Aerobic Cu-Catalyzed Oxidative 1:2 Coupling of Benzynes with Terminal Alkynes

Tianhao Lu, Yong Shen, Min Wang, Zibing Zhang, Shijun Li, Chunsong Xie*

College of Material, Chemistry and Chemical Engineering, Hangzhou Normal University, Hangzhou 310036, P. R. China.

chunsongxie@hznu.edu.cn

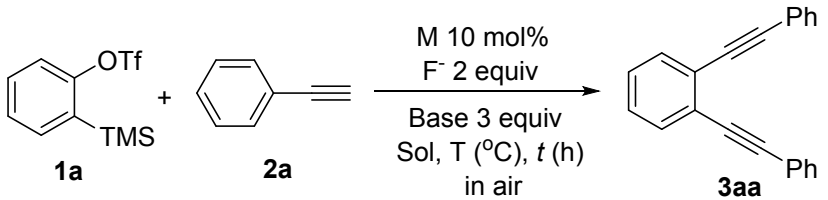
Supporting Information

Content

General All the reactions were carried out under air atmosphere in oven-dried flasks unless otherwise noted. CH_3CN and DCE were distilled from CaH_2 prior to use. Toluene, DME and THF were distilled from Na before use. Benzyne precursors **1a**-**1f** were all prepared from corresponding *ortho*-bromophenols according to similar procedures in a reference.[1] 2-Bromo-4,5-dimethylphenol for the benzyne precursor **1b** was synthesized from 3,4-dimethylphenol by a reference method.[2] Substrate **2l** was prepared by the reference method.[3] Substrate **4** was prepared by the reference method.[4] Substrate **1a'** was synthesized by reference methods.[5] Other materials were purchased from commercial sources and used without additional purification. ^{1}H NMR spectra were recorded at 500 MHz using TMS as an internal standard. ^{13}C NMR spectra were acquired at 125 MHz. Mass spectroscopy data were collected on a TOF-MS instrument. EPR spectra were recorded on a Bruker A300 EPR Spectrometer. The samples were taken out into a thin quartz tube and frozen by liquid nitrogen, then recorded by EPR spectrometer at indicated temperature and parameters.

Representative procedure of the reaction: To an oven-dried flask, benzyne precursor **1a** (0.5 mmol), ethynylbenzene **2a** (2.0 mmol), $CuCl_2 \cdot 2H_2O$ (0.05 mmol), CsF (1.0 mmol), Cs_2CO_3 (1.5 mmol) were added. Then, dry MeCN (2.5 mL) was injected by a syringe. The reaction mixture was allowed to stir in air at 60 ^{o}C for 6 hours. After the completion of the reaction, the mixture was filtered through a pad of celite. The filtrate was concentrated until the solvent was completely removed. The residue was then separated on a silica gel column using PE as an eluent, and the product **3aa** was obtained as a pale yellow powder (103 mg, 74% yield).

Table S1. The Optimization Work [a]



Entry	M	F-	Base	[S]	T (°C)	*t* h	Yield (%) [b]
1	CuI	CsF	Cs_2CO_3	MeCN	80	12	50
2	no	CsF	Cs_2CO_3	MeCN	80	12	trace
3	CuI	no	Cs_2CO_3	MeCN	80	12	trace
4	CuI	CsF	no	MeCN	80	12	10
5	CuI	CsF	K_2CO_3	MeCN	80	12	47
6	CuI	CsF	Na_2CO_3	MeCN	80	12	29
7 [c]	CuI	CsF	Et_3N	MeCN	80	12	13
8 [c]	CuI	CsF	DBU	MeCN	80	12	trace
9	CuI	CsF	Cs_2CO_3	DME	80	12	27
10	CuI	CsF	Cs_2CO_3	Toluene	80	12	Trace
11 [d]	CuI	CsF	Cs_2CO_3	THF	80	12	Trace
12	CuI	CsF	Cs_2CO_3	MeCN	100	12	15
13	CuI	CsF	Cs_2CO_3	MeCN	60	12	75
14	CuI	CsF	Cs_2CO_3	MeCN	40	12	58
15	CuBr	CsF	Cs_2CO_3	MeCN	60	12	76
16	CuCl	CsF	Cs_2CO_3	MeCN	60	12	69

17	$CuBr_2$	CsF	Cs_2CO_3	MeCN	60	12	77
18	$CuCl_2•2H_2O$	CsF	Cs_2CO_3	MeCN	60	12	78
19	$Cu(OAc)_2•H_2O$	CsF	Cs_2CO_3	MeCN	60	12	73
20	$CuCl_2•2H_2O$	CsF	Cs_2CO_3	MeCN	60	24	76
21	$CuCl_2•2H_2O$	CsF	Cs_2CO_3	MeCN	60	6	74
22	$CuCl_2•2H_2O$	CsF	Cs_2CO_3	MeCN	60	3	35
23 [e]	$CuCl_2•2H_2O$	CsF	Cs_2CO_3	MeCN	60	6	15
24 [f]	$CuCl_2•2H_2O$	KF/18-C-6	Cs_2CO_3	MeCN	60	6	17
25	$CuCl_2•2H_2O$	TBAF	Cs_2CO_3	MeCN	60	6	trace

[a] Reaction conditions: **1a** (0.5 mmol), **2a** (2.0 mmol), F^- (1.0 mmol), base (1.5 mmol), [S] (2.5 mL). [b] Isolated yields. [c] Base (3.0 mmol). [d] In sealed tube. [e] Under N_2. [f] 18-C-6 (1.0 mmol).

We commenced our study by selecting readily available benzyne precursor **1a**[1] and ethynylbenzene **2a** as model substrates (Table S1). Control experiments revealed that this reaction was fruitless in the absence of either copper catalyst or fluoride (Table S1, entries 2-3). Performing the reaction in the absence of Cs_2CO_3 just gave a 10% yield (Table S1, entry 4). The optimization on a variety of bases showed that Cs_2CO_3 was the best choice (Table S1, entries 5-8). When conducting the reaction in the presence of nitrogen-containing organic bases such as Et_3N and DBU, sluggish results were obtained which might be attributed to the competitively coordination of these organic bases with copper ions. The screening on reaction solvents disclosed MeCN was superior to other common solvents such as toluene or THF (Table S1, entries 9-11). Optimization on the reaction temperature showed that 60 ^oC was most suitable for the reaction (Table S1, entries 12-14). A wide selection of copper salts including both Cu(I) and Cu(II) were able to effect this reaction giving comparable yields of **3aa** (Table S1, entries 15-19). With regard to the reaction yield and cost of these copper salts, we chose $CuCl_2•2H_2O$ as the optimal catalyst for further studies. It should be noted

that lattice water in these copper salts had no deleterious effect on the reaction (Table S1, entries 18-19). This result together with the fact that this reaction could be performed in open air showed the convenience of handling this reaction. Different reaction time was tested indicating that 6 hours were adequate for this reaction (Table S1, entries 20-22). Shortening the reaction time to 3 hours furnished a lower yield while elongating it to 24 hours gave a comparable yield with 6 hours. Performing the reaction under N_2 afforded a lower yield (15%, Table S1, entry 23), implying the key role of atmospheric oxygen on the reaction. Finally, the optimization on the fluoride source revealed that CsF was the best choice with KF/18-C-6 and Bu_4NF both giving sluggish results (Table S1, entries 24-25).

EPR Experiments: At room temparature in air, benzyne precursor **1a** (0.5 mmol), ethynylbenzene **2a** (2.0 mmol), $CuCl_2 \cdot 2H_2O$ (0.05 mmol), Cs_2CO_3 (1.5 mmol) were added into a screw-capped glass vial fitted with a magnetic stirring bar. Once CsF (1.0 mmol) was added, the system was kept stirring for an indicated time, then the sample was taken out into a thin glass capillary tube and frozen by liquid nitrogen. EPR spectra was recorded at 120 K on EPR spectrometer operated at 9.409 GHz. Typical spectrometer parameters are shown as follows, scan range: 2000 G; center field set: 3357 G; time constant: 163.84 ms; scan time: 81.92 s; modulation amplitude: 4.0 G; modulation frequency: 100 kHz; receiver gain: 1.00×103; microwave power: 1.797 mW.

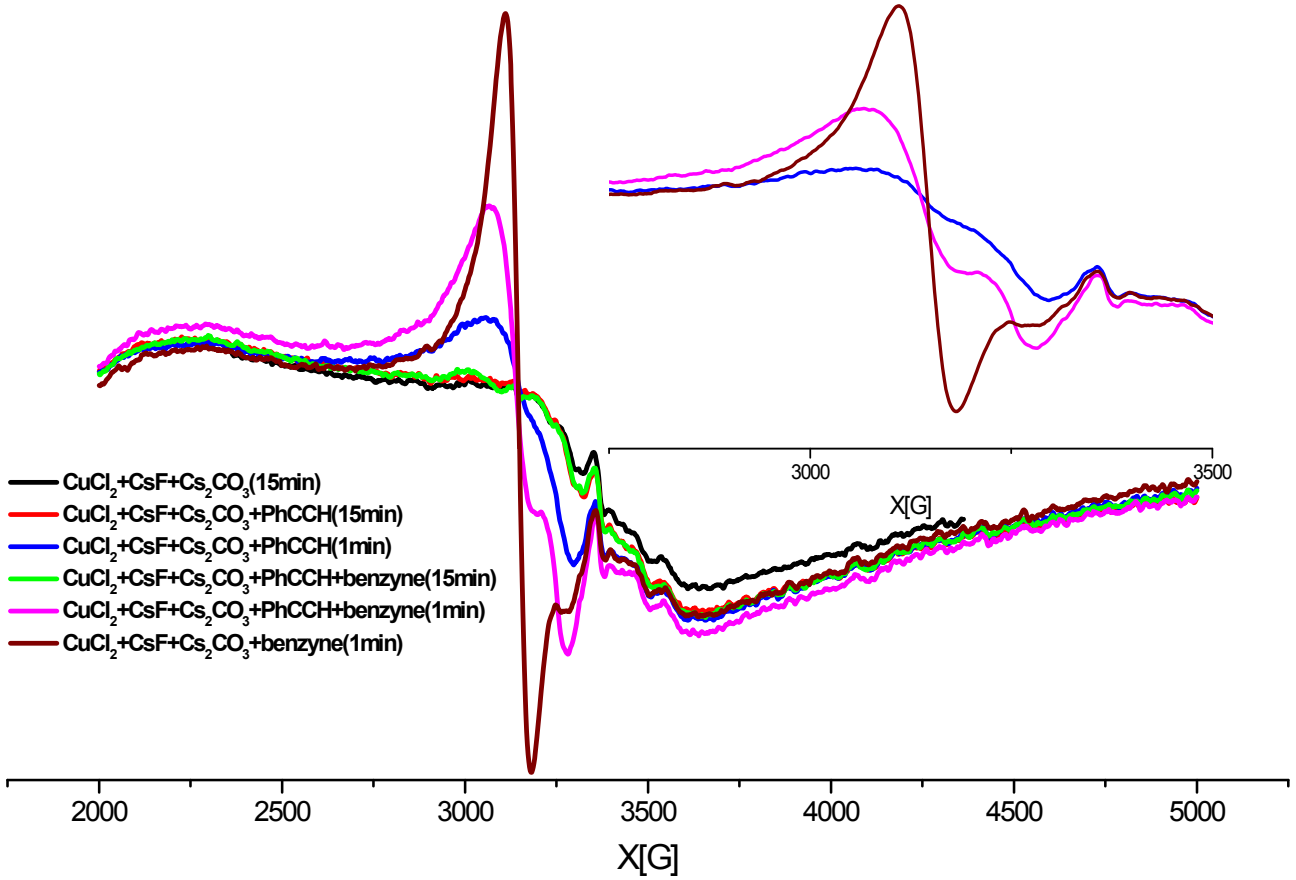
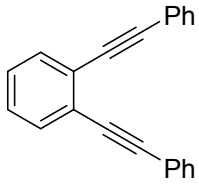


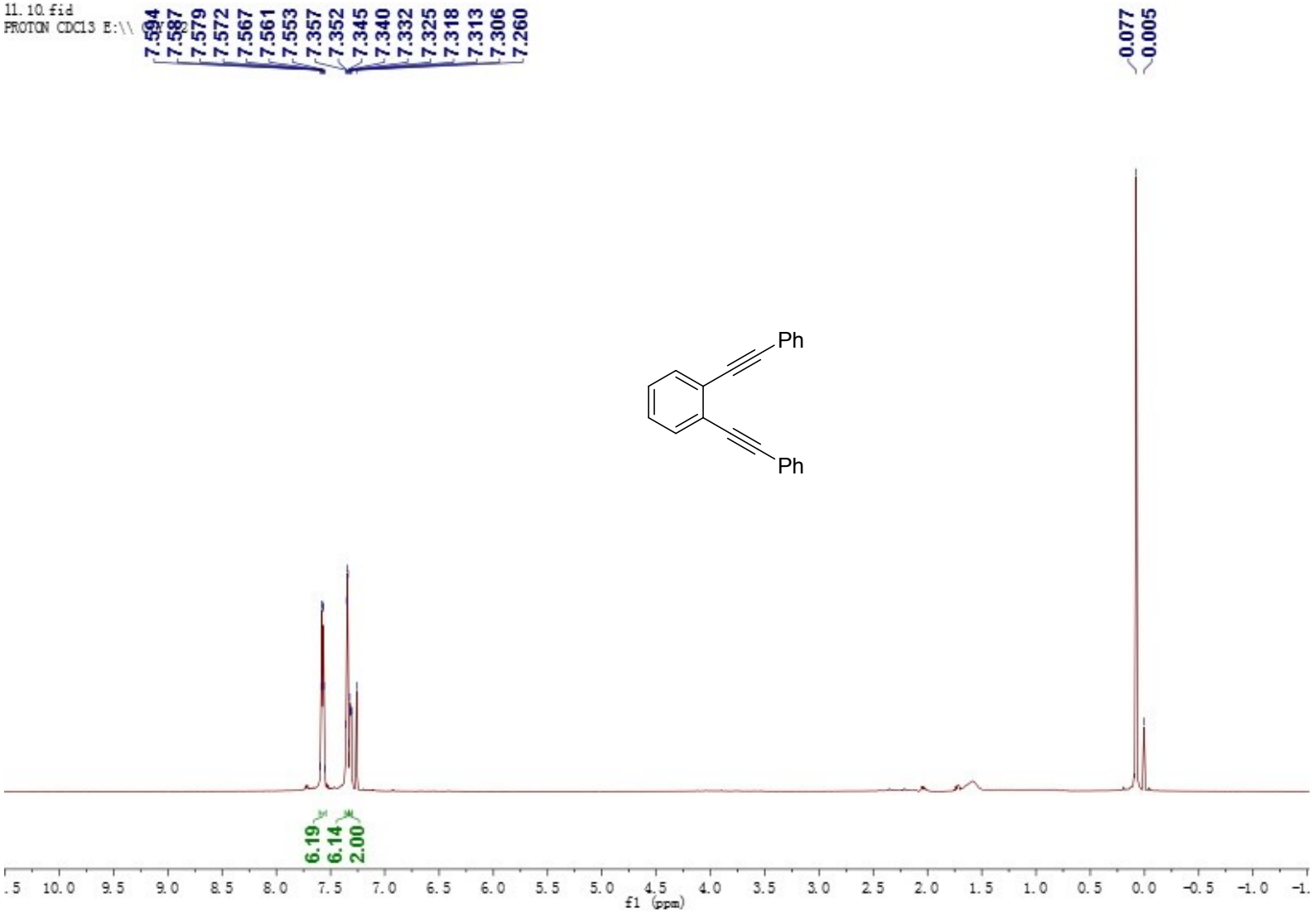
Figure S1. EPR (120K) analysis of several systems relevant to the reaction.

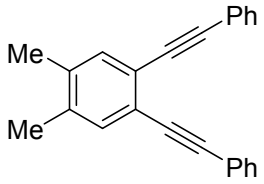
Spectroscopic data of the products



3aa, cas. 13203-60-6, ref. [6].

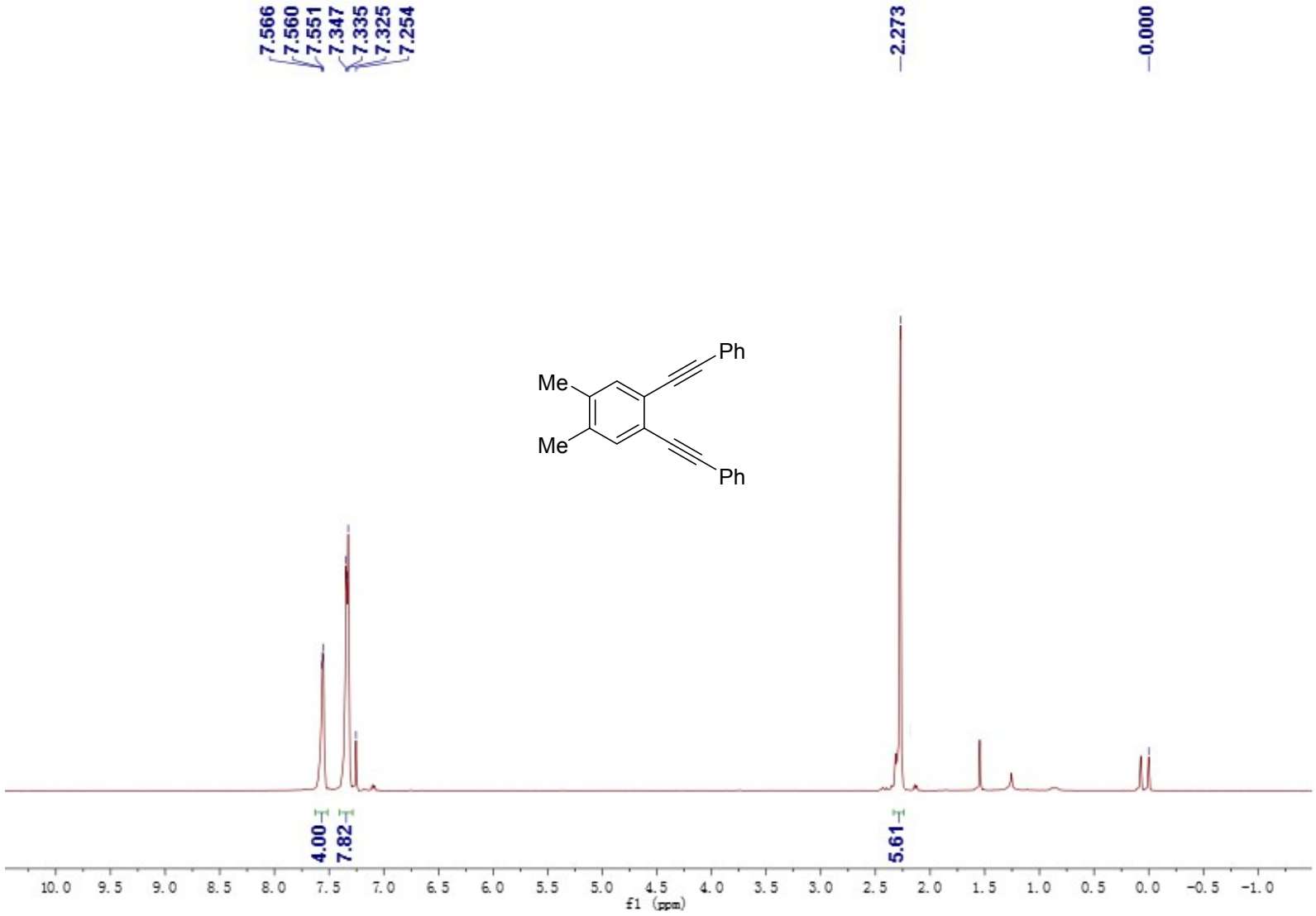
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.59 (m, 6H), 7.33-7.36 (m, 6H), 7.31 (dd, *J* = 7.5 Hz, 2H). TOF-MS (ESI) Calcd for $C_{22}H_{14}$: $[M+H]^+$ 279.1174; Found, 279.1172.

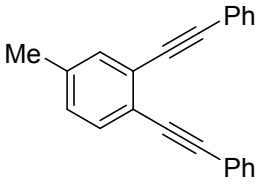

11.10.fid
PROTON CDCl3 E:\\
7.594
7.587
7.579
7.572
7.567
7.561
7.553
7.357
7.352
7.345
7.340
7.332
7.325
7.318
7.313
7.306
7.260
0.077
0.005
Ph
Ph
6.19
6.14
2.00
f1 (ppm)



3ba, cas. 27286-84-6, ref. [7].

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.57 (m, 4H), 7.33-7.85 (m, 8H), 2.27 (s, 6H). TOF-MS (EI) Calcd for $C_{24}H_{18}$: $[M+H]^+$ 307.1487; Found, 307.1531.

