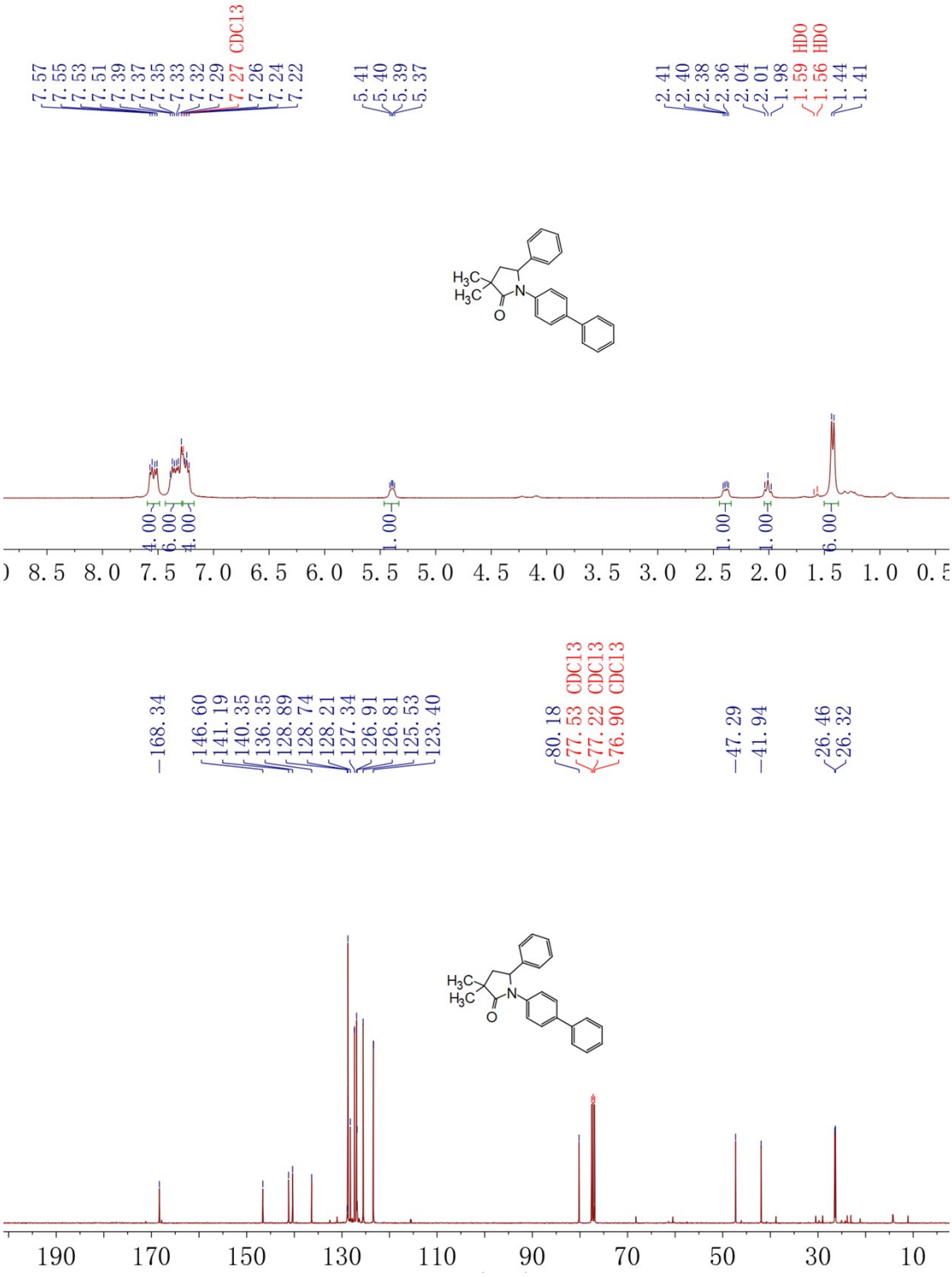
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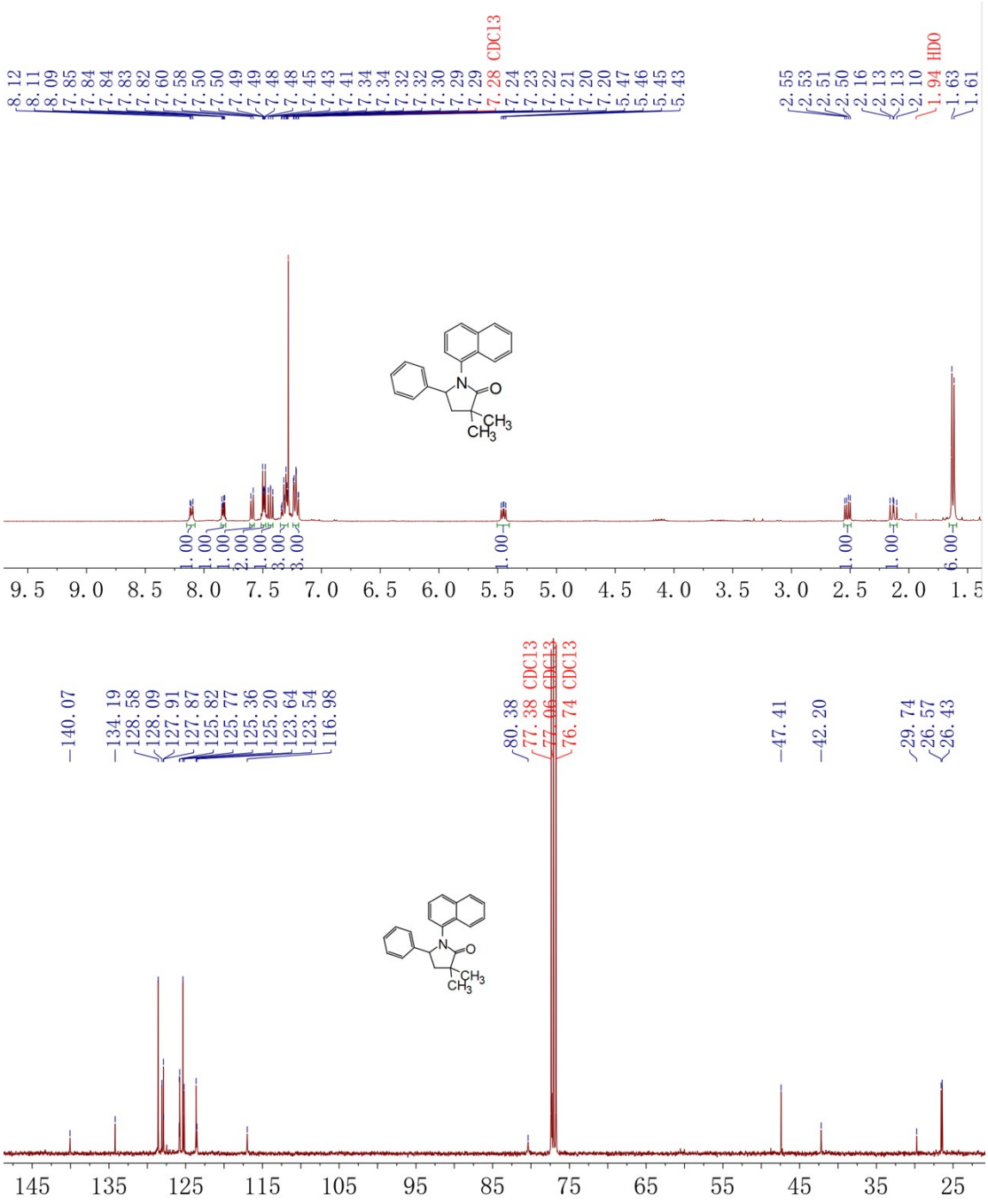
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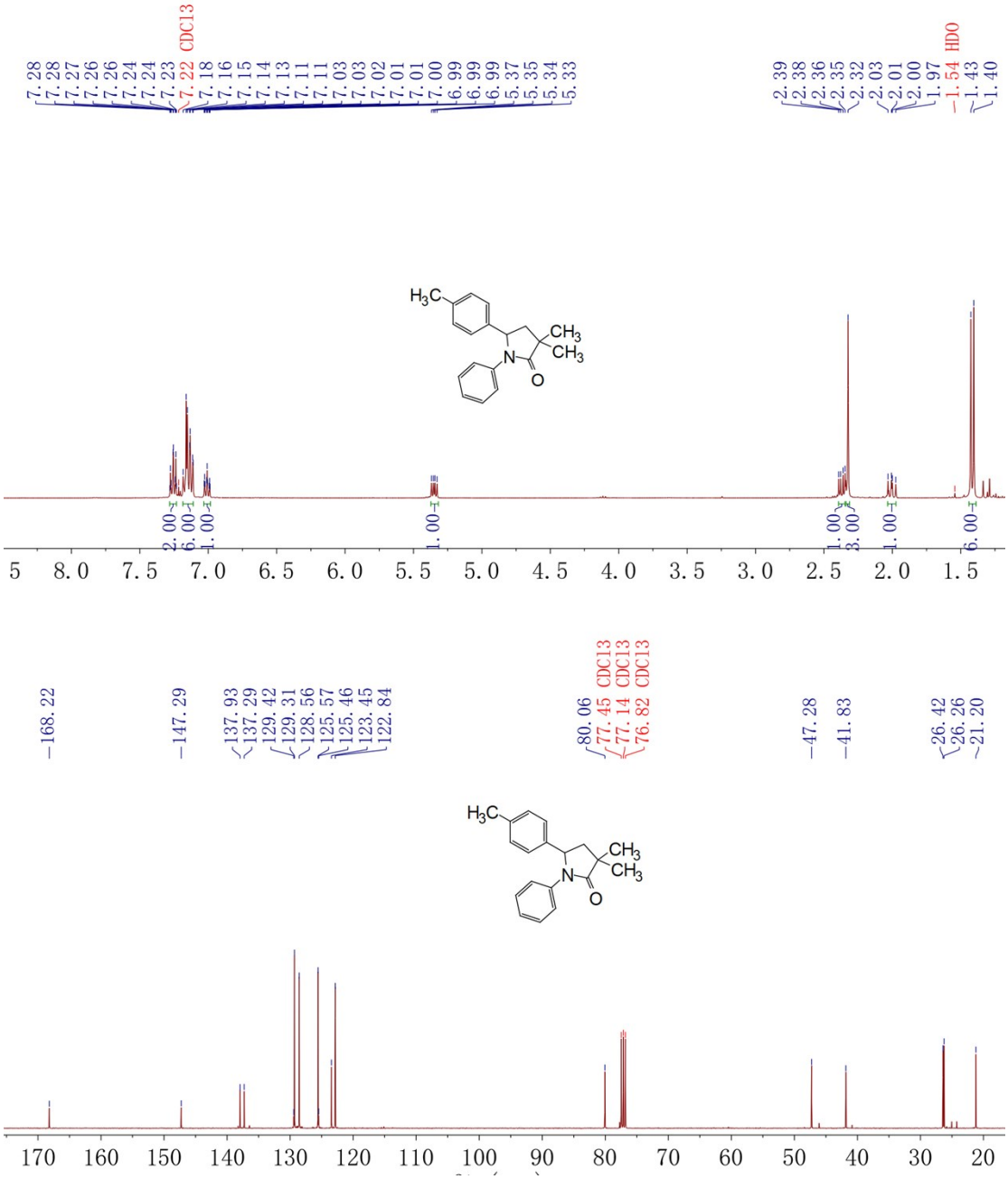
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