Supplementary Information

Iodine-Catalyzed C-H/S-H Oxidative Coupling: from 1,3-Diketones and Thiophenols to β-Dicarbonyl Thioethers

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General Information

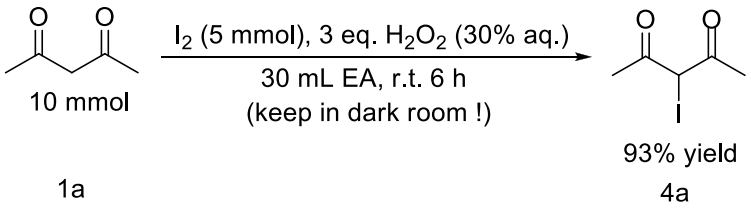
All reactions were isolated from oxygen by a nitrogen atmosphere in a sealed Schlenk tube. All glassware was fully dried at 110 ^{o}C in oven for hours and cooled down under vacuum. Diketones, iodine, ethyl acetate and DTBP (Di-*tert*-butyl peroxide, Chemical Purity) were all purchased from Sinopharm Chemical Reagent Co., Ltd. All thiophenols were purchased from Tianjin Heowns Biochem. Co., Ltd. Unless otherwise noted, other materials were obtained from commercial suppliers and used without further purification. Thin layer chromatography (TLC) employed glass 0.25 mm silica gel plates. Chromatography columns were packed with 200-300 mesh silica gel in petroleum ether (bp. 60-90 ^{o}C). Gas chromatographic analyses were performed on Varian GC 2000 gas chromatography instrument with a FID detector. GC-MS spectra were recorded on a Varian GC-MS 3900-2100T. ^{1}H, ^{13}C and ^{19}F NMR data were recorded with Bruker ADVANCE III (400 MHz) spectrometers with tetramethylsilane as an internal standard. High resolution mass spectra (HRMS) were measured with a Waters Micromass GCT instrument with ionisation mode of EI^{+}, accurate masses are reported for the molecular ion ([M]+). All chemical shifts (δ) are reported in ppm and coupling constants (*J*) in Hz. All chemical shifts are reported relative to tetramethylsilane (0 ppm) and *d*-solvent peaks (77.3 ppm, chloroform), respectively.

General Procedure

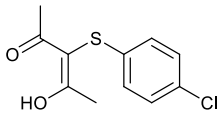
A sealed Schlenk tube was firsted fulled dried under vacuum and then filled with N_2. Under the protection of N_2, diketone (0.45 mmol), thiophenol (0.3 mmol), *t*-BuOO*t*-Bu (131.4 mg, 0.9 mmol) and ethyl acetate (2 mL) were then injected into the tube by syringes (or by spoon if thiophenol is solid). After stirring for several minutes, iodine (7.6 mg, 0.03 mmol) was added into the reaction tube. The reaction was then heated up to 120 ^oC (**Warning:** boiling point of ethly acetate is only 80 ^oC. So this reaction is of potential danger, please do this reaction in highly qualified sealed Schlenk tube and put the heater in fume hood!) and kept stirring for 6 hours. After completion of the reaction, the mixture was cooled to R.T. and then quenched sodium sulfite solution. The solution was extracted with ethyl acetate (3 × 5 mL). The organic layers were combined and dried over sodium sulfate. The pure product was obtained by flash column chromatography on silica gel (with petroleum ether : dichloromethane = 3 : 1).

Control experiments from 1a to 4a

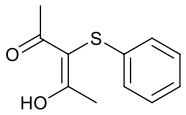
As 4a intermediate is not stable at 120 ^oC, we have done the stoichimetric experiment from 1a to 4a at room temperature (we used H_2O_2 instead of DTBP because DTBP decompose too slowly at r.t.). Finally, the 4a could be obtained in 93% yield, which matched well with our mechanism.



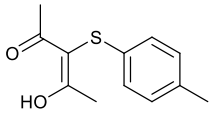
Detailed Descriptions for Products



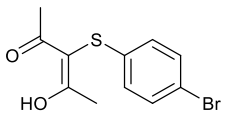
3-(4-chlorophenylthio)-4-hydroxypent-3-en-2-one (3a): Isolated yield = 85%. White solid. Melting point = 63 ^{o}C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.29 (s, 1H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.02 (d, *J* = 8.4 Hz, 2H), 2.33 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.5, 136.6, 131.3, 129.5, 126.1, 101.5, 24.6. HRMS (EI^+) calcd for $C_{11}H_{11}ClO_2S$ $[M]^+$: 242.0168; found: 242.0173.



4-hydroxy-3-(phenylthio)pent-3-en-2-one (3b): Isolated yield = 88%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.28 (s, 1H), 7.28 (m, 2H), 7.14 (m, 1H), 7.10 (m, 2H), 2.34 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.6, 138.0, 129.5, 125.5, 124.9, 101.8, 24.7. HRMS (EI^+) calcd for $C_{11}H_{12}O_2S$ $[M]^+$: 208.0558; found: 208.0562.

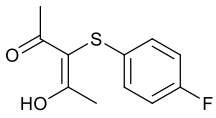


4-hydroxy-3-(p-tolylthio)pent-3-en-2-one (3c): Isolated yield = 51%. White solid. Melting point = 21 ^{o}C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.24 (s, 1H), 7.09 (d, *J* = 8.0 Hz, 2H), 6.99 (d, *J* = 8.2 Hz, 2H), 2.34 (s, 6H), 2.30 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.5, 135.3, 134.4, 130.2, 125.1, 102.3, 24.7, 21.1. HRMS (EI^+) calcd for $C_{12}H_{14}O_2S$ $[M]^+$: 222.0715; found: 222.0713.

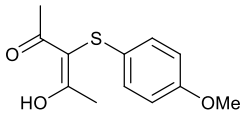


3-(4-bromophenylthio)-4-hydroxypent-3-en-2-one (3d): Isolated yield = 83%. White solid. Melting

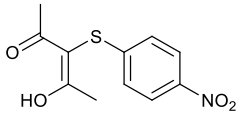
point = 87 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.30 (s, 1H), 7.39 (d, *J* = 8.2 Hz, 2H), 6.96 (d, *J* = 8.2 Hz, 2H), 2.32 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.5, 137.3, 132.4, 126.4, 119.0, 101.3, 24.6. HRMS (EI^+) calcd for $C_{11}H_{11}BrO_2S$ $[M]^+$: 285.9663; found: 285.9666.



3-(4-fluorophenylthio)-4-hydroxypent-3-en-2-one (3e): Isolated yield = 55%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.27 (s, 1H), 7.05 (d, *J* = 8.3 Hz, 2H), 7.01 (d, *J* = 8.2 Hz, 2H), 2.34 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.4, 161.3 (d, *J* = 164.6 Hz), 133.0 (d, *J* = 3.0 Hz), 126.7 (d, *J* = 8.1 Hz), 116.6 (d, *J* = 22.2 Hz), 102.4, 24.6. ^{19}F NMR (377 MHz, $CDCl_3$) δ -117.5. HRMS (EI^+) calcd for $C_{11}H_{11}FO_2S$ $[M]^+$: 226.0464; found: 226.0468.

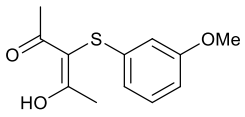


4-hydroxy-3-(4-methoxyphenylthio)pent-3-en-2-one (3f): Isolated yield = 70%. White solid. Melting point = 78 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.20 (s, 1H), 7.04 (d, *J* = 8.8 Hz, 2H), 6.84 (d, *J* = 8.8 Hz, 2H), 3.78 (s, 3H), 2.36 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.3, 158.2, 128.7, 127.2, 115.2, 103.4, 55.7, 24.8. HRMS (EI^+) calcd for $C_{12}H_{14}O_3S$ $[M]^+$: 238.0664; found: 238.0663.

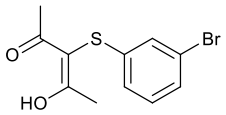


4-hydroxy-3-(4-nitrophenylthio)pent-3-en-2-one (3g): Isolated yield = 72%. White solid. Melting point = 119 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.40 (s, 1H), 8.15 (d, *J* = 8.8 Hz, 2H), 7.22 (d, *J* = 9.1 Hz, 2H), 2.33 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.6, 147.7, 145.6, 124.6, 124.4, 99.9, 24.4. HRMS (EI^+)

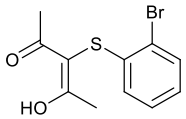
calcd for $C_{11}H_{11}NO_4S$ $[M]^+$: 253.0409; found: 253.0416.



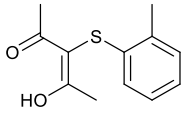
4-hydroxy-3-(3-methoxyphenylthio)pent-3-en-2-one (3h): Isolated yield = 62%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.30 (s, 1H), 7.20 (t, *J* = 8.0 Hz, 1H), 6.68 (m, 1H), 6.66 (m, 1H), 6.63 (m, 1H), 3.79 (s, 3H), 2.34 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.6, 160.5, 139.5, 130.4, 117.1, 110.7, 101.6, 55.5, 24.7. HRMS (EI^+) calcd for $C_{12}H_{14}O_3S$ $[M]^+$: 238.0664; found: 238.0666.



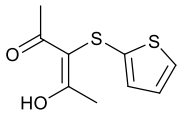
4-hydroxy-3-(3-methoxyphenylthio)pent-3-en-2-one (3i): Isolated yield = 55%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.34 (s, 1H), 7.26 (m, 1H), 7.20 (m, 1H), 7.14 (t, *J* = 7.9 Hz, 1H), 7.01 (m, 1H), 2.34 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.7, 140.5, 130.8, 128.6, 127.3, 123.7, 123.3, 101.0, 24.7. HRMS (EI^+) calcd for $C_{11}H_{11}BrO_2S[M]^+$: 285.9663; found: 285.9668.



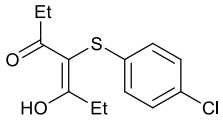
3-(2-bromophenylthio)-4-hydroxypent-3-en-2-one (3j): Isolated yield = 57%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.40 (s, 1H), 7.53 (dd, J_1 = 7.8 Hz, J_2 = 1.3 Hz, 1H), 7.24 (td, J_1 = 7.8 Hz, J_2 = 1.2 Hz, 1H), 7.01 (td, J_1 = 7.8 Hz, J_2 = 1.2 Hz, 1H), 6.84 (dd, J_1 = 8.0 Hz, J_2 = 1.3 Hz, 1H), 2.31 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.8, 138.8, 133.5, 128.3, 126.5, 124.6, 120.4, 101.2, 24.5. HRMS (EI^+) calcd for $C_{11}H_{11}BrO_2S[M]^+$: 285.9663; found: 285.9659.



