Synthesis of 5-(Trifluoromethyl)pyrazolines by Formal [4+1]-Annulation of Fluorinated Sulfur Ylides and Azoalkenes

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Supporting Information

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1. General methods:

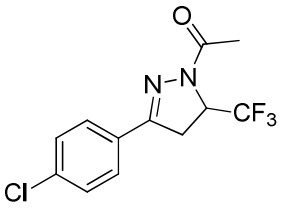
Unless otherwise stated, all commercial reagents were used as received. All solvents were dried and distilled according to standard procedures. Flash column chromatography was performed using silica gel (60 Å pore size, 32–63μm, standard grade). Analytical thin–layer chromatography was performed using glass plates pre-coated with 0.25 mm 230–400 mesh silica gel impregnated with a fluorescent indicator (254 nm). Thin layer chromatography plates were visualized by exposure to ultraviolet light. Organic solutions were concentrated on rotary evaporators at ~20 Torr at 25–35°C. The ^{1}H, ^{1}and ^{13}C NMR spectra were recorded on a 400 or 600 MHz spectrometer with chloroform-*d* as a solvent at 20−25 °C. High-resolution mass spectra (HRMS) were recorded on FT-ICR MS spectrometer. Melting points are uncorrected. All chemical shift values are quoted in ppm and coupling constants quoted in Hz. The α-chloro- and α-bromo-hydrazones **1** were prepared according to the literature procedures.[1] Fluorinated sulfur ylide precursors **2a** and **2b** were prepared following the literature procedures.[2]

(1) (a) Hu, X.-Q.; Chen, J.-R.; Gao, S.; Feng, B.; Lu, L.-Q.; Xiao, W.-J. *Chem. Commun*. **2013**, *49*, 7905. (b) Zhao, H.-W.; Pang, H.-L.; Tian, T.; Li, B.; Chen, X.-Q.; Song, X.-Q.; Meng, W.; Yang, Z.; Liu, Y.-Y.; Zhao, Y.-D. *Adv. Synth. Catal*. **2016**, *358*, 1826.

(2) (a) Duan, Y.; Zhou, B.; Lin, J.-H.; Xiao, J.-C. *Chem. Commun*. **2015**, *51*, 13127. (b) Wang, S.-M.; Song, H.-X.; Wang, X.-Y.; Liu, N.; Qin, H.-L.; Jia, C.-P. *Chem. Commun*. **2016**, *52*, 11893.

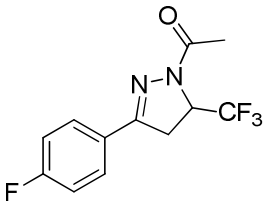
2. General experimental procedure for the [4+1]-annulation of α-halo-hydrazones 1 with fluorinated sulfur ylide 2a:

To the mixture of (2,2,2-trifluoroethyl)diphenylsulfonium triflate **2a** (0.3 mmol, 126mg), α-halo-hydrazones **1** (0.15mmol), K_2CO_3 (0.45 mmol, 62 mg) and 4 Å MS (0.4 g) was added tetrahydrofuran (6 mL) under argon atmosphere. The resulting mixture was stirred at rt until the starting material **1** was consumed (monitored by TLC). After filtration, the solvent was removed and the residue was purified by column chromatography on silica gel (EtOAc/petroleum ether, 1:4) to provide the product **3**.



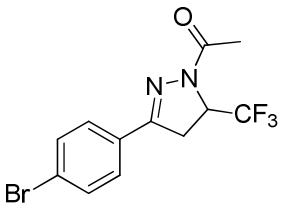
1-(3-(4-Chlorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3a**)

White solid (42 mg, 96% yield); mp 120–121 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.5 Hz, 2H), 7.42 (d, *J* = 8.5 Hz, 2H), 5.25–5.20 (m, 1H), 3.48 (dd, *J* = 18.0, 11.5 Hz, 1H), 3.33 (dd, *J* = 18.0, 3.7 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.06, 153.19, 137.00, 129.15, 128.72, 127.90, 124.16 (q, *J* = 281.0 Hz), 56.23 (q, *J* = 33.0 Hz), 34.17, 21.91. HRMS (ESI) calcd for $C_{12}H_{10}ClF_3N_2NaO$ $[M + Na]^+$ 313.0326, found 313.0327.



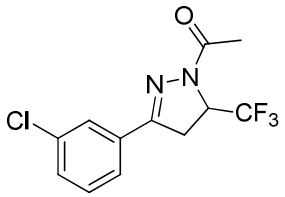
1-(3-(4-Fluorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3b**)

Pale yellow solid (38 mg, 92% yield); mp 127–128 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (dd, *J* = 8.8, 5.3 Hz, 2H), 7.13 (t, *J* = 8.6 Hz, 2H), 5.26–5.20 (m, 1H), 3.48 (dd, *J* = 18.0, 11.5 Hz, 1H), 3.33 (dd, *J* = 18.0, 3.7 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.08, 164.26 (d, *J* = 250.8 Hz), 153.27, 128.73 (d, *J* = 8.6 Hz), 126.50 (d, *J* = 3.3 Hz), 124.19 (q, *J* = 281.0 Hz), 116.06 (d, *J* = 22.0 Hz), 56.17 (q, *J* = 32.8 Hz), 34.27, 21.89. HRMS (ESI) calcd for $C_{12}H_{10}F_4N_2NaO$ $[M + Na]^+$ 297.0621, found 297.0622.



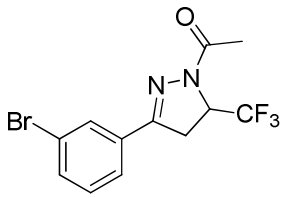
1-(3-(4-Bromophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3c**)

White solid (42 mg, 84% yield); mp 101–102 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61–7.56 (m, 4H), 5.26–5.20 (m, 1H), 3.48 (dd, *J* = 18.0, 11.5 Hz, 1H), 3.33 (dd, *J* = 18.0, 3.7 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.04, 153.27, 132.08, 129.13, 128.06, 125.32, 124.14 (q, *J* = 280.8 Hz), 56.21 (q, *J* = 32.8 Hz), 34.10, 21.90. HRMS (ESI) calcd for $C_{12}H_{10}BrF_3N_2NaO$ $[M + Na]^+$ 356.9821, found 356.9822.



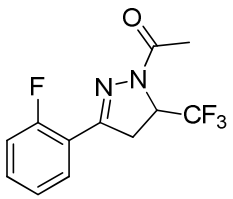
1-(3-(3-Chlorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3d**)

Pale yellow solid (30 mg, 69% yield); mp 81–82 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74–7.73 (m, 1H), 7.59 (d, *J* = 7.6 Hz, 1H), 7.44 (dd, *J* = 6.8, 1.6 Hz, 1H), 7.38 (t, *J* = 7.8 Hz, 1H), 5.31–5.17 (m, 1H), 3.49 (dd, *J* = 18.0, 11.5 Hz, 1H), 3.34 (dd, *J* = 18.0, 3.8 Hz, 1H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.10, 152.95, 135.02, 131.99, 130.83, 130.12, 126.63, 124.76, 124.13 (q, *J* = 280.9 Hz), 56.23 (q, *J* = 33.1 Hz), 34.14, 21.92. HRMS (ESI) calcd for $C_{12}H_{10}ClF_3N_2NaO$ $[M + Na]^+$ 313.0326, found 313.0325.



1-(3-(3-Bromophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3e**)

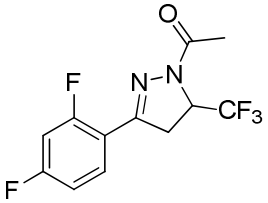
White solid (38 mg, 76% yield); mp 71–72 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.59 (d, *J* = 8.1 Hz, 1H), 7.32 (t, *J* = 7.9 Hz, 1H), 5.30–5.17 (m, 1H), 3.48 (dd, *J* = 18.0, 11.5 Hz, 1H), 3.33 (dd, *J* = 18.1, 3.8 Hz, 1H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.08, 152.85, 133.72, 132.22, 130.34, 129.52, 125.20, 124.13 (q, *J* = 281.0 Hz), 123.01, 56.23 (q, *J* = 33.0 Hz), 34.11, 21.92. HRMS (ESI) calcd for $C_{12}H_{10}BrF_3N_2NaO$ $[M + Na]^+$ 356.9821, found 356.9817.



1-(3-(2-Fluorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3f**)

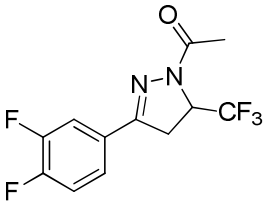
Pale yellow solid (27 mg, 65% yield); mp 92–93 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (td, *J* = 7.7, 1.6 Hz, 1H), 7.48–7.39 (m, 1H), 7.22 (t, *J* = 7.6 Hz, 1H), 7.14 (dd, *J* = 11.4, 8.4 Hz, 1H), 5.20 (m, 1H) , 3.60 (ddd, *J* = 18.8, 11.4, 2.7 Hz, 1H), 3.51–3.44 (m, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.12, 161.19 (d, *J* = 251.7 Hz), 151.29 (d, *J* = 2.3 Hz), 132.54 (d, *J* = 8.7 Hz), 128.82 (d, *J* = 2.7 Hz), 124.62 (d, *J* = 3.3 Hz), 124.22 (q, *J* = 281.0 Hz), 118.35 (d, *J* = 10.9 Hz), 116.58 (d, *J* = 22.1 Hz),

56.11 (qd, J = 32.6, 2.9 Hz), 36.51 (d, J = 8.7 Hz), 21.92. HRMS (ESI) calcd for $C_{12}H_{10}F_4N_2NaO$ $[M + Na]^+$ 297.0621, found 297.0619.



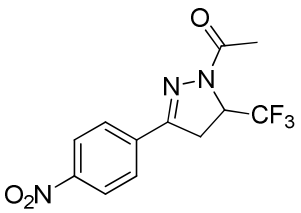
1-(3-(2,4-Difluorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1H-pyrazol-1-yl)ethanone (**3g**)

Pale yellow solid (31 mg, 72% yield); mp 79–80 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (td, J = 8.6, 6.6 Hz, 1H), 7.00–6.95 (m, 1H), 6.90 (ddd, J = 11.2, 8.6, 2.4 Hz, 1H), 5.24–5.18 (m, 1H), 3.58 (ddd, J = 18.7, 11.4, 2.6 Hz, 1H), 3.45 (dt, J = 18.8, 3.3 Hz, 1H), 2.41 (s, 3H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 170.06, 164.43 (dd, J = 253.6, 12.2 Hz), 161.51 (dd, J = 254.1, 12.0 Hz), 150.37, 130.17 (dd, J = 9.8, 4.5 Hz), 124.17 (q, J = 281.0 Hz), 114.87 (dd, J = 11.1, 4.0 Hz), 112.52 (dd, J = 21.6, 3.2 Hz), 104.81 (t, J = 25.7 Hz), 56.08 (qd, J = 33.1, 2.3 Hz), 36.33 (d, J = 8.2 Hz), 21.90. HRMS (ESI) calcd for $C_{12}H_9F_5N_2NaO$ $[M + Na]^+$ 315.0527, found 315.0526.



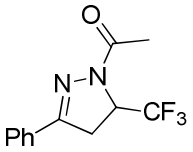
1-(3-(3,4-Difluorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3h**)

White solid (32 mg, 73% yield); mp 126–127 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (ddd, J = 10.8, 7.6, 2.1 Hz, 1H), 7.44–7.40 (m, 1H), 7.24 (dd, J = 17.9, 8.3 Hz, 1H), 5.27–5.21 (m, 1H), 3.48 (dd, J = 18.0, 11.5 Hz, 1H), 3.32 (dd, J = 18.0, 3.8 Hz, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.03, 152.28, 151.98 (dd, J = 254.5, 12.9 Hz), 150.57 (dd, J = 250.2, 12.9 Hz), 127.42 (dd, J = 6.1, 4.1 Hz), 124.11 (q, J = 281.0 Hz), 123.28 (dd, J = 6.7, 3.6 Hz), 117.87 (d, J = 17.9 Hz), 115.63 (d, J = 18.9 Hz), 56.36 (q, J = 32.7 Hz), 34.17, 21.88. HRMS (ESI) calcd for $C_{12}H_9F_5N_2NaO$ $[M + Na]^+$ 315.0527, found 315.0526.

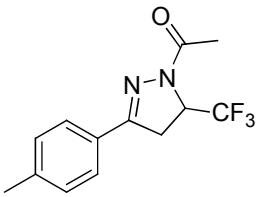


1-(3-(4-Nitrophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3i**)

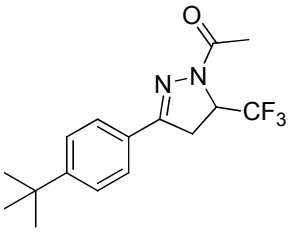
Pale yellow solid (42 mg, 92% yield); mp 148–149 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.30 (d, *J* = 8.9 Hz, 2H), 7.90 (d, *J* = 8.9 Hz, 2H), 5.32–5.25 (m, 1H), 3.56 (dd, *J* = 18.1, 11.6 Hz, 1H), 3.40 (dd, *J* = 18.1, 3.8 Hz, 1H), 2.46 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.04, 151.98, 148.90, 136.09, 127.42, 124.12, 124.03 (q, *J* = 281.0 Hz), 56.61 (q, *J* = 33.0 Hz), 34.10, 21.94. HRMS (ESI) calcd for $C_{12}H_9F_3N_3O_3$ $[M - H]^-$ 300.0601, found 300.0601.



1-(3-Phenyl-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3j**)
Pale yellow solid (35 mg, 90% yield); mp 99–100 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78–7.70 (m, 2H), 7.50–7.40 (m, 3H), 5.29–5.17 (m, 1H), 3.50 (dd, *J* = 18.0, 11.4 Hz, 1H), 3.36 (dd, *J* = 18.0, 3.7 Hz, 1H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.13, 154.30, 130.89, 130.20, 128.83, 126.66, 124.24 (q, *J* = 280.9 Hz), 56.08 (q, *J* = 32.9 Hz), 34.23, 21.93. HRMS (ESI) calcd for $C_{12}H_{11}F_3N_2NaO$ $[M + Na]^+$ 279.0716, found 279.07146.

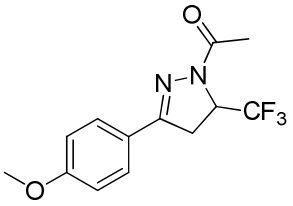


1-(3-(*p*-Tolyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3k**)
White solid (35 mg, 86% yield); mp 113–114 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.0 Hz, 2H), 7.24 (d, *J* = 8.1 Hz, 2H), 5.23–5.18 (m, 1H), 3.48 (dd, *J* = 17.9, 11.4 Hz, 1H), 3.34 (dd, *J* = 18.0, 3.6 Hz, 1H), 2.42 (s, 3H), 2.40 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.11, 154.37, 141.37, 129.53, 127.45, 126.63, 124.27 (q, *J* = 281.0 Hz), 56.01 (q, *J* = 33.0 Hz), 34.26, 21.92, 21.49. HRMS (ESI) calcd for $C_{13}H_{13}F_3N_2NaO$ $[M + Na]^+$ 293.0872, found 293.0874.



