Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Supporting information for:

Photo-induced Oxidative Cleavage of C–C Double Bond for the Synthesis of Biaryl Methanone via $CeCl_3$ Catalysis

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Supporting Information

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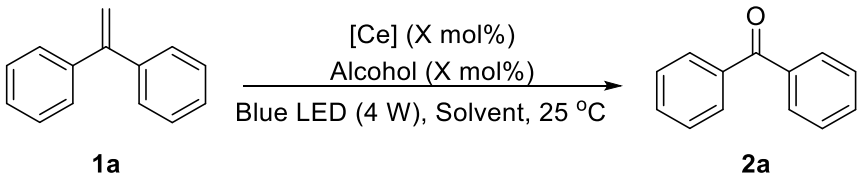
1. General Information

Unless otherwise indicated, all reactions and manipulations were performed under air. The photocatalytic reactions were performed on WATTCAS Parallel Light Reactor (WP-TEC-1020SL). All starting materials and solvents were purchased from Adamas-beta, Alfa Aesar, Chempur, Merck as well as Sigma Aldrich, and used without further purification, unless otherwise stated. All reactions were monitored by TLC with silica gel-coated plates. Column chromatography was carried out on silica gel, particle size 37-48 μm, using flash techniques. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker Ascend 400 (400 MHz) spectrometer. ^{1}H NMR are referenced to the residual solvent peak at 7.26 ppm ($CDCl_3$), and quoted in ppm to 2 decimal places with coupling constants (*J*) to the nearest 0.1 Hz. ^{13}C NMR spectra, recorded at 101 MHz, are referenced to the solvent peak at 77.16 ppm ($CDCl_3$), and quoted in ppm to 2 decimal placeS with coupling constants (*J*) to the nearest 1 Hz.

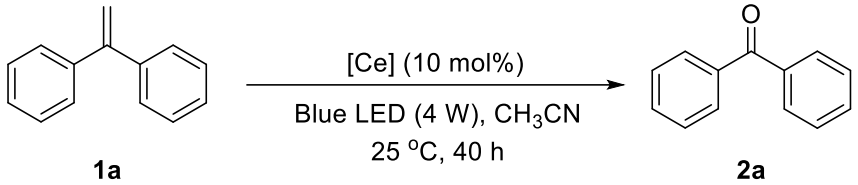
2. Optimization of the reaction conditions



A mixture of stilbene, catalyst, additive (alcohol) and solvent were added into a quartz tube which was placed in a photochemical reactor. The

reaction mixture was stirred at the designed temperature under air. After concentrated under reduced pressure, the residue was purified by flash column chromatography on silica gel and eluted with EtOAc/petroleum ether (1/100~10/1) to afford the desired product.

Table 1. Screening of catalysts[a]

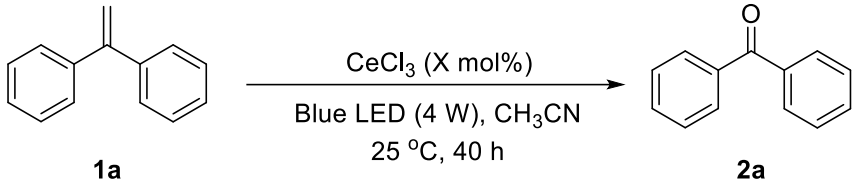


1a **2a**

Entry	Ce(10mol%)	Yield (%)
1	-	0
2	$CeCl_3$	52
3	$CeBr_3$	42
4	$Ce(acac)_3$. xH_2O	35
5	Ce $(OAc)_3$	38
6	Ce $(OTf)_3$	40

[a] Reaction conditions: **1a** (0.2mmol), [Ce] (10 mol%), CH_3CN (1.0 mL) at room temperature (25°C), Blue LED (405-410 nm, 4 W) for 40 h, isolated yield.

Table 2. screening of the catalyst loading[a]

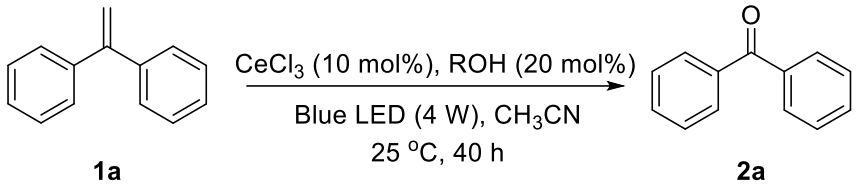


1a **2a**

Entry	$CeCl_3$(X mol%)	Yield (%)
1	1	40
2	5	45
3	10	50
4	20	53

[a] Reaction conditions: **1a** (0.2mmol), $CeCl_3$ (X mol%), CH_3CN (1.0 mL) at room temperature (25°C), Blue LED (405-410 nm, 4 W) for 40 h, isolated yield.

Table 3. Screening of the additives[a]

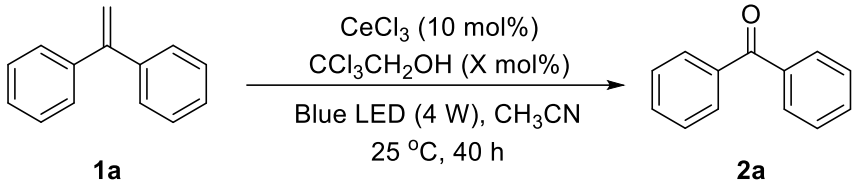


1a **2a**

Entry	ROH	Yield (%)
1	-	52
2	IPA	71
3	EtOH	68
4	CH_3OH	60
5	CCl_3CH_2OH	92
6	TFE	65
7	HFIP	60
8	TAA	62
9	EG	63

[a] Reaction conditions: **1a** (0.2mmol), $CeCl_3$ (10 mol%), ROH (20 mol%), CH_3CN (1.0 mL) at room temperature (25℃), Blue LED (405-410 nm, 4 W) for 40 h, isolated yield.

Table 4. Screening of the amount of alcohol[a]

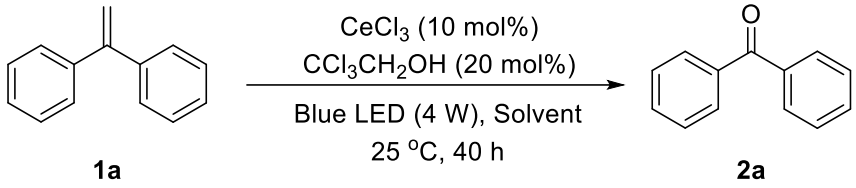


1a **2a**

Entry	CCl_3CH_2OH (X mol%)	Yield (%)
1	10	72
2	20	92
3	40	81
4	60	82
5	100	84

[a] Reaction conditions: **1a** (0.2mmol), $CeCl_3$ (10 mol%), CCl_3CH_2OH (X mol%), CH_3CN (1.0 mL) at room temperature (25℃), Blue LED (405-410 nm, 4 W) for 40 h, isolated yield.

Table 5. Screening of solvents[a]

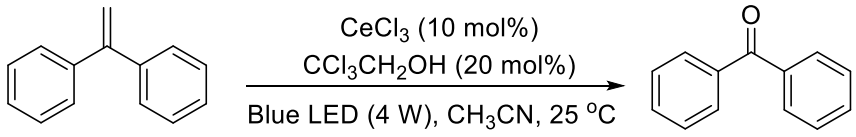


1a **2a**

Entry	Solvent	Yield (%)
1	DMSO	60
2	DMF	65
3	DMAC	63
4	THF	64
5	MeCN	92
6	DCM	73
7	DCE	60
8	Acetone	62
9	CCl_3CH_2OH	55
10	Chlorobenzene	62

[a] Reaction conditions: **1a** (0.2mmol), $CeCl_3$ (10 mol%), CCl_3CH_2OH (20 mol%), solvent (1.0 mL) at room temperature (25°C), Blue LED (405-410 nm, 4 W) for 40 h, isolated yield.

Table 6. Screening of reaction time[a]

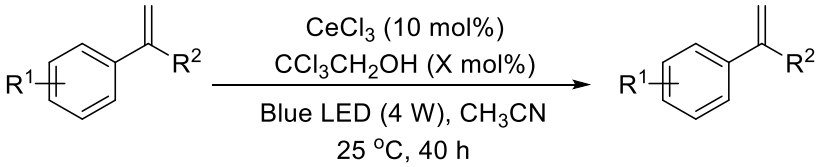


1a **2a**

Entry	Time (h)	Yield (%)
1	16	60
2	24	65
3	36	74
4	40	92

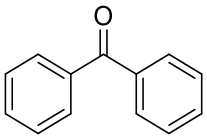
[a] Reaction conditions: **1a** (0.2mmol), $CeCl_3$ (10 mol%), CCl_3CH_2OH (20 mol%), CH_3CN (1.0 mL) at room temperature (25°C), Blue LED (405-410 nm, 4 W), isolated yield.

3. General procedure for Ce-catalyzed photooxidative cleavage of olefins



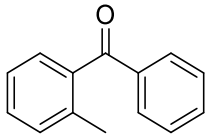
A mixture of olefin (0.2 mmol), $CeCl_3$ (10 mol%, 4.9 mg), CCl_3CH_2OH (20 mol%, 5.9 mg) and CH_3CN (1.0 mL) was added into a quartz tube which was placed in a photochemical reactor (Blue LED, 405-410 nm, 4 W). The reaction mixture was stirred at 25 °C under air for 40 h. After concentrated under reduced pressure, the residue was purified by flash column chromatography on silica gel and eluted with EtOAc/petroleum ether (1/100~10/1) to afford the desired product.

4. Experimental characterization data for products



Benzophenone (2a). The product **2a** was obtained via the *general procedure* using ethene-1,1-diyldibenzene **1a** (36.0 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (33.5 mg, 92%). Known compound, mp 48-49 °C, spectroscopic data matched those previously reported.[1]

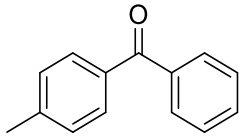
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 7.8 Hz, 4H), 7.63 (t, *J* = 7.4 Hz, 2H), 7.52 (t, *J* = 7.6 Hz, 4H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.86, 137.65 (2C), 132.37 (2C), 130.02 (4C), 128.26 (4C).



2-Methylbenzophenone (2b). The product **2b** was obtained in 2 W Blue LED via the *modified procedure* using 1-methyl-2-(1-phenylvinyl) benzene **1b** (38.8 mg, 0.2 mmol) and isolated by flash column chromatography as colorless liquid (25.1 mg, 64%).

Known compound, spectroscopic data matched those previously reported.[2]

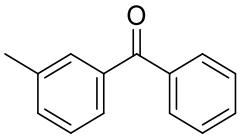
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, *J* = 7.5 Hz, 2H), 7.54 (t, *J* = 7.3 Hz, 1H), 7.46 - 7.29 (m, 4H), 7.29 -7.20 (m, 2H), 2.36 (s, 3H);^{13}C NMR (101 MHz, $CDCl_3$) δ 198.25, 138.70, 137.82, 136.67, 133.10, 131.04, 130.25, 130.05 (2C), 128.49 (2C), 125.24, 19.94.



4-Methylbenzophenone (2c). The product **2c** was obtained via the *general procedure* using 1-methyl-4-(1-phenylvinyl) benzene **1c** (38.8 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (34.8 mg, 89%).

Known compound, mp 59-61 ^{o}C, spectroscopic data matched those previously reported.[3]

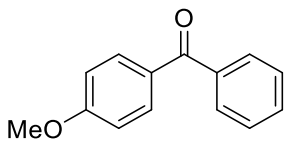
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, *J* = 1.3 Hz, 2H), 7.73 (d, *J* = 8.1 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.45 (t, *J* = 7.6 Hz, 2H), 7.26 (d, *J* = 8.0 Hz, 2H), 2.41 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.16, 143.13, 137.98, 134.92, 132.11, 130.23(2C), 129.85(2C), 128.97(2C), 128.20(2C), 21.56.



3-Methylbenzophenone (2d). The product **2d** was obtained via the *general procedure* using 1-methyl-3-(1-phenylvinyl) benzene **1d** (38.8 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (32.9 mg, 84%).

Known compound, spectroscopic data matched those previously reported.[4]

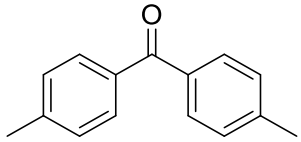
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, *J* = 7.7 Hz, 2H), 7.66 (s, 1H), 7.57 (dd, *J* = 15.5, 7.4 Hz, 2H), 7.46 (t, *J* = 7.6 Hz, 2H), 7.36 (dt, *J* = 14.8, 7.5 Hz, 2H), 2.40 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.64, 138.09, 137.79, 137.68, 133.16, 132.30, 130.40 (2C), 129.98 (2C), 128.24, 128.11, 127.31, 21.29.



4-Methoxybenzophenone (2e). The product **2e** was obtained in 2 W Blue LED via the *general procedure* using 1-methoxy-4-(1-phenylvinyl) benzene **1e** (42 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (35.2 mg, 83%).

Known compound, mp 60-62 ^{o}C, spectroscopic data matched those previously reported.[1]

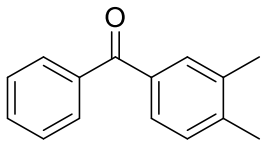
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (s, 2H), 7.77 (d, *J* = 7.9 Hz, 2H), 7.56 (t, J = 7.1 Hz, 1H), 7.47 (t, *J* = 7.6 Hz, 2H), 6.96 (d, *J* = 8.5 Hz, 2H), 3.86 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 195.35, 163.24, 138.31, 132.47 (2C), 131.84, 130.13, 129.65 (2C), 128.17 (2C), 113.58 (2C), 55.42.



4,4'-Dimethylbenzophenone (2f). The product **2f** was obtained via the *general procedure* using 4,4'-(ethene-1,1-diyl) bis(methylbenzene) **1f** (41.6 mg, 0.2 mmol) and isolated by flash column chromatography as a brown solid (36.1 mg, 86%).

Known compound, mp 95-97 ^{o}C, spectroscopic data matched those previously reported.[5]

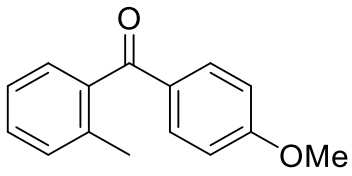
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8.1 Hz, 2H), 7.31 (d, *J* = 7.9 Hz, 2H), 2.48 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.16, 142.87, 135.27, 130.15, 128.89, 21.58.



3,4-Dimethylbenzophenone (2g). The product **2g** was obtained via the *general procedure* using 1,2-dimethyl-4-(1-phenylvinyl) benzene **1g** (41.6 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (33.6 mg, 80%).

Known compound, mp 46-48 ^{o}C, spectroscopic data matched those previously reported.[6]

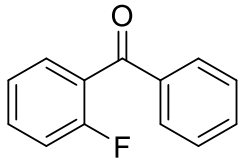
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 - 7.81 (m, 2H), 7.67 (s, 1H), 7.60 (dd, *J* = 12.4, 5.2, 4.1 Hz, 2H), 7.51 (t, *J* = 7.5 Hz, 2H), 7.27 (d, *J* = 7.8 Hz, 1H), 2.39 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.61, 141.91, 138.13, 136.71, 135.36, 132.05, 131.17, 129.90 (2C), 129.45, 128.17 (2C), 128.01, 19.95, 19.71.



(4-Methoxyphenyl) (2-methylphenyl) methanone (2h). The product **2e** was obtained in 10 W Blue LED via the *modified procedure* using 1-(1-(4-methoxyphenyl) vinyl)-2-methylbenzene **1h** (44.8 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (33.5 mg, 74%).

Known compound, spectroscopic data matched those previously reported.[7]

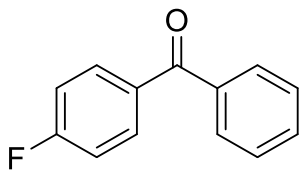
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (dd, *J* = 6.7, 4.8 Hz, 2H), 7.37 (td, *J* = 7.5, 1.5 Hz, 1H), 7.31 (s, 1H), 7.26 (d, *J* = 3.4 Hz, 1H), 7.24 (t, *J* = 7.5 Hz, 1H), 6.92 (t, *J* = 5.8 Hz, 2H), 3.84 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.11, 163.75, 139.28, 136.08, 132.41 (2C), 130.82, 130.53, 129.77, 127.89, 125.18, 113.75 (2C), 55.34, 19.71.



2-Fluorobenzophenone (2i). The product **2i** was obtained via the *general procedure* using 1-fluoro-2-(1-phenylvinyl) benzene **1i** (39.6 mg, 0.2 mmol) and isolated by flash column chromatography as a colorless oil (29.6 mg, 74%).

Known compound, spectroscopic data matched those previously reported**.**[8]

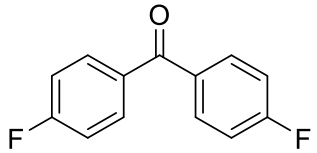
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 - 7.84 (m, 2H), 7.61 - 7.43 (m, 5H), 7.25 (td, *J* = 7.6, 0.8 Hz, 1H), 7.18 - 7.11 (m, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 193.29, 161.32 (d, *J* = 254 Hz), 137.41, 133.40, 133.10 (d, *J* = 8 Hz), 130.68 (d, *J* = 2 Hz), 129.76 (2C), 128.47 (2C), 127.13 (d, *J* = 14 Hz), 124.31 (d, *J* = 4 Hz), 116.34 (d, *J* = 22 Hz).



4-Fluoroacetophenone (2j). The product **2j** was obtained via the *general procedure* using 1-fluoro-4-(1-phenylvinyl) benzene **1j** (39.6 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (34.4 mg, 86%).

Known compound, spectroscopic data matched those previously reported.[9]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 - 7.81 (m, 2H), 7.80 - 7.74 (m, 2H), 7.58 (dd, *J* = 10.6, 4.3 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.20 - 7.08 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 194.99, 166.59 (d, *J* = 255 Hz), 137.51, 133.84 (d, *J* = 3 Hz), 132.64 (d, *J* = 2 Hz, 2C), 132.39, 129.80 (2C), 128.32 (2C), 115.49 (d, *J* = 22 Hz, 2C).

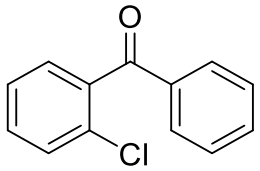


Bis (4-fluorophenyl)-methanone (2k). The product **2k** was obtained via the *general procedure* using 4,4'-(ethene-1,1-diyl) bis(fluorobenzene) **1k** (43.2 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (30.5 mg, 70%).

Known compound, mp 107-109 ^{o}C, spectroscopic data matched those previously reported.[4]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 - 7.82 (m, 1H), 7.21 (dd, *J* = 8.9, 4.3, 2.2 Hz, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 193.70, 166.65 (d, *J* = 256 Hz,

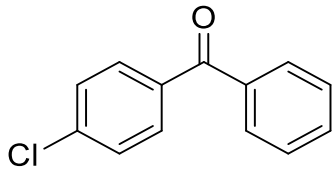
2C), 133.74 (d, *J* = 3 Hz, 2C), 132.49 (d, *J* = 9 Hz, 4C), 115.62 (d, *J* = 21 Hz, 4C).



2-Chlorobenzophenone (2l). The product **2l** was obtained in 10 W Blue LED via the *modified procedure* using 1-chloro-4-(1-phenylvinyl) benzene **1l** (42.8 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (33.8 mg, 78%).

Known compound, mp 51-54 ^{o}C, spectroscopic data matched those previously reported.[10]

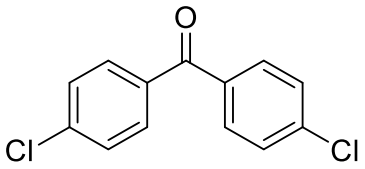
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 7.9 Hz, 2H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.46 (dd, *J* = 11.2, 8.9, 5.2 Hz, 4H), 7.43 - 7.35 (m, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 195.16, 138.63, 136.51, 133.69, 131.26, 131.14, 130.03 (2C), 129.10, 128.62 (2C), 126.70.



4-Chlorobenzophenone (2m). The product **2m** was obtained via the *general procedure* using 1-chloro-4-(1-phenylvinyl) benzene **1m** (42.8 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (35.5 mg, 82%).

Known compound, mp 75-77 ^{o}C, spectroscopic data matched those previously reported.[1]

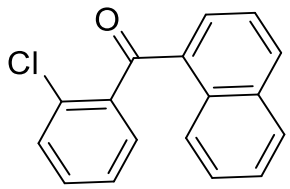
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (dd, *J* = 15.8, 8.2 Hz, 4H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.45 - 7.34 (m, 4H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 194.91, 138.67, 137.18, 135.85, 132.53, 131.37 (2C), 129.83 (2C), 128.54 (2C), 128.35 (2C).



4,4'-Dichlorobenzophenone (2n). The product **2n** was obtained via the *general procedure* using 4,4'-(ethene-1,1-diyl) bis(chlorobenzene) **1n** (49.6 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (44.2 mg, 88%).

Known compound, mp 145-147 ^{o}C, spectroscopic data matched those previously reported.[4]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8.5 Hz, 1H), 7.49 (d, *J* = 8.4 Hz, 1H); 13C NMR (101 MHz, $CDCl_3$) δ 194.07, 139.11 (2C), 135.53 (2C), 131.26 (4C), 128.73 (4C).

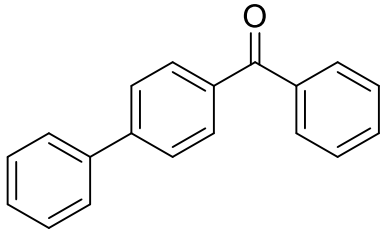


(2-chlorophenyl) (naphthalen-1-yl) methanone (2o). The product **2o** was obtained in 10 W Blue LED via the *modified procedure* using 1-(1-(2-

chlorophenyl) vinyl) naphthalene **1o** (52.8 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (21.3 mg, 40%).

Known compound, mp 84-86 ^{o}C, spectroscopic data matched those previously reported.[11]

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.94 (d, *J* = 8.5 Hz, 1H), 8.08 (d, *J* = 8.2 Hz, 1H), 7.97 (d, *J* = 8.1 Hz, 1H), 7.71 (dd, *J* = 8.5, 6.9, 1.3 Hz, 1H), 7.62 (dd, *J* = 12.0, 4.0 Hz, 2H), 7.58 -7.53 (m, 1H), 7.51 - 7.48 (m, 2H), 7.46 (dd, *J* = 7.9, 3.8 Hz, 1H), 7.41 (dd, *J* = 7.4, 6.5, 2.3 Hz, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.03, 139.99, 134.40, 134.02, 133.76, 132.09, 131.79, 131.52, 130.98, 130.32, 130.14, 128.53, 128.39, 126.71, 126.67, 126.00, 124.30.

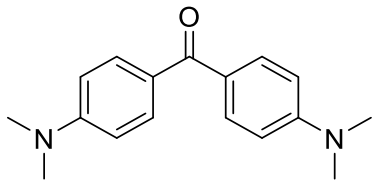


4-Benzoylbiphenyl (2p). The product **2p** was obtained via the *general procedure* using 4-(1-phenylvinyl)-1,1'-biphenyl **1p** (51.2 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (45.5mg, 88%).

Known compound, mp 100-103 ^{o}C, spectroscopic data matched those previously reported.[12]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (dd, *J* = 19.8, 7.9 Hz, 4H), 7.74 (dd, *J* = 18.9, 7.7 Hz, 4H), 7.65 (t, *J* = 7.4 Hz, 1H), 7.55 (dd, *J* = 14.8, 7.6 Hz, 4H), 7.46 (t, *J* = 7.3 Hz, 1H);^{13}C NMR (101 MHz, $CDCl_3$) δ 196.19, 145.22,

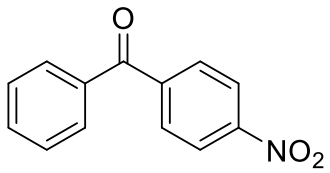
139.98, 137.87, 136.34, 132.40, 130.77 (2C), 130.03 (2C), 129.05 (2C), 128.38 (2C), 128.27, 127.34 (2C), 127.00 (2C).



4,4'-Bis (dimethylamino) benzophenone (2q). The product **2q** was obtained via the *general procedure* using 4,4'-(ethene-1,1-diyl) bis (N, N-dimethylaniline) **1q** (53.2 mg, 0.2 mmol) and isolated by flash column chromatography as a green solid (32.8 mg, 65%).

Known compound, mp 171-174 ^{o}C, spectroscopic data matched those previously reported.[13]

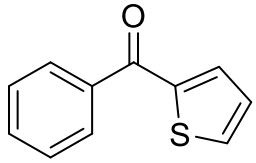
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (s, 4H), 6.75 (s, 4H), 3.11 (s, 12H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 193.97, 152.72 (2C), 132.16 (4C), 126.42 (2C), 110.59 (4C), 40.08 (4C).



4-Nitrobenzophenone (2r). The product **2r** was obtained via the *general procedure* using 1-nitro-4-(1-phenylvinyl) benzene **1r** (45 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (30.9 mg, 68%).

Known compound, mp 135-138 ^{o}C, spectroscopic data matched those previously reported.[1]

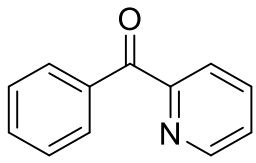
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.37 (d, *J* = 8.3 Hz, 2H), 7.97 (d, *J* = 8.3 Hz, 2H), 7.84 (d, *J* = 7.5 Hz, 2H), 7.69 (t, *J* = 7.2 Hz, 1H), 7.56 (t, *J* = 7.4 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 194.71, 149.85, 142.90, 136.32, 133.42, 130.64 (2C), 130.06 (2C), 128.66 (2C), 123.50 (2C).



2-benzoylthiophene (2s). The product **2s** was obtained via the *general procedure* using 2-(1-phenylvinyl) thiophene **1s** (37.2mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (28.6 mg, 76%).

Known compound, spectroscopic data matched those previously reported.[1]

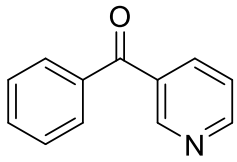
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 - 7.88 (m, 2H), 7.77 (d, *J* = 4.7 Hz, 1H), 7.70 (d, *J* = 3.4 Hz, 1H), 7.64 (dd, *J* = 8.4, 6.4 Hz, 1H), 7.54 (t, *J* = 7.6 Hz, 2H), 7.21 (dd, *J* = 7.7, 3.5 Hz, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 188.17, 143.65, 138.20, 134.77, 134.14, 132.23, 129.14 (2C), 128.40 (2C), 127.93.



2-benzoyl pyridine (2t). The product **2t** was obtained in 10 W Blue LED via the *modified procedure* using 2-(1-phenylvinyl) pyridine **1t** (36.2mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (25.6mg, 70%).

Known compound, mp 40-44 ^{o}C, spectroscopic data matched those previously reported.[10]

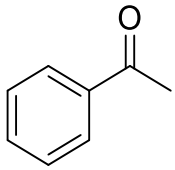
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.75 (s, 1H), 8.11 (d, *J* = 7.4 Hz, 2H), 8.09 - 8.04 (m, 1H), 7.92 (dd, *J* = 7.5, 4.6, 1.7 Hz, 1H), 7.65 - 7.59 (m, 1H), 7.54 - 7.48 (m, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 193.79, 155.17, 148.54, 137.01, 136.33, 132.87, 130.98 (2C), 128.14 (2C), 126.11, 124.56.



3-benzoyl pyridine (2u). The product **2u** was obtained via the *general procedure* using 3-(1-phenylvinyl) pyridine **1u** (36.2mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (27 mg, 72%).

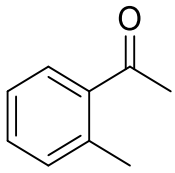
Known compound, spectroscopic data matched those previously reported.[14]

^{1}H NMR (400 MHz, $CDCl_3$) δ 8.98 (s, 1H), 8.82 - 8.75 (m, 1H), 8.10 (tt, *J* = 5.3, 3.5, 1.7 Hz, 1H), 7.83 - 7.77 (m, 2H), 7.65 - 7.58 (m, 1H), 7.54 - 7.47 (m, 2H), 7.44 (dt, *J* = 8.0, 4.8 Hz, 1H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 194.72, 152.75, 150.85, 137.06, 136.70, 133.12, 133.07, 129.93 (2C), 128.55 (2C), 123.26.



Acetophenone (4a). The product **4a** was obtained via the *general procedure* using prop-1-en-2-ylbenzene **3a** (23.6 mg, 0.2 mmol) and isolated by flash column chromatography as colorless oil (17.3 mg, 72%). Known compound, spectroscopic data matched those previously reported.[15]

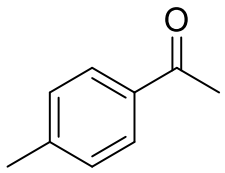
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (s, 2H), 7.60 (t, J = 7.4 Hz, 1H), 7.50 (t, *J* = 7.7 Hz, 2H), 2.64 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.03, 137.20, 133.03, 128.53 (2C), 128.26 (2C), 26.50.



2'-Methylacetophenone (4b). The product **4b** was obtained via the *general procedure* using 1-methyl-2-(prop-1-en-2-yl) benzene **3b** (26.4 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (18.2 mg, 68%).

Known compound, spectroscopic data matched those previously reported.[16]

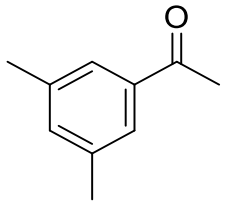
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.68 (d, *J* = 7.6 Hz, 1H), 7.36 (t, *J* = 7.5 Hz, 1H), 7.24 (dd, *J* = 12.7, 7.5 Hz, 2H), 2.56 (s, 3H), 2.54 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 201.45, 138.25, 137.68, 131.96, 131.41, 129.27, 125.65, 29.37, 21.43.



4’-Methylacetophenone (4c). The product **4c** was obtained via the *general procedure* using 1-methyl-4-(prop-1-en-2-yl) benzene **3c** (26.4 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (19.6 mg, 73 %).

Known compound, spectroscopic data matched those previously reported.[17]

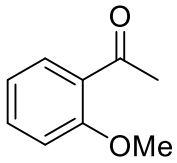
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86 (d, *J* = 8.2 Hz, 2H), 7.26 (d, *J* = 8.4 Hz, 2H), 2.57 (s, 3H), 2.41 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.60, 143.74, 134.77, 129.18 (2C), 128.37 (2C), 26.36, 21.50.



3,5-DiMethylacetoph (4d). The product **4d** was obtained via the *general procedure* using 1,3-dimethyl-5-(prop-1-en-2-yl) benzene **3d** (29.2 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (20.8 mg, 70%).

Known compound, spectroscopic data matched those previously reported**.**[18]

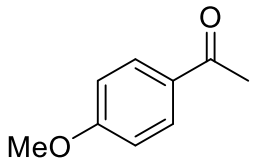
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (s, 2H), 7.21 (s, 1H), 2.59 (s, 3H), 2.39 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.40, 138.12, 137.30, 134.63 (2C), 126.07 (2C), 26.57, 21.12 (2C).



