Synthesis of γ-keto sulfones by copper catalyzed oxidative sulfonylation of tertiary cyclopropanols

Yulia A. Konik,[a] Gábor Zoltán Elek,[b] Sandra Kaabel,[b] Ivar Järving,[b] Margus Lopp[b] and Dzmitry G. Kananovich[b] *

[a] Department of Organic Chemistry, Belarusian State University,
Leningradskaya 14, 220050, Minsk, Belarus;
[b] Department of Chemistry and Biotechnology, Tallinn University of Technology,
Akadeemia tee 15, 12618 Tallinn, Estonia

*E-mail: *dzmitry.kananovich@ttu.ee*

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I. General information

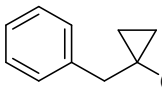
Solvents were purchased from Sigma-Aldrich, Honeywell, Fluorochem, Penta and used as obtained without any further purification. All other chemicals were purchased from Sigma-Aldrich, Fluorochem, TCI and Alfa Aesar. Fluorinated methylsulfinate salts (CHF_2SO_2Na and CH_2FSO_2Na) were ordered from Aspira Scientific.

Silica gel 40 – 100 μm was used for column chromatography; silica gel 60 F_{254} plates were used for TLC. ^1H NMR (400 MHz), ^{13}C NMR (100.6 MHz) and ^{19}F NMR (376 MHz) spectra were recorded on a Bruker Avance III spectrometer. Chemical shifts were given in δ value with $CHCl_3$ (δ = 7.26) and $CDCl_3$ (δ = 77.16) as internal standards for ^1H NMR and ^{13}C NMR spectra, respectively. FT-IR spectra were recorded on a Bruker Tensor 27 FT spectrometer. HRMS data was obtained on an Agilent HPLC/Q-TOF G6540A Mass Spectrometer using APCI or AJESI methods in positive ion detection modes. GC-MS analysis was performed on a Shimadzu GCMS-QP2010 instrument. Melting points were determined with Stuart SMP40 apparatus.

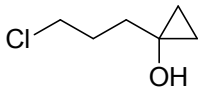
II. Synthesis and characterization of cyclopropanols

Cyclopropanols were synthesized using the Kulinkovich reaction.[1]

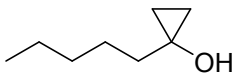
General procedure for cyclopropanation of carboxylic esters. Preparation of cyclopropanols 1a-c, 1g. To a stirred solution of ester (25 mmol) and titanium(IV) isopropoxide (0.74 mL, 2.5 mmol, 10 mol%) in diethyl ether (50 mL) was added slowly over 2–3 h at room temperature a solution of EtMgBr (60 mmol) in diethyl ether (60 mL). The reaction mixture was stirred for additional 30 min and then cooled with an ice bath. The reaction mixture was hydrolyzed by slow addition of cold 10% H_2SO_4 solution (50 mL) and then extracted with ether (3 × 40 mL). The combined organic layers were washed with saturated $NaHCO_3$ solution, brine and dried ($MgSO_4$). After evaporation of solvent under reduced pressure the cyclopropanol products can be purified using distillation or column chromatography on silica gel. However, in most cases they are pure enough to be used directly in the next step. The following cyclopropanol products were synthesized using the procedure described above:



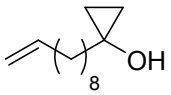
1-Benzylcyclopropanol (1a), starting from isopropyl phenylacetate.[2] Yield 88% (3.26 g). Purified using short-column silica gel chromatography. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.37 − 7.22 (m, 5H), 2.89 (s, 2H), 1.93 (s, 1H), 0.83 – 0.80 (m, 2H), 0.66 – 0.63 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 138.73, 129.57, 128.68, 126.79, 56.30, 44.26, 13.41.



1-(3-Chloropropyl)cyclopropanol (1c), starting from ethyl 4-chlorobutanoate.[3] Yield 86% (2.89 g). Purified using short-column silica gel chromatography. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.64 (t, *J* = 6.5 Hz, 2H), 2.08 – 2.01 (m, 2H), 1.80 (br s, 1H), 1.72 – 1.67 (m, 2H), 0.79 − 0.71 (m, 2H), 0.55 − 0.44 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 55.25, 45.22, 35.63, 29.34, 13.82.

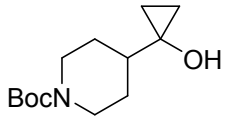


1-Amylcyclopropanol (1b), starting from methyl hexanoate.[1] Yield 95% (3.04 g). Used as obtained without any purification. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.82 (br s, 1H), 1.57−1.46 (m, 4H), 1.36 − 1.27 (m, 4H), 0.92 – 0.88 (m, 3H), 0.74 – 0.72 (m. 2H), 0.45 – 0.43 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 56.02, 38.41, 32.02, 25.74, 22.86, 14.20, 13.64.

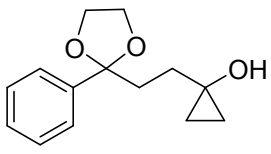


1-(9-Decenyl)cyclopropanol (1g), starting from methyl 10-undecenoate. Yield 84% (4.12 g). Purified using short-column silica gel chromatography. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.81 (ddt, *J* = 17.0, 10.2, 6.7 Hz, 1H), 4.99 (ddt, *J* = 17.0, 2.2, 1.7 Hz, 1H), 4.93 (ddt, *J* = 10.2, 2.2, 1.2 Hz, 1H), 2.07 – 2.01 (m, 2H), 1.75 (s, 1H), 1.58−1.44 (m, 4H), 1.43–1.23 (m, 10H), 0.74 – 0.71 (m, 2H), 0.45 – 0.42 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 139.38, 114.26, 56.05, 38.44, 33.96, 29.81, 29.78, 29.59, 29.28, 29.08, 26.06, 13.67. HRMS (APCI) calcd. for $C_{13}H_{25}O^+$ $[M+H]^+$ 197.1900, found *m/z* 197.1904.

Preparation of cyclopropanols 1d, 1f, 1h. To a stirred solution of ester (10 mmol) and titanium(IV) isopropoxide (0.75 mL, 2.5 mmol, 25 mol%) in THF (60 mL) was added slowly over 3–4 h at room temperature a solution of EtMgBr (25 mmol) in THF (25 mL). The solvent (THF) was evaporated under reduced pressure prior to the hydrolysis. The reaction mixture was diluted with CH_2Cl_2 (50 mL), cooled with ice bath, hydrolyzed with water or NH_4Cl (1–2 mL) and filtered through layer of silica. The filter cake was thoroughly washed with CH_2Cl_2 or ethyl acetate (5 × 40 mL). After evaporation of solvent under reduced pressure the cyclopropanol products were purified by recrystallization or by short-column silica gel chromatography or used directly in the next step without any purification.

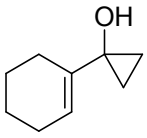


***tert*-Butyl 4-(1-hydroxycyclopropyl)piperidine-1-carboxylate (1d)**, starting from the corresponding ethyl ester. Yield 68% (1.64 g). Purified by recrystallization from cyclohexane (mp 118 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 4.19 (br s, 2H), 2.63 (br t, *J* = 12.9 Hz, 2H), 1.81 (br s, 1H), 1.71 – 1.63 (m, 2H), 1.55 – 1.35 (m, 2H), 1.46 (s, 9H), 1.12 (tt, *J* = 12.1, 3.5 Hz, 1H), 0.75 – 0.72 (m, 2H), 0.49 – 0.46 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 154.97, 79.50, 58.74, 44.00, 43.50, 28.62, 28.09, 12.77. HRMS (AJESI) calcd. for $C_{13}H_{23}NO_3Na^+$ $[M+Na]^+$ 264.1570, found *m/z* 264.1571.

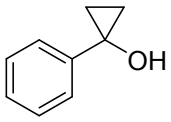


1-(2-(2-Phenyl-1,3-dioxolan-2-yl)ethyl)cyclopropanol (1f), starting from methyl 3-(2-phenyl-1,3-dioxolan-2-yl)propanoate. Yield 95% (2.23 g). Used as obtained without any purification. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51−7.44 (m, 2H), 7.40 – 7.25 (m, 3H), 4.06 – 4.03 (m, 2H), 3.80 – 3.77 (m, 2H), 3.00 (br s, 1H), 2.23– 2.12 (t, *J* = 7.3 Hz, 2H), 1.65 (t, *J* = 7.3 Hz, 2H), 0.73 – 0.70 (m, 2H), 0.41 – 0.38 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 142.39, 128.29, 128.06, 125.84,

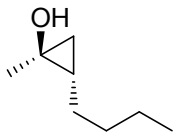
110.47, 64.57, 55.77, 37.43, 32.34, 13.82. HRMS (APCI) calcd. for $C_{14}H_{19}O_3^+$ $[M+H]^+$ 235.1329, found *m/z* 235.1316.



1-(Cyclohex-1-en-1-yl)cyclopropanol (1h), starting from methyl cyclohex-1-enecarboxylate. Yield 45% (0.447 g). Purified using short-column silica gel (with triethylamine pretreatment) chromatography. 1H NMR (400 MHz, $CDCl_3$) δ 5.78 – 5.76 (m, 1H), 2.08 – 2.01 (m, 2H), 1.96 – 1.92 (m, 2H), 1.89 (br s, 1H), 1.69 – 1.60 (m, 2H), 1.60 – 1.52 (m, 2H), 0.87 – 0.81 (m, 2H), 0.80 – 0.74 (m, 2H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 138.45, 121.32, 58.71, 25.17, 25.14, 22.90, 22.52, 13.29.



Preparation of 1-phenylcyclopropanol (1e).[4] A 1.5 M solution of MeMgBr in diethyl ether (20 mL, 30 mmol) was added within 5 min to a solution of titanium(IV) isopropoxide (5.68 g, 20 mmol) in Et_2O. The resulting yellow solution was cooled to 0 °C and methyl benzoate (20 mmol, 2.72 g, in 10 mL of Et_2O) was then added. EtMgBr (30 mL of a 1 M solution in Et_2O, 30 mmol) was added over 30–40 min. The resulting reaction mixture was allowed to warm to room temperature, then stirred for an additional hour, quenched at 0 °C by careful addition of cold 10% H_2SO_4 solution (80 mL), and was extracted with Et_2O (3 × 20 mL). The combined organic layers were washed with saturated $NaHCO_3$ solution, brine and dried ($MgSO_4$). After evaporation of solvent under reduced pressure the cyclopropanol product was isolated by column chromatography on silica gel (petroleum ether/EtOAc). Yield 45% (1.2 g). ^1H NMR (400 MHz, $CDCl_3$): δ 7.37 – 7.18 (m, 5H), 2.52 (s, 1H), 1.26 – 1.23 (m, 2H), 1.04 – 1.01 (m, 2H).



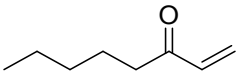
***cis*-2-Butyl-1-methylcyclopropanol (14)**. Prepared from ethyl acetate and *n*-$C_6H_{13}MgBr$ following published procedure.[5] ^1H NMR (400 MHz, $CDCl_3$): δ = 1.82 (br s, 1H, OH), 1.40 (d, *J* = 0.6 Hz, 3H), 1.43-1.23 (m, 5H), 1.21-1.08 (m, 1H), 1.02-0.92 (m, 1H), 0.89 (t, *J* = 7.0 Hz, 3H), 0.82 (ddq, *J* = 10.1, 5.1, 0.6 Hz, 1H), 0.05 (dd, *J* = 6.4, 5.1 Hz, 1H); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 55.81, 32.06, 29.72, 25.81, 22.66, 20.69, 20.41, 14.23.

References:

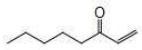
1. J. K. Cha and O. G. Kulinkovich, *Org. React.*, **2012**, *77*, 1.
2. M. Limbach, S. Dalai, A. de Meijere. *Adv. Synth. Catal*. **2004**, *346*, 760.
3. O. Kulinkovich, N. Masalov, V. Tyvorskii, N. De Kimpe, M. Keppens, *Tetrahedron Lett*. **1996**, *37*, 1095.
4. K. Nomura and S. Matsubara, *Chemistry – An Asian Journal*, **2010**, *5*, 147.
5. O. G. Kulinkovich, D. G. Kananovich, *Eur. J. Org. Chem*. **2007**, 2121.

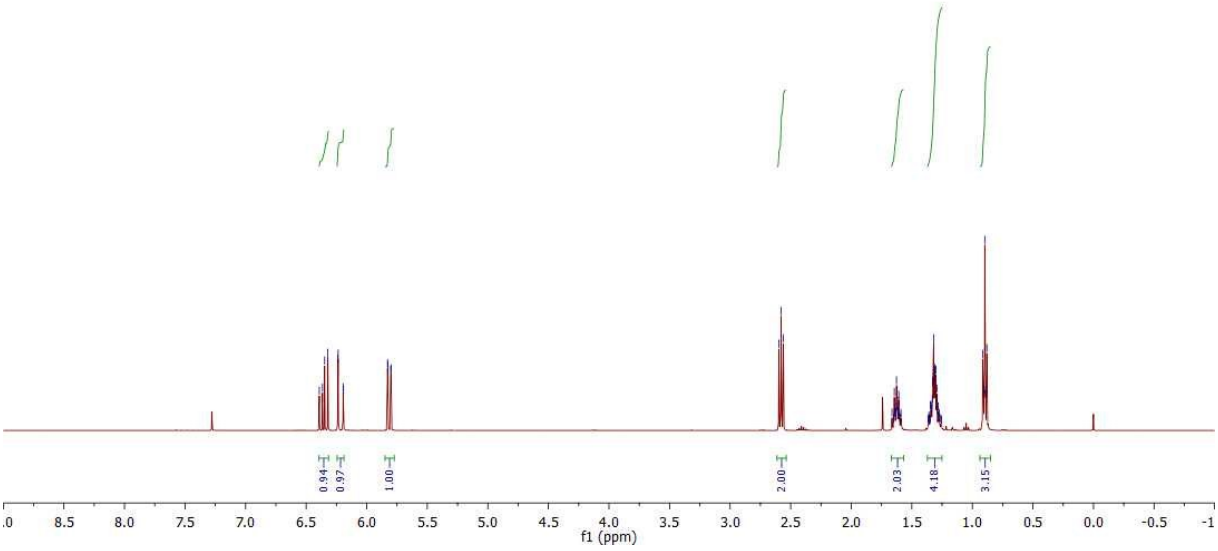
III. Oxidation experiments: synthesis of enones (12b; 15)