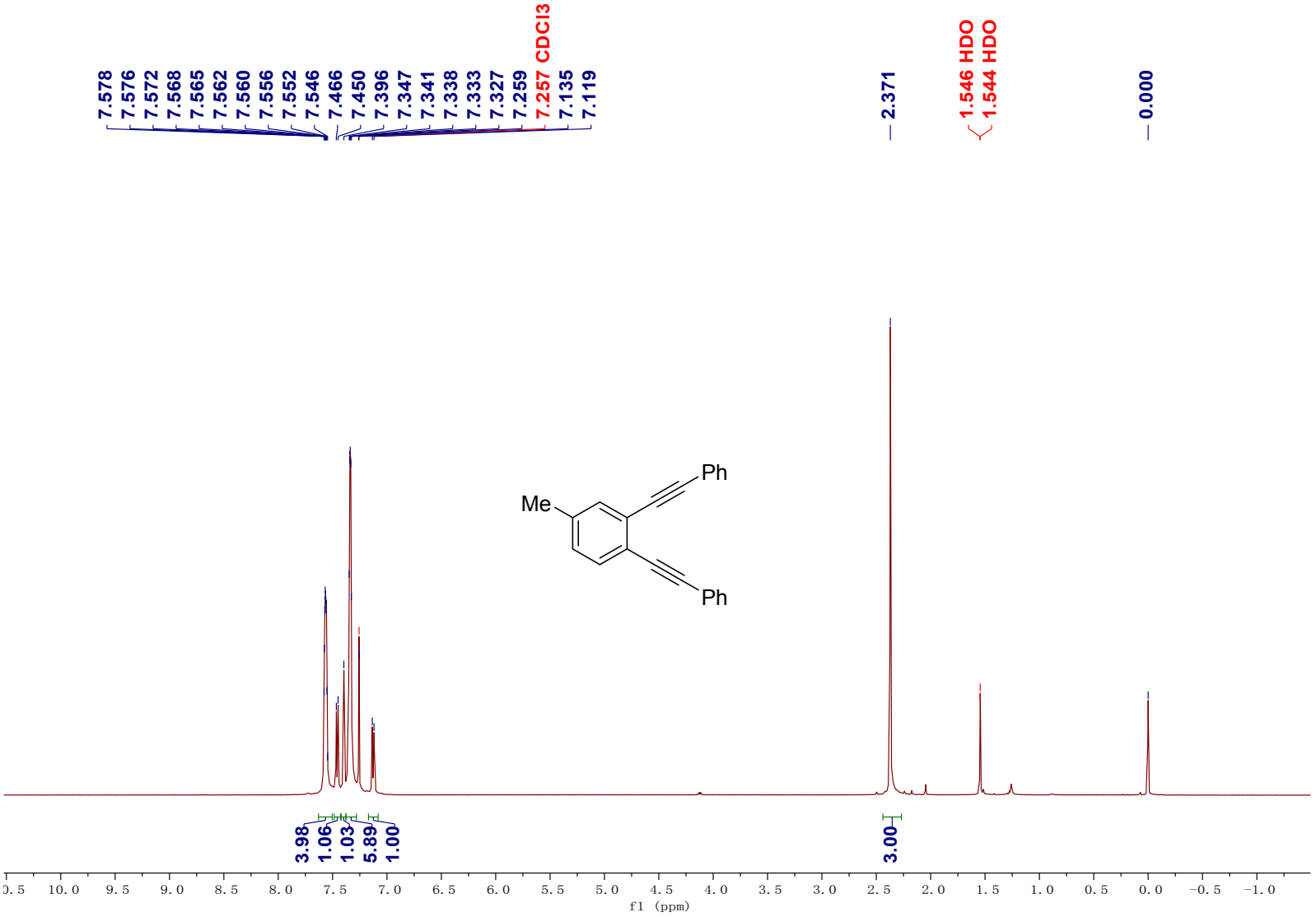

7.566
7.560
7.551
7.347
7.335
7.325
7.254
2.273
0.000
Me
Me
Ph
Ph
4.00
7.82
5.61
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

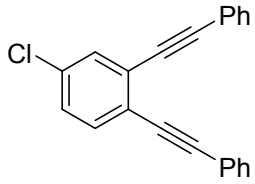


3ca, cas 165544-43-4, ref. [8].

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.58 (m, 4H), 7.46 (d, J = 8.0 Hz, 1H), 7.40 (s, 1H), 7.33-7.35 (m, 6H), 7.13 (d, J = 8.0 Hz, 1H), 2.37 (s, 3H).

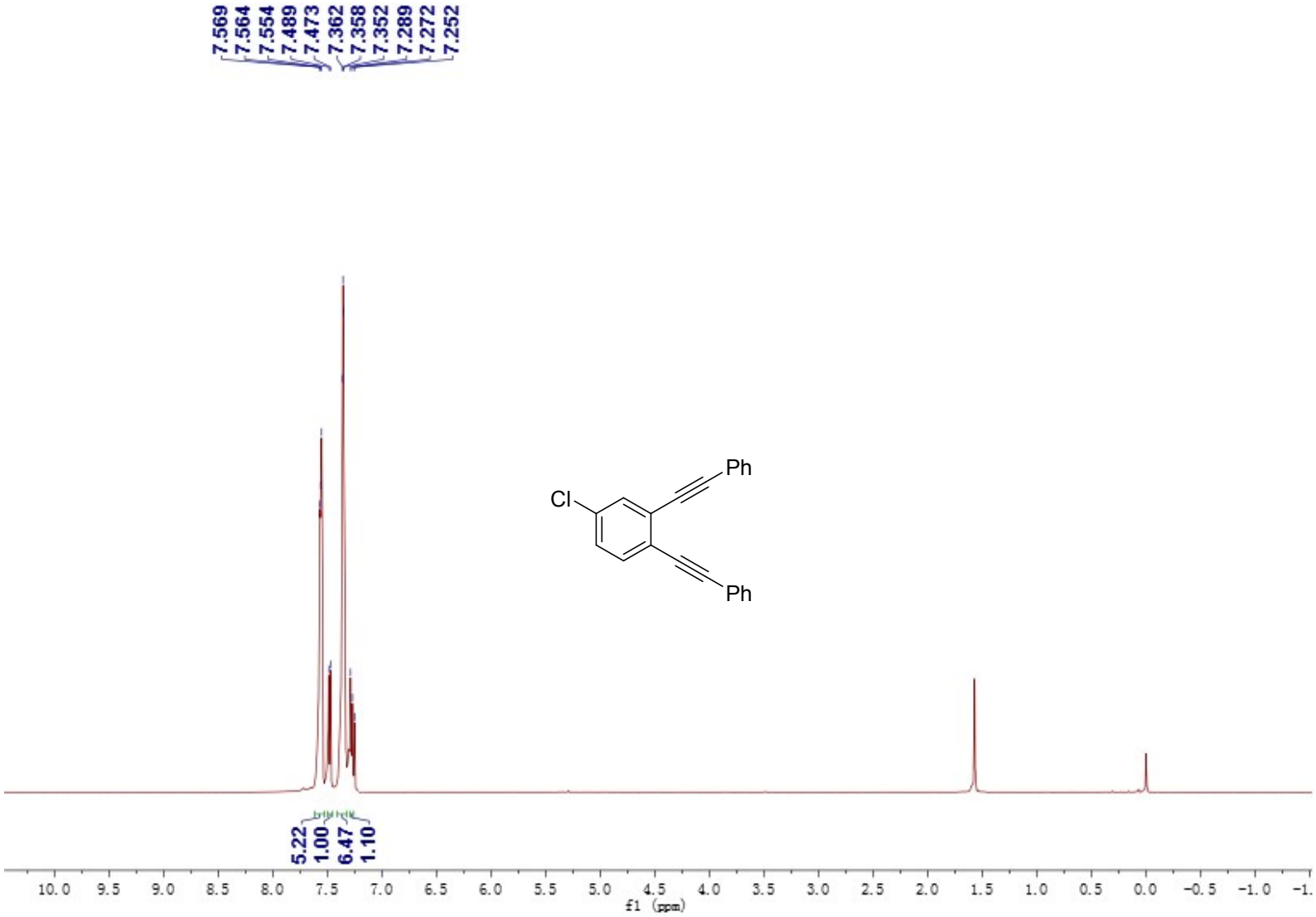
TOF-MS (EI) Calcd for $C_{26}H_{16}$: $[M+H]^+$ 293.1330; Found, 293.1331.

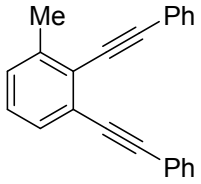

7.578
7.576
7.572
7.568
7.565
7.562
7.560
7.556
7.552
7.546
7.466
7.450
7.396
7.347
7.341
7.338
7.333
7.327
7.259
7.257 CDCl3
7.135
7.119
2.371
1.546 HDO
1.544 HDO
0.000
Me
Ph
Ph
3.98
1.06
1.03
5.89
1.00
3.00
f1 (ppm)



3da, cas. 165544-44-5, Ref. [8].

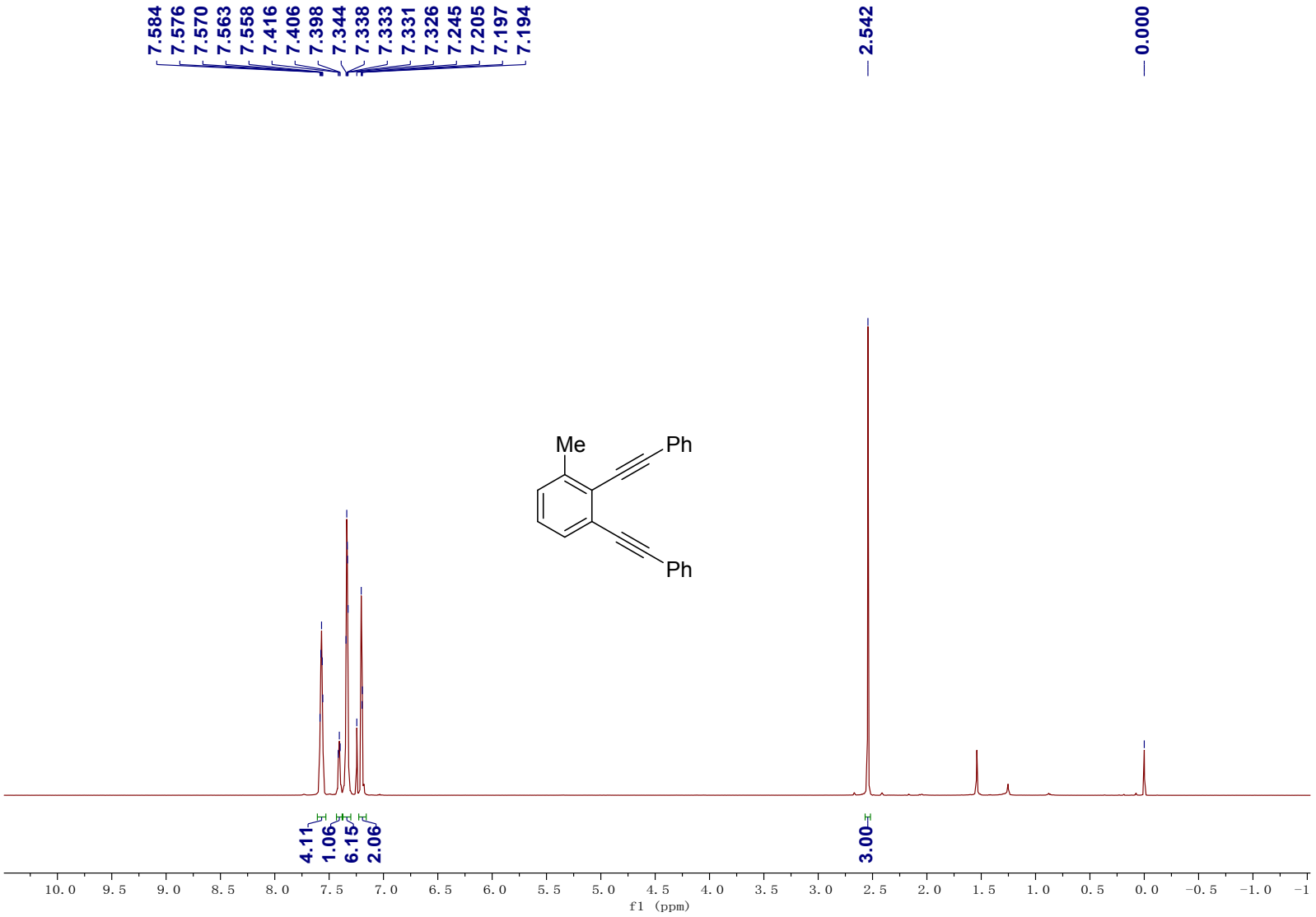
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55-7.57 (m, 5H), 7.48 (d, J = 8.0 Hz, 1H), 7.35-7.36 (m, 6H), 7.27 (d, J = 8.5 Hz, 1H). TOF-MS (EI) Calcd for $C_{22}H_{13}Cl$: $[M+H]^+$ 313.0784; Found, 313.1618.

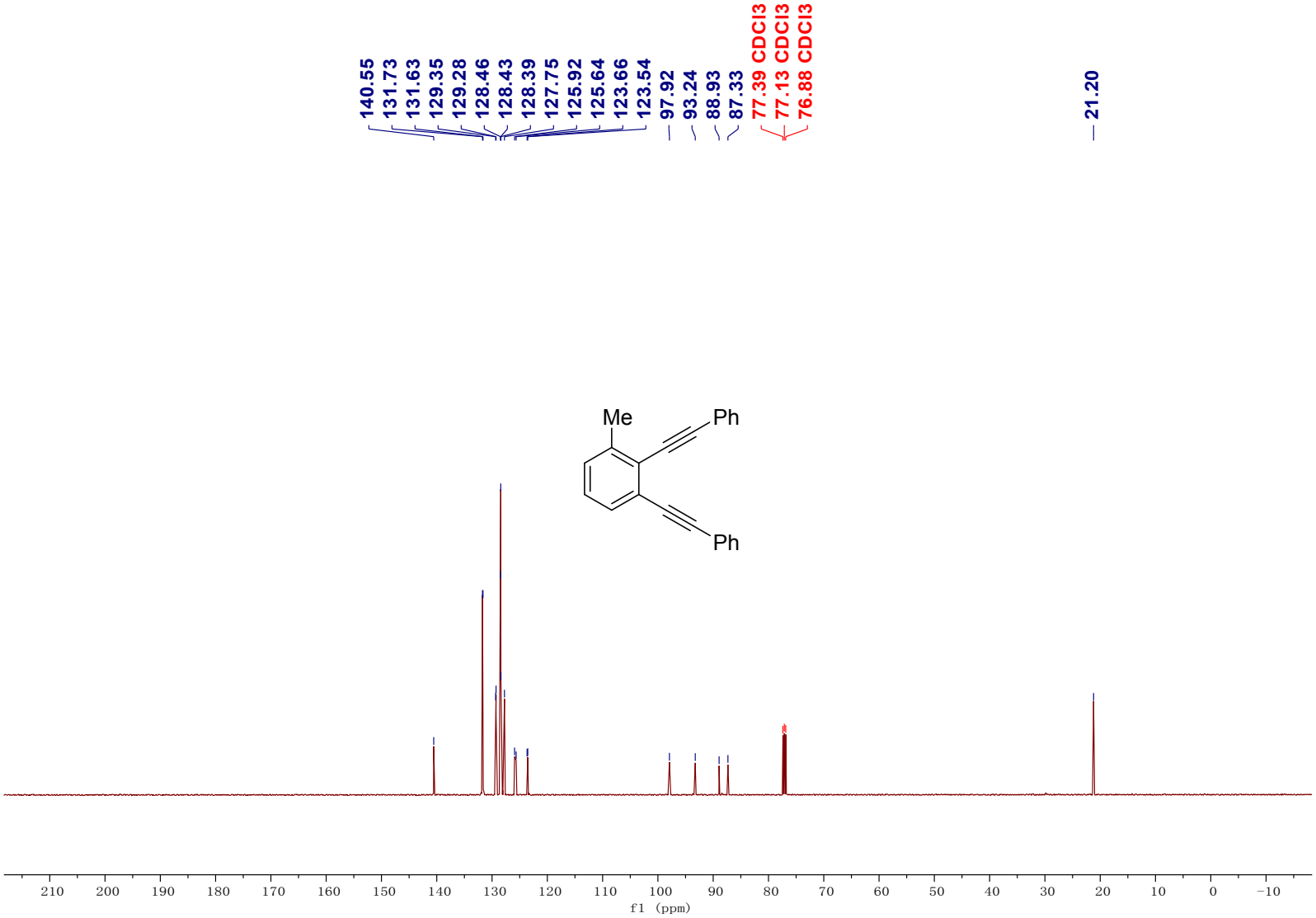

7.569
7.564
7.554
7.489
7.473
7.362
7.358
7.352
7.289
7.272
7.252
Cl
Ph
Ph
5.22
1.00
6.47
1.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.
f1 (ppm)

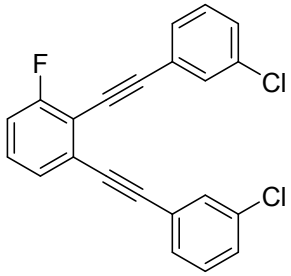


3ea, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.56-7.58 (m, 4H), 7.41 (t, J = 4.5 Hz, 1H), 7.33-7.34 (m, 6H), 7.20 (m, 2H), 2.54 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 140.6, 131.7, 131.6, 129.4, 129.3, 128.5, 128.4, 128.3, 127.7, 125.9, 125.6, 123.7, 123.5, 97.9, 93.2, 88.9, 87.3, 21.2. TOF-MS (EI) Calcd for $C_{26}H_{16}$: $[M+H]^+$ 293.1330; Found, 293.1331.

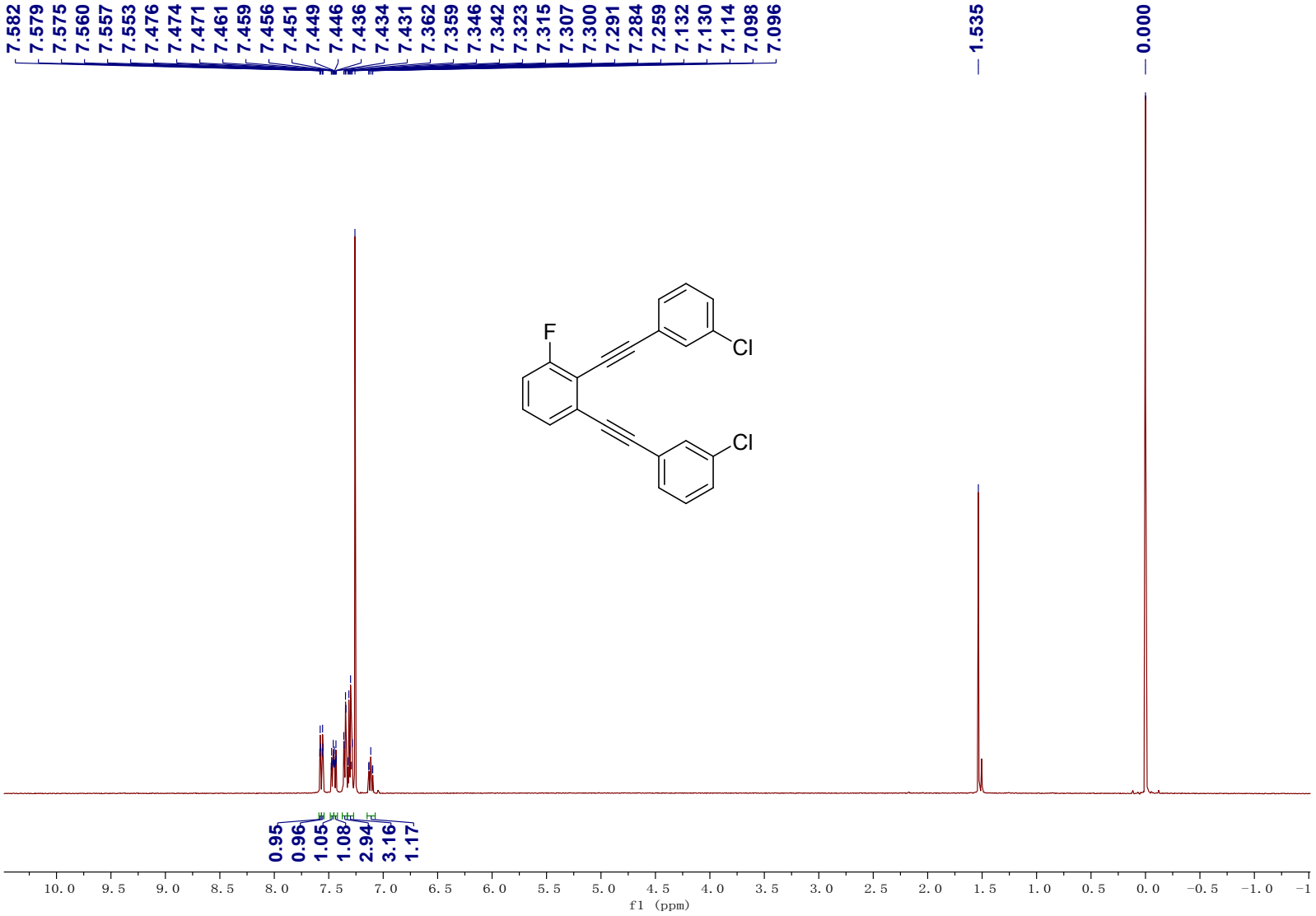

7.584
7.576
7.570
7.563
7.558
7.416
7.406
7.398
7.344
7.338
7.333
7.331
7.326
7.245
7.205
7.197
7.194
2.542
0.000
Me
Ph
Ph
4.11
1.06
6.15
2.06
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.0 −1
f1 (ppm)

