Supporting Information

A highly efficient Pd-catalyzed decarboxylative *ortho*-arylation of amides with aryl acylperoxides

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Table of Contents for Supporting Information

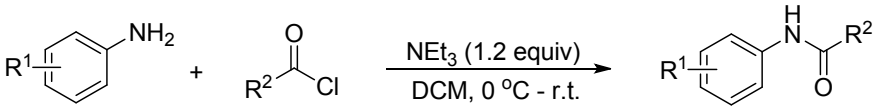
1. General information

All the solvents and commercially available reagents were purchased from commercial suppliers. Solvents (CH_3CN, DMF, DCE, DME, DMSO, 1,4-dioxane or toluene) were dried. Molecular sieves were activated before use. ^{1}H NMR and ^{13}C NMR spectra were recorded on a 400 MHz Bruker FT-NMR spectrometers (400 MHz or 100 MHz, respectively). All chemical shifts are given as δ value (ppm) with reference to tetramethylsilane (TMS) as an internal standard. The peak patterns are indicated as follows: s, singlet; d, doublet; t, triplet; m, multiplet; q, quartet. The coupling constants, *J*, are reported in Hertz (Hz). The infrared spectra were obtained using a Thermo Nicolet 6700 Spectrometer. High Resolution Mass (MS) analysis was obtained using Agilent Technologies 6540 UHD Accurate-Mass Q-TOF LC/MS system with Electrospray Ionization (ESI). Melting points were measured on a Mel-Temp apparatus and are uncorrected.

2. Preparation of the starting materials

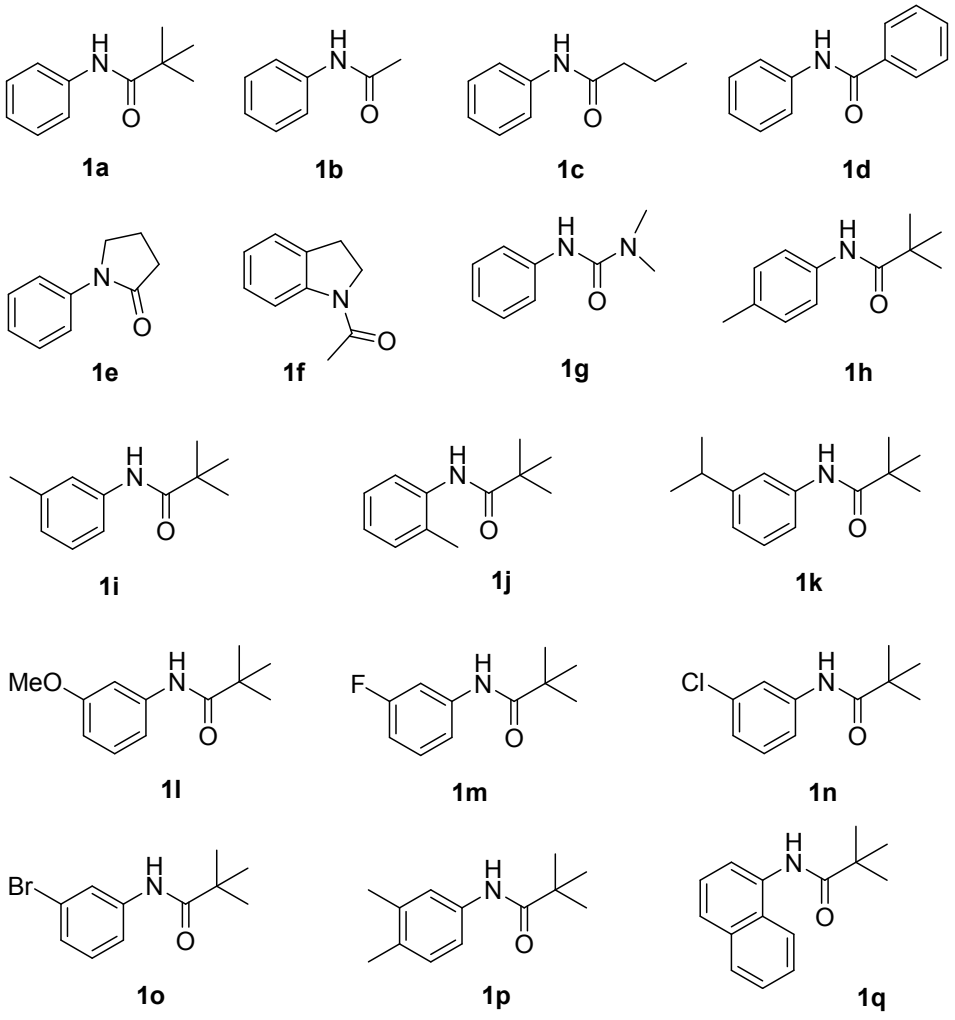
Anilides **1b** and **1e** were purchased from Alfa Aesar. Benzoyl peroxide (**2a**) was purchased from Aldrich. Other starting materials used in the reaction, including **1a**, **1c**, **1d**, **1f**–**1q**, **2b**–**2j**, and **5a**–**5k** were prepared according to the reported literatureres.[1-4]

2.1 General procedure for the preparation of 1a, **1c**, **1d**, **1f**, and **1h–1q**[1]

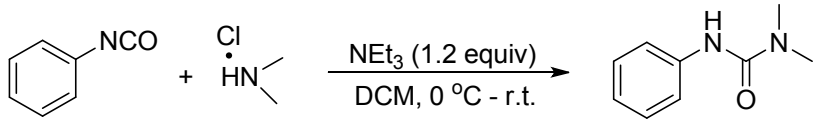


1a, 1c, 1d, 1f
1h– 1q

A round-bottom flask was charged with acyl chloride (10 mmol) in dichloromethane (DCM, 10 mL), and the solution was cooled to 0 °C in an ice-bath. Then triethylamine (12 mmol) and aniline (10 mmol) were added slowly. The mixture was stirred for 12 h at room temperature (monitored by TLC). After the reaction was completed, it was quenched with a solution of HCl (aq. 1.0 mol/L). The resulting mixture was then extracted with DCM. The combined organic layers were dried by Na_2SO_4 and evaporated in vacuum to afford the crude product, which was further purified by recrystallizing from DCM/hexane to give the desired product.



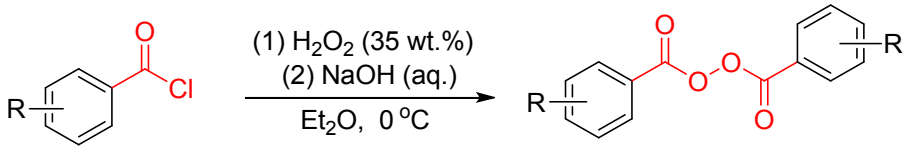
2.2 General procedure for the preparation of 1g[2]



1g

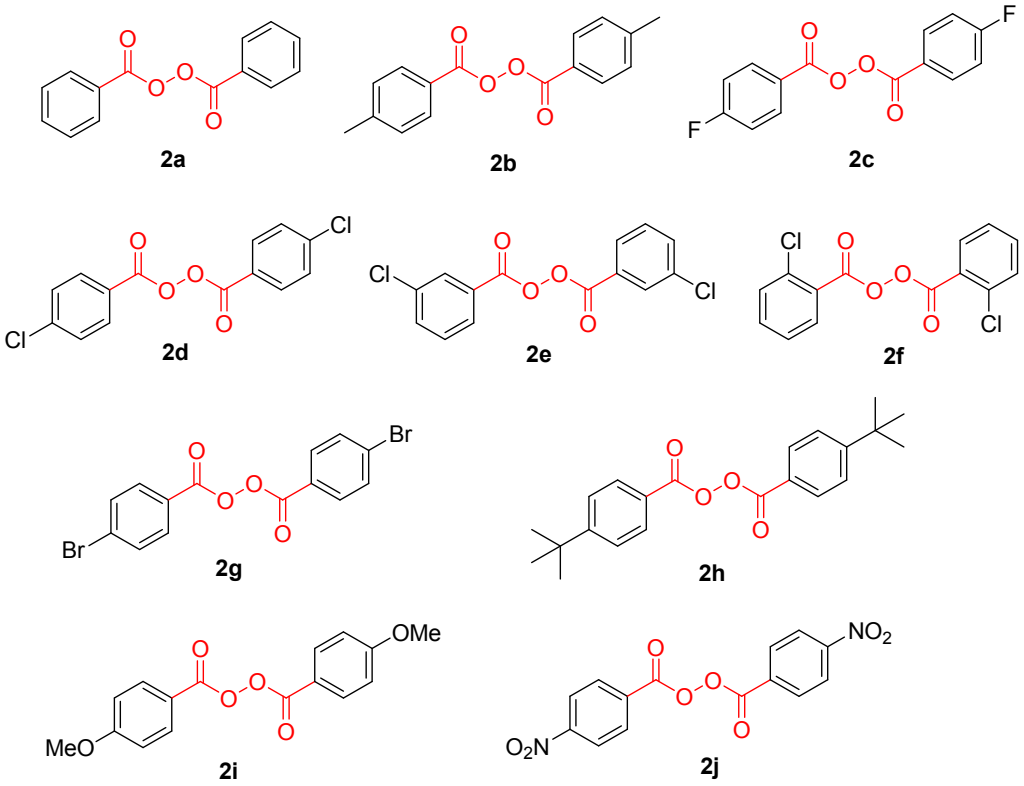
In a round-bottom flask charged with a solution of dimethylamine hydrochloride (12 mmol) in dry dichloromethane (DCM, 20 mL) at 0 ºC, triethylamine (12 mmol) was added and then the solution was stirred for 10 minutes. To this solution, phenyl isocyanate (10 mmol) was added and the mixture was allowed to stir at room temperature for 16 h (monitored by TLC). After the reaction was completed, the solution was washed with HCl (aq. 2.0 mol/L, 3×10 mL) and extracted with DCM (30 mL), dried over Na_2SO_4, filtered and evaporated in vacuum to afford the crude product. The resulting white solid was recrystallised from toluene to yield pure urea **1g**.

2.3 General procedure for the preparation of aryl acylperoxides 2b−2j[3]

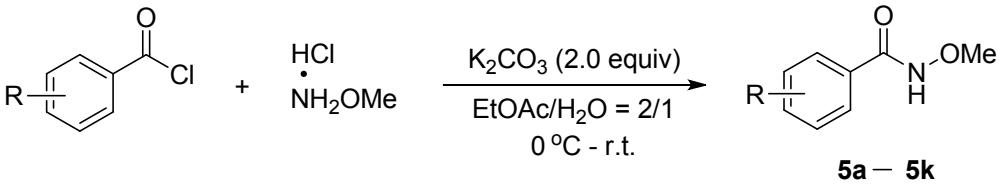


2b − 2j

In a round-bottomed flask, the solution of acid chloride (10 mmol) in diethyl ether (5 mL) was cooled to 0 °C in an ice-bath. Then, hydrogen peroxide (0.556 g, 35 wt.% in H_2O, 5.73 mmol) was added dropwise over 10 minutes to the cold solution. This was followed by the dropwise addition of an aqueous solution of NaOH (0.506g, 12.64 mmol, 4 mL) over 20 minutes. The resulting white precipitate was collected by filtration. After washing with water (3×5 mL) and diethyl ether (3×5 mL), the solid was crystallized from a cold acetone/water mixture (v/v = 1/3) to give the pure aryl acylperoxide.

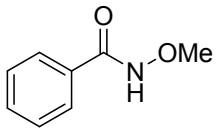


2.4 General procedure for the preparation of 5a–5k[4]

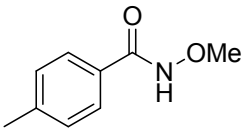


5a – 5k

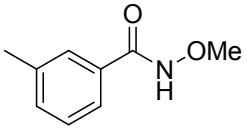
In a round-bottomed flask, *O*-methylhydroxylamine hydrochloride (10 mmol) and K_2CO_3 (20 mmol) were dissolved in water (15 mL) and EtOAc (30 mL). The solution was cooled to 0 °C in an ice-bath and then acyl chloride (10 mmol) was added. After the solution was stirred at room temperature overnight, the aqueous layer was separated and the organic layer was washed with water and brine. After it was dried by Na_2SO_4, evaporation of the solvent gave the crude product. Recrystallization of crude product from petroleum ether/ethyl acetate gave the pure desired product.



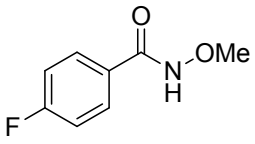
5a



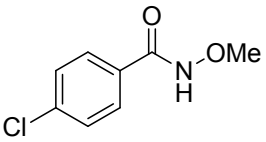
5b



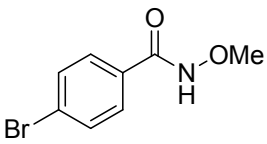
5c



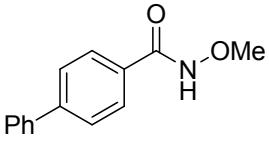
5d



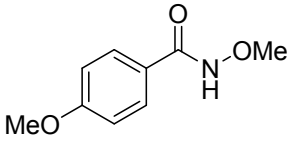
5e



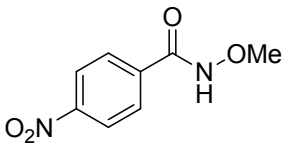
5f



5g



5h



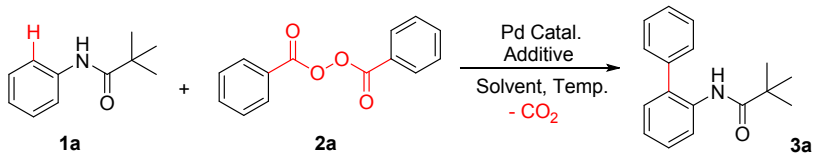
5k

3. General procedure for the reactions

3.1 Optimization of the reaction conditions in decarboxylative *ortho*-arylation of anilides with aryl acylperoxides

Under air atmosphere, a 25 mL sealable reaction tube with a Teflon-coated screw cap equipped with a magnetic stir bar was charged with *N*-phenylpivalamide (**1a**, 0.25 mmol), benzoyl peroxide (**2a**, 0.40 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), additive (0.50 mmol, 2.0 equiv), activated 3Å molecular sieves (70 mg) and solvent (2.0 mL). Then the reaction vessel was placed in an oil bath at 80 ^oC for 32 h (monitored by TLC). After the reaction was completed, it was cooled to room temperature and quenched with K_2CO_3 (aq.), then extracted with ethyl acetate and dried with Na_2SO_4. The resulting solution was directly filtered through a pad of silica gel using a sintered glass funnel, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluant: petroleum ether/ethyl acetate = 15/1) to give the desired product (**3a**).

Table S1 Optimization of the decarboxylative *ortho*-arylation of *N*-phenylpivalamide (**1a**) with benzoyl peroxide (**2a**)[a]

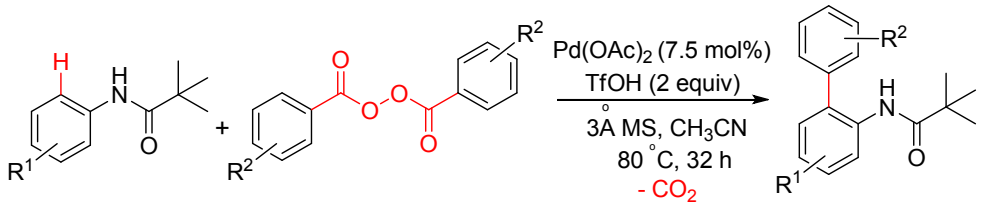


1a **2a** **3a**

Entry	Catalyst	Additive	Solvent	Temp. (°C)	Yield (%)[b]
1	$Pd(OAc)_2$	TfOH/−	CH_3CN	80	53
2	*$Pd(OAc)_2$*	*TfOH/3Å MS*	*CH_3CN*	*80*	*77*
3	$Pd(OAc)_2$	TfOH/4Å MS	CH_3CN	80	61
4	$Pd(OAc)_2$	−/3Å MS	CH_3CN	80	N.R.
5	$Pd(OAc)_2$	K_2CO_3/3Å MS	CH_3CN	80	N.R.
6	$Pd(OAc)_2$	Na_2CO_3/3Å MS	CH_3CN	80	N.R.
7	$Pd(OAc)_2$	NEt_3/3Å MS	CH_3CN	80	N.R.
8	$Pd(OAc)_2$	TFA/3Å MS	CH_3CN	80	N.R.
9	$Pd(OAc)_2$	HOAc/3Å MS	CH_3CN	80	N.R.
10	$Pd(OAc)_2$	PivOH/3Å MS	CH_3CN	80	N.R.
11	$Pd(OAc)_2$	*p*-TsOH/3Å MS	CH_3CN	80	31
12	$Pd(OAc)_2$	CH_3SO_3H/3Å MS	CH_3CN	80	35
13	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	38[c]
14	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	57[d]
15	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	58[e]
16	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	60	18
17	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	100	65
18	–	TfOH	CH_3CN	80	N.R.
19	–	–	CH_3CN	80	N.R.
20	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	61[f]
21	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	78[g]
22	$Pd(TFA)_2$	TfOH/3Å MS	CH_3CN	80	51
23	$PdCl_2$	TfOH/3Å MS	CH_3CN	80	43
24	$Pd(PPh_3)_2Cl$	TfOH/3Å MS	CH_3CN	80	29
25	$Pd(PPh_3)_4$	TfOH/3Å MS	CH_3CN	80	38
26	$Pd(OAc)_2$	TfOH/3Å MS	toluene	80	<5
27	$Pd(OAc)_2$	TfOH/3Å MS	DCE	80	trace
28	$Pd(OAc)_2$	TfOH/3Å MS	1,4-dioxane	80	trace
29	$Pd(OAc)_2$	TfOH/3Å MS	DMF	80	N.R.
30	$Pd(OAc)_2$	TfOH/3Å MS	DMSO	80	N.R.
31	$Pd(OAc)_2$	TfOH/3Å MS	DME	80	10
32	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN/HOAc=1/1	80	13
33	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	50[h]
34	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	55[i]

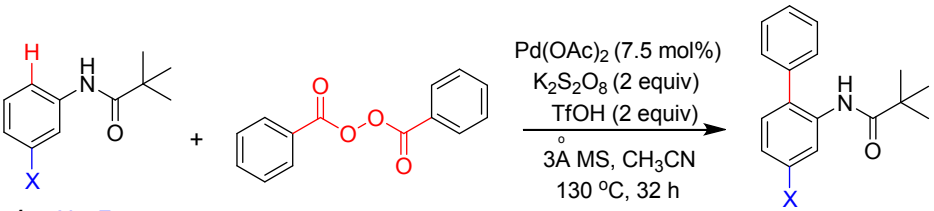
[a] Reaction conditions: **1a** (0.25 mmol), **2a** (1.6 equiv, 0.4 mmol), $Pd(OAc)_2$ (7.5 mol%), additive (2.0 equiv, 0.5 mmol), activated 3Å MS (70 mg), solvent (2.0 mL), air atmosphere, 80 °C, 32 h. [b] Isolated yields. [c] TfOH (1.0 equiv) was used. [d] TfOH (4.0 equiv) was used. [e] for 24 h. [f] $Pd(OAc)_2$ (5.0 mol%) was used. [g] $Pd(OAc)_2$ (10 mol%) was used. [h] **2a** (1.2 equiv) was used. [i] **2a** (2.0 equiv) was used.

3.2 General procedure for the decarboxylative *ortho*-arylation reactions of anilides with aryl acylperoxides



Under air atmosphere, a 25 mL sealable reaction tube with a Teflon-coated screw cap equipped with a magnetic stir bar was charged with anilide (0.25 mmol), aryl acylperoxide (0.40 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), TfOH (0.50 mmol, 2.0 equiv), activated 3Å molecular sieves (70 mg) and CH_3CN (2.0 mL). Then the reaction vessel was placed in an oil bath at 80 °C for 32 h (monitored by TLC). After the reaction was completed, it was cooled to room temperature and quenched with K_2CO_3 (aq.), then extracted with ethyl acetate and dried with Na_2SO_4. The resulting solution was directly filtered through a pad of silica gel using a sintered glass funnel, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluant: petroleum ether/ethyl acetate) to give the desired product.

3.3 General procedure for the decarboxylative *ortho*-arylation reactions of anilides 1m, 1n, 1o with benzoyl peroxide (2a)



Under air atmosphere, a 25 mL sealable reaction tube with a Teflon-coated screw cap equipped with a magnetic stir bar was charged with **1m**, **1n** or **1o** (0.25 mmol), benzoyl peroxide (**2a**, 0.40 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), $K_2S_2O_8$ (2.0

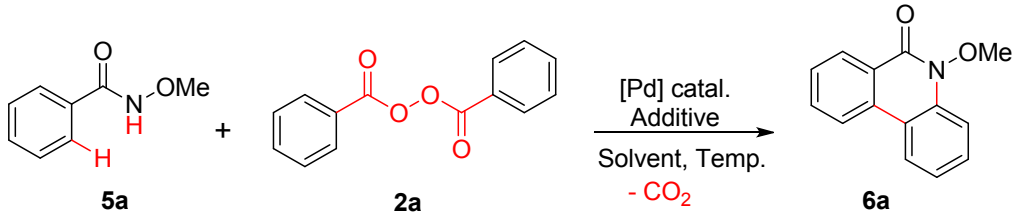
equiv) was added as co-oxidant, TfOH (2.0 equiv), activated 3Å molecular sieves (70 mg) and CH_3CN (2.0 mL), at 130 °C for 32 h (monitored by TLC). After the reaction was completed, it was cooled to room temperature and quenched with K_2CO_3 (aq.), then extracted with ethyl acetate and dried with Na_2SO_4. The resulting solution was directly filtered through a pad of silica gel using a sintered glass funnel, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluant: petroleum ether/ethyl acetate =15/1) to give the desired product (**3m**, **3n**, or **3o**).

3.4 Optimization of the decarboxylative arylation and cyclization of *N*-methoxybenzamide with benzoyl peroxide for the synthesis of phenanthridinone

Under air atmosphere, a 25 mL sealable reaction tube with a Teflon-coated screw cap equipped with a magnetic stir bar was charged with *N*-methoxybenzamide (**5a**, 0.25 mmol), benzoyl peroxide (**2a**, 0.40 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), additive (0.50 mmol, 2.0 equiv), activated 4Å molecular sieves (70 mg) and solvent (2.0 mL). Then the reaction vessel placed in an oil bath at 80 °C for 24 h (monitored by TLC). After the reaction was completed, it was cooled to room temperature and quenched with K_2CO_3 (aq.), then extracted with ethyl acetate and dried with Na_2SO_4. The resulting solution was directly filtered through a pad of silica gel using a sintered glass funnel, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluant: petroleum ether/ethyl acetate = 4/1) to give the desired product (**6a**).

Table S2 Optimization of the decarboxylative arylation and cyclization of

benzamides with benzoyl peroxide for the synthesis of phenanthridinone [a]

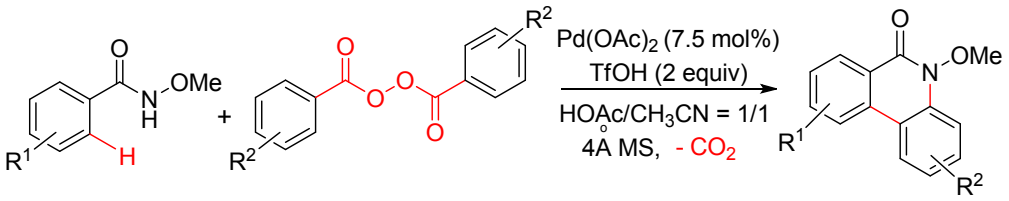


5a **2a** **6a**

Entry	Catalyst	Additive	Solvent	Temp. (°C)	Yield (%)[b]
1	$Pd(OAc)_2$	TfOH/3Å MS	CH_3CN	80	21[c]
2	$Pd(OAc)_2$	TfOH/3Å MS	HOAc/CH_3CN=1/1	80	47
3	*$Pd(OAc)_2$*	*TfOH/4Å MS*	*HOAc/CH_3CN=1/1*	*80*	*60*
4	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=2/1	80	41
5	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/2	80	52
6	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/3	80	44
7	$Pd(OAc)_2$	TfOH/−	HOAc/CH_3CN=1/1	80	25
8	$Pd(OAc)_2$	−/4Å MS	HOAc/CH_3CN=1/1	80	<10
9	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	47[d]
10	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	40[e]
11	$Pd(OAc)_2$	TFA/4Å MS	HOAc/CH_3CN=1/1	80	13
12	$Pd(OAc)_2$	PivOH/4Å MS	HOAc/CH_3CN=1/1	80	10
13	$Pd(OAc)_2$	*p*-TsOH/4ÅMS	HOAc/CH_3CN=1/1	80	15
14	–	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	N.R.
15	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	62[f]
16	$Pd(TFA)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	47
17	$PdCl_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	<10
18	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	50[g]
19	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	80	48[h]
20	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	60	36
21	$Pd(OAc)_2$	TfOH/4Å MS	HOAc/CH_3CN=1/1	100	41

[a] Reaction conditions: **5a** (0.25 mmol), **2a** (0.4 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), additive (2.0 equiv, 0.5 mmol), activated MS (70 mg), solvent (2.0 mL), air atmosphere, at 80 °C for 24 h. [b] Isolated yields. [c] 32h. [d] TfOH (1.0 equiv) was used. [e] TfOH (4.0 equiv) was used. [f] $Pd(OAc)_2$ (10 mol%) was used. [g] **2a** (1.2 equiv) was used. [h] **2a** (2.0 equiv) was used.

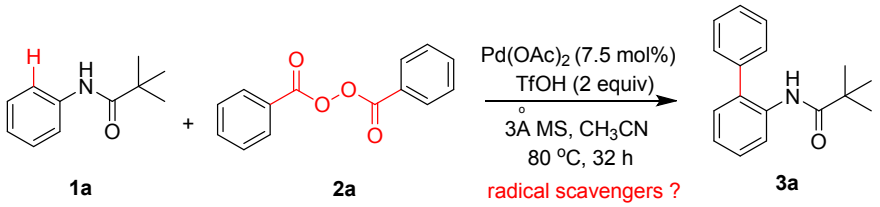
3.5 General procedure for the decarboxylative arylation and cyclization of *N*-methoxyarylamides with aryl acylperoxides to phenanthridinones



Under air atmosphere, a 25 mL sealable reaction tube with a Teflon-coated screw cap equipped with a magnetic stir bar was charged with *N*-methoxyarylamide (0.25 mmol), aryl acylperoxide (0.40 mmol, 1.6 equiv), $Pd(OAc)_2$ (7.5 mol%), TfOH (0.50 mmol, 2.0 equiv), activated 4Å molecular sieves (70 mg) and $HOAc/CH_3CN$ (V/V = 1/1, 2.0 mL). Then the reaction vessel was placed in an oil bath at 80 ^oC for 24 h (monitored by TLC). After the reaction was completed, it was cooled to room temperature and quenched with K_2CO_3 (aq.), then extracted with ethyl acetate and dried with Na_2SO_4. The resulting solution was directly filtered through a pad of silica gel using a sintered glass funnel, and concentrated under reduced pressure. The residue was purified by flash chromatography on silica gel (eluant: petroleum ether/ethyl acetate) to give the desired product phenanthridinone.

4. Mechanistic studies

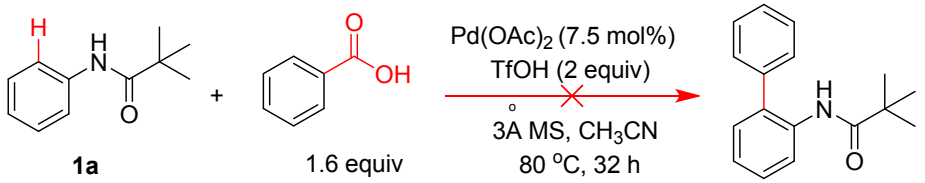
4.1 **Table S3** the effect of radical scavengers on the model reaction



1a + **2a** → **3a**

radical scavenger	amount (mol%)	yield of **3a** (%)	yield of **1a** (%)
no	0	77	12
TEMPO	50	17	74
	100	trace	90
ascorbic acid	50	18	75
	100	trace	94

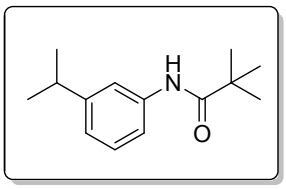
4.2 The control experiment



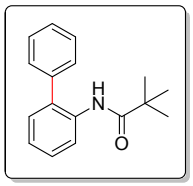
1a + 1.6 equiv

3a (not found !)

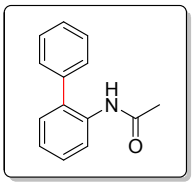
5. Characterization data for the products



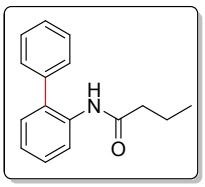
1k, *N*-(3-*iso*-Propylphenyl)pivalamide. White solid. mp 89 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 7.48 (s, 2H), 7.35–7.33 (m, 1H), 7.24–7.20 (m, 1H), 6.98–6.96 (m, 1H), 2.91–2.83 (m, 1H), 1.32 (s, 9H), 1.24 (d, *J* = 8.0 Hz, 6H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.52, 149.75, 138.00, 128.65, 122.19, 118.14, 117.47, 39.46, 34.05, 27.52, 23.79. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{22}NO$: 220.1701 Found: 220.1698. **IR** (KBr, ν/cm^{-1}) 3287, 1655.



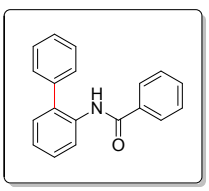
3a, ***N*-([1,1'-Biphenyl]-2-yl)pivalamide.** Yellow solid. mp 65–67 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.37 (d, *J* = 8.0 Hz, 1H), 7.52–7.37 (m, 7H), 7.26–7.24 (m, 1H), 7.19–7.15 (m, 1H), 1.10 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.14, 138.03, 135.07, 132.11, 129.57, 129.22, 128.91, 128.35, 127.92, 123.76, 120.83, 39.65, 27.24. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{17}H_{20}NO$: 254.1545 Found: 254.1544. **IR** (KBr, ν/cm^{-1}) 3263, 1646.



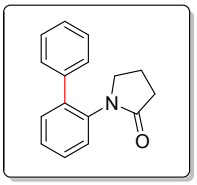
3b, *N*-([1,1'-Biphenyl]-2-yl)acetamide.[5] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.24 (d, *J* = 8.0 Hz, 1H), 7.51–7.47 (m, 2H), 7.44–7.42 (m, 1H), 7.39–7.35 (m, 3H), 7.26–7.17 (m, 3H), 2.01 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 168.20, 138.12, 134.60, 132.30, 129.95, 129.10, 128.94, 128.27, 127.83, 124.32, 121.79, 24.36. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{14}NO$: 212.1075 Found: 212.1073.



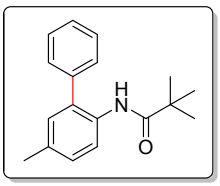
3c, *N*-([1,1'-Biphenyl]-2-yl)butyramide. White solid. mp 86 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.31 (d, *J* = 8.0 Hz, 1H), 7.52–7.48 (m, 2H), 7.45–7.43 (m, 1H), 7.41–7.36 (m, 3H), 7.27–7.25 (m, 1H), 7.20–7.16 (m, 2 H), 2.18 (t, *J* = 8.0 Hz, 2H), 1.67–1.58 (m, 2H), 0.93 (t, *J* = 8.0 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 170.97, 138.10, 134.68, 132.08, 129.88, 129.16, 128.94, 128.30, 127.86, 124.09, 121.49, 39.60, 18.76, 13.53. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{16}H_{18}NO$: 240.1388 Found: 240.1392. **IR** (KBr, ν/cm^{-1}) 3249, 1648.



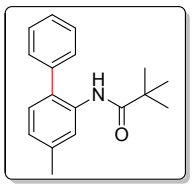
3d, *N*-([1,1'-Biphenyl]-2-yl)benzamide. Yellow solid. mp 77–79 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.56 (d, *J* = 8.0 Hz, 1H), 8.03 (br, s, 1H), 7.63–7.61 (m, 2H), 7.55–7.52 (m, 2H), 7.49–7.43 (m, 5H), 7.42–7.38 (m, 2H), 7.33–7.31 (m, 1H), 7.26–7.22 (m, 1H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 164.86, 138.00, 134.84, 134.71, 132.30, 131.59, 129.87, 129.25, 129.11, 128.62, 128.49, 128.07, 126.70, 124.26, 121.10. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{19}H_{16}NO$: 274.1232 Found: 274.1228. **IR** (KBr, ν/cm^{-1}) 3264, 1664.



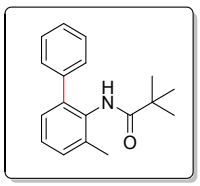
3e, 1-([1,1'-Biphenyl]-2-yl)pyrrolidin-2-one.[6] Yellow oil. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 7.42–7.31 (m, 9H), 3.20 (t, *J* = 8.0 Hz, 2H), 2.42 (t, *J* = 8.0 Hz, 2H), 1.89–1.82 (m, 2H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 175.51, 139.55, 139.03, 136.25, 130.73, 128.45, 128.31, 128.29, 128.25, 127.92, 127.48, 50.07, 31.09, 18.87. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{16}H_{16}NO$: 238.1232 Found: 238.1230.