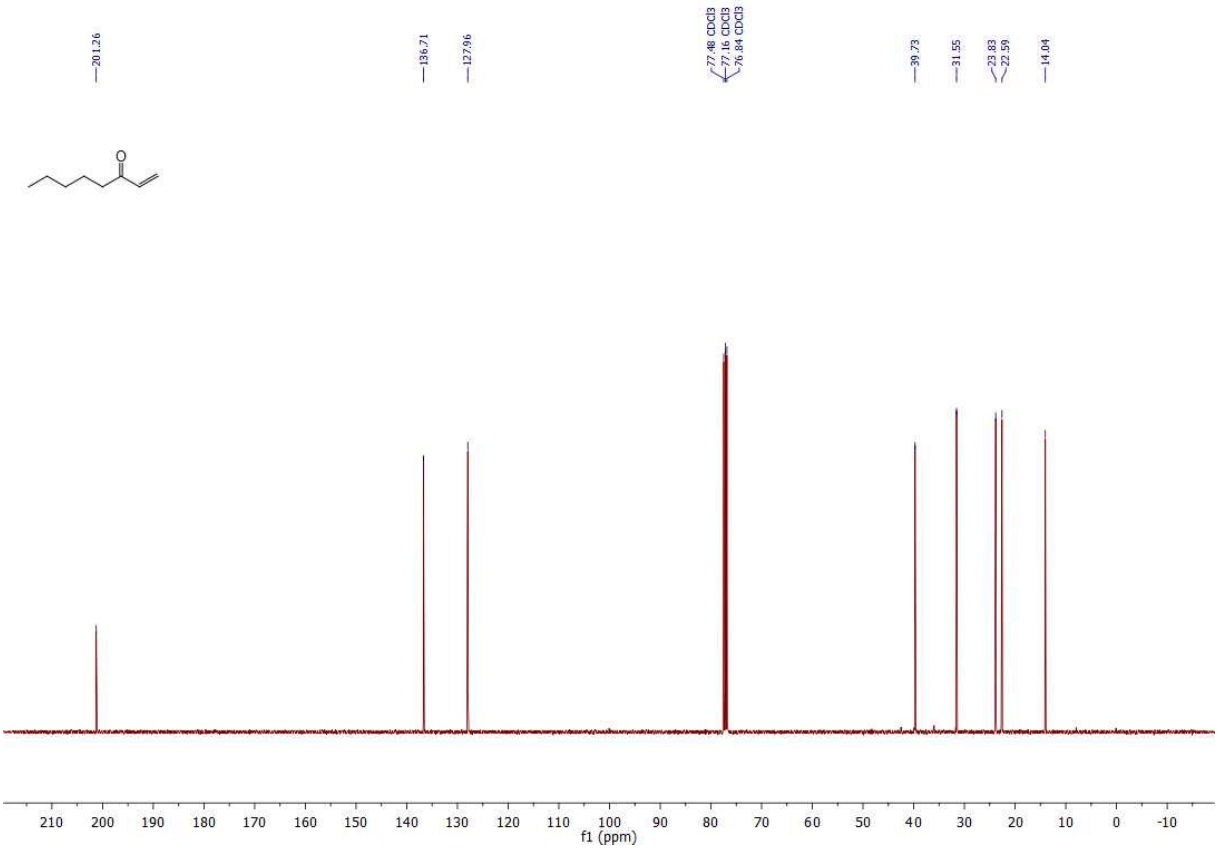
General procedure: A 25 ml round-shaped flask was charged with $Cu(OAc)_2 \cdot H_2O$ (200 mg, 1 mmol) and with cyclopropanol (**1b** or **14**; 1.0 mmol). The mixture was dissolved in MeOH (4 mL). To the stirred mixture, TBHP in water (70% by weight, 0.2 ml, 1.5 mmol, 1.5 eq.) was added dropwise in 20 minutes. The flask was stirred until total conversion of the starting material (TLC monitoring, **12b**: 0.5 h; **15**: 3 h). After completion of the reaction, saturated aq. NH_4Cl (2 mL) and 1M HCl (2 mL) were added. The resulted mixture was extracted with DCM (3 x 5 ml) and dried ($MgSO_4$). After removal of the solvent under reduced pressure, **12b**; **15**: were isolated by silica gel column chromatography (PE: EtOAc = 20:1).

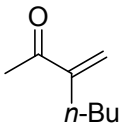


oct-1-en-3-one (12b), colorless oil. Isolated by silica gel column chromatography (PE: EtOAc = 20:1). Yield 83% (105 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.36 (dd, *J* = 17.7, 10.5 Hz, 1H), 6.22 (dd, *J* = 17.7, 1.3 Hz, 1H), 5.82 (dd, *J* = 10.5, 1.3 Hz, 1H), 2.58 (t, *J* = 7.4 Hz, 2H), 1.67 – 1.58 (m, 2H), 1.34 – 1.29 (m, 4H), 0.90 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 201.26, 136.71, 127.96, 39.73, 31.55, 23.83, 22.59, 14.04. R_f 0.81 (PE/EA 5:1).

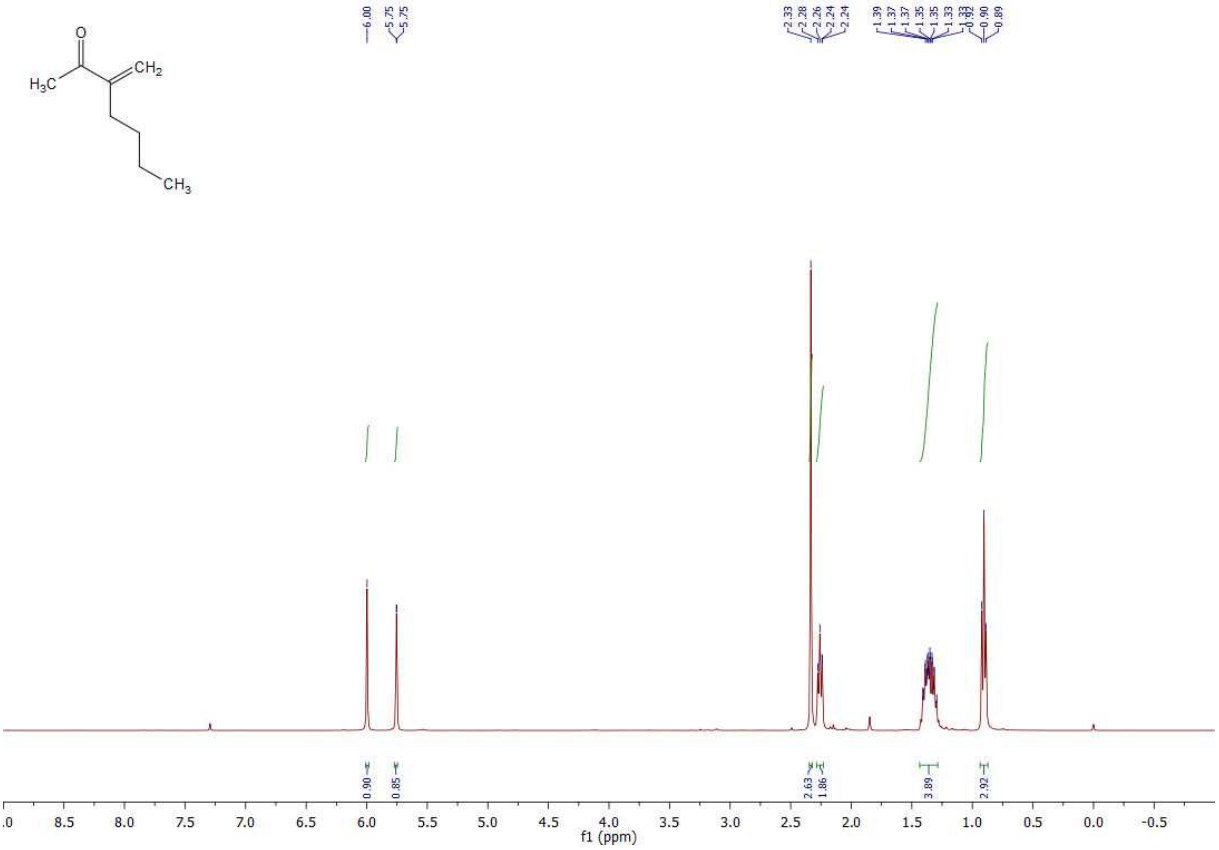








3-methyleneheptan-2-one (15), colorless oil. Isolated by silica gel column chromatography (PE: EtOAc = 20:1). Yield 63% (80 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.00 (s, 1H), 5.75 (s, 1H), 2.33 (s, 3H), 2.25 (t, *J* = 7.0 Hz, 2H), 1.44 – 1.29 (m, 4H), 0.90 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 199.97, 149.46, 124.73, 30.69, 30.35, 26.04, 22.53, 13.99. R_f 0.95 (PE/EA 5:1)


6.00
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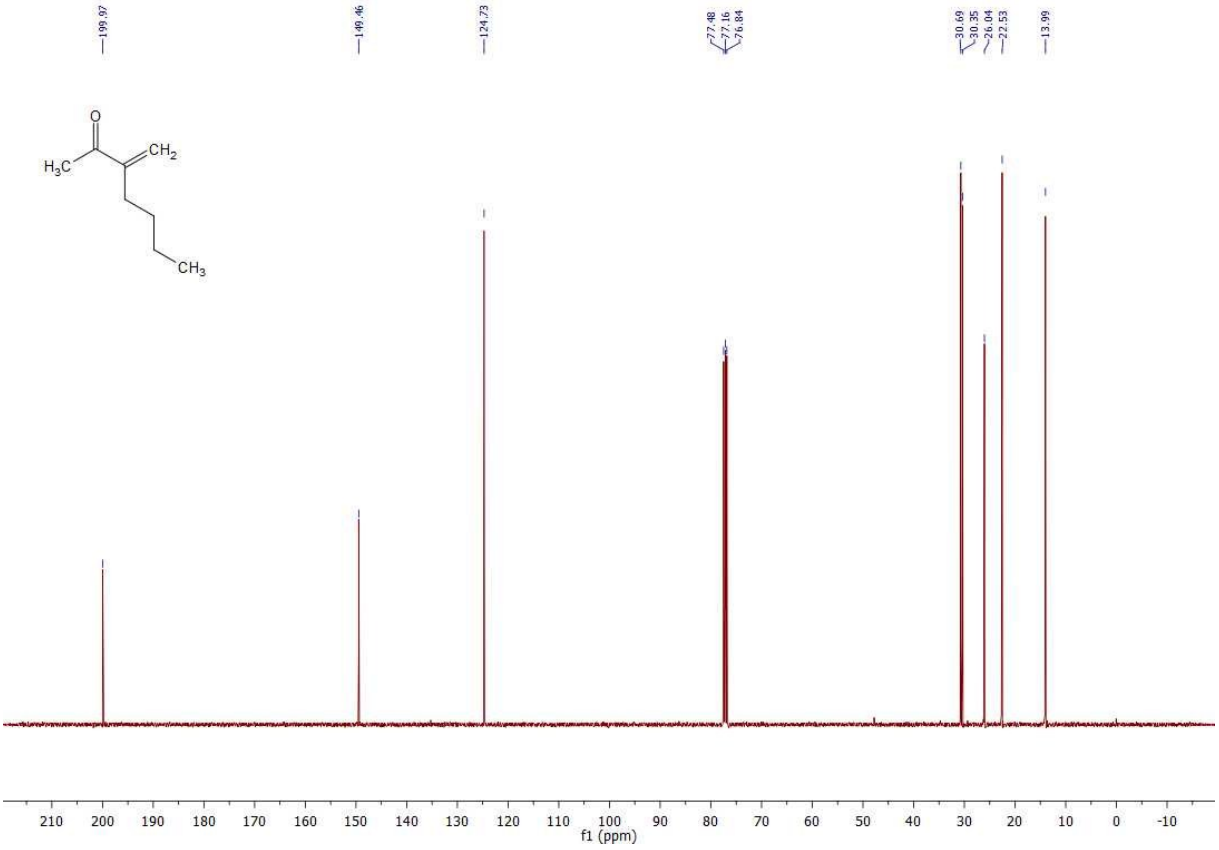
199.97
149.46
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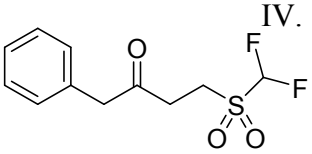
13.99
f1 (ppm)

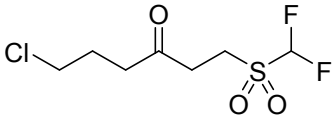
IV. Synthesis and characterization of γ-keto sulfones

Representative procedure for preparation of γ-keto fluorosulfones – Method A

A 10 ml glass vial was charged with $Cu(OAc)_2 \cdot H_2O$ (100 mg, 0.5 mmol, 1 eq.), $Fe(OAc)_2$ (17 mg, 0.1 mmol, 0.2 eq.) and CHF_2SO_2Na (210 mg, 1.5 mmol) or CH_2FSO_2Na (180 mg, 1.5 mmol). The mixture of salts was suspended in MeOH (0.5 mL), followed by the addition of cyclopropanol **1** (0.5 mmol) in MeOH (1.5 ml). To the stirred mixture, TBHP in water (70% by weight, 0.2 ml, 1.5 mmol, 1.5 eq.) was added dropwise for 20 minutes. The solution was stirred for 24 hours and if necessary the reaction mixture was left standing for another 48 h (monitored by TLC) at room temperature. After completion of the reaction (TLC monitoring) saturated aq. NH_4Cl (2 mL) was added. The resulted mixture was extracted with DCM (4 x 5 ml) and dried ($MgSO_4$). After removal of the solvent under reduced pressure, the solid residue was washed with hexane and filtered. Crystals were purified by dissolution in polar solvent (e.g. chloroform) and subsequent sedimentation by hexane or by silica gel column chromatography.

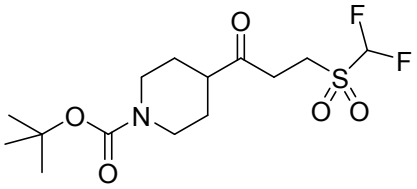
IV. 

4-((Difluoromethyl)sulfonyl)-1-phenylbutan-2-one (2a), colorless needles. Recrystallized from hexane/chloroform (mp 108 °C). Yield 61% (80 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.28 (m, 3H), 7.25 – 7.15 (m, 2H), 6.16 (t, *J* = 52.9 Hz, 1H), 3.79 (s, 2H), 3.41 (t, *J* = 7.2 Hz, 2H), 3.05 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 203.47, 133.00, 129.51, 129.21, 127.77, 114.83 (t, *J* = 285.9 Hz), 49.99, 43.01, 33.21. ^{19}F NMR (376 MHz, $CDCl_3$) δ -122.91 (d, *J* = 53.0 Hz). HRMS (AJESI) calcd for $C_{11}H_{12}F_2O_3SNa^+$ $[M + Na]^+$ 285.0367, found m/z 285.0370. R_f 0.15 (PE/EA 10:1). IR (KBr): ν = 1715, 1345, 1160, 1108 cm^{-1}.

