Supporting Information

Metal-Free, Catalytic Regioselective Oxidative Conversion of Vinylarenes: A Mild Approach to Phenylacetic Acid Derivatives

Srujana Kodumuri,[a] Swamy Peraka,[a,b] Naresh Mameda,[a,b] Durgaiah Chevella,[a] Rammurthy Banothu[a,b] and Narender Nama *[a,b]

[a] I&PC Division, CSIR-Indian Institute of Chemical Technology, Hyderabad 500 007, India

[b] Academy of Scientific and Innovative Research, Hyderabad 500 007, India

Tel.: +91–40-27191703; Fax: +91-40-27160387/27160757;

E-mail: narendern33@yahoo.co.in; nama@iict.res.in

Table of contents

1. **Experimental section…….S2-S3**
2. **Spectroscopic data of all products ……...S4-S6**
3. **Copies of ^{1}H and ^{13}C NMR spectra of all products….……S7-S24**
4. **Notes and references…….S25**

1. Experimental section

i) General Information

All chemicals (reagent grade) were purchased from Sigma-Aldrich and used as received without further purification. ^{1}H NMR spectra were recorded at 300 or 500 MHz and ^{13}C NMR spectra at 75 or 125 MHz in $CDCl_3$. The chemical shifts (δ) are reported in ppm units relative to TMS as an internal standard for ^{1}H NMR and $CDCl_3$ for ^{13}C NMR spectra. Coupling constants (J) are reported in hertz (Hz) and multiplicities are indicated as follows: s (singlet), brs (broad singlet), d (doublet), dd (doublet of doublet), m (multiplet). TLC inspections were performed on Silica gel 60 F_{254} plates. Column chromatography was performed on silica gel (100-200 mesh) using *n*-hexane-EtOAc as eluent.

ii) Typical procedure for the oxidative conversion of styrene (1a) to phenyl acetic acid (2a)

To a oven dried doubled necked round bottom flask charged with 4 mL of 1,2-dimethoxy ethane (DME) and 1 mL of water was added I_2 (0.025 g; 10 mol%) and styrene (**1a**) (0.104 g, 0.114 mL; 1 mmol). The mixture was stirred for 1 min and the oxone (1.229 g; 2 mmol) was slowly added and continued the stirring at room temperature. The reaction was stopped after 6 h (after completion of the reaction indicated by TLC). The product mixture was extracted with ethyl acetate (3 x 25 mL) and the combined organic layers treated with 5% aqueous sodium thiosulfate (5 mL) solution. Next, the organic layer was dried over anhydrous Na_2SO_4. The solvent was removed on vacuo and the residue was purified by column chromatography (on silica gel using *n*-hexane-ethyl acetate as eluent) to yield **2a** in 0.120 g (88%) as colourless solid.

iii) General procedure for the oxidative conversion of 1b-1s

All the reactions of the substrates **1b-1s** were carried out using the typical procedure used for the oxidative conversion of styrene (**1a**) to phenyl acetic acid (**2a**)**.**

iv) Typical procedure for large-scale experiment (20 mmol scale reaction of styrene (1a))

To a oven dried doubled necked round bottom flask charged with 40 mL of 1,2-dimethoxy ethane (DME) and 10 mL of water was added I_2 (0.507 g; 10 mol%) and styrene (**1a**) (2.083 g, 2.29 mL; 20 mmol). The mixture was stirred for 1 min and the oxone (24.590 g;

40 mmol) was slowly added and continued the stirring at room temperature. The reaction was stopped after 6 h (after completion of the reaction indicated by TLC). The product mixture was extracted with ethyl acetate (1 x 150 and 2 x 100 mL) and the combined organic layers treated with 5% aqueous sodium thiosulfate (25 mL) solution. Next, the organic layer was dried over anhydrous Na_2SO_4. The solvent was removed on vacuo and the residue was purified by column chromatography (on silica gel using *n*-hexane-ethyl acetate as eluent) to yield **2a** in 2.258 g (83%) as colourless solid.

v) Typical procedure for large-scale experiment (45 mmol scale reaction of styrene (1a))

To a oven dried doubled necked round bottom flask charged with 80 mL of 1,2-dimethoxy ethane (DME) and 20 mL of water was added I_2 (1.142 g; 10 mol%) and styrene (**1a**) (4.686 g, 5.15 mL; 45 mmol). The mixture was stirred for 1 min and the oxone (55.328 g; 90 mmol) was slowly added and continued the stirring at room temperature. The reaction was stopped after 6 h (after completion of the reaction indicated by TLC). The product mixture was extracted with ethyl acetate (1 x 200 and 2 x 125 mL) and the combined organic layers treated with 5% aqueous sodium thiosulfate (60 mL) solution. Next, the organic layer was dried over anhydrous Na_2SO_4. The solvent was removed on vacuo and the residue was purified by column chromatography (on silica gel using *n*-hexane-ethyl acetate as eluent) to yield **2a** in 5.202 g (85%) as colourless solid.

vi) Typical procedure for large-scale experiment (100 mmol scale reaction of styrene (1a))

To a oven dried doubled necked round bottom flask charged with 120 mL of 1,2-dimethoxy ethane (DME) and 30 mL of water was added I_2 (2.538 g; 10 mol%) and styrene (**1a**) (10.414 g, 11.45 mL; 100 mmol). The mixture was stirred for 1 min and the oxone (122.952 g; 200 mmol) was slowly added and continued the stirring at room temperature. The reaction was stopped after 6 h (after completion of the reaction indicated by TLC). The product mixture was extracted with ethyl acetate (1 x 250 and 2 x 150 mL) and the combined organic layers treated with 5% aqueous sodium thiosulfate (120 mL) solution. Next, the organic layer was dried over anhydrous Na_2SO_4. The solvent was removed on vacuo and the residue was purified by column chromatography (on silica gel using *n*-hexane-ethyl acetate as eluent) to yield **2a** in 11.696 g (86%) as colourless solid.

2. Spectroscopic data:

2-Phenylacetic acid (2a)[1]

^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.24-7.36 (m, 5H), 3.64 (s, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) = 177.88, 133.18, 129.34, 128.61, 127.33, 41.01.

2-(*p*-tolyl)Acetic acid (2b) [2]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) =7.12-7.17 (m, 4H), 3.60 (s, 2H), 2.32 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) =178.21, 136.90, 130.15, 129.25, 129.13, 40.58, 21.00.

2,4-Dimethylphenylacetic acid(2c)[3]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 6.96-7.08 (m, 3H), 3.61 (s, 2H), 2.29 (s, 3H), 2.27 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) = 178.12, 137.25, 136.65, 131.20, 130.16, 128.93, 126.82, 38.44, 20.95, 19.42.

(4- *tert*-butylphenyl)Acetic acid (2d)[4]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 7.34 (d, J = 8.24 Hz, 2H), 7.21 (d, J =8.39 Hz, 2H), 3.59 (s, 2H), 1.30 (s, 9H).

^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) =178.18, 150.08, 130.15, 128.96, 125.50, 40.52, 34.38, 31.24.

2-(4-methoxyphenyl)Acetic acid (2e)[1]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 7.19 (d, J = 8.69 Hz, 2H), 6.86 (d, J = 8.69 Hz, 2H), 3.79 (s, 3H), 3.58 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) =177.75, 158.81, 130.37, 125.34, 114.04, 55.23, 40.09.

(2-methoxyphenyl)Acetic acid (2f)[5]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 7.18-7.29 (m, 2H), 6.88-6.94 (m, 2H), 3.83 (s, 3H), 3.66 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) =176.64, 157.38, 130.96, 128.84, 122.33, 120.61, 110.53, 55.47, 35.75.

2-(4-fluorophenyl)Acetic acid (2g)[6]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 10.54 (brs, 1H), 7.23 (dd, J = 5.47, 8.68 Hz, 2H), 7.00 (t, J = 8.68 Hz, 2H), 3.60 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) =177.47, 163.09, 130.90, 128.86, 115.42, 40.10.

2-(4-chlorophenyl)Acetic acid (2h)[7]

^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.30 (d, J = 8.43 Hz, 2H), 7.21 (d, J =8.55 Hz, 2H), 3.61 (s, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) =177.33, 133.35, 131.55, 130.71, 128.76, 40.27.

2-(4-bromophenyl)Acetic acid (2i)[8]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 7.46 (d, J = 8.39 Hz, 2H), 7.16 (d, J = 8.39 Hz, 2H), 3.60 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 177.07, 132.11, 131.71, 131.06, 121.43, 40.34.

2-(3-bromophenyl)Acetic acid (2j)[2]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 10.95 (brs, 1H), 7.40-7.44 (m, 2H), 7.18-7.20 (m, 2H), 3.61 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 177.31, 135.23, 132.38, 130.47, 130.07, 128.02, 122.51, 40.50.

3-Nitrophenylacetic acid (2k)[9a,b]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 8.16-8.20 (m, 2H), 7.64-7.66 (m, 1H), 7.52-7.56 (m, 1H), 3.81 (s, 2H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 176.41, 148.28, 135.64, 135.00, 129.52, 124.45, 122.48, 40.33.

1-Phenyl-2-propanone (2m)[10]

^{1}H NMR (500 MHz, CDCl3): δ (ppm) = 7.31-7.34 (m, 2H), 7.25-7.28 (m, 1H), 7.19-7.21 (m, 2H), 3.69 (s, 2H), 2.14 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 206.31, 134.14, 129.29, 128.64, 126.95, 50.91, 29.16.

1-(4-chlorophenyl)-2-Propanone (2n)[11]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 7.31 (d, J = 8.39 Hz, 2H), 7.13 (d, J = 8.54 Hz, 2H), 3.67 (s, 2H), 2.17 (s, 3H).

^{13}C NMR (125 MHz, CDCl3): δ (ppm) = 205.56, 132.89, 132.51, 130.69, 128.74, 49.93, 29.32.

2-Phenylpropionic acid (2o)[12a,b]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 7.25-7.33 (m, 5H), 3.74 (q, J = 7.17 Hz, 1H), 1.51 (d, J = 7.17 Hz, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 180.09, 139.78, 128.63, 127.56, 127.33, 45.29, 18.11.

Cyclohexane-1,2-diol(2p)[13]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 4.54-4.60 (m, 1H), 3.53-3.58 (m, 1H), 2.00-2.10 (m, 2H), 1.69-1.74 (m, 2H), 1.25-1.37 (m, 4H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 75.81, 32.80, 24.29.

1-Methyl-cyclohexane-1,2-diol (2q)[14]

^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) = 3.47-3.51 (m, 1H), 3.16 (brs, 2H), 1.84 (brs, 1H), 1.57-1.77 (m, 3H), 1.25-1.42 (m, 4H), 1.18 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 77.16, 74.13, 38.58, 31.02, 24.08, 23.20, 19.38.

Octane-1,2-diol (2r)[15]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 3.74–3.63 (m, 2H), 3.43 (dd, J = 18.82, 7.70 Hz, 1H), 2.48 (brs, 2H), 1.48-1.23 (m, 10H), 0.88 (t, J = 6.60 Hz, 3H).

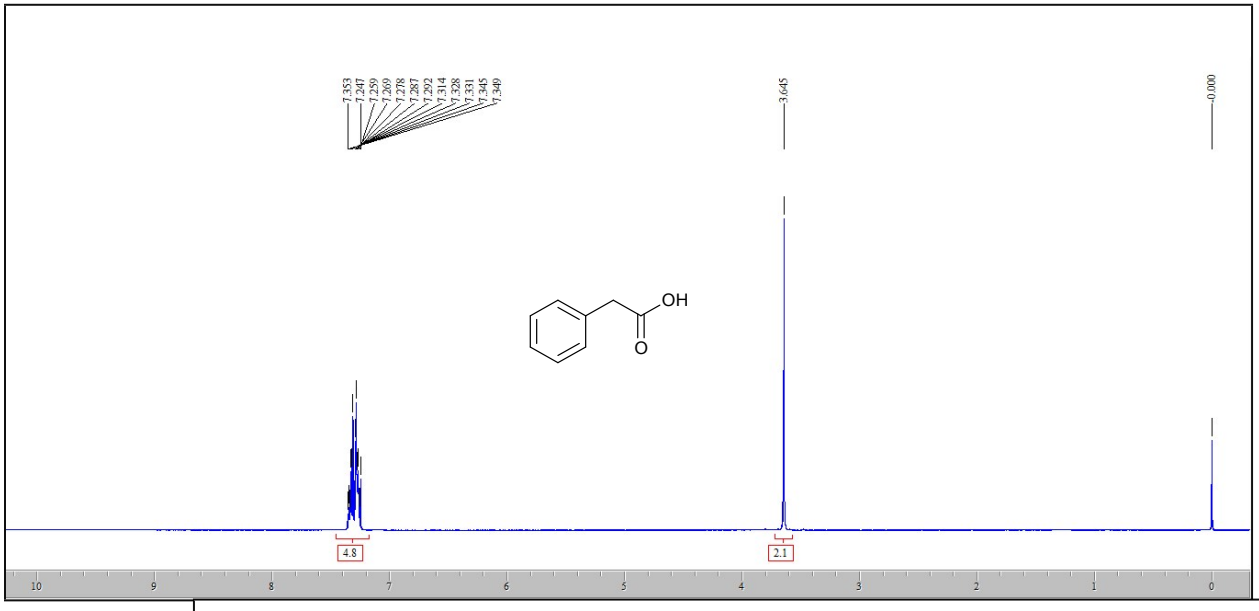
^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 72.33, 66.78, 33.13, 31.72, 29.28, 25.48, 22.56, 14.03.