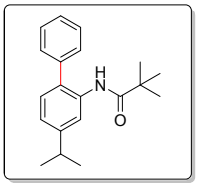
3h, *N*-(5-Methyl-[1,1'-biphenyl]-2-yl)pivalamide. Yellow solid. mp 91–92 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.21 (d, *J* = 8.0 Hz, 1H), 7.50–7.47 (m, 2H), 7.43–7.35 (m, 4H), 7.19 (d, *J* = 8.0 Hz, 1H), 7.07 (s, 1H), 2.36 (s, 3H), 1.11 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.06, 138.23, 133.40, 132.49, 132.30, 130.16, 129.18, 128.82, 127.79, 121.11, 39.55, 27.27, 20.69. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{22}NO$: 268.1701 Found: 268.1701. **IR** (KBr, ν/cm^{-1}) 3294, 1645.



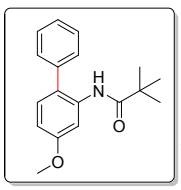
3i, *N*-(4-Methyl-[1,1'-biphenyl]-2-yl)pivalamide.[6] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.25 (s, 1H), 7.51–7.35 (m, 6H), 7.16–7.14 (m, 1H), 7.00–6.98 (m, 1H), 2.41 (s, 3H), 1.11 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ = 176.20, 138.39, 138.07, 134.81, 129.40, 129.33, 128.88, 127.75, 124.56, 121.34, 39.67, 27.25, 21.36. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{22}NO$: 268.1701 Found: 268.1700.



3j, *N*-(3-Methyl-[1,1'-biphenyl]-2-yl)pivalamide.[7] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 7.42–7.35 (m, 3H), 7.31–7.29 (m, 2H), 7.26–7.25 (m, 2H), 7.18–7.16 (m, 1H), 6.82 (br, s, 1H), 2.27 (s, 3H), 1.12 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.59, 139.51, 139.44, 136.49, 132.72, 129.95, 128.87, 128.12, 127.50, 127.24, 126.87, 38.97, 27.37, 18.37. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{22}NO$: 268.1701 Found: 268.1702.

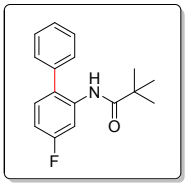


3k, *N*-(4-*iso*-Propyl-[1,1'-biphenyl]-2-yl)pivalamide. Yellow solid. mp 99–100 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.34 (s, 1H), 7.51–7.47 (m, 3H), 7.43–7.37 (m, 3H), 7.20–7.18 (m, 1H), 7.06–7.04 (m, 1H), 3.04–2.93 (m, 1H), 1.33 (d, *J* = 8.0 Hz, 6H), 1.12 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.16, 149.43, 138.11, 134.96, 129.57, 129.48, 129.33, 128.89, 127.75, 121.82, 118.89, 39.70, 34.11, 27.28, 23.83. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{20}H_{26}NO$: 296.2014 Found: 296.2010. **IR** (KBr, ν/cm^{-1}) 3286, 1643.

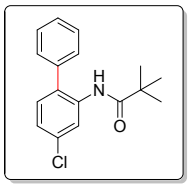


3l, *N*-(4-Methoxy-[1,1'-biphenyl]-2-yl)pivalamide.[8] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.15 (d, *J* = 2.4 Hz, 1H), 7.55 (br, s, 1H), 7.51–7.47 (m, 2H), 7.43–7.39 (m, 1H), 7.36–7.34 (m, 2H), 7.15 (d, *J* = 8.0 Hz, 1H), 6.73 (dd, *J* = 8.0 Hz, 2.4 Hz, 1H), 3.88 (s, 3H), 1.11 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.29, 159.62, 137.83, 136.09,

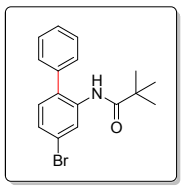
130.23, 129.49, 128.95, 127.67, 124.13, 110.51, 105.05, 55.33, 39.80, 27.23. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{18}H_{22}NO_2$: 284.1651 Found: 284.1649.



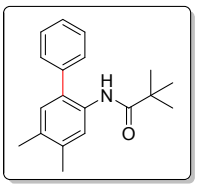
3m, *N*-(4-Fluoro-[1,1'-biphenyl]-2-yl)pivalamide.[7] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.28 (dd, *J* = 12.0 Hz, 2.4 Hz, 1H), 7.56–7.49 (m, 3H), 7.46–7.42 (m, 1H), 7.34–7.32 (m, 2H), 7.19–7.16 (m, 1H), 6.86–6.82 (m, 1H), 1.09 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.25, 162.34 (d, *J* = 243.0 Hz), 137.09 (d, *J* = 1.0 Hz), 136.46 (d, *J* = 11.8 Hz), 130.47 (d, *J* = 9.3 Hz), 129.32, 129.12, 128.19, 127.48 (d, *J* = 3.2 Hz), 110.20 (d, *J* = 21.6 Hz), 107.70 (d, *J* = 27.7 Hz), 39.76, 27.14. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{17}H_{19}FNO$: 272.1451 Found: 272.1451.



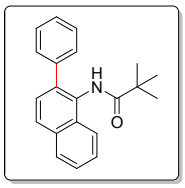
3n, *N*-(4-Chloro-[1,1'-biphenyl]-2-yl)pivalamide. Yellow solid. mp 96–97 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.52 (d, *J* = 1.6 Hz, 1H), 7.53–7.43 (m, 4H), 7.35–7.33 (m, 2H), 7.18–7.12 (m, 2H), 1.10 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.26, 136.92, 136.05, 134.09, 130.39, 130.08, 129.14, 128.30, 123.68, 120.52, 39.75, 27.16. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{17}H_{19}ClNO$: 288.1155 Found: 288.1154. **IR** (KBr, ν/cm^{-1}) 3229, 1648.



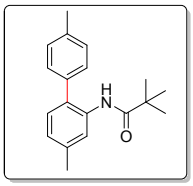
3o, *N*-(4-Bromo-[1,1'-biphenyl]-2-yl)pivalamide. Yellow solid. mp 110 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.67 (d, *J* = 2.0 Hz, 1H), 7.53–7.43 (m, 4H), 7.34–7.33 (m, 2H), 7.30–7.27 (m, 1H), 7.11–7.09 (m, 1H), 1.09 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.23, 136.92, 136.22, 130.69, 130.59, 129.14, 129.06, 128.33, 126.65, 123.37, 122.08, 39.74, 27.16. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{17}H_{19}BrNO$: 332.0650 Found: 332.0642. **IR** (KBr, ν/cm^{-1}) 3240, 1647.



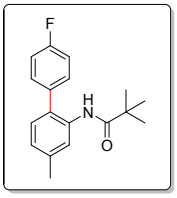
3p, *N*-(4,5-Dimethyl-[1,1'-biphenyl]-2-yl)pivalamide.[6] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.15 (s, 1H), 7.50–7.46 (m, 2H), 7.42–7.35 (m, 4H), 7.04 (s, 1H), 2.33 (s, 3H), 2.27 (s, 3H), 1.12 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.13, 138.16, 136.70, 132.54, 132.15, 130.65, 129.91, 129.28, 128.80, 127.63, 122.31, 39.57, 27.28, 19.65, 19.06. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{19}H_{24}NO$: 282.1858 Found: 282.1857.



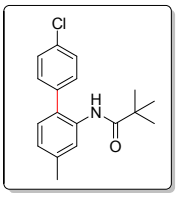
3q, *N*-(2-Phenylnaphthalen-1-yl)pivalamide. Yellow solid. mp 171–172 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 7.90–7.82 (m, 3H), 7.57–7.39 (m, 8H), 7.20 (br, s, 1H), 1.20 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 177.63, 139.63, 136.96, 133.53, 130.68, 129.89, 129.02, 128.18, 128.04, 127.55, 127.51, 127.35, 126.73, 125.95, 123.50, 39.14, 27.47. **HRMS (ESI) [M+H]**$^+$ Calcd. for $C_{21}H_{22}NO$: 304.1701 Found: 304.1699. **IR** (KBr, ν/cm^{-1}) 3262, 1649.



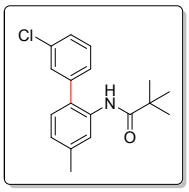
3r, *N*-(4,4'-Dimethyl-[1,1'-biphenyl]-2-yl)pivalamide.[7] Yellow oil. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.27 (s, 1H), 7.53 (br, s, 1H), 7.31–7.25 (m, 4H), 7.14–7.12 (m, 1H), 6.99–6.97 (m, 1H), 2.44 (s, 3H), 2.42 (s, 3H), 1.14 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.18, 138.11, 137.51, 135.03, 134.91, 129.58, 129.53, 129.25, 129.18, 124.52, 121.26, 39.69, 27.31, 21.36, 21.09. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{19}H_{24}NO$: 282.1858 Found: 282.1856.



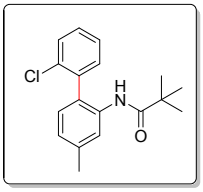
3s, *N*-(4'-Fluoro-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. White solid. mp 103–104 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.18 (s, 1H), 7.35–7.31 (m, 3H), 7.20–7.16 (m, 2H), 7.12–7.10 (m, 1H), 6.99–6.98 (m, 1H), 2.40 (s, 3H), 1.12 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.22, 162.29 (d, *J* = 246.1 Hz), 138.61, 134.78, 134.04 (d, *J* = 3.4 Hz), 131.05 (d, *J* = 8.0 Hz), 129.53, 128.50, 124.76, 121.78, 115.83 (d, *J* = 21.3 Hz), 39.65, 27.27, 21.32. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{21}FNO$: 286.1607 Found: 286.1606. **IR** (KBr, ν/cm^{-1}) 3276, 1644.



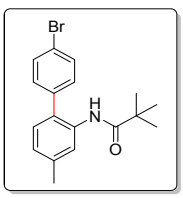
3t, *N*-(4'-Chloro-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. White solid. mp 132–133 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.16 (s, 1H), 7.47–7.45 (m, 2H), 7.33–7.29 (m, 3H), 7.11–7.09 (m, 1H), 7.00–6.98 (m, 1H), 2.40 (s, 3H), 1.14 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.27, 138.81, 136.58, 134.59, 133.83, 130.67, 129.47, 129.04, 128.37, 124.93, 122.02, 39.68, 27.31, 21.34. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{21}ClNO$: 302.1312 Found: 302.1308. **IR** (KBr, ν/cm^{-1}) 3273, 1647.



3u, *N*-(3'-Chloro-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. Yellow solid. mp 100–101 °C. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.14 (s, 1H), 7.43–7.37 (m, 4H), 7.26–7.24 (m, 1H), 7.13–7.11 (m, 1H), 7.01–6.99 (m, 1H), 2.40 (s, 3H), 1.15 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.26, 139.98, 138.95, 134.70, 134.54, 130.11, 129.46, 129.35, 128.30, 127.79, 127.46, 125.01, 122.25, 39.67, 27.28, 21.34. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{21}ClNO$: 302.1312 Found: 302.1306. **IR** (KBr, ν/cm^{-1}) 3320, 1644.

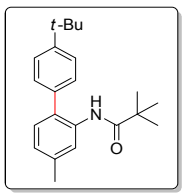


3v, *N*-(2'-Chloro-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. Yellow oil. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.13 (s, 1H), 7.55–7.53 (m, 1H), 7.39–7.37 (m, 2H), 7.33–7.29 (m, 1H), 7.13 (br, s, 1H), 7.10–7.08 (m, 1H), 7.03–7.01 (m, 1H), 2.42 (s, 3H), 1.07 (s, 9H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 176.21, 139.07, 136.78, 135.08, 133.74, 132.01, 129.64, 129.51, 129.26, 127.28, 127.25, 124.75, 121.93, 39.49, 27.11, 21.43. **HRMS (ESI) $[M+H]^+$** Calcd. for $C_{18}H_{21}ClNO$: 302.1312 Found: 302.1314. **IR** (KBr, ν/cm^{-1}) 3441, 1692.

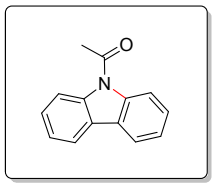


3w, *N*-(4'-Bromo-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. White

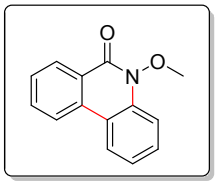
solid. mp 139 °C. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.15 (s, 1H), 7.62–7.60 (m, 2H), 7.32 (br, s, 1H), 7.25–7.23 (m, 2H), 7.11–7.09 (m, 1H), 7.00–6.98 (m, 1H), 2.40 (s, 3H), 1.14 (s, 9H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 176.26, 138.83, 137.09, 134.54, 131.99, 130.97, 129.41, 128.40, 124.95, 122.10, 121.94, 39.67, 27.31, 21.33. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{18}H_{21}BrNO$: 346.0807 Found: 346.0809. **IR** (KBr, ν/cm^{-1}) 3266, 1646.



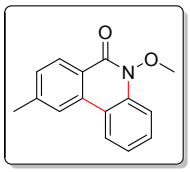
3x, *N*-(4'-(*tert*-Butyl)-4-methyl-[1,1'-biphenyl]-2-yl)pivalamide. White solid. mp 109–110 °C. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.24 (s, 1H), 7.52–7.47 (m, 3H), 7.30–7.28 (m, 2H), 7.16–7.14 (m, 1H), 6.99–6.97 (m, 1H), 2.41 (s, 3H), 1.38 (s, 9H), 1.10 (s, 9H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 176.17, 150.87, 138.16, 134.97, 129.34, 129.26, 129.00, 125.74, 124.48, 121.20, 39.65, 34.53, 31.19, 27.19, 21.35. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{22}H_{30}NO$: 324.2327 Found: 324.2325. **IR** (KBr, ν/cm^{-1}) 3277, 1647.



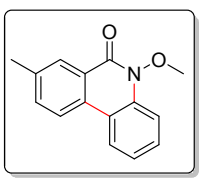
4b, 1-(9*H*-Carbazol-9-yl)ethanone.[5] White solid. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.22 (d, *J* = 8.0 Hz, 2H), 8.00 (d, *J* = 8.0 Hz, 2H), 7.51–7.47 (m, 2H), 7.42–7.38 (m, 2H), 2.89 (s, 3H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 169.91, 138.55, 127.21, 126.31, 123.54, 119.70, 116.13, 27.56. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{12}NO$: 210.0919 Found: 210.0906.



6a, 5-Methoxyphenanthridin-6(5*H*)-one.[9,10] White solid. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.53 (d, *J* = 8.0 Hz, 1H), 8.23–8.20 (m, 2H), 7.75–7.72 (m, 1H), 7.65–7.63 (m, 1H), 7.58–7.53 (m, 2H), 7.33–7.29 (m, 1H), 4.13 (s, 3H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 157.12, 135.68, 132.83, 132.45, 129.79, 128.34, 127.88, 126.19, 123.05, 123.04, 121.78, 118.40, 112.45, 62.56. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{12}NO_2$: 226.0868 Found: 226.0864.

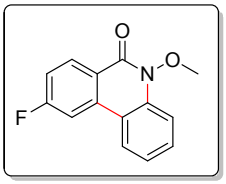


6b, 5-Methoxy-9-methylphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.45 (d, *J* = 8.0 Hz, 1H), 8.26 (d, *J* = 8.0 Hz, 1H), 8.06 (s, 1H), 7.68–7.66 (m, 1H), 7.60–7.56 (m, 1H), 7.42 (d, *J* = 8.0 Hz, 1H), 7.36–7.32 (m, 1H), 4.14 (s, 3H), 2.57 (s, 3H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 157.21, 143.07, 135.87, 132.85, 129.67, 129.35, 128.40, 123.95, 123.02, 122.90, 121.85, 118.41, 112.48, 62.55, 22.00. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{15}H_{14}NO_2$: 240.1025 Found: 240.1029.

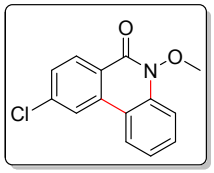


6c, 5-Methoxy-8-methylphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, CDCl$_3$)**: δ = 8.37 (s, 1H), 8.24 (d, *J* = 8.0 Hz, 1H), 8.17 (d, *J* = 8.0 Hz, 1H), 7.69–7.67 (m, 1H), 7.61–7.55 (m, 2H), 7.36–7.33 (m, 1H), 4.15 (s, 3H), 2.54 (s, 3H); **^{13}C NMR (100 MHz, CDCl$_3$)**: δ = 157.24, 138.23, 135.38, 133.83, 130.41, 129.31, 128.15,

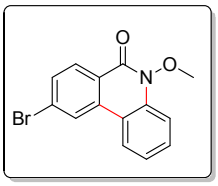
126.11, 123.00, 122.83, 121.81, 118.60, 112.46, 62.53, 21.18. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{15}H_{14}NO_2$: 240.1025 Found: 240.1022.



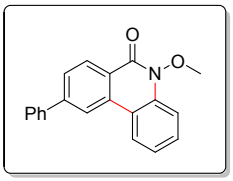
6d, 9-Fluoro-5-methoxyphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.55 (dd, *J* = 8.0 Hz, 6.0 Hz, 1H), 8.10 (d, *J* = 8.0 Hz, 1H), 7.83 (dd, *J* = 12.0 Hz, 2.0 Hz, 1H), 7.66–7.58 (m, 2H), 7.35–7.31 (m, 1H), 7.29–7.24 (m, 1H), 4.13 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 165.52 (d, *J* = 251.0 Hz), 156.46, 136.12, 135.45 (d, *J* = 10.0 Hz), 131.51 (d, *J* = 10.0 Hz), 130.56, 123.28, 123.14, 122.71 (d, *J* = 2.0 Hz), 117.57 (d, *J* = 3.0 Hz), 116.17 (d, *J* = 23.0 Hz), 112.64, 107.82 (d, *J* = 24.0 Hz), 62.64. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}FNO_2$: 244.0774 Found: 244.0769.



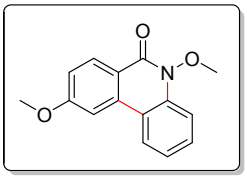
6e, 9-Chloro-5-methoxyphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.47 (d, *J* = 8.0 Hz, 1H), 8.20 (d, *J* = 1.6 Hz, 1H), 8.16 (d, *J* = 8.0 Hz, 1H), 7.67–7.59 (m, 2H), 7.53 (dd, *J* = 8.0 Hz, 1.6 Hz, 1H), 7.37–7.33 (m, 1H), 4.14 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 156.51, 139.33, 136.13, 134.30, 130.57, 130.14, 128.32, 124.57, 123.26, 123.19, 121.76, 117.29, 112.65, 62.66. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}ClNO_2$: 260.0478 Found: 260.0474.



6f, 9-Bromo-5-methoxyphenanthridin-6(5*H*)-one.[10] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.36 (d, *J* = 8.0 Hz, 1H), 8.33 (d, *J* = 1.2 Hz, 1H), 8.12 (d, *J* = 8.0 Hz, 1H), 7.67–7.56 (m, 3H), 7.34–7.30 (m, 1H), 4.12 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 156.59, 136.06, 134.39, 131.12, 130.56, 130.11, 127.94, 124.89, 124.84, 123.27, 123.16, 117.14, 112.62, 62.65. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}BrNO_2$: 303.9973 Found: 303.9971.

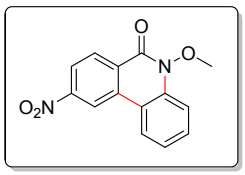


6g, 5-Methoxy-9-phenylphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.63 (d, *J* = 8.0 Hz, 1H), 8.46 (s, 1H), 8.36 (d, *J* = 8.0 Hz, 1H), 7.83 (dd, *J* = 8.0 Hz, 1.2 Hz, 1H), 7.75–7.70 (m, 3H), 7.63–7.60 (m, 1H), 7.56–7.52 (m, 2H), 7.48–7.44 (m, 1H), 7.40–7.36 (m, 1H), 4.17 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 157.10, 145.44, 140.10, 136.00, 133.23, 129.96, 129.03, 128.94, 128.27, 127.44, 127.12, 125.08, 123.11, 123.07, 120.32, 118.50, 112.61, 62.62. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{20}H_{16}NO_2$: 302.1181 Found: 302.1177.

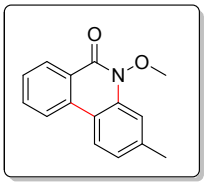


6h, 5,9-Dimethoxyphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.48 (d, *J* = 8.0 Hz, 1H), 8.18 (d, *J* = 8.0 Hz, 1H), 7.66–7.62 (m, 2H), 7.60–7.56 (m, 1H), 7.35–7.31 (m, 1H), 7.16 (dd, *J* = 8.0 Hz, 2.0 Hz, 1H), 4.13 (s, 3H), 3.99 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 163.03, 157.03, 136.12, 134.80, 130.52, 129.95, 123.08, 122.79, 119.77, 118.17, 115.76,

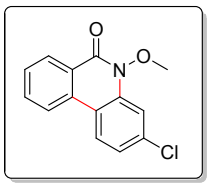
112.54, 104.82, 62.58, 55.47. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{15}H_{14}NO_3$: 256.0974 Found: 256.0970.



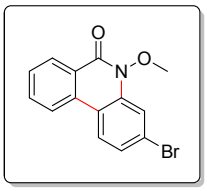
6i, 5-Methoxy-9-nitrophenanthridin-6(5*H*)-one.[10] Yellow solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 9.13 (d, *J* = 1.6 Hz, 1H), 8.75–8.72 (m, 1H), 8.38–8.33 (m, 2H), 7.75–7.68 (m, 2H), 7.48–7.44 (m, 1H), 4.18 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 155.71, 150.42, 136.32, 134.04, 131.43, 130.49, 130.18, 123.84, 123.57, 121.60, 117.65, 117.24, 112.93, 62.82. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}N_2O_4$: 271.0719 Found: 271.0714.



6j, 5-Methoxy-3-methylphenanthridin-6(5*H*)-one.[9,10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.53 (d, *J* = 8.0 Hz, 1H), 8.21 (d, *J* = 8.0 Hz, 1H), 8.12 (d, *J* = 8.0 Hz, 1H), 7.76–7.72 (m, 1H), 7.58–7.54 (m, 1H), 7.47 (s, 1H), 7.15 (d, *J* = 8.0 Hz, 1H), 4.14 (s, 3H), 2.52 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 157.31, 140.42, 135.67, 133.00, 132.41, 128.35, 127.41, 125.79, 124.27, 122.99, 121.56, 116.05, 112.55, 62.54, 21.73. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{15}H_{14}NO_2$: 240.1025 Found: 240.1023.



6k, 3-Chloro-5-methoxyphenanthridin-6(5*H*)-one.[9] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.54 (d, *J* = 8.0 Hz, 1H), 8.22–8.16 (m, 2H), 7.81–7.77 (m, 1H), 7.67 (d, *J* = 2.0 Hz, 1H), 7.64–7.60 (m, 1H), 7.31(dd, *J* = 8.0 Hz, 2.0 Hz, 1H), 4.15 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 157.13, 136.58, 135.96, 132.77, 132.21, 128.54, 128.24, 126.00, 124.42, 123.35, 121.78, 116.94, 112.50, 62.81. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}ClNO_2$: 260.0478 Found: 260.0479.



6l, 3-Bromo-5-methoxyphenanthridin-6(5*H*)-one.[10] White solid. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ = 8.54 (d, *J* = 8.0 Hz, 1H), 8.22 (d, *J* = 8.0 Hz, 1H), 8.10 (d, *J* = 8.0 Hz, 1H), 7.84–7.83 (m, 1H), 7.81–7.77 (m, 1H), 7.65–7.61 (m, 1H), 7.46 (dd, *J* = 8.0 Hz, 1.6 Hz, 1H), 4.15 (s, 3H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ = 157.04, 136.64, 132.76, 132.24, 128.56, 128.32, 126.18, 126.10, 124.51, 123.95, 121.75, 117.34, 115.40, 62.82. **HRMS (ESI) [M+H]$^+$** Calcd. for $C_{14}H_{11}BrNO_2$: 303.9973 Found: 303.9969.

6. References

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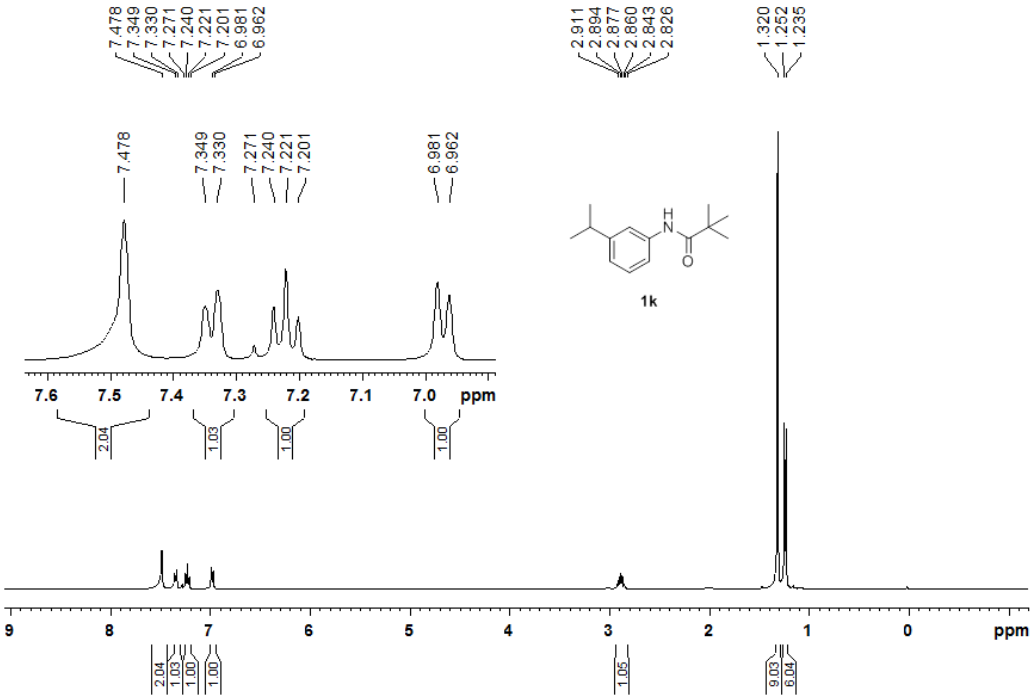
7. ^{1}H and ^{13}C NMR spectra of the products


7.478
7.349
7.330
7.271
7.240
7.221
7.201
6.981
6.962
2.911
2.894
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2.843
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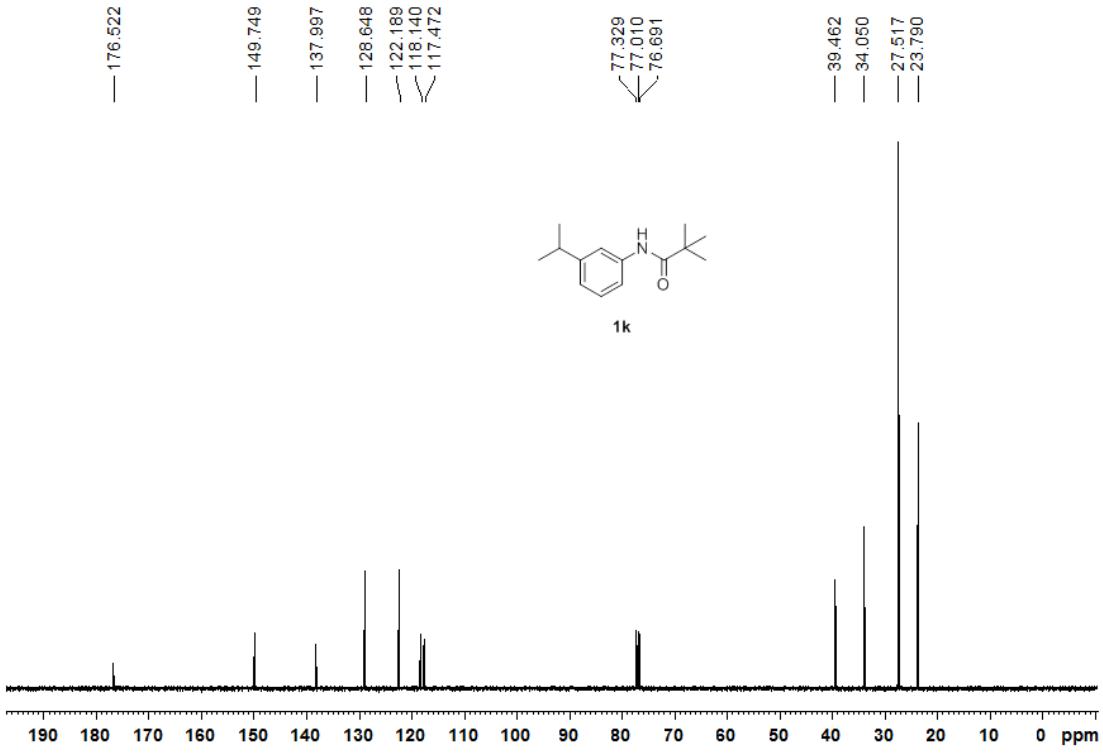
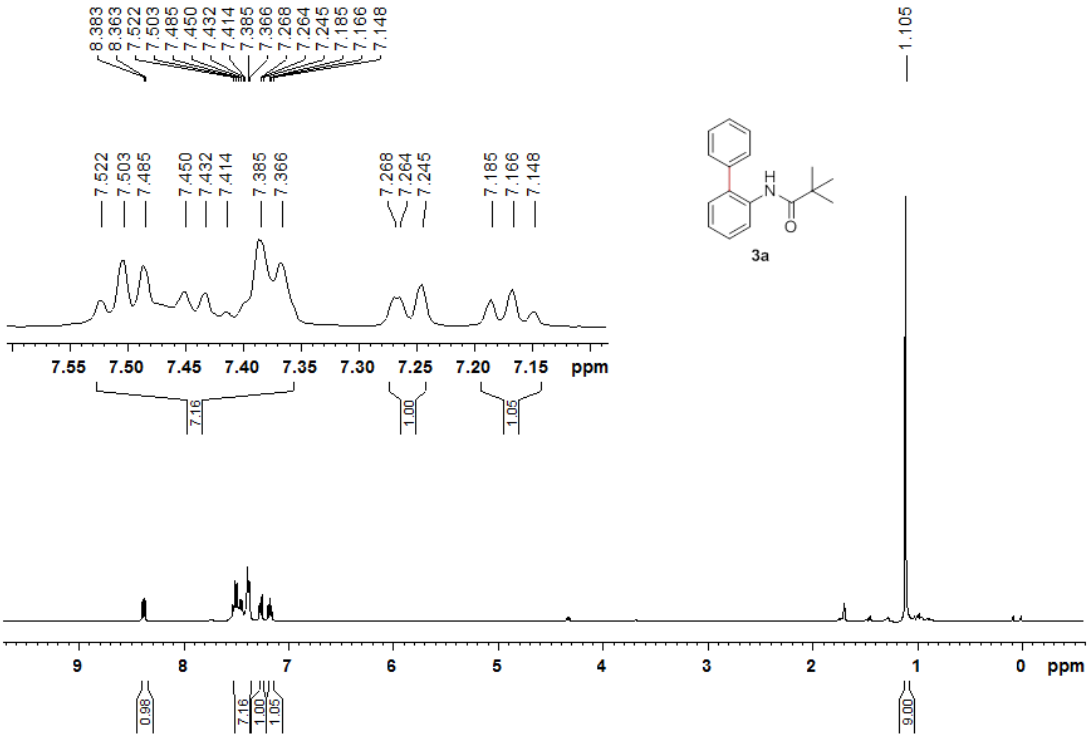
1.03
1.00
1.00
1.05
9.03
6.04