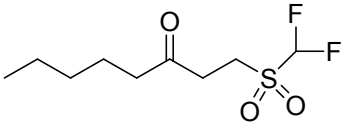
V. 

6-Chloro-1-((difluoromethyl)sulfonyl)hexan-3-one (2c), colorless needles. Recrystallized from hexane/chloroform (mp 62 °C). Yield 41% (51 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.18 (t, *J* = 52.9 Hz, 1H), 3.59 (t, *J* = 6.2 Hz, 2H), 3.47 (t, *J* = 7.1 Hz, 2H), 3.05 (t, *J* = 7.1 Hz, 2H), 2.73 (t, *J* = 7.0 Hz, 2H), 2.24 – 1.95 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 204.58, 115.06 (t, *J* = 285.9 Hz), 44.18, 42.87, 39.39, 34.12, 26.19. ^{19}F NMR (376 MHz, $CDCl_3$) δ -122.77 (d, *J* = 52.8 Hz). HRMS (AJESI) calcd for $C_7H_{11}ClF_2O_3SNa^+$ $[M + Na]^+$

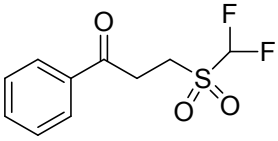
270.9978, found m/z 270.9976. R_f 0.2 (PE/EA 10:1). IR (KBr): ν = 1717, 1340, 1328, 1154, 1107 cm^{-1}.



tert-Butyl 4-(3-((difluoromethyl)sulfonyl)propanoyl)piperidine-1-carboxylate (2d), white crystalline product. After removal of DCM, the crystals were recrystallized from hexane/chloroform (mp 114-115 °C). Yield 43% (76 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.18 (t, *J* = 52.9 Hz, 1H), 4.13 (br s, 2H), 3.46 (t, *J* = 7.1 Hz, 2H), 3.06 (t, *J* = 7.1 Hz, 2H), 2.79 (br t, *J* = 12.2 Hz, 2H), 2.55 (tt, *J* = 11.4, 3.7 Hz, 1H), 1.86 – 1.83 (m, 2H), 1.72 – 1.51 (m, 2H), 1.45 (s, 9H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 207.16, 154.69, 115.04 (t, *J* = 285.9 Hz), 79.96, 48.63, 43.28 (br s), 42.91, 32.06, 28.54, 27.52. ^{19}F NMR (376 MHz, $CDCl_3$) δ -122.83 (d, *J* = 55.1 Hz). HRMS (AJSESI) calcd for $C_{14}H_{23}F_2NO_5SNa^+$ $[M + Na]^+$ 378.1157, found m/z 378.1168. R_f 0.15 (PE/EA 3:1). IR (KBr): ν = 1417, 1675, 1351, 1165 cm^{-1}.

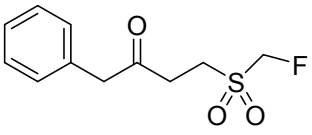


1-((Difluoromethyl)sulfonyl)octan-3-one (2b), white, crystalline product (mp 56 °C). The solution was stirred for 72 hours. After completion of the reaction (TLC monitoring) besides saturated aq. NH_4Cl (2 mL), 1M HCl (2 ml) was added. Isolated by column chromatography, eluent petroleum ether/ethyl acetate. Yield 67% (81 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.19 (t, *J* = 52.9 Hz, 1H), 3.45 (t, *J* = 7.2 Hz, 2H), 3.02 (t, *J* = 7.2 Hz, 2H), 2.50 (t, *J* = 7.5 Hz, 2H), 1.64 – 1.58 (m, 2H), 1.36 – 1.21 (m, 4H), 0.90 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 205.97, 115.03 (t, *J* = 285.8 Hz), 42.99, 42.79, 33.84, 31.37, 23.53, 22.51, 14.01. ^{19}F NMR (376 MHz, $CDCl_3$) δ -123.04 (d, *J* = 52.6 Hz). HRMS (AJESI) calcd for $C_9H_{16}F_2O_3SNa^+$ $[M + Na]^+$ 265.0680, found m/z 265.0686. R_f 0.47 (PE/EA 5:1). IR (KBr): ν = 1708, 1348, 1163, 1113 cm^{-1}.

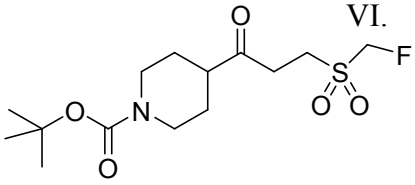


3-((Difluoromethyl)sulfonyl)-1-phenylpropan-1-one (2e), white, crystalline product (mp 94 °C). The solution was stirred for 72 hours. After completion of the reaction (TLC monitoring) besides saturated aq. NH_4Cl (2 mL), 1M HCl (2 ml) was added. Isolated by column chromatography, eluent petroleum ether/ethyl acetate. Yield 77% (96 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 – 7.97 (m, 2H), 7.66 – 7.62 (m, 1H), 7.55 – 7.48 (m, 2H), 6.26 (t, *J* = 52.9 Hz, 1H), 3.70 – 3.58 (m, 4H). ^{13}C NMR (100.6

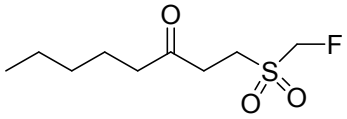
MHz, $CDCl_3$) δ 194.98, 135.52, 134.31, 129.08, 128.32, 115.09 (t, *J* = 286.0 Hz), 43.46, 30.54. ^{19}F NMR (376 MHz, $CDCl_3$) δ -122.84 (d, *J* = 52.6 Hz). HRMS (AJESI) calcd for $C_{10}H_{10}F_2O_3SNa^+$ $[M + Na]^+$ 271.0211, found m/z 271.0214. R_f 0.15 (PE/EA 5:1). IR (KBr): ν = 1688, 1342, 1164, 1114, 1062 cm^{-1}.



4-((Fluoromethyl)sulfonyl)-1-phenylbutan-2-one (4a), colorless needles. Recrystallized from hexane/diethyl ether (mp 72 °C). Yield 28% (34 mg). ^1H NMR (400 MHz, $CDCl_3$) δ 7.40 – 7.27 (m, 3H), 7.24 – 7.16 (m, 2H), 5.08 (d, *J* = 47.0 Hz, 2H), 3.78 (s, 2H), 3.38 (t, *J* = 7.0 Hz, 2H), 3.05 (t, *J* = 7.0 Hz, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 203.92, 133.13, 129.52, 129.16, 127.70, 91.11 (d, J = 219.1 Hz), 49.97, 45.70, 33.75. ^{19}F NMR (376 MHz, $CDCl_3$) δ -211.70 (t, *J* = 47.0 Hz). HRMS (AJESI) calcd for $C_{11}H_{13}FO_3SNa^+$ $[M + Na]^+$ 267.0462, found m/z 267.0457. R_f 0.1 (PE/EA 10:1). IR (KBr): ν = 1716, 1339, 1318, 1139, 1062 cm^{-1}.



VI. **tert-Butyl 4-(3-((fluoromethyl)sulfonyl)propanoyl)-piperidine-1-carboxylate (4d)**, viscous oil. After removal of DCM, the residue was purified by column chromatography on silica gel, eluent petroleum ether/ethyl-acetate (5:1 to 1:1). Yield 46% (78 mg). ^1H NMR (400 MHz, $CDCl_3$) δ 5.10 (d, *J* = 47.0 Hz, 2H), 4.10 (br s, 2H), 3.40 (t, *J* = 6.9 Hz, 2H), 3.04 (t, *J* = 6.9 Hz, 2H), 2.76 (t, *J* = 12.0 Hz, 2H), 2.53 (tt, *J* = 11.4, 3.7 Hz, 1H), 1.82 (d, *J* = 11.8 Hz, 2H), 1.61 – 1.46 (m, 2H), 1.43 (s, 9H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 207.64, 154.64, 91.18 (d, *J* = 218.7 Hz), 79.84, 48.51, 45.58, 43.14 (br s), 32.46, 28.47, 27.46. ^{19}F NMR (376 MHz, $CDCl_3$) δ -211.71 (t, *J* = 47.0 Hz). HRMS (AJSESI) calcd for $C_{14}H_{24}FNO_5SNa^+$ $[M + Na]^+$ 360.1251, found m/z 360.1244. R_f 0.2 (PE/EA 3:1).



1-((Fluoromethyl)sulfonyl)octan-3-one (4b), white, crystalline product. The solution was stirred for 72 hours. After completion of the reaction (TLC monitoring) besides saturated aq. NH_4Cl (2 mL), 1M HCl (2 ml) was added. Recrystallized from petroleum ether/ethyl acetate (mp 62 °C). Yield 70% (79 mg). ^1H NMR (400 MHz, $CDCl_3$) δ 5.12 (d, *J* = 47.0 Hz, 2H), 3.42 (t, *J* = 7.0 Hz,

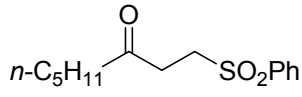
2H), 3.01 (t, J = 7.0 Hz, 2H), 2.49 (t, J = 7.5 Hz, 2H), 1.63 – 1.58 (m, 2H), 1.33 – 1.26 (m, 4H), 0.90 (t, J = 7.0 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.42, 91.17 (d, J = 219.1 Hz), 45.69, 42.78, 34.35, 31.38, 23.53, 22.52, 14.02. ^{19}F NMR (376 MHz, $CDCl_3$) δ -211.74 (t, J = 47.0 Hz). HRMS (AJESI) calcd for $C_9H_{18}FO_3S^+$ $[M + H]^+$ 225.0955, found m/z 225.0962. R_f 0.09 (PE/EA 5:1). IR (KBr): ν = 1707, 1324, 1137, 1057 cm^{-1}.

General procedure for preparation of γ-keto sulfones (Method B).

A 25 ml round-shaped flask was charged with $Cu(OAc)_2 \cdot H_2O$ (200 mg, 1 mmol, 1 eq.) and sulfinate salt (1.5 mmol, 1.5 eq.). The mixture of salts were suspended in MeOH (2 mL), followed by the addition of cyclopropanol **1** (1 mmol, 1 eq.) in MeOH (2 ml). To the stirred mixture, TBHP in water (70% by weight, 0.2 ml, 1.5 mmol, 1.5 eq.) was added dropwise in 20 minutes. The flask was stirred until total conversion of the starting material (TLC monitoring, usually <1 h). After completion of the reaction, saturated aq. NH_4Cl (2 mL) and 1M HCl (2 mL) were added. The resulted mixture was extracted with DCM (3 x 5 ml) and dried ($MgSO_4$). After removal of the solvent under reduced pressure, products were isolated by silica gel column chromatography or by filtration of the solid products followed by hexane washing of the precipitated crystals.

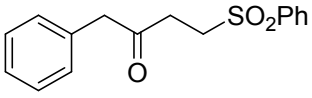
General procedure for preparation of γ-keto sulfones (Method C).

A 25 ml round-shaped flask was charged with $Cu(OAc)_2 \cdot H_2O$ (200 mg, 1 mmol, 1 eq.) and sulfinate salt (1.5 mmol, 1.5 eq.). The mixture of salts were suspended in MeOH (2 mL), followed by the addition of cyclopropanol **1** (1 mmol, 1 eq.) in MeOH (2 ml). The flask was stirred under air until total conversion of the starting material (TLC monitoring, usually 2–5 h). After completion of the reaction, saturated aq. NH_4Cl (2 mL) and 1M HCl (2 mL) were added. The resulted mixture was extracted with DCM (3 x 5 ml) and dried ($MgSO_4$). After removal of the solvent under reduced pressure, products were isolated by silica gel column chromatography or by filtration of the solid products followed by hexane washing of the precipitated crystals.

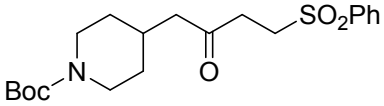


1-(Phenylsulfonyl)octan-3-one (3b), yellowish oil. Isolated by column chromatography, eluent dichloromethane/methanol. Method C: yield 90% (242 mg). Method B: yield 84% (224 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 – 7.90 (m, 2H), 7.70 – 7.65 (m, 1H), 7.61 – 7.56 (m, 2H), 3.39 (t, J = 8 Hz, 2H), 2.90 (t,

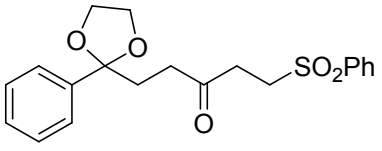
J = 8 Hz, 2H), 2.42 (t, *J* = 7.5 Hz, 2H), 1.58 – 1.51 (m, 2H), 1.35 – 1.18 (m, 4H), 0.88 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.43, 139.16, 134.05, 129.54, 128.11, 50.70, 42.99, 34.99, 31.38, 23.51, 22.51, 14.01. HRMS (AJESI) calcd. for $C_9H_{18}O_3SNa^+$ $[M+Na]^+$ 229.0869, found *m/z* 229.0871. R_f= 0.26 (PE/EA 5:1). IR (neat): ν = 1712, 1274, 1124 cm^{-1}.



1-Phenyl-4-(phenylsulfonyl)butan-2-one (3a), yellowish oil. Isolated by column chromatography, eluent petroleum ether/ethyl acetate. Method C: yield 55% (159 mg). Method B: yield 47% (136 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 – 7.85 (m, 2H), 7.69 – 7.64 (m, 1H), 7.59 – 7.53 (m, 2H), 7.36 – 7.27 (m, 3H), 7.18 – 7.13 (m, 2H), 3.71 (s, 2H), 3.37 (t, *J* = 8 Hz, 2H), 2.95 (t, *J* = 8 Hz, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 203.81, 139.06, 134.06, 133.28, 129.52, 129.51, 128.08, 127.57, 50.70, 50.17, 34.37. HRMS (AJESI) calcd. for $C_{16}H_{17}O_3S^+$ $[M+H]^+$ 289.0893, found *m/z* 289.0886. R_f= 0.26 (PE/EA 4:1). IR (neat): ν = 1720, 1308, 1149 cm^{-1}. NMR spectra are in agreement with literature data.[1]

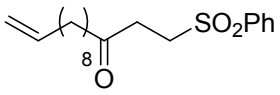


***tert*-Butyl 4-(3-(phenylsulfonyl)propanoyl)piperidine-1-carboxylate (3d)**, yellowish oil. Isolated by column chromatography, eluent petroleum ether/ethyl acetate. After completion of the reaction, work-up was performed with saturated aq. NH_4Cl (4 mL). Method B: yield 73% (279 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 – 7.88 (m, 2H), 7.71 – 7.66 (m, 1H), 7.62 – 7.56 (m, 2H), 4.10 (br s, 2H), 3.39 (t, *J* = 8 Hz, 2H), 2.97 (t, *J* = 8 Hz, 2H), 2.76 (br t, *J* = 12.2 Hz, 2H), 2.50 (tt, *J* = 11.4, 3.7 Hz, 1H), 1.79 (br d, *J* = 12.0 Hz, 2H), 1.62 – 1.46 (m, 2H), 1.47 – 1.42 (s, 9H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 207.61, 154.72, 139.16, 134.13, 129.58, 128.08, 79.91, 50.65, 48.79, 42.91 (broad), 33.06, 28.56, 27.53. HRMS (AJESI) calcd. for $C_{19}H_{27}NO_5SNa^+$ $[M+Na]^+$ 404.1502, found *m/z* 404.1497. R_f= 0.46 (PE/EA 1:1). IR (neat): ν = 1689, 1308, 1152 cm^{-1}.

