# *Supporting Information*

# *Direct C2-Arylation of Indoles Enabled by Photoinduced XAT and Co-Mediated Desaturation*

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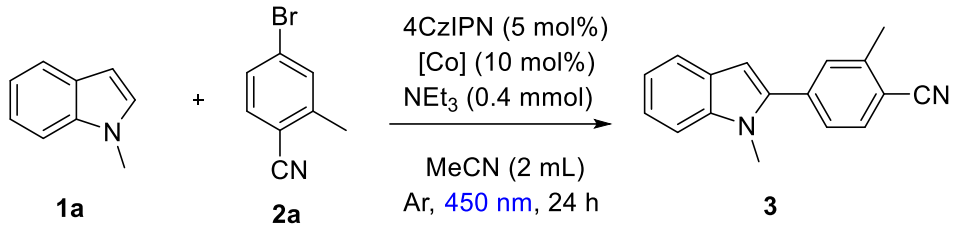
## 1. General Experimental Methods

Unless otherwise noted, all solvents and reagents were purchased from commercial suppliers and used without further purification. $^{1}$H NMR spectra were recorded at 400 MHz on a Bruker AVANCE III HD 400 spectrometer. The chemical shifts were recorded in *ppm* relative to tetramethyl silane and with the solvent resonance as the internal standard. Data were reported as follows: chemical shift, multiplicity (s = singlet; d = doublet; dd = doublet of doublet; t= triplet; q = quartet; *br* s = broad singlet; m = multiplet), coupling constants (Hz), integration. $^{19}$F NMR data were collected at 376 MHz with complete proton decoupling. $^{13}$C NMR data were collected at 100 MHz with complete proton decoupling. Infrared spectra (IR) were measured by FT-IR apparatus. High resolution mass spectroscopy (HRMS) was recorded on TOF MS ES$^{+}$ Mass spectrometer and acetonitrile was used to dissolve the sample. Column chromatography was carried out on silica gel (200-300 mesh, Petroleum PE/EtOAc solvent systems). Melting points (m.p.) were measured by Büchi 510 melting point apparatus and uncorrected.

## 2. Optimization of Reaction Conditions

### 2.1 Screening of cobalt catalyst[a]

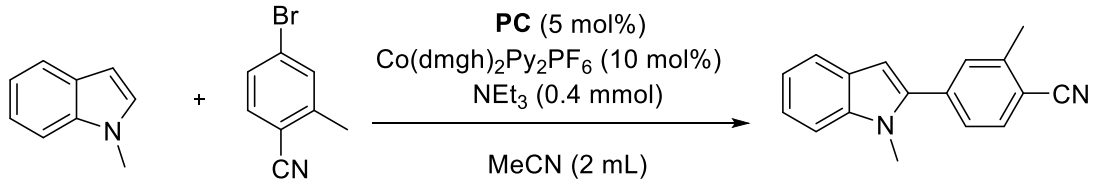



**1a** **2a** **3**

| Entry | Co-catalyst | Yield (%)[b] | Entry | Co-catalyst | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | $CoCl_2$ | 25 | 5 | $Co(Salen)_2$ | 23 |
| 2 | $CoBr_2$ | 28 | 6 | $Co(dmgh)_2Py_2PF_6$ | 78 |
| 3 | $CoI_2$ | n.d. | 7 | $Co(dmgh)_2$(4-COOMePy)Cl | 48 |
| 4 | $Co(OAc)_2$ | n.d. | 8 | $Co(dmgh)_2$(4-$NMe_2$Py)Cl | 50 |

[a]Unless otherwise noted, all reactions were carried out using **1a** (1.0 mmol, 5.0 equiv.), **2a** (0.2 mmol, 1.0 equiv.), 4CzIPN (5 mol%), [Co] (10 mol%), $NEt_3$ (0.4 mmol), MeCN (2.0 mL) at ambient temperature, under Ar atmosphere for 24 h, 30 W blue LEDs; [b]Yield of the isolated product.

### 2.2 Screening of photocatalyst[a]



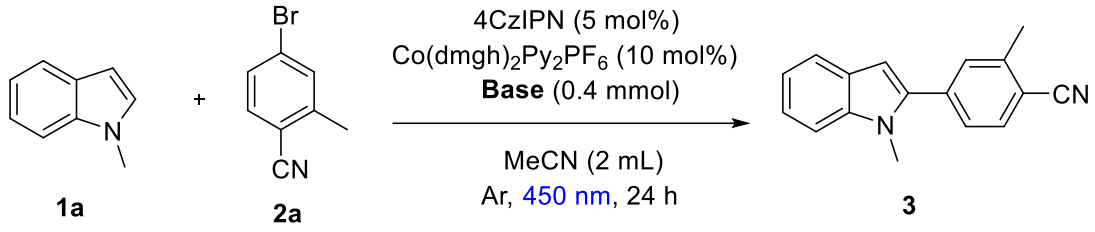

**1a** **2a** **3**

| Entry | Photocatalyst | Yield (%)[b] |
|---|---|---|
| 1 | $Ir(ppy)_3$ | n.d. |
| 2 | $[Ir(dF(CF_3)ppy)_2dtbbpy]PF_6$ | 38 |
| 3 | $[Ir(dF(CF_3)ppy)_2$(4, 4'-$dCF_3$)bpy$]PF_6$ | 40 |
| 4 | $[Ir(ppy)_2dtbbpy]PF_6$ | 44 |

[a]Unless otherwise noted, all reactions were carried out using **1a** (1.0 mmol, 5.0 equiv.), **2a** (0.2 mmol, 1.0 equiv.), **PC** (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%),

$NEt_3$ (0.4 mmol), MeCN (2.0 mL) at ambient temperature, under Ar atmosphere for 24 h, 30 W blue LEDs; [b]Yield of the isolated product.

**2.3 Screening of base[a]**

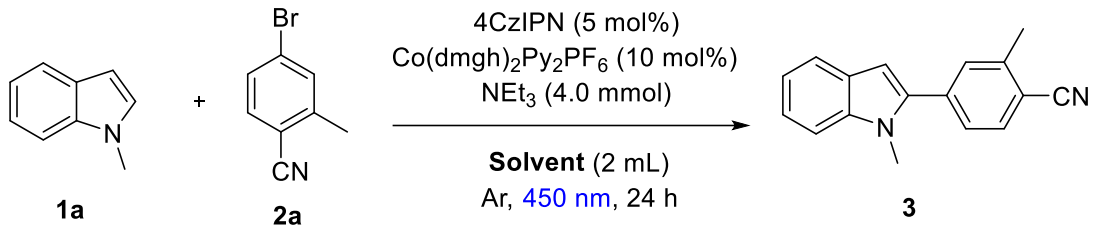



**1a** **2a** **3**

| Entry | Base | Yield (%)[b] | Entry | Base | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | DBU | n.d. | 6 | KI | n.d. |
| 2 | $K_2CO_3$ | 30 | 7 | DIPEA | 24 |
| 3 | $K_3PO_4$ | n.d. | 8 | $NEt_3$ (20 mol%) | trace |
| 4 | $K_2HPO_4$ | n.d. | 9 | DABCO (0.6 mmol) | 52 |
| 5 | NaOAc | n.d. | 10 | DABCO | 23 |

[a]Unless otherwise noted, all reactions were carried out using **1a** (1.0 mmol, 5.0 equiv.), **2a** (0.2 mmol, 1.0 equiv.), 4CzIPN (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%), Base (0.4 mmol), MeCN (2.0 mL) at ambient temperature, under Ar atmosphere for 24 h, 30 W blue LEDs; [b]Yield of the isolated product.

**2.4 Screening of solvent[a]**



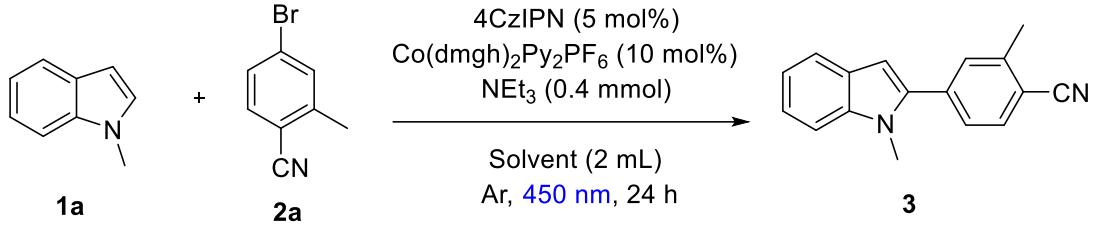

**1a** **2a** **3**

| Entry | Solvent | Yield (%)[b] | Entry | Solvent | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | EA | 23 | 5 | DMF | n.d. |
| 2 | DCM | n.d. | 6 | Toluene | n.d. |
| 3 | Dioxane | 30 | 7 | THF | 49 |
| 4 | DMSO | n.d. | 8 | DMA | n.d. |

[a]Unless otherwise noted, all reactions were carried out using **1a** (1.0 mmol, 5.0 equiv.), **2a** (0.2 mmol, 1.0 equiv.), 4CzIPN (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%), $NEt_3$ (0.4 mmol), Solvent

(2.0 mL) at ambient temperature, under Ar atmosphere for 24 h, 30 W blue LEDs; [b]Yield of the isolated product.

## 2.5 Screening of equivalents[a]

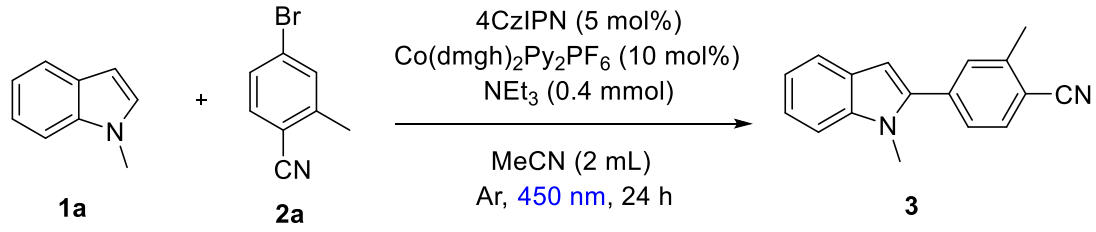



**1a** **2a** **3**

| Entry | Equivalent | Yield (%)[b] |
|---|---|---|
| 1 | **1a**:**2a**=0.4 mmol:0.2 mmol | 32 |
| 2 | **1a**:**2a**=0.6 mmol:0.2 mmol | 56 |

[a]Unless otherwise noted, all reactions were carried out using **1a**, **2a**, 4CzIPN (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%), $NEt_3$ (0.4 mmol), MeCN (2.0 mL) at ambient temperature, under Ar atmosphere for 24 h, 30 W blue LEDs. [b]1,3,5-Trimethoxybenzene as internal standard.

## 2.6 Control Experiment[a]

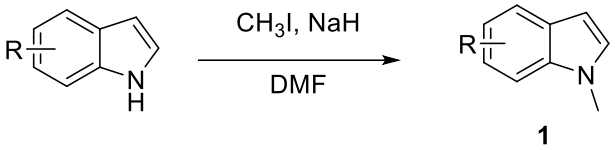



**1a** **2a** **3**

| Entry | PC | [Co] | Base | Light | Heating | Yield (%) |
|---|---|---|---|---|---|---|
| 1 | - | + | + | + | - | n.d. |
| 2 | + | - | + | + | - | 23 |
| 3 | + | + | - | + | - | n.d. |
| 4 | + | + | + | - | - | n.d. |
| 5 | + | + | + | + | + | n.d. |
| 6 | + | + | + | + | - | 78 |

## 3. Experimental Procedures

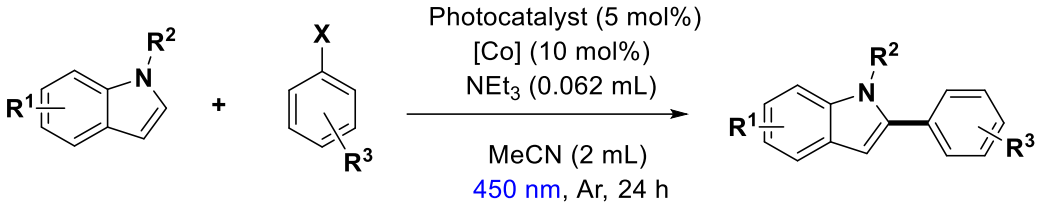
### 3.1 General procedure for the preparation of compound *N*-methylindole




1

To a two-necked flask equipped with a magnetic stirring bar, substituted or unsubstituted indoles (5.0 mmol, 1.0 eq.) and DMF (0 .25 M) were added under an Ar atmosphere. Then, the solution was cooled to 0 °C and NaH (5.0 mmol, 1.0 eq.) stored in coal oil was added. After the mixture was stirred for 30 minutes at room temperature, $CH_3I$ (6 mmol, 1.2 eq.) was added dropwise, and the mixture was stirred at room temperature overnight. Thereafter, the reaction was quenched with sat. aq. $NH_4Cl$ and extracted with EtOAc. The combined organic phase was dried over $MgSO_4$ and evaporated under reduced pressure. Purification of the residue by column chromatography (PE/EA = 19:1) afforded the desired 1-methylindoles.

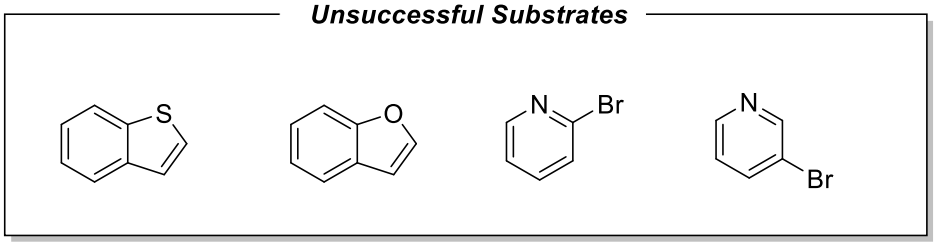
### 3.2 General procedure for the preparation of compound 3-33



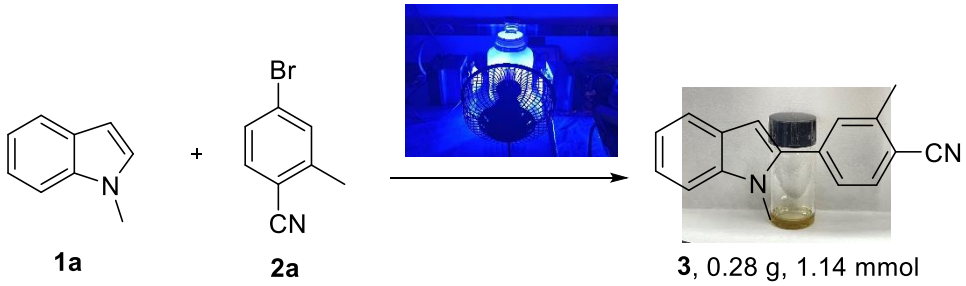

**1,** 1.0 mmol **2,** 0.2 mmol **3**

To a reaction tube equipped with a magnetic stirring bar, compound **1** (1.0 mmol, 5.0 equiv.), compound **2** (0.2 mmol, 1.0 equiv.), photocatalyst (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%), $NEt_3$ (0.4 mmol, 2.0 equiv.) and MeCN (0.1 M) were added. The resulting mixture was charged with argon, then stirred and irradiated by a 30 W blue LED at ambient temperature for 24 h. Thereafter, the solvent was removed under reduced pressure and then purified by column chromatography to afford the desired products.

### 3.3 Failed substrates



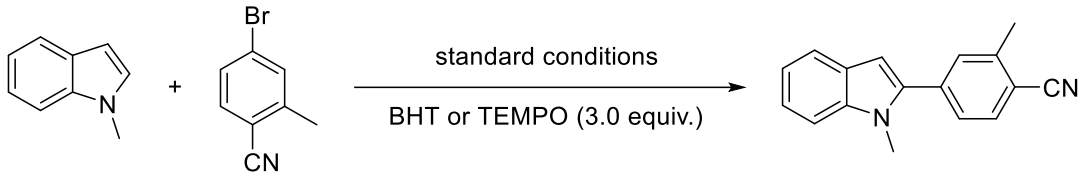

### 3.4 Scale-up reaction




To a reaction tube equipped with a magnetic stirring bar, **1a** (10 mmol, 5.0 equiv.), **2a** (2.0 mmol, 1.0 equiv.), 4CzIPN (5 mol%), $Co(dmgh)_2Py_2PF_6$ (10 mol%), $NEt_3$ (4.0 mmol, 2.0 equiv.) and MeCN (0.1 M) were added. The resulting mixture was charged with argon, then stirred and irradiated by two 30 W blue LEDs at ambient temperature for 24 h. Thereafter, the reaction mixture was evaporated under reduced pressure and then purified by column chromatography to afford the desired products.

# 4. Control Experiments

## 4.1 Trapping Experiment




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

| Entry | Conditions | Yield(%) |
|---|---|---|
| 1 | BHT (3.0 eq) | 19 |
| 2 | TEMPO (3.0 eq) | n.d. |

Radical trapping experiments between **1a** and **2a** were conducted under standard conditions with two trapping agents (BHT or TEMPO) to determine the putative radical. The desired product **3** was obtained in 19% yield when BHT was added and no product was detected when TEMPO was added. The corresponding coupled products between BHT/TEMPO radical and the aryl radicals/indole C-3 radicals mixture were successfully detected by HRMS (Figure S1). HRMS (EI): $C_{32}H_{39}N_2O^+$, $[M+H]^+$ calcd: 467.3057, found: 467.3065 (BHT-adduct); HRMS (EI): $C_{26}H_{34}N_3O^+$, $[M+H]^+$ calcd: 404.2696, found: 404.2696 (TEMPO-adduct). HRMS (EI): $C_{23}H_{30}NO^+$, $[M+H]^+$ calcd: 336.2322, found: 336.2299 (BHT-adduct). HRMS (EI): $C_{17}H_{24}N_2NaO^+$, $[M+Na]^+$ calcd:295.1781, found: 295.1782 (TEMPO-adduct).

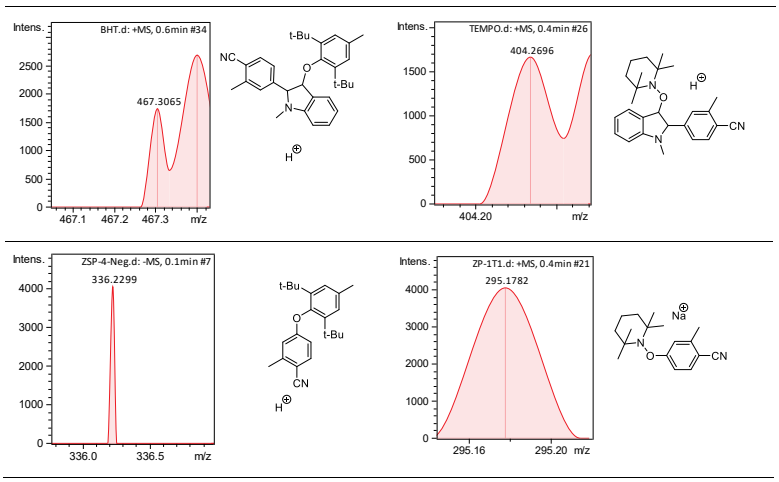



**Figure S1**. Crude ESI-MS of the radical-trapping experiments

## 4.2 Emission Quenching Experiments

All fluorescence measurements were recorded using a Hitachi FL-7000 Fluorometer. Quenching studies were conducted in acetone. All 4CzIPN solutions (concentration of $1\times10^{-5}$ M) were excited at 360 nm and the emission intensity was collected at 560 nm.

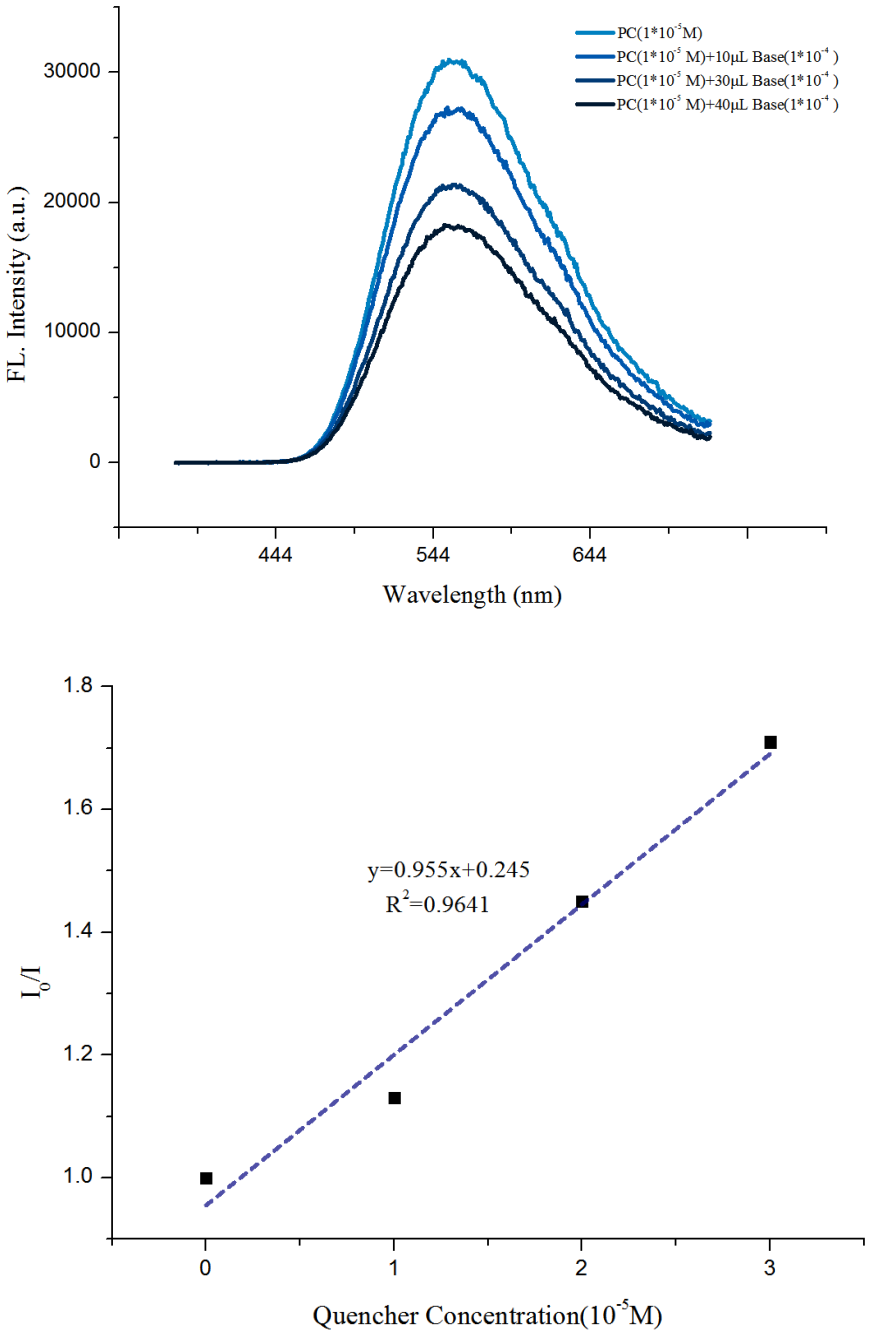



**Figure S2**. Quenching of the 4CzIPN emission ($5\times10^{-3}$ M in MeCN) in the presence of increasing amounts of $NEt_3$

### 4.3 On-off Experiments

The light on/off experiment of the model reaction was performed parallelly on a 0.20 mmol scale following the standard procedure by adding 1.0 equiv. 1,3,5-trimethoxylbenzene as internal standard. The reaction started with successive irradiation and black periods to study the influence of continuous irradiation of the visible-light for the progress photochemical reaction. After being irradiated with 30 W blue LEDs for 2 h, an aliquot (200 μL) from the reaction mixture was transferred into a nuclear magnetic tube charged with 0.4 mL $CDCl_3$-*d1*. The yield of the desired product **3b** was determined by $^1H$ NMR. The reaction was then stirred with light-off for 2 h and the yield was determined by $^1H$ NMR. All of the following yields were analyzed in the identical way after a 2 h light-on or light-off. These results revealed that light is a necessary component of the reaction.

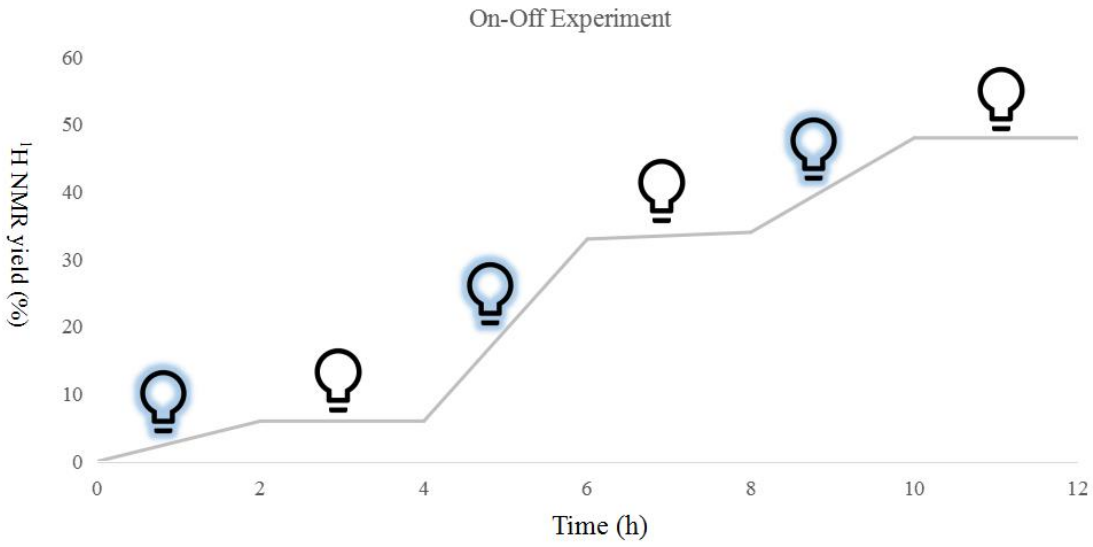
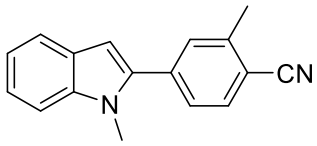



**Figure S3**. On-off experiments of C2-arylation of indoles

## 5. Characterization Data of Compounds 3-33

Product **3** (a pale yellow oil)




38.4 mg, yield: 78%; purified by flash column chromatography (PE/EA = 100/1)

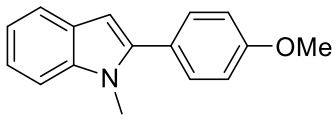
**IR** (neat) *v* 1604, 1463, 1450, 1315, 836, 790, 758, 724 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.66 (dd, $J$ = 14.9, 7.9 Hz, 2H), 7.47 (s, 1H), 7.41 (d, $J$ = 6.8 Hz, 1H), 7.37 (d, $J$ = 8.2 Hz, 1H), 7.31 – 7.26 (m, 1H), 7.16 (t, $J$ = 7.4 Hz, 1H), 6.63 (d, $J$ = 0.9 Hz, 1H), 3.76 (s, 3H), 2.62 (s, 3H);

**$^{13}$C NMR** (100 MHz, Chloroform-*d*) $\delta$ 142.2, 137.2, 132.6, 130.7, 127.8, 126.7, 122.6, 120.9, 120.3, 111.8, 109.8, 103.3, 31.5, 20.7;

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{17}H_{14}N_2Na^+$ 269.1049; Found: 269.1069.

Product **4** (white solid)



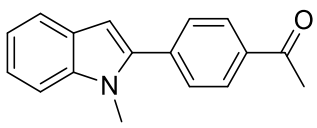

20.9 mg, yield: 46%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.62 (d, $J$ = 7.8 Hz, 1H), 7.44 (d, $J$ = 8.7 Hz, 2H), 7.35 (d, $J$ = 8.3 Hz, 1H), 7.22 (d, $J$ = 8.1 Hz, 1H), 7.13 (t, $J$ = 7.4 Hz, 1H), 7.01 (d, $J$ = 8.7 Hz, 2H), 6.50 (s, 1H), 3.88 (s, 3H), 3.73 (s, 3H).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{16}NO^+$ 238.1226; Found: 238.1227.

Analytic data of **4** was consistent with the reported data.[1]

Product **5** (white solid)




26.9 mg, yield: 53%; purified by flash column chromatography (PE/EA = 100/1)

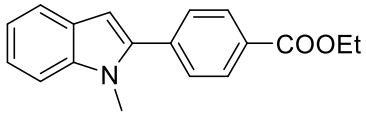
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.07 (d, $J$ = 8.3 Hz, 2H), 7.68 – 7.62 (m, 3H),

7.39 (d, *J* = 8.3 Hz, 1H), 7.30 (d, *J* = 8.0 Hz, 1H), 7.19 – 7.14 (m, 1H), 6.67 (s, 1H), 3.79 (s, 3H), 2.67 (s, 3H).

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{17}H_{15}NNaO^+$ 272.1046; Found: 272.1046.

Analytic data of **5** was consistent with the reported data.[2]

Product **6** (white solid)



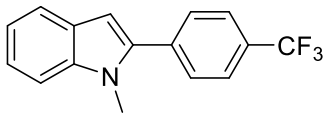

22.3 mg, yield: 40%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.14 (d, *J* = 8.4 Hz, 2H), 7.65 (d, *J* = 7.9 Hz, 1H), 7.59 (d, *J* = 8.4 Hz, 2H), 7.38 (d, *J* = 8.2 Hz, 1H), 7.29 (d, *J* = 7.1 Hz, 1H), 7.16 (t, *J* = 7.8 Hz, 1H), 6.65 (s, 1H), 4.42 (q, *J* = 7.1 Hz, 2H), 3.78 (s, 3H), 1.43 (t, *J* = 7.1 Hz, 3H);

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{18}H_{18}NO_2^+$ 280.1332; Found: 280.1332.

Analytic data of **6** was consistent with the reported data.[3]

Product **7** (white solid)




24.2 mg, yield: 46%; purified by flash column chromatography (PE/EA = 100/1)

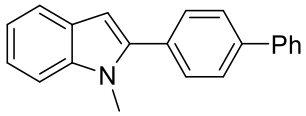
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.73 (d, *J* = 8.1 Hz, 2H), 7.65 (t, *J* = 7.2 Hz, 3H), 7.38 (d, *J* = 8.2 Hz, 1H), 7.29 (d, *J* = 7.2 Hz, 1H), 7.17 (t, *J* = 7.4 Hz, 1H), 6.63 (s, 1H), 3.77 (s, 3H).

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -62.568.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{13}F_3N^+$ 276.0995; Found: 276.0990.

Analytic data of **7** was consistent with the reported data.[3]

Product **8** (white solid)



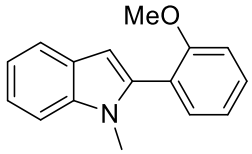

19.8 mg, yield: 36%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.70 (d, $J$ = 8.3 Hz, 2H), 7.68 – 7.64 (m, 3H), 7.60 (d, $J$ = 8.3 Hz, 2H), 7.48 (t, $J$ = 7.6 Hz, 2H), 7.38 (dt, $J$ = 7.2, 3.0 Hz, 2H), 7.28 (s, 1H), 7.15 (t, $J$ = 7.4 Hz, 1H), 6.62 (s, 1H), 3.80 (s, 3H).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{21}H_{18}N^+$ 284.1434; Found: 284.1435.

Analytic data of **8** was consistent with the reported data.[4]

Product **9** (white solid)



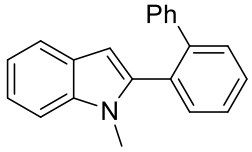

16.6 mg, yield: 34%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.63 (d, $J$ = 7.8 Hz, 1H), 7.43 (td, $J$ = 8.3, 1.7 Hz, 1H), 7.39 – 7.34 (m, 2H), 7.23 (t, $J$ = 7.6 Hz, 1H), 7.12 (t, $J$ = 7.4 Hz, 1H), 7.06 (t, $J$ = 7.2 Hz, 1H), 7.01 (d, $J$ = 8.3 Hz, 1H), 6.50 (s, 1H), 3.82 (s, 3H), 3.59 (s, 3H).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{16}NO^+$ 238.1226; Found: 238.1236.

Analytic data of **9** was consistent with the reported data.[3]

Product **10** (white solid)



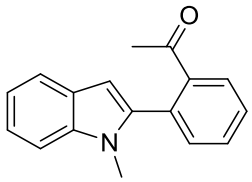

33.9 mg, yield: 60%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.61 (d, $J$ = 7.5 Hz, 1H), 7.55 – 7.50 (m, 3H), 7.47 – 7.40 (m, 2H), 7.18 (t, $J$ = 4.1 Hz, 4H), 7.15 – 7.10 (m, 3H), 6.52 (s, 1H), 3.05 (s, 3H).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{21}H_{18}N^+$ 284.1434; Found: 284.1441.