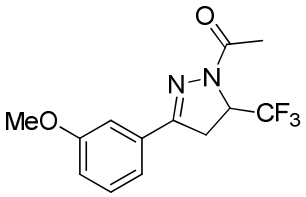
1-(3-(4-(*tert*-Butyl)phenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3l**)
Pale yellow solid (43 mg, 92% yield); mp 92–93 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.5 Hz, 2H), 7.46 (d, *J* = 8.5 Hz, 2H), 5.23–5.18 (m 1H), 3.49 (dd, *J* = 18.0, 11.4 Hz, 1H), 3.34 (dd, *J* = 18.0, 3.7 Hz, 1H), 2.42 (s, 3H), 1.34 (s, 9H). ^{13}C

NMR (101 MHz, $CDCl_3$) δ 170.11, 154.50, 154.33, 127.42, 126.50, 125.79, 124.27 (q, J = 281.0 Hz), 56.00 (q, J = 33.0 Hz), 34.93, 34.26, 31.08, 21.92. HRMS (ESI) calcd for $C_{16}H_{19}F_3N_2NaO$ $[M + Na]^+$ 335.1341, found 335.1345.



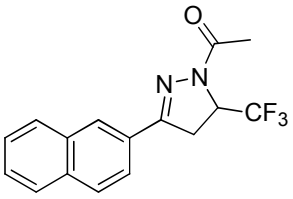
1-(3-(4-Methoxyphenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3m**)

Pale yellow solid (27 mg, 62% yield); mp 104–105 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, J = 8.4 Hz, 2H), 6.94 (d, J = 8.4 Hz, 2H), 5.23–5.17 (m, 1H), 3.86 (s, 1H), 3.46 (dd, J = 17.9, 11.4 Hz, 1H), 3.32 (dd, J = 17.9, 3.3 Hz, 1H), 2.41 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.08, 161.77, 154.04, 128.33, 124.31 (q, J = 281.0 Hz), 122.83, 114.27, 56.00 (q, J = 33.0 Hz), 55.42, 34.29, 21.93. HRMS (ESI) calcd for $C_{13}H_{13}F_3N_2NaO_2$ $[M + Na]^+$ 309.0821, found 309.0823.



1-(3-(3-Methoxyphenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3n**)

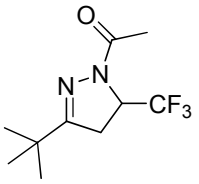
White solid (30 mg, 71% yield); mp 82–83 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 (t, J = 7.9 Hz, 1H), 7.30 (s, 1H), 7.27 (d, J = 6.0 Hz, 1H), 7.01 (dd, J = 8.2, 2.3 Hz, 1H), 5.25–5.19 (m, 1H), 3.87 (s, 3H), 3.49 (dd, J = 18.0, 11.5 Hz, 1H), 3.34 (dd, J = 18.0, 3.5 Hz, 1H), 2.43 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.10, 159.81, 154.24, 131.48, 129.88, 124.22 (q, J = 281.0 Hz), 119.29, 116.73, 111.68, 56.09 (q, J = 32.7 Hz), 55.37, 34.31, 21.92. HRMS (ESI) calcd for $C_{13}H_{13}F_3N_2NaO_2$ $[M + Na]^+$ 309.0821, found 309.0820.



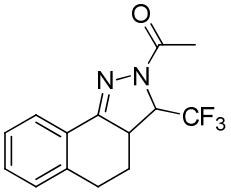
1-(3-(Naphthalen-2-yl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3o**)

White solid (44 mg, 96% yield); mp 177–178 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01

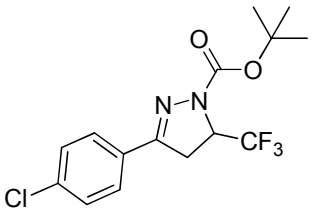
(dd, J = 8.7, 1.4 Hz, 1H), 7.98 (s, 1H), 7.87 (dd, J = 8.6, 4.6 Hz, 3H), 7.59–7.52 (m, 2H), 5.30–5.25 (m, 1H), 3.61 (dd, J = 17.9, 11.2 Hz, 1H), 3.50 (dd, J = 17.9, 3.9 Hz, 1H), 2.48 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.15, 154.33, 134.37, 132.87, 128.72, 128.46, 127.89, 127.81, 127.60, 127.43, 126.95, 124.30 (q, J = 281.0 Hz), 123.08, 56.23 (q, J = 33.0 Hz), 34.22, 21.99. HRMS (ESI) calcd for $C_{16}H_{13}F_3N_2NaO$ $[M + Na]^+$ 329.0872, found 329.0872.



1-(3-(*tert*-Butyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)ethanone (**3p**)
Pale yellow oil (11 mg, 31% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.09–5.03 (m, 1H), 3.08 (dd, J = 18.1, 11.1 Hz, 1H), 2.95 (dd, J = 18.2, 3.4 Hz, 1H), 2.31 (s, 3H), 1.21 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.03, 165.95, 124.33 (q, J = 282.7 Hz), 55.71 (q, J = 32.5 Hz), 34.00, 33.28, 27.71, 21.70. HRMS (ESI) calcd for $C_{10}H_{15}F_3N_2NaO$ $[M + Na]^+$ 259.1029, found 259.1029.

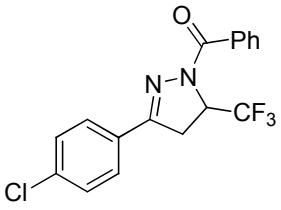


1-(3-(Trifluoromethyl)-3,3a,4,5-tetrahydro-2*H*-benzo[*g*]indazol-2-yl)ethanone (**3q**)
Pale yellow solid (18 mg, 42% yield); mp 109–110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 7.8 Hz, 1H), 7.38 (td, J = 7.5, 1.1 Hz, 1H), 7.29 (t, J = 7.5 Hz, 1H), 7.24 (d, J = 7.7 Hz, 1H), 5.25 (dq, J = 10.3, 7.8 Hz 1H), 3.54 (ddd, J = 13.8, 10.5, 4.6 Hz 1H), 3.06 (ddd, J = 16.7, 4.2, 2.6 Hz, 1H), 2.93 (ddd, J = 16.4, 12.8, 4.4 Hz,1H), 2.43–2.39 (m, 1H), 2.42 (s, 3H), 2.12–2.01 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.41, 156.13, 139.57, 131.11, 129.01, 126.91, 126.00, 125.17, 123.85 (q, J = 283.6 Hz), 57.72 (q, J = 31.0 Hz), 46.11, 29.76, 22.70, 21.71. HRMS (ESI) calcd for $C_{14}H_{13}F_3N_2NaO$ $[M + Na]^+$ 305.0872, found 305.0874.



tert-butyl
3-(4-Chlorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazole-1-carboxylate (**3r**)
Pale yellow solid (25 mg, 47% yield); mp 131–132 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (d, J = 8.4 Hz, 2H), 7.39 (d, J = 8.4 Hz, 2H), 5.04–4.91 (m, 1H), 3.52 (dd, J =

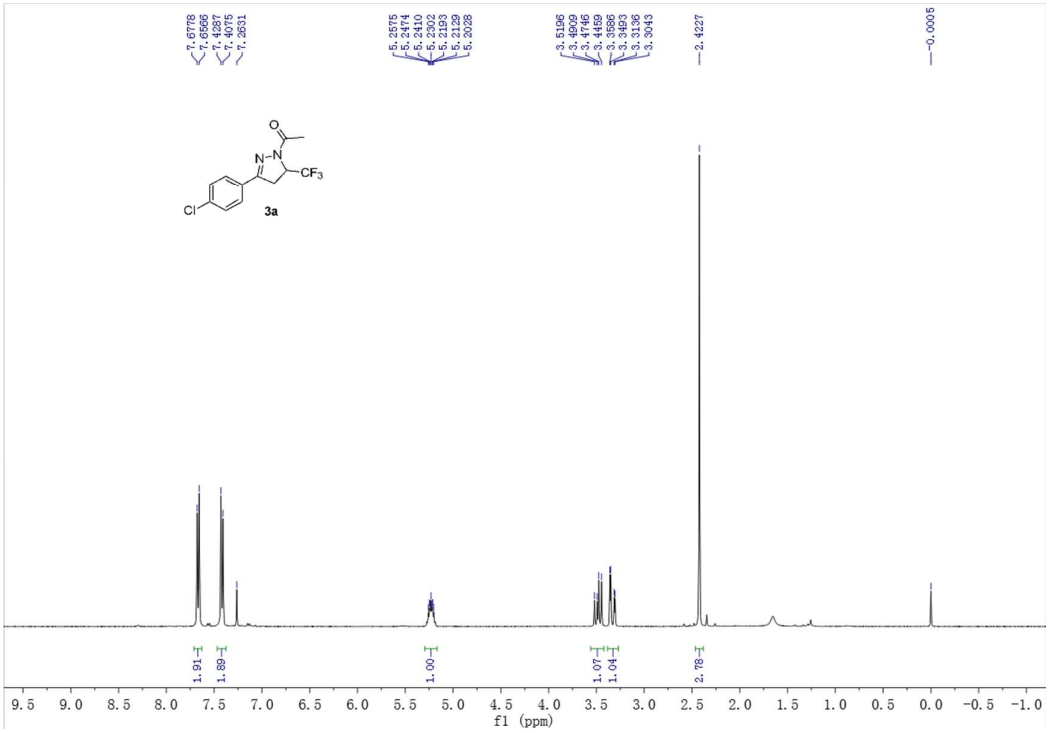
17.8, 11.8 Hz, 1H), 3.31 (dd, *J* = 17.8, 3.6 Hz, 1H), 1.57 (s, 9H). ^{13}C NMR (100MHz, $CDCl_3$) δ 152.46, 151.46, 136.62, 128.95, 128.86, 127.99, 124.21 (q, *J* = 281.0 Hz), 82.85, 58.10 (q, *J* = 32.1 Hz), 34.51, 28.09. HRMS (ESI) calcd for $C_{15}H_{16}ClF_3N_2NaO_2$ $[M + Na]^+$ 371.0745, found 371.0745.

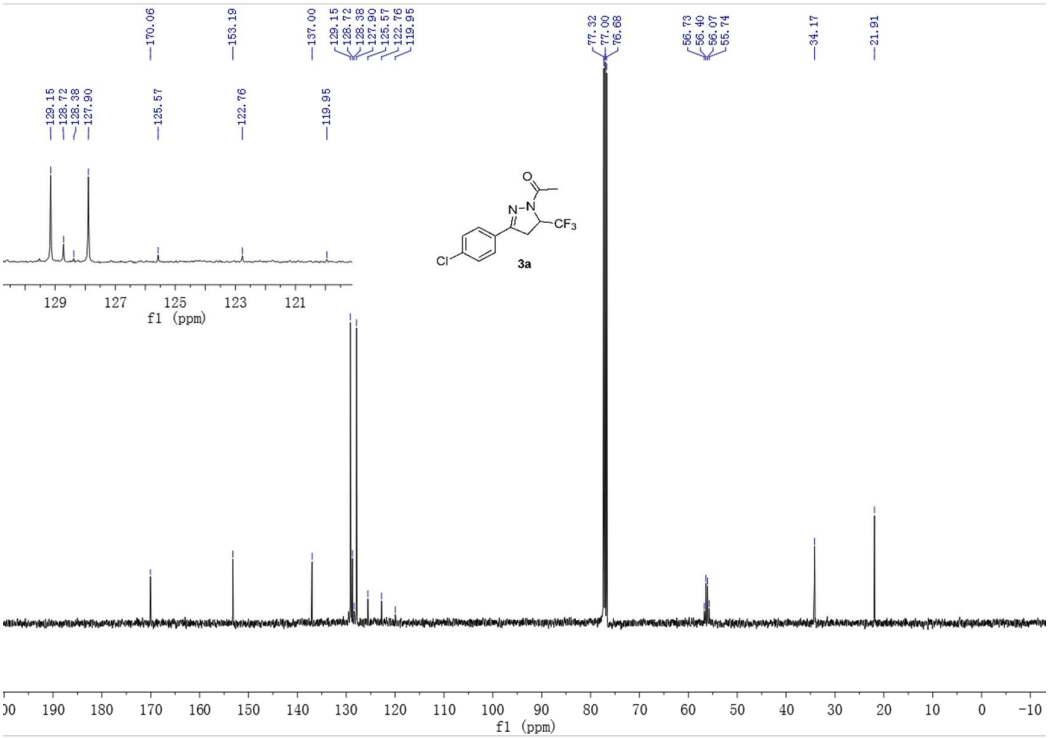


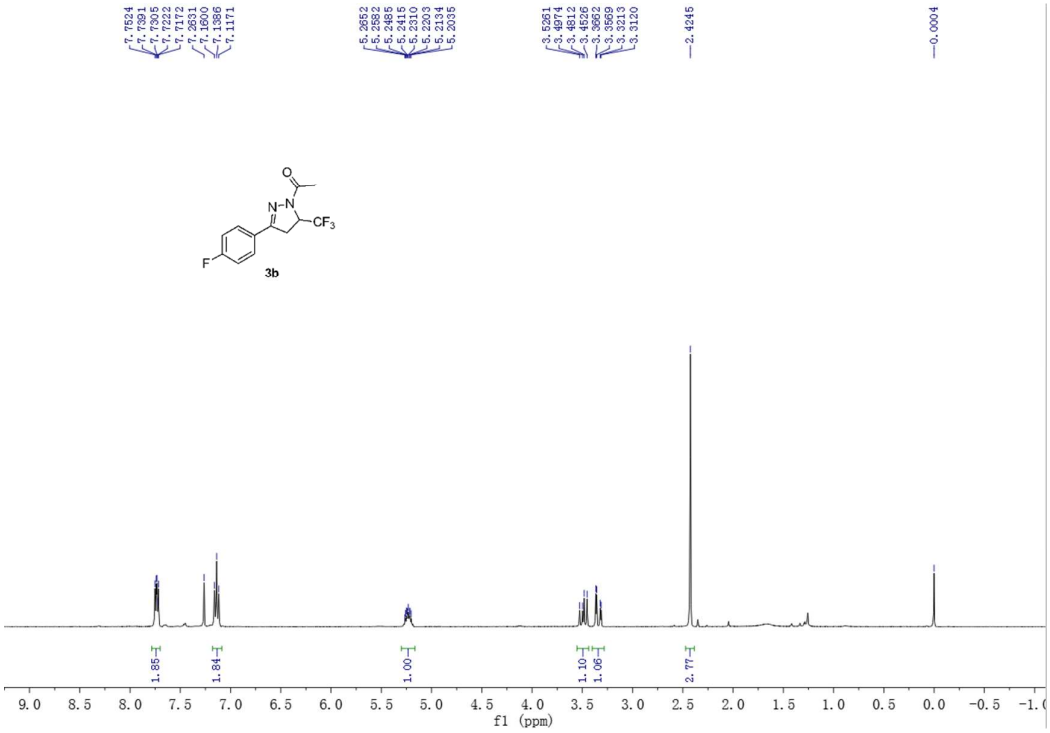
(3-(4-Chlorophenyl)-5-(trifluoromethyl)-4,5-dihydro-1*H*-pyrazol-1-yl)(phenyl)metha none (**3s**)

Yellow solid (19 mg, 36% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03–7.98 (m, 2H), 7.59 (d, *J* = 8.6 Hz, 2H), 7.53 (t, *J* = 7.3 Hz, 1H), 7.46 (t, *J* = 7.4 Hz, 2H), 7.37 (d, *J* = 8.6 Hz, 2H), 5.60–5.50 (m, 1H), 3.51 (dd, *J* = 18.0, 11.6 Hz, 1H), 3.37 (dd, *J* = 18.0, 4.2 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.23, 153.65, 136.97, 133.06, 131.67, 130.20, 129.08, 128.65, 128.02, 127.74, 124.39 (q, *J* = 282.6 Hz), 56.96 (q, *J* = 32.5 Hz), 33.42. HRMS (ESI) calcd for $C_{17}H_{11}ClF_3N_2O$ $[M - H]^-$ 351.0517, found 351.0516.