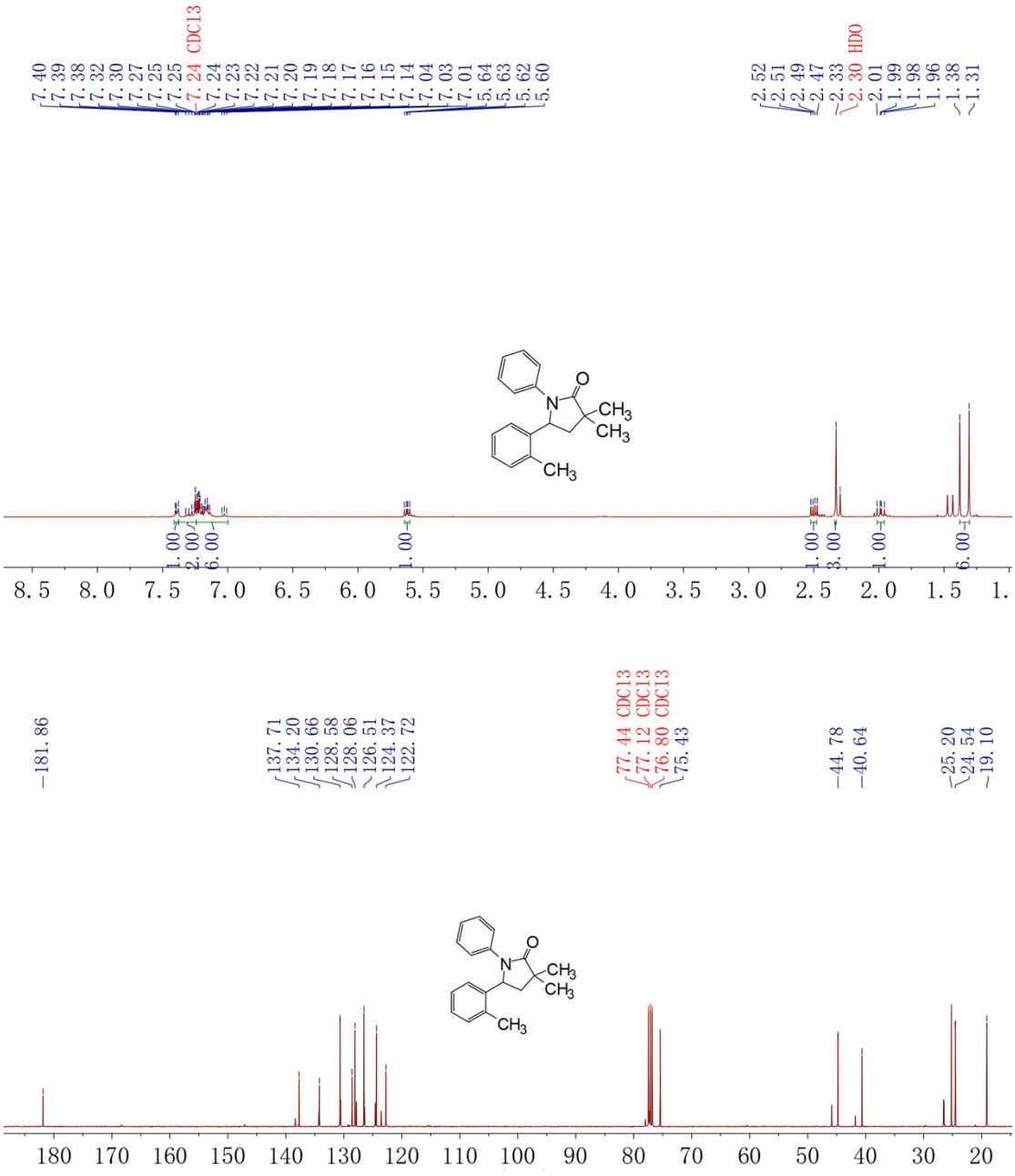
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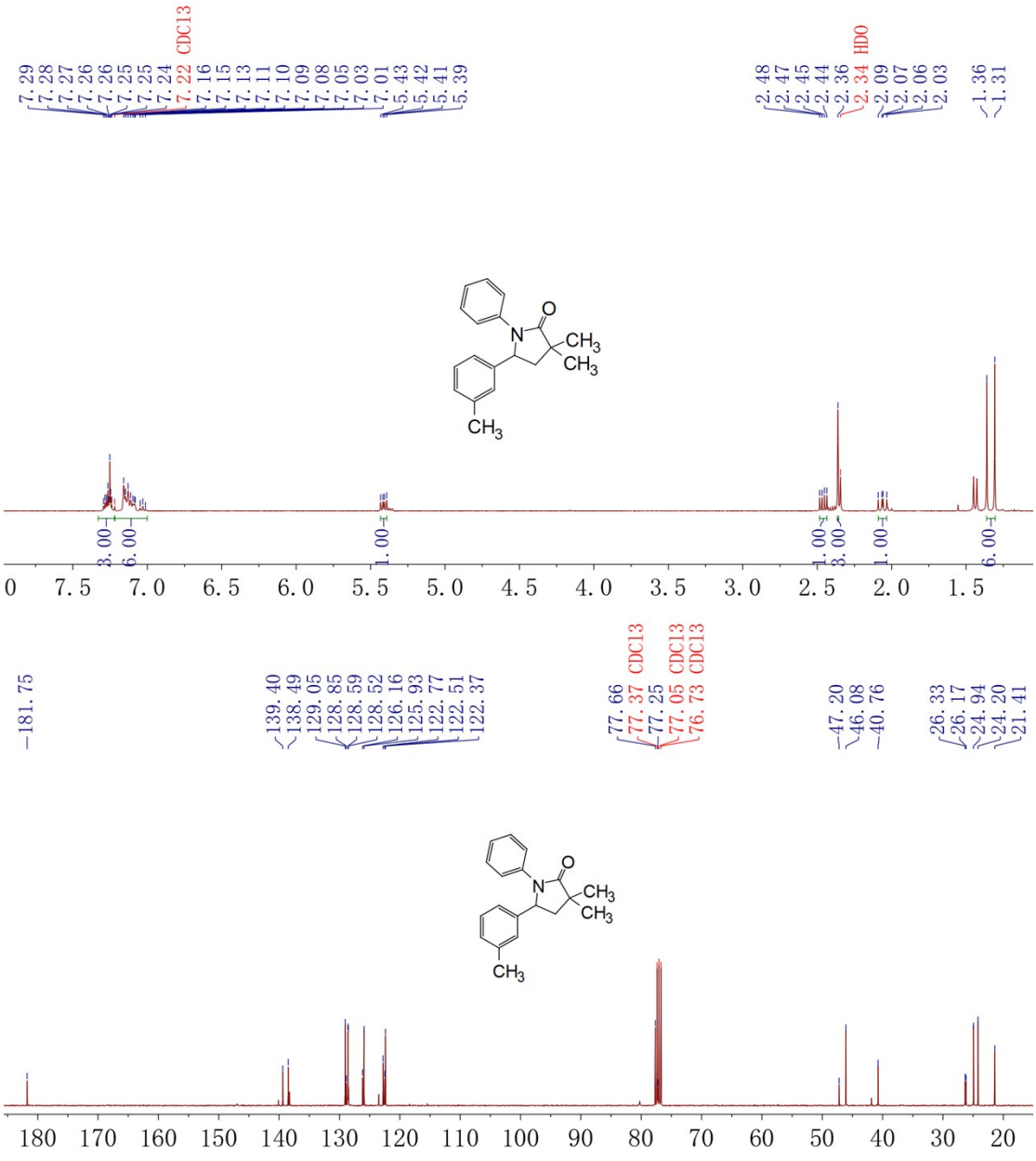
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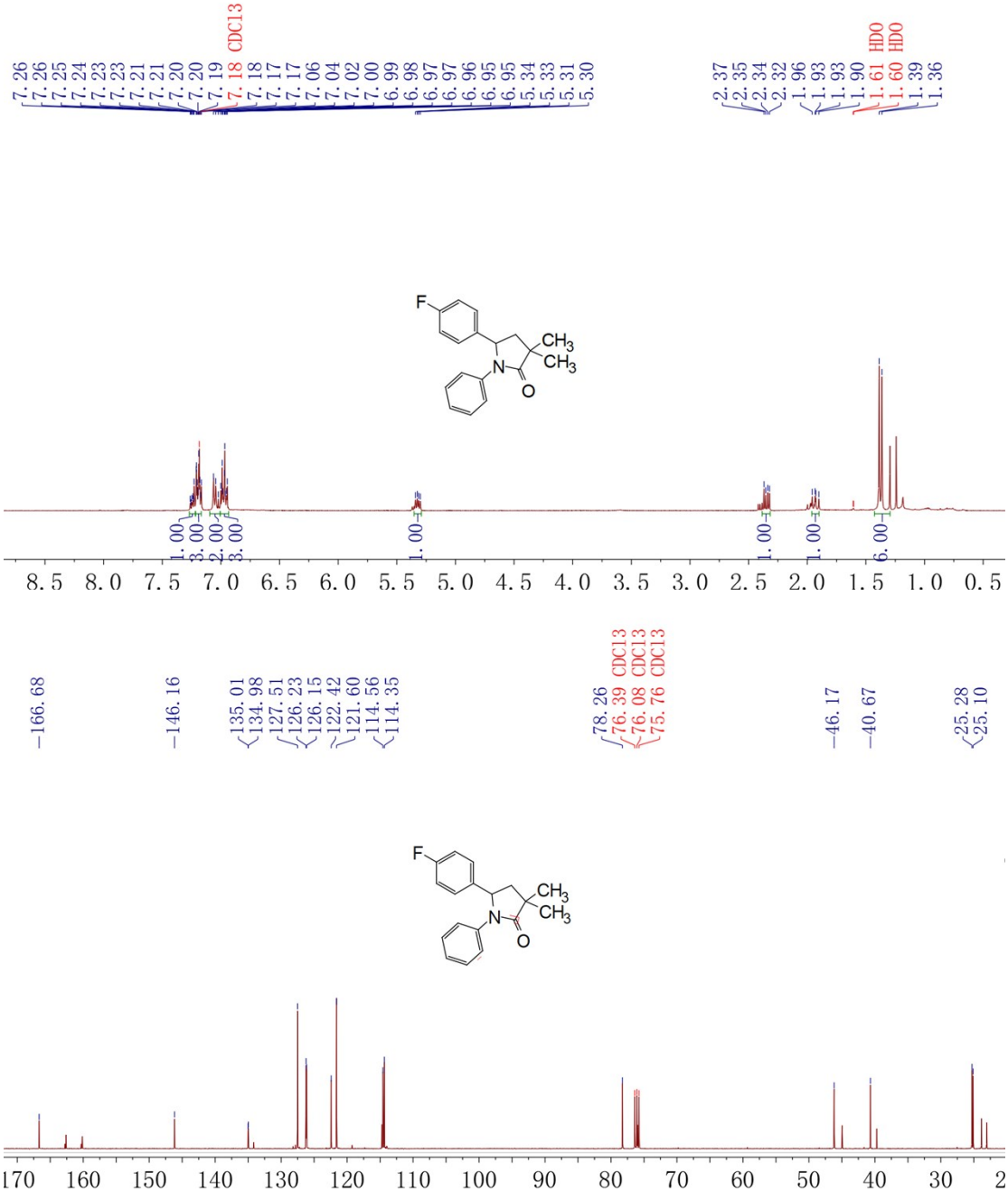
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