Analytic data of **10** was consistent with the reported data.[5]

Product **11** (a pale red oil)



21.9 mg, yield: 44%; purified by flash column chromatography (PE/EA = 100/1)

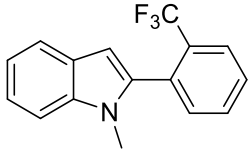
**IR** (neat) *v* 2986, 2918, 1679, 1398, 1389, 1267, 1230, 916 $cm^{-1}$;

**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.69 (d, *J* = 7.6 Hz, 1H), 7.64 (d, *J* = 7.9 Hz, 1H), 7.59 – 7.49 (m, 2H), 7.47 – 7.42 (m, 1H), 7.37 (d, *J* = 8.3 Hz, 1H), 7.28 (d, *J* = 7.1 Hz, 1H), 7.17 (t, *J* = 7.4 Hz, 1H), 6.52 (s, 1H), 3.56 (s, 3H), 1.98 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 203.1, 141.7, 139.1, 137.9, 131.6, 130.8, 128.7, 128.0, 122.1, 120.7, 120.1, 109.6, 103.2, 30.7, 29.2.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{17}H_{15}NNaO^+$ 272.1046; Found: 272.1046.

Product **12** (a pale red oil)



33.6 mg, yield: 61%; purified by flash column chromatography (PE/EA = 100/1)

**IR** (neat) *v* 1717, 1277, 1258, 1201, 1133, 1097, 1033, 955 $cm^{-1}$;

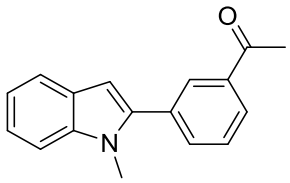
**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.82 (d, *J* = 7.6 Hz, 1H), 7.62 (dt, *J* = 20.1, 7.6 Hz, 3H), 7.42 (d, *J* = 7.4 Hz, 1H), 7.36 (d, *J* = 8.2 Hz, 1H), 7.28 (d, *J* = 7.4 Hz, 1H), 7.16 (t, *J* = 7.4 Hz, 1H), 6.53 (s, 1H), 3.49 (s, 3H);

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -59.043.

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 137.3, 136.7, 133.2, 131.7 (q, $^{3}J_{C\text{-}F}$ = 2.3 Hz) 131.2, 130.7(q, $^{2}J_{C\text{-}F}$ = 29.9 Hz), 128.8, 127.7, 126.2 (q, $^{3}J_{C\text{-}F}$ = 5.1 Hz), 123.7(q, $^{1}J_{C\text{-}F}$ = 273.7 Hz), 121.8, 120.7, 119.8, 109.4, 103.3, 30.5.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{16}H_{12}F_3NNa^+$ 298.0814; Found: 298.0814.

Product **13** (a pale yellow oil)



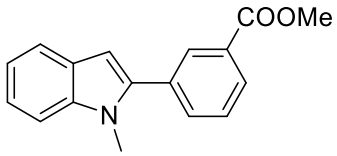
25.9 mg, yield: 51%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-d) δ 8.11 (t, *J* = 1.6 Hz, 1H), 7.99 (dt, *J* = 7.7, 1.4 Hz, 1H), 7.72 (dt, *J* = 7.6, 1.4 Hz, 1H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.58 (t, *J* = 7.7 Hz, 1H), 7.39 (d, *J* = 8.2 Hz, 1H), 7.31 – 7.27 (m, 1H), 7.19 – 7.14 (m, 1H), 6.62 (s, 1H), 3.76 (s, 3H), 2.66 (s, 3H).

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{17}H_{15}NKO^+$ 288.0785; Found: 288.0788.

Analytic data of **13** was consistent with the reported data.[4]

Product **14** (white solid)



**m.p.** 290-292 °C, 19.1 mg, yield: 36%; purified by flash column chromatography (PE/EA = 100/1)

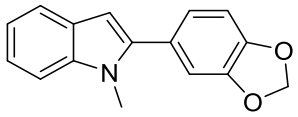
**IR** (neat) *v* 2920, 1720, 1270, 1210, 1110, 1082, 1037, 970 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) *δ* 8.20 (s, 1H), 8.07 (d, *J* = 7.8 Hz, 1H), 7.71 (d, *J* = 7.7 Hz, 1H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.55 (t, *J* = 7.7 Hz, 1H), 7.38 (d, *J* = 8.1 Hz, 1H), 7.28 (d, *J* = 7.9 Hz, 1H), 7.16 (t, *J* = 7.4 Hz, 1H), 6.62 (s, 1H), 3.95 (s, 3H), 3.76 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) *δ* 133.6, 133.2, 130.5, 130.3, 128.9, 128.7, 127.9, 122.0, 120.6, 120.0, 109.7, 102.3, 52.3, 31.2.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{17}H_{16}NO_2^+$ 266.1176; Found: 266.1176

Product **15** (white solid)



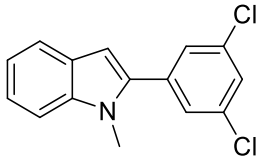
30.1 mg, yield: 60%; purified by flash column chromatography (PE/EA = 100/1)

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.62 (d, $J$ = 7.8 Hz, 1H), 7.35 (d, $J$ = 8.1 Hz, 1H), 7.23 (d, $J$ = 7.4 Hz, 1H), 7.14 (t, $J$ = 7.4 Hz, 1H), 6.98 (d, $J$ = 6.1 Hz, 2H), 6.92 (d, $J$ = 8.4 Hz, 1H), 6.50 (s, 1H), 6.04 (s, 2H), 3.73 (s, 3H).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{14}NO_2^+$ 252.1019; Found: 252.1019.

Analytic data of **15** was consistent with the reported data.[6]

Product **16** (yellow solid)




**m.p.** 105-107 °C, 19.8 mg, yield: 36%; purified by flash column chromatography (PE/EA = 100/1)

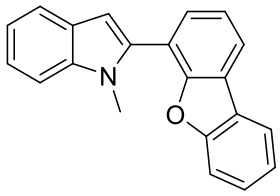
**IR** (neat) $v$ 1722, 1280, 1254, 1200, 1130, 1113, 998, 955 cm$^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.64 (d, $J$ = 7.9 Hz, 1H), 7.37 (d, $J$ = 14.6 Hz, 4H), 7.31 – 7.26 (m, 1H), 7.16 (t, $J$ = 7.4 Hz, 1H), 6.60 (s, 1H), 3.75 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 138.7, 138.5, 135.8, 135.1, 127.8, 127.7, 127.5, 122.5, 120.9, 120.3, 109.8, 103.1, 31.3.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{15}H_{12}Cl_2N^+$ 276.0341; Found: 276.0344.

Product **17** (white solid)




**m.p.** 114-116 °C,19.6 mg, yield: 36%; purified by flash column chromatography (PE/EA = 100/1)

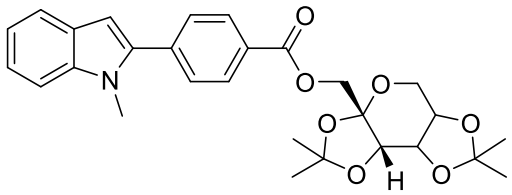
**IR** (neat) $v$ 1720, 1662, 1398, 1212, 1131, 1098, 1001, 935 cm$^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.05 – 7.99 (m, 2H), 7.70 (d, $J$ = 7.9 Hz, 1H), 7.56 (d, $J$ = 7.9 Hz, 2H), 7.46 (qd, $J$ = 8.1, 6.8, 1.8 Hz, 3H), 7.38 (t, $J$ = 7.5 Hz, 1H), 7.32 – 7.27 (m, 1H), 7.18 (t, $J$ = 7.4 Hz, 1H), 6.enne78 (s, 1H), 3.75 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 156.2, 138.3, 136.1, 128.9, 128.1, 127.5, 124.7, 123.0, 122.9, 121.9, 120.8, 120.7, 120.7, 119.8, 117.7, 111.9, 109.7, 103.1, 31.3.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{21}H_{15}NO^+$ 298.1226; Found: 298.1226.

Product **18** (a pale yellow oil)



29.6 mg, yield: 30%; purified by flash column chromatography (PE/EA = 100/1)

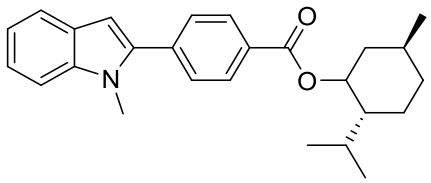
**IR** (neat) *v* 2930, 2928, 1729, 1604, 1425, 1300, 1228, 1080,975 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.14 (d, *J* = 8.4 Hz, 2H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.59 (d, *J* = 8.4 Hz, 2H), 7.38 (d, *J* = 8.1 Hz, 1H), 7.29 (d, *J* = 7.1 Hz, 1H), 7.16 (t, *J* = 7.8 Hz, 1H), 6.64 (s, 1H), 3.78 (s, 3H), 2.16 (d, *J* = 11.7 Hz, 1H), 2.00 (td, *J* = 7.0, 2.8 Hz, 1H), 1.75 (d, *J* = 11.8 Hz, 2H), 1.60 (d, *J* = 14.7 Hz, 2H), 1.15 (t, *J* = 11.6 Hz, 2H), 0.94 (dd, *J* = 6.8, 2.2 Hz, 8H), 0.82 (d, *J* = 6.9 Hz, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 165.8, 137.1, 130.0, 129.8, 129.0, 122.3, 120.7, 120.1, 109.7, 102.8, 75.0, 47.4, 41.0, 34.4, 31.5, 26.6, 23.7, 22.1, 20.8, 16.6.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{28}H_{31}N_2O_7^+$ 516.1993; Found: 516.1989.

Product **19** (a pale yellow oil)



31.9 mg, yield: 41%; purified by flash column chromatography (PE/EA = 100/1)

**IR** (neat) *v* 2929, 1798, 1730, 1600, 1428, 1297, 1206, 1078, 977 $cm^{-1}$;

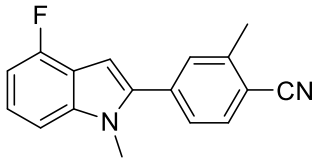
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.17 (d, *J* = 8.1 Hz, 2H), 7.65 (d, *J* = 7.8 Hz, 1H), 7.60 (d, *J* = 8.1 Hz, 2H), 7.38 (d, *J* = 8.2 Hz, 1H), 7.29 (d, *J* = 7.2 Hz, 1H), 7.16 (t, *J* = 7.4 Hz, 1H), 6.65 (s, 1H), 4.71 (d, *J* = 11.8 Hz, 1H), 4.67 (s, 1H), 4.49 (d, *J* = 2.3 Hz,

1H), 4.38 (d, $J$ = 11.8 Hz, 1H), 4.27 (d, $J$ = 7.8 Hz, 1H), 3.97 (d, $J$ = 12.6 Hz, 1H), 3.82 (d, $J$ = 13.0 Hz, 1H), 3.77 (s, 3H), 1.36-1.57 (m, 12 H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 165.7, 130.0, 129.0, 127.9, 122.4, 120.2, 109.8, 109.2, 108.9, 103.0, 101.7, 70.8, 70.7, 70.2, 65.6, 61.4, 31.4, 26.6, 25.9, 25.6, 24.1.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{26}H_{32}NO_2^+$ 390.2428; Found: 390.2427.

Product **20** (a pale yellow solid)




**m.p.** 125-127 °C, 22.2 mg, yield: 43%; purified by flash column chromatography (PE/EA = 100/1)

**IR** (neat) $v$ 2918, 1605, 1485, 1464, 1217, 1189, 1143, 1077 cm$^{-1}$;

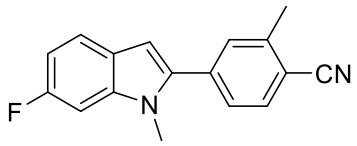
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.39 (d, $J$ = 4.6 Hz, 1H), 7.94 (d, $J$ = 7.8 Hz, 1H), 7.72 (d, $J$ = 8.0 Hz, 1H), 7.52 (s, 1H), 7.47 (d, $J$ = 7.9 Hz, 1H), 7.13 (dd, $J$ = 7.8, 4.7 Hz, 1H), 6.60 (s, 1H), 3.91 (s, 3H), 2.65 (s, 3H).

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -121.841.

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.4, 141.4 (d, $^3J_{C\text{-}F}$ = 11.0 Hz), 136.6, 131.7 (d, $^1J_{C\text{-}F}$ = 196.4 Hz), 126.8, 123.1 (d, $^3J_{C\text{-}F}$ = 7.8 Hz), 112.1, 116.9 (d, $^2J_{C\text{-}F}$ = 22.6 Hz) 105.9 (d, $^4J_{C\text{-}F}$ = 3.5 Hz), 105.1 (d, $^2J_{C\text{-}F}$ = 18.9 Hz), 99.1, 31.9, 20.7.

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{17}H_{13}FKN_2^+$ 303.0694; Found: 303.0687.

Product **21** (a pale yellow solid)




**m.p.** 128-130 °C, 19.5 mg, yield: 37%; purified by flash column chromatography (PE/EA = 100/1)

**IR** (neat) $v$ 2918, 1605, 1485, 1464, 1217, 1189, 1143, 1077 cm$^{-1}$;

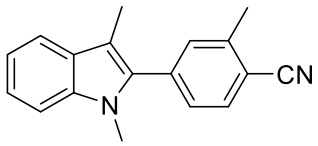
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.69 (d, $J$ = 8.0 Hz, 1H), 7.57 – 7.52 (m, 1H), 7.46 (s, 1H), 7.42 – 7.38 (m, 1H), 7.05 (dd, $J$ = 9.8, 2.0 Hz, 1H), 6.96 – 6.92 (m, 1H), 6.60 (s, 1H), 3.72 (s, 3H), 2.63 (s, 3H).

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -118.979

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.3, 140.1 (d, $^3J_{C\text{-}F}$ = 5.7 Hz), 136.9, 131.9, 131.6 (d, $^1J_{C\text{-}F}$ = 217.1 Hz), 129.1, 126.6, 124.2, 121.7 (d, $^3J_{C\text{-}F}$ = 10.0 Hz), 111.9, 109.1 (d, $^2J_{C\text{-}F}$ = 24.6 Hz), 103.3, 101.5, 96.3 (d, $^2J_{C\text{-}F}$ = 26.3 Hz), 31.7, 20.7.

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{17}H_{13}FKN_2^+$ 303.0694; Found: 303.0702.

Product **22** (a pale yellow solid)




**m.p.** 289-291 °C, 31.7 mg, yield: 61%; purified by flash column chromatography (PE/EA = 100/1)

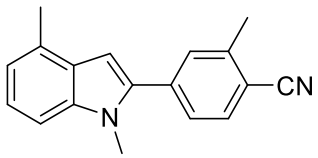
**IR** (neat) $\nu$ 2978, 2924, 1607, 1503, 1289, 1074, 762, 742 cm$^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.71 (d, $J$ = 7.9 Hz, 1H), 7.61 (d, $J$ = 7.8 Hz, 1H), 7.38 – 7.28 (m, 4H), 7.21 – 7.15 (m, 1H), 3.62 (s, 3H), 2.63 (s, 3H), 2.29 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.0, 137.7, 136.8, 135.7, 132.5, 132.1, 128.3, 122.6, 119.5, 119.2, 118.2, 111.7, 110.2, 109.5, 31.2, 20.7, 9.5.

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{18}H_{16}KN_2^+$ 299.0945; Found: 299.0967.

Product **23** (a pale yellow solid)




**m.p.** 290-292 °C, 14.0 mg, yield: 40%; purified by flash column chromatography (PE/EA = 100/1)

**IR** (neat) $\nu$ 2966, 2919, 1602, 1376, 1229, 1066, 905, 841 cm$^{-1}$;

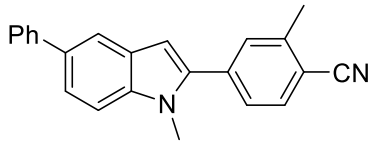
**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.69 (d, $J$ = 8.0 Hz, 1H), 7.49 (s, 1H), 7.43 (d, $J$

= 8.0 Hz, 1H), 7.22 (s, 2H), 6.97 (d, *J* = 5.7 Hz, 1H), 6.65 (s, 1H), 3.76 (s, 3H), 2.63 (s, 3H), 2.57 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.3, 139.0, 138.8, 137.3, 132.6, 130.6, 127.7, 126.7, 122.8, 120.5, 118.2, 111.6, 107.4, 102.0, 77.4, 31.7, 20.7, 18.7.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{18}H_{16}N_2Na^+$ 283.1206; Found: 283.1205.

Product **24** (a pale yellow oil)




36.1 mg, yield: 53%; purified by flash column chromatography (PE/EA = 100/1)

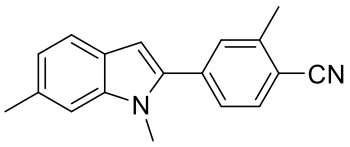
**IR** (neat) *v* 2919, 1478, 1445, 1399, 1034, 985, 845, 789 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.74 – 7.67 (m, 4H), 7.57 (s, 1H), 7.50 – 7.42 (m, 5H), 7.35 (t, *J* = 7.4 Hz, 1H), 6.66 (s, 1H), 3.82 (s, 3H), 2.64 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.3, 140.2, 139.6, 137.1, 136.2, 132.7, 130.6, 128.8, 127.5, 126.8, 126.7, 121.1, 120.3, 108.4, 103.2, 31.6, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{23}H_{19}N_2^+$ 323.1543; Found: 323.1548.

Product **25** (a pale yellow solid)




**m.p.** 280-282 °C, 20.8 mg, yield: 42%; purified by flash column chromatography (PE/EA = 100/1)

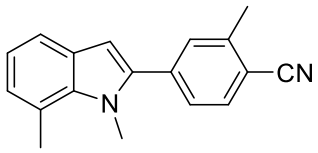
**IR** (neat) *v* 2967, 2925, 1584, 1410, 1374, 1255, 1168, 796 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.69 (d, *J* = 8.0 Hz, 1H), 7.49 (s, 1H), 7.43 (d, *J* = 8.0 Hz, 1H), 7.22 (s, 2H), 6.97 (d, *J* = 5.7 Hz, 1H), 6.65 (s, 1H), 3.76 (s, 3H), 2.63 (s, 3H), 2.57 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.2, 139.5, 137.4, 132.6, 130.5, 126.6, 125.6, 122.1, 120.5, 109.8, 103.3, 31.4, 22.0, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{18}H_{17}N_2^+$ 261.1386; Found: 261.1381.

Product **26** (colorless oil)




16.1 mg, yield: 31%; purified by flash column chromatography (PE/EA = 100/1)

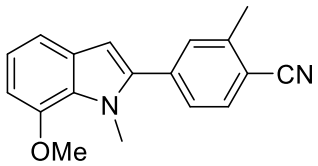
**IR** (neat) *v* 2966, 2921, 1606, 1454, 1318, 1094, 975, 832 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.68 (d, $J$ = 8.0 Hz, 1H), 7.45 (s, 1H), 7.40 (d, $J$ = 8.0 Hz, 1H), 7.22 (d, $J$ = 7.8 Hz, 1H), 7.03 (t, $J$ = 7.8 Hz, 1H), 6.68 (d, $J$ = 7.7 Hz, 1H), 6.55 (s, 1H), 3.72 (s, 3H), 2.61 (s, 3H), 2.52 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.2, 139.5, 137.4, 132.6, 130.6, 130.5, 126.6, 125.6, 122.1, 120.5, 109.8, 103.3, 31.4, 22.0, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{18}H_{17}N_2^+$ 261.1386; Found: 261.1386.

Product **27** (white solid)




**m.p.** 255-257 °C, 24.9 mg, yield: 44%; purified by flash column chromatography (PE/EA = 100/1)

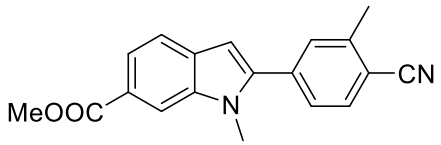
**IR** (neat) *v* 2218, 1604, 1493, 1464, 1252, 1214, 1028, 988 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.67 (d, $J$ = 7.9 Hz, 1H), 7.51 (d, $J$ = 8.4 Hz, 1H), 7.45 (s, 1H), 7.39 (d, $J$ = 8.1 Hz, 1H), 6.83 (m, $J$ = 10.4 Hz, 2H), 6.57 (s, 1H), 3.91 (s, 3H), 3.72 (s, 3H), 2.62 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 157.0, 142.2, 140.0, 138.6, 137.3, 132.6, 130.3, 126.4, 122.0, 121.6, 118.2, 110.4, 103.4, 93.2, 55.8, 31.7, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{18}H_{17}N_2O^+$ 277.1335; Found: 277.1330.

Product **28** (a pale yellow solid)




**m.p.** 104-106 °C, 14.0 mg, yield: 51%; purified by flash column chromatography (PE/EA = 100/1)

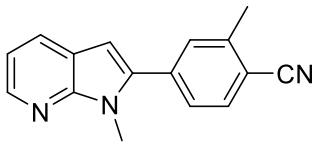
**IR** (neat) *v* 2918, 1704, 1607, 1427, 1309, 1225, 1077, 878 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.16 (s, 1H), 7.85 (d, *J* = 9.6 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.66 (d, *J* = 8.2 Hz, 1H), 7.50 (s, 1H), 7.44 (d, *J* = 8.0 Hz, 1H), 6.66 (s, 1H), 3.97 (s, 3H), 3.83 (s, 3H), 2.64 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 168.0, 142.7, 142.4, 138.2, 136.5, 132.7, 131.3, 130.8, 126.9, 124.0, 121.3, 120.4, 117.9, 112.3, 103.4, 52.1, 31.7, 20.7.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{19}H_{16}N_2NaO_2^+$ 327.1104; Found: 327.1104.

Product **29** (a pale yellow solid)




**m.p.** 128-130 °C, 22.7 mg, yield: 47%; purified by flash column chromatography (PE/EA = 100/1)

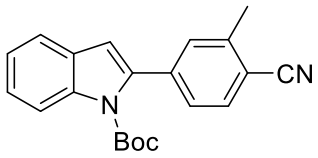
**IR** (neat) *v* 1616, 1457, 1369, 1310, 836, 789, 724, 667 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.39 (d, *J* = 4.6 Hz, 1H), 7.94 (d, *J* = 7.8 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.52 (s, 1H), 7.47 (d, *J* = 7.9 Hz, 1H), 7.13 (dd, *J* = 7.8, 4.7 Hz, 1H), 6.60 (s, 1H), 3.91 (s, 3H), 2.65 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 143.6, 136.7, 132.8, 130.5, 128.8, 126.6, 120.4, 118.0, 116.5, 101.0, 30.2, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{14}N_3^+$ 248.1182; Found: 248.1182.

Product **30** (a pale yellow solid)




**m.p.** 95-97 °C, 23.3 mg, yield: 35%; purified by flash column chromatography (PE/EA = 100/1)

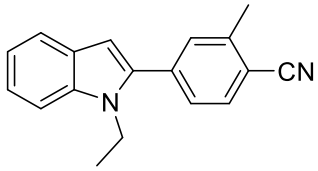
**IR** (neat) *v* 2920, 1725, 1623, 1430, 1299, 1225, 1069, 970 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.19 (d, *J* = 7.7 Hz, 1H), 7.63 (d, *J* = 8.0 Hz, 1H), 7.57 (d, *J* = 7.9 Hz, 1H), 7.39 (s, 1H), 7.34 (td, *J* = 8.1, 1.4 Hz, 2H), 7.30 – 7.26 (m, 1H), 6.62 (s, 1H), 2.60 (s, 3H), 1.37 (s, 9H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 149.9, 141.4, 139.3, 138.6, 137.7, 132.0, 130.3, 129.0, 126.5, 125.1, 123.3, 120.9, 115.4, 111.4, 84.1, 28.2, 27.7, 20.5.

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{21}H_{20}KN_2O_2^+$ 355.1417; Found: 355.1415.

Product **31** (a pale yellow solid)




**m.p.** 90-92 °C, 21.3 mg, yield: 41%; purified by flash column chromatography (PE/EA = 100/1)

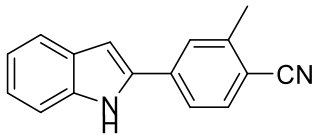
**IR** (neat) *v* 2925, 1730, 1598, 1428, 1313, 1230, 1066, 972 $cm^{-1}$;

**$^1$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.69 (d, *J* = 8.0 Hz, 1H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.46 (s, 1H), 7.41 (d, *J* = 8.2 Hz, 2H), 7.28 (dd, *J* = 7.1, 1.1 Hz, 1H), 7.19 – 7.13 (m, 1H), 6.59 (s, 1H), 4.21 (q, *J* = 7.2 Hz, 2H), 2.63 (s, 3H), 1.32 (t, *J* = 7.2 Hz, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.3, 139.1, 137.8, 137.6, 132.6, 130.7, 128.1, 126.7, 122.5, 121.0, 120.2, 118.0, 111.9, 110.1, 103.7, 39.0, 20.7, 15.4.

**HRMS** (ESI) m/z: $[M+K]^+$ Calcd for: $C_{18}H_{16}KN_2^+$ 299.0945; Found: 299.0947

Product **32** (a pale yellow solid)




**m.p.** 154-156 °C, 10.7 mg, yield: 44%; purified by flash column chromatography (PE/EA = 20/1)

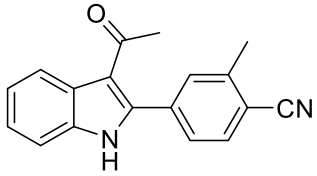
**IR** (neat) *v* 1622, 1575, 1428, 1407, 1369, 1220, 1052, 966 $cm^{-1}$;

**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.41 (s, 1H), 7.65 (d, *J* = 8.0 Hz, 2H), 7.60 (s, 1H), 7.55 (d, *J* = 8.1 Hz, 1H), 7.42 (d, *J* = 8.2 Hz, 1H), 7.25 – 7.21 (m, 1H), 7.15 (t, *J* = 7.5 Hz, 1H), 6.96 – 6.92 (m, 1H), 2.61 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 142.7, 137.3, 135.7, 133.2, 126.3, 123.5, 122.6, 121.2, 120.8, 111.1, 102.5, 20.7.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{16}H_{12}N_2Na^+$ 255.0893; Found: 255.0901.

Product **33** (a pale yellow solid)




**m.p.** 238-240 °C, 28.5 mg, yield: 52%; purified by flash column chromatography (PE/EA = 100/3)

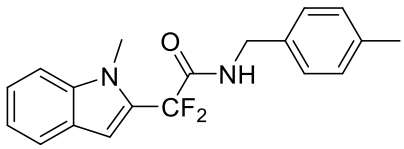
**IR** (neat) *v* 2918, 1623, 1437, 1289, 1167, 1072, 1016, 953 $cm^{-1}$;

**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.62 (s, 1H), 8.23 (dd, *J* = 5.9, 3.4 Hz, 1H), 7.70 (d, *J* = 7.9 Hz, 1H), 7.55 (s, 1H), 7.51 (d, *J* = 8.0 Hz, 1H), 7.43 – 7.39 (m, 1H), 7.33 (dt, *J* = 6.1, 3.5 Hz, 2H), 2.62 (s, 3H), 2.36 (s, 3H).

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 194.7, 142.4, 141.3, 137.0, 135.4, 132.6, 131.3, 127.6, 127.0, 124.1, 122.9, 122.2, 117.5, 116.3, 113.7, 111.2, 30.9, 20.6.

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{18}H_{15}N_2O^+$ 275.1179; Found: 275.1179.

Product **34** (a pale yellow solid)



42.0 mg, yield: 61%; purified by flash column chromatography (PE/EA = 100/3)

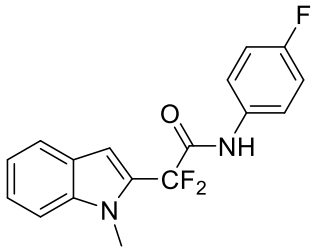
**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 7.61 (d, $J$ = 8.0 Hz, 1H), 7.41 – 7.27 (m, 2H), 7.14 (dd, $J$ = 7.9, 4.3 Hz, 5H), 6.77 (s, 1H), 6.70 (s, 1H), 4.49 (d, $J$ = 5.8 Hz, 2H), 3.88 (s, 3H), 2.33 (s, 3H).

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -97.81.

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 162.8 (t, $^{2}J_{C\text{-}F}$ = 30.1 Hz), 133.6, 129.7 (t, $^{2}J_{C\text{-}F}$ = 28.1 Hz), 129.6, 127.9, 126.0, 124.0, 121.9, 120.4, 112.8 (t, $^{1}J_{C\text{-}F}$ = 249.0 Hz), 109.8, 104.9 (t, $^{3}J_{C\text{-}F}$ = 6.5 Hz), 43.6, 31.3 (t, $^{4}J_{C\text{-}F}$ = 3.1 Hz), 21.1.

**HRMS** (ESI) m/z: $[M+Na]^+$ Calcd for: $C_{19}H_{18}F_2N_2ONa^+$ 351.1279; Found: 351.1292.

Product **35** (a pale yellow solid)



42.6 mg, yield: 67%; purified by flash column chromatography (PE/EA = 100/3)

**$^{1}$H NMR** (400 MHz, Chloroform-*d*) $\delta$ 8.07 (s, 1H), 7.62 (d, $J$ = 8.0 Hz, 1H), 7.55 (dd, $J$ = 9.0, 4.7 Hz, 2H), 7.42 – 7.31 (m, 2H), 7.20 – 7.12 (m, 1H), 7.10 – 7.00 (m, 2H), 6.85 (s, 1H), 3.92 (s, 3H).

**$^{19}$F NMR** (376 MHz, Chloroform-*d*) $\delta$ -97.44, -115.70

**$^{13}$C NMR** (101 MHz, Chloroform-*d*) $\delta$ 161.4, 160.7 (t, $^{2}J_{C\text{-}F}$ = 30.1 Hz), 159.0, 139.1, 131.9 (d, $^{4}J_{C\text{-}F}$ = 2.9 Hz), 129.1, 126.0, 124.2, 122.2, 122.0, 120.5, 116.0 (d, $^{2}J_{C\text{-}F}$ = 22.8 Hz), 112.7 (t, $^{1}J_{C\text{-}F}$ = 249.9 Hz), 109.8, 105.2 (t, $^{3}J_{C\text{-}F}$ = 6.5 Hz), 31.4 (t, $^{4}J_{C\text{-}F}$ = 3.1 Hz).

**HRMS** (ESI) m/z: $[M+H]^+$ Calcd for: $C_{17}H_{14}F_3N_2O^+$ 319.1053; Found: 319.1056.

## 6. Density Functional Theory (DFT) Calculation Details

All computations were carried out with Gaussian 16, Revision C.01.[7] Geometry optimizations were performed using ωB97X-D functional with def2-SVP basis set for all structures.[8-10] Vibrational frequency calculations were conducted at the same level as the geometry optimizations, to derive the thermochemical correction terms as well as to confirm the stationary points as either minima (no imaginary frequency) or saddle points (only one imaginary frequency) on the potential energy surface. After geometry optimizations, single point energy calculations were performed at ωB97X-D/def2-TZVPP theoretical level. Solvent effect was considered using SMD solvent model during the optimization and single point energy calculations (solvent = acetonitrile).[11]

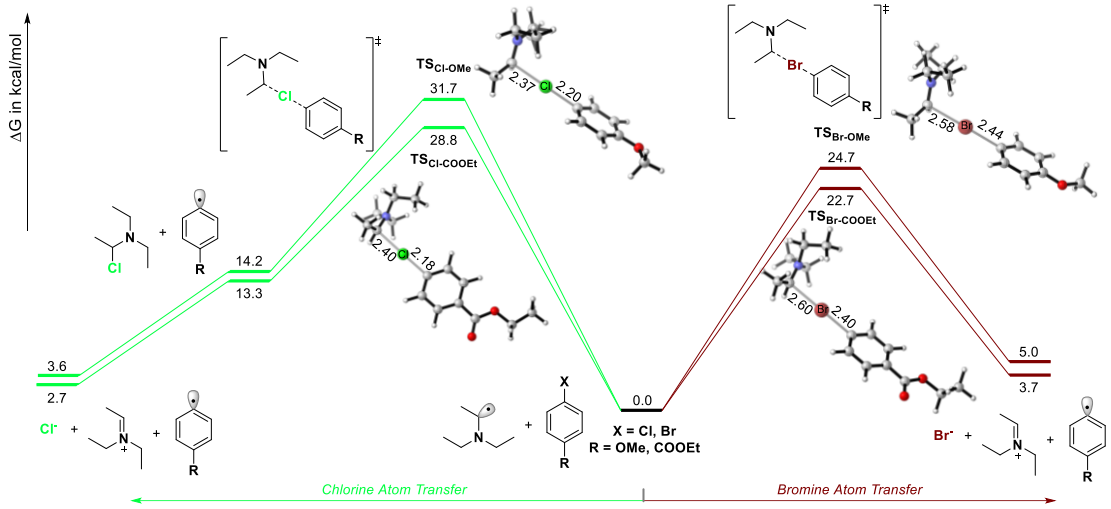
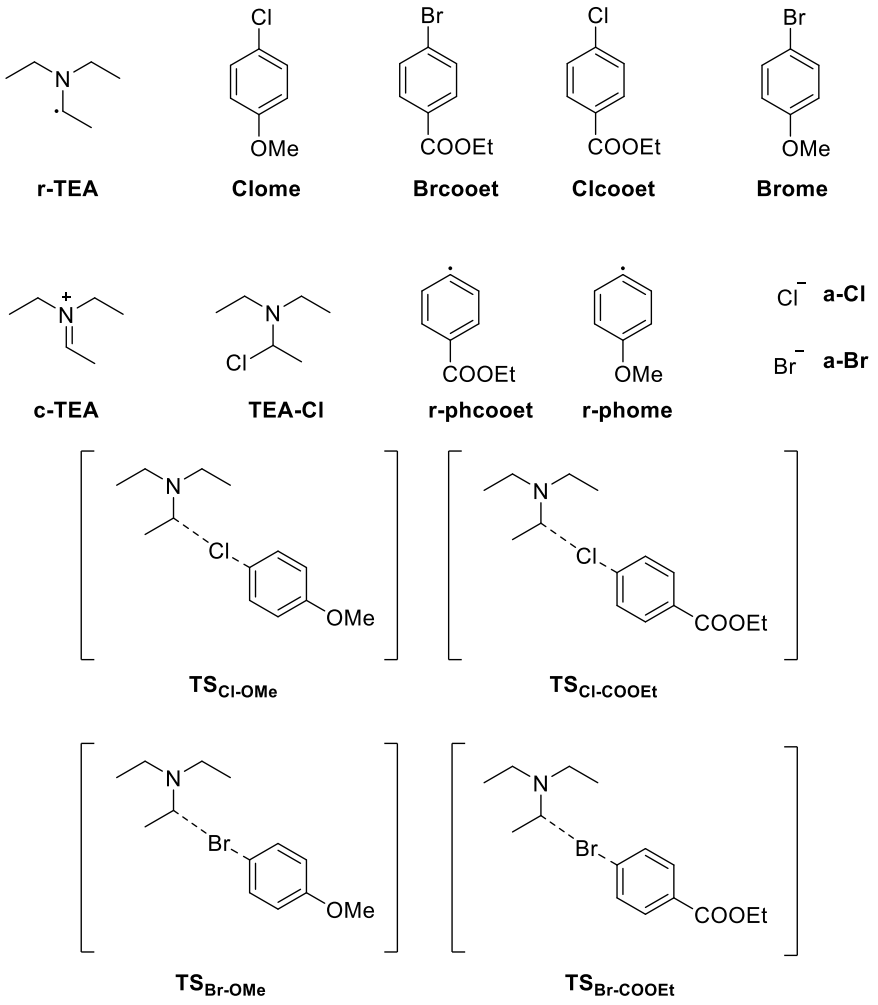



**Figure S4**. DFT studies on the XAT stepsat ωB97XD/def2-TZVPP-SMD(MeCN)//ωB97XD/def2-SVP-SMD(MeCN) level. The relative Gibbs free energies and distances were shown in kcal/mol and angstrom, respectively.