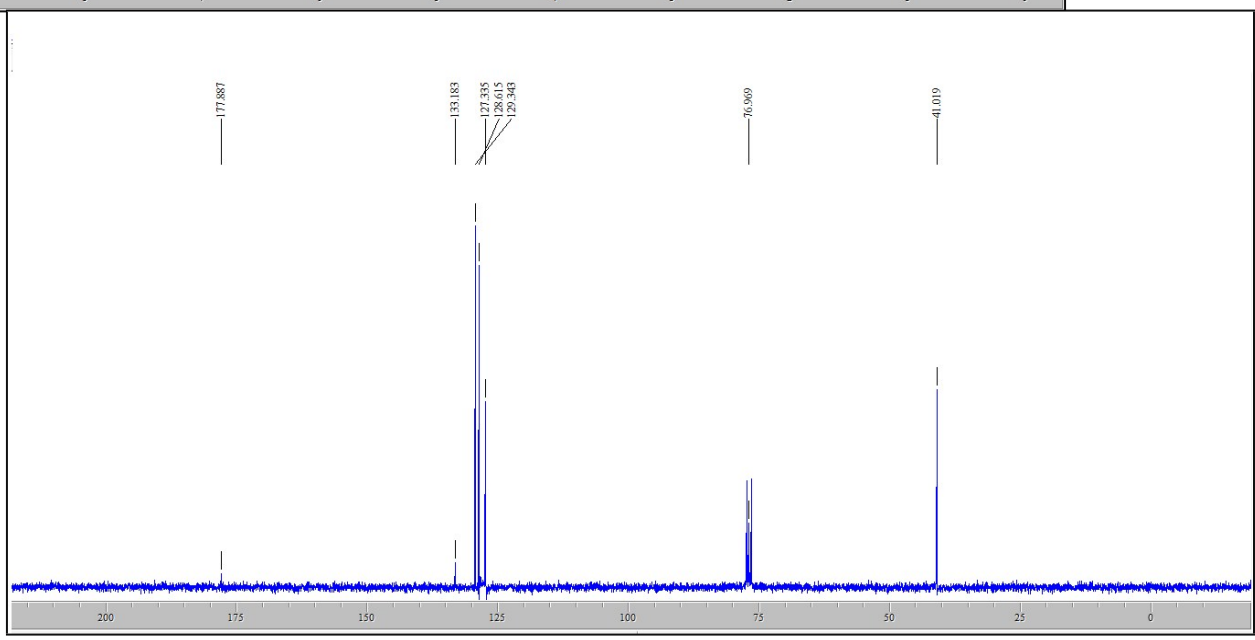
Octane-2,3-diol (2s)[16a,b]

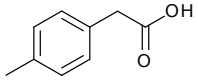
^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 3.75-3.85 (m, 1H), 3.60-3.65 (m, 1H), 2.06 (s, 2H), 1.26–1.50 (m, 8H), 1.14 (d, J = 6.60 Hz, 3H), 0.89 (t, J = 6.60 Hz, 3H).

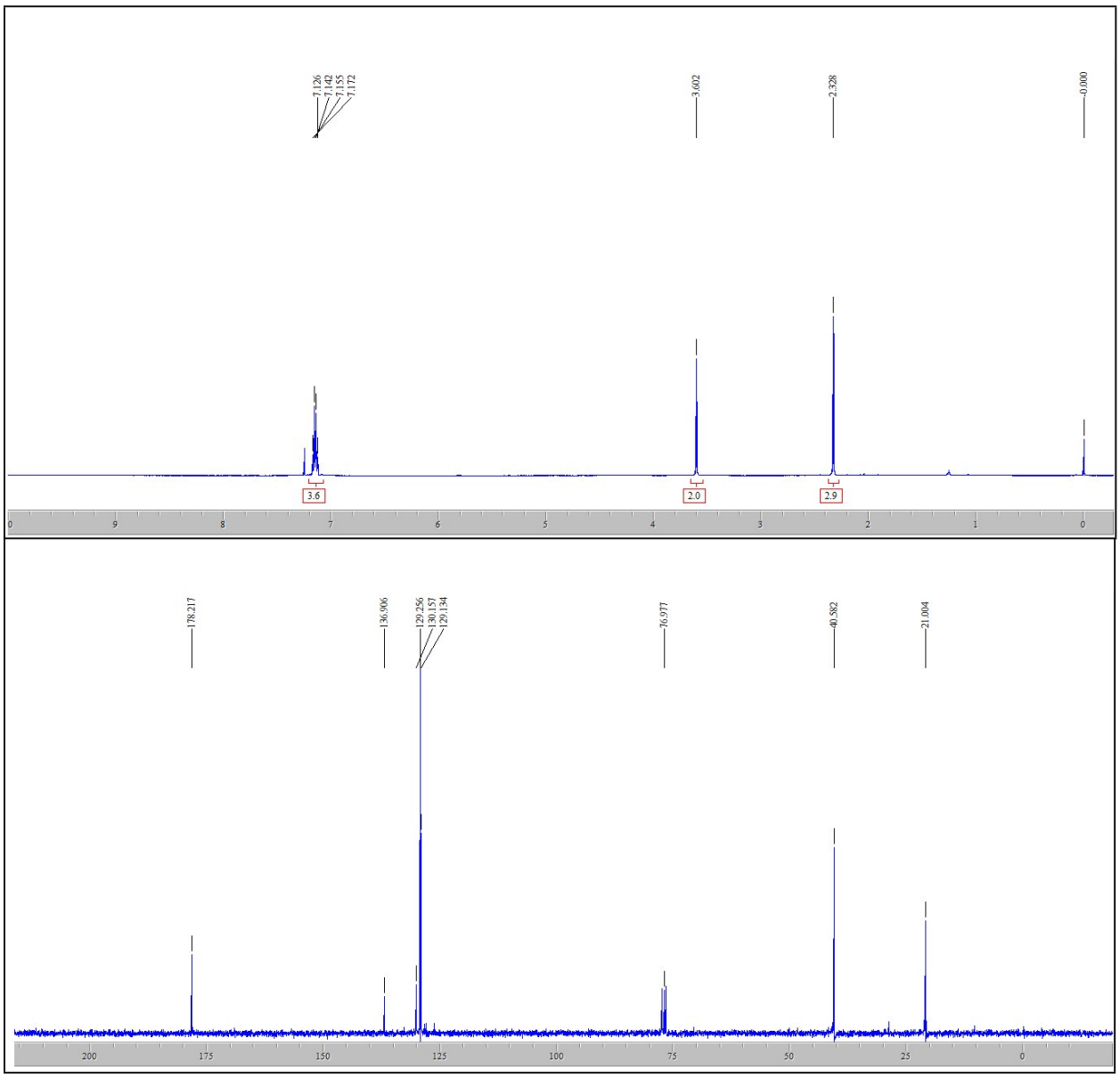
^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) = 74.90, 70.40, 31.83, 31.70, 25.67, 22.55, 16.45, 13.99.

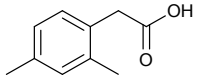
Copies of ^{1}H and ^{13}C NMR spectra:

