

Synthesis of Primary *N*-arylthioglyoxamides from Anilines, Elemental Sulfur and Primary C–H Bonds in Acetophenones

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Supporting information

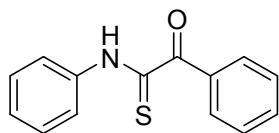
1. Materials and instrumentation

All reagents and starting materials were commercially obtained from Sigma-Aldrich, Acros, AK Scientific and were used as received without any further purification unless otherwise noted. Gas chromatographic (GC) analyses were performed using a Shimadzu GC 2010-Plus equipped with a flame ionization detector (FID) and an SPB-5 column (length = 30 m, inner diameter = 0.25 mm, and film thickness = 0.25 μm). GC-MS analyses were analyzed on a Shimadzu GCMS-QP2010Ultra with a ZB-5MS column (length = 30 m, inner diameter = 0.25 mm, and film thickness = 0.25 μm). The ¹H NMR and ¹³C NMR were recorded on Bruker AV 500 spectrometers using residual solvent peak as a reference. HR-MS spectra were recorded by an Agilent HPLC 1200 Series coupled to Bruker micrOTOF-QII.

2. Characterization of the products

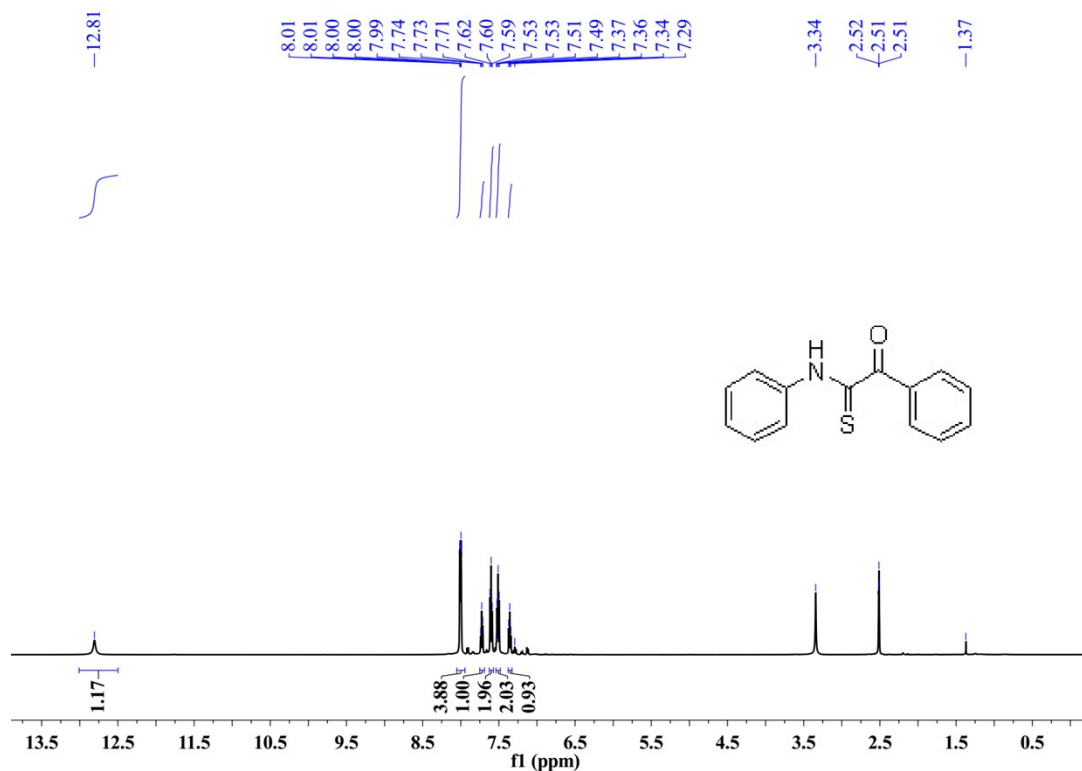
2-Oxo-*N*,2-diphenylethanethioamide¹

Yellow solid, mp 88–90 °C

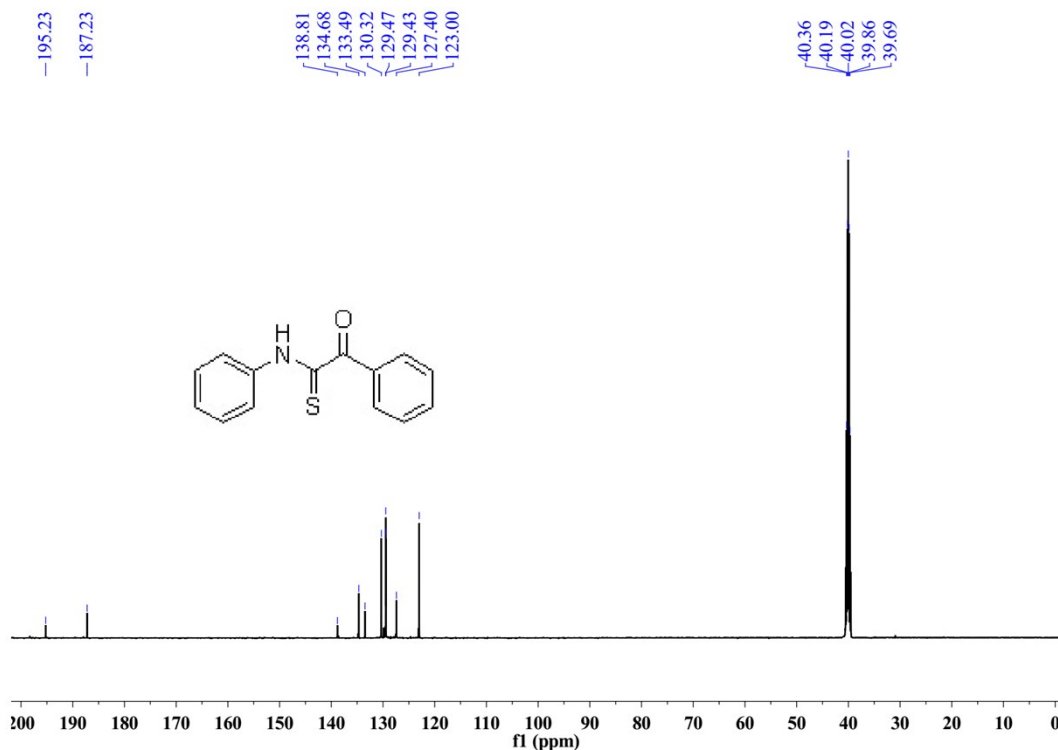


¹H NMR (500 MHz, DMSO-*d*₆, ppm) δ 12.81 (s, 1H), 8.04 – 7.97 (m, 4H), 7.73 (t, *J* = 7.4 Hz, 1H), 7.60 (t, *J* = 7.7 Hz, 2H), 7.51 (t, *J* = 7.9 Hz, 2H), 7.36 (t, *J* = 7.4 Hz, 1H).

¹³C NMR (126 MHz, DMSO-*d*₆, ppm) δ 195.2, 187.2, 138.8, 134.7, 133.5, 130.3, 129.5, 129.4, 127.4, 123.0.

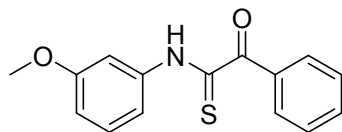


¹ H.-Z. Li, W.-J. Xue and A.-X. Wu, *Tetrahedron*, 2014, **70**, 4645.



***N*-(3-Methoxyphenyl)-2-oxo-2-phenylethanethioamide**

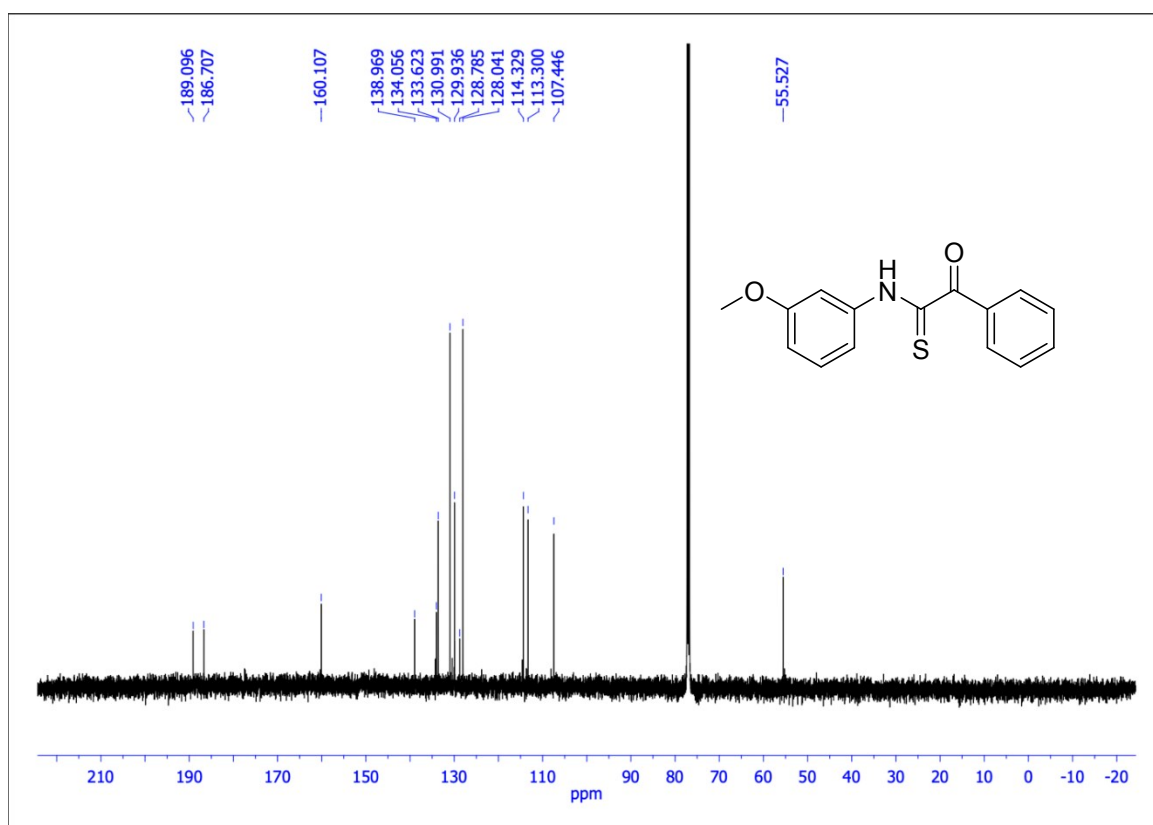
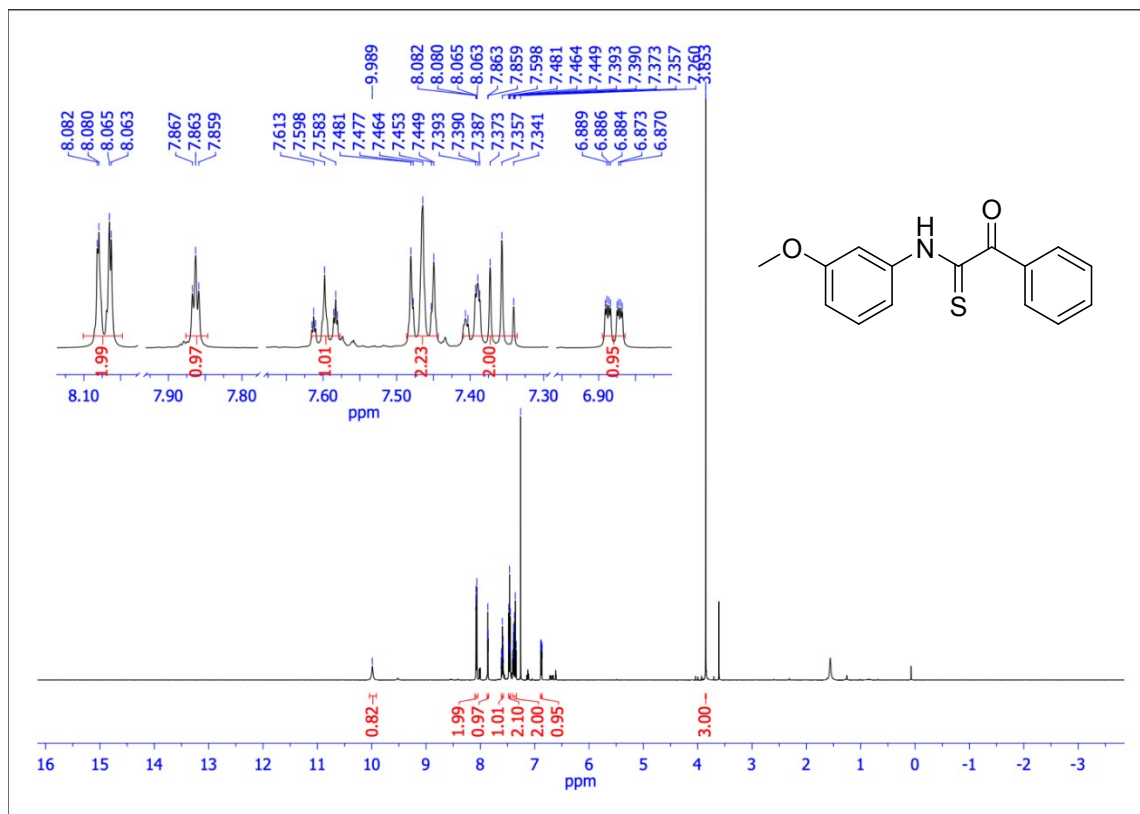
Yellow solid, mp 108–110 °C



^1H NMR (500 MHz, CDCl_3 , ppm) δ 9.99 (bs, 1H), 8.07 (dd, $J = 8.4, 1.2$ Hz, 1H), 7.86 (t, $J = 2.2$ Hz, 1H), 7.62 – 7.58 (m, 1H), 7.49 – 7.44 (m, 1H), 7.38 (ddd, $J = 23.1, 11.4, 4.9$ Hz, 1H), 6.88 (ddd, $J = 8.0, 2.4, 1.1$ Hz, 1H), 3.85 (bs, 2H).

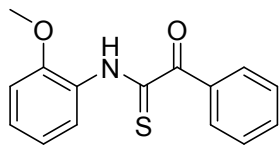
^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 189.1, 186.7, 160.1, 139.0, 134.1, 133.62, 131.0, 129.9, 128.8, 128.0, 114.3, 113.3, 107.4, 55.5.

HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{14}\text{NO}_2\text{S}$: 272.0740, found: 272.0742.