### 6.1 Coordinates and Energies of Stationary Points

**r-TEA**

Electronic energy: -291.7925667 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -291.6342733 a.u.

| | | | |
|---|---|---|---|
| N | -0.13565500 | -0.17153900 | -0.01363500 |
| C | 0.73290000 | -1.15149400 | -0.47974300 |
| H | 0.22430900 | -1.99637400 | -0.95683300 |
| C | -1.46217600 | -0.06689200 | -0.59730200 |
| H | -1.61024100 | 0.94731800 | -1.01015800 |
| H | -1.52238200 | -0.75610200 | -1.45323500 |
| C | 0.38131600 | 1.01699500 | 0.63864400 |
| H | -0.45889700 | 1.51556100 | 1.14709800 |
| H | 1.08285300 | 0.71920000 | 1.43381000 |
| C | 2.01470800 | -1.42392800 | 0.23932500 |
| H | 2.55613900 | -2.23938200 | -0.26302900 |
| H | 2.69150600 | -0.55169700 | 0.26395700 |
| H | 1.86513500 | -1.73465900 | 1.29548900 |
| C | 1.06553000 | 1.99920000 | -0.31023100 |
| H | 0.37363300 | 2.33721100 | -1.09788800 |
| H | 1.41517400 | 2.88781700 | 0.23784200 |
| H | 1.93567700 | 1.53339300 | -0.79845900 |
| C | -2.57093700 | -0.38436000 | 0.39853200 |
| H | -3.56021700 | -0.28522000 | -0.07526800 |
| H | -2.47029200 | -1.41395300 | 0.77606500 |
| H | -2.54085900 | 0.30052900 | 1.26071000 |

## Clome

Electronic energy: -806.4054932 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -806.3135905 a.u.

| | | | |
|---|---|---|---|
| C | 0.52779500 | 1.40778100 | -0.00003800 |
| C | -0.85243500 | 1.26115500 | 0.00020200 |
| C | -1.40715000 | -0.02078700 | 0.00001500 |
| C | -0.58985800 | -1.14513600 | -0.00045200 |
| C | 0.79896200 | -0.99786100 | -0.00074900 |
| C | 1.36771500 | 0.28221400 | -0.00053000 |
| H | 0.98002300 | 2.40162800 | 0.00015800 |
| H | -1.49799000 | 2.14135700 | 0.00055000 |
| H | -1.02794200 | -2.14494200 | -0.00067600 |
| H | 1.42121700 | -1.89314200 | -0.00116300 |
| Cl | -3.14855400 | -0.20914900 | 0.00031100 |
| O | 2.69034100 | 0.52570100 | -0.00109900 |
| C | 3.58786100 | -0.56135300 | 0.00132900 |
| H | 4.59753900 | -0.13243400 | 0.00259400 |
| H | 3.46474500 | -1.18848500 | 0.90028900 |
| H | 3.46774600 | -1.19012800 | -0.89690000 |

**Brcooet**

Electronic energy: -3073.0994233 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -3072.9744296 a.u.

| | | | |
|---|---|---|---|
| C | -0.43691600 | -0.84889400 | -0.00005800 |
| C | 0.93533300 | -1.08363600 | -0.00008200 |
| C | 1.81053100 | 0.00273100 | -0.00018800 |
| C | 1.33711000 | 1.31534700 | 0.00015200 |
| C | -0.03654000 | 1.53602300 | 0.00026400 |
| C | -0.93010900 | 0.46033500 | 0.00006600 |
| H | -1.12679000 | -1.69358300 | -0.00004400 |
| H | 1.31474600 | -2.10675300 | -0.00002700 |
| H | 2.02875500 | 2.15944400 | 0.00032200 |

| | | | |
|---|---|---|---|
| H | -0.42628700 | 2.55552700 | 0.00053400 |
| Br | 3.67946400 | -0.31002600 | 0.00004600 |
| C | -2.39525900 | 0.75862700 | 0.00022800 |
| O | -2.85353300 | 1.87703400 | 0.00144400 |
| O | -3.13948100 | -0.34086700 | -0.00258500 |
| C | -4.56335300 | -0.17568000 | -0.00230700 |
| H | -4.85325400 | 0.40871200 | 0.88457900 |
| H | -4.85407600 | 0.40259800 | -0.89300600 |
| C | -5.19315000 | -1.54611500 | 0.00255200 |
| H | -6.28817600 | -1.44530500 | 0.00264800 |
| H | -4.89934400 | -2.11879700 | -0.88970100 |
| H | -4.89858700 | -2.11270400 | 0.89844100 |

**Brome**

Electronic energy: -2920.4099530 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -2920.3196116 a.u.

| | | | |
|---|---|---|---|
| C | 1.44846400 | -0.98557500 | 0.00015900 |
| C | 0.05632700 | -1.09917600 | 0.00007000 |
| C | -0.73588300 | 0.04371400 | -0.00001500 |
| C | -0.14846500 | 1.31164400 | -0.00013100 |
| C | 1.23490700 | 1.42567300 | -0.00007100 |
| C | 2.04776100 | 0.28045300 | 0.00017000 |
| H | 2.04920000 | -1.89549100 | 0.00017600 |
| H | -0.39844300 | -2.09178000 | 0.00005600 |
| H | -0.76600700 | 2.21190000 | -0.00032200 |
| H | 1.71027400 | 2.40867500 | -0.00019300 |
| Br | -2.62814500 | -0.11554100 | -0.00001300 |
| O | 3.37515900 | 0.49215200 | 0.00048600 |
| C | 4.24707600 | -0.61590500 | -0.00040500 |

| | | | |
|---|---|---|---|
| H | 4.11033800 | -1.23995500 | -0.89942300 |
| H | 5.26640400 | -0.21057400 | -0.00036400 |
| H | 4.11093200 | -1.24102200 | 0.89796700 |

**a-Cl**

Electronic energy: -460.3779592 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -460.3929819 a.u.

| | | | |
|---|---|---|---|
| Cl | 0.00000000 | 0.00000000 | 0.00000000 |

**c-TEA**

Electronic energy: -291.7020698 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -291.5382414 a.u.

| | | | |
|---|---|---|---|
| N | -0.11046900 | -0.13608400 | -0.09505500 |
| C | 0.55554600 | -1.21941900 | -0.27767500 |
| H | 0.04223800 | -2.00253800 | -0.84717700 |
| C | -1.47660500 | 0.00193400 | -0.63751200 |
| H | -1.56056300 | 1.02794200 | -1.02061900 |
| H | -1.56727700 | -0.68601200 | -1.48705200 |
| C | 0.41911000 | 1.03411800 | 0.63064100 |
| H | -0.44759000 | 1.56250600 | 1.04651900 |
| H | 1.02128800 | 0.67822700 | 1.47491400 |
| C | 1.92183900 | -1.50706100 | 0.18837400 |
| H | 2.52888700 | -1.75935400 | -0.69582500 |
| H | 2.39980500 | -0.69618200 | 0.74675300 |
| H | 1.88347600 | -2.41993300 | 0.80399600 |
| C | 1.21853600 | 1.93996300 | -0.28979800 |
| H | 0.60577100 | 2.28704600 | -1.13480100 |
| H | 1.55553200 | 2.82009000 | 0.27553500 |
| H | 2.10374500 | 1.42072400 | -0.68559800 |
| C | -2.53241500 | -0.28448100 | 0.41465900 |

| | | | |
|---|---|---|---|
| H | -3.52723200 | -0.14737700 | -0.03218000 |
| H | -2.45266100 | -1.32051400 | 0.77536900 |
| H | -2.44820300 | 0.39763900 | 1.27341500 |

**TEA-Cl**

Electronic energy: -752.0766166 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -751.9143383 a.u.

| | | | |
|---|---|---|---|
| N | -0.52005600 | 0.46739300 | 0.47109100 |
| C | 0.28129000 | -0.60869500 | 0.72281900 |
| H | -0.29838600 | -1.50419300 | 0.95716200 |
| C | -1.72707600 | 0.25297700 | -0.32194200 |
| H | -2.32260100 | 1.17507200 | -0.24909000 |
| H | -1.45485800 | 0.12775600 | -1.38741800 |
| C | 0.03888600 | 1.81340000 | 0.39813900 |
| H | -0.79336800 | 2.51308400 | 0.57209200 |
| H | 0.73312100 | 1.95299400 | 1.23812900 |
| C | 1.45845300 | -0.42611100 | 1.64426800 |
| H | 1.95584500 | -1.39108600 | 1.80128700 |
| H | 2.19729500 | 0.28384400 | 1.24989800 |
| H | 1.09588100 | -0.05681400 | 2.61715800 |
| C | 0.73522600 | 2.16103200 | -0.91426300 |
| H | 0.04626500 | 2.08148000 | -1.76926300 |
| H | 1.10383300 | 3.19746800 | -0.87436100 |
| H | 1.58759300 | 1.49318000 | -1.10302000 |
| C | -2.57419200 | -0.92847800 | 0.12176800 |
| H | -3.52927700 | -0.91148700 | -0.42340800 |
| H | -2.09298300 | -1.89348500 | -0.09619500 |
| H | -2.79312000 | -0.87892600 | 1.19988100 |
| Cl | 1.11350800 | -1.35561100 | -0.99619000 |

**r-phcooet**

Electronic energy: -498.7916336 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -498.6677649 a.u.

| | | | |
|---|---|---|---|
| C | -1.00180400 | -1.18203400 | -0.00098800 |
| C | -2.31830000 | -1.65689600 | -0.00076300 |
| C | -3.31468000 | -0.70522100 | 0.00035200 |
| C | -3.13575400 | 0.66124800 | 0.00119400 |
| C | -1.81216800 | 1.11302600 | 0.00087400 |
| C | -0.75131900 | 0.19733000 | -0.00017700 |
| H | -0.16819700 | -1.88637400 | -0.00184000 |
| H | -2.52574400 | -2.72999400 | -0.00144100 |
| H | -3.96998200 | 1.36743200 | 0.00206700 |
| H | -1.59304500 | 2.18304200 | 0.00144800 |
| C | 0.64097700 | 0.74197900 | -0.00047900 |
| O | 0.90338600 | 1.92209500 | -0.00131500 |
| O | 1.56345300 | -0.21411200 | 0.00013400 |
| C | 2.93757600 | 0.19206500 | -0.00031300 |
| H | 3.12502500 | 0.81326600 | -0.88983400 |
| H | 3.12493100 | 0.81558100 | 0.88759800 |
| C | 3.79214600 | -1.05092100 | 0.00133300 |
| H | 4.85407000 | -0.76534500 | 0.00104200 |
| H | 3.59902700 | -1.66131300 | 0.89608800 |
| H | 3.59916000 | -1.66361400 | -0.89187700 |

**a-Br**

Electronic energy: -2574.3806009 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -2574.3967764 a.u.

| | | | |
|---|---|---|---|
| Br | 0.00000000 | 0.00000000 | 0.00000000 |

**r-phome**

Electronic energy: -346.1005259 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -346.0108478 a.u.

| | | | |
|---|---|---|---|
| C | 0.00170900 | 1.07661400 | 0.00004600 |
| C | -1.36250200 | 1.41206400 | 0.00000700 |
| C | -2.27138400 | 0.38066400 | -0.00003300 |
| C | -1.94509000 | -0.96174100 | -0.00004000 |
| C | -0.58752200 | -1.28527200 | 0.00000100 |
| C | 0.38771600 | -0.27170300 | 0.00004400 |
| H | 0.74418300 | 1.87593100 | 0.00008500 |
| H | -1.66471500 | 2.46303600 | 0.00001200 |
| H | -2.70084600 | -1.75208600 | -0.00007200 |
| H | -0.25981400 | -2.32757500 | -0.00000100 |
| O | 1.66961100 | -0.68885600 | 0.00009700 |
| C | 2.70157900 | 0.26963700 | -0.00008800 |
| H | 2.66557700 | 0.90915000 | 0.89832200 |
| H | 3.64634100 | -0.28823000 | -0.00017500 |
| H | 2.66534700 | 0.90904800 | -0.89856200 |

**Clcooet**

Electronic energy: -2574.3806009 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -2574.3967764 a.u.

| | | | |
|---|---|---|---|
| C | 0.24350000 | -0.92149200 | 0.00014700 |
| C | 1.60494600 | -1.20979600 | 0.00011400 |
| C | 2.52010300 | -0.15753300 | -0.00000800 |
| C | 2.10055700 | 1.17271200 | -0.00010300 |
| C | 0.73721300 | 1.44679900 | -0.00006900 |
| C | -0.19801500 | 0.40647000 | 0.00006200 |
| H | -0.47968100 | -1.73795000 | 0.00023600 |

| | | | |
|---|---|---|---|
| H | 1.95353300 | -2.24363100 | 0.00017300 |
| H | 2.83178300 | 1.98257300 | -0.00021500 |
| H | 0.38698300 | 2.48054900 | -0.00014600 |
| Cl | 4.22818600 | -0.51296600 | -0.00006200 |
| C | -1.64987000 | 0.76134800 | 0.00007800 |
| O | -2.06485000 | 1.89668400 | -0.00012500 |
| O | -2.43632300 | -0.30865200 | 0.00035600 |
| C | -3.85268700 | -0.08897300 | 0.00024600 |
| H | -4.12092400 | 0.50250300 | 0.88929300 |
| H | -4.12066800 | 0.50333500 | -0.88831600 |
| C | -4.53439400 | -1.43443900 | -0.00045900 |
| H | -5.62479200 | -1.29201400 | -0.00023300 |
| H | -4.26216900 | -2.01437400 | -0.89487500 |
| H | -4.26195700 | -2.01538500 | 0.89323800 |

**$TS_{Br\text{-}OMe}$**

Electronic energy: -3212.1851148 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -3211.9145929 a.u.

| | | | |
|---|---|---|---|
| N | -3.73339900 | -0.18673000 | -0.14120500 |
| C | -3.14527900 | 0.33902700 | 0.92624700 |
| H | -2.98787200 | -0.36051300 | 1.74914900 |
| C | -3.75057500 | -1.63804200 | -0.30938600 |
| H | -3.54330500 | -1.85840800 | -1.36759800 |
| H | -2.91593400 | -2.05742300 | 0.27058100 |
| C | -4.18384200 | 0.61747700 | -1.27330700 |
| H | -4.98749500 | 0.05298700 | -1.76796400 |
| H | -4.63925300 | 1.54270700 | -0.89476400 |
| C | -3.27639900 | 1.78621800 | 1.26668600 |
| H | -2.65936300 | 2.01938600 | 2.14222800 |

| | | | |
|---|---|---|---|
| H | -2.97394100 | 2.44490500 | 0.44145300 |
| H | -4.33054200 | 2.00603100 | 1.51397700 |
| C | -3.06954200 | 0.93185400 | -2.26264800 |
| H | -2.62324500 | 0.00889800 | -2.66286900 |
| H | -3.47550300 | 1.51110000 | -3.10524600 |
| H | -2.26804100 | 1.51426000 | -1.78598200 |
| C | -5.07353700 | -2.25376600 | 0.11705700 |
| H | -5.05174700 | -3.34206200 | -0.04248900 |
| H | -5.26586800 | -2.06506800 | 1.18426200 |
| H | -5.91151700 | -1.84088800 | -0.46536800 |
| C | 3.88108700 | -1.10222800 | 0.08142900 |
| C | 2.49324000 | -1.06232700 | 0.29012100 |
| C | 1.81820400 | 0.14463300 | 0.23753800 |
| C | 2.49723800 | 1.33004600 | -0.02229000 |
| C | 3.87598200 | 1.30254700 | -0.23122900 |
| C | 4.57620300 | 0.08560100 | -0.18093000 |
| H | 4.40261900 | -2.05995100 | 0.12590000 |
| H | 1.95895700 | -1.99604700 | 0.49407100 |
| H | 1.96295800 | 2.28471800 | -0.06524900 |
| H | 4.43638500 | 2.21838100 | -0.43780300 |
| Br | -0.59453000 | 0.20926900 | 0.57865300 |
| O | 5.90987400 | 0.15592600 | -0.39648700 |
| C | 6.66802100 | -1.02784500 | -0.36317900 |
| H | 6.34364200 | -1.74575700 | -1.13629200 |
| H | 7.70846500 | -0.74100900 | -0.56267400 |
| H | 6.61913200 | -1.52011900 | 0.62349900 |

**$TS_{Br\text{-}COOEt}$**

Electronic energy: -3364.8783158 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -3364.5724988

a.u.

| | | | |
|---|---|---|---|
| N | -4.70781900 | -0.44444000 | -0.04385200 |
| C | -4.24350400 | 0.69070600 | 0.45889800 |
| H | -4.09985100 | 0.68553500 | 1.54095200 |
| C | -4.63006400 | -1.66870200 | 0.75085800 |
| H | -4.31892400 | -2.48587300 | 0.08253600 |
| H | -3.82823800 | -1.54153700 | 1.49212400 |
| C | -5.11877500 | -0.58322700 | -1.43839500 |
| H | -5.84524300 | -1.40778300 | -1.47803600 |
| H | -5.65789900 | 0.32409800 | -1.74265100 |
| C | -4.47600800 | 2.00620900 | -0.20485100 |
| H | -3.93941600 | 2.79504200 | 0.33511400 |
| H | -4.14946000 | 2.01626000 | -1.25340500 |
| H | -5.55581700 | 2.23898800 | -0.17904300 |
| C | -3.95202400 | -0.85822900 | -2.37751300 |
| H | -3.41967500 | -1.77721200 | -2.08913900 |
| H | -4.32630400 | -0.98503400 | -3.40415500 |
| H | -3.22821200 | -0.03067100 | -2.36503700 |
| C | -5.94940800 | -2.00187900 | 1.42860900 |
| H | -5.85325300 | -2.93709900 | 1.99983300 |
| H | -6.24371800 | -1.20099900 | 2.12389700 |
| H | -6.75503200 | -2.13495600 | 0.69035100 |
| C | 2.79517200 | -0.71114200 | 0.08806000 |
| C | 1.40120900 | -0.67612800 | 0.16395500 |
| C | 0.75171700 | 0.55186700 | 0.19753600 |
| C | 1.45785000 | 1.74825700 | 0.15706000 |
| C | 2.85081100 | 1.71363800 | 0.08056000 |
| C | 3.52557600 | 0.48532900 | 0.04628700 |
| H | 3.32236200 | -1.66691700 | 0.06123500 |
| H | 0.83339700 | -1.61114200 | 0.19588200 |

| | | | |
|---|---|---|---|
| H | 0.93495300 | 2.70923700 | 0.18419600 |
| H | 3.43294800 | 2.63787100 | 0.04728100 |
| Br | -1.64368100 | 0.60702300 | 0.33094600 |
| C | 5.01451500 | 0.50112900 | -0.03454300 |
| O | 5.68223900 | 1.50946600 | -0.07756700 |
| O | 5.54213000 | -0.72108200 | -0.05457500 |
| C | 6.96762300 | -0.82333200 | -0.13179500 |
| H | 7.31408300 | -0.31478500 | -1.04502700 |
| H | 7.41146300 | -0.29903100 | 0.72883600 |
| C | 7.33210700 | -2.28738500 | -0.13853100 |
| H | 8.42514700 | -2.39355700 | -0.19689100 |
| H | 6.98572400 | -2.78438300 | 0.77995100 |
| H | 6.88878200 | -2.80051700 | -1.00500000 |

**TS$_{Cl\text{-}OMe}$**

Electronic energy: -1098.1696970 a.u.

Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -1097.8974003 a.u.

| | | | |
|---|---|---|---|
| N | -3.72966800 | -0.00813800 | 0.19066200 |
| C | -3.13495100 | -0.10613800 | -1.00879400 |
| H | -3.09180500 | 0.82483800 | -1.57391700 |
| C | -3.67559300 | 1.24708300 | 0.93950600 |
| H | -4.54135900 | 1.24968500 | 1.61858100 |
| H | -2.76941000 | 1.24014800 | 1.57287900 |
| C | -4.02082200 | -1.19596700 | 0.98799500 |
| H | -4.83192700 | -0.92747400 | 1.68109300 |
| H | -4.42281800 | -1.97392900 | 0.32500700 |
| C | -3.21531700 | -1.36306400 | -1.81375300 |
| H | -2.63998000 | -1.24203300 | -2.73987500 |
| H | -2.82494800 | -2.23854300 | -1.27648100 |

| | | | |
|---|---|---|---|
| H | -4.26593100 | -1.56871300 | -2.08643600 |
| C | -2.82410000 | -1.73213400 | 1.76614000 |
| H | -2.44441400 | -0.98792800 | 2.48238000 |
| H | -3.12286600 | -2.62659400 | 2.33304900 |
| H | -2.00052200 | -2.00257900 | 1.09006100 |
| C | -3.68706100 | 2.50615100 | 0.09303100 |
| H | -3.77430800 | 3.37622900 | 0.75968100 |
| H | -2.75879800 | 2.62577300 | -0.48413000 |
| H | -4.54298300 | 2.52080500 | -0.59934400 |
| C | 3.35769600 | 1.44907700 | 0.11357200 |
| C | 1.98422900 | 1.38726700 | -0.11687100 |
| C | 1.38701000 | 0.15370900 | -0.34781200 |
| C | 2.13071400 | -1.01235600 | -0.35229300 |
| C | 3.51369000 | -0.96044900 | -0.12192000 |
| C | 4.13059100 | 0.27560300 | 0.11308300 |
| H | 3.85826200 | 2.40315100 | 0.29875900 |
| H | 1.39132200 | 2.30740900 | -0.11345600 |
| H | 1.65410900 | -1.98116000 | -0.53381400 |
| H | 4.09311400 | -1.88520800 | -0.12775500 |
| Cl | -0.78850700 | 0.04638900 | -0.67950900 |
| O | 5.45213100 | 0.43331500 | 0.34700200 |
| C | 6.28146300 | -0.70283900 | 0.36408600 |
| H | 7.29881100 | -0.34620800 | 0.56959200 |
| H | 5.98781100 | -1.41343400 | 1.15582500 |
| H | 6.27859700 | -1.22806600 | -0.60652000 |

**TS$_{Cl\text{-}COOEt}$**

Electronic energy: -1250.8637397 a.u.

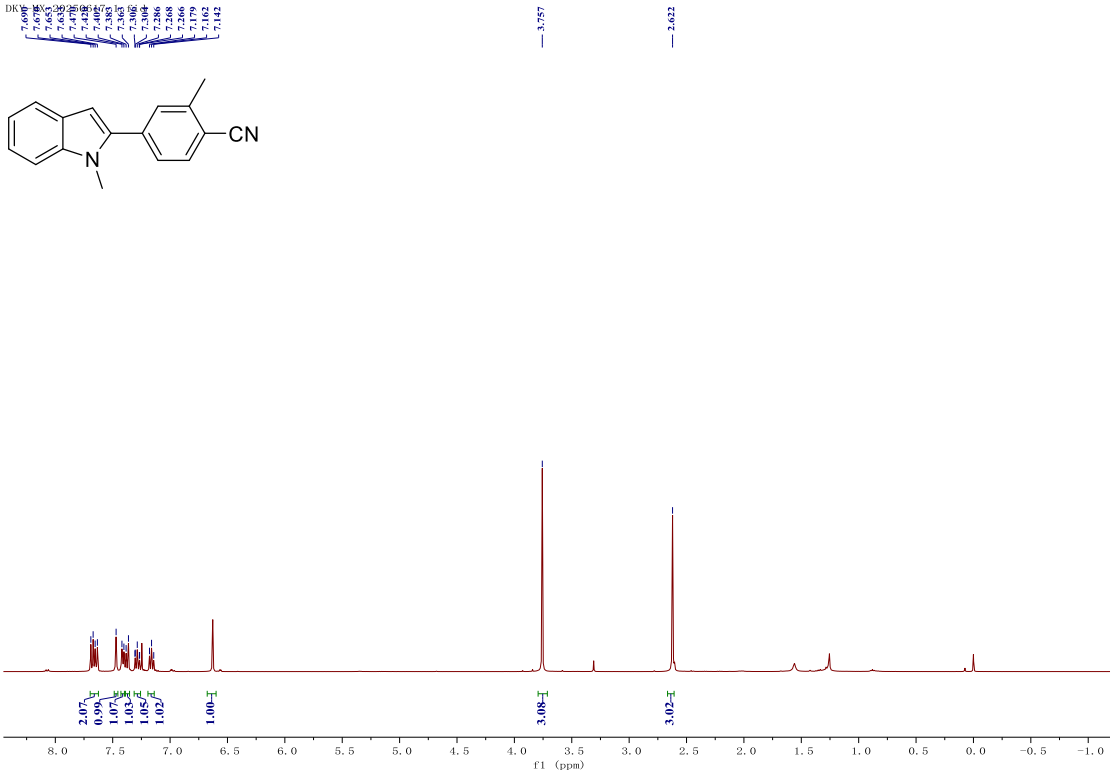
Gibbs free energy at 298 K (ωB97X-D/def2-TZVPP/SMD(MeCN)): -1250.5573838 a.u.

| | | | |
|---|---|---|---|
| N | -4.66506600 | 0.31893700 | -0.09826800 |
| C | -4.20739500 | -0.90139500 | 0.20173300 |
| H | -4.18853000 | -1.59399100 | -0.64282100 |
| C | -4.65410100 | 0.76165800 | -1.48925200 |
| H | -4.29515100 | 1.80229800 | -1.51529300 |
| H | -3.91191900 | 0.16029900 | -2.03383000 |
| C | -4.93291500 | 1.32876100 | 0.91860400 |
| H | -5.65610800 | 2.03779400 | 0.48901500 |
| H | -5.43480300 | 0.85267200 | 1.77251000 |
| C | -4.38380800 | -1.48911600 | 1.56307500 |
| H | -3.87797000 | -2.46097700 | 1.61539400 |
| H | -3.97957800 | -0.84505500 | 2.35652900 |
| H | -5.45823200 | -1.64782300 | 1.76638000 |
| C | -3.68041000 | 2.06499000 | 1.37844800 |
| H | -3.18416600 | 2.56729400 | 0.53383800 |
| H | -3.94817000 | 2.83010200 | 2.12248800 |
| H | -2.95808700 | 1.37070900 | 1.83099900 |
| C | -6.02243000 | 0.65465800 | -2.14428700 |
| H | -5.97526300 | 1.01290500 | -3.18362900 |
| H | -6.36918400 | -0.39005400 | -2.15501400 |
| H | -6.76830100 | 1.26176100 | -1.60835600 |
| C | 2.38182500 | 0.58452500 | 0.07156800 |
| C | 0.98849700 | 0.51320700 | 0.12379300 |
| C | 0.37184900 | -0.72640800 | 0.02228300 |
| C | 1.10031000 | -1.89870200 | -0.12924900 |
| C | 2.49260100 | -1.82578100 | -0.18110900 |
| C | 3.13870200 | -0.58596900 | -0.08138900 |
| H | 2.88723100 | 1.54909300 | 0.14950000 |
| H | 0.39644400 | 1.42586400 | 0.24278300 |
| H | 0.59619100 | -2.86665800 | -0.20752900 |

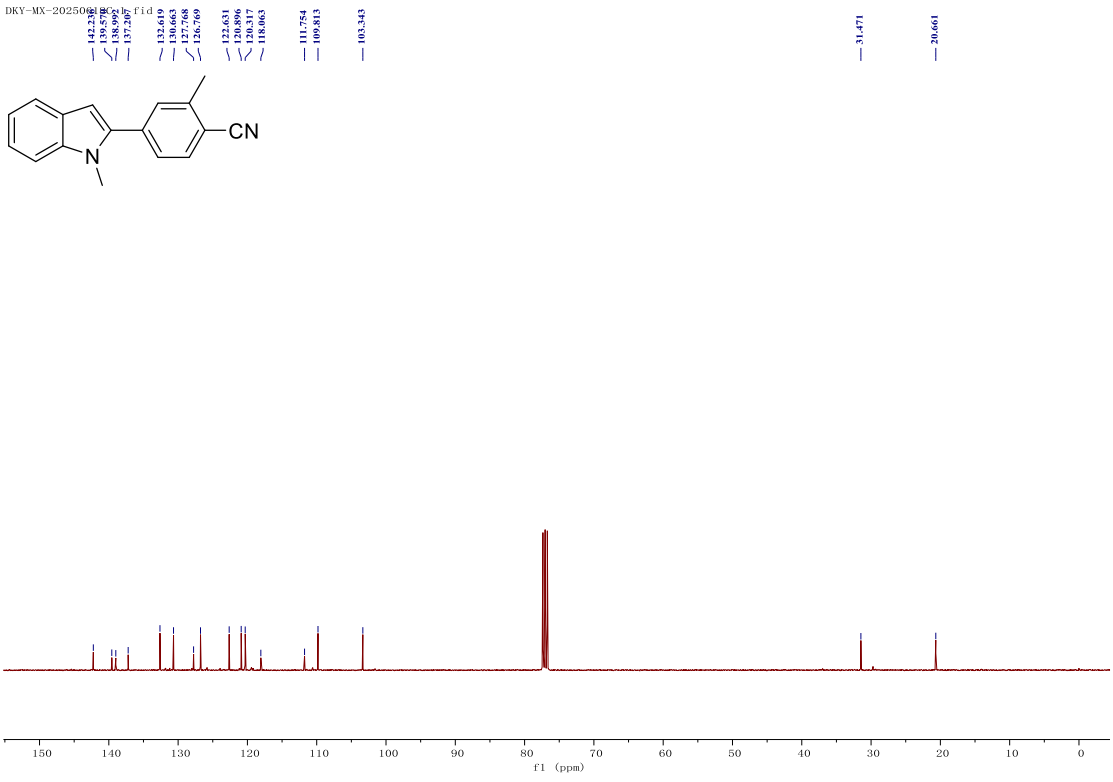
| | | | |
|---|---|---|---|
| H | 3.09560300 | -2.72920100 | -0.29982500 |
| Cl | -1.80577700 | -0.82616400 | 0.09562100 |
| C | 4.62922900 | -0.56216900 | -0.14326200 |
| O | 5.31858800 | -1.54789800 | -0.27350700 |
| O | 5.12883900 | 0.66691000 | -0.03981100 |
| C | 6.55281300 | 0.80657400 | -0.08870600 |
| H | 6.99851900 | 0.21297700 | 0.72461100 |
| H | 6.92009300 | 0.39358400 | -1.04112100 |
| C | 6.88428200 | 2.27217200 | 0.04632200 |
| H | 7.97520000 | 2.40654400 | 0.01133600 |
| H | 6.43837600 | 2.85478400 | -0.77360800 |
| H | 6.51775900 | 2.67318500 | 1.00308400 |