176.522
149.749
137.997
128.648
122.189
118.140
117.472
77.329
77.010
76.691
39.462
34.050
27.517
23.790
1k
ppm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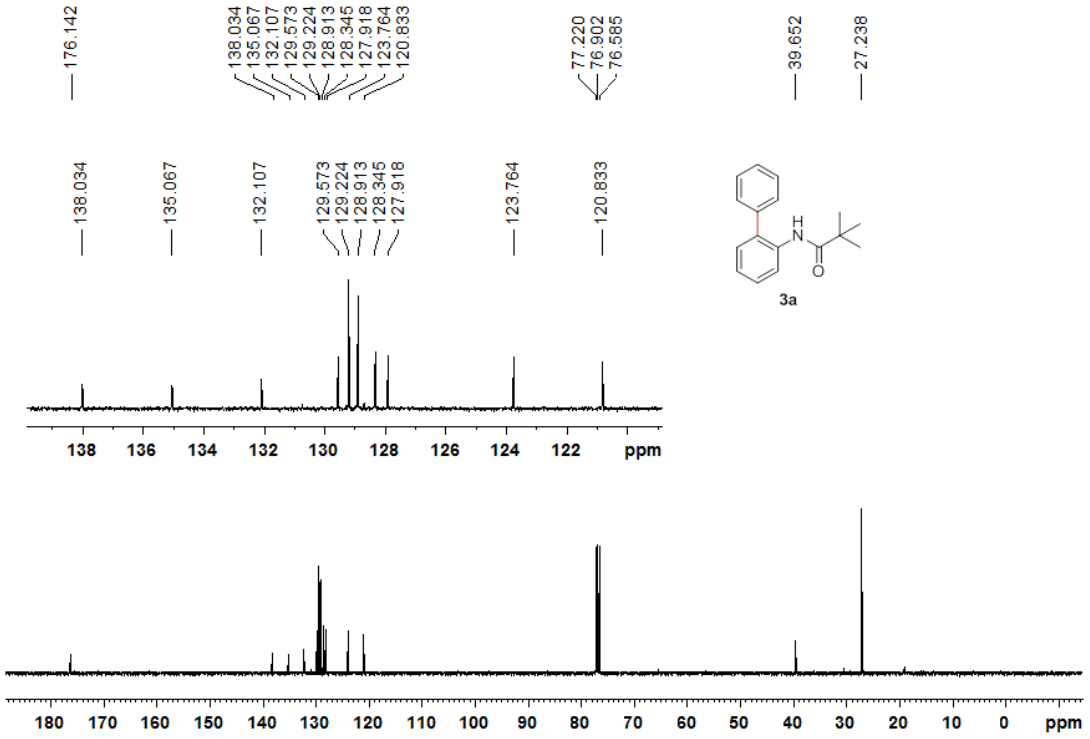
7.450
7.432
7.414
7.385
7.366
7.268
7.264
7.245
7.185
7.166
7.148
1.105
3a
7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 ppm
7.16
1.00
1.05
9 8 7 6 5 4 3 2 1 0 ppm
0.98
7.16
1.00
1.05
9.00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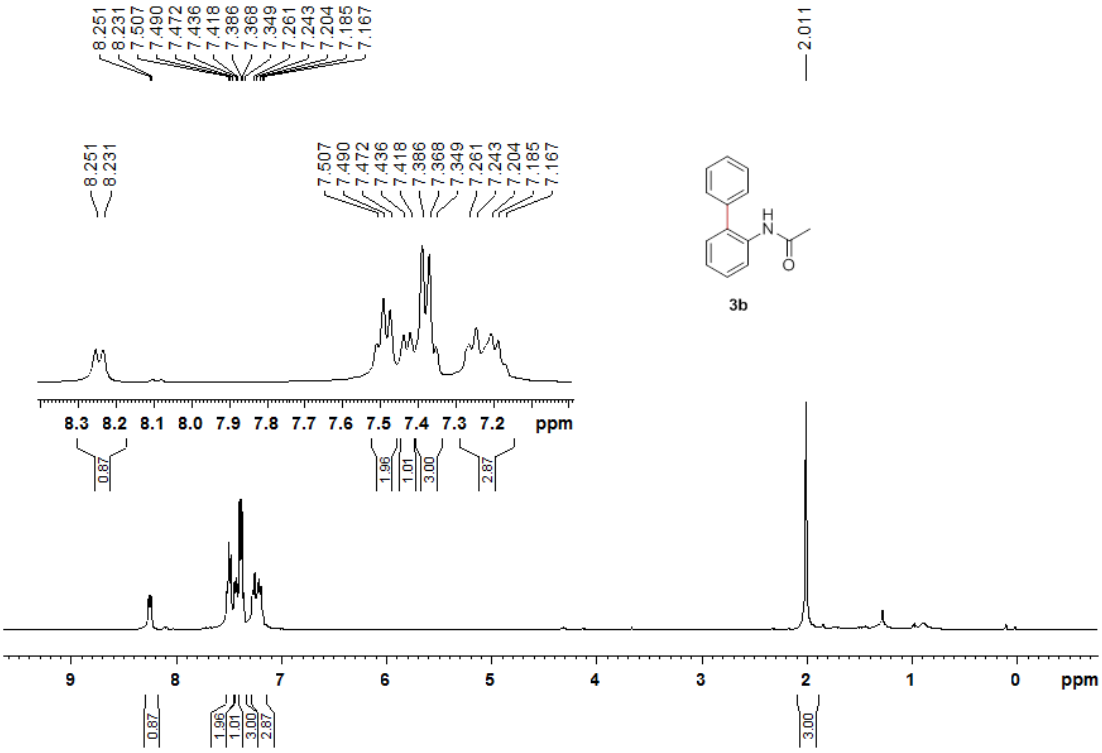
135.067
132.107
129.573
129.224
128.913
128.345
127.918
123.764
120.833
77.220
76.902
76.585
39.652
27.238
3a
138 136 134 132 130 128 126 124 122 ppm
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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8.231
7.507
7.490
7.472
7.436
7.418
7.386
7.368
7.349
7.261
7.243
7.204
7.185
7.167
2.011
3b
8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 ppm
0.87
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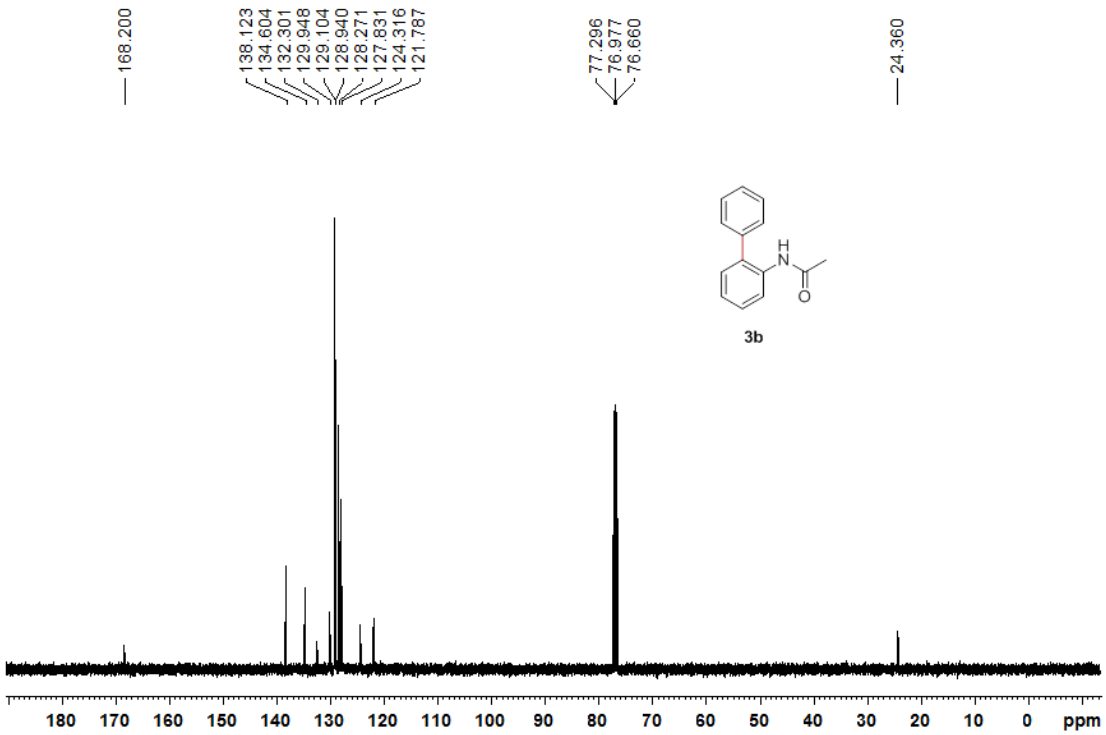
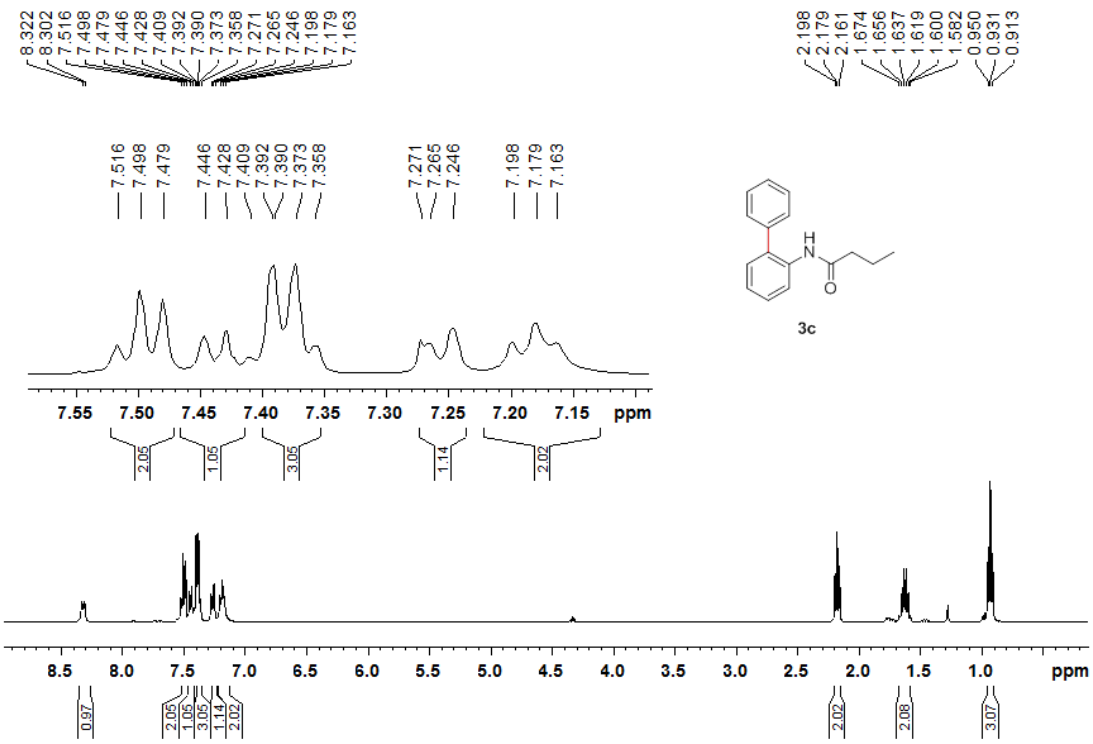
1.01
3.00
2.87
9 8 7 6 5 4 3 2 1 0 ppm
3.00


168.200
138.123
134.604
132.301
129.948
129.104
128.940
128.271
127.831
124.316
121.787
77.296
76.977
76.660
24.360
3b
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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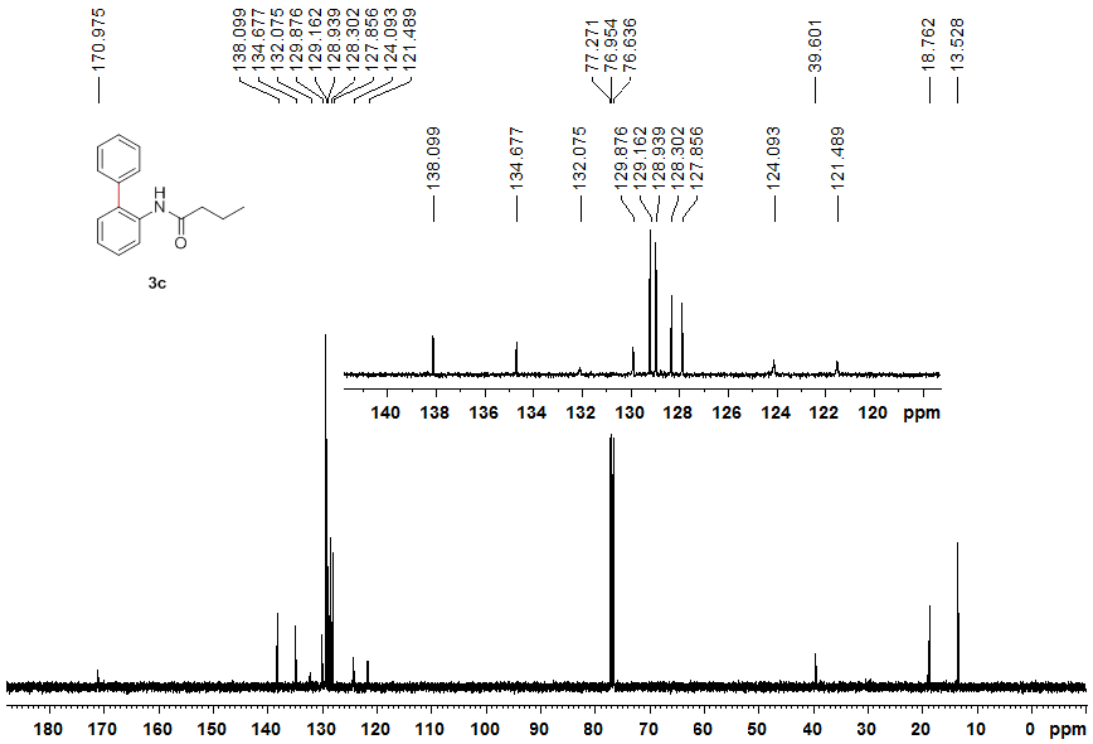
8.302
7.516
7.498
7.479
7.446
7.428
7.409
7.392
7.390
7.373
7.358
7.271
7.265
7.246
7.198
7.179
7.163
2.198
2.179
2.161
1.674
1.656
1.637
1.619
1.600
1.582
0.950
0.931
0.913
3c
7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 ppm
2.05 1.05 3.05 1.14 2.02
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 ppm
0.97 2.05 1.05 3.05 1.14 2.02 2.02 2.08 3.07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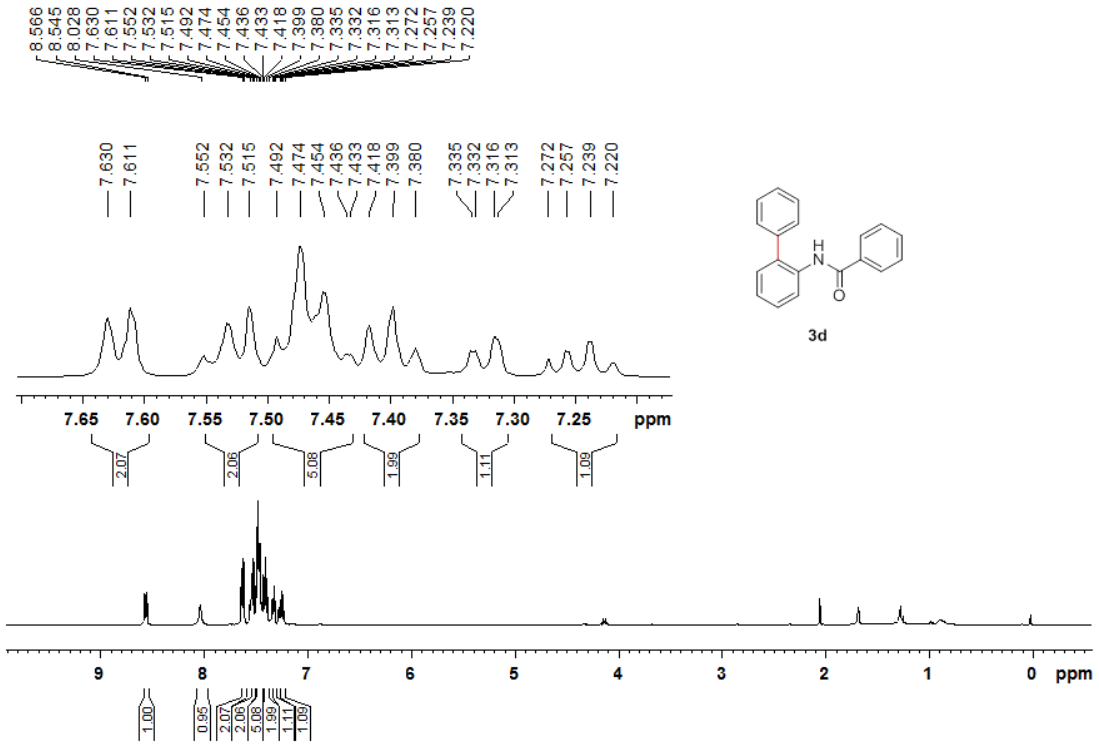
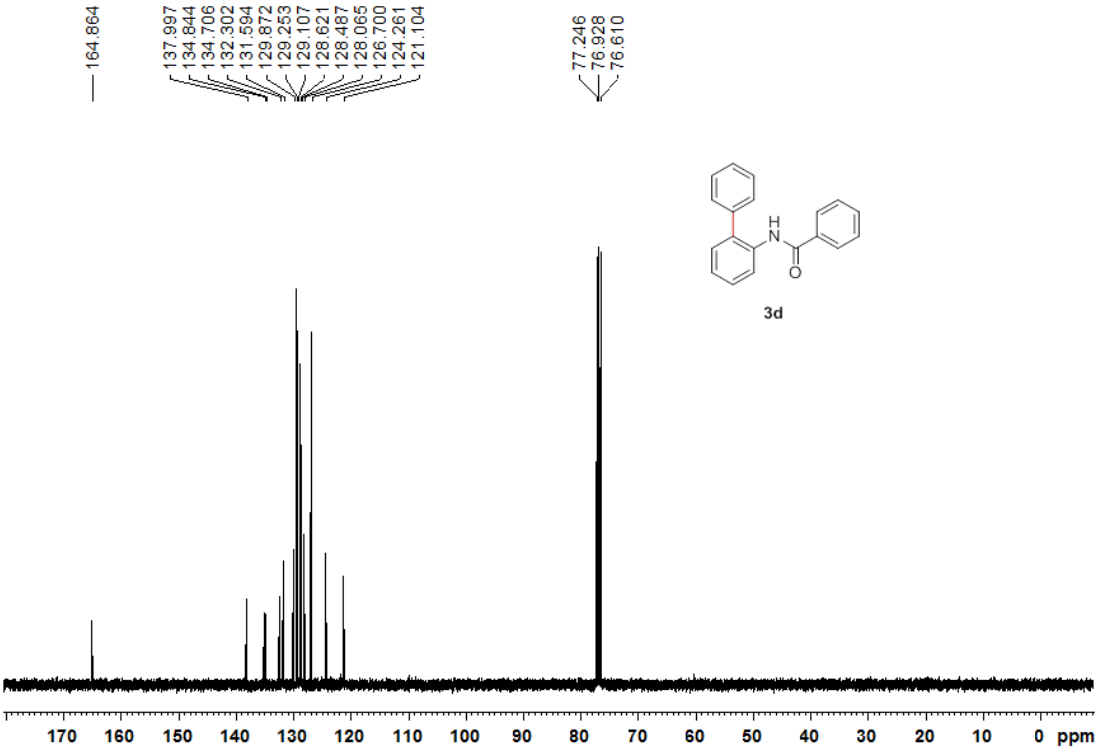
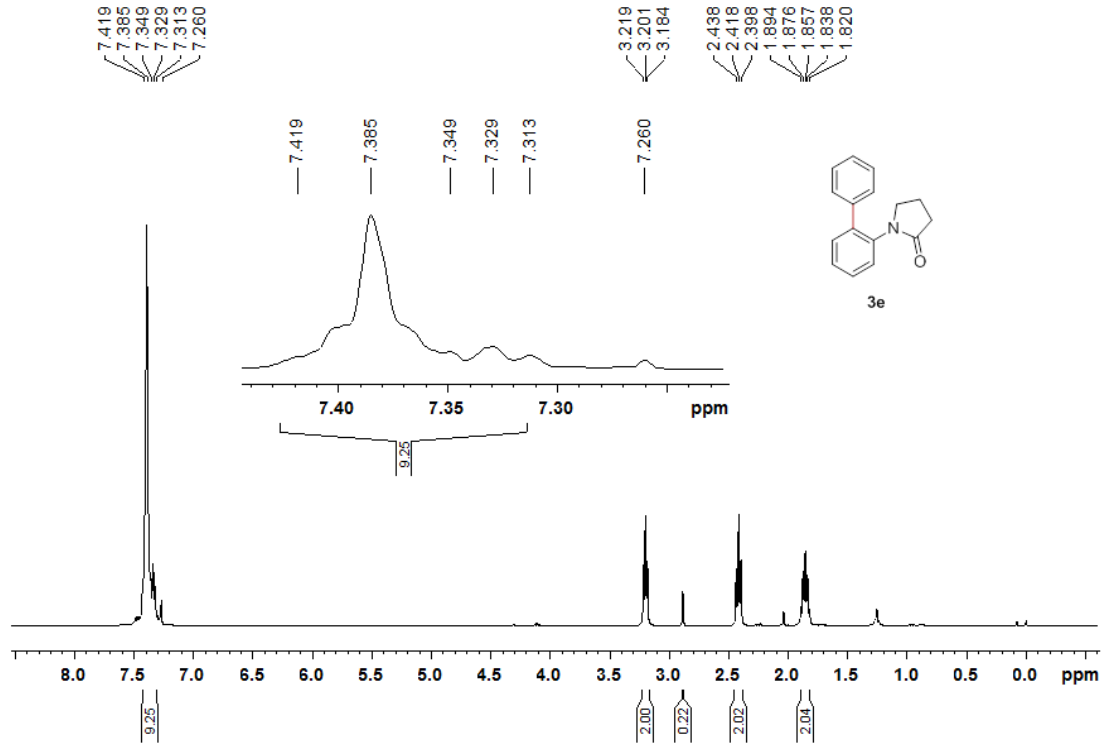
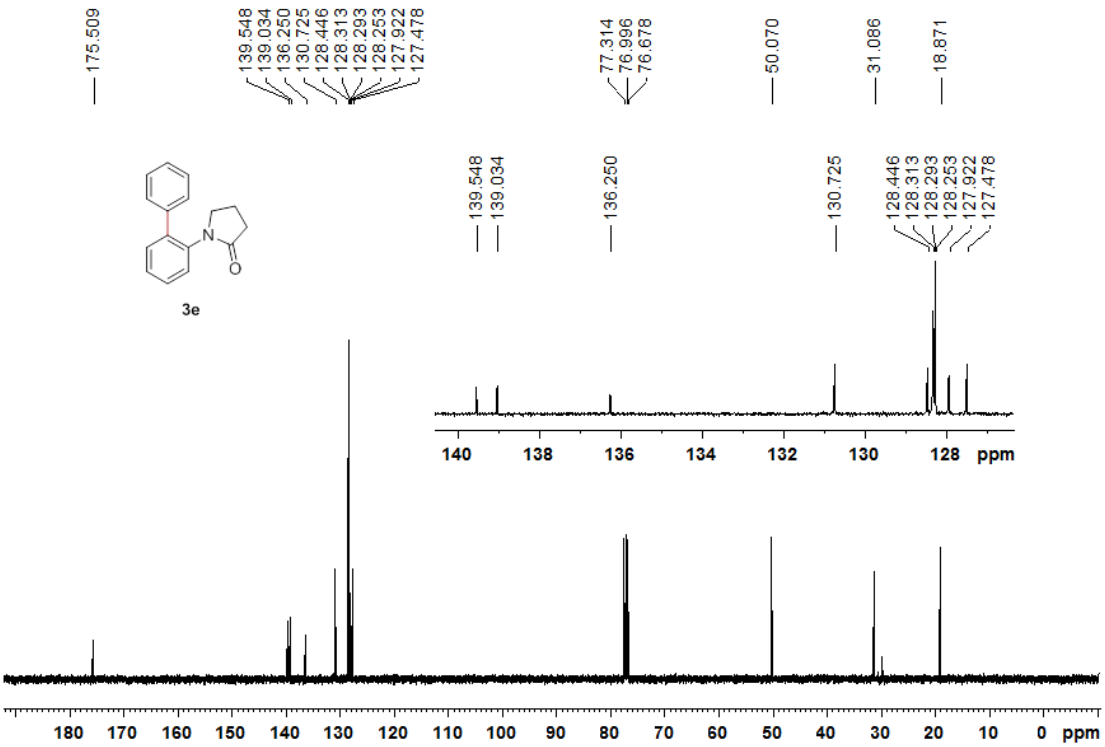
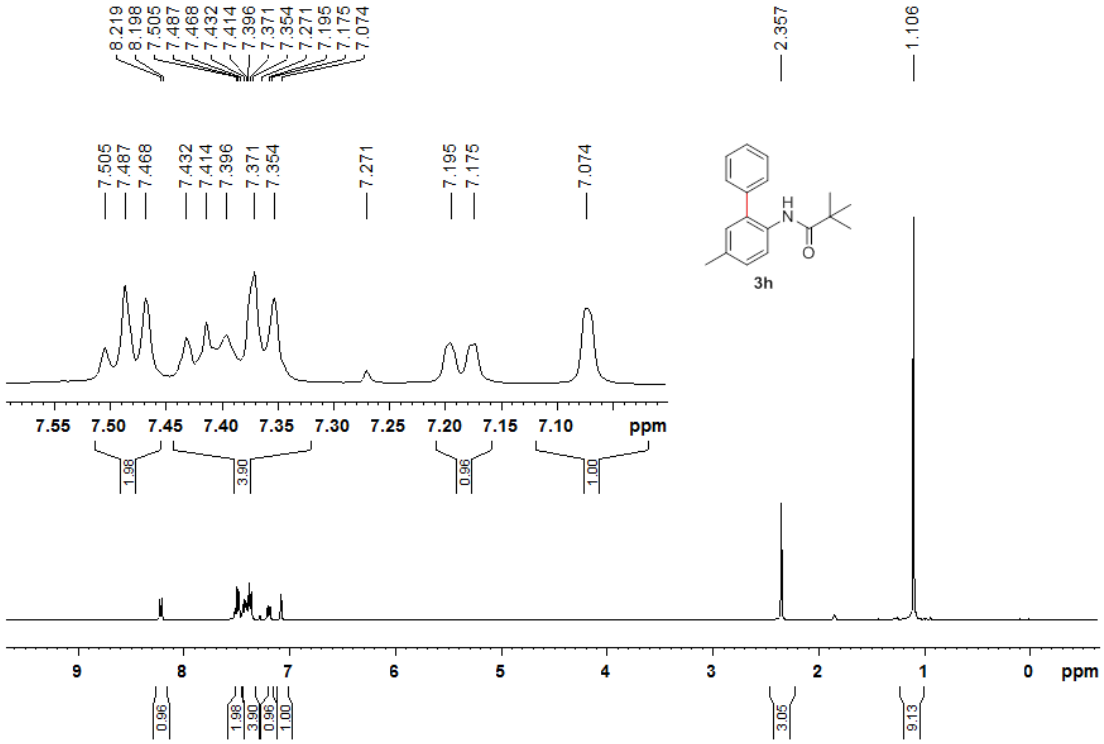
138.099
134.677
132.075
129.876
129.162
128.939
128.302
127.856
124.093
121.489
77.271
76.954
76.636
39.601
18.762
13.528
3c
140 138 136 134 132 130 128 126 124 122 120 ppm
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


8.566
8.545
8.028
7.630
7.611
7.552
7.532
7.515
7.492
7.474
7.454
7.436
7.433
7.418
7.399
7.380
7.335
7.332
7.316
7.313
7.272
7.257
7.239
7.220
7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
ppm
2.07
2.06
5.08
1.99
1.11
1.09
9
8
7
6
5
4
3
2
1
0
ppm
1.00
0.95
2.07
2.06
5.08
1.99
1.11
1.09
3d


164.864
137.997
134.844
134.706
132.302
131.594
129.872
129.253
129.107
128.621
128.487
128.065
126.700
124.261
121.104
77.246
76.928
76.610
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm
3d


7.419
7.385
7.349
7.329
7.313
7.260
3.219
3.201
3.184
2.438
2.418
2.398
1.894
1.876
1.857
1.838
1.820
3e
7.40
7.35
7.30
ppm
9.25
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
ppm
9.25
2.00
0.22
2.02
2.04


175.509
139.548
139.034
136.250
130.725
128.446
128.313
128.293
128.253
127.922
127.478
77.314
76.996
76.678
50.070
31.086
18.871
3e
140
138
136
134
132
130
128
ppm
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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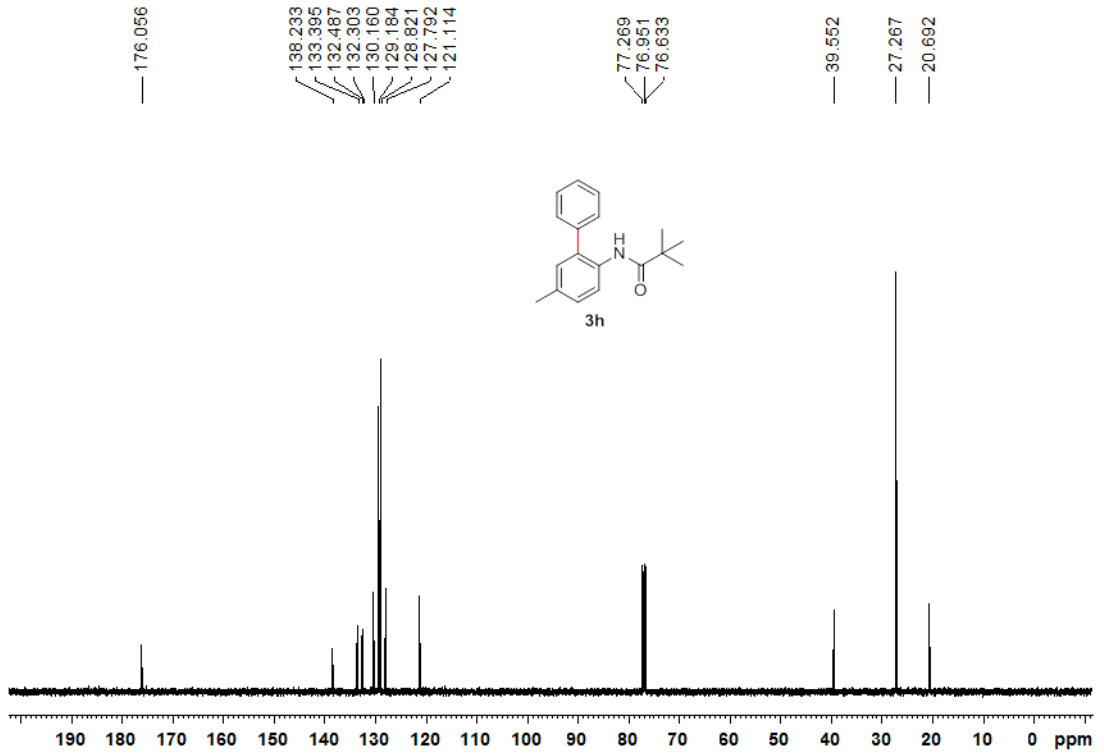
8.198
7.505
7.487
7.468
7.432
7.414
7.396
7.371
7.354
7.271
7.195
7.175
7.074
2.357
1.106
3h
7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 ppm
1.98
3.90
0.96
1.00
9 8 7 6 5 4 3 2 1 0 ppm
0.96
1.98
3.90
0.96
1.00
3.05
9.13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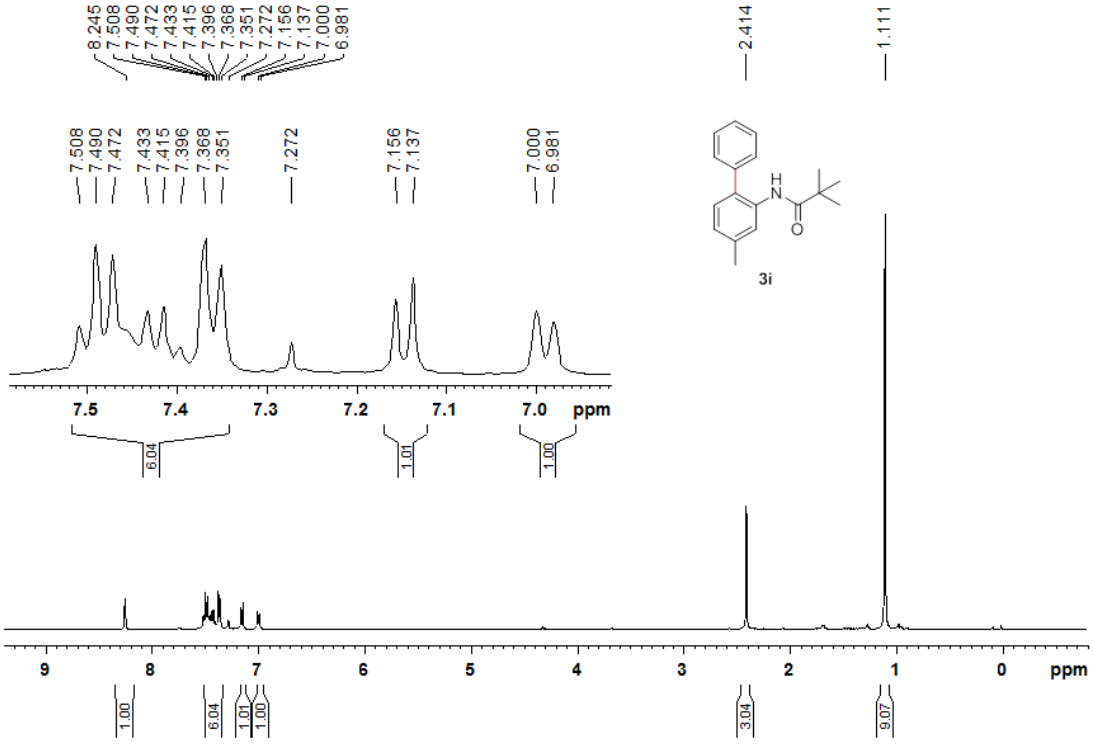
138.233
133.395
132.487
132.303
130.160
129.184
128.821
127.792
121.114
77.269
76.951
76.633
39.552
27.267
20.692
3h
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