N-(2-Methoxyphenyl)-2-oxo-2-phenylethanethioamide

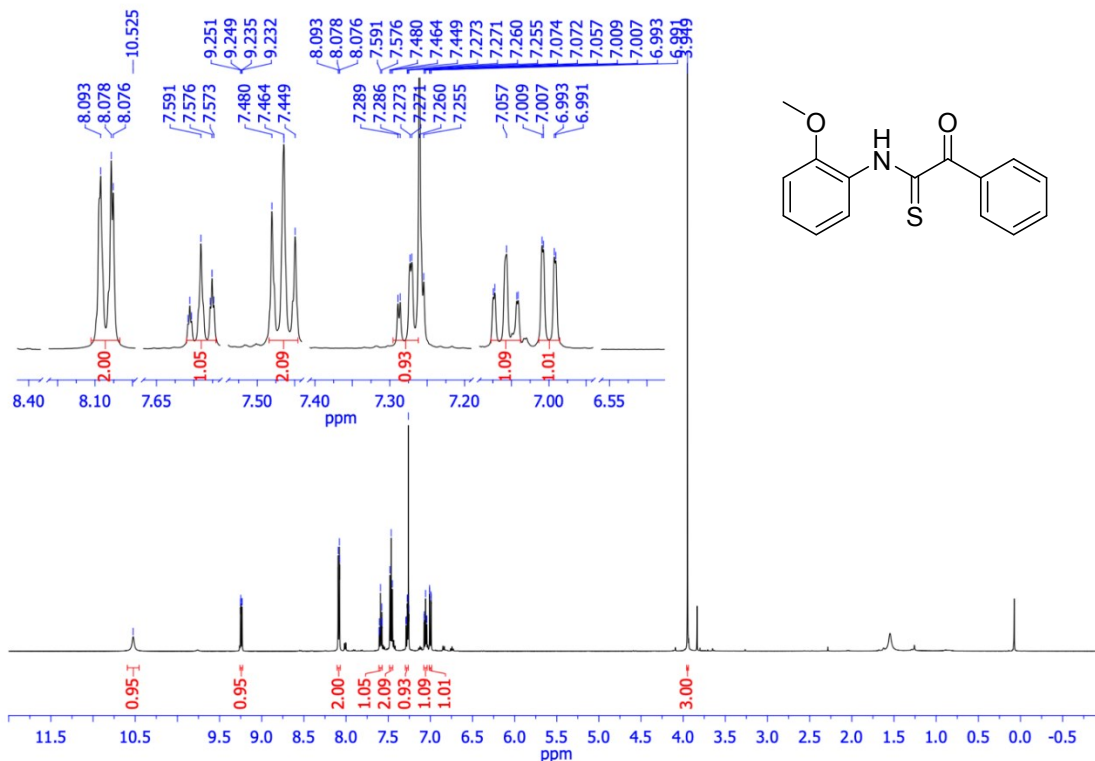
Yellow solid, mp 103–107 °C

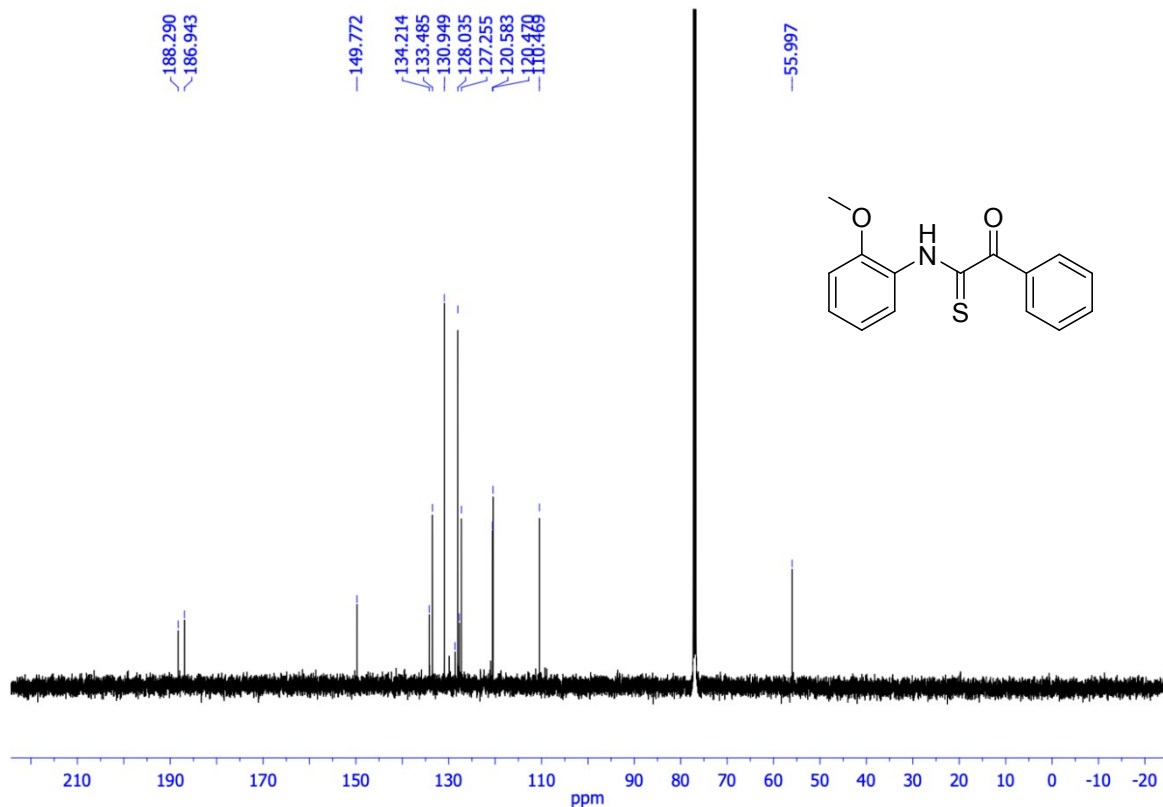


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.53 (bs, 1H), 9.24 (dd, $J = 8.1, 1.4$ Hz, 1H), 8.10 – 8.07 (m, 2H), 7.61 – 7.57 (m, 1H), 7.46 (t, $J = 7.8$ Hz, 2H), 7.30 – 7.25 (m, 2H), 7.08 – 7.04 (m, 1H), 7.00 (dd, $J = 8.2, 1.0$ Hz, 1H), 3.95 (bs, 3H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 188.3, 186.9, 149.8, 134.2, 133.5, 130.9, 128.0, 127.2, 120.58, 120.47, 110.5, 56.0. One carbon signal could not be located.

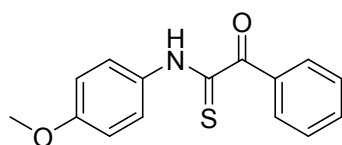
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{14}\text{NO}_2\text{S}$: 272.0740, found: 272.0732.





***N*-(4-Methoxyphenyl)-2-oxo-2-phenylethanethioamide¹**

Yellow solid, mp 108–110 °C

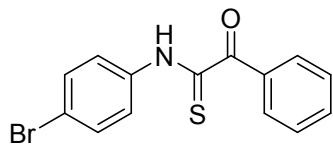


¹H NMR (500 MHz, CDCl₃, ppm) δ 9.95 (bs, 1H), 8.08 (dd, *J* = 8.3, 1.1 Hz, 1H), 7.92 – 7.88 (m, 1H), 7.62 – 7.57 (m, 1H), 7.46 (t, *J* = 7.8 Hz, 1H), 6.99 – 6.96 (m, 1H), 3.85 (bs, 1H).

¹³C NMR (126 MHz, CDCl₃, ppm) δ 188.4, 187.0, 158.4, 134.2, 133.6, 130.97, 130.93, 129.8, 128.7, 128.0, 125.1, 123.9, 114.7, 114.3, 55.6.

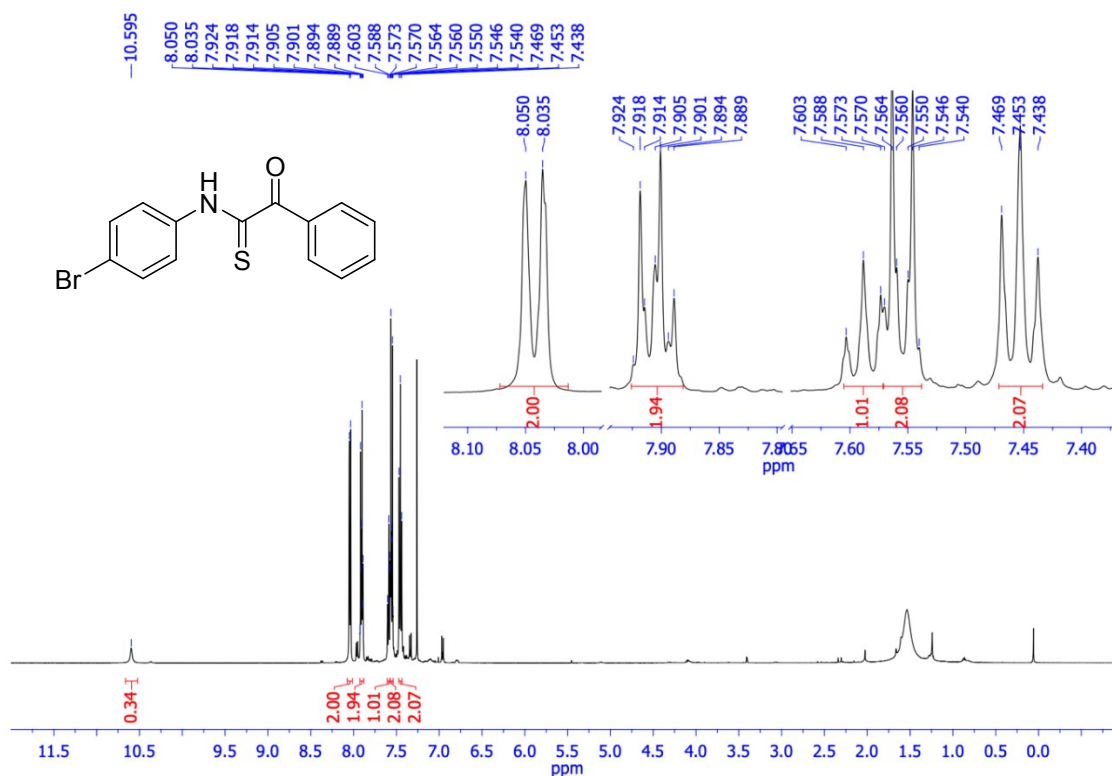
N-(4-Bromophenyl)-2-oxo-2-phenylethanethioamide¹

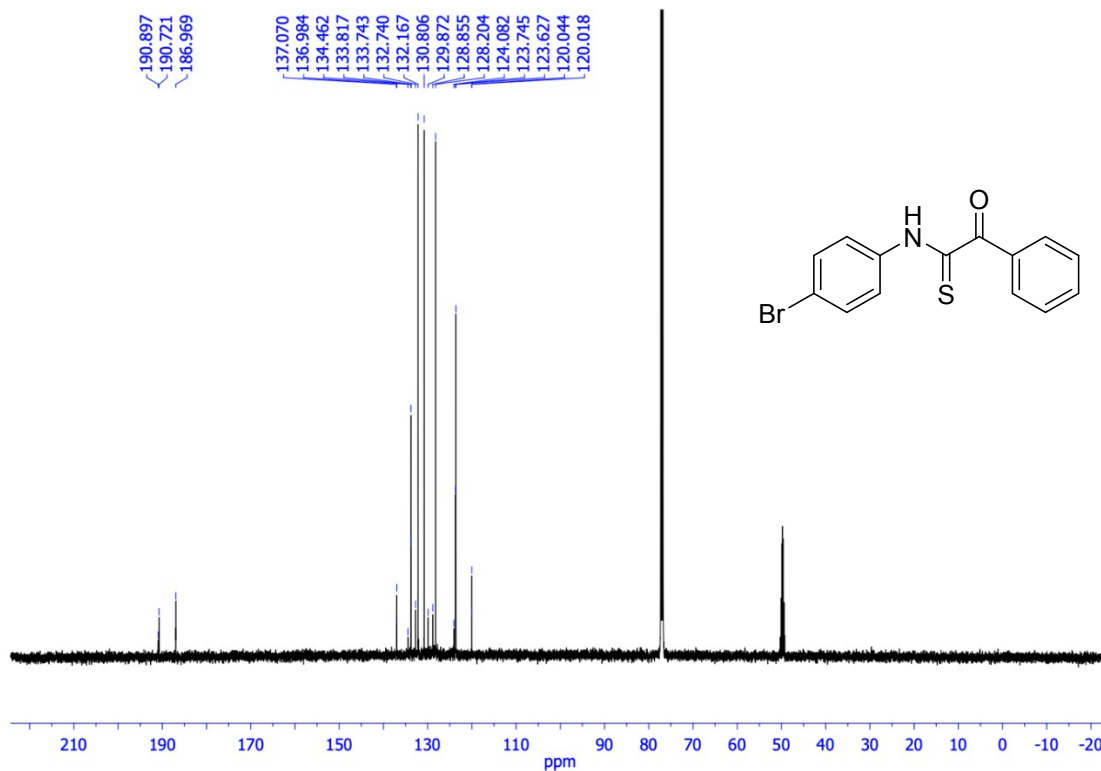
Tan solid, mp 125–127 °C



¹H NMR (500 MHz, CDCl₃, ppm) δ 10.60 (bs, 1H), 8.04 (d, *J* = 7.3 Hz, 1H), 7.93 – 7.88 (m, 1H), 7.58 (dd, *J* = 11.9, 4.4 Hz, 1H), 7.57 – 7.54 (m, 1H), 7.45 (t, *J* = 7.8 Hz, 1H).

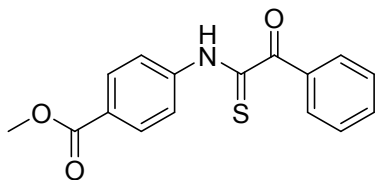
¹³C NMR (126 MHz, CDCl₃, ppm) δ 190.9, 186.9, 137.0, 133.8, 133.7, 132.7, 130.8, 128.2, 123.7, 120.3.





Methyl 4-(2-oxo-2-phenylethanothioamido)benzoate

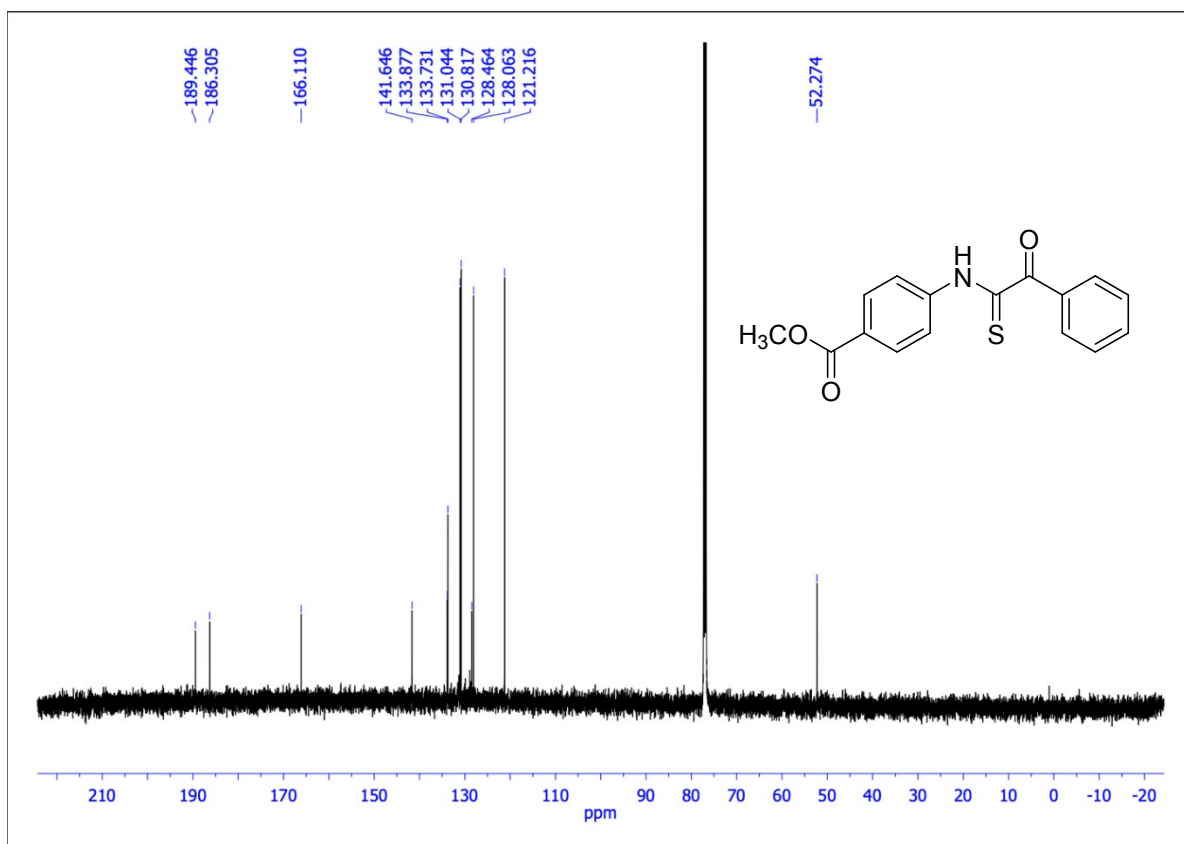
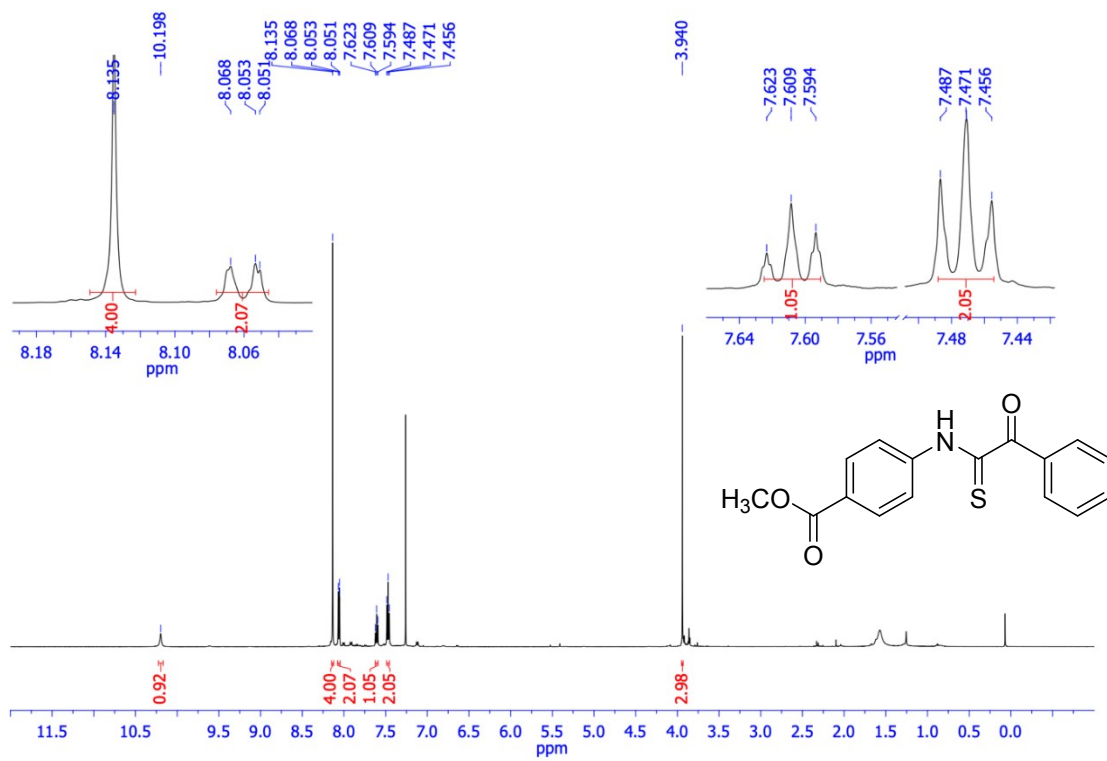
Yellow solid, mp 131–135 °C (decomposed)



^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.20 (bs, 1H), 8.14 (bs, 3H), 8.08 – 8.05 (m, 2H), 7.61 (t, $J = 7.5$ Hz, 1H), 7.47 (t, $J = 7.8$ Hz, 2H), 3.94 (bs, 3H).