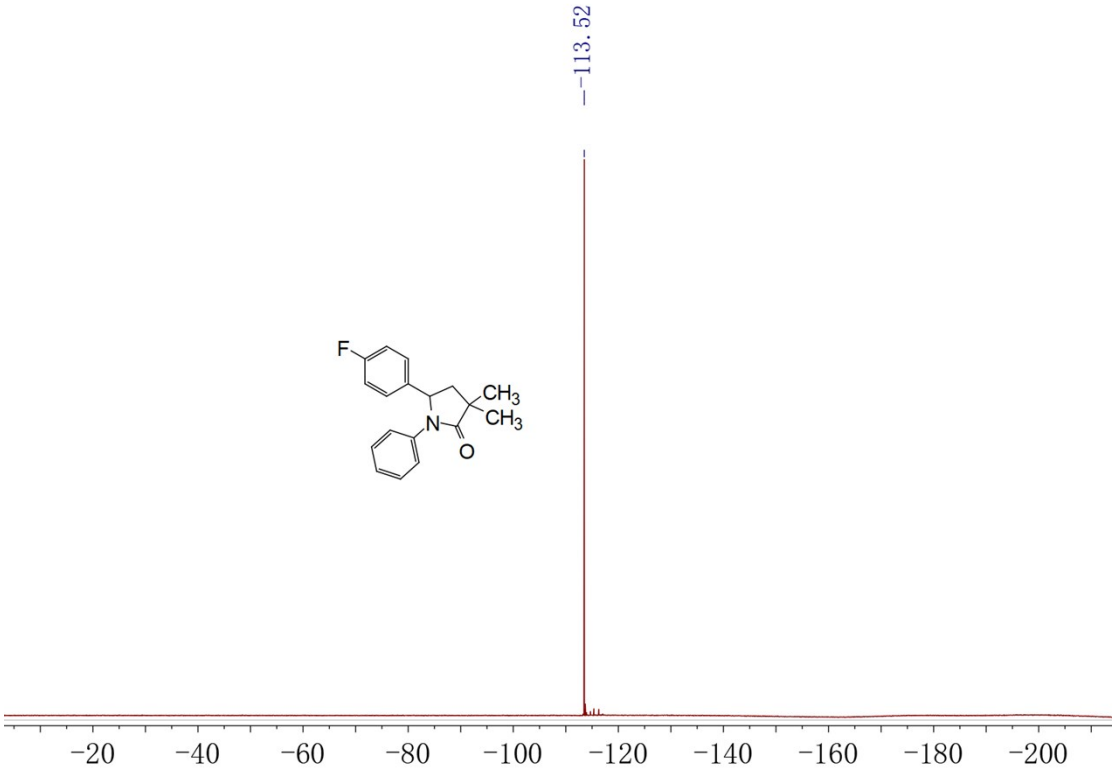
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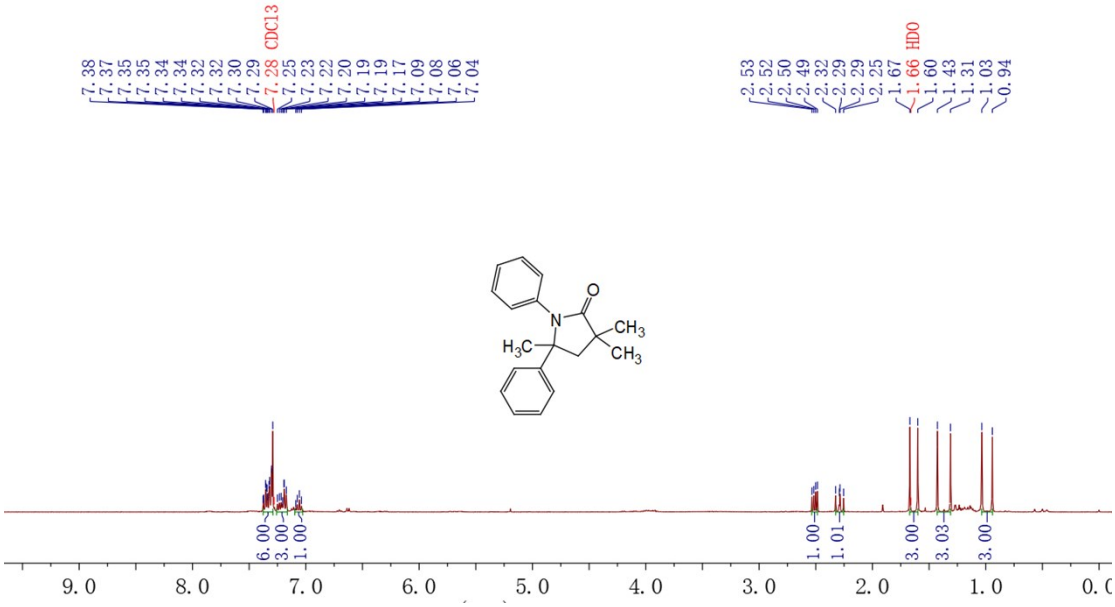
4faa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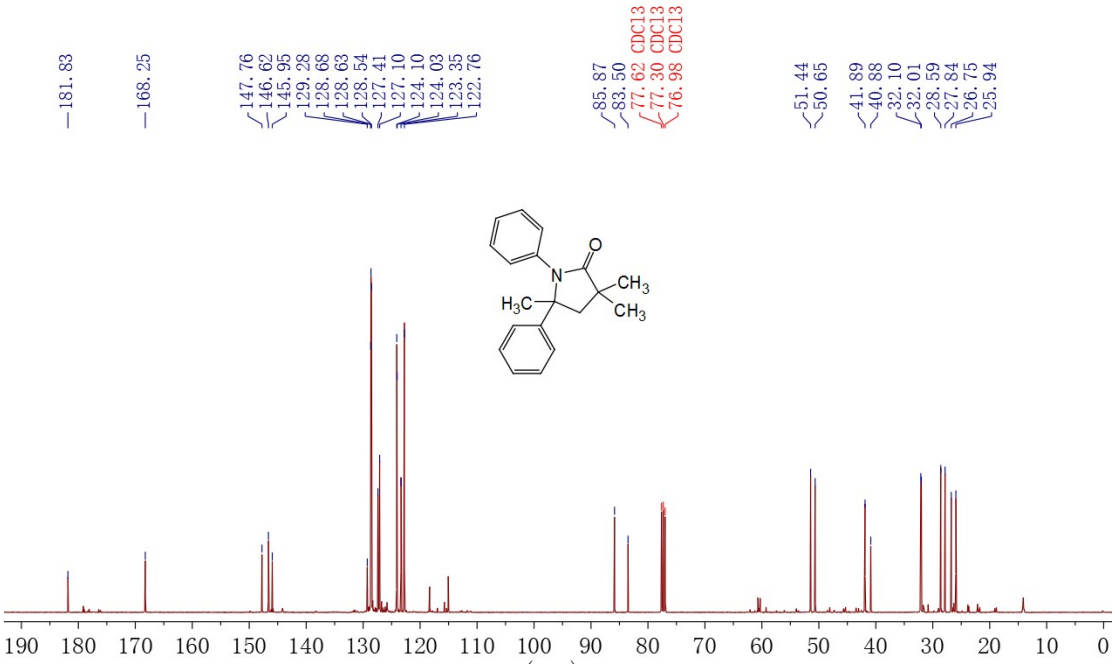
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83.50