8.245
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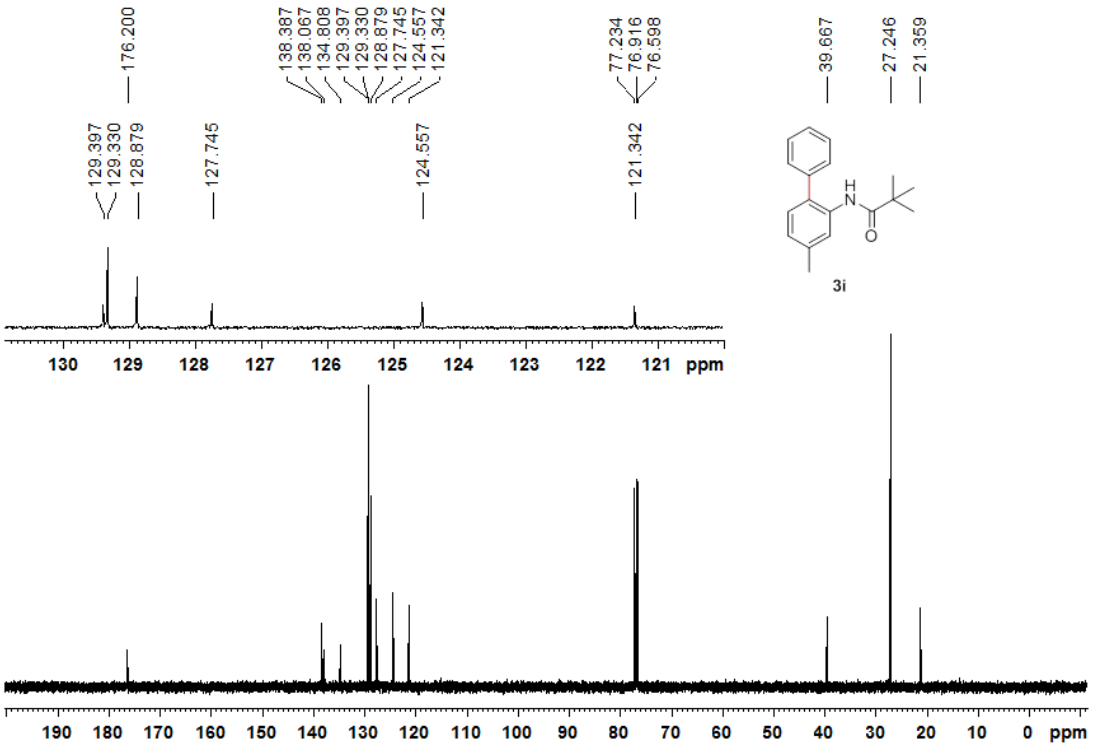
7.490
7.472
7.433
7.415
7.396
7.368
7.351
7.272
7.156
7.137
7.000
6.981
2.414
1.111
3i
7.5
7.4
7.3
7.2
7.1
7.0
ppm
6.04
1.01
1.00
9
8
7
6
5
4
3
2
1
0
ppm
1.00
6.04
1.01
1.00
3.04
9.07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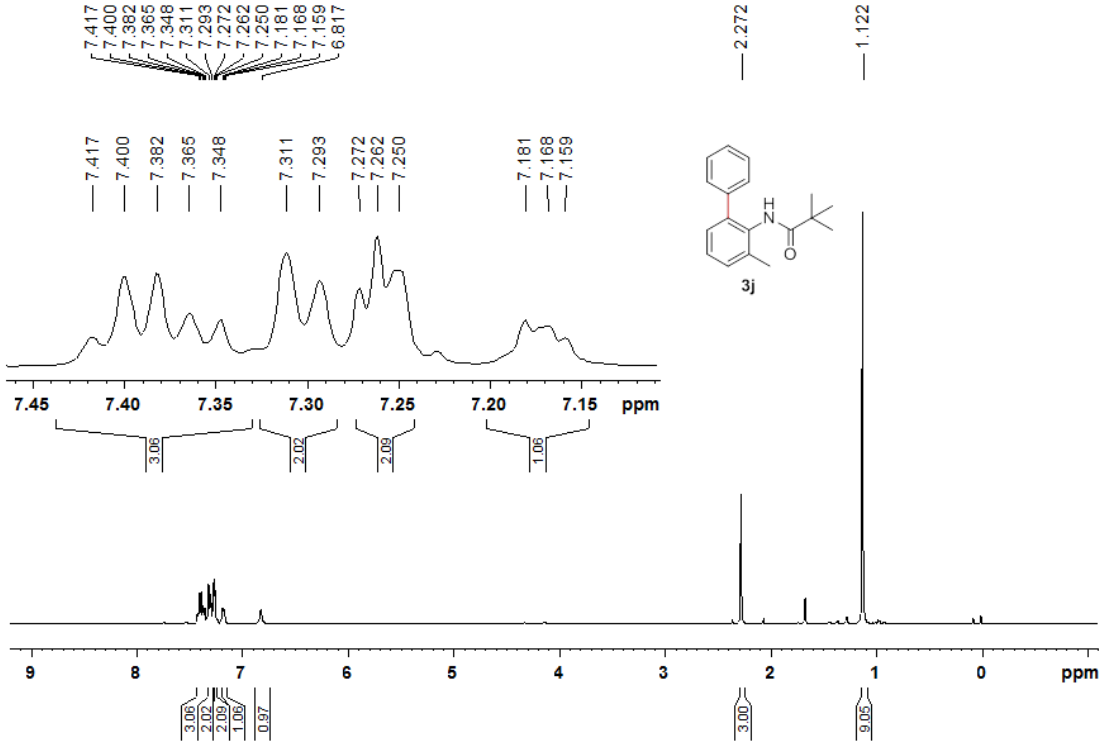
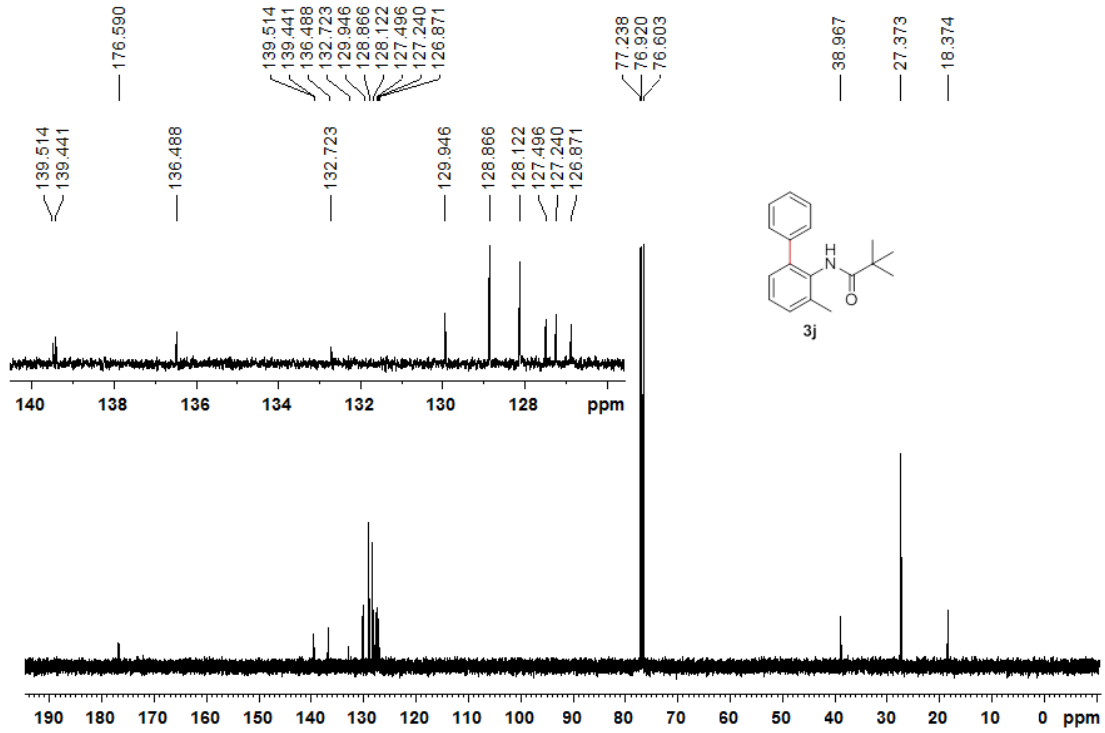
138.387
138.067
134.808
129.397
129.330
128.879
127.745
124.557
121.342
77.234
76.916
76.598
39.667
27.246
21.359
3i
130
129
128
127
126
125
124
123
122
121
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


7.417
7.400
7.382
7.365
7.348
7.311
7.293
7.272
7.262
7.250
7.181
7.168
7.159
6.817
2.272
1.122
3j
7.45
7.40
7.35
7.30
7.25
7.20
7.15
ppm
3.06
2.02
2.09
1.06
9
8
7
6
5
4
3
2
1
0
ppm
3.06
2.02
2.09
1.06
0.97
3.00
9.05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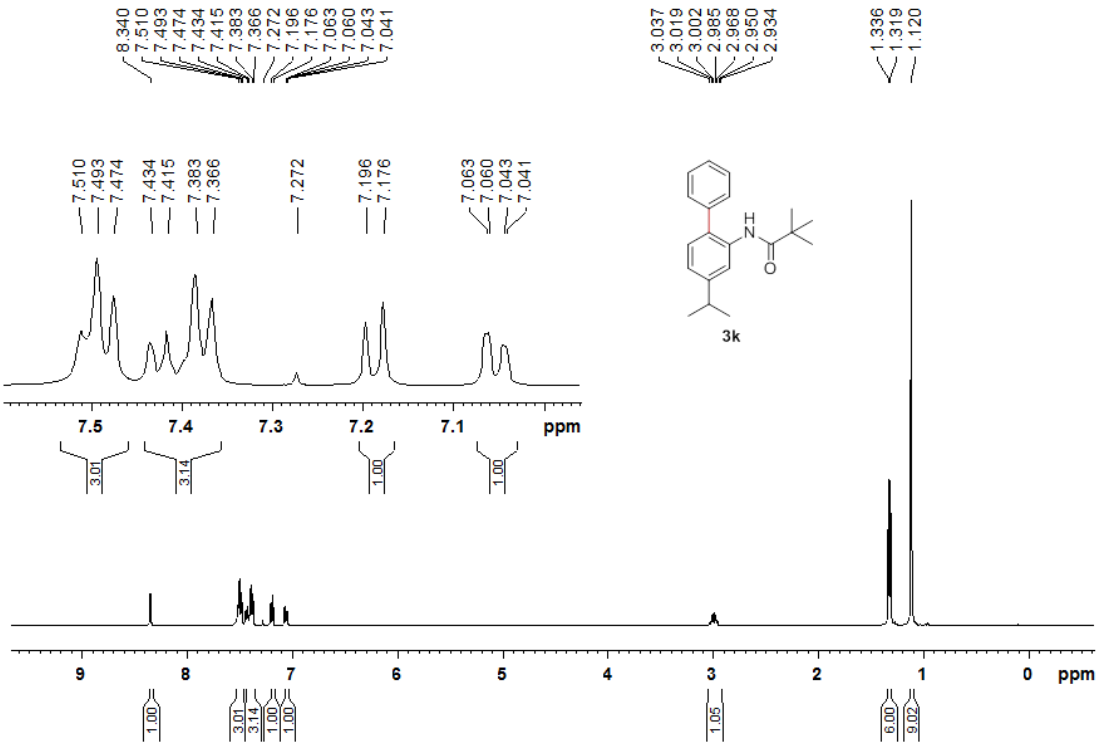
139.441
136.488
132.723
129.946
128.866
128.122
127.496
127.240
126.871
77.238
76.920
76.603
38.967
27.373
18.374
3j
140
138
136
134
132
130
128
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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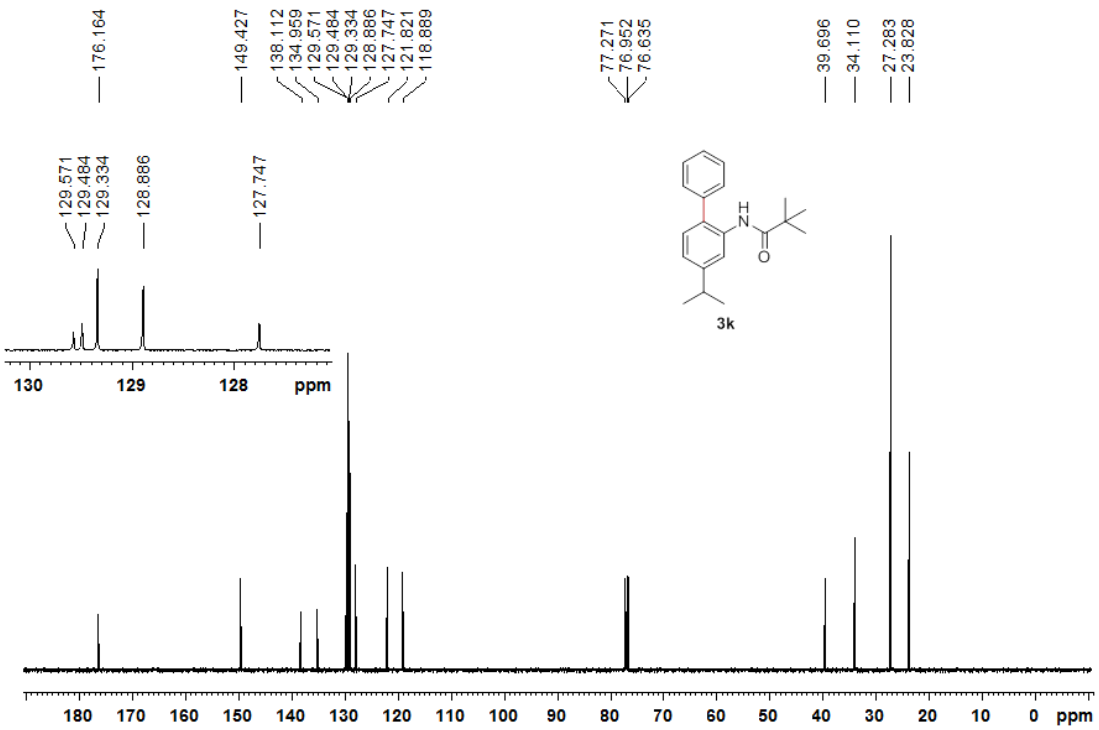
7.415
7.383
7.366
7.272
7.196
7.176
7.063
7.060
7.043
7.041
3.037
3.019
3.002
2.985
2.968
2.950
2.934
1.336
1.319
1.120
3k
ppm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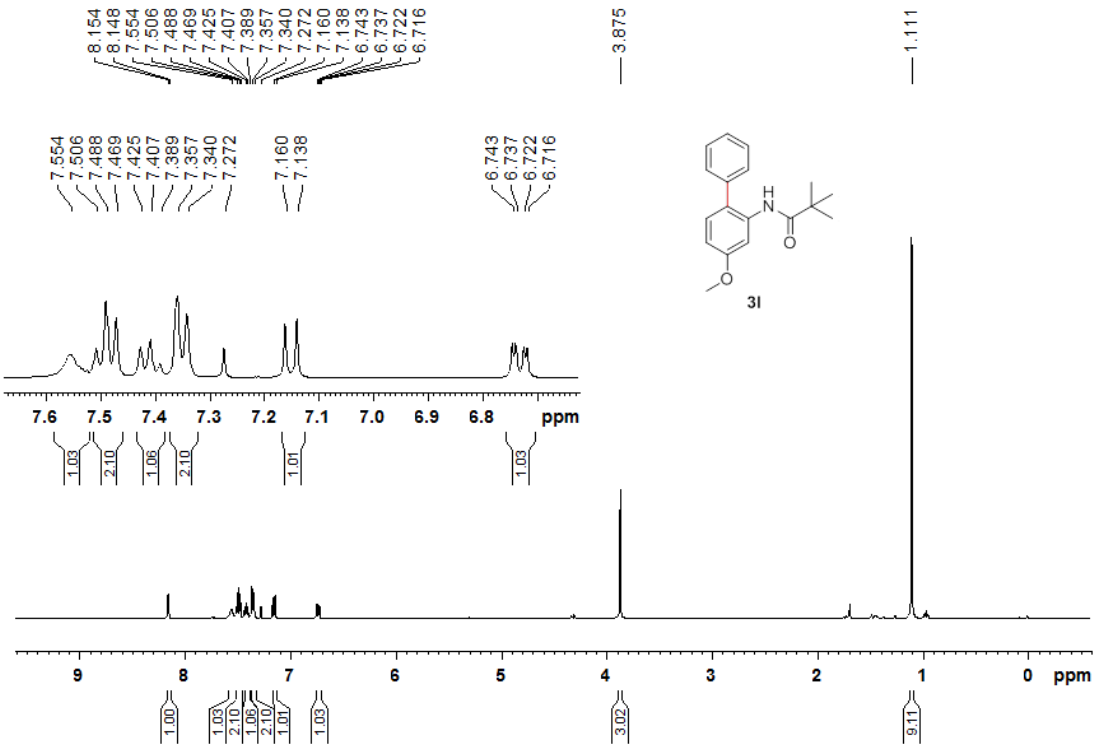
134.959
129.571
129.484
129.334
128.886
127.747
121.821
118.889
77.271
76.952
76.635
39.696
34.110
27.283
23.828
3k
ppm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7.506
7.488
7.469
7.425
7.407
7.389
7.357
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7.272
7.160
7.138
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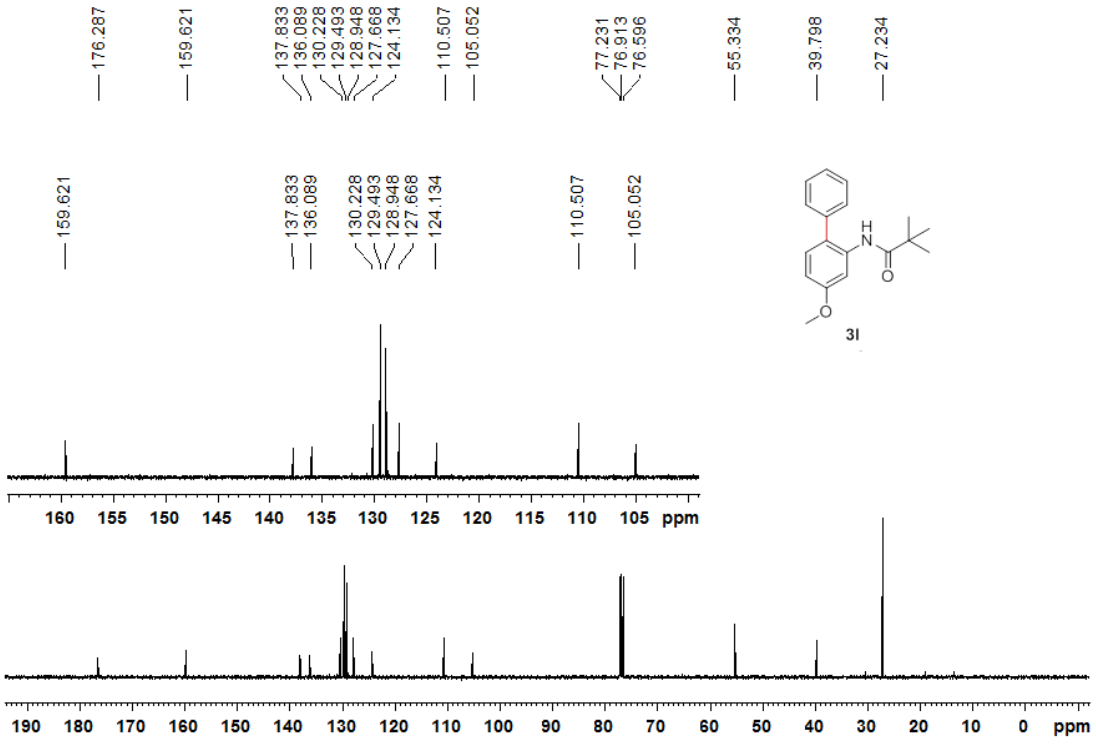
6.737
6.722
6.716
3.875
1.111
3l
ppm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129.493
128.948
127.668
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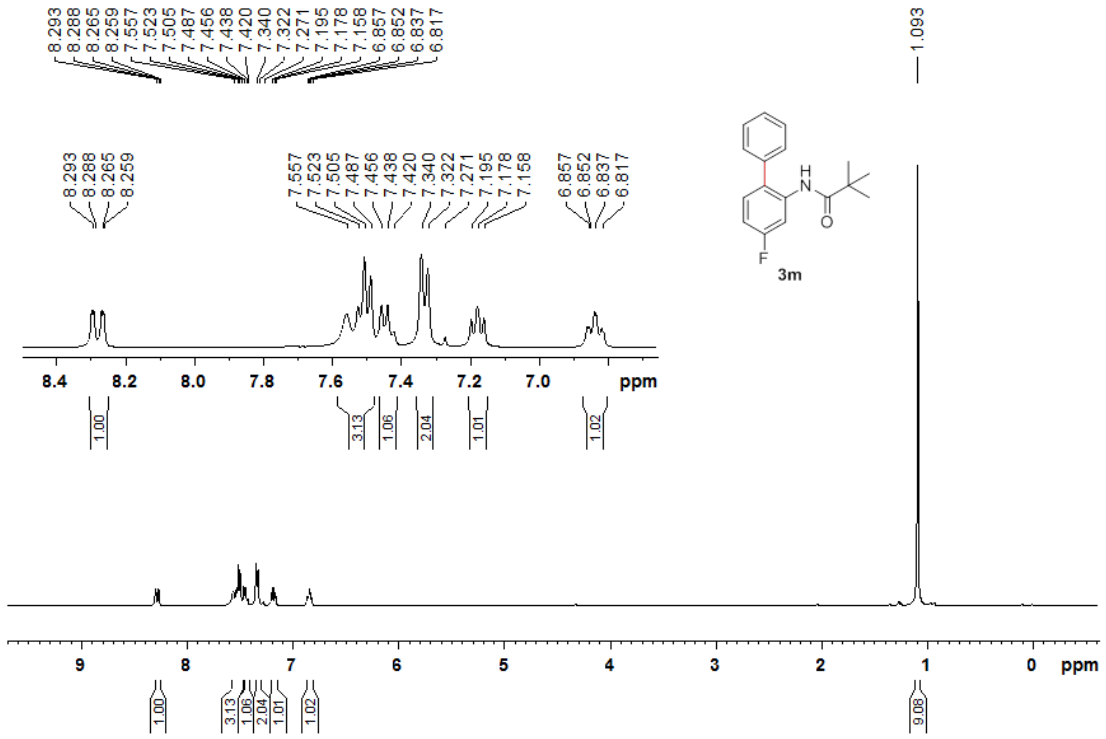
105.052
77.231
76.913
76.596
55.334
39.798
27.234
3l
ppm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8.265
8.259
7.557
7.523
7.505
7.487
7.456
7.438
7.420
7.340
7.322
7.271
7.195
7.178
7.158
6.857
6.852
6.837
6.817
1.093
3m
8.4
8.2
8.0
7.8
7.6
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7.2
7.0
ppm
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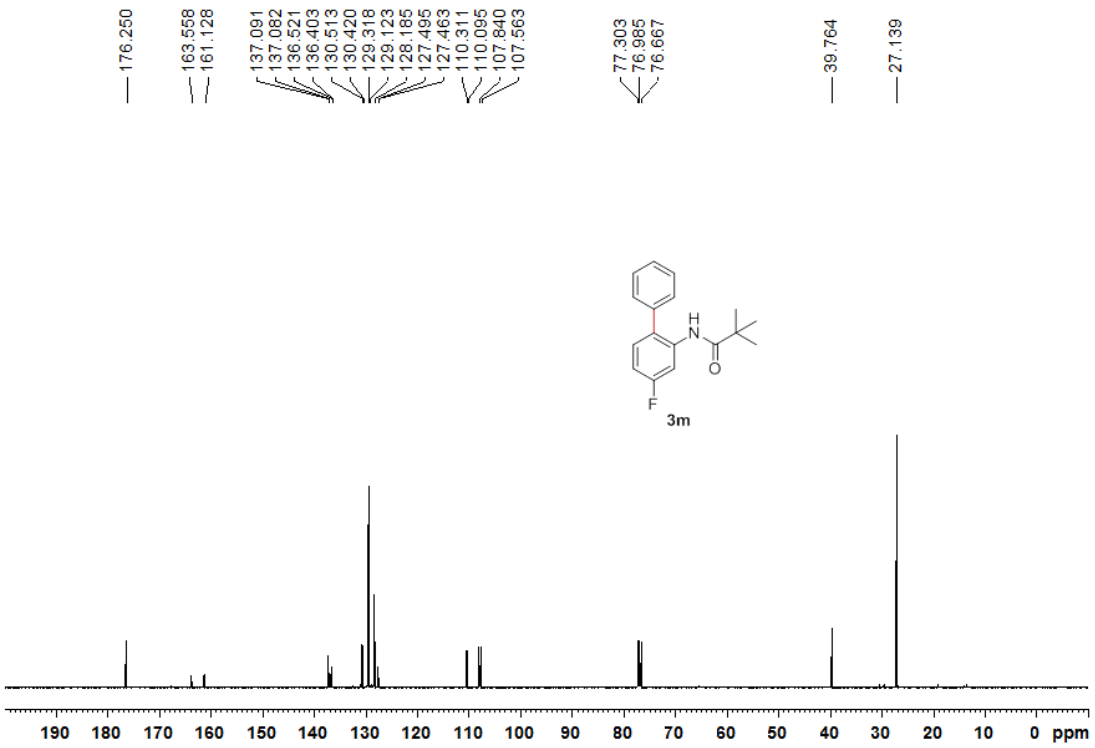
3.13
1.06
2.04
1.01
1.02
9.08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161.128
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136.521
136.403
130.513
130.420
129.318
129.123
128.185
127.495
127.463
110.311
110.095
107.840
107.563
77.303
76.985
76.667
39.764
27.139
3m
190
180
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140
130
120
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100
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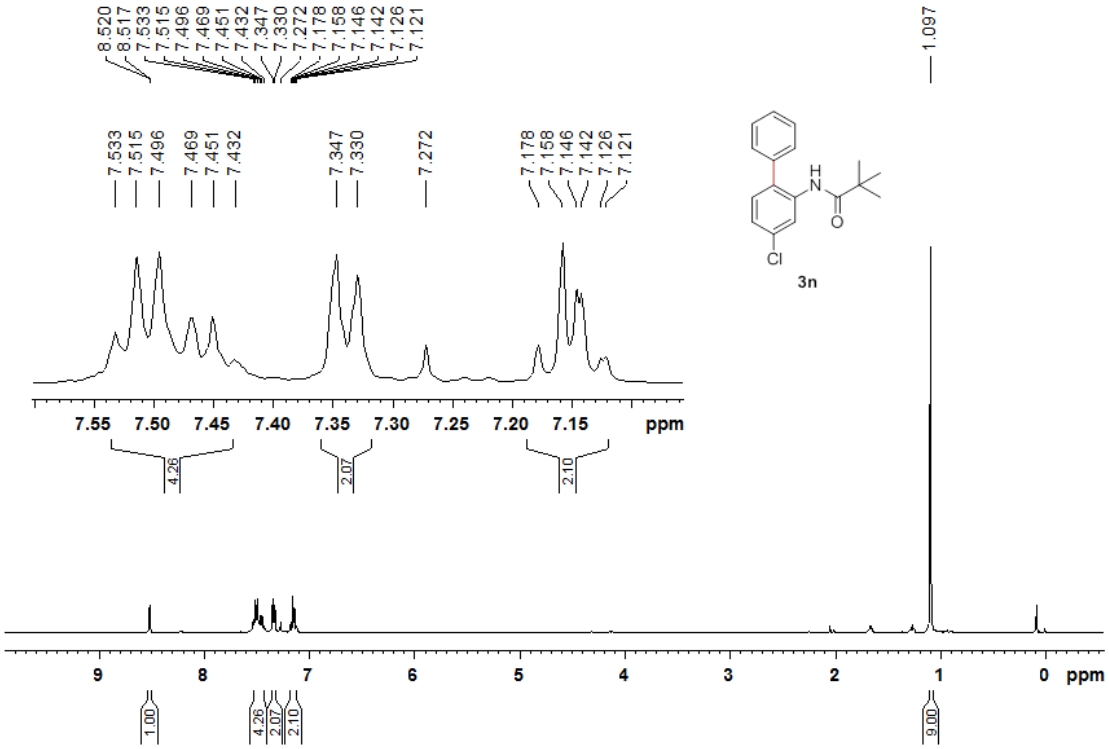
80
70
60
50
40
30
20
10
0
ppm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7.515
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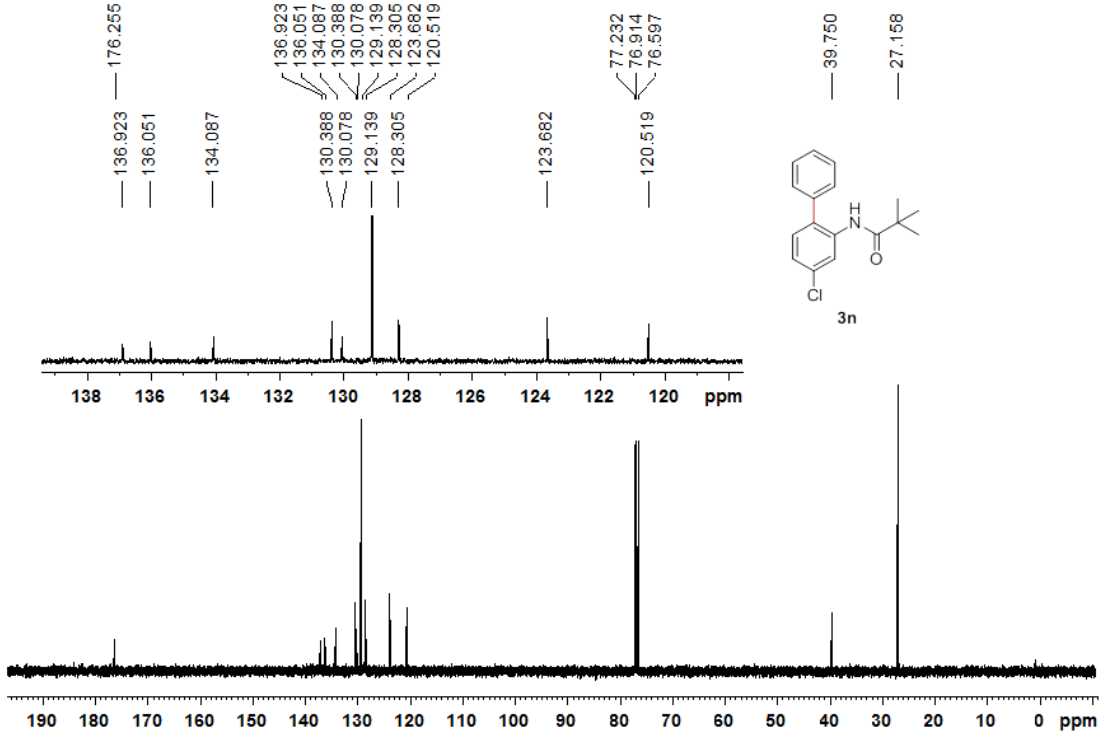
7.469
7.451
7.432
7.347
7.330
7.272
7.178
7.158
7.146
7.142
7.126
7.121
1.097
3n
7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 ppm
4.26
2.07
2.10
9 8 7 6 5 4 3 2 1 0 ppm
1.00
4.26
2.07
2.10
9.00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136.051
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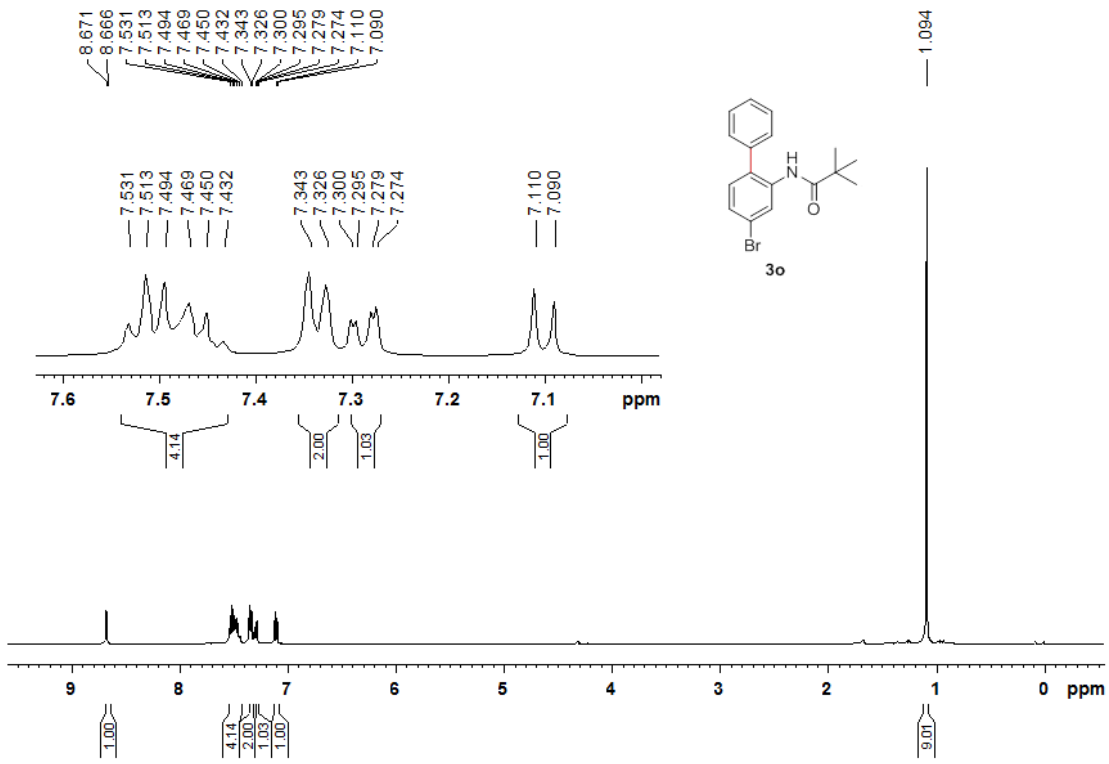
130.078
129.139
128.305
123.682
120.519
77.232
76.914
76.597
39.750
27.158
3n
138 136 134 132 130 128 126 124 122 120 ppm
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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7.432
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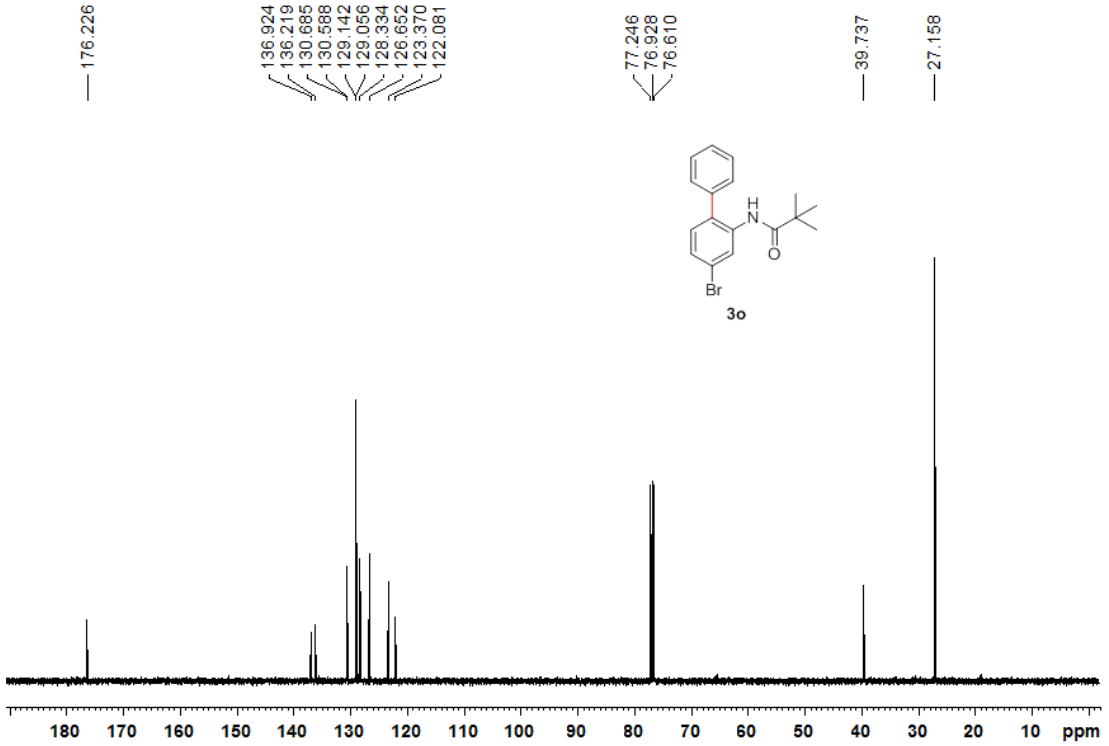
7.295
7.279
7.274
7.110
7.090
1.094
Br
3o
7.6
7.5
7.4
7.3
7.2
7.1
ppm
4.14
2.00
1.03
1.00
9
8
7
6
5
4
3
2
1
0
ppm
1.00
4.14
2.00
1.03
1.00
9.01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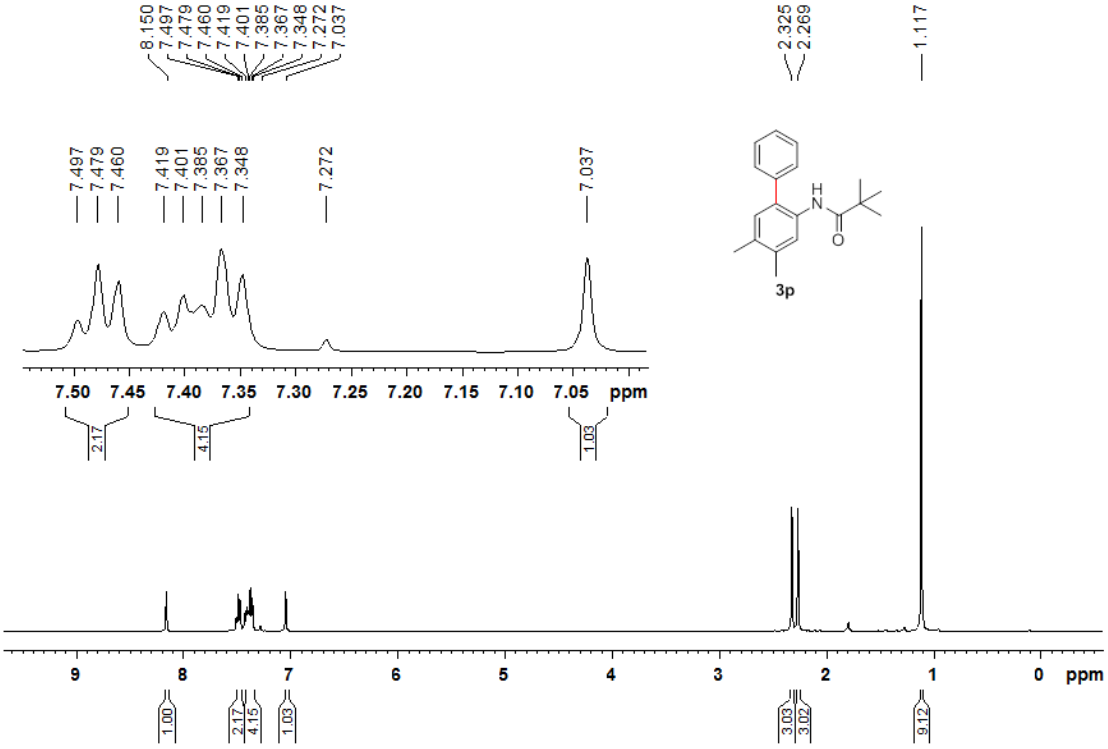
130.588
129.142
129.056
128.334
126.652
123.370
122.081
77.246
76.928
76.610
39.737
27.158
Br
3o
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm


