Advanced Synthesis & Catalysis

Supporting Information

A Copper-Catalyzed Sonogashira Coupling Reaction of Diverse Activated Alkyl Halides with Terminal Alkynes Under Ambient Conditions

Yu-Xi Cao, Xiao-Yang Dong, Jun Yang, Sheng-Peng Jiang, Shuangliu Zhou, Zhong-Liang Li,* Guo-Qiang Chen,* and Xin-Yuan Liu*

Supporting Information

A Copper-Catalyzed Sonogashira Coupling Reaction of Diverse Activated Alkyl Halides with Terminal Alkynes Under Ambient Conditions

Yu-Xi Cao,[a] Xiao-Yang Dong,[b] Jun Yang,[b,d] Sheng-Peng Jiang,[b] Shuangliu Zhou,[d] Zhong-Liang Li,[c,*] Guo-Qiang Chen,[a,*] and Xin-Yuan Liu[b,*]

[a] College of Chemistry and Environmental Engineering, Shenzhen University, 1066 Xueyuan Road, Shenzhen, China

[b] Shenzhen Grubbs Institute and Department of Chemistry, Guangdong Provincial Key Laboratory of Catalytic Chemistry, Southern University of Science and Technology, Shenzhen, 518055, China

[c] Academy for Advanced Interdisciplinary Studies and Department of Chemistry, Southern University of Science and Technology, Shenzhen, 518055, China

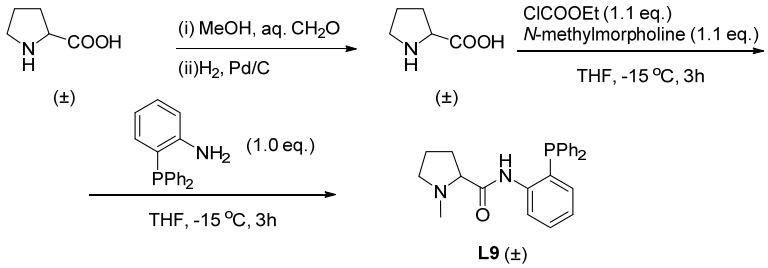
[d] College of Chemistry and Materials Science, Anhui Normal University, Wuhu, Anhui 241000, China.

General information

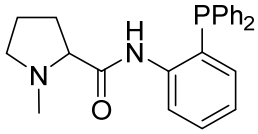
Unless otherwise noted, most of reactions were performed under argon atmosphere using Schlenk techniques. Analytical thin layer chromatography (TLC) was performed on precoated silica gel 60 GF254 plates. Flash column chromatography was performed using Tsingdao silica gel (60, particle size 0.040-0.063 mm). NMR spectra were recorded on Bruker DRX-500 and DPX 400 spectrometer at 400 or 500 MHz for ^{1}H NMR, 100 or 125 MHz for ^{13}C NMR and 376 MHz for ^{19}F NMR in $CDCl_3$. Chemical shifts (δ values) were reported in ppm downfield from internal TMS for ^{1}H NMR, $CDCl_3$ for ^{13}C NMR, and external 85% H_3PO_4 for ^{31}P NMR, respectively. Mass spectrometric data were obtained using Bruker Apex IV RTMS. The solvents were purified by following standard procedures[1].

General Procedure

Synthesis of Ligand L9

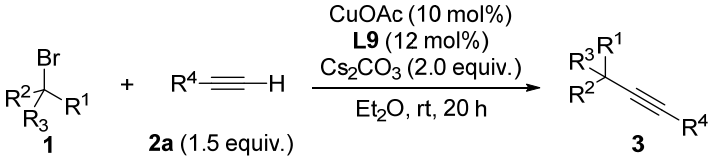


L9 was synthesized according to reported literature[2]. (*S*)-**L9** was synthesized in a similar procedure from L-proline.



^{1}H NMR (400 MHz, $CDCl_3$) δ 10.10 (s, 1H), 8.33 – 8.26 (m, 1H)., 7.45 – 7.19 (m, 11H), 7.00 (t, *J* = 8.1 Hz, 1H), 6.86 – 6.69 (m, 1H), 2.99 – 2.88 (m, 2H), 2.33 – 2.21 (m, 1H), 2.18 (s, 3H), 2.16 – 2.06 (m, 1H), 1.75 – 1.56 (m, 2H), 1.52 – 1.39 (m, 1H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 173.1, 173.1, 140.7, 140.5, 134.9, 134.8, 134.8, 134.1, 134.0, 133.9, 133.8, 133.2, 129.9, 129.2, 128.8, 128.7, 128.7, 128.7, 126.6, 126.5, 124.3, 121.1, 121.1, 69.3, 56.5, 41.5, 31.1, 24.5.
^{31}P NMR (162 MHz, $CDCl_3$) δ -17.5.

Typical Procedure

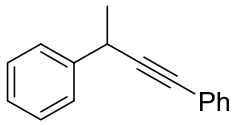


To a 10-mL Schlenk tube was added CuOAc (6.1 mg, 0.05 mmol), **L9** (23.3 mg, 0.06

mmol), Cs_2CO_3 (1.0 mmol), and anhydrous Et_2O (2.0 mL). Then, aryl bromide **1a** (0.5 mmol) and alkyne **2a** (0.75 mmol) were sequentially added into the mixture. The reaction mixture was stirred at room temperature for 20 h. After completion of the reaction as indicated by TLC, the precipitate was filtered off and concentrated in vacuo. The residue was purified by flash column chromatography on silica gel with PE to afford **3a**.

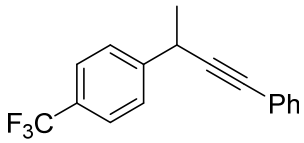
The synthesis of other products is the same as that described for synthesis of 3a, unless the scale is noted.

but-1-yne-1,3-diyldibenzene (3a)[3]



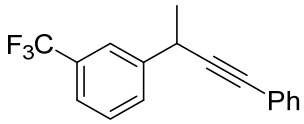
Compound **3a**: (90% yield, 93 mg, colorless oil,) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 – 7.47 (m, 4H), 7.46 – 7.27 (m, 6H), 4.06 (q, *J* = 7.1 Hz, 1H), 1.66 (d, *J* = 7.1 Hz, 3H).
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}$ $[M + H]^+$ 206.1090, found 206.1096.
87% yield from the reaction of the corresponding benzyl chloride and **2a**.

1-(4-phenylbut-3-yn-2-yl)-4-(trifluoromethyl)benzene (3b)



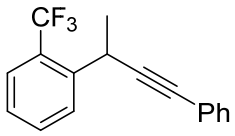
Compound **3b**: (72% yield, 98 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 – 7.53 (m, 4H), 7.47 – 7.42 (m, 2H), 7.34 – 7.28 (m, 3H), 4.04 (q, *J* = 7.2 Hz, 1H), 1.59 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 147.3, 131.6, 129.1 (q, *J* = 32.3 Hz), 128.3, 128.0, 127.4, 125.7 (q, *J* = 273.0 Hz), 125.5 (q, *J* = 3.7 Hz), 91.4, 83.1, 32.4, 24.3.
^{19}F NMR (376 MHz, $CDCl_3$) δ -62.4.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{14}F_3$ $[M + H]^+$ 275.1042, found 275.1036.

1-(4-phenylbut-3-yn-2-yl)-3-(trifluoromethyl)benzene (3c)



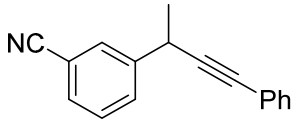
Compound **3c**: (78% yield, 106 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 – 7.62 (m, 2H), 7.54 – 7.41 (m, 4H), 7.34 – 7.28 (m, 3H), 4.05 (q, *J* = 7.1 Hz, 1H), 1.60 (d, *J* = 7.1 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 144.3, 131.6, 130.9 (q, *J* = 22.5 Hz), 130.4, 129.0, 128.3, 128.0, 125.6 (q, *J* = 272.0 Hz), 123.7 (dq, *J* = 15.8, 3.8 Hz), 123.6 (q, *J* = 3.9 Hz), 123.3, 91.4, 83.1, 32.4, 24.3.
^{19}F NMR (376 MHz, $CDCl_3$) δ -62.5.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{14}F_3$ $[M + H]^+$ 275.1042, found 275.1037.

1-(4-phenylbut-3-yn-2-yl)-2-(trifluoromethyl)benzene (3d)



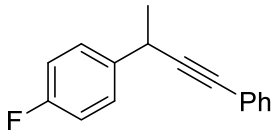
Compound **3d**: (51% yield, 70 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (d, *J* = 7.9 Hz, 1H), 7.64 – 7.51 (m, 2H), 7.44 – 7.40 (m, 2H), 7.37 – 7.26 (m, 4H), 4.37 (q, *J* = 7.0 Hz, 1H), 1.58 (d, *J* = 6.9 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) 142.7, 132.5, 132.3, 131.6, 129.5, 128.2, 127.9, 127.2 (q, *J* = 275.0 Hz), 126.7, 125.7 (q, *J* = 3.8 Hz), 123.4, 92.4, 81.7, 28.7, 25.1.
^{19}F NMR (376 MHz, $CDCl_3$) δ -59.0.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{14}F_3$ $[M + H]^+$ 275.1042, found 275.1037.

3-(4-phenylbut-3-yn-2-yl)benzonitrile (3e)



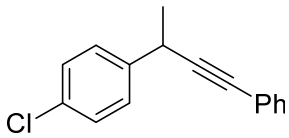
Compound **3e**: (73% yield, 84 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 – 7.74 (m, 1H), 7.70 – 7.66 (m, 1H), 7.56 – 7.52 (m, 1H), 7.47 – 7.42 (m, 3H), 7.33 – 7.28 (m, 3H), 4.02 (q, *J* = 7.1 Hz, 1H), 1.58 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 144.8, 131.7, 131.6, 130.7, 130.5, 129.4, 128.3, 128.2, 123.1, 118.9, 112.6, 90.8, 83.5, 32.2, 24.3.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{14}N$ $[M + H]^+$ 232.1121, found 232.1117.

1-fluoro-4-(4-phenylbut-3-yn-2-yl)benzene (3f)



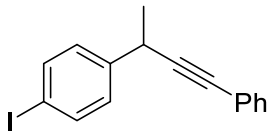
Compound **3f**: (62% yield, 68 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.37 (m, 4H), 7.33 – 7.22 (m, 3H), 7.02 (t, *J* = 8.7 Hz, 2H), 3.97 (q, *J* = 7.1 Hz, 1H), 1.56 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 160.5 (d, *J* = 245.0 Hz), 139.0, 131.6 (d, *J* = 8.4 Hz), 128.5 (d, *J* = 8.0 Hz), 128.3, 127.9, 123.6, 115.4 (d, *J* = 21.2 Hz), 92.3, 82.6, 31.8, 24.6.
^{19}F NMR (376 MHz, $CDCl_3$) δ -116.6.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}F$ $[M + H]^+$ 225.1074, found 225.1070.

1-chloro-4-(4-phenylbut-3-yn-2-yl)benzene (3g)



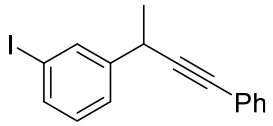
Compound **3g**: (77% yield, 92 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 – 7.40 (m, 2H), 7.39 – 7.34 (m, 2H), 7.33 – 7.24 (m, 5H), 3.94 (q, *J* = 7.1 Hz, 1H), 1.55 (d, *J* = 7.1 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 141.9, 132.4, 131.7, 128.7, 128.4, 128.3, 127.9, 123.5, 92.0, 82.8, 32.0, 24.4.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}Cl$ $[M + H]^+$ 240.0700, found 241.0775.

1-iodo-4-(4-phenylbut-3-yn-2-yl)benzene (3h)



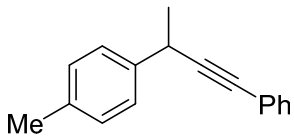
Compound **3h**: (80% yield, 132 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, *J* = 8.4 Hz, 2H), 7.45 – 7.39 (m, 2H), 7.32 – 7.26 (m, 3H), 7.20 (d, *J* = 8.3 Hz, 2H), 3.92 (q, *J* = 7.1 Hz, 1H), 1.55 (d, *J* = 7.1 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 143.1, 137.6, 131.6, 129.1, 128.3, 127.9, 123.5, 91.9, 91.8, 82.8, 32.1, 24.3.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}I$ $[M + H]^+$ 333.0135, found 333.0128.

1-iodo-3-(4-phenylbut-3-yn-2-yl)benzene (3i)



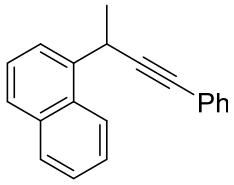
Compound **3i**: (75% yield, 124 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (s, 1H), 7.58 (d, *J* = 7.9 Hz, 1H), 7.47 – 7.38 (m, 3H), 7.32 – 7.26 (m, 3H), 7.08 (t, *J* = 7.8 Hz, 1H), 3.92 (q, *J* = 7.1 Hz, 1H), 1.56 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 145.7, 136.1, 135.8, 131.7, 130.3, 128.3, 127.9, 126.3, 123.5, 94.5, 91.6, 83.0, 32.1, 24.4.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}I$ $[M + H]^+$ 333.0135, found 333.0129.

1-methyl-4-(4-phenylbut-3-yn-2-yl)benzene (3j)



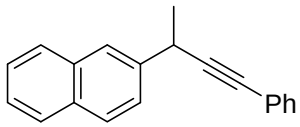
Compound **3j**: (83% yield, 90 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.40 (m, 2H), 7.36 – 7.31 (m, 2H), 7.27 (dd, *J* = 5.1, 2.1 Hz, 3H), 7.17 – 7.11 (m, 2H), 3.94 (q, *J* = 7.1 Hz, 1H), 2.33 (s, 3H), 1.56 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 140.4, 136.3, 131.7, 129.3, 128.2, 127.7, 126.9, 123.9, 92.9, 82.3, 32.1, 24.6, 21.1.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{17}$ $[M + H]^+$ 221.1325, found 221.1321.

1-(4-phenylbut-3-yn-2-yl)naphthalene (3k)



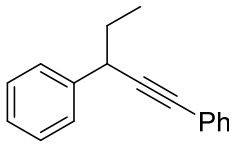
Compound **3k**: (65% yield, 83 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (d, *J* = 8.5 Hz, 1H), 8.00 – 7.77 (m, 3H), 7.65 – 7.48 (m, 5H), 7.39 – 7.31 (m, 3H), 4.80 (q, *J* = 7.0 Hz, 1H), 1.80 (d, *J* = 7.1 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 138.9, 134.1, 131.7, 130.6, 129.0, 128.3, 127.8, 127.6, 126.1, 125.7, 125.6, 124.4, 123.8, 123.2, 92.9, 82.7, 29.2, 23.4.
HRMS (ESI) *m/z* calcd. for $C_{20}H_{17}[M + H]^+$ 257.1352, found 257.1319.

2-(4-phenylbut-3-yn-2-yl)naphthalene (3l)



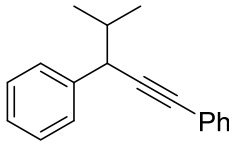
Compound **3l**: (78% yield, 100 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 – 7.77 (m, 4H), 7.57 (dd, *J* = 8.5, 1.8 Hz, 1H), 7.50 – 7.43 (m, 4H), 7.33 – 7.26 (m, 3H), 4.15 (q, *J* = 7.1 Hz, 1H), 1.66 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 140.7, 133.6, 132.5, 131.7, 128.3, 128.3, 127.8, 127.8, 127.6, 126.1, 125.6, 125.6, 125.2, 123.7, 92.6, 82.7, 32.7, 24.4.
HRMS (ESI) *m/z* calcd. for $C_{20}H_{17}$ $[M + H]^+$ 257.1325, found 257.1319.

pent-1-yne-1,3-diyldibenzene(3m) [3]



Compound **3m**: (80% yield, 88 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.41 (m, 4H), 7.35 – 7.24 (m, 6H), 3.79 (t, *J* = 7.7 Hz, 1H), 1.93 – 1.76 (m, 2H), 1.06 (t, *J* = 7.4 Hz, 3H).

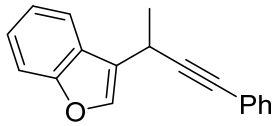
(4-methylpent-1-yne-1,3-diyl)dibenzene (3n) [3]



Compound **3n**: (49%, 57 mg, colorless oil)

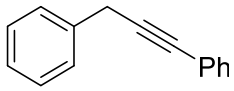
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 – 7.47 (m, 2H), 7.44 – 7.41 (m, 2H), 7.37 – 7.27 (6H), 3.76 (d, *J* = 6.0 Hz, 1H), 2.12 – 2.04 (m, 1H), 1.08 (t, *J* = 6.4 Hz, 3H), 1.03 (t, *J* = 6.4 Hz, 3H).

3-(4-phenylbut-3-yn-2-yl)benzofuran (3o)



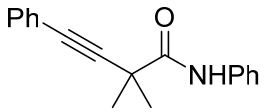
Compound **3o**: (60% yield, 73 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (dd, *J* = 7.5, 1.5 Hz, 1H), 7.61 (s, 1H), 7.52 – 7.39 (m, 3H), 7.34 – 7.22 (m, 5H), 4.16 (q, *J* = 7.0 Hz, 1H), 1.70 (d, *J* = 7.0 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 155.8, 141.1, 131.7, 128.3, 127.9, 126.7, 124.3, 123.5, 122.4, 122.3, 120.1, 111.7, 91.2, 81.5, 22.9, 21.7.
HRMS (ESI) *m/z* calcd. for $C_{18}H_{15}O$ $[M + H]^+$ 247.1117, found 247.1112.

prop-1-yne-1,3-diyldibenzene (3p)



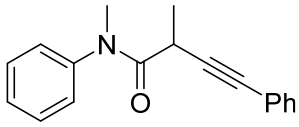
Compound **3p**: (77% yield, 74 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 – 7.38 (m, 4H), 7.36 – 7.21 (m, 6H), 3.82 (s, 2H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 136.8, 131.7, 128.6, 128.3, 128.0, 127.9, 126.7, 123.7, 87.6, 82.7, 25.8.
HRMS (ESI) *m/z* calcd. for $C_{15}H_{13}$ $[M + H]^+$ 193.1012, found 193.1010.

2,2-dimethyl-*N*,4-diphenylbut-3-ynamide (3q)[4]



Compound **3q**: (42% yield, 54 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.61 (brs, 1H), 7.58 (d, *J* = 8.3 Hz, 2H), 7.54 – 7.49 (m, 2H), 7.41 – 7.33 (m, 5H), 7.19 – 7.12 (m, 1H), 1.66 (s, 6H).

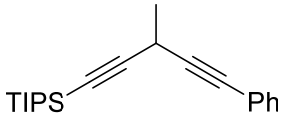
***N*,2-dimethyl-*N*,4-diphenylbut-3-ynamide (3r)**



Compound **3r**: (56% yield, 74 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 – 7.40 (m, 2H), 7.39 – 7.30 (m, 5H), 7.30 – 7.24 (m, 3H), 3.51 (q, *J* = 6.9 Hz, 1H), 3.31 (s, 3H), 1.41 (d, *J* = 6.9 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 170.6, 143.5, 131.7, 129.8, 128.2, 128.1, 127.9, 127.6, 123.3, 89.0, 81.7, 38.0, 30.6, 18.2.

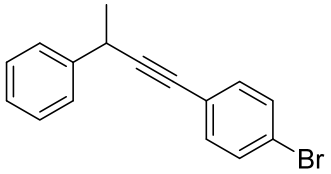
HRMS (ESI) *m/z* calcd. for $C_{18}H_{18}NO$ $[M + H]^+$ 264.1383, found 264.1378.

triisopropyl(3-methyl-5-phenylpenta-1,4-diyn-1-yl)silane (3s)



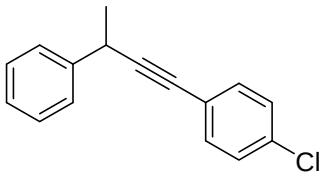
Compound **3s**: (64% yield, 99 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.37 (m, 2H), 7.33 – 7.23 (m, 3H), 3.70 (q, *J* = 7.0 Hz, 1H), 1.55 (d, *J* = 7.1 Hz, 3H), 1.12 – 1.05 (m, 21H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 131.7, 128.2, 127.9, 123.4, 107.5, 89.2, 80.7, 80.2, 22.7, 19.5, 18.6, 11.3.
HRMS (ESI) *m/z* calcd. for $C_{21}H_{31}Si$ $[M + H]^+$ 311.2190, found 311.2183.

1-bromo-4-(3-phenylbut-1-yn-1-yl)benzene (3t)



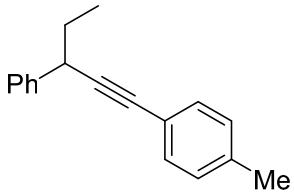
Compound **3t**: (81% yield, 115 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 – 7.39 (m, 4H), 7.37 – 7.22 (m, 5H), 3.95 (q, *J* = 7.1 Hz, 1H), 1.57 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 143.0, 133.1, 131.5, 128.6, 126.9, 126.8, 122.7, 121.9, 93.9, 81.4, 32.5, 24.4.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}Br$ $[M + H]^+$ 285.0273, found 285.0265.

1-chloro-4-(3-phenylbut-1-yn-1-yl)benzene (3u)



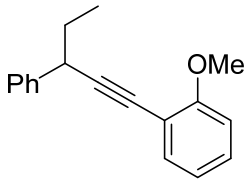
Compound **3u**: (95% yield, 114 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 – 7.40 (m, 2H), 7.37 – 7.31 (m, 4H), 7.28 – 7.21 (m, 3H), 3.96 (q, *J* = 7.2 Hz, 1H), 1.57 (d, *J* = 7.2 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 143.1, 133.7, 132.9, 128.6, 128.5, 126.9, 126.8, 122.3, 93.7, 81.4, 32.5, 24.4.
HRMS (ESI) *m/z* calcd. for $C_{16}H_{14}Cl$ $[M + H]^+$ 241.0779, found 241.0774.

1-methyl-4-(3-phenylpent-1-yn-1-yl)benzene (3v) [3]



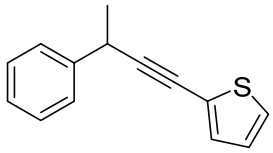
Compound **3v**: (57% yield, 66 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, *J* = 7.4 Hz, 2H), 7.27 – 7.23 (m, 4H), 7.16 (t, *J* = 7.4 Hz, 1H), 7.02 (d, *J* = 7.8 Hz, 2H), 3.70 (t, *J* = 6.8 Hz, 1H), 2.26 (s, 3H), 1.82-1.74 (m, 2H), 1.21 (t, *J* = 7.2 Hz, 3H).