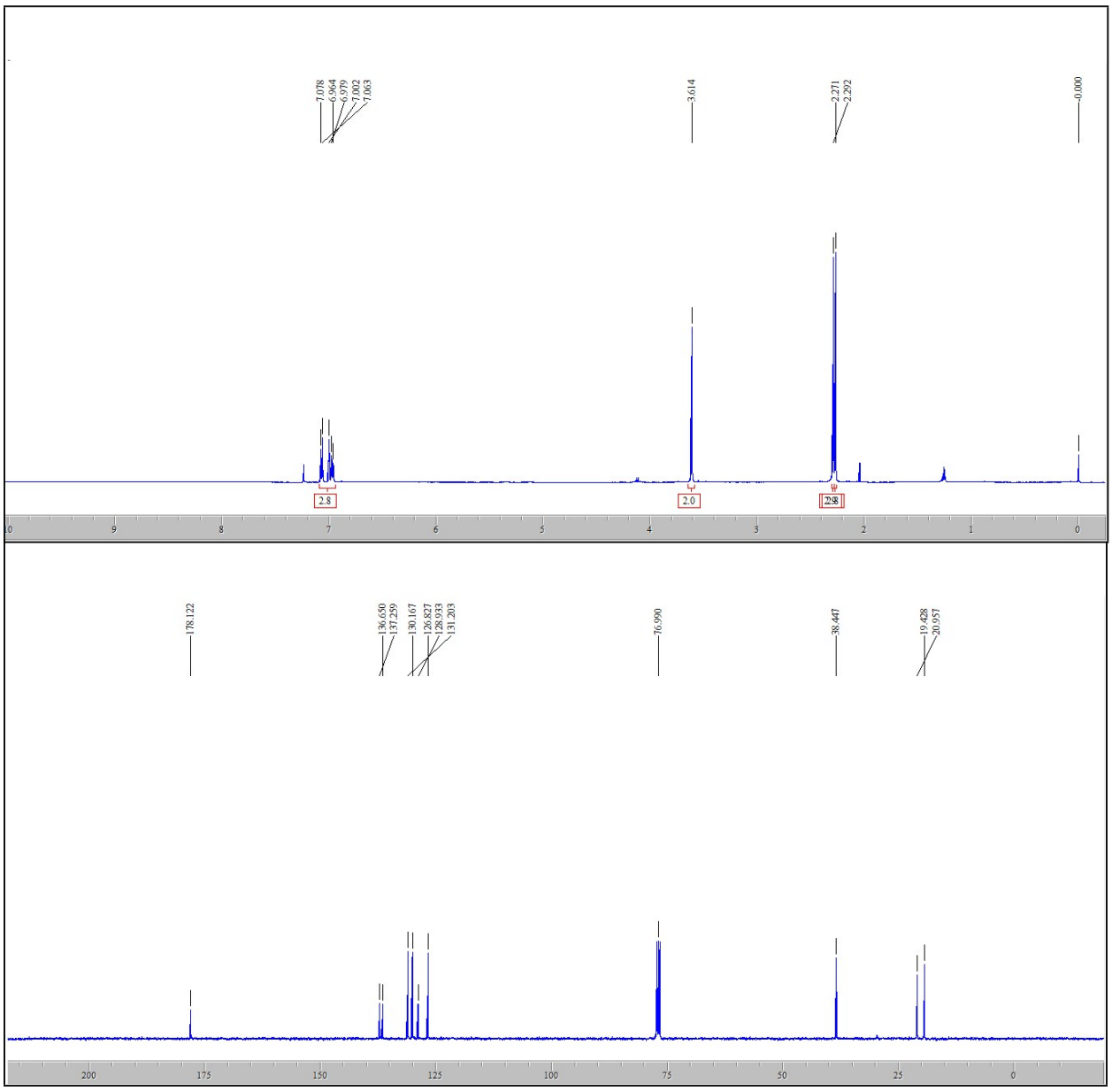


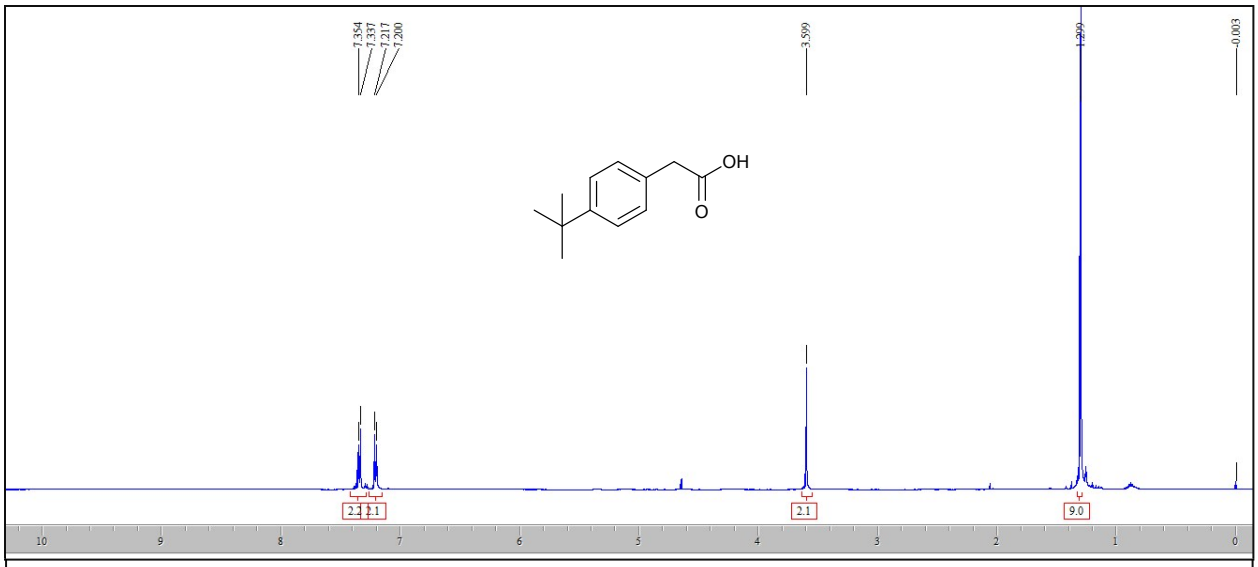


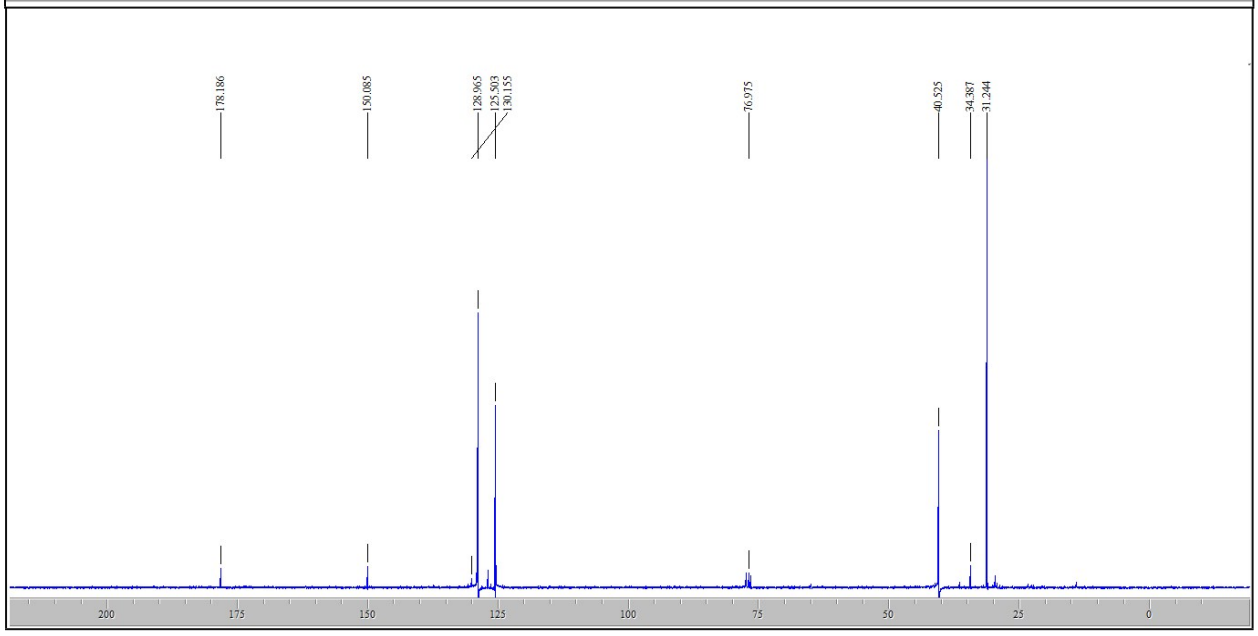


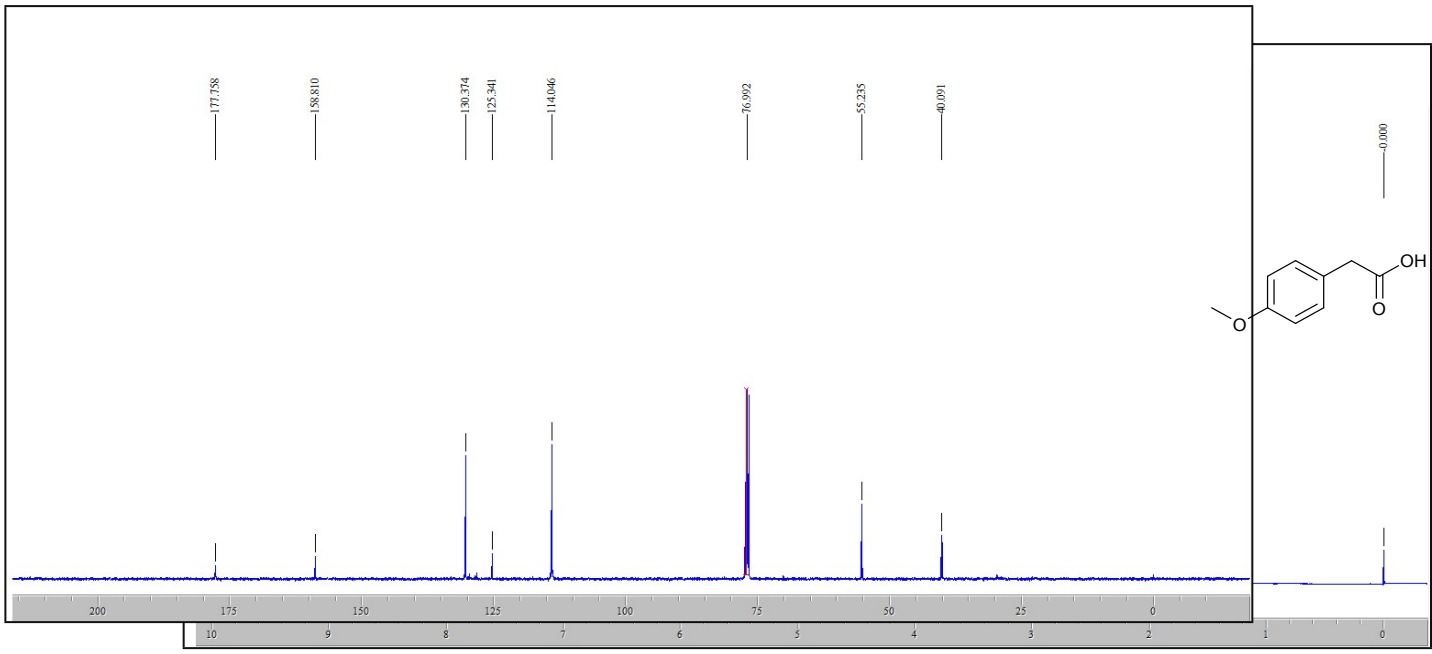

7.126
7.140
7.155
7.172
3.602
2.328
0.000
3.6
2.0
2.9
178.217
136.906
129.256
130.157
129.134
76.977
40.582
21.004