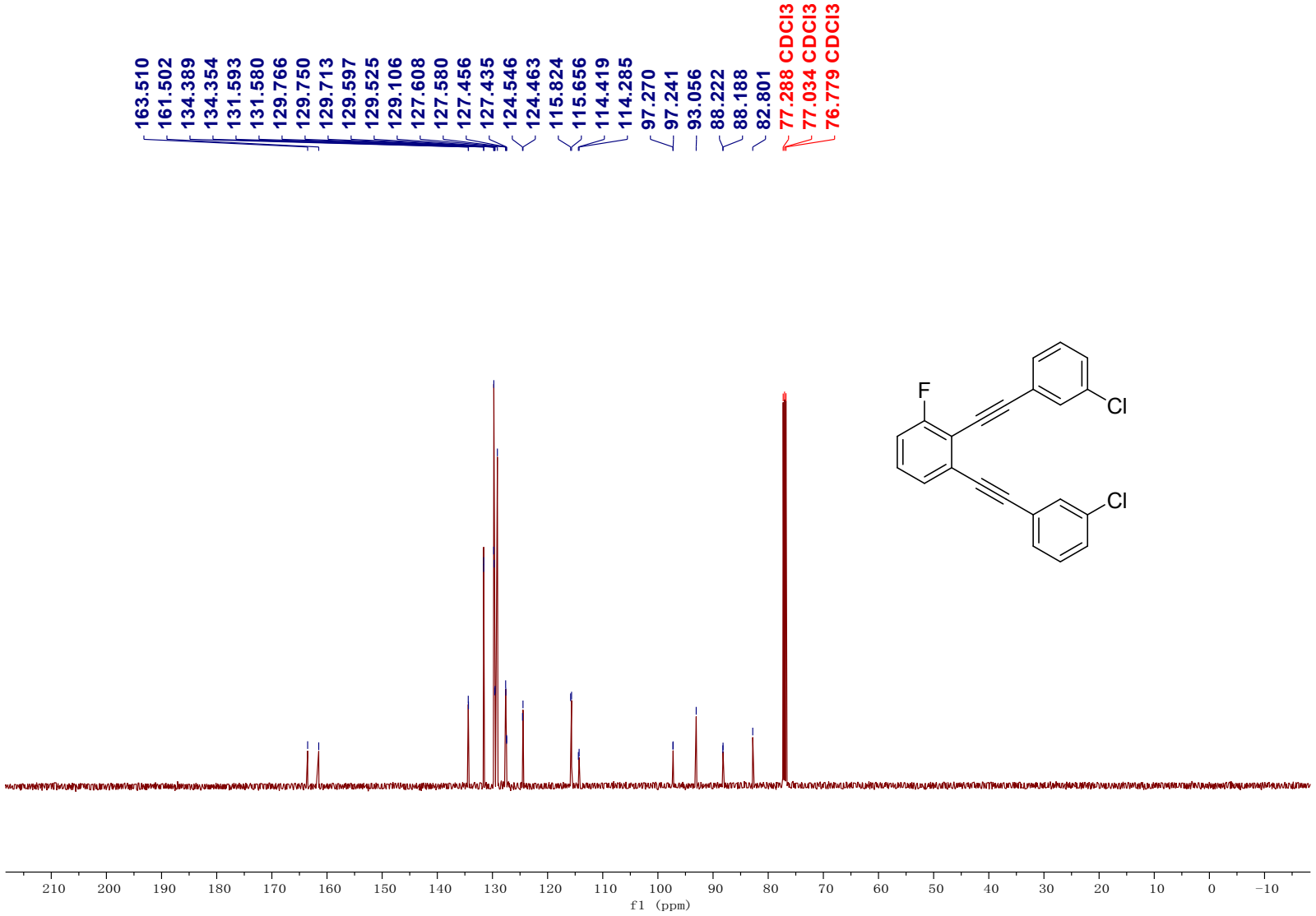

140.55
131.73
131.63
129.35
129.28
128.46
128.43
128.39
127.75
125.92
125.64
123.66
123.54
97.92
93.24
88.93
87.33
77.39 CDCl3
77.13 CDCl3
76.88 CDCl3
21.20
Me
Ph
Ph
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)

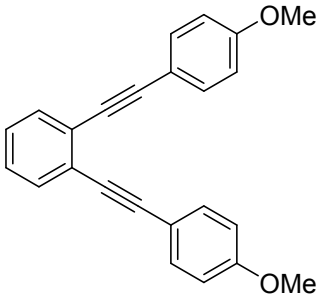


3fi, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 (t, *J* = 1.5 Hz, 1H), 7.56 (t, *J* = 1.5 Hz, 1H), 7.46 (dt, *J* = 7.5 Hz, 1.5 Hz, 1H), 7.44 (dt, *J* = 7.5 Hz, 1.5 Hz, 1H), 7.34-7.36 (m, 3H), 7.28-7.32 (m, 3H), 7.11 (td, *J* = 7.5 Hz, 1.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.5 (d, *J* = 251 Hz), 134.39, 134.35, 131.59, 131.58, 129.77, 129.75, 129.71, 129.6, 129.5, 129.1, 127.61, 127.58, 127.46, 127.44, 124.55, 124.46, 115.8, 115.6, 114.4, 114.3, 97.2 (d, *J* = 3.6 Hz), 93.0, 88.2 (d, *J* = 4.2 Hz), 82.8. TOF-MS (EI) Calcd for $C_{22}H_{11}Cl_2F$: $[M+H]^+$ 365.0300; Found, 365.0301.

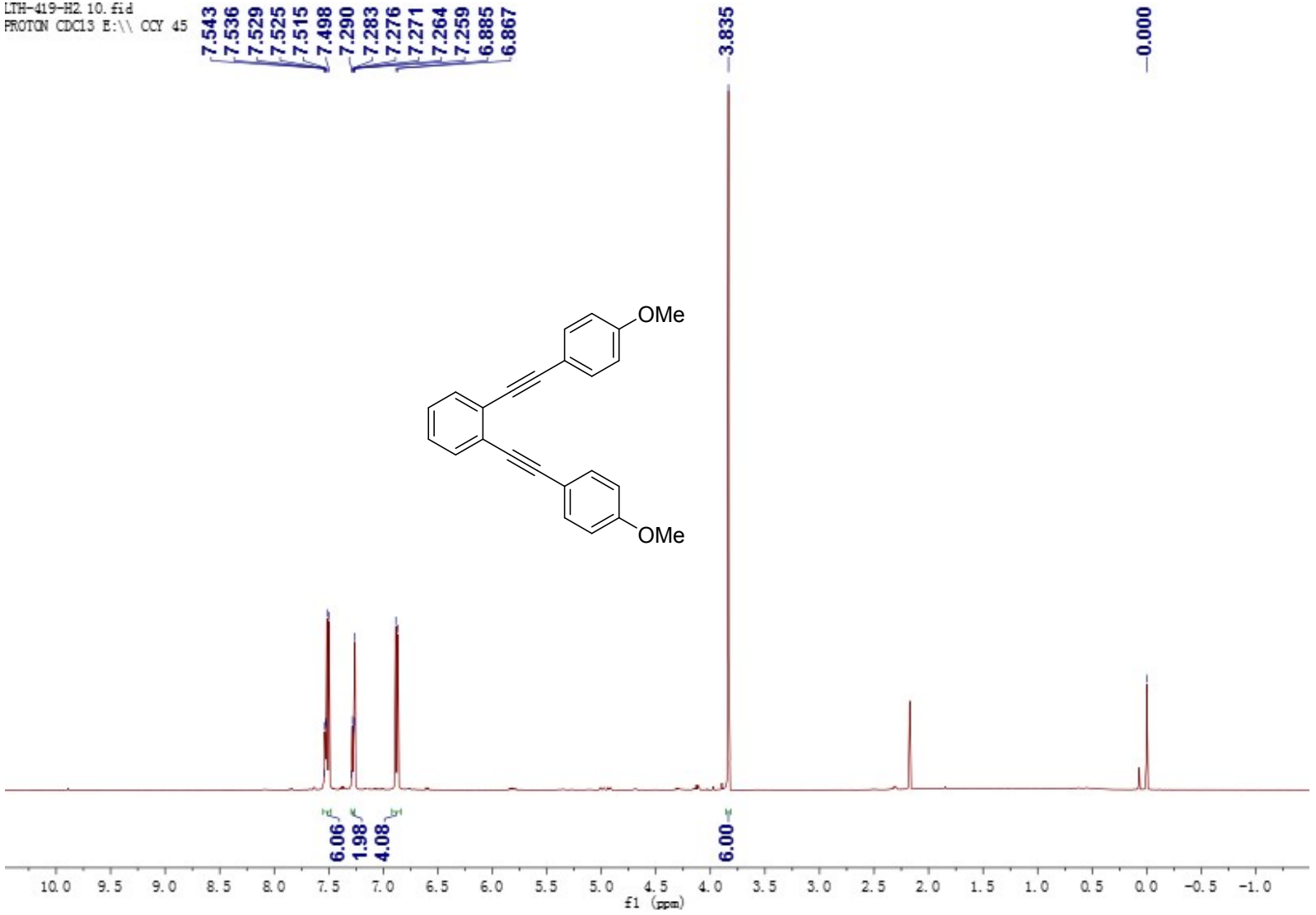

7.582
7.579
7.575
7.560
7.557
7.553
7.476
7.474
7.471
7.461
7.459
7.456
7.451
7.449
7.446
7.436
7.434
7.431
7.362
7.359
7.346
7.342
7.323
7.315
7.307
7.300
7.291
7.284
7.259
7.132
7.130
7.114
7.098
7.096
1.535
0.000
F
Cl
Cl
0.95
0.96
1.05
1.08
2.94
3.16
1.17
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.0 −1
f1 (ppm)

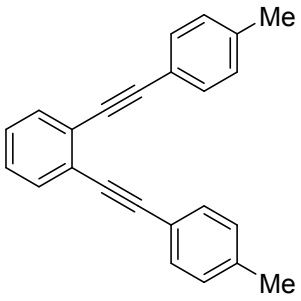

163.510
161.502
134.389
134.354
131.593
131.580
129.766
129.750
129.713
129.597
129.525
129.106
127.608
127.580
127.456
127.435
124.546
124.463
115.824
115.656
114.419
114.285
97.270
97.241
93.056
88.222
88.188
82.801
77.288 CDCl3
77.034 CDCl3
76.779 CDCl3
F
Cl
Cl
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)



3ab, cas 175548-65-9, ref. [6].

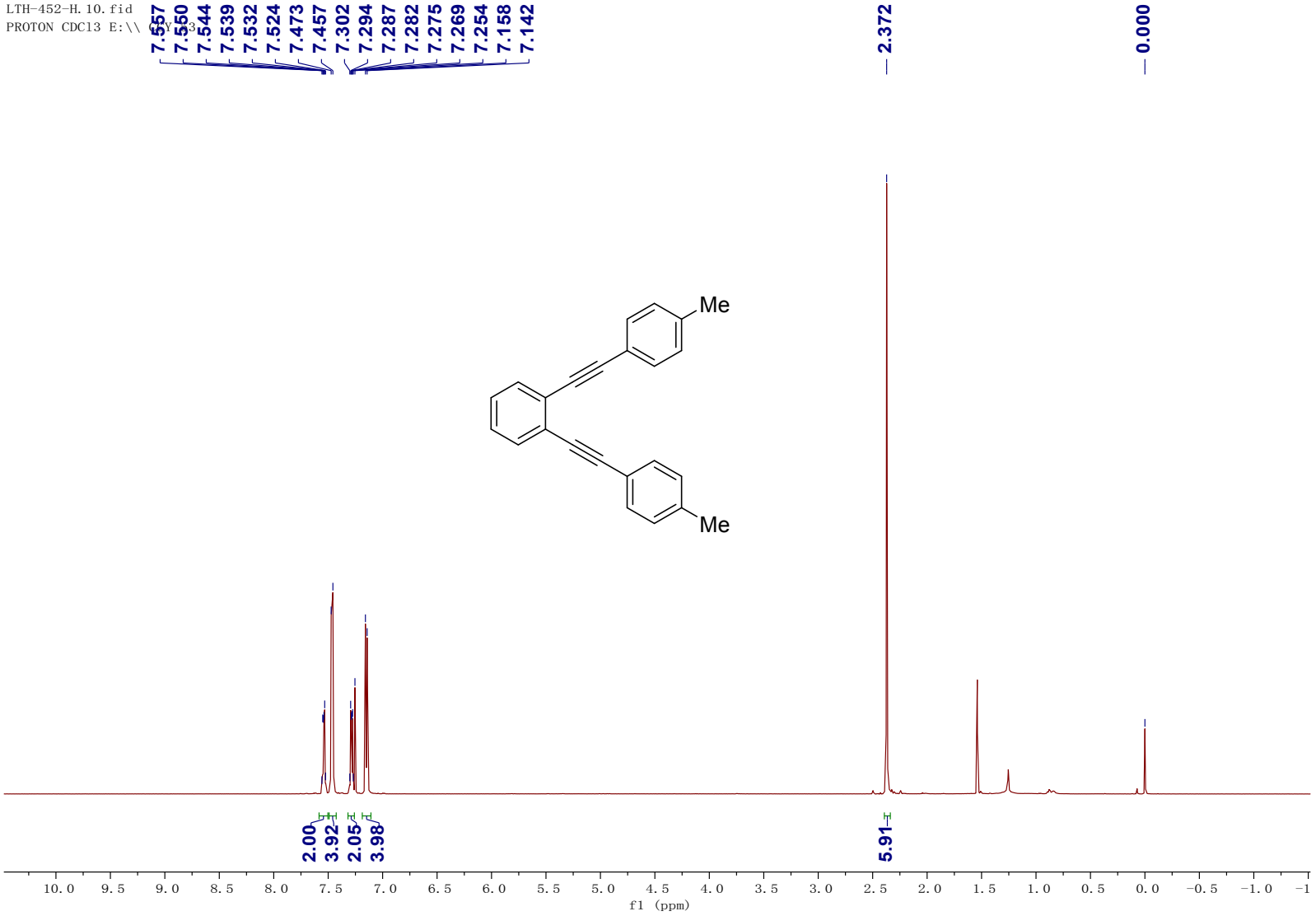
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53 (m, 2H), 7.50 (d, *J* = 8.5 Hz, 4H), 7.28 (m, 2H), 6.87 (d, *J* = 8.0 Hz, 4H), 3.84 (s, 6H). TOF-MS (EI) Calcd for $C_{24}H_{18}O_2$: $[M+H]^+$ 339.1385; Found, 339.1417.

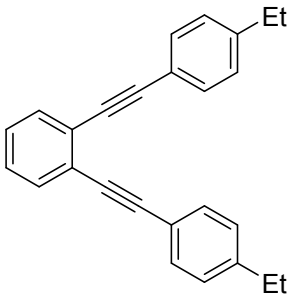

LTH-419-H2.10.fid
PROTON CDCl3 E:\\ CCY 45
7.543
7.536
7.529
7.525
7.515
7.498
7.290
7.283
7.276
7.271
7.264
7.259
6.885
6.867
3.835
0.000
OMe
OMe
6.06
1.98
4.08
6.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)



3ac, cas 731854-44-7, ref. [9].

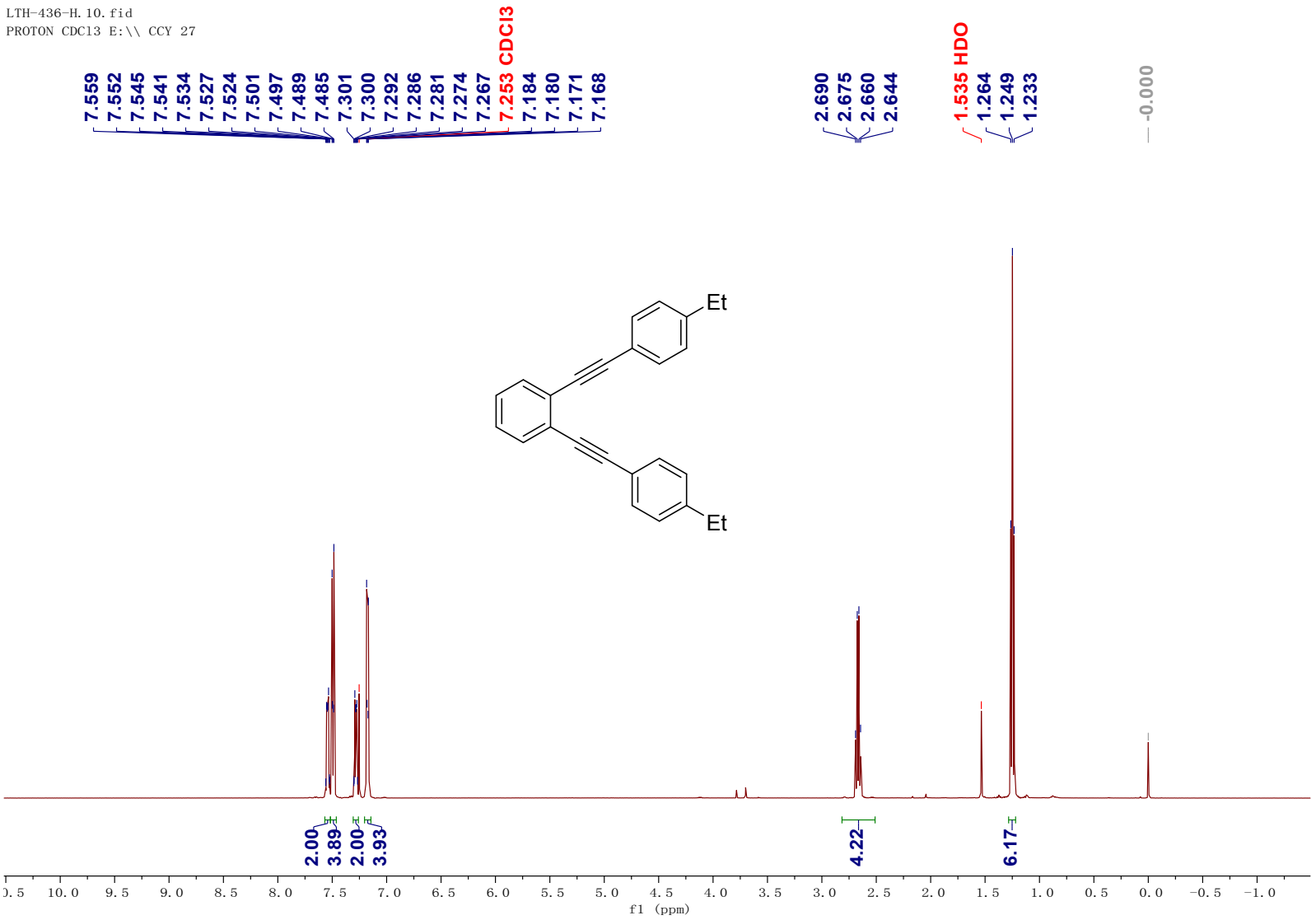
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.54 (m, 2H), 7.46 (d, J = 8.0 Hz, 4H), 7.28 (m, 2H), 7.15 (d, J = 8.0 Hz, 4H), 2.37 (s, 6H). TOF-MS (EI) Calcd for $C_{24}H_{18}$: $[M+H]^+$ 307.1487; Found, 307.1487.

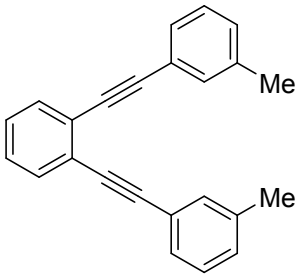

LTH-452-H.10.fid
PROTON CDC13 E:\\ Varian
7.557
7.550
7.544
7.539
7.532
7.524
7.473
7.457
7.302
7.294
7.287
7.282
7.275
7.269
7.254
7.158
7.142
2.372
0.000
Me
Me
2.00
3.92
2.05
3.98
5.91
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.0 −1
f1 (ppm)



3ad, cas 2032453-59-9, ref. [9].