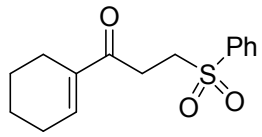


1-(2-Phenyl-1,3-dioxolan-2-yl)-5-(phenylsulfonyl)pentan-3-one (3f), yellowish oil. Isolated by column chromatography, eluent petroleum ether/ethyl acetate. After completion of the reaction, work-up was performed with saturated aq. NH_4Cl (4 mL). Method C: yield 76% (285 mg). Method B: yield 47% (175 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 – 7.89 (m, 2H), 7.69 – 7.64 (m, 1H), 7.61 – 7.54 (m, 2H), 7.42 – 7.38 (m, 2H), 7.36 – 7.29 (m, 3H), 3.97 – 3.94 (m, 2H), 3.75 – 3.72 (m, 2H), 3.36 (t, *J* = 8.0 Hz, 2H), 2.89 (t, *J* = 8.0 Hz, 2H), 2.51 (t, *J* = 7.2 Hz, 2H), 2.18 (t, *J* = 7.2 Hz, 2H).

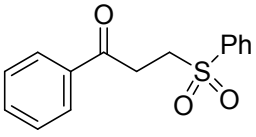
^{13}C NMR (100.6 MHz, $CDCl_3$) δ 205.66, 141.96, 139.13, 134.02, 129.52, 128.39, 128.28, 128.12, 109.58, 64.66, 50.80, 37.33, 35.02, 34.55. HRMS (AJESI) calcd. for $C_{20}H_{23}O_5S^+$ $[M+H]^+$ 375.1261, found *m/z* 375.1258. R_f = 0.25 (PE/EA 4:1). IR (neat): ν = 1715, 1308, 1152 cm^{-1}.



1-(Phenylsulfonyl)tridec-12-en-3-one (3g), white, crystalline product. Method B: yield 80% (270 mg). After removal of the solvent used for extraction, the crystals of product were filtered out and washed with hexane. Recrystallized from hexane (mp 58 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 – 7.89 (m, 2H), 7.69 – 7.65 (m, 1H), 7.61 – 7.55 (m, 2H), 5.86 – 5.75 (m, 1H), 5.02 – 4.90 (m, 2H), 3.38 (t, *J* = 8.0 Hz, 2H), 2.90 (t, *J* = 8.0 Hz, 2H), 2.42 (t, *J* = 7.5 Hz, 2H), 2.07 – 1.99 (m, 2H), 1.58 – 1.49 (m, 2H), 1.41 – 1.32 (m, 2H), 1.26 (s, 8H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.40, 139.28, 139.16, 134.05, 129.53, 128.10, 114.30, 50.70, 43.01, 34.99, 33.90, 29.39, 29.38, 29.19, 29.16, 29.00, 23.80. HRMS (AJESI) calcd. for $C_{19}H_{29}O_3S^+$ $[M+H]^+$ 337.1832, found *m/z* 337.1840. R_f = 0.39 (PE/EA 5:1). IR (KBr): ν = 1704, 1297, 1140 cm^{-1}.

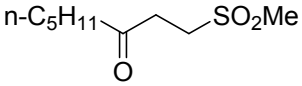


1-(Cyclohex-1-en-1-yl)-3-(phenylsulfonyl)propan-1-one (3h), colorless liquid. Method C: yield 94% (262 mg). Isolated by column chromatography, eluent petroleum ether/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 – 7.89 (m, 2H), 7.72 – 7.62 (m, 1H), 7.60 – 7.56 (m, 2H), 6.94 (m, *J* = 4.1, 2.3 Hz, 1H), 3.43 (t, *J* = 8 Hz, 2H), 3.15 (t, *J* = 8 Hz, 2H), 2.28 – 2.24 (m, 2H), 2.17 – 2.13 (m, 2H), 1.65 – 1.57 (m, 4H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 196.25, 141.65, 139.26, 138.76, 133.97, 129.49, 128.11, 51.39, 29.88, 26.27, 23.19, 21.88, 21.53. HRMS (AJESI) calcd. for $C_{15}H_{19}O_3S^+$ $[M+H]^+$ 279.1049, found *m/z* 279.1056. R_f = 0.14 (PE/EA 7:1). IR (neat): ν = 1666, 1307, 1150 cm^{-1}.

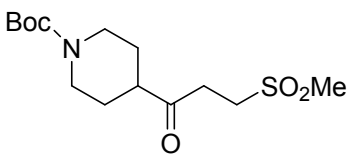


1-Phenyl-3-(phenylsulfonyl)propan-1-one (3e), white, crystalline product. Method C: yield 77% (210 mg). After removal of the solvent used for extraction, the crystals of product were filtered out and washed with petroleum ether: diethyl ether (10:1) solvent mixture. Recrystallized from petroleum ether: ethyl acetate (mp 98 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 – 7.91 (m, 4H), 7.70 – 7.65 (m, 1H), 7.63 – 7.55 (m, 3H), 7.50 – 7.46 (m, 2H), 3.60 – 3.54 (m, 2H), 3.54 – 3.48 (m, 2H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 195.56, 139.18, 135.92, 134.09, 133.94, 129.57, 128.94, 128.20, 128.13, 51.17, 31.5. HRMS (AJESI) calcd. for $C_{15}H_{15}O_3S^+$ $[M+H]^+$

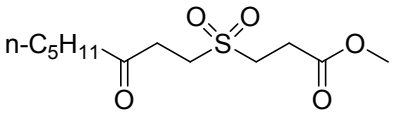
275.0736, found *m/z* 275.0738. R_f = 0.18 (PE/EA 5:1). IR (KBr): ν = 1687, 1307, 1142 cm^{-1} NMR spectra are in agreement with literature data.[2]



1-(Methylsulfonyl)octan-3-one (9b), white, crystalline product. Method C: yield 70% (144 mg). Method B: yield 66% (136 mg). After recrystallization, 76% was isolated (1.25 g) on a 1 g scale experiment with respect to the cyclopropanol, applying Method C. After removal of the solvent used for extraction, the crystals of product were filtered out and washed with hexane. Recrystallized from hexane (mp 83 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.33 (t, *J* = 7.1 Hz, 2H), 3.01 (t, *J* = 7.1 Hz, 2H), 2.94 (s, 3H), 2.49 (t, *J* = 7.5 Hz, 2H), 1.66 – 1.57 (m, 2H), 1.33 – 1.26 (m, 4H), 0.90 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.82, 49.10, 42.93, 41.82, 34.76, 31.41, 23.57, 22.52, 14.02. HRMS (AJESI) calcd. for $C_9H_{19}O_3S^+$ $[M+H]^+$ 207.1049, found *m/z* 207.1032. R_f = 0.09 (PE/EA 4:1). IR (KBr): ν = 1712, 1274, 1124 cm^{-1}.

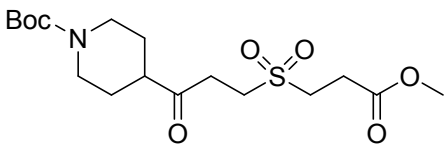


***tert*-Butyl 4-(3-(methylsulfonyl)propanoyl)piperidine-1-carboxylate (9d)**, beige, crystalline product. Method B: yield 47% (150 mg). After removal of the solvent used for extraction, the crystals of product were filtered out and washed with hexane. Recrystallized from hexane/acetone (mp 127 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.13 (br s, 2H), 3.34 (t, *J* = 7.0 Hz, 2H), 3.05 (t, *J* = 7.0 Hz, 2H), 2.95 (s, 3H), 2.79 (br t, *J* = 12.0 Hz, 2H), 2.55 (tt, *J* = 9.3, 5.7 Hz, 1H), 1.86 (br d, *J* = 12.4 Hz, 2H), 1.60 – 1.50 (m, 2H), 1.46 (s, 9H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 208.01, 154.68, 79.89, 49.03, 48.71, 43.20 (broad), 41.91, 32.79, 28.53, 27.53. HRMS (AJESI) calcd. for $C_{14}H_{26}NO_5S^+$ $[M+H]^+$ 320.1526, found *m/z* 320.1521. R_f = 0.31 (PE/EA 2:1). IR (KBr): ν = 1708, 1687, 1314, 1136 cm^{-1}.

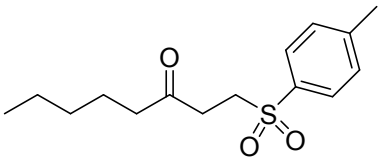


Methyl 3-((3-oxooctyl)sulfonyl)propanoate (10b), white, crystalline product. Method B: yield 71% (198 mg). After removal of the solvent used for extraction, the crystals of product were filtered out and washed with hexane. Recrystallized from hexane/ethyl acetate (mp 104 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.74 (s, 3H), 3.34 (t, *J* = 8 Hz, 2H), 3.31 (t, *J* = 8 Hz, 2H), 2.99 (t, *J* = 7.3 Hz, 2H), 2.89 (t, *J* = 7.3 Hz, 2H), 2.49 (t, *J* = 7.5 Hz, 2H), 1.65 –1.57 (m, 2H), 1.37 – 1.23 (m, 4H), 0.89 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.71, 170.92, 52.64, 49.10, 47.69, 42.94, 34.44, 31.41, 26.97, 23.58, 22.53, 14.03. HRMS

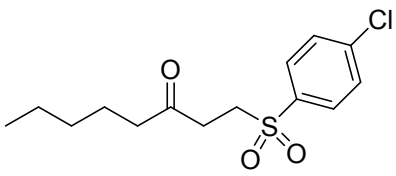
(AJESI) calcd. for $C_{12}H_{23}O_3S^+$ $[M+H]^+$ 279.1261, found *m/z* 279.1260. R_f = 0.07 (PE/EA 4:1). IR (KBr): ν = 1729, 1710, 1311, 1127 cm^{-1}.



***tert*-Butyl 4-(3-((3-methoxy-3-oxopropyl)sulfonyl)propanoyl)piperidine-1-carboxylate (10d)**, white, crystalline product. Method B: yield 66% (259 mg). After removal of the solvent used for extraction, the crystals of product were filtered out and washed with hexane. Recrystallized from hexane/acetone (mp 103 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.12 (br s, 2H), 3.75 (s, 3H), 3.34 (t, *J* = 8 Hz, 2H), 3.32 (t, *J* = 8 Hz, 2H), 3.04 (t, *J* = 7.2 Hz, 2H), 2.89 (t, *J* = 7.2 Hz, 2H), 2.79 (br t, *J* = 11.8 Hz, 2H), 2.58 – 2.51 (m, 1H), 1.85 (br d, *J* = 12.4 Hz, 2H), 1.62 – 1.51 (m, 2H), 1.46 (s, 9H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 207.90, 170.91, 154.71, 79.90, 52.65, 49.19, 48.75, 47.66, 43.12 (broad), 32.56, 28.55, 27.55, 26.96. HRMS (AJESI) calcd. for $C_{17}H_{29}NO_7SNa^+$ $[M+Na]^+$ 414.1557, found *m/z* 414.1559. R_f = 0.4 (PE/EA 2:1). IR (KBr): ν = 1706, 1270, 1126 cm^{-1}.

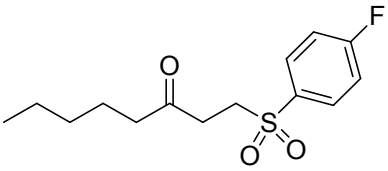


1-Tosyloctan-3-one (5b), colorless liquid. Method C: yield 85% (241 mg). Isolated by column chromatography, eluent petroleum ether/ethyl acetate. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, *J* = 8.0 Hz, 2H), 7.37 (d, *J* = 8.0 Hz, 2H), 3.36 (t, *J* = 7.5 Hz, 2H), 2.88 (t, *J* = 7.5 Hz, 2H), 2.46 (s, 3H), 2.41 (t, *J* = 7.4 Hz, 2H), 1.59 – 1.49 (m, 2H), 1.35 – 1.17 (m, 4H), 0.88 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.49, 145.05, 136.14, 130.11, 128.11, 50.75, 42.95, 35.11, 31.35, 23.47, 22.49, 21.77, 13.99. HRMS (AJESI) calcd. for $C_{15}H_{23}O_3S^+$ $[M+H]^+$ 283.1362, found *m/z* 283.1372. R_f = 0.29 (PE/EA 5:1). IR (neat): ν = 1707, 1286, 1137 cm^{-1}. NMR spectra are in agreement with literature data.[3]

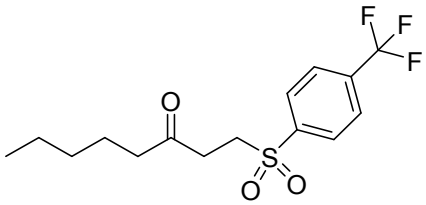


1-((4-Chlorophenyl)sulfonyl)octan-3-one (7b), white, crystalline product. Method C: yield 85% (257 mg). Recrystallized from petroleum ether: ethyl acetate (mp 71 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 – 7.83 (m, 2H), 7.58 – 7.53 (m, 2H), 3.38 (t, *J* = 8.1 Hz, 2H), 2.90 (t, *J* = 8.1, 2H), 2.43 (t, *J* = 7.4 Hz, 2H), 1.59 – 1.51 (m, 2H), 1.35 – 1.18 (m, 4H), 0.88 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.21, 140.88, 137.63, 129.88,

129.61, 50.75, 42.96, 34.90, 31.36, 23.49, 22.50, 14.00. HRMS (AJESI) calcd. for $C_{14}H_{20}ClO_3S^+$ $[M+H]^+$ 303.0816, found *m/z* 303.0827. R_f = 0.08 (PE/EA 5:1). IR (KBr): ν = 1706, 1303, 1159 cm^{-1}