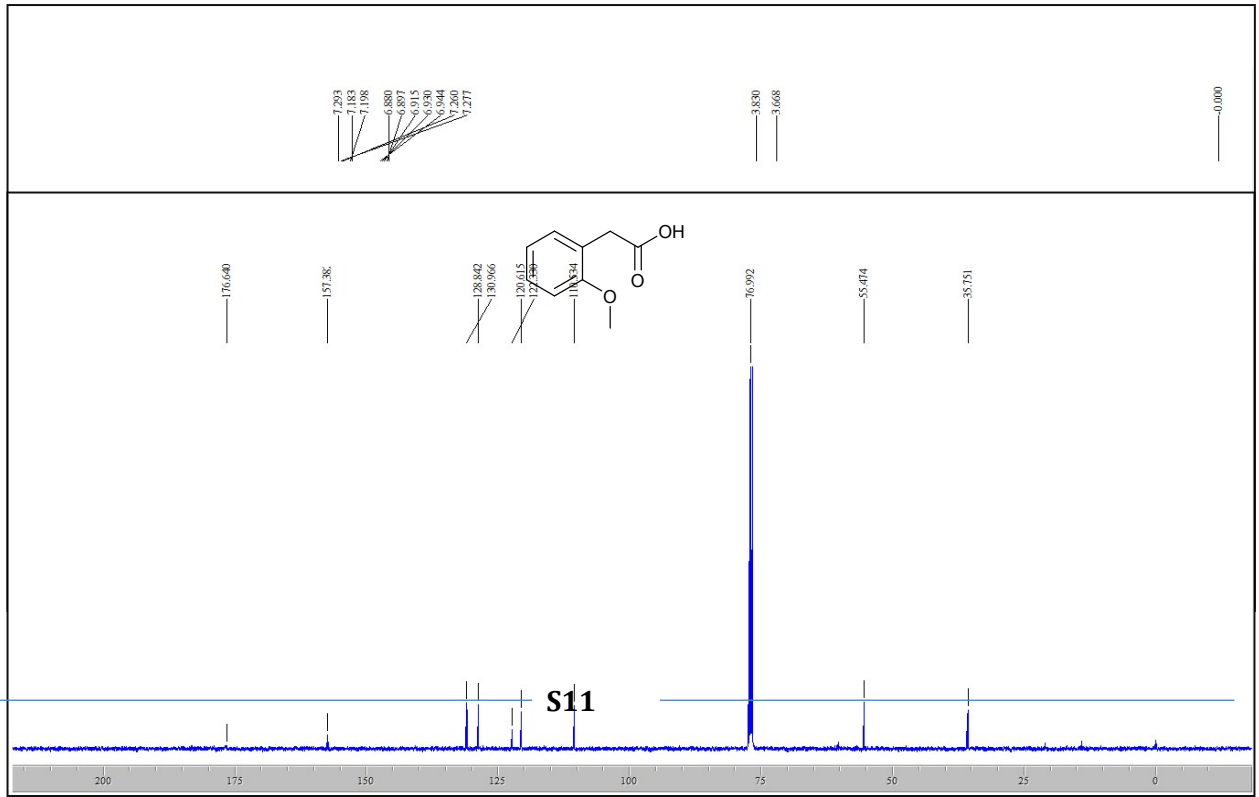

OH
O

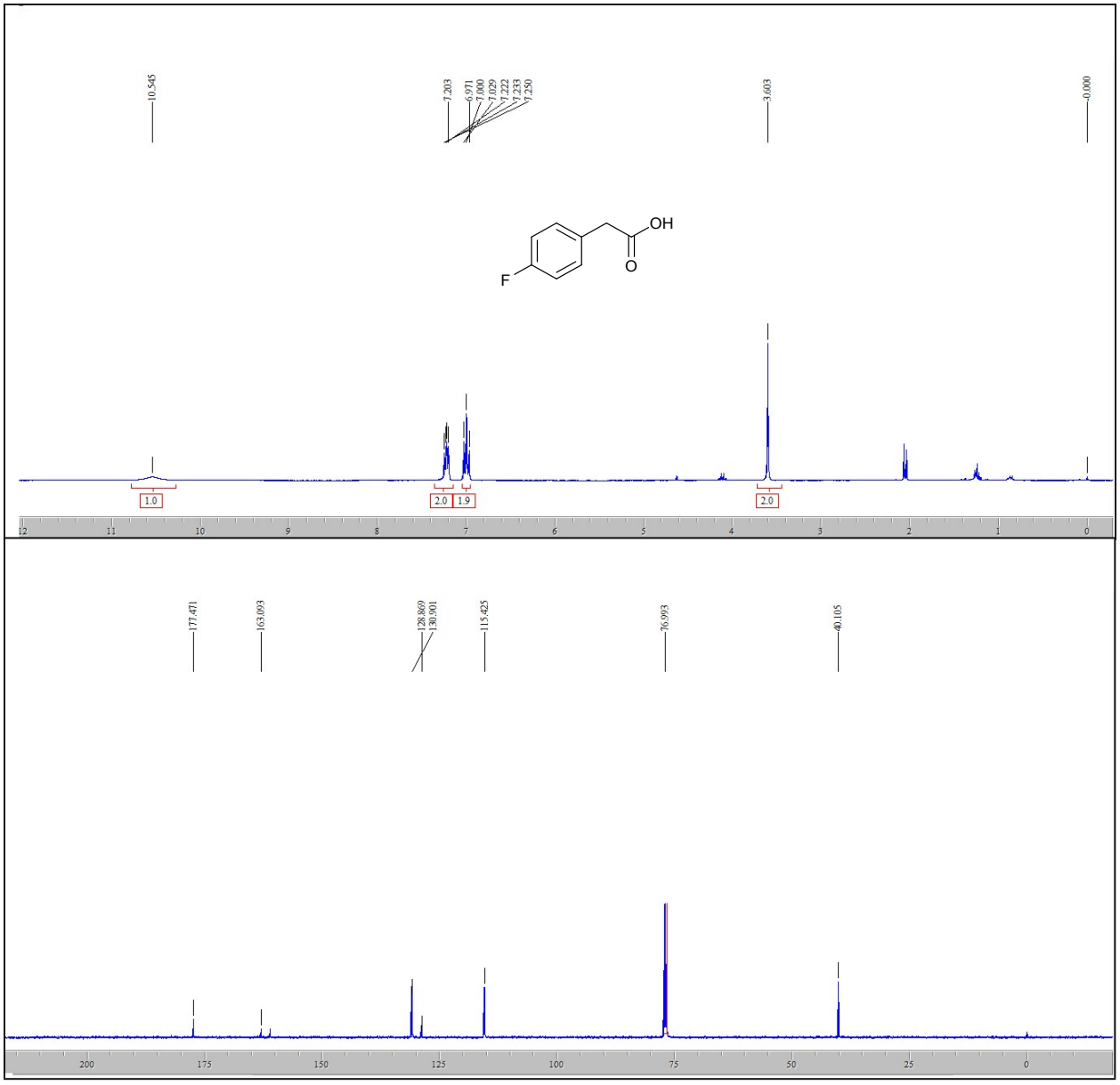

7.078
6.964
6.979
7.002
7.063
3.614
2.271
2.292
0.000
2.8
2.0
2.98
10
9
8
7
6
5
4
3
2
1
0
178.122
136.650
137.259
130.167
126.827
128.933
131.203
76.990
38.447
19.428
20.957
200
175
150
125
100
75
50
25
0

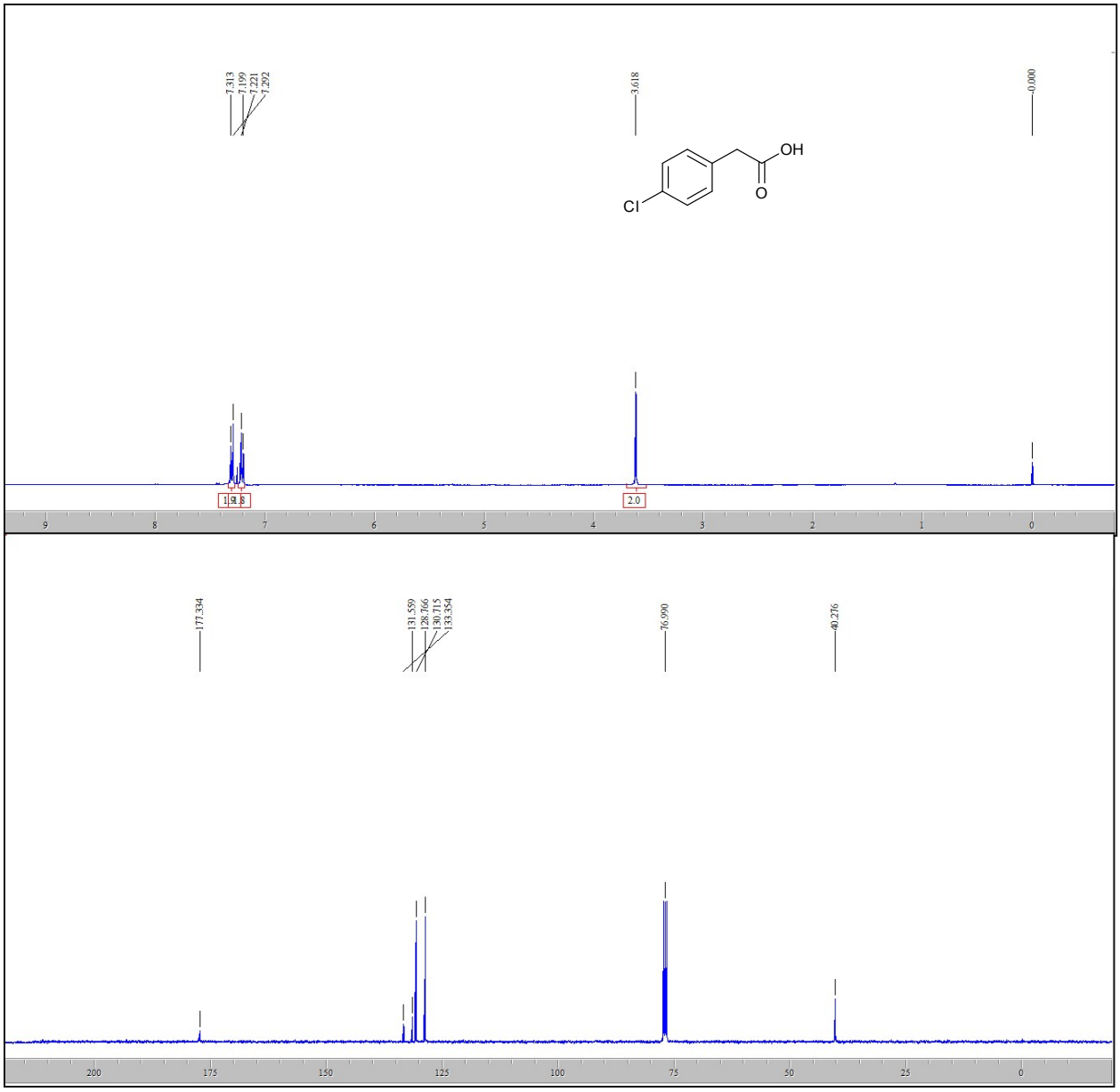

7.354
7.337
7.217
7.200
3.599
1.299
0.003
OH
O
2.2
2.1
2.1
9.0
10
9
8
7
6
5
4
3
2
1
0

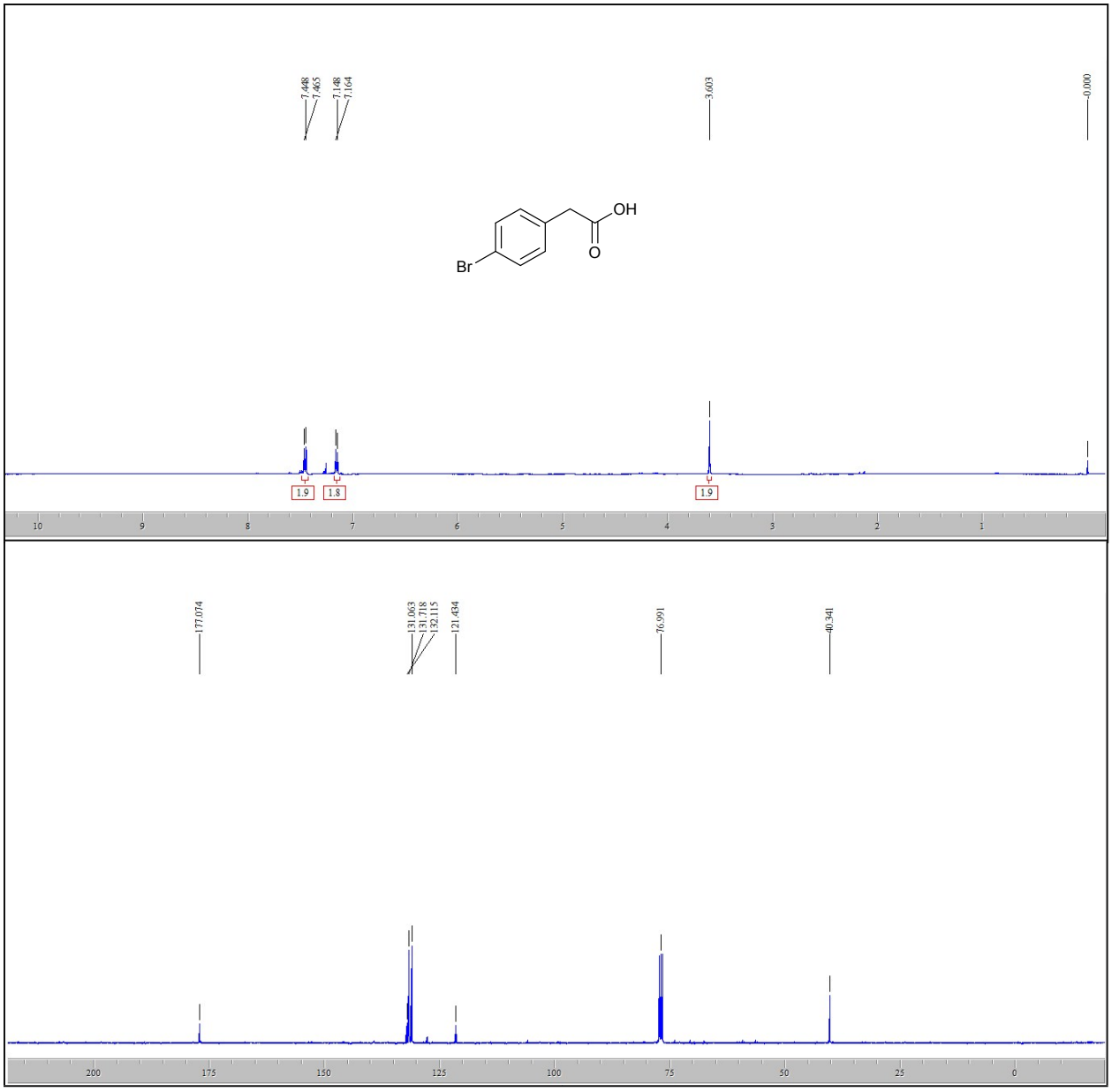

178.186
150.085
128.965
125.503
130.155
76.975
40.525
34.387
31.244
200
175
150
125
100
75
50
25
0