# 7. NMR Spectra of Compounds of 3-33

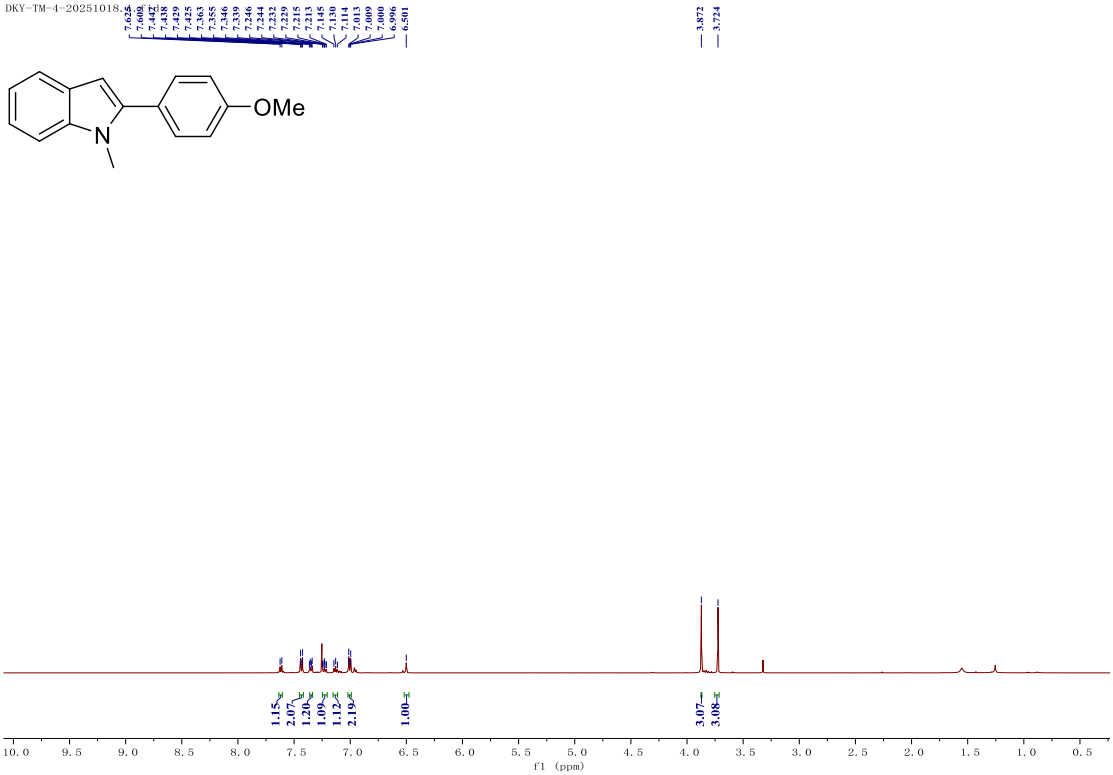
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 3



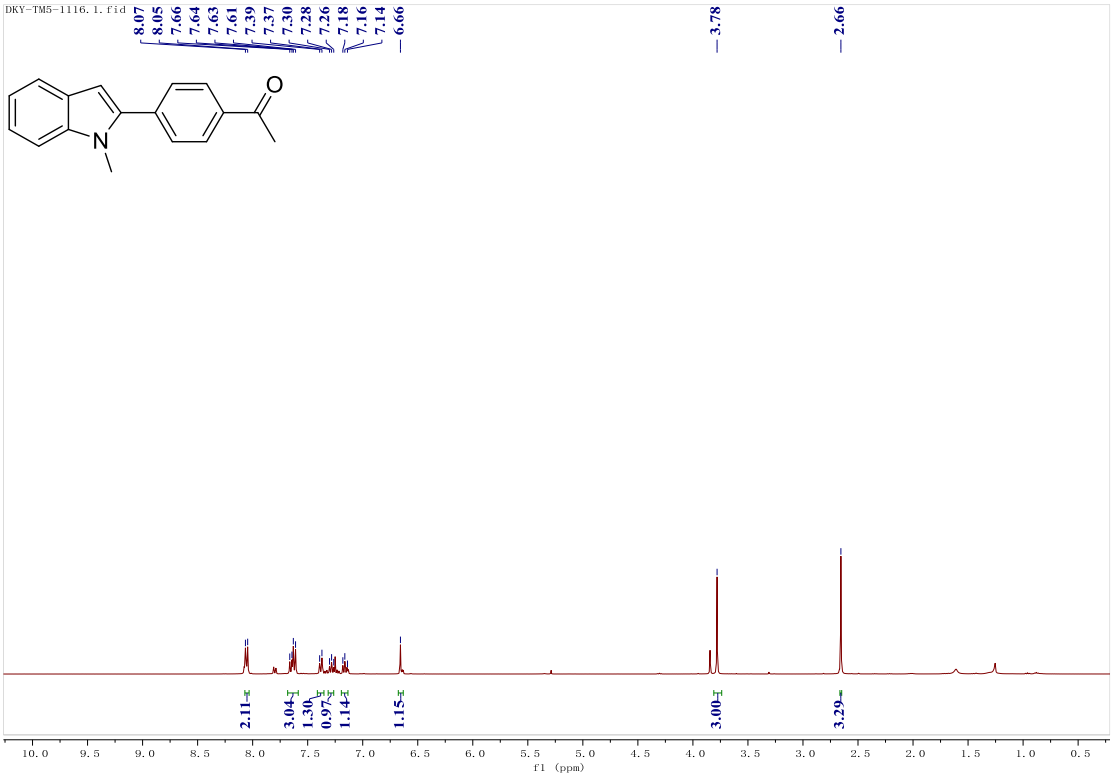

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 3



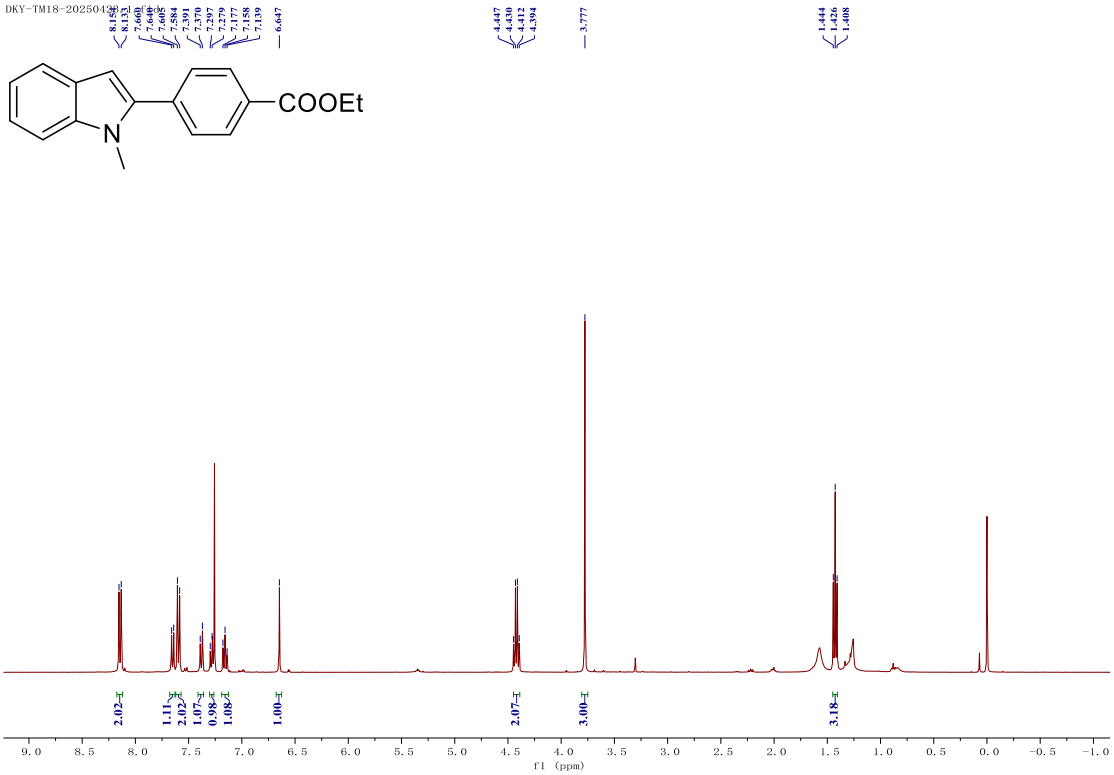
## $^1$H NMR (400MHz, $CDCl_3$) spectrum of 4



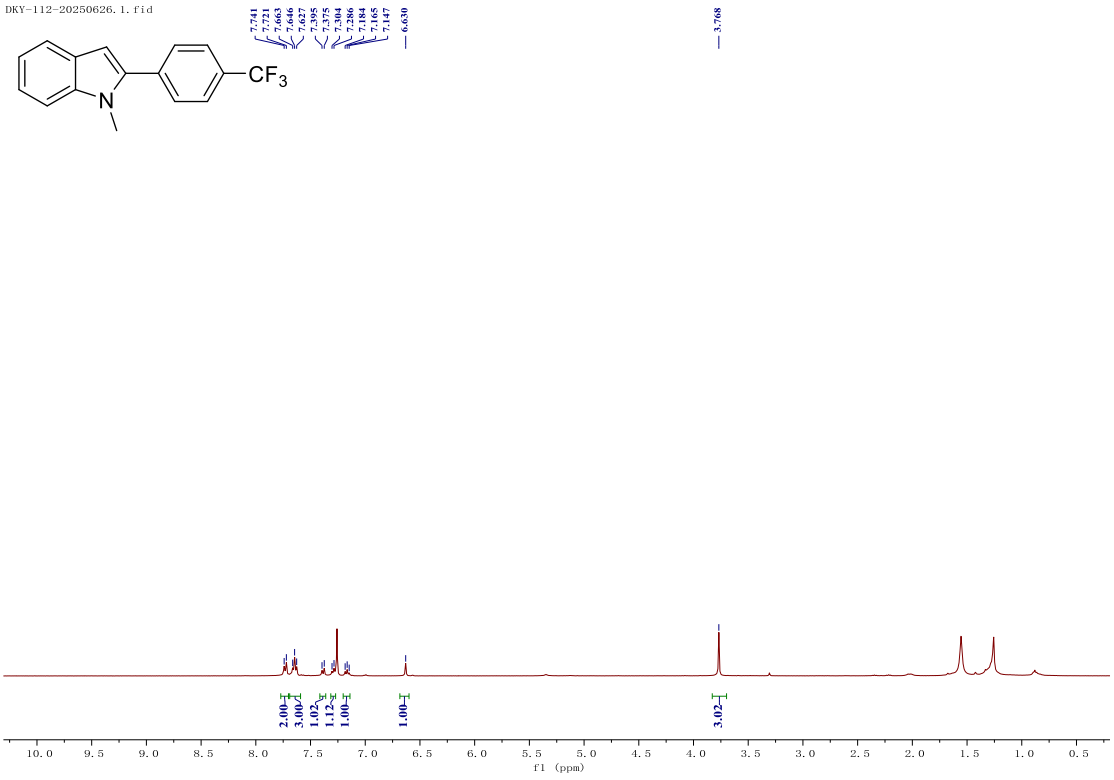

## $^1$H NMR (400MHz, CDCl3) spectrum of 5



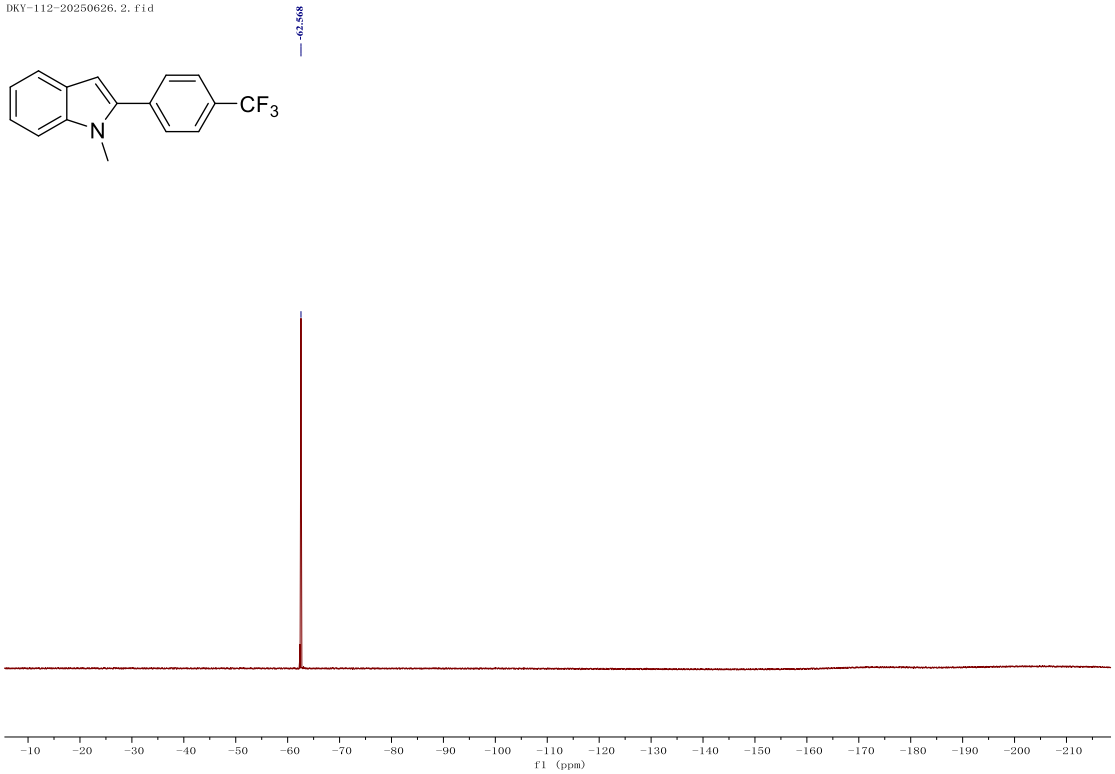
## $^1$H NMR (400MHz, $CDCl_3$) spectrum of 6



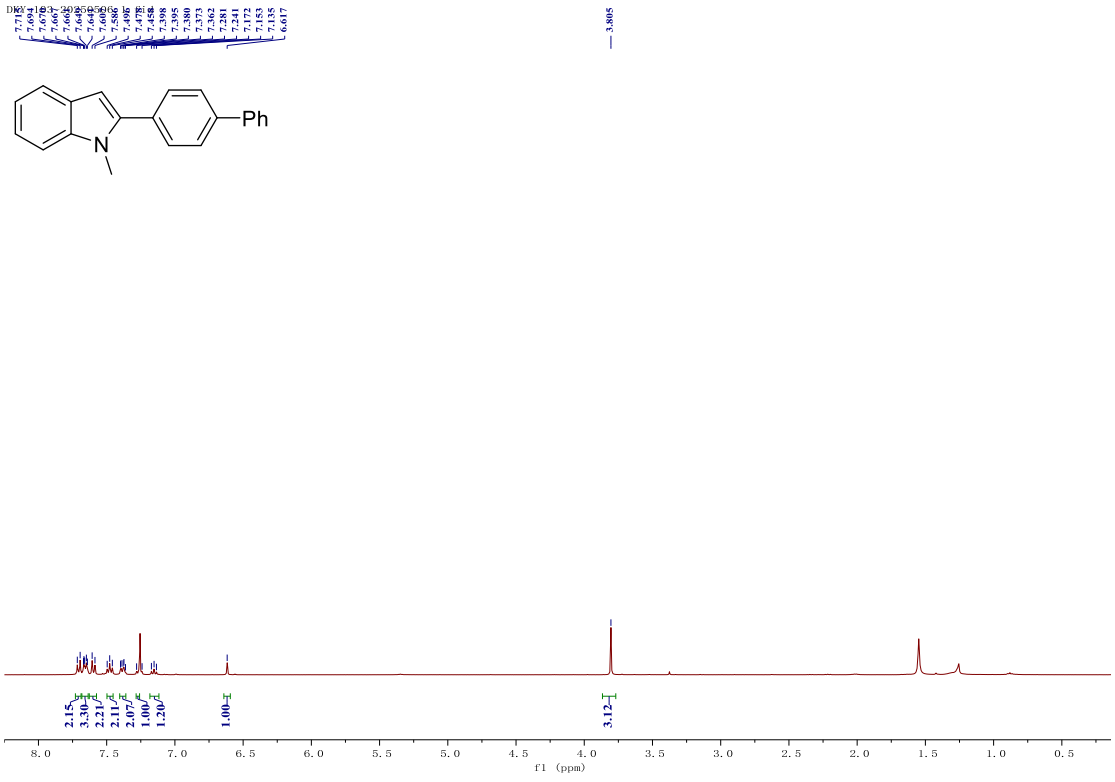

## $^1$H NMR (400MHz, $CDCl_3$) spectrum of 7



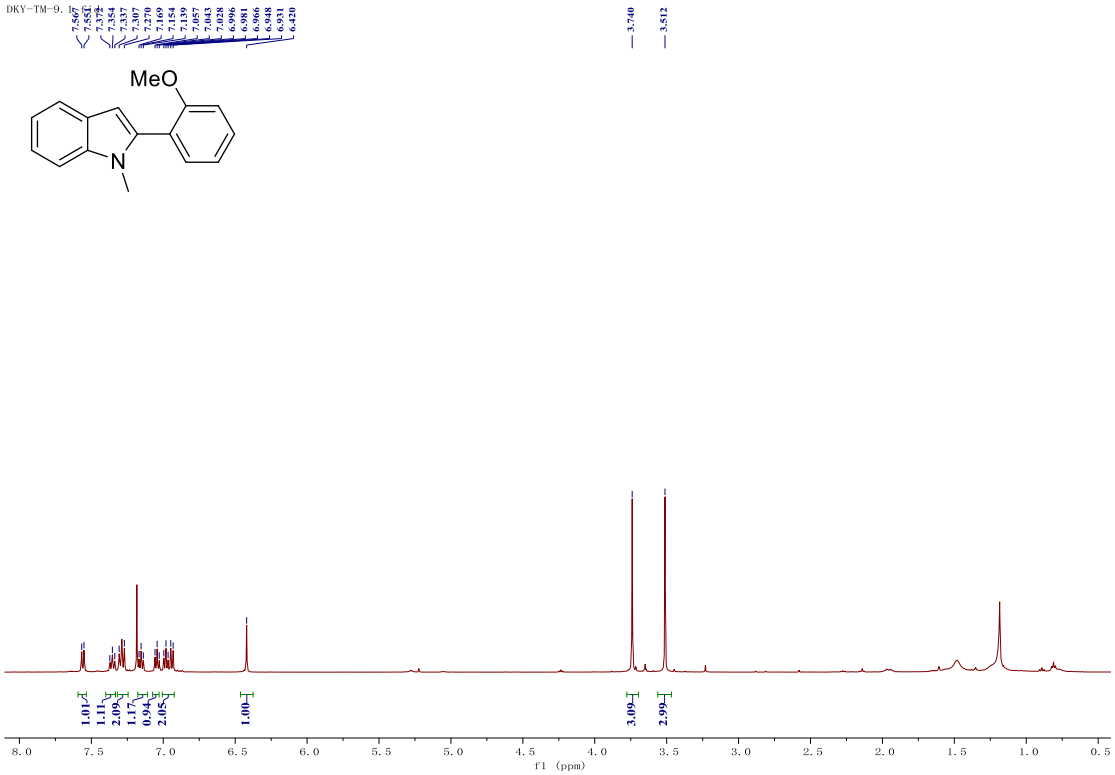
## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 7



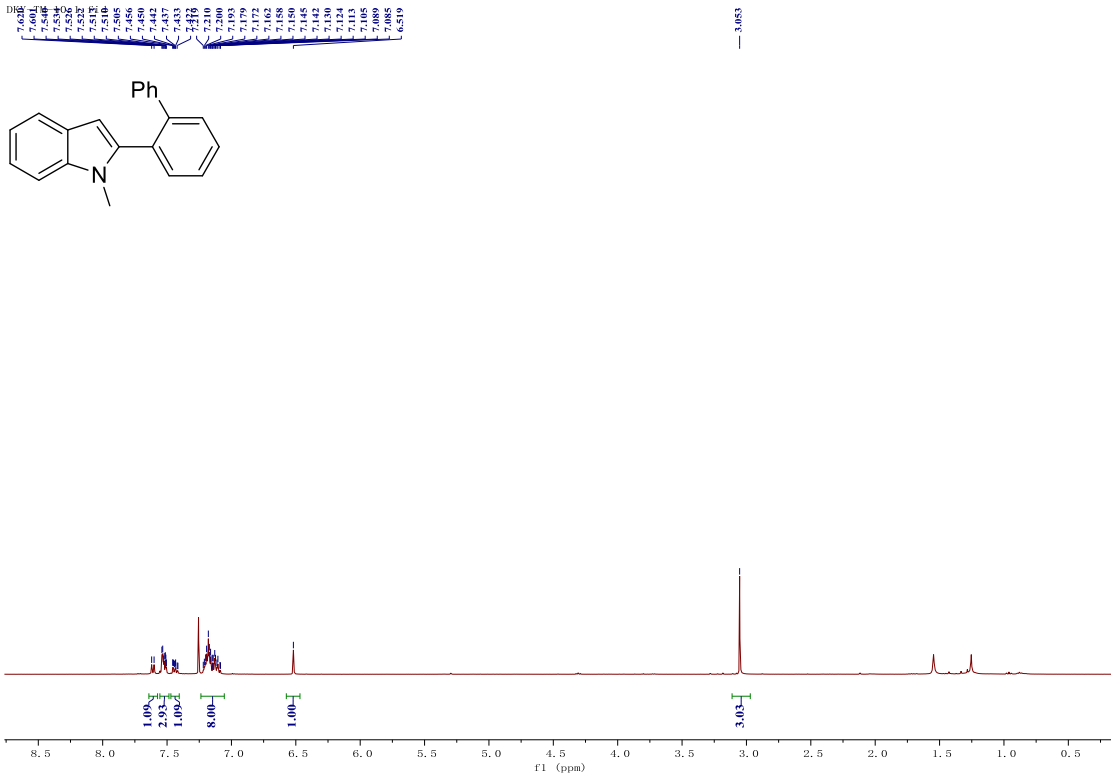

## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 8



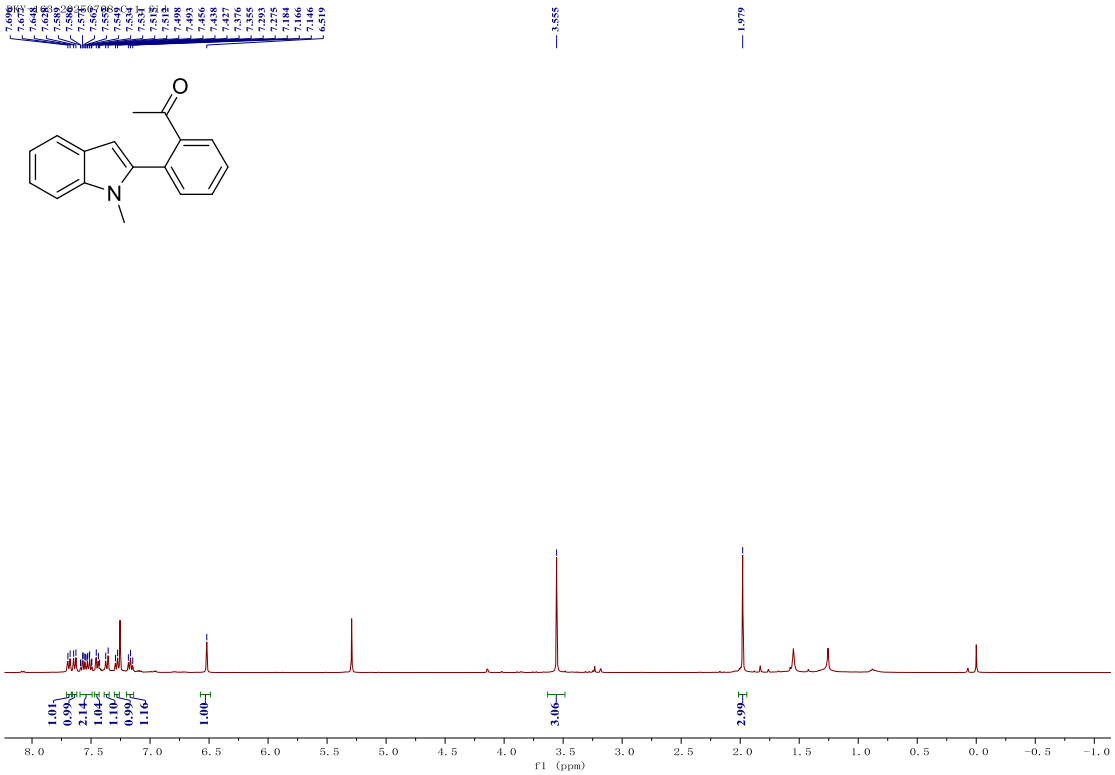
## $^1$H NMR (400MHz, $CDCl_3$) spectrum of 9



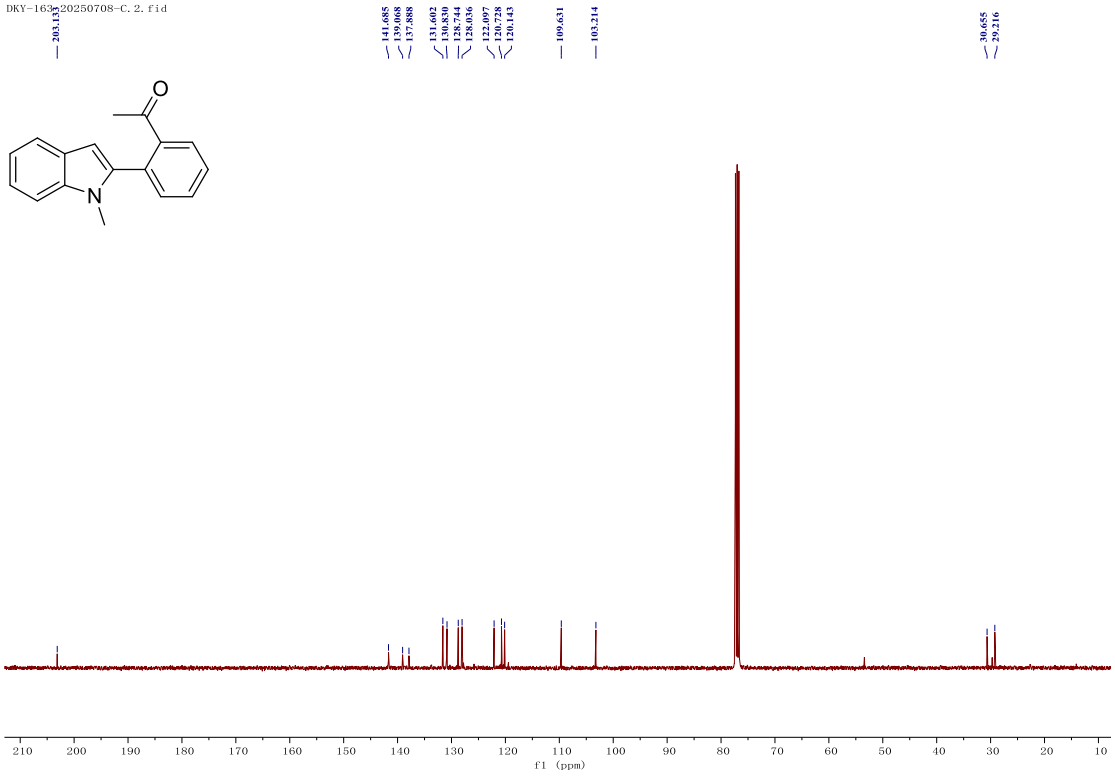

## $^1$H NMR (400MHz, $CDCl_3$) spectrum of 10



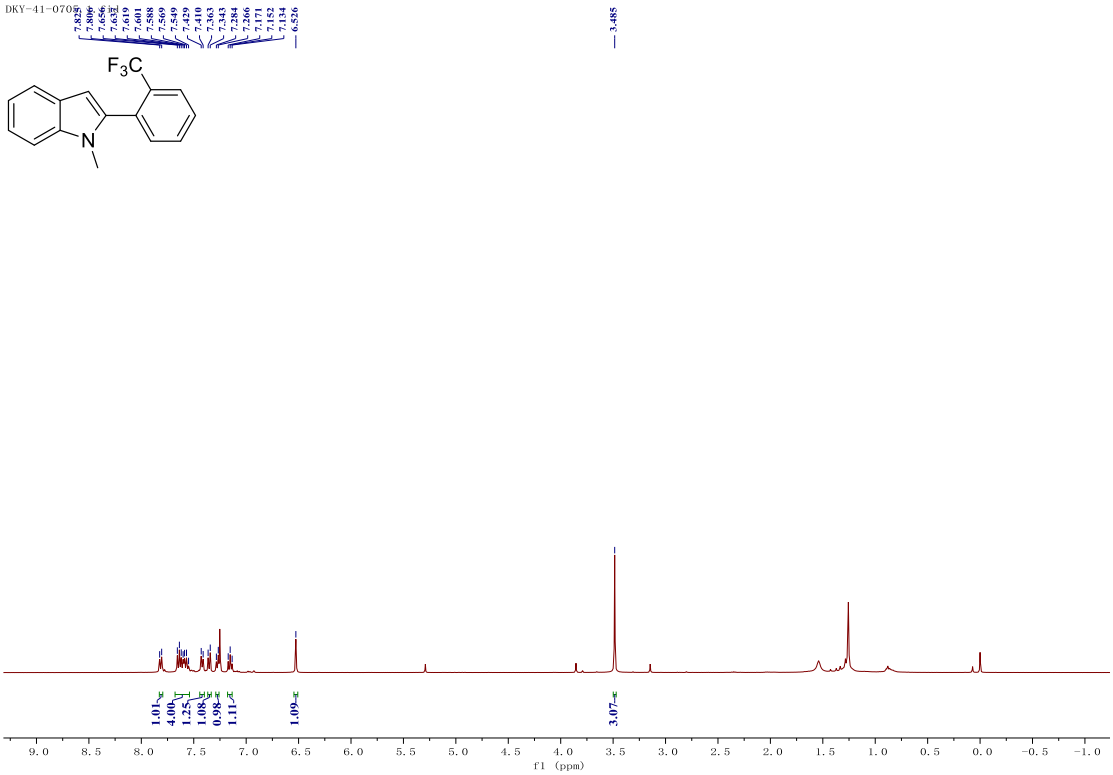
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 11



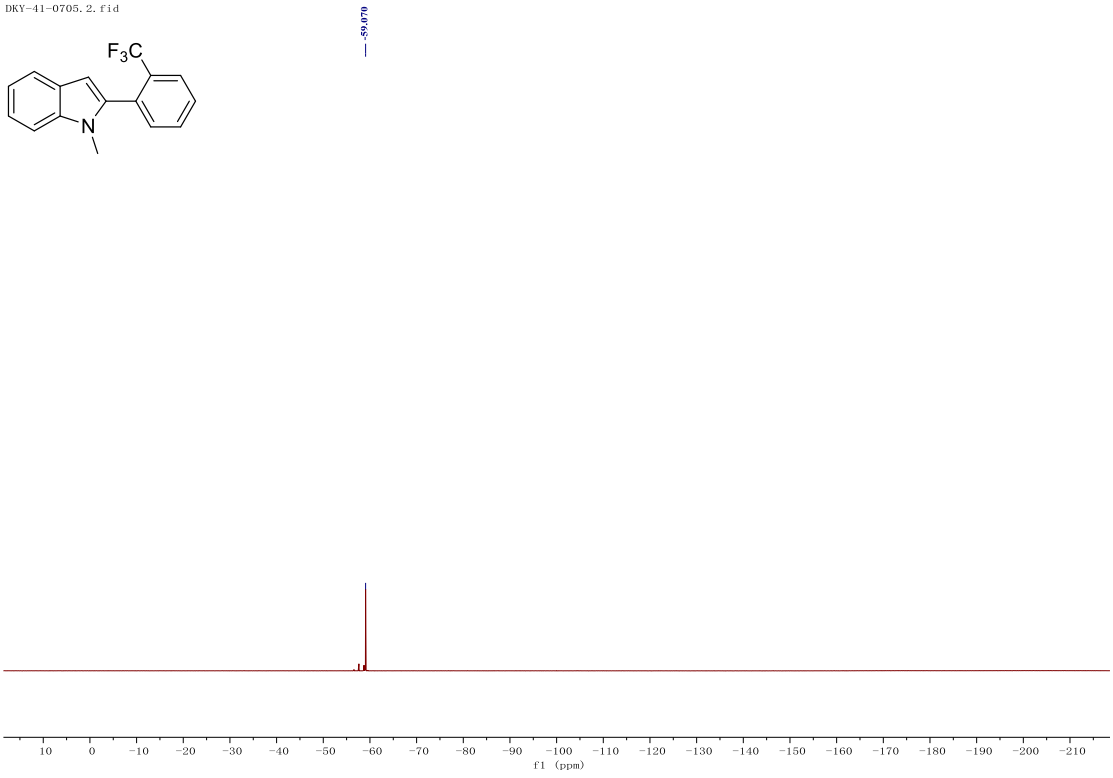

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 11



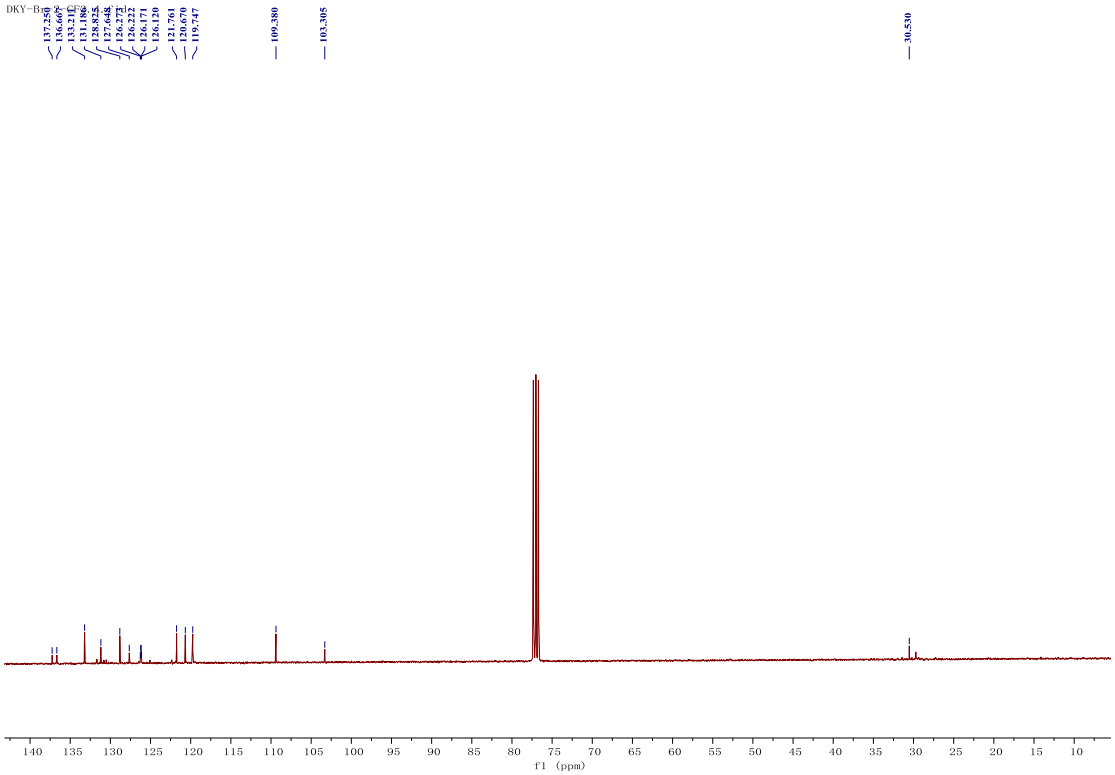
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 12