8.150
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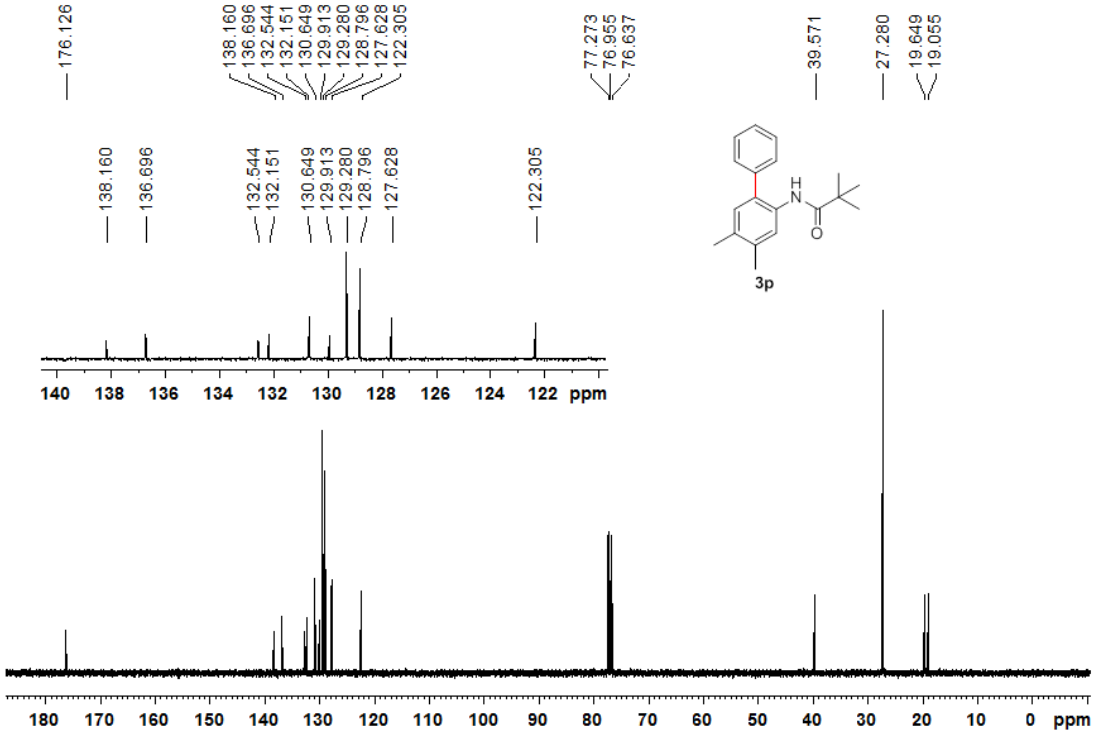
7.401
7.385
7.367
7.348
7.272
7.037
2.325
2.269
1.117
3p
7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 7.05 ppm
2.17
4.15
1.03
9 8 7 6 5 4 3 2 1 0 ppm
1.00
2.17
4.15
1.03
3.03
3.02
9.12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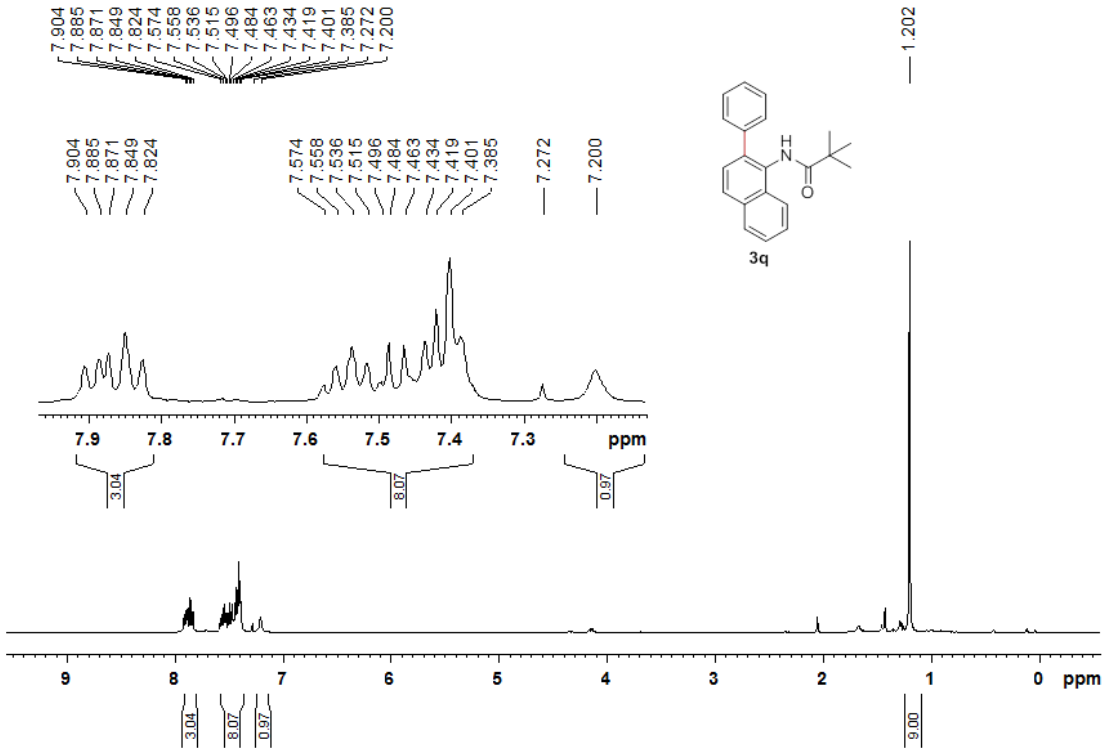
138.160
136.696
132.544
132.151
130.649
129.913
129.280
128.796
127.628
122.305
77.273
76.955
76.637
39.571
27.280
19.649
19.055
3p
140 138 136 134 132 130 128 126 124 122 ppm
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm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7.885
7.871
7.849
7.824
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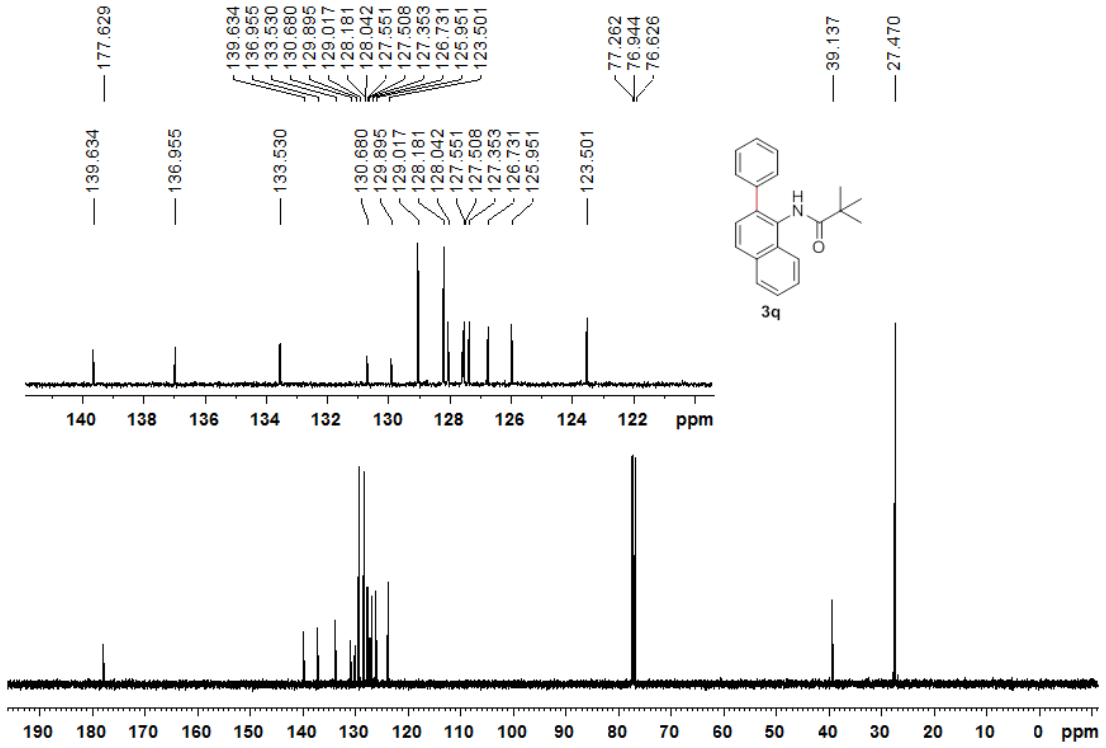
7.558
7.536
7.515
7.496
7.484
7.463
7.434
7.419
7.401
7.385
7.272
7.200
1.202
3q
7.9
7.8
7.7
7.6
7.5
7.4
7.3
ppm
3.04
8.07
0.97
9
8
7
6
5
4
3
2
1
0
ppm
3.04
8.07
0.97
9.00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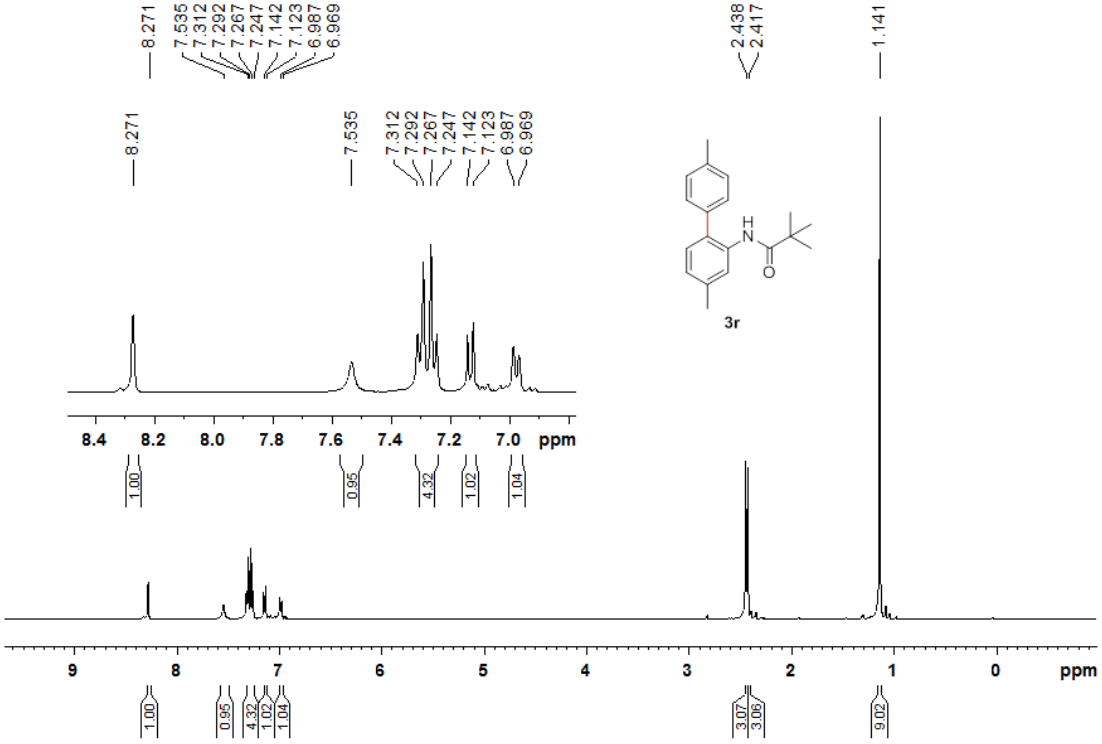
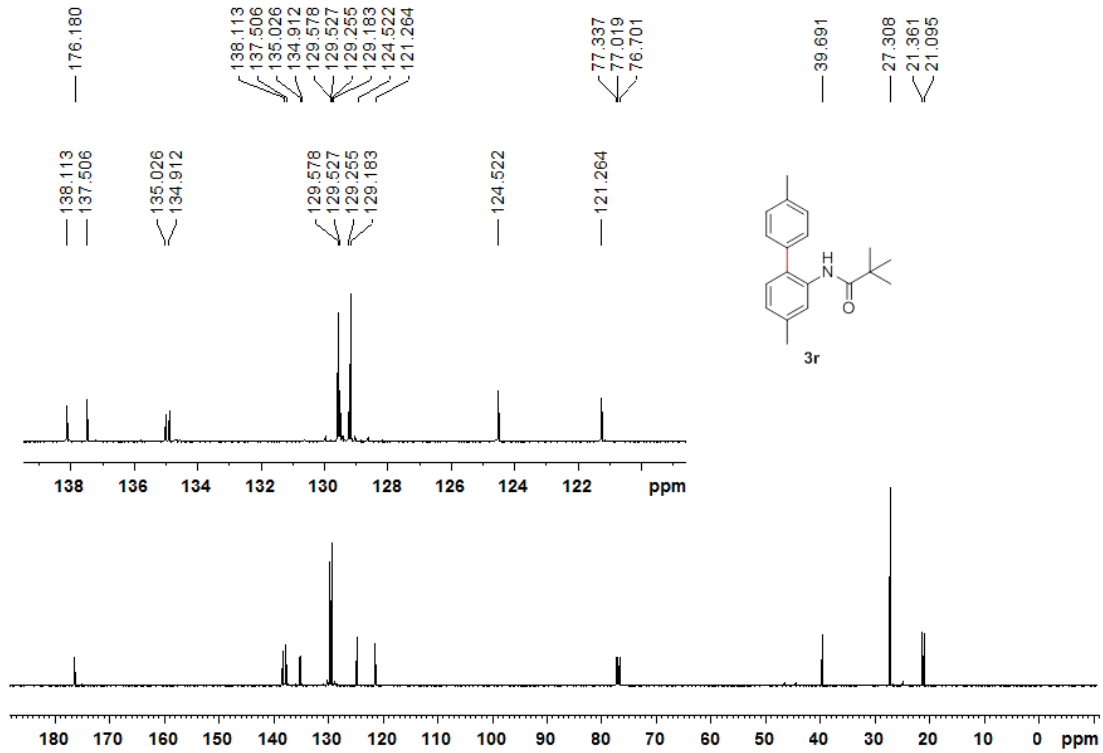
136.955
133.530
130.680
129.895
129.017
128.181
128.042
127.551
127.508
127.353
126.731
125.951
123.501
77.262
76.944
76.626
39.137
27.470
3q
140
138
136
134
132
130
128
126
124
122
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