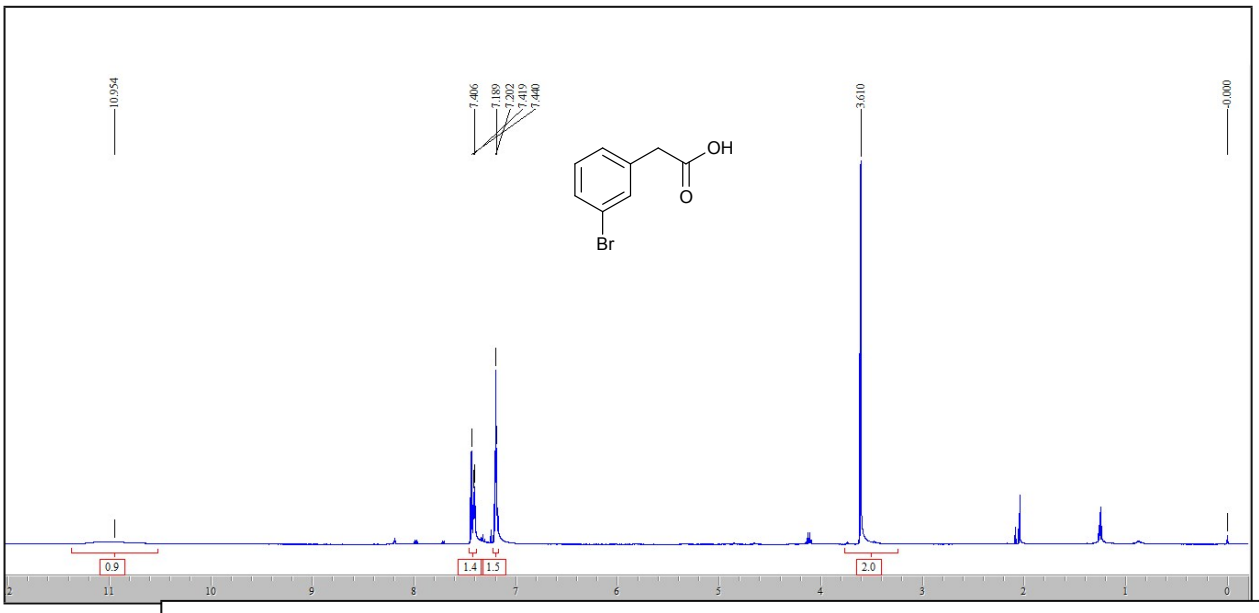

177.758
158.810
130.374
125.341
114.046
76.992
55.235
40.091
0.000
OH
O
O

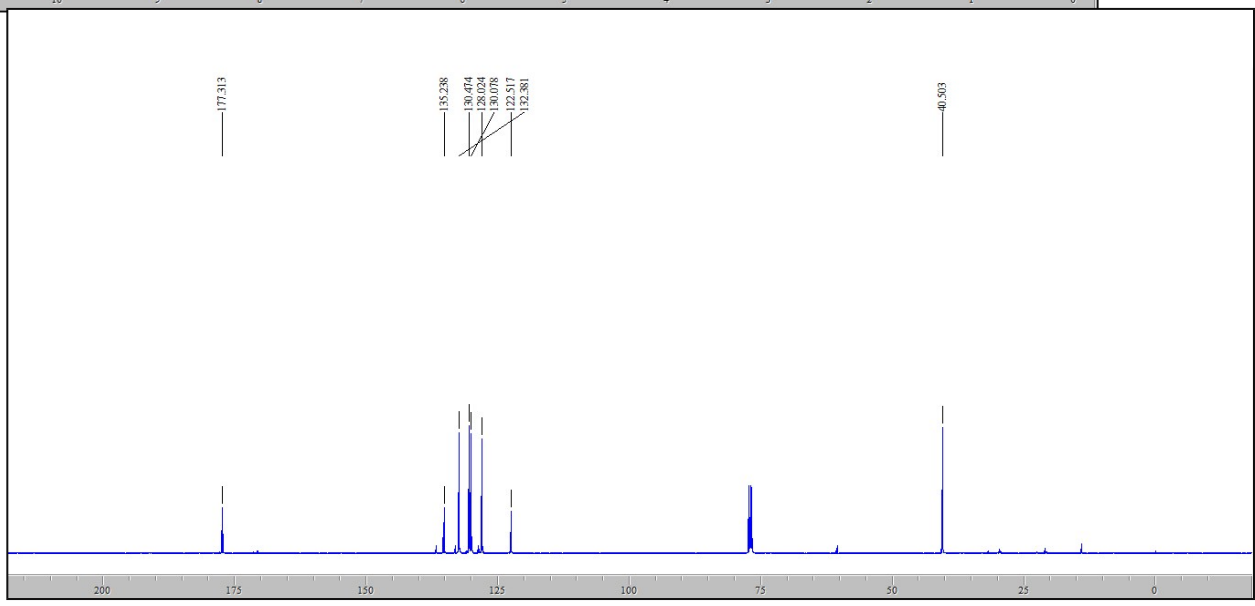

7.293
7.183
7.198
6.880
6.897
6.915
6.930
6.944
7.260
7.277
3.830
3.668
0.000
OH
O
O
176.640
157.382
128.842
130.966
120.615
114.734
76.992
55.474
35.751

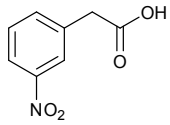

10.545
7.203
6.971
7.000
7.029
7.222
7.233
7.250
3.603
0.000
OH
O
F
1.0
2.0
1.9
2.0
177.471
163.093
128.869
130.901
115.425
76.993
40.105

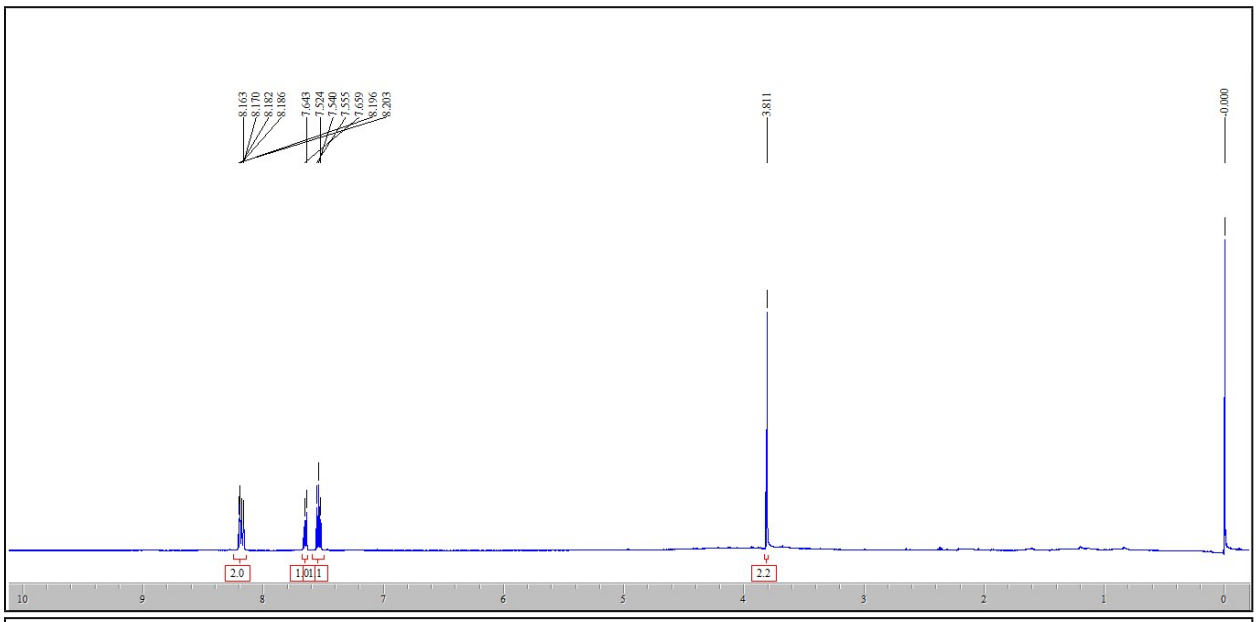

7.313
7.309
7.221
7.292
3.618
0.000
OH
O
Cl
2.0
9
8
7
6
5
4
3
2
1
0
177.334
131.559
128.766
130.715
133.354
76.990
40.276
200
175
150
125
100
75
50
25
0

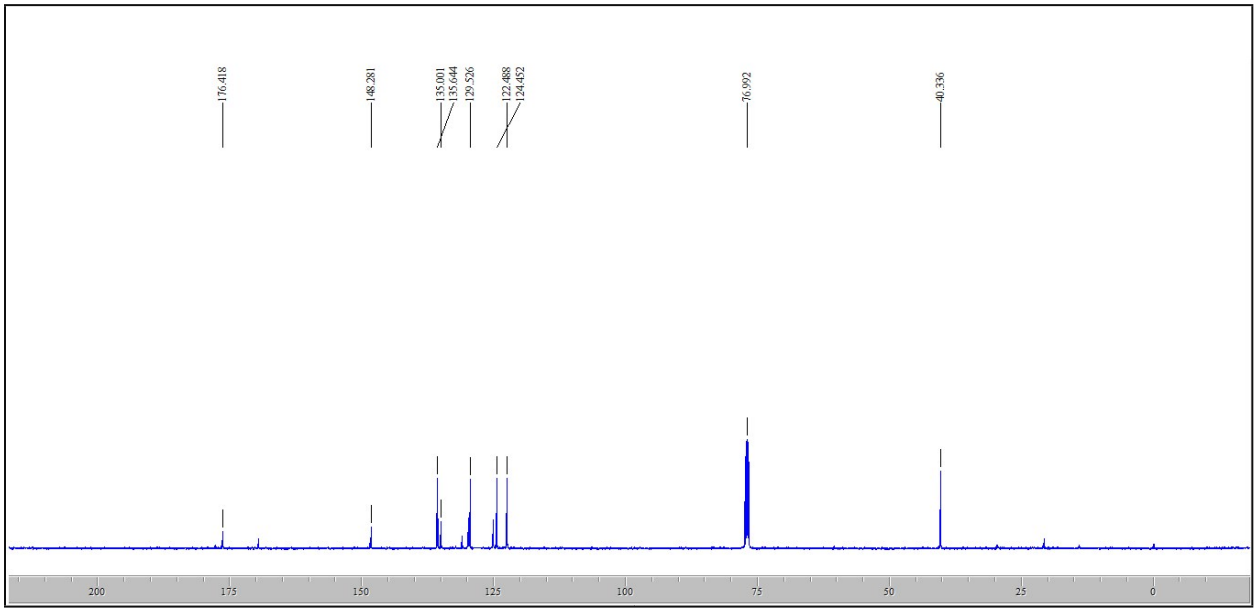

7.448
7.465
7.148
7.164
3.603
0.000
OH
O
Br
1.9
1.8
1.9
177.074
131.063
131.718
132.115
121.434
76.991
40.341