1-((4-Fluorophenyl)sulfonyl)octan-3-one (6b), white, crystalline product. Method C: yield 88% (252 mg). Recrystallized from petroleum ether: ethyl acetate (mp 76 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 7.97 – 7.90 (m, 2H), 7.29 – 7.23 (m, 2H), 3.38 (t, *J* = 8.1, 2H), 2.91 (t, *J* = 8.1, 2H), 2.43 (t, *J* = 7.4 Hz, 2H), 1.59 – 1.51 (m, 2H), 1.35 – 1.18 (m, 4H), 0.88 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.28, 166.06 (d, *J* = 256.8 Hz), 135.25 (d, *J* = 3.3 Hz) , 131.00 (d, *J* = 9.6 Hz) 116.87 (d, *J* = 22.7 Hz), 50.84, 42.96, 34.94, 31.36, 23.49, 22.49, 13.99. ^{19}F NMR (376 MHz, $CDCl_3$) δ -103.02 (m). HRMS (AJESI) calcd. for $C_{14}H_{20}FO_3S^+$ $[M+H]^+$ 287.1112, found *m/z* 287.1127. R_f = 0.17 (PE/EA 5:1). IR (KBr): ν = 1706, 1291, 1156 cm^{-1}

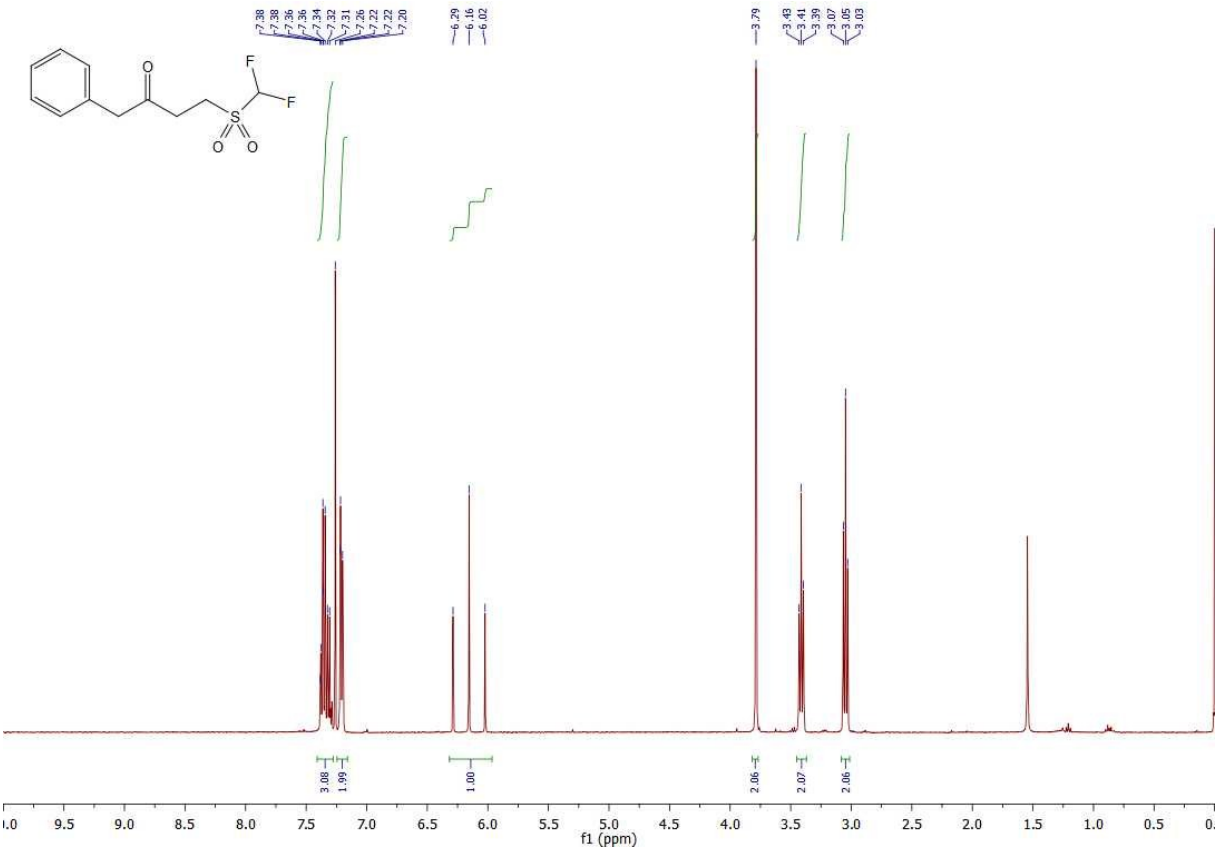


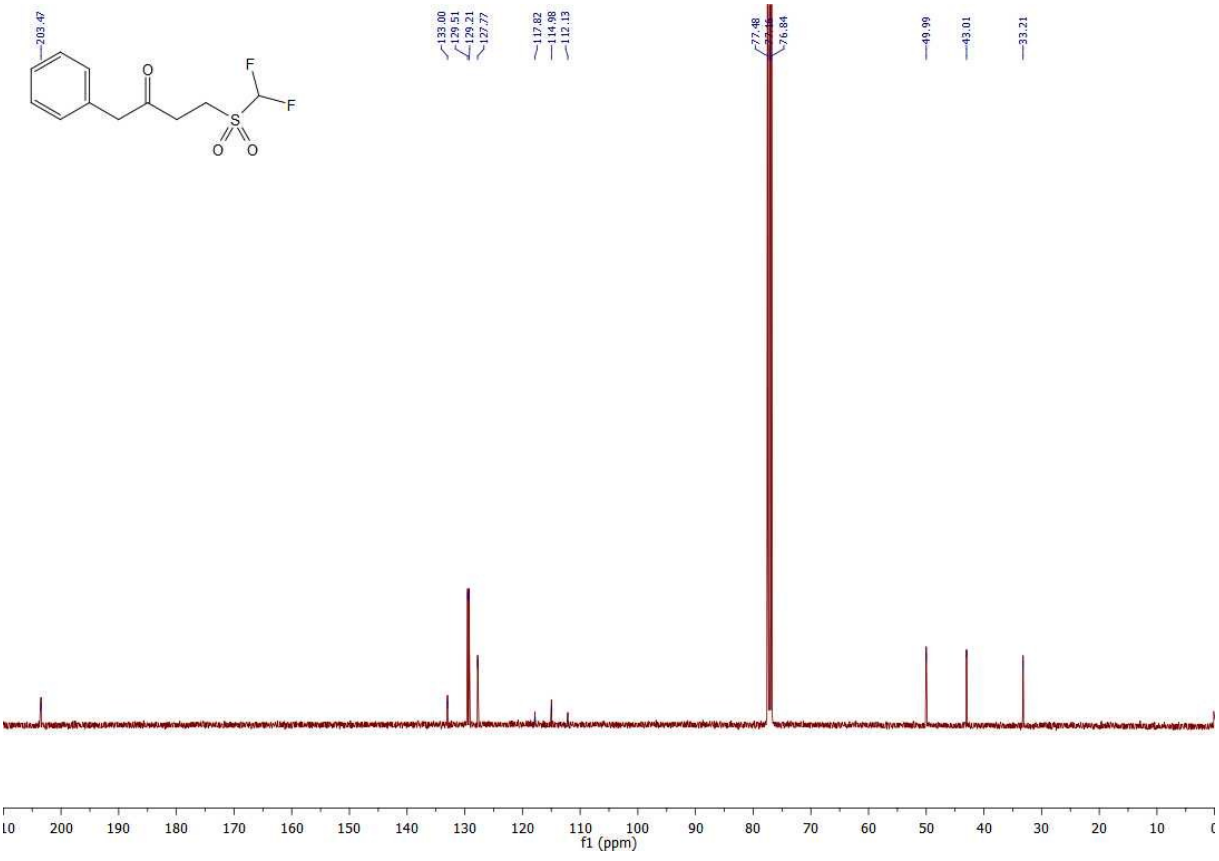
1-((4-(Trifluoromethyl)phenyl)sulfonyl)octan-3-one (8b), white, crystalline product. Method C: yield 83% (279 mg). Recrystallized from petroleum ether: ethyl acetate (mp 78 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.06 (d, *J* = 8.0 Hz, 2H), 7.86 (d, *J* = 8.0 Hz, 2H), 3.42 (t, *J* = 8.0 Hz, 2H), 2.93 (t, *J* = 8.0 Hz, 2H), 2.44 (t, *J* = 7.5 Hz, 2H), 1.60 – 1.51 (m, 2H), 1.35 – 1.18 (m, 4H), 0.88 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 206.02, 142.73, 135.79 (q, *J* = 33.2 Hz), 128.80, 126.70 (q, *J* = 3.7 Hz), 123.18 (q, *J* = 273.2 Hz), 50.63, 42.95, 34.72, 31.35, 23.47, 22.49, 13.98. ^{19}F NMR (376 MHz, $CDCl_3$) δ -63.24 (s). HRMS (AJESI) calcd. for $C_{15}H_{20}F_3O_3S^+$ $[M+H]^+$ 337.1080, found *m/z* 337.1076. R_f = 0.23 (PE/EA 5:1). IR (KBr): ν = 1709, 1323, 1105 cm^{-1}

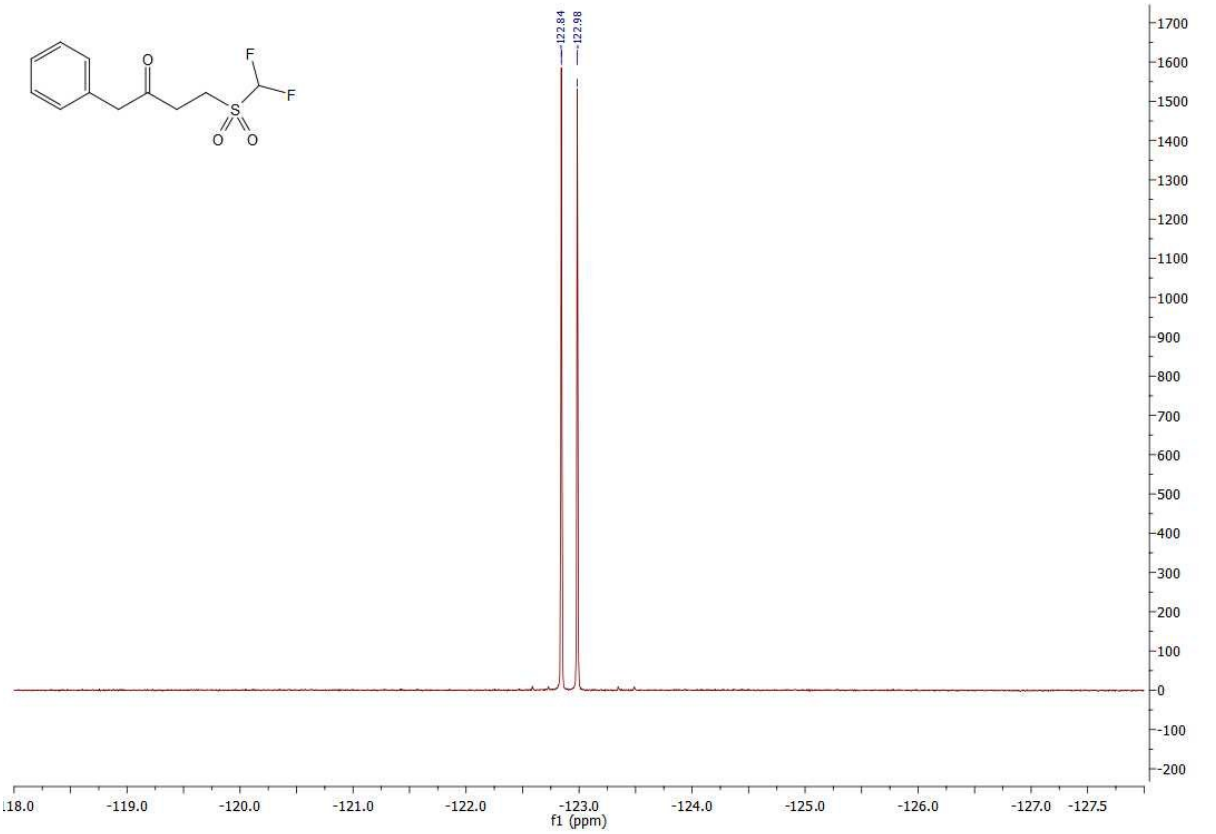
References:

1. A. Bhunia, S. R. Yetra, S. S. Bhojgude, A. T. Biju, *Org. Lett.*, **2012**, *14*, 2830.
2. J. Y. Lee, K.-C. Lim, X. Meng, S. Kim, *Synlett,* **2010**, *11*, 1647.
3. M. Vellakkaran, M. M. S. Andappan, K. Nagaiah, J. B. Nanubolu, *Eur. J. Org. Chem.*, **1996**, *21*, 3575.