2-Methoxyacetophenone (4e). The product **4e** was obtained via the *general procedure* using 1-methoxy-2-(prop-1-en-2-yl) benzene **3e** (29.6 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (15.3 mg, 51 %).

Known compound, spectroscopic data matched those previously reported.[16]

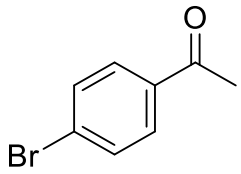
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (dd, *J* = 7.7, 1.2 Hz, 1H), 7.50 - 7.44 (m, 1H), 7.03 - 6.96 (m, 2H), 3.92 (s, 3H), 2.63 (s, 3H)； ^{13}C NMR (101 MHz, $CDCl_3$) δ 199.67, 158.90, 133.62, 130.23, 120.47, 111.61, 55.41, 31.72.



4-Methoxyacetophenone (4f). The product **4f** was obtained via the *general procedure* using 1-methoxy-4-(prop-1-en-2-yl) benzene **3f** (29.6 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (19.2 mg, 64%).

Known compound, mp 36-38 ^{o}C, spectroscopic data matched those previously reported.[17]

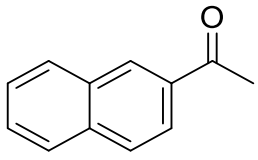
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 8.8 Hz, 2H), 6.96 (d, *J* = 8.8 Hz, 2H), 3.90 (s, 3H), 2.58 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.64, 163.48, 130.53, 130.37 (2C), 113.66 (2C), 55.40, 26.22.



4'-Bromoacetophenone (4g). The product **4g** was obtained via the *general procedure* using 1-bromo-4-(prop-1-en-2-yl) benzene **3g** (39.2 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (19.9 mg, 50%).

Known compound, mp 48-51 ^{o}C, spectroscopic data matched those previously reported.[19]

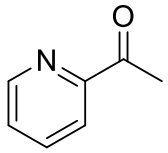
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 8.3 Hz, 2H), 2.60 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 196.84, 135.87, 131.85 (2C), 129.79 (2C), 128.23, 26.43.



2-Acetonaphthone (4h). The product **4h** was obtained via the *general procedure* using 2-(prop-1-en-2-yl) naphthalene **3h** (33.6 mg, 0.2 mmol) and isolated by flash column chromatography as a white solid (24.1 mg, 71%).

Known compound, mp 55-57 ^{o}C, spectroscopic data matched those previously reported.[17]

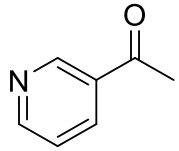
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (s, 1H), 8.08 (d, *J* = 8.6 Hz, 1H), 8.00 (d, *J* = 8.0 Hz, 1H), 7.92 (dd, *J* = 7.9, 5.5 Hz, 2H), 7.62 (dt, *J* = 14.9, 6.9 Hz, 2H), 2.76 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.97, 135.60, 134.56, 132.55, 130.12, 129.53, 128.43, 128.39, 127.76, 126.75, 26.60.



1-(pyridin-2-yl)ethan-1-one (4i). The product **4i** was obtained via the *general procedure* using 2-(prop-1-en-2-yl) pyridine **3i** (23.8 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (8.3 mg, 34 %).

Known compound, spectroscopic data matched those previously reported.[20]

^{1}H NMR (600 MHz, Chloroform-d) δ 8.66 – 8.62 (m, 1H), 8.03 – 7.95 (m, 1H), 7.79 (tt, J = 7.77, 1.48 Hz, 1H), 7.42 (ddd, J = 7.55, 4.78, 1.35 Hz, 1H), 2.68 (s, 3H). ^{13}C NMR (151 MHz, CDCl3) δ 200.08, 153.56, 148.96, 136.81, 127.07, 121.61, 25.74.

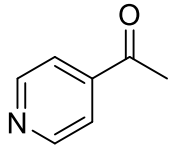


1-(pyridin-3-yl)ethan-1-one (4j). The product **4j** was obtained via the *general procedure* using 3-(prop-1-en-2-yl) pyridine **3j** (23.8 mg, 0.2

mmol) and isolated by flash column chromatography as yellow oil (9.9 mg, 41 %).

Known compound, spectroscopic data matched those previously reported.[20]

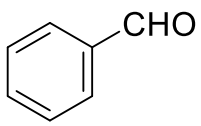
^{1}H NMR (600 MHz, Chloroform-d) δ 9.09 (qd, J = 2.18, 1.36 Hz, 1H), 8.70 (dq, J = 4.87, 1.61 Hz, 1H), 8.16 (dq, J = 7.98, 1.78 Hz, 1H), 7.36 (dddd, J = 6.79, 4.81, 2.48, 1.26 Hz, 1H), 2.57 (s, 3H).^{13}C NMR (151 MHz, CDCl3) δ 196.69, 153.50, 149.89, 135.41, 132.22, 123.59, 26.67.



4-Acetylpyridine (4k). The product **4k** was obtained via the *general procedure* using 4-(prop-1-en-2-yl) pyridine **3k** (23.8 mg, 0.2 mmol) and isolated by flash column chromatography as yellow oil (6.1 mg, 25 %).

Known compound, spectroscopic data matched those previously reported.[20]

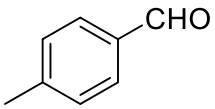
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.79 (dd, *J* = 4.5, 1.6 Hz, 2H), 7.71 (dd, *J* = 4.4, 1.6 Hz, 2H), 2.62 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.24, 150.89, 142.75, 121.16, 26.53.



Benzaldehyde (4l). The product **4l** was obtained via the *general procedure* using styrene **3l** (20.8 mg, 0.2 mmol) and isolated by flash column chromatography as colorless liquid (13.6 mg, 64%).

Known compound, spectroscopic data matched those previously reported.[21]

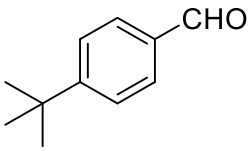
^{1}H NMR (400 MHz, $CDCl_3$) δ 9.96 (s, 1H), 7.82 (d, *J* = 7.9 Hz, 2H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.6 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 192.22, 136.39, 134.35, 129.61 (2C), 128.92 (2C).



p-Tolualdehyde (4m). The product **4m** was obtained via the *general procedure* using 1-methyl-4-vinylbenzene **3m** (23.6 mg, 0.2 mmol) and isolated by flash column chromatography as colorless liquid (14.7 mg, 61%).

Known compound, spectroscopic data matched those previously reported.[22]

^{1}H NMR (400 MHz, $CDCl_3$) δ 9.91 (s, 1H), 7.72 (d, *J* = 8.1 Hz, 2H), 7.27 (d, *J* = 7.9 Hz, 2H), 2.38 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 191.69, 145.37, 134.24, 129.70 (2C), 129.65 (2C), 21.66.

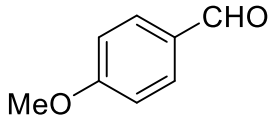


4-tert-Butylbenzaldehyde (4n). The product **4n** was obtained via the *general procedure* using 1-(tert-butyl)-4-vinylbenzene **3l** (32 mg, 0.2

mmol) and isolated by flash column chromatography as colorless liquid (23 mg, 71%).

Known compound, spectroscopic data matched those previously reported.[23]

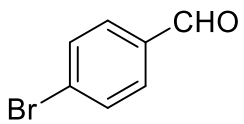
^{1}H NMR (400 MHz, $CDCl_3$) δ 9.99 (s, 1H), 7.83 (d, *J* = 8.2 Hz, 2H), 7.56 (d, *J* = 8.2 Hz, 2H), 1.36 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 191.81, 158.33, 134.14, 129.63 (2C), 125.92 (2C), 35.26, 31.01 (3C).



***p*-Anisaldehyde (4o).** The product **4o** was obtained via the *general procedure* using 1-methoxy-4-vinylbenzene **3o** (26.8 mg, 0.2 mmol) and isolated by flash column chromatography as colorless liquid (25.2 mg, 60%).

Known compound, spectroscopic data matched those previously reported.[24]

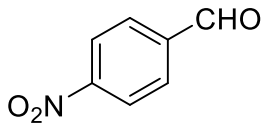
^{1}H NMR (400 MHz, $CDCl_3$) δ 9.71 (s, 1H), 7.67 - 7.63 (m, 2H), 6.82 (d, *J* = 8.8 Hz, 2H), 3.68 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 190.44, 164.44, 131.69 (2C), 129.83, 114.16 (2C), 55.30.



4-Bromobenzaldehyde (4p). The product **4p** was obtained via the *general procedure* using 1-bromo-4-vinylbenzene **3p** (36.4 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (20 mg, 54%).

Known compound, mp 65-68 °C, spectroscopic data matched those previously reported.[24]

^{1}H NMR (400 MHz, $CDCl_3$) δ 10.02 (s, 1H), 7.80 - 7.77 (m, 2H), 7.72 (d, *J* = 8.4 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 190.92, 135.13, 132.42 (2C), 130.92 (2C), 129.73.



4-Nitrobenzaldehyde (4q). The product **4q** was obtained via the *general procedure* using 1-nitro-4-vinylbenzene **3q** (29.8 mg, 0.2 mmol) and isolated by flash column chromatography as a yellow solid (15.1 mg, 50%). Known compound, mp 104-106 °C, spectroscopic data matched those previously reported.[24]

^{1}H NMR (400 MHz, $CDCl_3$) δ 10.19 (s, 1H), 8.41 (d, *J* = 8.6 Hz, 2H), 8.11 (d, *J* = 8.5 Hz, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 190.22, 151.15, 140.07, 130.45 (2C), 124.28 (2C).

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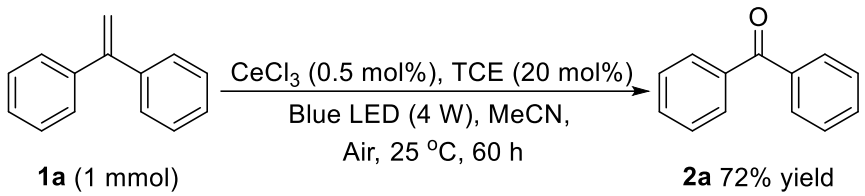
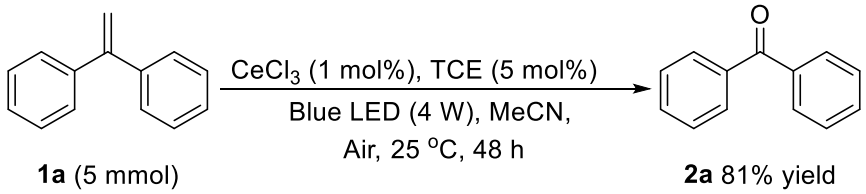
5. The reaction practicability emanations

5.1 Reaction with low catalyst loading



A mixture of ethene-1,1-diyldibenzene (1.0 mmol, 180.1 mg), $CeCl_3$ (0.5 mol%, 1.3 mg), CCl_3CH_2OH (20 mol%, 29.8 mg) and CH_3CN (4.0 mL) was added into a quartz tube which was placed in a photochemical reactor (Blue LED, 405-410 nm, 4 W)). The reaction mixture was stirred at 25 °C under air for 60 h. After concentrated under reduced pressure, the residue was purified by flash column chromatography on silica gel and eluted with EtOAc/petroleum ether (1/100~10/1) to afford the desired product.

5.2 5 mmol scale reaction



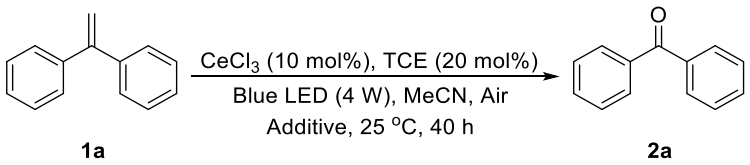
A mixture of ethene-1,1-diyldibenzene (5.0 mmol, 901.3 mg), $CeCl_3$ (1 mol%, 13.5 mg), CCl_3CH_2OH (5 mol%, 37.4 mg) and CH_3CN (10.0 mL) was added into a quartz tube which was placed in a photochemical reactor (Blue LED, 405-410 nm, 4 W)). The reaction mixture was stirred at 25 °C

under air for 48 h. After concentrated under reduced pressure, the residue was purified by flash column chromatography on silica gel and eluted with EtOAc/petroleum ether (1/100~10/1) to afford the desired product.

6. Mechanistic studies

6.1 Control experiments

To explore the reaction mechanism for our oxidative process, some control experiments were first carried out.



1a **2a**

Entry	Additive	Yield (%)
1	No catalyst	No reaction
2	No light	No reaction
3	N_2-atmosphere	No reaction

Reaction condition: **1a** (0.2mmol), $CeCl_3$ (10 mol%), TCE (20 mol%), CH_3CN (1.0 mL) at room temperature (25℃), Blue LED (5 W) for 40 h.

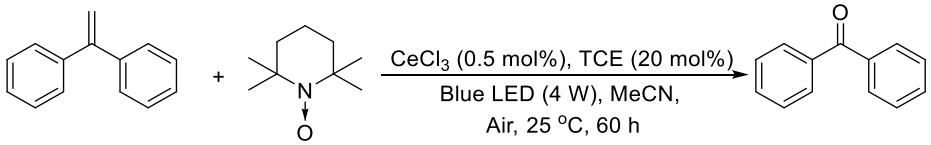
The results demonstrated that light, Ce catalyst and air, none of these three can be excluded. The absence of any one lead to the complete inhibition of this oxidative process.

6.2 Radical scavenger effect studies

To further investigate the reaction mechanism for this photocatalytic reaction, radical scavengers, such as TEMPO and BHT, were employed in the standard reaction, and the reaction was inhibited obviously. This result suggested that a free radical process might be involved in the present oxidative reaction.

a) Reaction in the presence of TEMPO

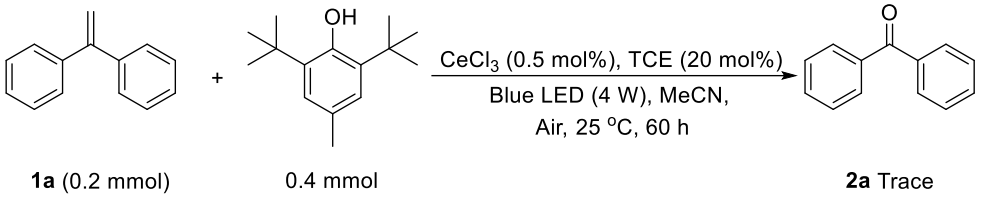
A mixture of ethene-1,1-diyldibenzene (0.2 mmol, 36.0 mg), $CeCl_3$ (10 mol%, 4.9 mg), CCl_3CH_2OH (20 mol%, 5.9 mg), TEMPO (0.4 mmol, 62.4 mg) and CH_3CN (1.0 mL) was added into a quartz tube which was placed in a photochemical reactor (Blue LED, 405-410 nm, 4 W)). The reaction mixture was stirred at 25 ^oC under air. After 40 h, no desired product was observed.



b) Reaction in the presence of BHT

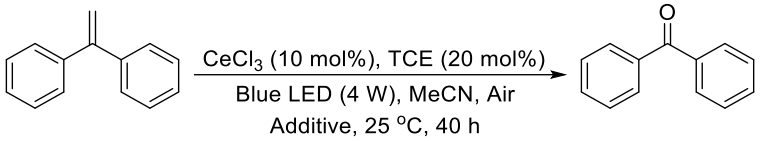
A mixture of ethene-1,1-diyldibenzene (0.2 mmol, 36.0 mg), $CeCl_3$ (10 mol%, 4.9 mg), CCl_3CH_2OH (20 mol%, 5.9 mg), BHT (0.4 mmol, 88.1 mg) and CH_3CN (1.0 mL) was added into a quartz tube which was placed in a photochemical reactor (Blue LED, 405-410 nm, 4 W)). The

reaction mixture was stirred at 25 °C under air. After 40 h, only trace amount of product was observed.



6.3 Quenching experiments

Finally, some quenching reagents were subjected to the reaction.



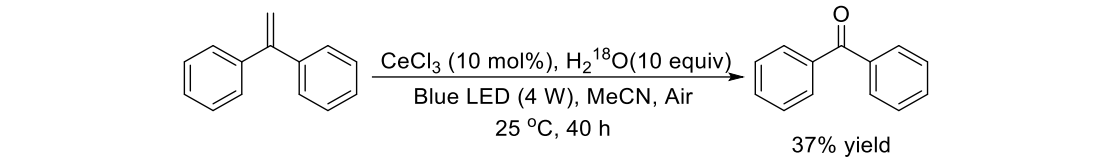
Entry	Quenching reagent	Yield (%)
1	$CuCl_2$ (1.0 equiv.)	Trace
2	Benzoquinone (1.0 equiv.)	8%

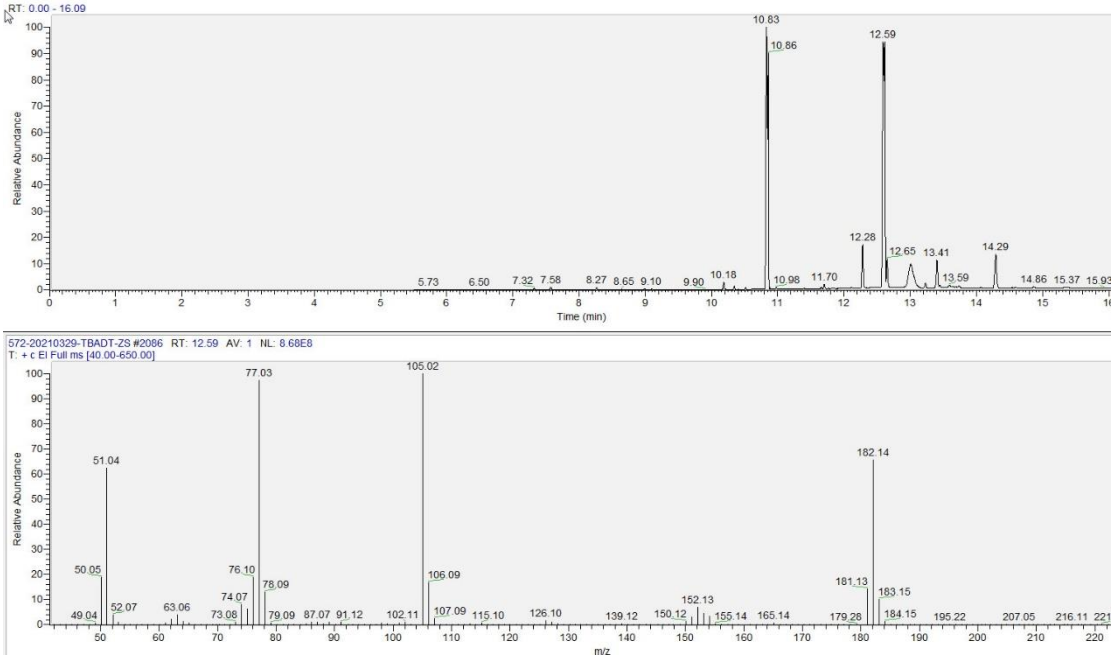
Reaction condition: **1a** (0.2mmol), $CeCl_3$ (10 mol%), TCE (20 mol%), CH_3CN (1.0 mL) at room temperature (25℃), Blue LED (5 W) for 40 h.

When $CuCl_2$ was added, only trace amount of product was observed, which proved the involvement of a single electron processes. Then benzoquinone was subjected and 8% of product was obtained, demonstrating superoxide radicals was involved in the reaction.

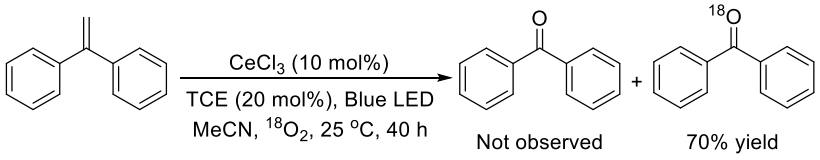
6.4 ^{18}O *labeling experiment*

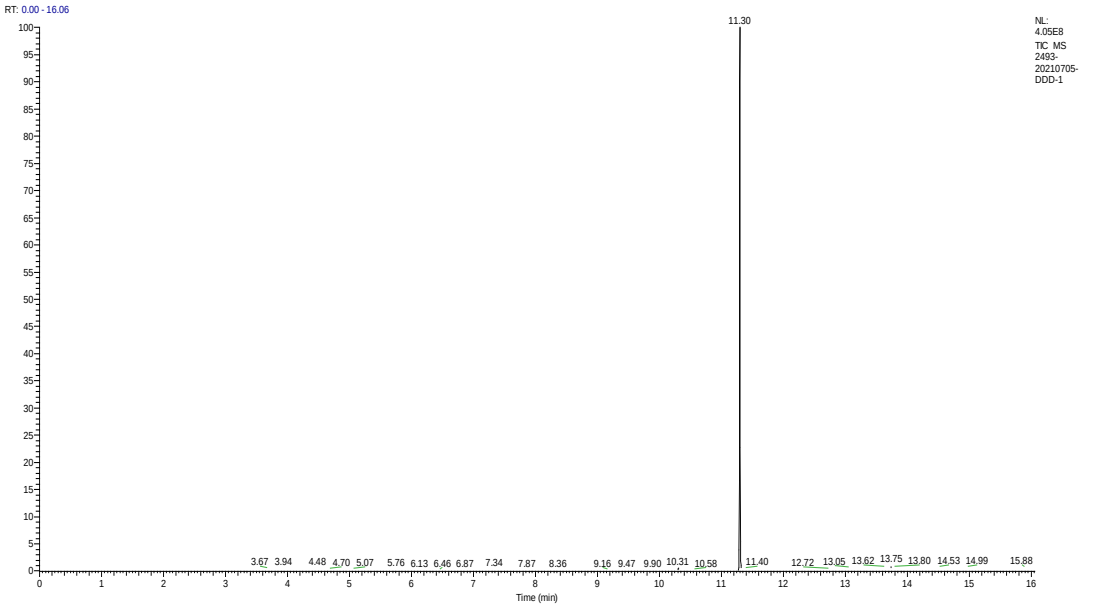
In order to show the actual source of oxygen in the ketone product, $H_2{}^{18}O$ was first used to instead TCE as the additive for the reaction.

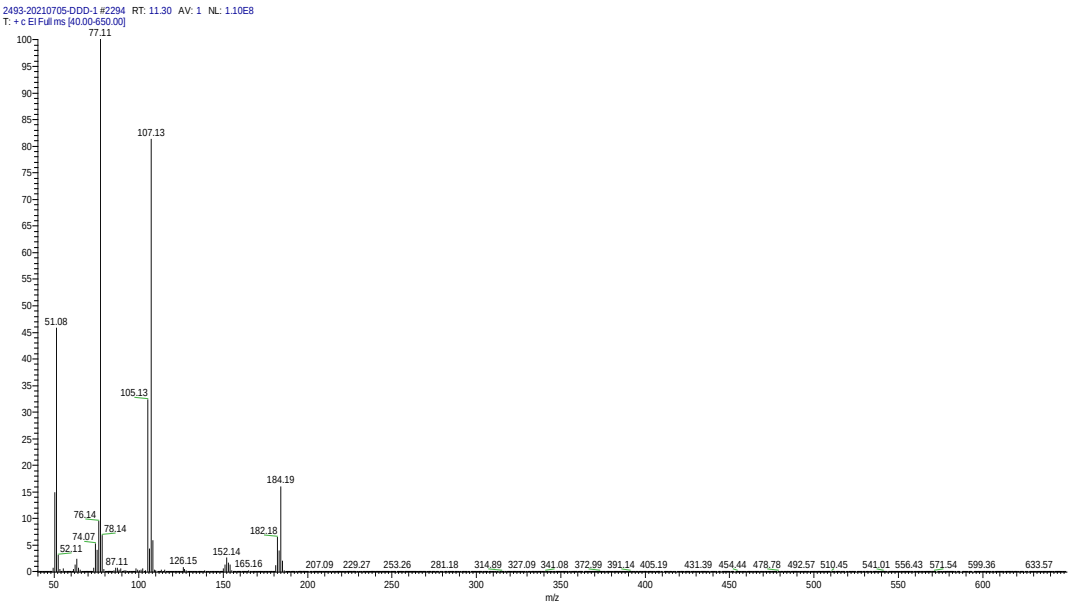




Besides, the reaction involved $^{18}O_2$ was carried out and the ^{18}O labelled product was generated in 70% yield.



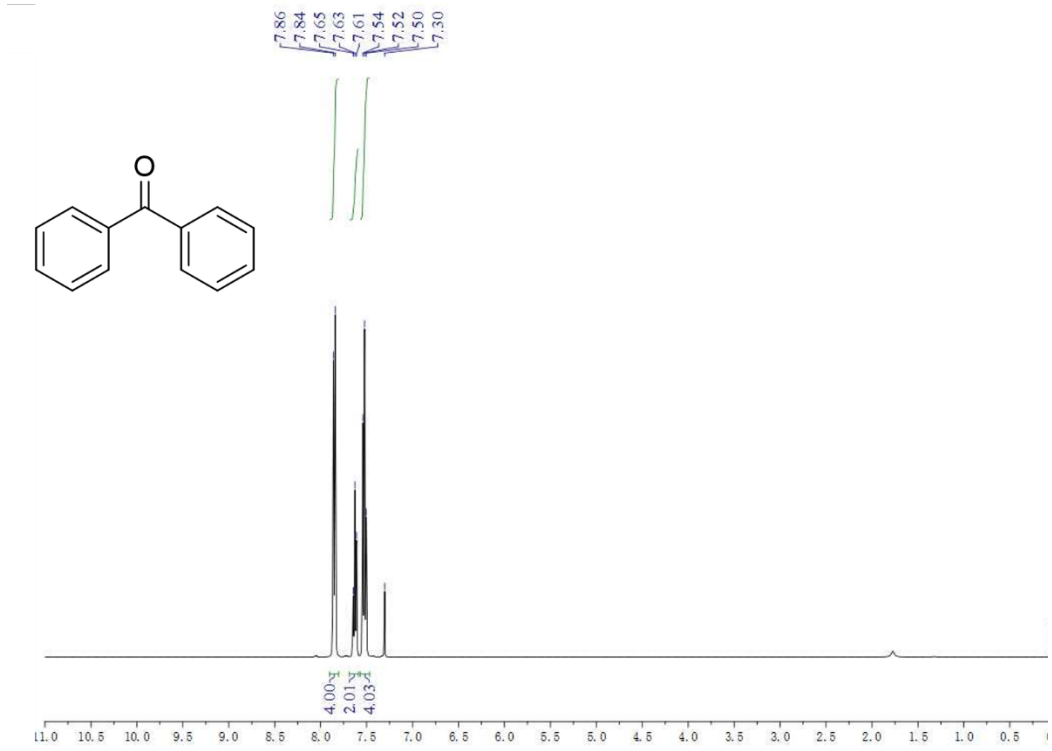




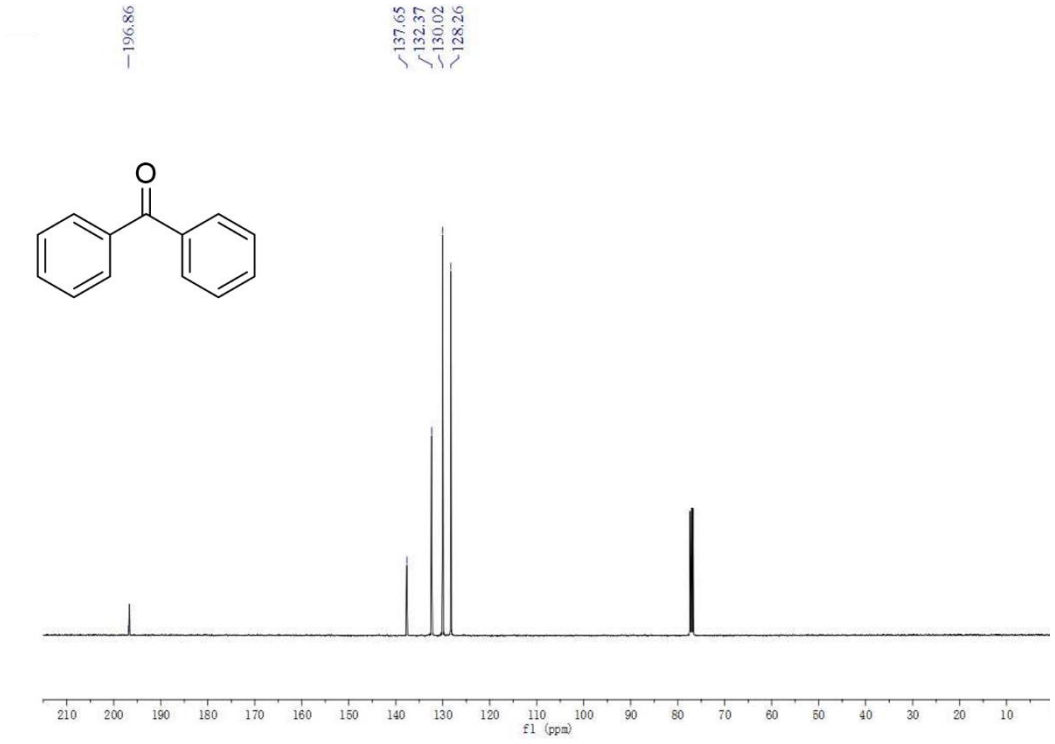
The products were detected by GC-MS and both results demonstrated that the oxygen of product was from dioxygen in the air, rather than from the H_2O or alcohols.