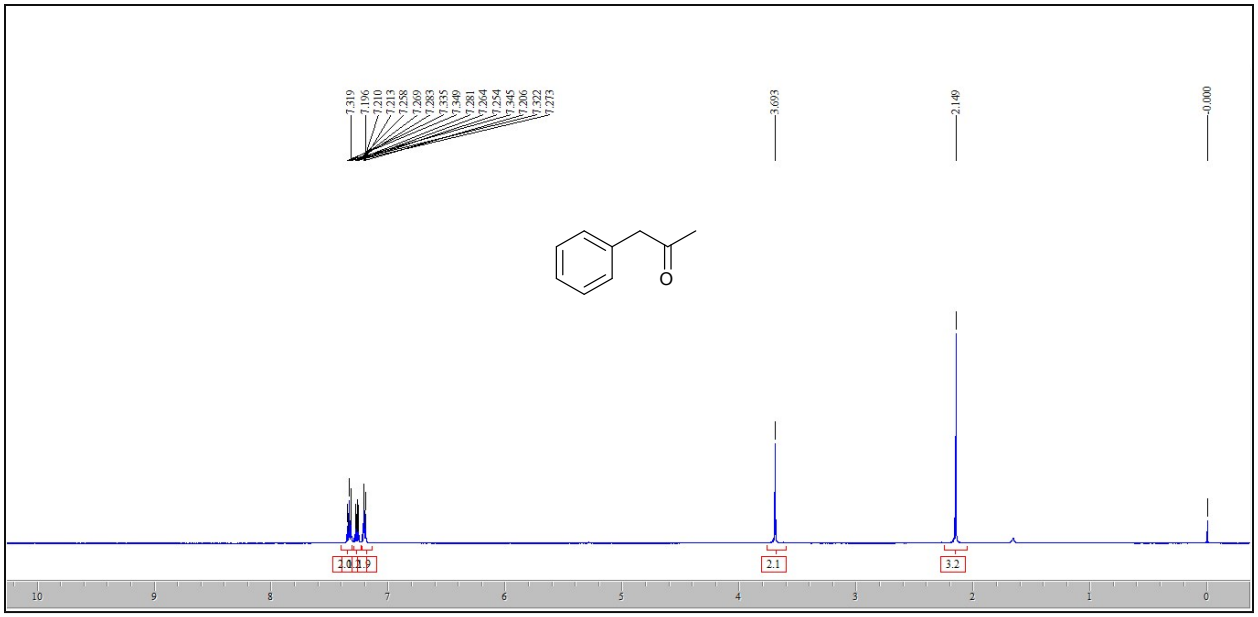

10.954
7.406
7.189
7.202
7.419
7.440
3.610
0.000
OH
O
Br
0.9
1.4
1.5
2.0

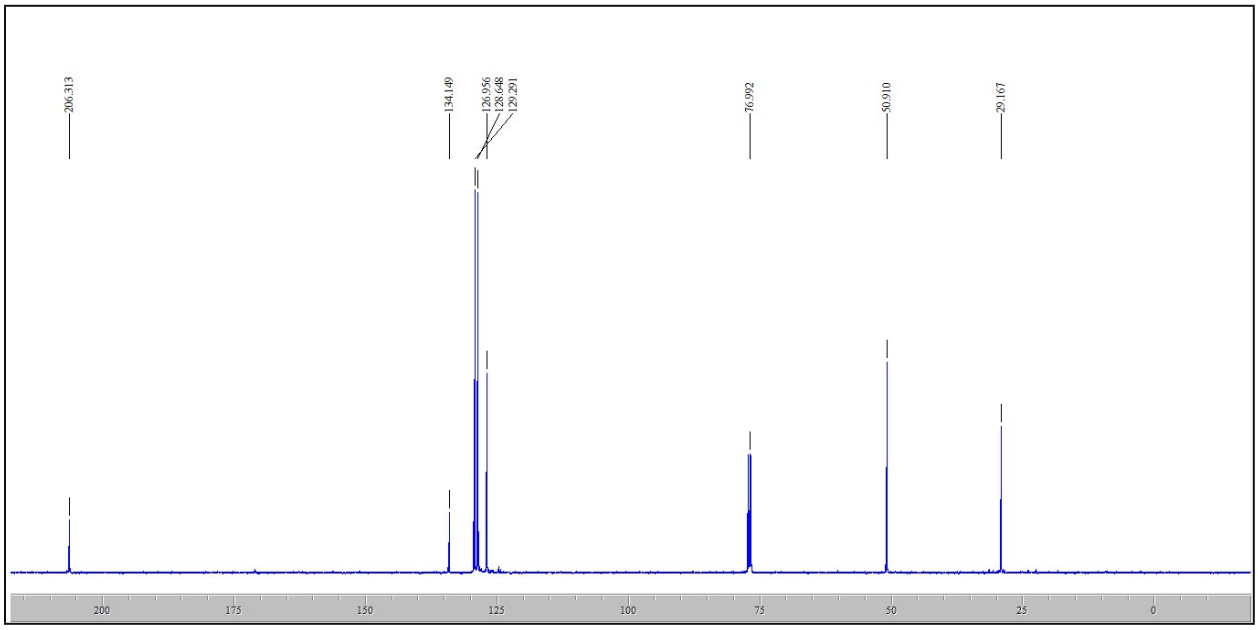

177.313
135.238
130.474
128.024
130.078
122.517
132.381
40.503

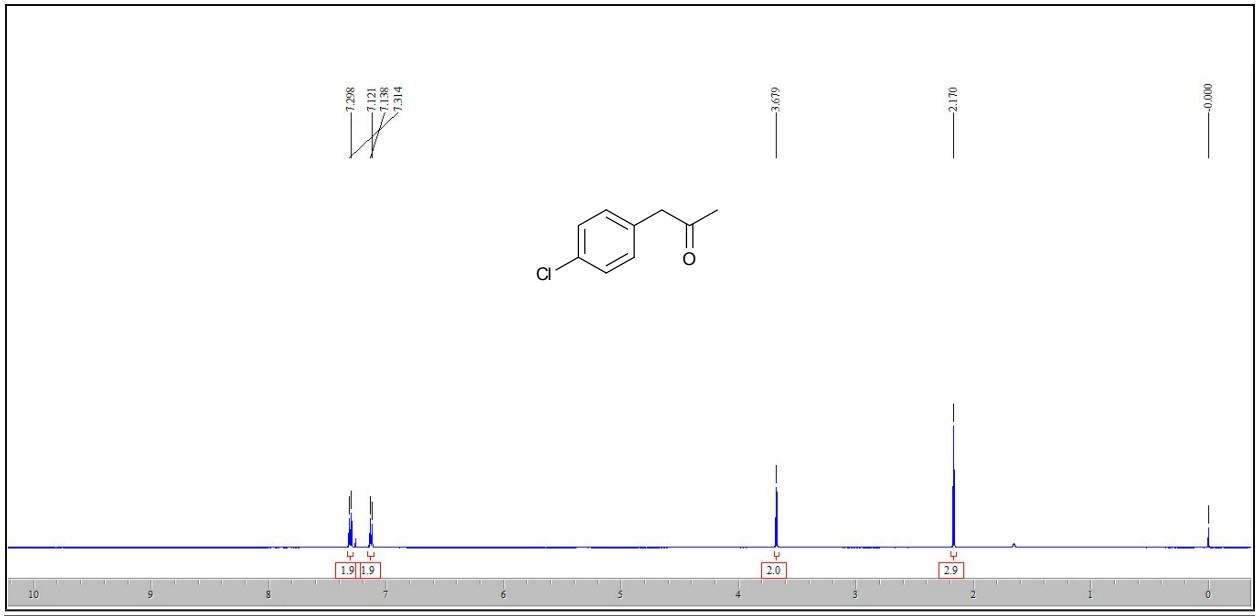

OH
O
NO2

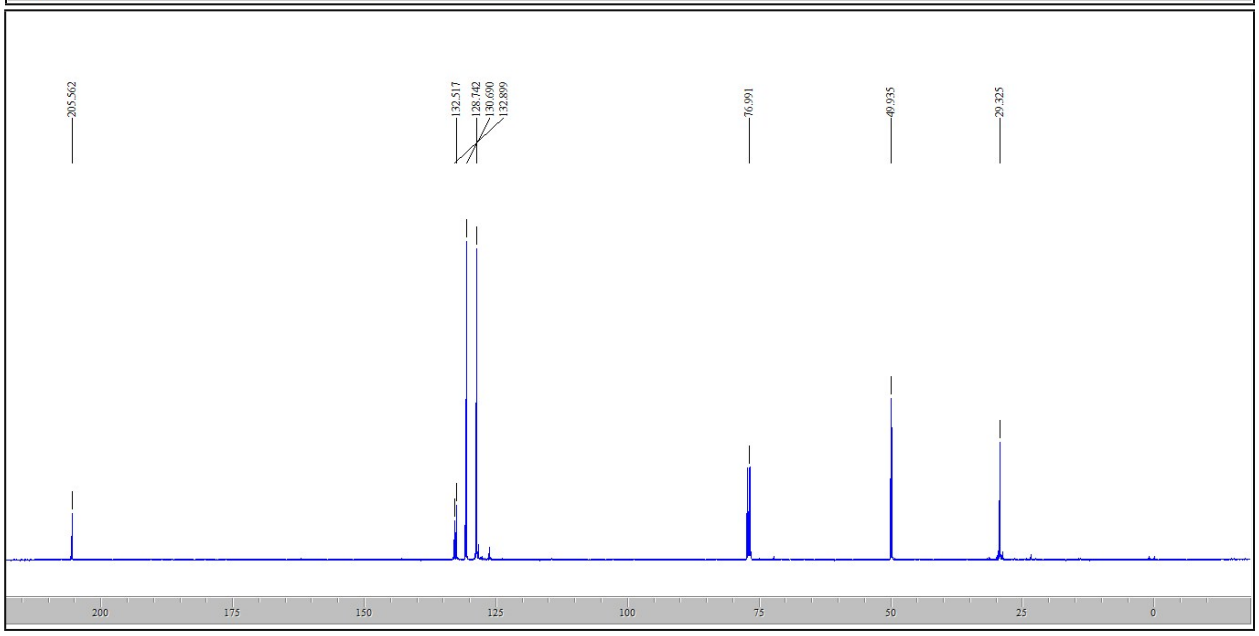

8.163
8.170
8.182
8.186
7.643
7.524
7.540
7.555
7.659
8.196
8.203
3.811
0.000
2.0
1.01
1
2.2
10
9
8
7
6
5
4
3
2
1
0

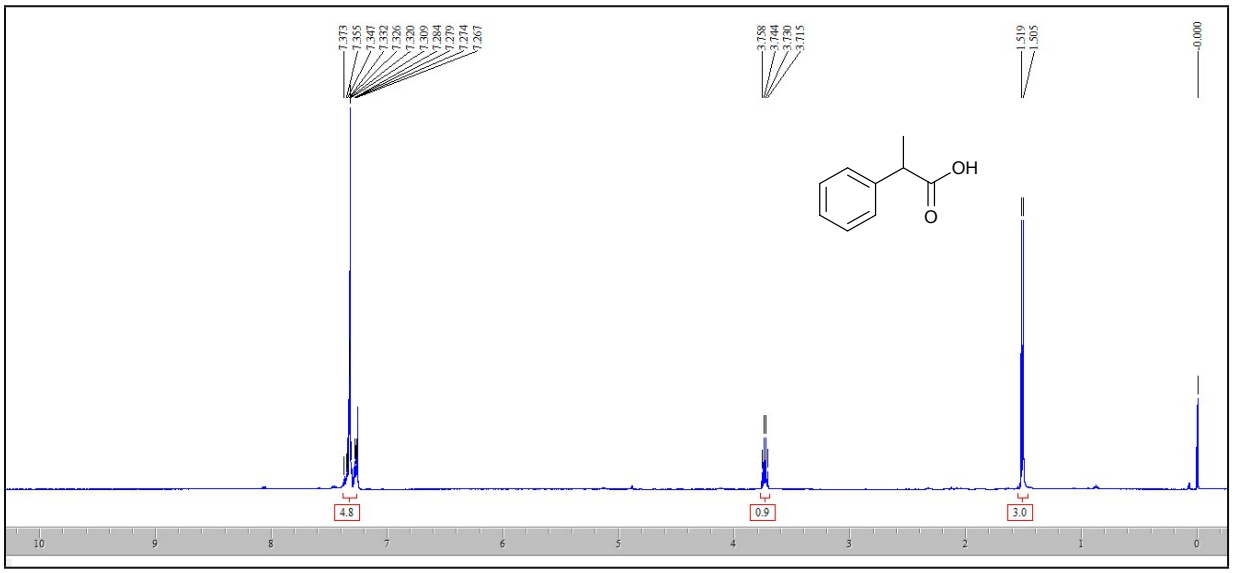

176.418
148.281
135.001
135.644
129.526
122.488
124.452
76.992
40.336
200
175
150
125
100
75
50
25
0

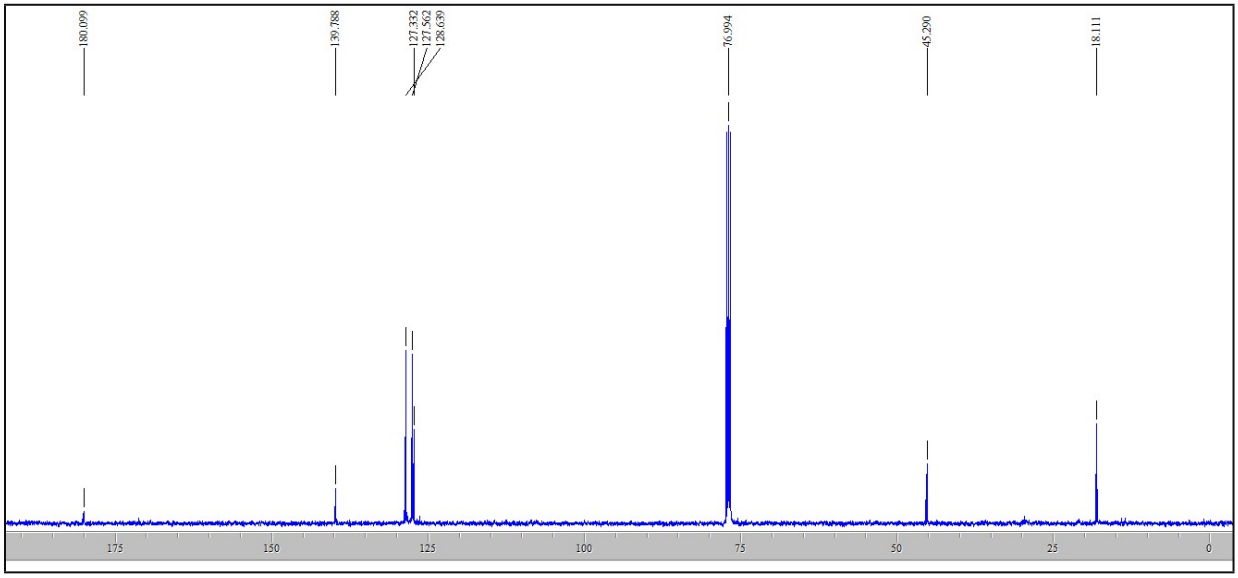

7.319
7.196
7.210
7.213
7.258
7.269
7.283
7.335
7.340
7.281
7.264
7.254
7.345
7.296
7.322
7.273
3.693
2.149
0.000
O
2.1
3.2
10
9
8
7
6
5
4
3
2
1
0