4-hydroxy-3-(o-tolylthio)pent-3-en-2-one (3k): Isolated yield = 45%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.34 (s, 1H), 7.15 (d, *J* = 7.6 Hz, 1H), 7.13 (t, *J* = 8.0 Hz, 1H), 7.05 (t, *J* = 7.6 Hz, 1H), 6.83 (d, *J* = 8.0 Hz, 1H), 2.38 (s, 3H), 2.31 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 198.6, 136.8, 134.6, 130.6, 127.0, 125.0, 122.9, 101.0, 24.6, 19.9. HRMS (EI^+) calcd for $C_{12}H_{14}O_2S$ $[M]^+$: 222.0715; found: 222.0719.



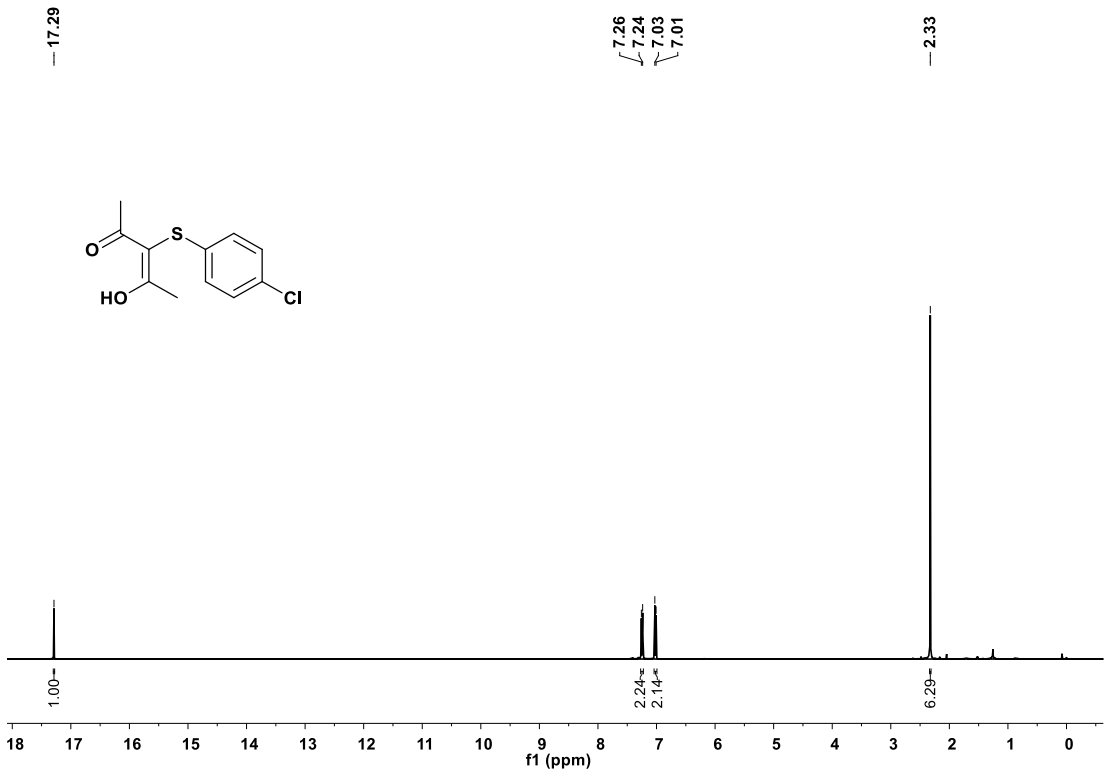
4-hydroxy-3-(thiophen-2-ylthio)pent-3-en-2-one (3l): Isolated yield = 28%. Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.10 (s, 1H), 7.23 (d, *J* = 4.2 Hz, 1H), 7.97 (d, *J* = 3.6 Hz, 1H), 6.93 (t, *J* = 4.4 Hz, 1H), 2.48 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.8, 138.1, 128.4, 127.8, 127.1, 106.3, 24.9. HRMS (EI^+) calcd for $C_9H_{10}O_2S_2$ $[M]^+$: 214.0122; found: 214.0123.

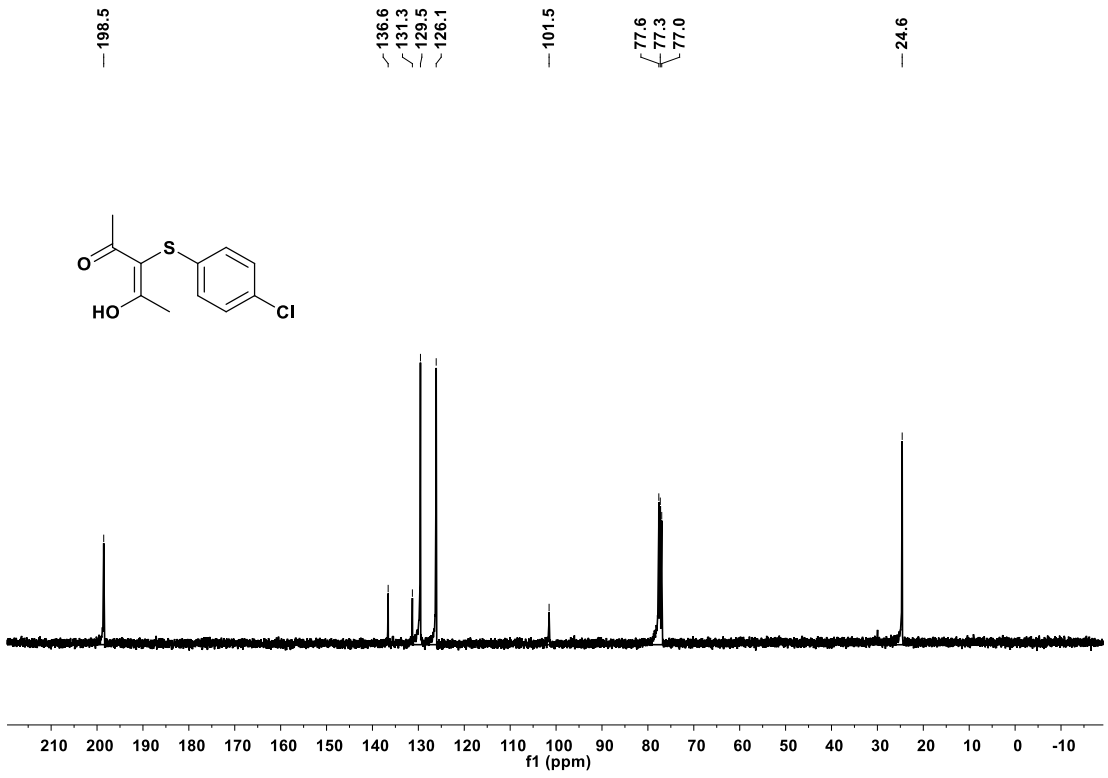


4-(4-chlorophenylthio)-5-hydroxyhept-4-en-3-one (3m): Isolated yield = 57%. White solid. Melting point = 16 ^{o}C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 17.47 (s, 1H), 7.24 (d, *J* = 8.8 Hz, 2H), 7.00 (d, *J* = 8.8 Hz, 2H), 2.70 (s, 4H), 1.10 (t, *J* = 7.8 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 210.6, 137.1, 131.2, 129.5, 126.0, 100.0, 30.2, 9.8. HRMS (EI^+) calcd for $C_{13}H_{15}ClO_2S$ $[M]^+$: 270.0481; found: 270.0478.

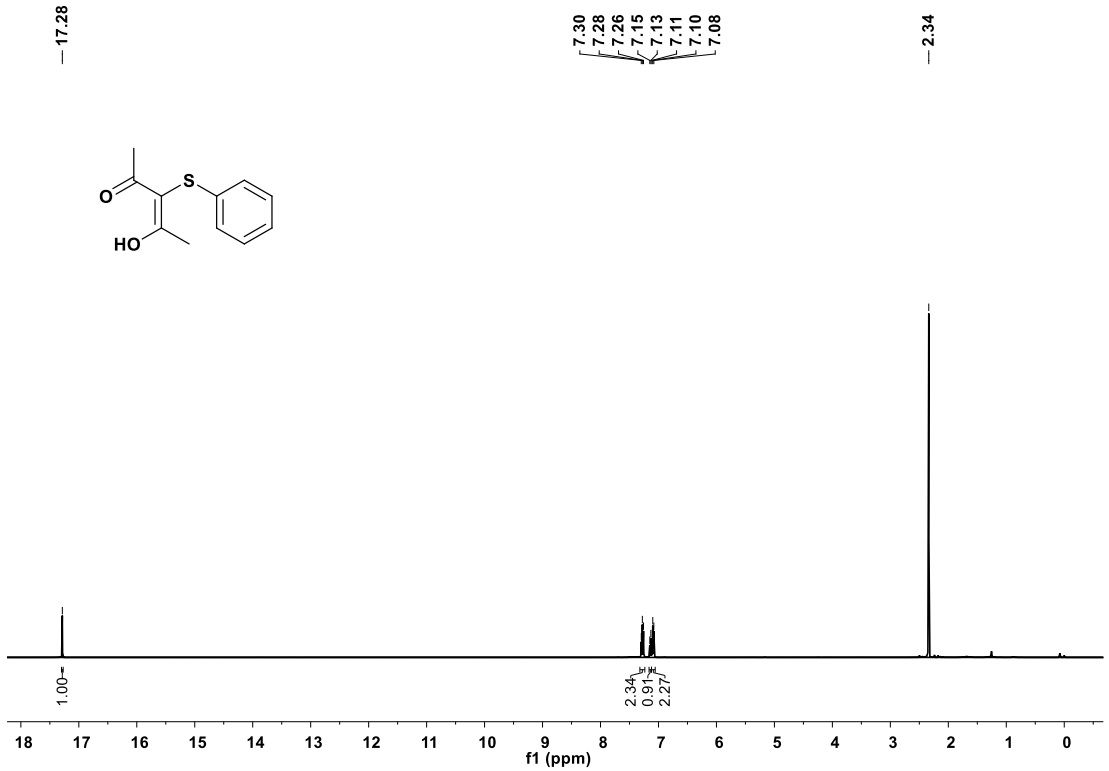
Copies of product ^{1}H, ^{13}C and ^{19}F NMR