1-methoxy-2-(3-phenylpent-1-yn-1-yl)benzene (3w) [3]



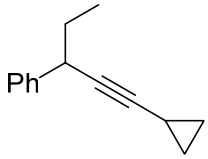
Compound **3w**: (78% yield, 95 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 – 7.38 (m, 2H), 7.36 – 7.32 (m, 1H), 7.28 – 7.16 (m, 4H), 6.84 – 6.78 (m, 2H), 3.84 – 3.76 (m, 4H), 1.84 – 1.78 (m, 2H), 1.00 (t, *J* = 7.1 Hz, 3H)

2-(3-phenylbut-1-yn-1-yl)thiophene (3x)



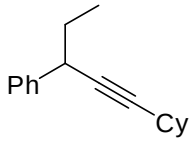
Compound **3x**: (88% yield, 93 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 – 7.38 (m, 2H), 7.36 – 7.29 (m, 2H), 7.25 – 7.20 (m, 1H), 7.17 – 7.13 (m, 2H), 6.95 – 6.89 (m, 1H), 3.97 (q, *J* = 7.1 Hz, 1H), 1.56 (d, *J* = 7.1 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 143.0, 131.4, 128.7, 127.0, 126.9, 126.9, 126.3, 123.9, 96.6, 75.7, 32.8, 24.3.
HRMS (ESI) *m/z* calcd. for $C_{14}H_{13}S$ $[M + H]^+$ 213.0732, found 213.0729.

(1-cyclopropylpent-1-yn-3-yl)benzene (3y) [3]



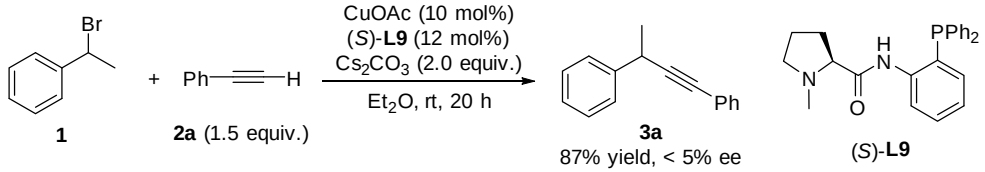
Compound **3y**: (39% yield, 36 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 – 7.30 (m, 4H), 7.25 – 7.22 (m, 1H), 3.55 – 3.51 (m, 1H), 1.80 – 1.66 (m, 2H), 1.34 – 1.28 (m, 1H), 0.98 (t, *J* = 7.4 Hz, 3H), 0.78 – 0.66 (m, 4H).

(1-cyclohexylpent-1-yn-3-yl)benzene (3z)

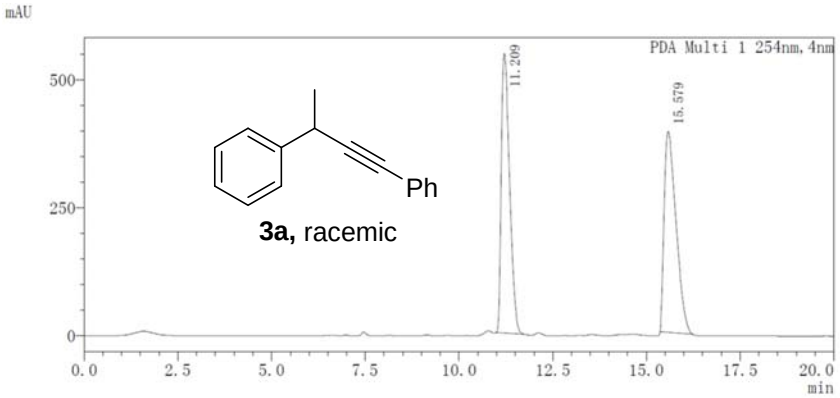


Compound **3z**: (35% yield, 40 mg, colorless oil)
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 – 7.31 (m, 4H), 7.23 (t, *J* = 6.8 Hz, 1H), 3.60 – 3.57 (m, 1H), 2.48 – 2.44 (m, 1H), 1.84 – 1.71 (m, 7H), 1.55 – 1.28 (m, 5H), 1.00 (t, *J* = 6.8 Hz, 3H).
^{13}C NMR (100 MHz, $CDCl_3$) δ 142.9, 128.2, 127.5, 126.3, 87.7, 81.4, 39.3, 33.1, 32.0, 29.1, 26.0, 24.8, 11.7.
HRMS (ESI) *m/z* calcd. for $C_{17}H_{23}$ $[M + H]^+$ 227.1794, found 227.1787.

Asymmetric trial with chiral ligand (*S*)-L9

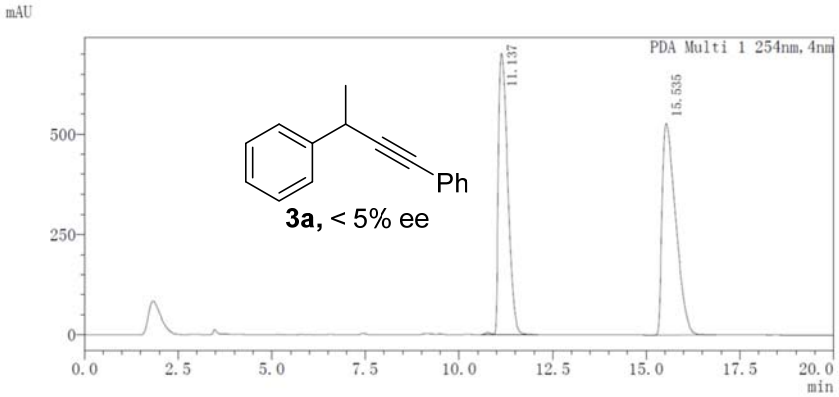


The experiment procedure is the same to that of racemic reaction.
3a (< 5% ee, Chiralcel OD-3; eluent: hexane; flow rate: 1.0 mL/min).



PDA Ch1 254nm

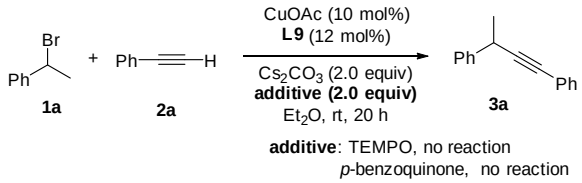
Peak#	Ret. Time	Area	面积%
1	11.209	8900153	49.815
2	15.579	8966431	50.185
总计		17866584	100.000



PDA Ch1 254nm

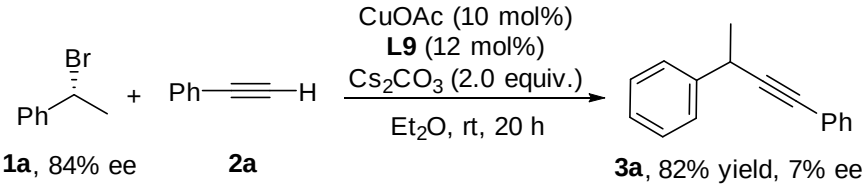
Peak#	Ret. Time	Area	面积%
1	11.137	12145170	47.700
2	15.535	13316367	52.300
总计		25461538	100.000

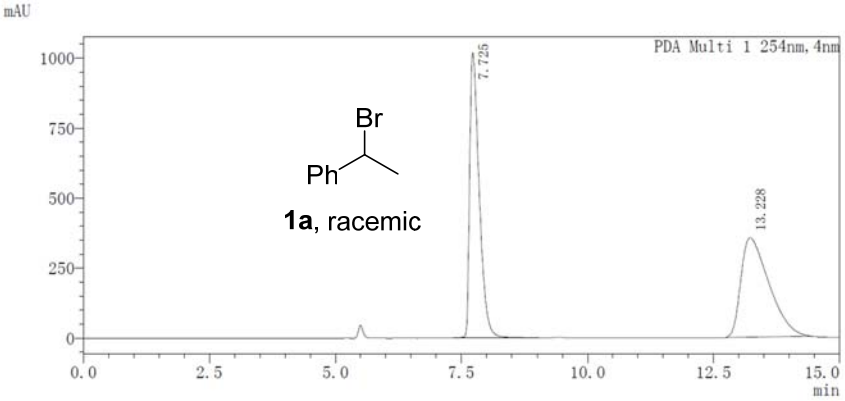
Mechanistic studies



To a 10-mL Schlenk tube equipped with a magnetic stir bar was added CuOAc (2.4 mg, 0.05 mmol), **L9** (9.3 mg, 0.06 mmol), Cs_2CO_3 (130 mg, 0.40 mmol), additive (2.0 equiv.) and anhydrous Et_2O (1.0 mL). Then, aryl bromide **1a** (0.20 mmol) and alkyne **2a** (0.30 mmol) were sequentially added into the mixture. The reaction mixture was stirred at room temperature for 20 h. After completion of the reaction as indicated by TLC, the precipitate was filtered off and concentrated in vacuo. The conversion of substrate was detected by ^{1}H NMR analysis of the crude reaction mixture.

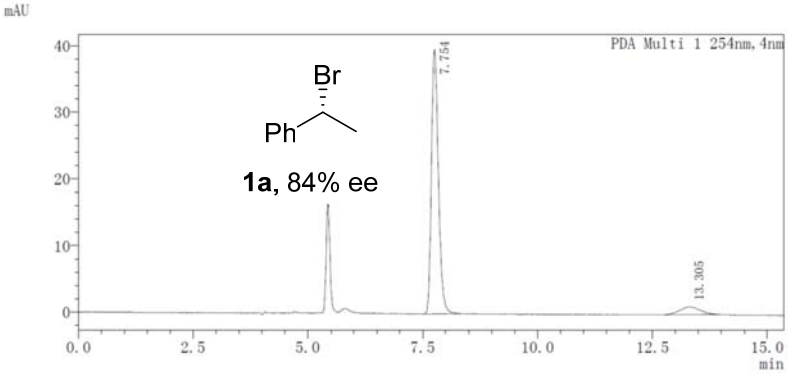
(*R*)-1-phenylethyl bromide (84% ee, Chiralcel AY-3, eluent: hexane; flow rate: 0.80 ml/min) was synthesized according to reported literature[5].
3a (7% ee, Chiralcel OD-3; eluent: hexane; flow rate: 1.0 mL/min).





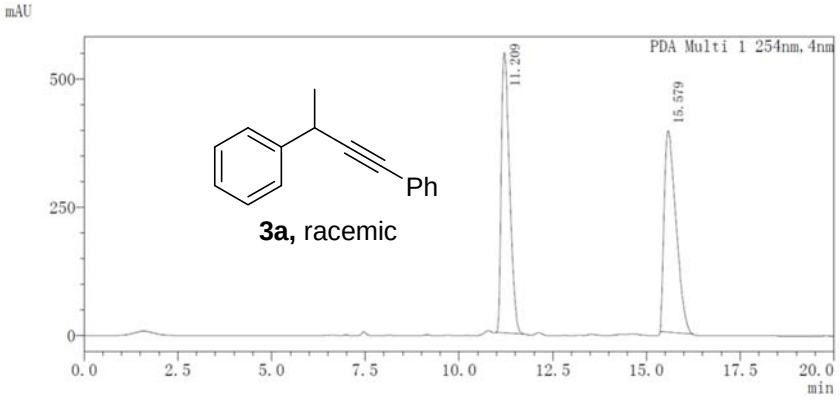
PDA Ch1 254nm

Peak#	Ret. Time	Area	面积%
1	7.725	13426225	49.302
2	13.228	13806445	50.698
总计		27232670	100.000



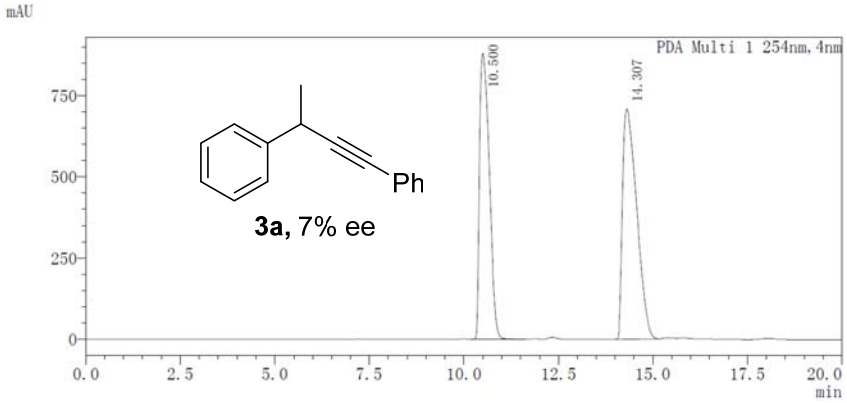
PDA Ch1 254nm

Peak#	Ret. Time	Area	面积%
1	7.754	421462	92.152
2	13.305	35892	7.848
总计		457354	100.000



PDA Ch1 254nm

Peak#	Ret. Time	Area	面积%
1	11.209	8900153	49.815
2	15.579	8966431	50.185
总计		17866584	100.000

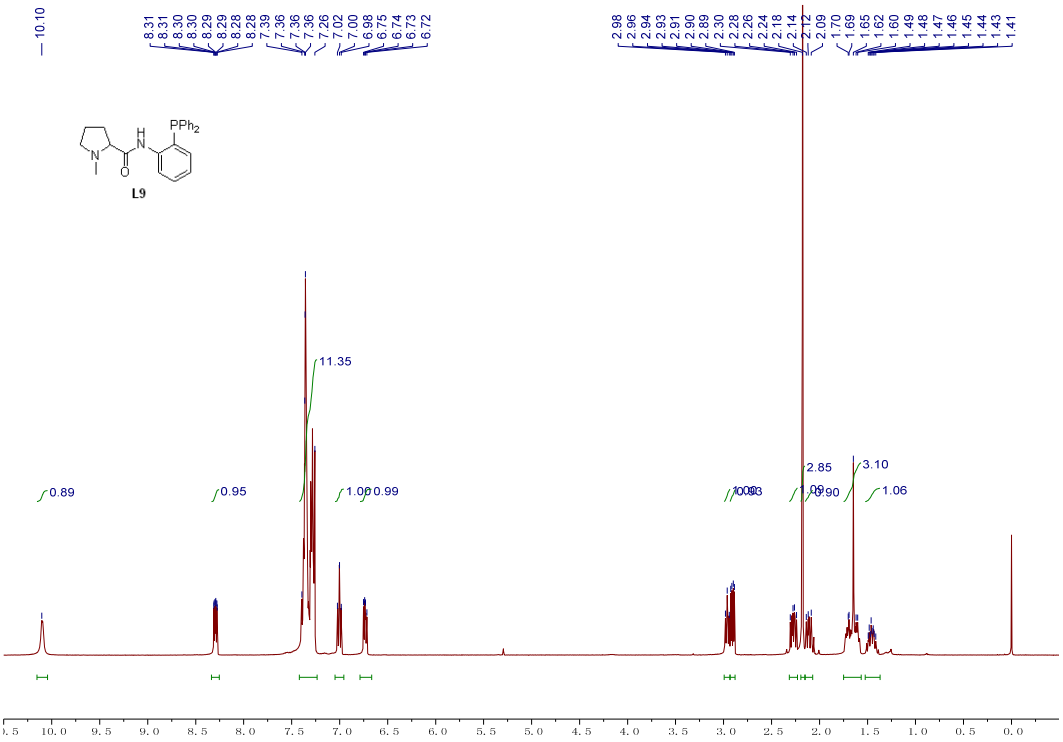


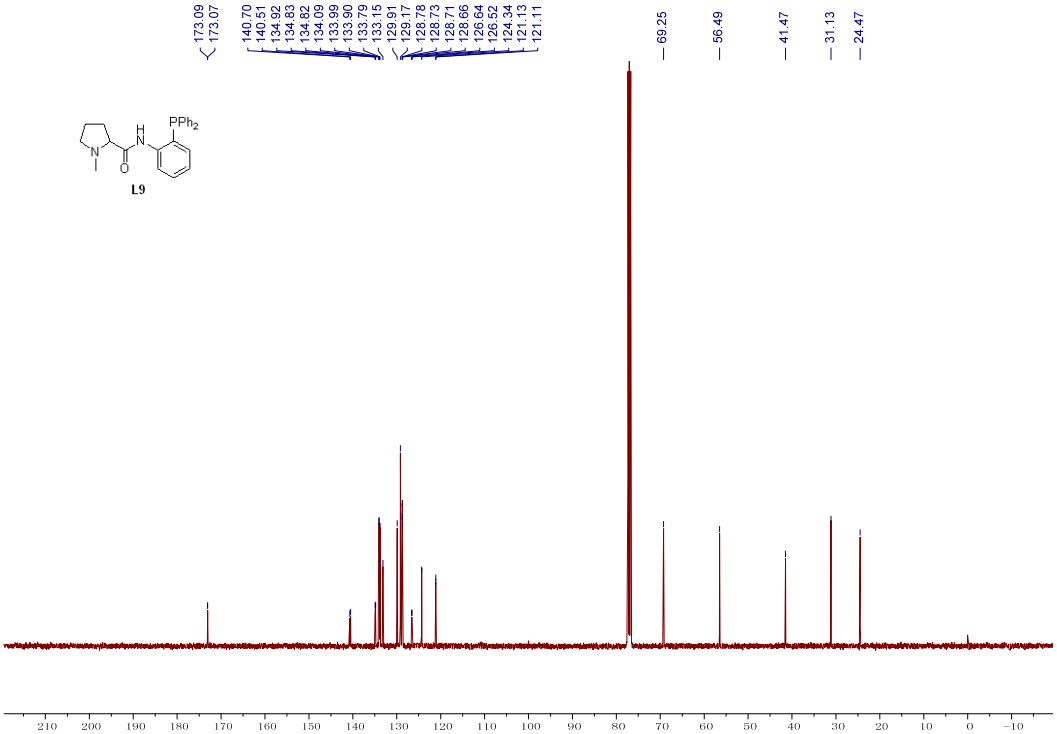
3a, 7% ee

PDA Ch1 254nm

Peak#	Ret. Time	Area	面积%
1	10.500	15970662	46.284
2	14.307	18535026	53.716
总计		34505688	100.000