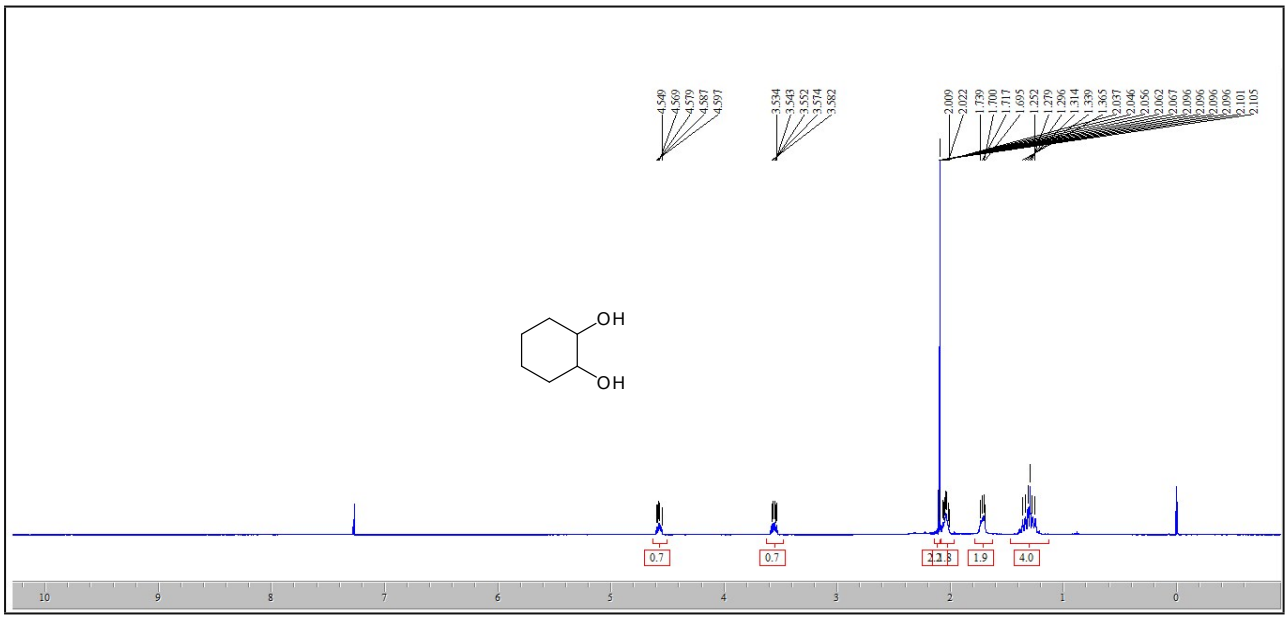

206.313
134.149
126.956
128.648
129.291
76.992
50.910
29.167
200
175
150
125
100
75
50
25
0

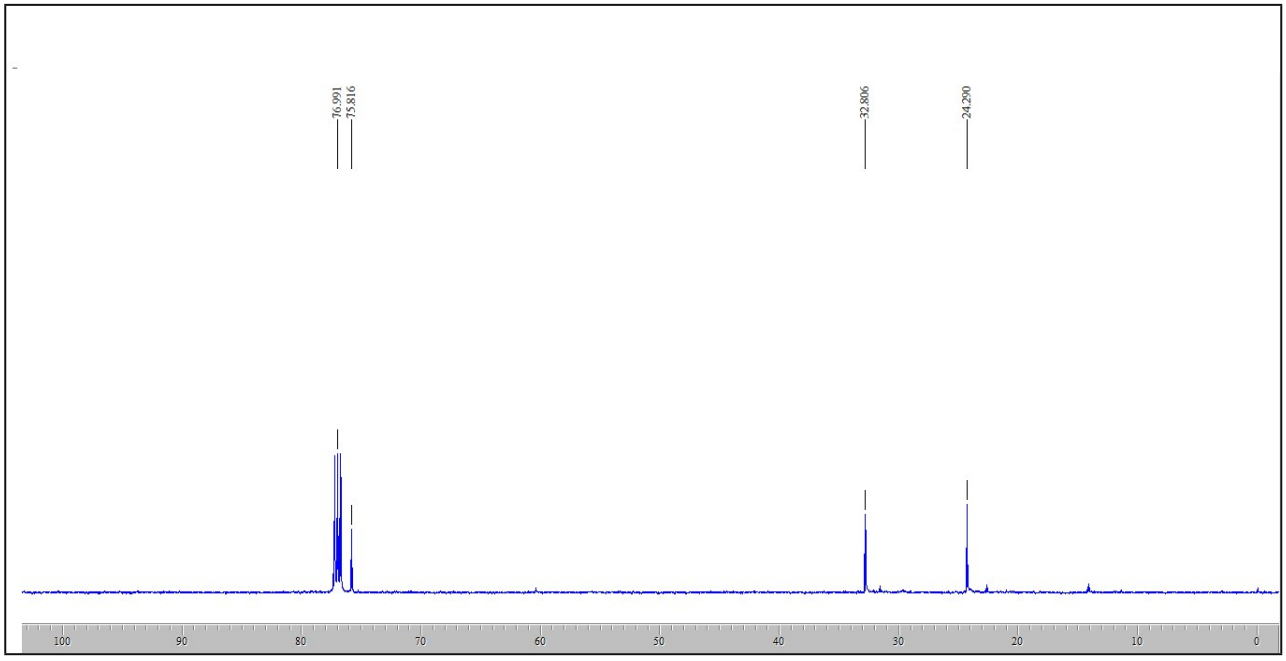

7.298
7.121
7.138
7.314
3.679
2.170
0.000
Cl
O
1.9
1.9
2.0
2.9
10
9
8
7
6
5
4
3
2
1
0

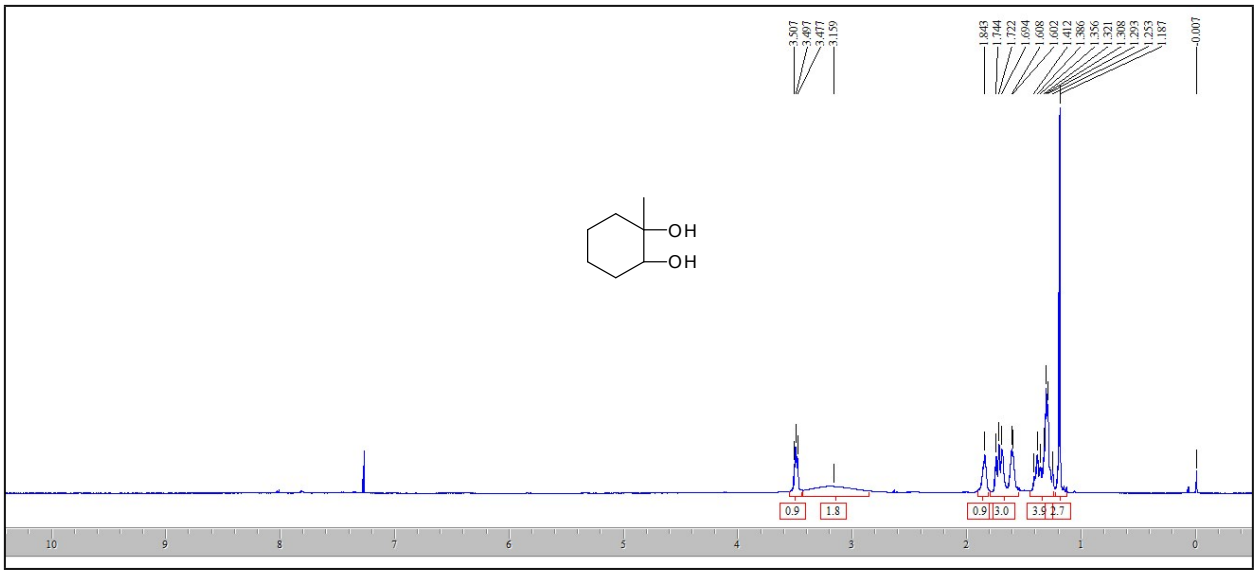

205.562
132.517
128.742
130.690
132.899
76.991
49.935
29.325
200
175
150
125
100
75
50
25
0

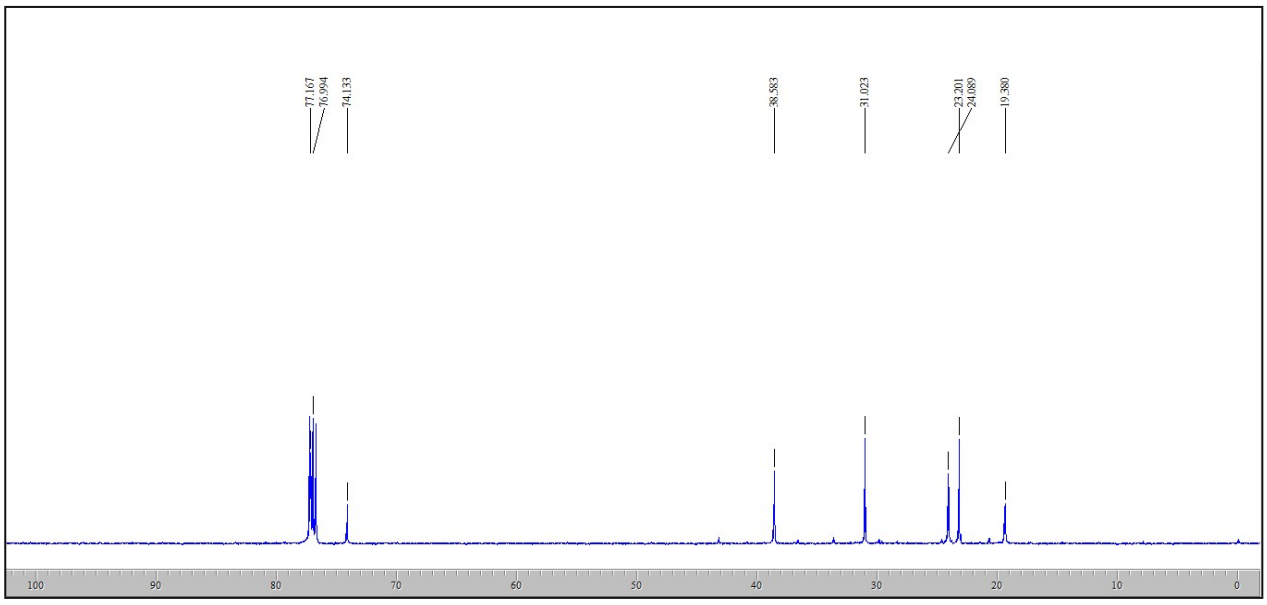

7.373
7.355
7.347
7.332
7.326
7.320
7.300
7.284
7.279
7.274
7.267
3.758
3.744
3.730
3.715
1.519
1.505
0.000
OH
O
4.8
0.9
3.0
10
9
8
7
6
5
4
3
2
1
0

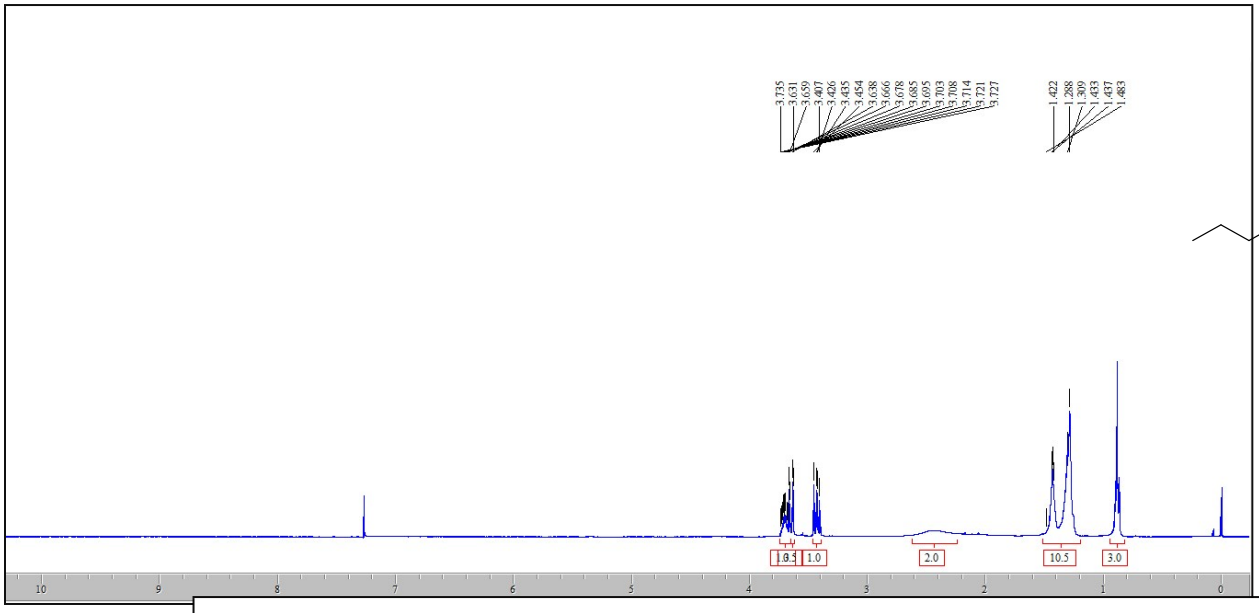

180.099
139.788
127.332
127.562
128.699
76.994
45.290
18.111
175
150
125
100
75
50
25
0