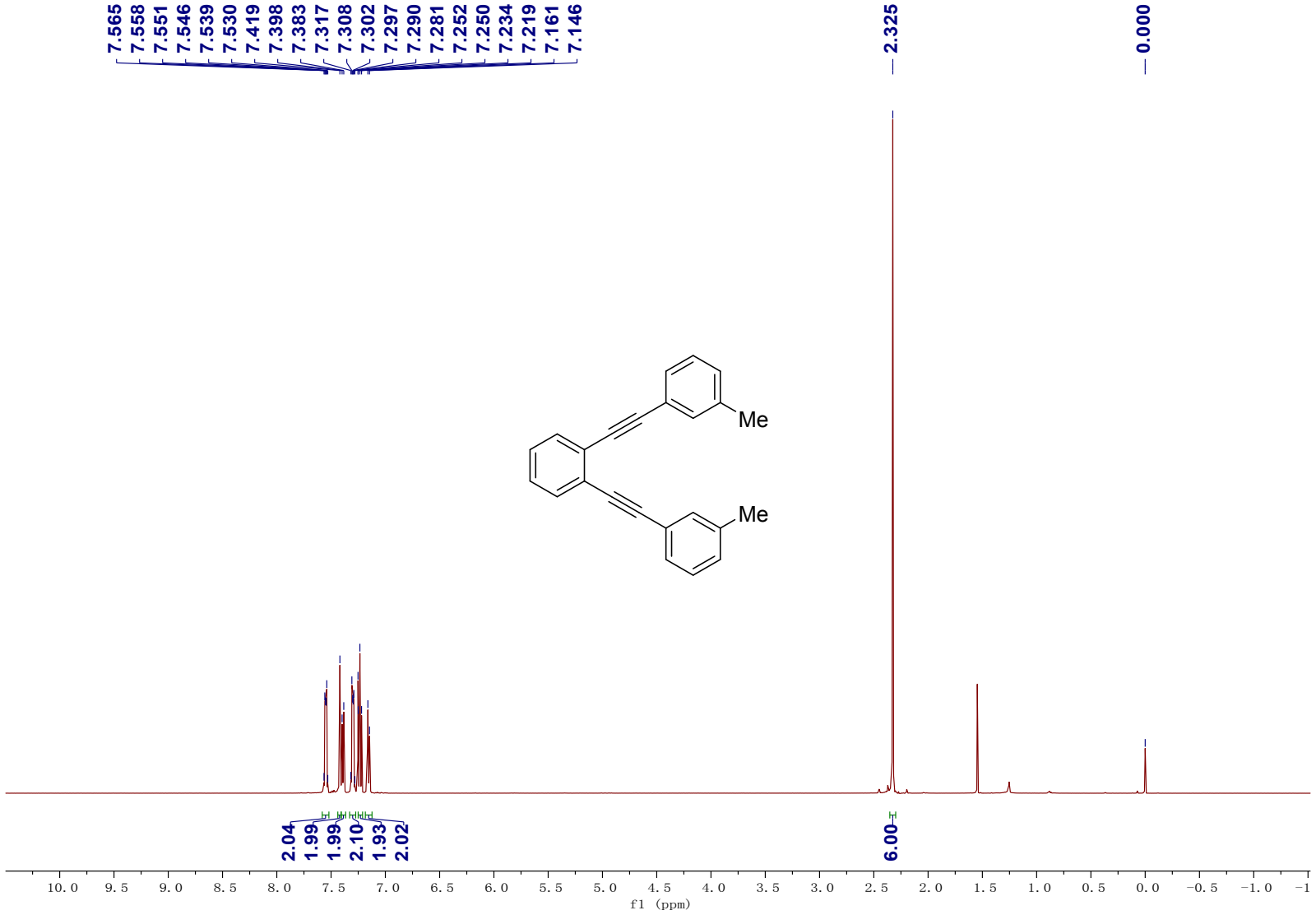
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.54 (dd, *J* = 8.0 Hz, 2H), 7.49 (d, *J* = 8.0 Hz, 4H), 7.28 (dd, *J* = 8.0 Hz, 2H), 7.17 (d, *J* = 8.0 Hz, 4H), 2.67 (q, *J* = 7.5 Hz, 4H), 1.25 (t, *J* = 7.5 Hz, 6H). TOF-MS (EI) Calcd for $C_{26}H_{22}$: $[M+H]^+$ 335.1800; Found, 335.1867.

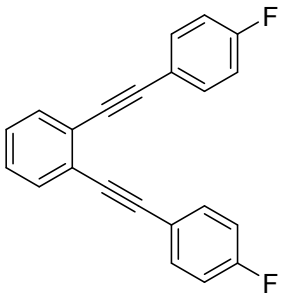

LTH-436-H.10.fid
PROTON CDCl3 E:\\ CCY 27
7.559
7.552
7.545
7.541
7.534
7.527
7.524
7.501
7.497
7.489
7.485
7.301
7.300
7.292
7.286
7.281
7.274
7.267
7.253 CDCl3
7.184
7.180
7.171
7.168
2.690
2.675
2.660
2.644
1.535 HDO
1.264
1.249
1.233
-0.000
Et
Et
2.00
3.89
2.00
3.93
4.22
6.17
f1 (ppm)



3ae, cas 2032453-58-8, ref. [9].

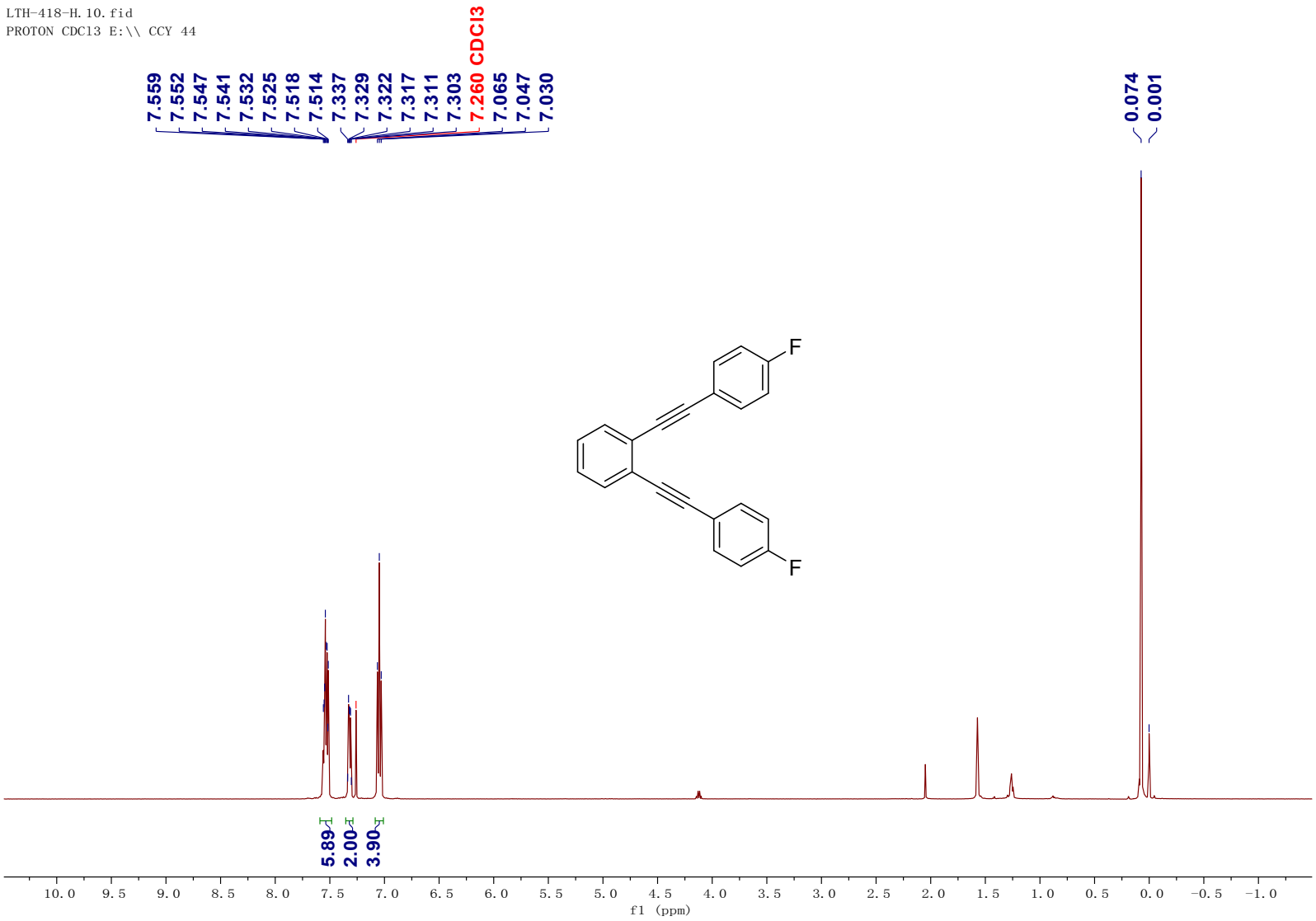
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 (m, 2H), 7.42 (s, 2H), 7.39 (d, *J* = 7.5 Hz, 2H), 7.30 (m, 2H), 7.23 (t, *J* = 7.0 Hz, 2H), 7.15 (d, *J* = 7.5 Hz, 2H), 2.32 (s, 6H). TOF-MS (EI) Calcd for $C_{24}H_{18}$: $[M+H]^+$ 307.1487; Found, 307.1487.

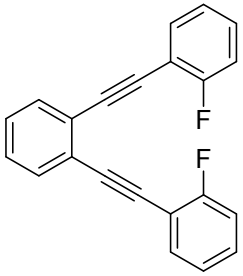

7.565
7.558
7.551
7.546
7.539
7.530
7.419
7.398
7.383
7.317
7.308
7.302
7.297
7.290
7.281
7.252
7.250
7.234
7.219
7.161
7.146
2.325
0.000
Me
Me
2.04
1.99
1.99
2.10
1.93
2.02
6.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.0 −1
f1 (ppm)



3af, cas 731854-45-8, ref. [6].

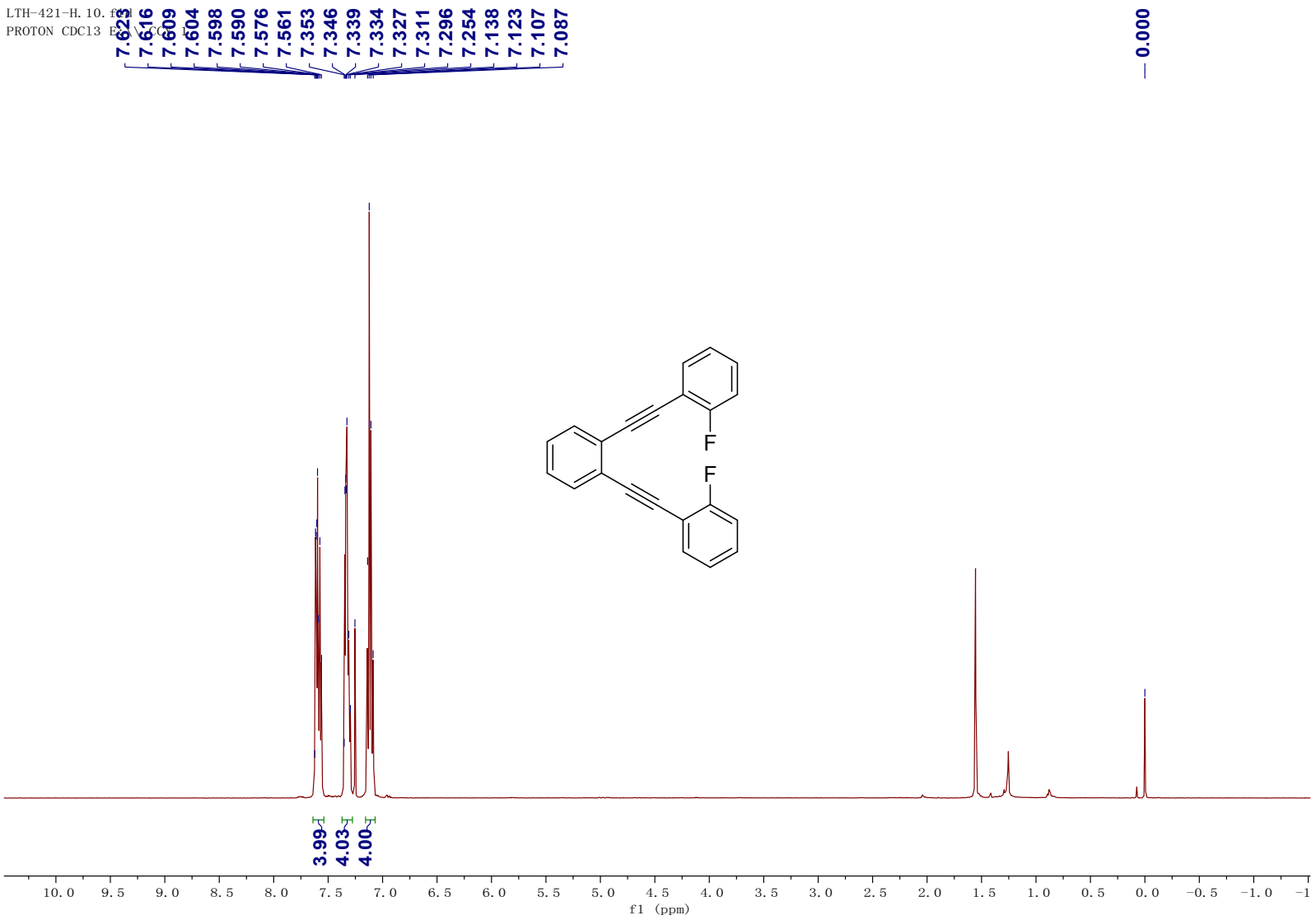
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.51-7.56 (m, 6H), 7.30–7.34 (m, 2H), 7.05 (t, J = 8.5 Hz, 4H). TOF-MS (EI) Calcd for $C_{22}H_{12}F_2$: $[M+H]^+$ 315.0985; Found, 315.0984.


LTH-418-H.10.fid
PROTON CDCl3 E:\\ CCY 44
7.559
7.552
7.547
7.541
7.532
7.525
7.518
7.514
7.337
7.329
7.322
7.317
7.311
7.303
7.260 CDCl3
7.065
7.047
7.030
0.074
0.001
F
F
5.89
2.00
3.90
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 -0.5 -1.0
f1 (ppm)

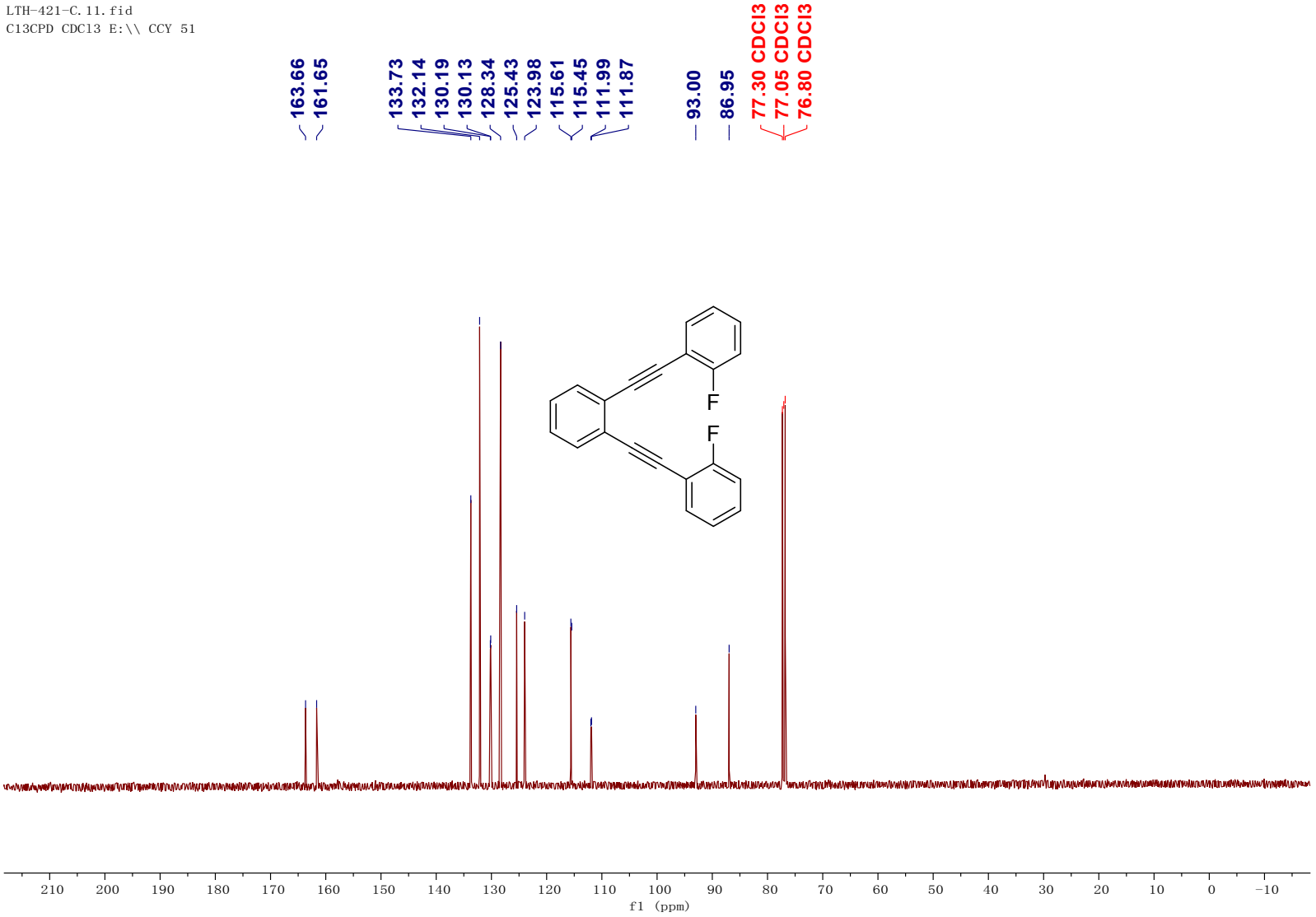


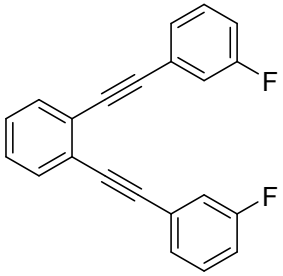
3ag, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.56-7.62 (m, 4H), 7.30-7.35 (m, 4H), 7.09-7.14 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.6 (d, J = 250 Hz), 133.7, 132.1, 130.1 (d, J = 7.5 Hz), 128.3, 125.4, 123.9, 115.5 (d, J = 20 Hz), 111.9 (d, J = 15 Hz), 93.0, 86.9. TOF-MS (EI) Calcd for $C_{22}H_{12}F_2$: $[M+H]^+$ 315.0985; Found, 315.0984.


LTH-421-H.10.fid
PROTON CDC13 EXCITE
7.623
7.616
7.609
7.604
7.598
7.590
7.576
7.561
7.353
7.346
7.339
7.334
7.327
7.311
7.296
7.254
7.138
7.123
7.107
7.087
0.000
F
F
3.99
4.03
4.00
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 -0.5 -1.0 -1
f1 (ppm)

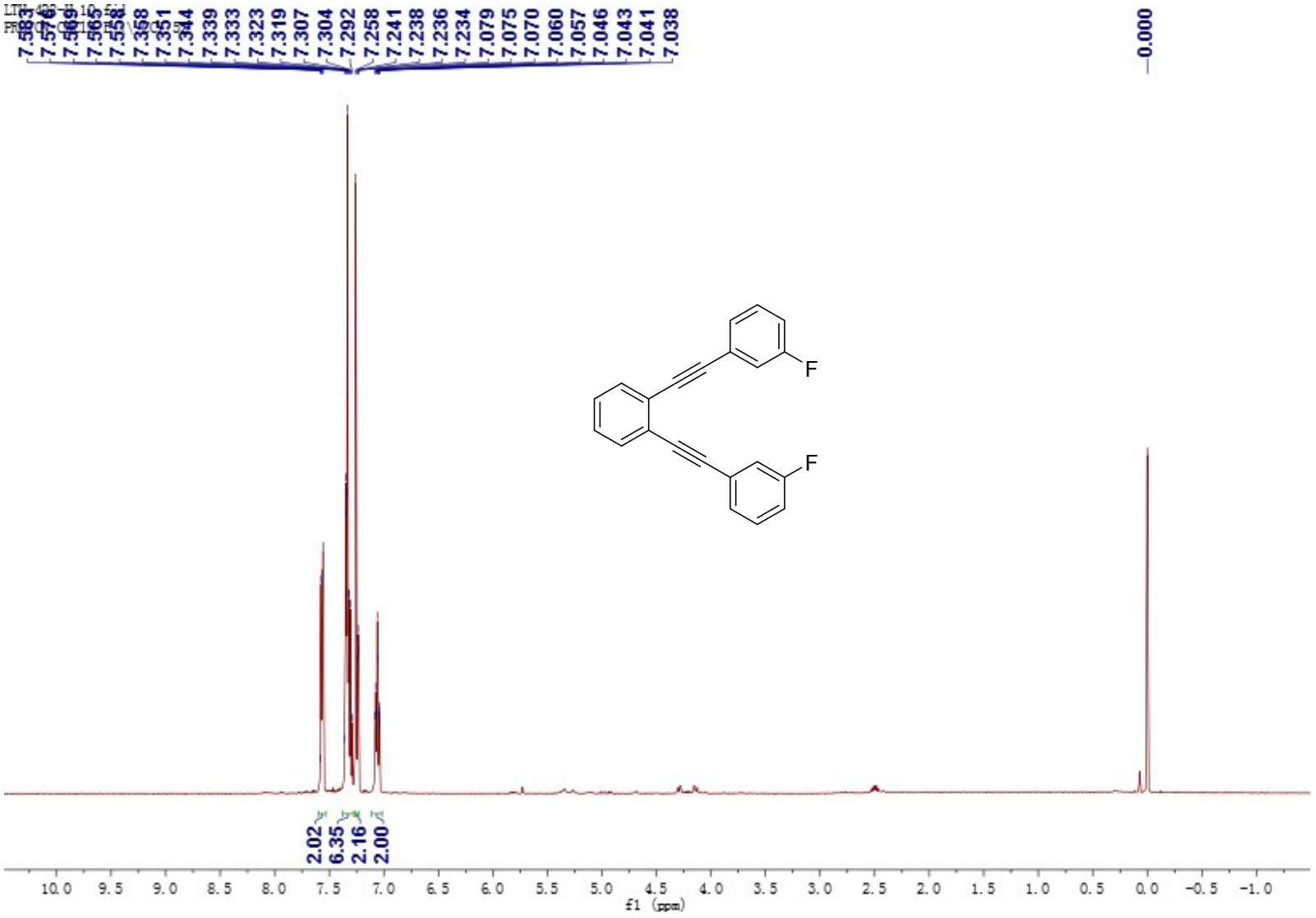
LTH-421-C.11.fid
C13CPD CDCl3 E:\\ CCY 51