3a





3b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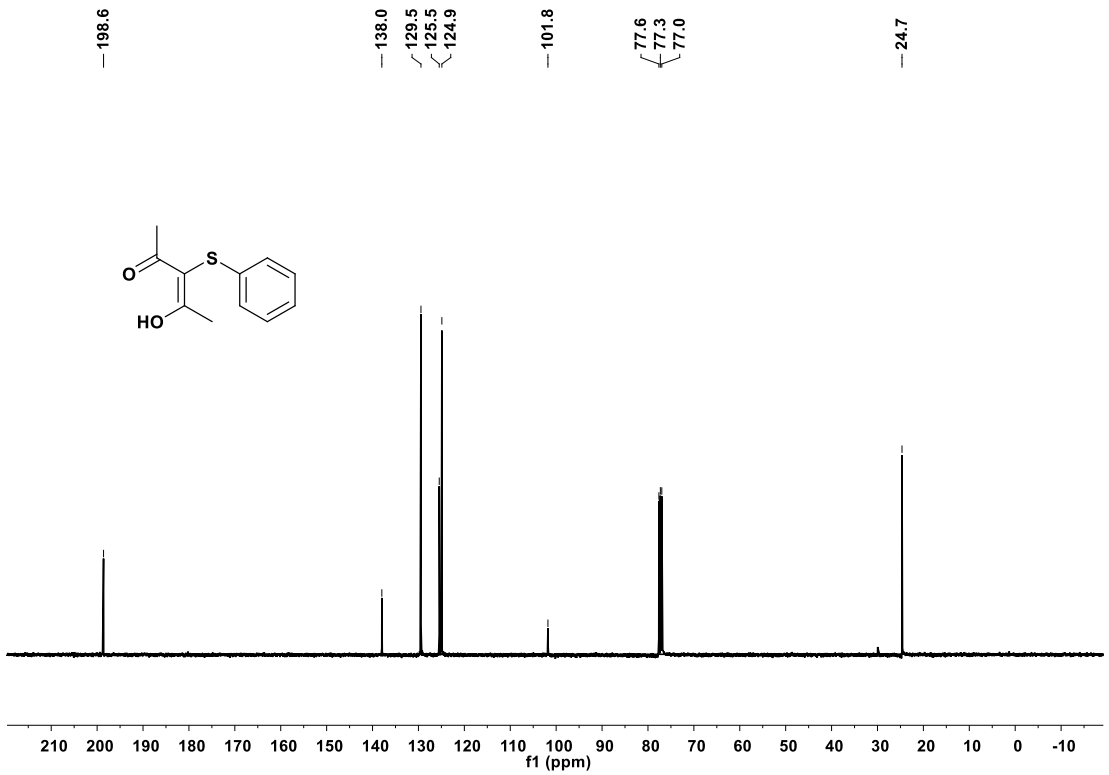
7.28
7.26
7.15
7.13
7.11
7.10
7.08
2.34
O
S
HO
1.00
2.34
0.91
2.27
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


198.6
138.0
129.5
125.5
124.9
101.8
77.6
77.3
77.0
24.7
O
S
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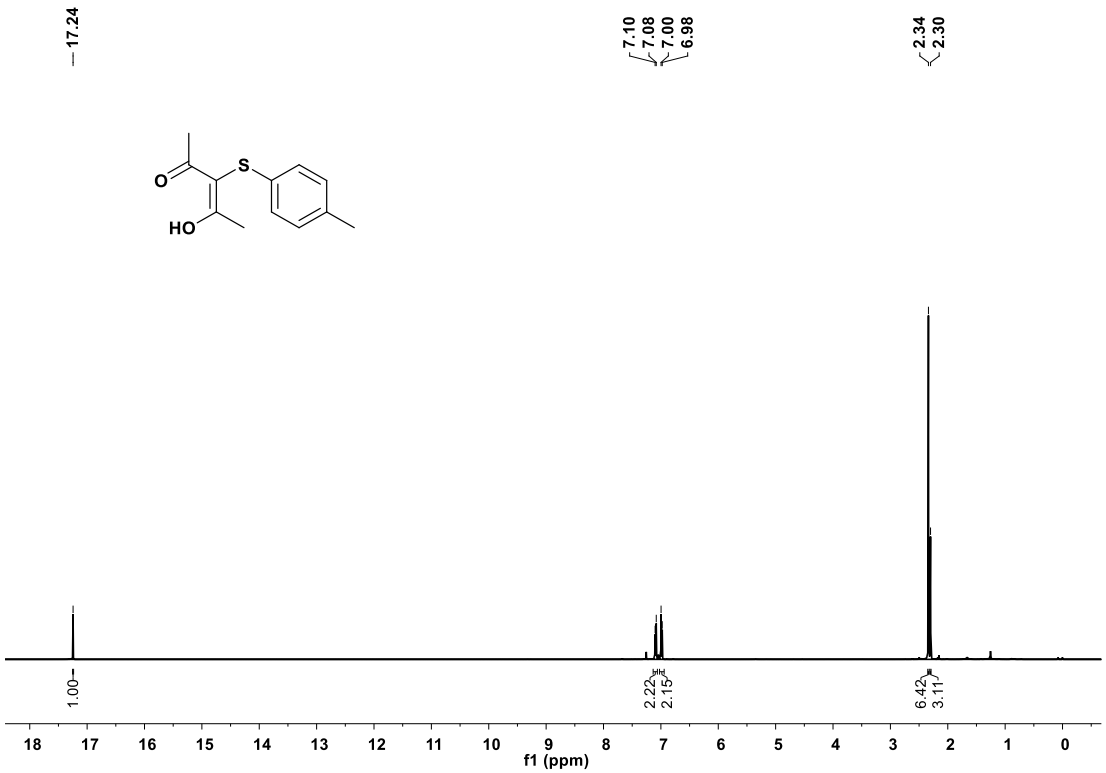
f1 (ppm)

3c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7.00
6.98
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2.30
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S
HO
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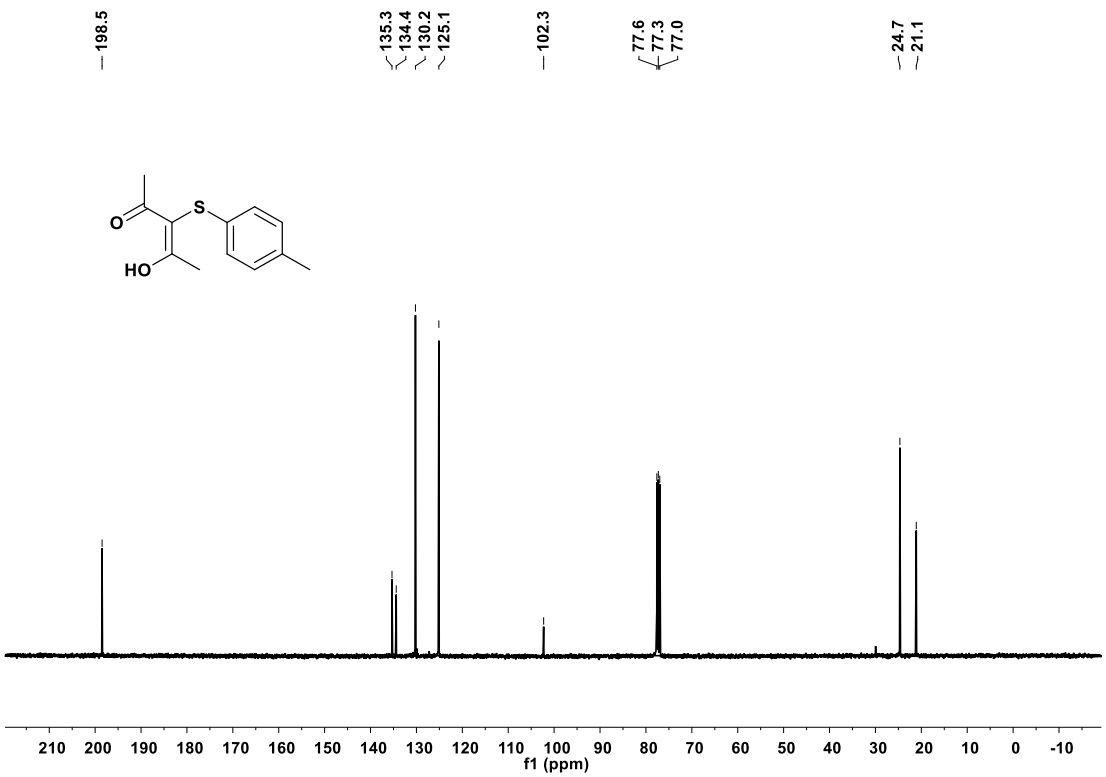
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)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134.4
130.2
125.1
102.3
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24.7
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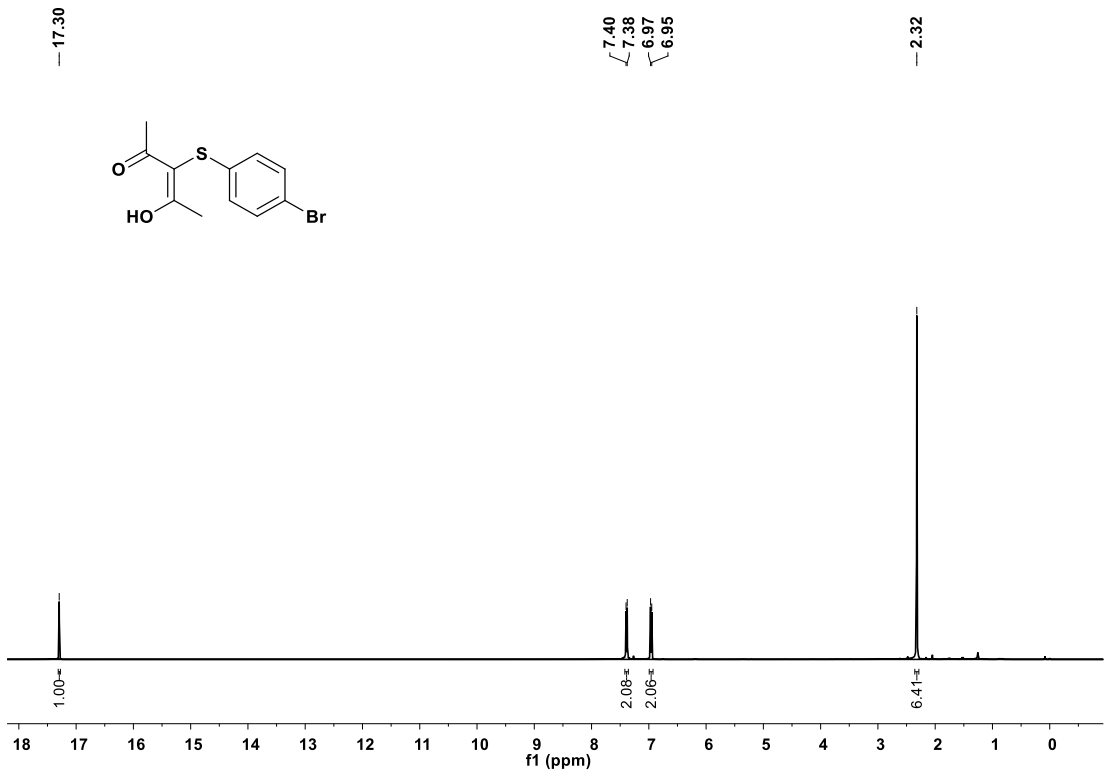
f1 (ppm)