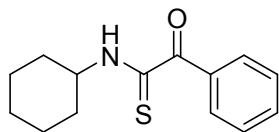
^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 189.4, 186.3, 166.1, 141.6, 133.8, 133.7, 131.0, 130.8, 128.5, 128.1, 121.2, 52.3.

HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{16}\text{H}_{14}\text{NO}_3\text{S}$: 300.0689, found: 300.0686.



***N*-Cyclohexyl-2-oxo-2-phenylethanethioamide**

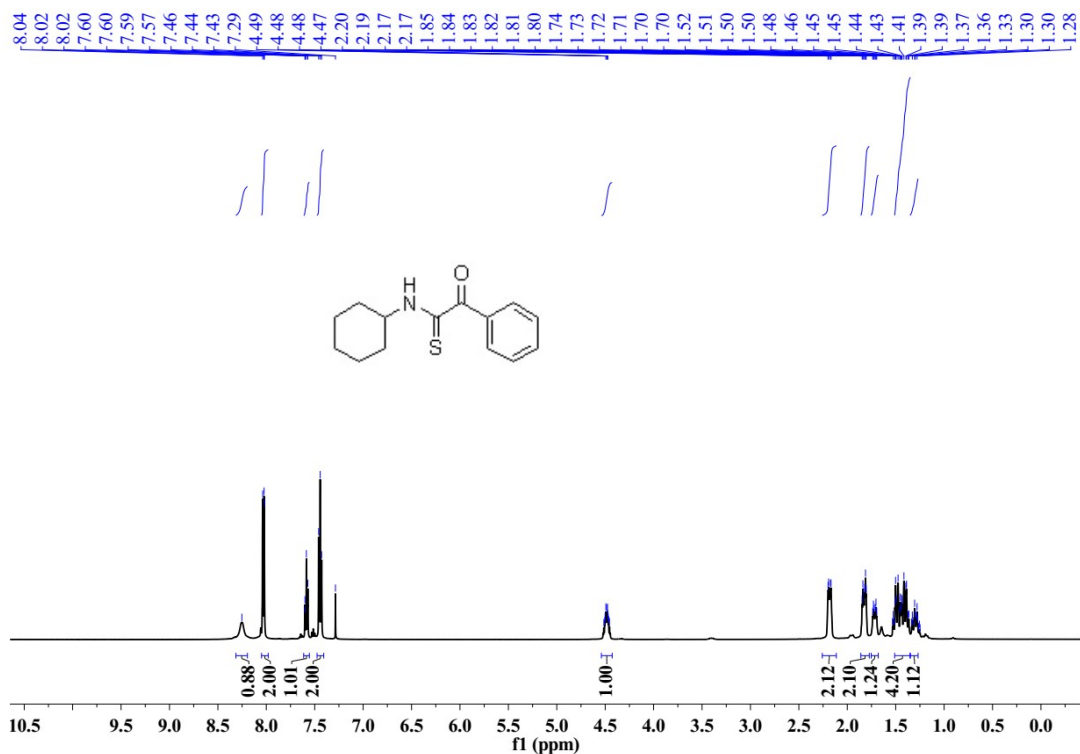
Tan solid, mp 80–83 °C

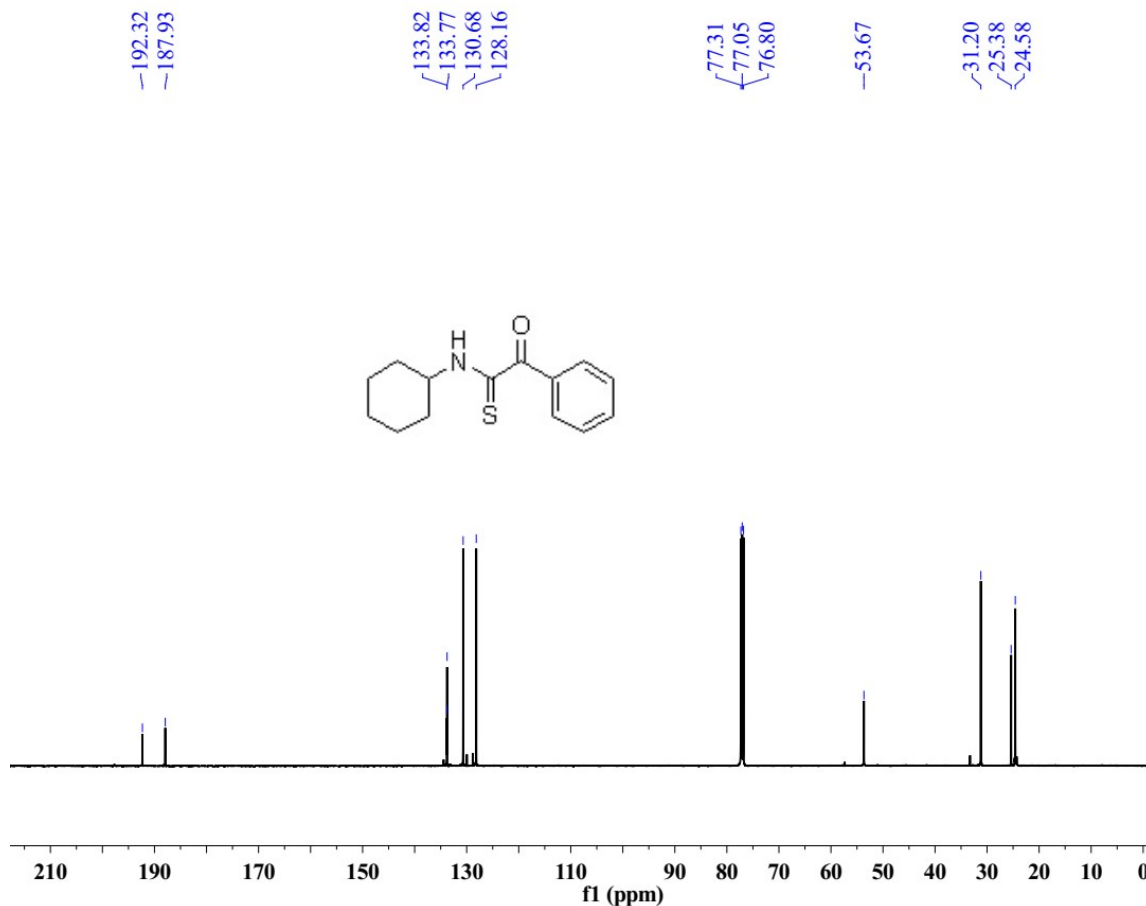


^1H NMR (500 MHz, CDCl_3 , ppm) δ 8.25 (s, 1H), 8.04 – 7.98 (m, 2H), 7.59 (dd, $J = 10.6$, 4.3 Hz, 1H), 7.44 (t, $J = 7.8$ Hz, 2H), 4.53 – 4.44 (m, 1H), 2.18 (dd, $J = 12.1$, 3.2 Hz, 2H), 1.86 – 1.78 (m, 2H), 1.76 – 1.68 (m, 1H), 1.51 – 1.35 (m, 4H), 1.30 (ddd, $J = 13.1$, 6.9, 3.5 Hz, 1H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 192.3, 187.9, 133.8, 133.8, 130.7, 128.2, 53.7, 31.2, 25.4, 24.6.

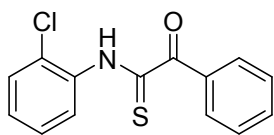
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{14}\text{H}_{18}\text{NOS}$: 248.1104, found: 248.1110.





***N*-(2-chlorophenyl)-2-oxo-2-phenylethanesulfonamide**

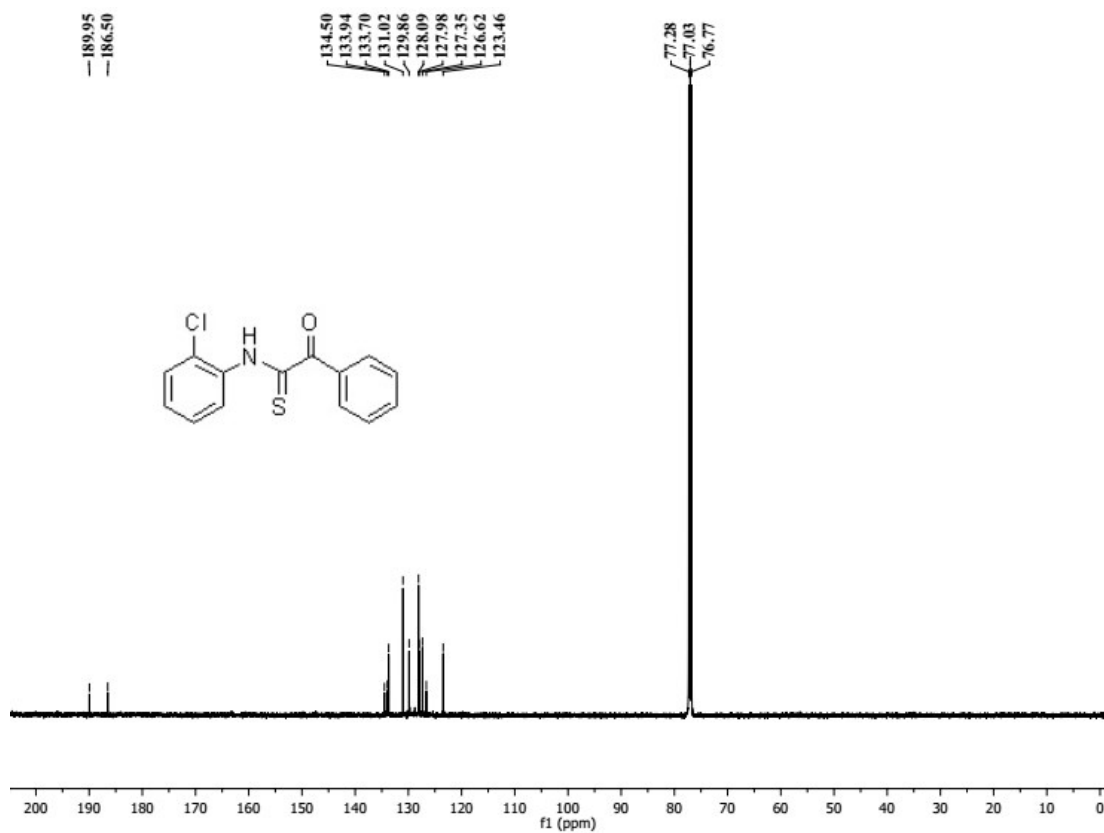
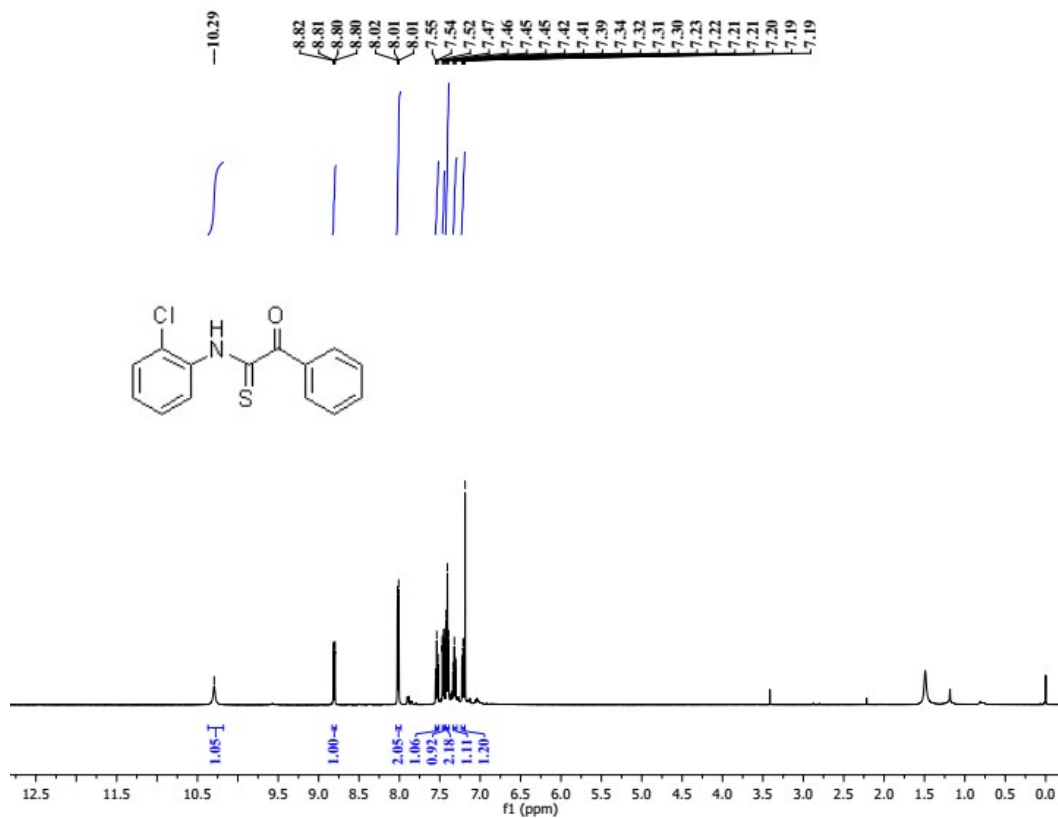
Yellow solid, mp 115–117 °C



¹H NMR (500 MHz, CDCl₃, ppm) δ 10.29 (s, 1H), 8.81 (dd, *J* = 8.2, 1.2 Hz, 1H), 8.04 – 7.97 (m, 2H), 7.54 (t, *J* = 7.5 Hz, 1H), 7.46 (dd, *J* = 8.0, 1.3 Hz, 1H), 7.41 (t, *J* = 7.8 Hz, 2H), 7.32 (dd, *J* = 12.0, 4.7 Hz, 1H), 7.21 (td, *J* = 7.9, 1.4 Hz, 1H).

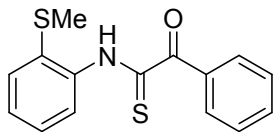
¹³C NMR (126 MHz, CDCl₃, ppm) δ 189.9, 186.5, 134.5, 133.9, 133.7, 131.0, 129.9, 128.1, 128.0, 127.3, 126.6, 123.5.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₁₄H₁₁³⁵ClNOS: 278.0215, found: 278.0212.