3. NMR spectra of compounds 3



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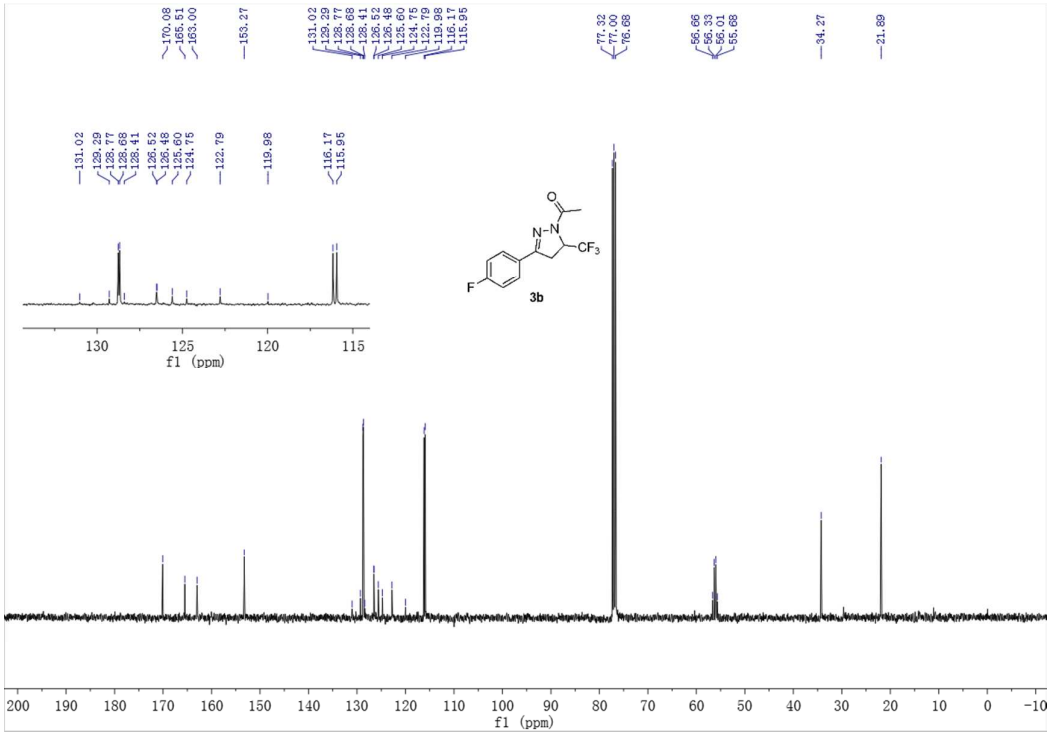
f1 (ppm)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CF3
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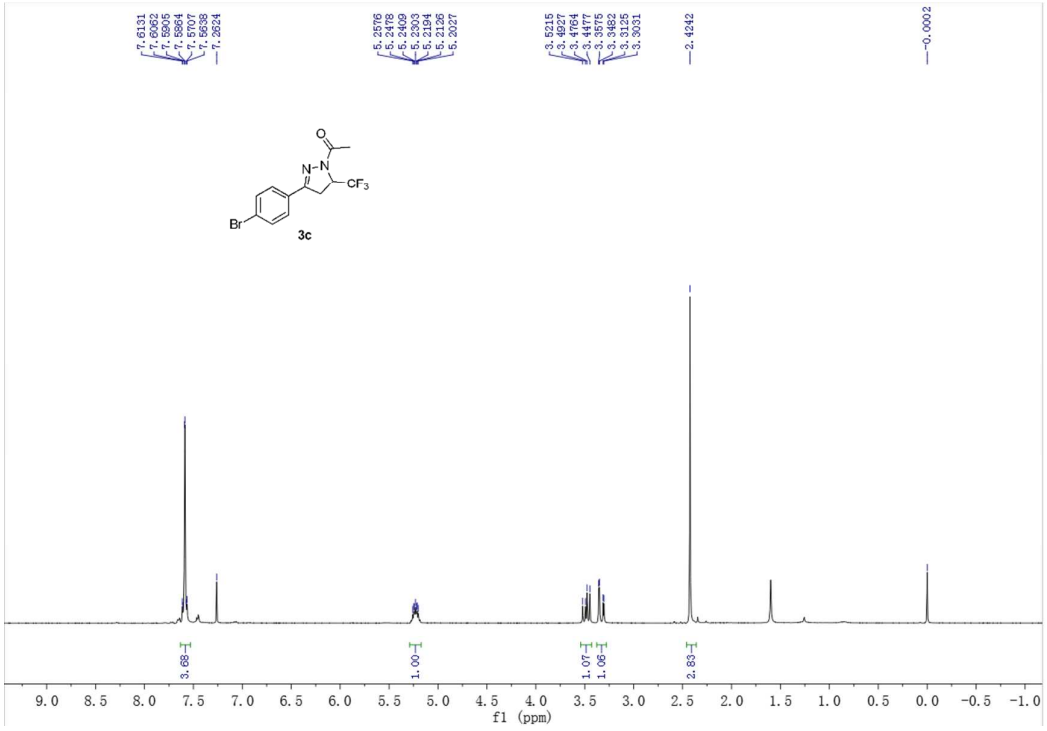
3b
f1 (ppm)
f1 (ppm)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N
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Br
3c
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1.00
1.07
1.06
2.83
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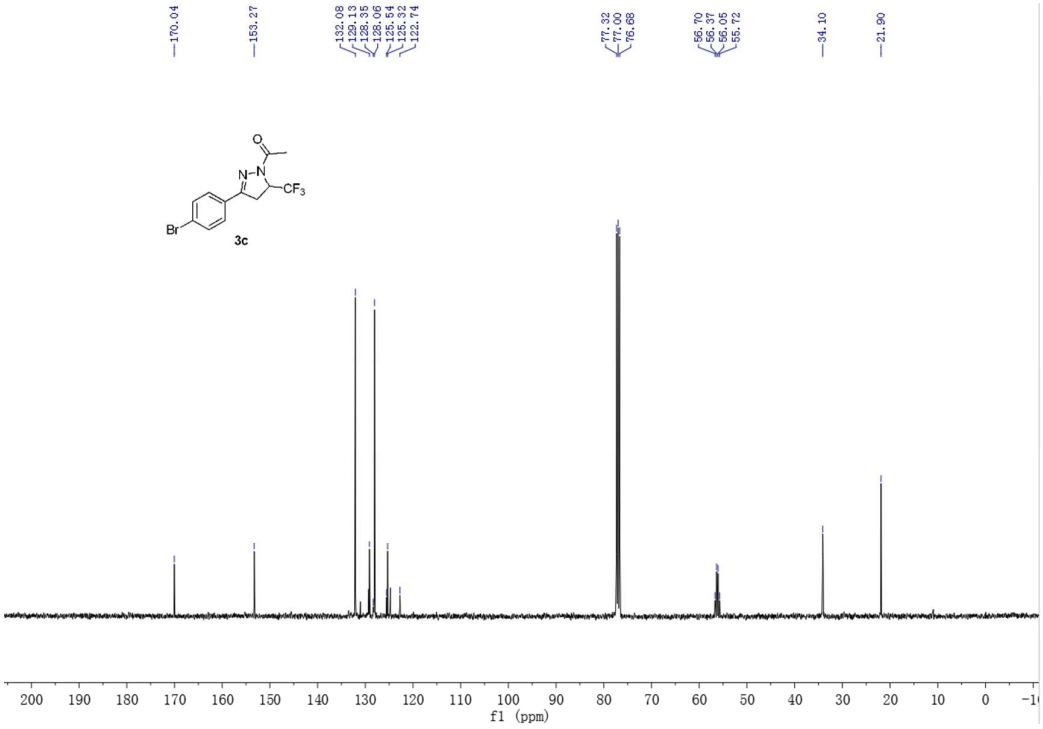
f1 (ppm)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56.05
55.72
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N
CF3
Br
3c
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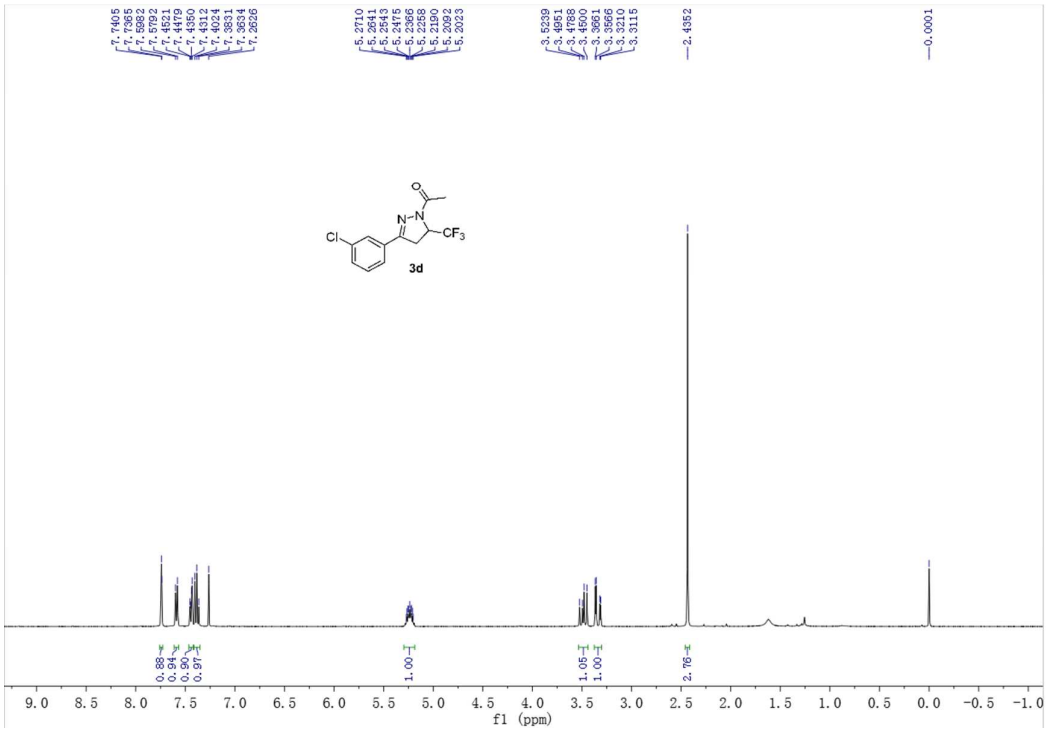
f1 (ppm)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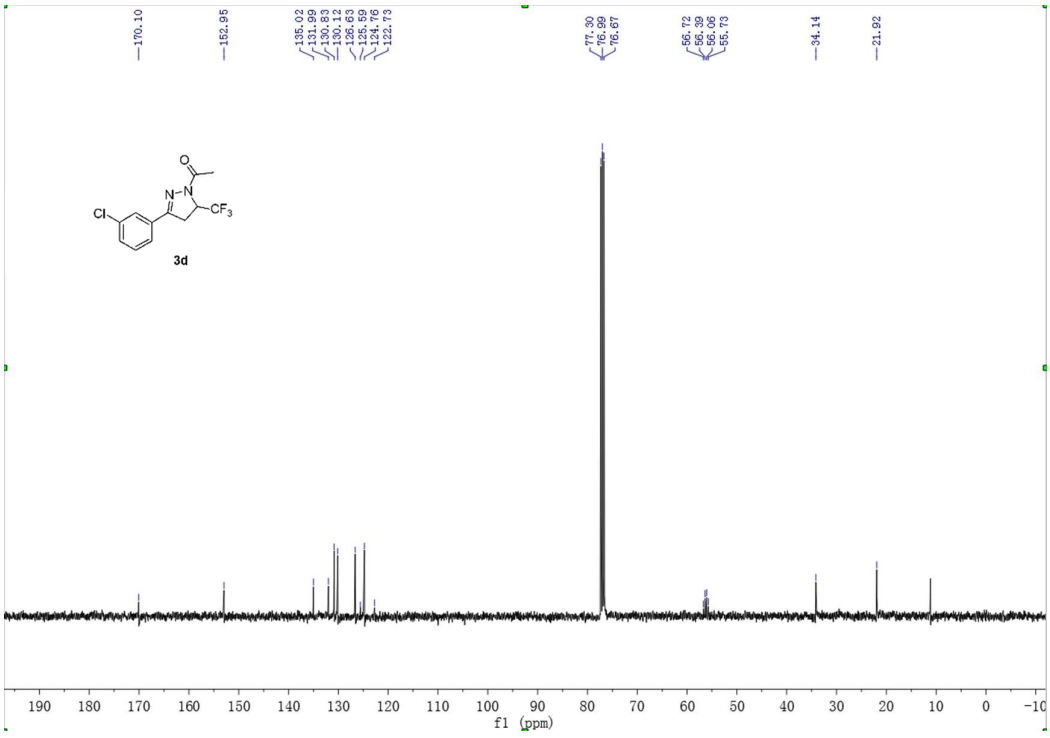
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Cl
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N
O
CF3
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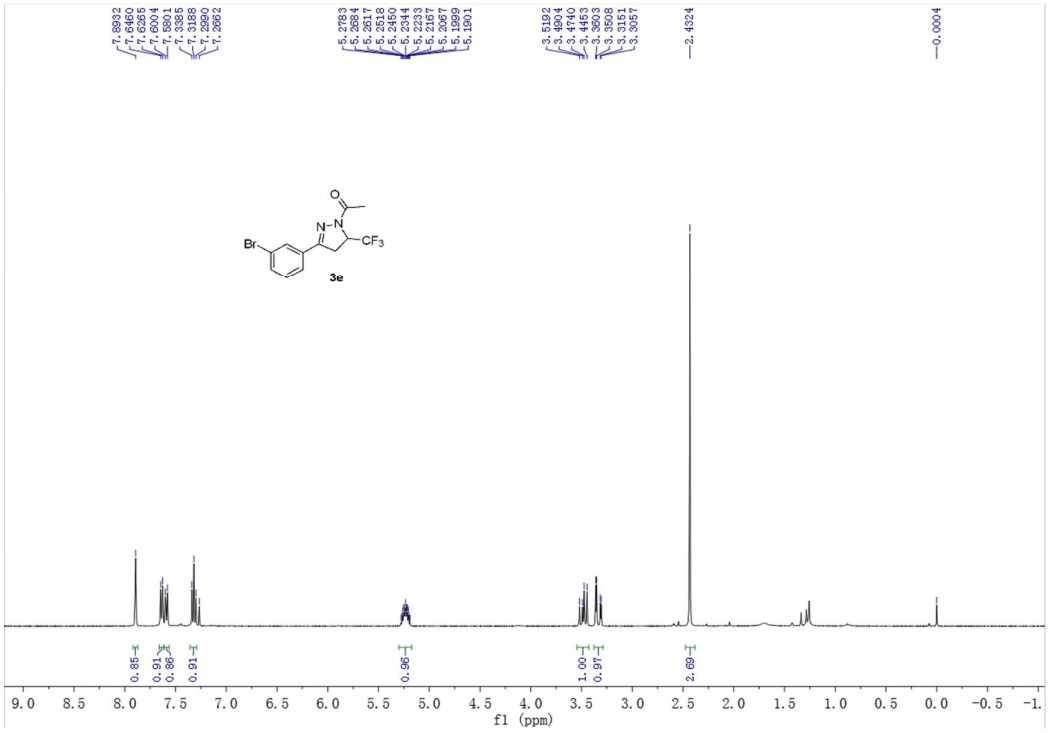