7. NMR spectra

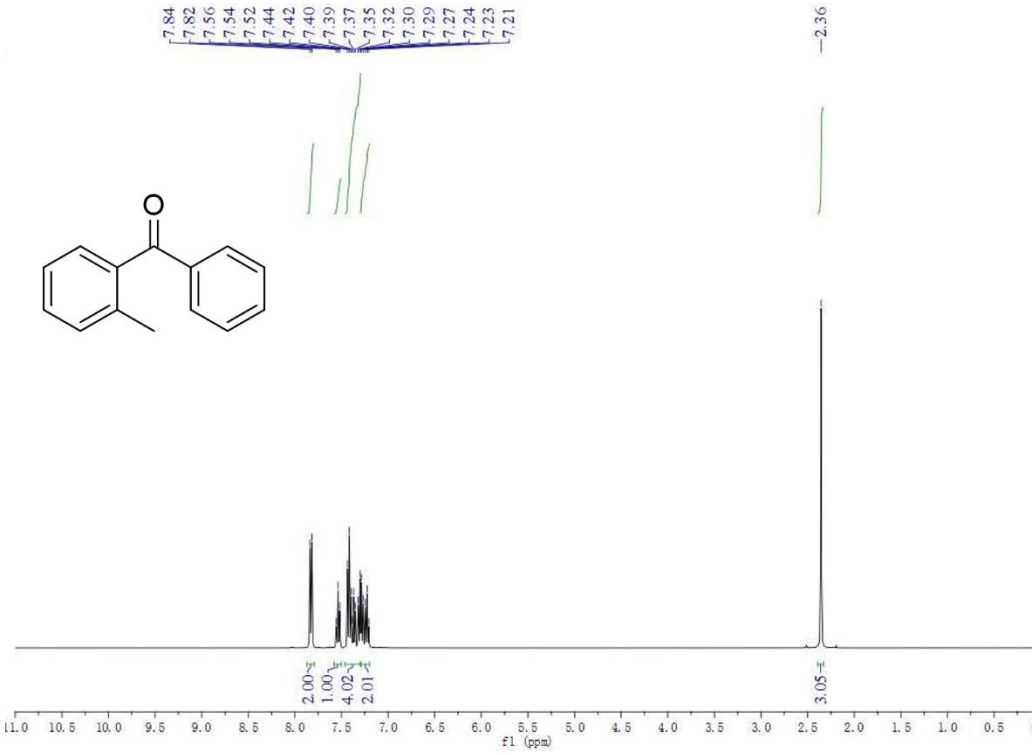
^{1}H NMR spectrum of **2a** in $CDCl_3$ at 400 MHz



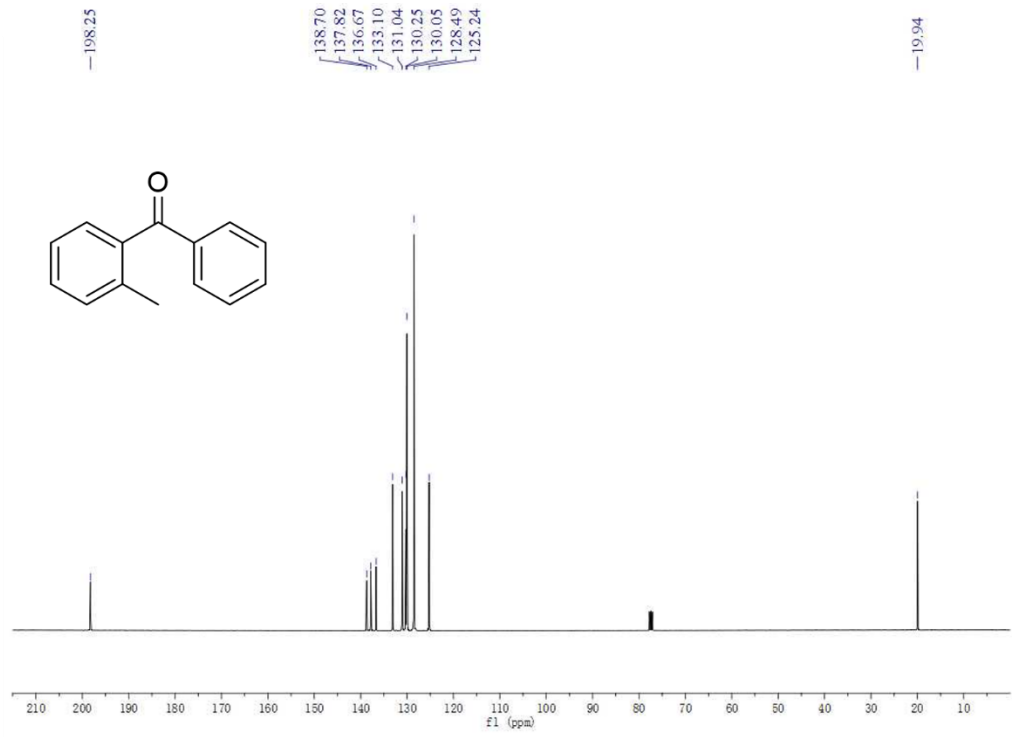
^{13}C NMR spectrum of **2a** in $CDCl_3$ at 101 MHz



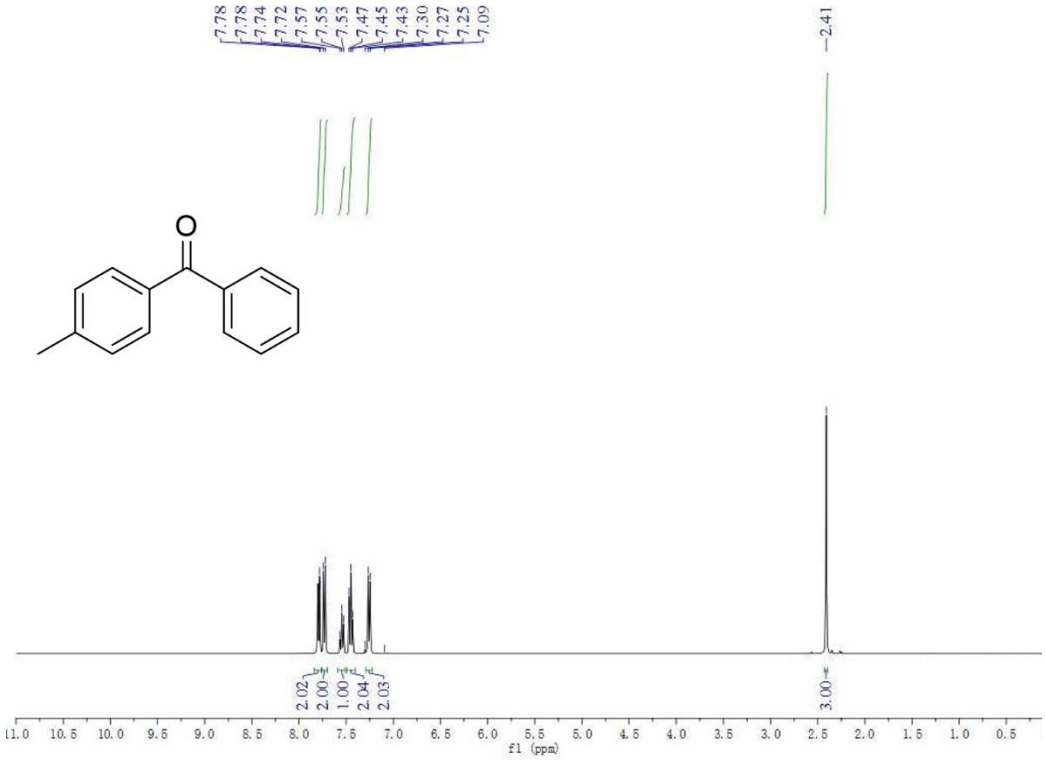
^{1}H NMR spectrum of **2b** in $CDCl_3$ at 400 MHz



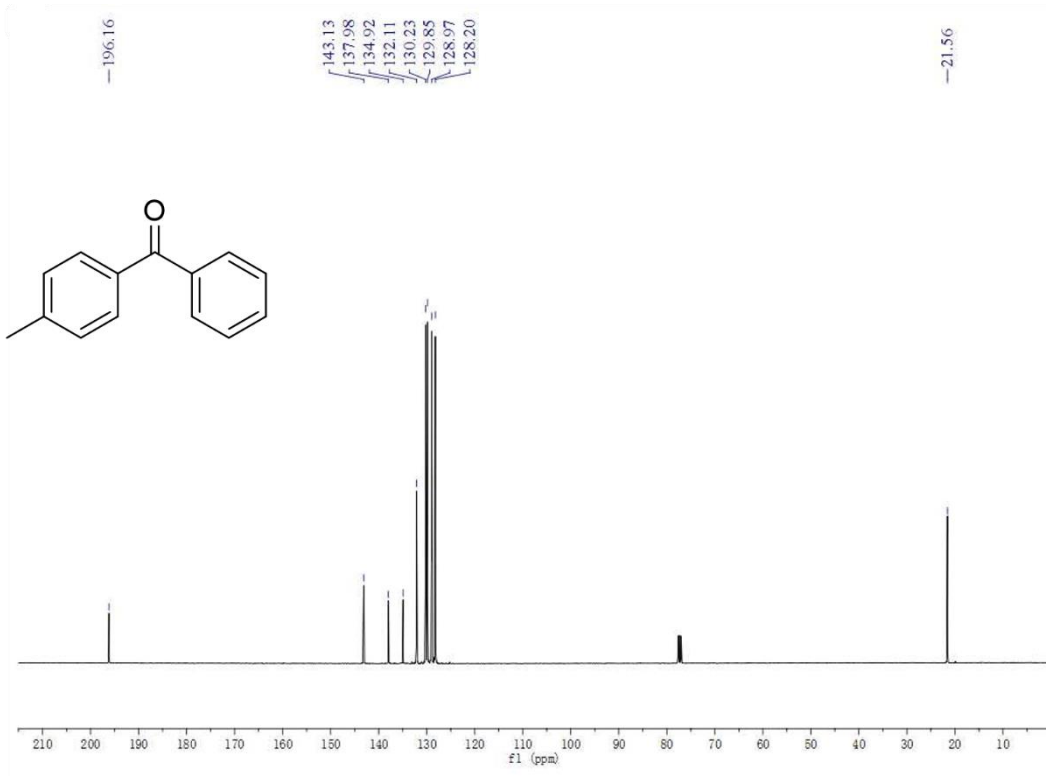
^{13}C NMR spectrum of **2b** in $CDCl_3$ at 101 MHz



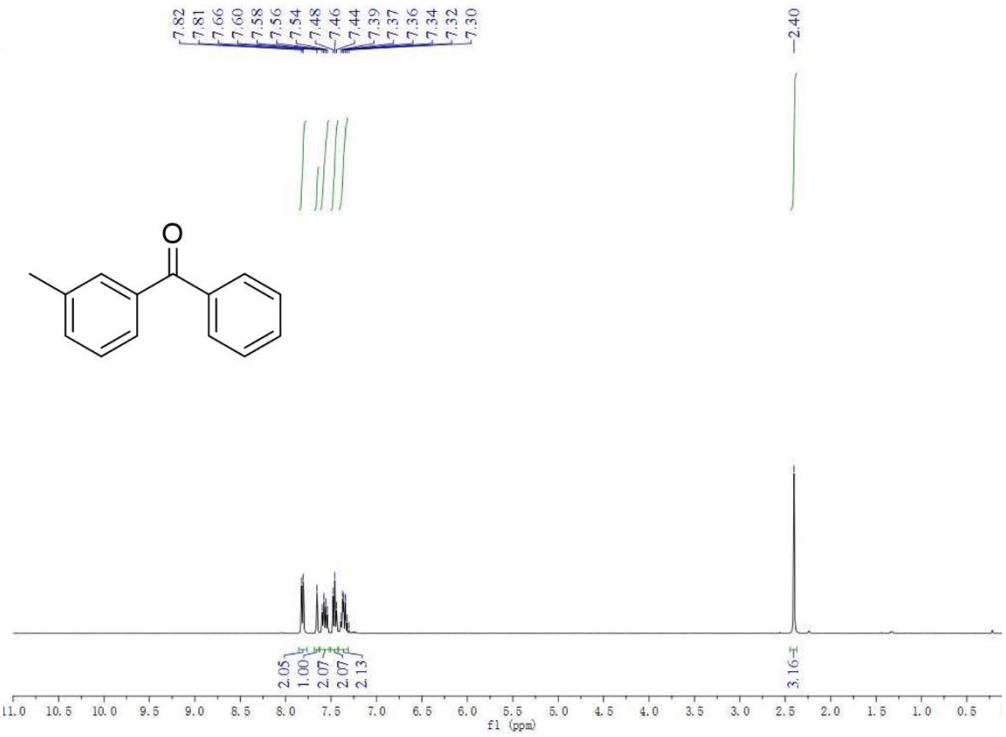
^{1}H NMR spectrum of **2c** in $CDCl_3$ at 400 MHz



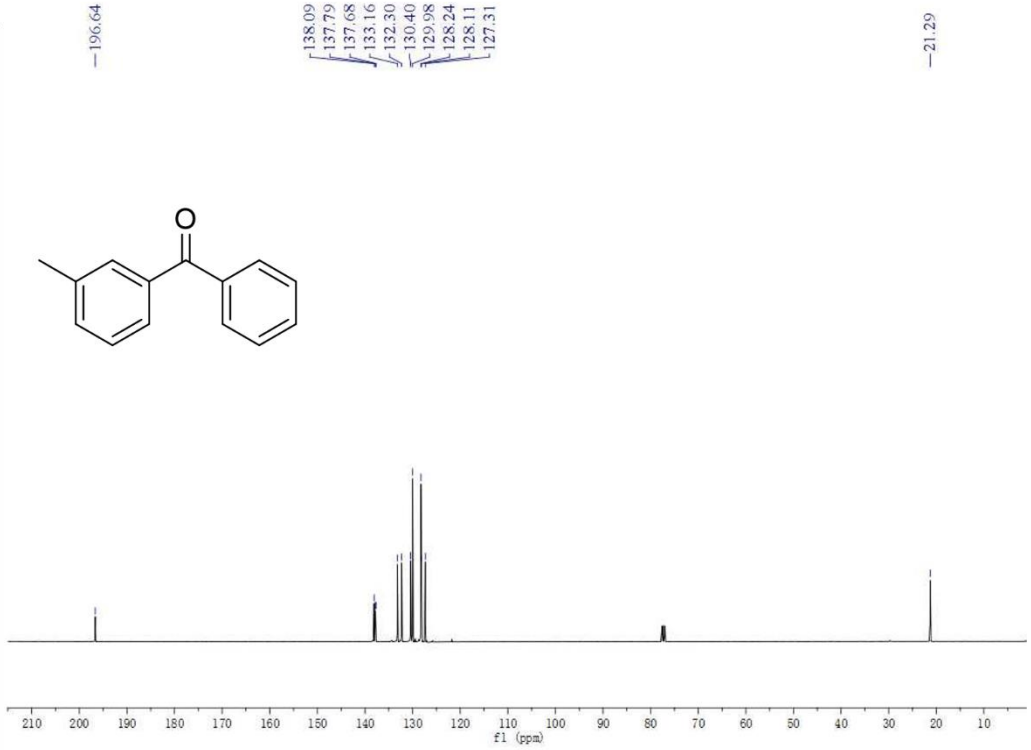
^{13}C NMR spectrum of **2c** in $CDCl_3$ at 101 MHz



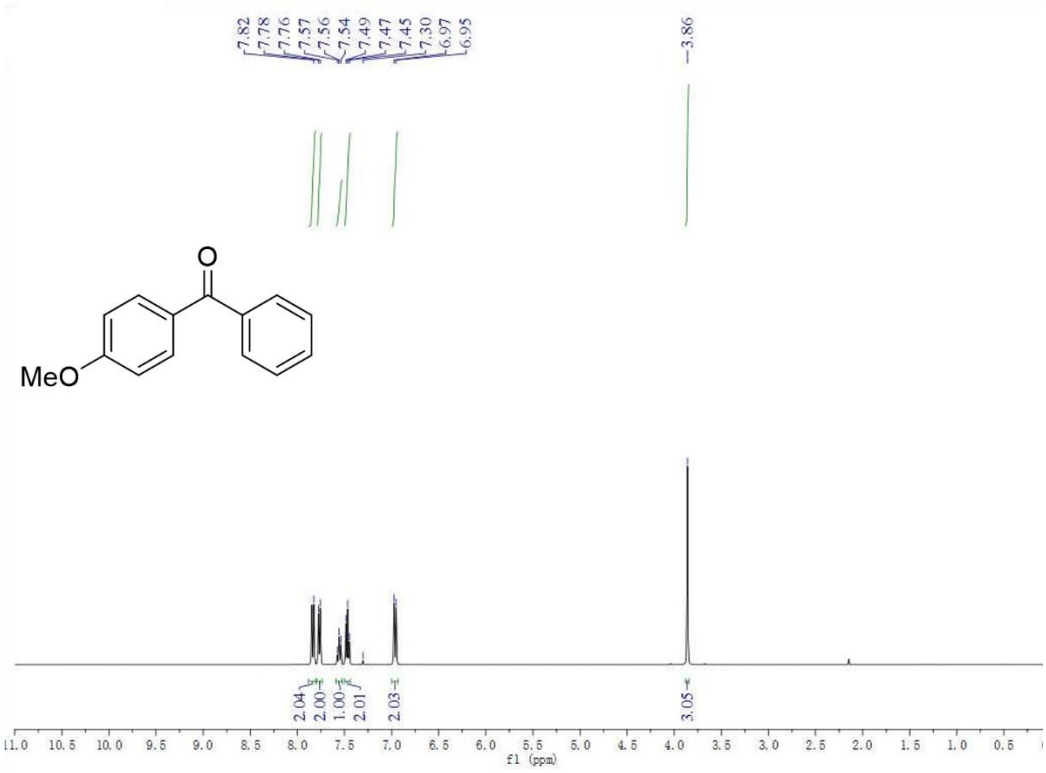
^{1}H NMR spectrum of **2d** in $CDCl_3$ at 400 MHz



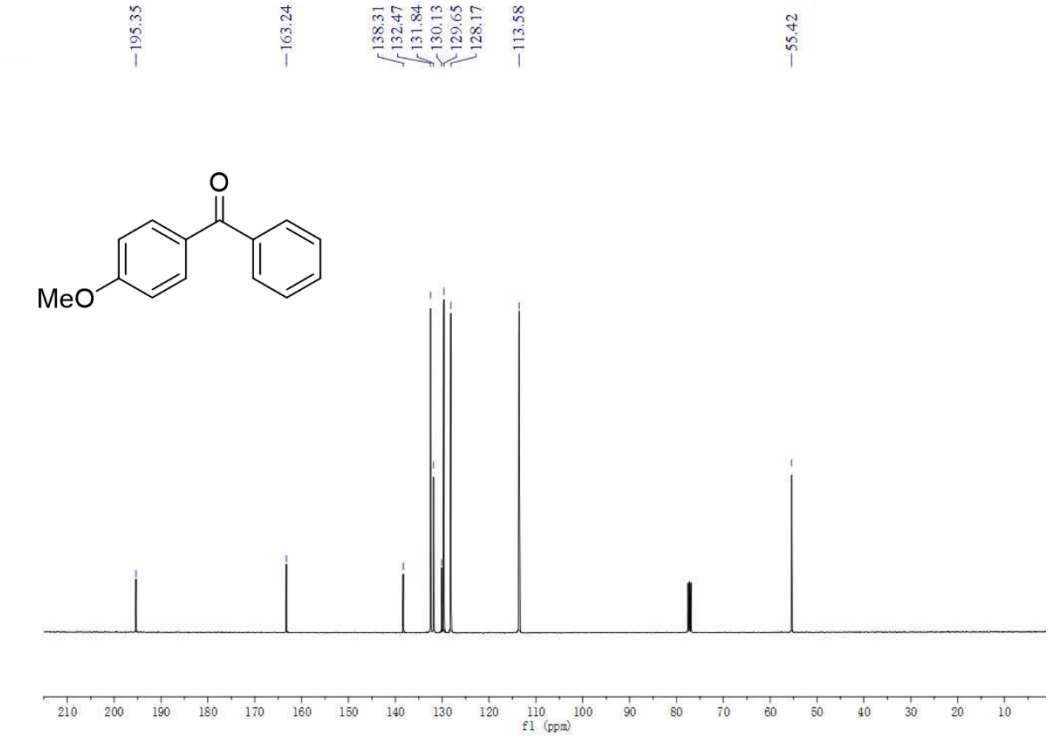
^{13}C NMR spectrum of **2d** in $CDCl_3$ at 101 MHz



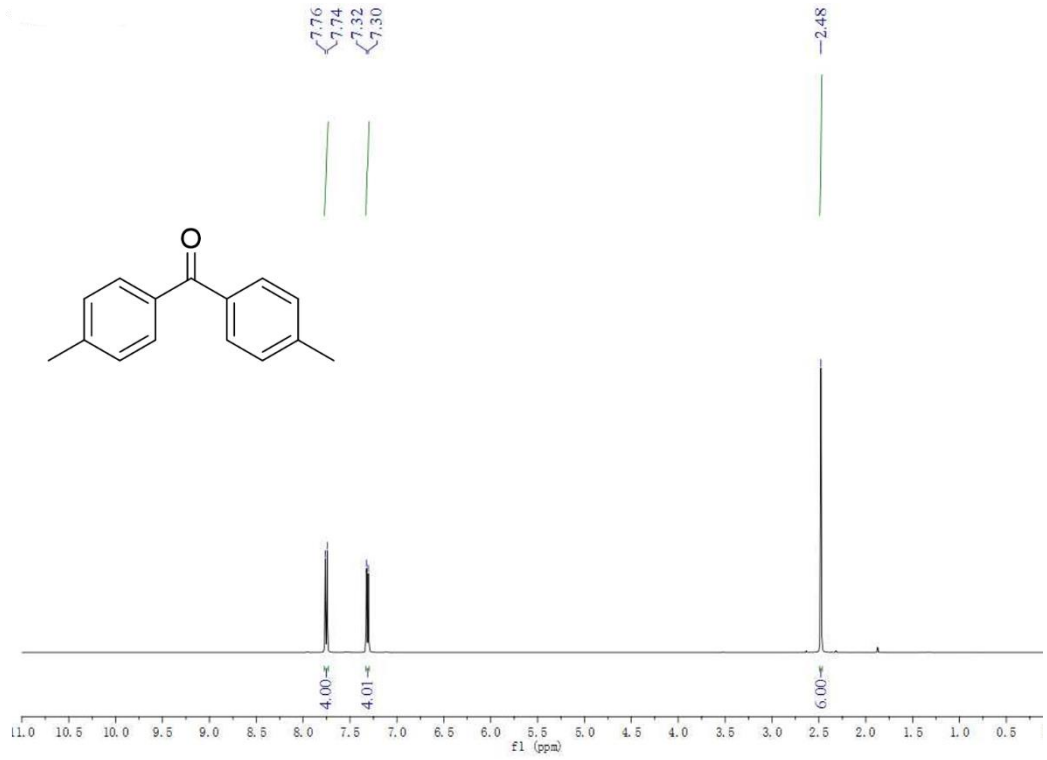
^{1}H NMR spectrum of **2e** in $CDCl_3$ at 400 MHz



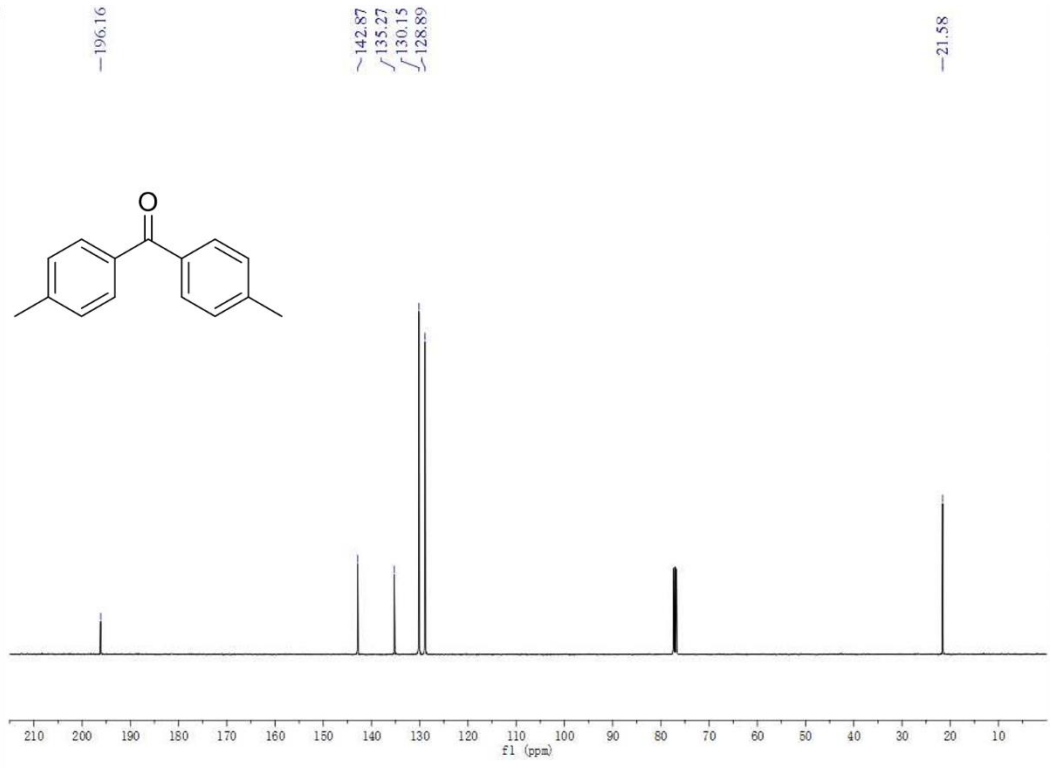
^{13}C NMR spectrum of **2e** in $CDCl_3$ at 101 MHz



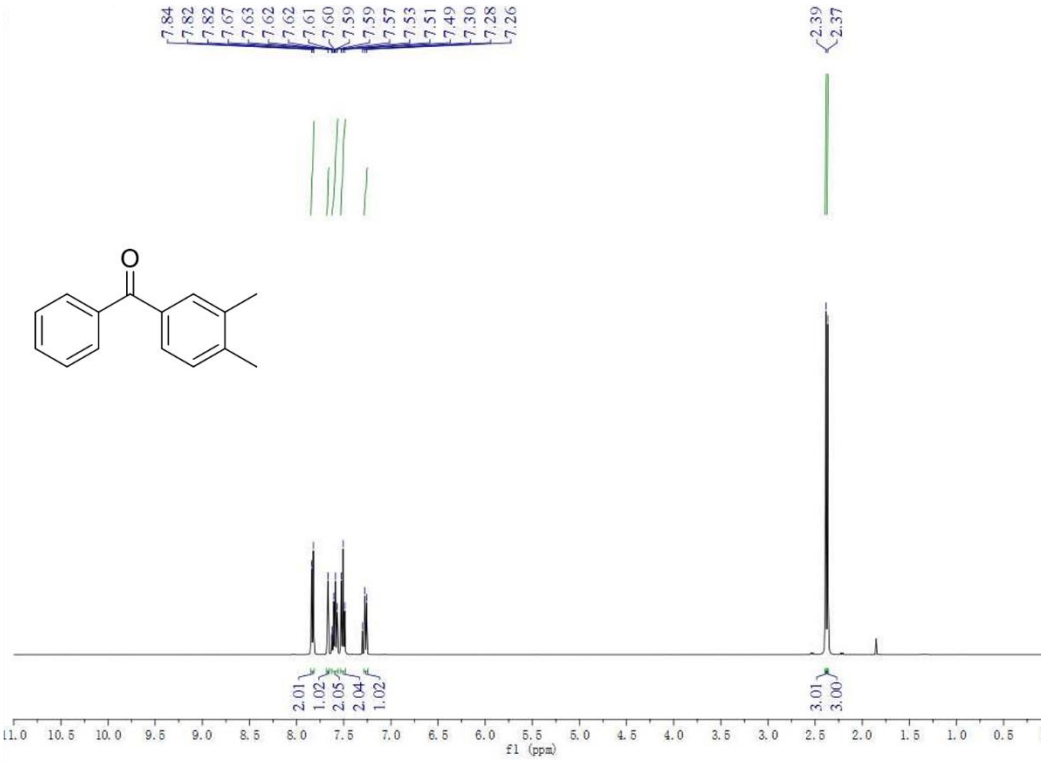
^{1}H NMR spectrum of **2f** in $CDCl_3$ at 400 MHz



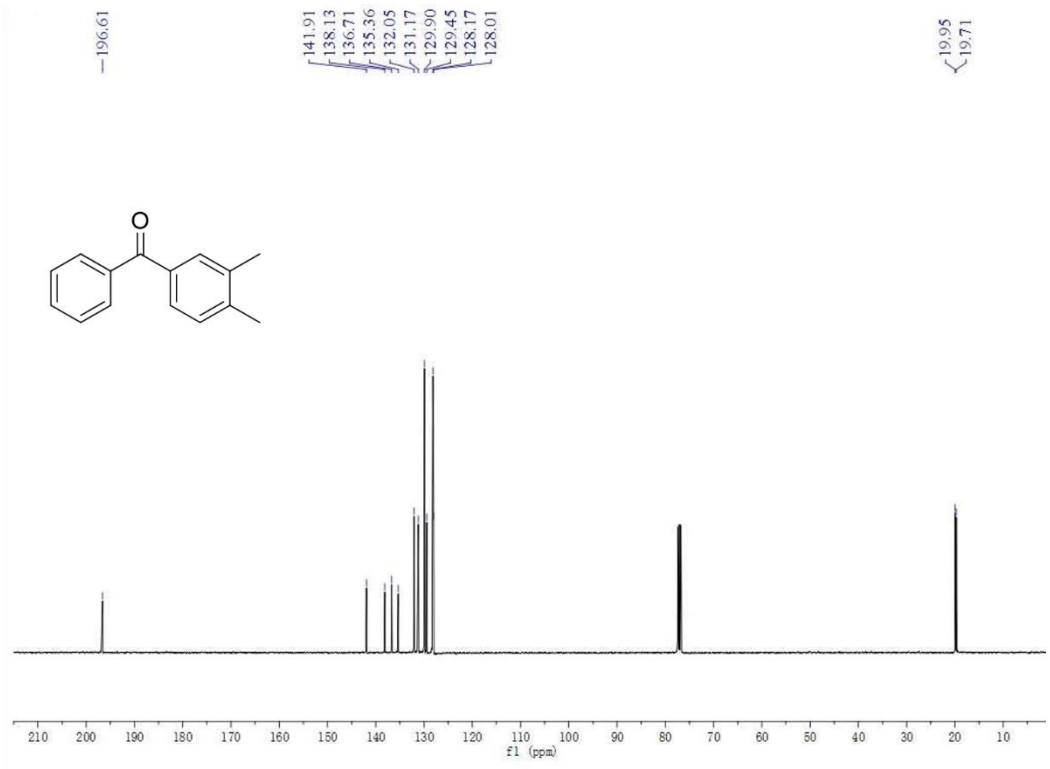
^{13}C NMR spectrum of **2f** in $CDCl_3$ at 101 MHz



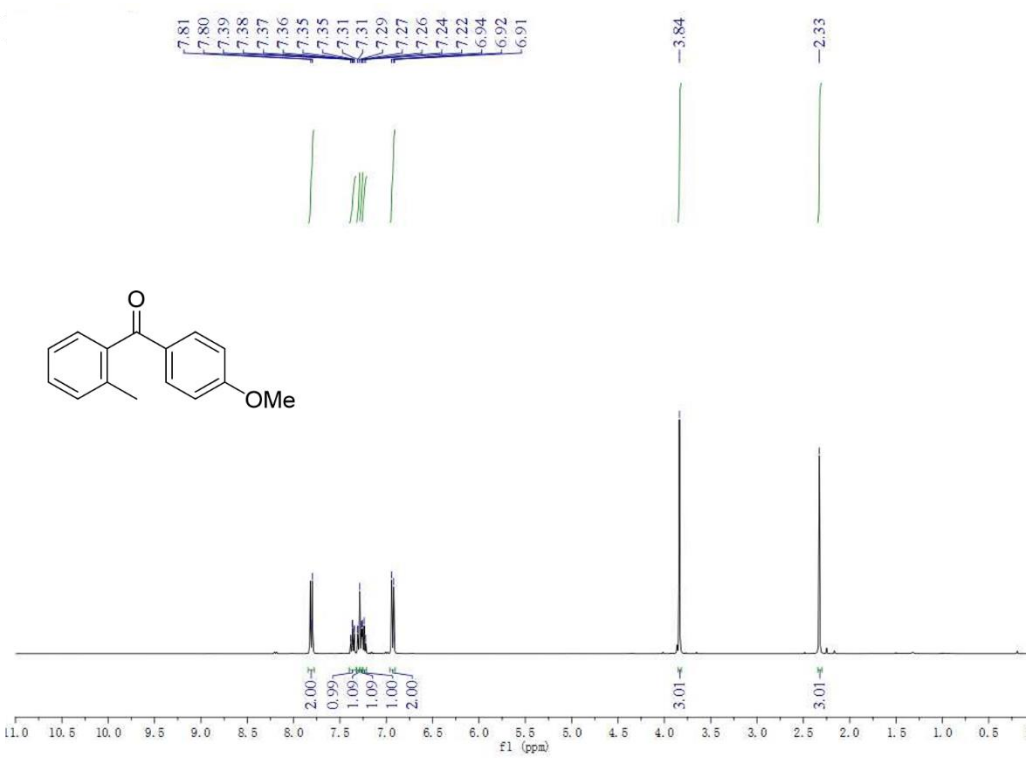
^{1}H NMR spectrum of **2g** in $CDCl_3$ at 400 MHz