N-(2-(methylthio)phenyl)-2-oxo-2-phenylethanethioamide

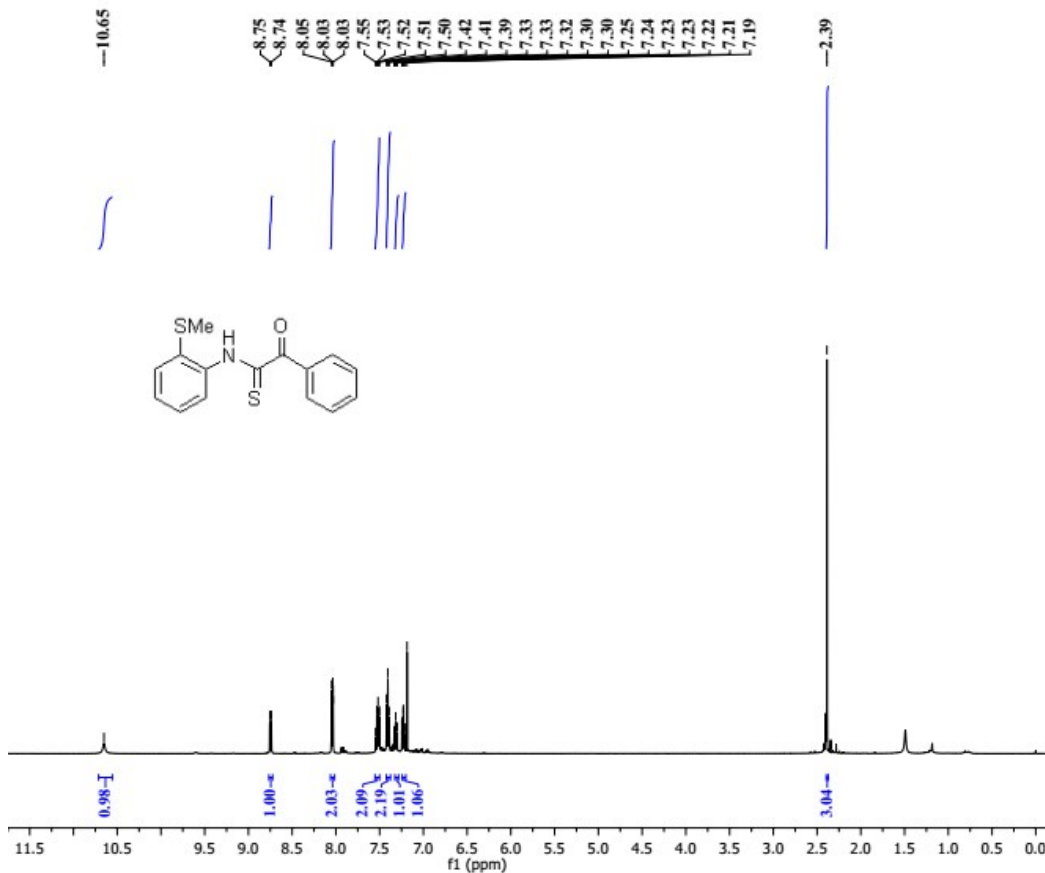
Yellow solid, mp 118–122 °C

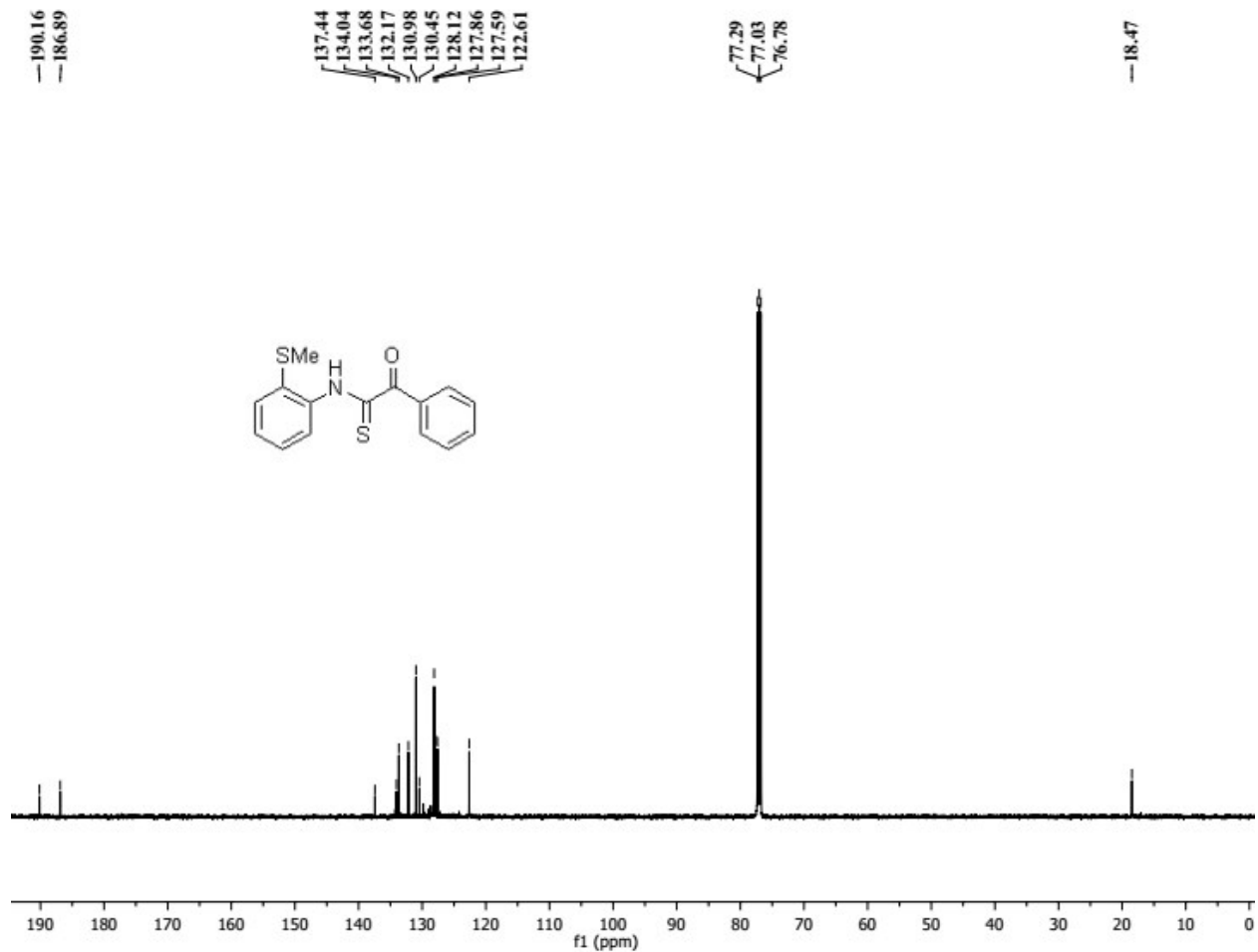


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.65 (s, 1H), 8.75 (d, $J = 8.1$ Hz, 1H), 8.06 – 8.02 (m, 2H), 7.55 – 7.50 (m, 2H), 7.41 (t, $J = 7.8$ Hz, 2H), 7.31 (dd, $J = 11.1, 4.5$ Hz, 1H), 7.23 (td, $J = 7.6, 1.3$ Hz, 1H), 2.39 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 190.2, 186.9, 137.4, 134.0, 133.7, 132.2, 131.0, 130.4, 128.1, 127.9, 127.6, 122.6, 18.5.

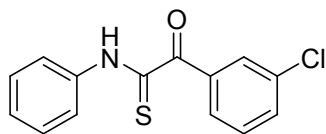
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{14}\text{NOS}_2$: 288.0511, found: 288.0515.





2-(3-Chlorophenyl)-2-oxo-N-phenylethanethioamide

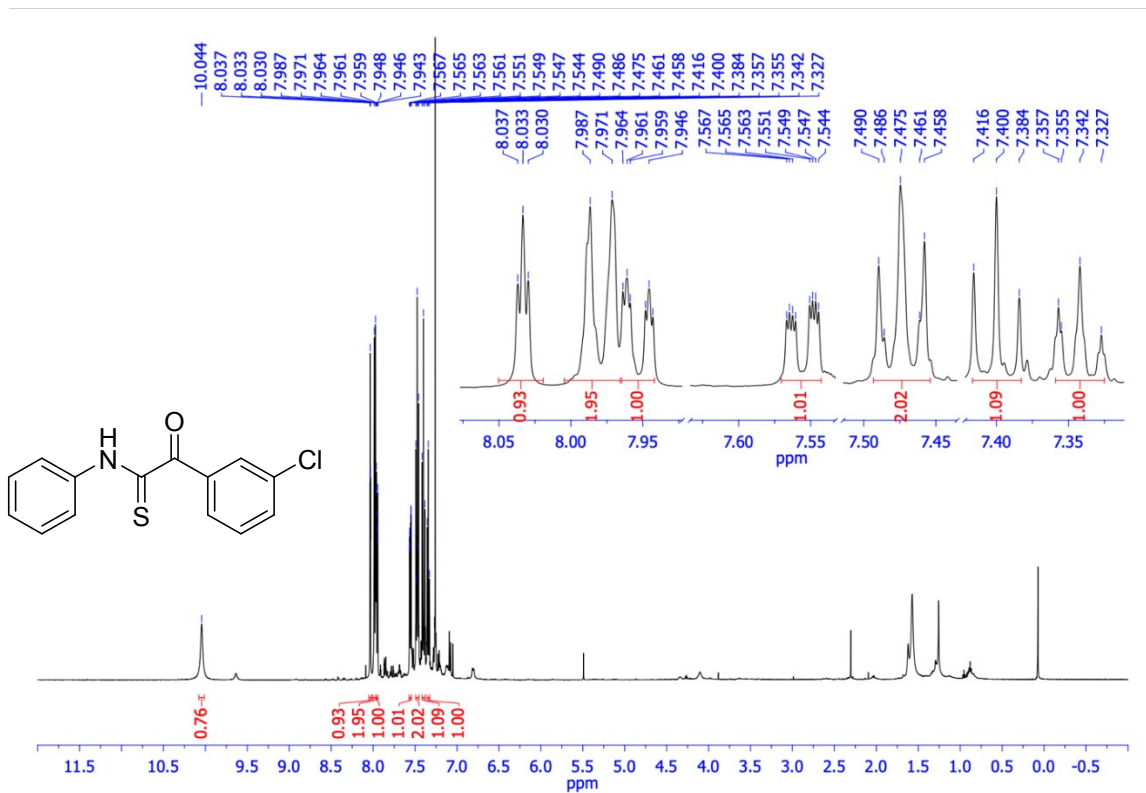
Yellow solid, mp 115–117 °C

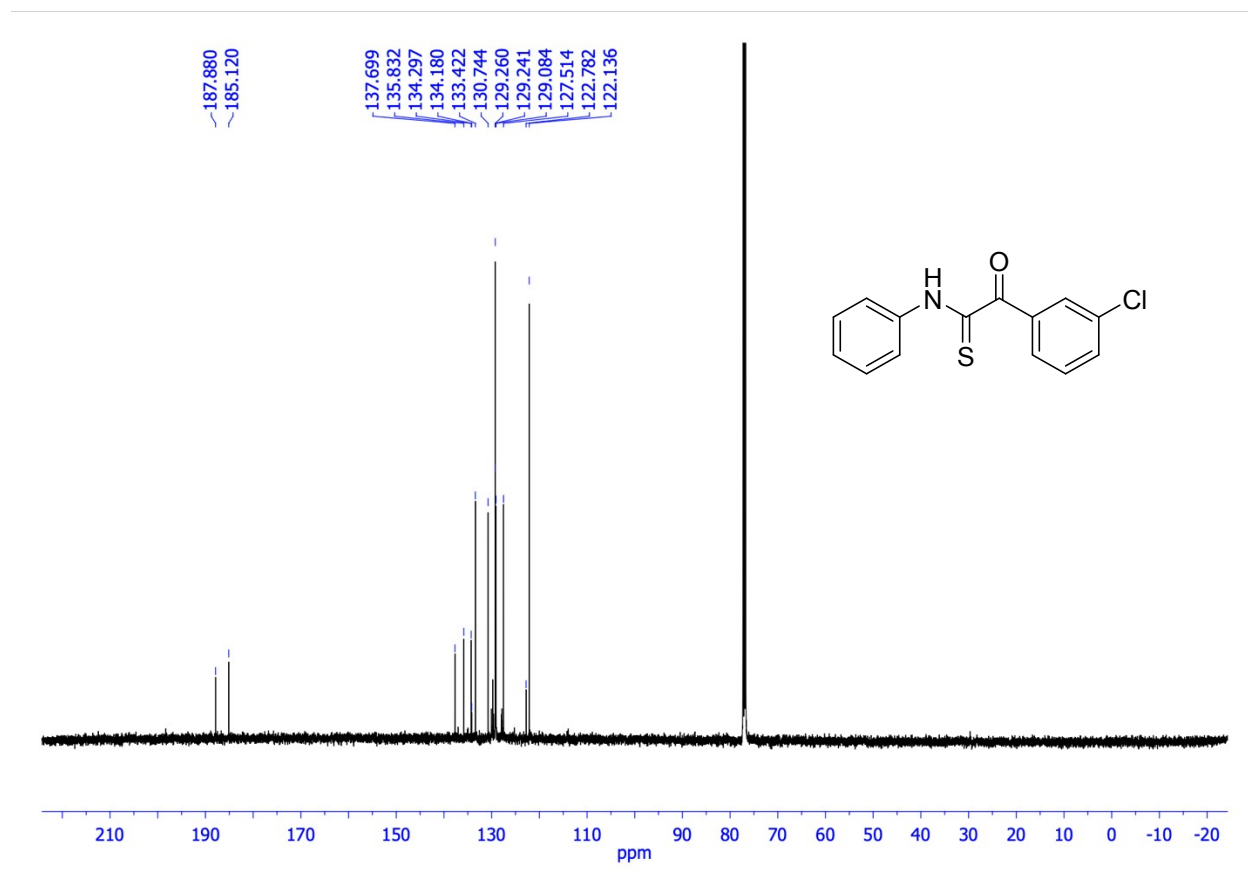


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.04 (bs, 1H), 8.03 (t, $J = 1.8$ Hz, 1H), 7.98 (d, $J = 7.7$ Hz, 2H), 7.97 – 7.94 (m, 1H), 7.56 (ddd, $J = 8.0, 2.1, 1.0$ Hz, 1H), 7.49 – 7.46 (m, 2H), 7.40 (dd, $J = 9.2, 6.6$ Hz, 1H), 7.35 (dd, $J = 10.7, 4.2$ Hz, 1H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 187.9, 185.1, 137.7, 135.8, 134.3, 133.4, 130.7, 129.3, 129.0, 127.5, 122.8, 122.1.

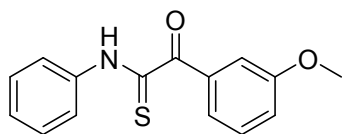
HRMS (ESI): m/z $[M+H]^+$ calcd for $C_{14}H_{11}^{35}ClNO$: 278.0215, found: 278.0210.