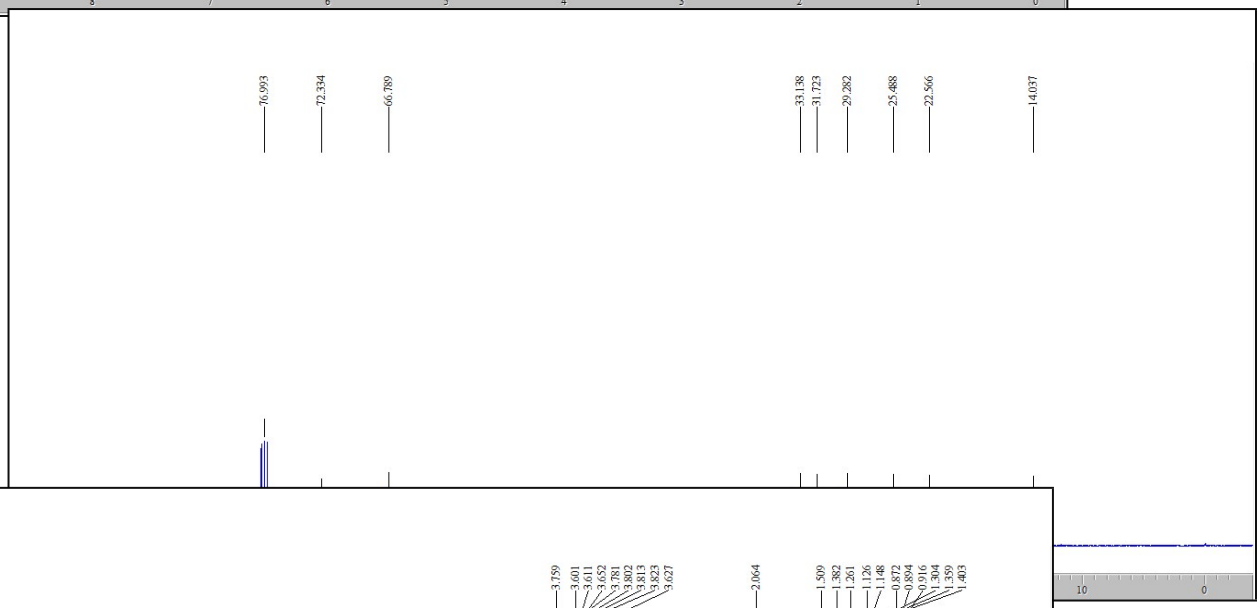

4.549
4.569
4.579
4.587
4.597
3.534
3.543
3.552
3.574
3.582
2.009
2.022
1.739
1.700
1.717
1.695
1.252
1.279
1.296
1.314
1.339
1.365
1.037
1.046
2.056
2.062
2.067
2.096
2.096
2.096
2.096
2.101
2.105
OH
OH
0.7
0.7
1.9
4.0
10
9
8
7
6
5
4
3
2
1
0

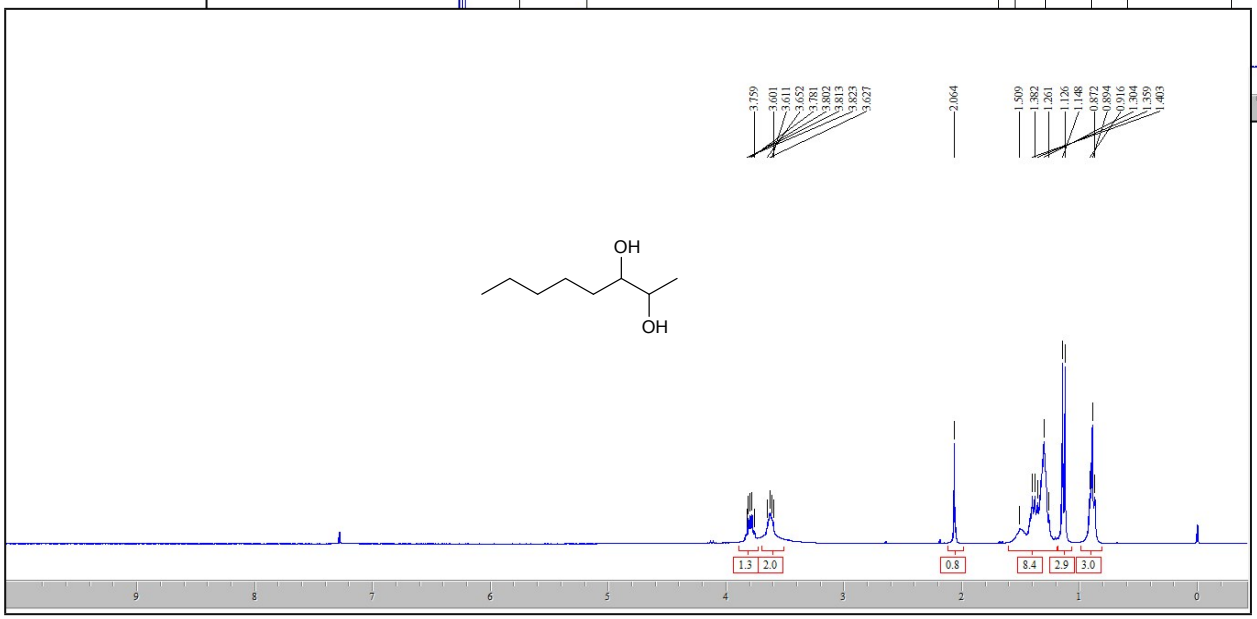

76.991
75.816
32.806
24.290
100
90
80
70
60
50
40
30
20
10
0

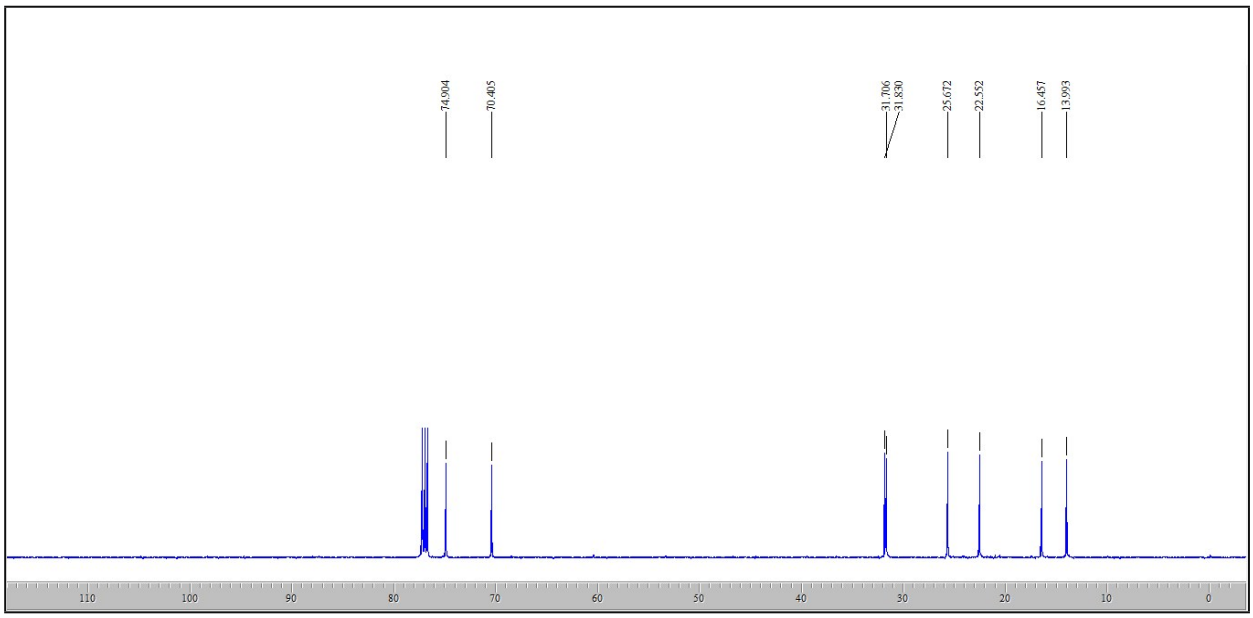

3.507
3.497
3.477
3.159
1.843
1.744
1.722
1.694
1.608
1.602
1.412
1.386
1.356
1.321
1.308
1.293
1.253
1.187
0.007
OH
OH
0.9
1.8
0.9
3.0
3.9
2.7
10
9
8
7
6
5
4
3
2
1
0


77.167
76.994
74.133
38.583
31.023
23.201
24.089
19.380
100
90
80
70
60
50
40
30
20
10
0


3.735
3.631
3.659
3.407
3.406
3.435
3.454
3.638
3.666
3.678
3.685
3.695
3.703
3.708
3.714
3.721
3.727
1.422
1.288
1.309
1.433
1.437
1.483
OH
OH
1.0
1.0
2.0
10.5
3.0


76.993
72.334
66.789
33.138
31.723
29.282
25.488
22.566
14.037


3.759
3.601
3.611
3.652
3.781
3.802
3.813
3.823
3.627
2.064
1.509
1.382
1.261
1.126
1.148
0.872
0.894
0.916
1.304
1.359
1.403
OH
OH
1.3
2.0
0.8
8.4
2.9
3.0



Notes and references

1 T. León, A. Correa and R. Martin, *J. Am. Chem. Soc.,* 2013, **135***,* 1221.

2 M. She, D. Xiao, B. Yin, Z. Yang, P. Liu, J. Li and Z. Shi, *Tetrahedron,* 2013, **69**, 7264.

3 A. A. Ibragimov and S. Yu. Yunusov, *Chem. Nat. Compd*., 1985, **21**, 502.

4 S. Kamijo, Y. Amaoka and M. Inoue, *Synthesis*, 2010, 2475.

5 P. Fleming and D. F. O'Shea, *J. Am. Chem. Soc.,* 2011, **133**, 1698.

6 M. She, D. Xiao, B. Yin, Z. Yang, P. Liu, J. Li and Z. Shi, *Tetrahedron,* 2013, **69**, 7264.

7 J. E. Milne, J. A. Murry, A. King and R. D. Larsen, *J. Org. Chem*., 2009, **74**, 445.

8 J. E. Milne, T. Storz, J. T. Colyer, O. R. Thiel, M. D. Seran , R. D. Larsen and J. A. Murry, *J. Org. Chem*., 2011, **76**, 9519.

9 (a) J. McNulty and P. Das, *Tetrahedron*, 2009, **65**, 7794; (b) P. Strazzolini, G. Verado, F. Gorassini and A. G. Giumanini, *Bull. Chem. Soc. Jpn.*, 1995, **68**, 1157.

10 Y. F. Wang, Y. R. Gao, S. Mao, Y. L. Zhang, D. D. Guo, Z. L. Yan, S. H. Guo and Y. Q. Wang, *Org. Lett.,* 2014, **16**, 1610.

11 Z. Duo, J. Yongwen and M. Dawei, *Tetrahedron,* 2014, **70**, 3327.

12 (a) J. J. R. Frew, K. Damian, H. Van Rensburg, A. M. Z. Slawin, R. P. Tooze and M. L. Clarke, *Chem. Eur. J*., 2009, **15**, 10504. (b) M. D. Greenhalgh and S. P. Thomas, *J. Am. Chem. Soc.* 2012, **134**, 11900.

13 Y. Liu, M. Wang, W. Ren, Y, Xu and X. B. Lu, *Angew. Chem. Int. Ed.*, 2015, **54**, 7042.

14 B. Balagam, R. Mitra and D. E. Richardson, *Tetrahedron Lett*., 2008, **49**, 1071.

15 B. Plietker, M. Niggemann and A. Pollrich, *Org. Biomol. Chem*. 2004, **2**, 1116.

16 (a) W. Kroutil, M. Mischitz and K. Faber, *J. Chem. Soc., Perkin Trans. 1.*, 1997**,** 3629; (b) A. Closson, M. Johansson and J. E. Bäckvall, *Chem. Commun***.,** 2004, 1494.