8.271
7.535
7.312
7.292
7.267
7.247
7.142
7.123
6.987
6.969
2.438
2.417
1.141
3r
ppm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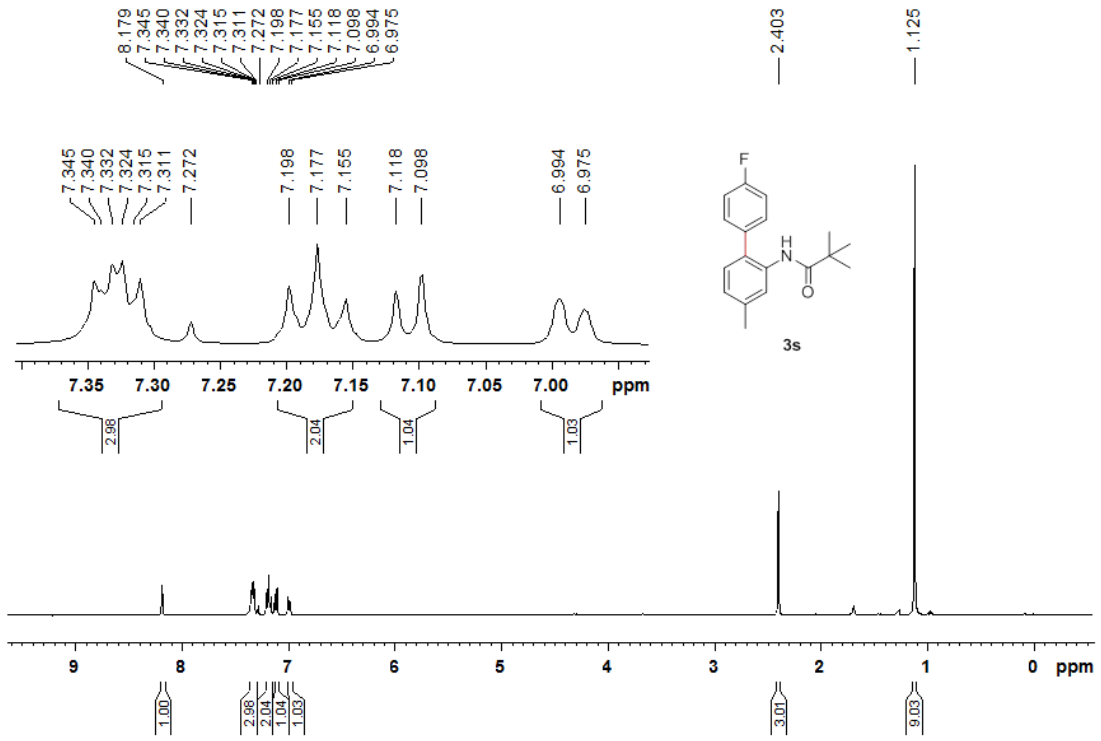
138.113
137.506
135.026
134.912
129.578
129.527
129.255
129.183
124.522
121.264
77.337
77.019
76.701
39.691
27.308
21.361
21.095
3r
ppm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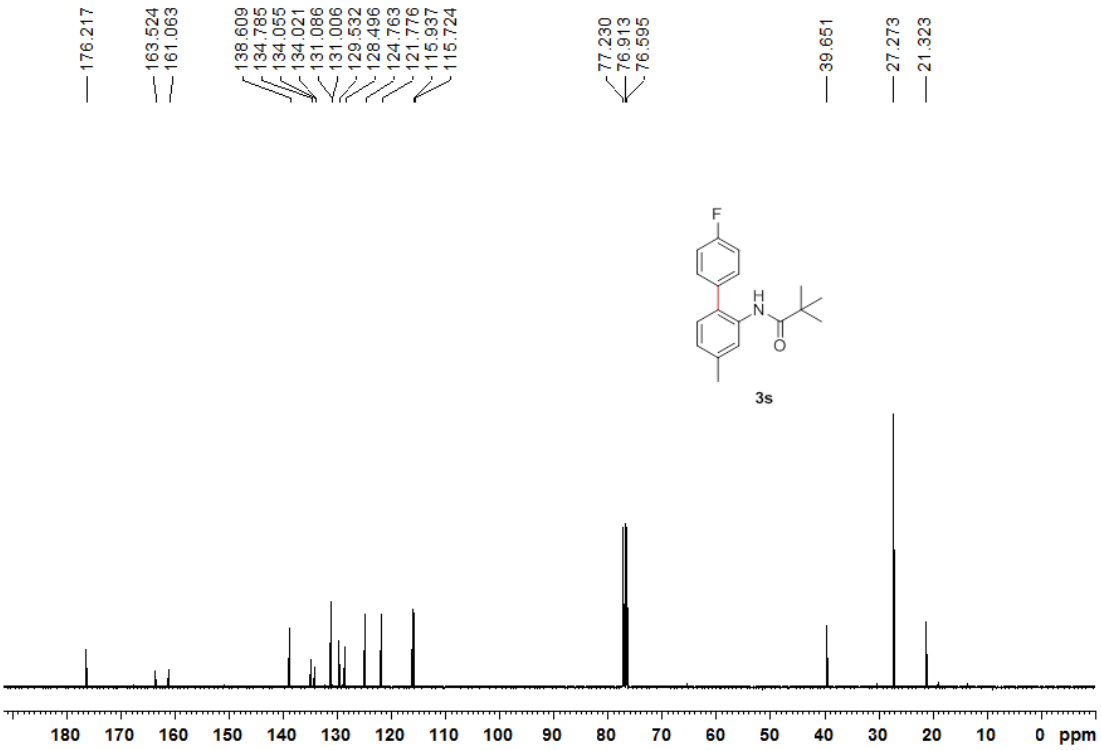
7.345
7.340
7.332
7.324
7.315
7.311
7.272
7.198
7.177
7.155
7.118
7.098
6.994
6.975
2.403
1.125
F
N
H
O
3s
7.35
7.30
7.25
7.20
7.15
7.10
7.05
7.00
ppm
2.96
2.04
1.04
1.03
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.98
2.04
1.04
1.03
3.01
9.03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163.524
161.063
138.609
134.785
134.055
134.021
131.086
131.006
129.532
128.496
124.763
121.776
115.937
115.724
77.230
76.913
76.595
39.651
27.273
21.323
F
N
H
O
3s
180
170
160
150
140
130
120
110
100
90
80
70
60
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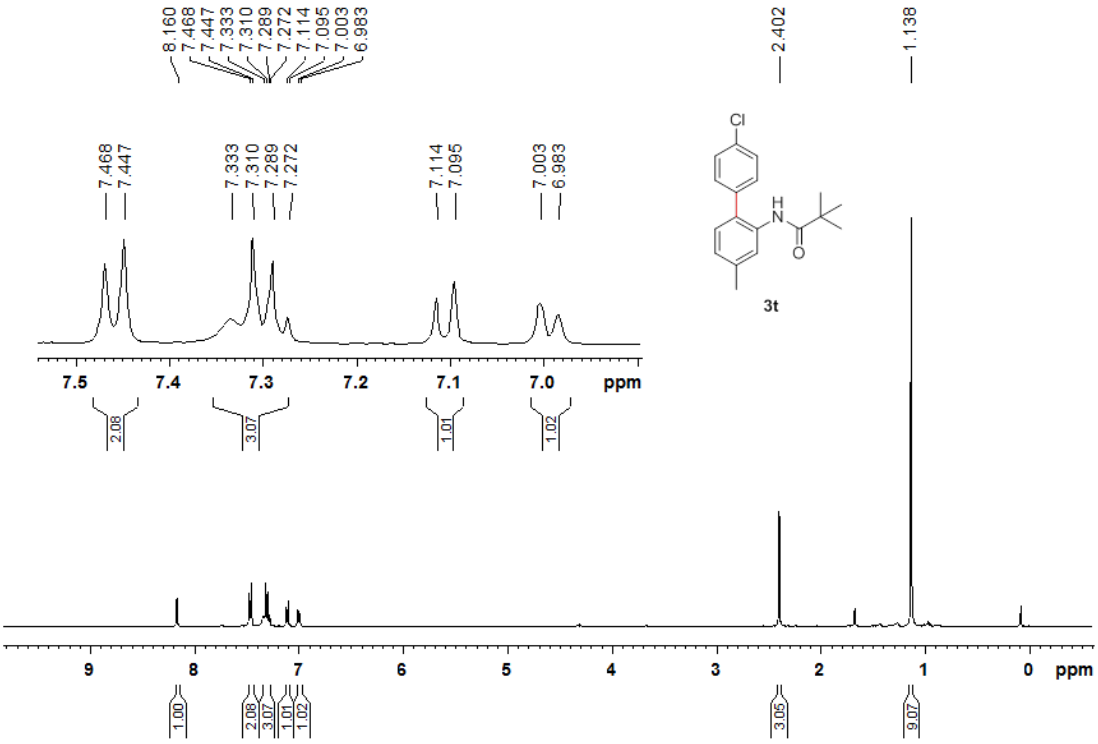
40
30
20
10
0
ppm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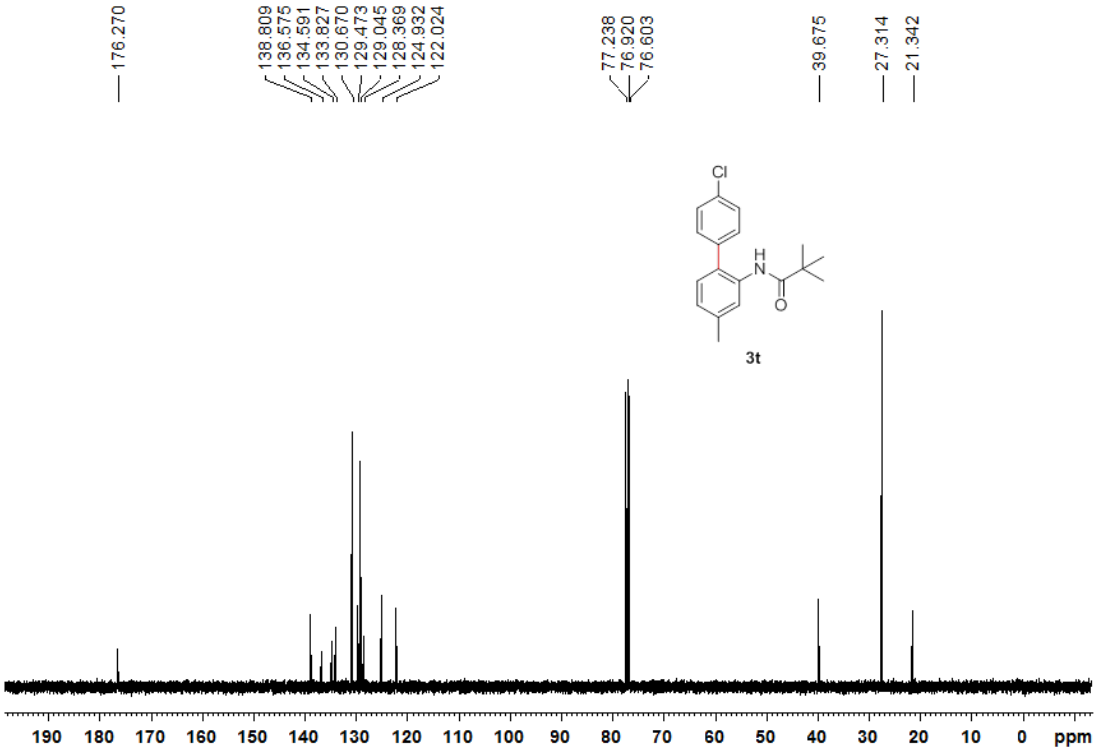
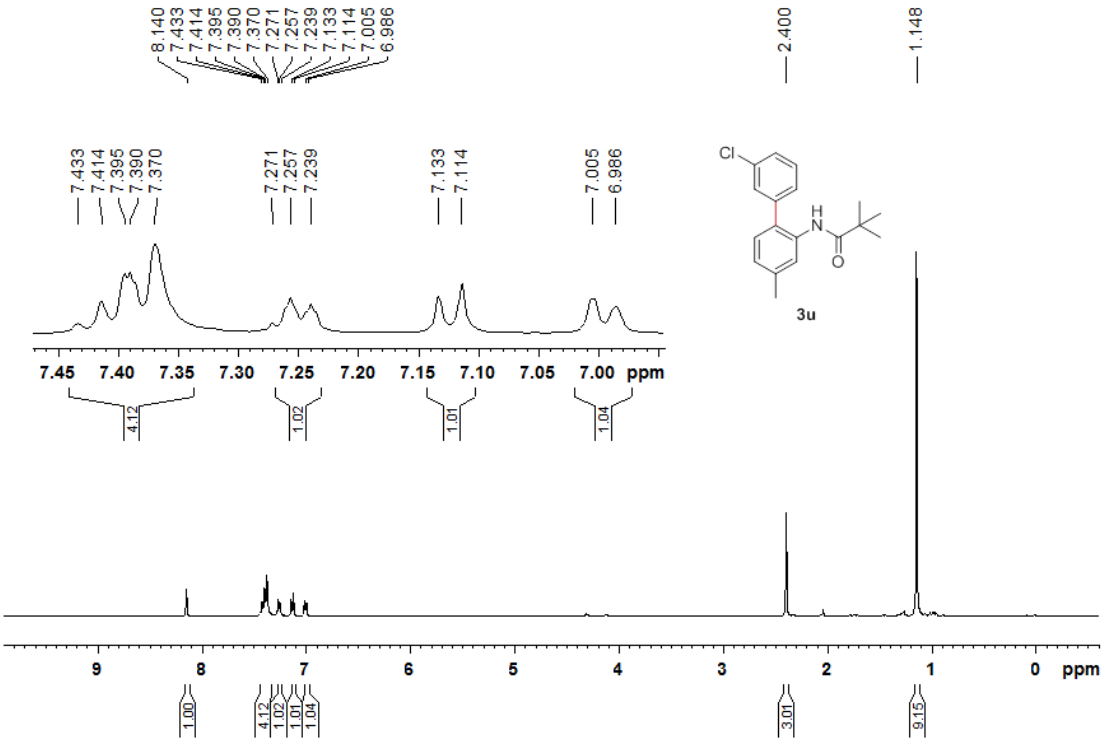
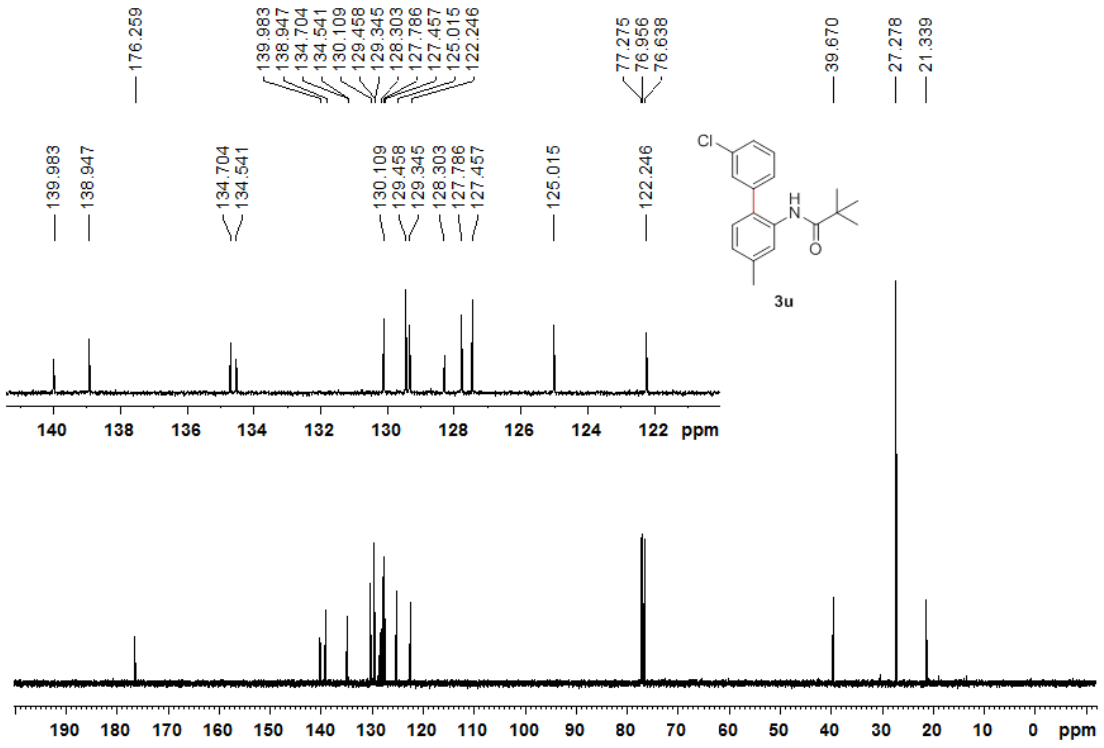
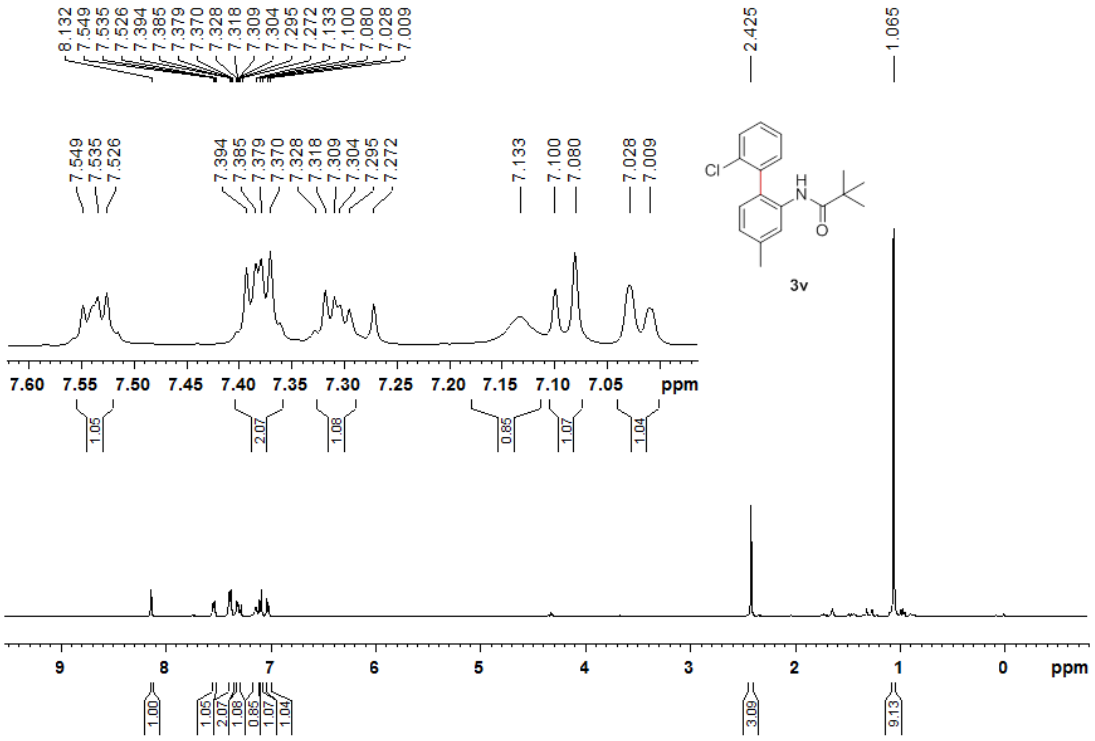
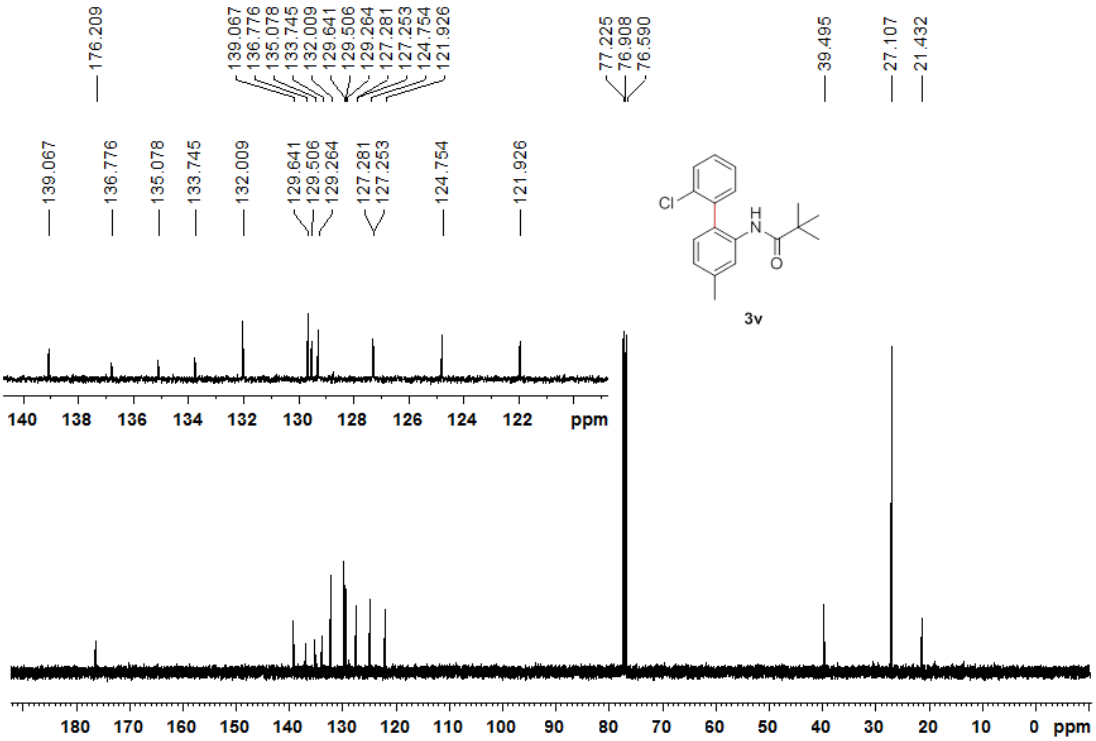
7.468
7.447
7.333
7.310
7.289
7.272
7.114
7.095
7.003
6.983
2.402
1.138
Cl
H
N
O
3t
7.5
7.4
7.3
7.2
7.1
7.0
ppm
2.08
3.07
1.01
1.02
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.08
3.07
1.01
1.02
3.05
9.07


176.270
138.809
136.575
134.591
133.827
130.670
129.473
129.045
128.369
124.932
122.024
77.238
76.920
76.603
39.675
27.314
21.342
Cl
H
N
O
3t
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


8.140
7.433
7.414
7.395
7.390
7.370
7.271
7.257
7.239
7.133
7.114
7.005
6.986
2.400
1.148
Cl
N
H
O
3u
7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 7.05 7.00 ppm
4.12
1.02
1.01
1.04
9 8 7 6 5 4 3 2 1 0 ppm
1.00
4.12
1.02
1.01
1.04
3.01
9.15


176.259
139.983
138.947
134.704
134.541
130.109
129.458
129.345
128.303
127.786
127.457
125.015
122.246
77.275
76.956
76.638
39.670
27.278
21.339
Cl
N
H
O
3u
140 138 136 134 132 130 128 126 124 122 ppm
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


8.132
7.549
7.535
7.526
7.394
7.385
7.379
7.370
7.328
7.318
7.309
7.304
7.295
7.272
7.133
7.100
7.080
7.028
7.009
2.425
1.065
Cl
N
H
O
3v
7.60 7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 7.05 ppm
1.05
2.07
1.08
0.85
1.07
1.04
9 8 7 6 5 4 3 2 1 0 ppm
1.00
3.09
9.13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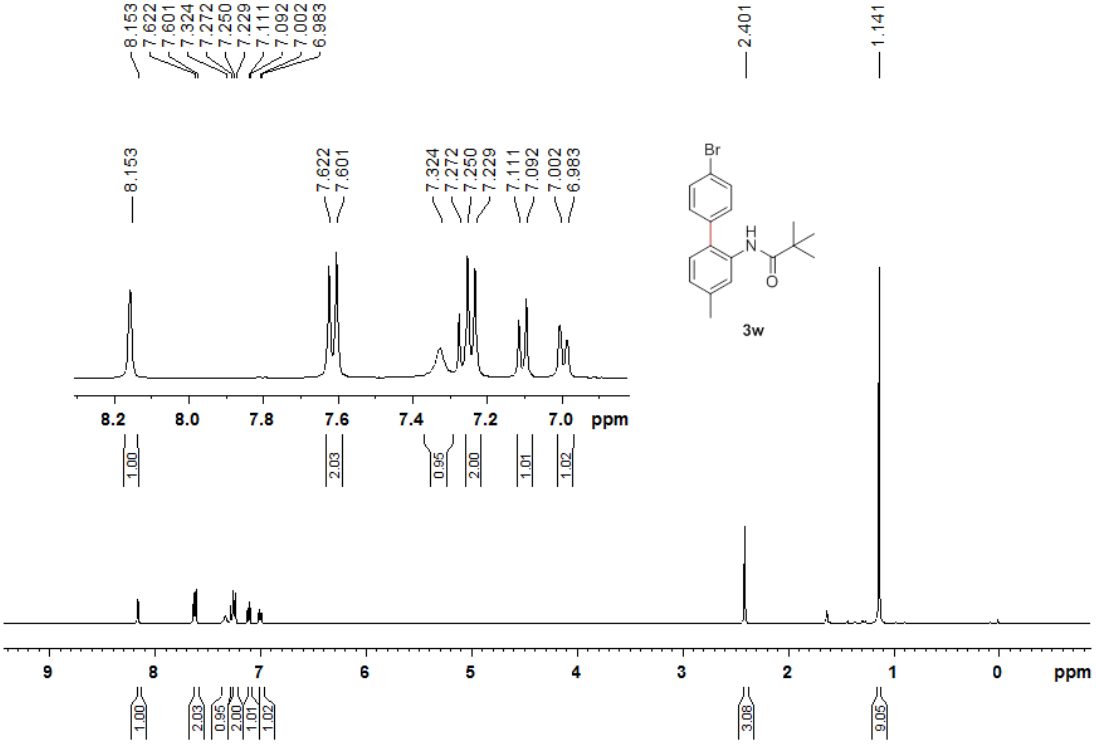
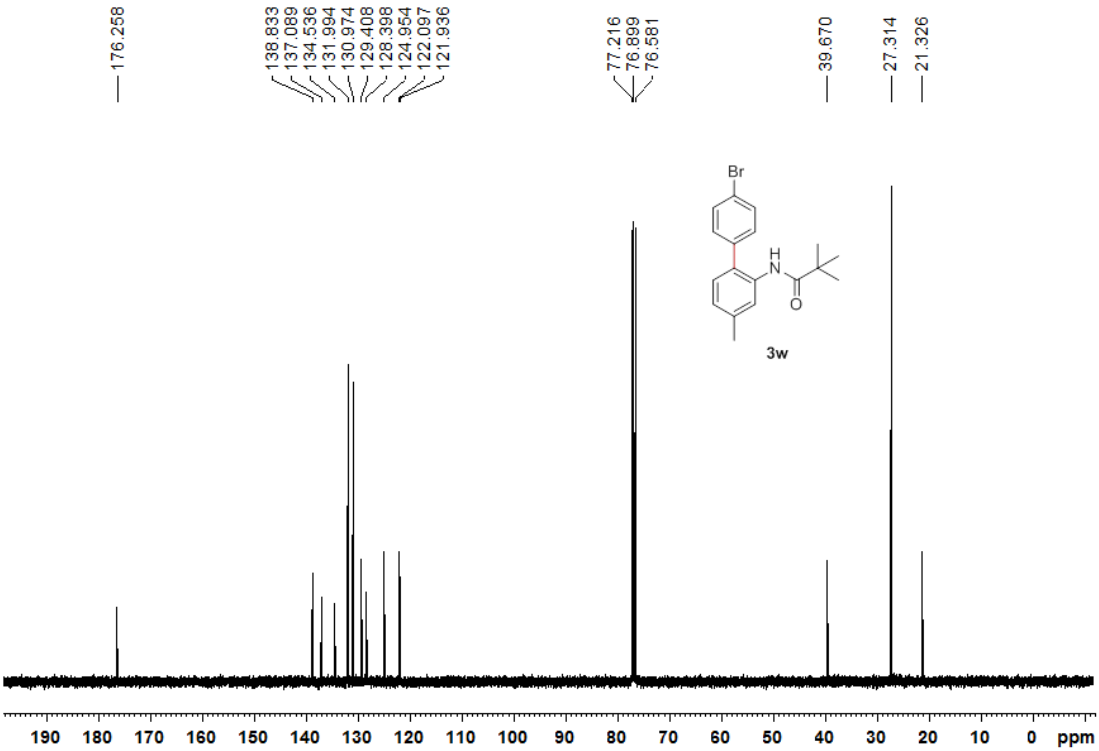
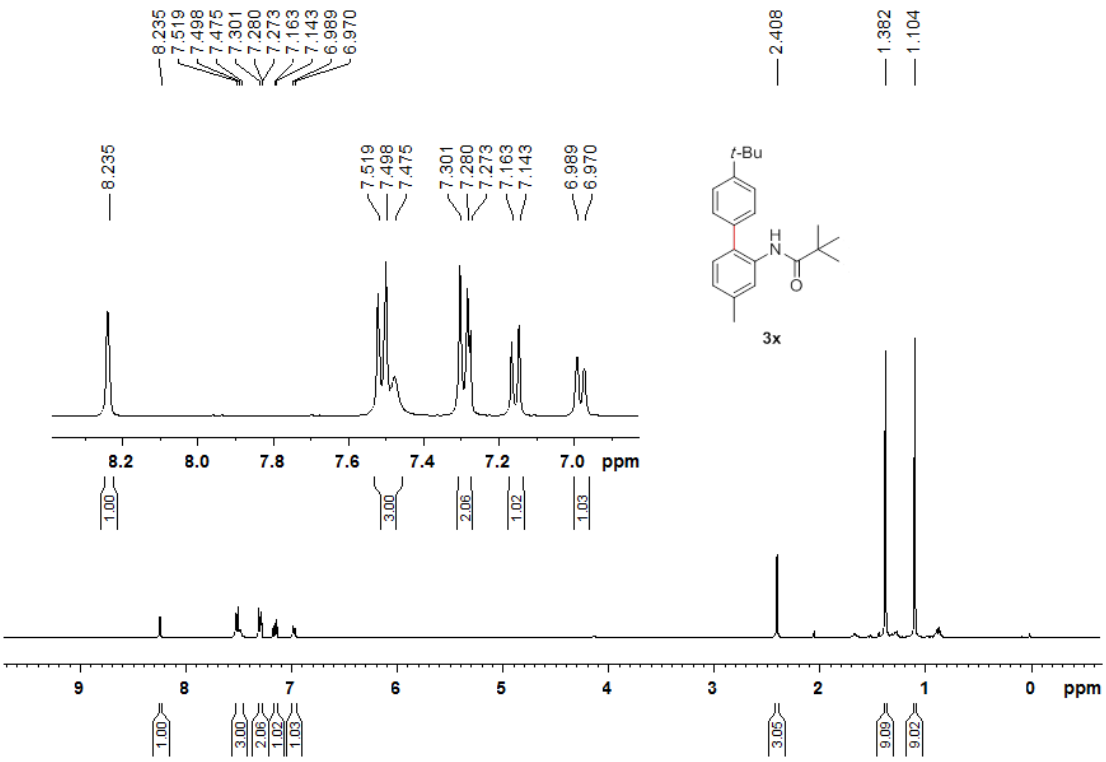
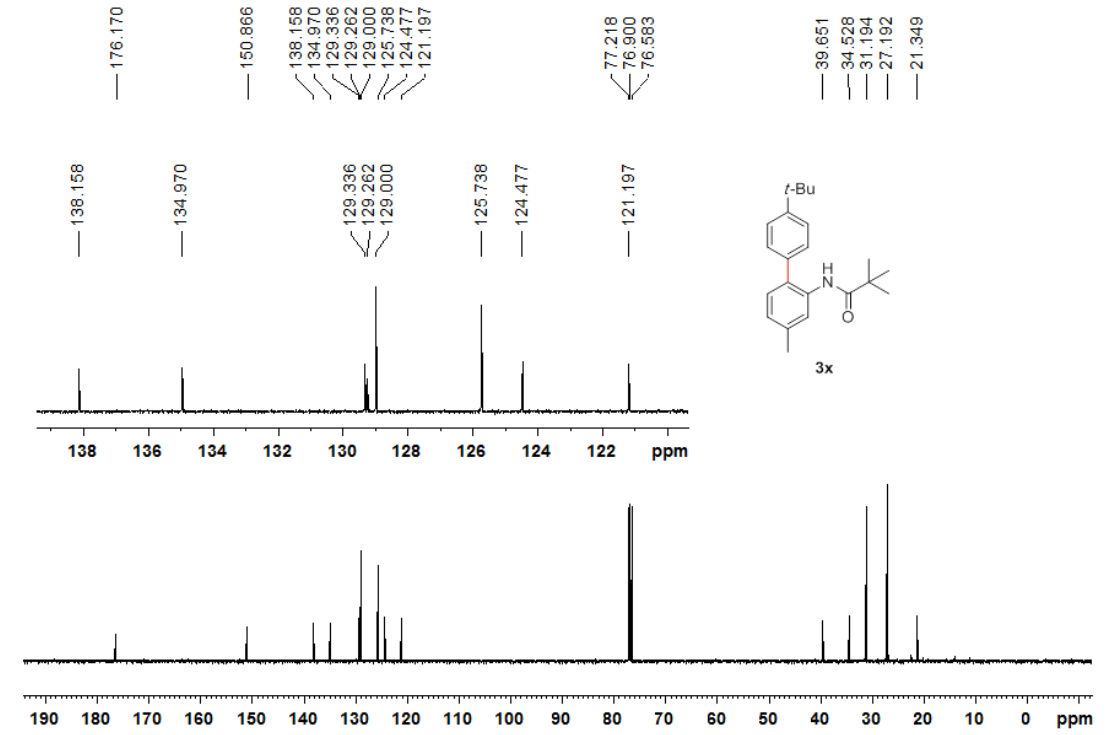
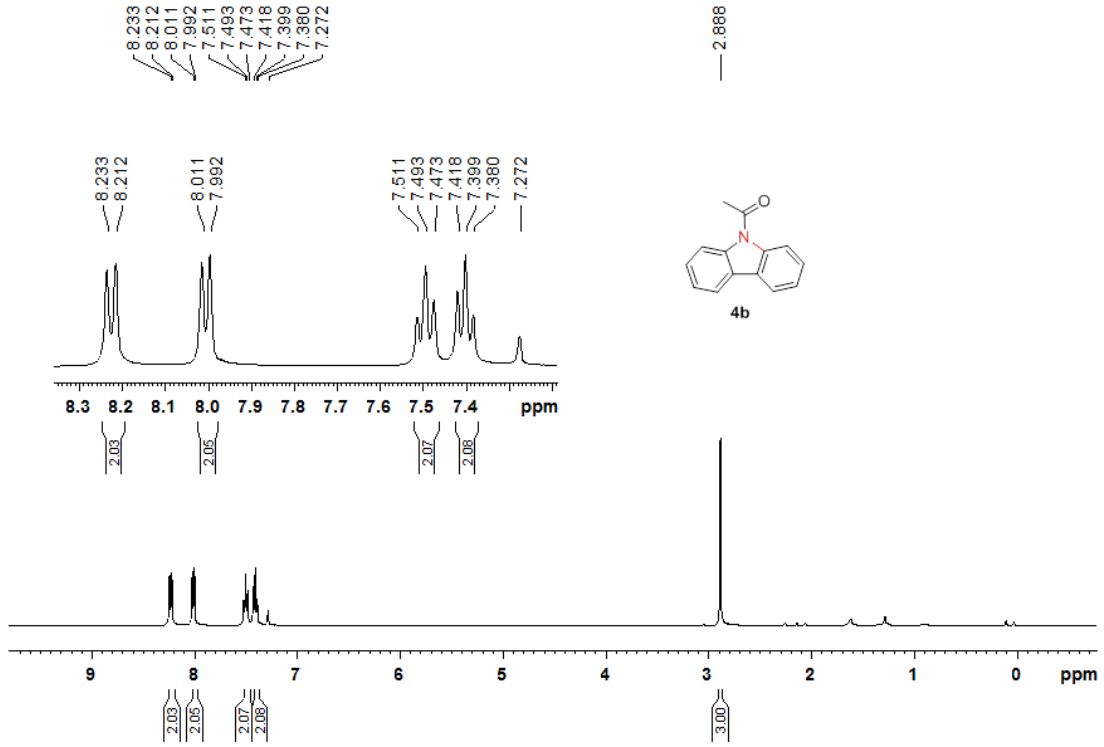
136.776
135.078
133.745
132.009
129.641
129.506
129.264
127.281
127.253
124.754
121.926
77.225
76.908
76.590
39.495
27.107
21.432
Cl
N
H
O
3v
140 138 136 134 132 130 128 126 124 122 ppm
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

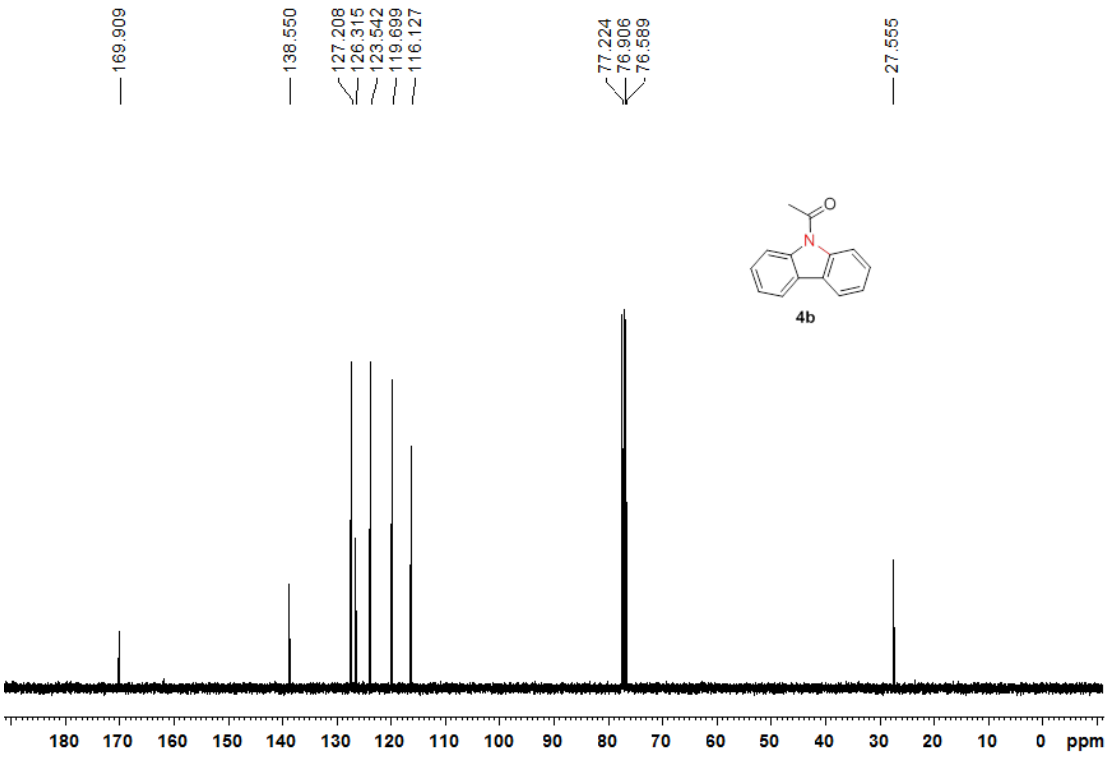

8.153
7.622
7.601
7.324
7.272
7.250
7.229
7.111
7.092
7.002
6.983
2.401
1.141
Br
N
H
O
3w
ppm


176.258
138.833
137.089
134.536
131.994
130.974
129.408
128.398
124.954
122.097
121.936
77.216
76.899
76.581
39.670
27.314
21.326
Br
N
H
O
3w
ppm


8.235
7.519
7.498
7.475
7.301
7.280
7.273
7.163
7.143
6.989
6.970
2.408
1.382
1.104
t-Bu
H
N
O
3x
8.2
8.0
7.8
7.6
7.4
7.2
7.0
ppm
1.00
3.00
2.06
1.02
1.03
9
8
7
6
5
4
3
2
1
0
ppm
1.00
3.00
2.06
1.02
1.03
3.05
9.09
9.02


176.170
150.866
138.158
134.970
129.336
129.262
129.000
125.738
124.477
121.197
77.218
76.900
76.583
39.651
34.528
31.194
27.192
21.349
138.158
134.970
129.336
129.262
129.000
125.738
124.477
121.197
t-Bu
H
N
O
3x
138
136
134
132
130
128
126
124
122
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


8.233
8.212
8.011
7.992
7.511
7.493
7.473
7.418
7.399
7.380
7.272
2.888
4b
8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 ppm
2.03
2.05
2.07
2.08
9 8 7 6 5 4 3 2 1 0 ppm
3.00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126.315
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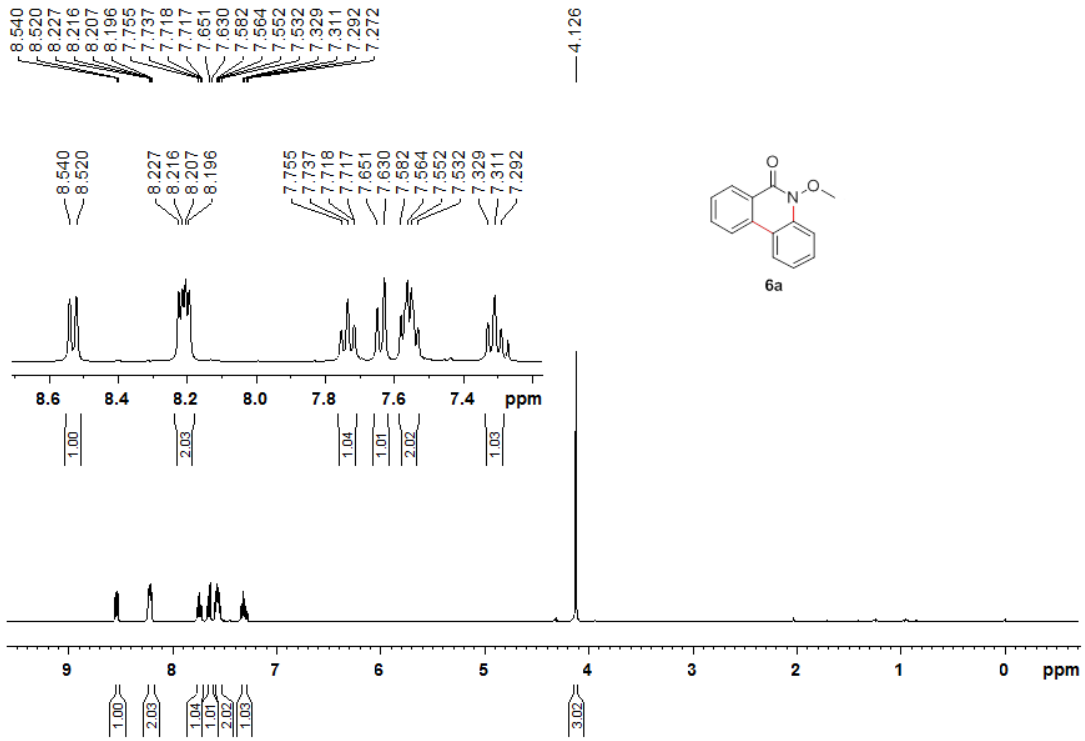
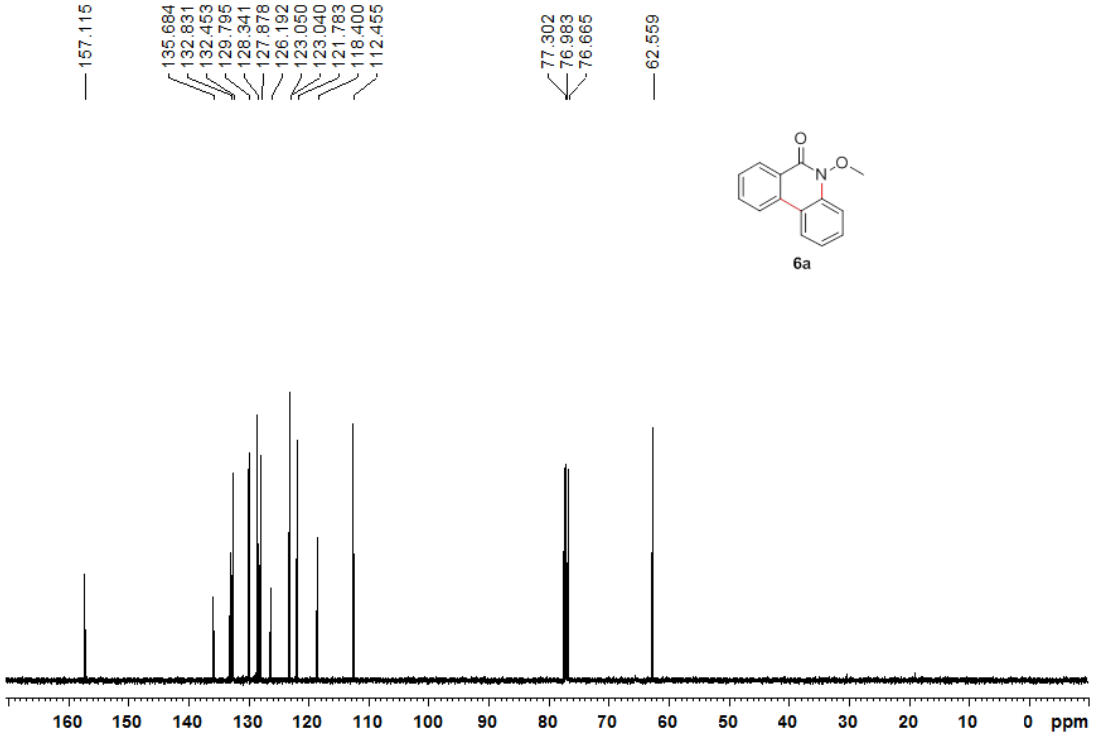
119.699
116.127
77.224
76.906
76.589
27.555
4b
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