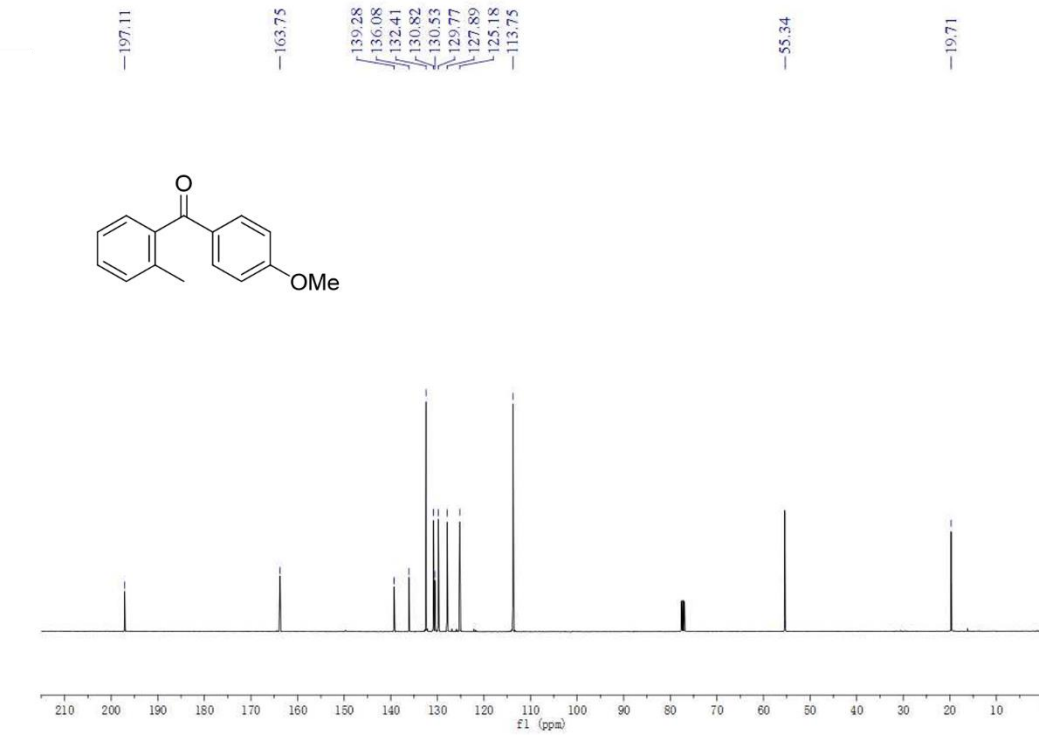
^{13}C NMR spectrum of **2g** in $CDCl_3$ at 101 MHz



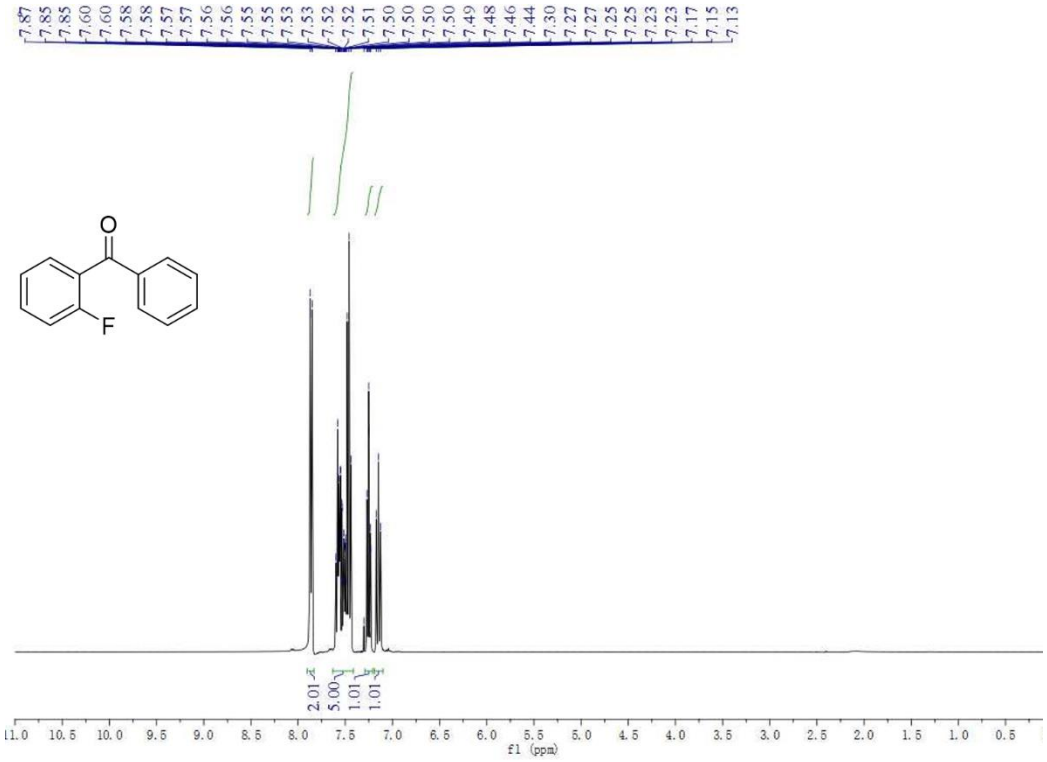
^{1}H NMR spectrum of **2h** in $CDCl_3$ at 400 MHz



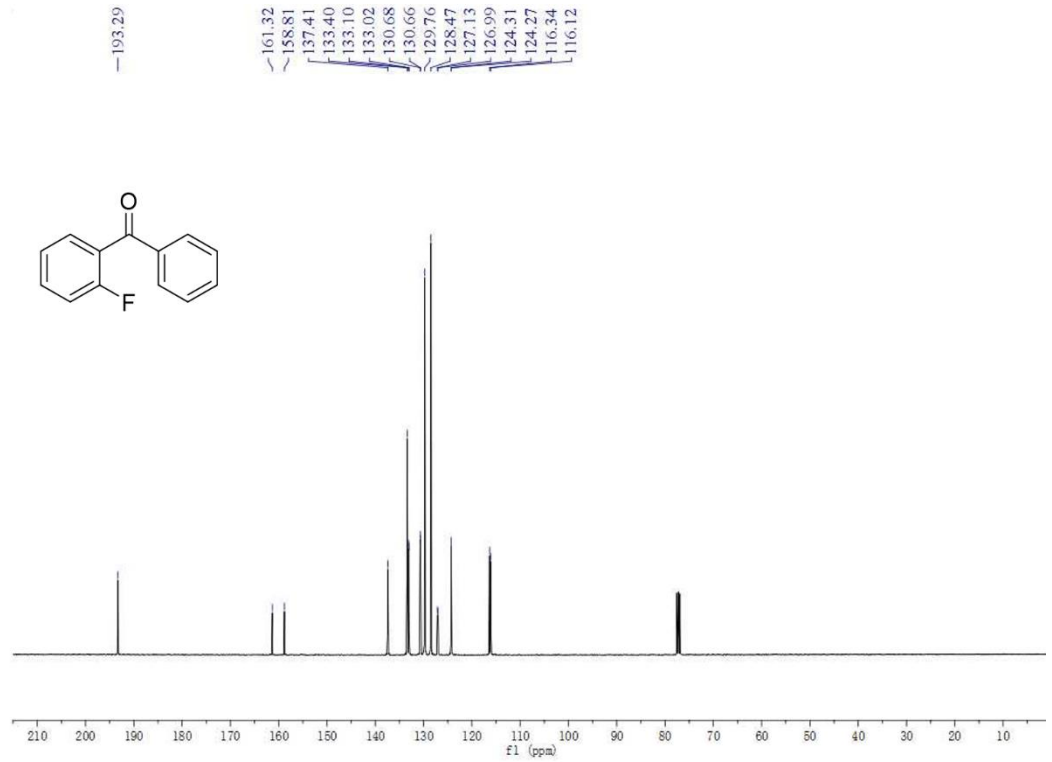
^{13}C NMR spectrum of **2h** in $CDCl_3$ at 101 MHz



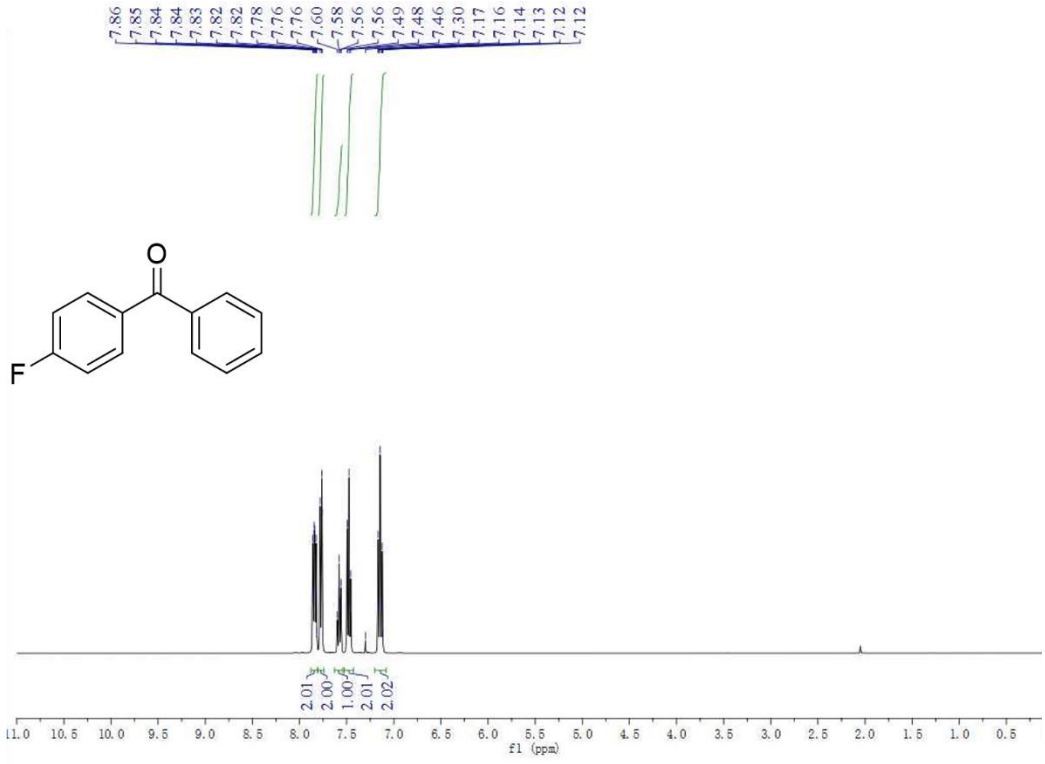
^{1}H NMR spectrum of **2i** in $CDCl_3$ at 400 MHz



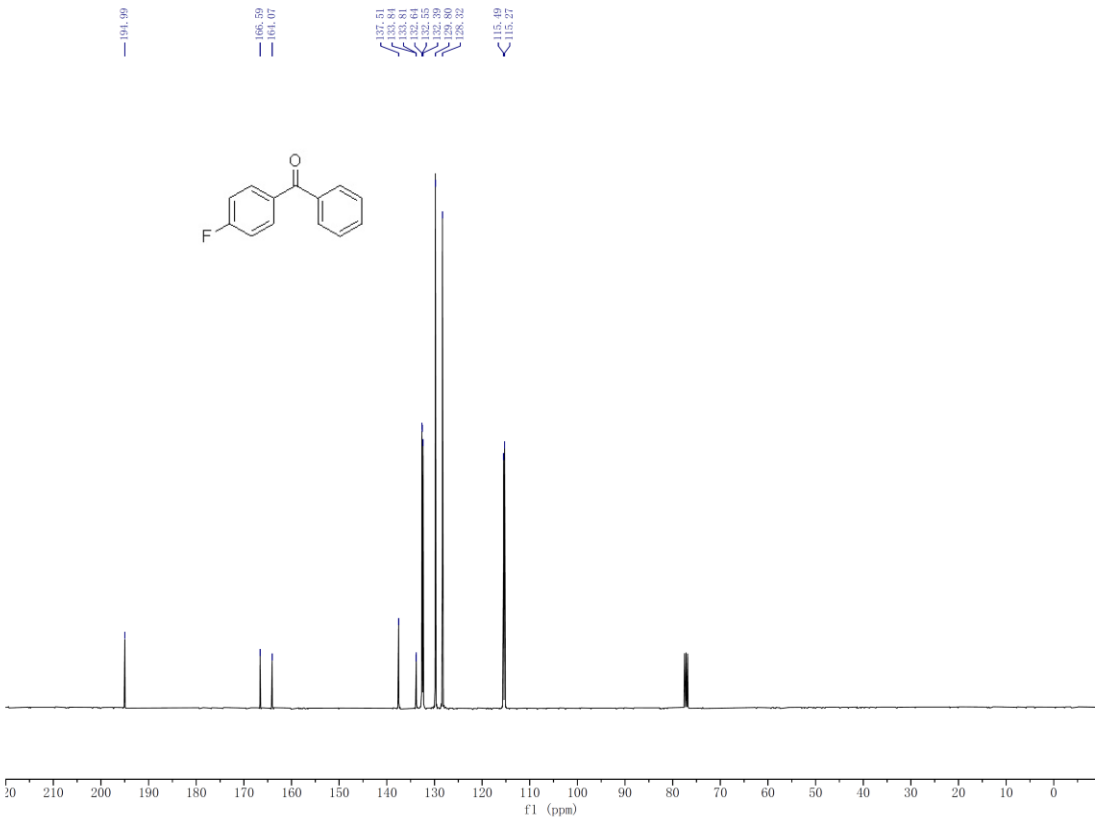
^{13}C NMR spectrum of **2i** in $CDCl_3$ at 101 MHz



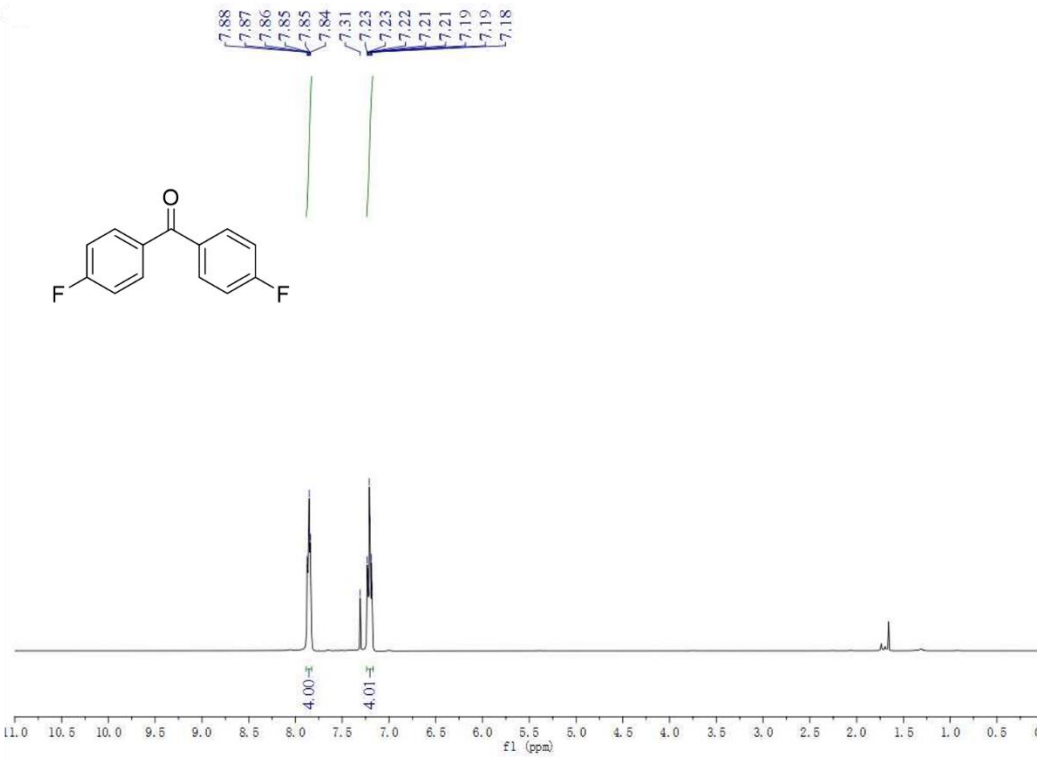
^{1}H NMR spectrum of **2j** in $CDCl_3$ at 400 MHz



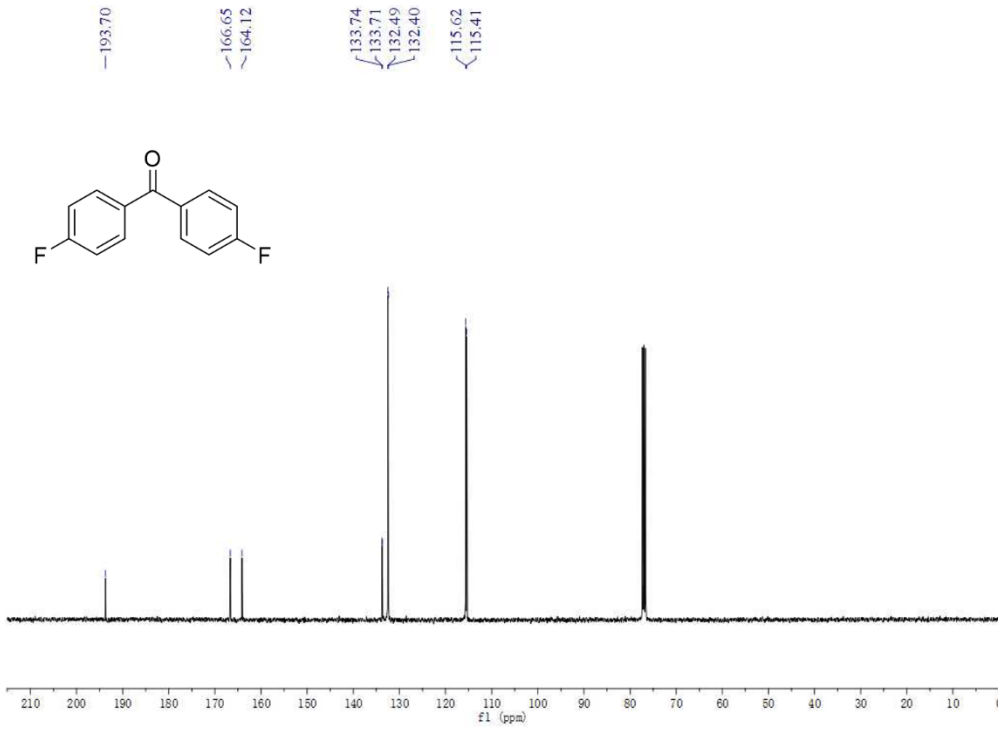
^{13}C NMR spectrum of **2j** in $CDCl_3$ at 101 MHz



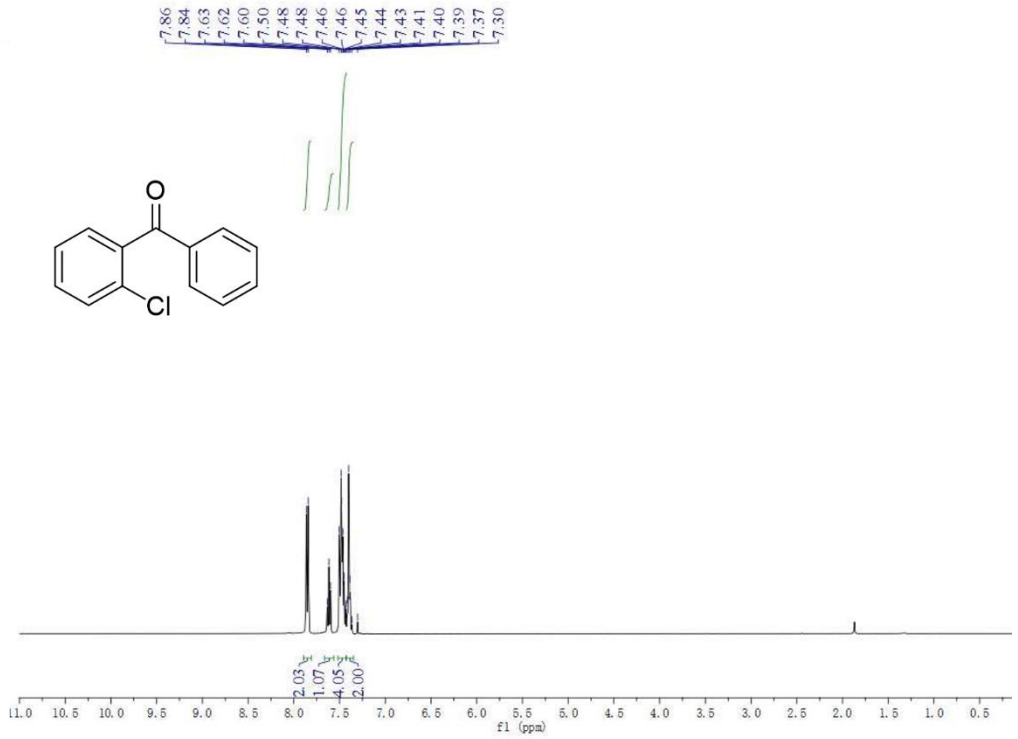
^{1}H NMR spectrum of **2k** in $CDCl_3$ at 400 MHz



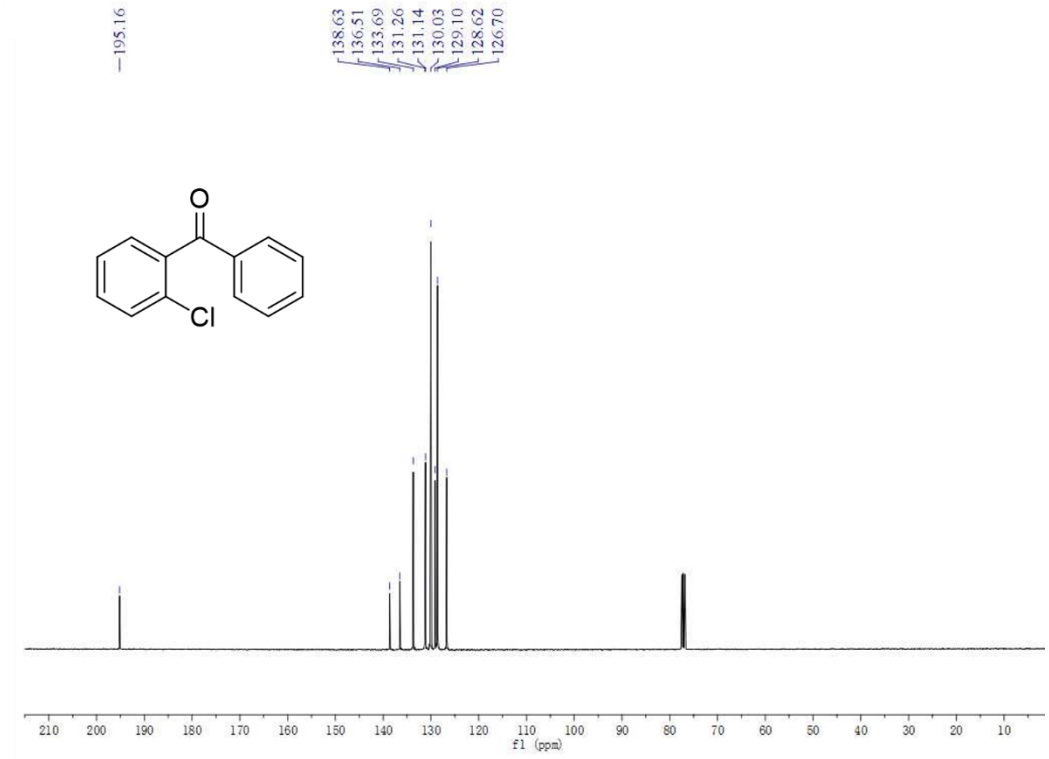
^{13}C NMR spectrum of **2k** in $CDCl_3$ at 101 MHz



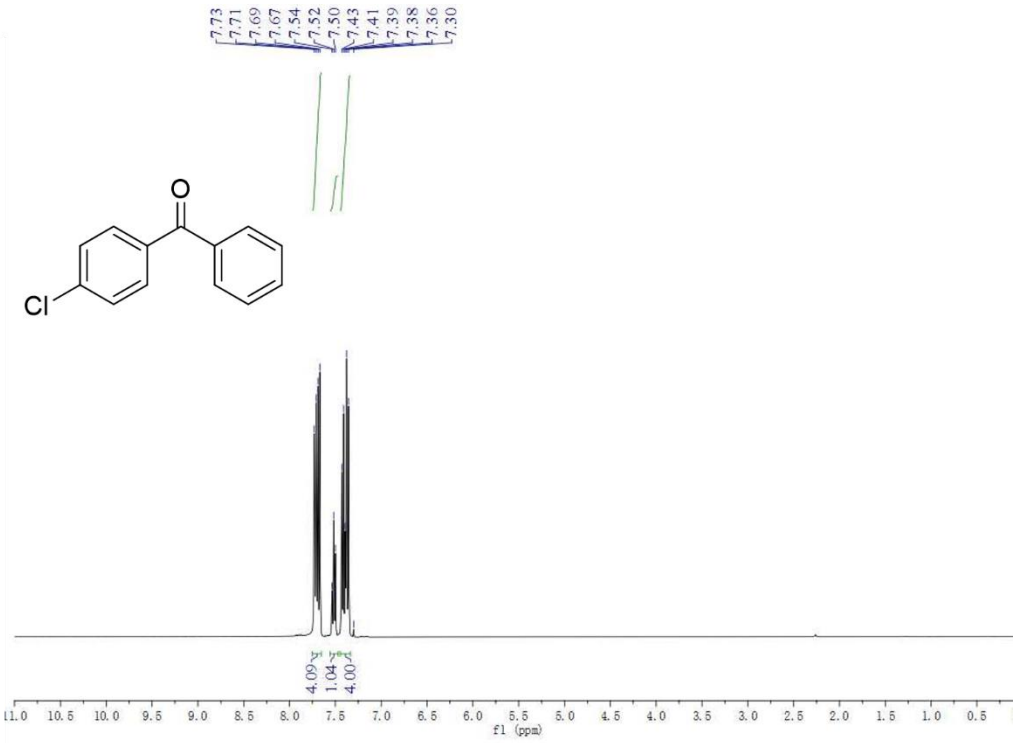
^{1}H NMR spectrum of **2l** in $CDCl_3$ at 400 MHz



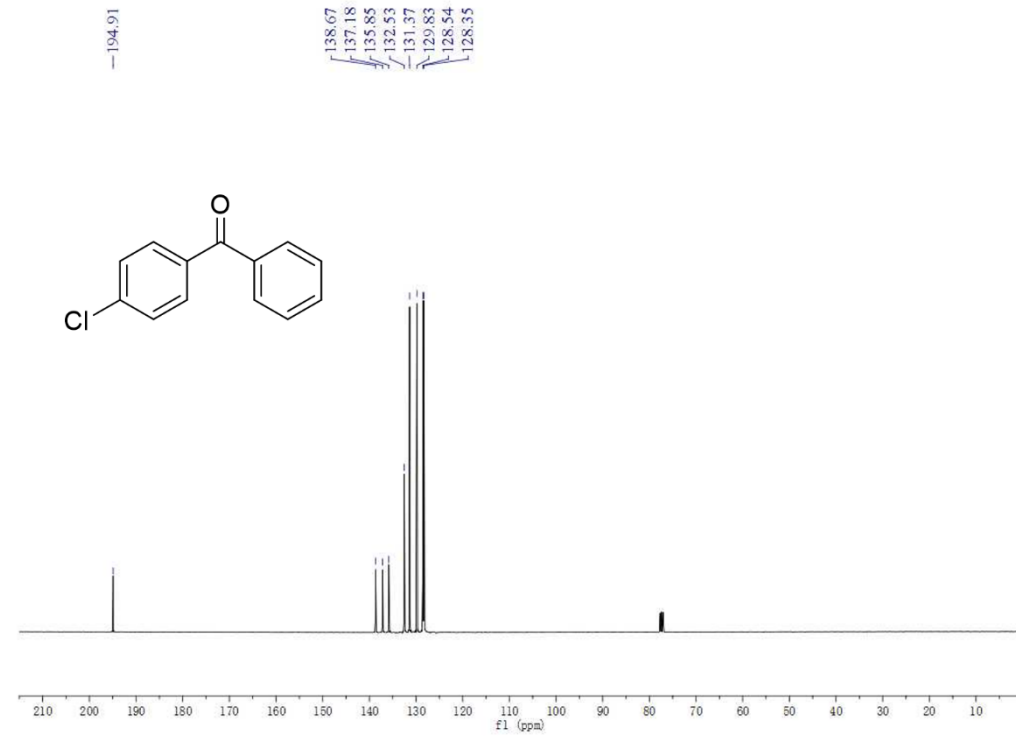
^{13}C NMR spectrum of **2l** in $CDCl_3$ at 101 MHz



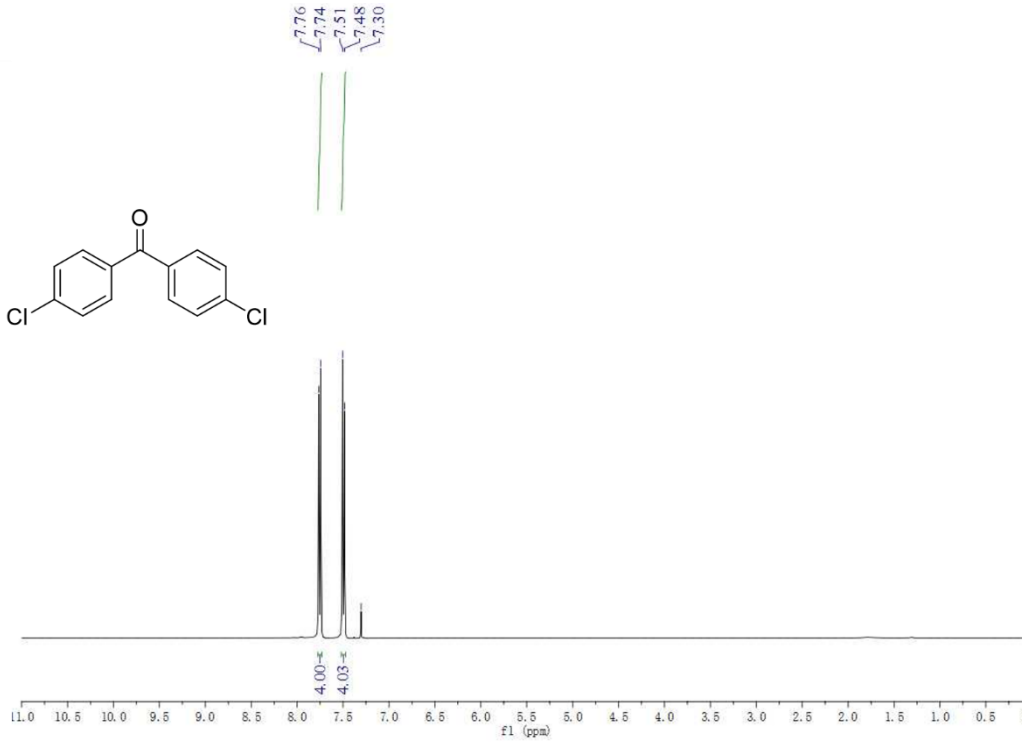
^{1}H NMR spectrum of **2m** in $CDCl_3$ at 400 MHz