3d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6.97
6.95
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S
HO
Br
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2.08
2.06
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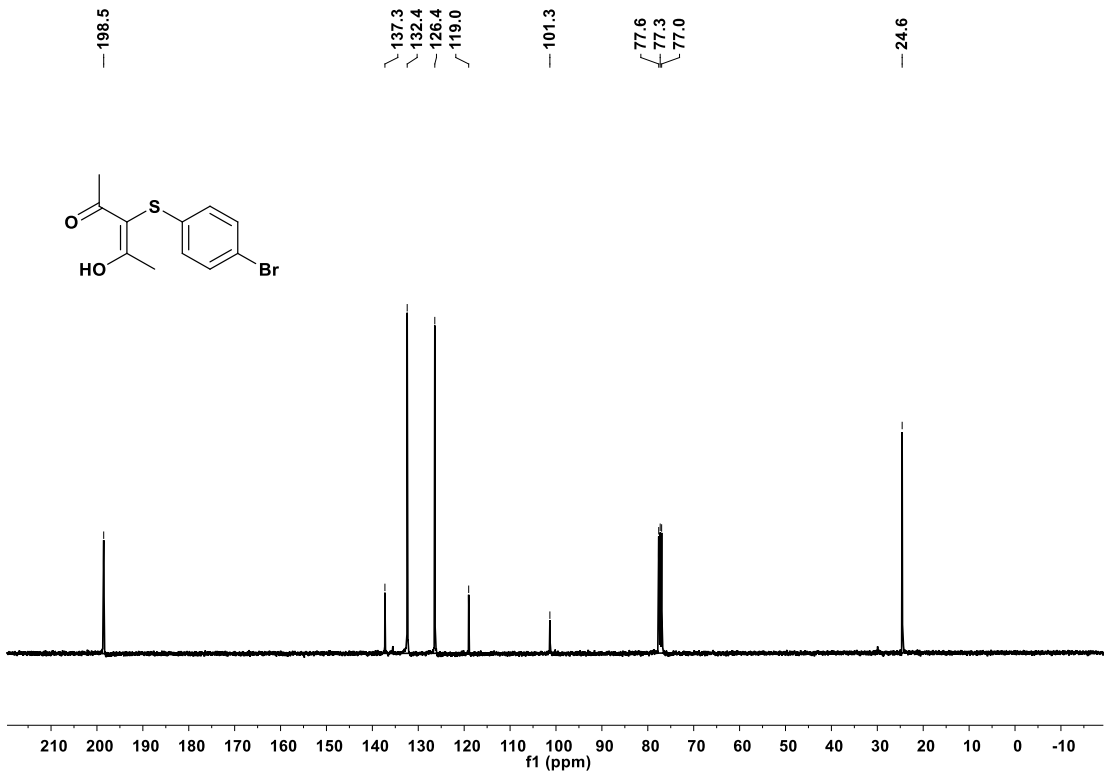
f1 (ppm)


198.5
137.3
132.4
126.4
119.0
101.3
77.6
77.3
77.0
24.6
O
S
HO
Br
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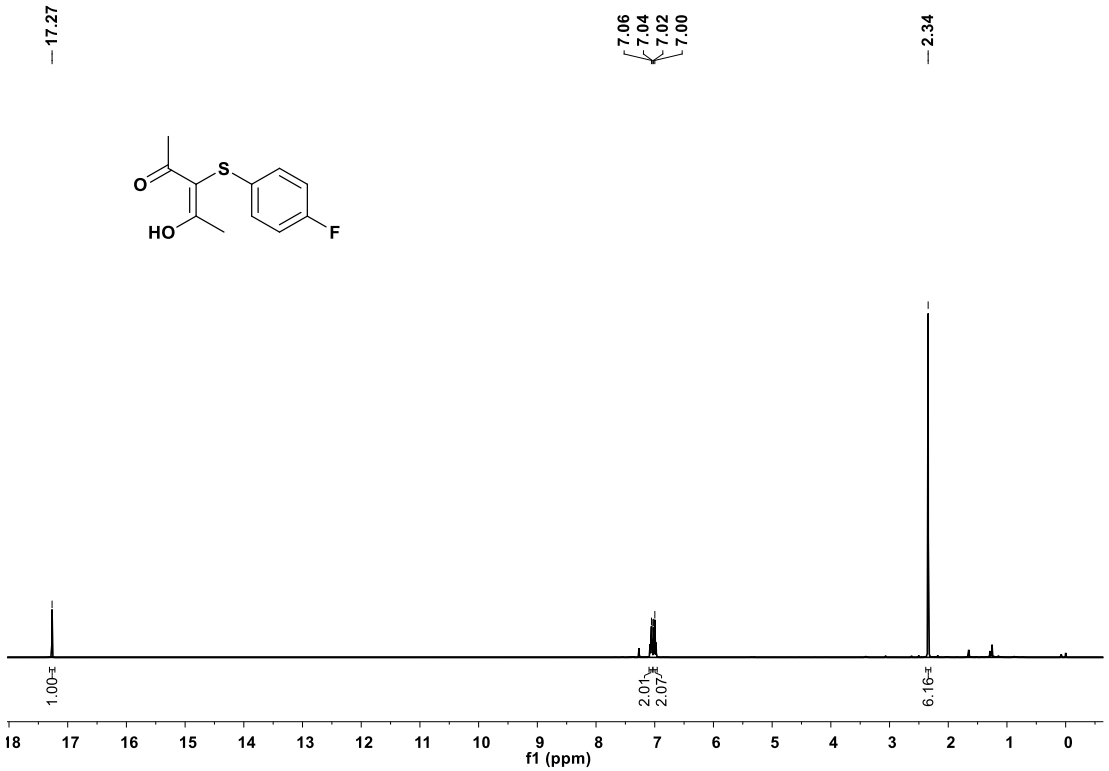
f1 (ppm)