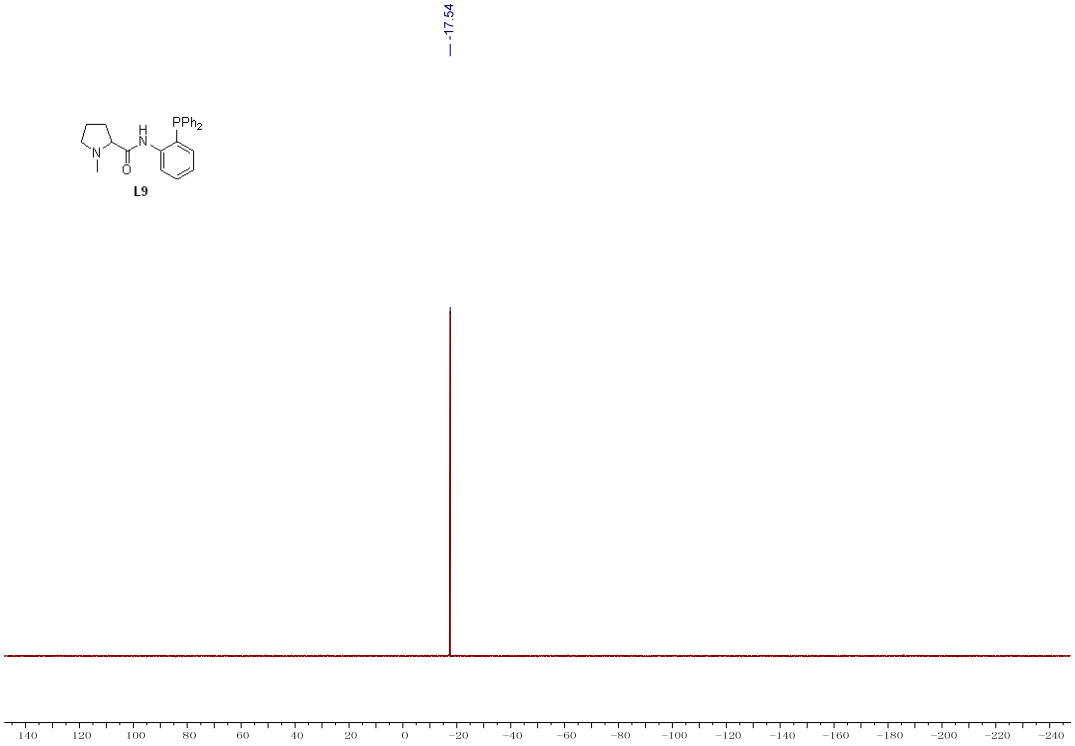
NMR Analysis

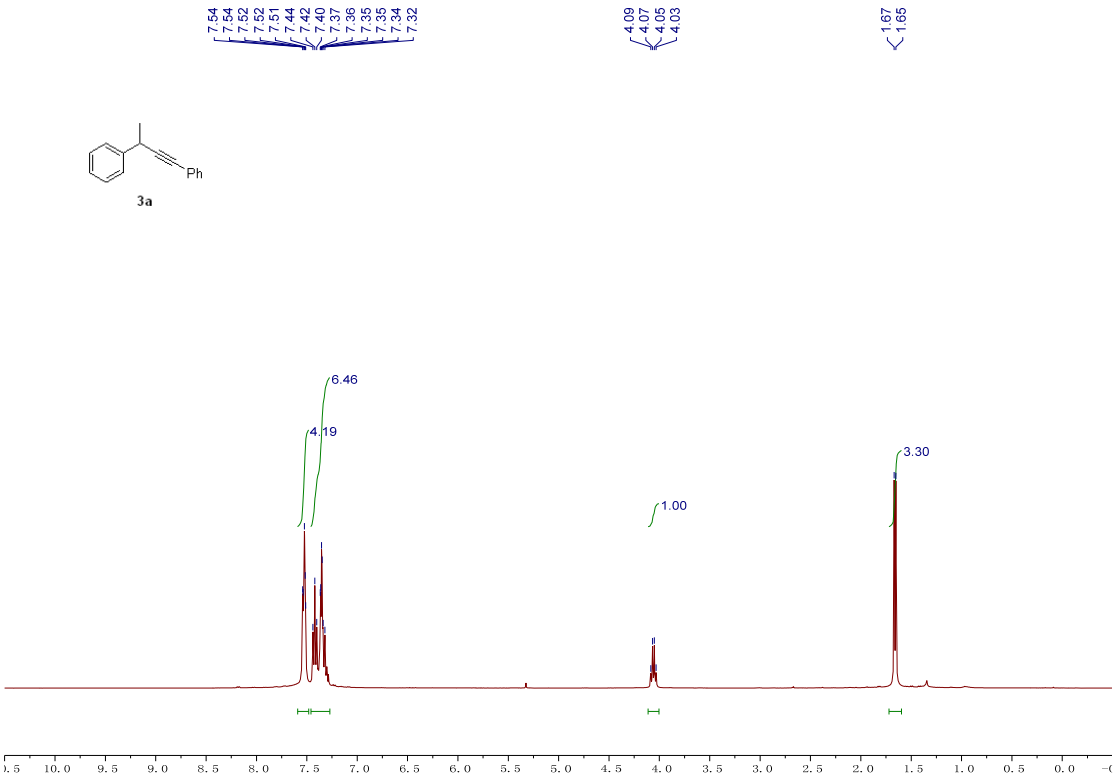


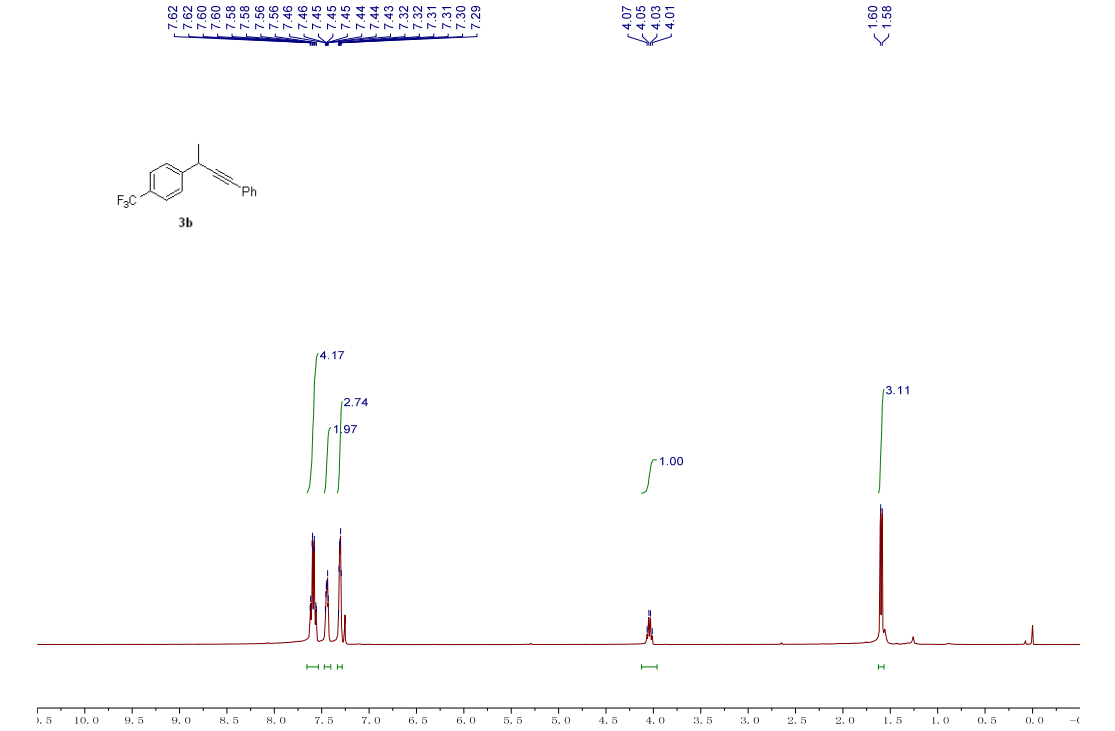


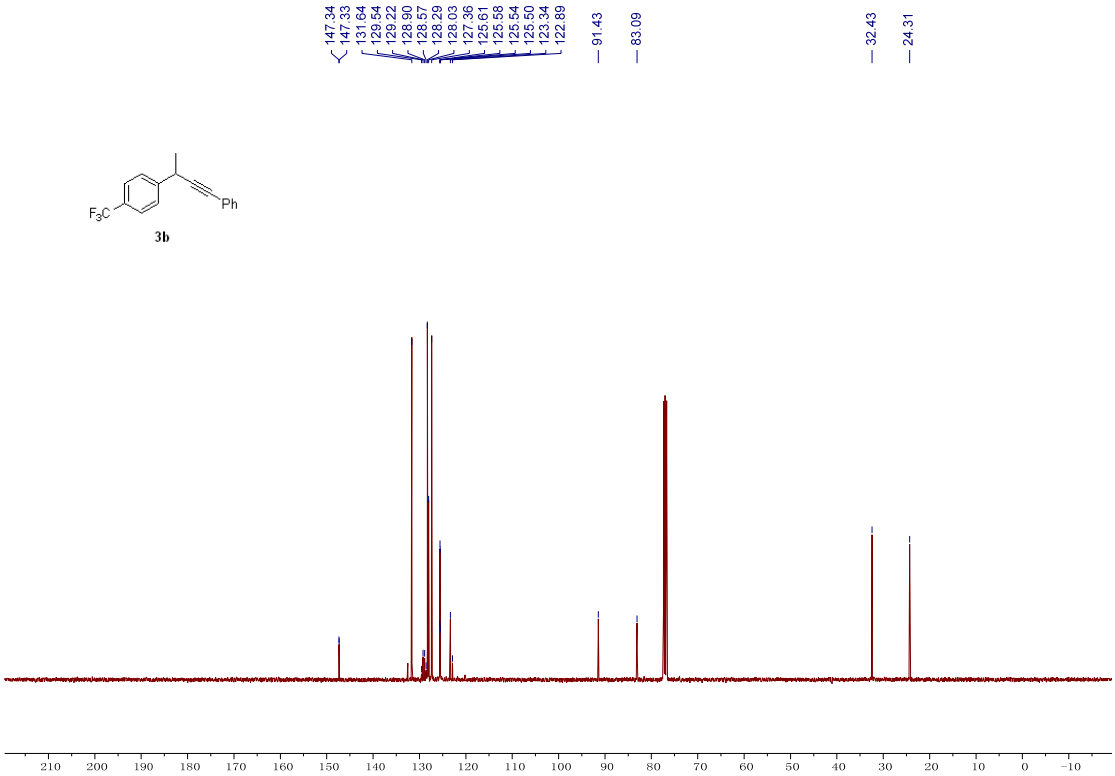
PPh2
H
N
N
O

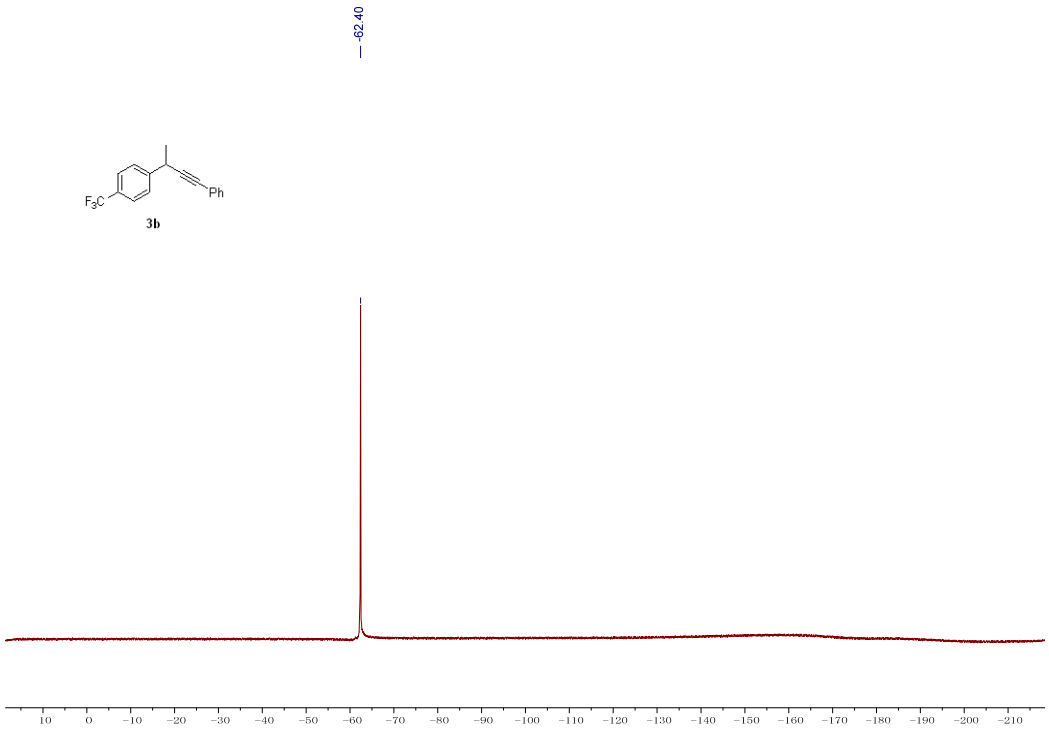
L9

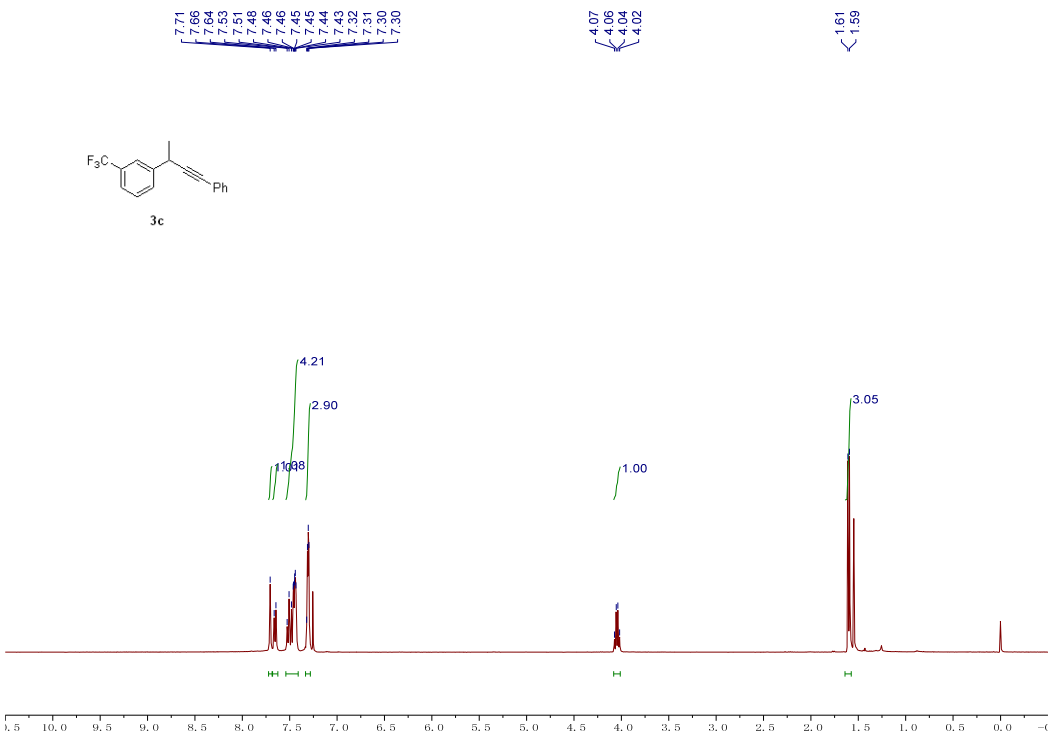

-17.54
140
120
100
80
60
40
20
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
−220
−240

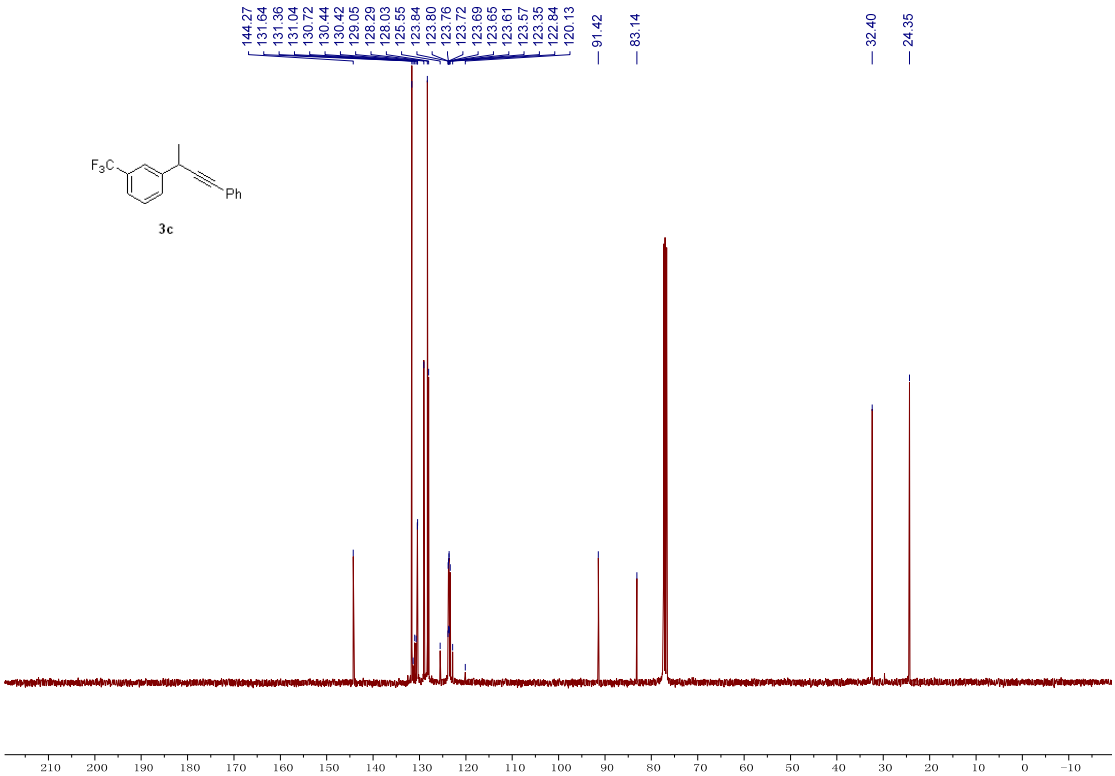

7.54
7.54
7.52
7.52
7.51
7.44
7.42
7.40
7.37
7.36
7.35
7.35
7.34
7.32
4.09
4.07
4.05
4.03
1.67
1.65
Ph
3a
6.46
4.19
1.00
3.30


7.62
7.62
7.60
7.60
7.58
7.58
7.56
7.56
7.46
7.46
7.45
7.45
7.44
7.44
7.43
7.32
7.32
7.31
7.31
7.30
7.29
4.07
4.05
4.03
4.01
1.60
1.58
F3C
Ph
3b
4.17
2.74
1.97
1.00
3.11


147.34
147.33
131.64
129.54
129.22
128.90
128.57
128.29
128.03
127.36
125.61
125.58
125.54
125.50
123.34
122.89
91.43
83.09
32.43
24.31
F3C
Ph
3b

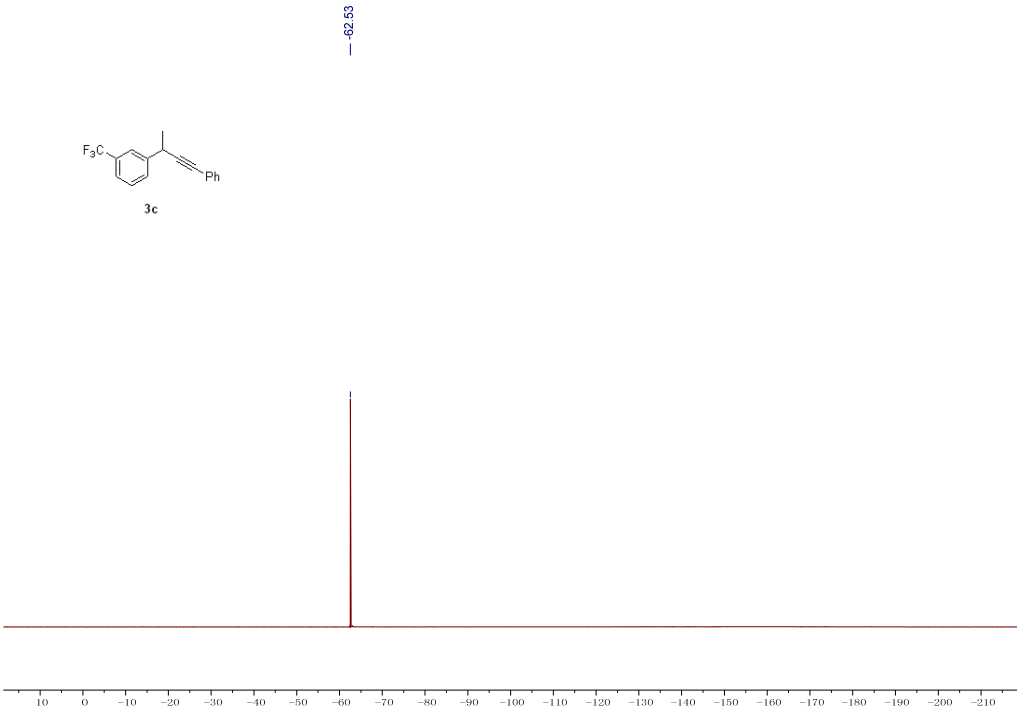

-62.40
F3C
Ph
3b


7.71
7.66
7.64
7.53
7.51
7.48
7.46
7.46
7.45
7.45
7.44
7.43
7.32
7.31
7.30
7.30
4.07
4.06
4.04
4.02
1.61
1.59
F3C
Ph
3c
4.21
2.90
1.00
3.05


144.27
131.64
131.36
131.04
130.72
130.44
130.42
129.05
128.29
128.03
125.55
123.84
123.80
123.76
123.72
123.69
123.65
123.61
123.57
123.35
122.84
120.13
91.42
83.14
32.40
24.35
F3C
Ph
3c