V. Copies of ^{1}H, ^{13}C and ^{19}F NMR spectra



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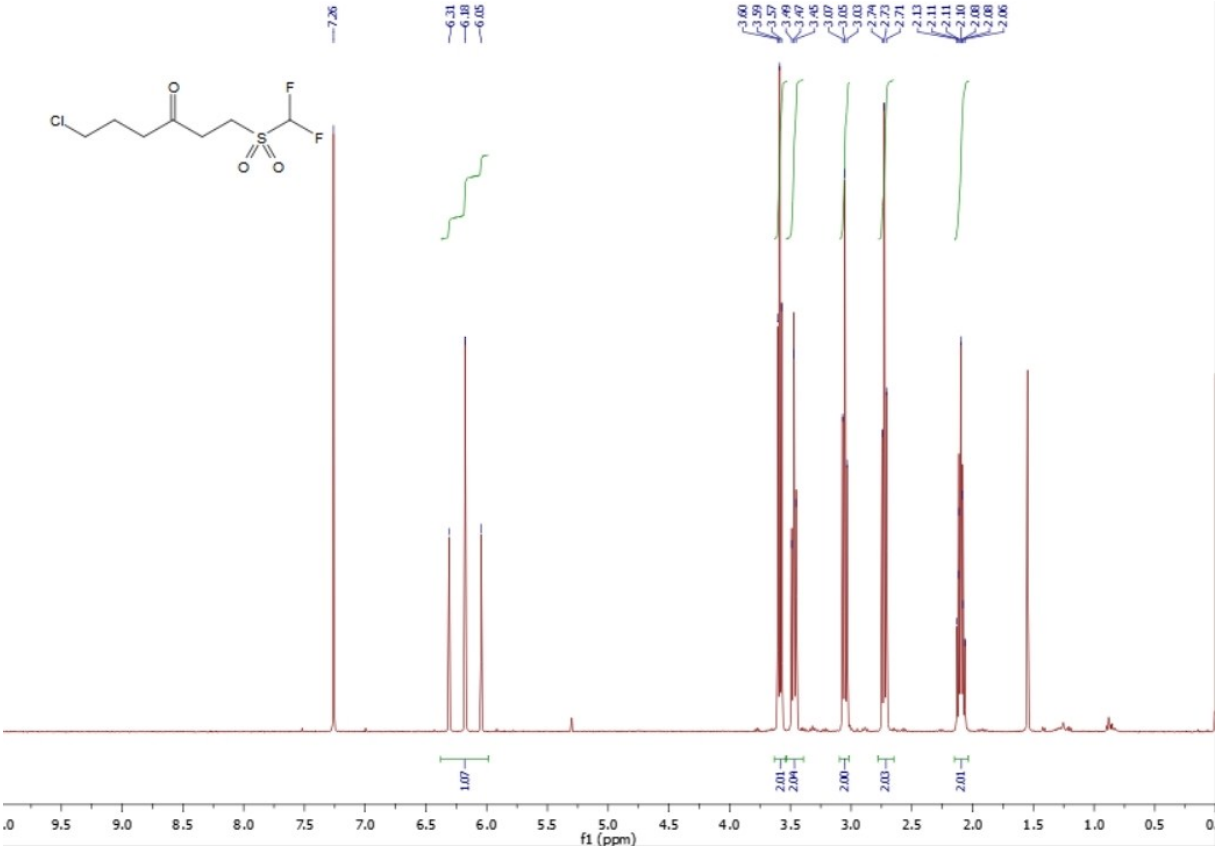
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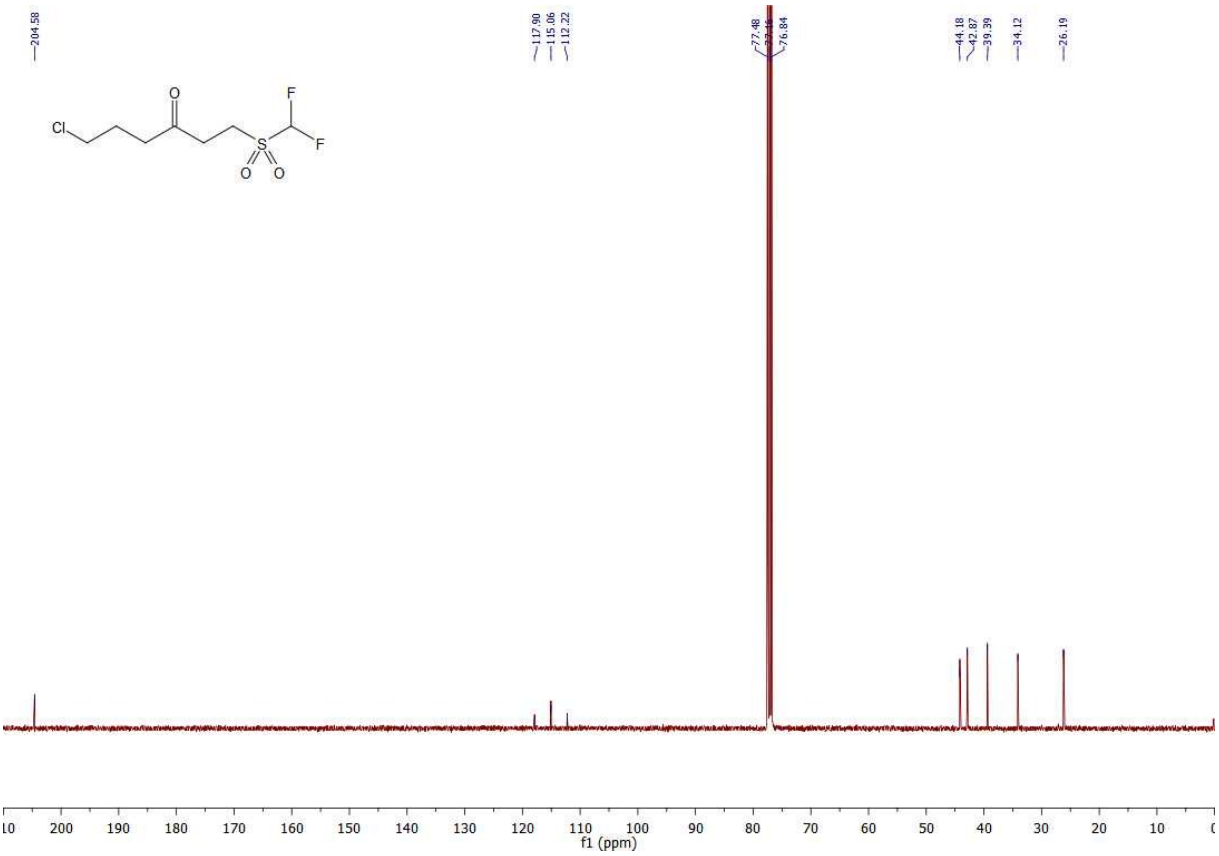
f1 (ppm)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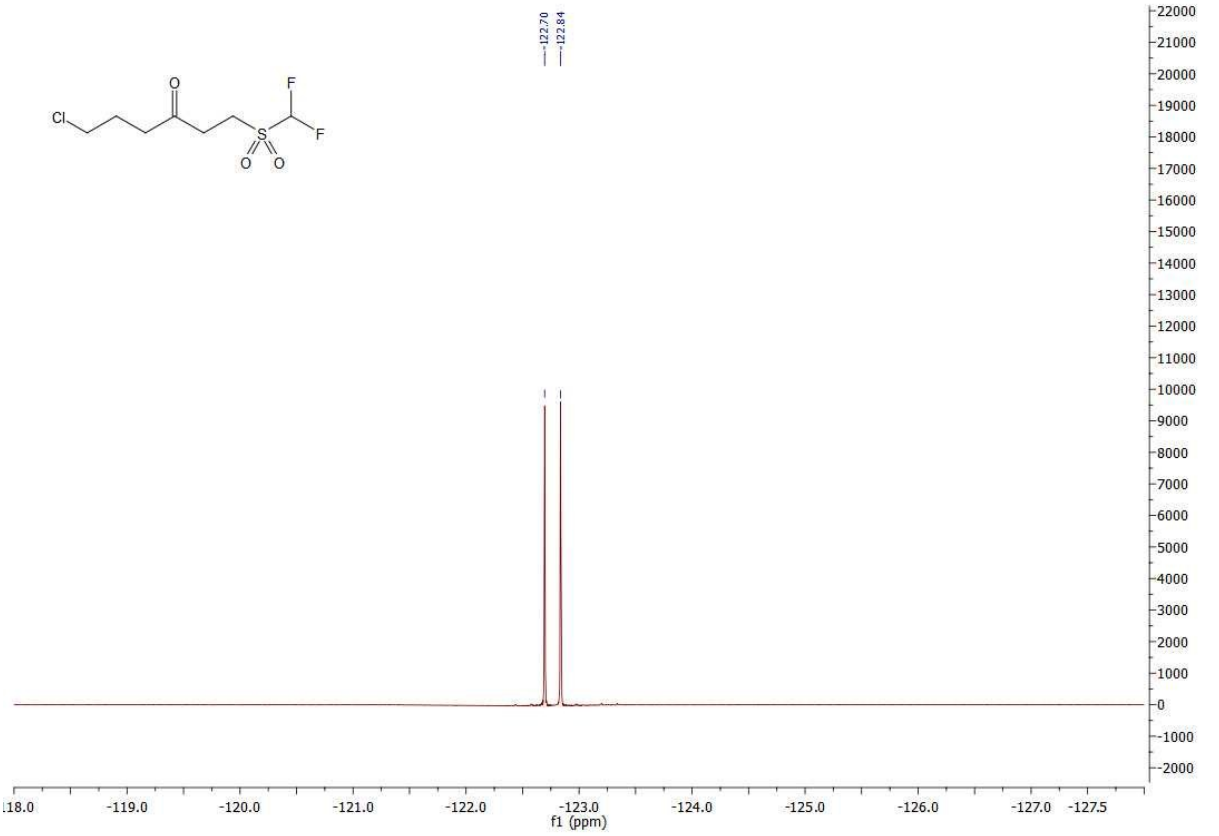
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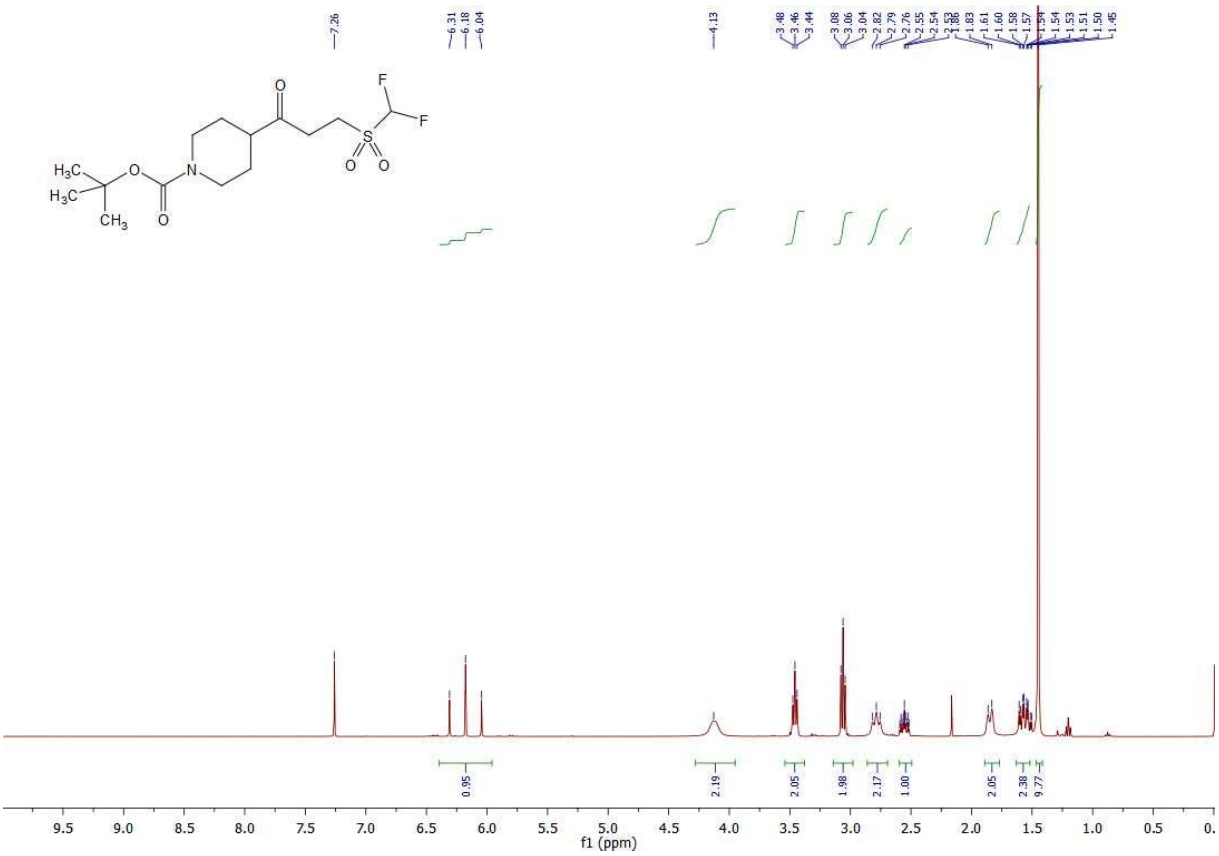
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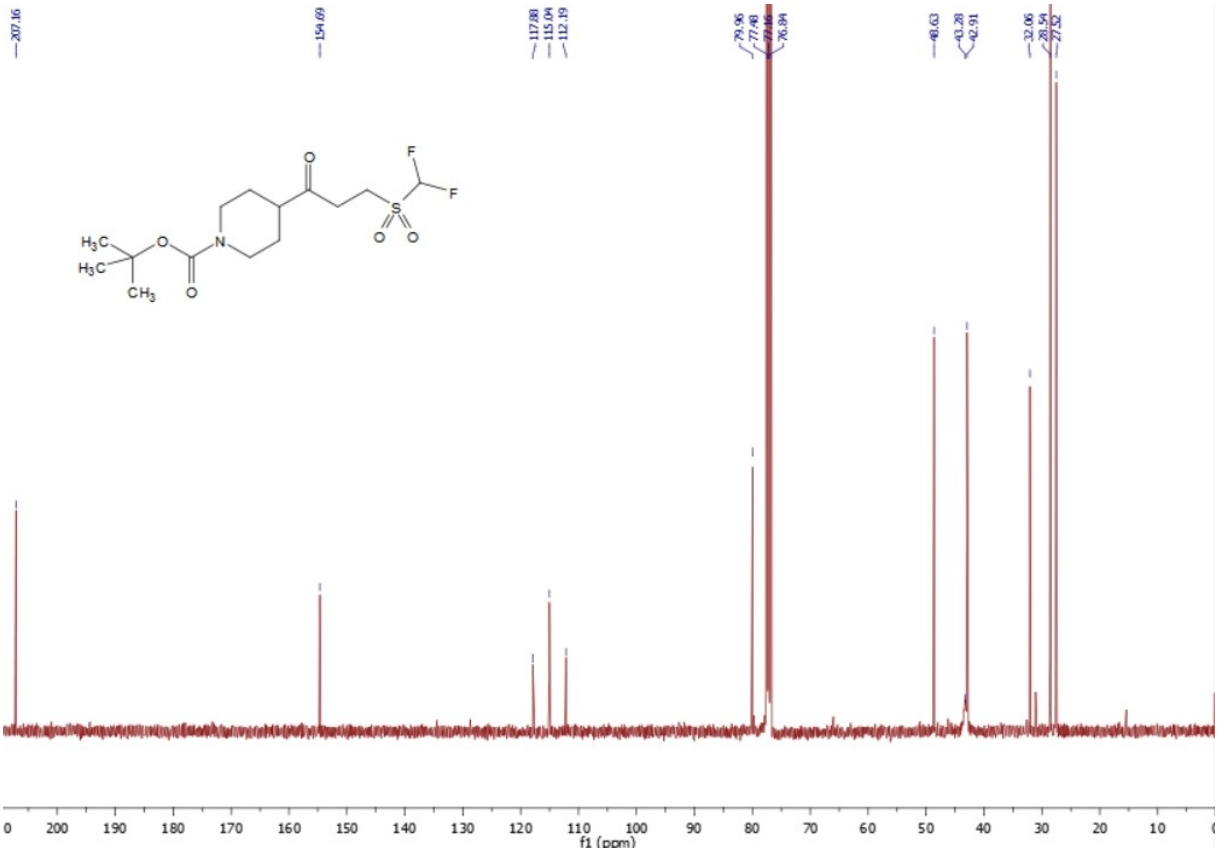
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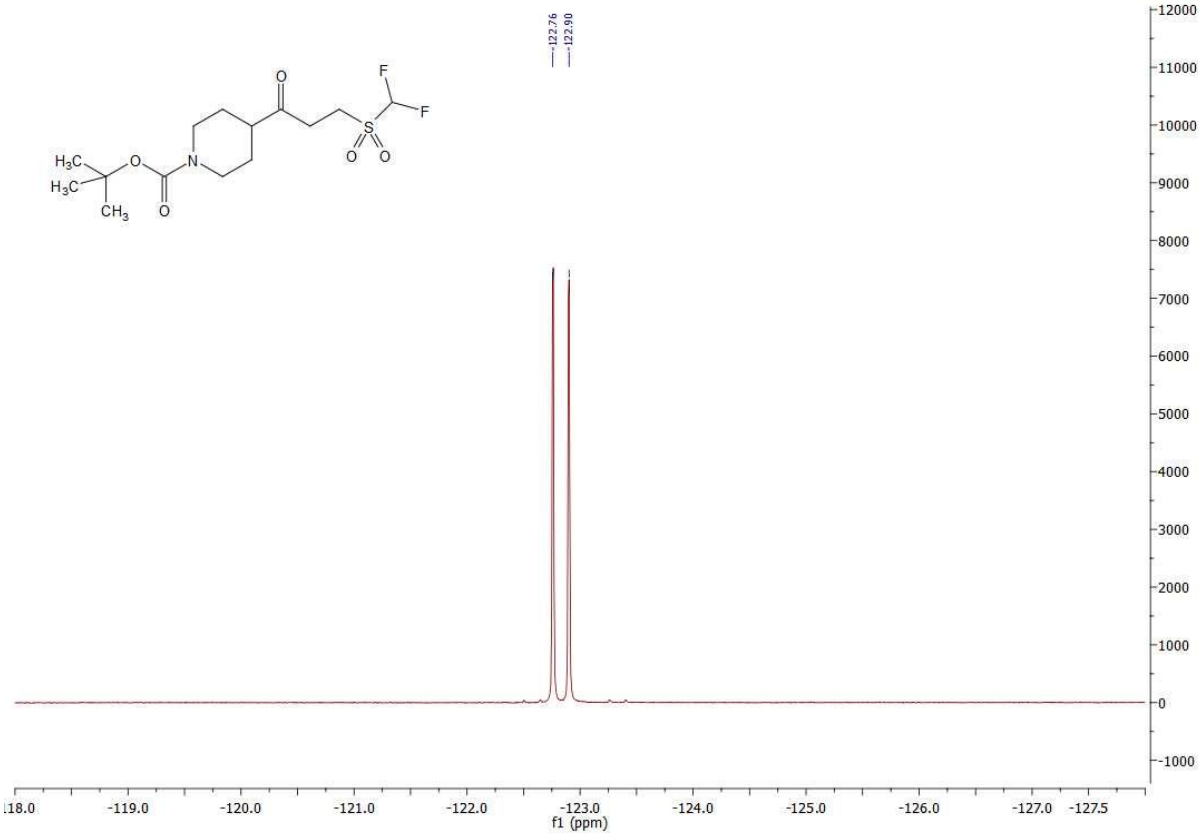