3e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S
HO
F
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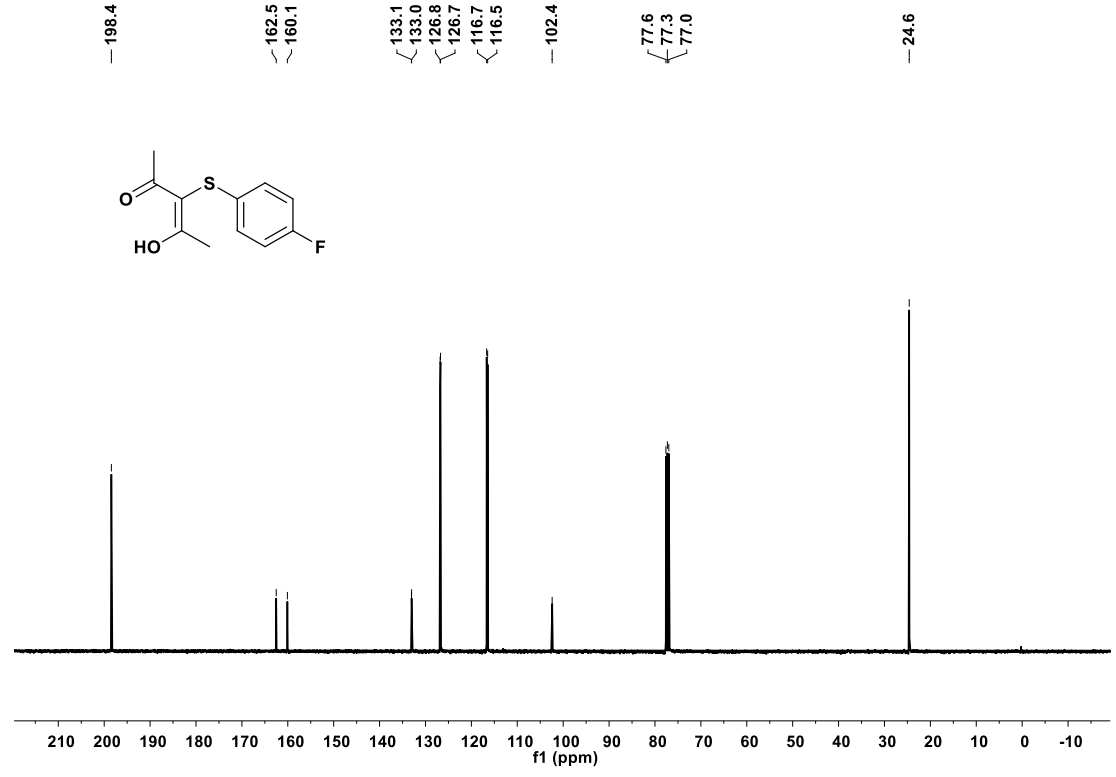
2.01
2.07
6.16
f1 (ppm)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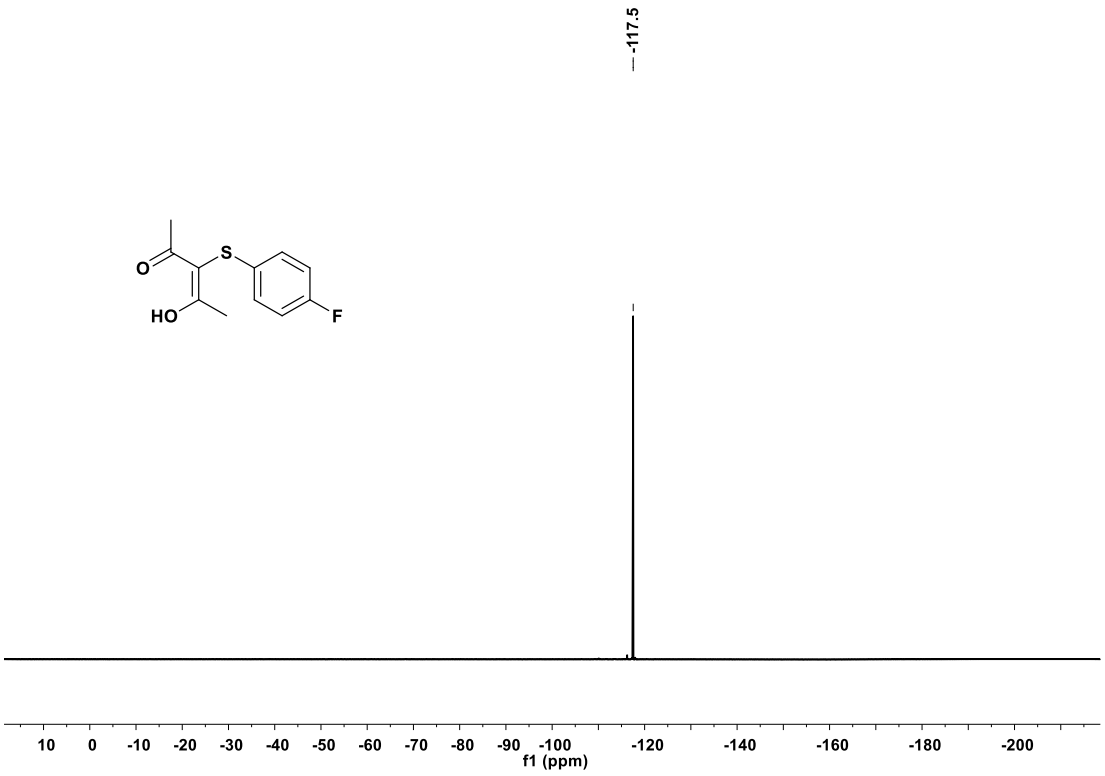
24.6
O
S
HO
F
f1 (ppm)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O
S
HO
F
10
0
-10
-20
-30
-40
-50
-60
-70
-80
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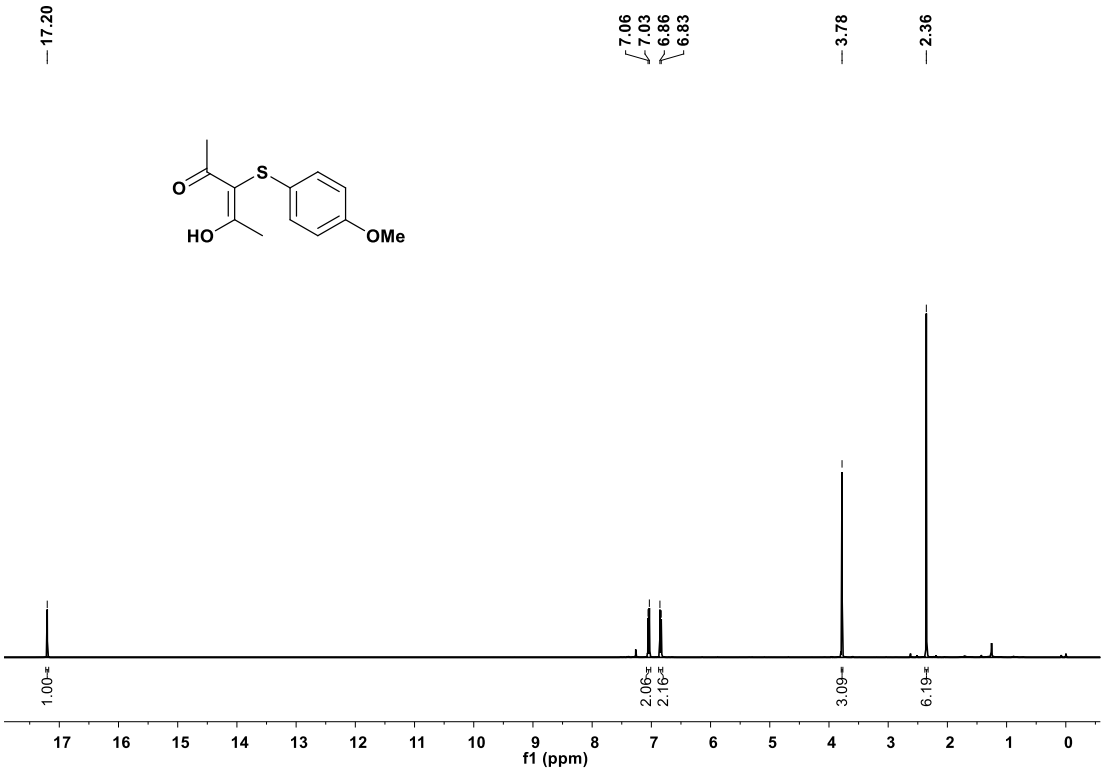
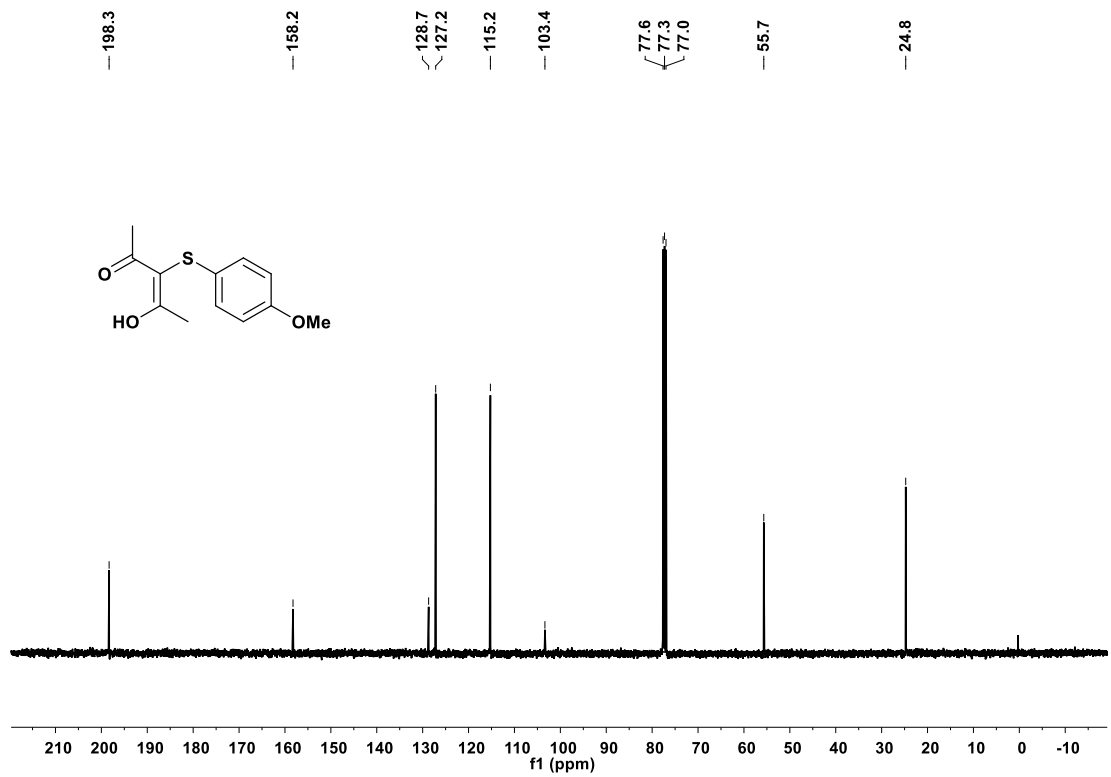
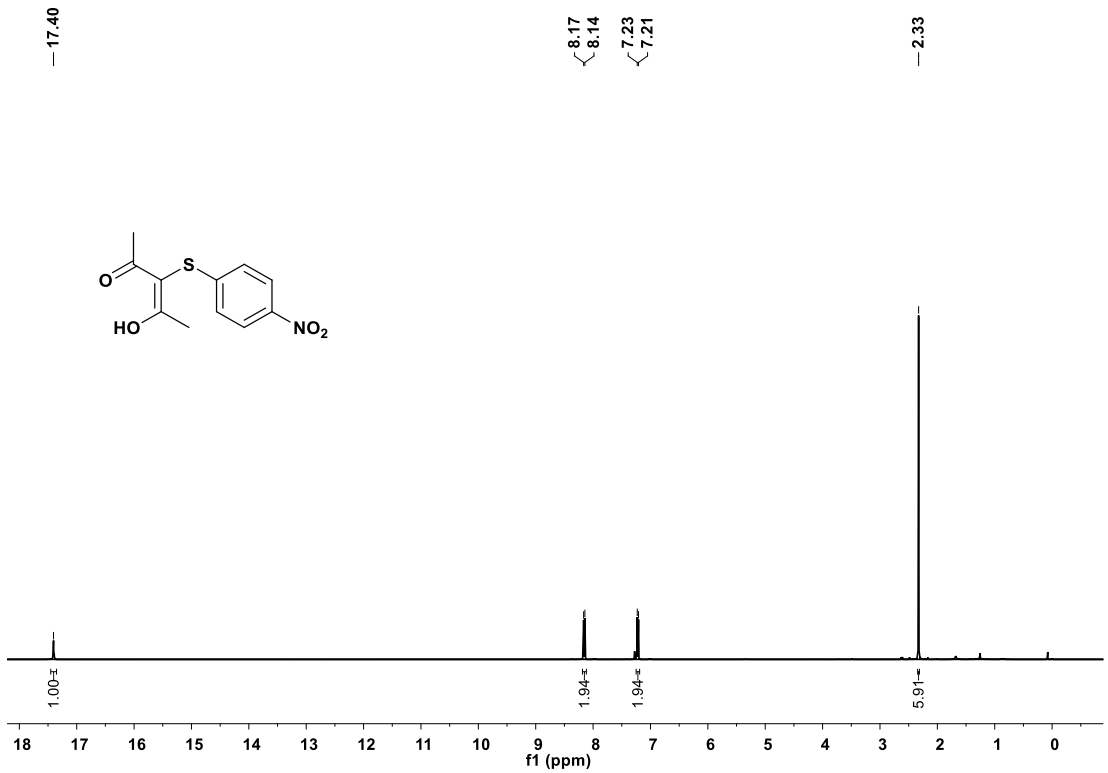
-100
-120
-140
-160
-180
-200
f1 (ppm)

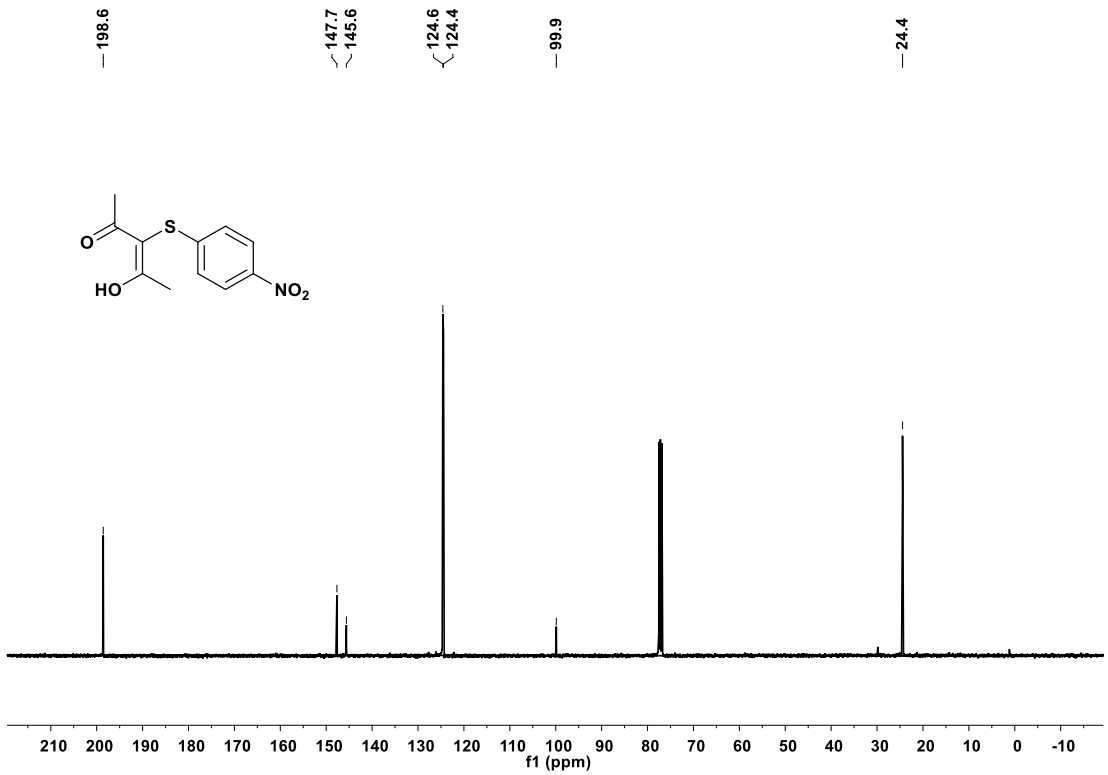
3f


17.20
7.06
7.03
6.86
6.83
3.78
2.36
O
S
HO
OMe
1.00
2.06
2.16
3.09
6.19
17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