2-(3-Methoxyphenyl)-2-oxo-N-phenylethanethioamide

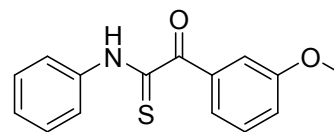
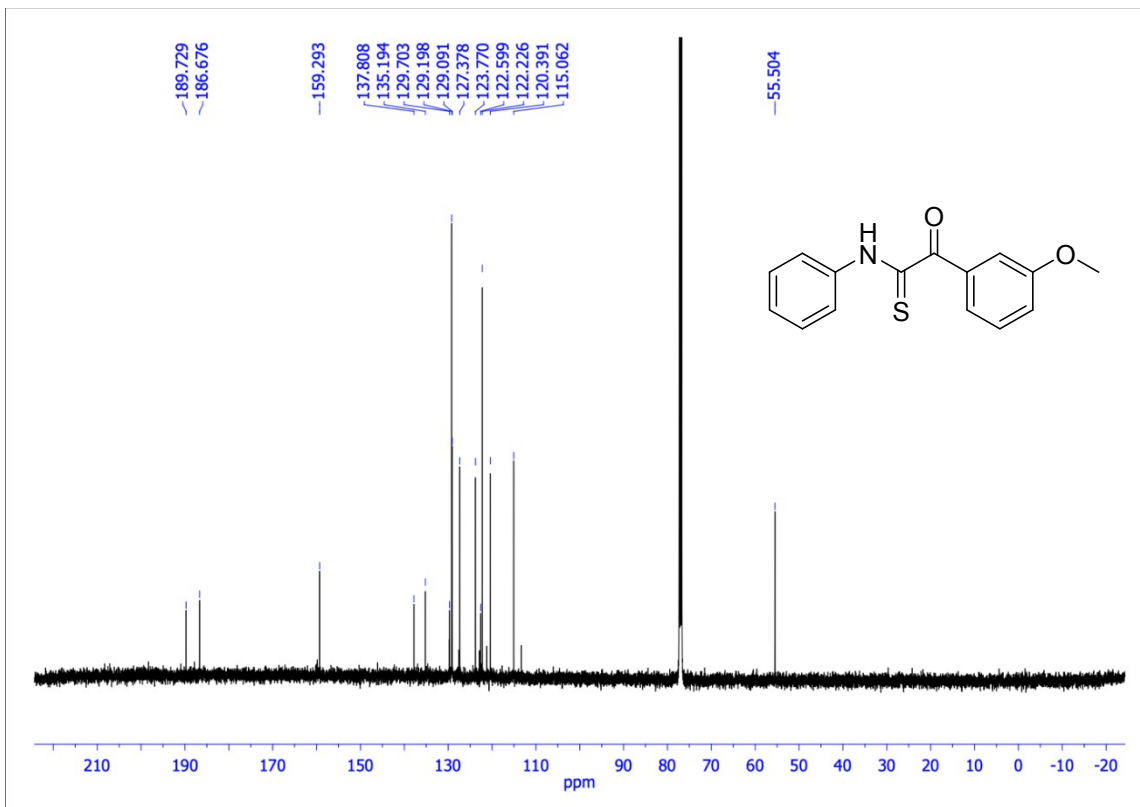
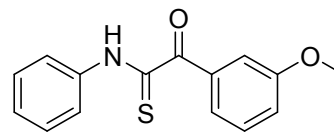
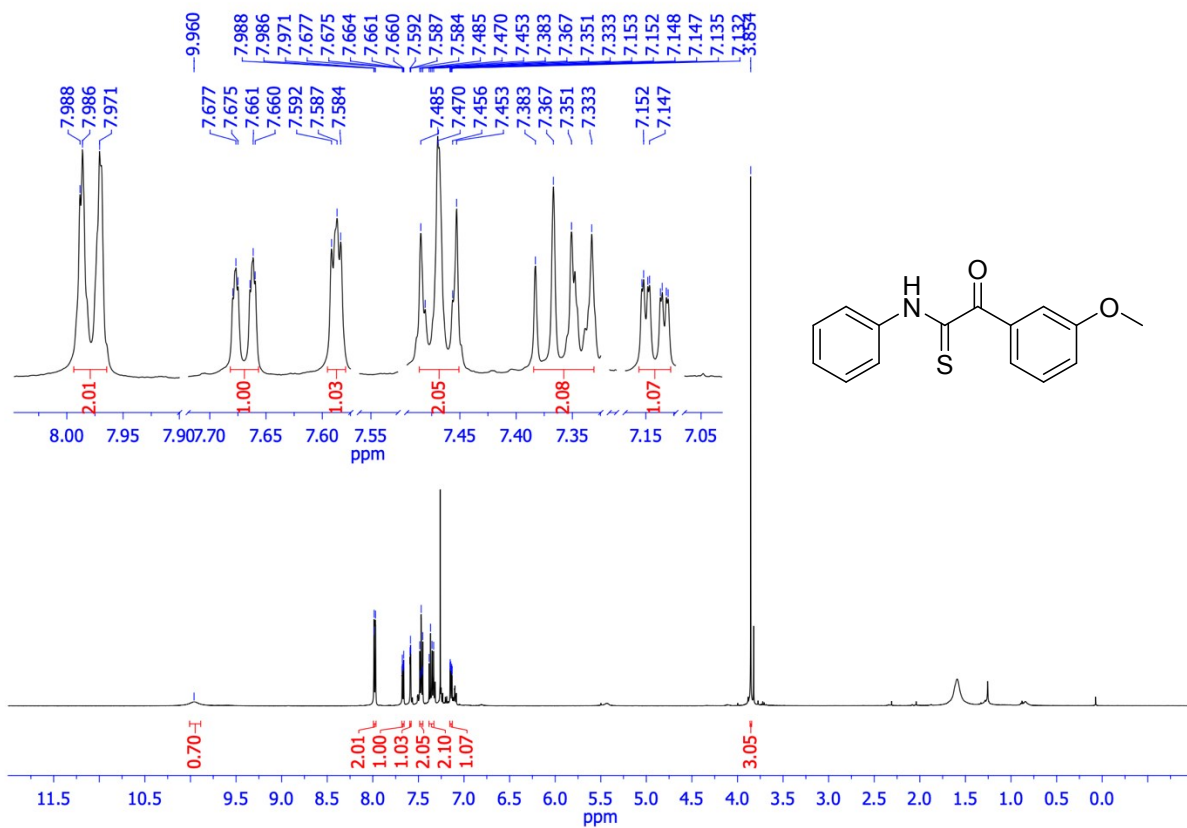
Yellow oil which slowly solidified under air



¹H NMR (500 MHz, CDCl₃, ppm) δ 9.96 (bs, 1H), 7.99 – 7.96 (m, 1H), 7.68 – 7.65 (m, 1H), 7.60 – 7.58 (m, 1H), 7.49 – 7.45 (m, 1H), 7.39 – 7.33 (m, 1H), 7.14 (ddd, *J* = 8.3, 2.6, 0.8 Hz, 1H), 3.85 (bs, 2H).

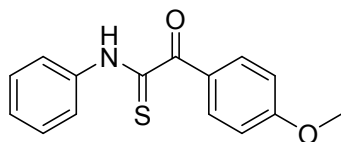
¹³C NMR (126 MHz, CDCl₃, ppm) δ 189.7, 186.6, 159.2, 137.8, 135.2, 129.7, 129.2, 127.4, 123.8, 122.6, 120.4, 115.0.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₁₅H₁₄NO₂S: 272.0740, found: 272.0733.



2-(4-Methoxyphenyl)-2-oxo-N-phenylethanethioamide

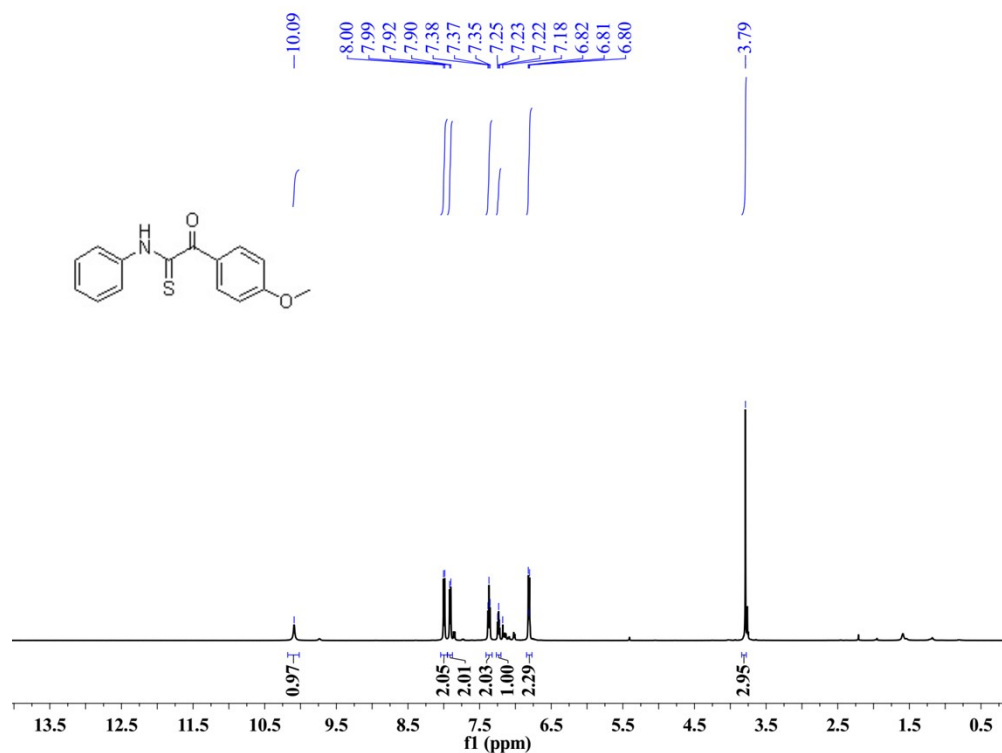
Yellow oil which slowly solidified under air

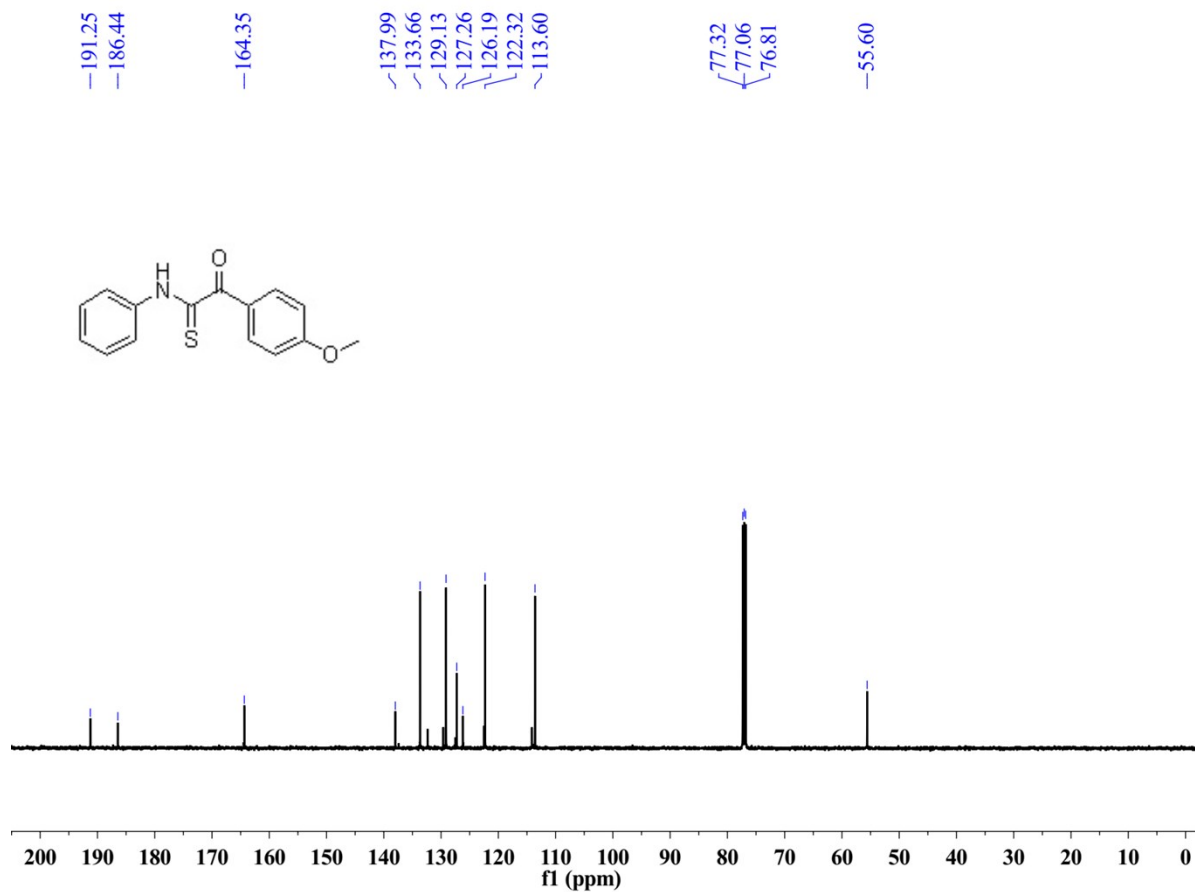


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.09 (s, 1H), 7.99 (d, $J = 8.8$ Hz, 2H), 7.91 (d, $J = 7.8$ Hz, 2H), 7.37 (t, $J = 7.9$ Hz, 2H), 7.23 (t, $J = 7.4$ Hz, 1H), 6.85 – 6.77 (m, 2H), 3.79 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 191.2, 186.4, 164.3, 138.0, 133.6, 129.1, 127.3, 126.2, 122.3, 113.6, 55.6.

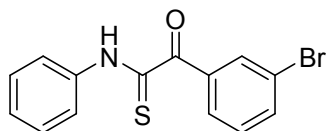
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{14}\text{NO}_2\text{S}$: 272.0740, found: 272.0738.





2-(3-Bromophenyl)-2-oxo-N-phenylethanethioamide

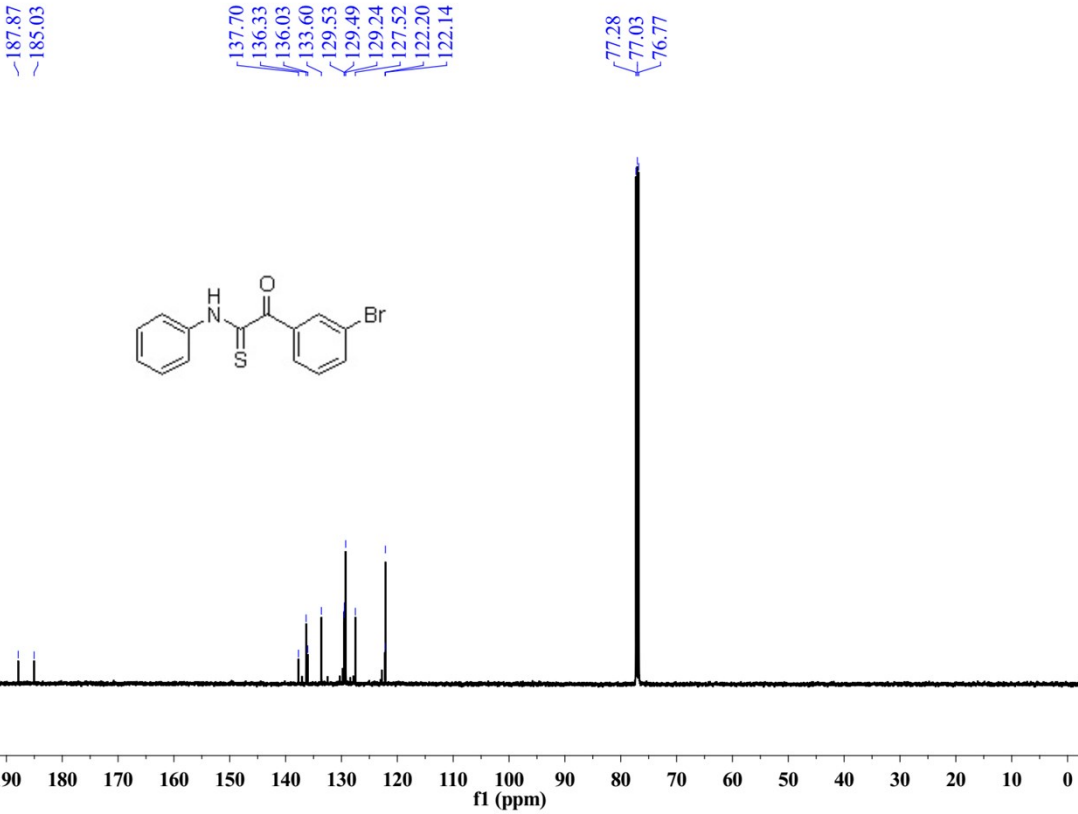
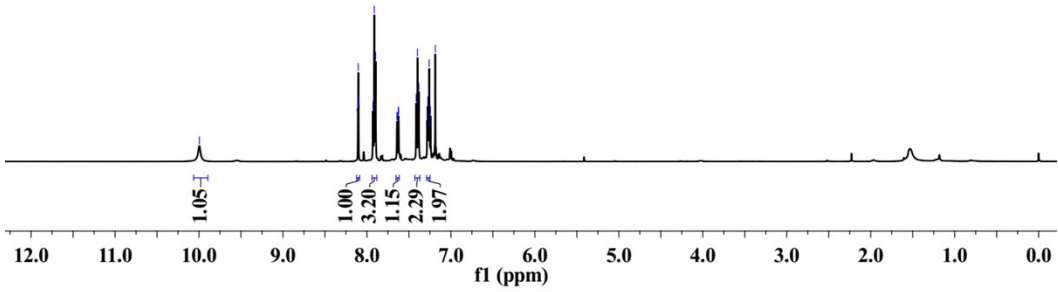
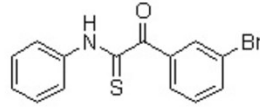
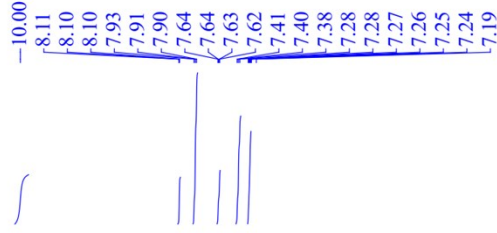
Yellow solid, mp 131–133 °C



^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.00 (s, 1H), 8.10 (t, $J = 1.7$ Hz, 1H), 7.91 (t, $J = 7.8$ Hz, 3H), 7.63 (dd, $J = 8.0, 0.8$ Hz, 1H), 7.40 (t, $J = 7.9$ Hz, 2H), 7.27 (dd, $J = 7.7, 3.5$ Hz, 2H).