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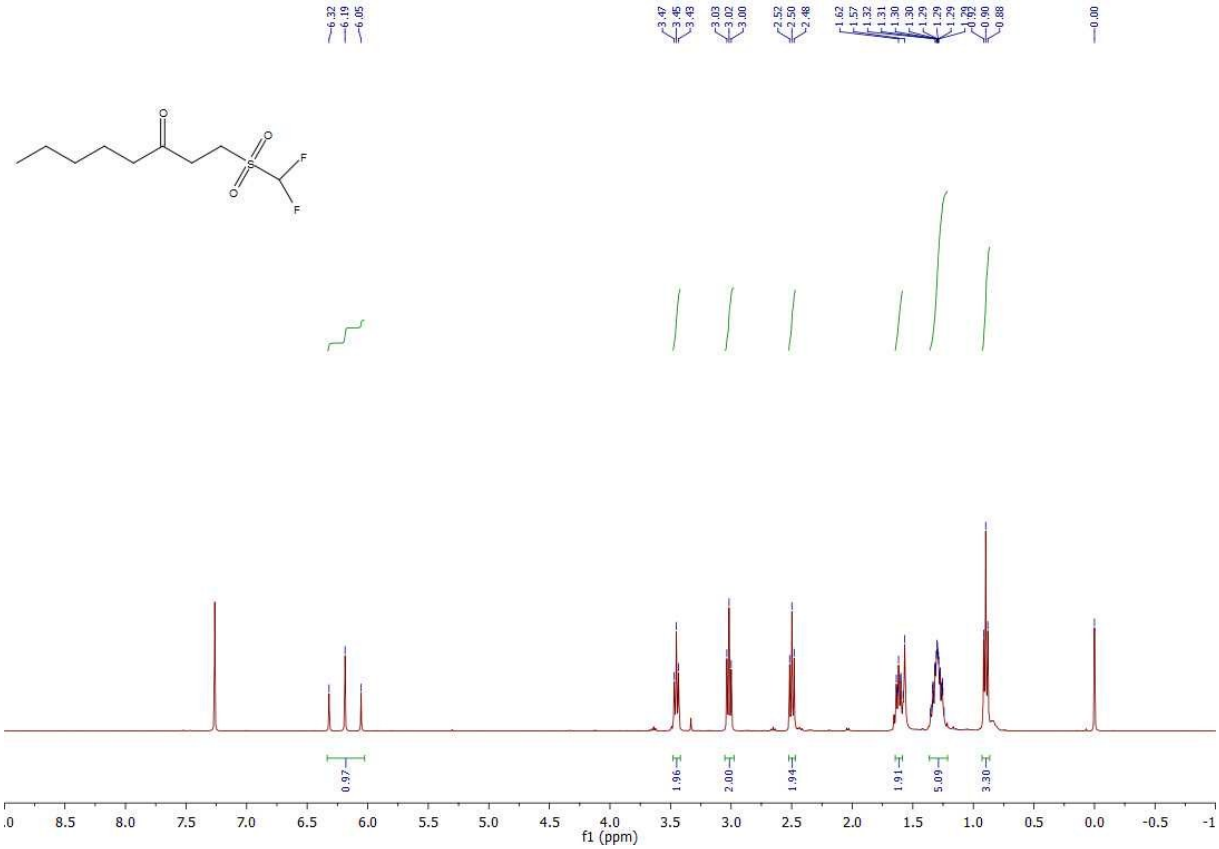
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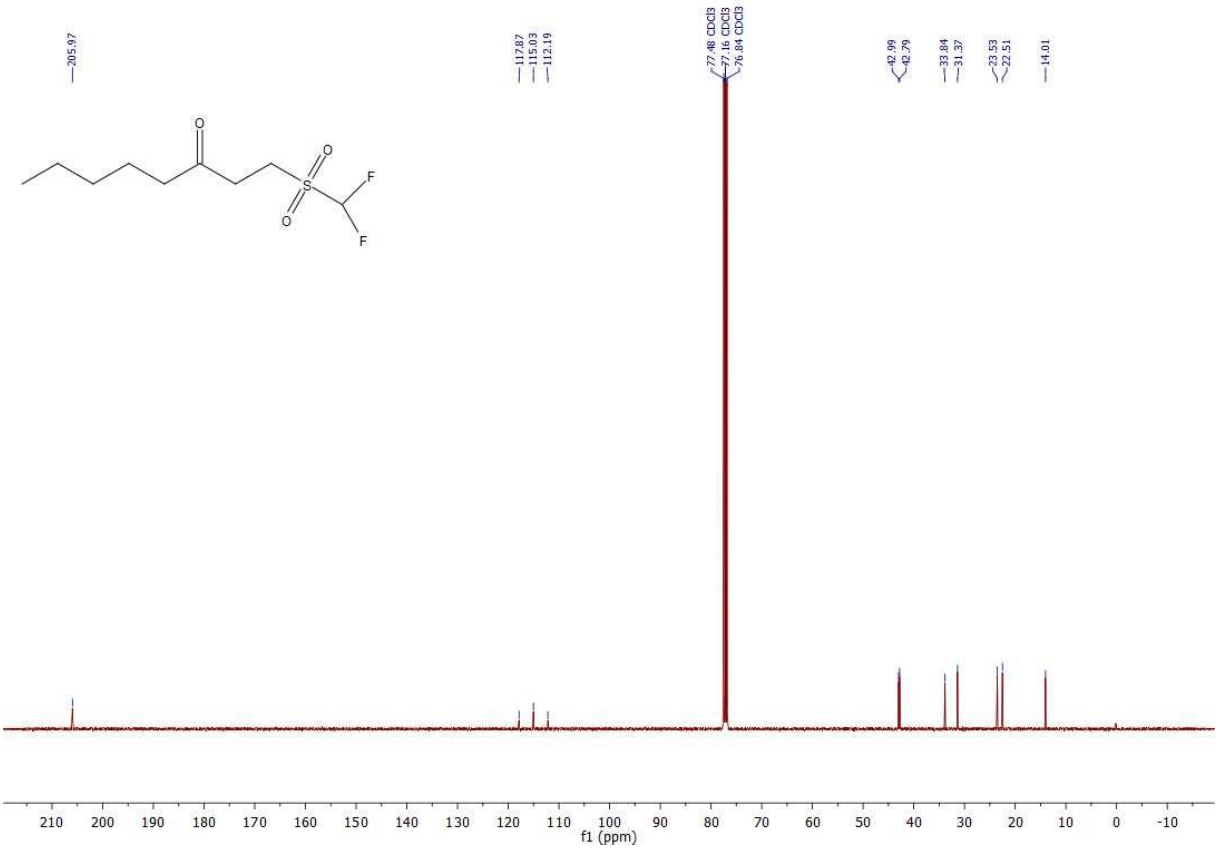
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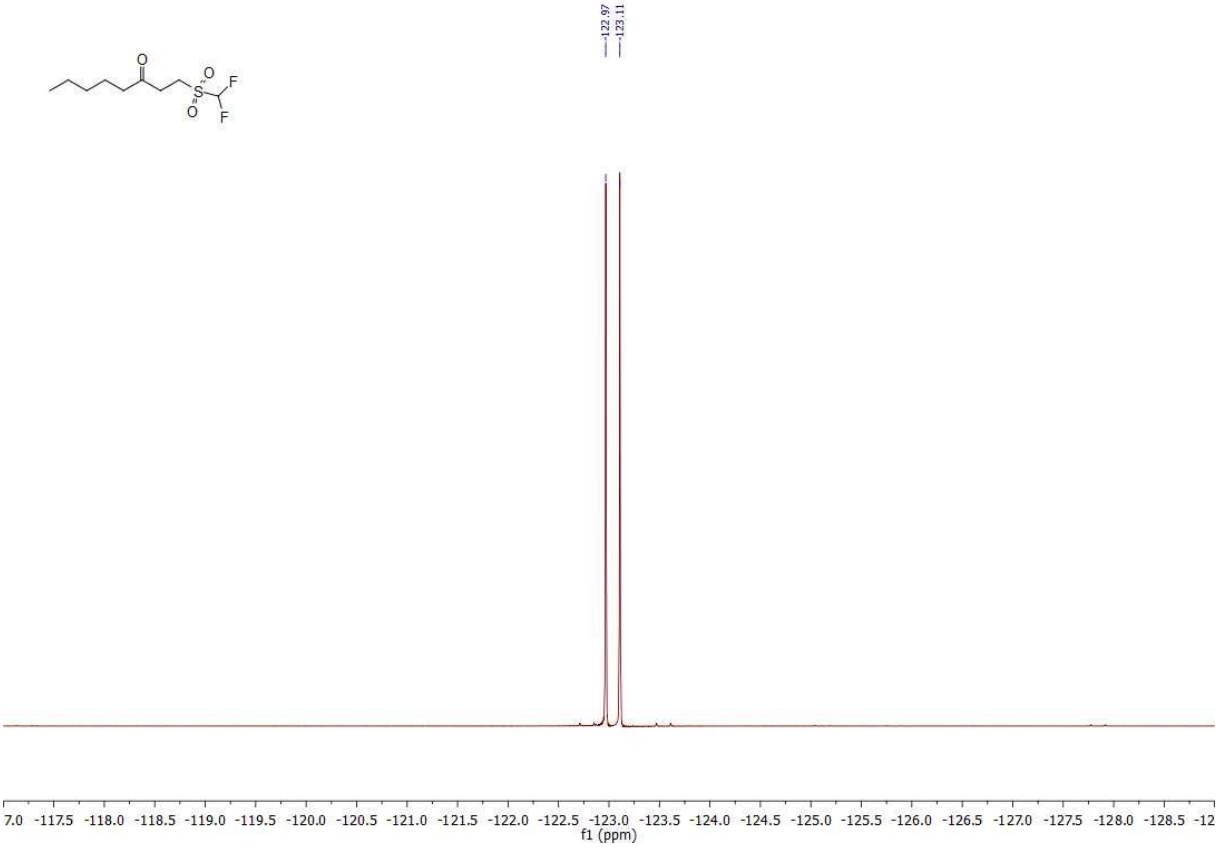
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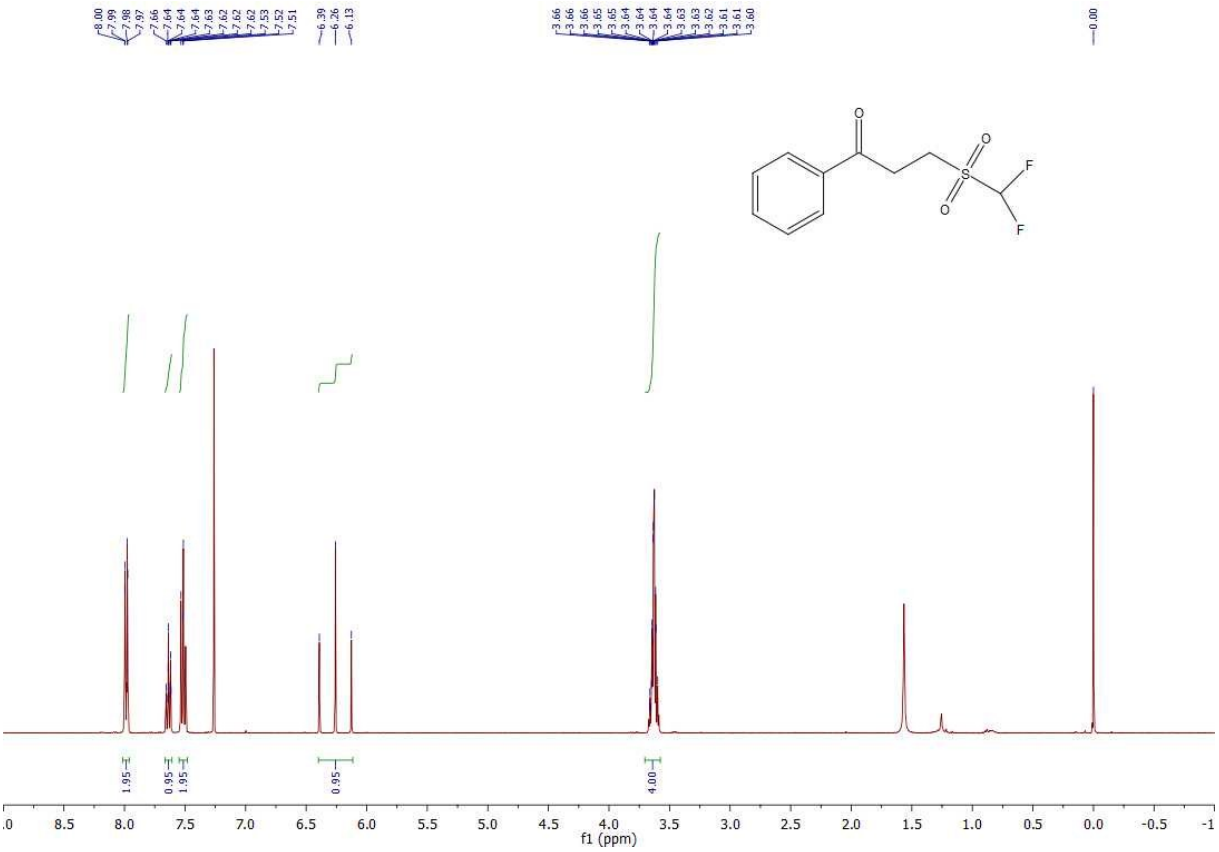
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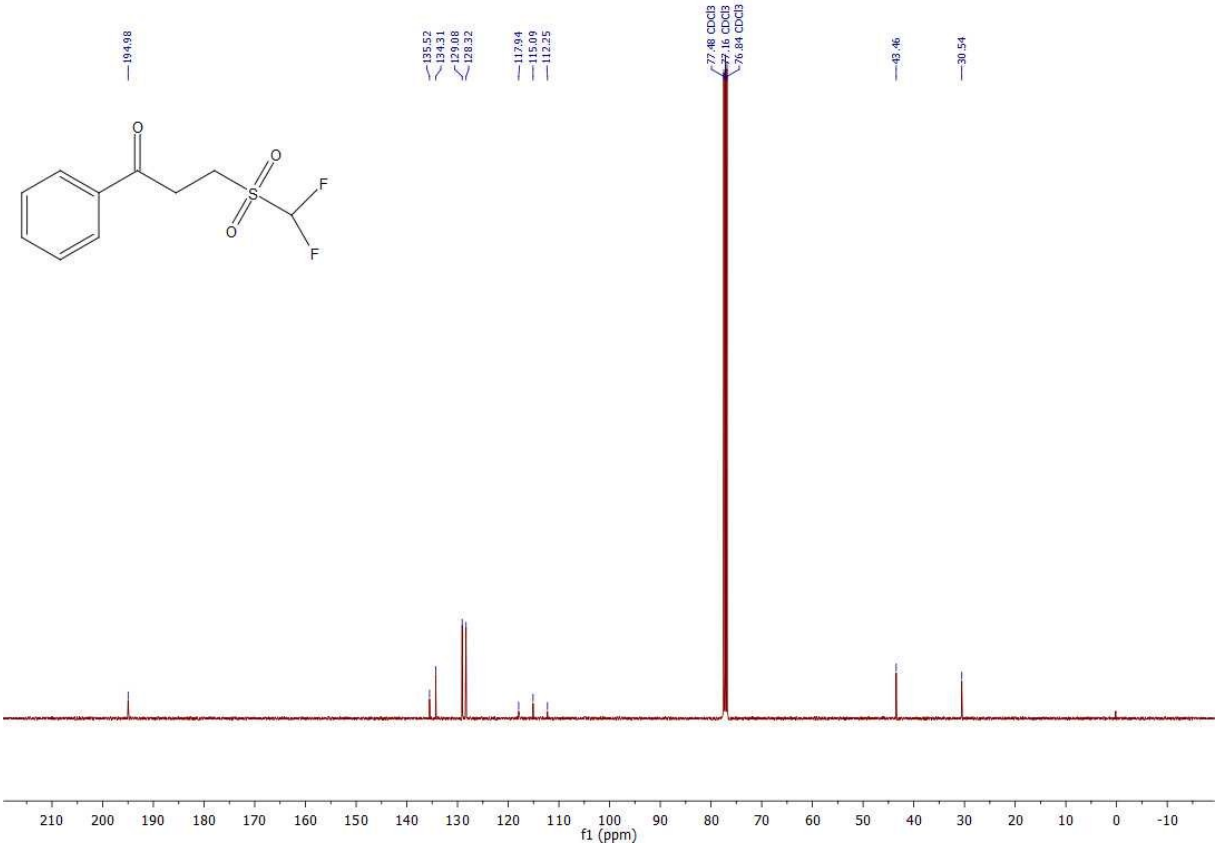
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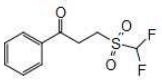