f1 (ppm)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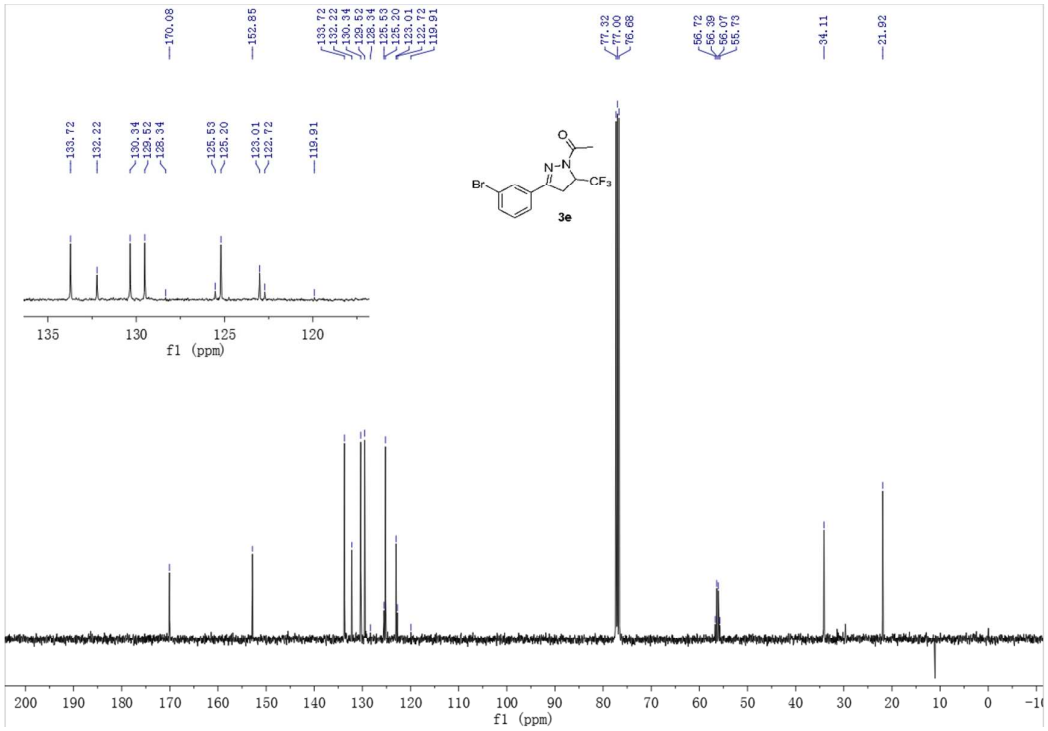
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Br
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f1 (ppm)
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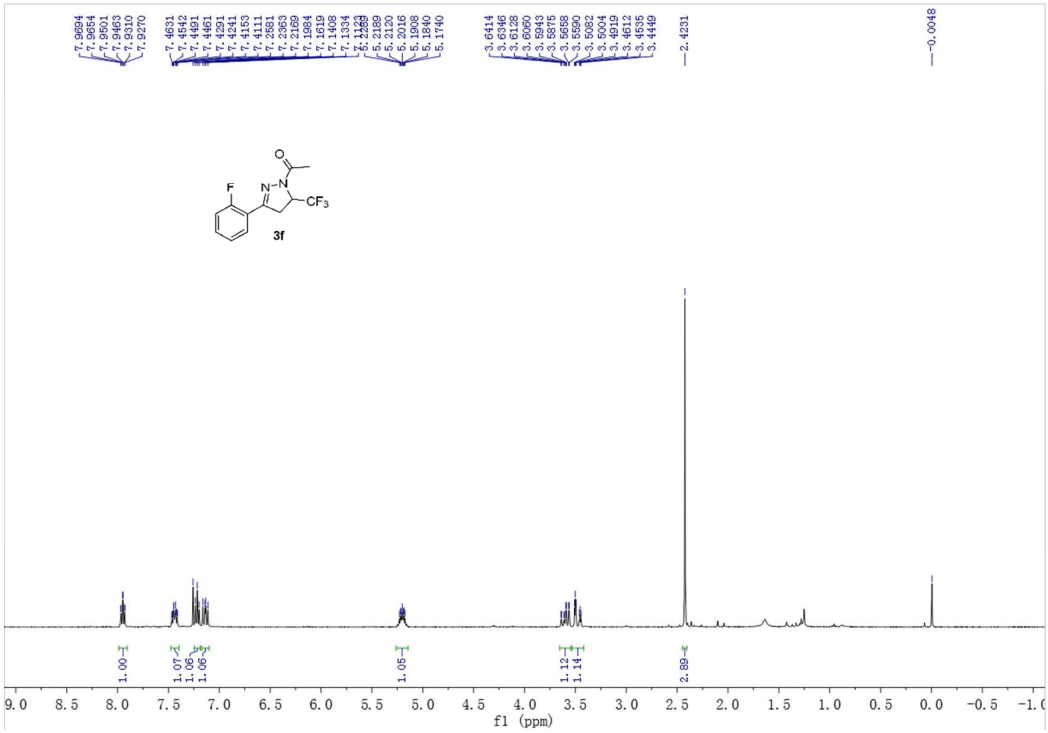
f1 (ppm)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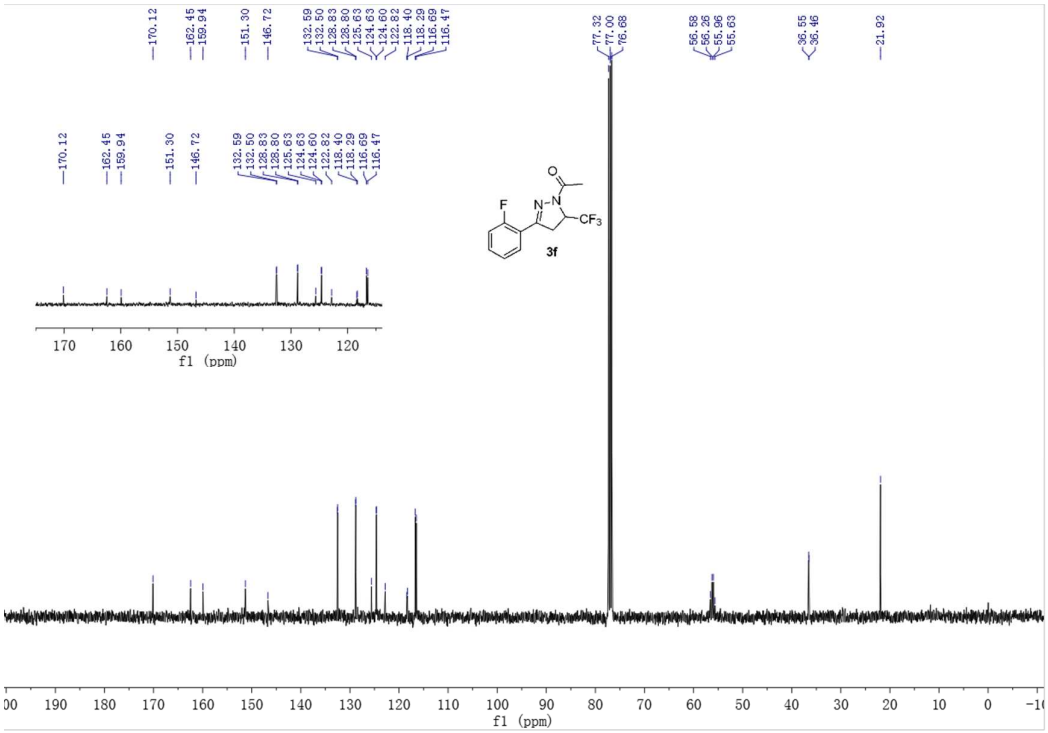
f1 (ppm)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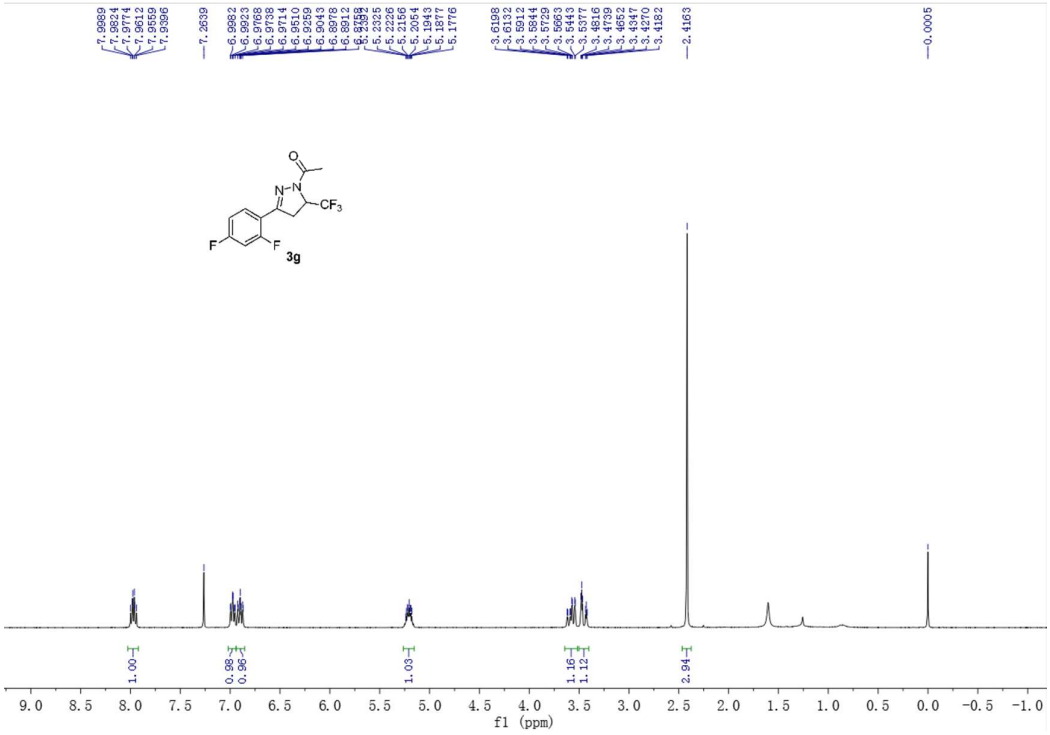
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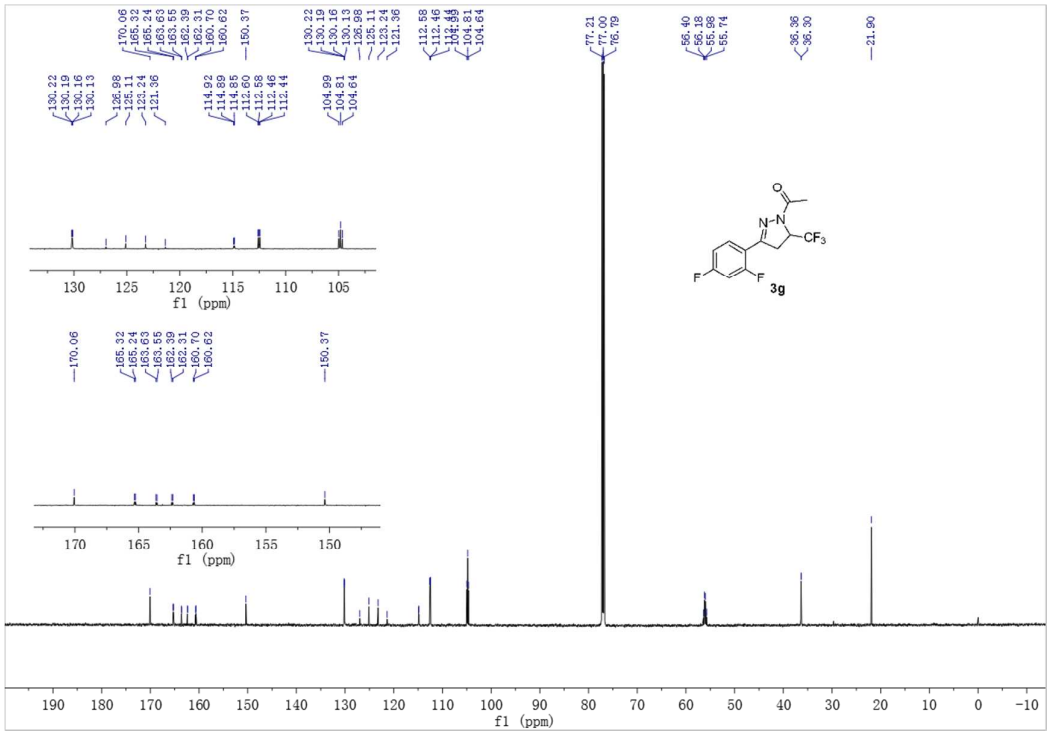
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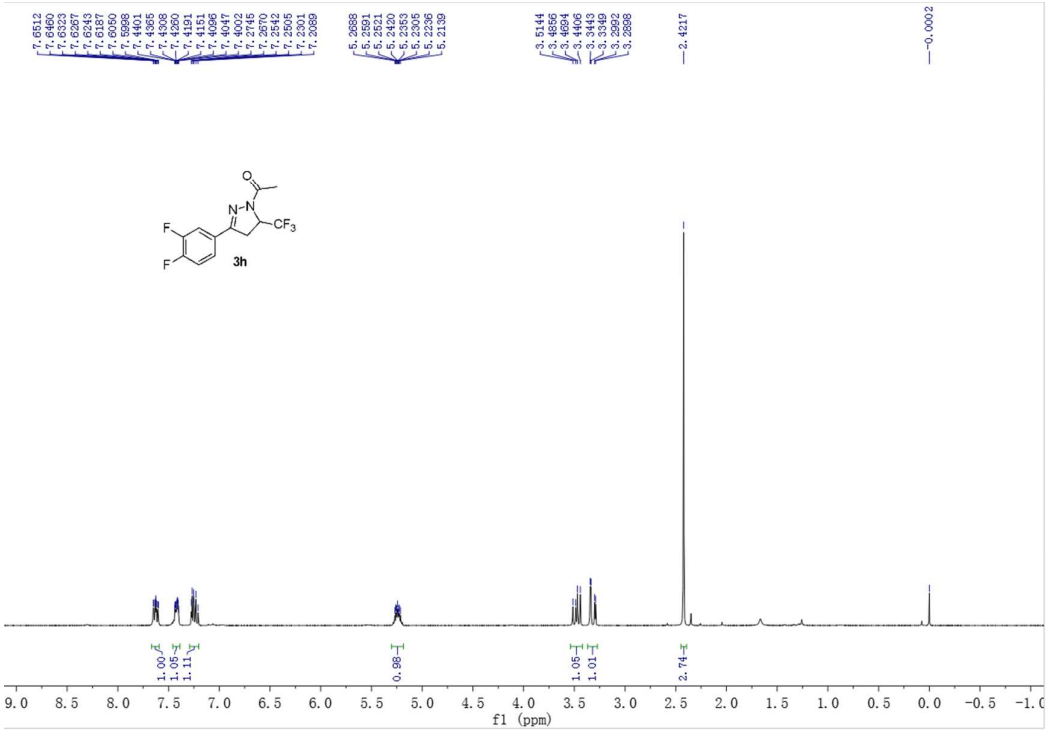
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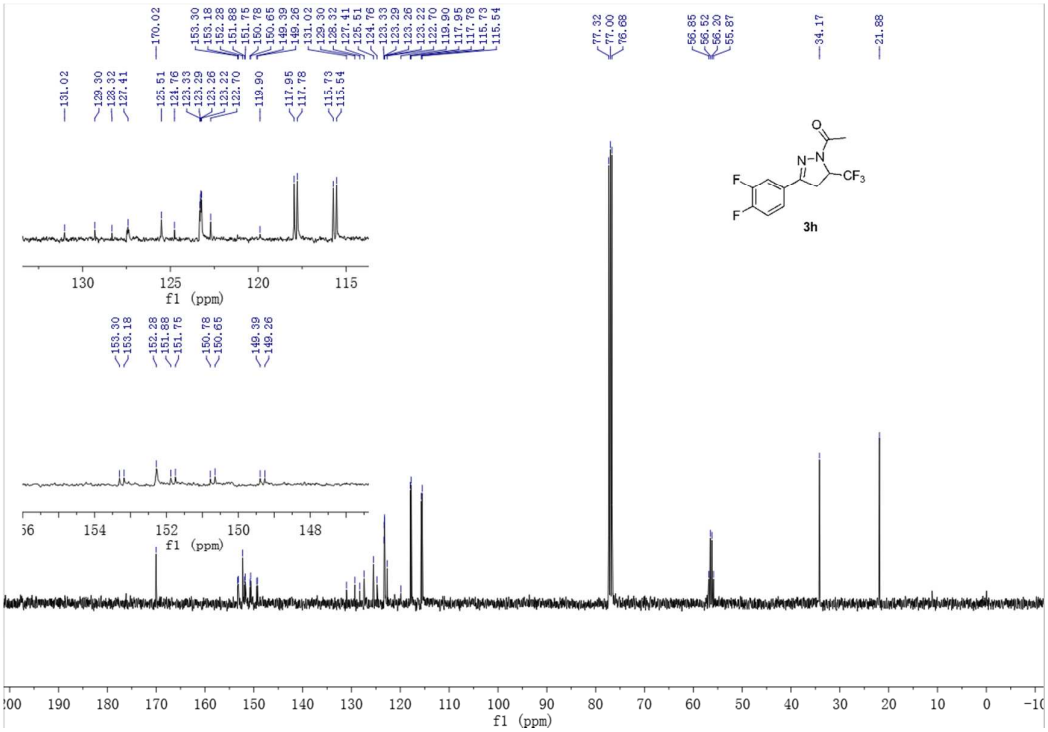
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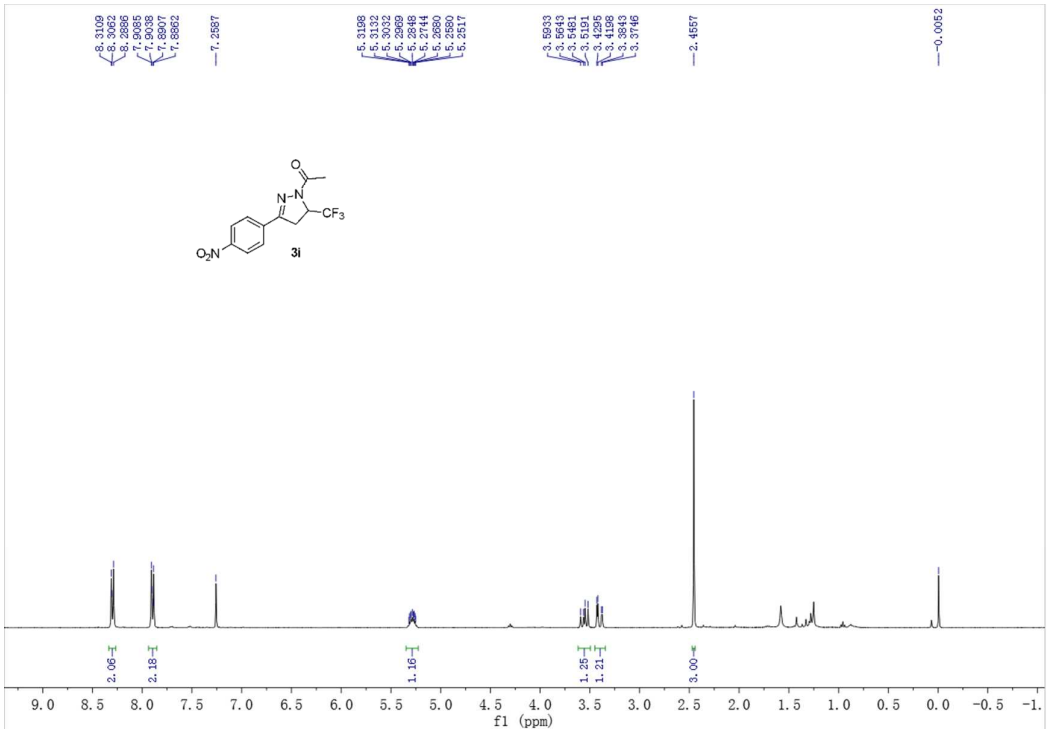
f1 (ppm)
f1 (ppm)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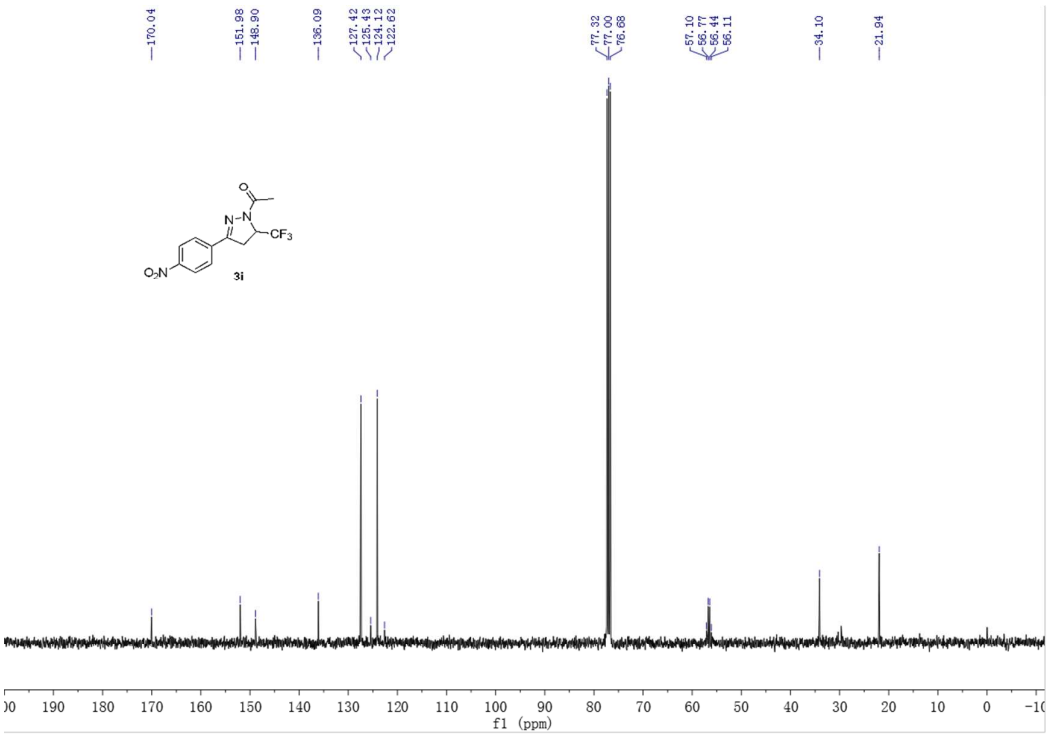
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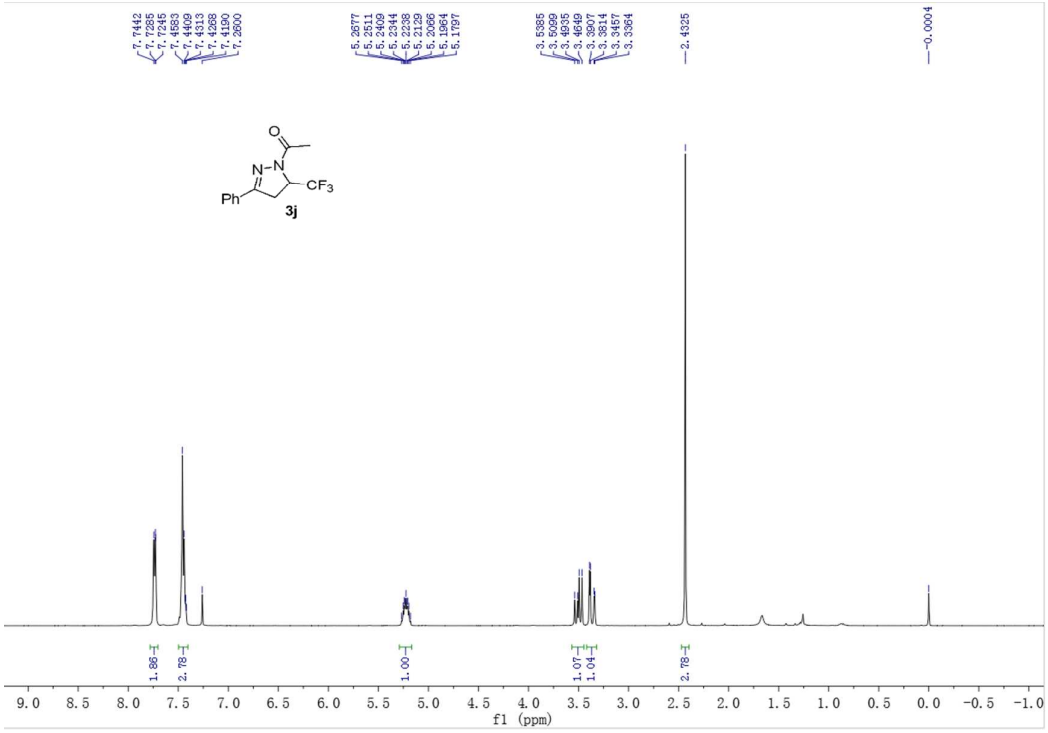
f1 (ppm)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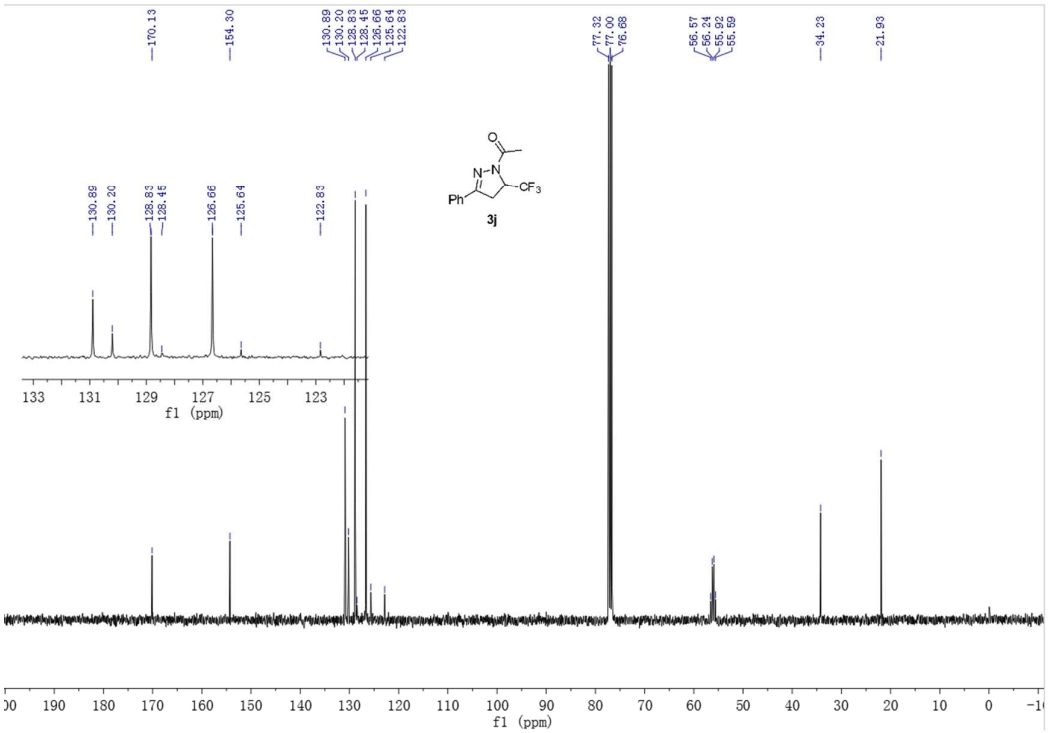