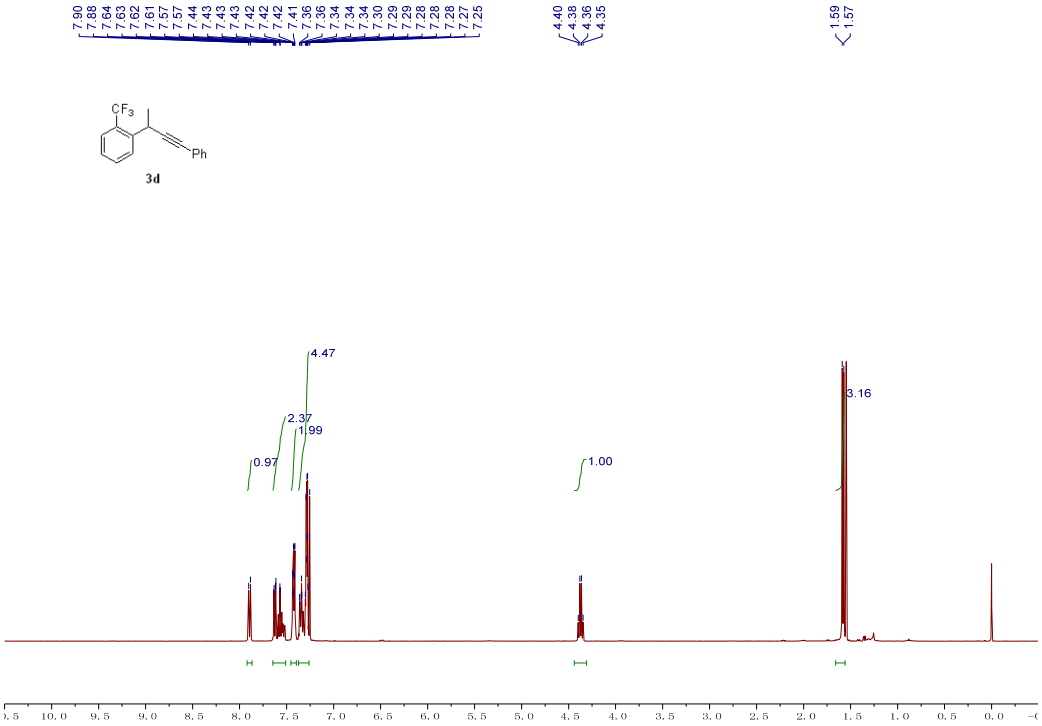
F3C
Ph

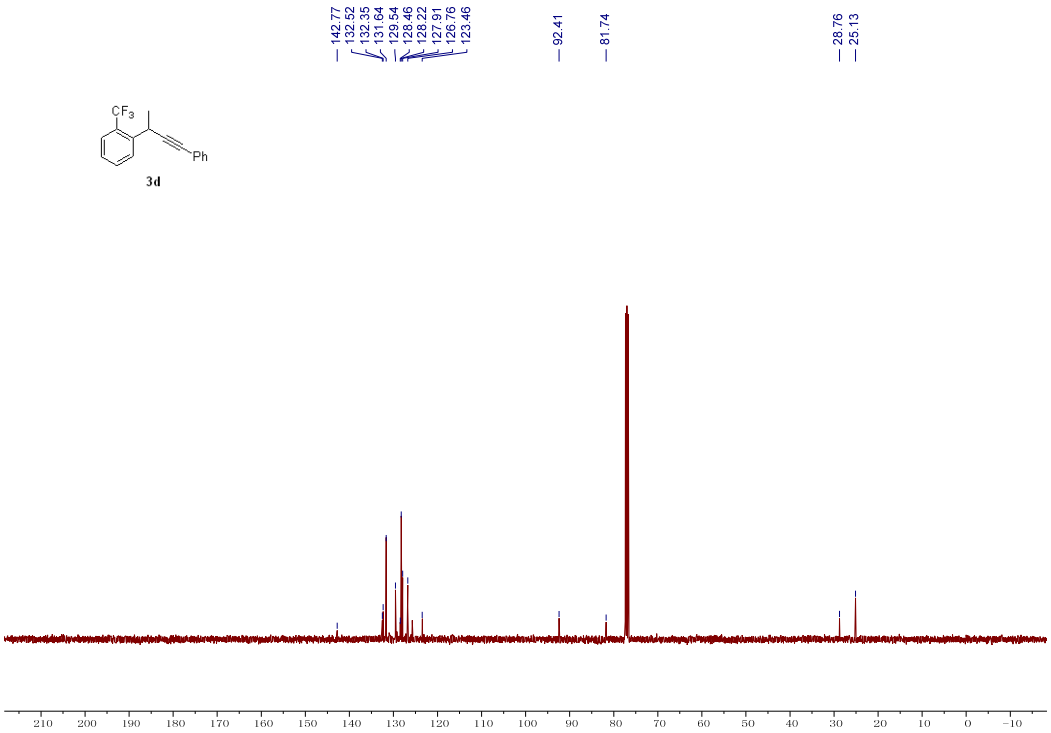
3c

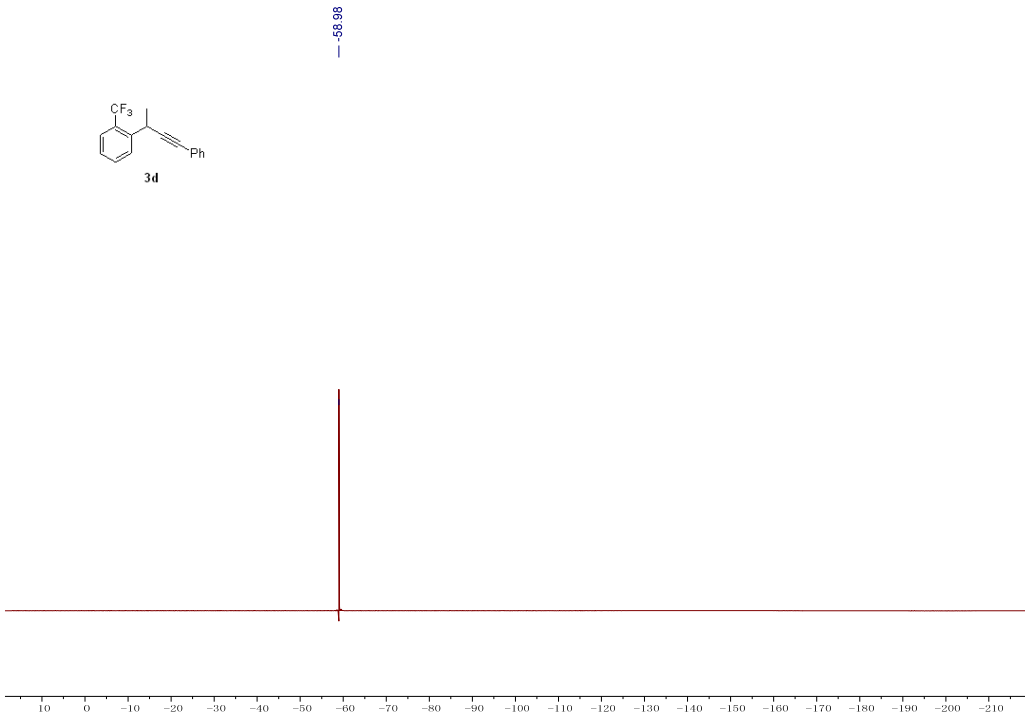

-62.53
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210

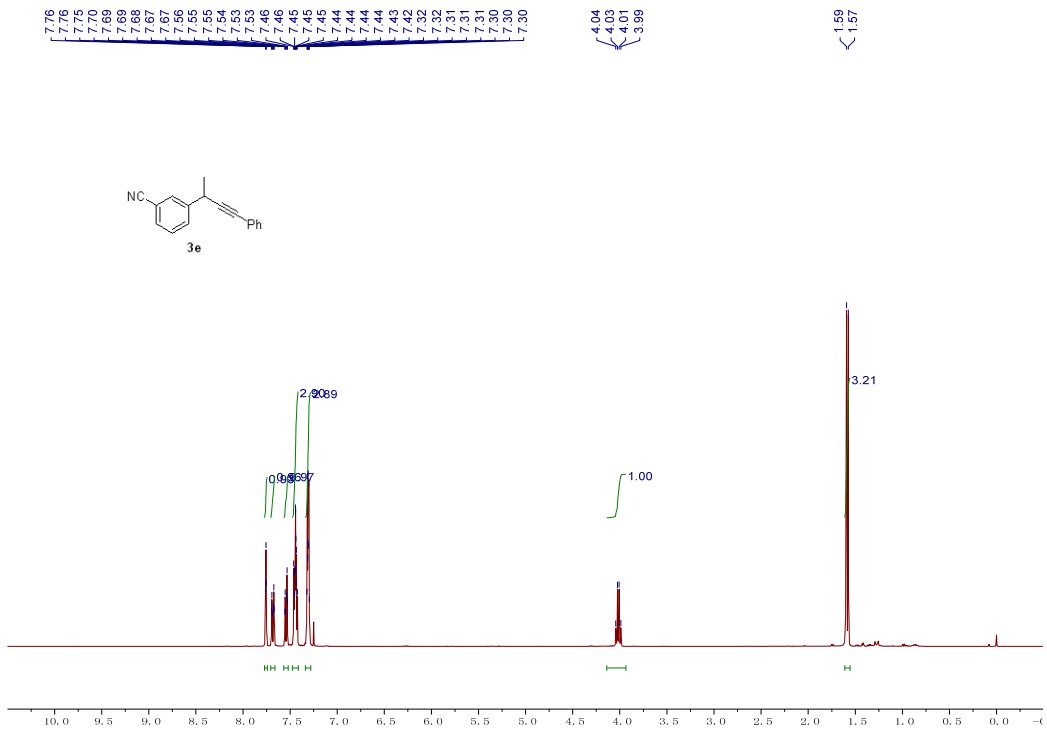
CF3
Ph

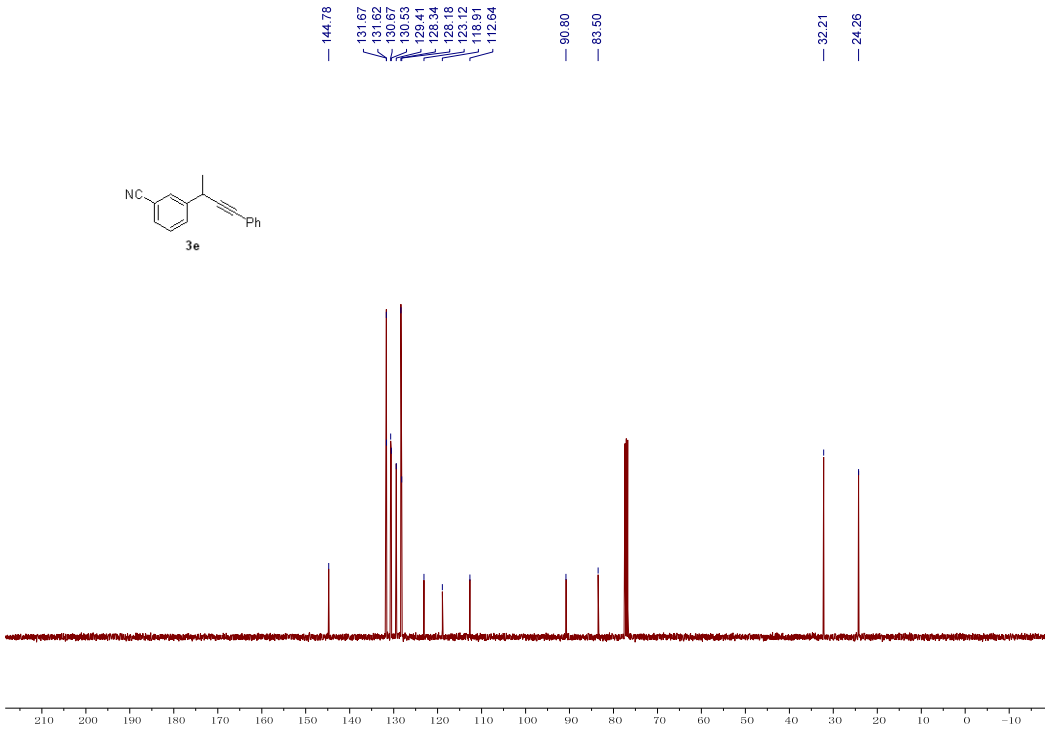
3d

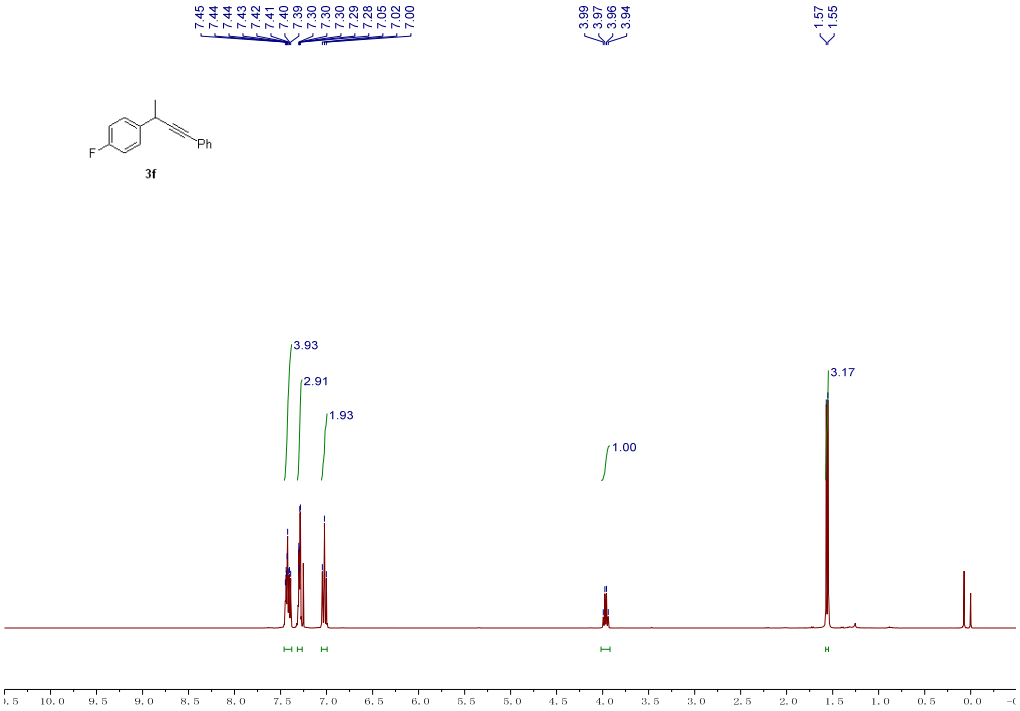

7.90
7.88
7.64
7.63
7.62
7.61
7.57
7.57
7.44
7.43
7.43
7.43
7.42
7.42
7.42
7.41
7.36
7.36
7.34
7.34
7.34
7.30
7.29
7.29
7.28
7.28
7.28
7.27
7.25
4.40
4.38
4.36
4.35
1.59
1.57
4.47
2.37
1.99
0.97
1.00
3.16
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

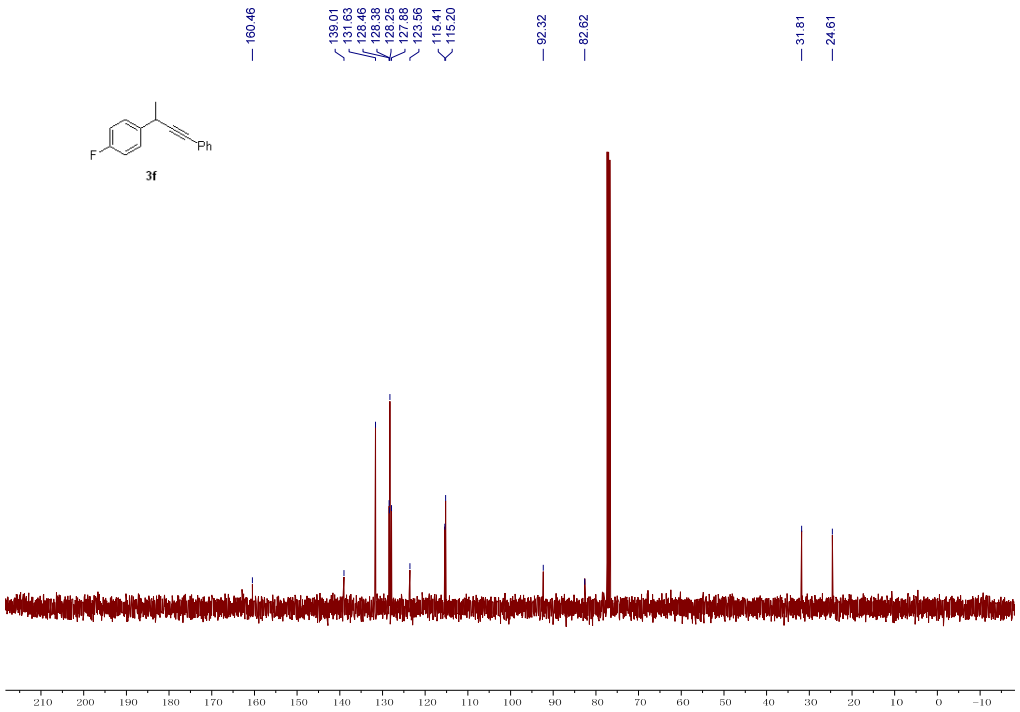

142.77
132.52
132.35
131.64
129.54
128.46
128.22
127.91
126.76
123.46
92.41
81.74
28.76
25.13
CF3
Ph
3d


-58.98
CF3
Ph
3d


7.76 7.76 7.75 7.70 7.69 7.69 7.68 7.67 7.67 7.66 7.55 7.55 7.54 7.53 7.53 7.46 7.45 7.45 7.45 7.44 7.44 7.44 7.44 7.43 7.42 7.32 7.32 7.31 7.31 7.30 7.30 7.30
4.04 4.03 4.01 3.99
1.59 1.57
NC
Ph
3e
3.21
1.00
10.0 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

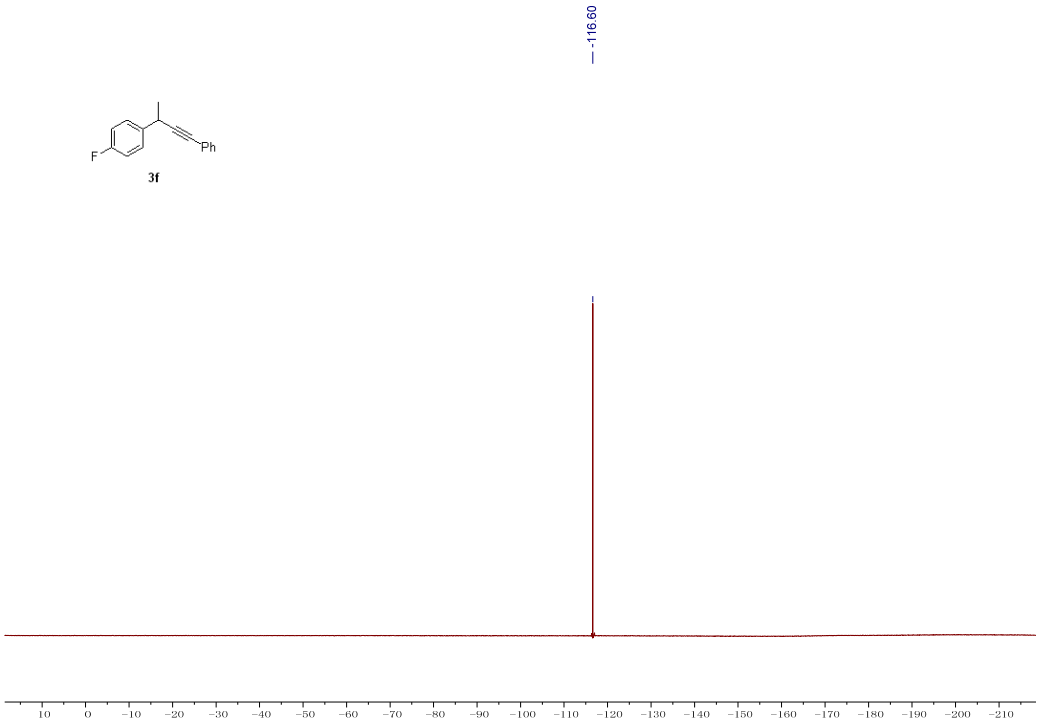

144.78
131.67 131.62 130.67 130.53 129.41 128.34 128.18 123.12 118.91 112.64
90.80
83.50
32.21
24.26
NC
Ph
3e
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10


7.45
7.44
7.44
7.43
7.42
7.41
7.40
7.39
7.30
7.30
7.30
7.29
7.28
7.05
7.02
7.00
3.99
3.97
3.96
3.94
1.57
1.55
F
Ph
3f
3.93
2.91
1.93
1.00
3.17


160.46
139.01
131.63
128.46
128.38
128.25
127.88
123.56
115.41
115.20
92.32
82.62
31.81
24.61
F
Ph
3f

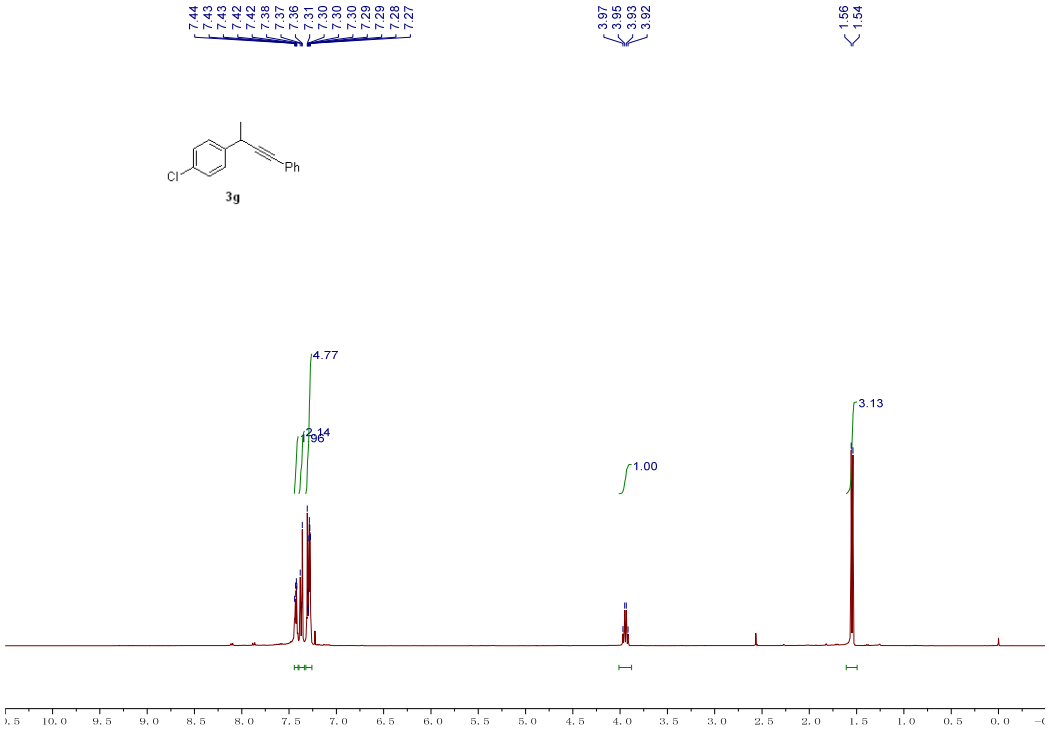
F
Ph

3f


-116.60
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210

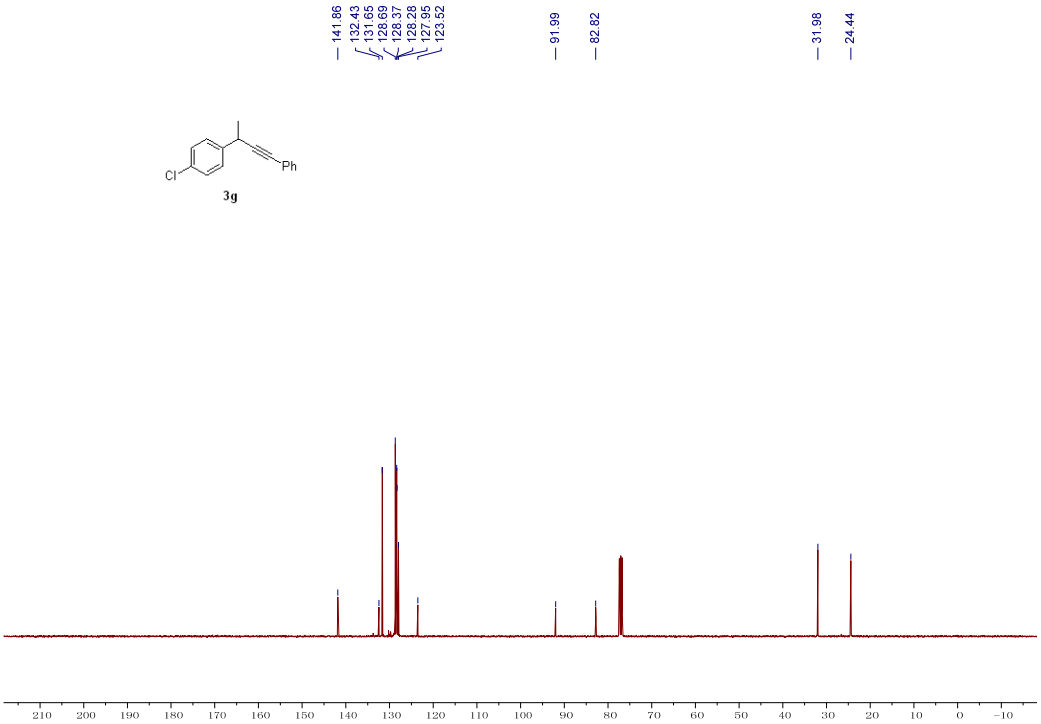
Cl
Ph

3g


7.44
7.43
7.43
7.42
7.42
7.38
7.37
7.36
7.31
7.30
7.30
7.30
7.29
7.29
7.28
7.27
3.97
3.95
3.93
3.92
1.56
1.54
4.77
2.14
1.96
1.00
3.13
10.0 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