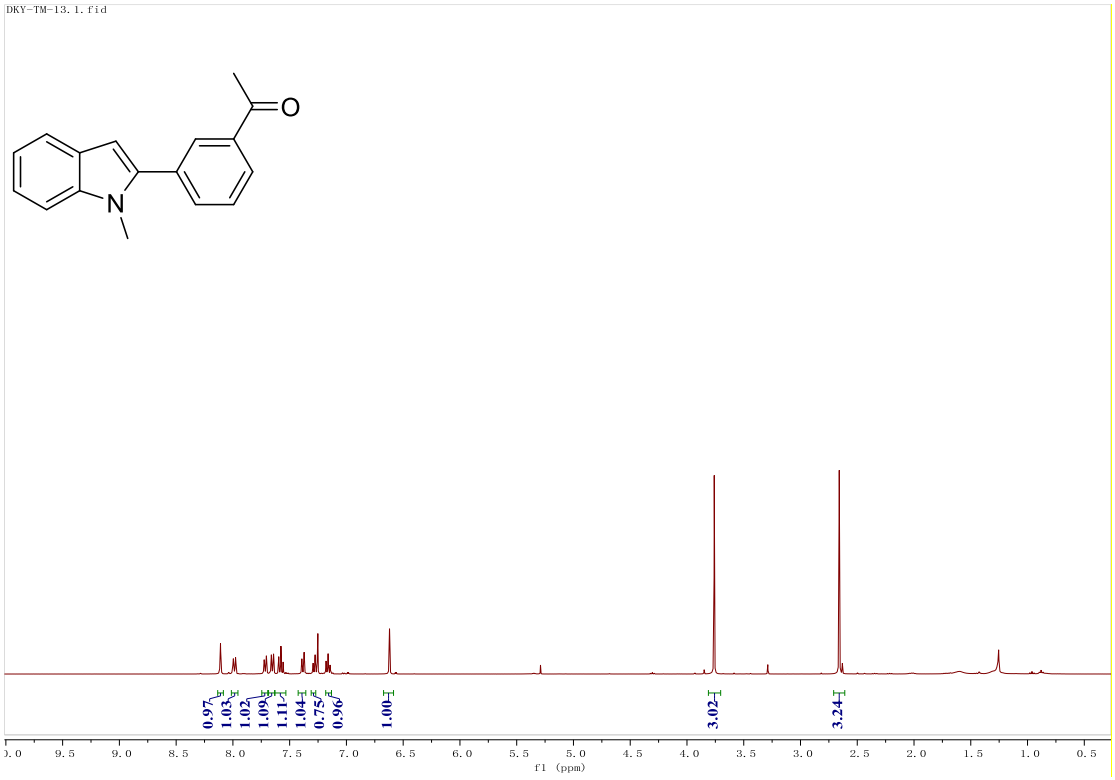

## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 12



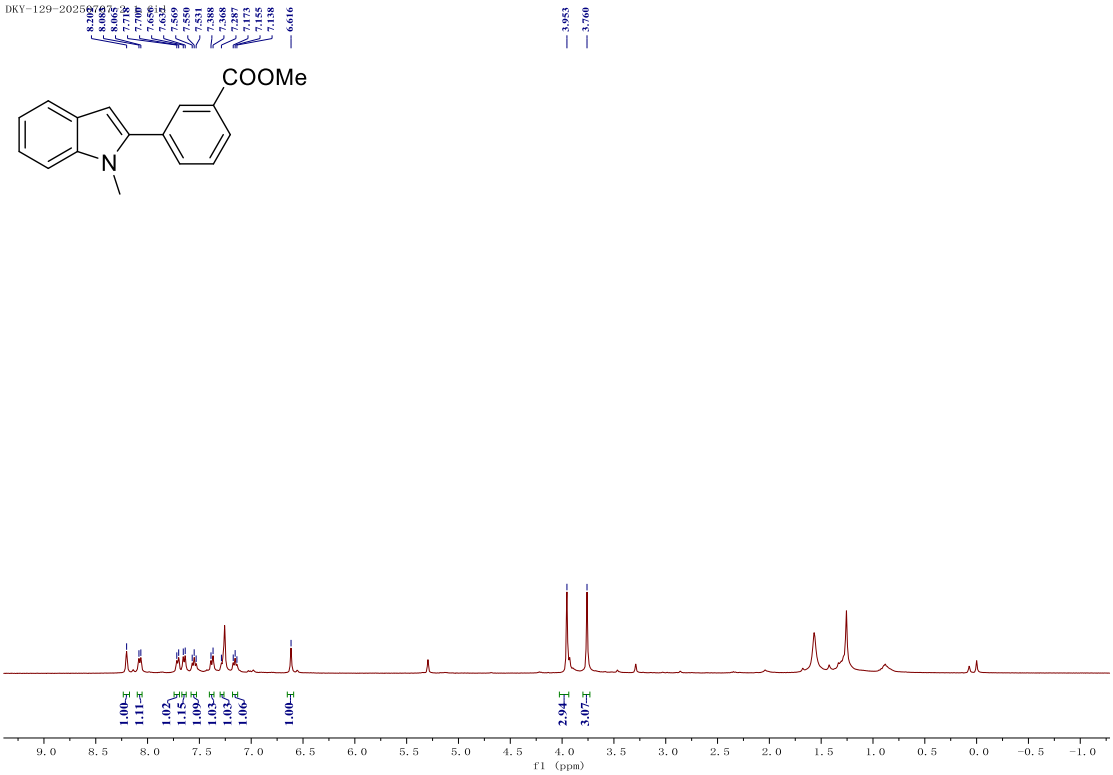
## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 12



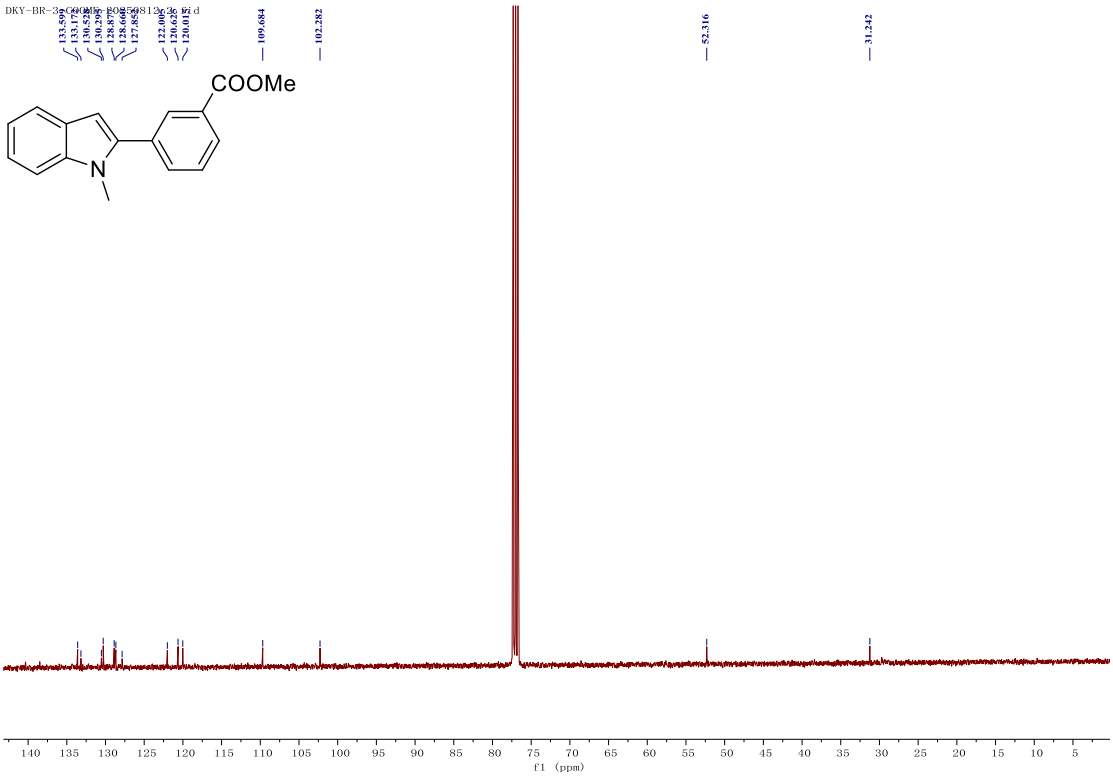

## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 13



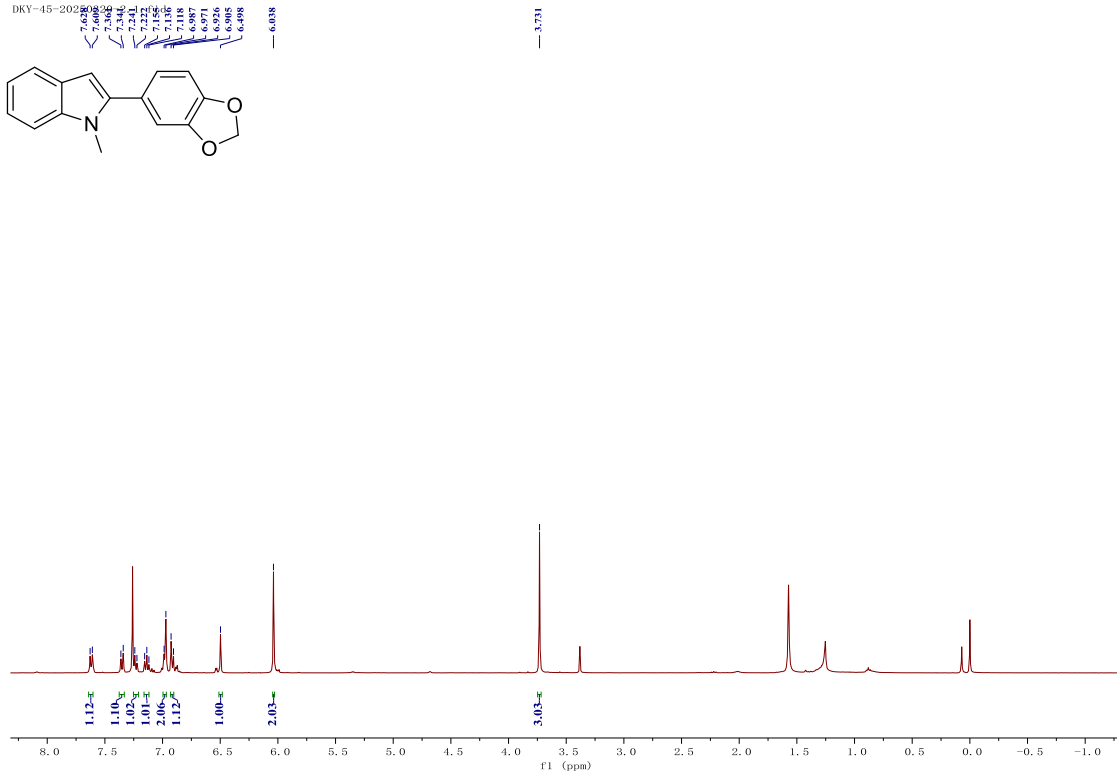
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 14



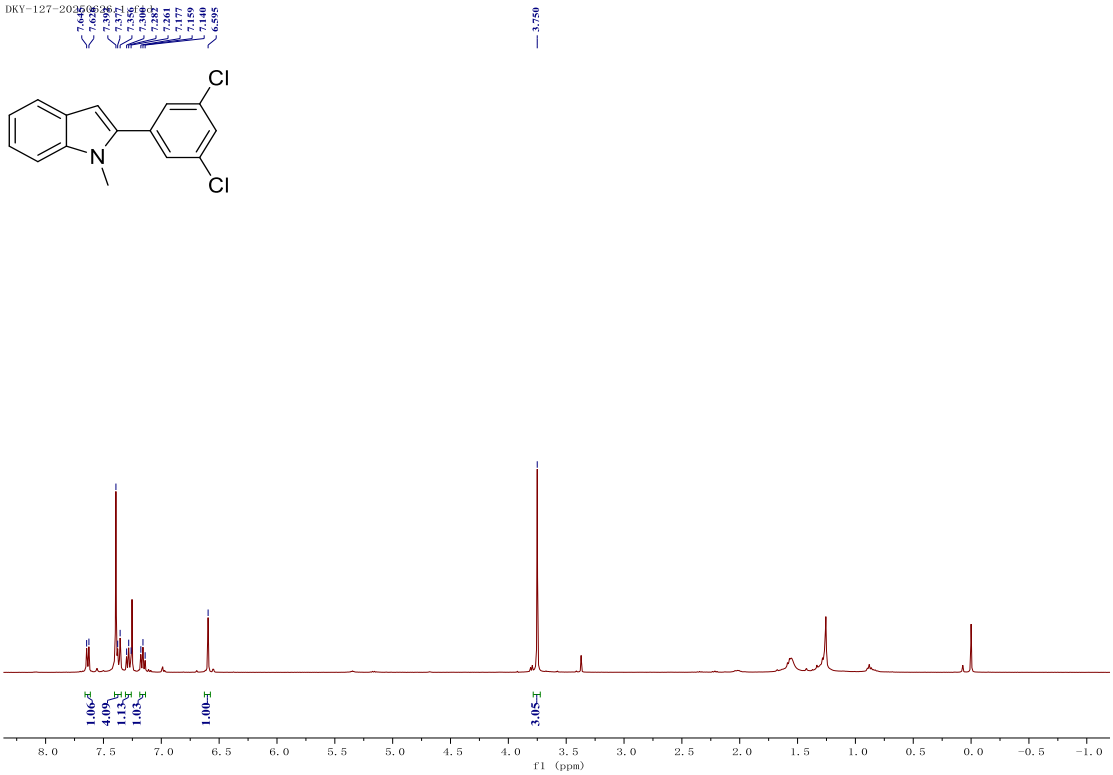

## $^{19}$C NMR (101MHz, $CDCl_3$) spectrum of 14



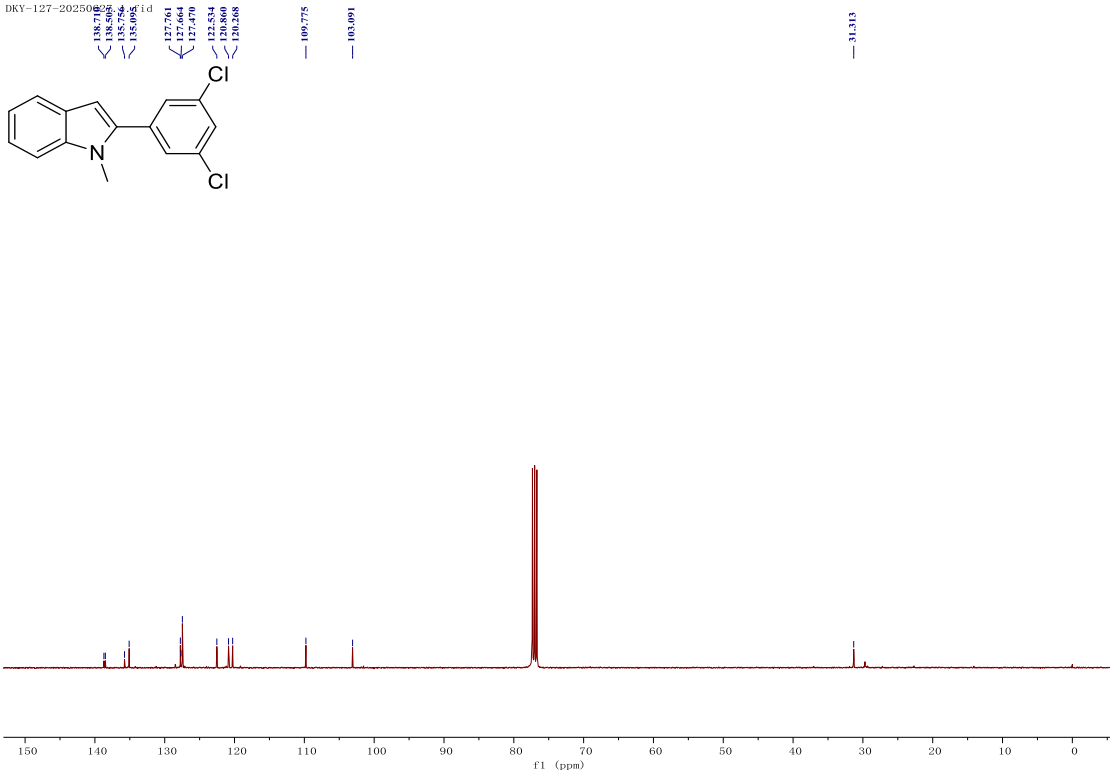
## $^{1}H$ NMR (400MHz, $CDCl_3$) spectrum of 15



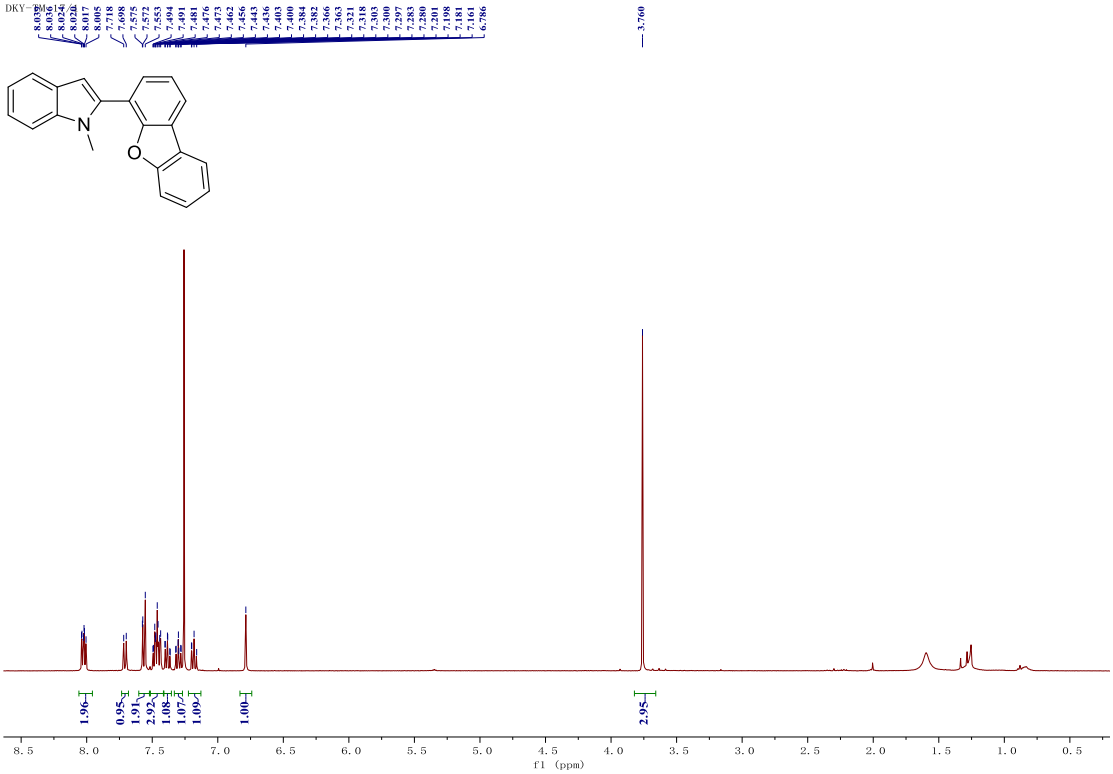
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 16



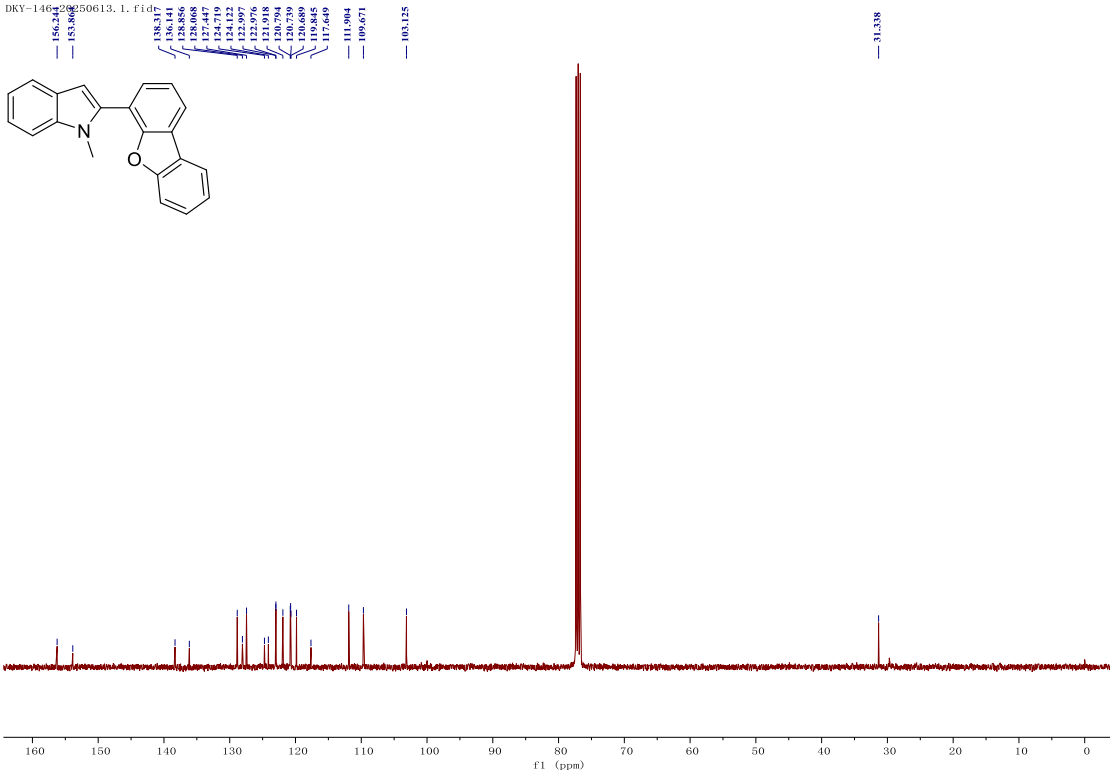

## $^{19}$C NMR (101MHz, $CDCl_3$) spectrum of 16



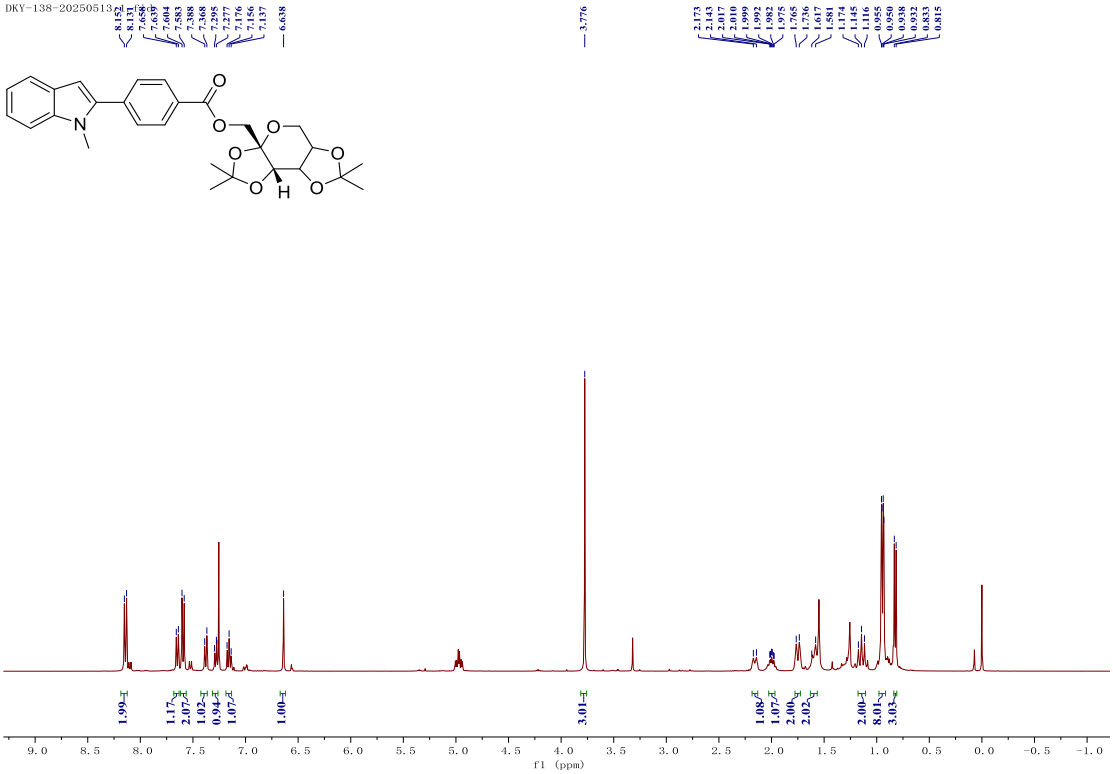
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 17



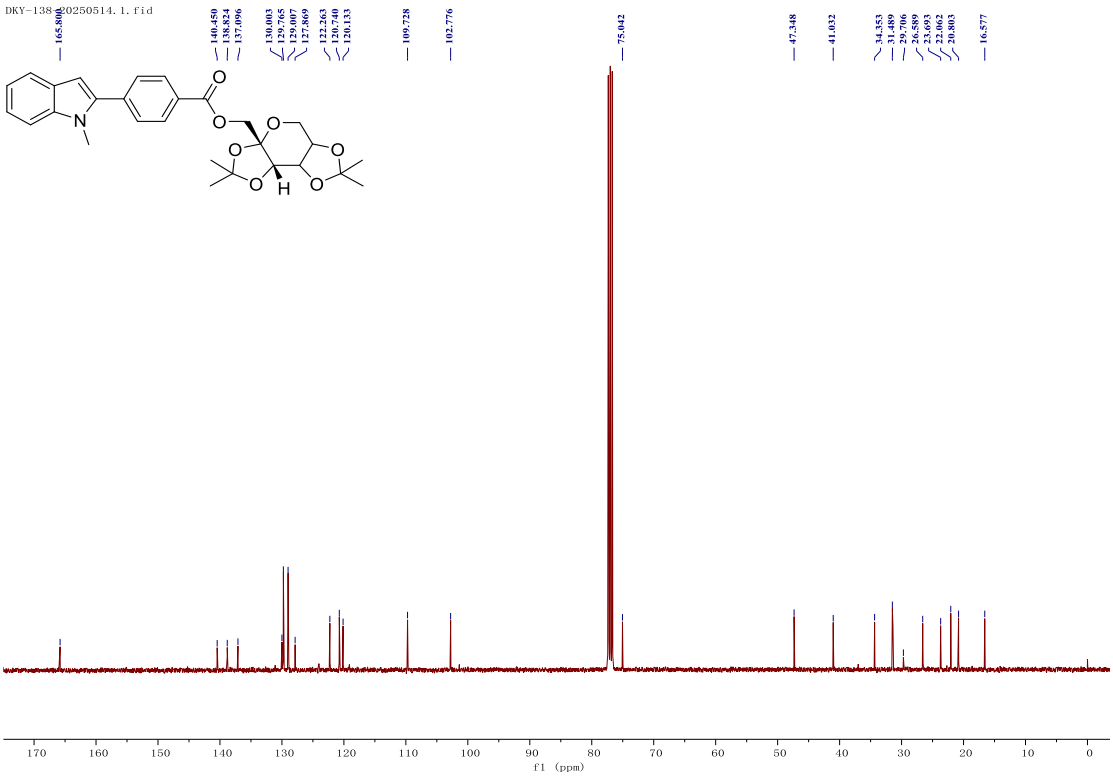

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 17



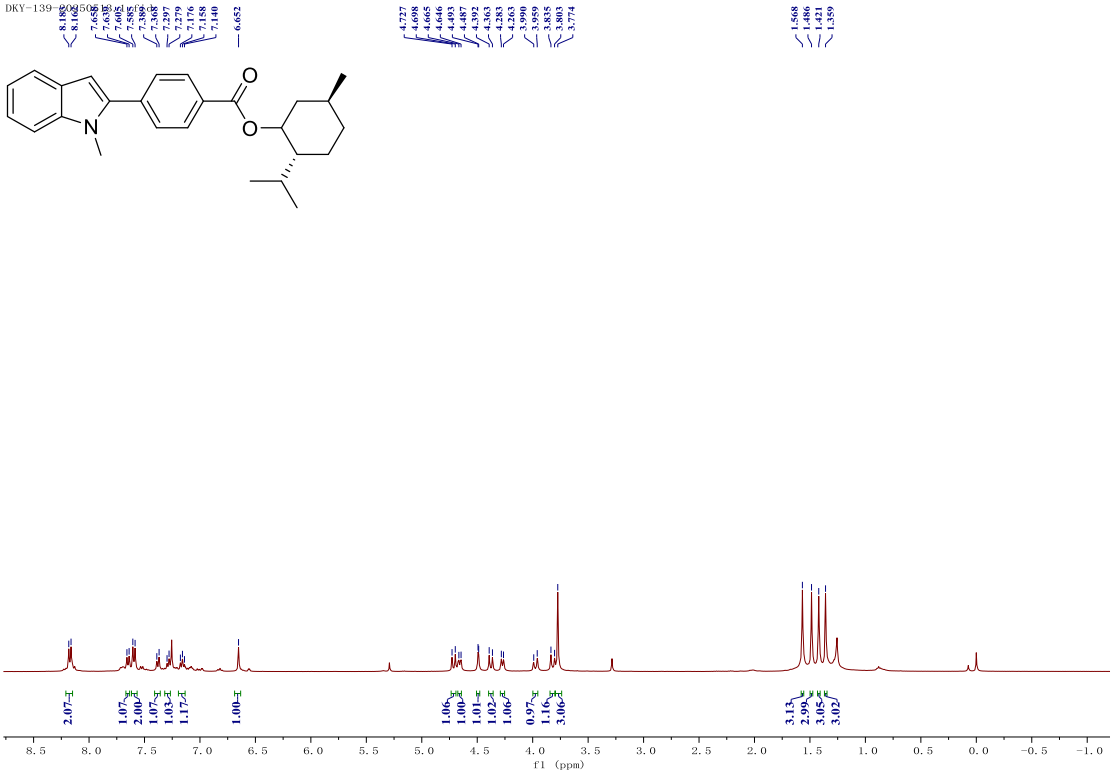
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 18