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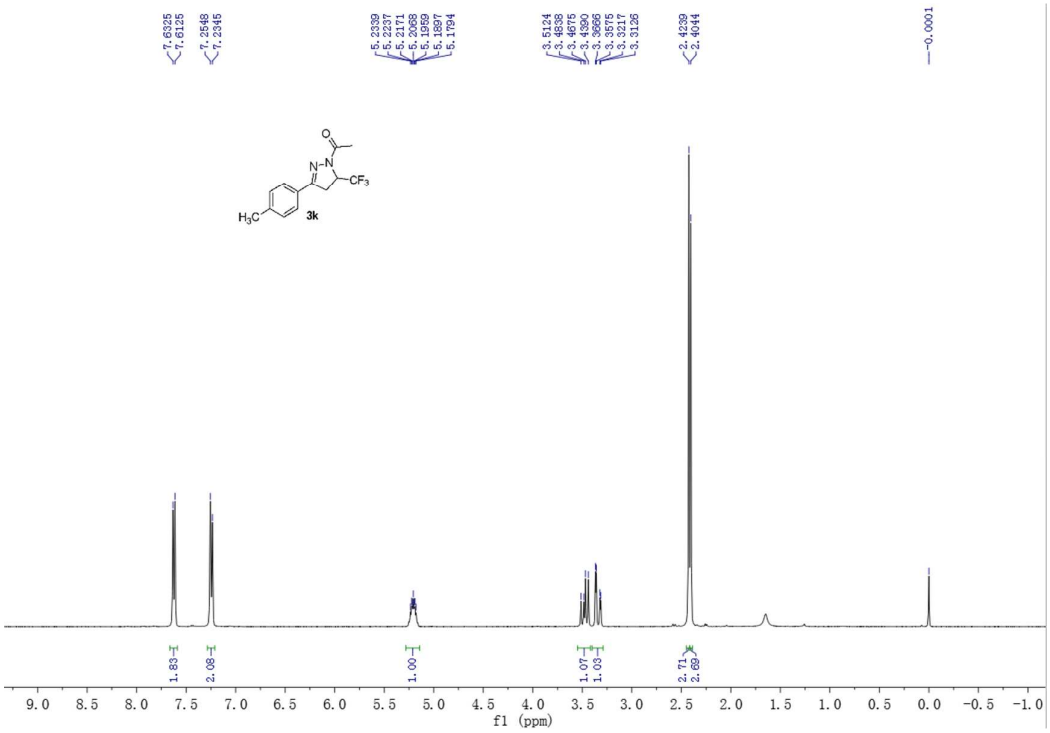
f1 (ppm)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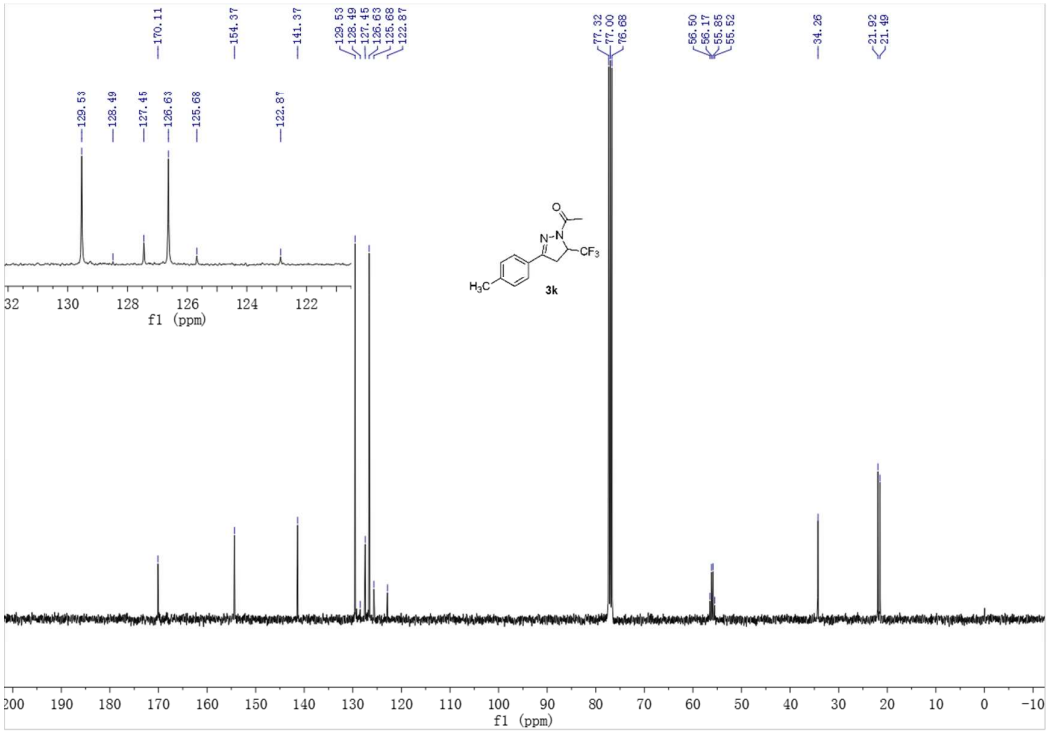
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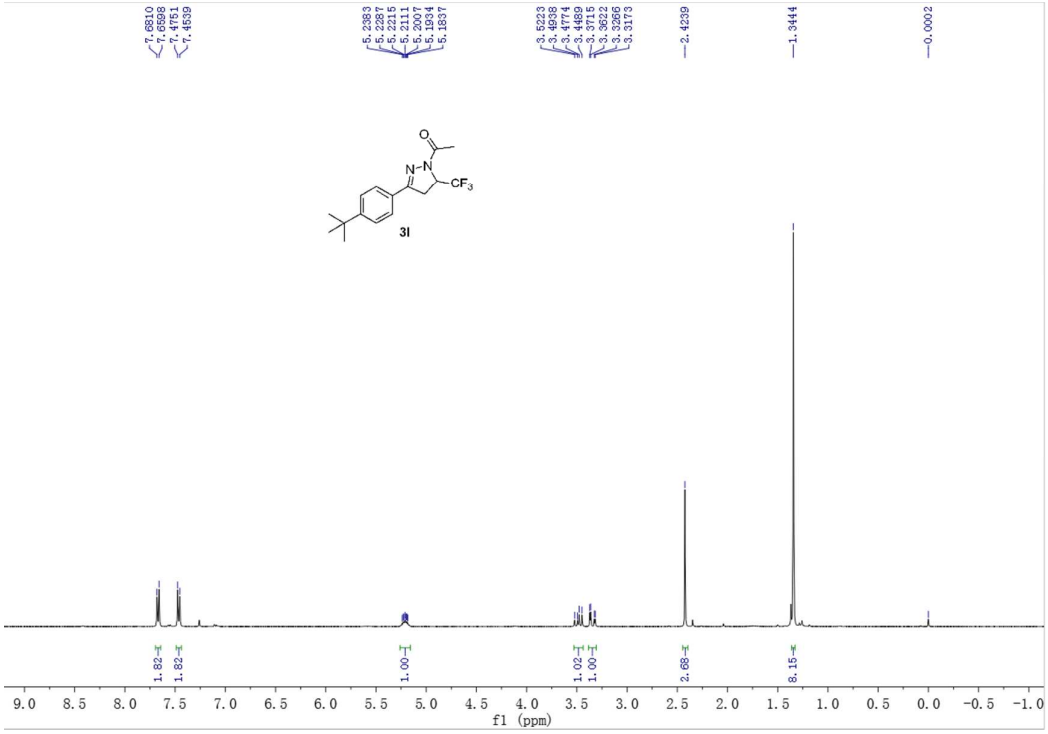
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7.4751
7.4539
5.2383
5.2287
5.2215
5.2111
5.2007
5.1934
5.1837
3.5223
3.4938
3.4774
3.4459
3.3715
3.3622
3.3266
3.3173
2.4239
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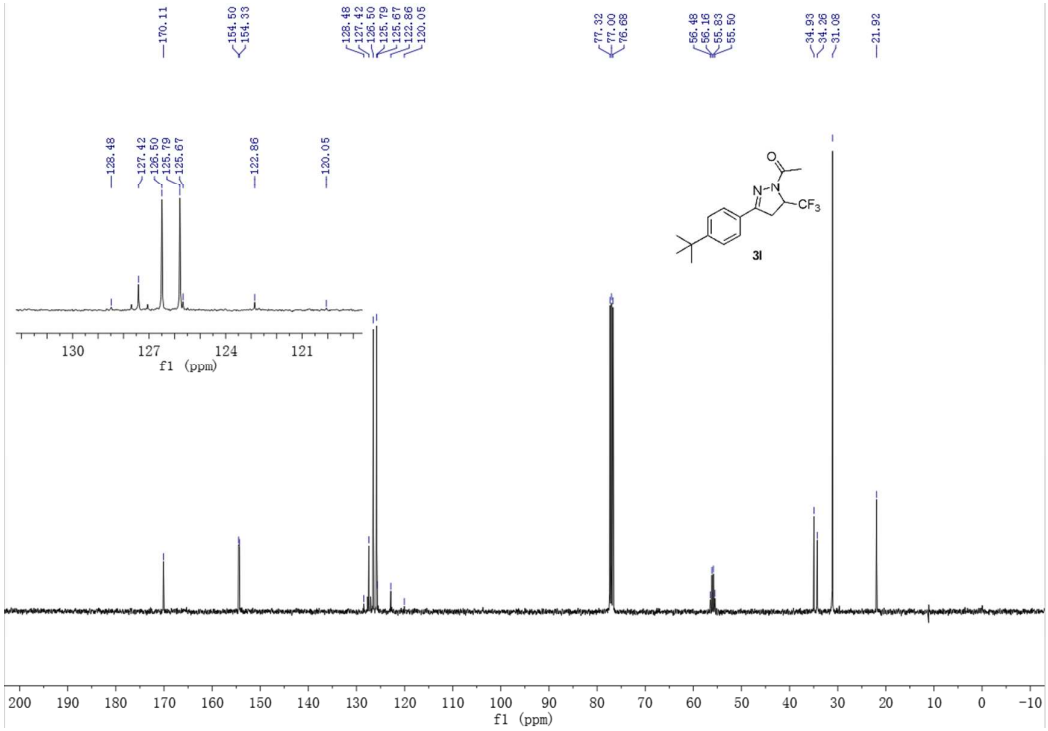
1.82
1.00
1.02
1.00
2.68
8.15
3l
f1 (ppm)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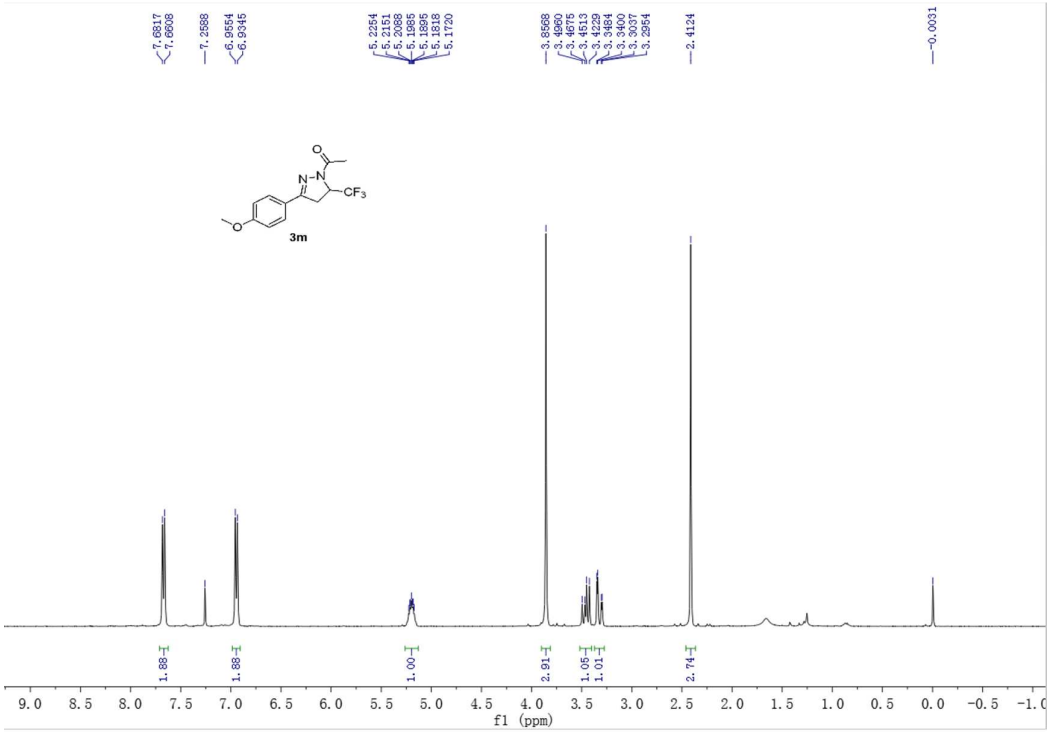
154.50
154.33
128.48
127.42
126.50
125.79
125.67
122.86
120.05
77.32
77.00
76.68
56.48
56.16
55.83
55.50
34.93
34.26
31.08
21.92
3l
f1 (ppm)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7.2588
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6.9345
5.2254
5.2151
5.2088
5.1985
5.1885
5.1818
5.1720
3.8568
3.4960
3.4675
3.4513
3.4229
3.3484
3.3400
3.3037
3.2954