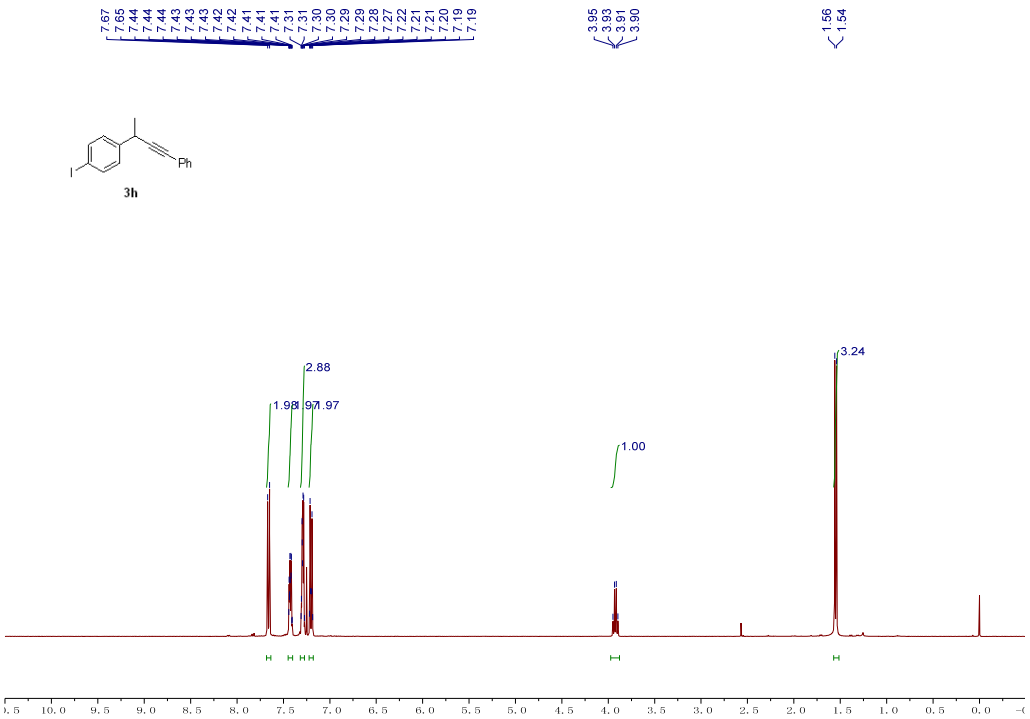
Cl
Ph

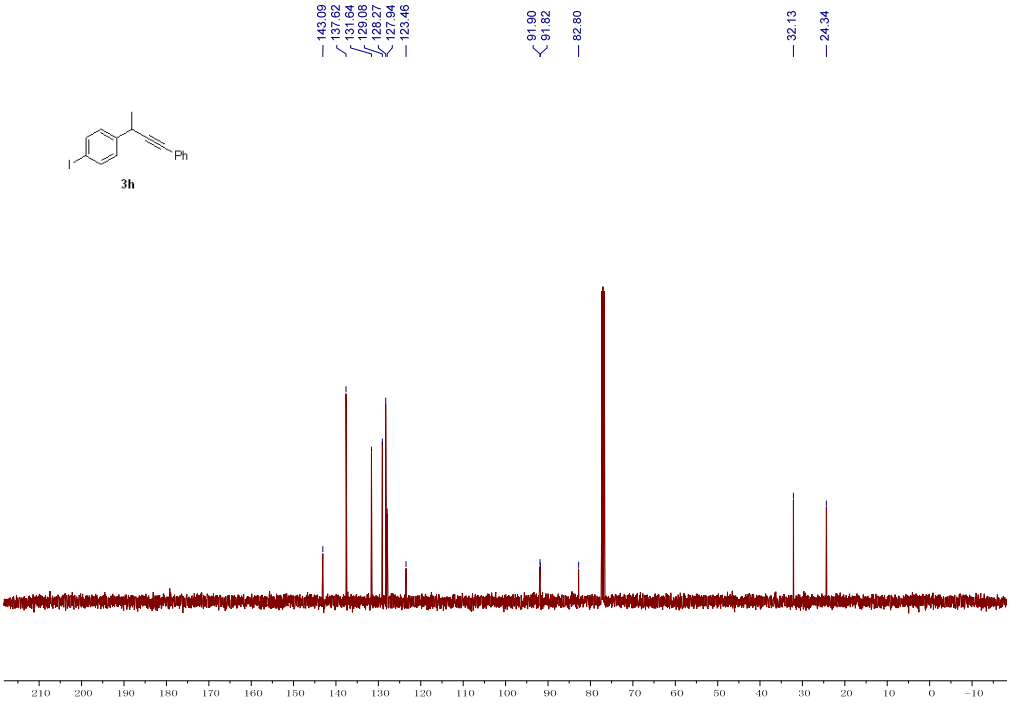
3g

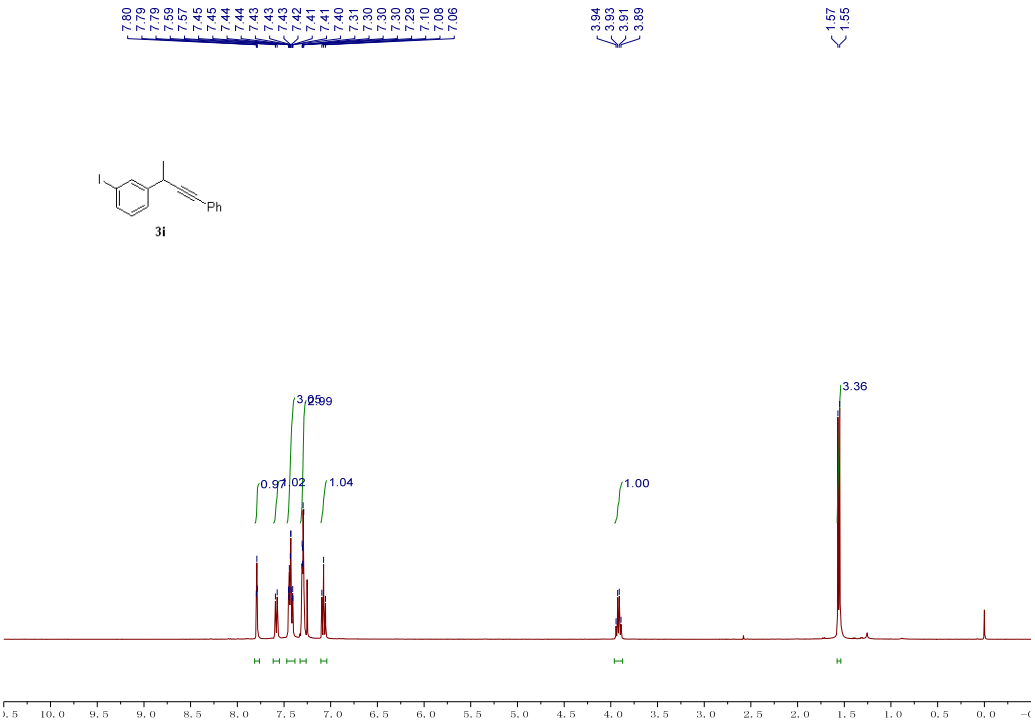

141.86
132.43
131.65
128.69
128.37
128.28
127.55
123.52
91.99
82.82
31.98
24.44
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 −10

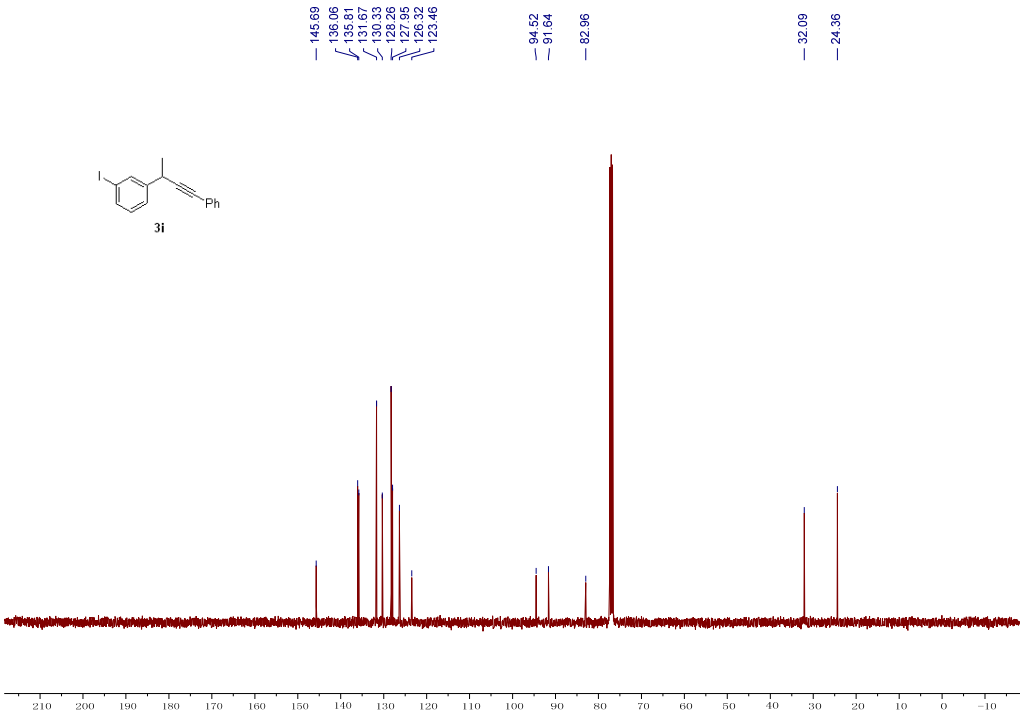
I
Ph

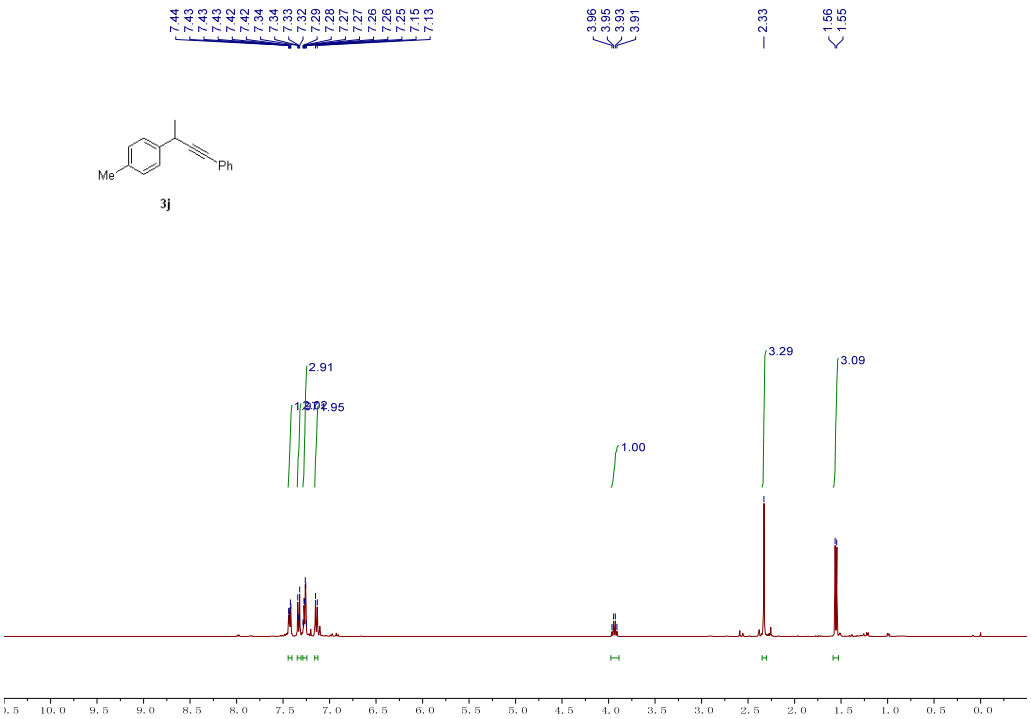
3h


7.67
7.65
7.44
7.44
7.44
7.43
7.43
7.43
7.42
7.42
7.41
7.41
7.41
7.31
7.30
7.30
7.29
7.29
7.28
7.27
7.22
7.21
7.21
7.20
7.19
7.19
3.95
3.93
3.91
3.90
1.56
1.54
2.88
1.98
1.97
1.97
1.00
3.24
10.0 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


143.09
137.62
131.64
129.08
128.27
127.94
123.46
91.90
91.82
82.80
32.13
24.34
I
Ph
3h

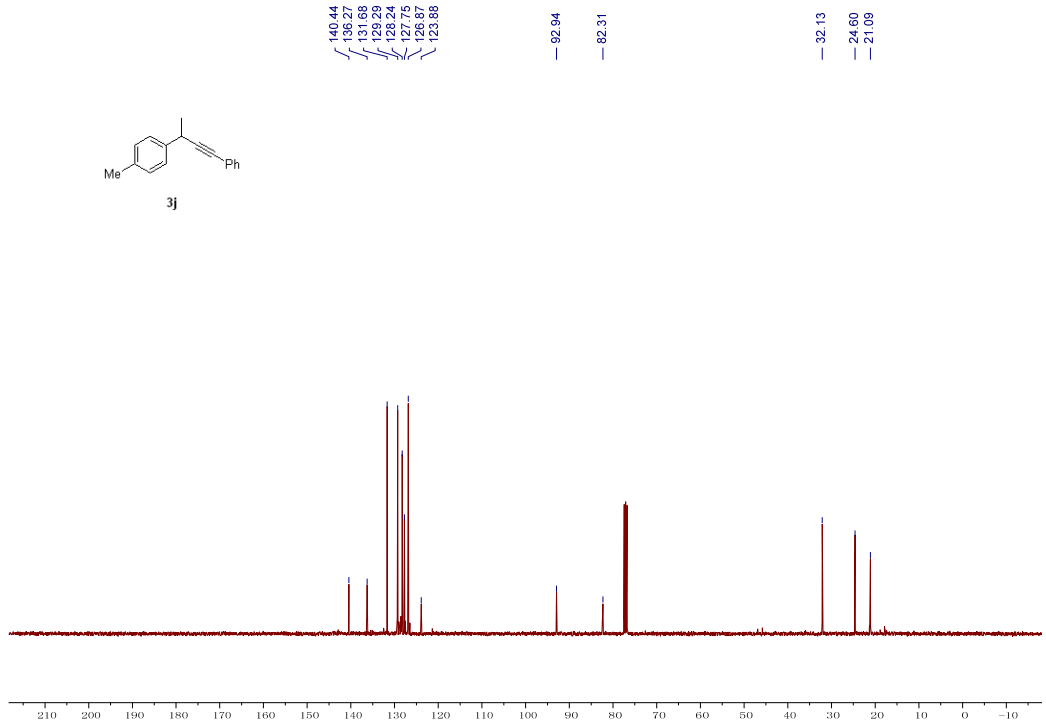

7.80
7.79
7.79
7.59
7.57
7.45
7.45
7.44
7.44
7.43
7.43
7.43
7.42
7.41
7.41
7.40
7.31
7.30
7.30
7.30
7.29
7.10
7.08
7.06
3.94
3.93
3.91
3.89
1.57
1.55
I
Ph
3i
3.25
3.99
0.97
1.02
1.04
1.00
3.36


145.69
136.06
133.81
131.67
130.33
129.26
127.95
126.32
123.46
94.52
91.64
82.96
32.09
24.36
I
Ph
3i


7.44
7.43
7.43
7.43
7.42
7.42
7.34
7.34
7.33
7.32
7.29
7.28
7.27
7.27
7.26
7.26
7.25
7.15
7.13
3.96
3.95
3.93
3.91
2.33
1.56
1.55
Me
Ph
3j
2.91
2.95
1.00
3.29
3.09

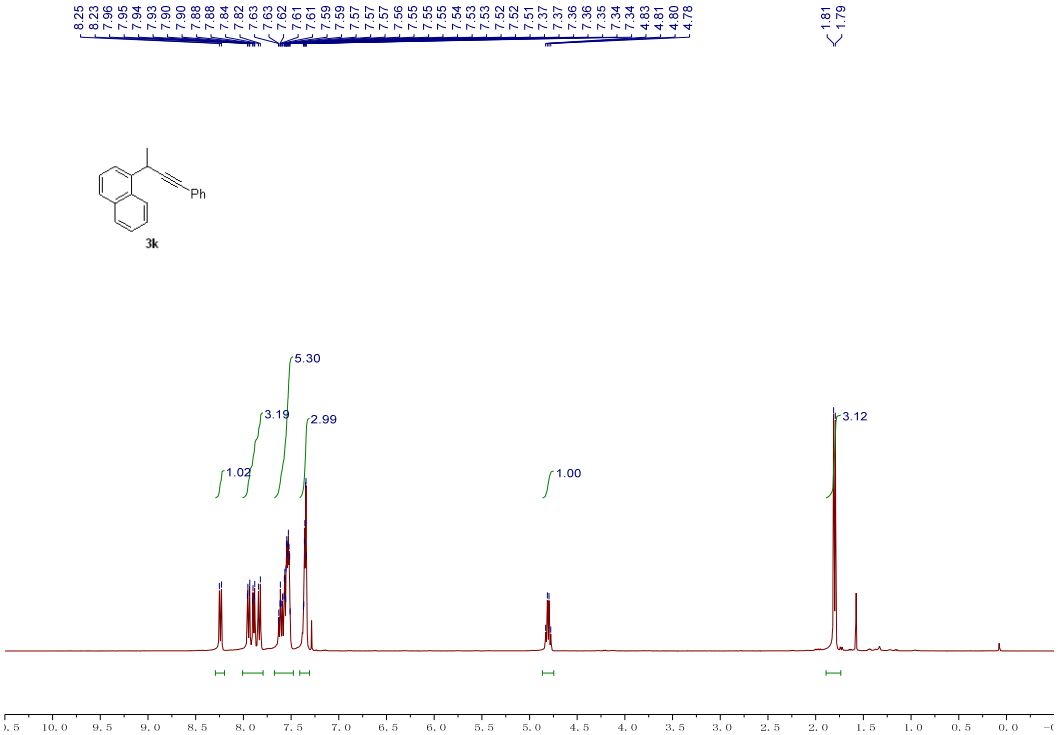
Me
Ph

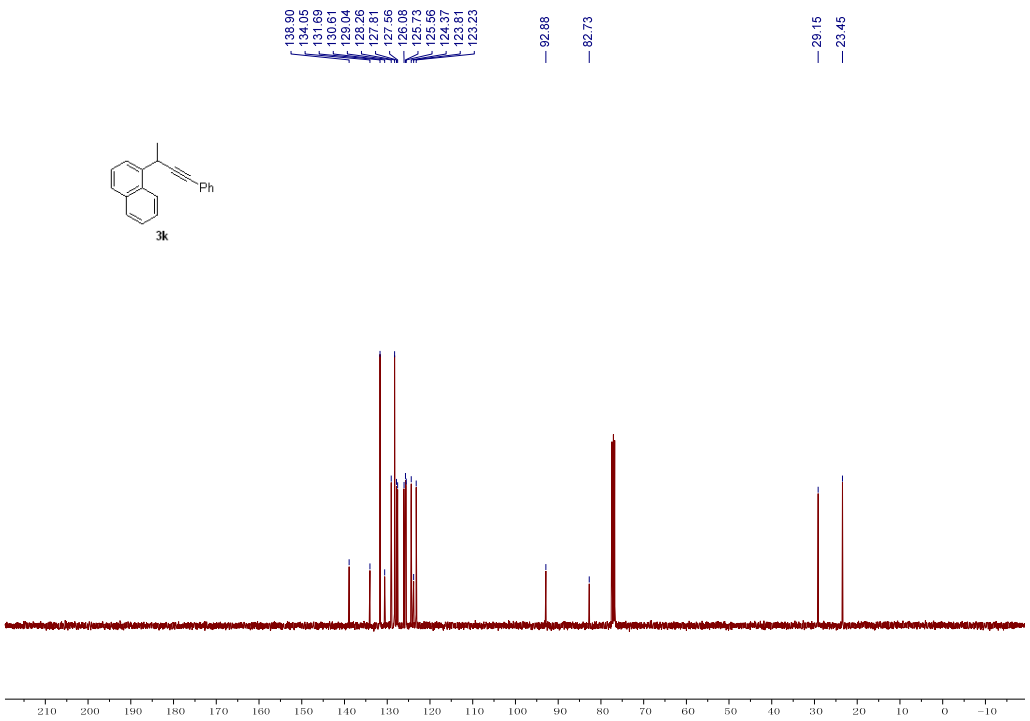
3j

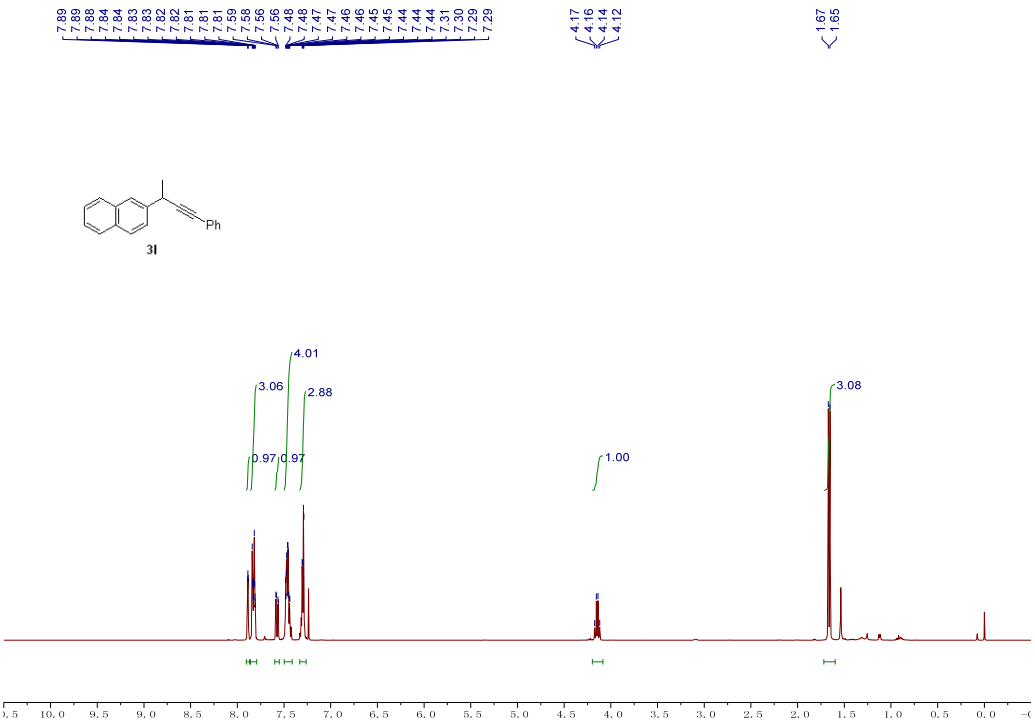

140.44
136.27
131.68
129.29
128.24
127.75
126.87
123.88
92.94
82.31
32.13
24.60
21.09