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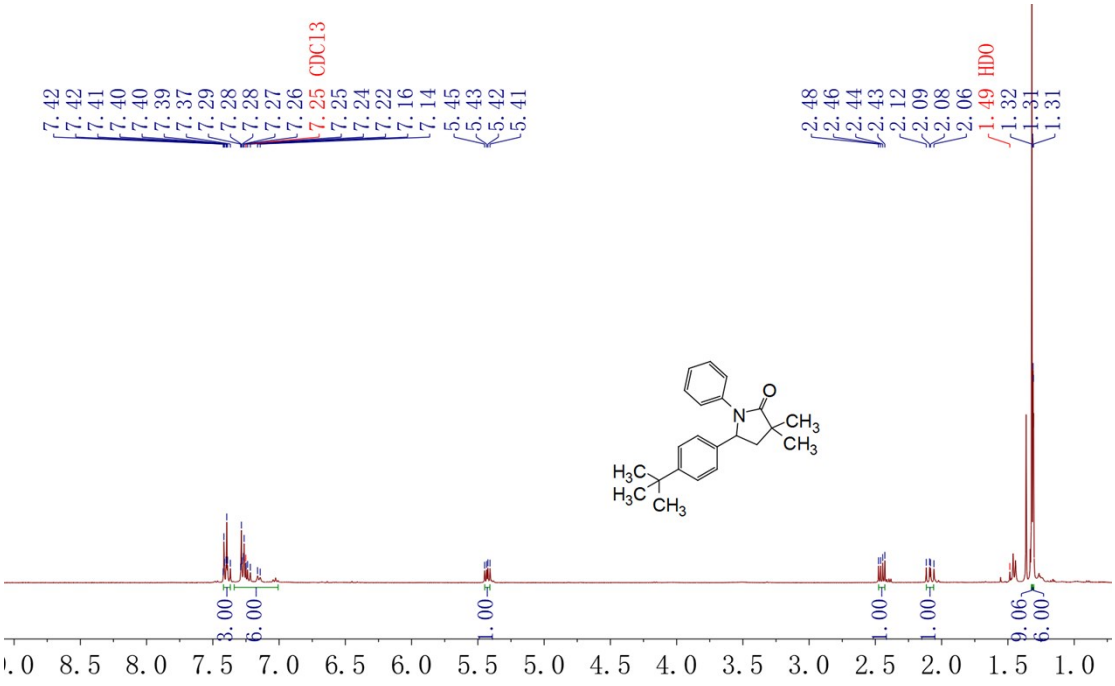
4gaa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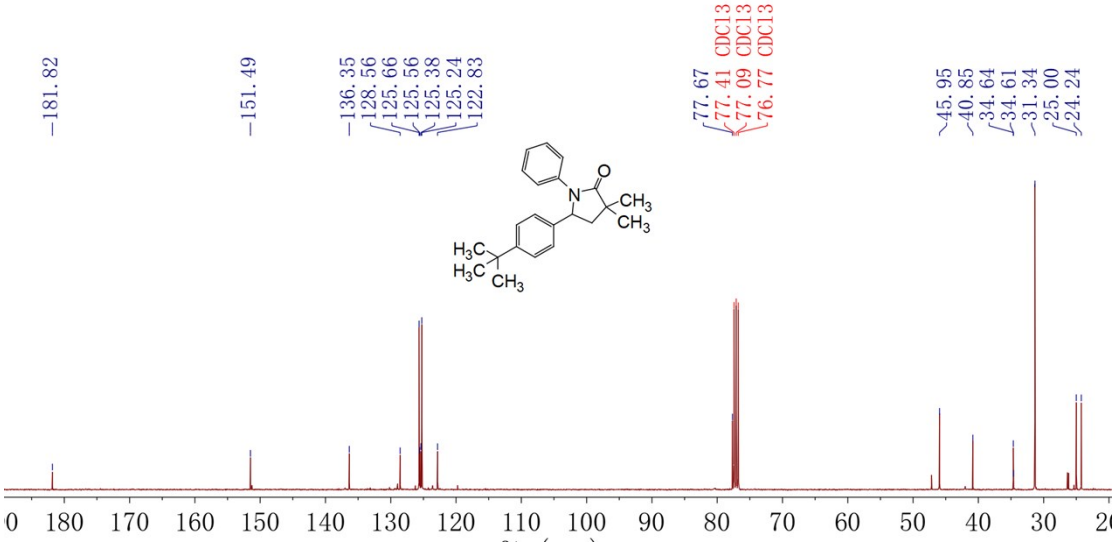
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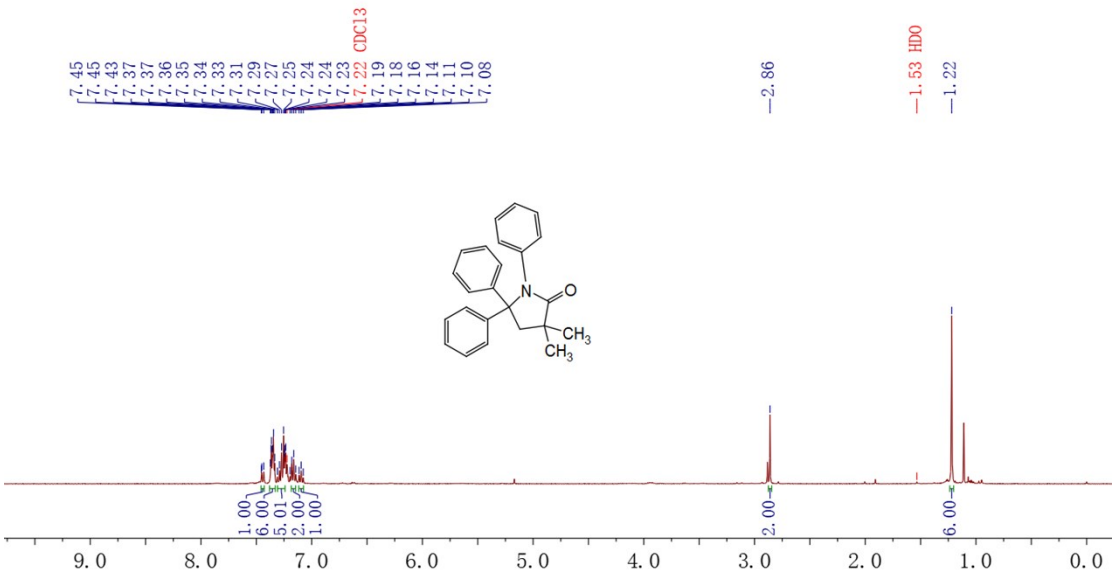