8.540
8.520
8.227
8.216
8.207
8.196
7.755
7.737
7.718
7.717
7.651
7.630
7.582
7.564
7.552
7.532
7.329
7.311
7.292
7.272
4.126
6a
ppm
1.00
2.03
1.04
1.01
2.02
1.03
3.02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132.453
129.795
128.341
127.878
126.192
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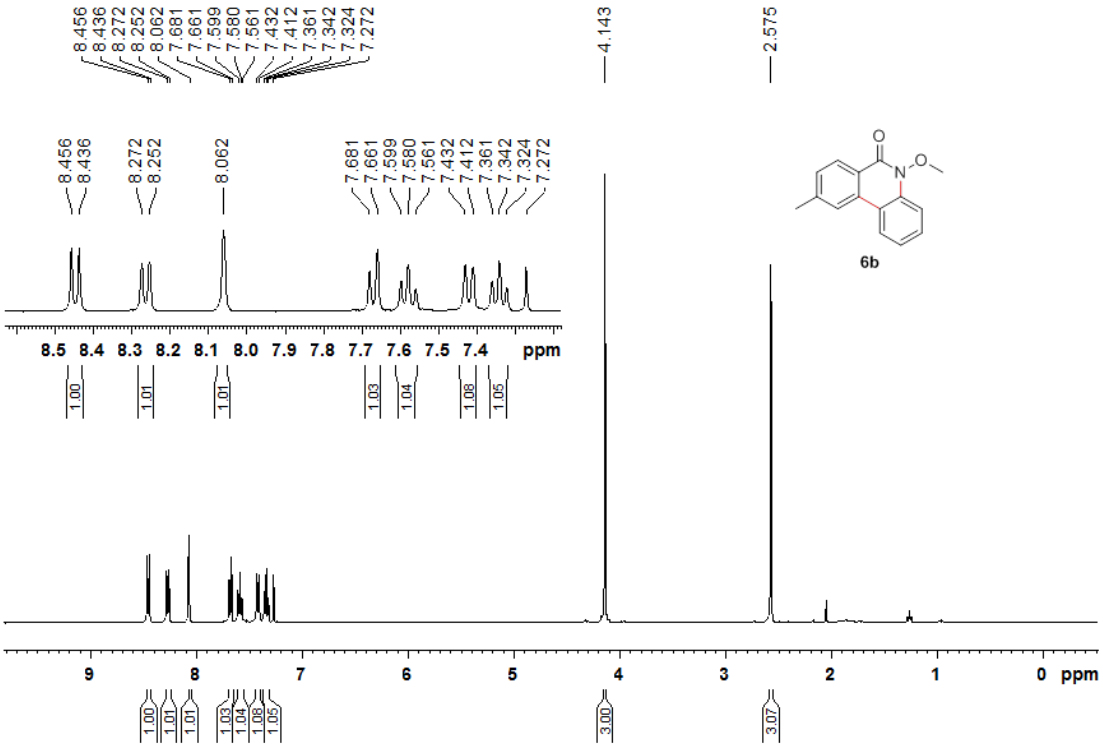
123.040
121.783
118.400
112.455
77.302
76.983
76.665
62.559
6a
ppm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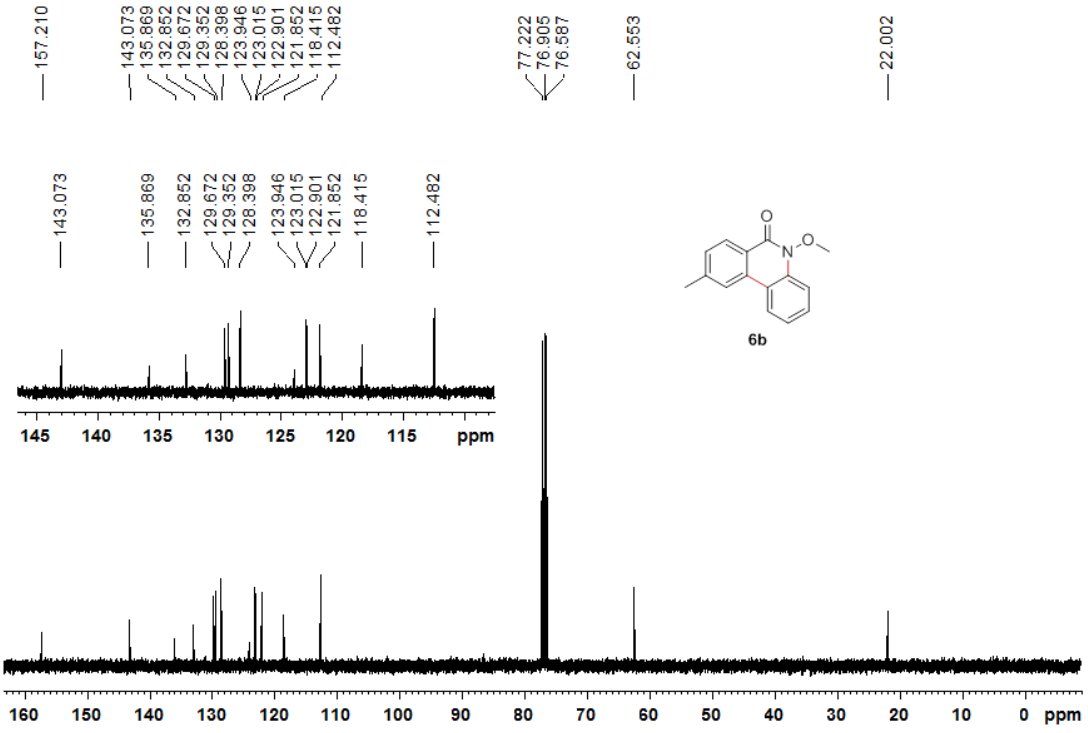
8.436
8.272
8.252
8.062
7.681
7.661
7.599
7.580
7.561
7.432
7.412
7.361
7.342
7.324
7.272
4.143
2.575
6b
ppm
1.00
1.01
1.01
1.03
1.04
1.08
1.05
3.00
3.07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143.073
135.869
132.852
129.672
129.352
128.398
123.946
123.015
122.901
121.852
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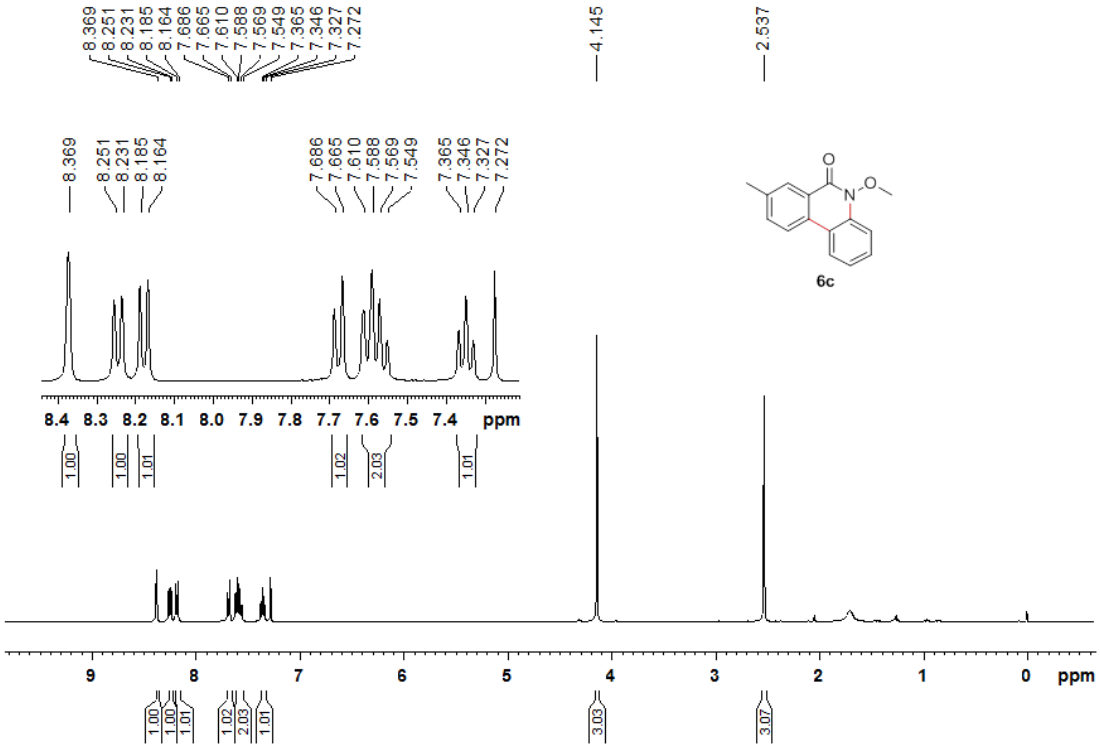
76.905
76.587
62.553
22.002
6b
ppm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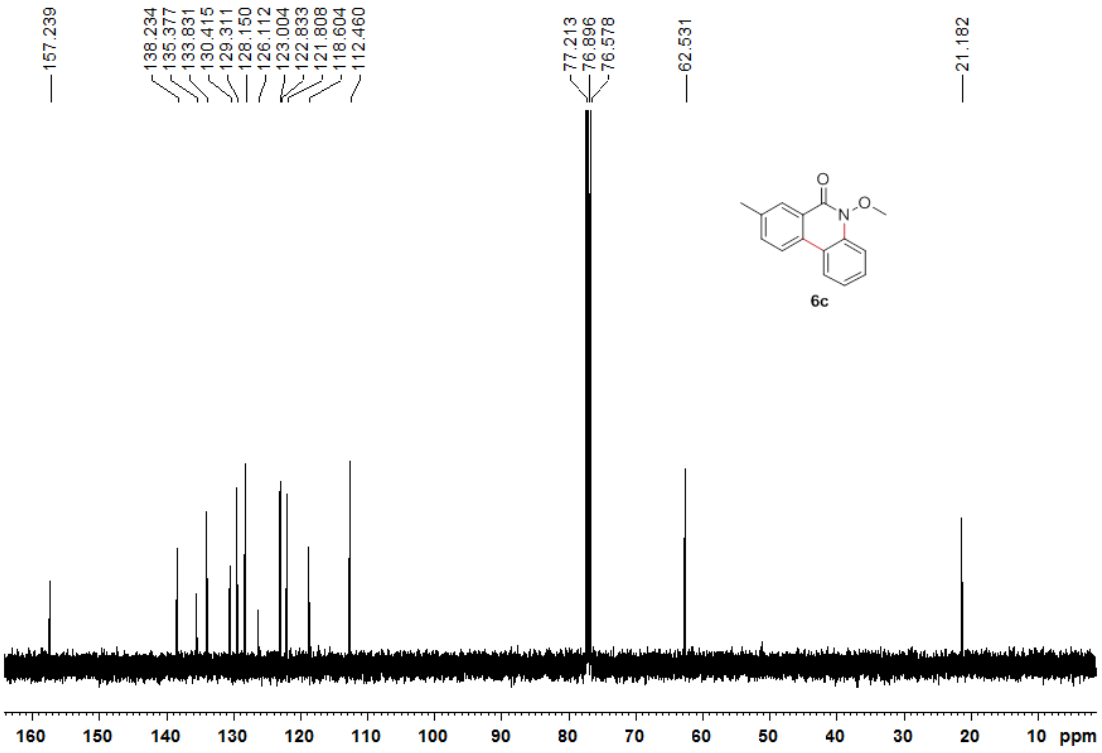
8.251
8.231
8.185
8.164
7.686
7.665
7.610
7.588
7.569
7.549
7.365
7.346
7.327
7.272
4.145
2.537
6c
8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 ppm
1.00
1.00
1.01
1.02
2.03
1.01
9 8 7 6 5 4 3 2 1 0 ppm
1.00
1.00
1.01
1.02
2.03
1.01
3.03
3.07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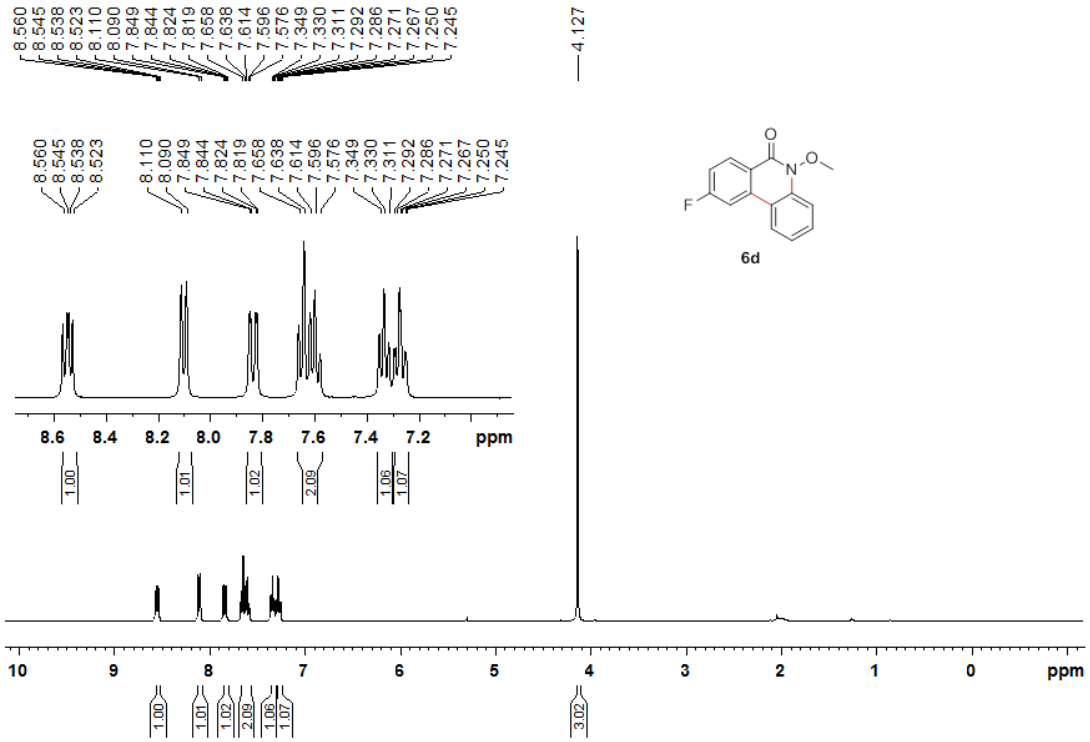
133.831
130.415
129.311
128.150
126.112
123.004
122.833
121.808
118.604
112.460
77.213
76.896
76.578
62.531
21.182
6c
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm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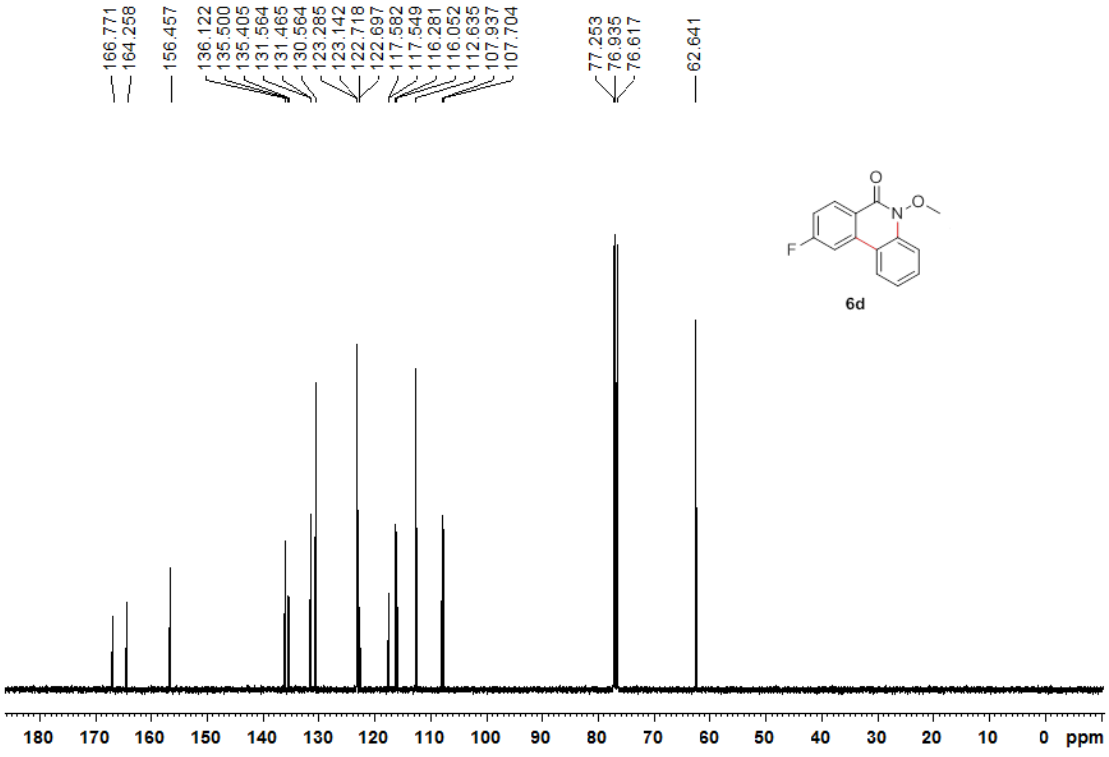
8.545
8.538
8.523
8.110
8.090
7.849
7.844
7.824
7.819
7.658
7.638
7.614
7.596
7.576
7.349
7.330
7.311
7.292
7.286
7.271
7.267
7.250
7.245
4.127
6d
ppm
1.00
1.01
1.02
2.09
1.06
1.07
3.02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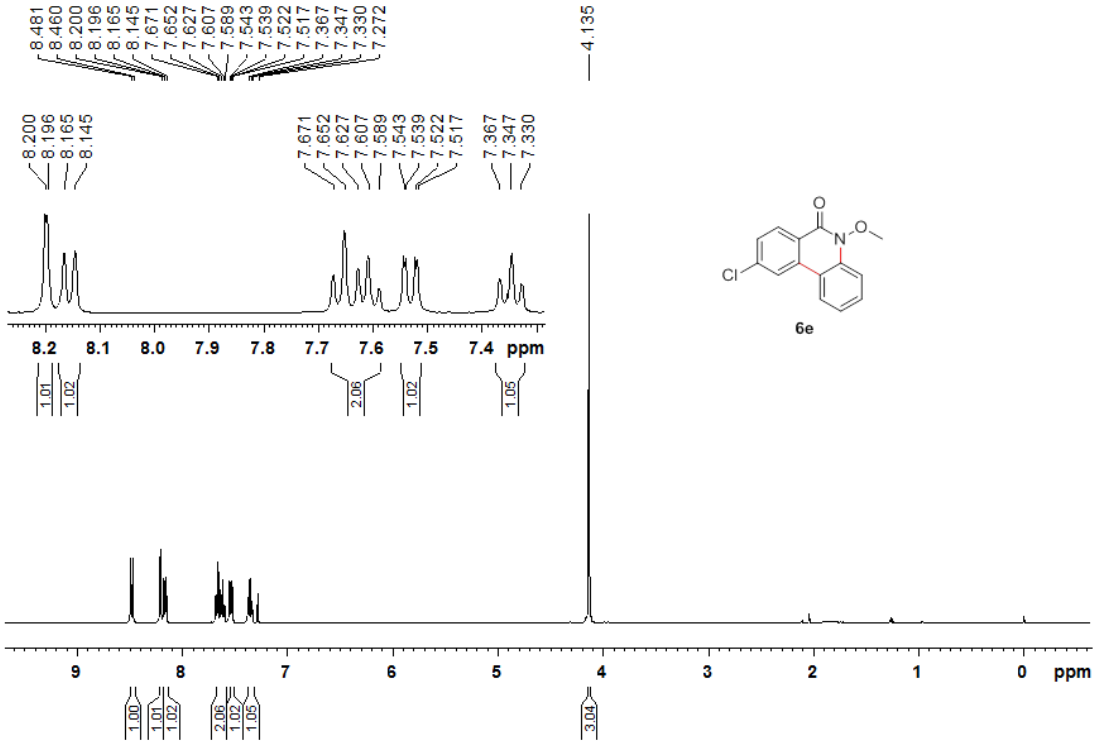
164.258
156.457
136.122
135.500
135.405
131.564
131.465
130.564
123.285
123.142
122.718
122.697
117.582
117.549
116.281
116.052
112.635
107.937
107.704
77.253
76.935
76.617
62.641
6d
ppm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8.145
7.671
7.652
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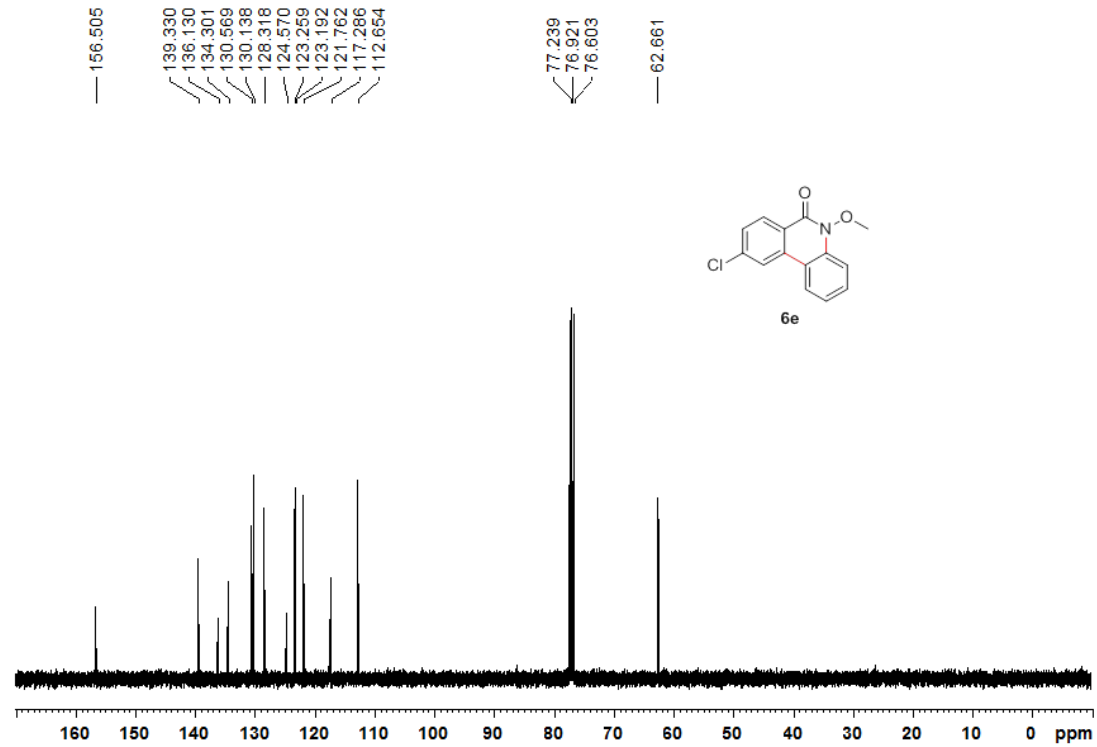
7.607
7.589
7.543
7.539
7.522
7.517
7.367
7.347
7.330
7.272
4.135
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
ppm
1.01
1.02
2.06
1.02
1.05
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.01
1.02
2.06
1.02
1.05
3.04
Cl
O
N
O
6e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139.330
136.130
134.301
130.569
130.138
128.318
124.570
123.259
123.192
121.762
117.286
112.654
77.239
76.921
76.603
62.661
Cl
O
N
O
6e
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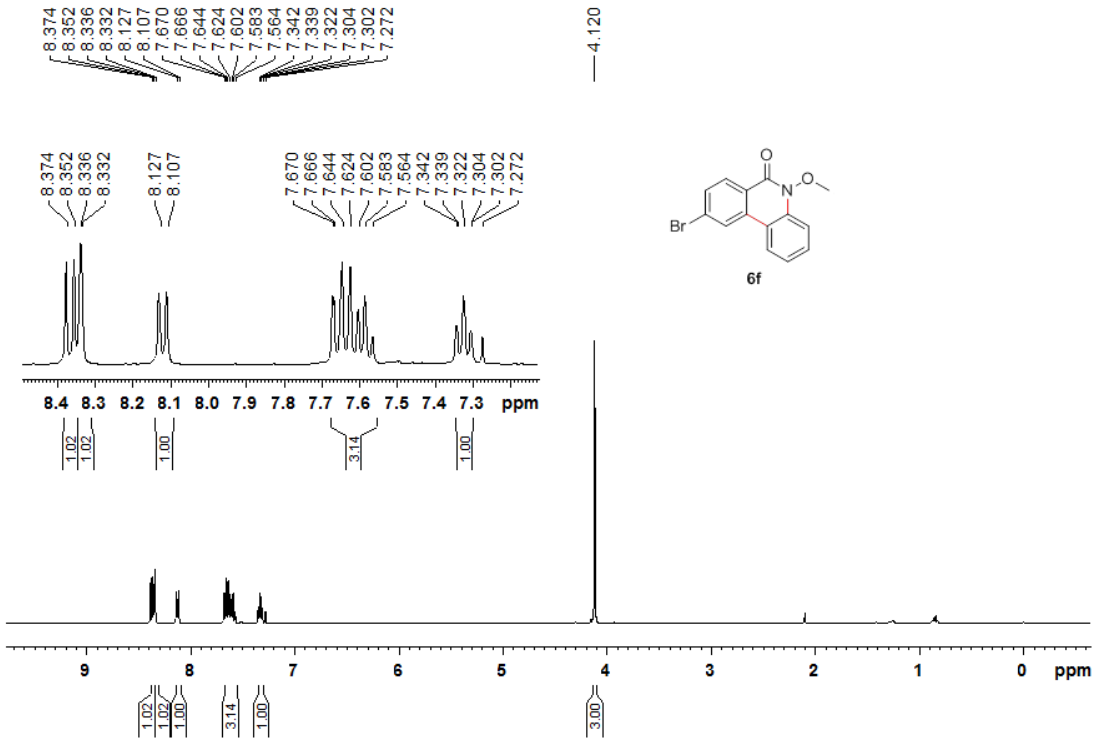
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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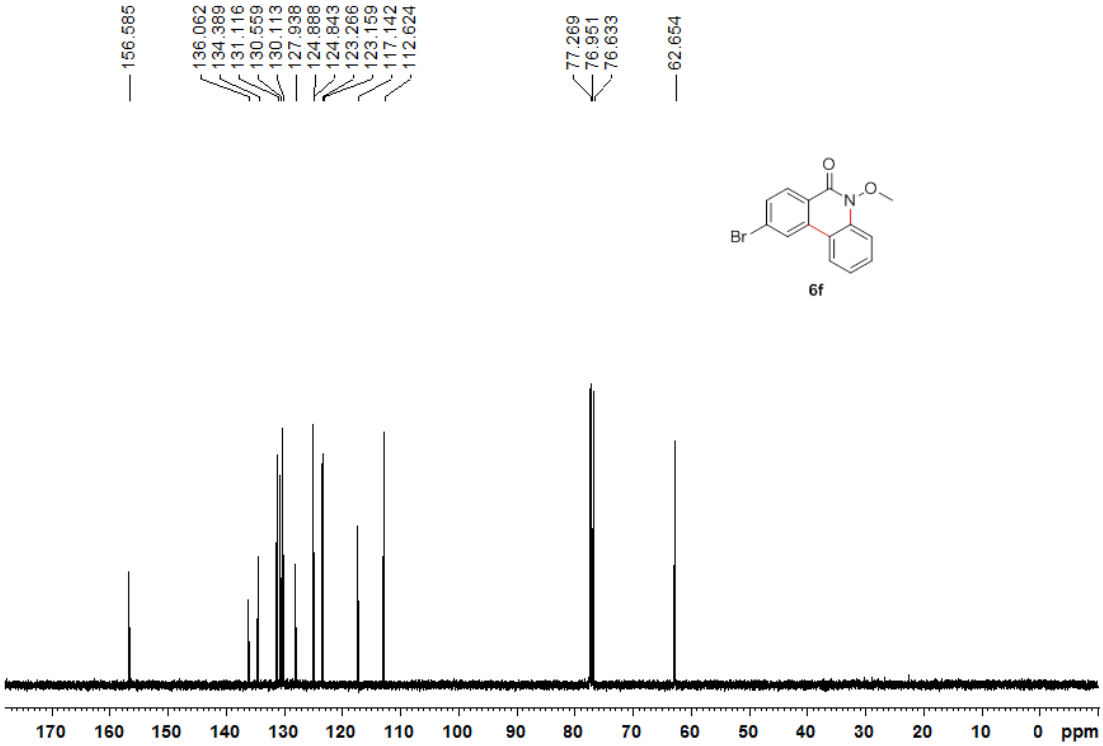
8.352
8.336
8.332
8.127
8.107
7.670
7.666
7.644
7.624
7.602
7.583
7.564
7.342
7.339
7.322
7.304
7.302
7.272
4.120
Br
O
N
O
6f
8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 ppm
1.02
1.02
1.00
3.14
1.00
9 8 7 6 5 4 3 2 1 0 ppm
1.02
1.02
1.00
3.14
1.00
3.00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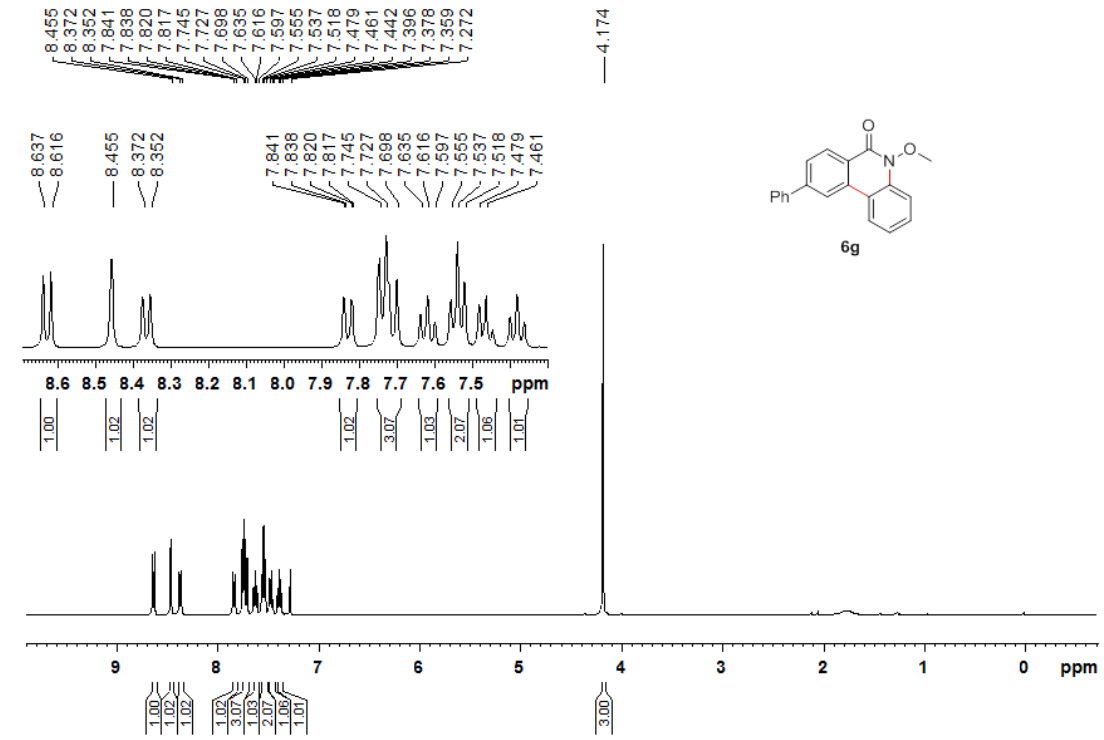
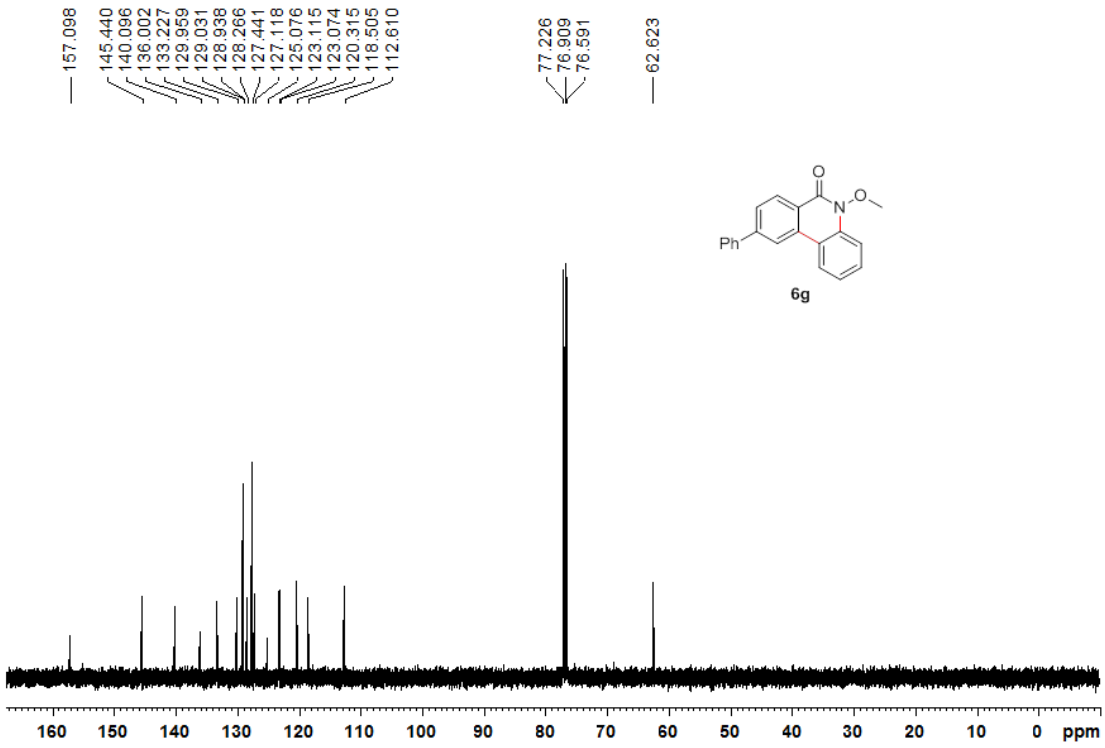
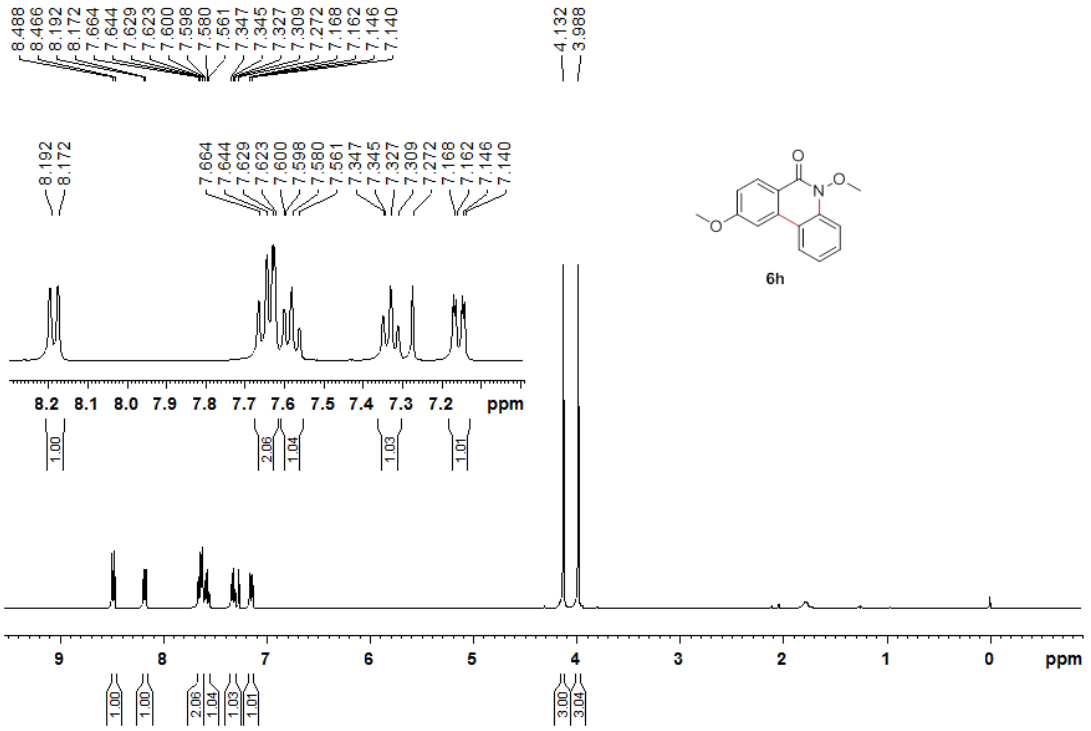
136.062
134.389
131.116
130.559
130.113
127.938
124.888
124.843
123.266
123.159
117.142
112.624
77.269
76.951
76.633
62.654
Br
O
N
O
6f
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