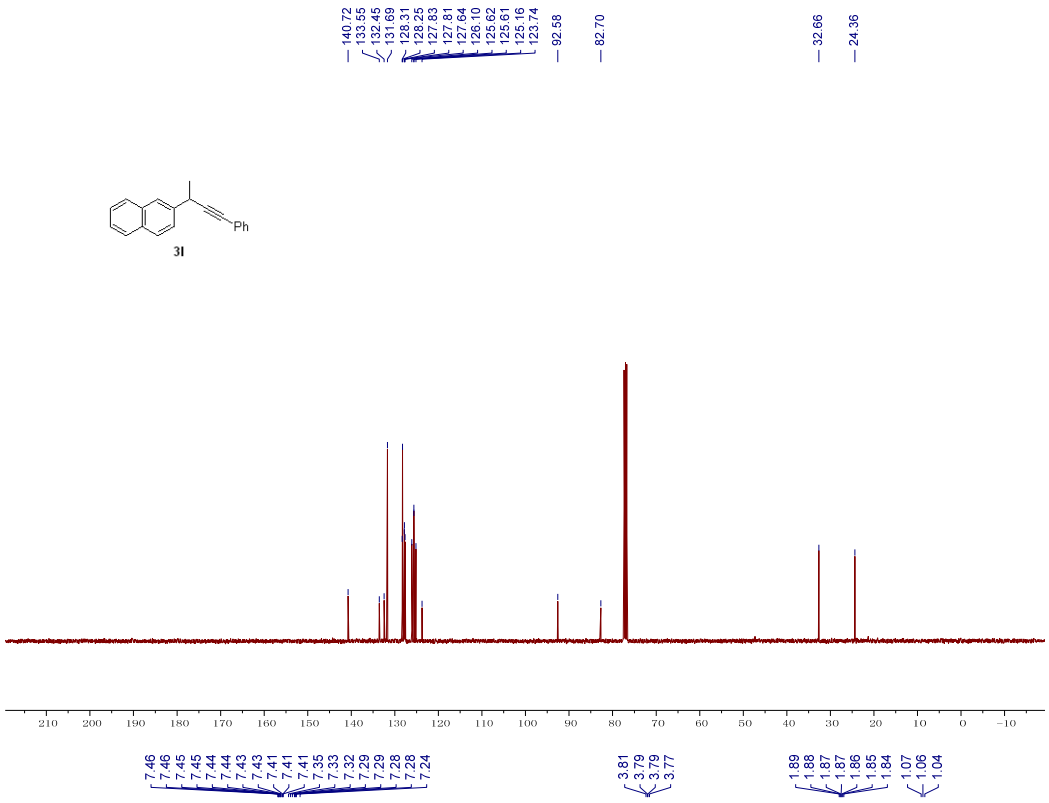
Ph

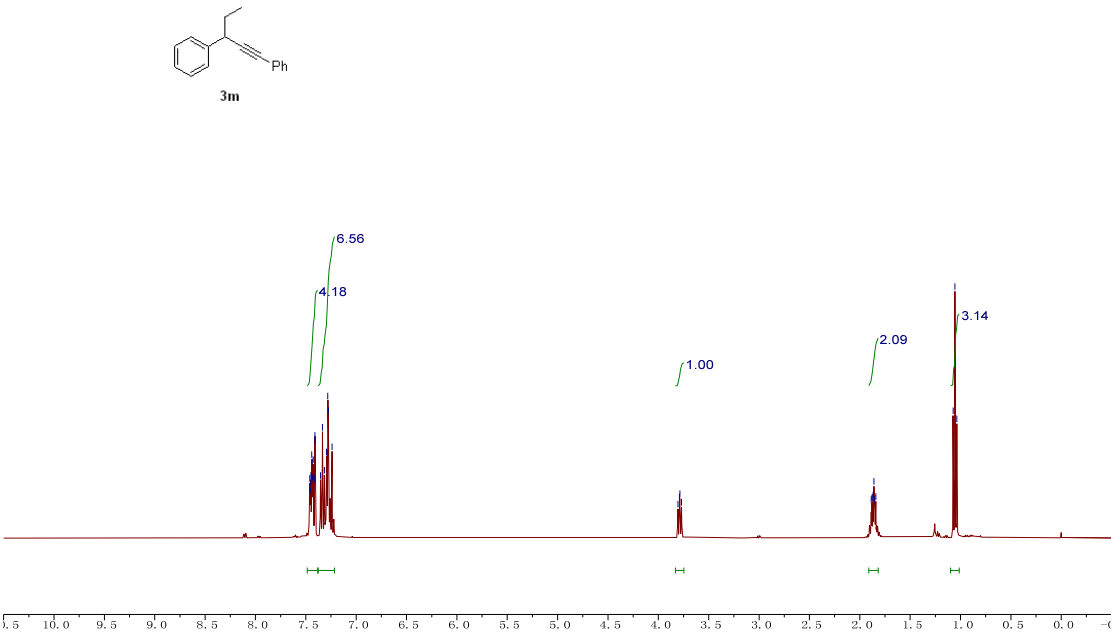
3k

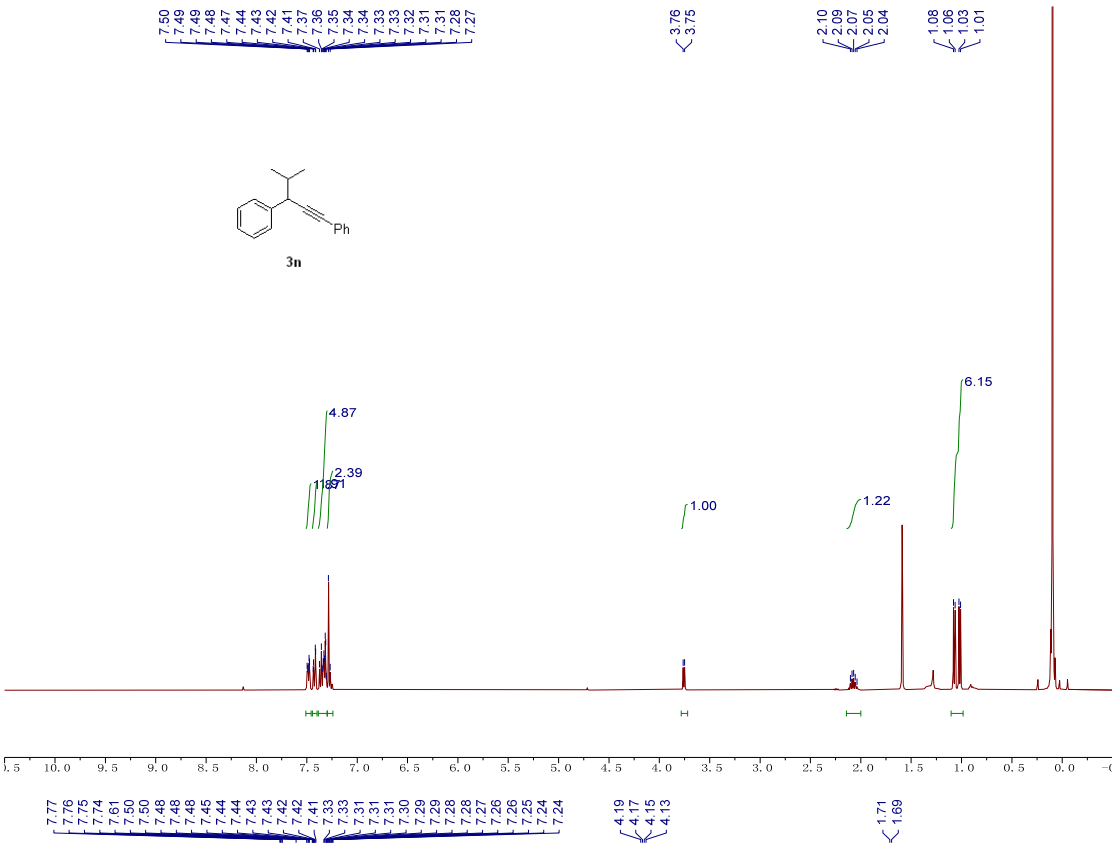

8.25
8.23
7.96
7.95
7.94
7.93
7.90
7.90
7.88
7.88
7.84
7.82
7.63
7.62
7.61
7.61
7.59
7.59
7.57
7.57
7.57
7.56
7.55
7.55
7.55
7.54
7.53
7.53
7.52
7.52
7.51
7.37
7.37
7.36
7.36
7.35
7.34
7.34
4.83
4.81
4.80
4.78
1.81
1.79
5.30
3.19
2.99
1.02
1.00
3.12

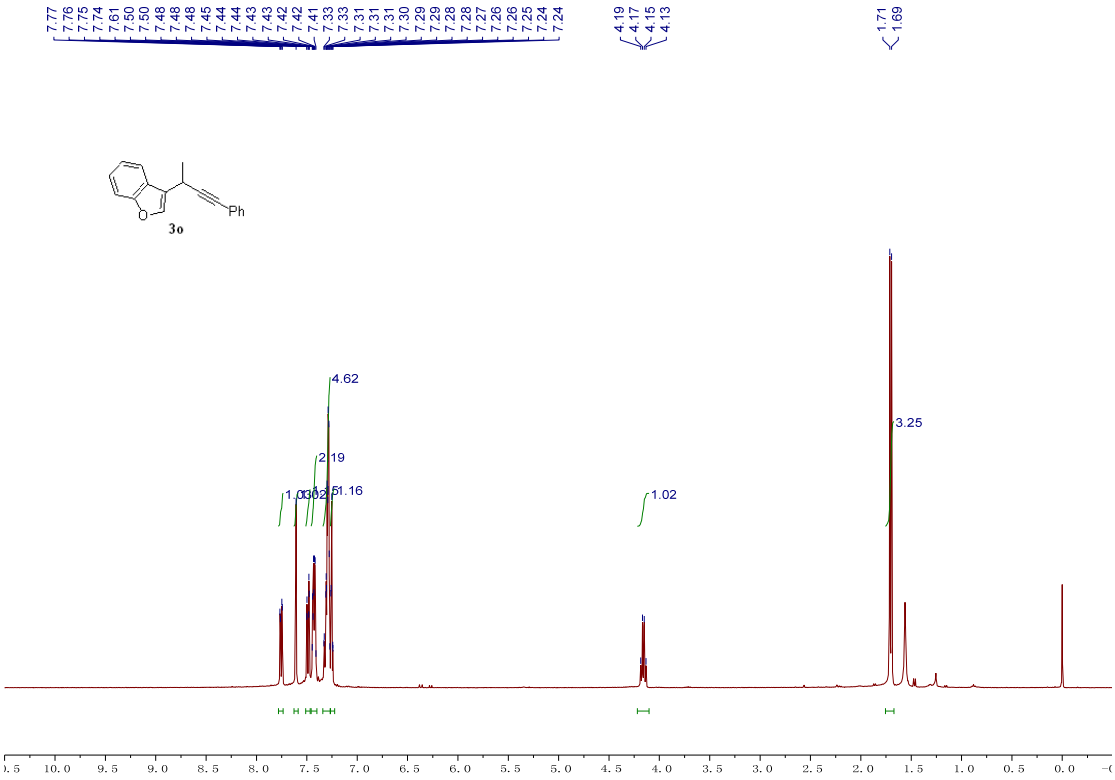

138.90
134.05
131.69
130.61
129.04
128.26
127.81
127.56
126.08
125.73
125.56
124.37
123.81
123.23
92.88
82.73
29.15
23.45
Ph
3k

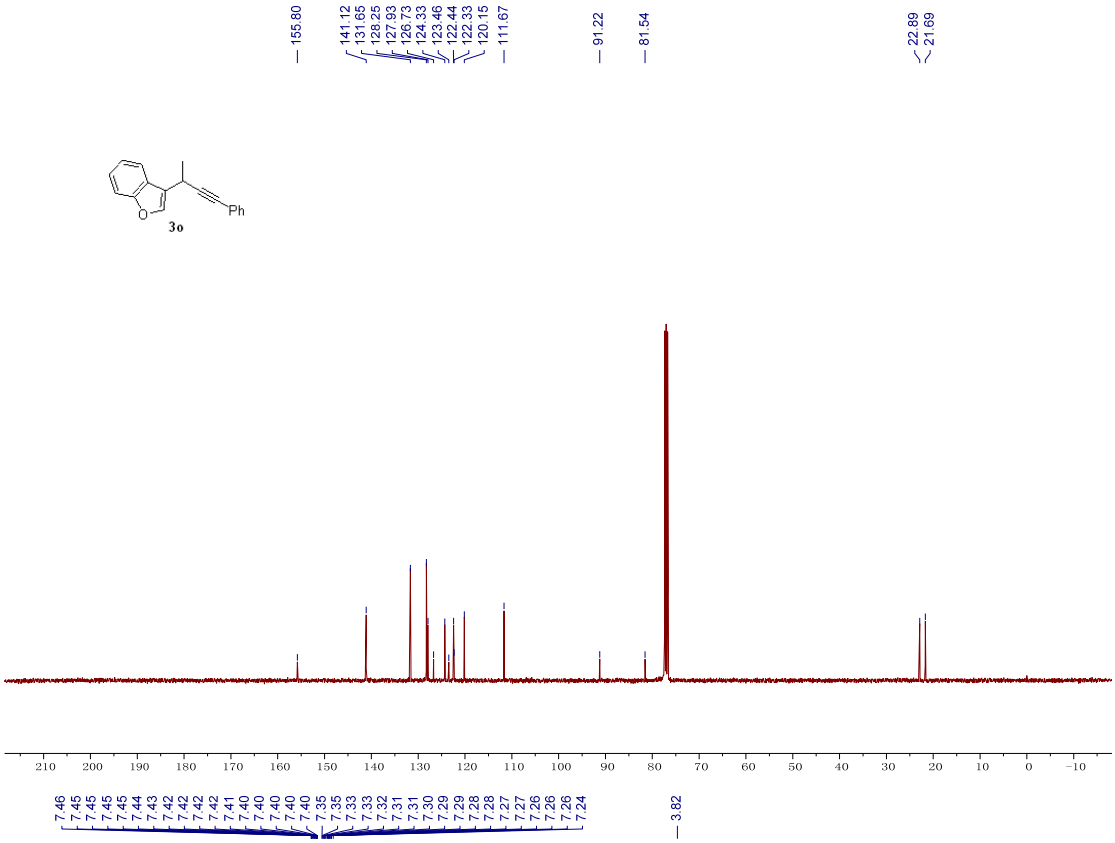

7.89
7.89
7.88
7.84
7.84
7.83
7.83
7.82
7.82
7.81
7.81
7.81
7.59
7.58
7.56
7.56
7.48
7.48
7.47
7.47
7.46
7.46
7.45
7.45
7.44
7.44
7.44
7.31
7.30
7.29
7.29
4.17
4.16
4.14
4.12
1.67
1.65
Ph
3l
4.01
3.06
2.88
0.97
0.97
1.00
3.08

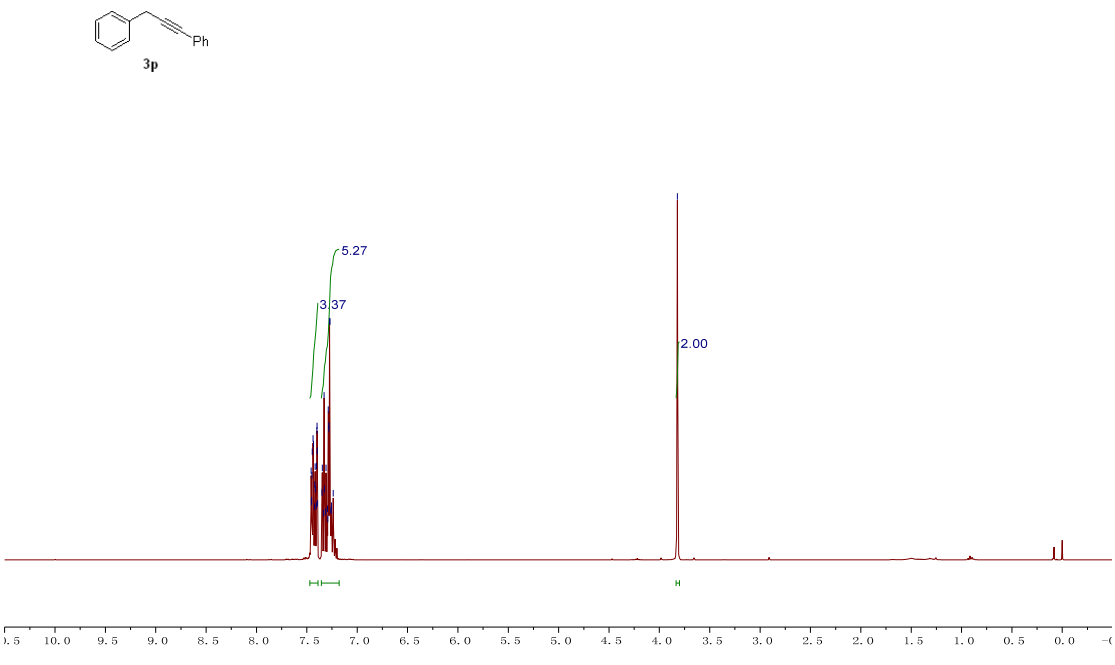

140.72
133.55
132.45
131.69
128.31
128.25
127.83
127.81
127.64
126.10
125.62
125.61
125.16
123.74
92.58
82.70
32.66
24.36
Ph
3l
7.46
7.46
7.45
7.45
7.44
7.44
7.43
7.43
7.41
7.41
7.41
7.35
7.33
7.32
7.29
7.29
7.28
7.28
7.24
3.81
3.79
3.79
3.77
1.89
1.88
1.87
1.87
1.86
1.85
1.84
1.07
1.06
1.04


Ph
3m
6.56
4.18
1.00
2.09
3.14


7.50 7.49 7.49 7.48 7.47 7.44 7.43 7.42 7.41 7.37 7.36 7.35 7.34 7.34 7.33 7.33 7.32 7.31 7.31 7.28 7.27
3.76 3.75
2.10 2.09 2.07 2.05 2.04
1.08 1.06 1.03 1.01
Ph
3n
4.87
2.39
1.00
1.22
6.15

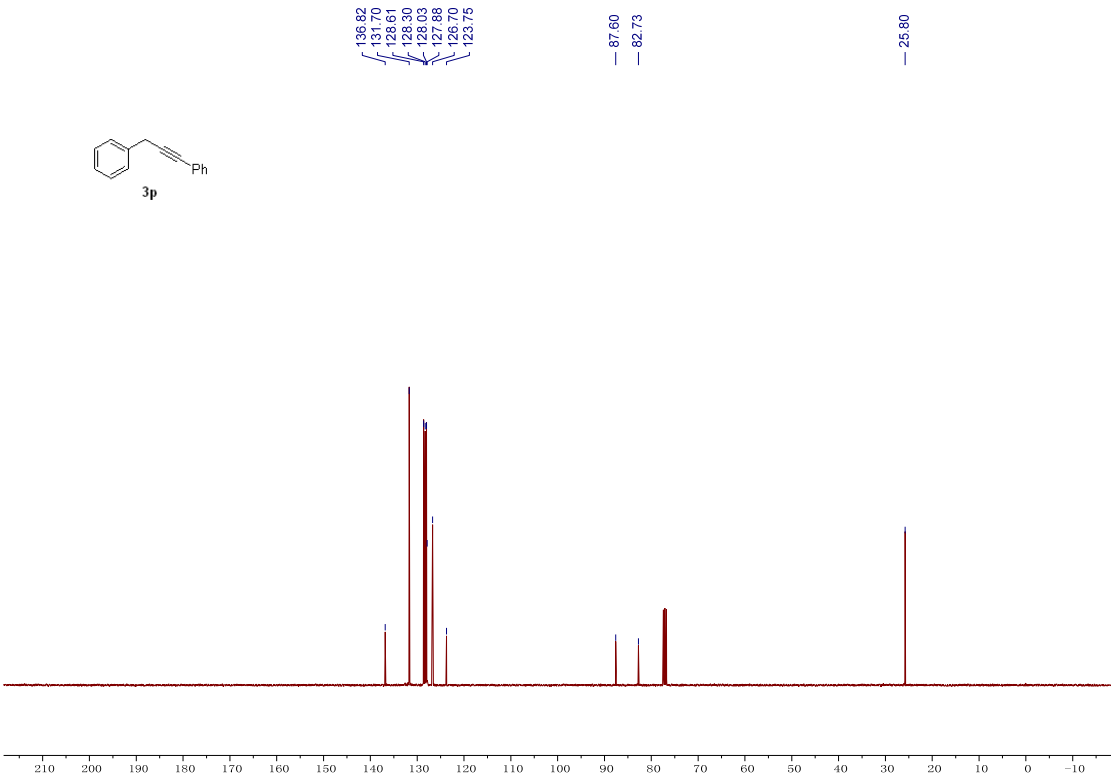

7.77 7.76 7.75 7.74 7.61 7.50 7.50 7.48 7.48 7.48 7.45 7.44 7.44 7.43 7.43 7.42 7.42 7.41 7.33 7.33 7.31 7.31 7.31 7.30 7.29 7.29 7.28 7.28 7.27 7.26 7.26 7.25 7.24 7.24
4.19 4.17 4.15 4.13
1.71 1.69
Ph
3o
4.62
2.19
1.16
1.02
3.25


155.80
141.12
131.65
128.25
127.93
126.73
124.33
123.46
122.44
122.33
120.15
111.67
91.22
81.54
22.89
21.69
Ph
3o
7.46
7.45
7.45
7.45
7.45
7.44
7.43
7.42
7.42
7.42
7.42
7.41
7.40
7.40
7.40
7.40
7.40
7.35
7.35
7.33
7.33
7.32
7.31
7.31
7.30
7.29
7.29
7.28
7.28
7.27
7.27
7.26
7.26
7.26
7.24
3.82