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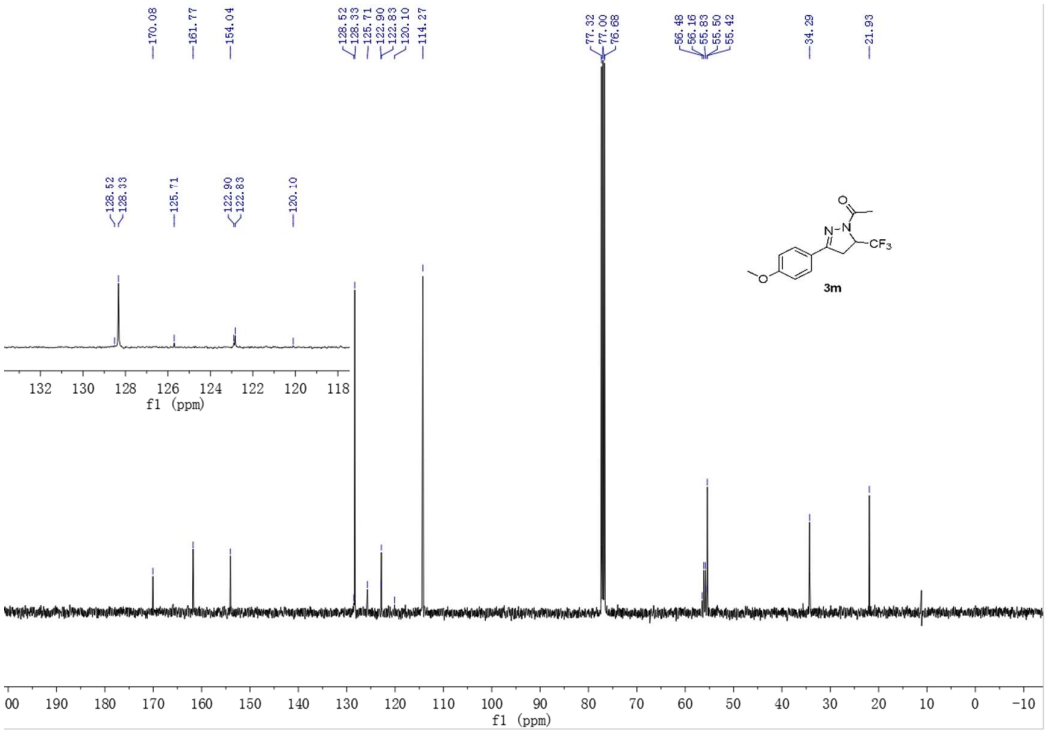
0.0031
3m
1.88
1.88
1.00
2.91
1.05
1.01
2.74
f1 (ppm)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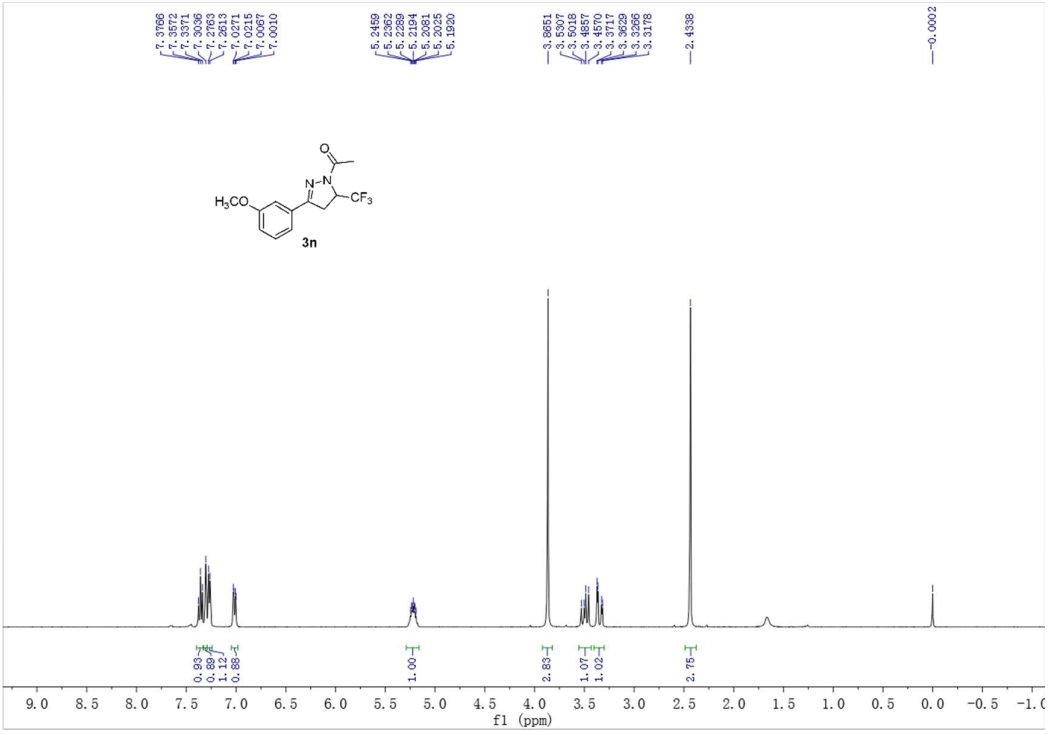
154.04
128.52
128.33
125.71
122.90
122.83
120.10
114.27
77.32
77.00
76.68
56.48
56.16
55.83
55.50
55.42
34.29
21.93
3m
f1 (ppm)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7.0271
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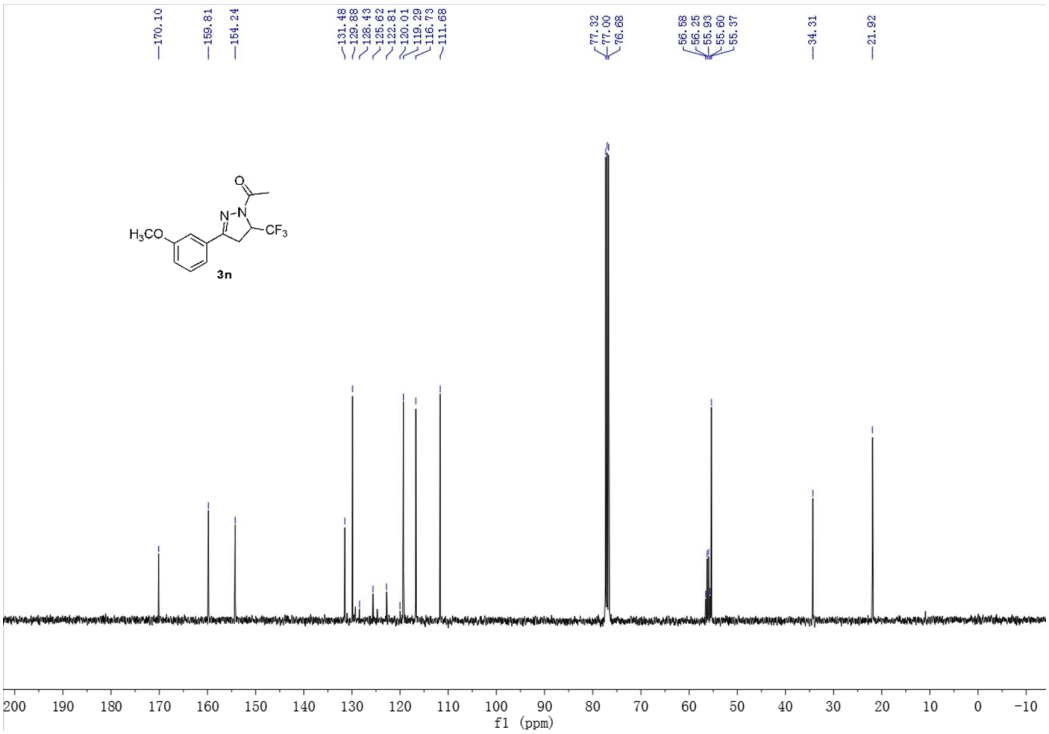
7.0010
5.2459
5.2362
5.2289
5.2194
5.2081
5.2025
5.1920
3.8651
3.5307
3.5018
3.4857
3.4570
3.3717
3.3629
3.3266
3.3178
2.4338
-0.0002
O
N
N
H3CO
CF3
3n
0.93
0.89
1.12
0.88
1.00
2.83
1.07
1.02
2.75
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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154.24
131.48
129.88
128.43
125.62
122.81
120.01
119.29
116.73
111.68
77.32
77.00
76.68
56.58
56.25
55.93
55.60
55.37
34.31
21.92
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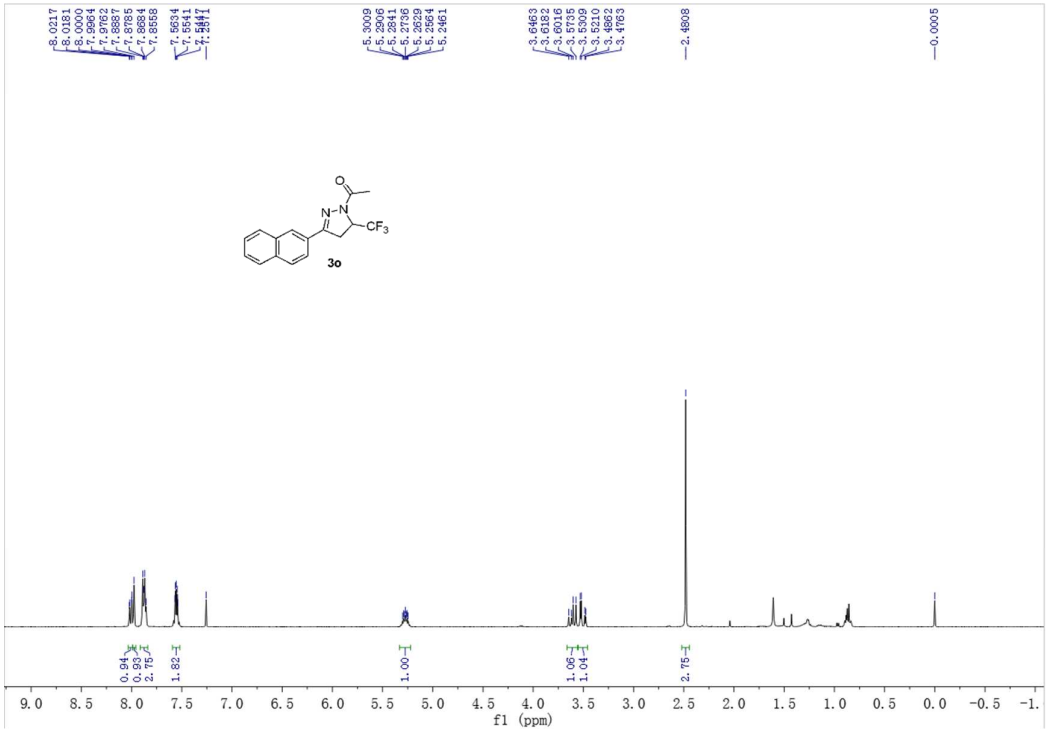
N
H3CO
CF3
3n
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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7.8785
7.8684
7.8558
7.5634