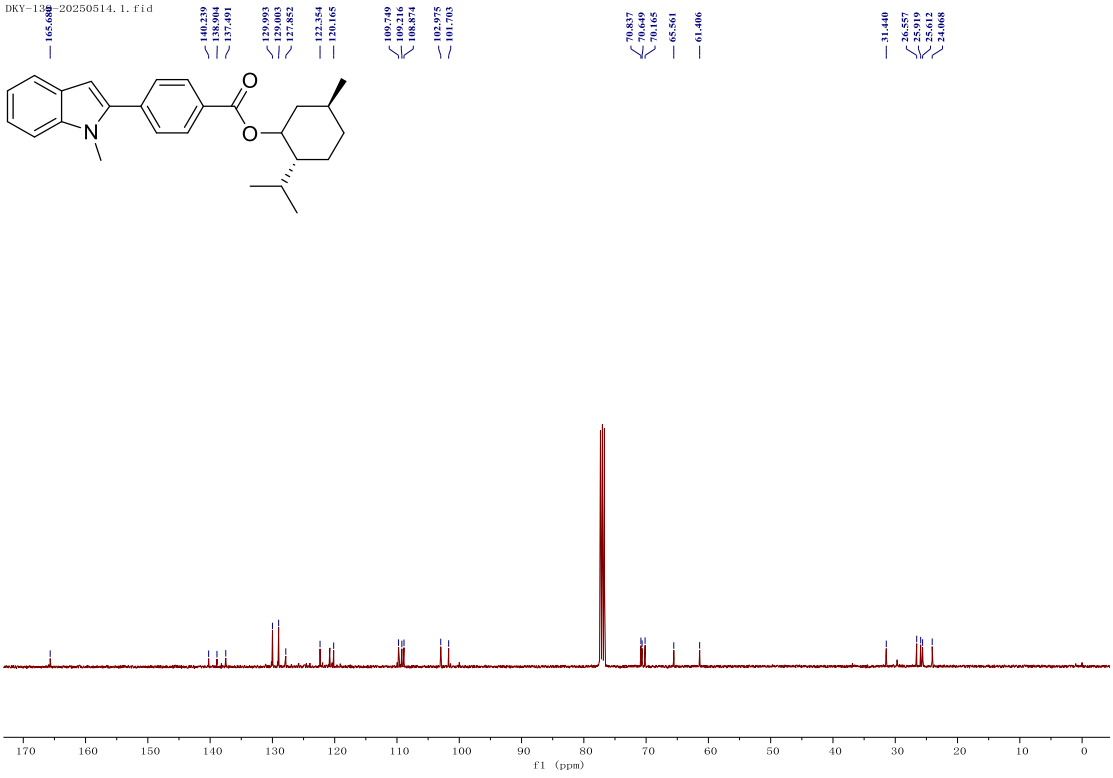

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 18



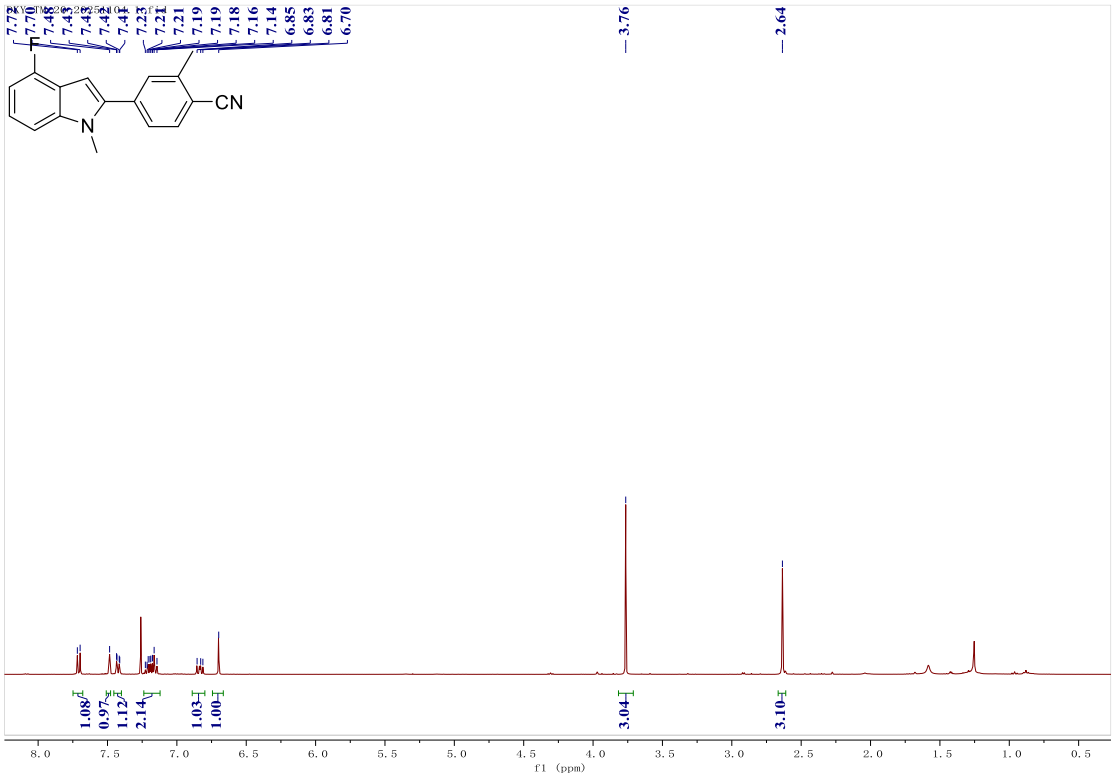
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 19



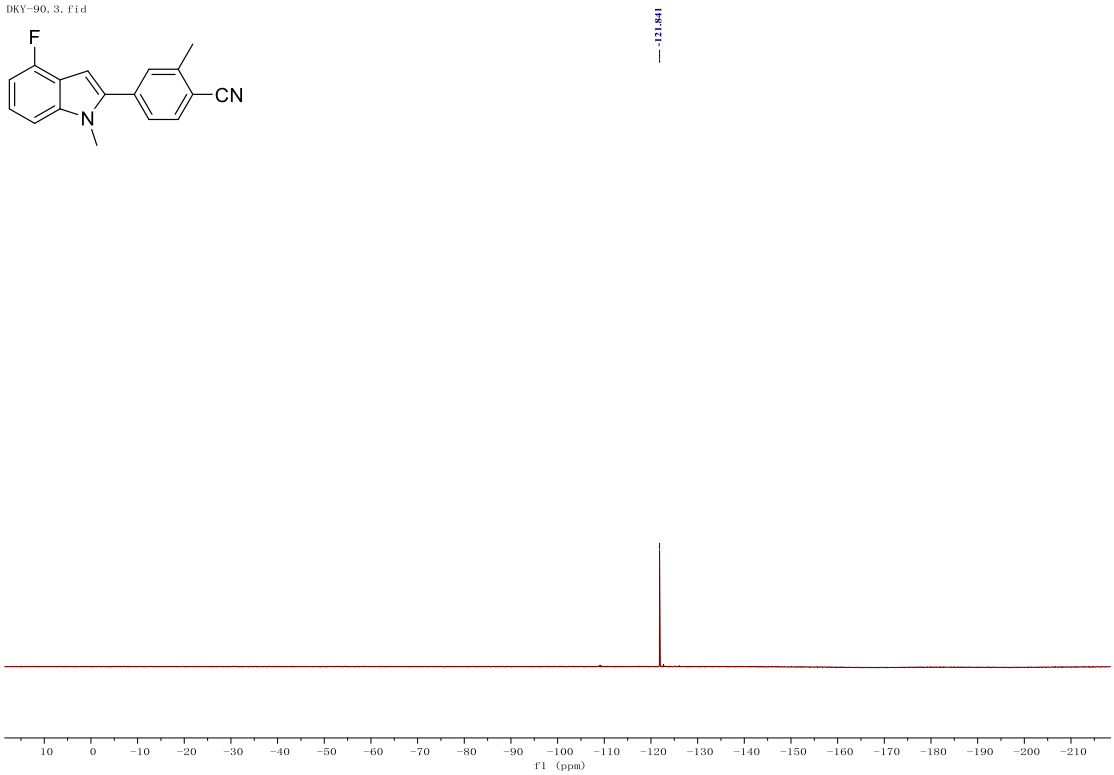

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 19



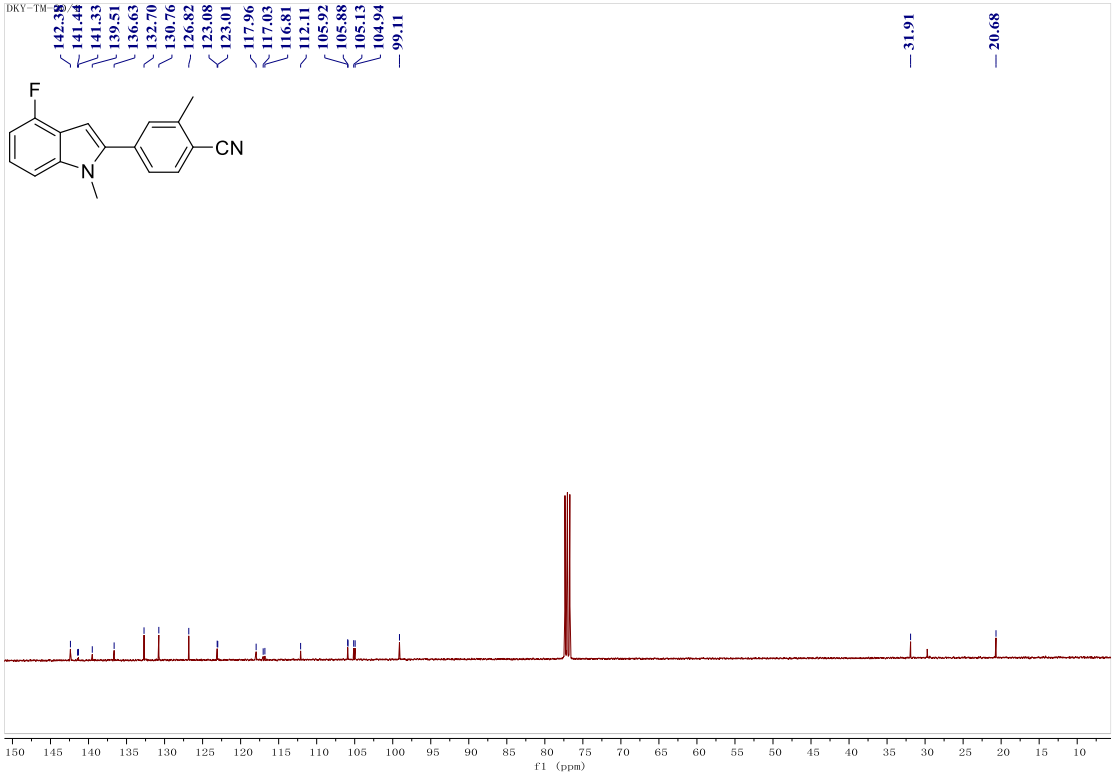
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 20



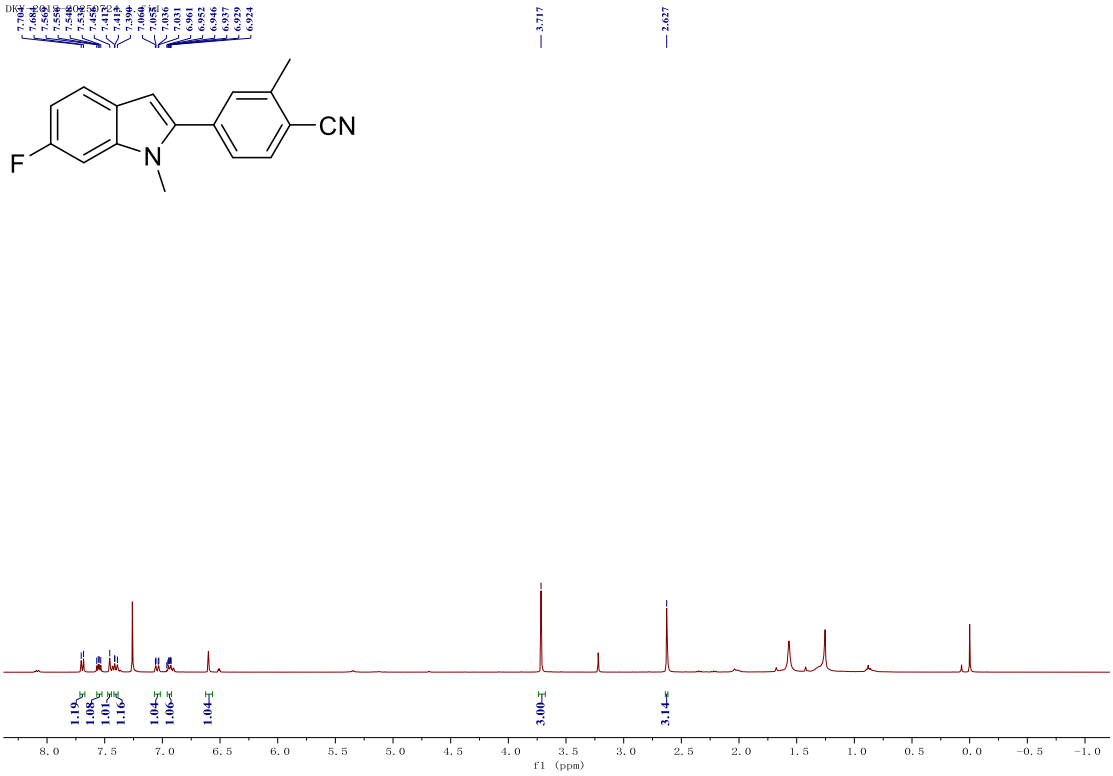

## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 20



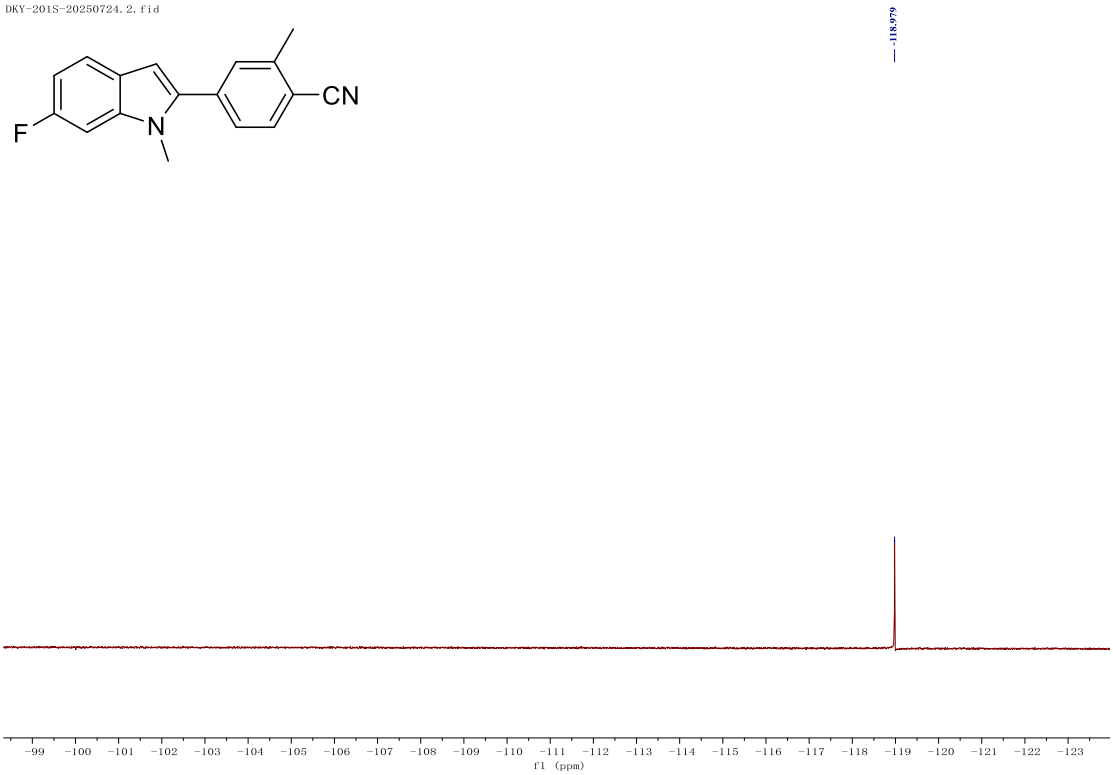
## $^{13}C$ NMR (101MHz, $CDCl_3$) spectrum of 20



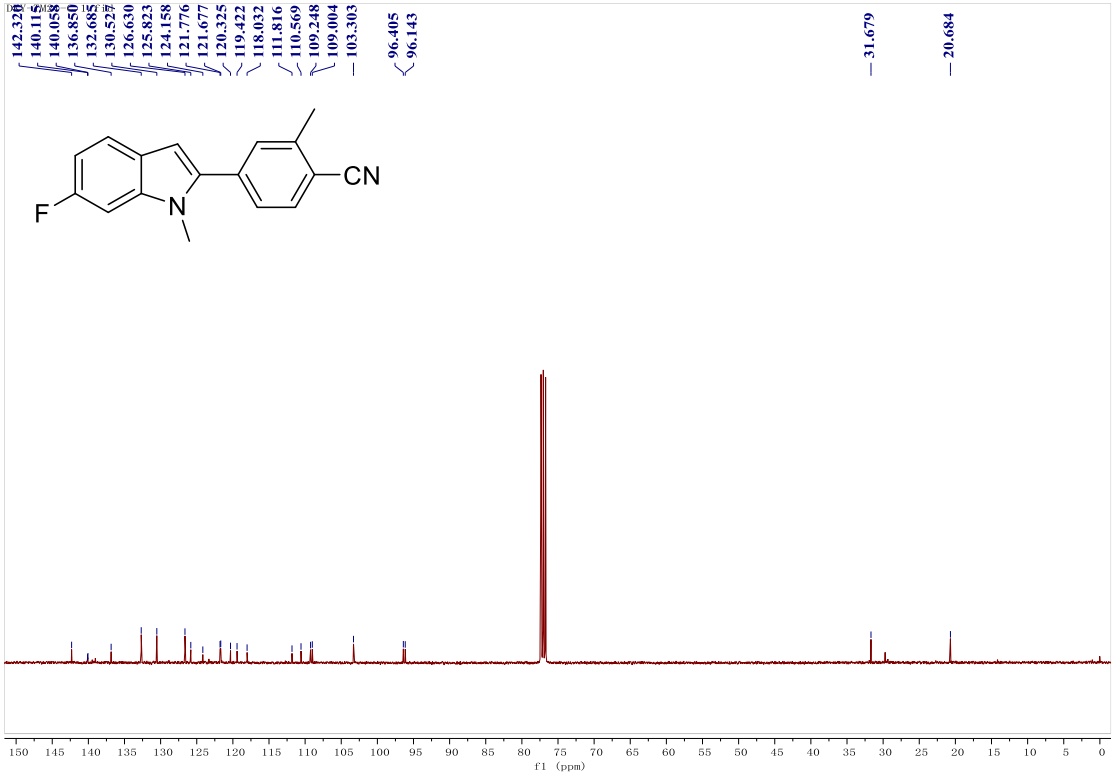
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 21



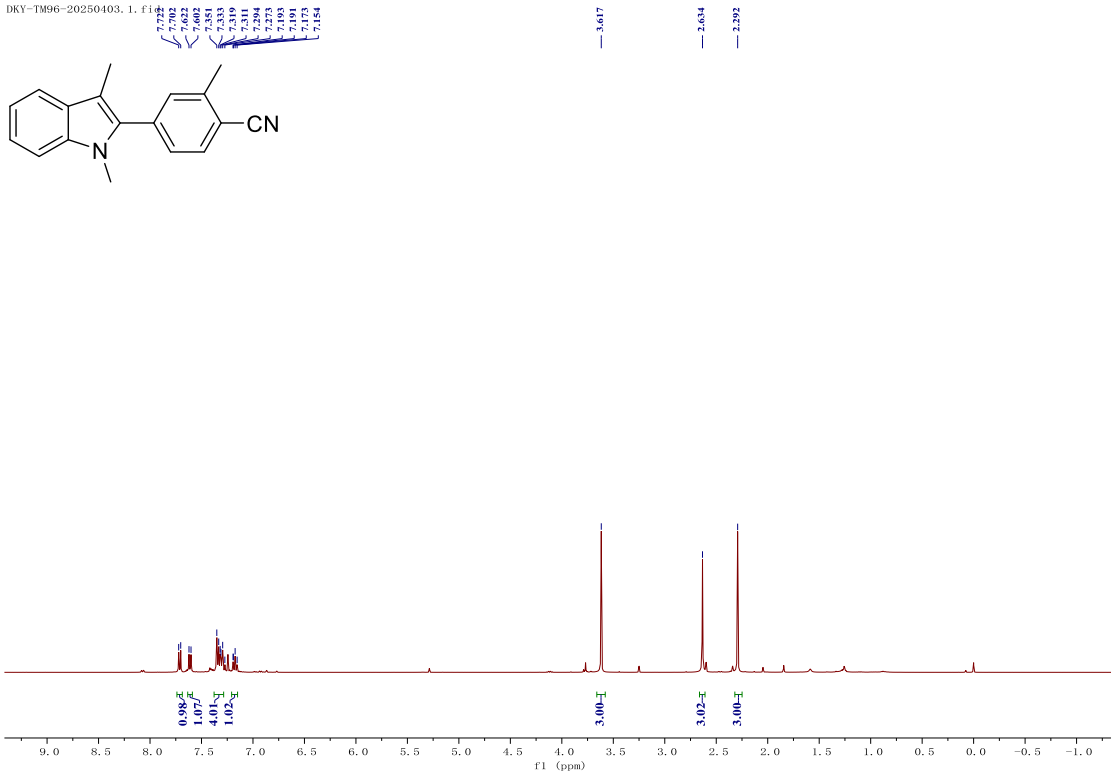

## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 21



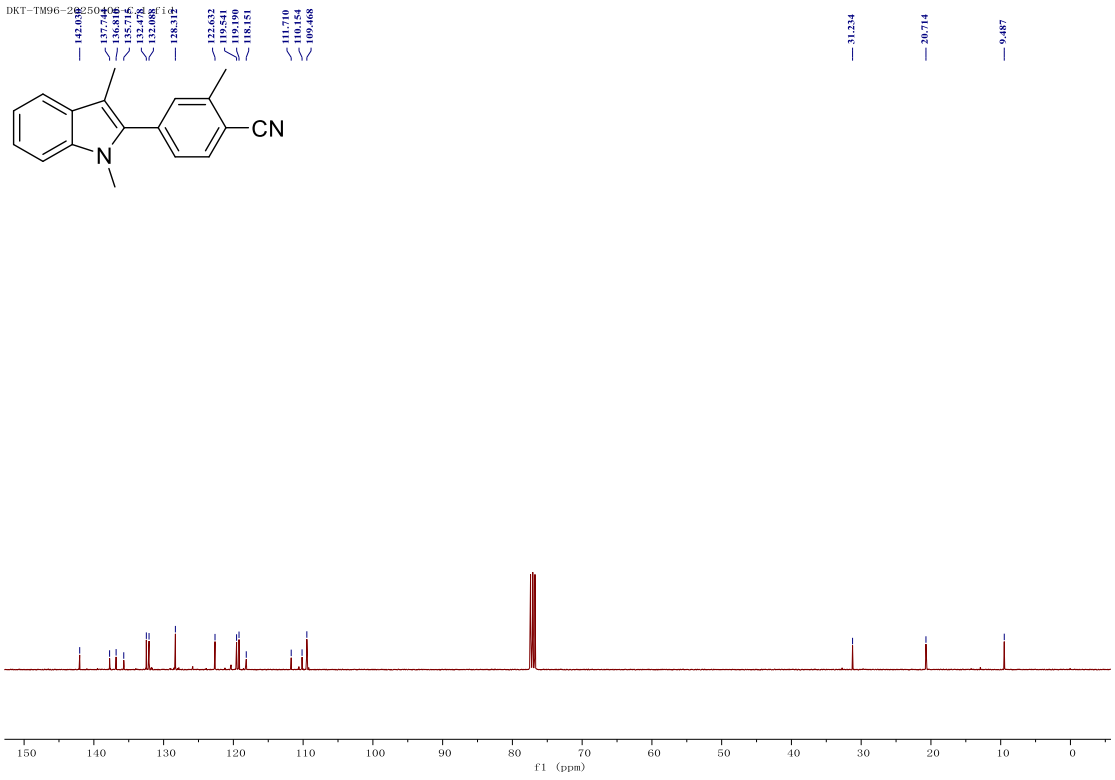
## $^{13}C$ NMR (101MHz, $CDCl_3$) spectrum of 21



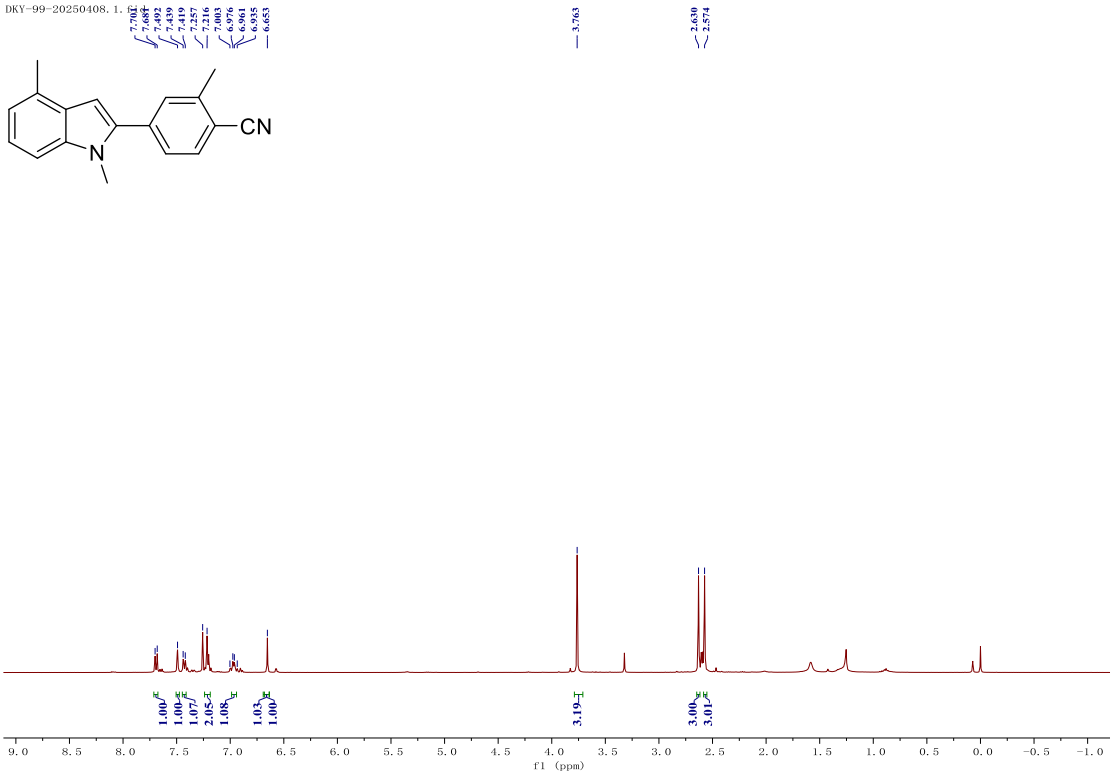
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 22



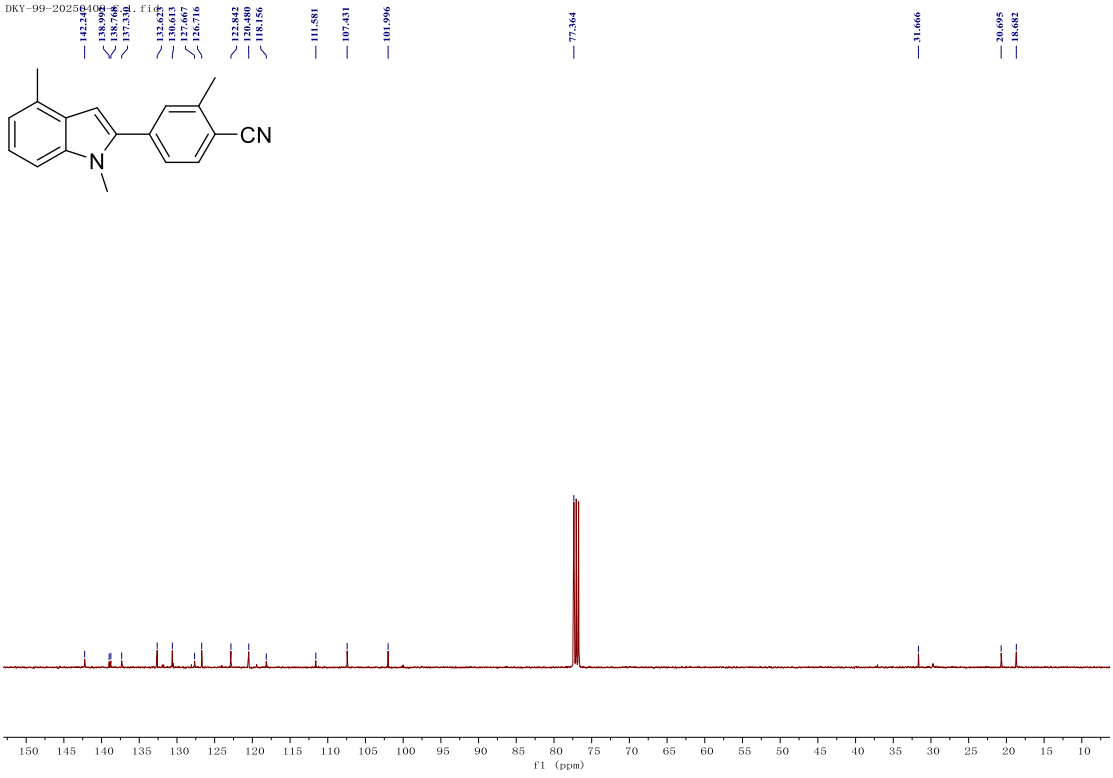

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 22



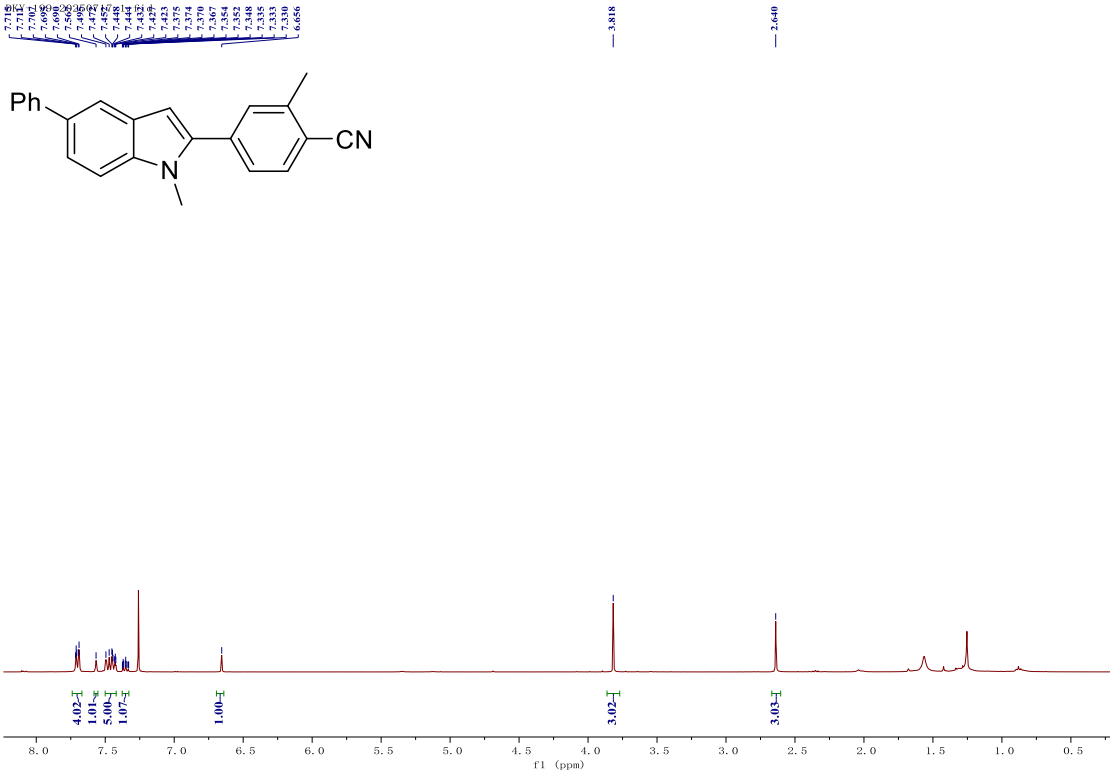
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 23