Ph
3p
5.27
3.37
2.00

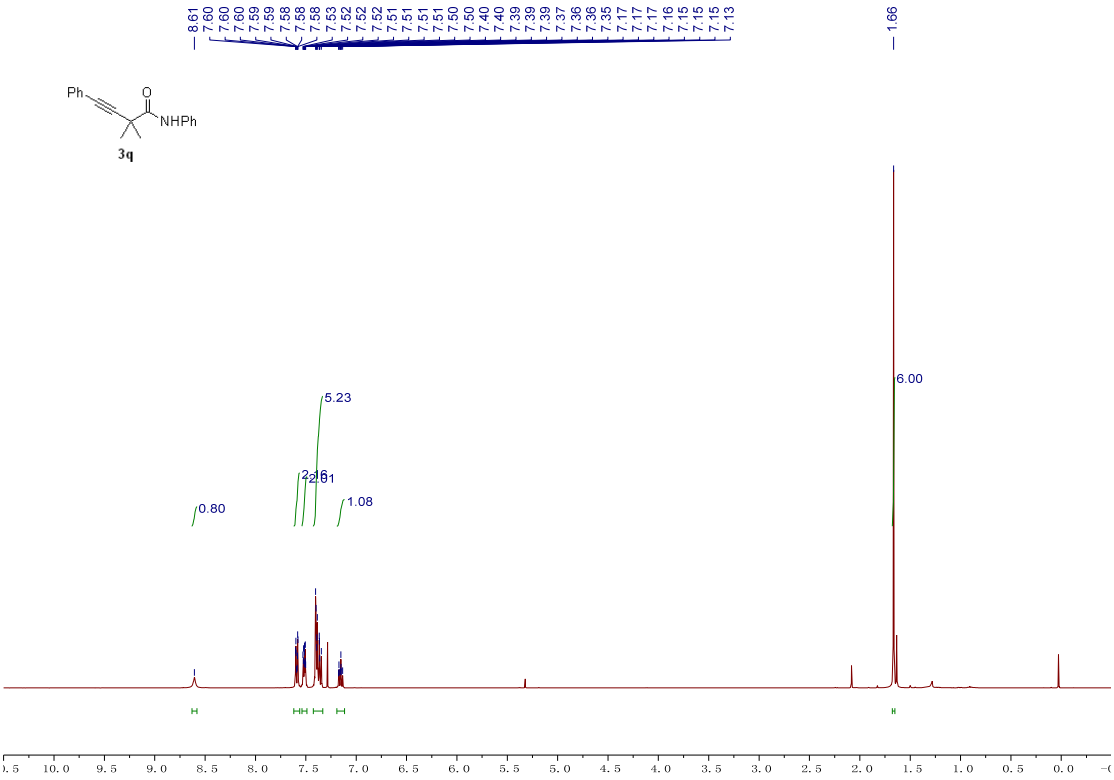
Ph

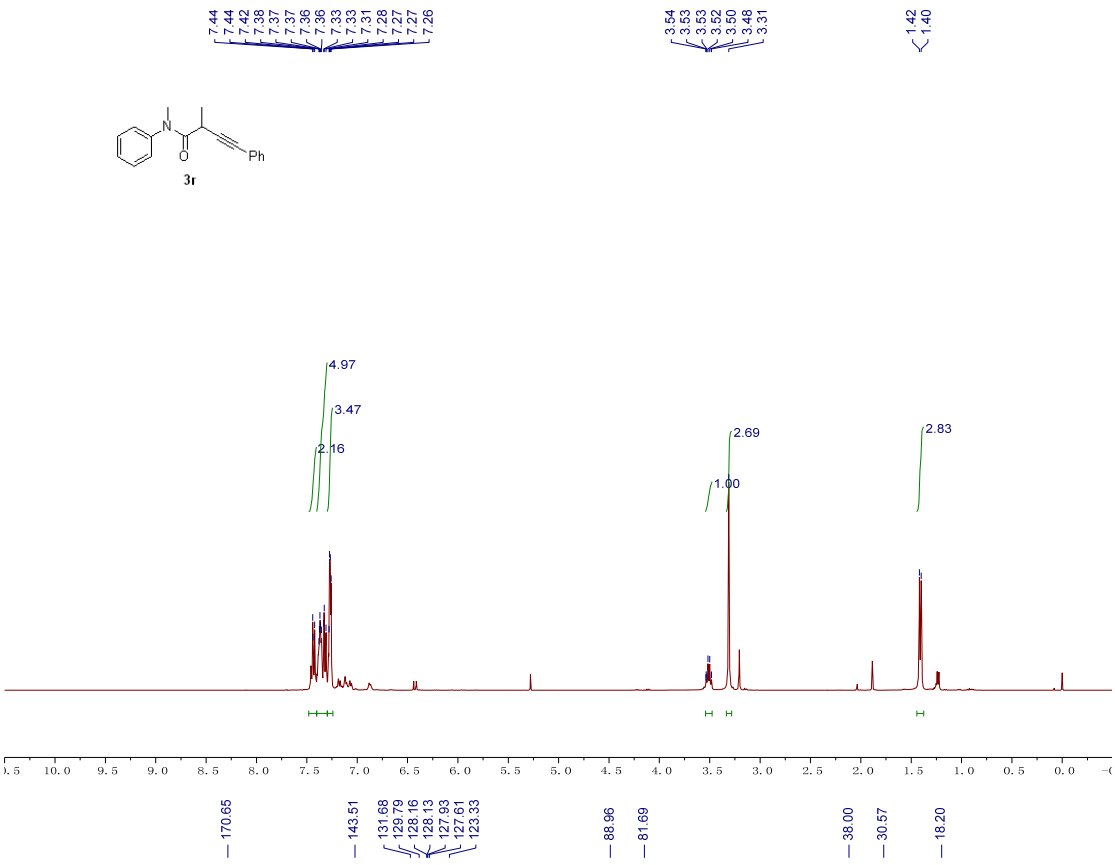
3p

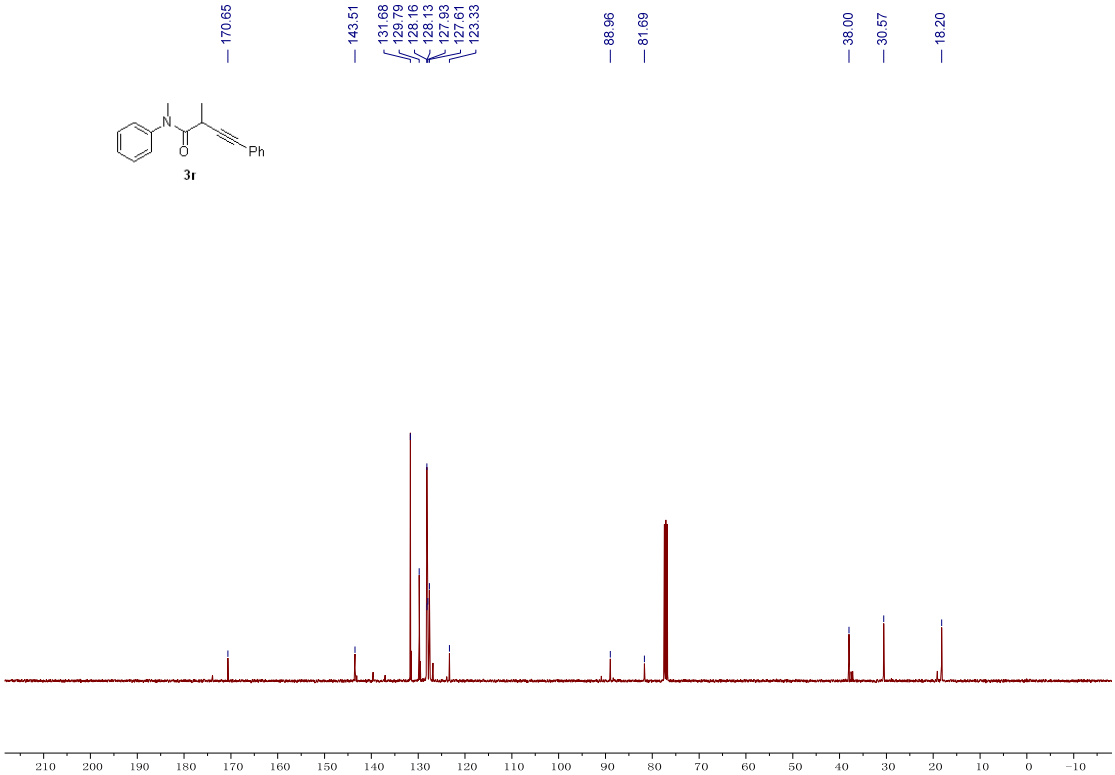

136.82
131.70
128.61
128.30
128.03
127.88
126.70
123.75
87.60
82.73
25.80
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 −10

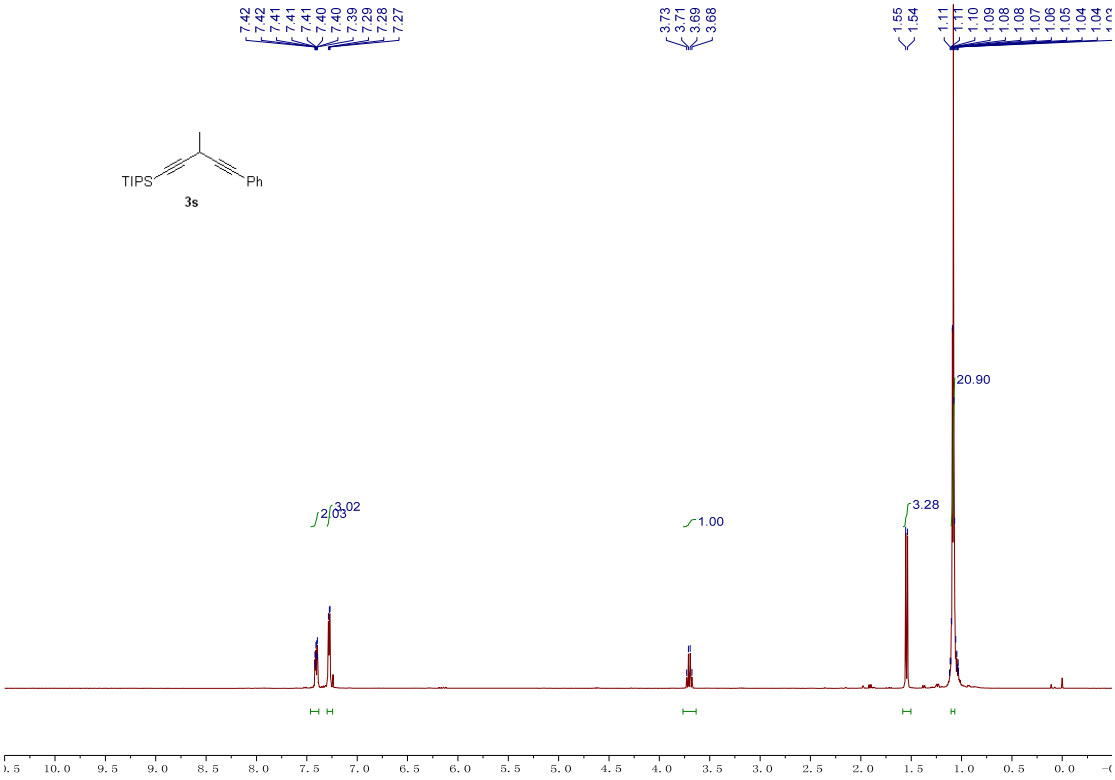
Ph
O
NHPh

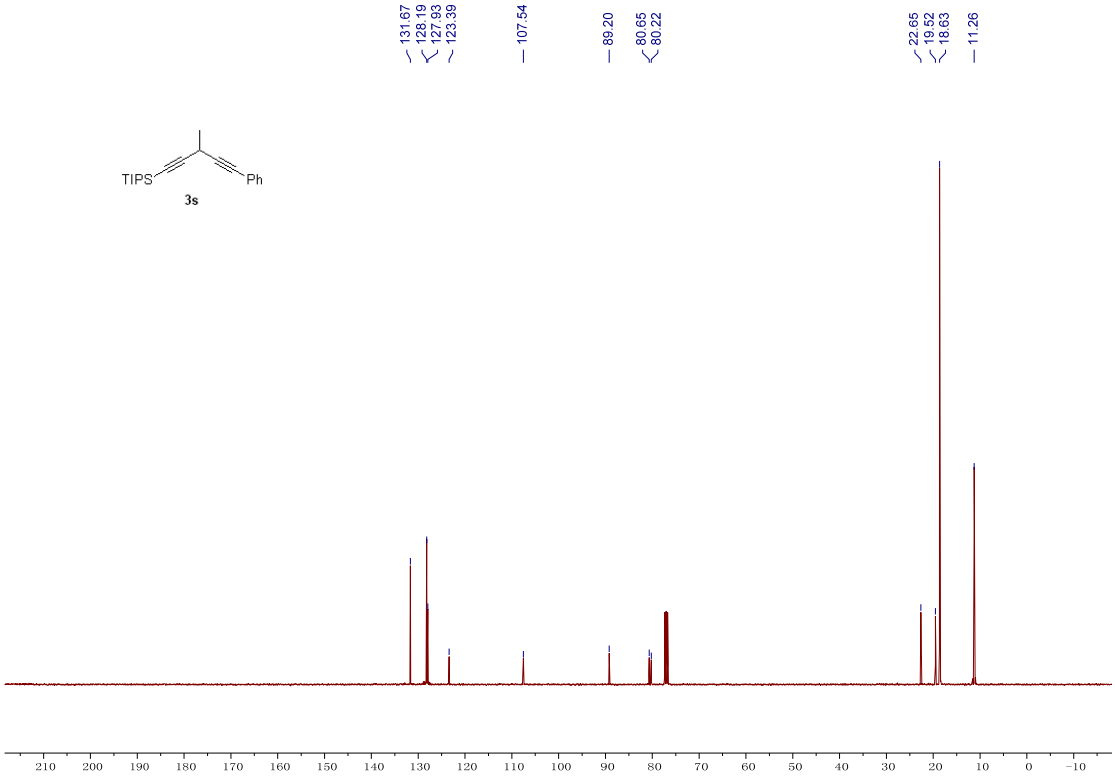
3q

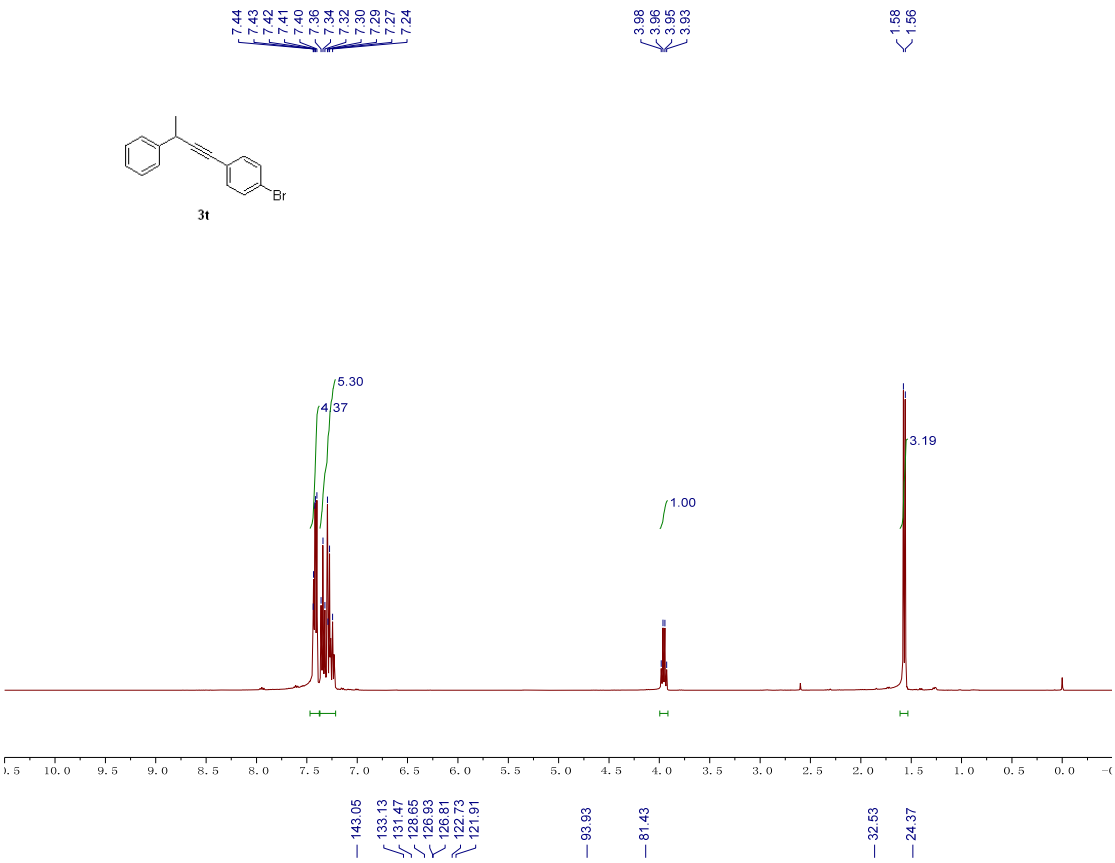

8.61
7.60
7.60
7.60
7.59
7.59
7.58
7.58
7.58
7.53
7.52
7.52
7.52
7.51
7.51
7.51
7.51
7.50
7.50
7.40
7.40
7.39
7.39
7.39
7.37
7.36
7.36
7.35
7.17
7.17
7.17
7.16
7.15
7.15
7.15
7.13
1.66
6.00
5.23
2.26
2.01
1.08
0.80
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

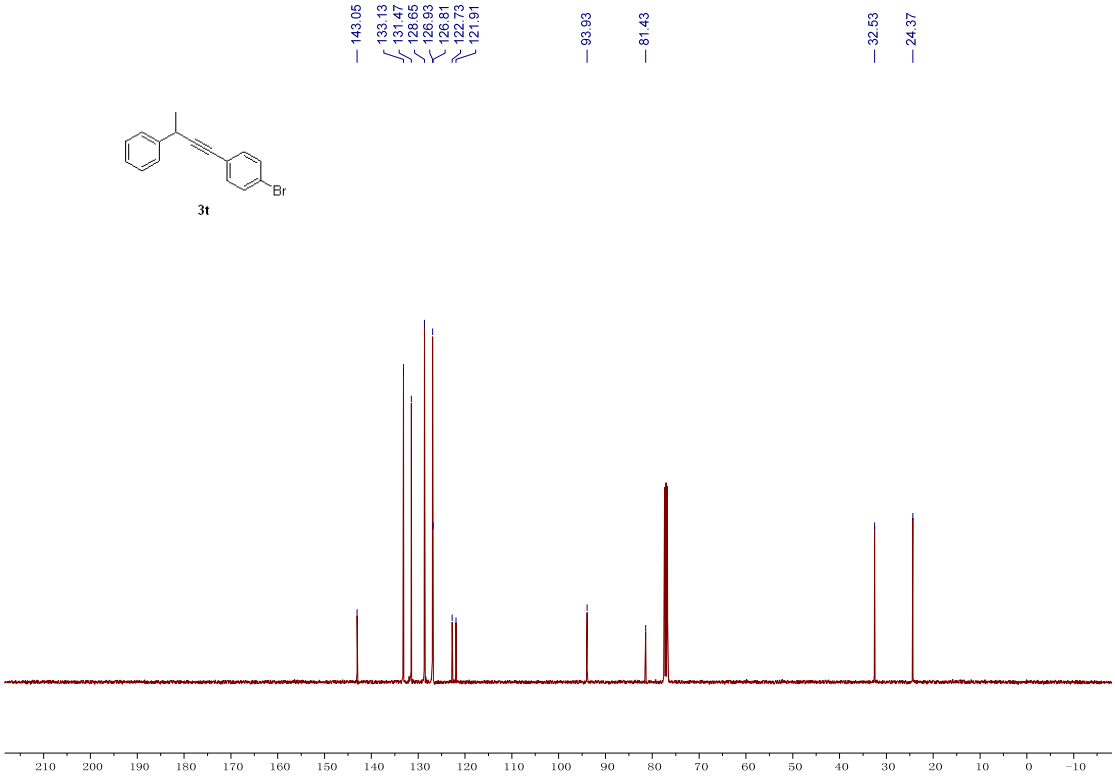

7.44
7.44
7.42
7.38
7.37
7.37
7.36
7.36
7.33
7.33
7.31
7.28
7.27
7.27
7.26
3.54
3.53
3.53
3.52
3.50
3.48
3.31
1.42
1.40
Ph
3r
4.97
3.47
2.16
2.69
1.00
2.83

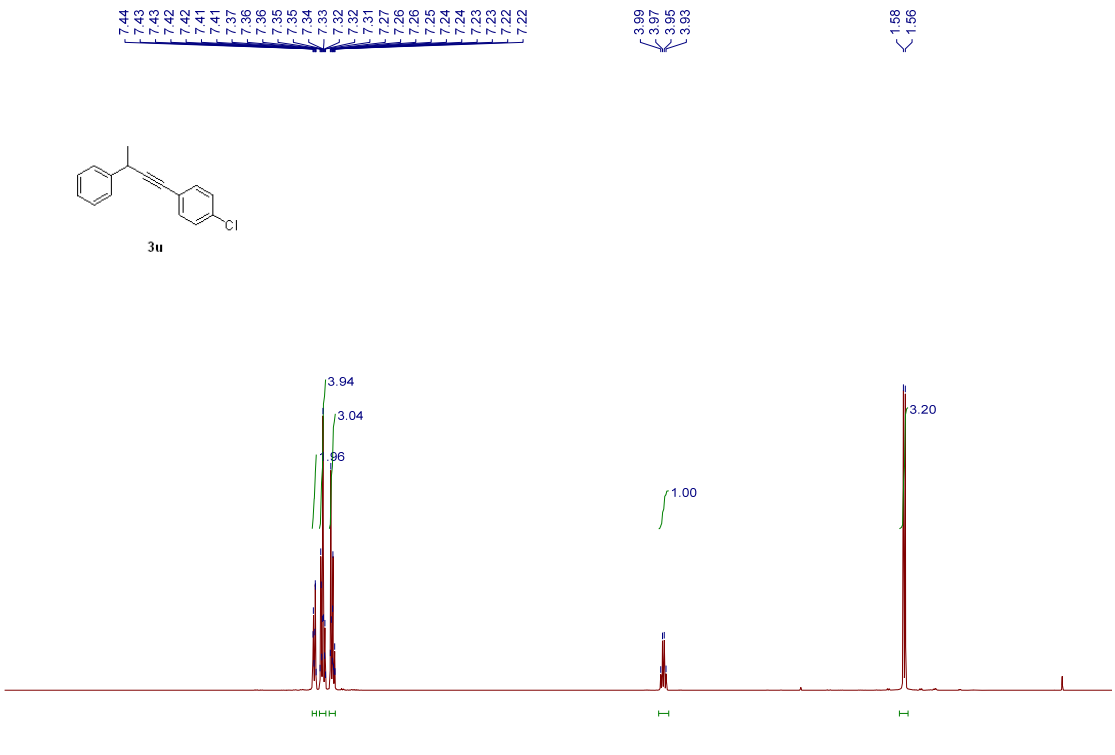

170.65
143.51
131.68
129.79
128.16
128.13
127.93
127.61
123.33
88.96
81.69
38.00
30.57
18.20
Ph
3r

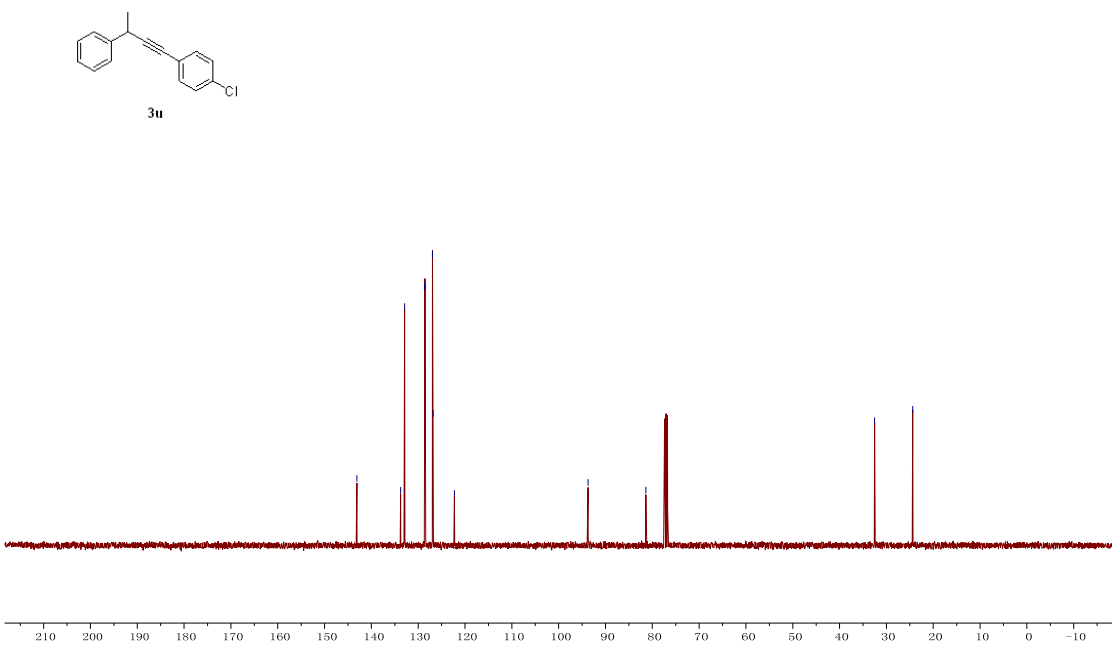

7.42
7.42
7.41
7.41
7.41
7.40
7.40
7.39
7.29
7.28
7.27
3.73
3.71
3.69
3.68
1.55
1.54
1.11
1.11
1.10
1.09
1.08
1.08
1.07
1.06
1.05
1.04
1.04
TIPS
Ph
3s
20.90
2.03
3.02
1.00
3.28