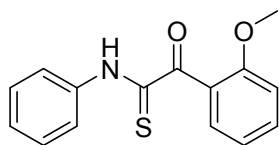
^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 187.9, 185.0, 137.7, 136.3, 136.0, 133.6, 129.53, 129.49, 129.2, 127.5, 122.2, 122.1.

HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{14}\text{H}_{11}^{79}\text{BrNOS}$: 319.9739, found: 319.9730.



2-(2-Methoxyphenyl)-2-oxo-N-phenylethanethioamide

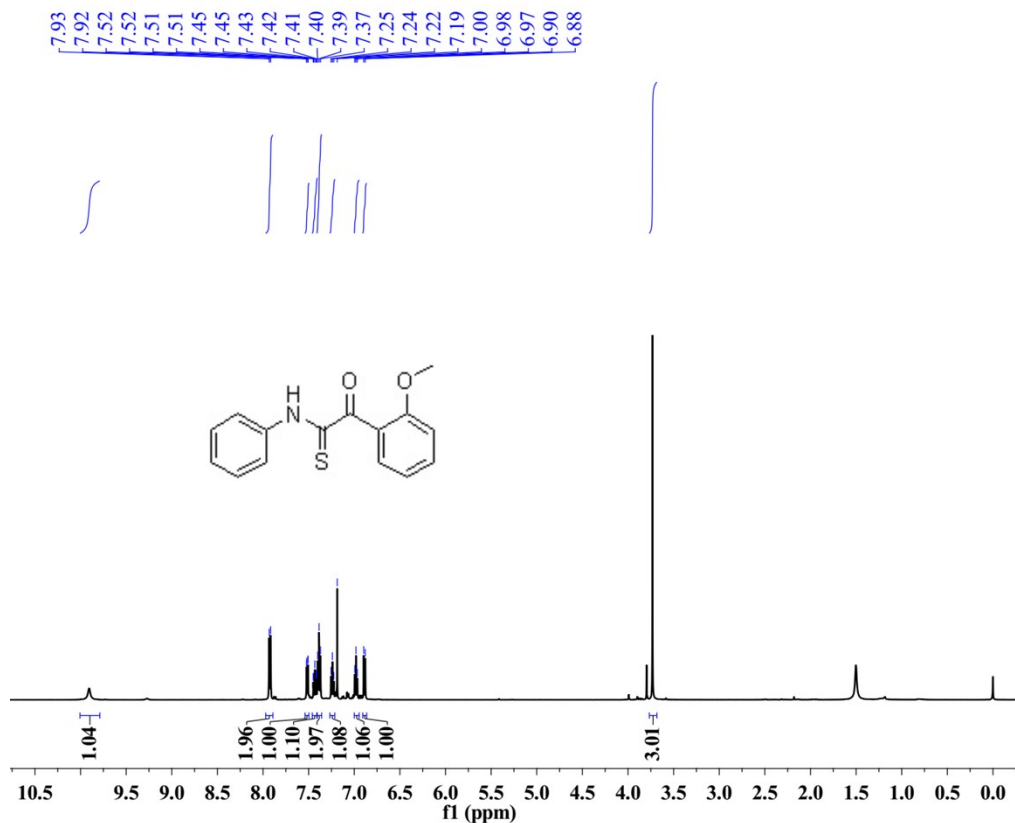
Yellow solid, mp 85–87 °C

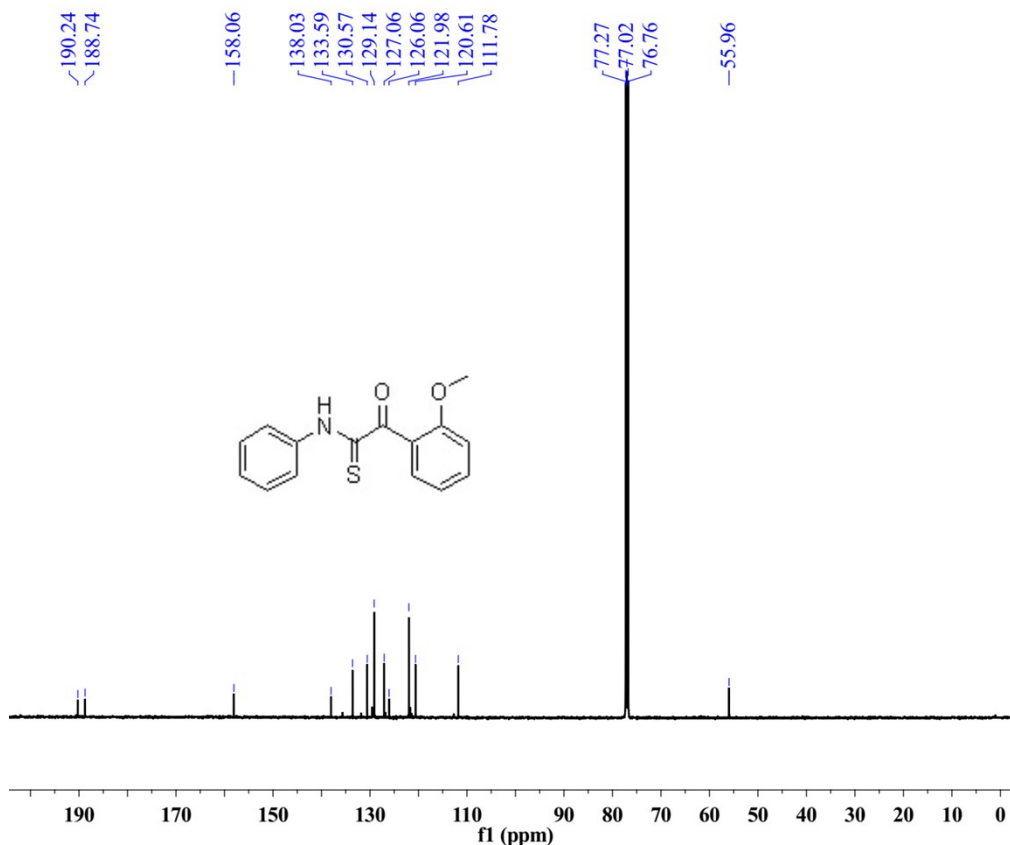


^1H NMR (500 MHz, CDCl_3 , ppm) δ 9.91 (s, 1H), 7.92 (d, $J = 7.7$ Hz, 2H), 7.51 (dd, $J = 7.6, 1.6$ Hz, 1H), 7.45 – 7.40 (m, 1H), 7.39 (t, $J = 7.9$ Hz, 2H), 7.24 (t, $J = 7.5$ Hz, 1H), 6.98 (t, $J = 7.2$ Hz, 1H), 6.89 (d, $J = 8.4$ Hz, 1H), 3.73 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 190.2, 188.7, 158.0, 138.0, 133.6, 130.6, 129.1, 127.1, 126.1, 122.0, 120.6, 111.8, 55.9.

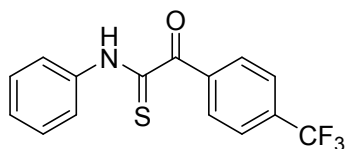
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{15}\text{H}_{14}\text{NO}_2\text{S}$: 272.0740, found: 272.0742.





2-Oxo-N-phenyl-2-(4-(trifluoromethyl)phenyl)ethanethioamide

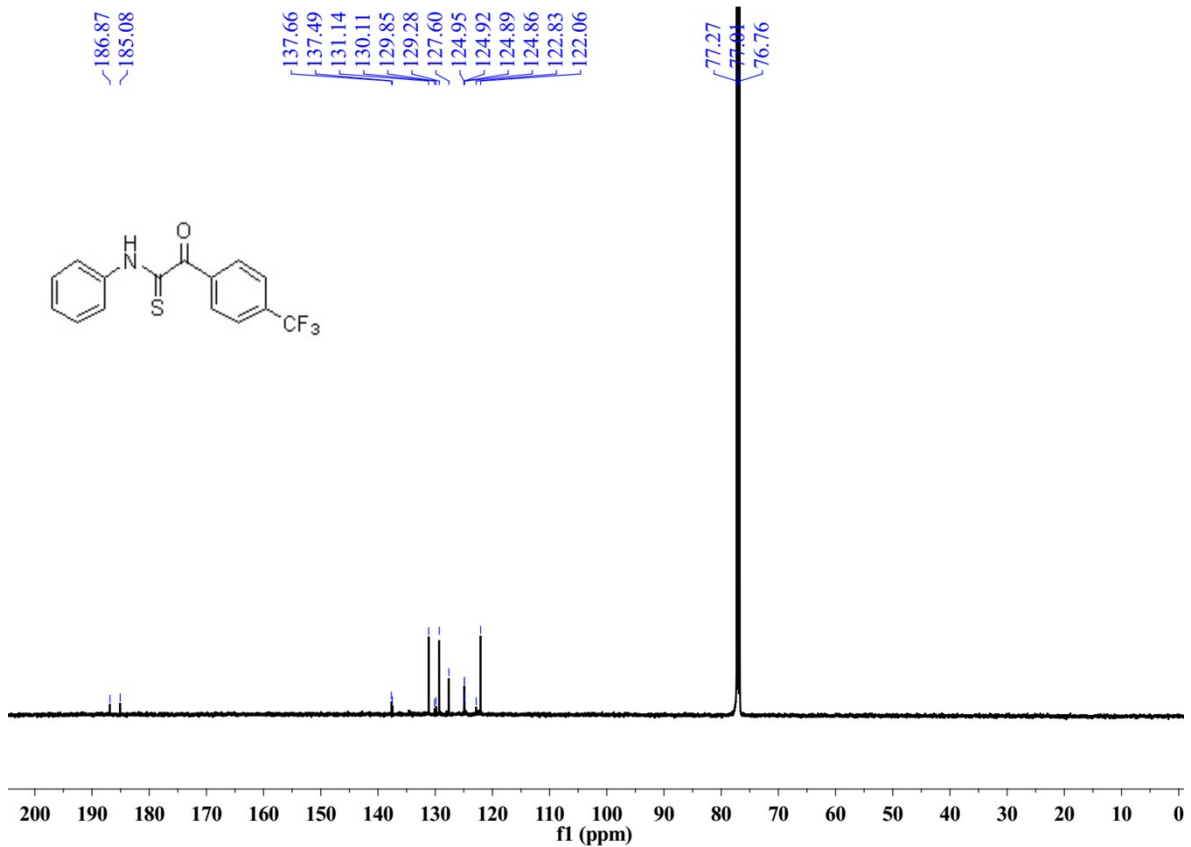
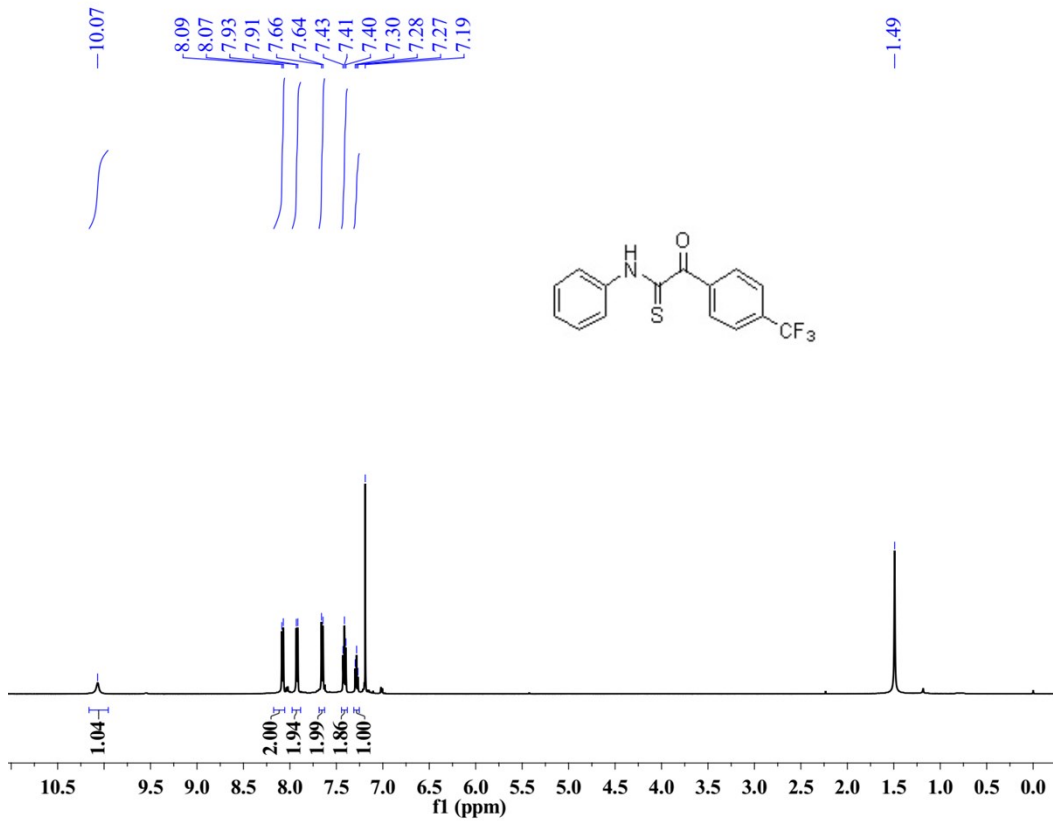
Yellow oil which slowly solidified under air.



¹H NMR (500 MHz, CDCl₃, ppm) δ 10.07 (s, 1H), 8.08 (d, *J* = 8.2 Hz, 2H), 7.92 (d, *J* = 8.0 Hz, 2H), 7.65 (d, *J* = 8.4 Hz, 2H), 7.41 (t, *J* = 7.9 Hz, 2H), 7.28 (t, *J* = 7.4 Hz, 1H).

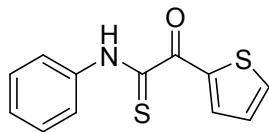
¹³C NMR (126 MHz, CDCl₃, ppm) δ 186.9, 185.1, 137.7, 137.5, 130.0 (q, *J* = 32.8 Hz), 131.1, 129.3, 127.6, 124.9 (q, *J* = 3.7 Hz), 123.8 (q, *J* = 264.6 Hz), 122.1.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₁₅H₁₁F₃NOS: 310.0508, found: 310.0502.



2-Oxo-N-phenyl-2-(thiophen-2-yl)ethanethioamide

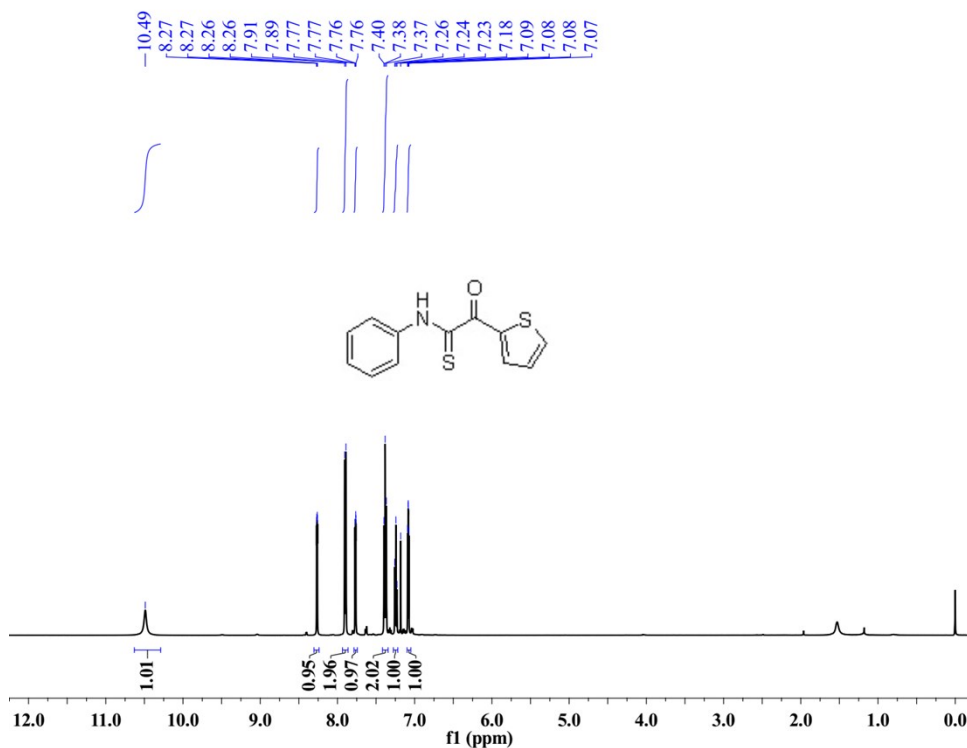
Colorless oil which slowly solidified under air.