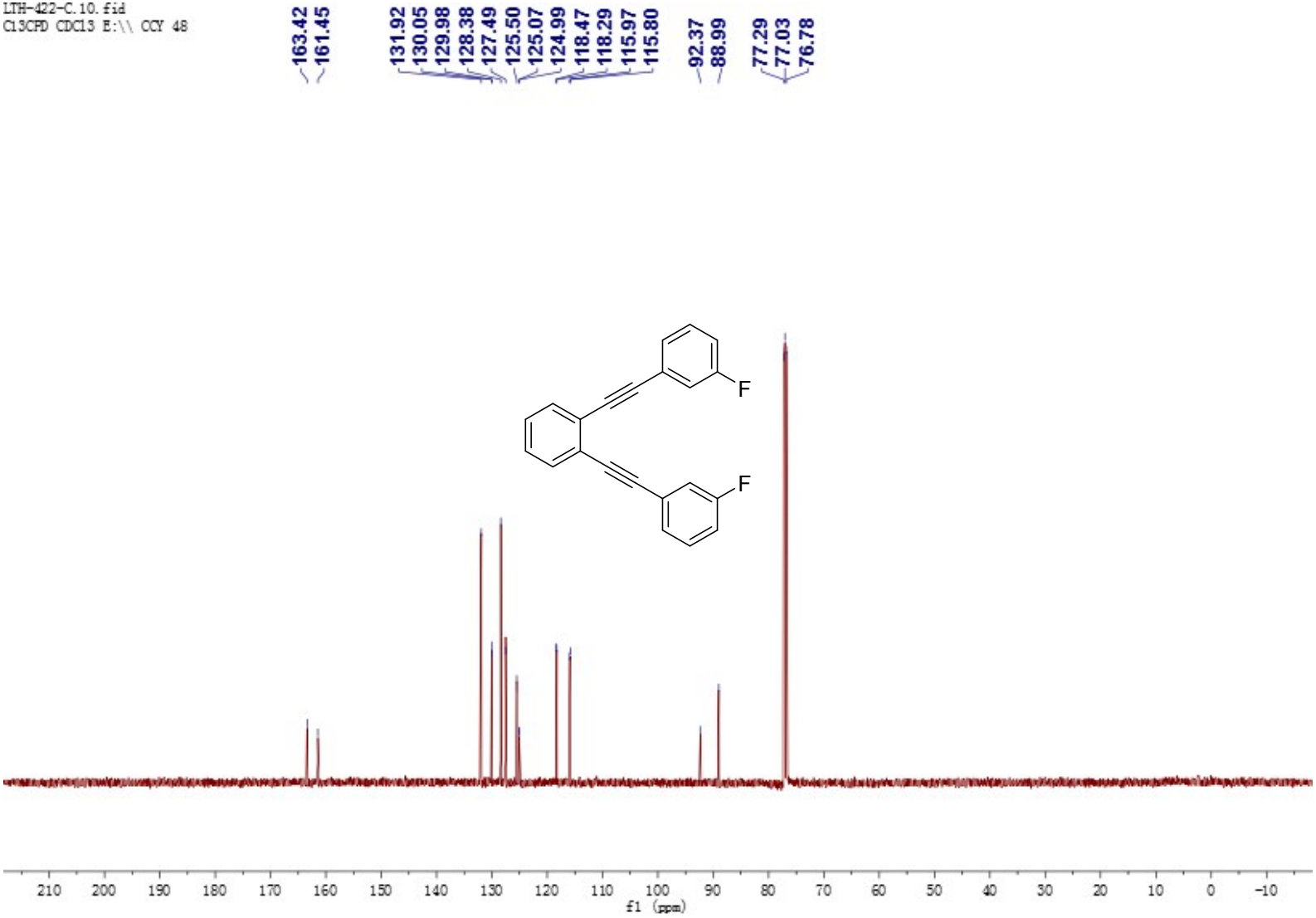


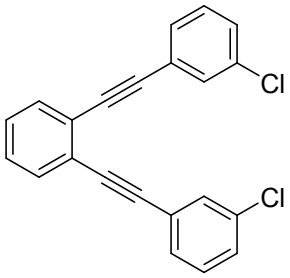


3ah, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.57 (m, 2H), 7.29-7.36 (m, 6H), 7.23-7.25 (m, 2H), 7.06 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.4 (d, J = 250 Hz), 131.9, 130.0 (d, J = 8.75 Hz), 128.4, 127.5, 125.5, 125.0 (d, J = 10 Hz), 118.4 (d, J = 22.5 Hz), 115.9 (d, J = 21.25 Hz), 92.4, 89.0. TOF-MS (EI) Calcd for Calcd for $C_{22}H_{12}F_2$: $[M+H]^+$ 315.0985; Found, 315.0984.

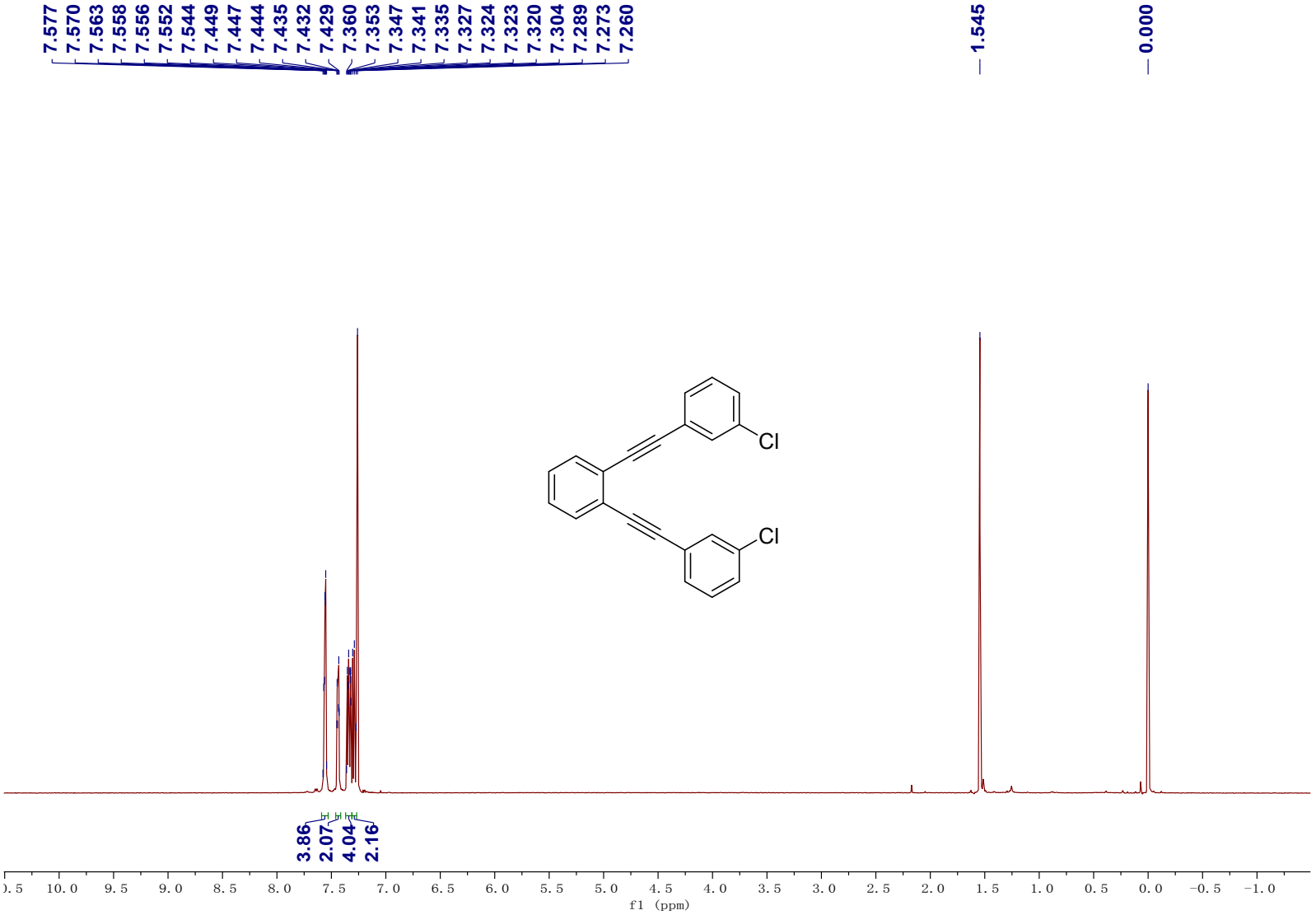

7.583
7.576
7.569
7.565
7.558
7.358
7.351
7.344
7.339
7.333
7.323
7.319
7.307
7.304
7.292
7.258
7.241
7.238
7.236
7.234
7.079
7.075
7.070
7.060
7.057
7.046
7.043
7.041
7.038
0.000
F
F
2.02
6.35
2.16
2.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
f1 (ppm)

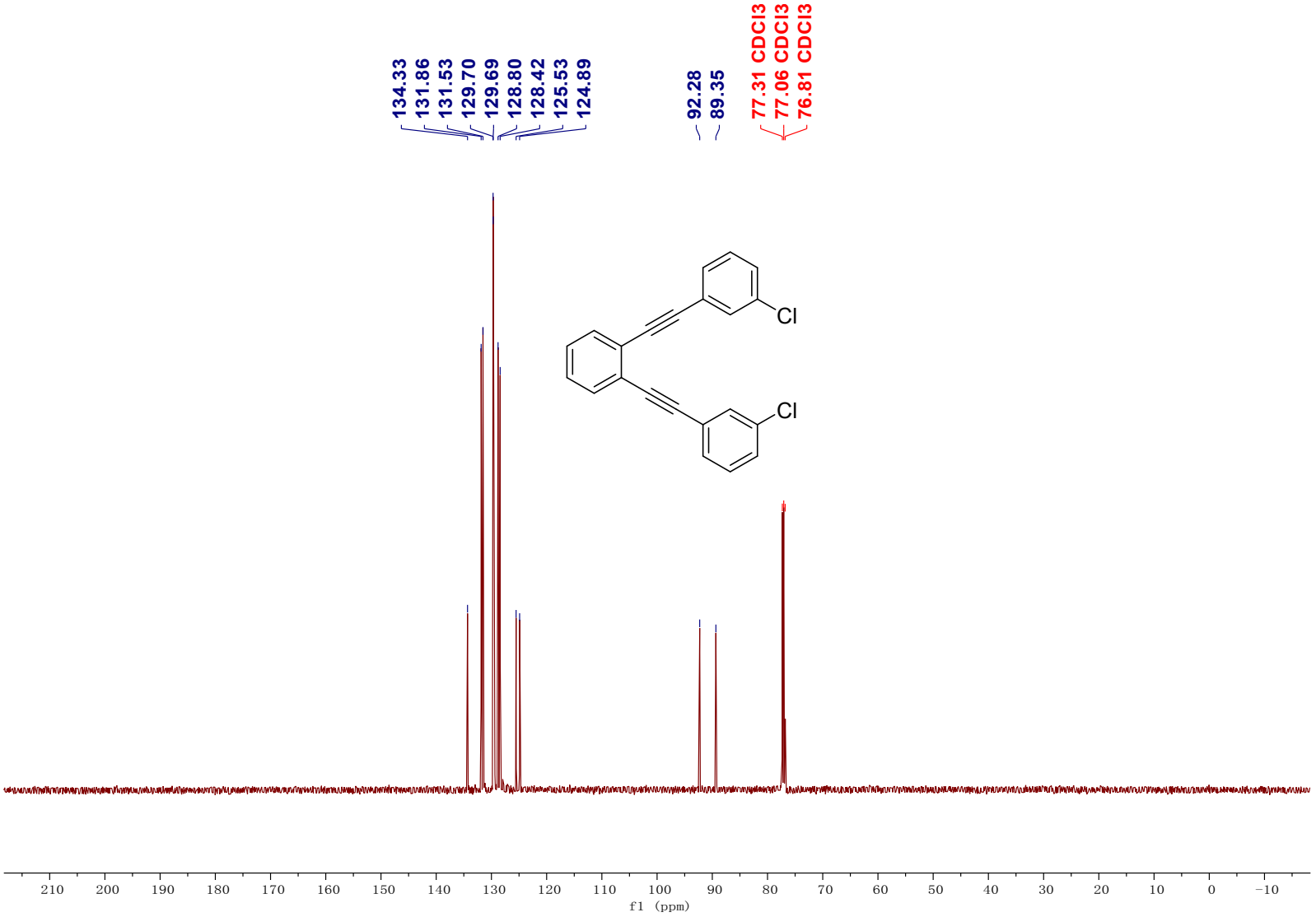

LTH-422-C.10.fid
C13CPD CDCl3 E:\\ CCY 48
163.42
161.45
131.92
130.05
129.98
128.38
127.49
125.50
125.07
124.99
118.47
118.29
115.97
115.80
92.37
88.99
77.29
77.03
76.78
F
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

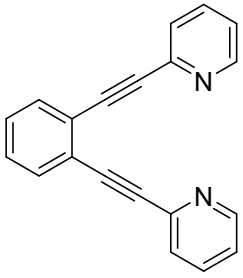


3ai, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.54-7.58 (m, 4H), 7.44 (dt, J = 8.5 Hz, 1.0 Hz, 2H), 7.32-7.36 (m, 4H), 7.29 (q, J = 8.0 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 134.3, 131.9, 131.5, 129.7, 129.6, 128.8, 128.4, 125.5, 124.9, 92.3, 89.4. TOF-MS (EI) Calcd for $C_{22}H_{12}Cl_2$: $[M+H]^+$ 347.0394; Found, 347.0387.

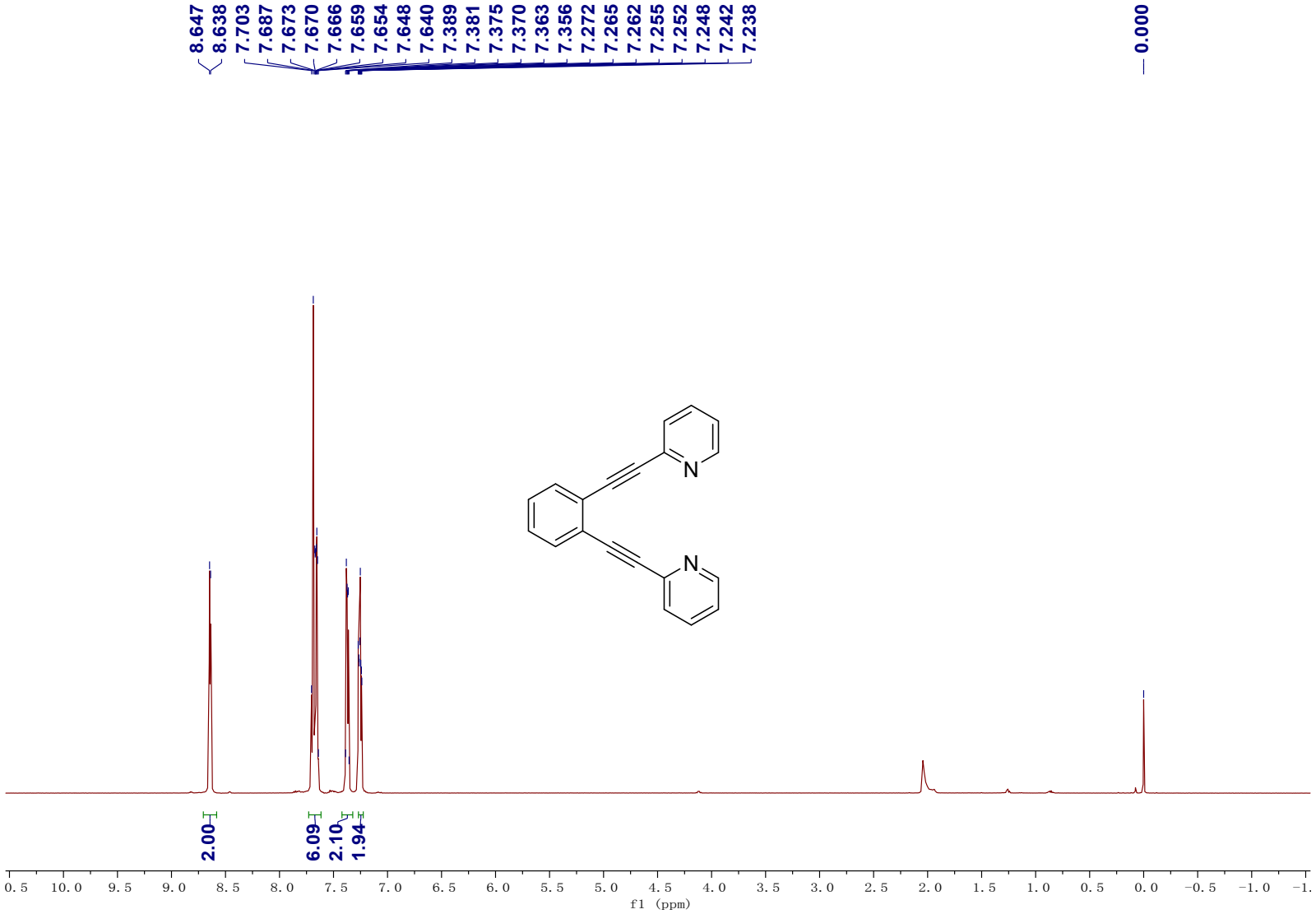

7.577
7.570
7.563
7.558
7.556
7.552
7.544
7.449
7.447
7.444
7.435
7.432
7.429
7.360
7.353
7.347
7.341
7.335
7.327
7.324
7.323
7.320
7.304
7.289
7.273
7.260
1.545
0.000
Cl
Cl
3.86
2.07
4.04
2.16
f1 (ppm)

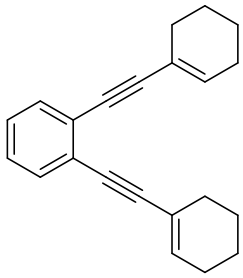

134.33
131.86
131.53
129.70
129.69
128.80
128.42
125.53
124.89
92.28
89.35
77.31 CDCl3
77.06 CDCl3
76.81 CDCl3
Cl
Cl
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)



3aj, cas. 350587-04-1, ref. [10].

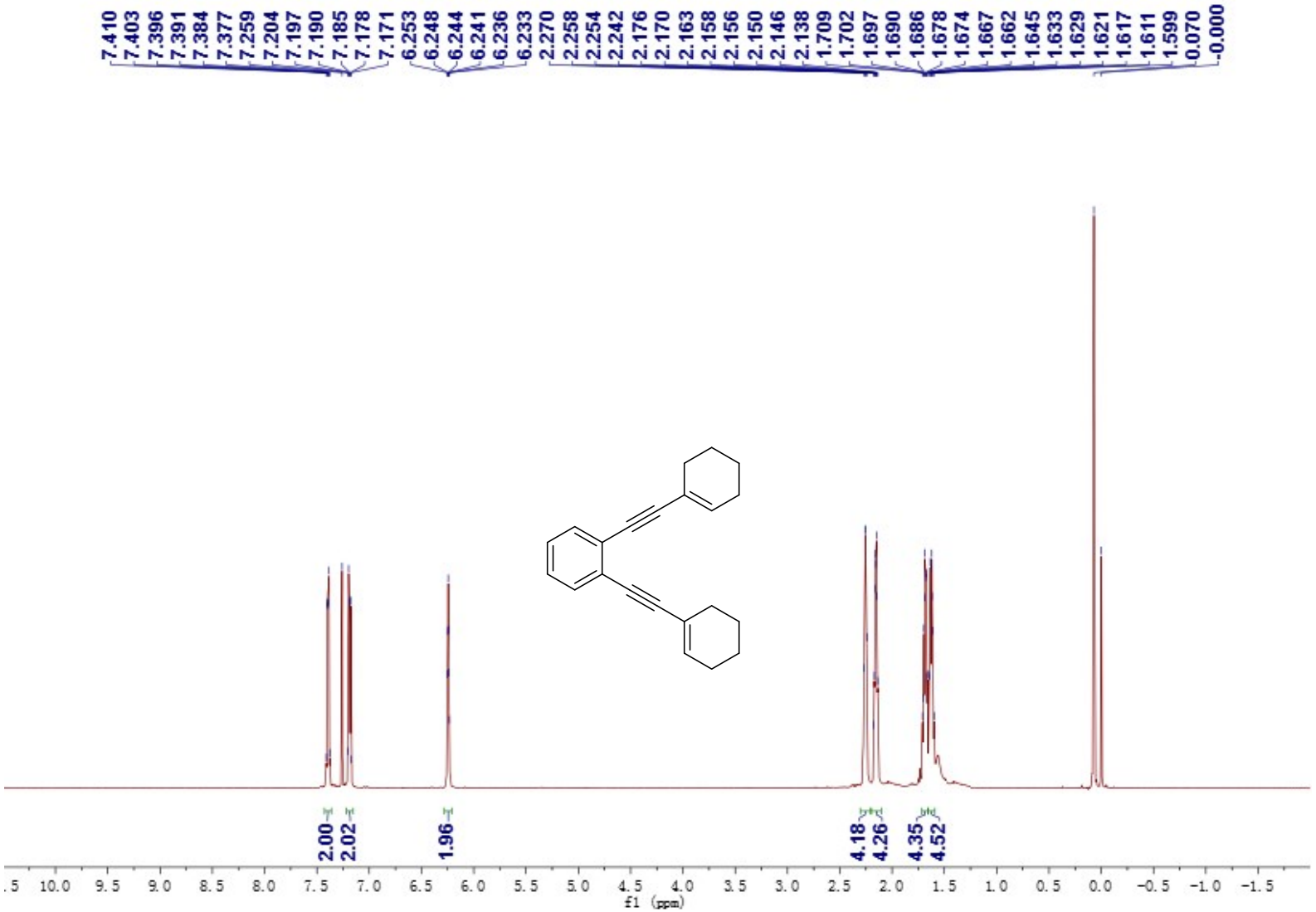
^{1}H NMR (500 MHz, $CDCl_3$) δ 8.64 (d, J = 8.5 Hz, 2H), 7.64-7.70 (m, 6H), 7.36-7.39 (m, 2H), 7.24-7.26 (m, 2H). TOF-MS (EI) Calcd for $C_{20}H_{12}N_2$: $[M+H]^+$ 281.1079; Found, 281.1107.