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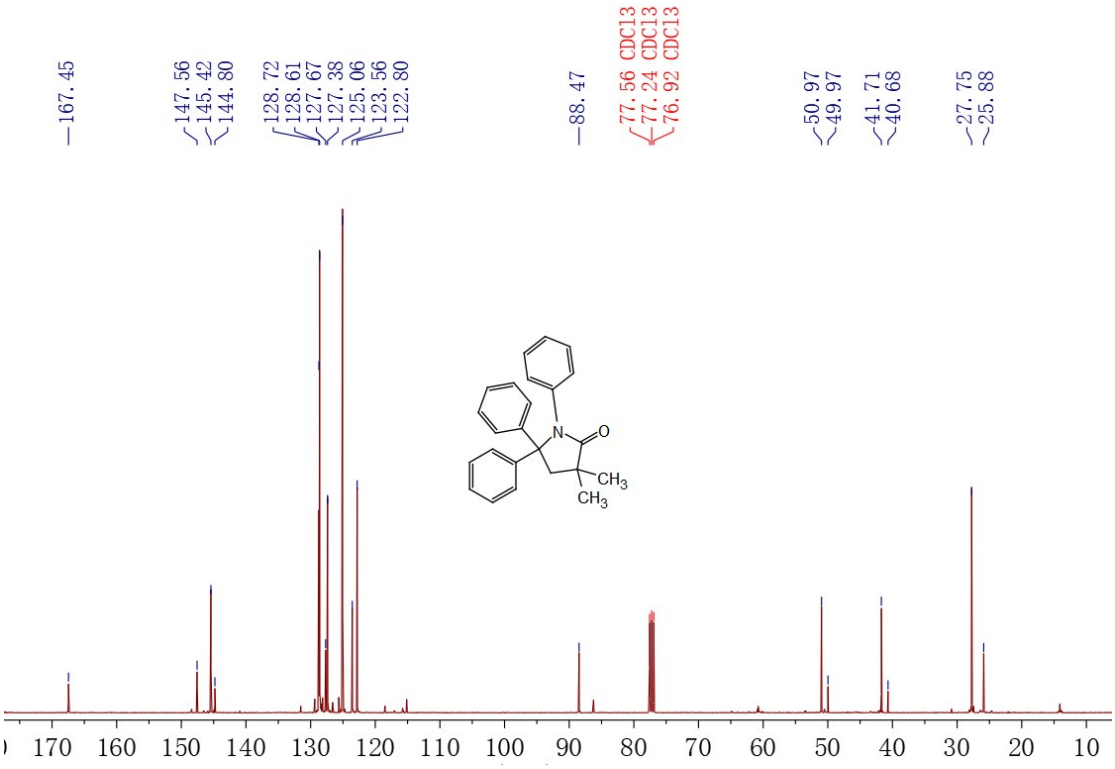
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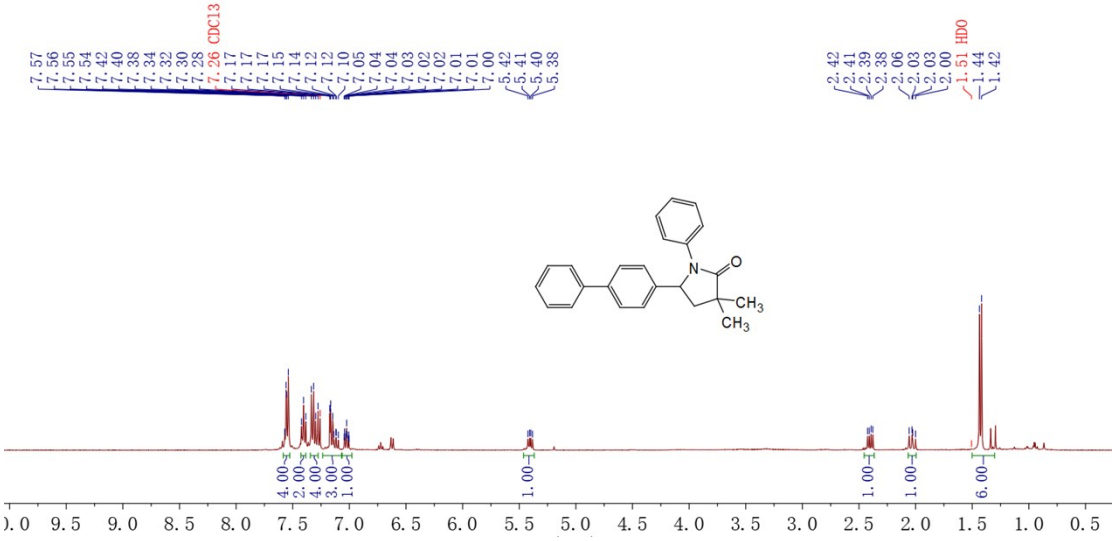
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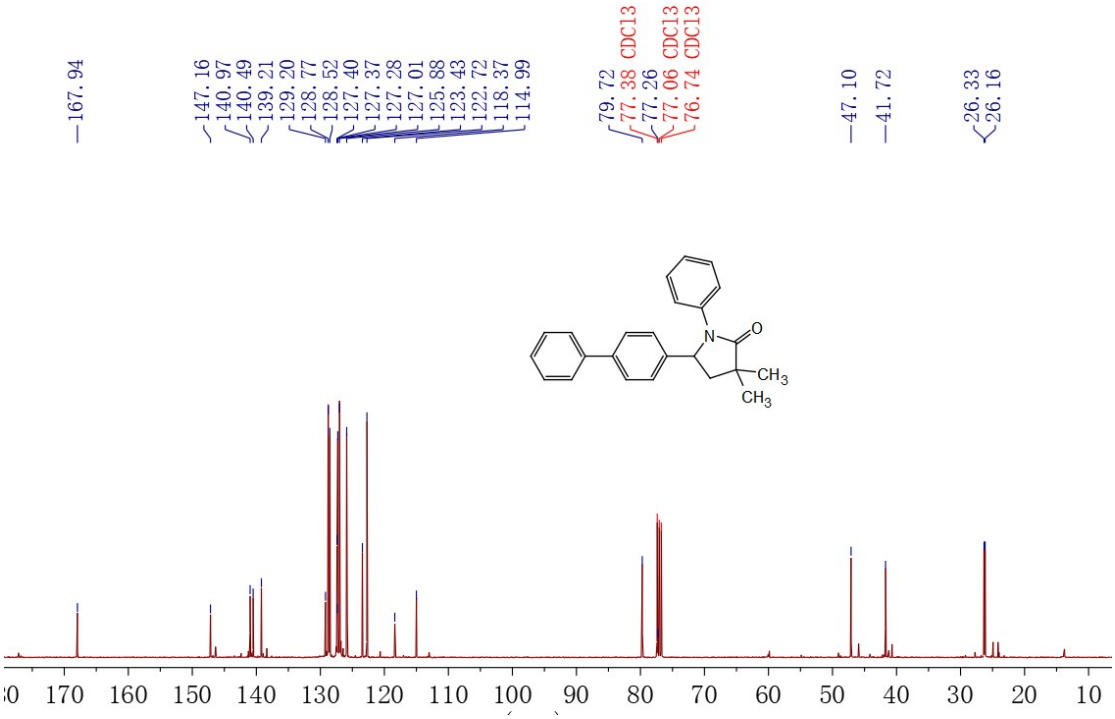