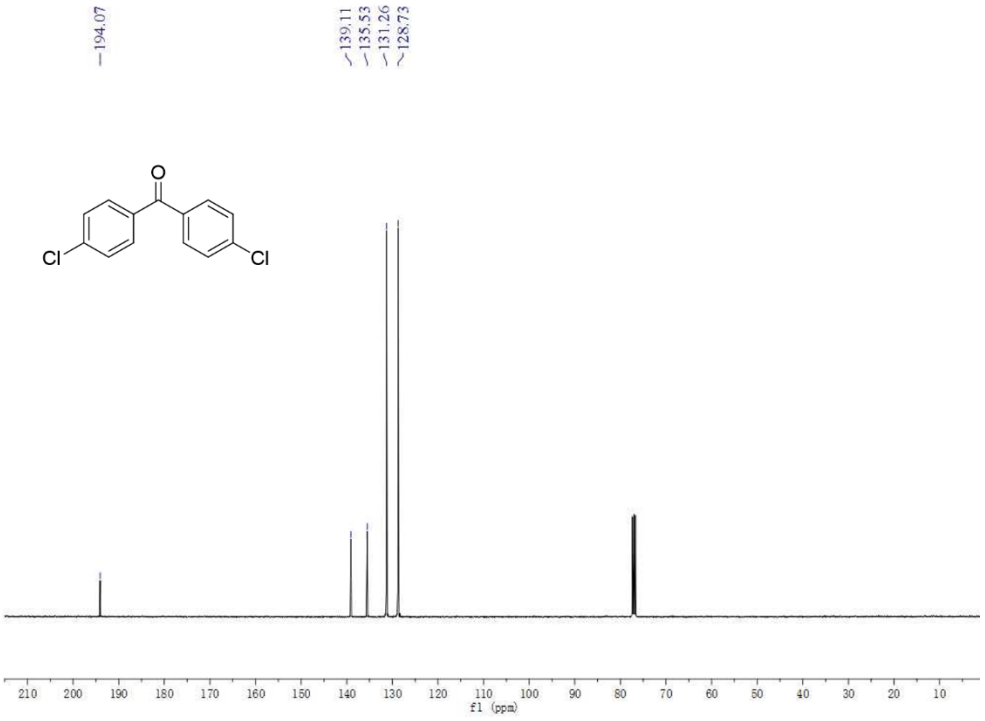
^{13}C NMR spectrum of **2m** in $CDCl_3$ at 101 MHz



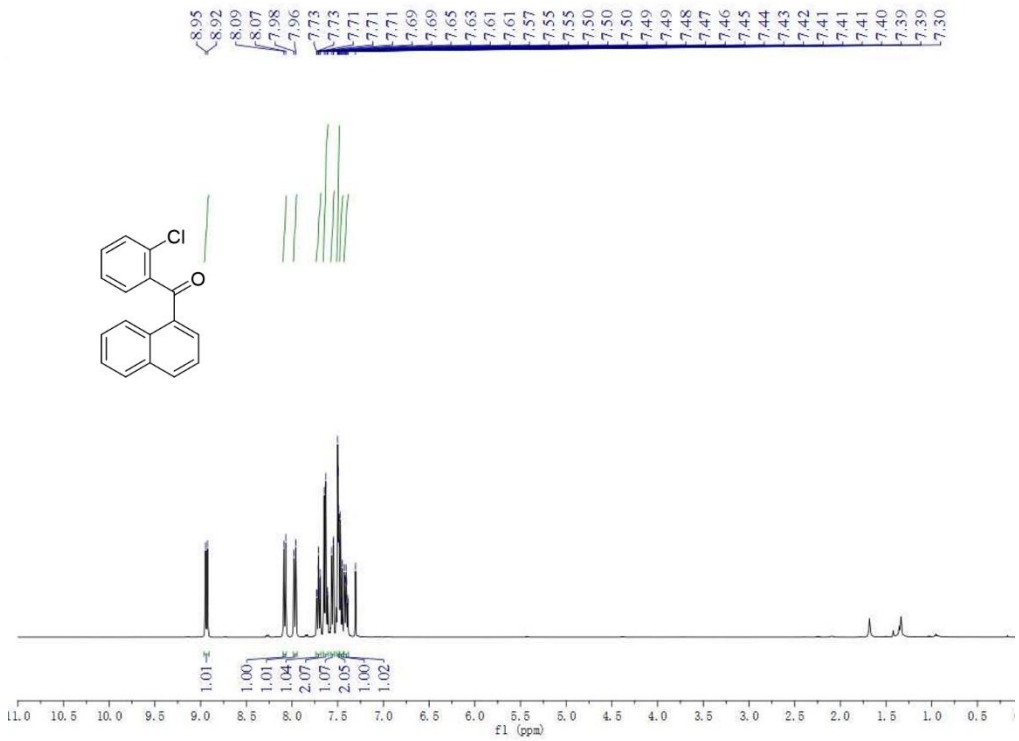
^{1}H NMR spectrum of **2n** in $CDCl_3$ at 400 MHz



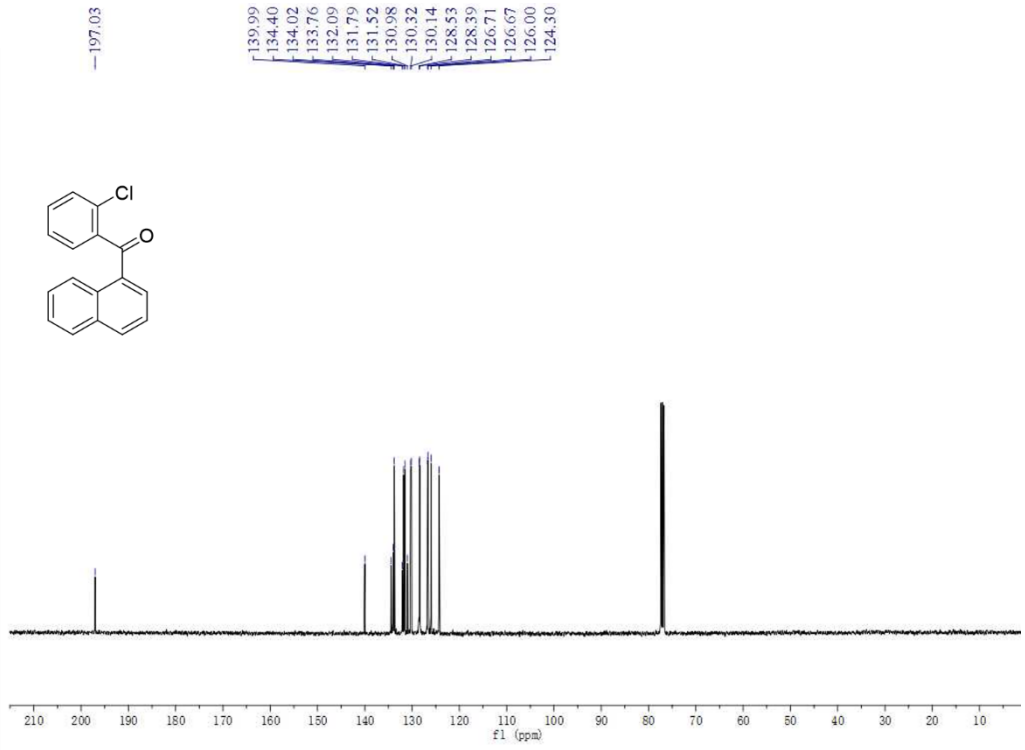
^{13}C NMR spectrum of **2n** in $CDCl_3$ at 101 MHz



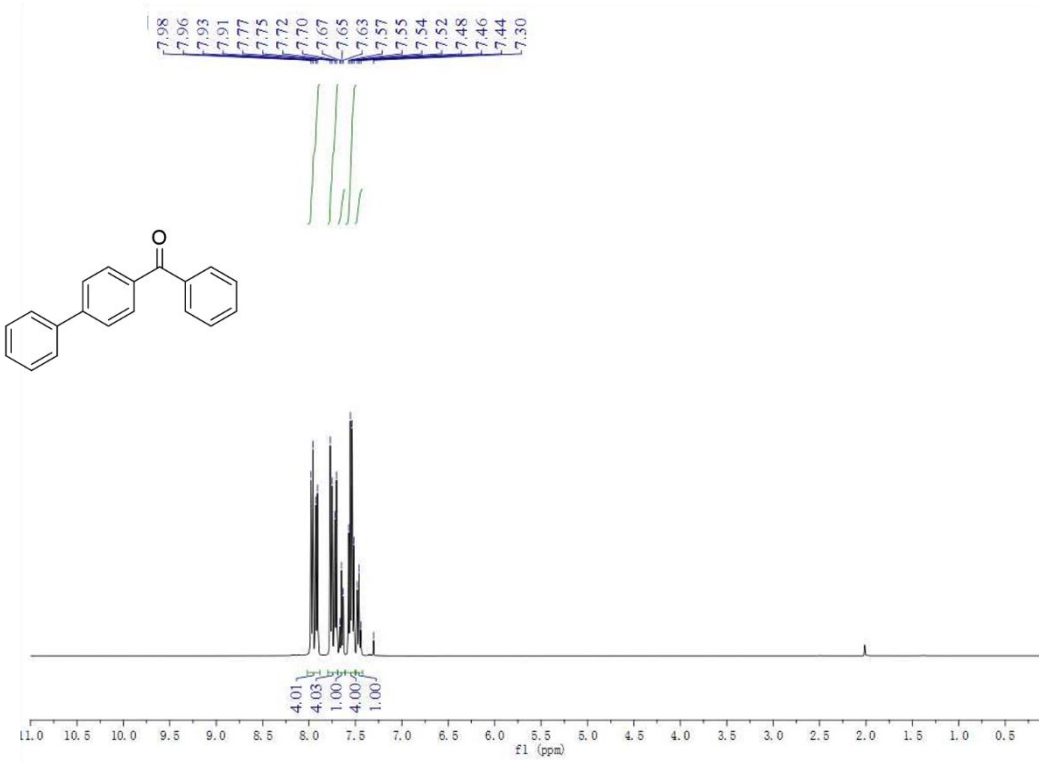
^{1}H NMR spectrum of **2o** in $CDCl_3$ at 400 MHz



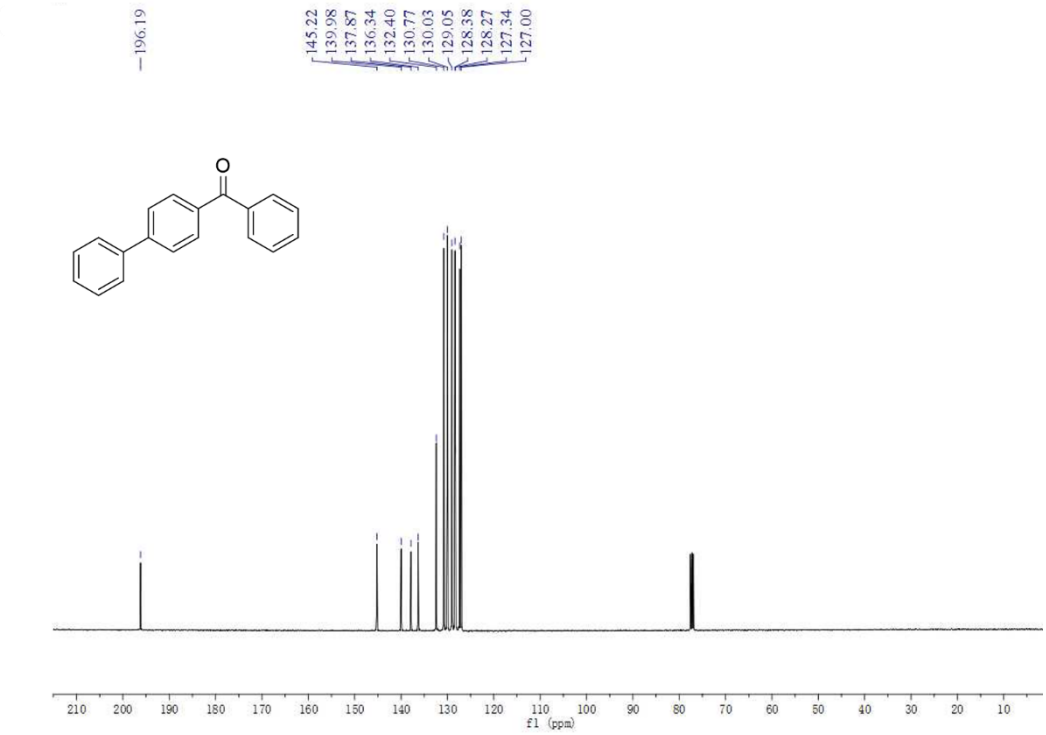
^{13}C NMR spectrum of **2o** in $CDCl_3$ at 101 MHz



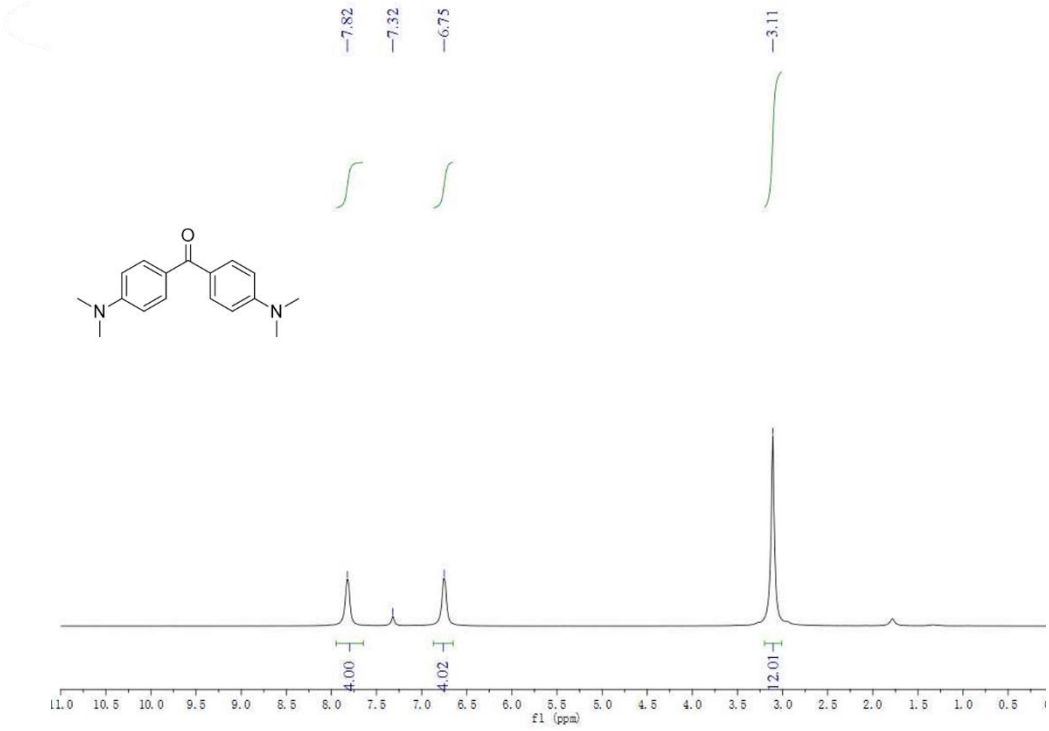
^{1}H NMR spectrum of **2p** in $CDCl_3$ at 400 MHz



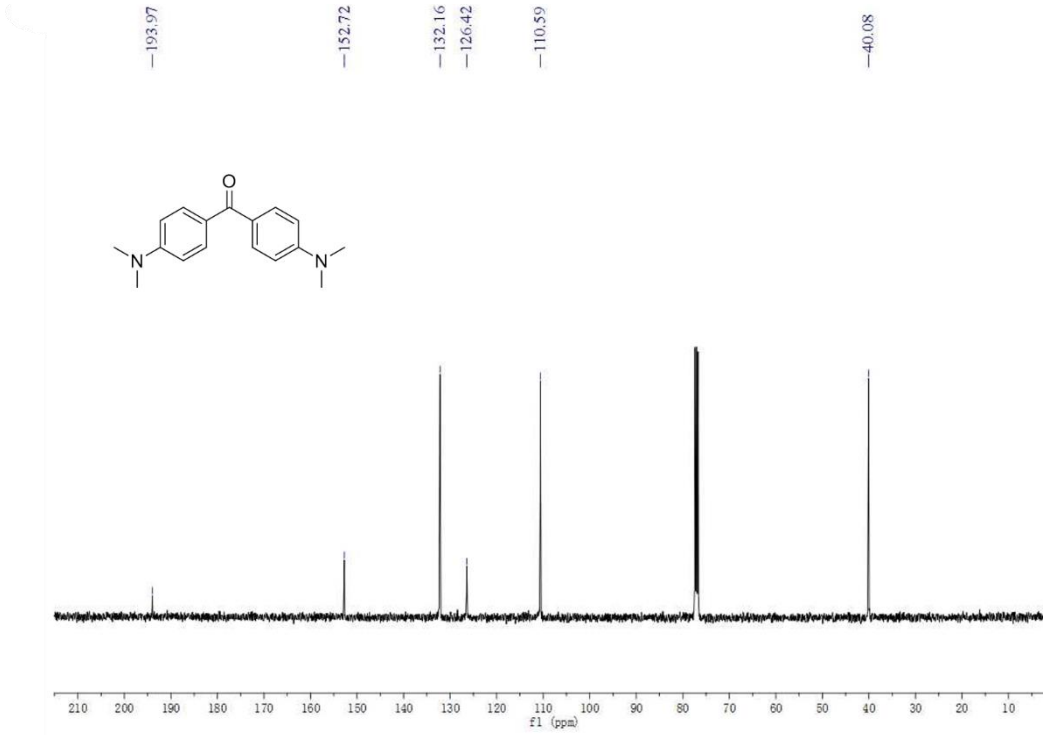
^{13}C NMR spectrum of **2p** in $CDCl_3$ at 101 MHz



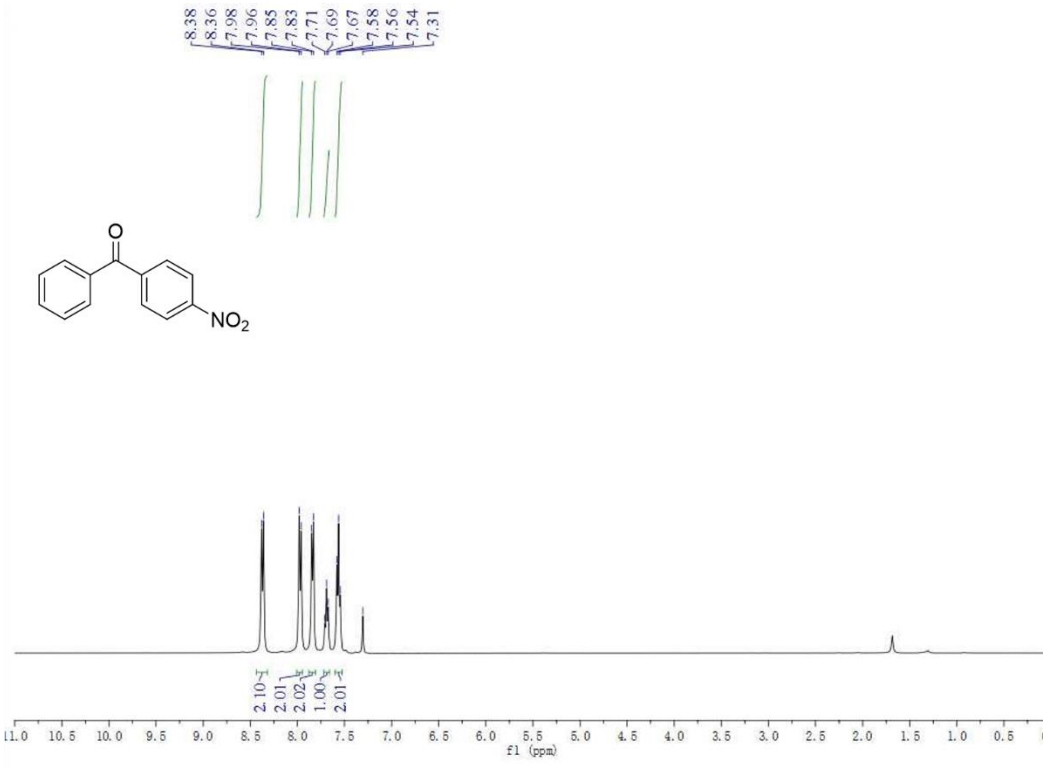
^{1}H NMR spectrum of **2q** in $CDCl_3$ at 400 MHz



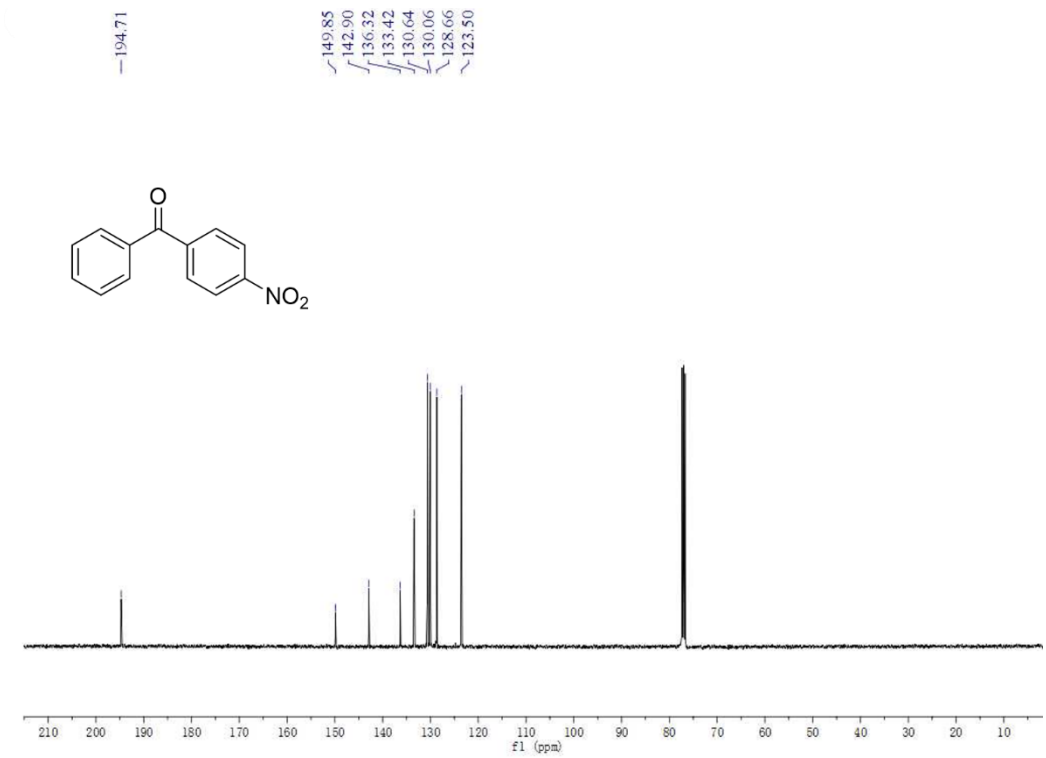
^{13}C NMR spectrum of **2q** in $CDCl_3$ at 101 MHz



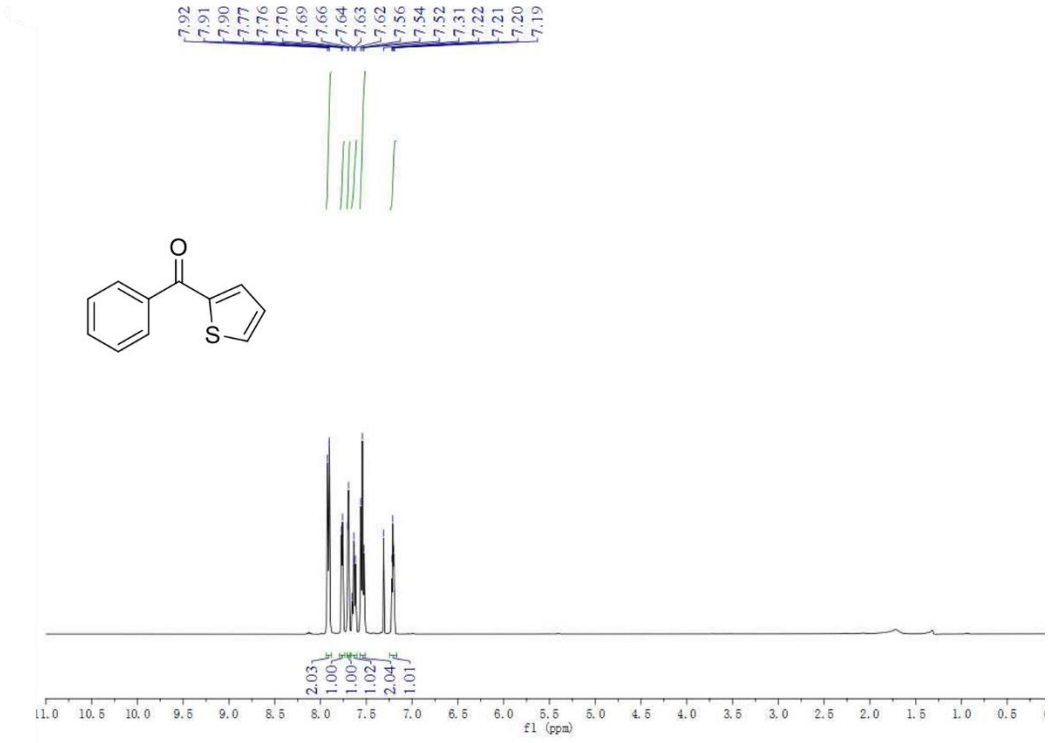
^{1}H NMR spectrum of **2r** in $CDCl_3$ at 400 MHz



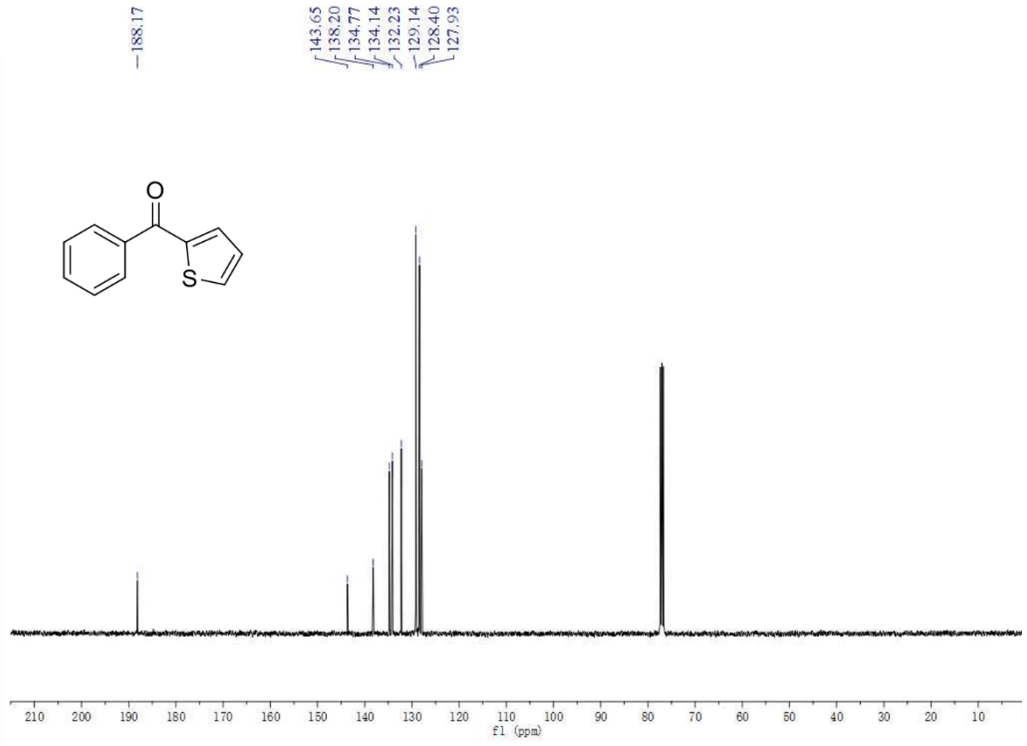
^{13}C NMR spectrum of **2r** in $CDCl_3$ at 101 MHz



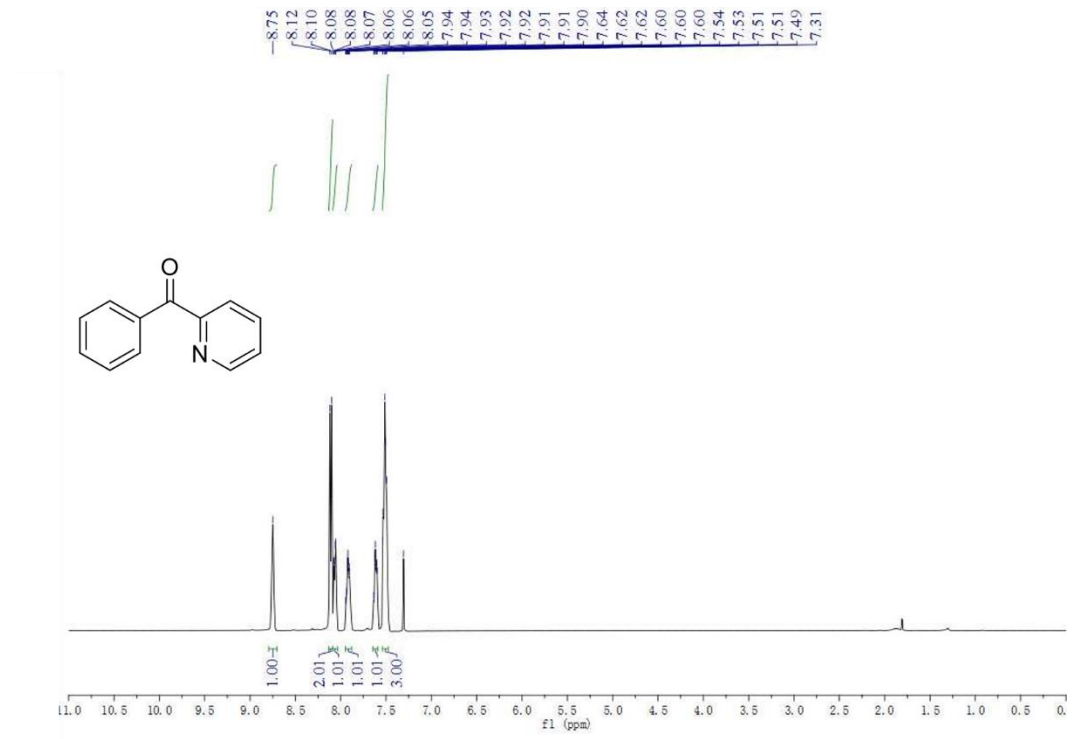
^{1}H NMR spectrum of **2s** in $CDCl_3$ at 400 MHz