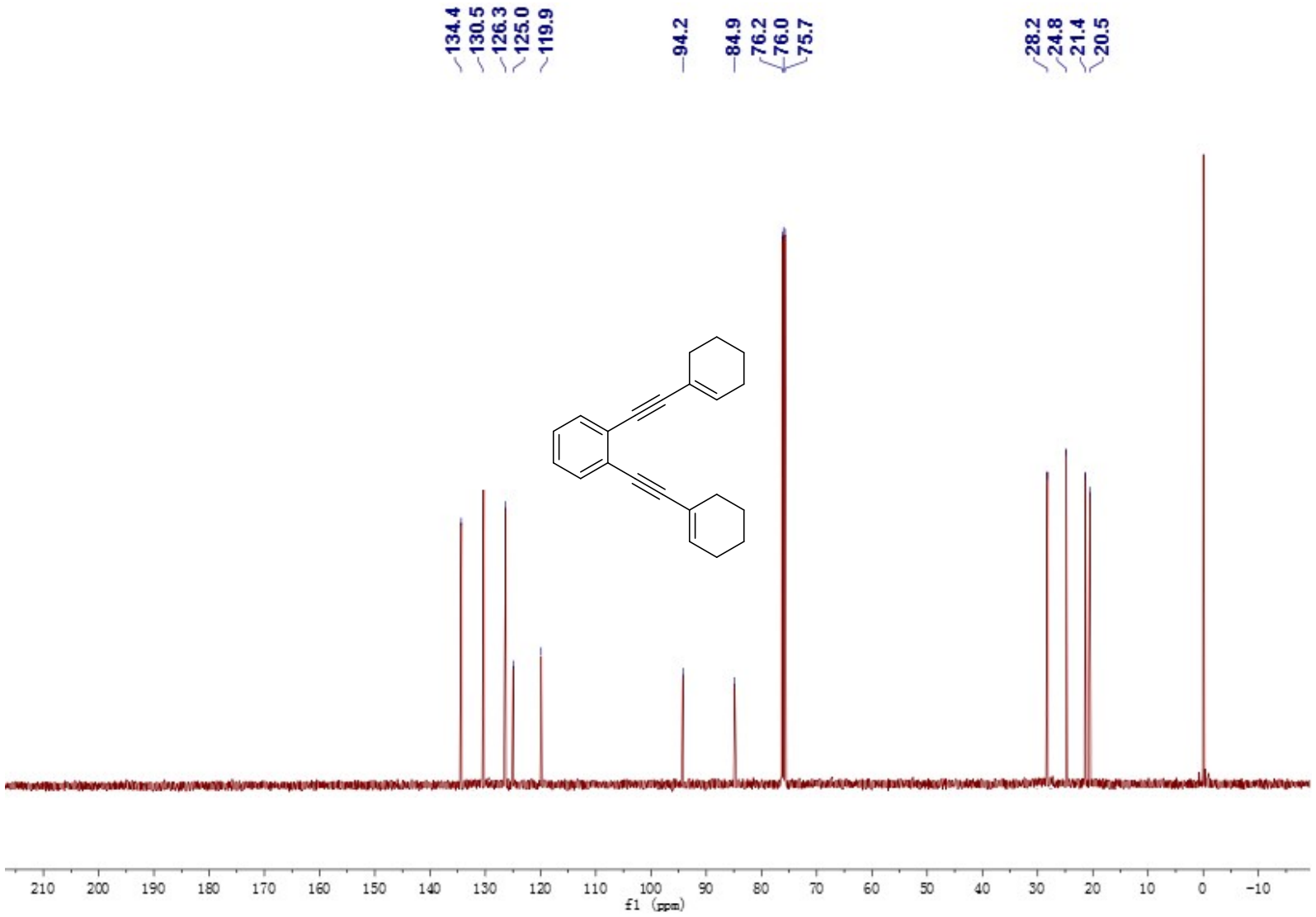

8.647
8.638
7.703
7.687
7.673
7.670
7.666
7.659
7.654
7.648
7.640
7.389
7.381
7.375
7.370
7.363
7.356
7.272
7.265
7.262
7.255
7.252
7.248
7.242
7.238
0.000
N
N
2.00
6.09
2.10
1.94
f1 (ppm)

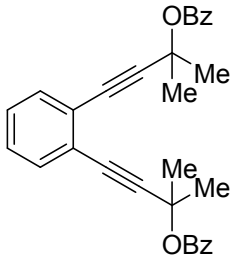


3ak, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 (m, 2H), 7.18 (m, 2H), 6.24 (m, 2H), 2.25 (m, 4H), 2.16 (m, 4H), 1.66-1.71 (m, 4H), 1.60-1.64 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 134.4, 130.5, 126.3, 125.0, 119.9, 94.2, 84.9, 28.2, 24.8, 21.4, 20.5. TOF-MS (EI) Calcd for $C_{22}H_{22}$: $[M+H]^+$ 287.1800; Found, 287.1748.

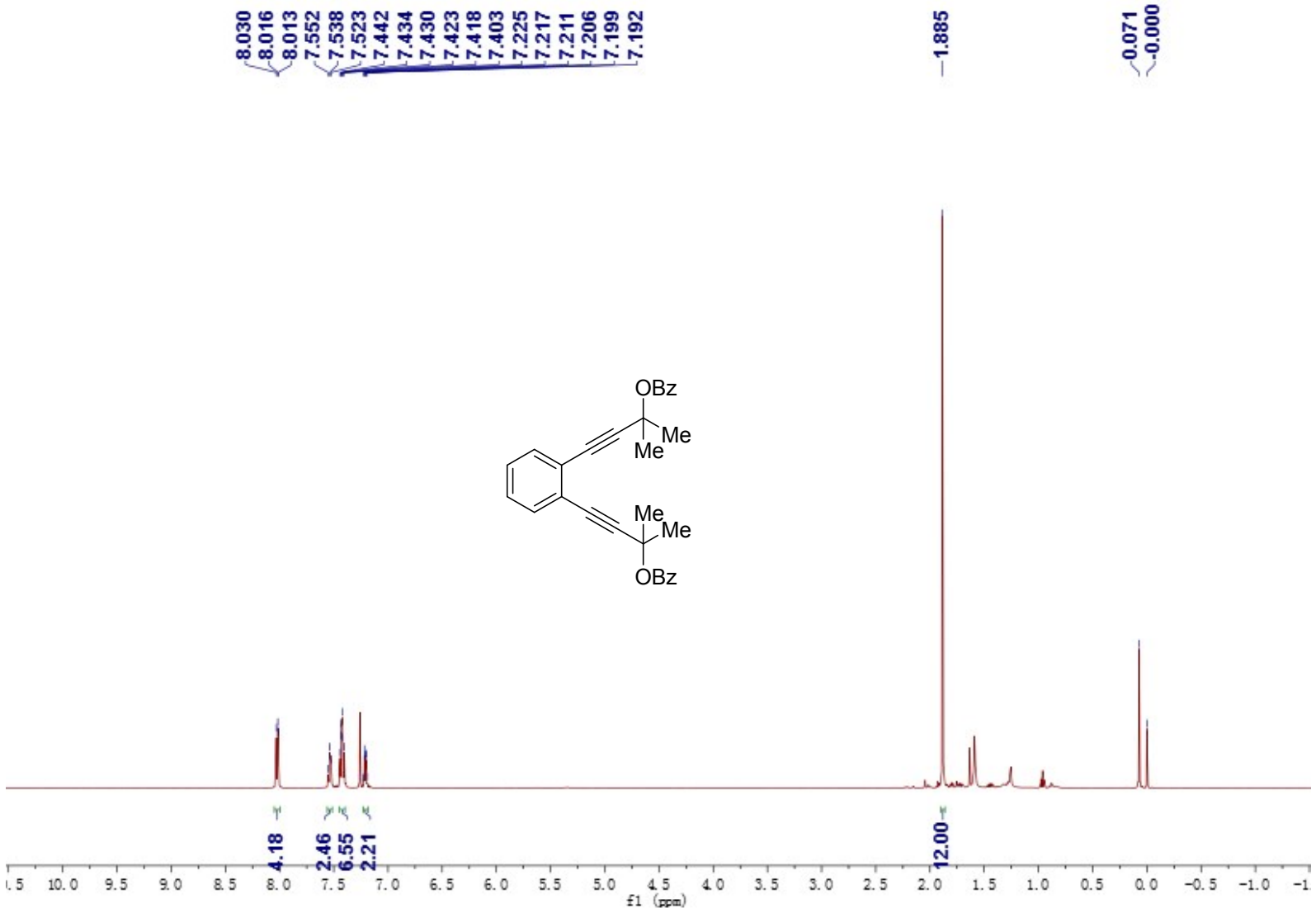

7.410
7.403
7.396
7.391
7.384
7.377
7.259
7.204
7.197
7.190
7.185
7.178
7.171
6.253
6.248
6.244
6.241
6.236
6.233
2.270
2.258
2.254
2.242
2.176
2.170
2.163
2.158
2.156
2.150
2.146
2.138
1.709
1.702
1.697
1.690
1.686
1.678
1.674
1.667
1.662
1.645
1.633
1.629
1.621
1.617
1.611
1.599
0.070
-0.000
2.00
2.02
1.96
4.18
4.26
4.35
4.52
f1 (ppm)

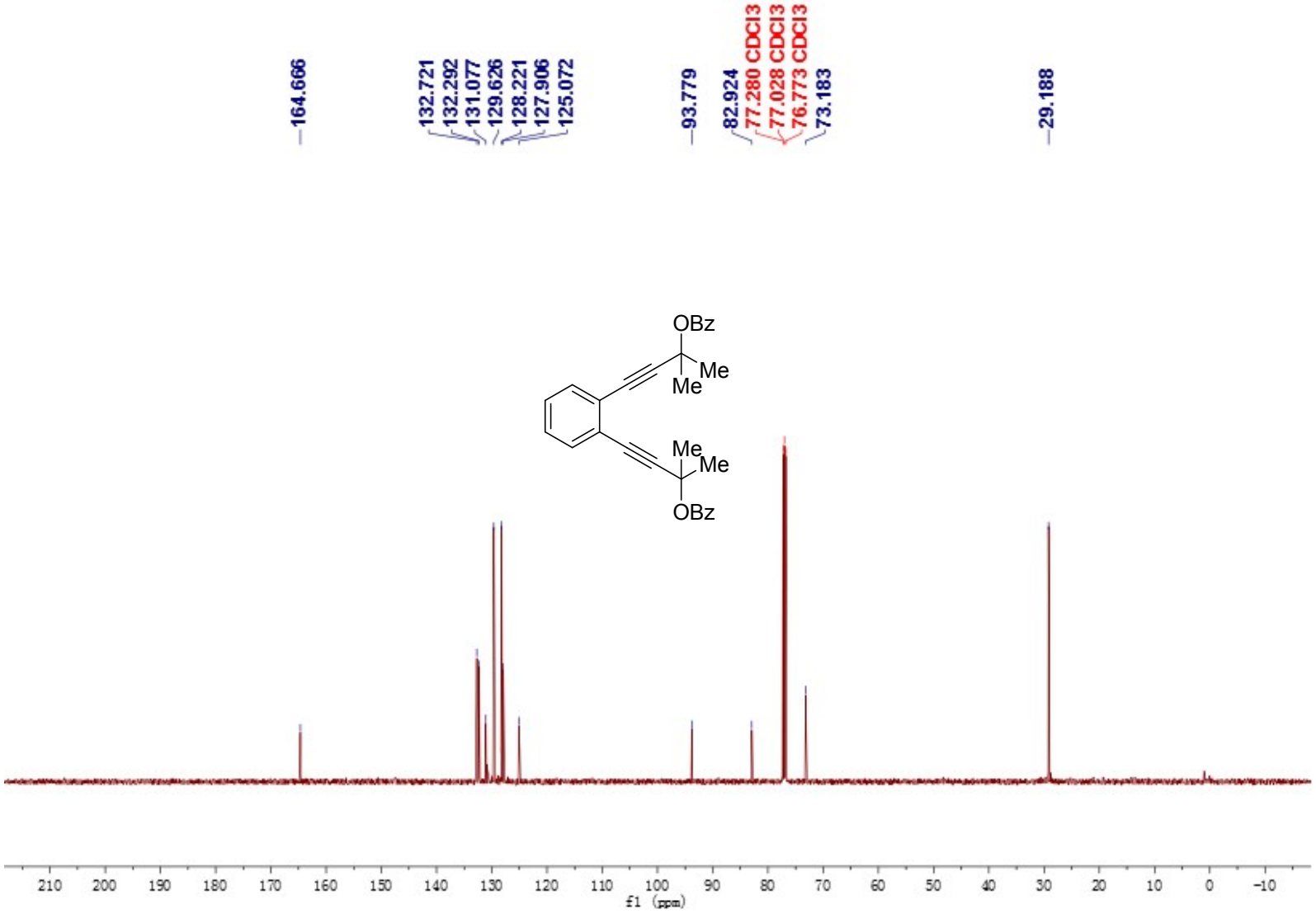

134.4
130.5
126.3
125.0
119.9
94.2
84.9
76.2
76.0
75.7
28.2
24.8
21.4
20.5
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 −10
f1 (ppm)

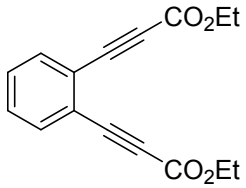


3al, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.02 (d, J = 8.0 Hz, 4H), 7.54 (t, J = 7.0 Hz, 2H), 7.40-7.44 (m, 6H), 7.19-7.23 (m, 2H), 1.88 (s, 12H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.7, 132.7, 132.3, 131.1, 129.6, 128.2, 127.9, 125.1, 93.8, 82.9, 73.2, 29.2. TOF-MS (ESI) Calcd for $C_{30}H_{26}O_4$: $[M+H]^+$ 451.1909; Found, 451.1872.

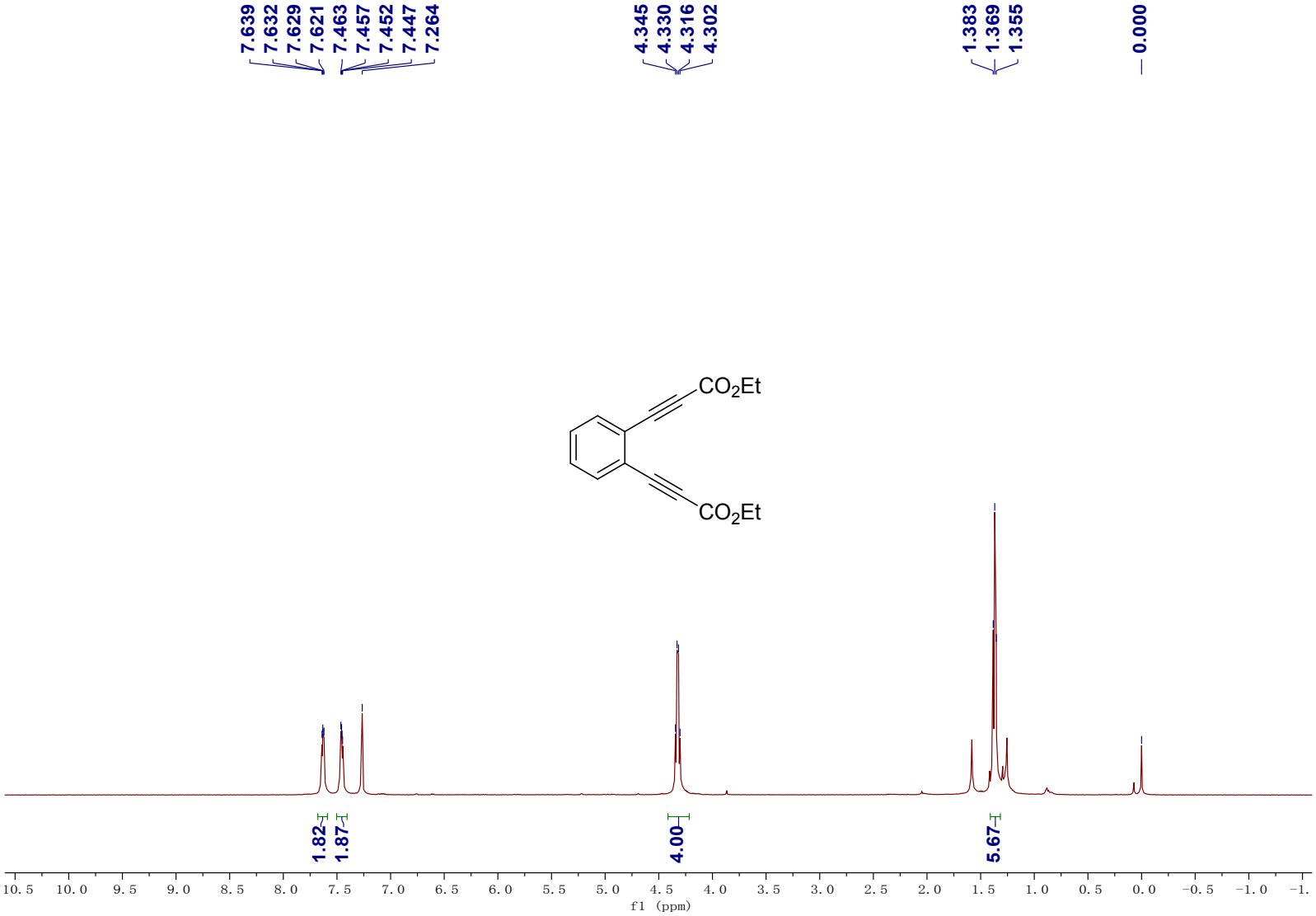

8.030
8.016
8.013
7.552
7.538
7.523
7.442
7.434
7.430
7.423
7.418
7.403
7.225
7.217
7.211
7.206
7.199
7.192
1.885
0.071
-0.000
OBz
Me
Me
Me
Me
OBz
4.18
2.46
6.55
2.21
12.00
f1 (ppm)

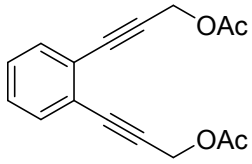

164.666
132.721
132.292
131.077
129.626
128.221
127.906
125.072
93.779
82.924
77.280 CDCl3
77.028 CDCl3
76.773 CDCl3
73.183
29.188
OBz
Me
Me
Me
Me
OBz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



3am, cas. 334868-10-9, ref. [11].

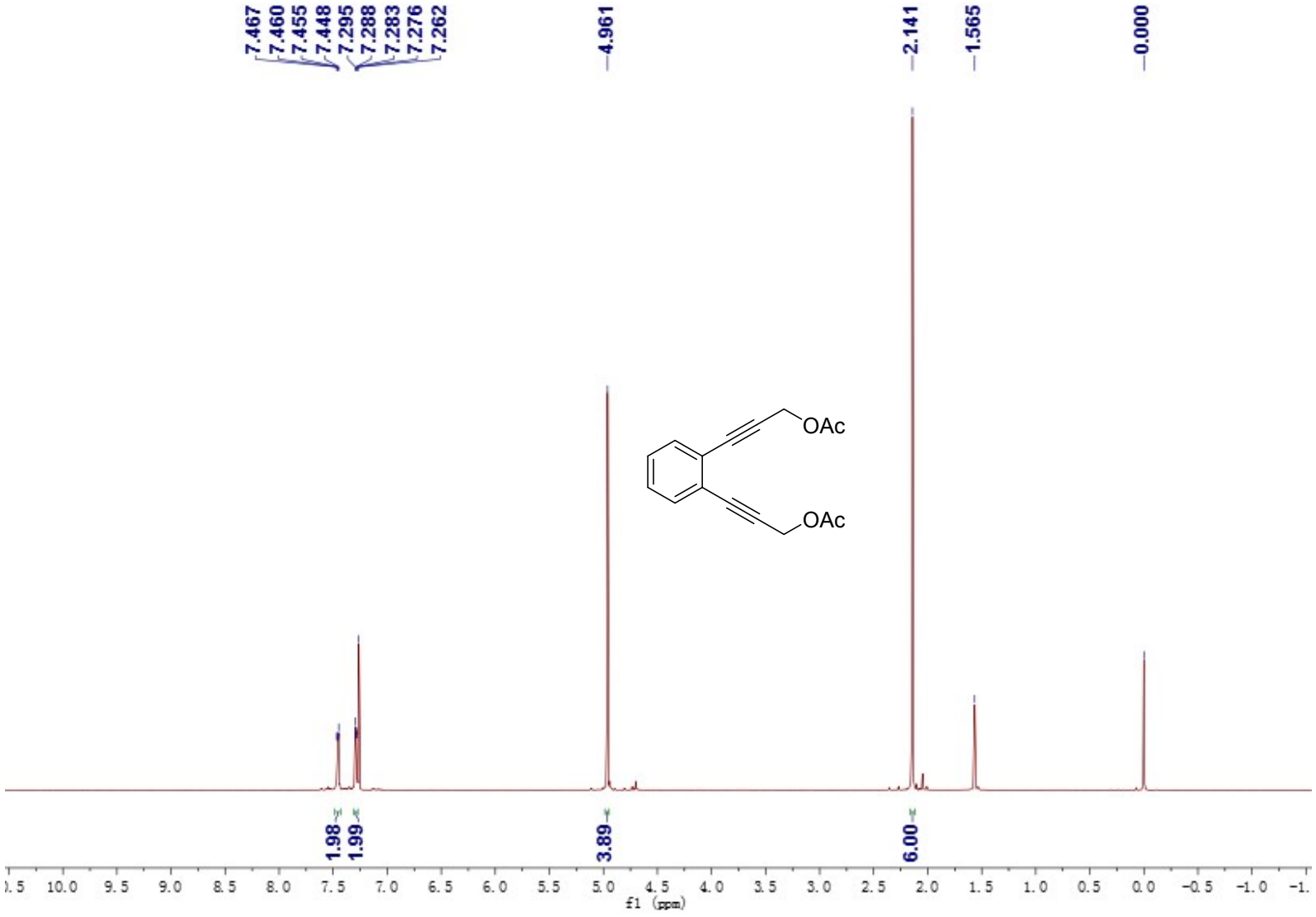
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62-7.64 (m, 2H), 7.45-7.46 (m, 2H), 4.32 (q, *J* = 7.0 Hz, 4H), 1.37 (t, *J* = 7.0 Hz, 6H). TOF-MS (ESI) Calcd for $C_{16}H_{14}O_4$: $[M+H]^+$ 271.0970; Found, 271.1008.