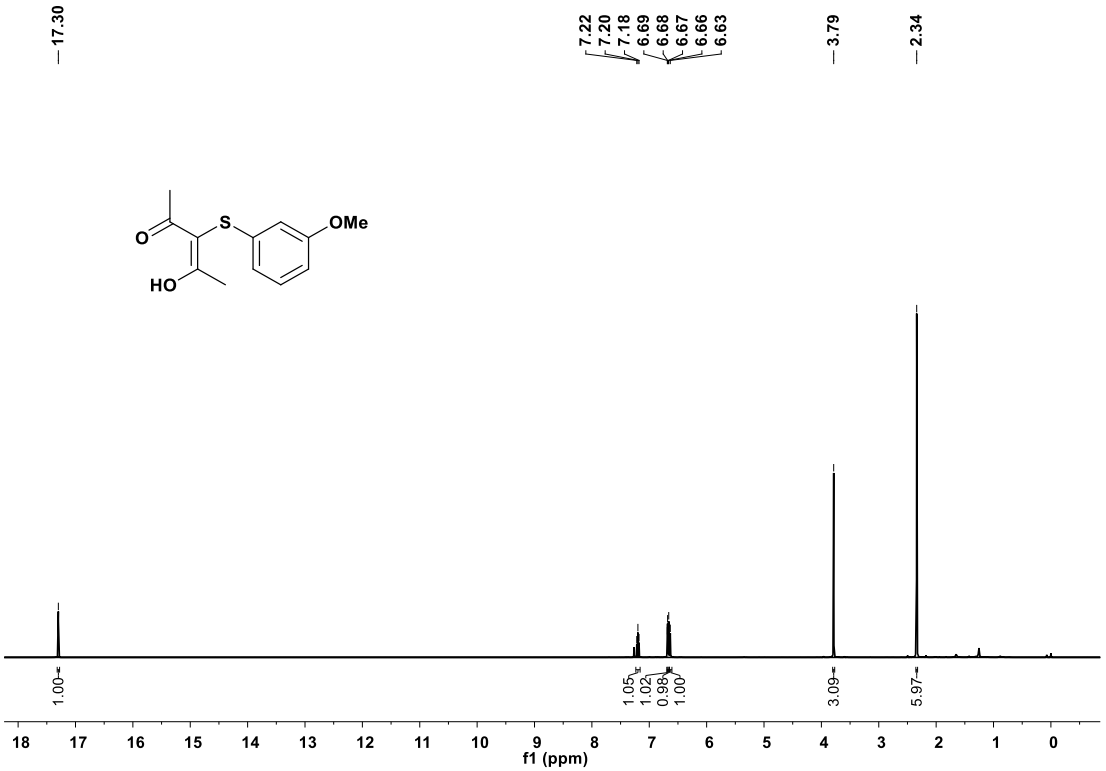

198.3
158.2
128.7
127.2
115.2
103.4
77.6
77.3
77.0
55.7
24.8
O
S
HO
OMe
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

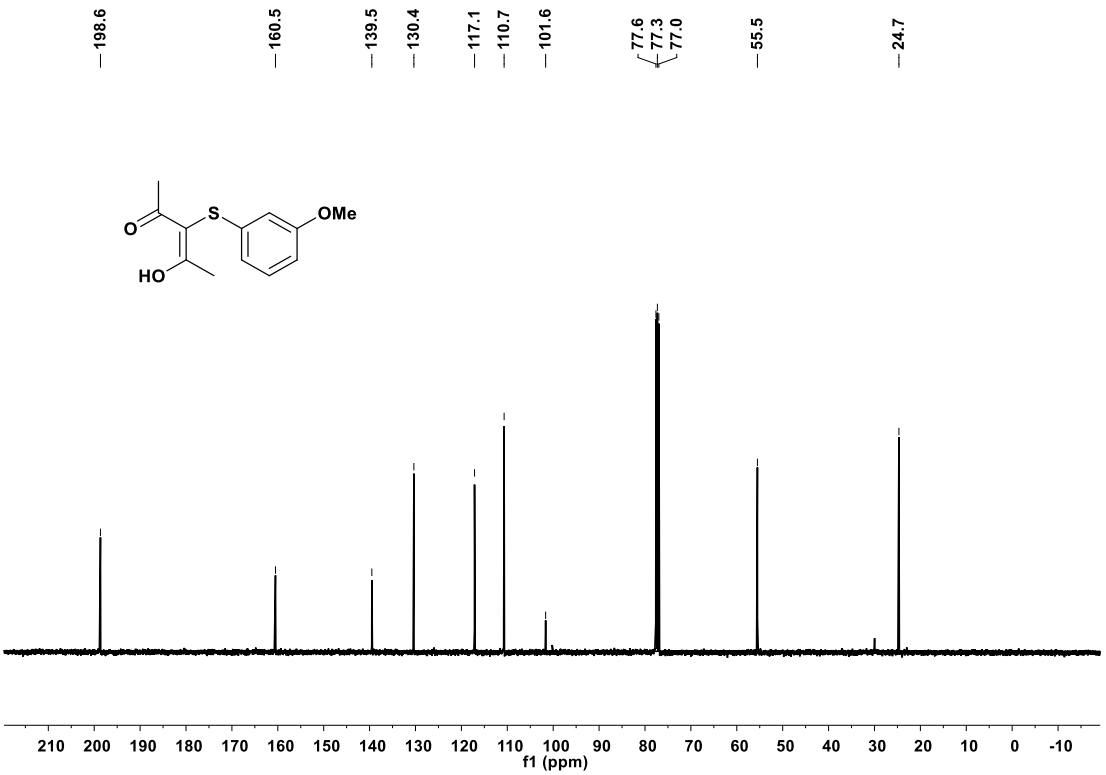
3g


17.40
8.17
8.14
7.23
7.21
2.33
O
S
HO
NO2
1.00
1.94
1.94
5.91
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

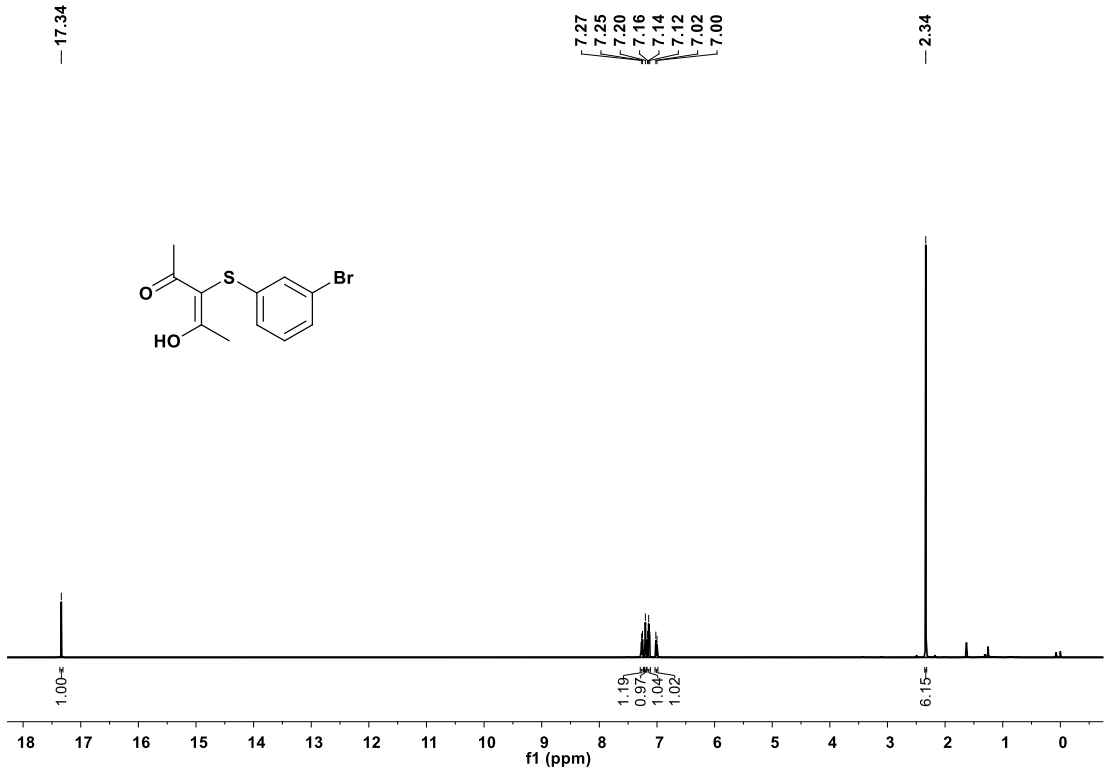

198.6
147.7
145.6
124.6
124.4
99.9
24.4
O
S
HO
NO2
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

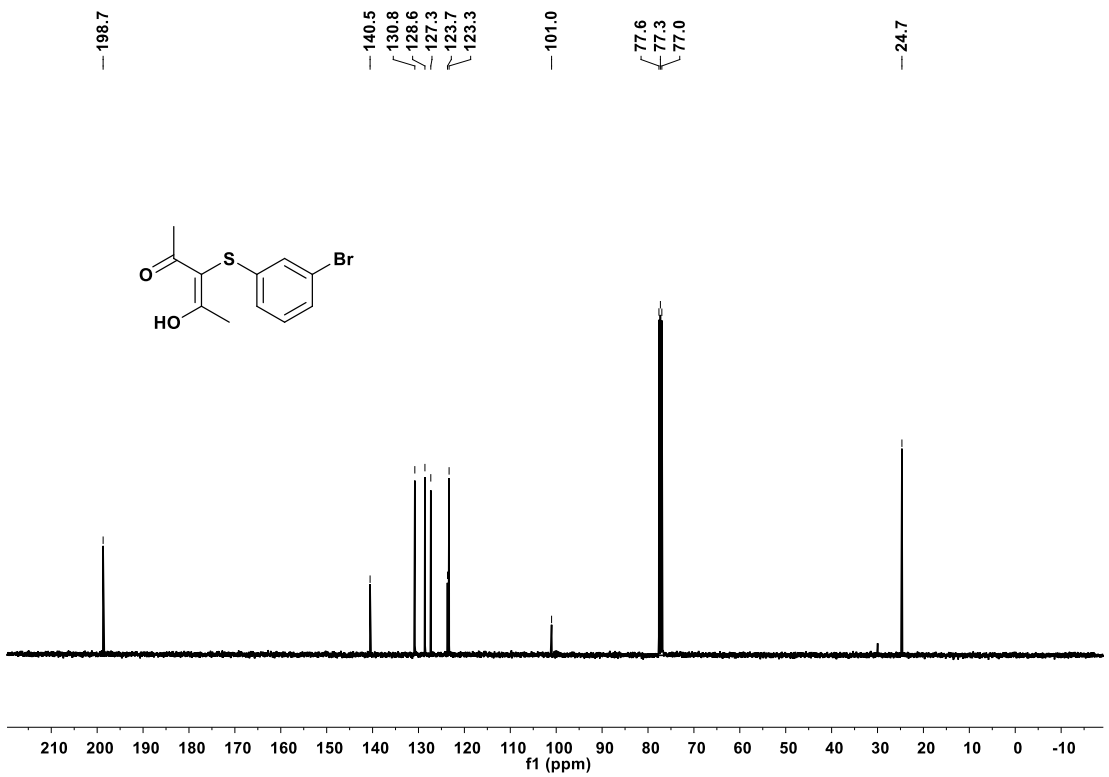
3h


17.30
7.22
7.20
7.18
6.69
6.68
6.67
6.66
6.63
3.79
2.34
O
S
OMe
HO
1.00
1.05
1.02
0.98
1.00
3.09
5.97
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