7.5541
7.5441
7.5411
5.3009
5.2906
5.2841
5.2736
5.2629
5.2564
5.2461
3.6463
3.6182
3.6016
3.5735
3.5309
3.5210
3.4852
3.4763
2.4808
0.0005
0.94
0.93
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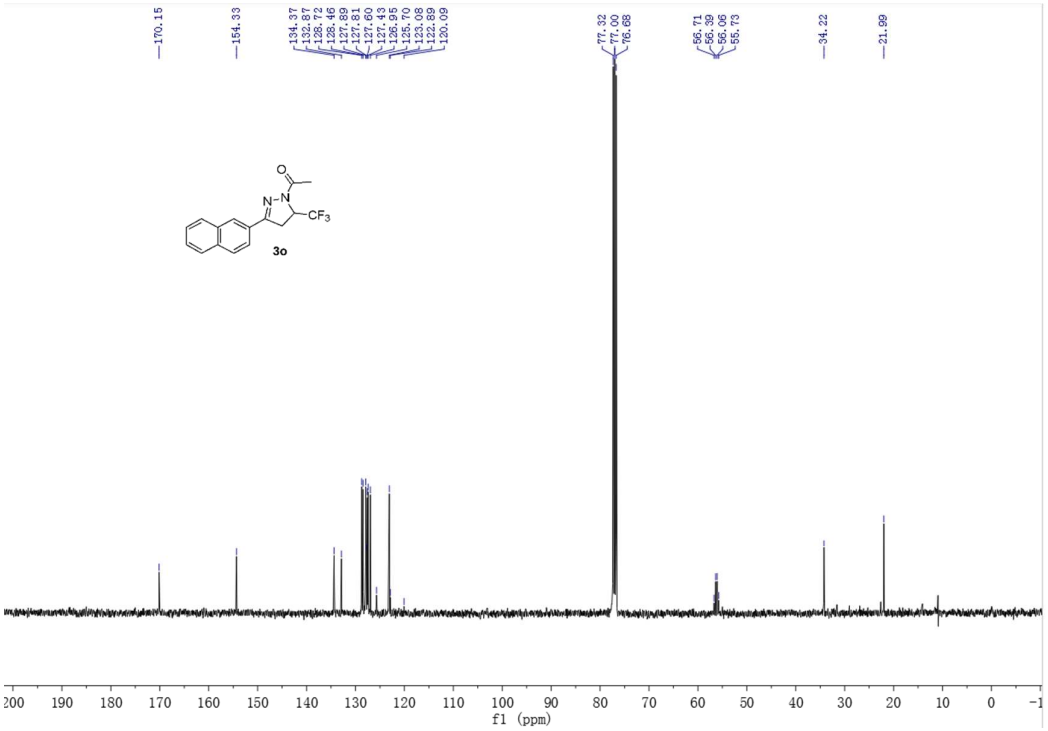
1.82
1.00
1.06
1.04
2.75
3o
f1 (ppm)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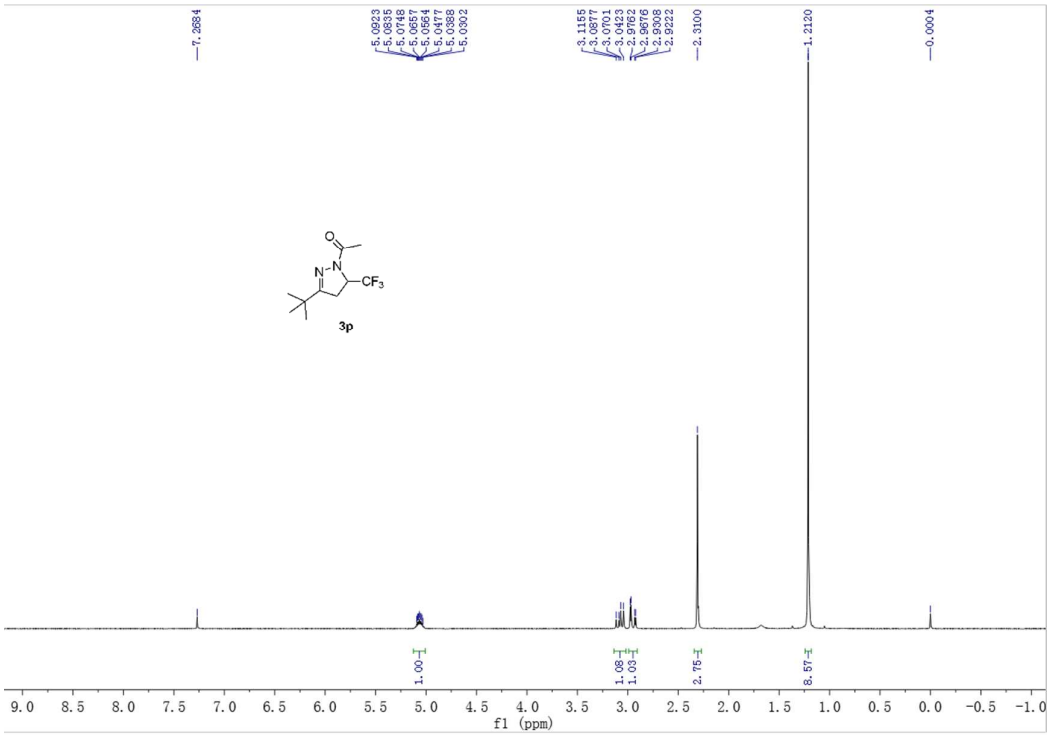
134.37
132.87
128.72
128.46
127.89
127.81
127.60
127.43
126.95
125.70
123.08
122.89
120.09
77.32
77.00
76.68
56.71
56.39
56.06
55.73
34.22
21.99
3o
f1 (ppm)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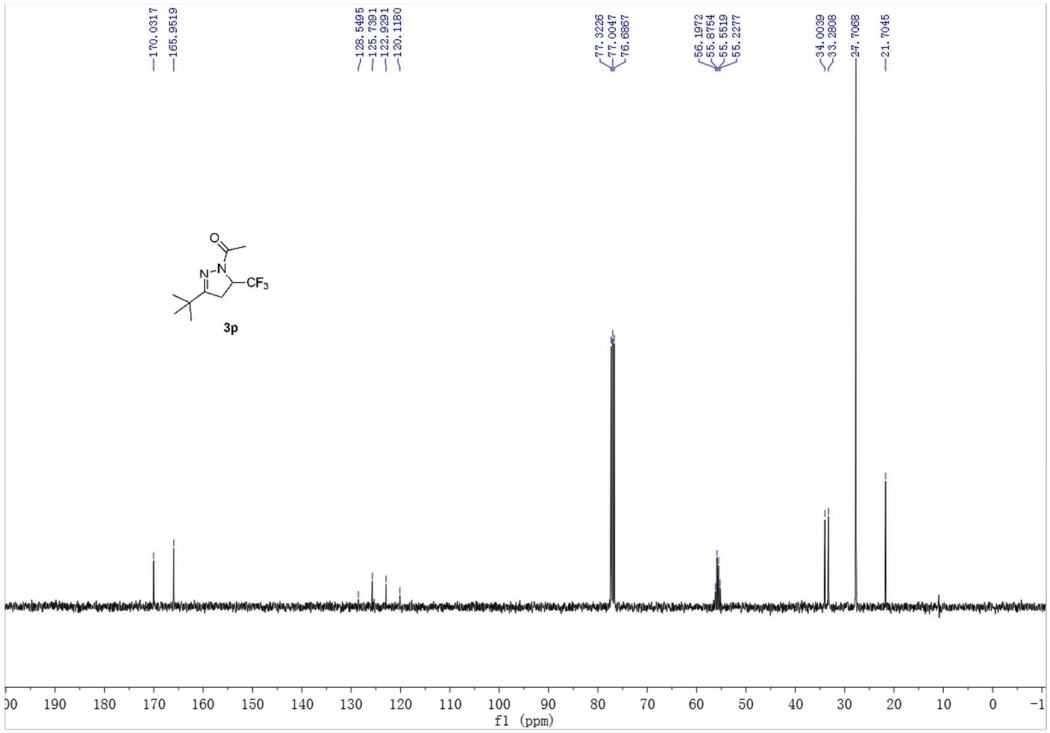
5.0835
5.0748
5.0657
5.0564
5.0477
5.0388
5.0302
3.1155
3.0877
3.0701
3.0483
2.9762
2.9676
2.9308
2.9222
2.3100
1.2120
0.0004
1.00
1.08
1.03
2.75
8.57
f1 (ppm)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125.7391
122.9291
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77.0047
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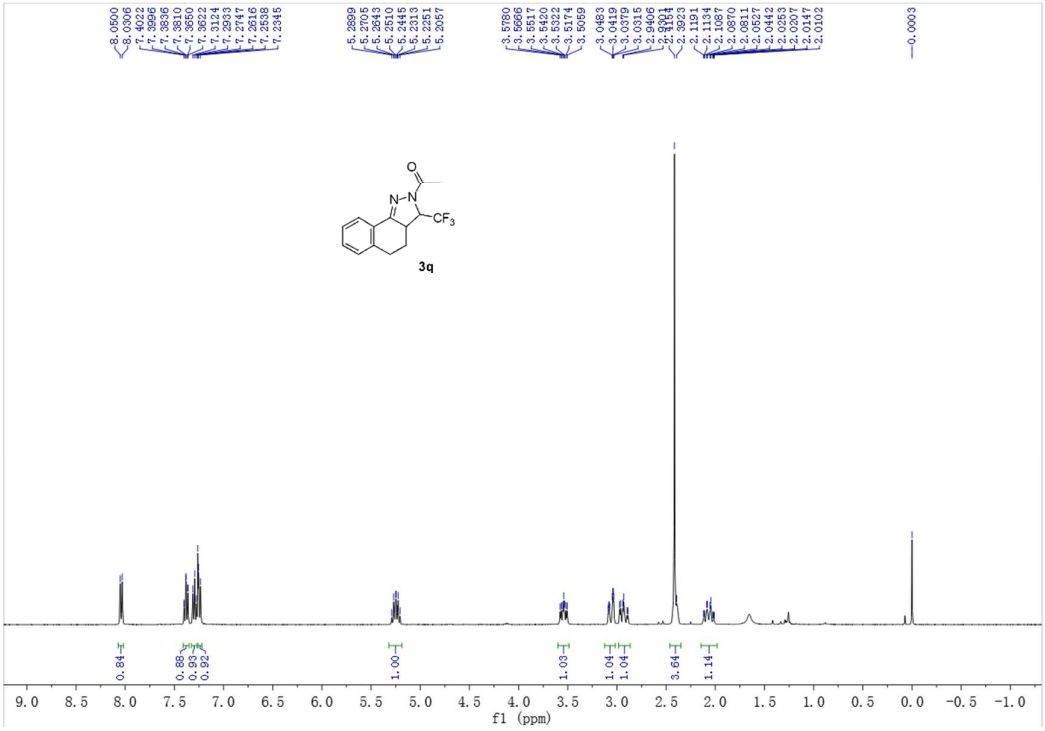
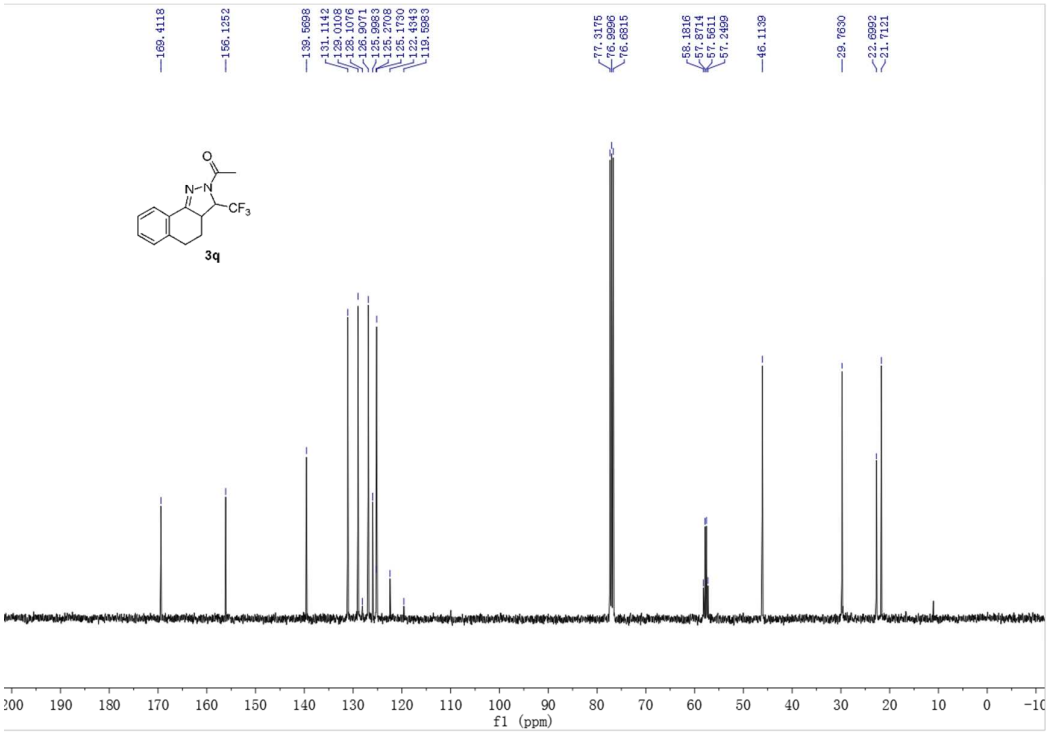
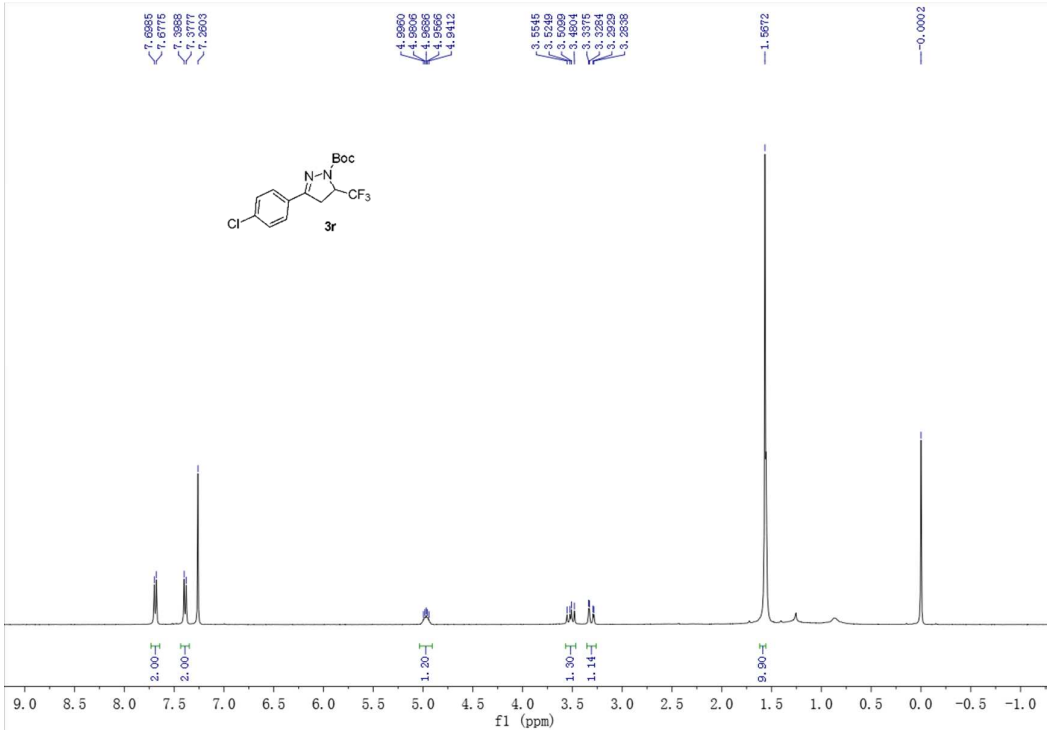
55.5519
55.2277
34.0039
33.2808
27.7068
21.7045
f1 (ppm)