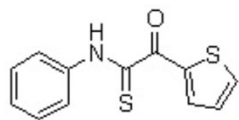
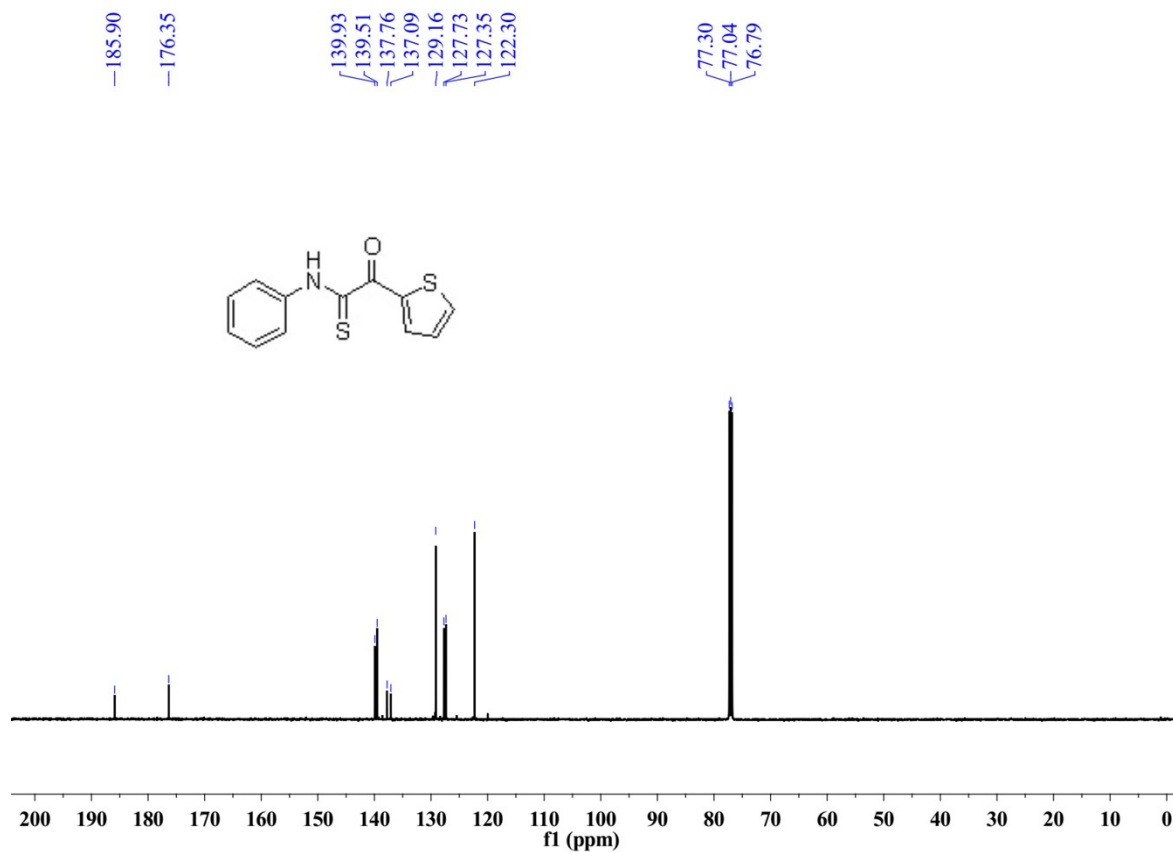


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.49 (bs, 1H), 8.26 (dd, $J = 3.9, 1.2$ Hz, 1H), 7.90 (d, $J = 7.8$ Hz, 2H), 7.77 (dd, $J = 4.9, 1.1$ Hz, 1H), 7.38 (t, $J = 7.9$ Hz, 2H), 7.24 (t, $J = 7.4$ Hz, 1H), 7.08 (dd, $J = 4.8, 4.1$ Hz, 1H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 185.9, 176.3, 139.9, 139.5, 137.7, 137.1, 129.1, 127.7, 127.3, 122.3.

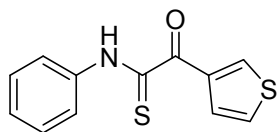
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{12}\text{H}_{10}\text{NOS}_2$: 248.0198, found: 248.0192.





2-Oxo-N-phenyl-2-(thiophen-3-yl)ethanethioamide

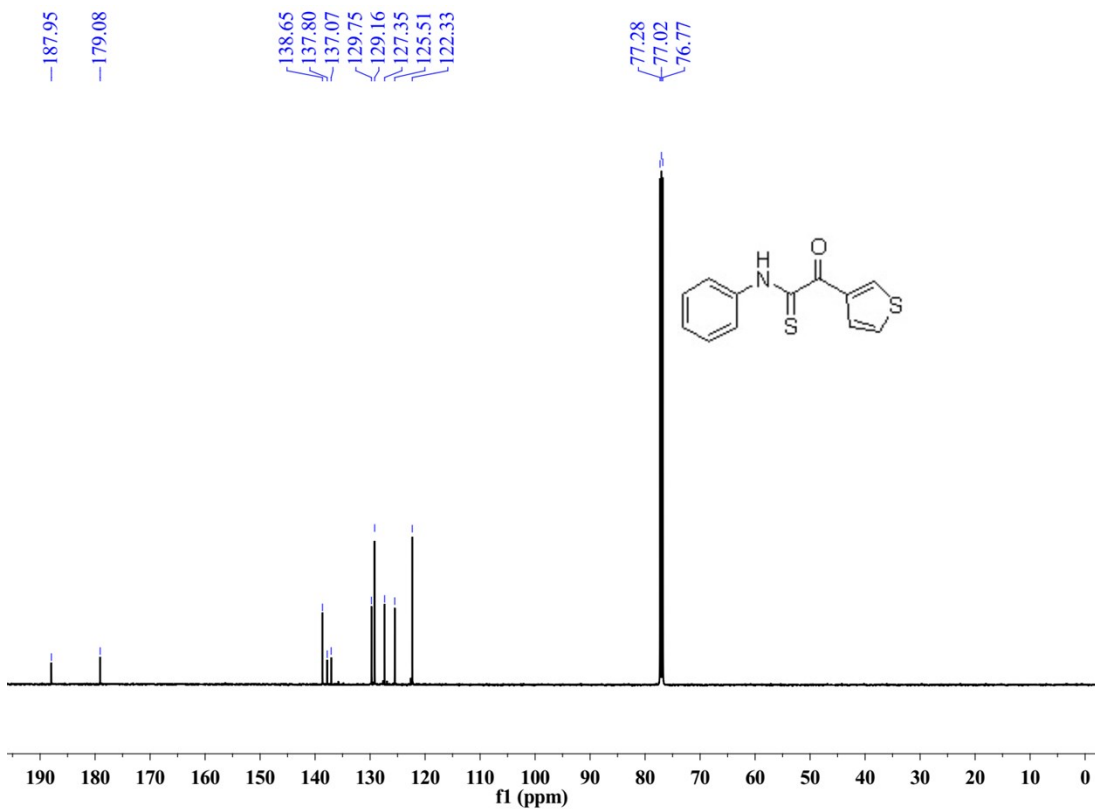
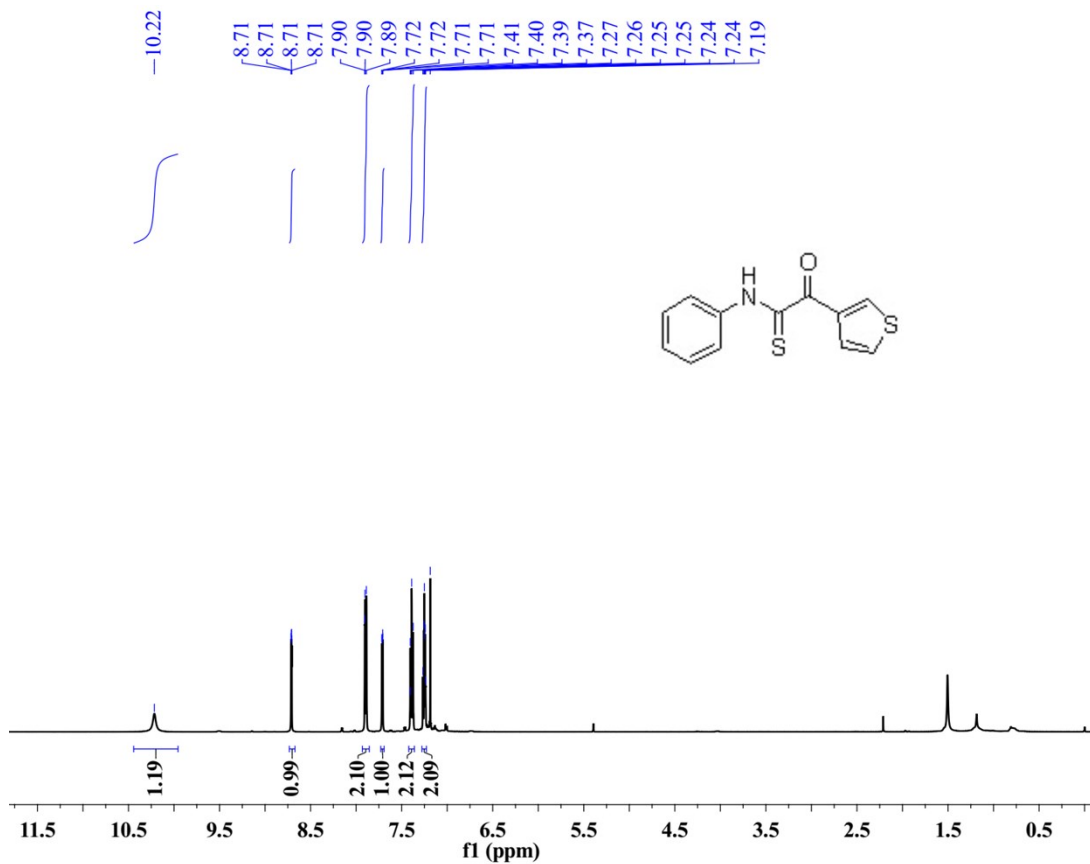
Yellow solid, mp 135–138 °C



^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.22 (bs, 1H), 8.71 (dd, $J = 2.9, 1.2$ Hz, 1H), 7.93 – 7.86 (m, 2H), 7.71 (dd, $J = 5.1, 1.2$ Hz, 1H), 7.39 (dd, $J = 10.8, 5.1$ Hz, 2H), 7.25 (dt, $J = 4.4, 3.4$ Hz, 2H).

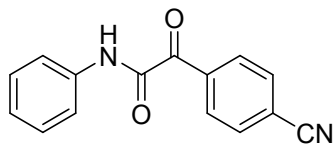
^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 187.9, 179.1, 138.6, 137.8, 137.1, 129.7, 129.2, 127.3, 125.5, 122.3.

HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{12}\text{H}_{10}\text{NOS}_2$: 248.0198, found: 248.0201.



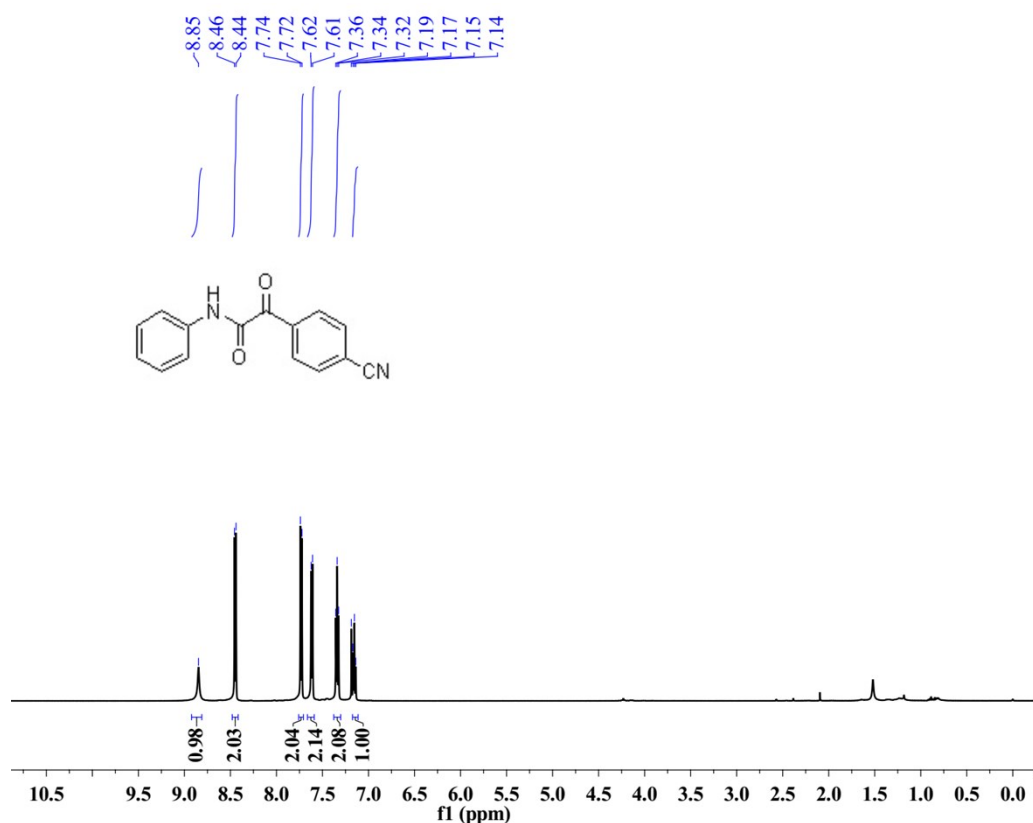
2-(4-Cyanophenyl)-2-oxo-N-phenylacetamide²

Yellow solid, mp 142–144 °C

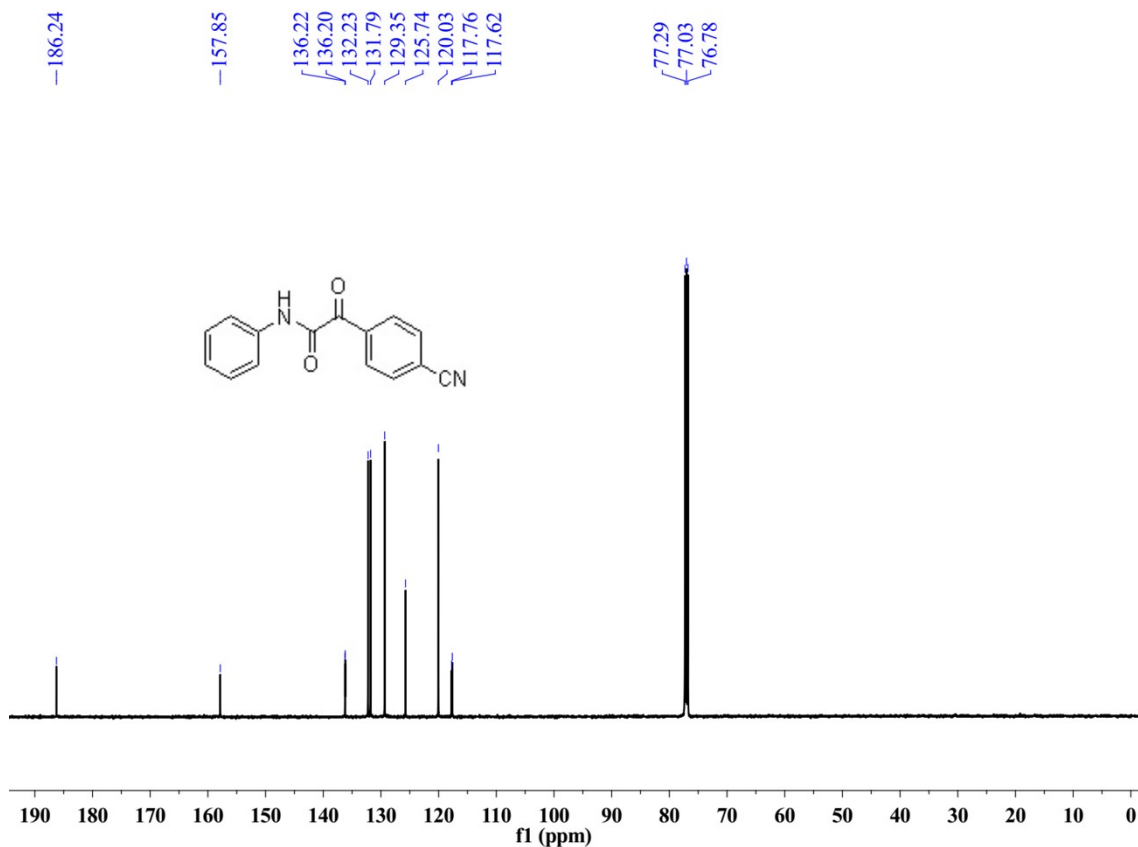


¹H NMR (500 MHz, CDCl₃, ppm) δ 8.85 (s, 1H), 8.45 (d, *J* = 8.6 Hz, 2H), 7.73 (d, *J* = 8.6 Hz, 2H), 7.62 (d, *J* = 7.7 Hz, 2H), 7.34 (t, *J* = 8.0 Hz, 2H), 7.15 (t, *J* = 7.4 Hz, 1H).