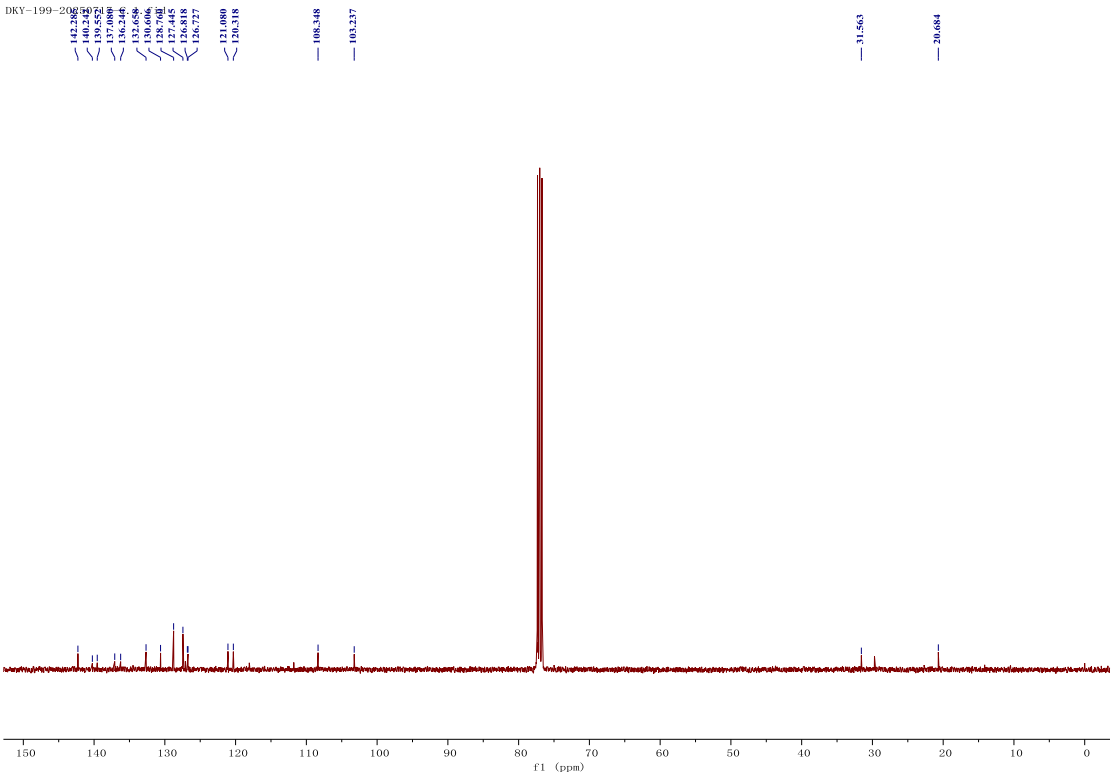

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 23



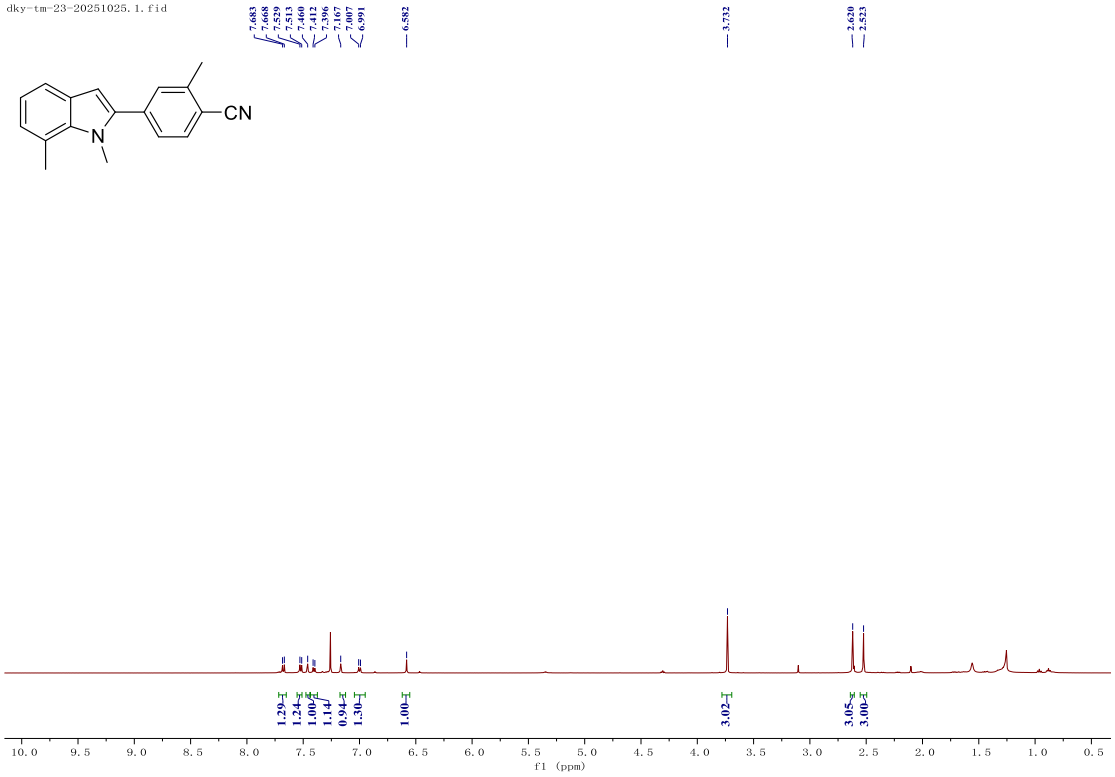
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 24



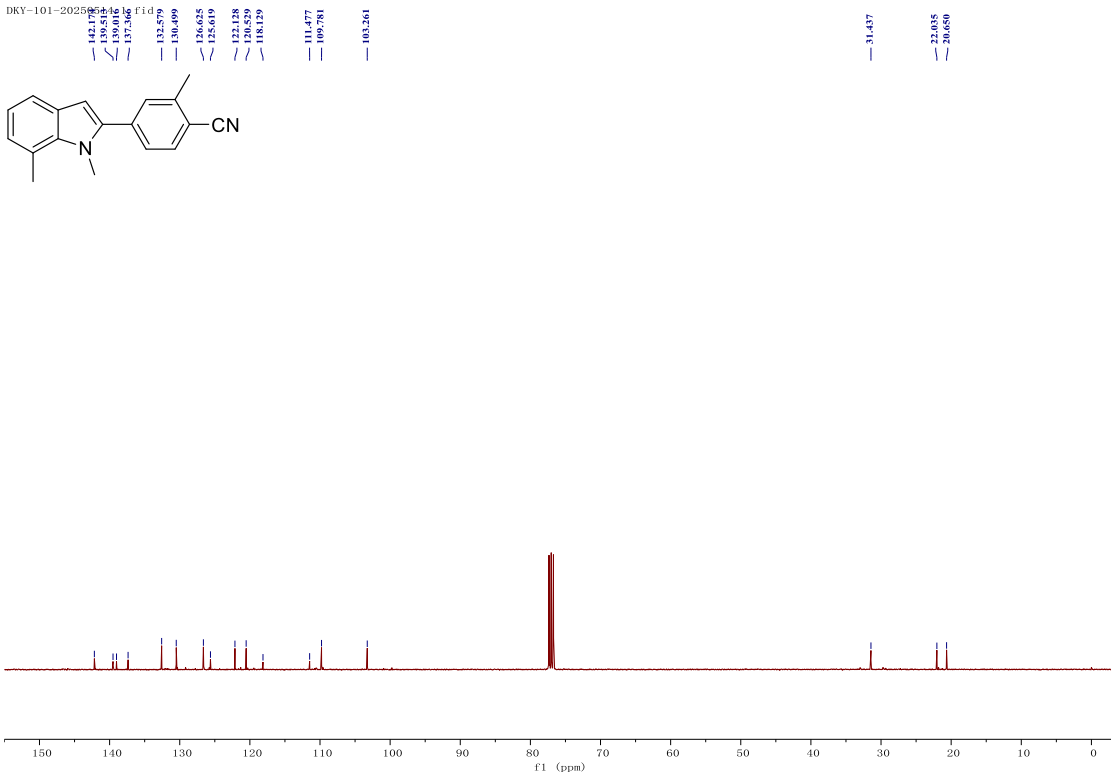

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 24



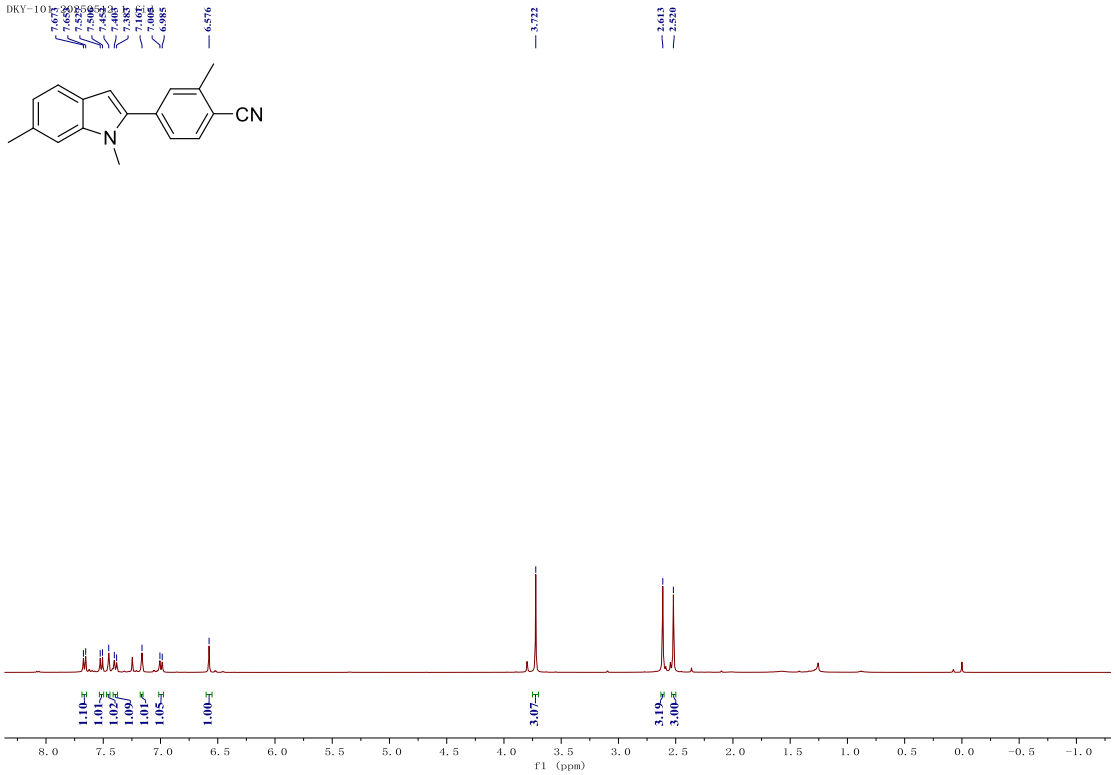
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 25



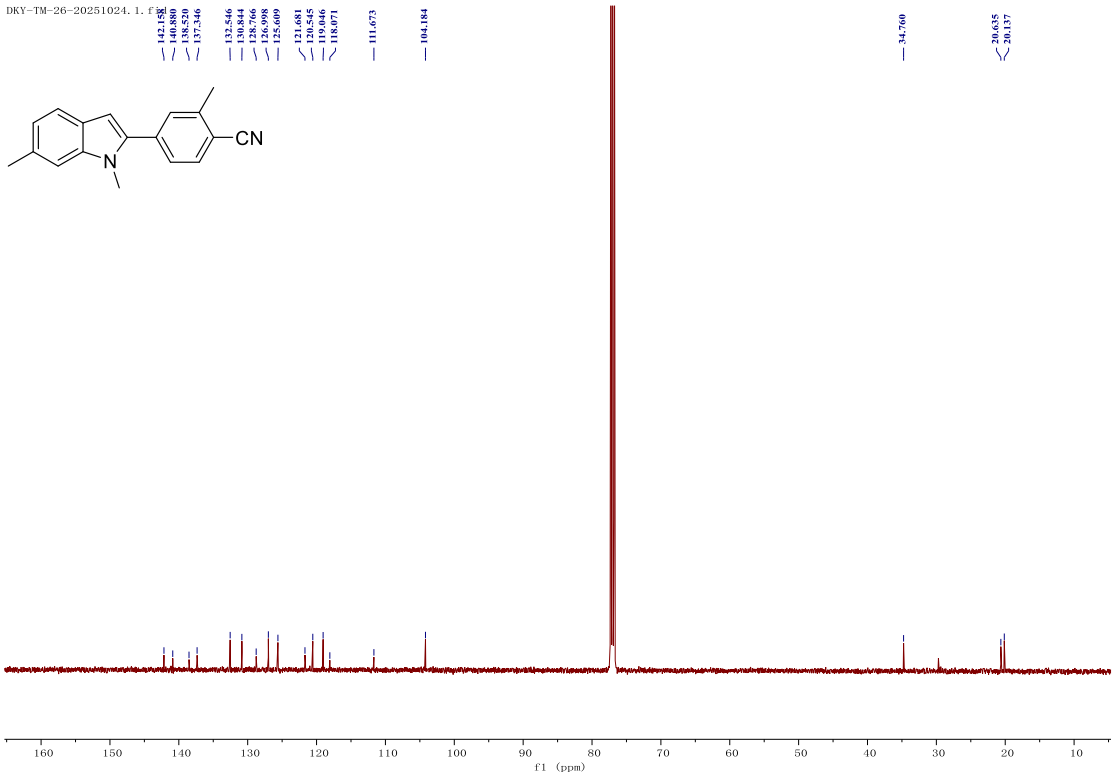

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 25



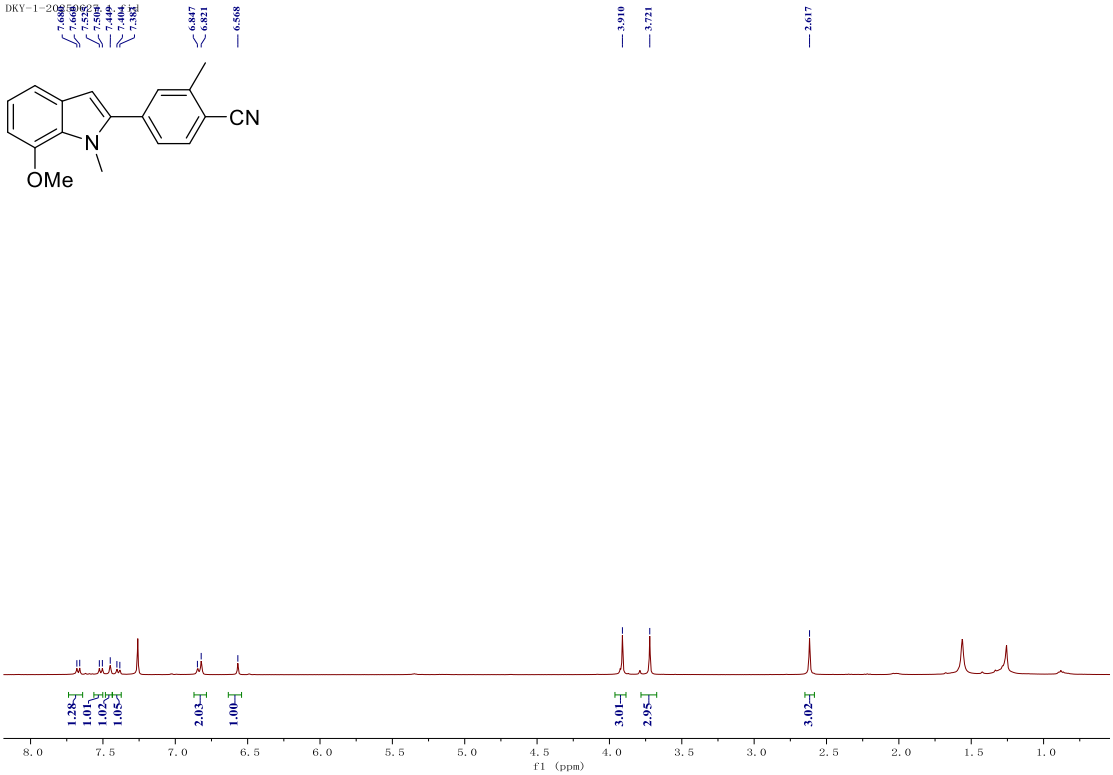
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 26



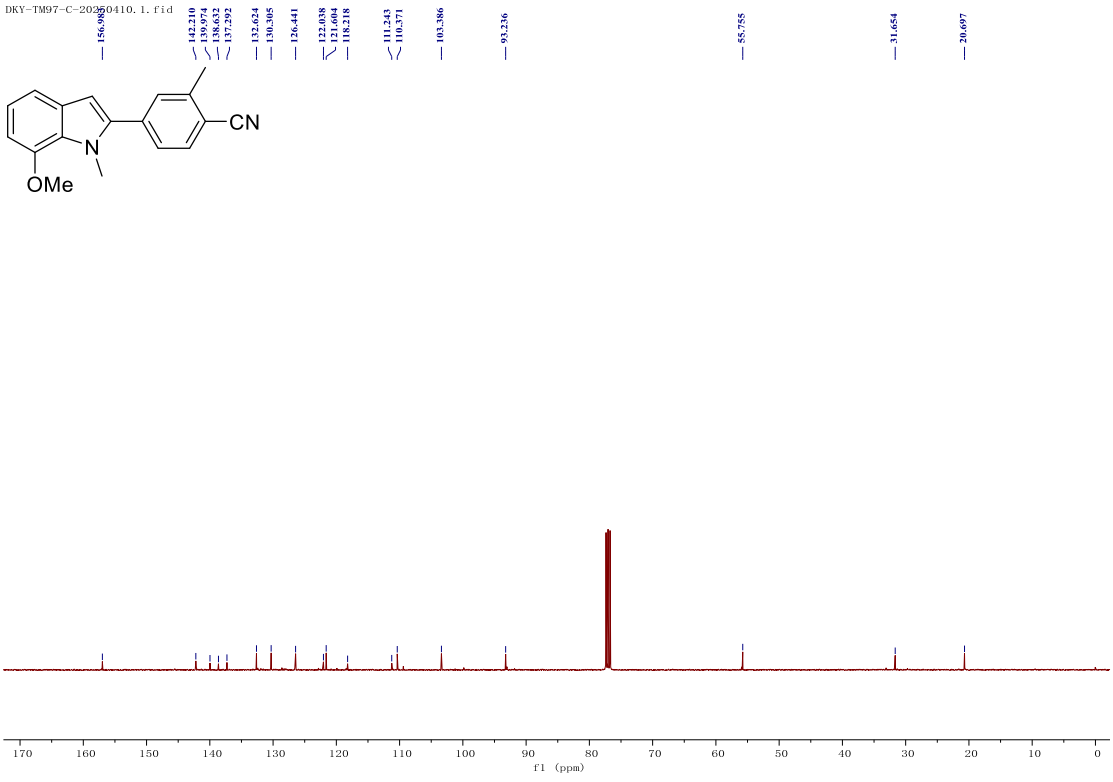

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 26



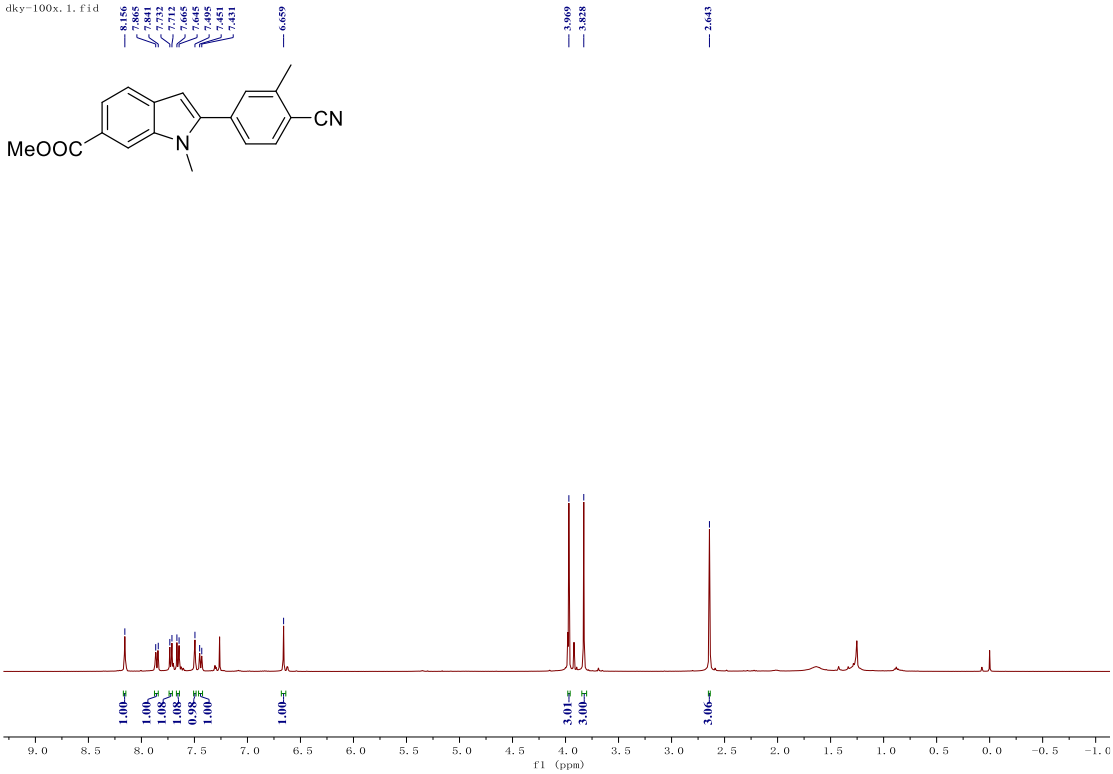
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 27



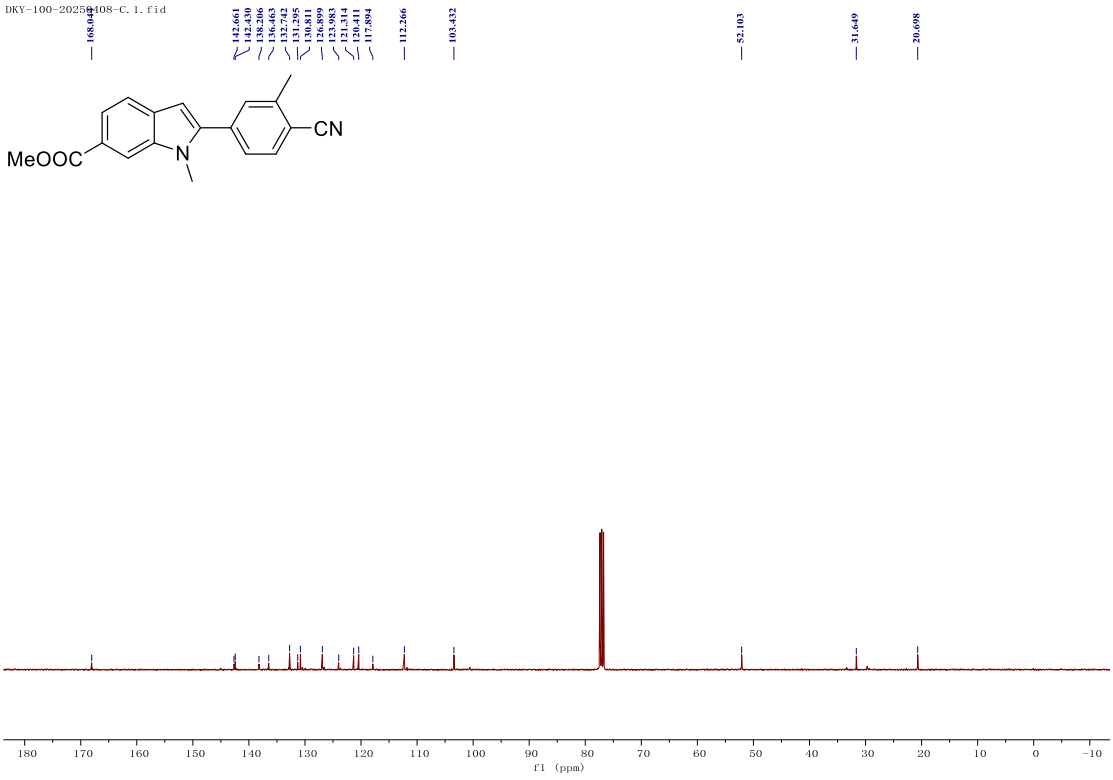

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 27



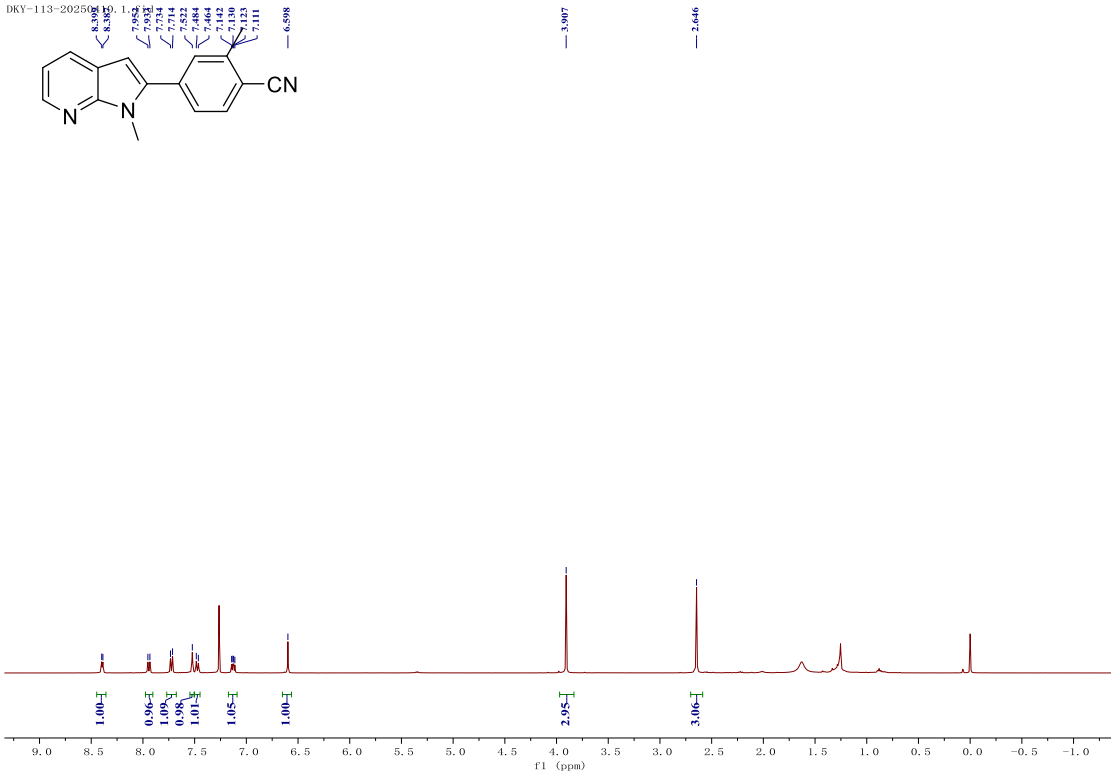
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 28



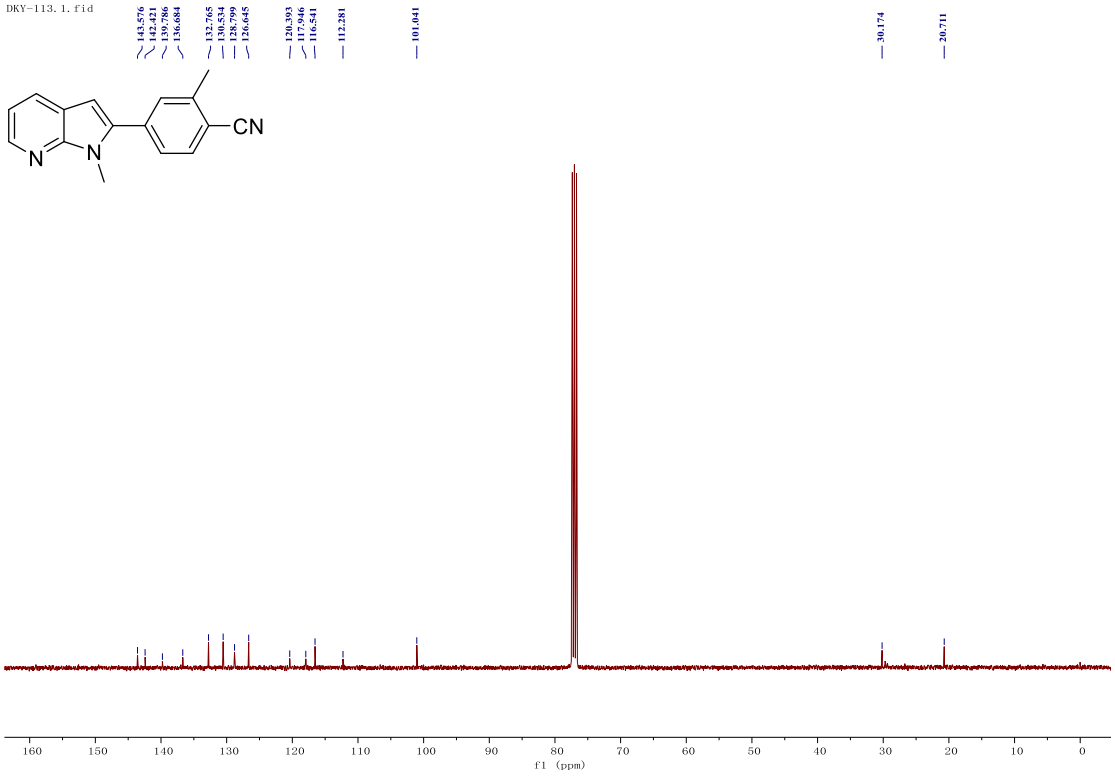

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 28



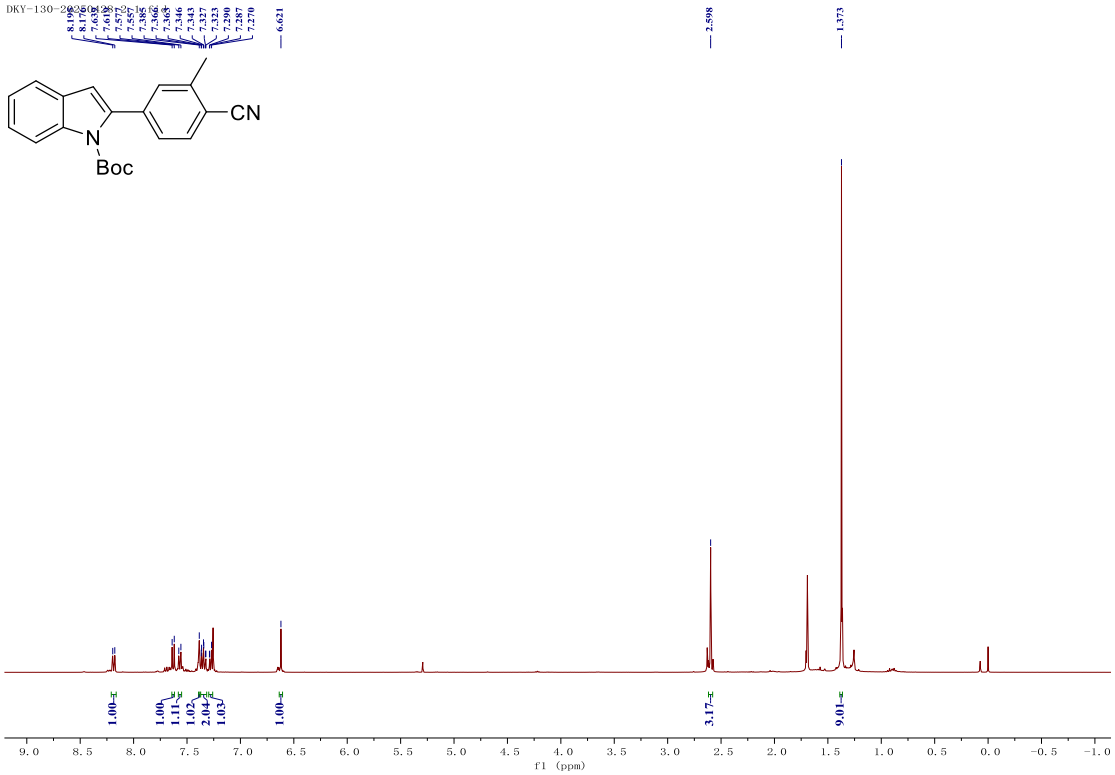
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 29