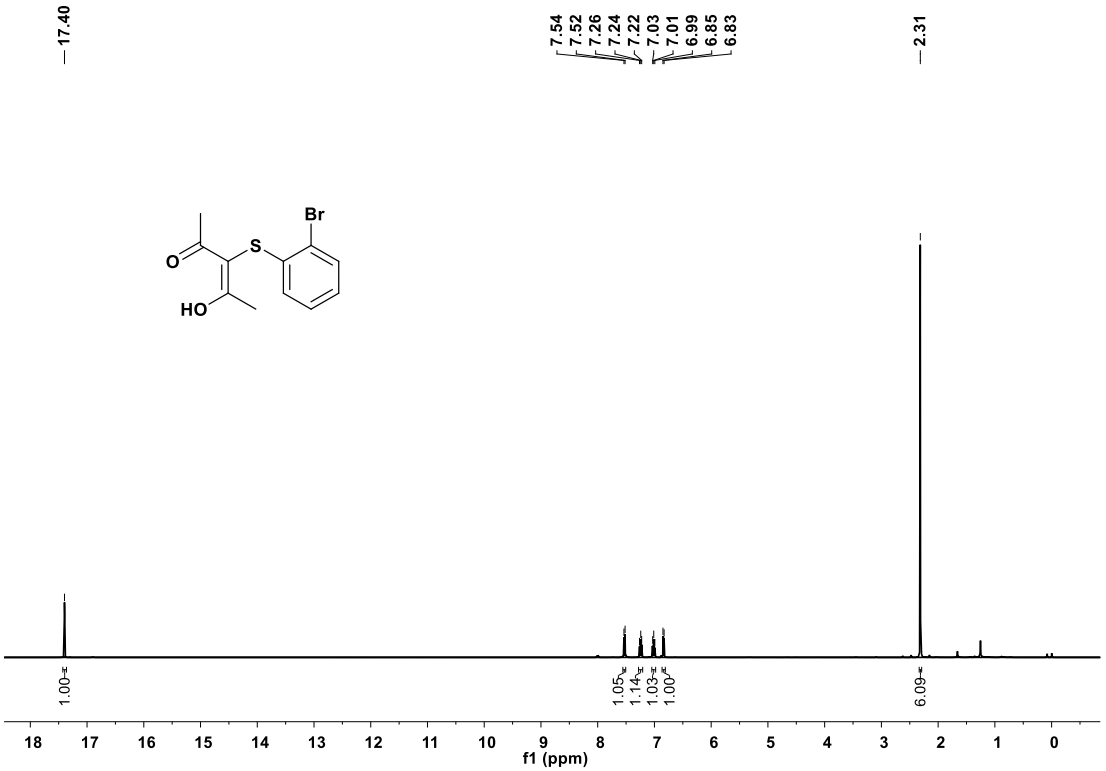

198.6
160.5
139.5
130.4
117.1
110.7
101.6
77.6
77.3
77.0
55.5
24.7
O
S
OMe
HO
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

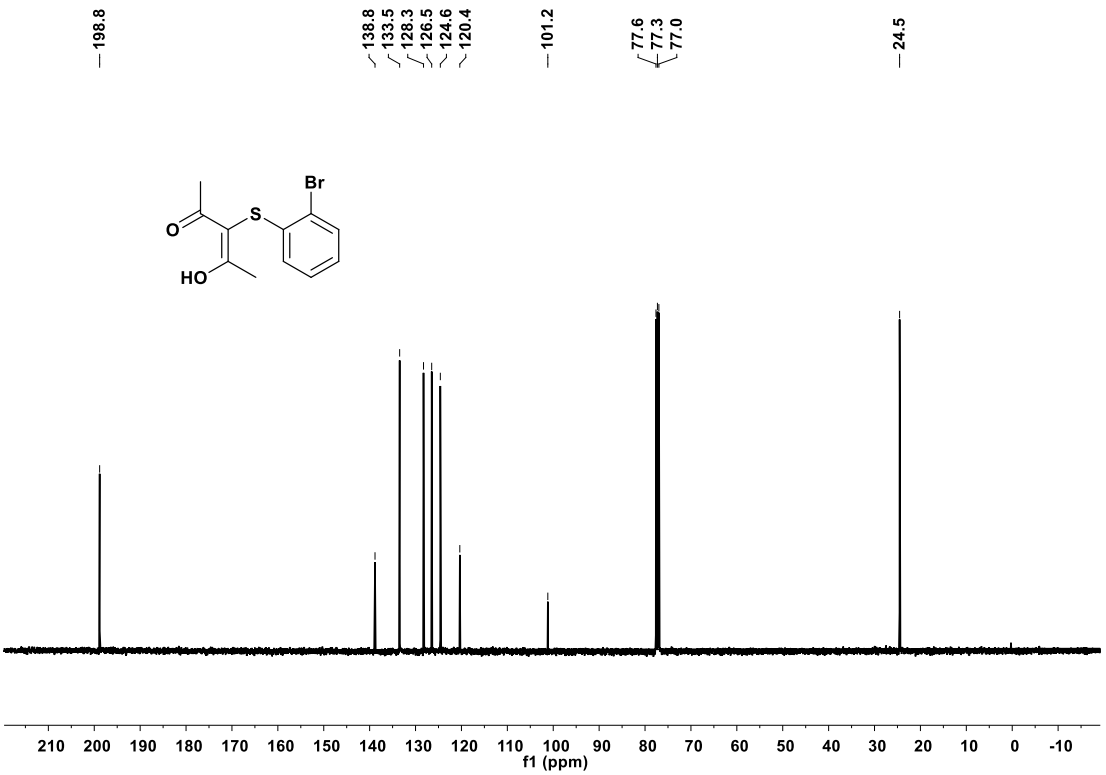
3i


17.34
7.27
7.25
7.20
7.16
7.14
7.12
7.02
7.00
2.34
O
S
Br
HO
1.00
1.19
0.97
1.04
1.02
6.15
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

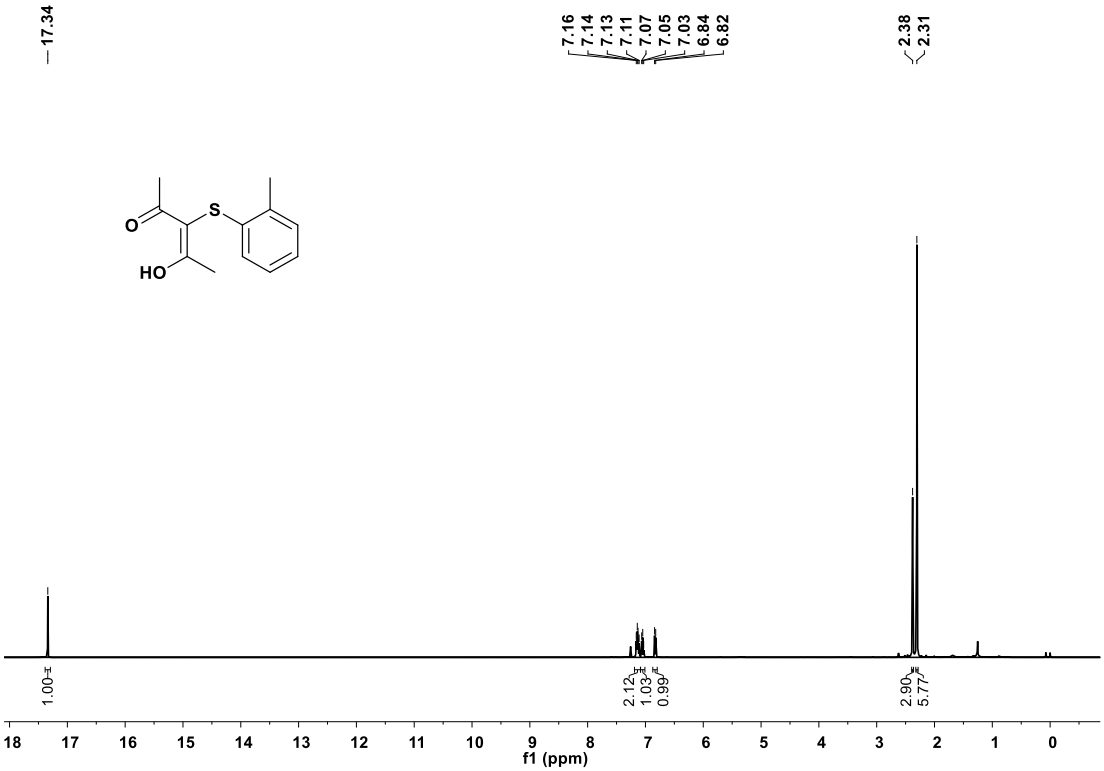

198.7
140.5
130.8
128.6
127.3
123.7
123.3
101.0
77.6
77.3
77.0
24.7
O
S
Br
HO
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

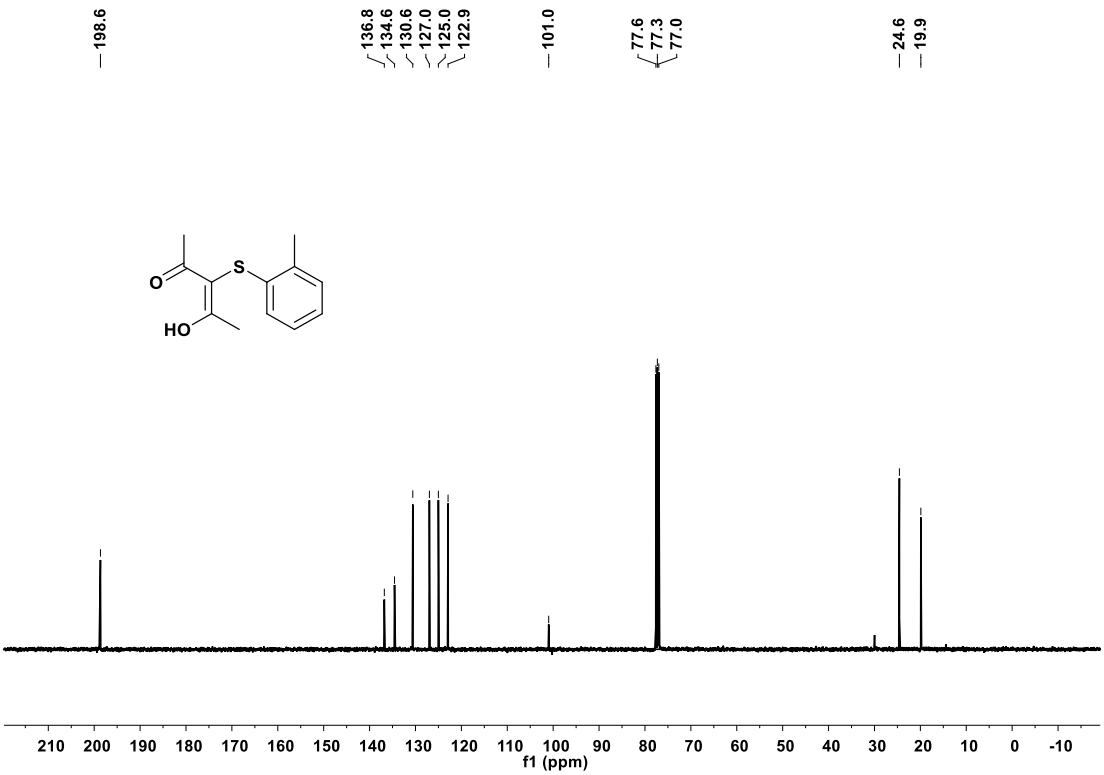
3j


17.40
7.54
7.52
7.26
7.24
7.22
7.03
7.01
6.99
6.85
6.83
2.31
Br
S
O
HO
1.00
1.05
1.14
1.03
1.00
6.09
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)