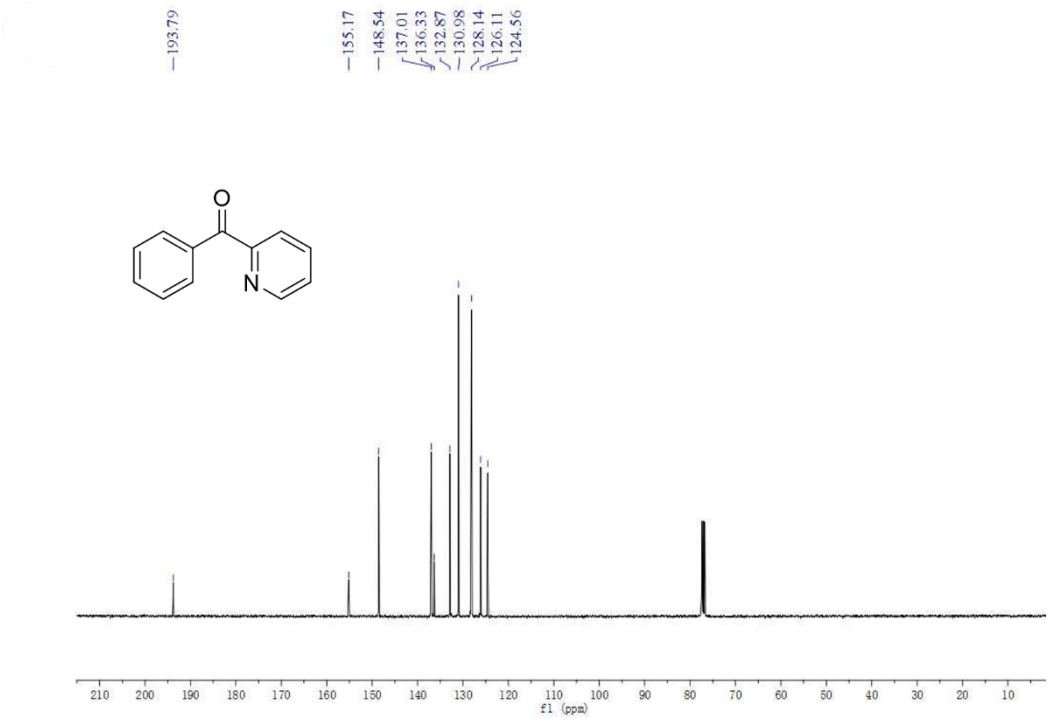
^{13}C NMR spectrum of **2s** in $CDCl_3$ at 101 MHz



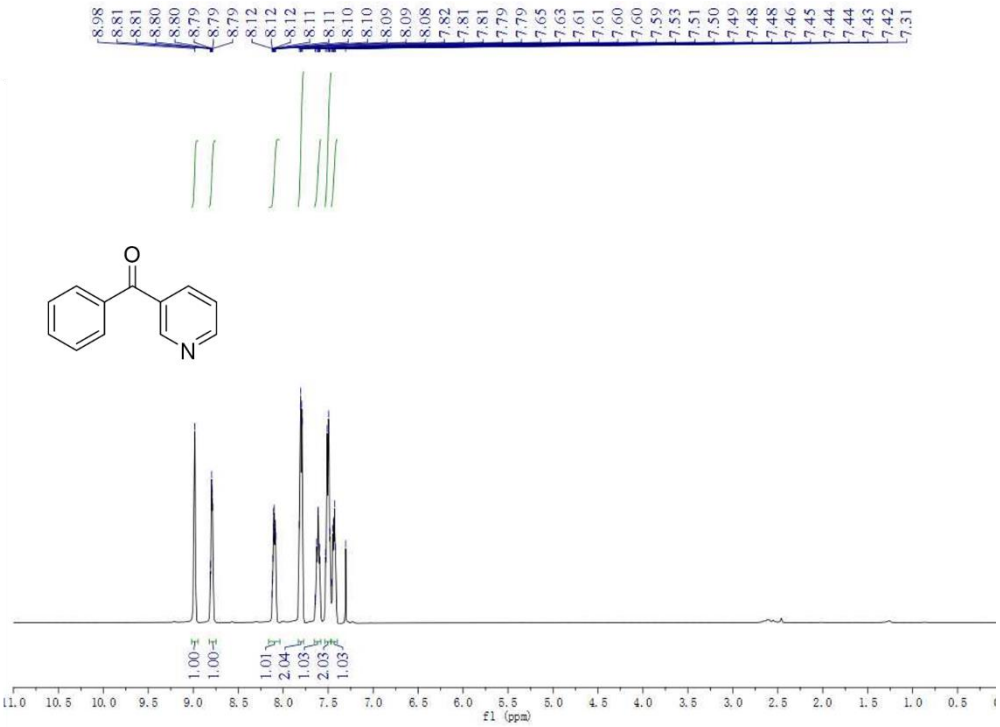
^{1}H NMR spectrum of **2t** in $CDCl_3$ at 400 MHz



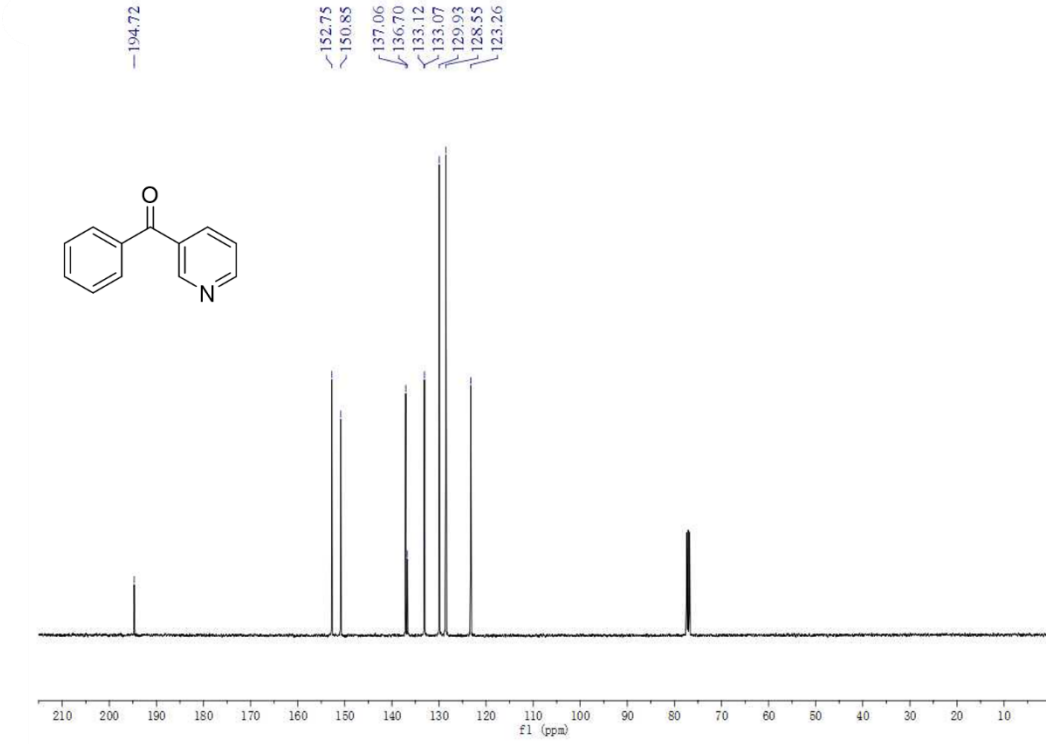
^{13}C NMR spectrum of **2t** in $CDCl_3$ at 101 MHz



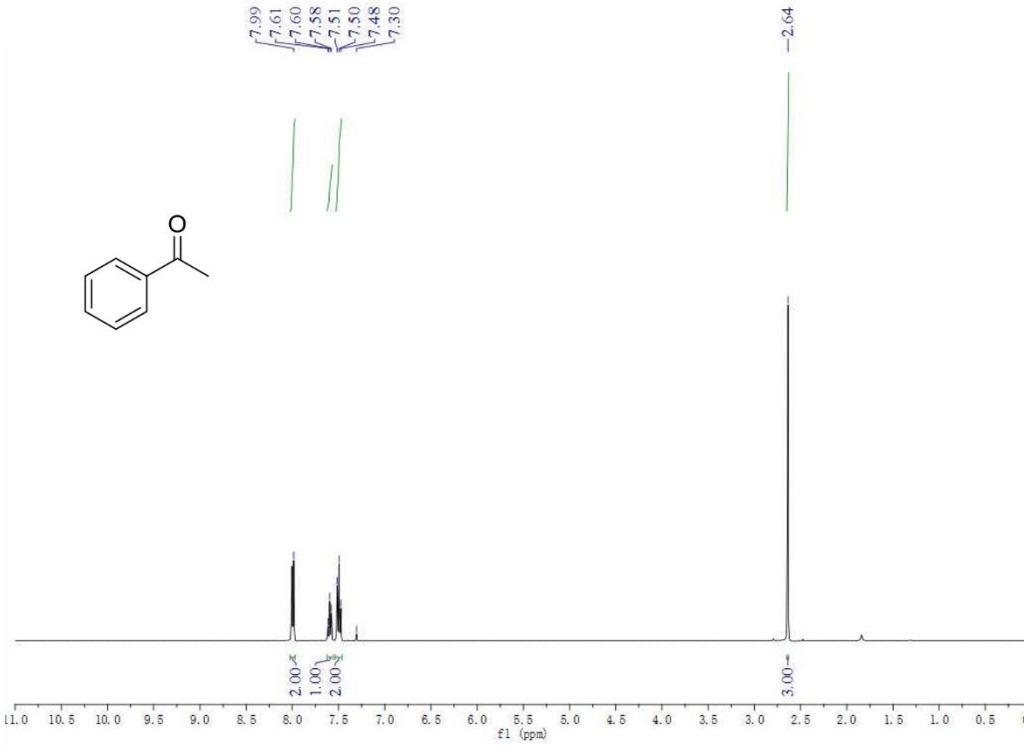
^{1}H NMR spectrum of **2u** in $CDCl_3$ at 400 MHz



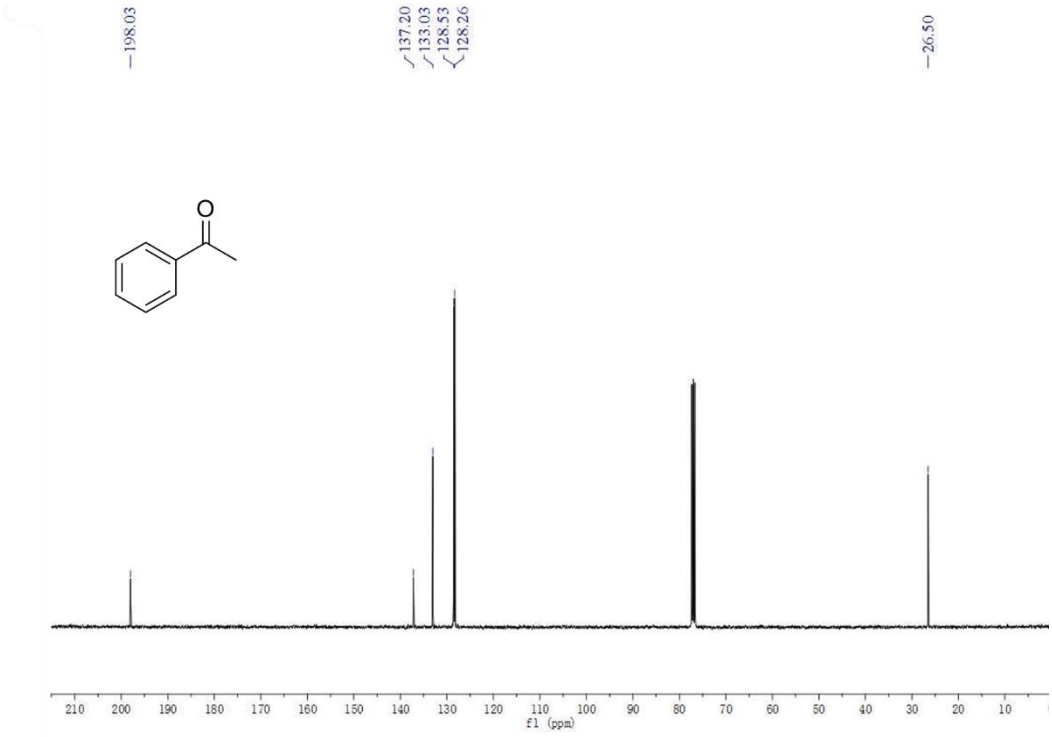
^{13}C NMR spectrum of **2u** in $CDCl_3$ at 101 MHz



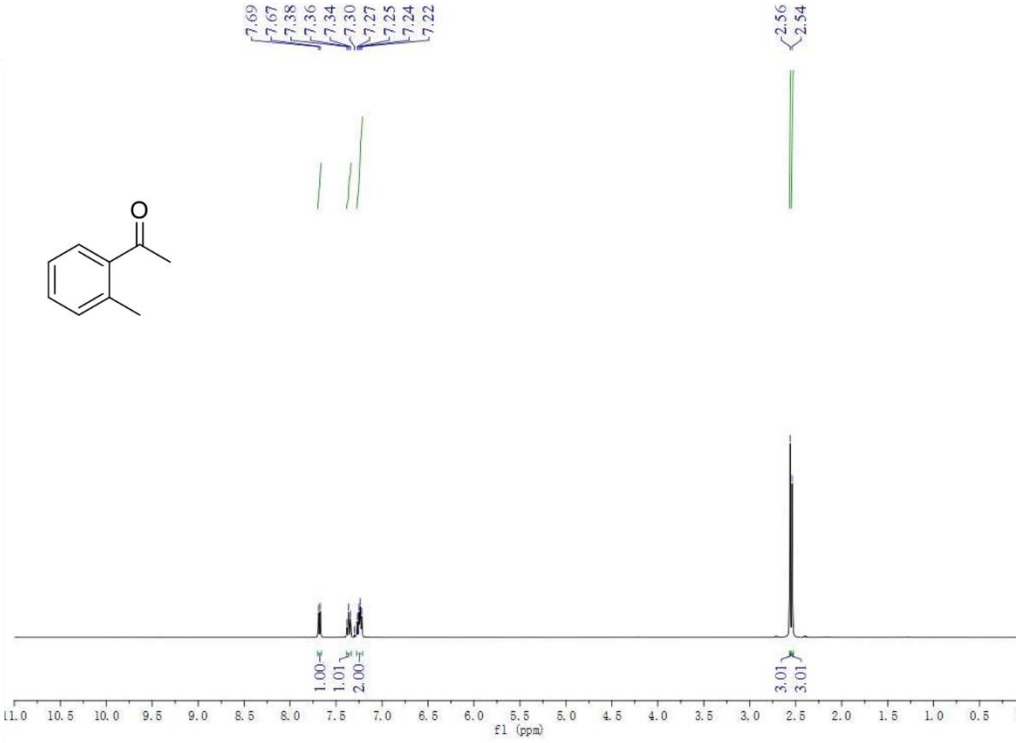
^{1}H NMR spectrum of **4a** in $CDCl_3$ at 400 MHz



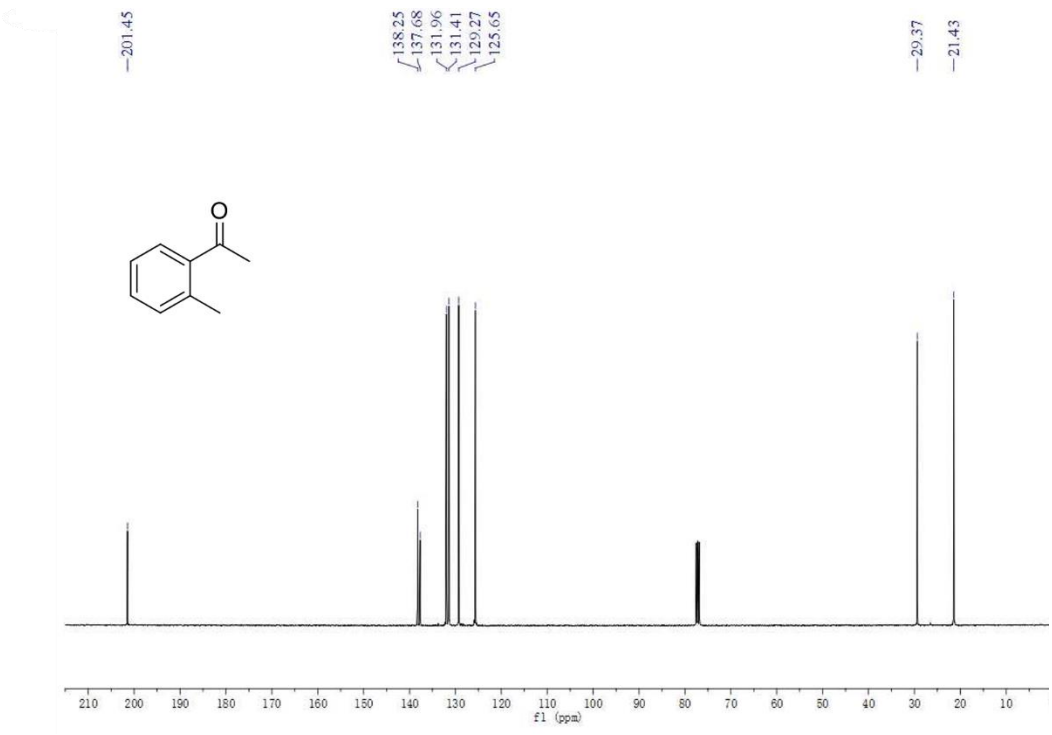
^{13}C NMR spectrum of **4a** in $CDCl_3$ at 101 MHz



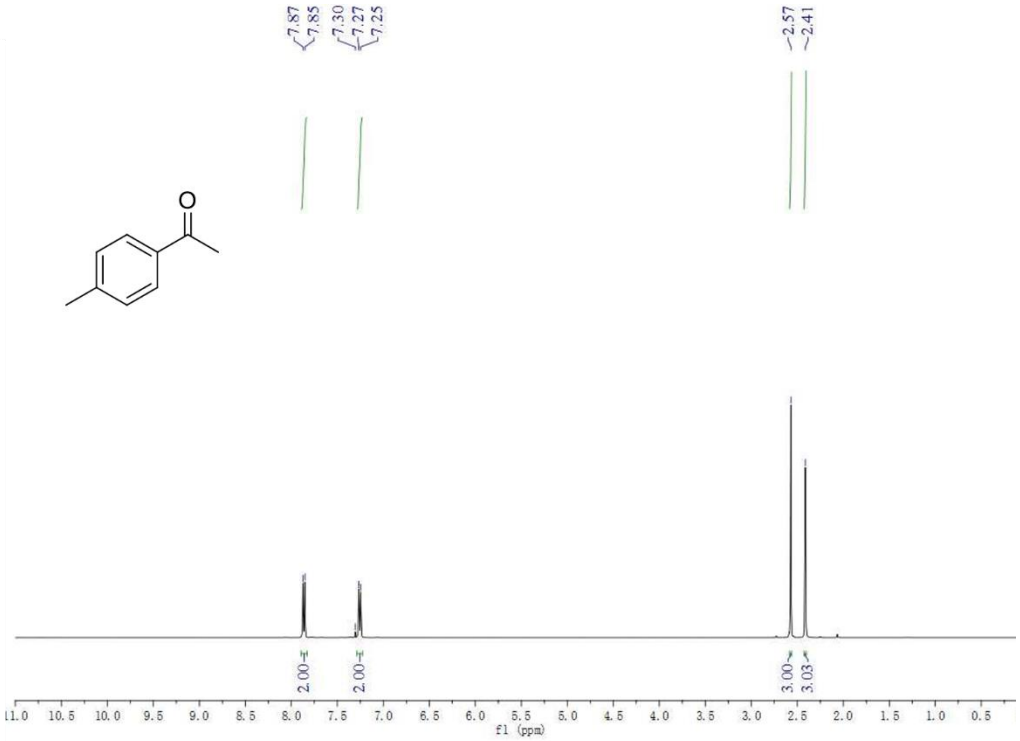
^{1}H NMR spectrum of **4b** in $CDCl_3$ at 400 MHz



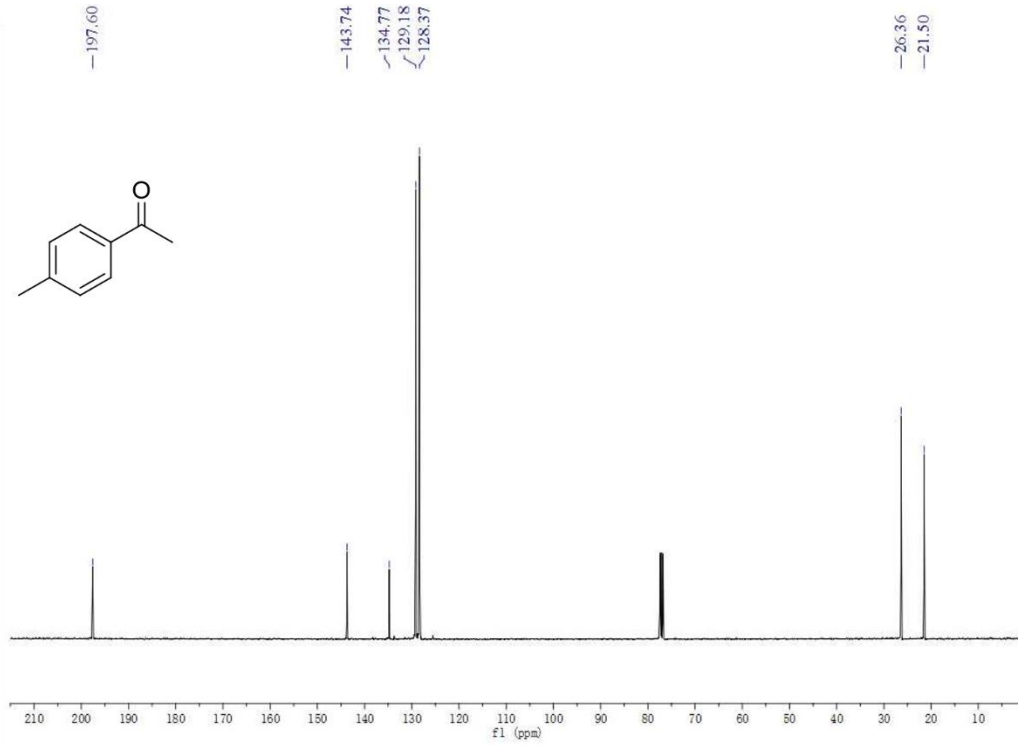
^{13}C NMR spectrum of **4b** in $CDCl_3$ at 101 MHz



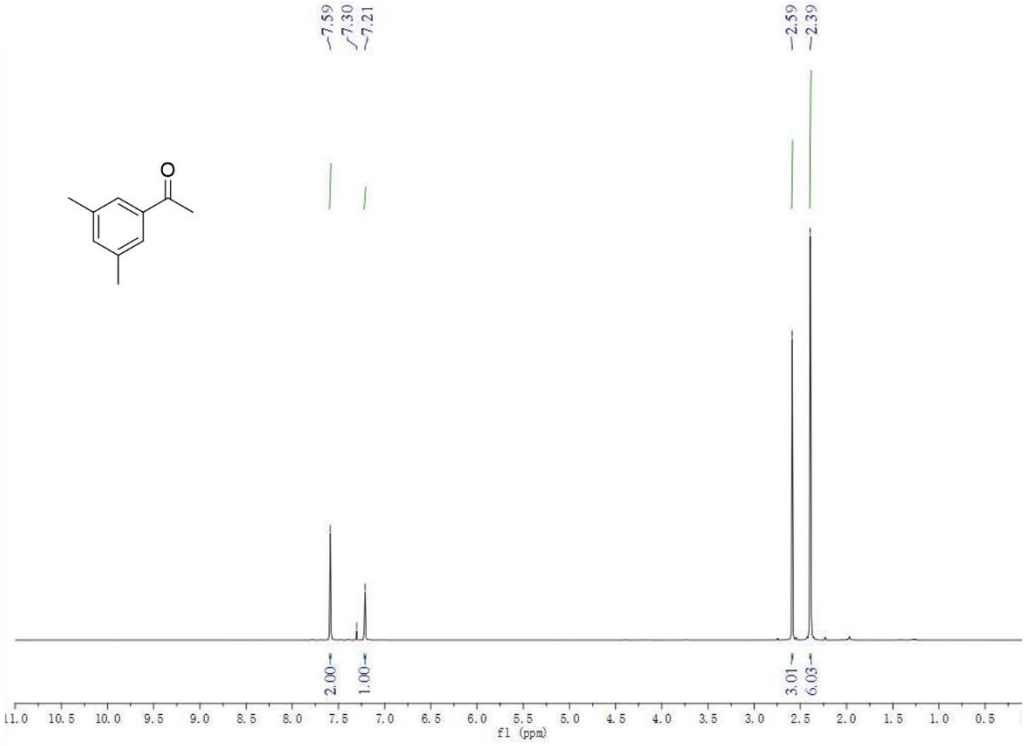
^{1}H NMR spectrum of **4c** in $CDCl_3$ at 400 MHz



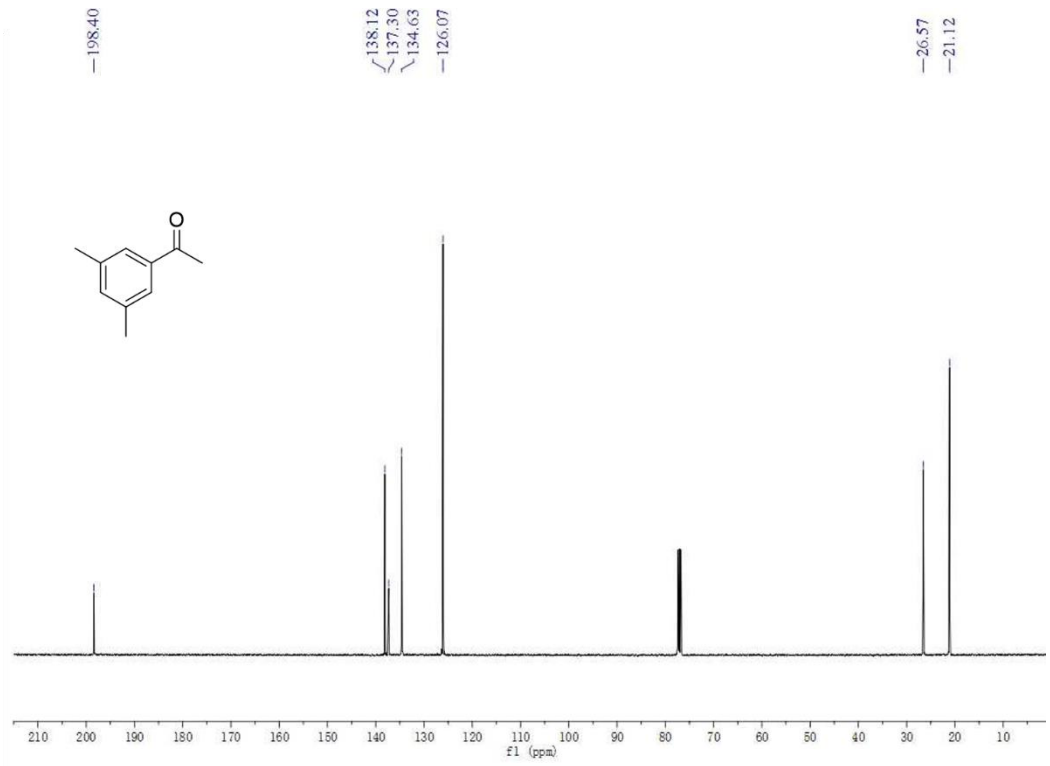
^{13}C NMR spectrum of **4c** in $CDCl_3$ at 101 MHz



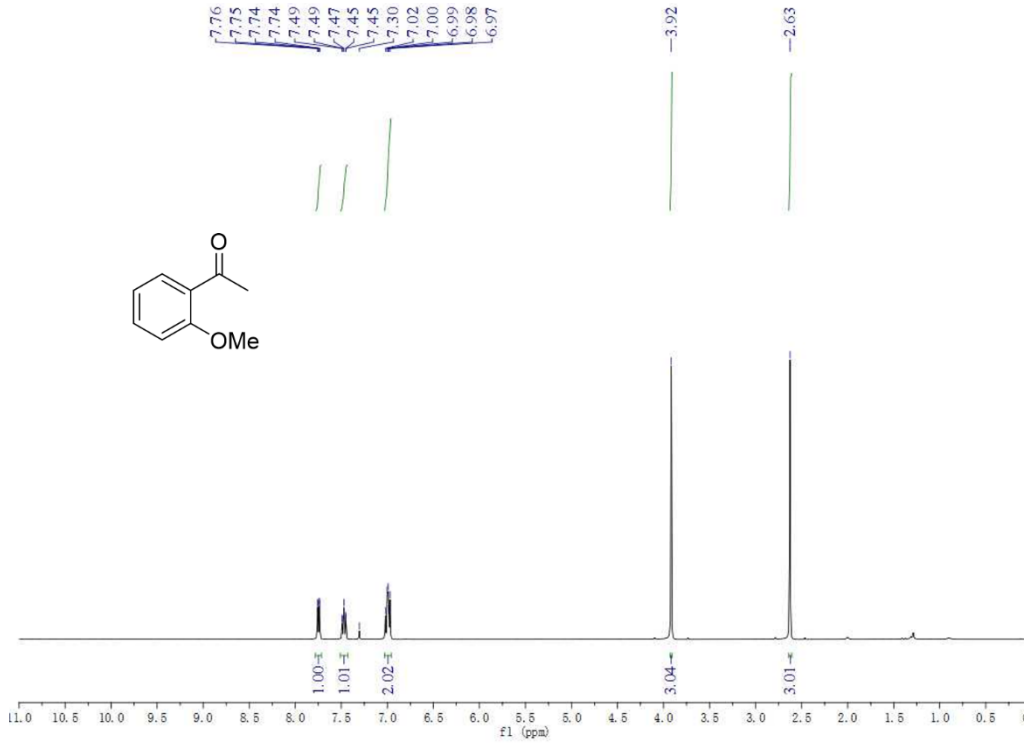
^{1}H NMR spectrum of **4d** in $CDCl_3$ at 400 MHz