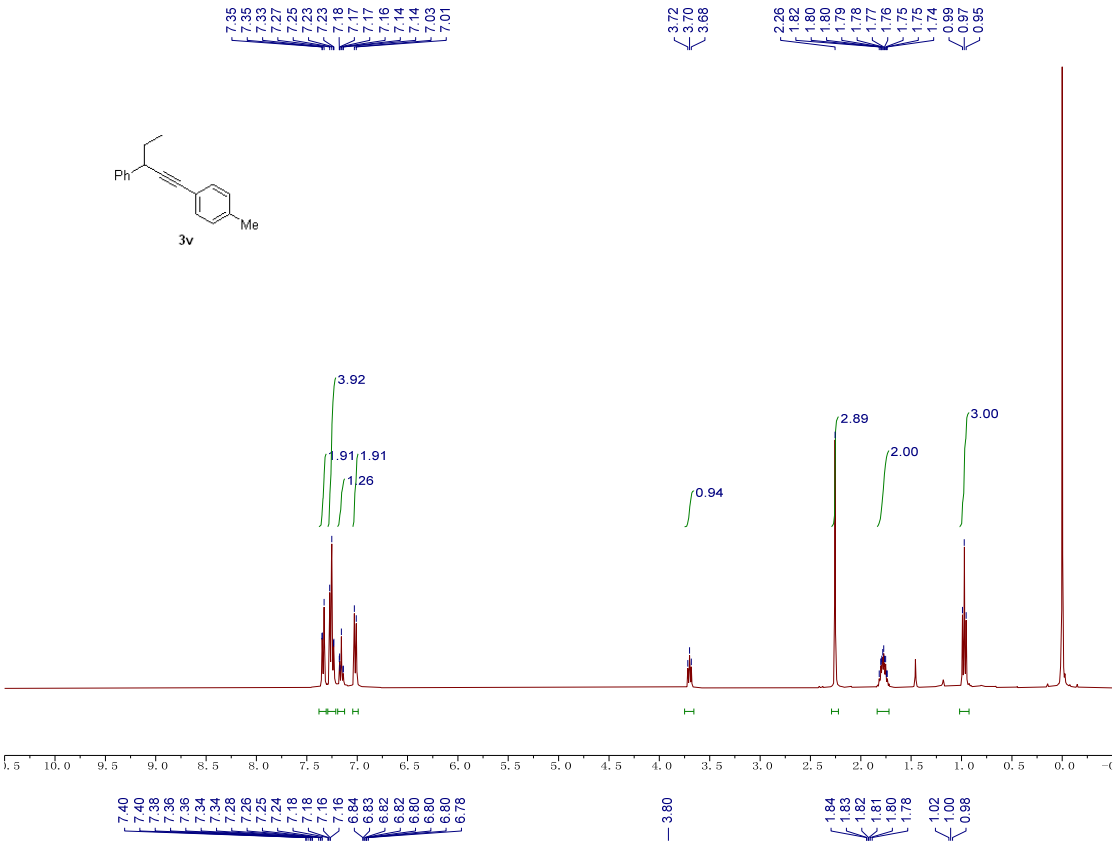

131.67
128.19
127.93
123.39
107.54
89.20
80.65
80.22
22.65
19.52
18.63
11.26
TIPS
Ph
3s

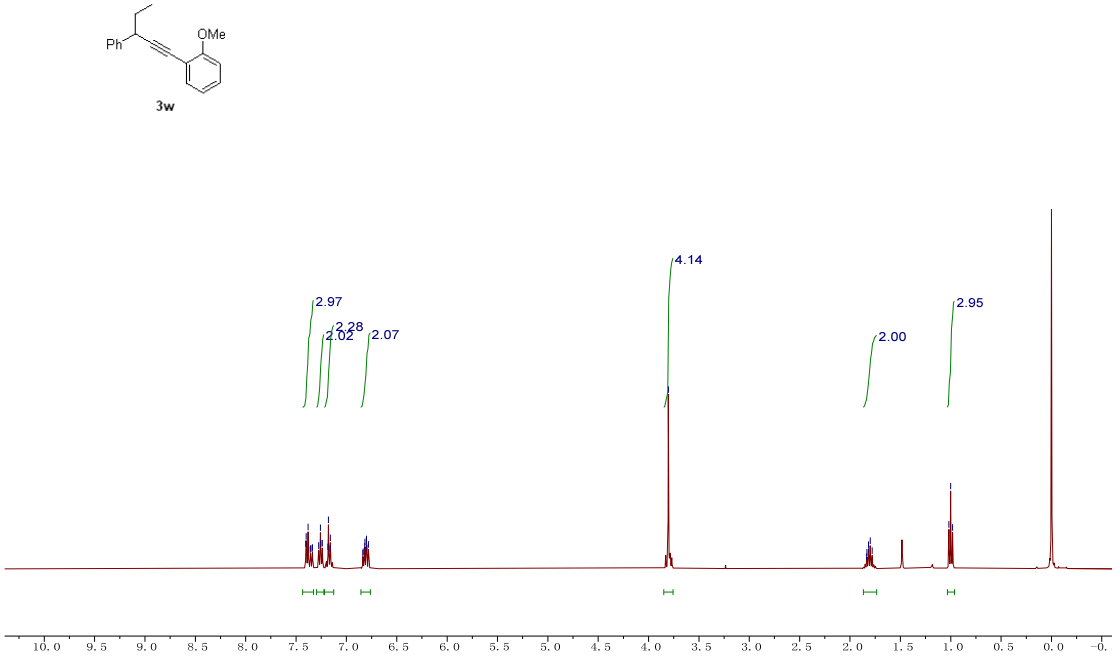

7.44
7.43
7.42
7.41
7.40
7.36
7.34
7.32
7.30
7.29
7.27
7.24
3.98
3.96
3.95
3.93
1.58
1.56
Br
3t
5.30
4.37
1.00
3.19

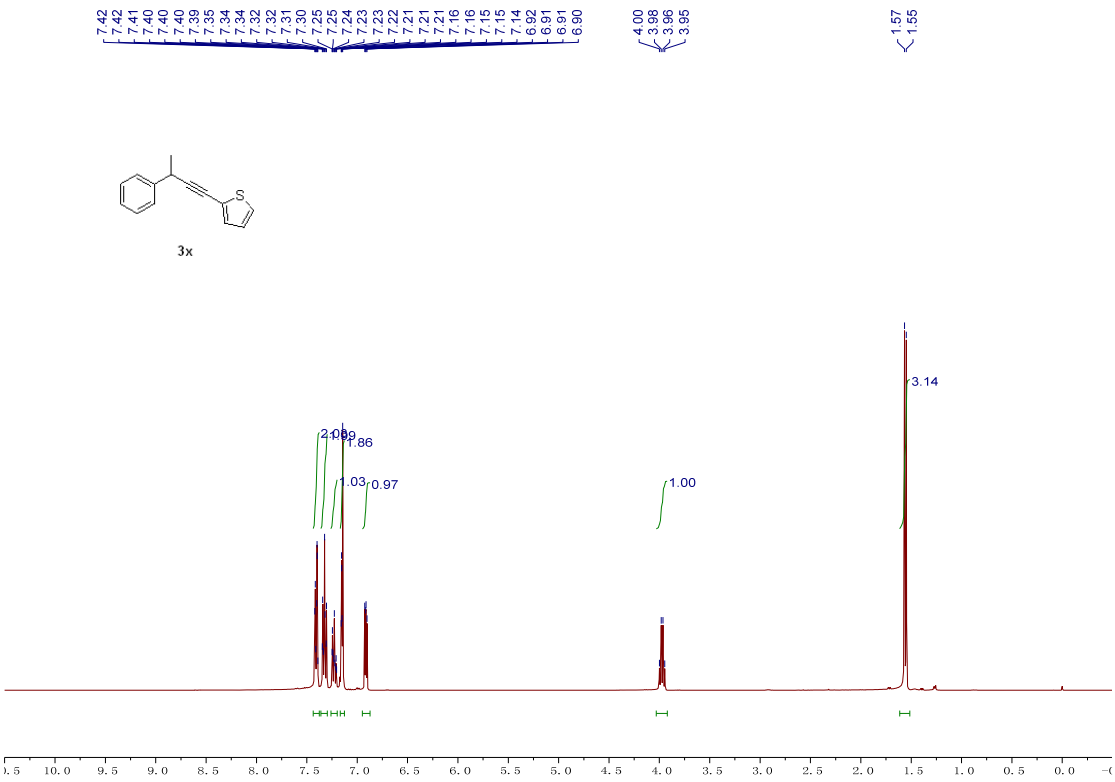

143.05
133.13
131.47
128.65
126.93
126.81
122.73
121.91
93.93
81.43
32.53
24.37
Br
3t

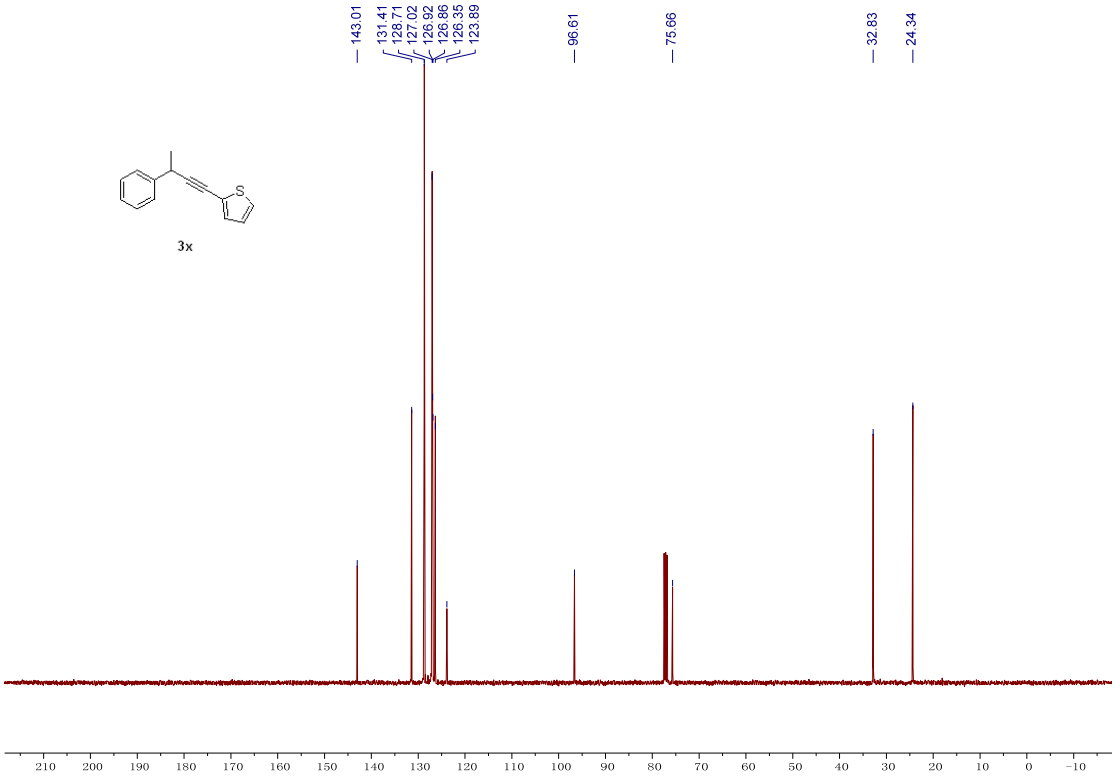

7.44
7.43
7.43
7.42
7.42
7.41
7.41
7.37
7.36
7.36
7.35
7.35
7.34
7.33
7.32
7.32
7.31
7.27
7.26
7.26
7.25
7.24
7.24
7.23
7.23
7.22
7.22
3.99
3.97
3.95
3.93
1.58
1.56
Cl
3u
3.94
3.04
1.96
1.00
3.20
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

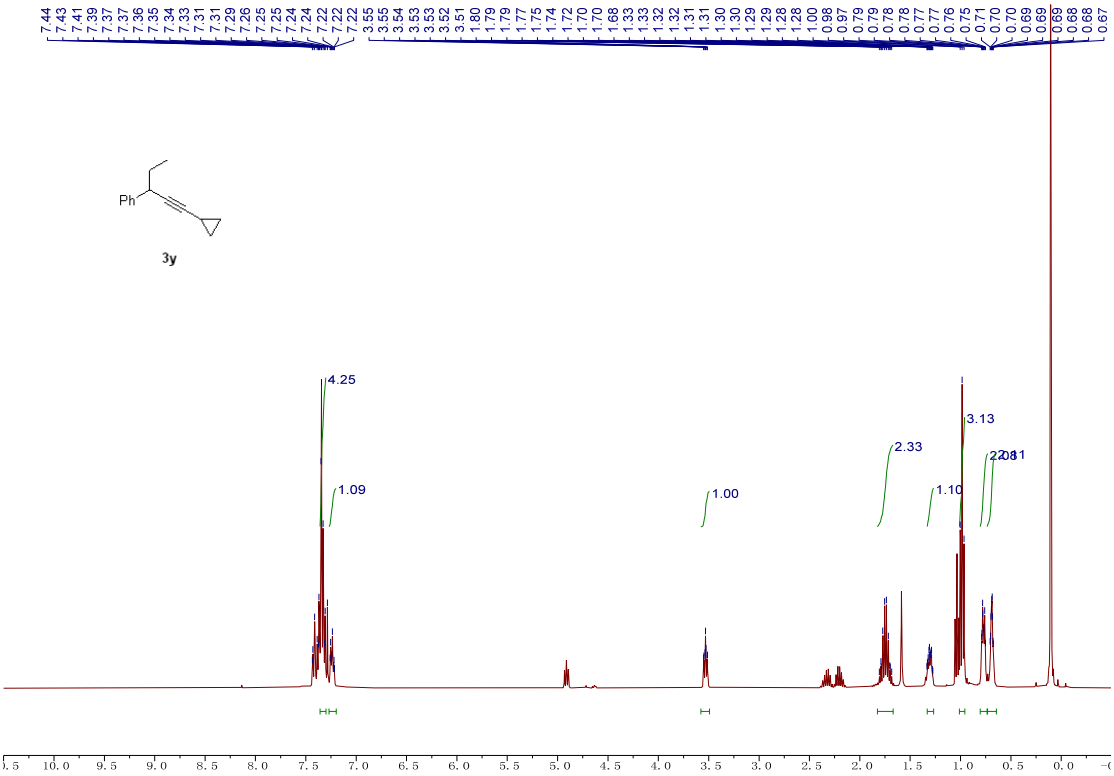

143.10
133.74
132.90
128.65
128.55
126.94
126.80
122.27
93.72
81.38
32.52
24.40
Cl
3u
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10

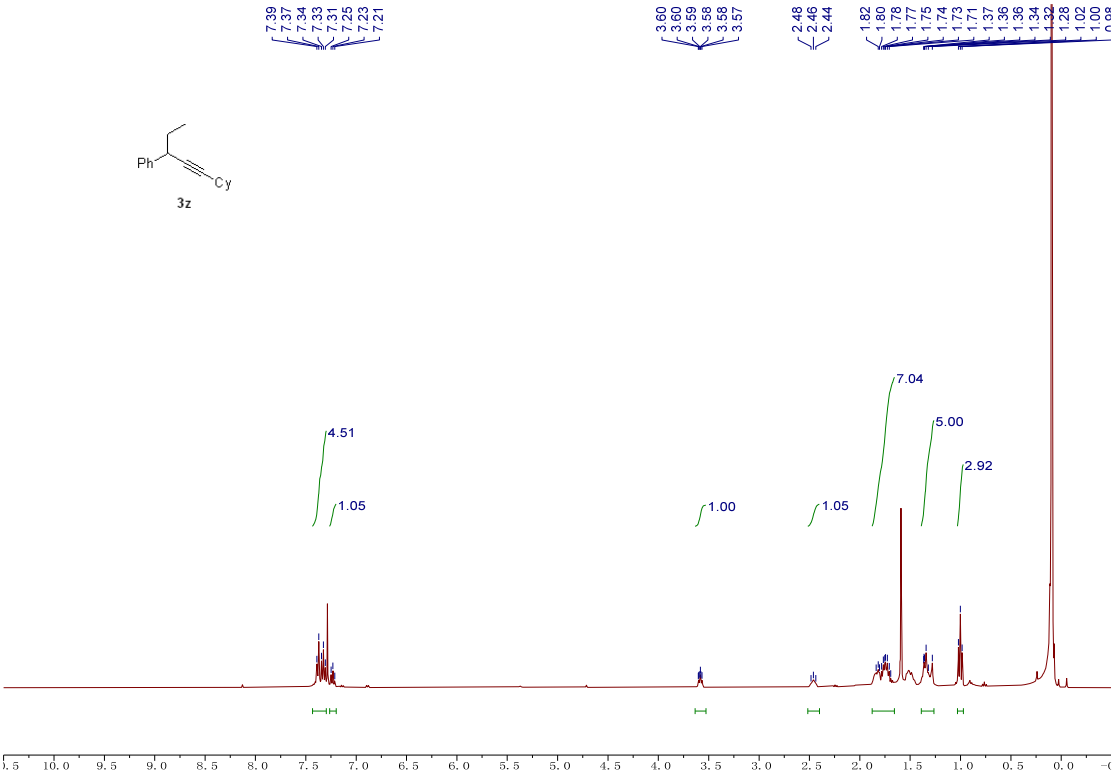

Ph
Me
3v
7.35 7.35 7.33 7.27 7.25 7.23 7.23 7.18 7.17 7.17 7.16 7.14 7.14 7.03 7.01
3.72 3.70 3.68
2.26 1.82 1.80 1.80 1.79 1.78 1.77 1.76 1.75 1.75 1.74
0.99 0.97 0.95
3.92
1.91 1.91
1.26
0.94
2.89
2.00
3.00

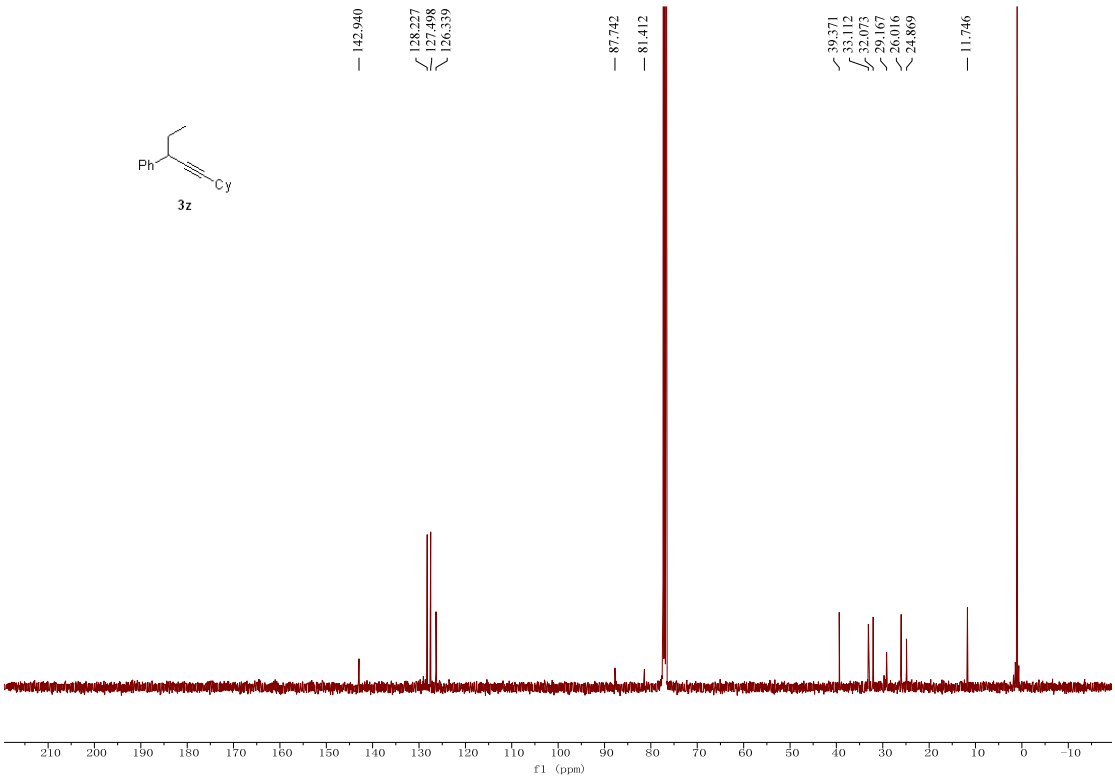

Ph
OMe
3w
7.40 7.40 7.38 7.36 7.36 7.34 7.34 7.28 7.26 7.25 7.24 7.18 7.18 7.16 7.16
6.84 6.83 6.82 6.82 6.80 6.80 6.80 6.78
3.80
1.84 1.83 1.82 1.81 1.80 1.78
1.02 1.00 0.98
2.97
2.28
2.02
2.07
4.14
2.00
2.95


7.42
7.42
7.41
7.40
7.40
7.40
7.39
7.35
7.34
7.34
7.32
7.32
7.31
7.30
7.25
7.25
7.24
7.23
7.23
7.22
7.21
7.21
7.21
7.16
7.16
7.15
7.15
7.14
6.92
6.91
6.91
6.90
4.00
3.98
3.96
3.95
1.57
1.55
S
3x
3.14
2.09
1.86
1.03
0.97
1.00


143.01
131.41
128.71
127.02
126.92
126.86
126.35
123.89
96.61
75.66
32.83
24.34
S
3x


Ph
3y
4.25
1.09
1.00
2.33
1.10
3.13


Ph
Cy
3z
4.51
1.05
1.00
1.05
7.04
5.00
2.92



References:

[1] W. L. F. Armarego, Chai, C. L. L., Purification of Laboratory Chemicals Fifth Edition, Elsevier/Butterworth-Heinemann, **2003**.

[2] T. Mino, A. Omura, Y. Uda, K. Wakui, Y. Haga, M. Sakamoto, T. Fujita, *Tetrahedron: Asymmetry* **2011**, *22*, 2024.

[3] X.-Y. Dong, Y.-F. Zhang, C.-L. Ma, Q.-S. Gu, F.-L. Wang, Z.-L. Li, S.-P. Jiang, X.-Y. Liu, *Nat. Chem.* **2019**, *11*, 1158.

[4] Y. Yamane, N. Miwa, T. Nishikata, *ACS Catal.* **2017**, *7*, 6872.

[5] C. Li, Y. Zhang, Q. Sun, T. Gu, H. Peng, W. Tang, *J. Am. Chem. Soc.* **2016**, *138*, 10774-10777.