¹³C NMR (126 MHz, CDCl₃, ppm) δ 186.2, 157.8, 136.2, 136.2, 132.2, 131.8, 129.3, 125.7, 120.0, 117.7, 117.6.

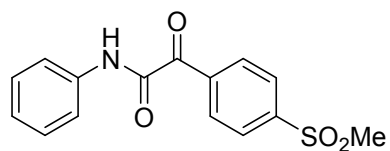


² A. Sagadevan, A. Ragupathi, C.-C. Lin, J. R. Hwu, and K. C. Hwang, *Green Chem.*, 2015, **17**, 1113.



2-(4-(Methylsulfonyl)phenyl)-2-oxo-N-phenylacetamide

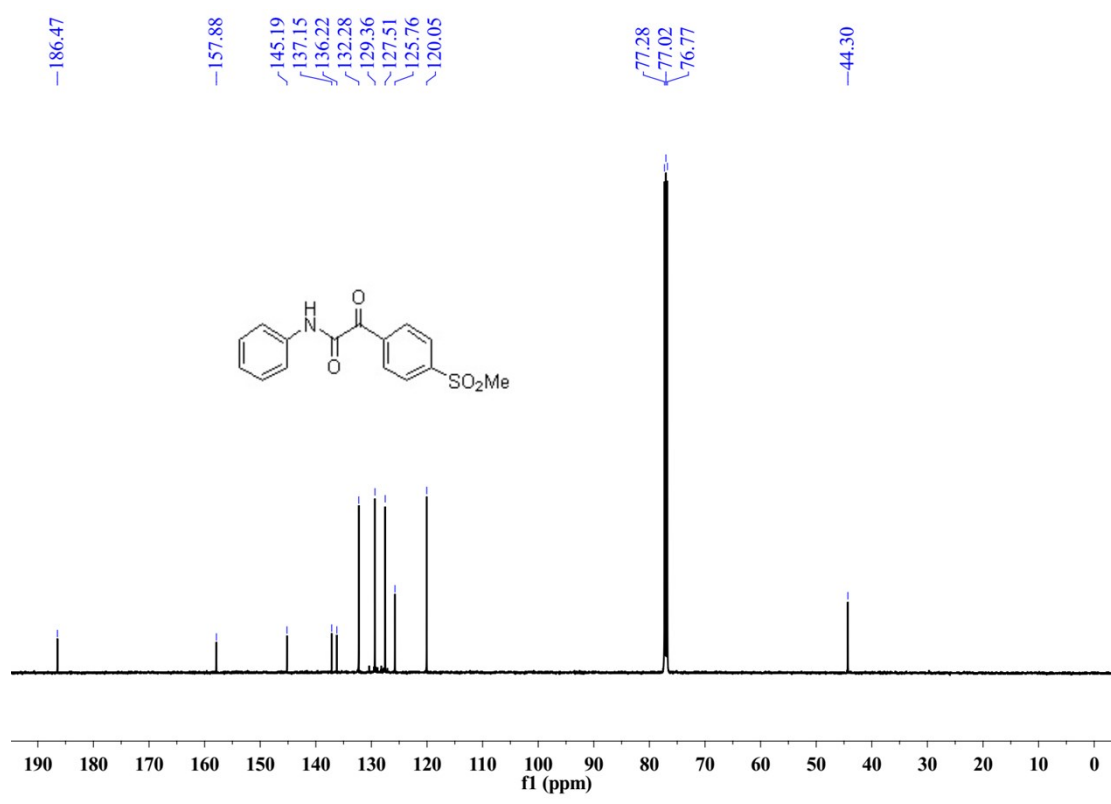
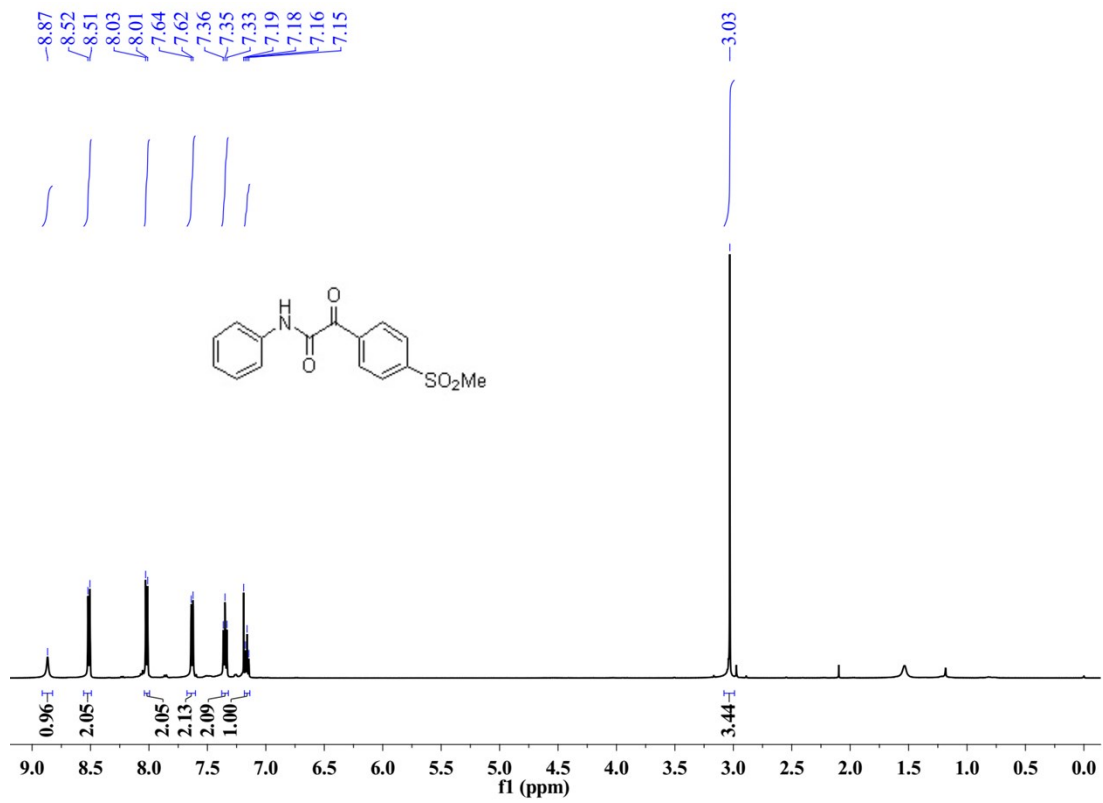
Yellow solid, mp 157–159 °C



¹H NMR (500 MHz, CDCl₃, ppm) δ 8.87 (s, 1H), 8.51 (d, *J* = 8.6 Hz, 2H), 8.02 (d, *J* = 8.6 Hz, 2H), 7.63 (d, *J* = 7.7 Hz, 2H), 7.35 (t, *J* = 8.0 Hz, 2H), 7.16 (t, *J* = 7.4 Hz, 1H), 3.03 (s, 3H).

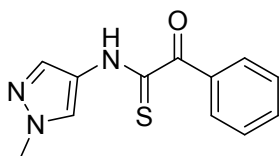
¹³C NMR (126 MHz, CDCl₃, ppm) δ 186.4, 157.9, 145.2, 137.1, 136.2, 132.3, 129.3, 127.5, 125.7, 120.0, 44.3.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₁₅H₁₄NO₄S: 304.0638, found: 304.0631.



N-(1-methyl-1*H*-pyrazol-4-yl)-2-oxo-2-phenylethioamide

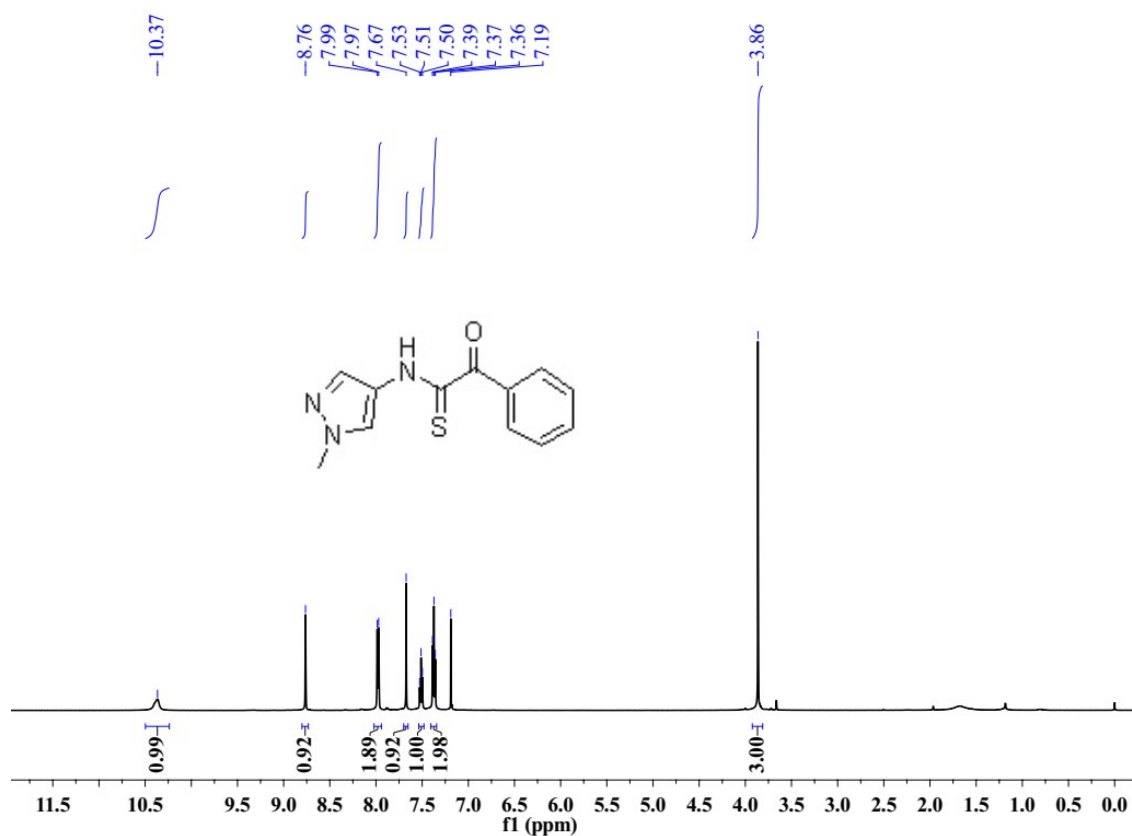
Yellow oil which slowly solidified under air

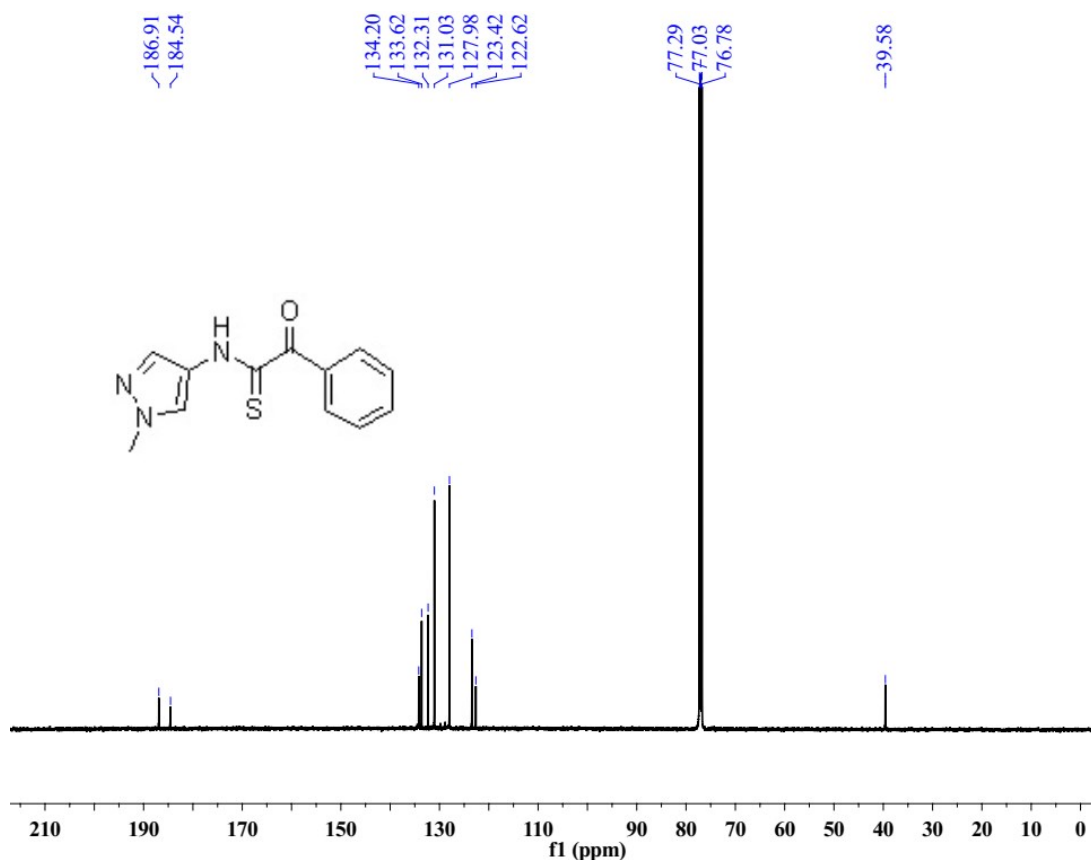


^1H NMR (500 MHz, CDCl_3 , ppm) δ 10.37 (s, 1H), 8.76 (s, 1H), 7.98 (d, $J = 7.3$ Hz, 2H), 7.67 (s, 1H), 7.51 (t, $J = 7.4$ Hz, 1H), 7.37 (t, $J = 7.8$ Hz, 2H), 3.86 (s, 3H).

^{13}C NMR (126 MHz, CDCl_3 , ppm) δ 186.9, 184.5, 134.2, 133.6, 132.3, 131.0, 128.0, 123.4, 122.6, 39.6.

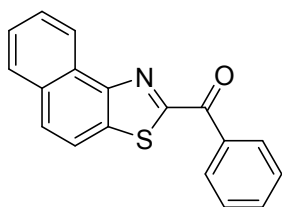
HRMS (ESI): m/z $[\text{M}+\text{H}]^+$ calcd for $\text{C}_{12}\text{H}_{12}\text{N}_3\text{OS}$: 246.0696, found: 246.0690.





Naphtho[1,2-*d*]thiazol-2-yl(phenyl)methanone

Yellow oil which slowly solidified under air



¹H NMR (500 MHz, CDCl₃, ppm) δ 8.79 (t, *J* = 7.0 Hz, 1H), 8.67 – 8.59 (m, 2H), 7.93 – 7.82 (m, 3H), 7.69 – 7.59 (m, 2H), 7.54 (dt, *J* = 25.2, 7.8 Hz, 3H).

¹³C NMR (126 MHz, CDCl₃, ppm) δ 184.7, 166.0, 150.6, 135.3, 135.2, 133.7, 132.1, 131.5, 129.7, 128.9, 128.5, 128.4, 127.7, 126.8, 123.8, 119.1.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₁₈H₁₂NOS: 290.0634, found: 290.0632.