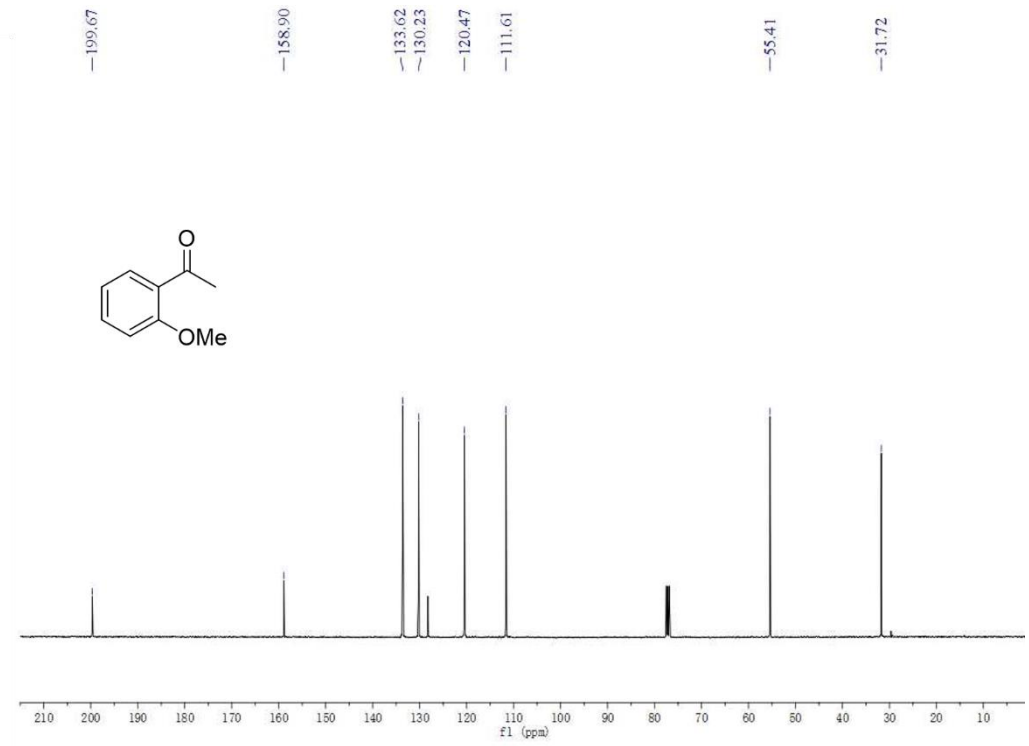
^{13}C NMR spectrum of **4d** in $CDCl_3$ at 101 MHz



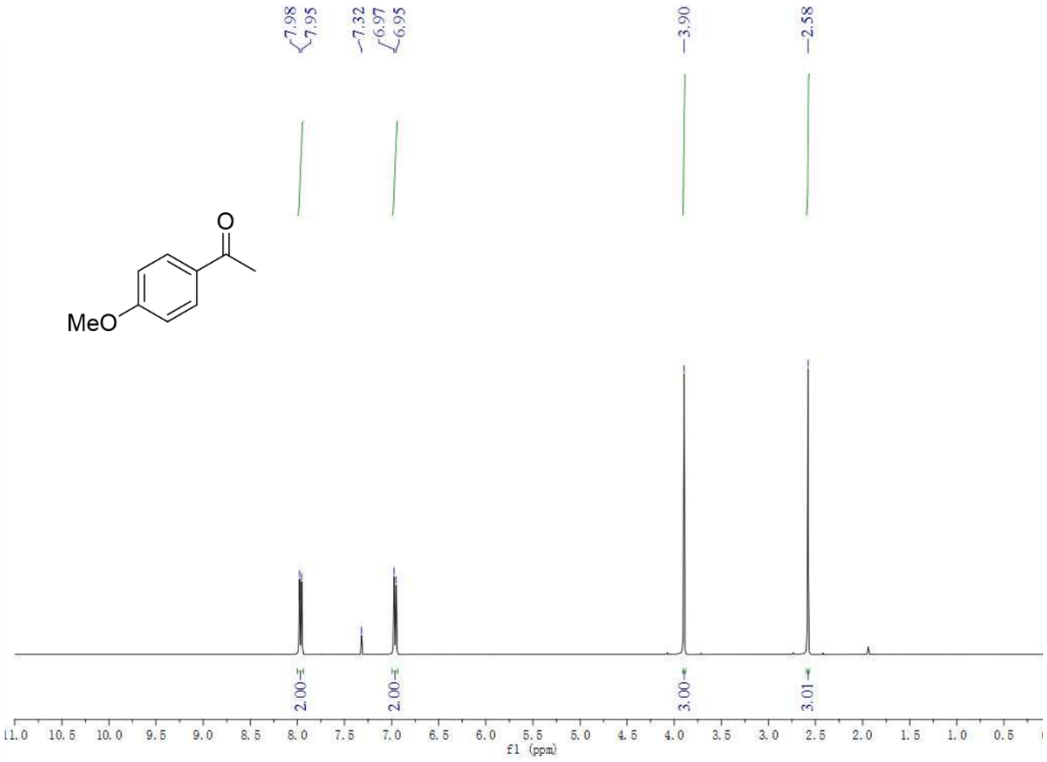
^{1}H NMR spectrum of **4e** in $CDCl_3$ at 400 MHz



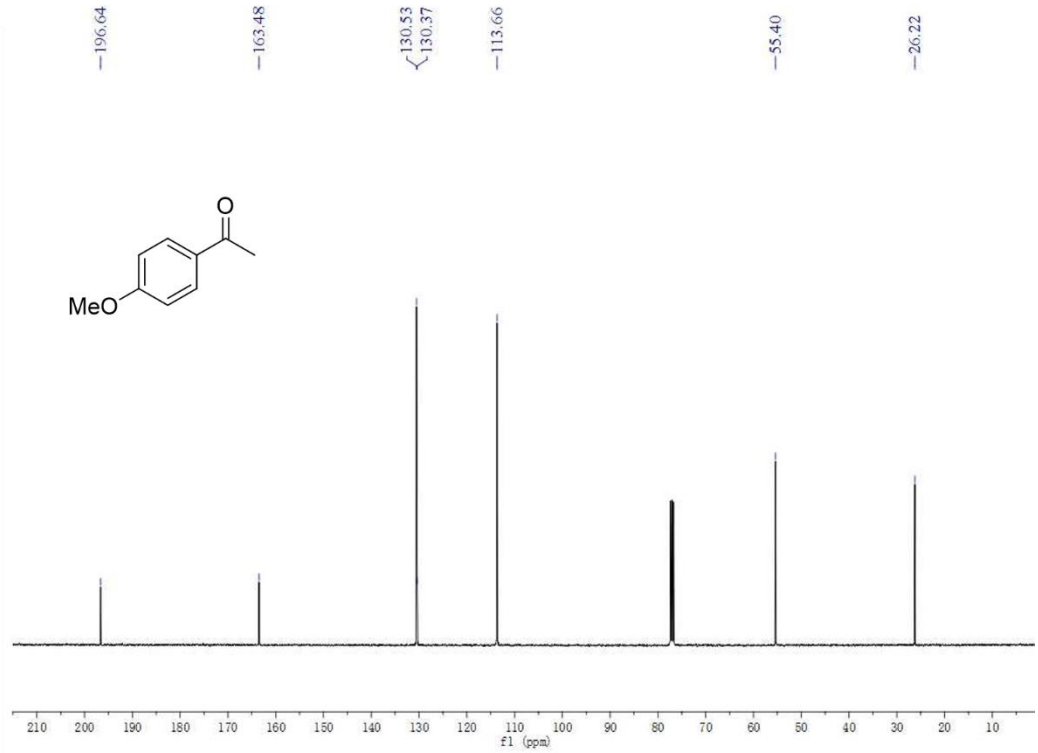
^{13}C NMR spectrum of **4e** in $CDCl_3$ at 101 MHz



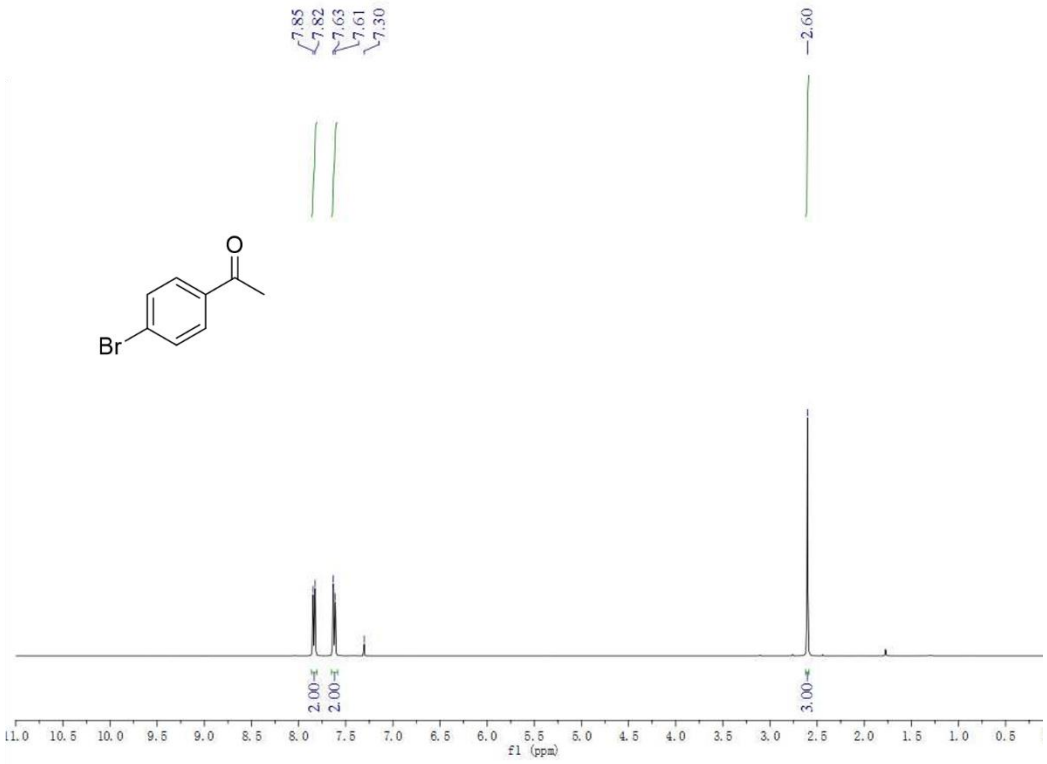
^{1}H NMR spectrum of **4f** in $CDCl_3$ at 400 MHz



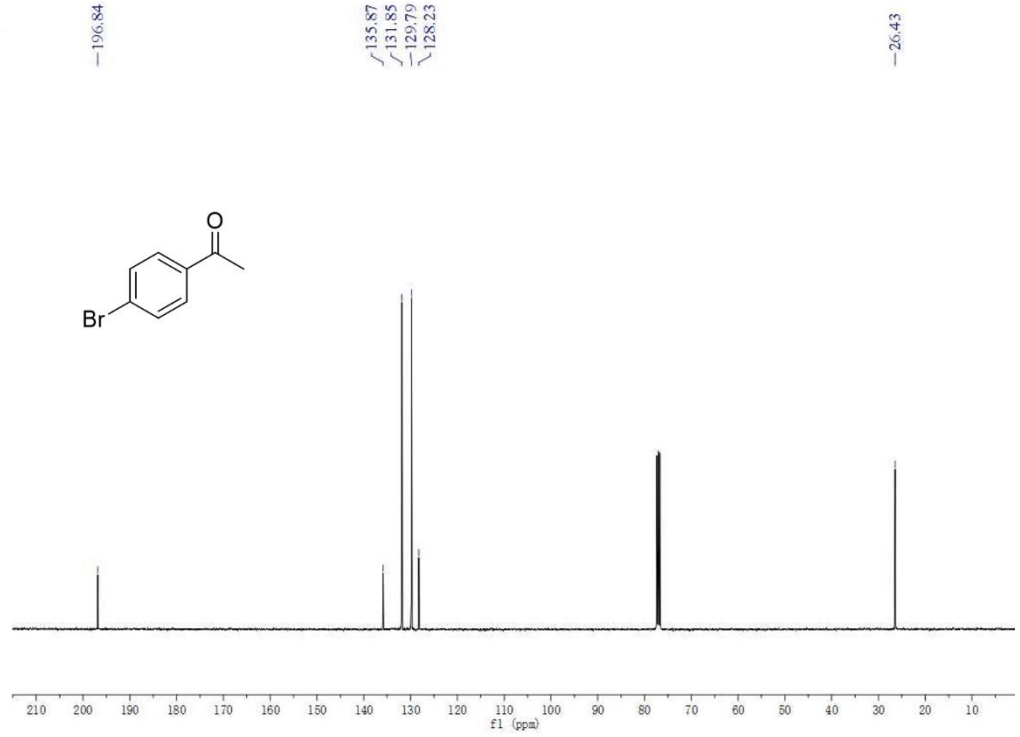
^{13}C NMR spectrum of **4f** in $CDCl_3$ at 101 MHz



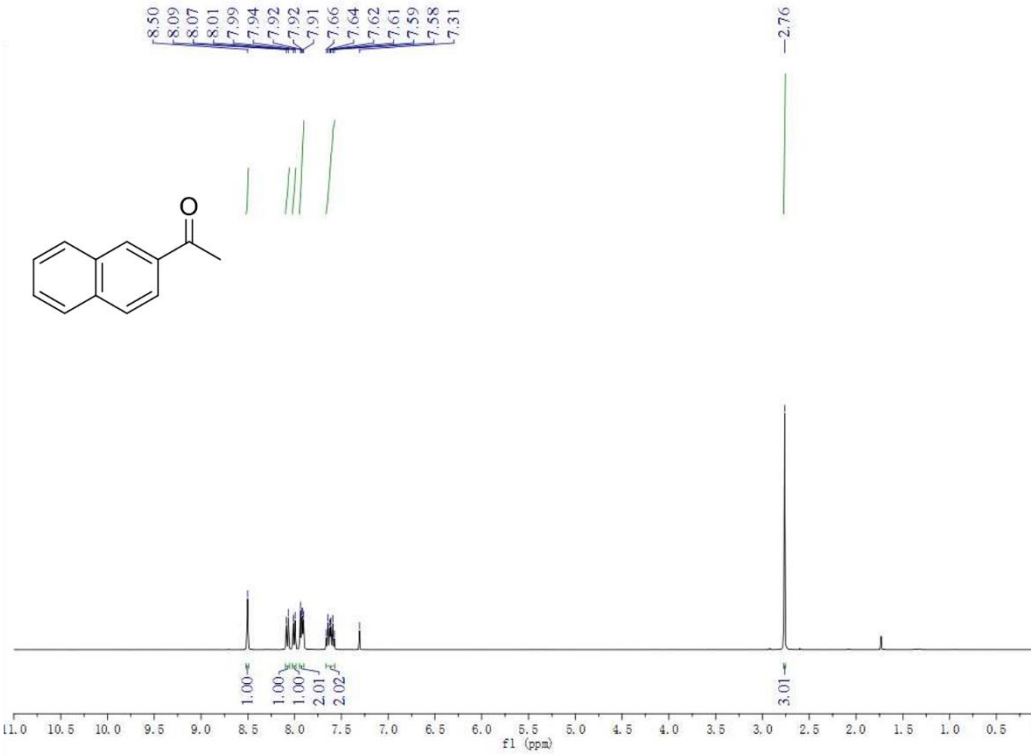
^{1}H NMR spectrum of **4g** in $CDCl_3$ at 400 MHz



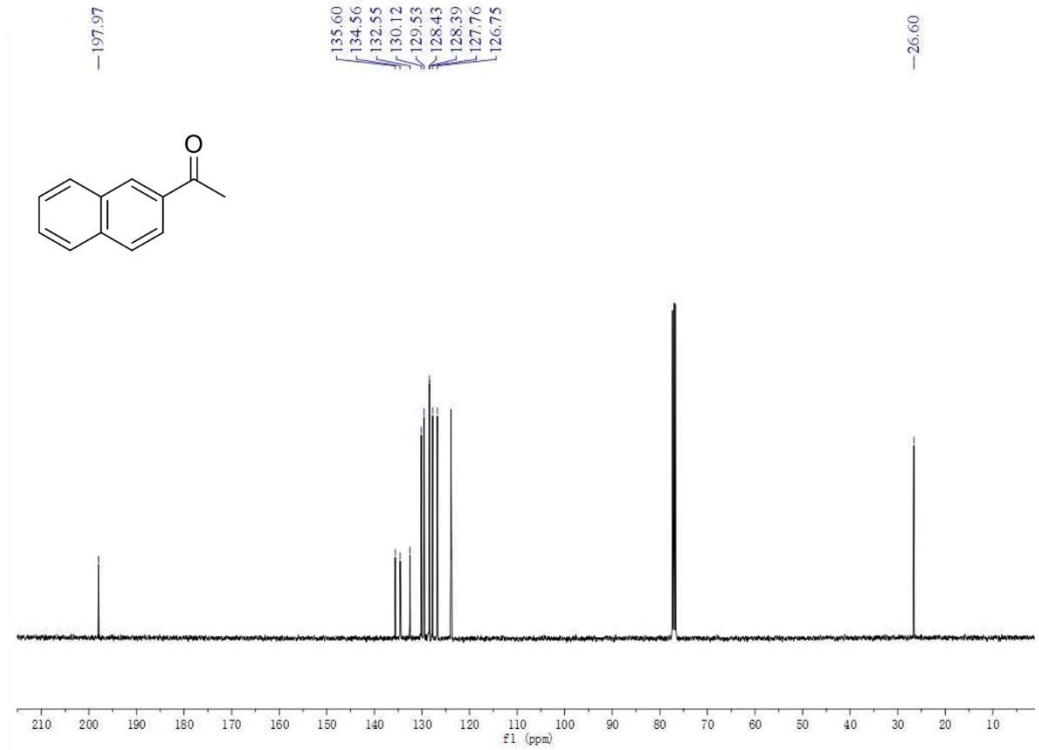
^{13}C NMR spectrum of **4g** in $CDCl_3$ at 101 MHz



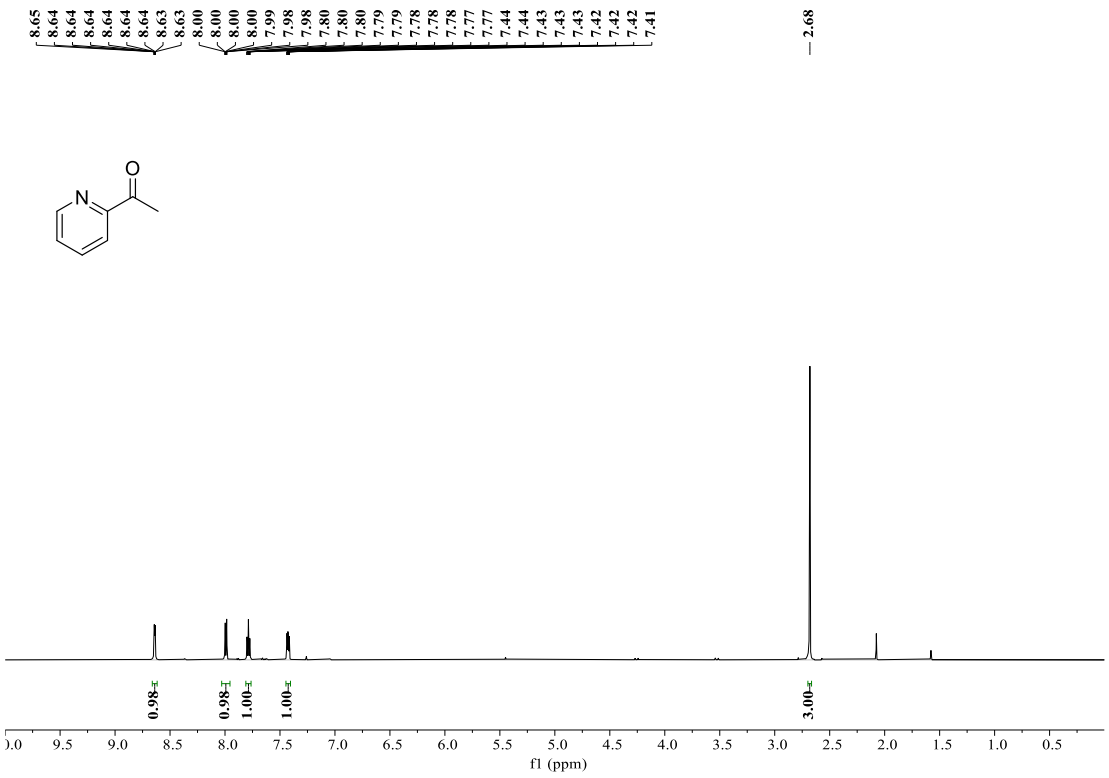
^{1}H NMR spectrum of **4h** in $CDCl_3$ at 400 MHz



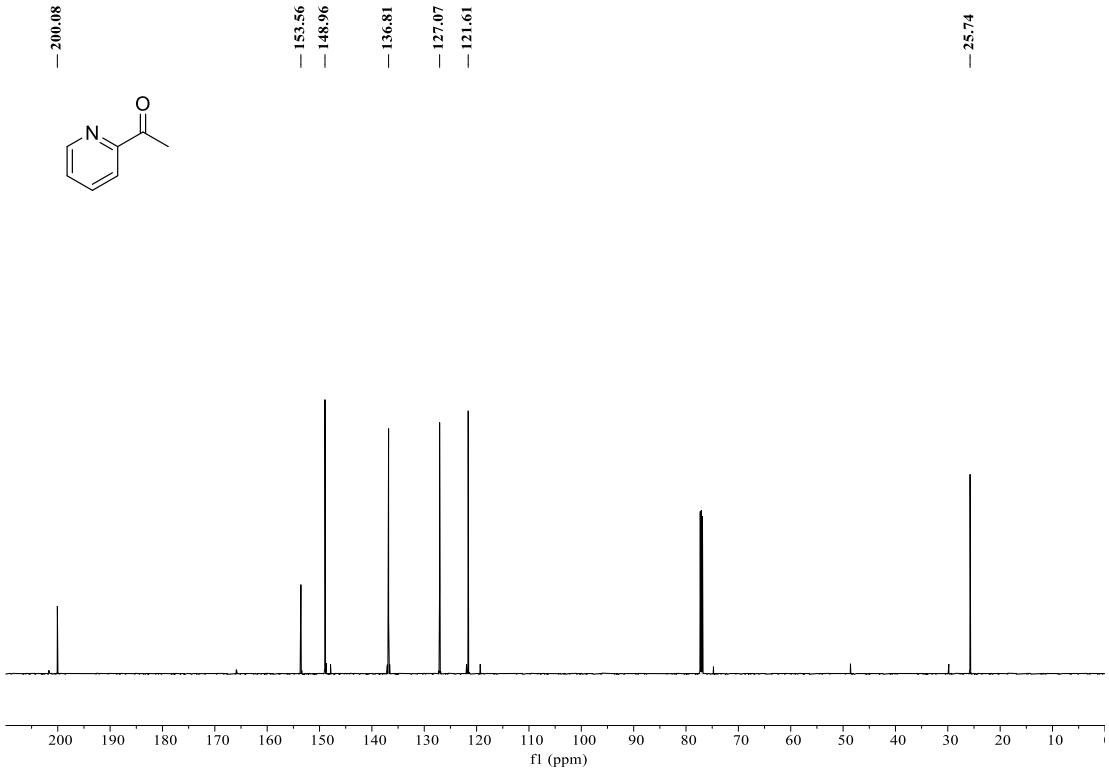
^{13}C NMR spectrum of **4h** in $CDCl_3$ at 101 MHz



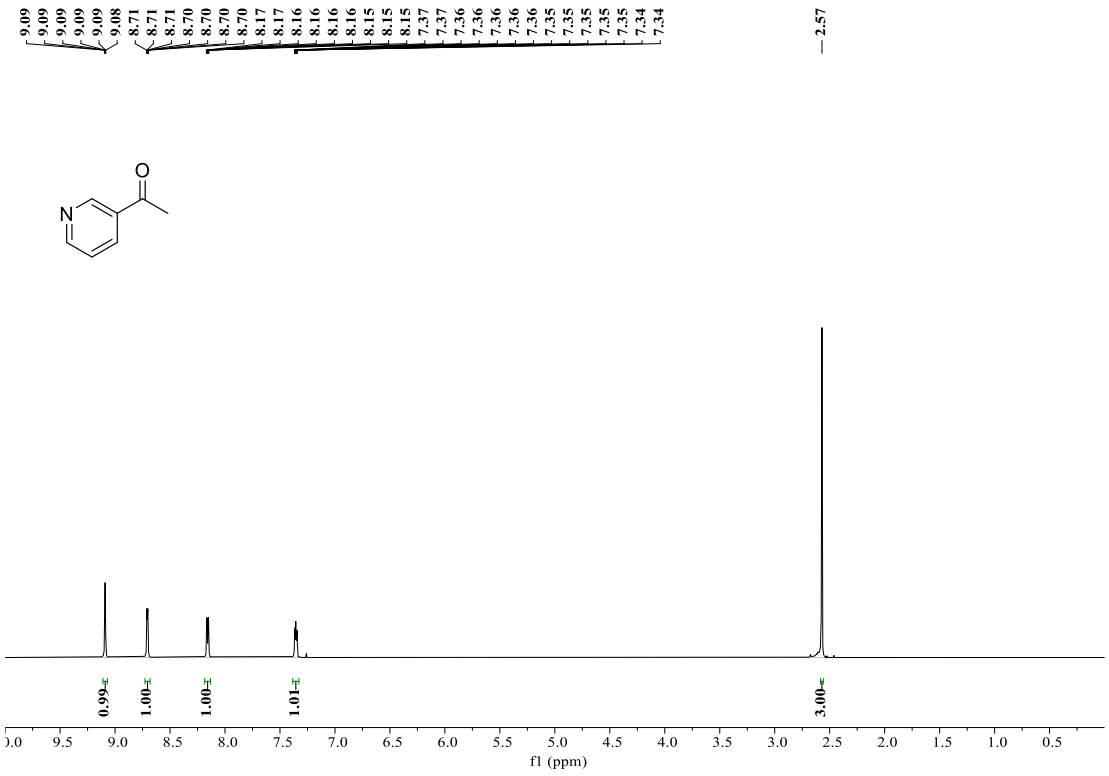
^{1}H NMR spectrum of **4i** in $CDCl_3$ at 400 MHz



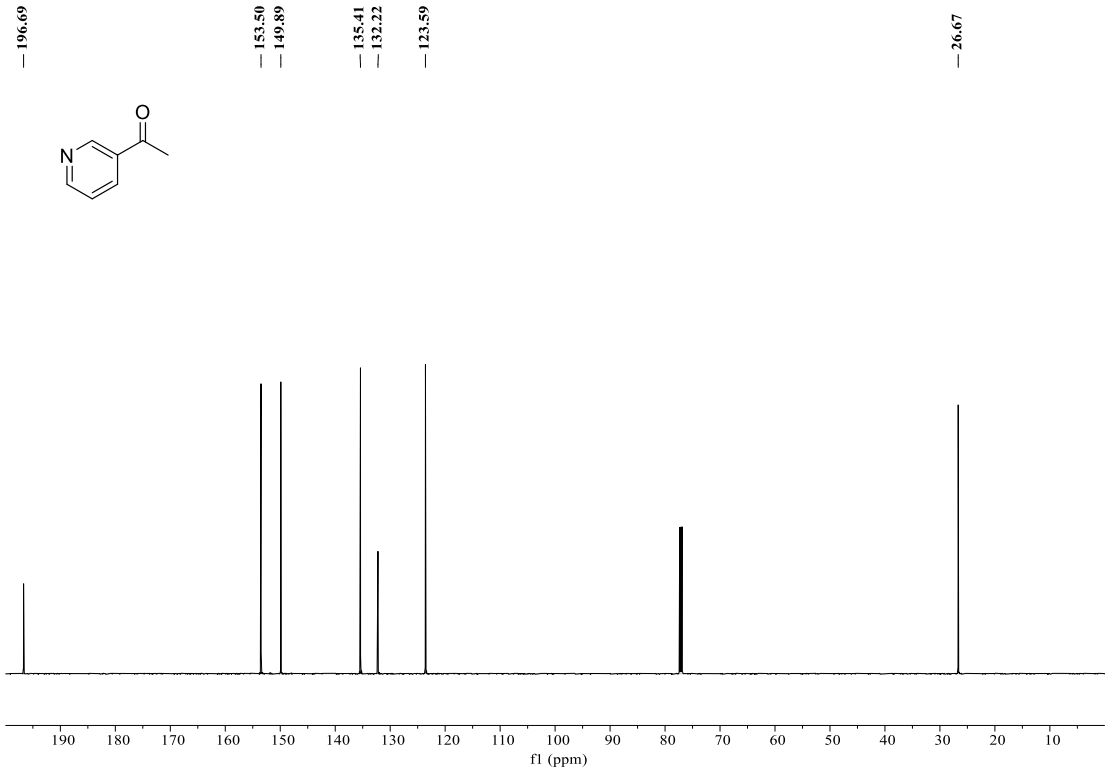
^{13}C NMR spectrum of **4i** in $CDCl_3$ at 151 MHz



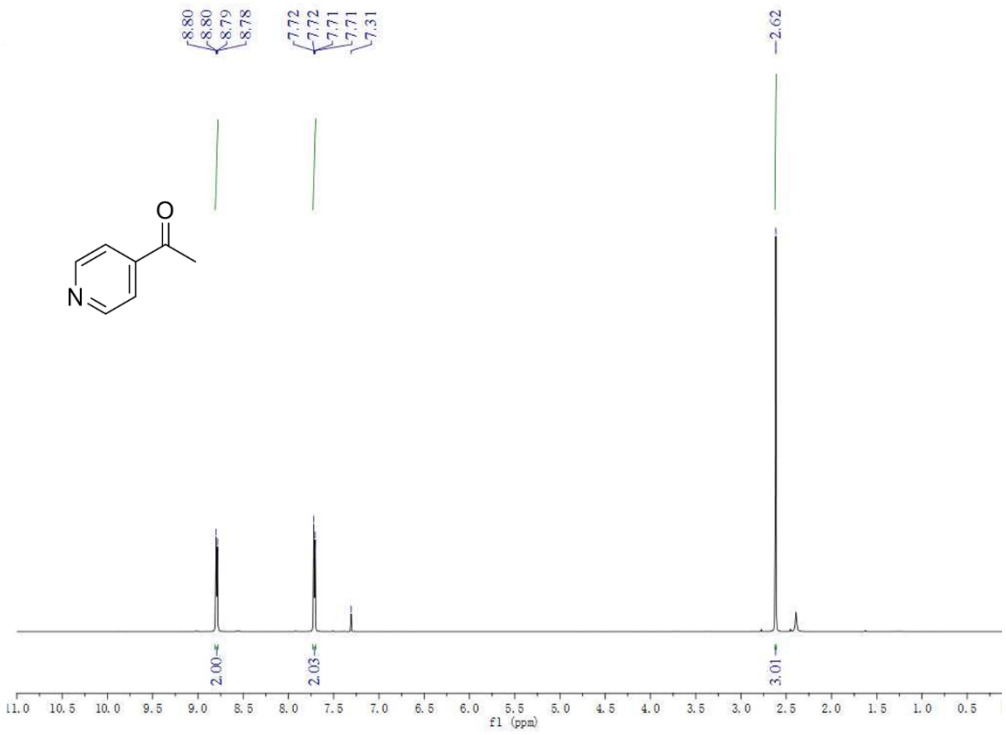
^{1}H NMR spectrum of **4j** in $CDCl_3$ at 400 MHz