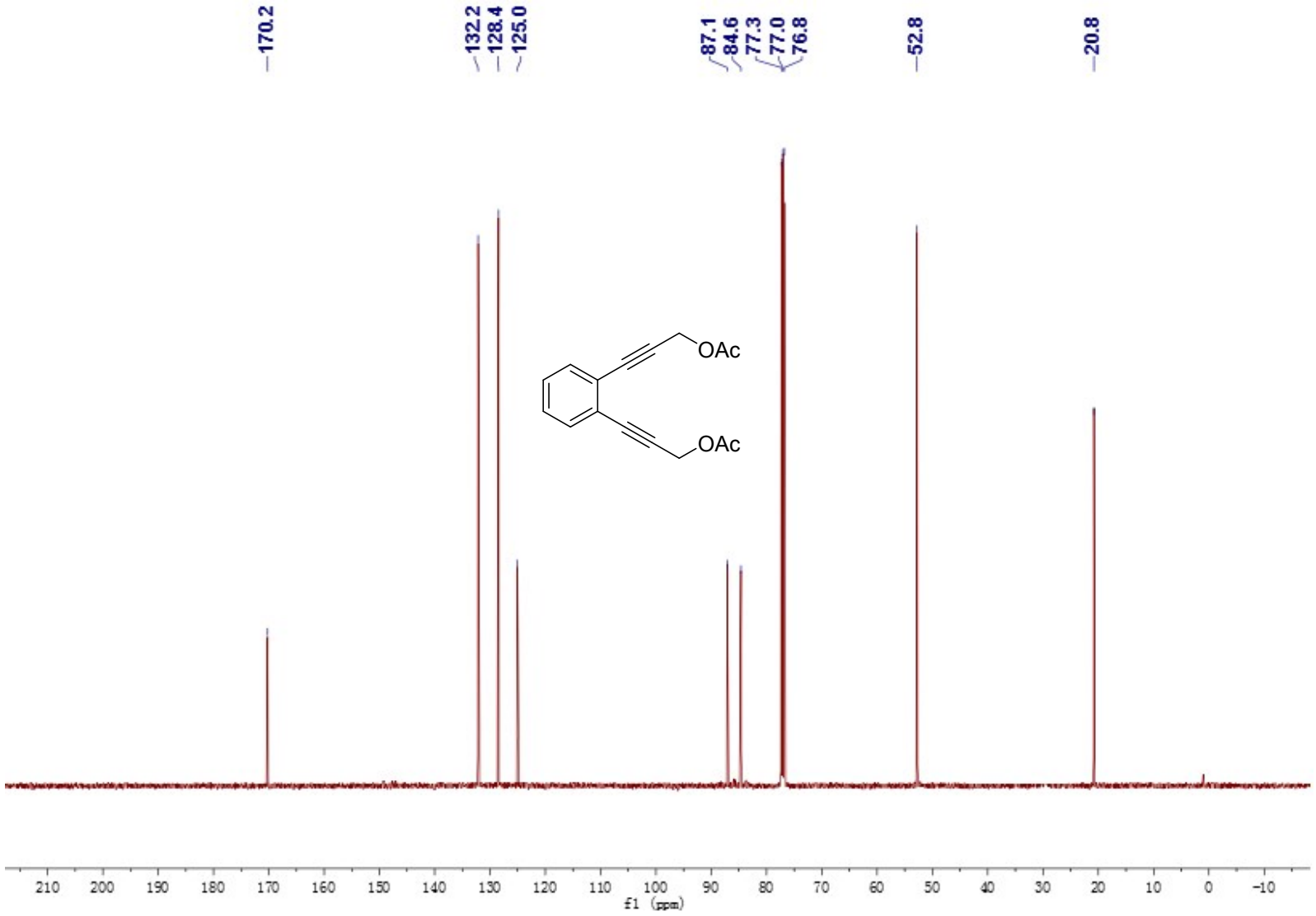

7.639
7.632
7.629
7.621
7.463
7.457
7.452
7.447
7.264
4.345
4.330
4.316
4.302
1.383
1.369
1.355
0.000
CO2Et
CO2Et
1.82
1.87
4.00
5.67
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.0 −1.
f1 (ppm)

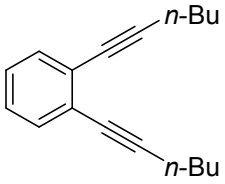


3an, cas. 220910-43-0.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46 (dd, *J* = 6.0 Hz, 3.5 Hz, 2H), 7.28 (d, *J* = 6.0 Hz, 3.5 Hz, 2H), 4.96 (s, 4H), 2.14 (s, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.2, 132.2, 128.4, 125.0, 87.1, 84.6, 52.8, 20.8. TOF-MS (ESI) Calcd for $C_{16}H_{14}O_4$: $[M+H]^+$ 271.0970; Found, 271.0961.

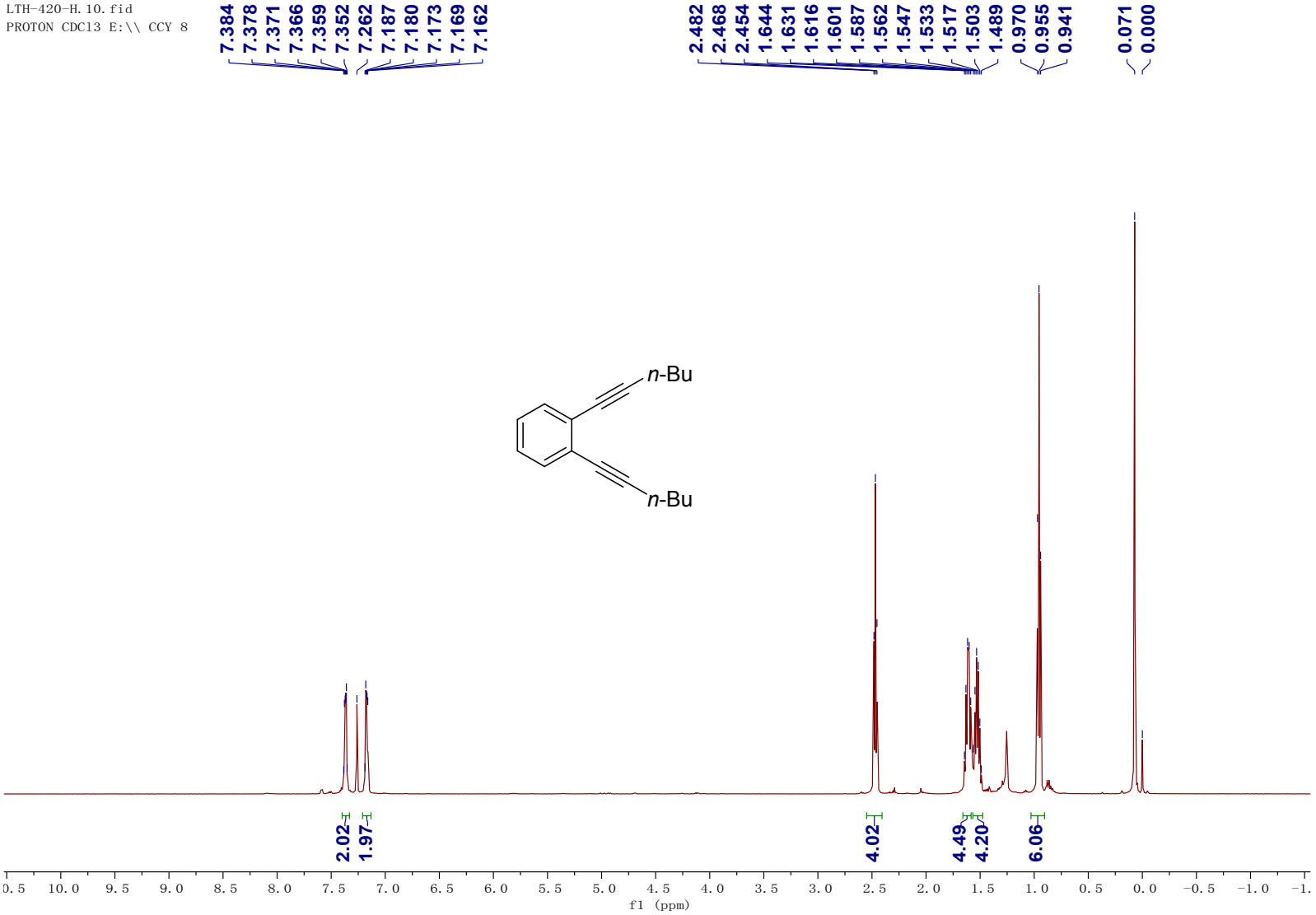

7.467
7.460
7.455
7.448
7.295
7.288
7.283
7.276
7.262
4.961
2.141
1.565
0.000
OAc
OAc
1.98
1.99
3.89
6.00
f1 (ppm)

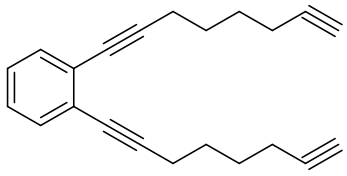

170.2
132.2
128.4
125.0
87.1
84.6
77.3
77.0
76.8
52.8
20.8
OAc
OAc
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



3ao, cas. 185038-15-7, ref. [12].

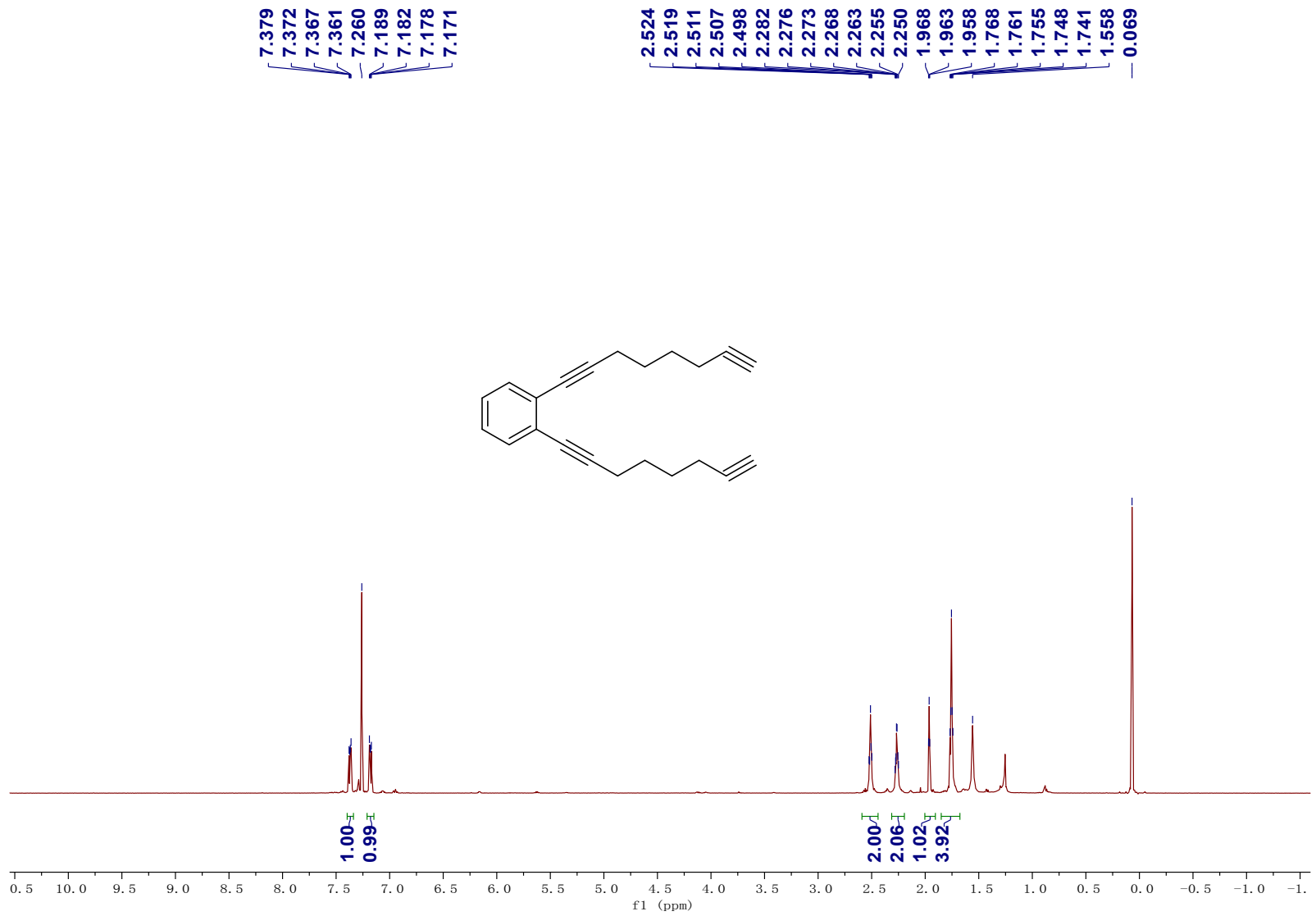
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37 (m, 2H), 7.17 (m, 2H), 2.47 (t, *J* = 7.0 Hz, 4H), 1.61 (m, 4H), 1.52 (m, 4H), 0.96 (t, *J* = 7.0 Hz, 6H). TOF-MS (ESI) Calcd for $C_{18}H_{22}$: $[M+H]^+$ 239.1800; Found, 239.1813.

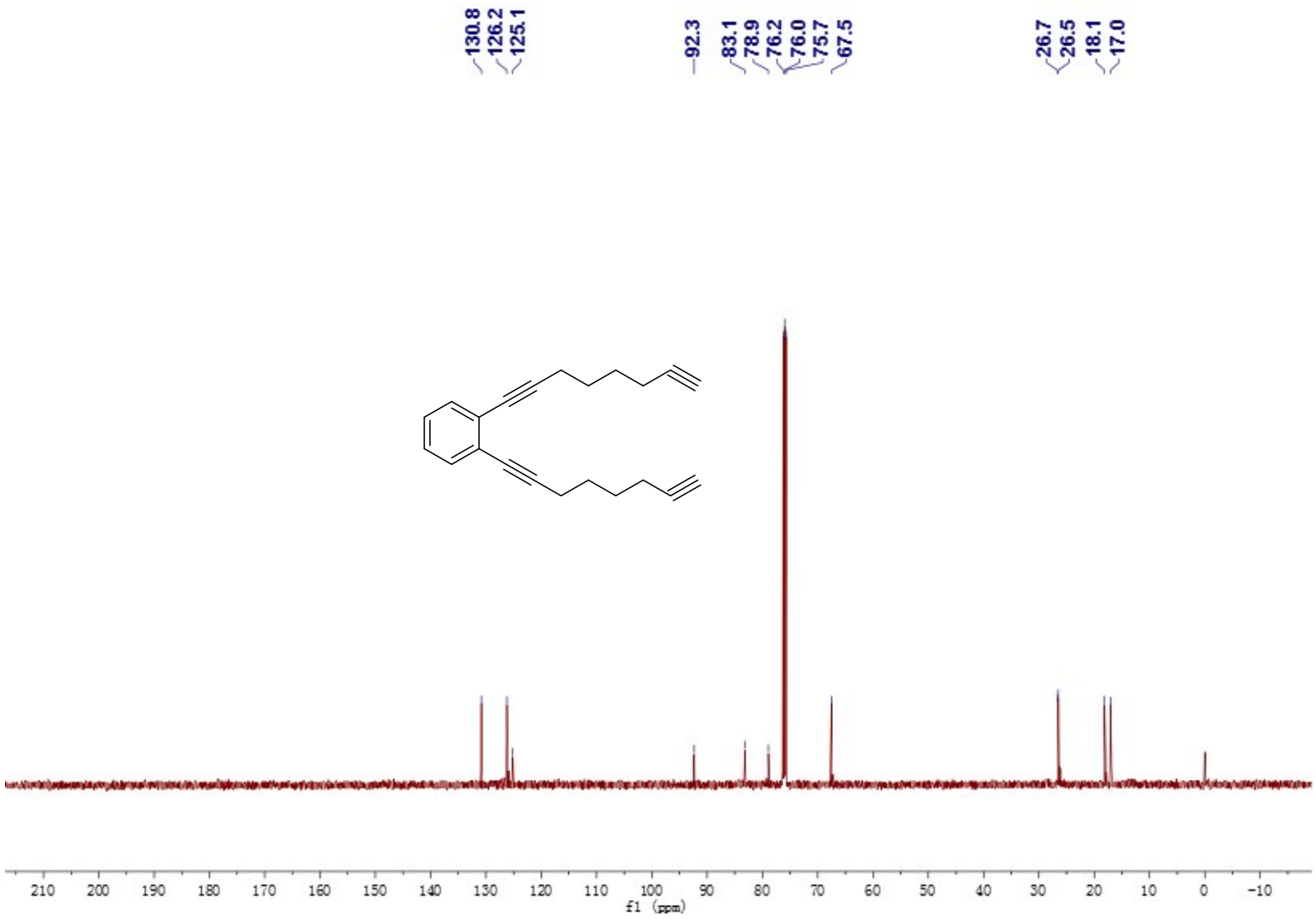

LTH-420-H.10.fid
PROTON CDCl3 E:\\ CCY 8
7.384
7.378
7.371
7.366
7.359
7.352
7.262
7.187
7.180
7.173
7.169
7.162
2.482
2.468
2.454
1.644
1.631
1.616
1.601
1.587
1.562
1.547
1.533
1.517
1.503
1.489
0.970
0.955
0.941
0.071
0.000
n-Bu
n-Bu
2.02
1.97
4.02
4.49
4.20
6.06
f1 (ppm)

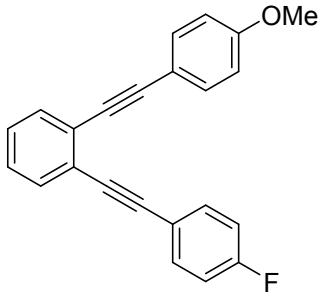


3ap, new compound.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37 (m, 2H), 7.18 (m, 2H), 2.51 (m, 2H), 2.27 (m, 2H), 1.96 (t, J = 2.5 Hz, 1H), 1.74-1.77 (m, 4H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 130.8, 126.2, 125.1, 92.3, 83.1, 78.9, 67.5, 26.7, 26.5, 18.1, 17.0. TOF-MS (ESI) Calcd for $C_{22}H_{22}$: $[M+H]^+$ 287.1800; Found, 287.1769.