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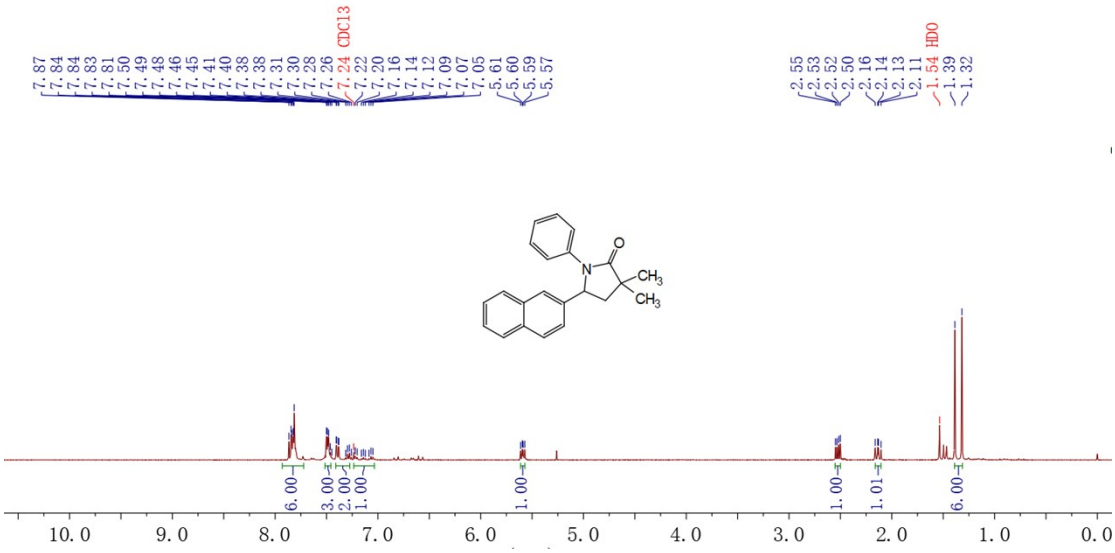
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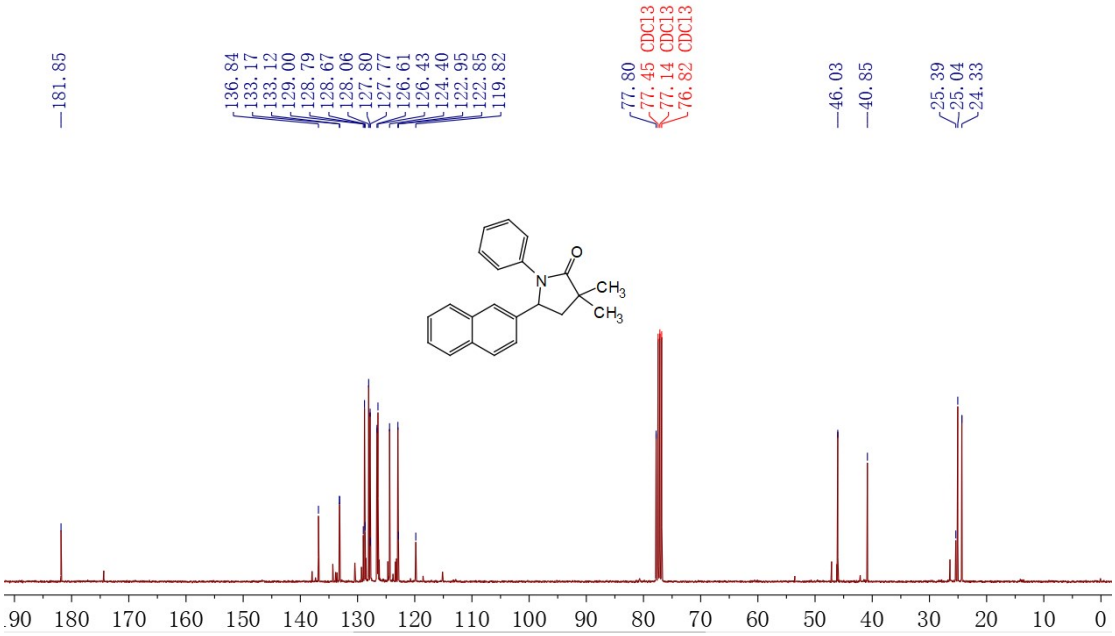
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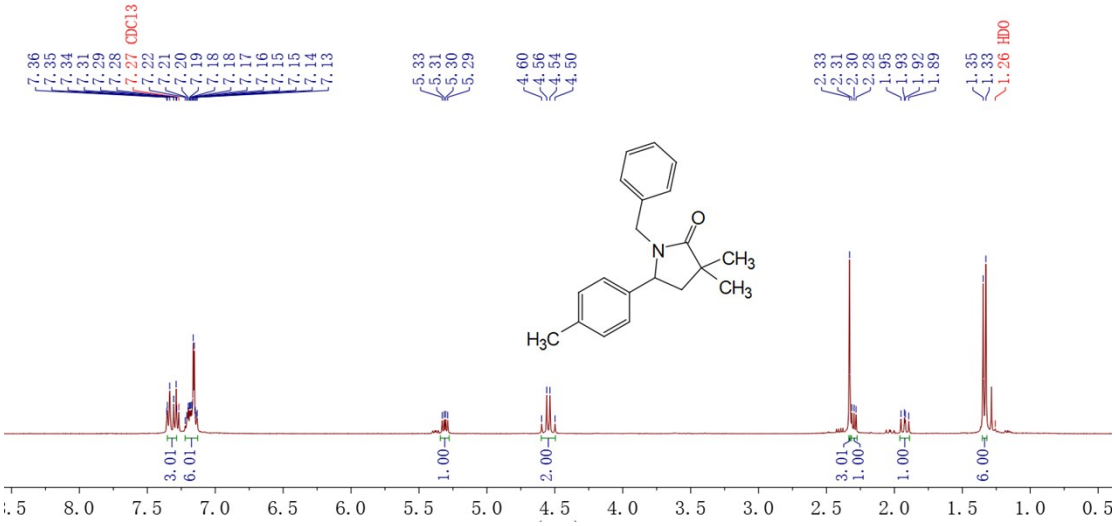