8.455
8.372
8.352
7.841
7.838
7.820
7.817
7.745
7.727
7.698
7.635
7.616
7.597
7.555
7.537
7.518
7.479
7.461
7.442
7.396
7.378
7.359
7.272
4.174
8.637
8.616
8.455
8.372
8.352
7.841
7.838
7.820
7.817
7.745
7.727
7.698
7.635
7.616
7.597
7.555
7.537
7.518
7.479
7.461
8.6 8.5 8.4 8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 ppm
1.00
1.02
1.02
1.02
1.02
3.07
1.03
2.07
1.06
1.01
9 8 7 6 5 4 3 2 1 0 ppm
1.00
1.02
1.02
1.02
3.07
1.03
2.07
1.06
1.01
3.00
Ph
O
N
O
6g


157.098
145.440
140.096
136.002
133.227
129.959
129.031
128.938
128.266
127.441
127.118
125.076
123.115
123.074
120.315
118.505
112.610
77.226
76.909
76.591
62.623
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm
Ph
O
N
O
6g


8.488
8.466
8.192
8.172
7.664
7.644
7.629
7.623
7.600
7.598
7.580
7.561
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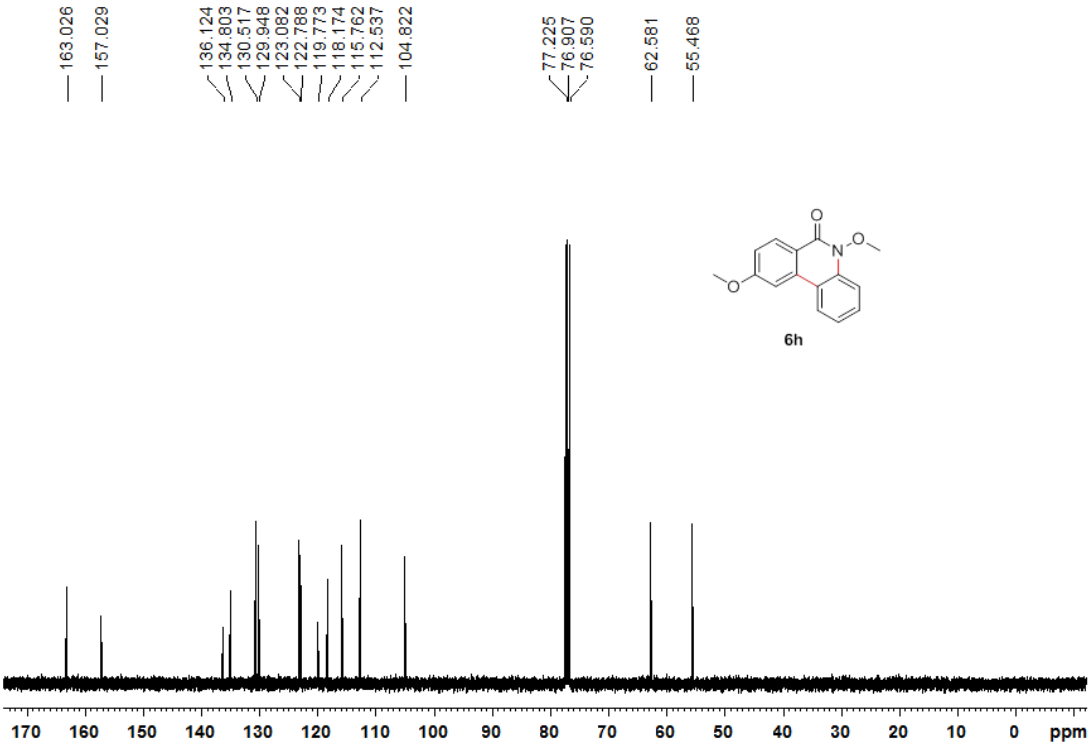
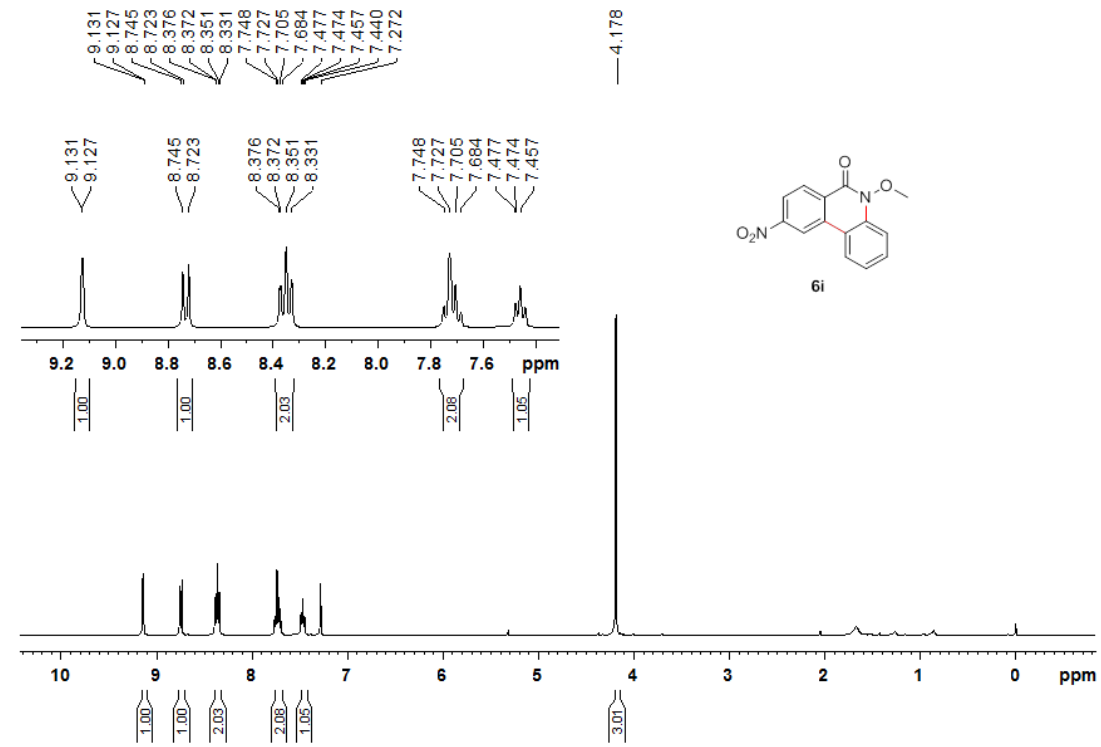
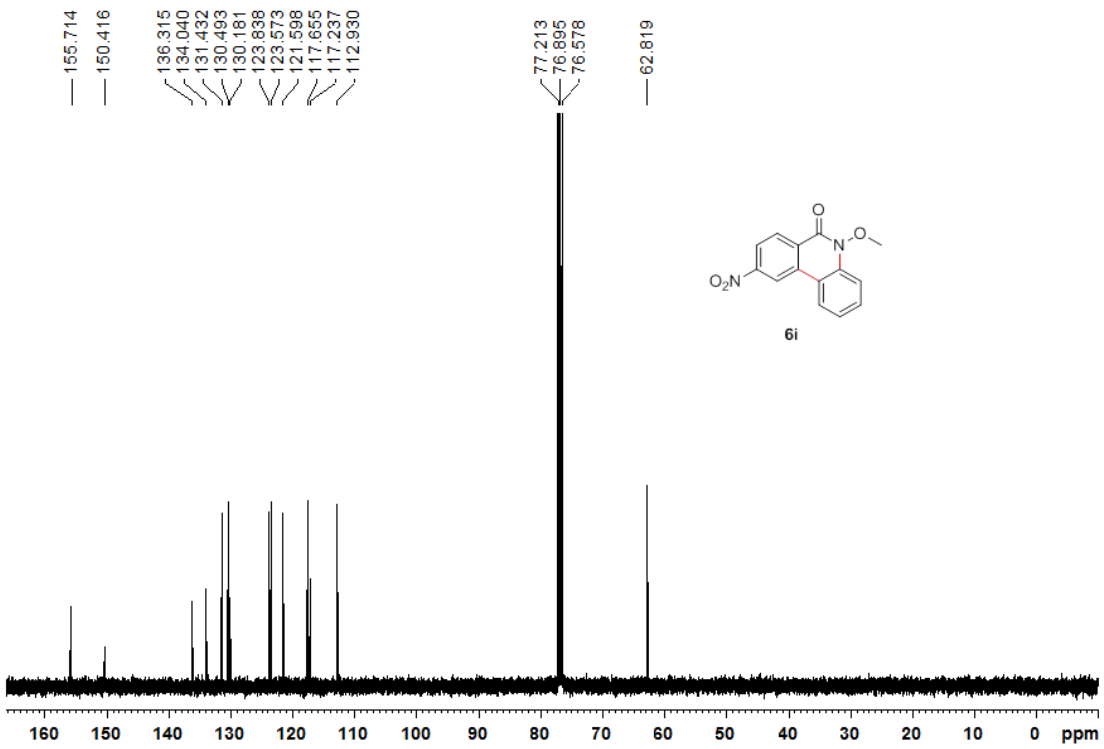
7.345
7.327
7.309
7.272
7.168
7.162
7.146
7.140
4.132
3.988
6h
ppm


163.026
157.029
136.124
134.803
130.517
129.948
123.082
122.788
119.773
118.174
115.762
112.537
104.822
77.225
76.907
76.590
62.581
55.468
6h
ppm


9.131
9.127
8.745
8.723
8.376
8.372
8.351
8.331
7.748
7.727
7.705
7.684
7.477
7.474
7.457
7.440
7.272
4.178
9.2
9.0
8.8
8.6
8.4
8.2
8.0
7.8
7.6
ppm
1.00
1.00
2.03
2.08
1.05
10
9
8
7
6
5
4
3
2
1
0
ppm
1.00
1.00
2.03
2.08
1.05
3.01
O2N
6i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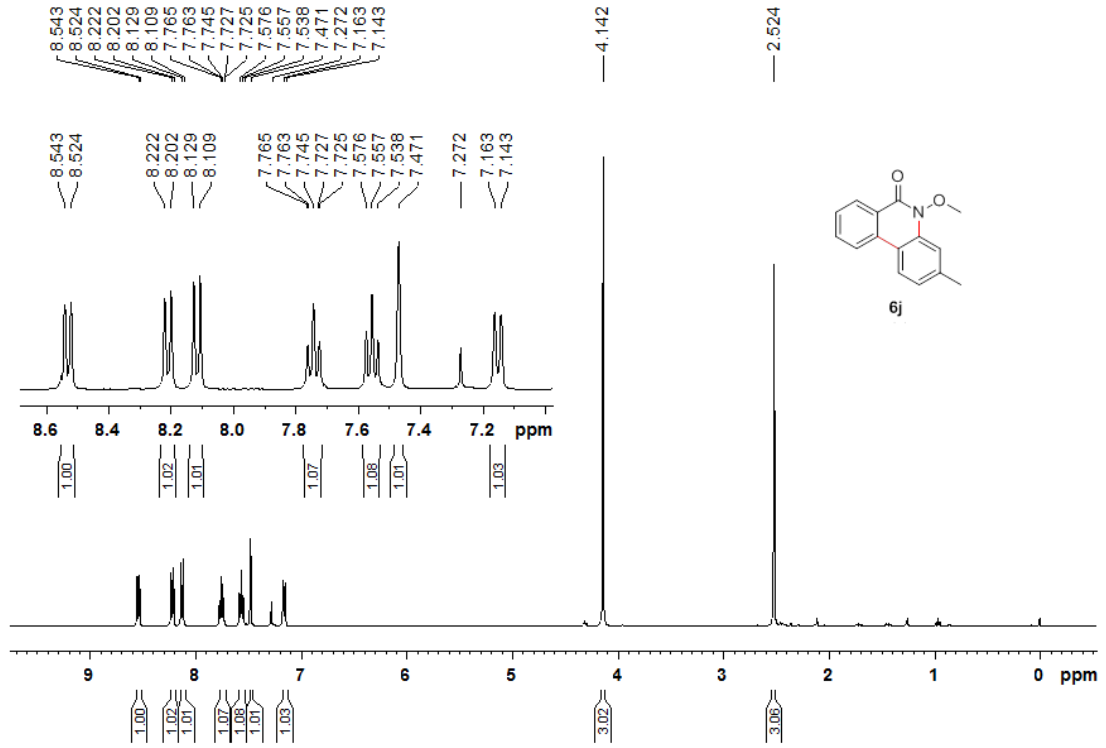
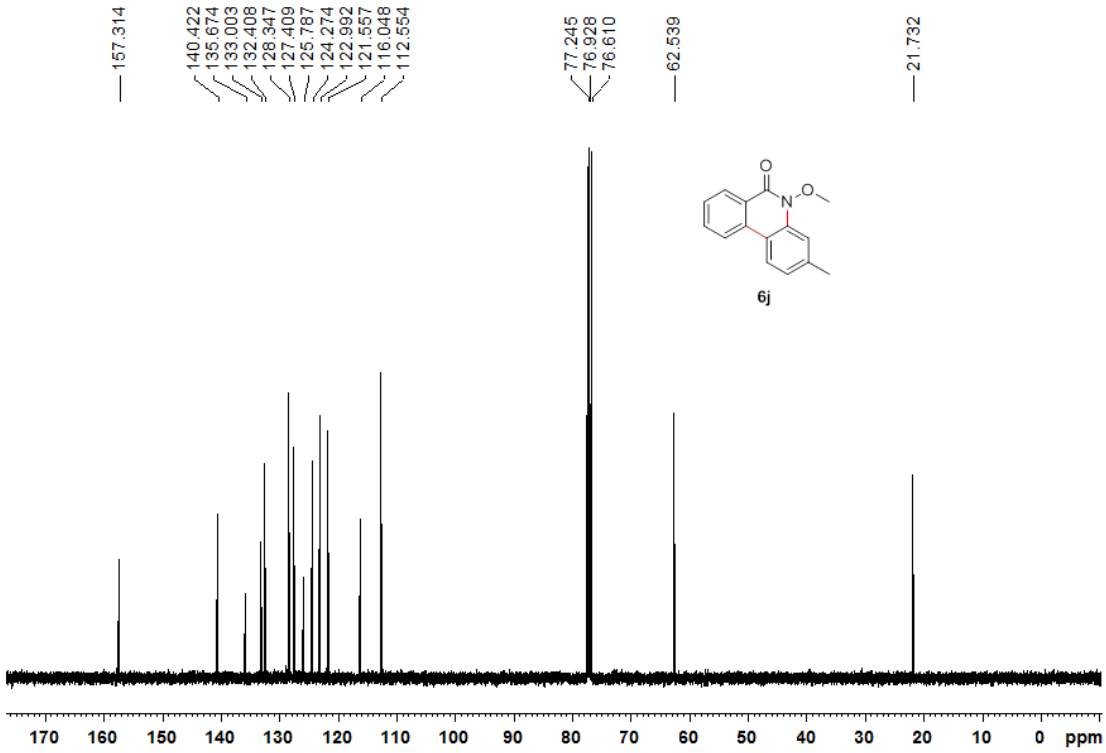
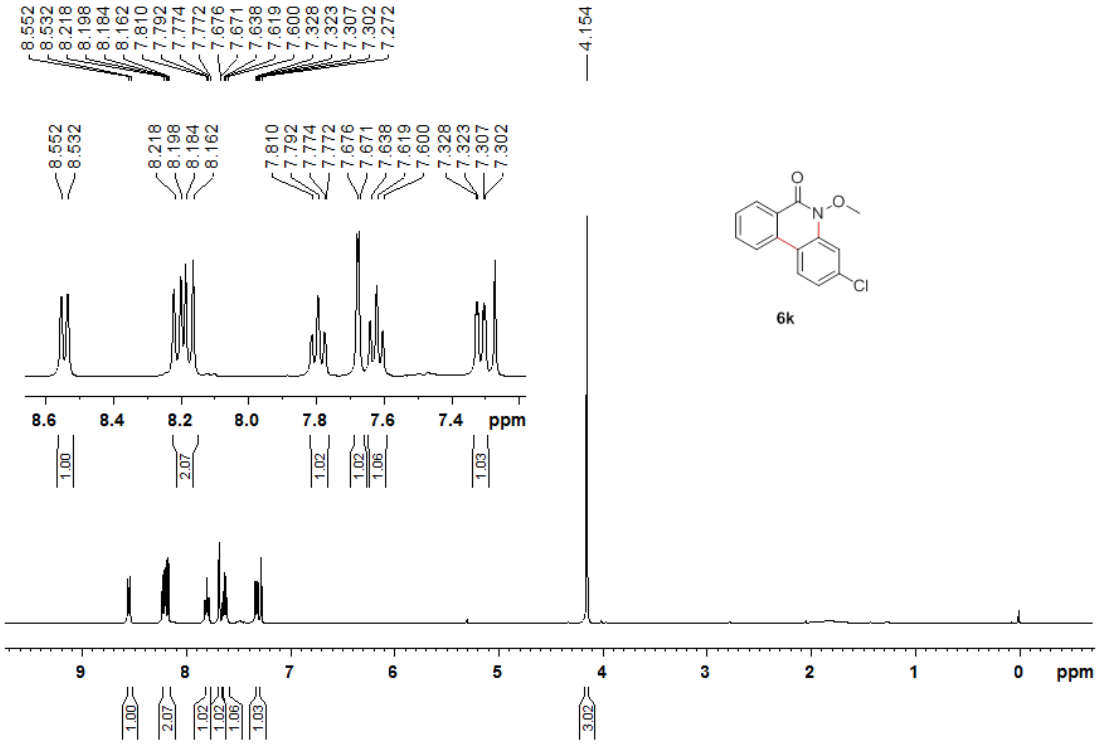
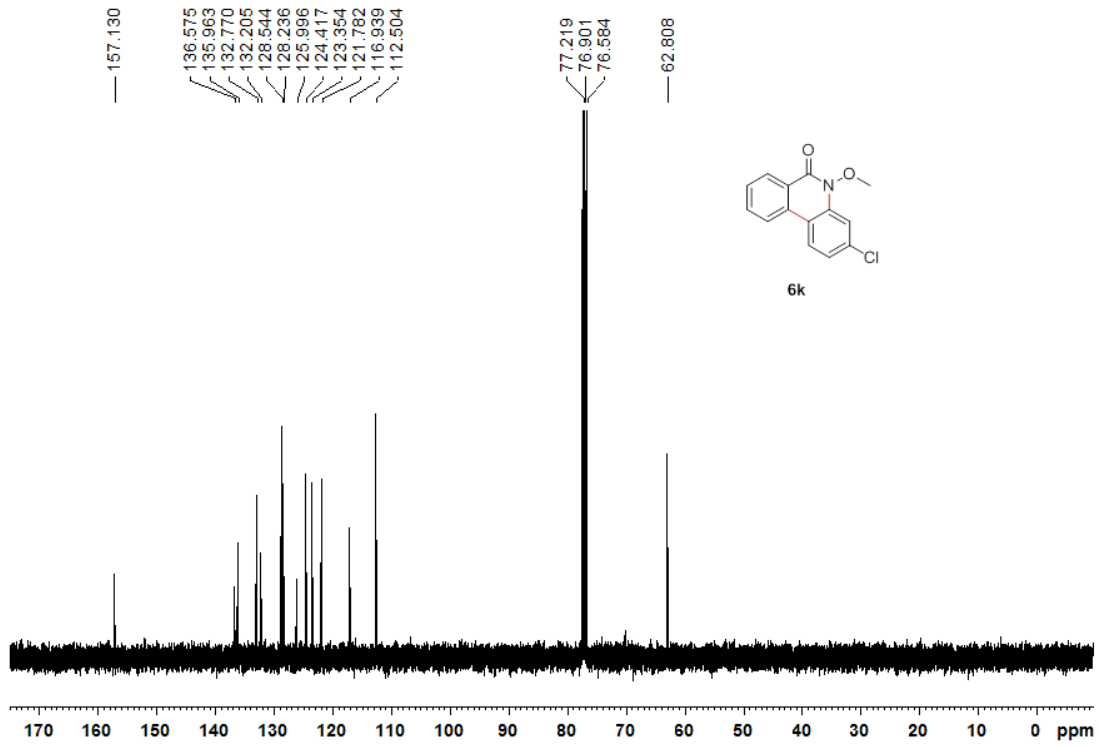
150.416
136.315
134.040
131.432
130.493
130.181
123.838
123.573
121.598
117.655
117.237
112.930
77.213
76.895
76.578
62.819
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm
O2N
6i


8.543
8.524
8.222
8.202
8.129
8.109
7.765
7.763
7.745
7.727
7.725
7.576
7.557
7.538
7.471
7.272
7.163
7.143
4.142
2.524
6j
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
ppm
1.00
1.02
1.01
1.07
1.08
1.01
1.03
9
8
7
6
5
4
3
2
1
0
ppm
3.02
3.06


157.314
140.422
135.674
133.003
132.408
128.347
127.409
125.787
124.274
122.992
121.557
116.048
112.554
77.245
76.928
76.610
62.539
21.732
6j
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


8.552
8.532
8.218
8.198
8.184
8.162
7.810
7.792
7.774
7.772
7.676
7.671
7.638
7.619
7.600
7.328
7.323
7.307
7.302
7.272
4.154
6k
ppm
1.00
2.07
1.02
1.02
1.06
1.03
3.02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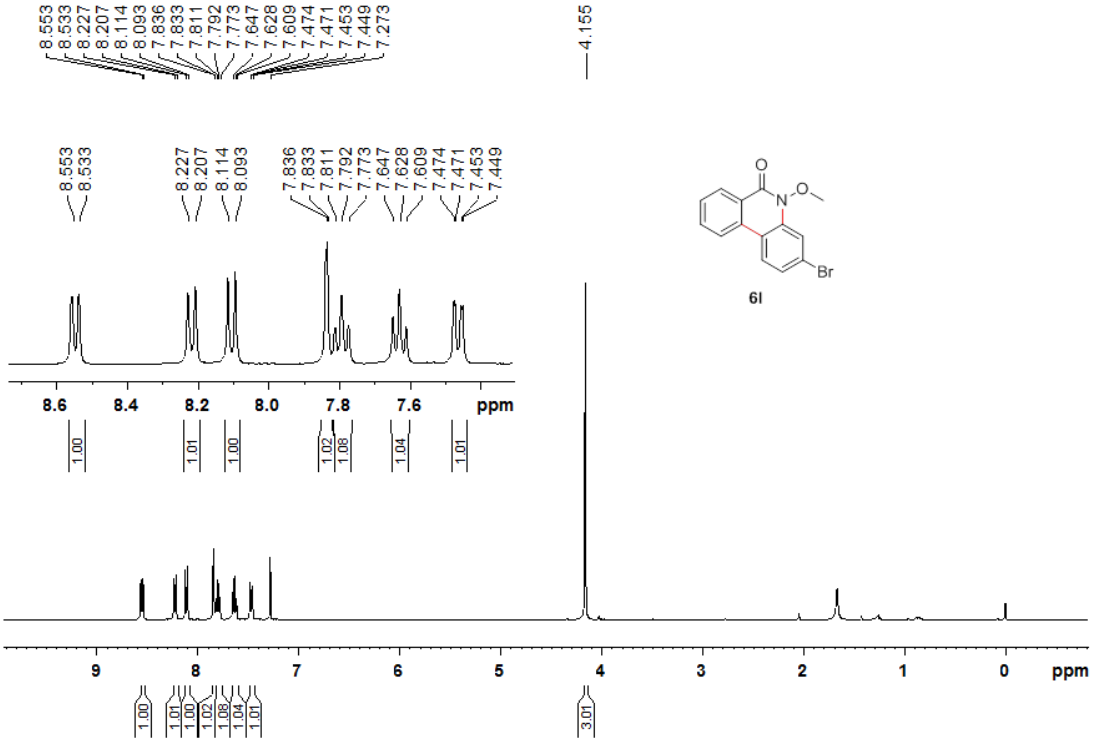
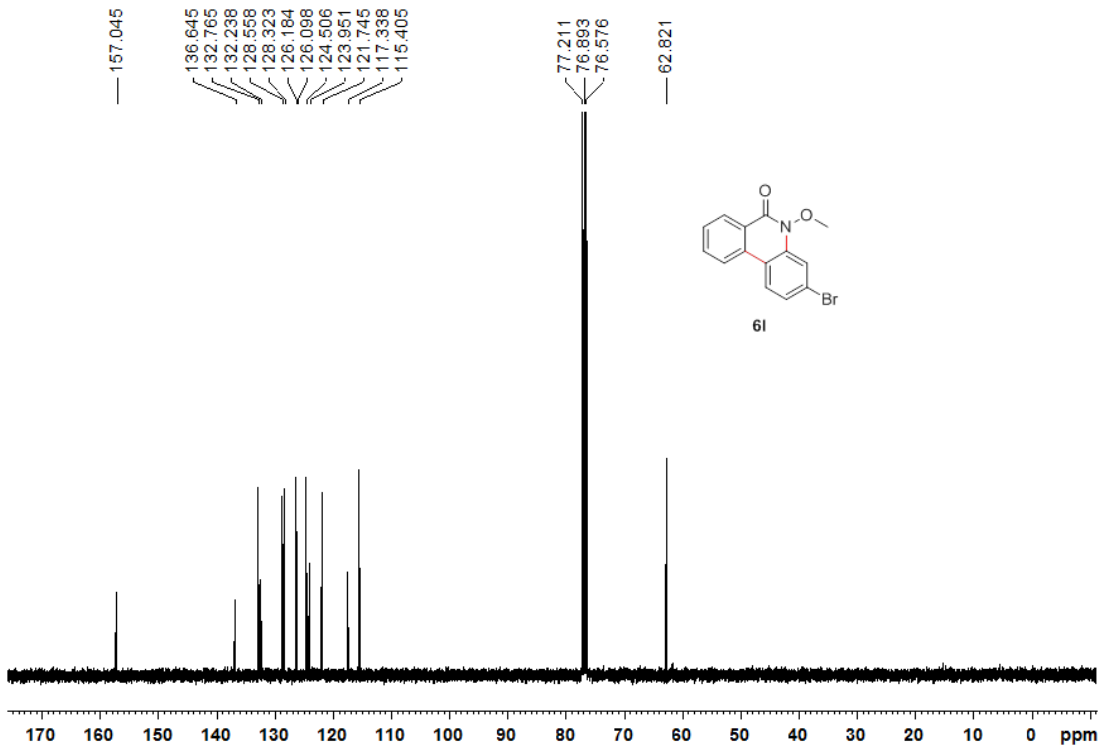
136.575
135.963
132.770
132.205
128.544
128.236
125.996
124.417
123.354
121.782
116.939
112.504
77.219
76.901
76.584
62.808
6k
ppm


8.553
8.533
8.227
8.207
8.114
8.093
7.836
7.833
7.811
7.792
7.773
7.647
7.628
7.609
7.474
7.471
7.453
7.449
7.273
4.155
6l
ppm


157.045
136.645
132.765
132.238
128.558
128.323
126.184
126.098
124.506
123.951
121.745
117.338
115.405
77.211
76.893
76.576
62.821
6l
ppm