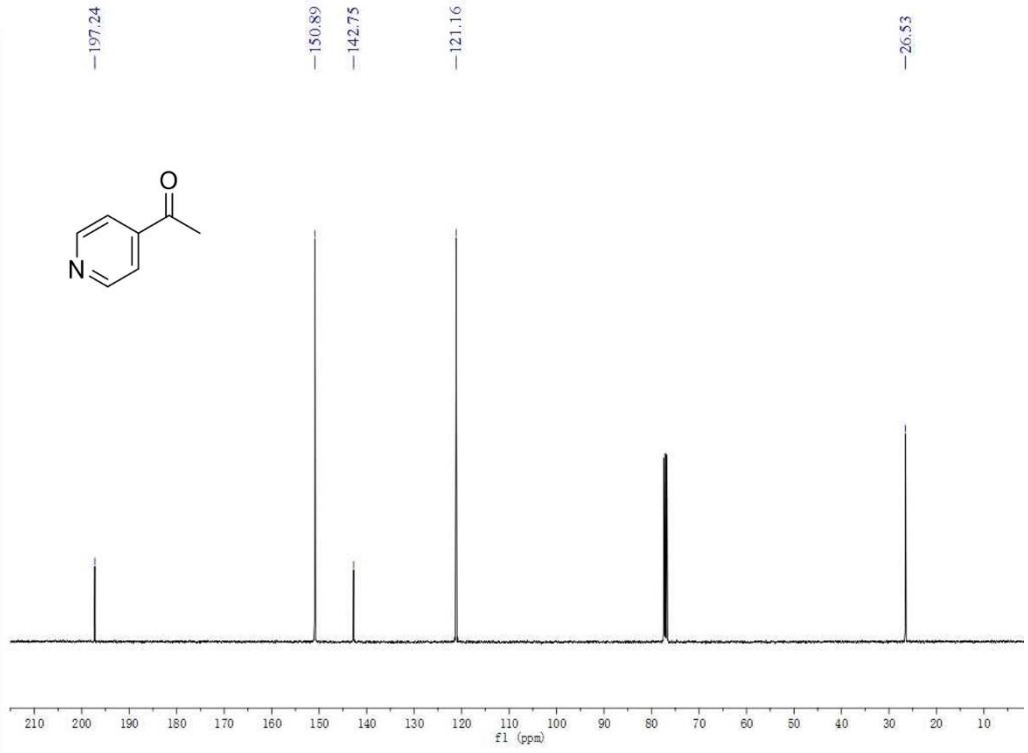
^{13}C NMR spectrum of **4j** in $CDCl_3$ at 151 MHz



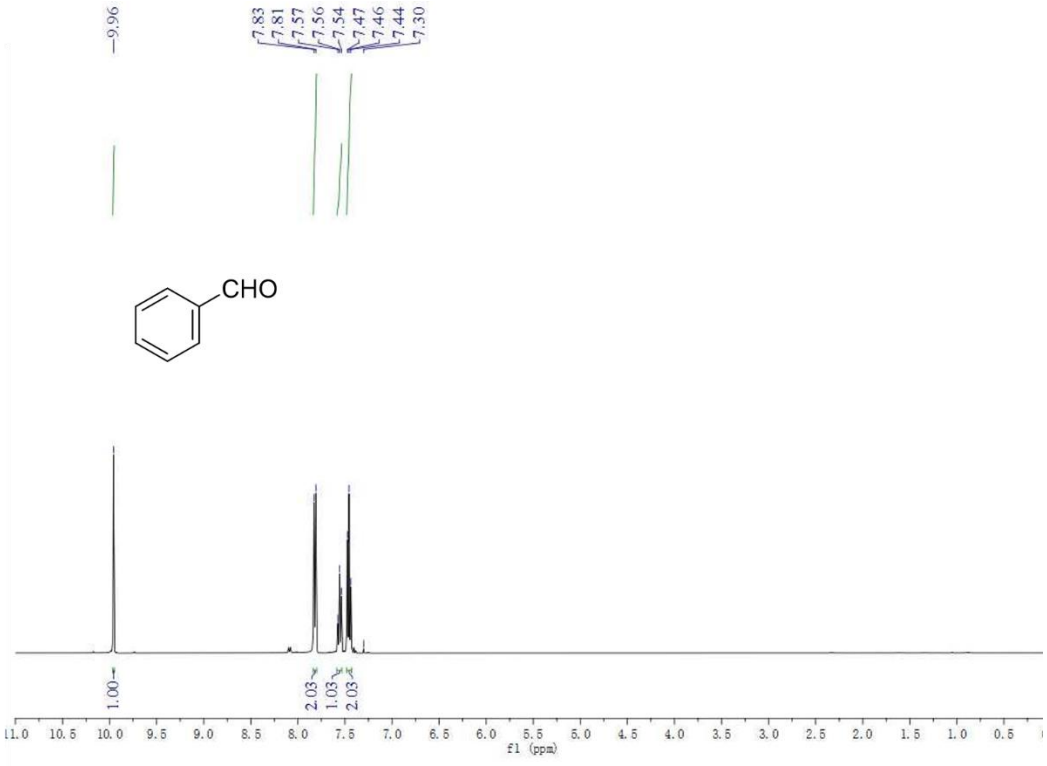
^{1}H NMR spectrum of **4k** in $CDCl_3$ at 400 MHz



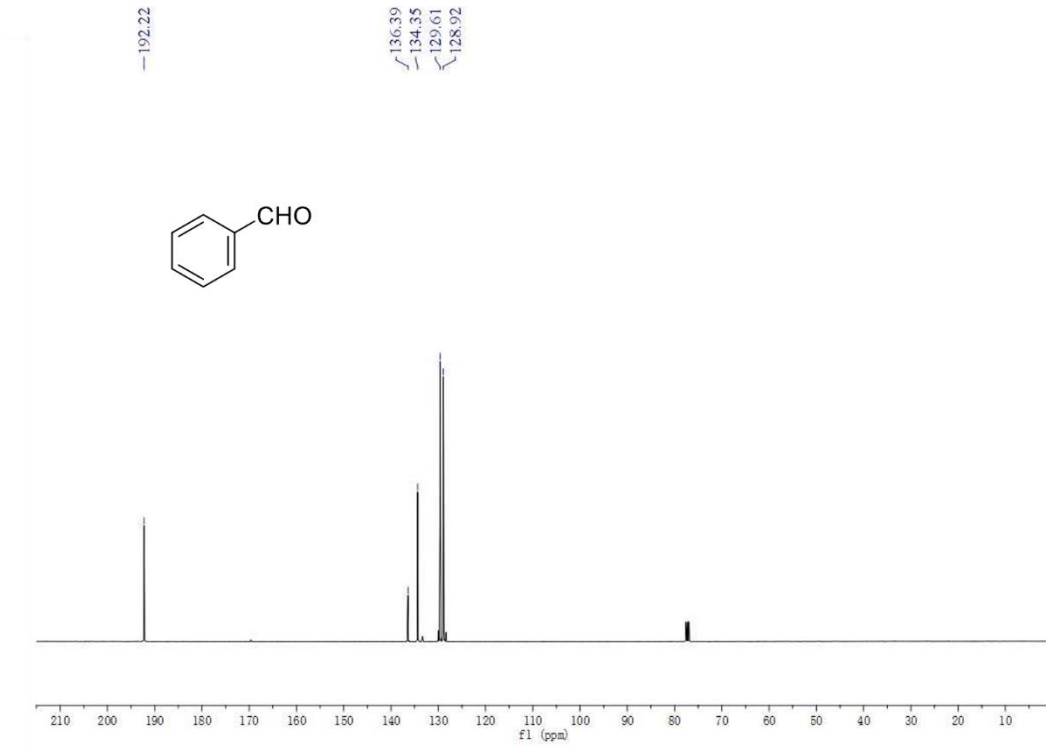
^{13}C NMR spectrum of **4k** in $CDCl_3$ at 101 MHz



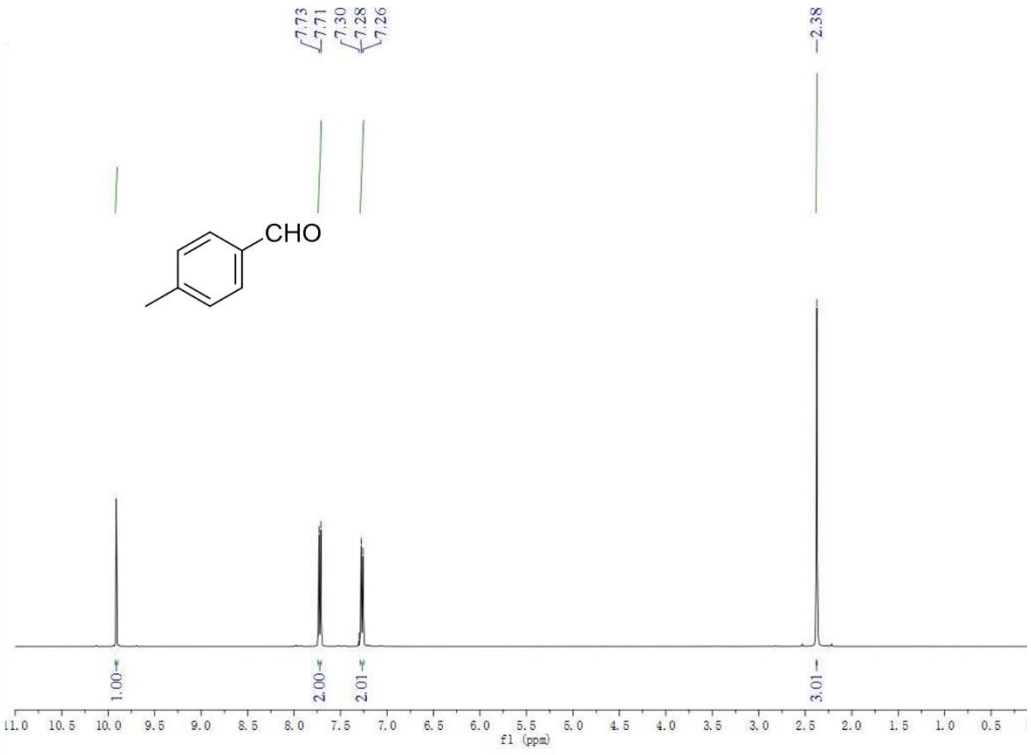
^{1}H NMR spectrum of **4l** in $CDCl_3$ at 400 MHz



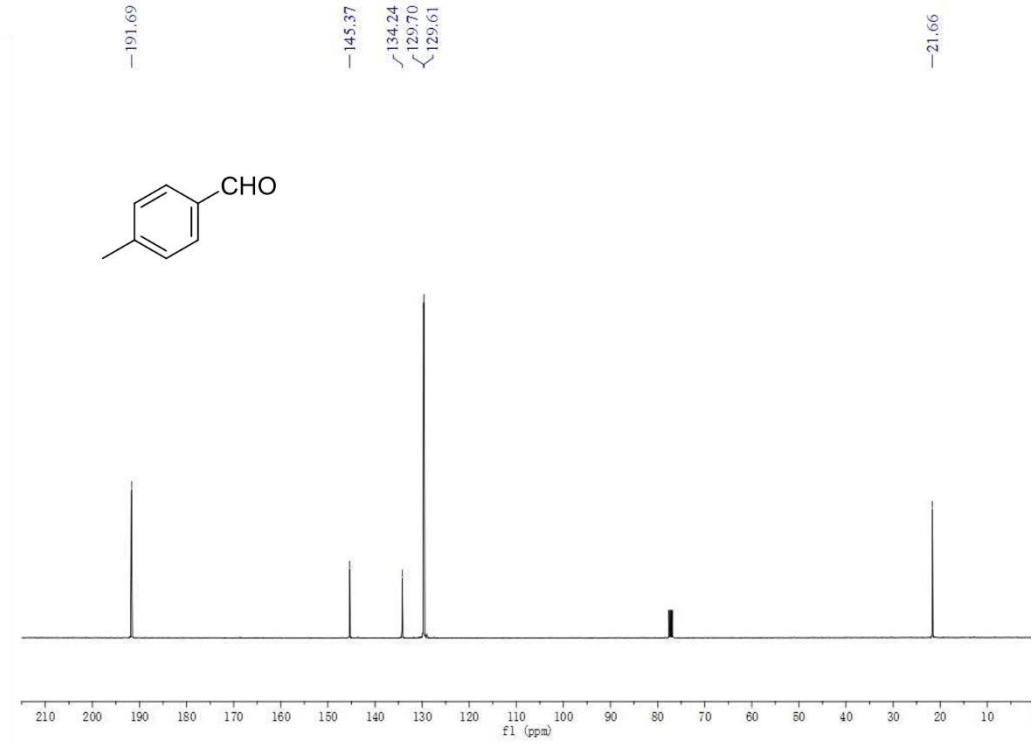
^{13}C NMR spectrum of **4l** in $CDCl_3$ at 101 MHz



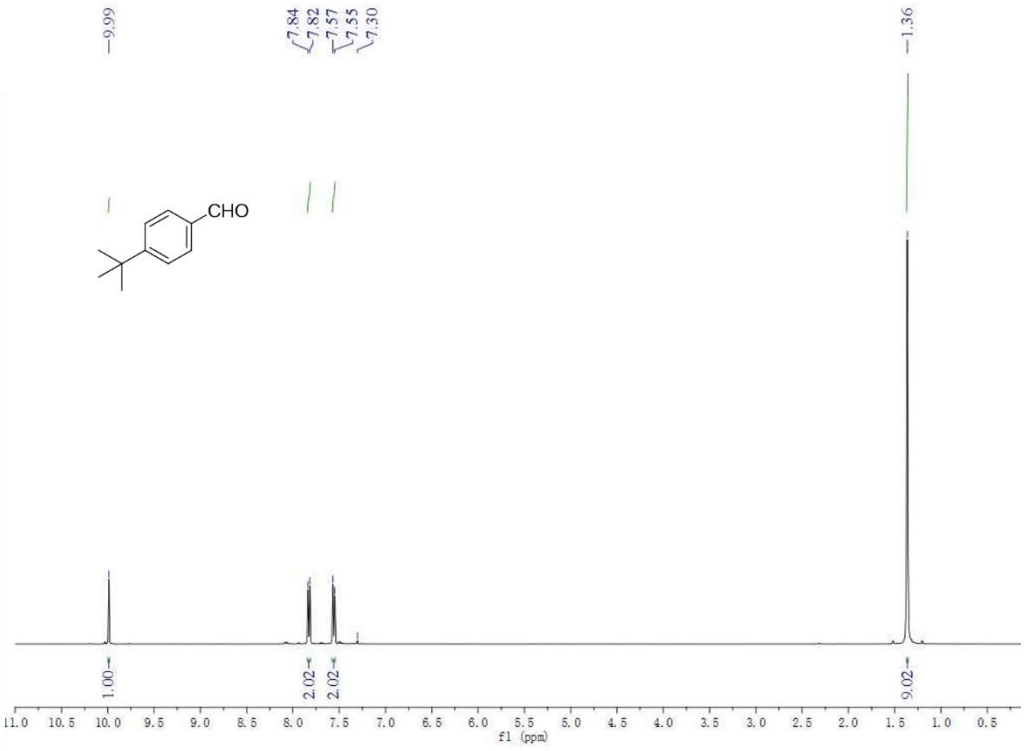
^{1}H NMR spectrum of **4m** in $CDCl_3$ at 400 MHz



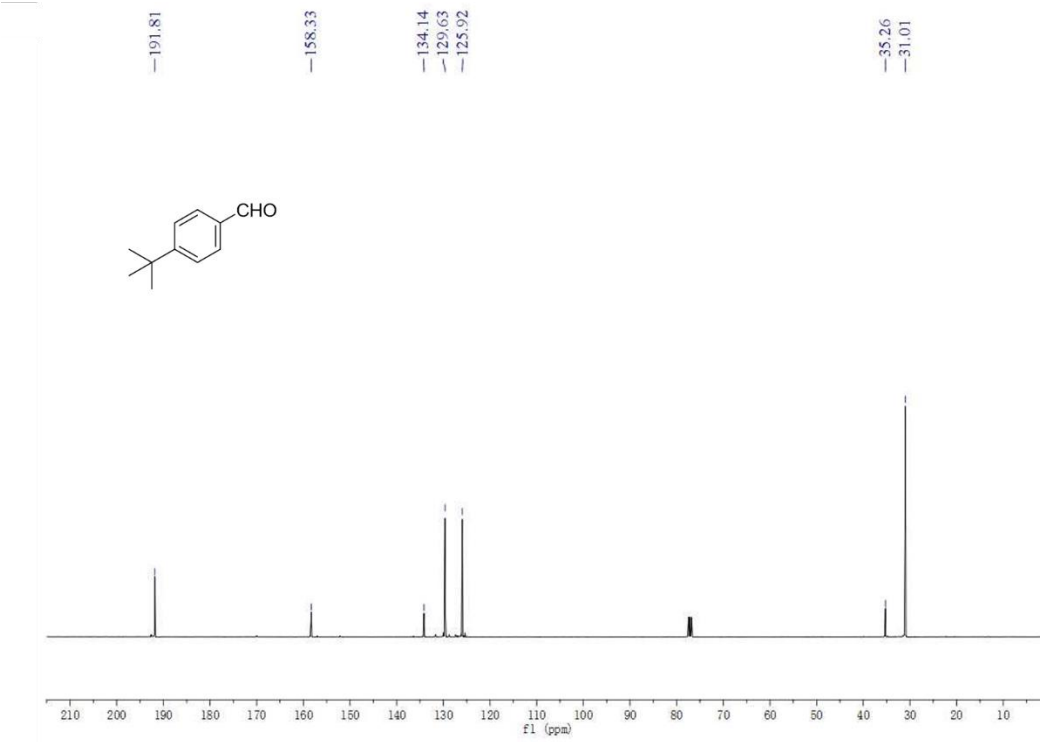
^{13}C NMR spectrum of **4m** in $CDCl_3$ at 101 MHz



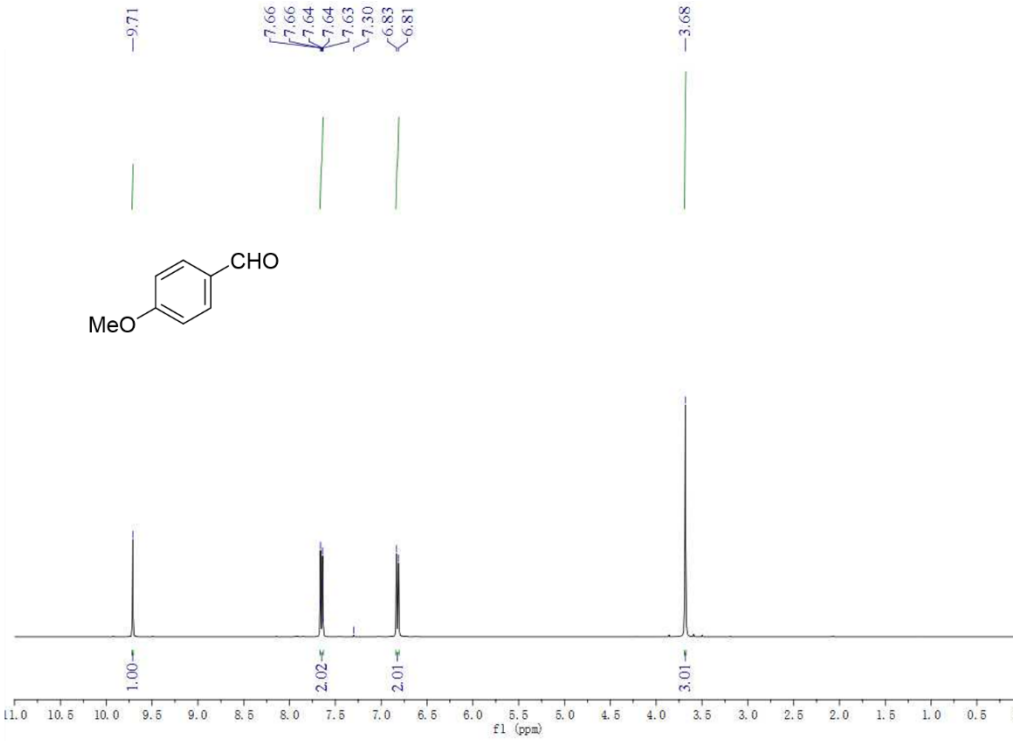
^{1}H NMR spectrum of **4n** in $CDCl_3$ at 400 MHz



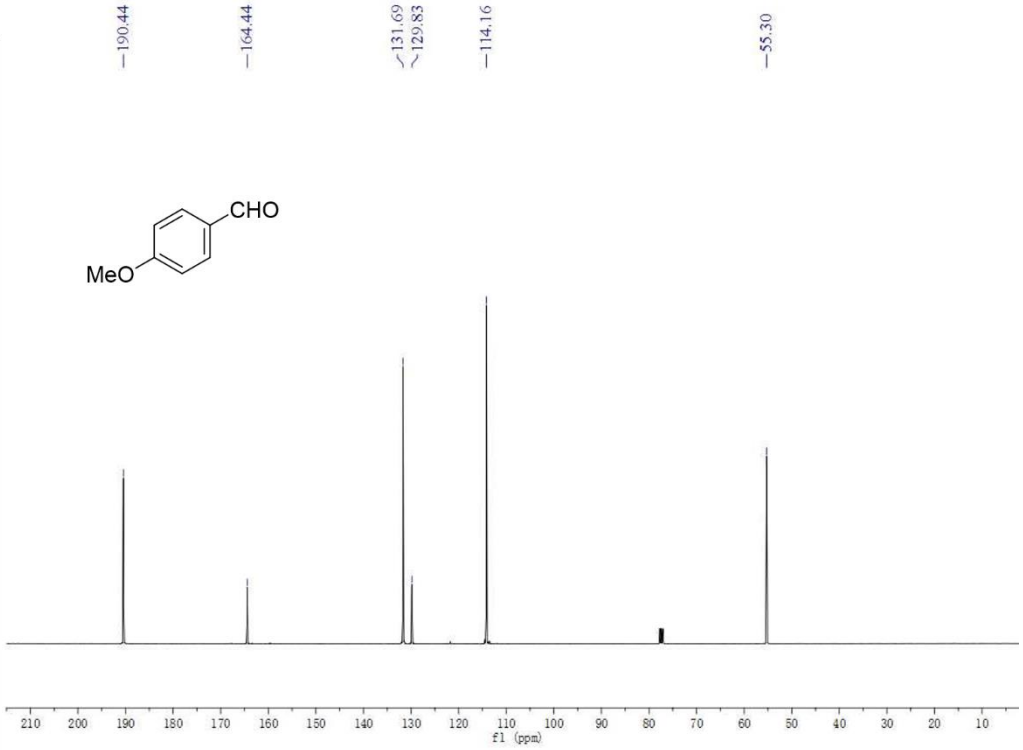
^{13}C NMR spectrum of **4n** in $CDCl_3$ at 101 MHz



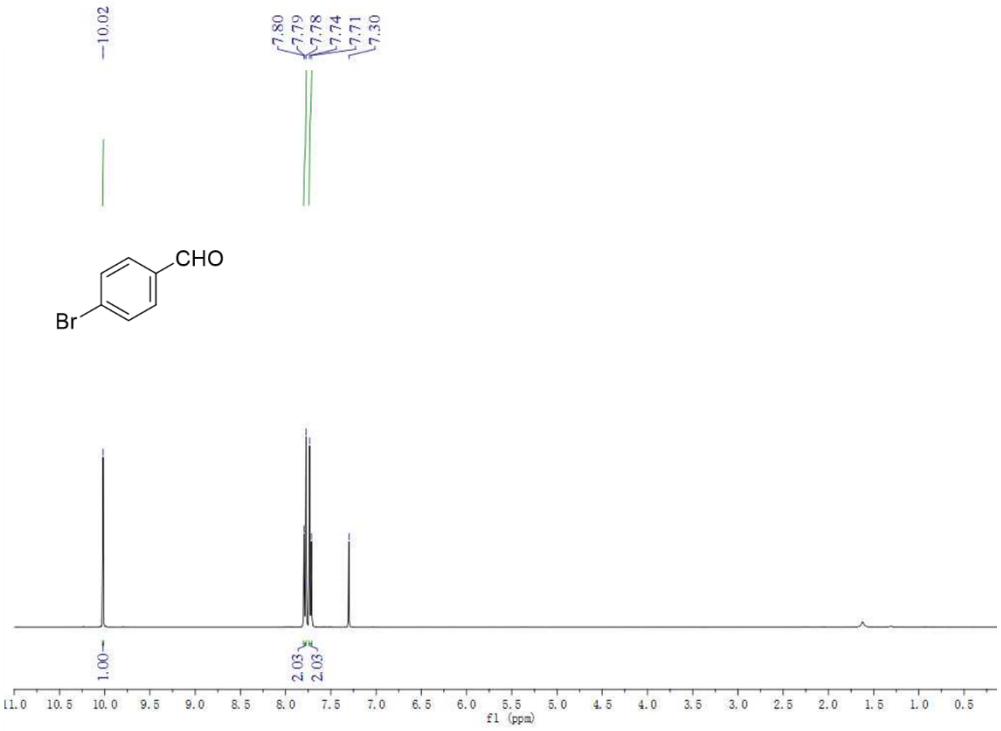
^{1}H NMR spectrum of **4o** in $CDCl_3$ at 400 MHz



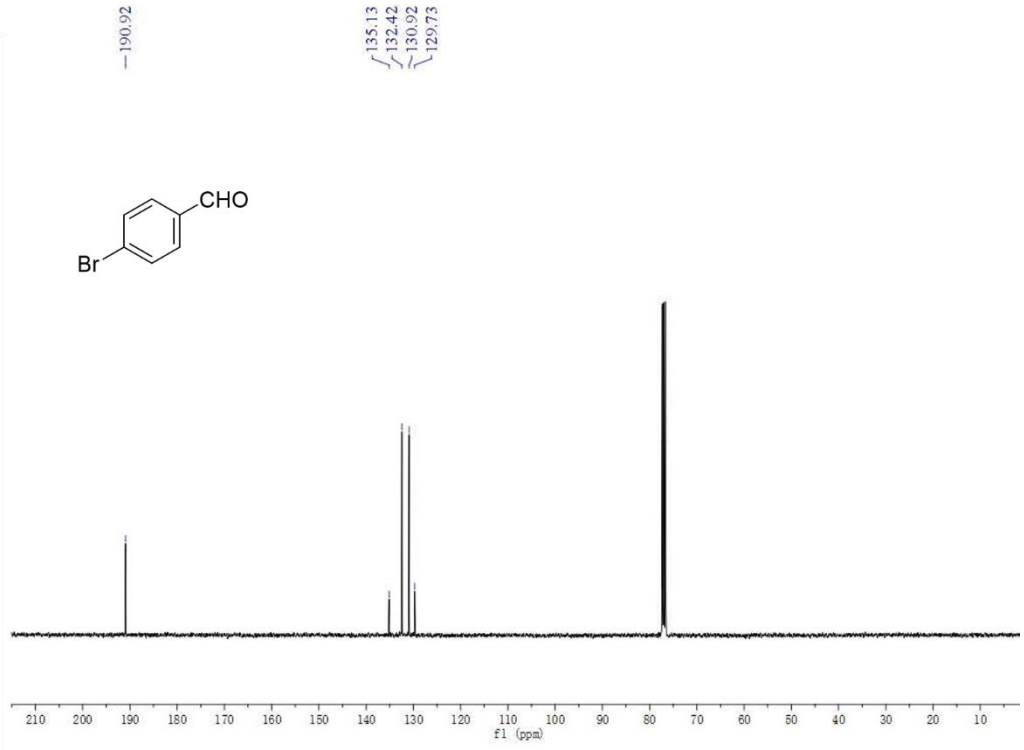
^{13}C NMR spectrum of **4o** in $CDCl_3$ at 101 MHz



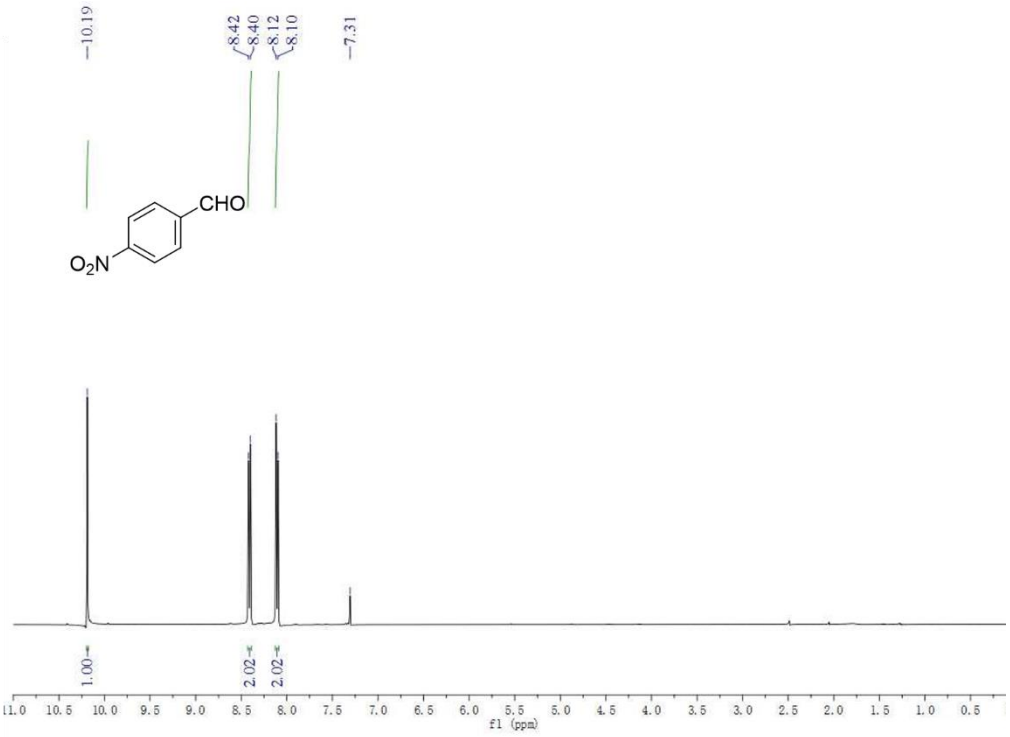
^{1}H NMR spectrum of **4p** in $CDCl_3$ at 400 MHz



^{13}C NMR spectrum of **4p** in $CDCl_3$ at 101 MHz



^{1}H NMR spectrum of **4q** in $CDCl_3$ at 400 MHz



^{13}C NMR spectrum of **4q** in $CDCl_3$ at 101 MHz