4bab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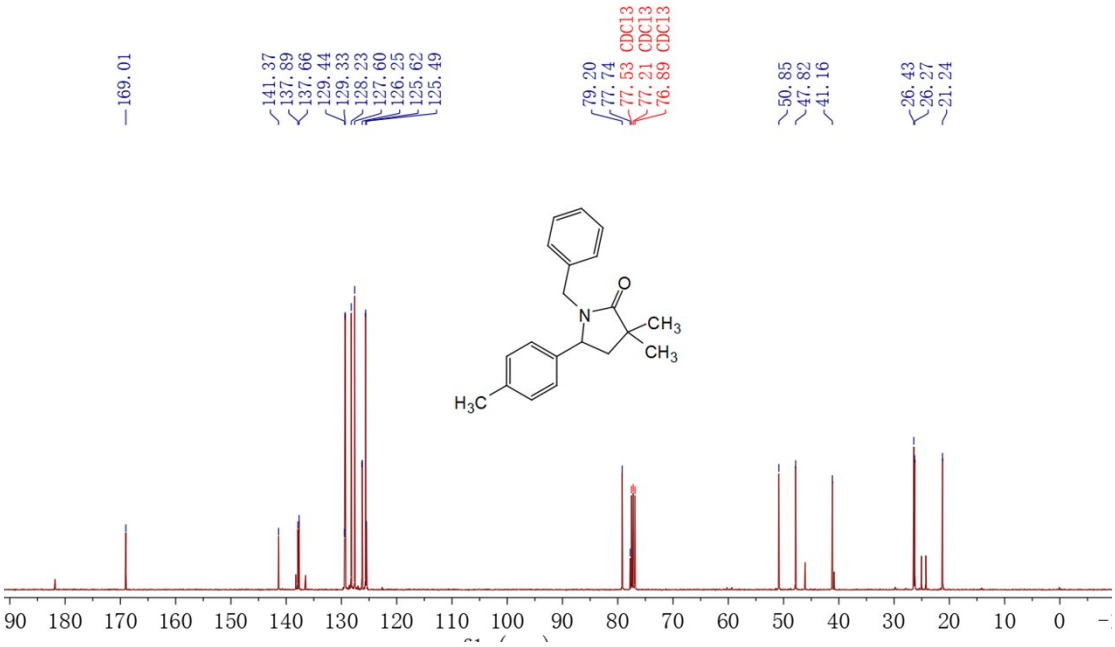
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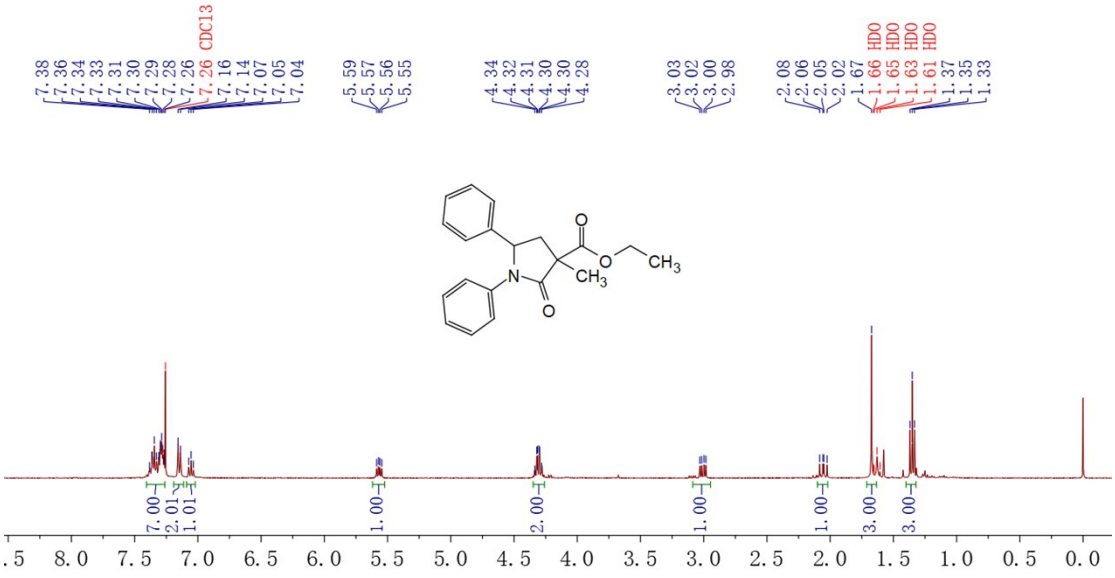
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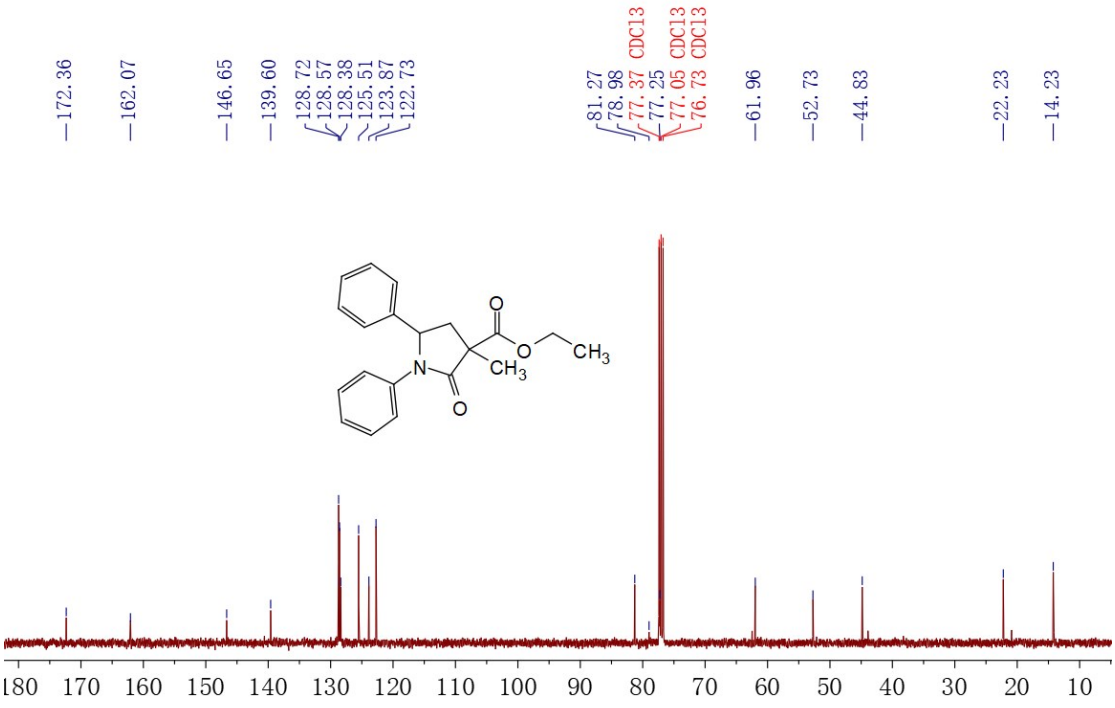