7.379
7.372
7.367
7.361
7.260
7.189
7.182
7.178
7.171
2.524
2.519
2.511
2.507
2.498
2.282
2.276
2.273
2.268
2.263
2.255
2.250
1.968
1.963
1.958
1.768
1.761
1.755
1.748
1.741
1.558
0.069
1.00
0.99
2.00
2.06
1.02
3.92
f1 (ppm)

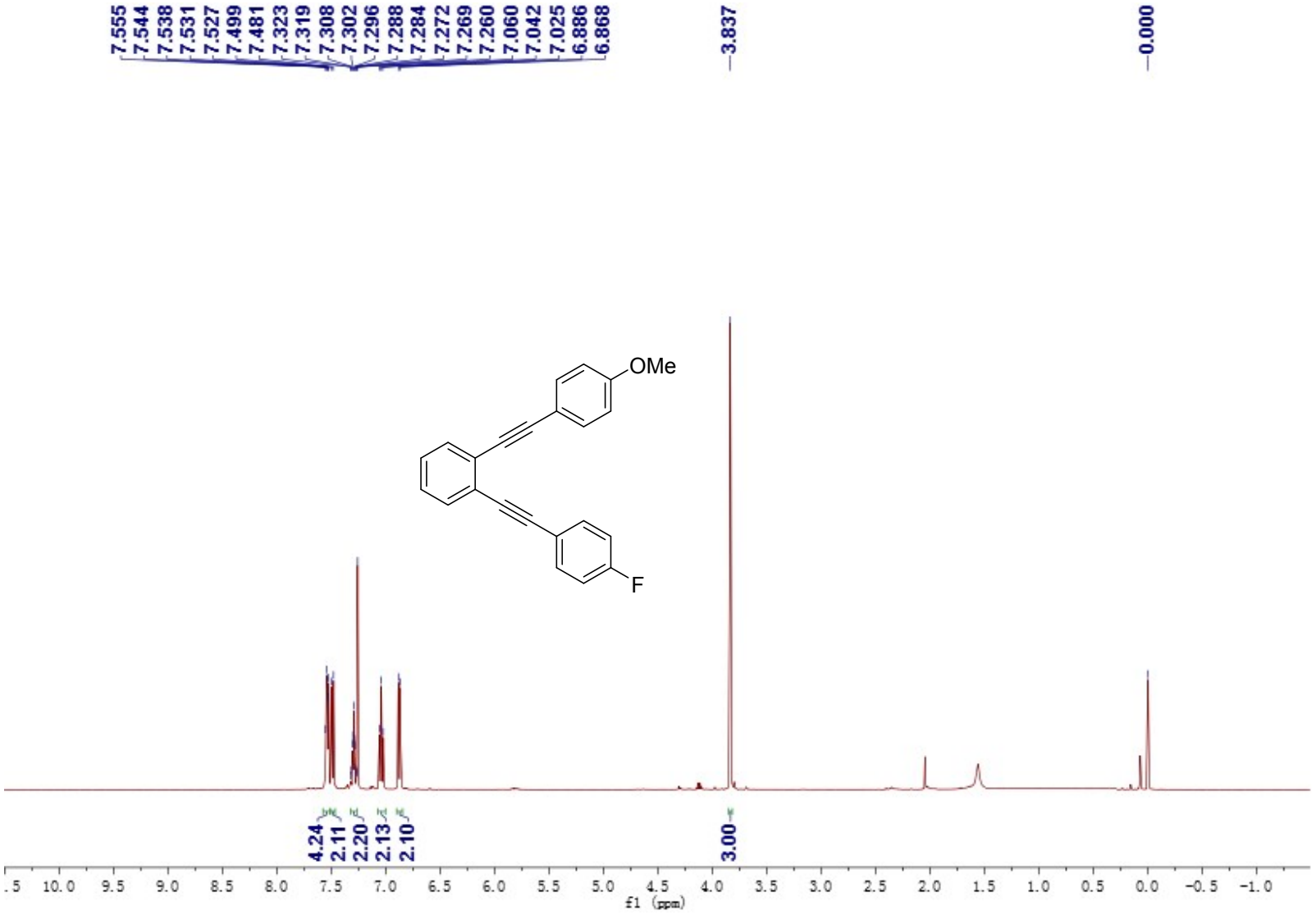

130.8
126.2
125.1
92.3
83.1
78.9
76.2
76.0
75.7
67.5
26.7
26.5
18.1
17.0
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

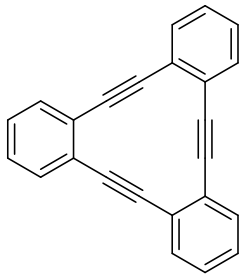


3abf, cas. 600707-32-2, ref. [13].

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53-7.56 (m, 4H), 7.49 (d, *J* = 9.0 Hz, 2H), 7.27-7.32 (m, 2H), 7.04 (t, *J* = 8.5 Hz, 2H), 6.88 (d, *J* = 9.0 Hz, 2H).

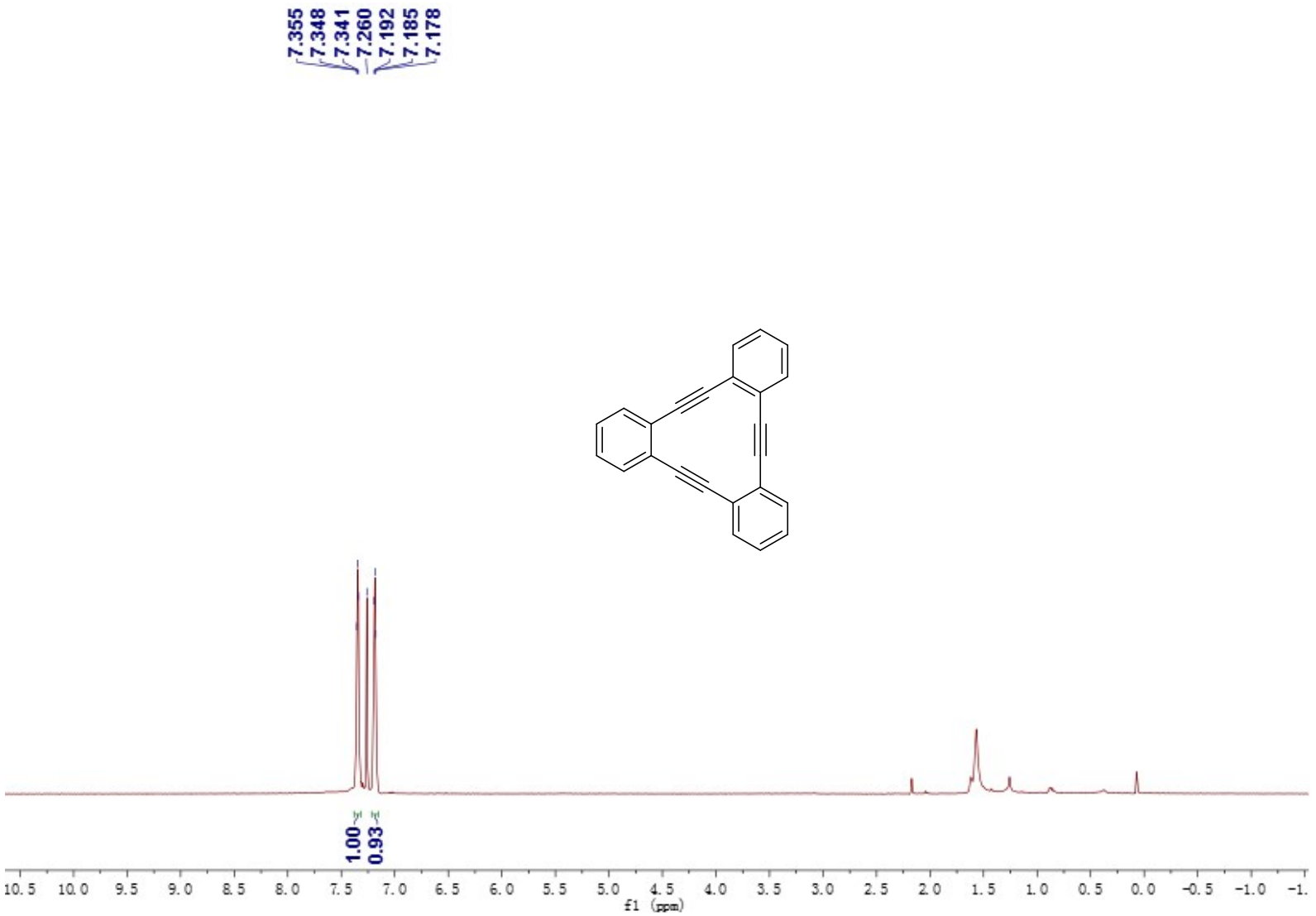
TOF-MS (ESI) Calcd for $C_{23}H_{15}FO$: $[M+H]^+$ 327.1185; Found, 327.1183.

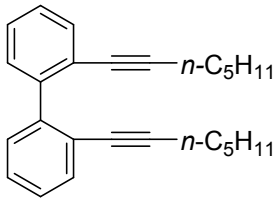

7.555
7.544
7.538
7.531
7.527
7.499
7.481
7.323
7.319
7.308
7.302
7.296
7.288
7.284
7.272
7.269
7.260
7.060
7.042
7.025
6.886
6.868
3.837
0.000
OMe
F
4.24
2.11
2.20
2.13
2.10
3.00
f1 (ppm)



5, cas. 5385-26-2, ref. [14].

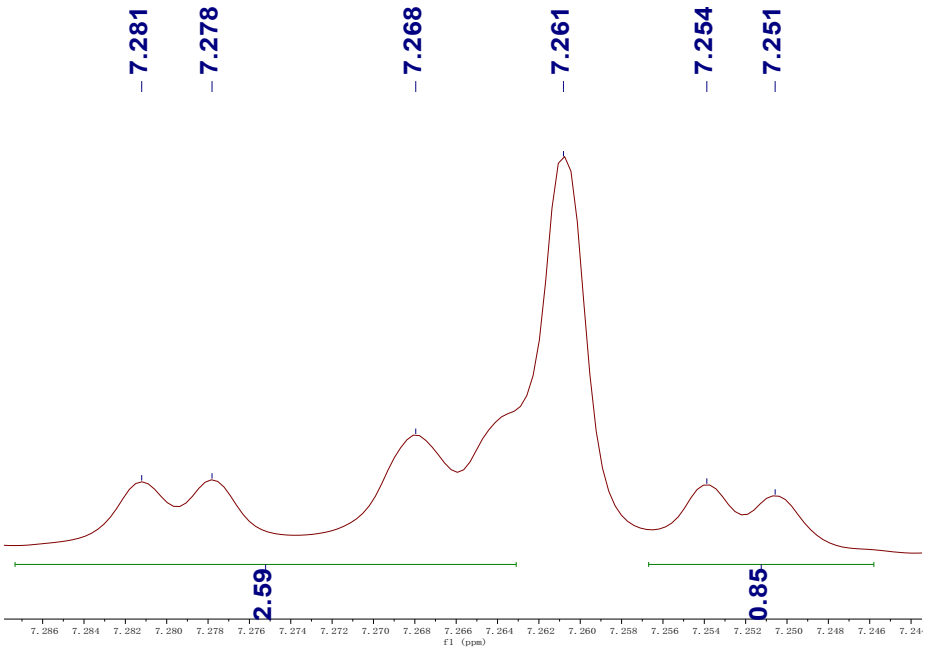
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.35 (m, 6H), 7.18 (m, 6H). TOF-MS (ESI) Calcd for $C_{24}H_{12}$: $[M+Na]^+$ 323.0837; Found, 323.0800.

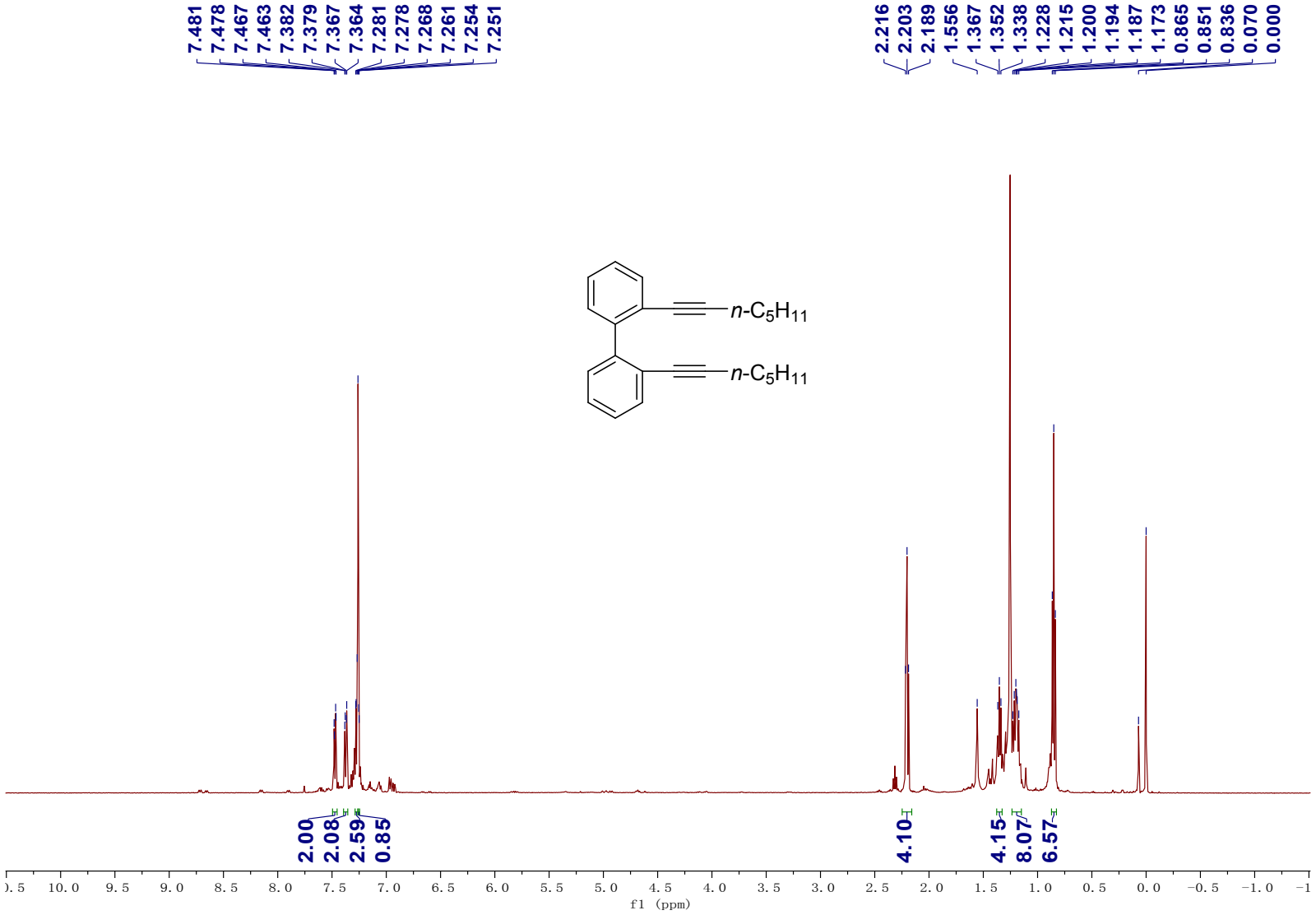

7.355
7.348
7.341
7.260
7.192
7.185
7.178
1.00
0.93
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.
f1 (ppm)

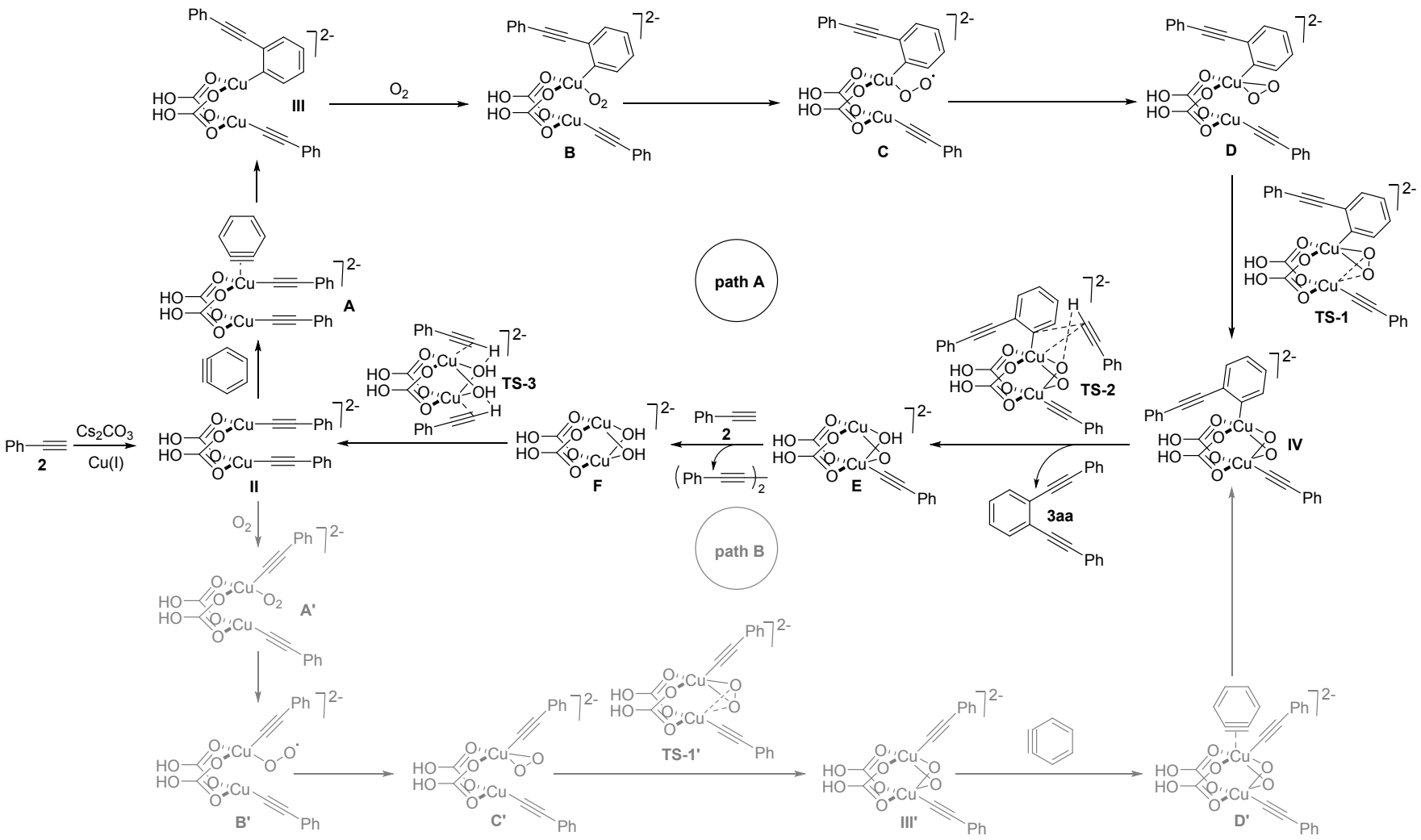


4', cas 836602-70-1.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 (d, *J* = 7.0 Hz, 2H), 7.37 (d, *J* = 7.5 Hz, 2H), 7.26 (m, 4H), 2.20 (t, *J* = 7.0 Hz, 4H), 1.35 (m, 4H), 1.71-1.23 (m, 8H), 0.85 (t, *J* = 7.0 Hz, 6H). TOF-MS (ESI) Calcd for $C_{26}H_{30}$: $[M+H]^+$ 343.2426; Found, 343.2421.


7.281
7.278
7.268
7.261
7.254
7.251
2.59
0.85
7.286 7.284 7.282 7.280 7.278 7.276 7.274 7.272 7.270 7.268 7.266 7.264 7.262 7.260 7.258 7.256 7.254 7.252 7.250 7.248 7.246
f1 (ppm)


7.481
7.478
7.467
7.463
7.382
7.379
7.367
7.364
7.281
7.278
7.268
7.261
7.254
7.251
2.216
2.203
2.189
1.556
1.367
1.352
1.338
1.228
1.215
1.200
1.194
1.187
1.173
0.865
0.851
0.836
0.070
0.000
n-C5H11
n-C5H11
2.00
2.08
2.59
0.85
4.10
4.15
8.07
6.57
f1 (ppm)



Scheme S1. Possible detailed catalytic cycles of the reaction.

In this proposal, we outlined HCO_3^- bridged dinuclear copper intermediates **II** for the reaction. However, it should be emphasized that the possibility analogous mononuclear copper intermediates might also be catalytically competent species for the reaction. Moreover, it should be pointed out that other coordinative ligands other than HCO_3^-, such as CO_3^{2-}, Cl^- etc. can not be exlcluded at present.

References

[1] Himeshima, Y.; Sonoda, T.; Kobayashi, H. *Chem. Lett.* **1983**, 1211-1214.

[2] Tello-Aburto, R.; Harned, A. M. *Org. Lett.* **2009**, *11*, 3998-4000.

[3] Pagar, V. V.; Jadhav, A. M.; Liu, R.-S. *J. Am. Chem.Soc.* **2011**, *133*, 20728−20731.

[4] Lin, J. Q.; Zou, C.; Zhang, X. B.; Gao, Q.; Suo, S.; Zhuo, Q. H.; Chang, X. Y.; Xie, M.; Lu, W. *Dalton Trans.* **2019**, *48*, 10417-10421.

[5] (a) Chen, M.; Su, N. J.; Deng, T. N.; Wink, D. J.; Zhao, Y. W.; Driver, T. G. *Org. Lett.* **2019**, *21*, 1555−1558. (b) Shinde, P. S.; Shaikh, A. C.; Patil, N. T. *Chem. Commun.* **2016**, *52*, 8152-8155.

[6] Kovalenko, S. V.; Peabody, S.; Manoharan, M.; Clark, R. J.; Alabugin, I. V. *Org. Lett.* **2004**, *6*, 2457-2460.

[7] Hashmi, A. S. K.; Braun, I.; Rudolph, M.; Rominger, F. *Organomet.* **2012**, *31*, 644–661.

[8] Peterson, P. W.; Shevchenko, N.; Breiner, B.; Manoharan, M.; Lufti, F.; Delaune, J.; Kingsley, M.; Kovnir, K.; Alabugin, I. V. *J. Am. Chem.*

Soc. **2016**, *138*, 15617-15628.

[9] Saunthwal, R. K.; Danodia, A. K.; Patel, M.; Kumar, S.; Verma, A. K. *Chem. Asian J.* **2016**, *11*, 3001-3007.

[10] Neverov, A. A.; Feng, H. X. M.; Hamilton, K.; Brown, R. S. *J. Org. Chem.* **2003**, *68*, 3802-3810.

[11] Shibata, T.; Uchiyama, T.; Yoshinami, Y.; Takayasu, S.; Tsuchikama, K.; Endo, K. *Chem. Commun.* **2012**, *48*, 1311-1313.

[12] Chen, S. D.; Li, Q. P.; Sun, S. Y.; Ding, Y.; Hu, A. G. Macromolecules **2017**, *50*, 534-541.

[13] Rao, M. L. N.; Dasgupta, P.; Islam, S. S. *Org. Chem. Front.* **2017**, *4*, 335-342.

[14] Li, Y.; Zhang, J. Y.; Wang, W. K.; Miao, Q.; She, X. G.; Pan, X. F. *J. Org. Chem.* **2005**, *70*, 3285-3287.