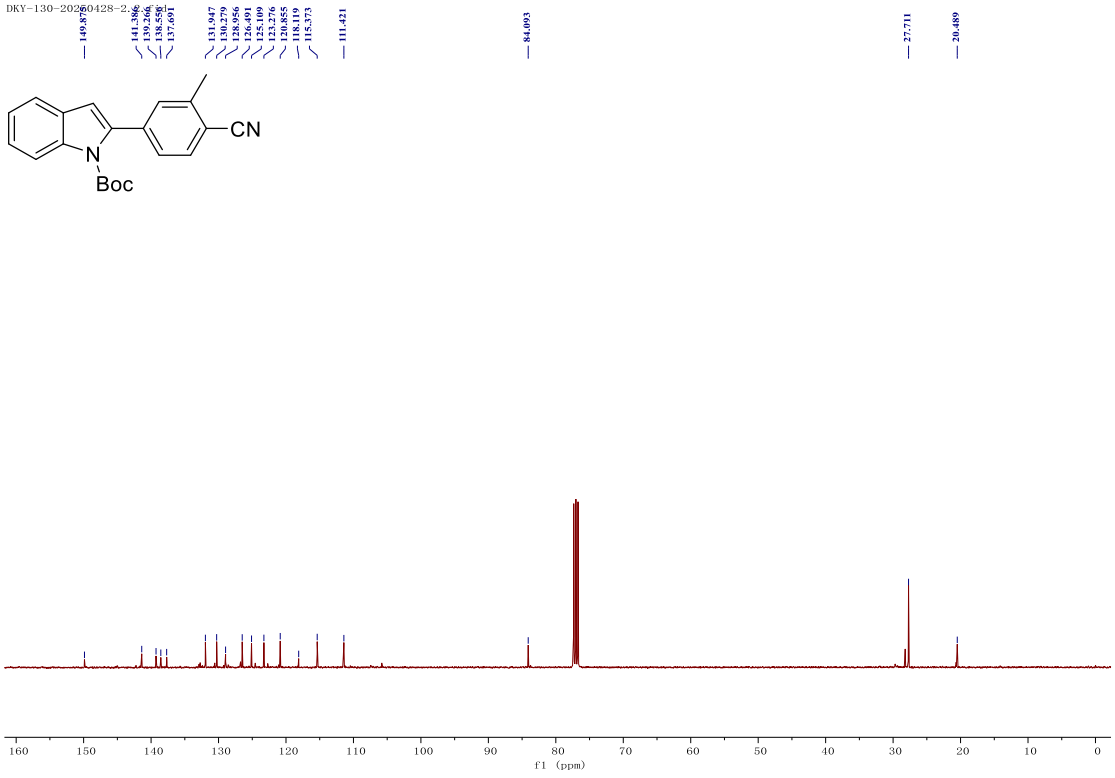

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 29



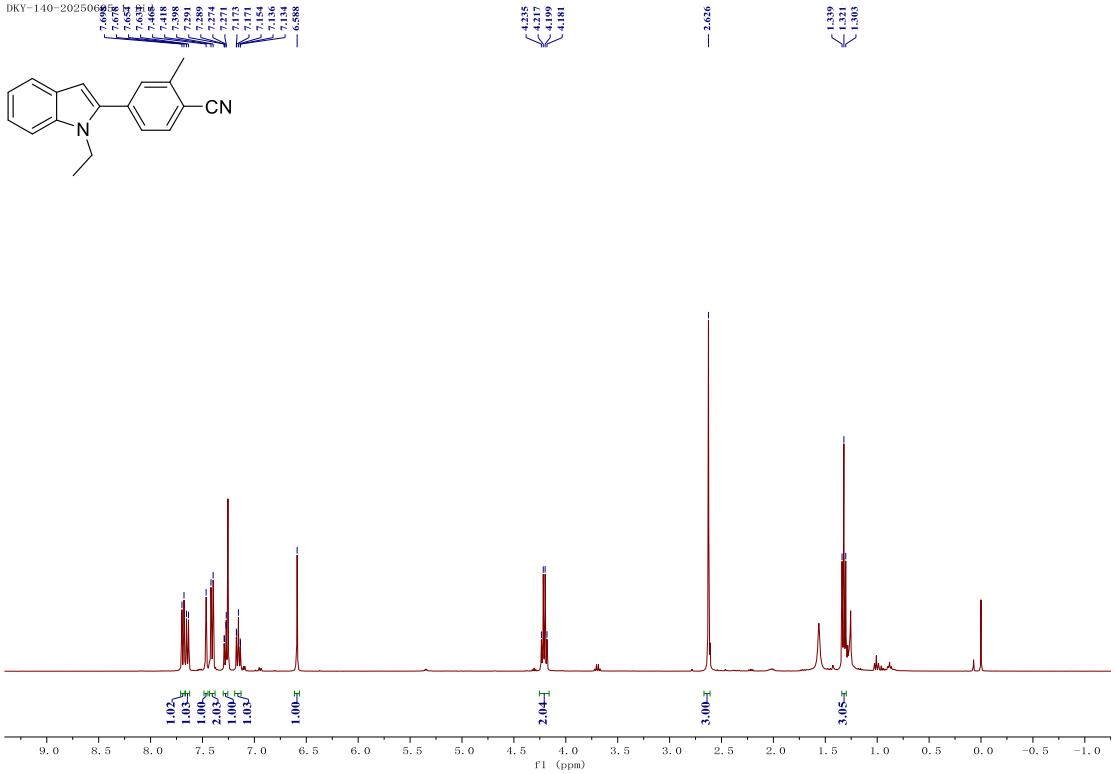
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 30



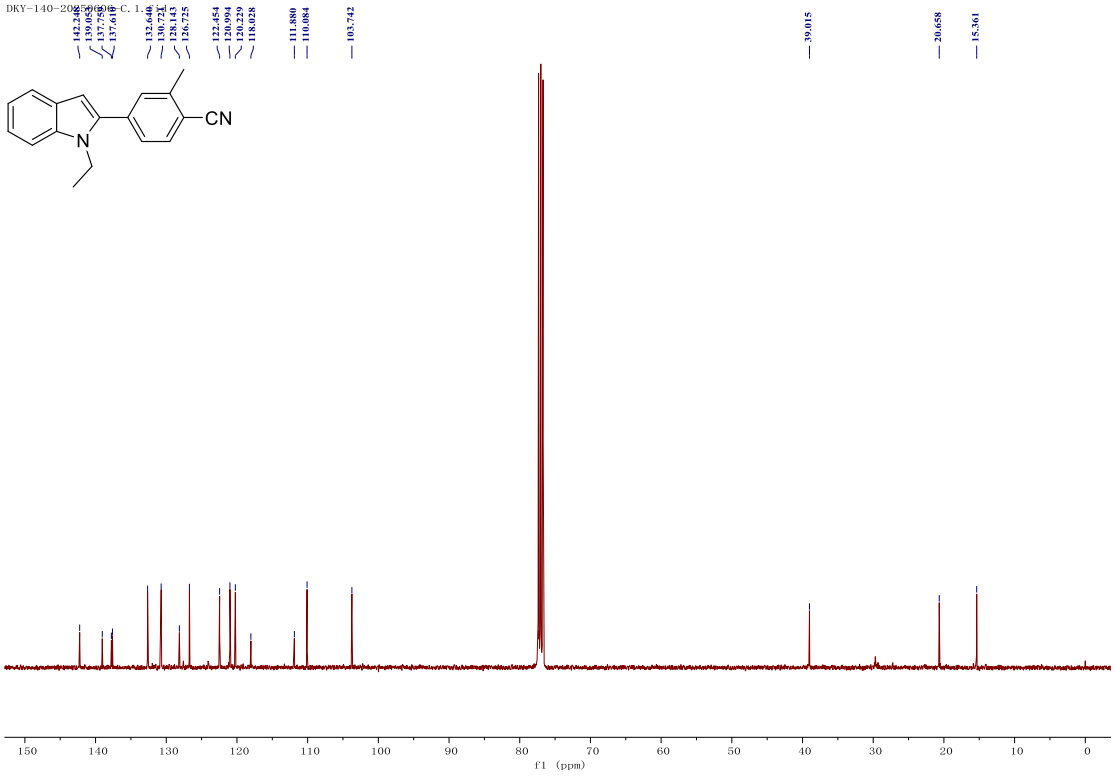

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 30



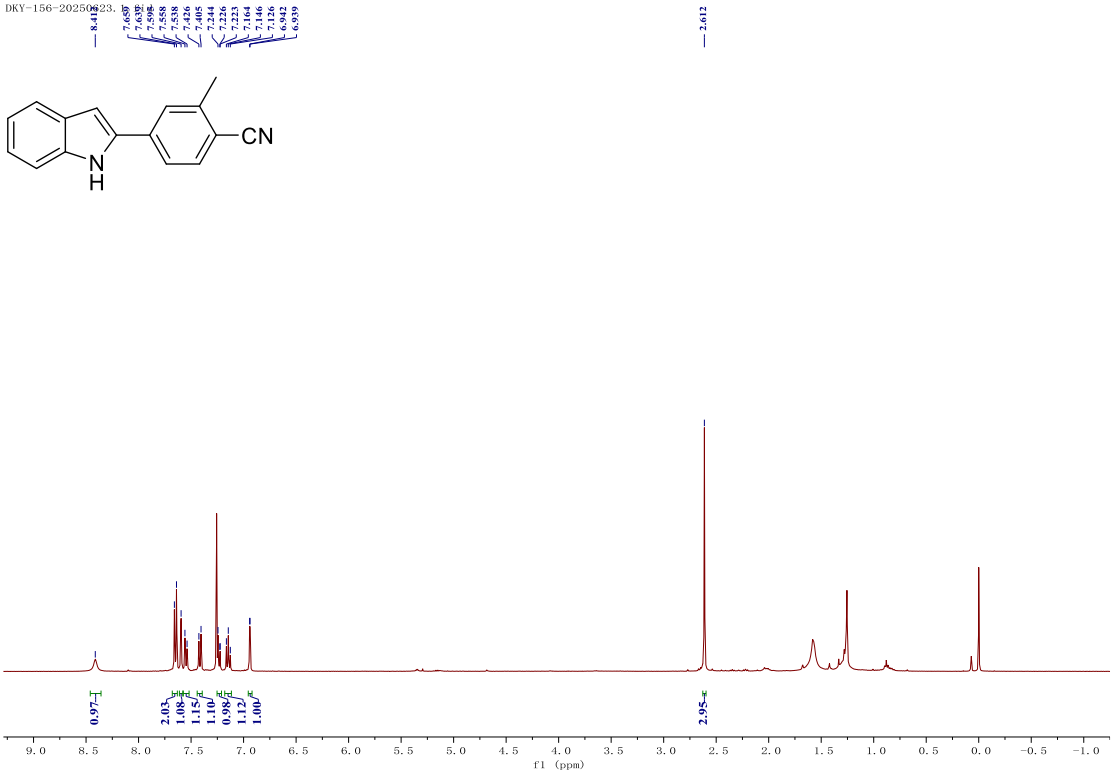
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 31



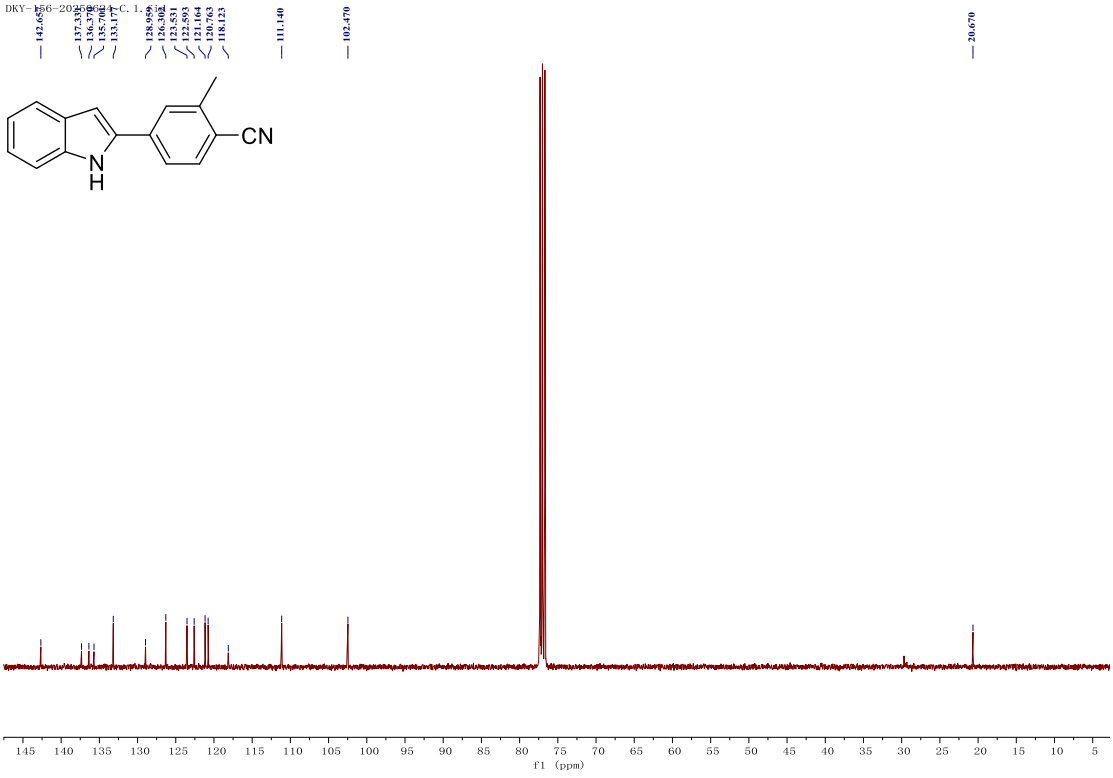

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 31



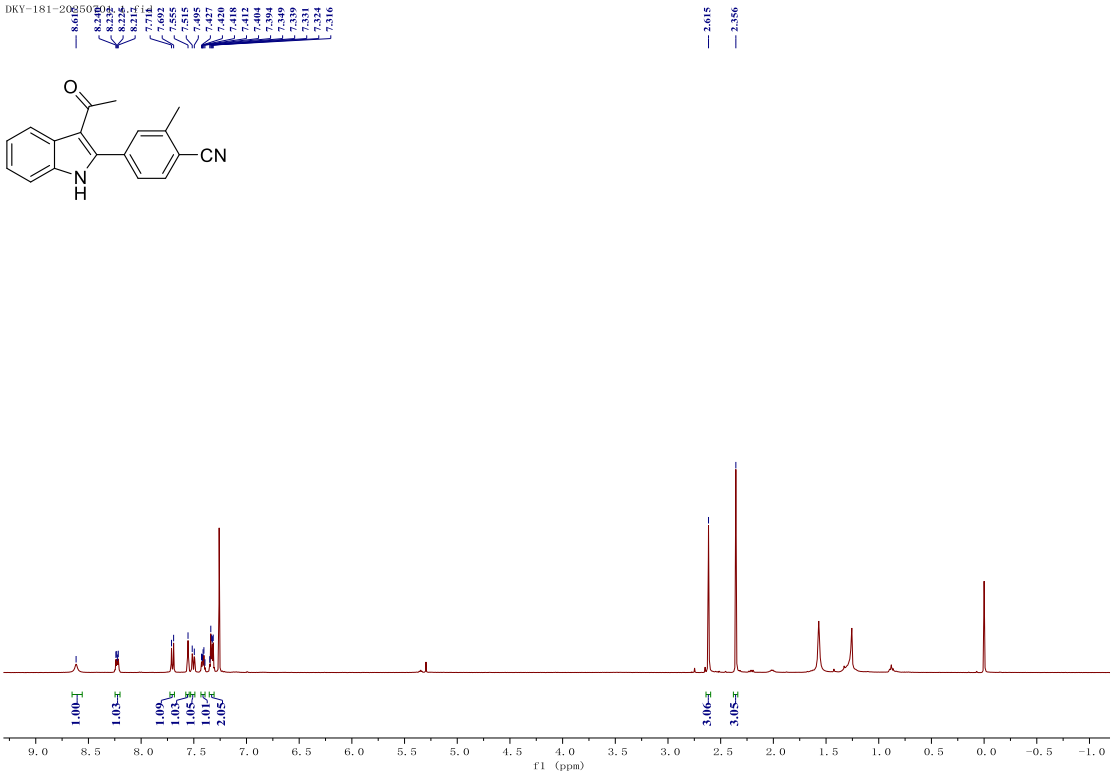
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 32



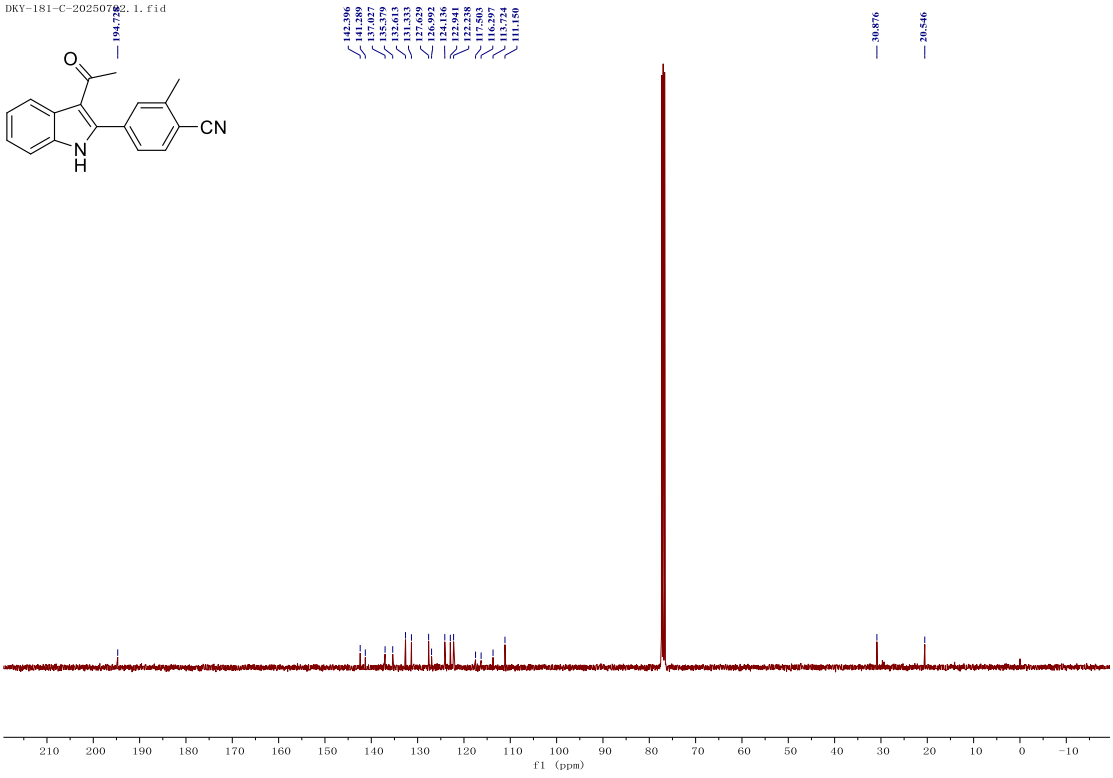

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 32



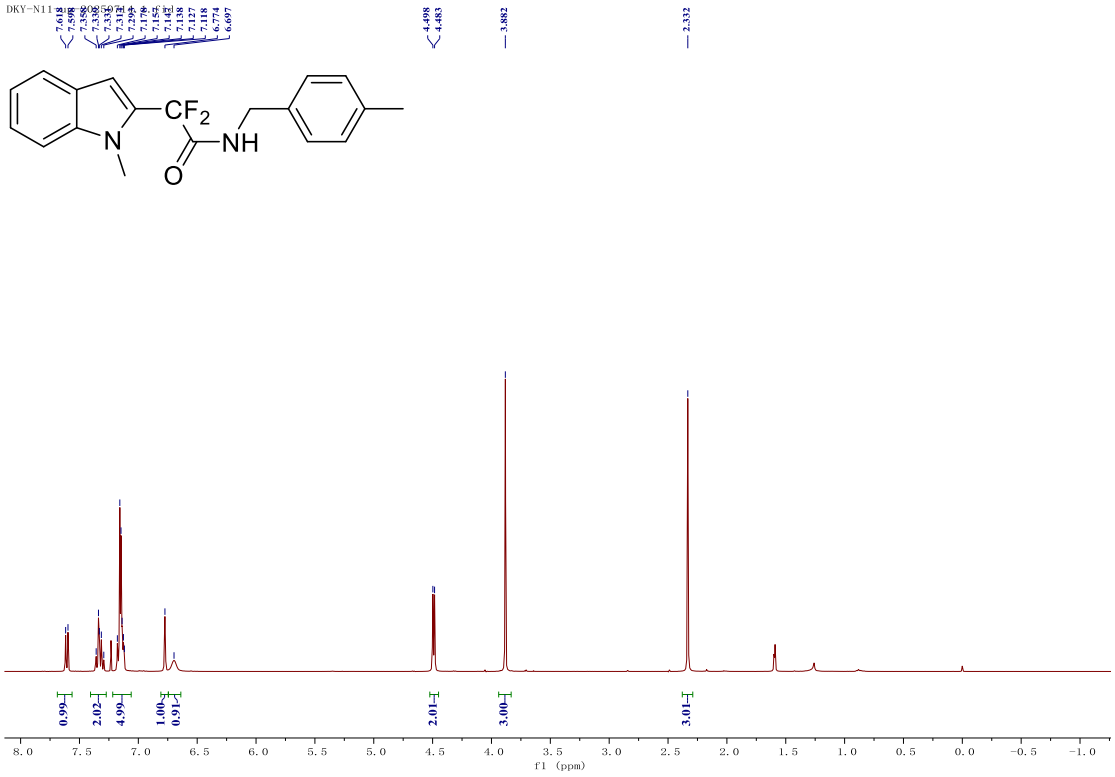
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 33



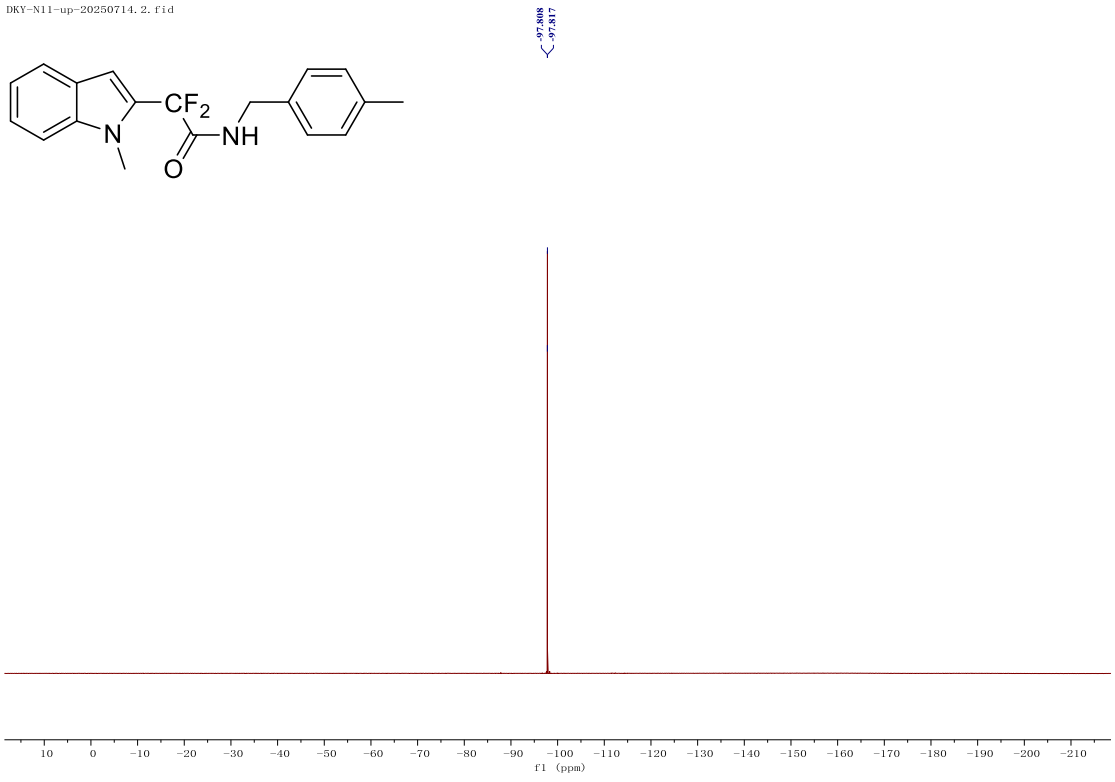

## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 33



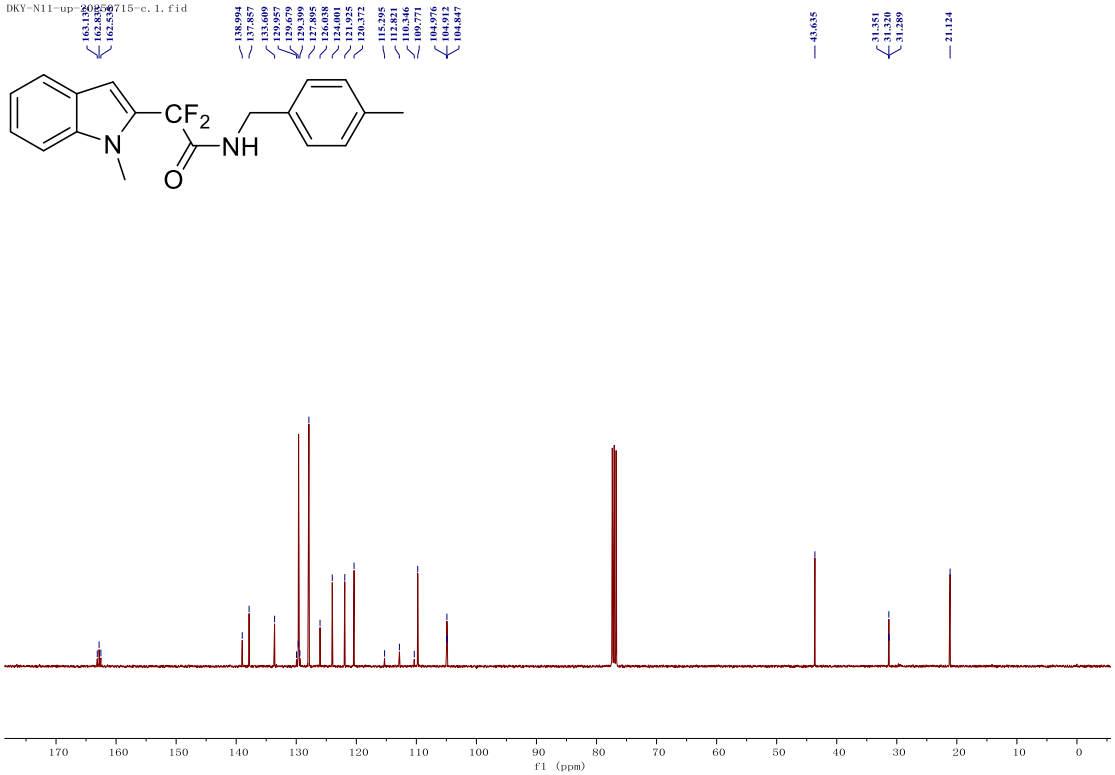
## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 34



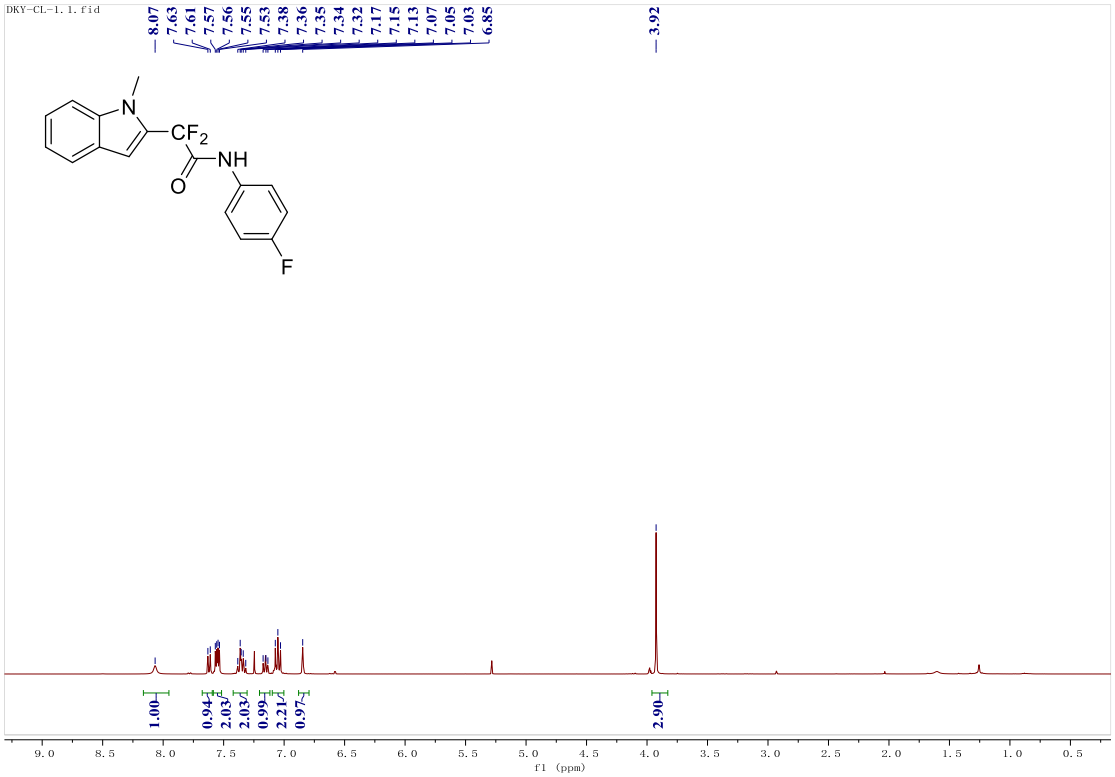

## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 34



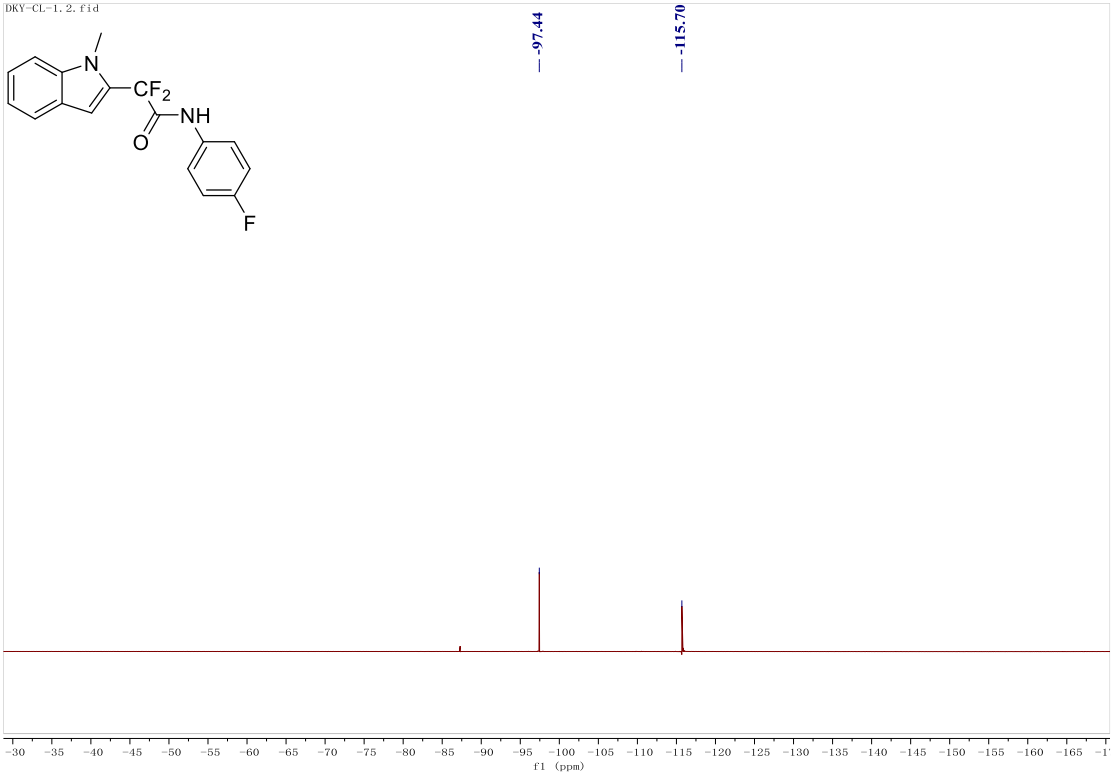
## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 34



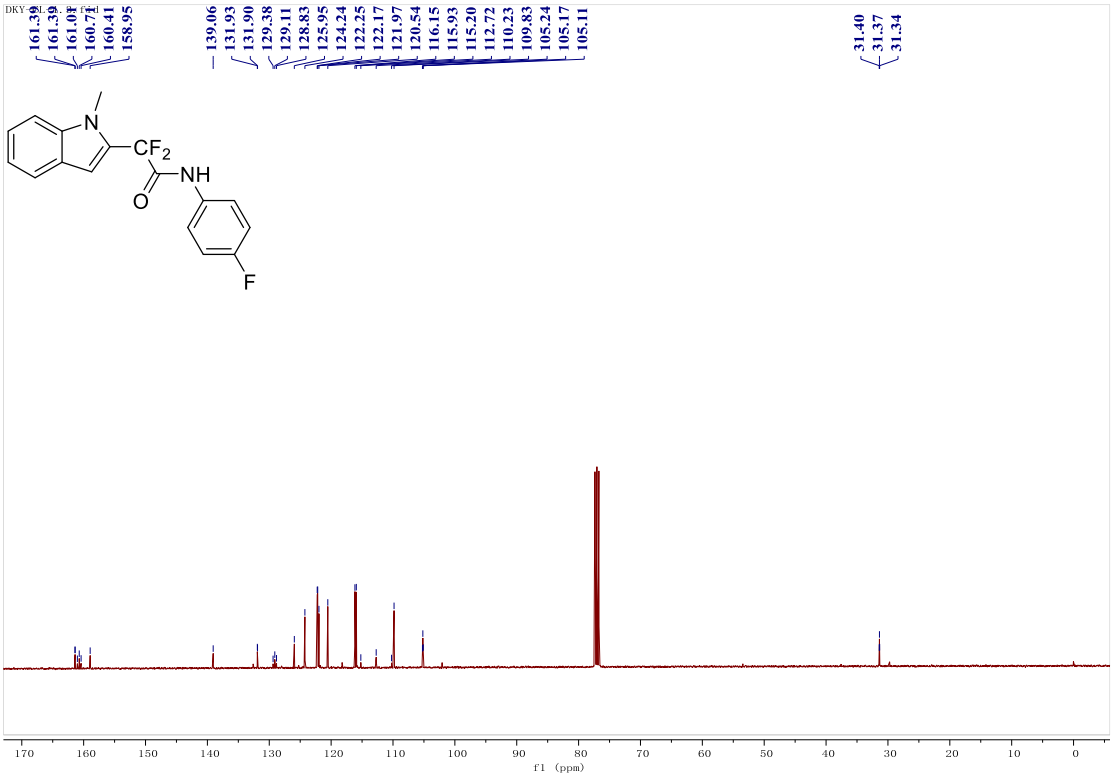

## $^{1}$H NMR (400MHz, $CDCl_3$) spectrum of 35



## $^{19}$F NMR (376MHz, $CDCl_3$) spectrum of 35




## $^{13}$C NMR (101MHz, $CDCl_3$) spectrum of 35



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