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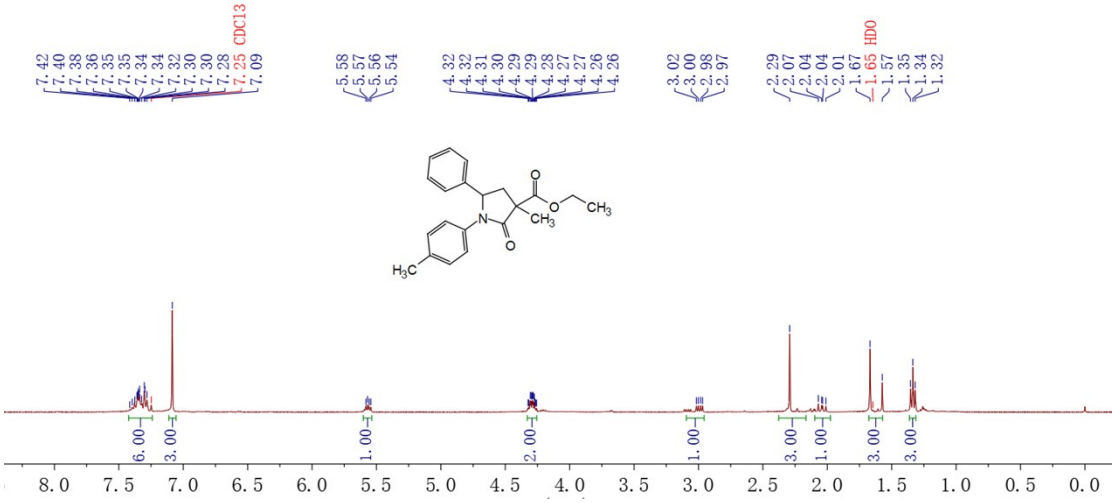
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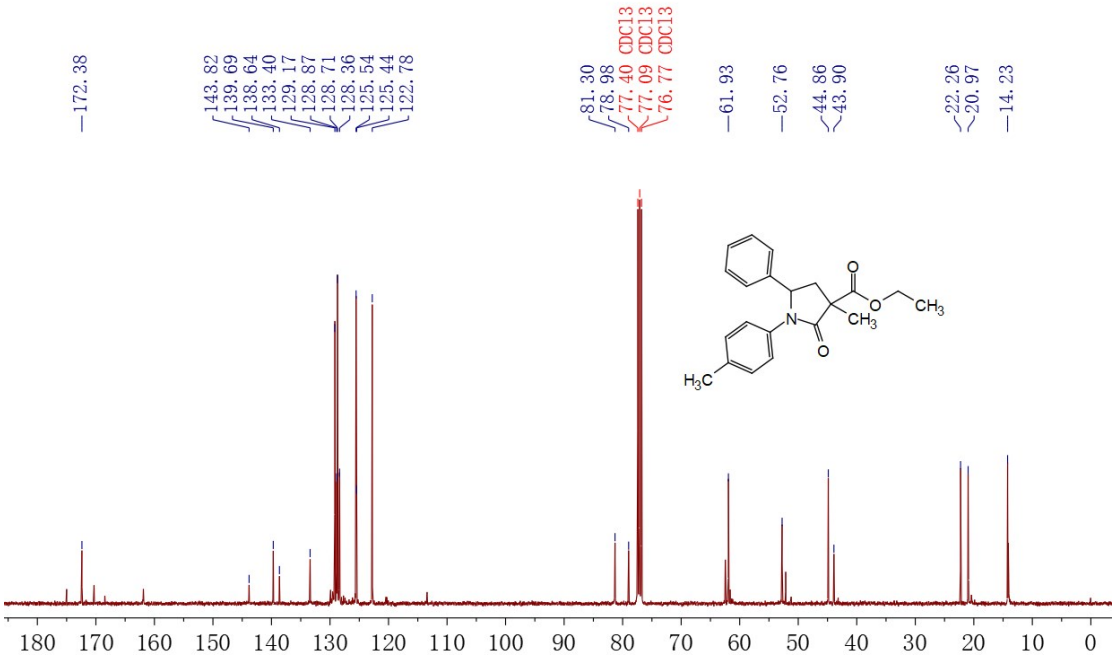
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