3q
f1 (ppm)


3q
f1 (ppm)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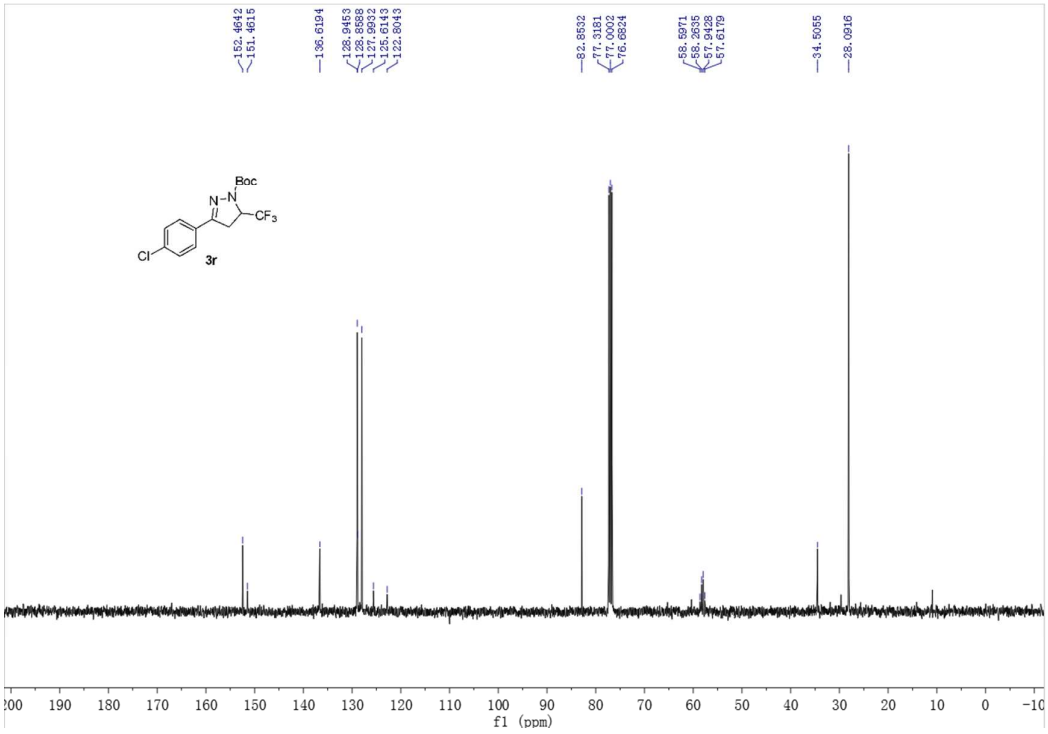
3.5545
3.5240
3.5069
3.4804
3.3375
3.3284
3.2929
3.2838
1.5672
-0.0002
Boc
N-N
CF3
Cl
3r
2.00
2.00
1.20
1.30
1.14
9.90
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)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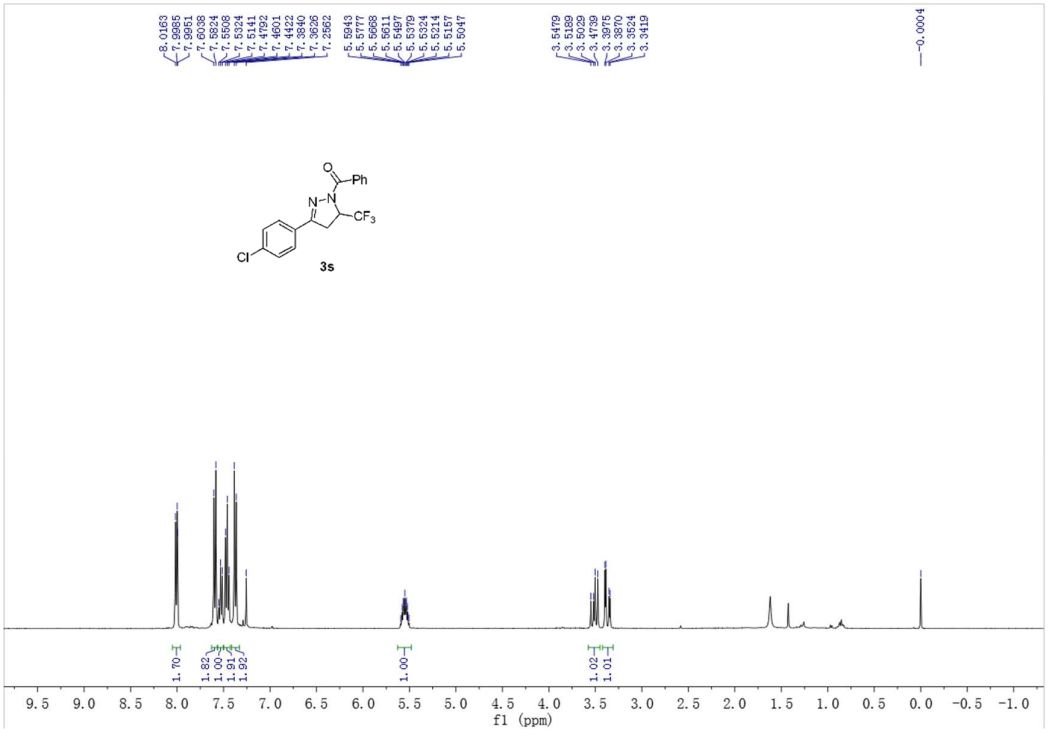
151.4615
136.6194
128.9453
128.8588
127.9932
125.6143
122.8043
82.8532
77.3181
77.0002
76.6824
58.5971
58.2635
57.9428
57.6179
34.5055
28.0916
Boc
N-N
CF3
Cl
3r
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)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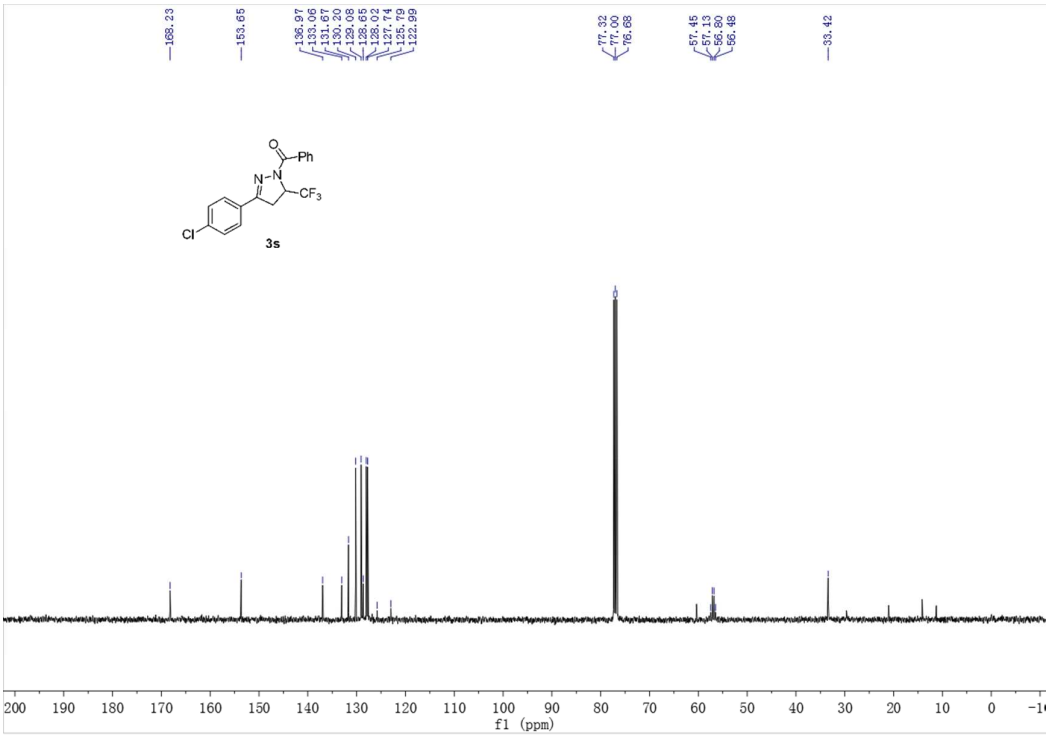
7.9961
7.6038
7.5824
7.5596
7.5324
7.5141
7.4792
7.4601
7.4422
7.3840
7.3626
7.2562
5.5943
5.5777
5.5688
5.5611
5.5497
5.5379
5.5274
5.5214
5.5157
5.5047
3.5479
3.5189
3.5029
3.4739
3.3975
3.3870
3.3524
3.3419
-0.0004
Ph
N
N
CF3
Cl
3s
1.70
1.82
1.00
1.91
1.92
1.00
1.02
1.01
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)


168.23
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131.67
130.20
129.08
128.65
128.02
127.74
125.79
122.99
77.32
77.00
76.68
57.45
57.13
56.80
56.48
33.42
Ph
N
N
CF3
Cl
3s
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)