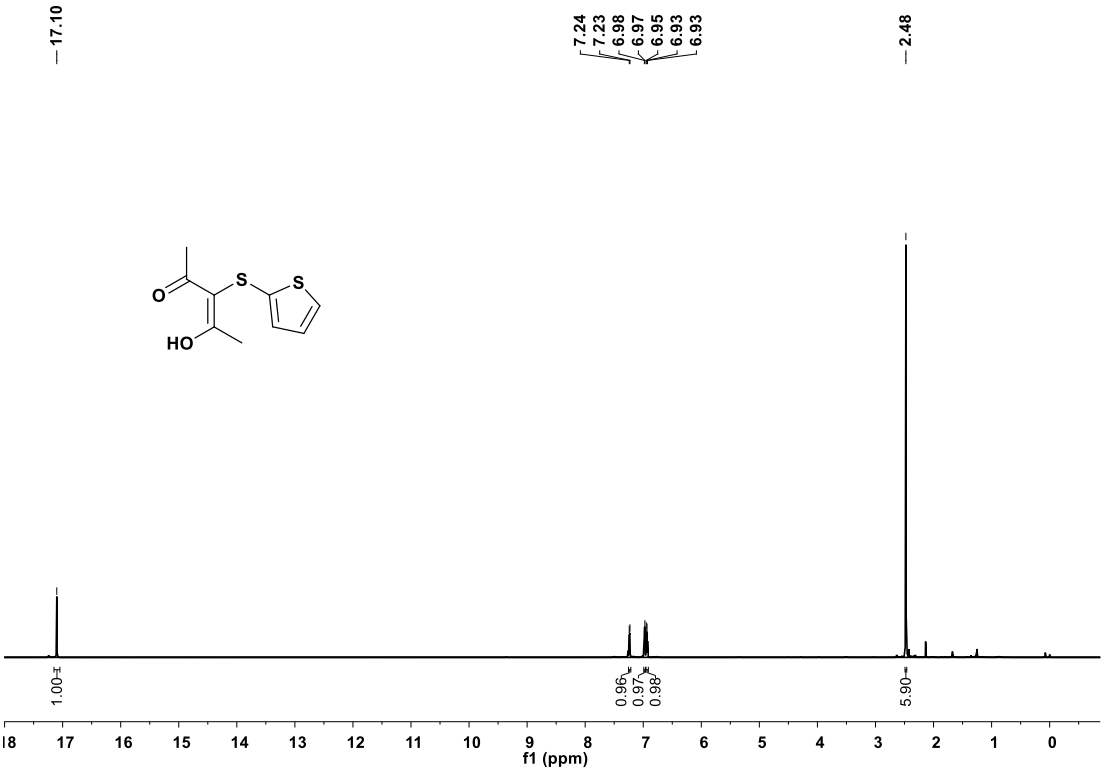

198.8
138.8
133.5
128.3
126.5
124.6
120.4
101.2
77.6
77.3
77.0
24.5
Br
S
O
HO
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

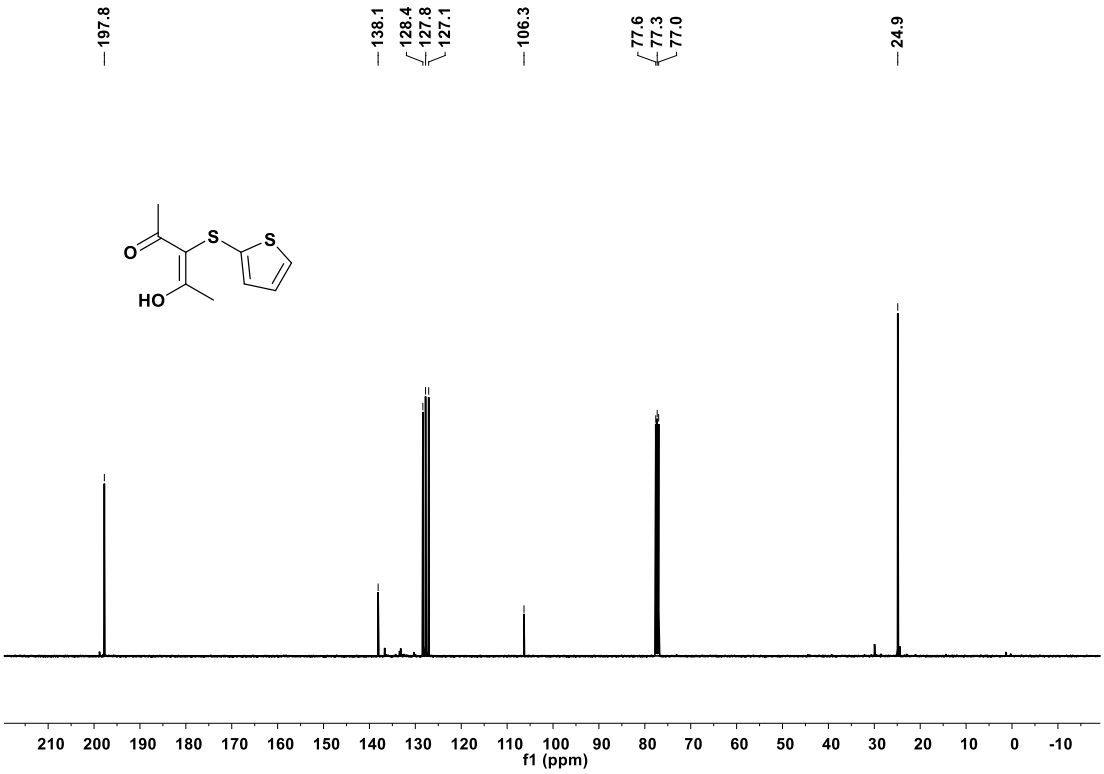
3k


17.34
7.16
7.14
7.13
7.11
7.07
7.05
7.03
6.84
6.82
2.38
2.31
O
S
HO
1.00
2.12
1.03
0.99
2.90
5.77
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
f1 (ppm)


198.6
136.8
134.6
130.6
127.0
125.0
122.9
101.0
77.6
77.3
77.0
24.6
19.9
O
S
HO
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)

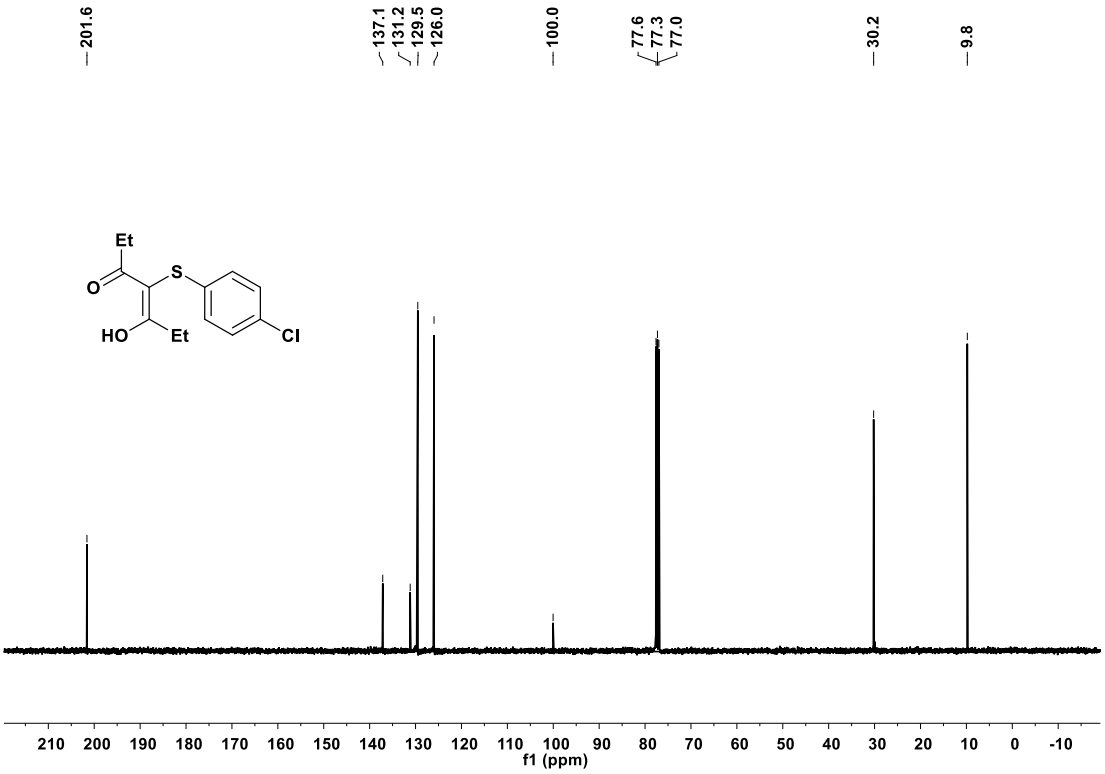
3l


17.10
7.24
7.23
6.98
6.97
6.95
6.93
6.93
2.48
O
S
S
HO
1.00
0.96
0.97
0.98
5.90
f1 (ppm)


197.8
138.1
128.4
127.8
127.1
106.3
77.6
77.3
77.0
24.9
O
S
S
HO
f1 (ppm)

3m


17.47
7.25
7.23
7.02
6.99
2.70
1.12
1.10
1.08
Et
O
S
HO
Et
Cl
1.00
2.02
2.03
4.65
6.36
f1 (ppm)


201.6
137.1
131.2
129.5
126.0
100.0
77.6
77.3
77.0
30.2
9.8
Et
O
S
HO
Et
Cl
f1 (ppm)