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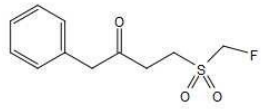

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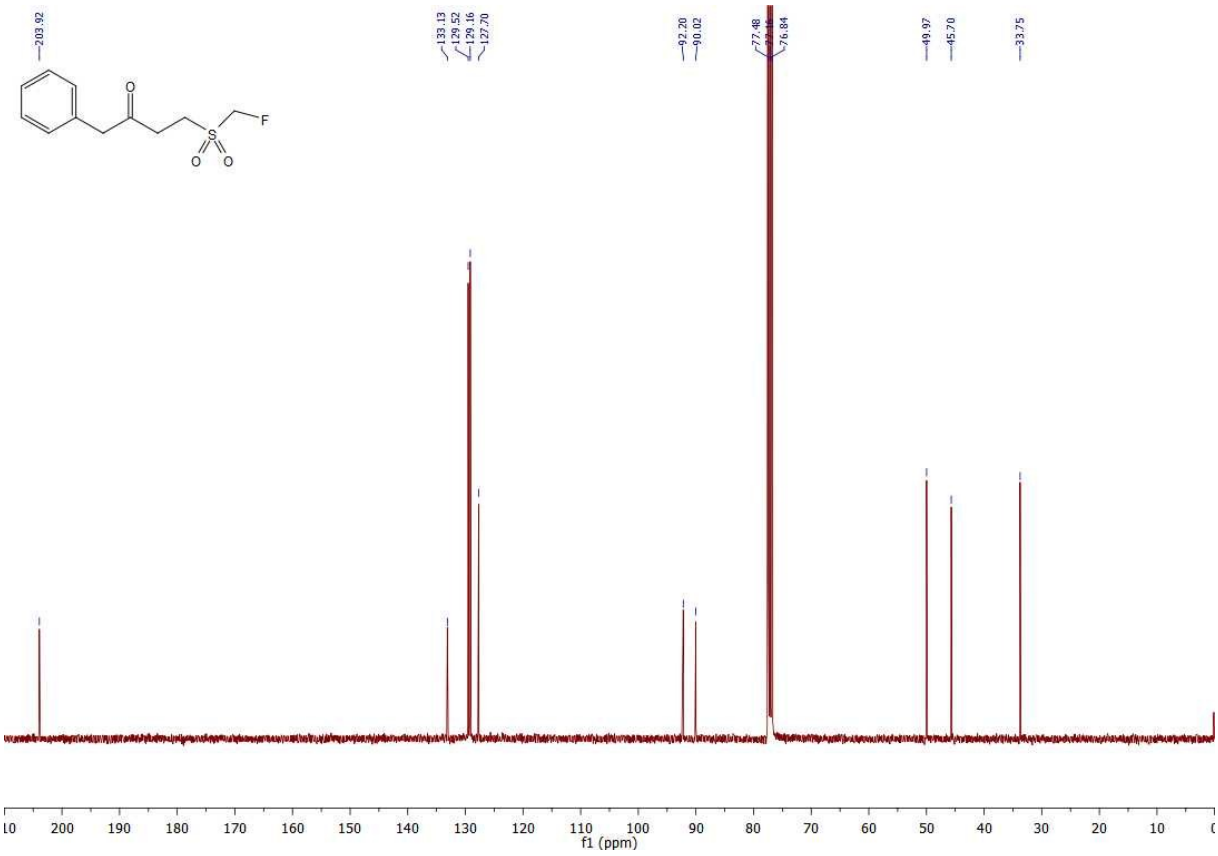
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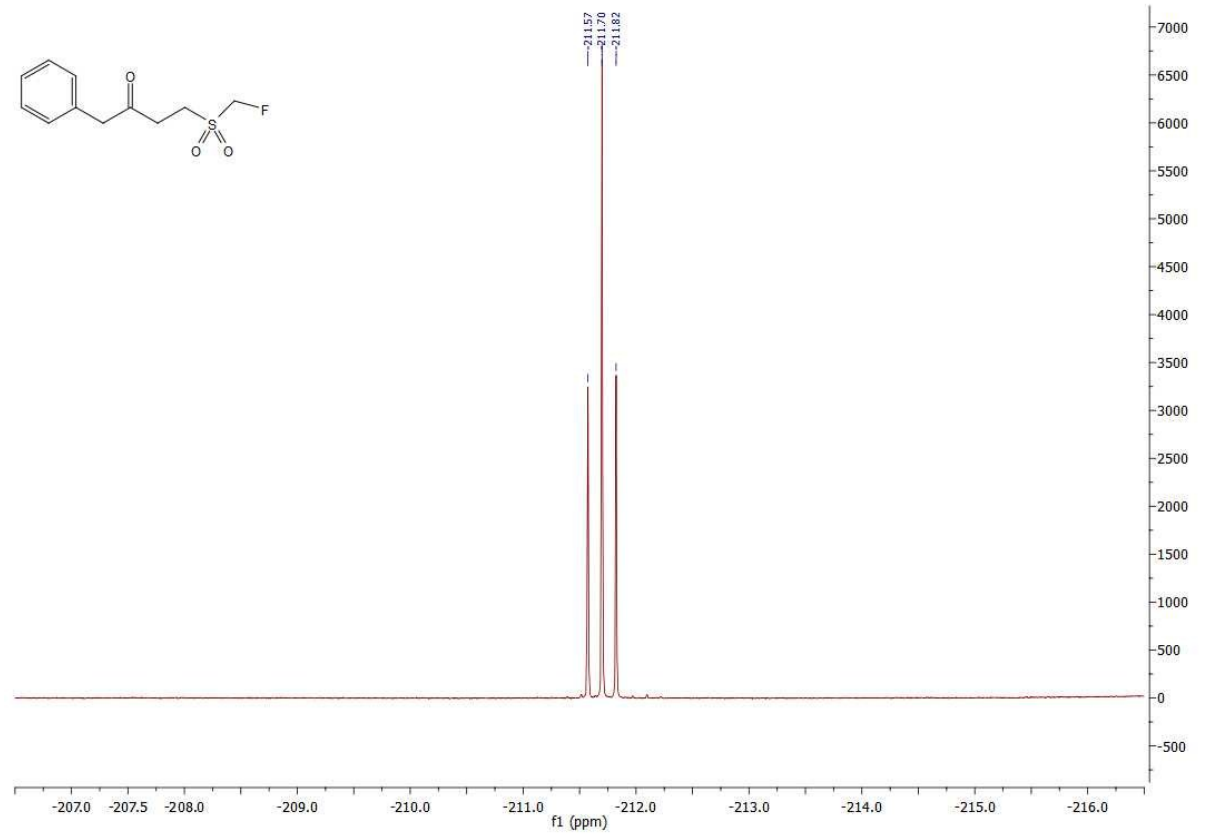
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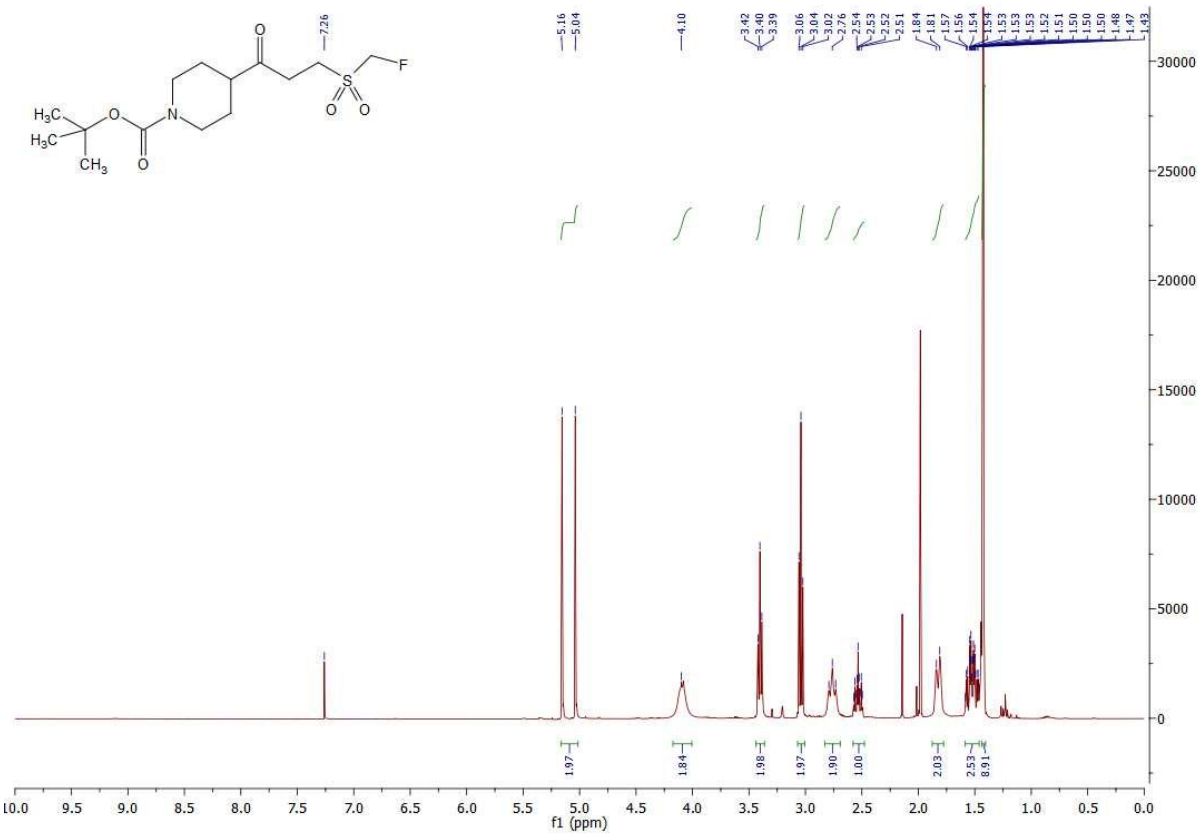
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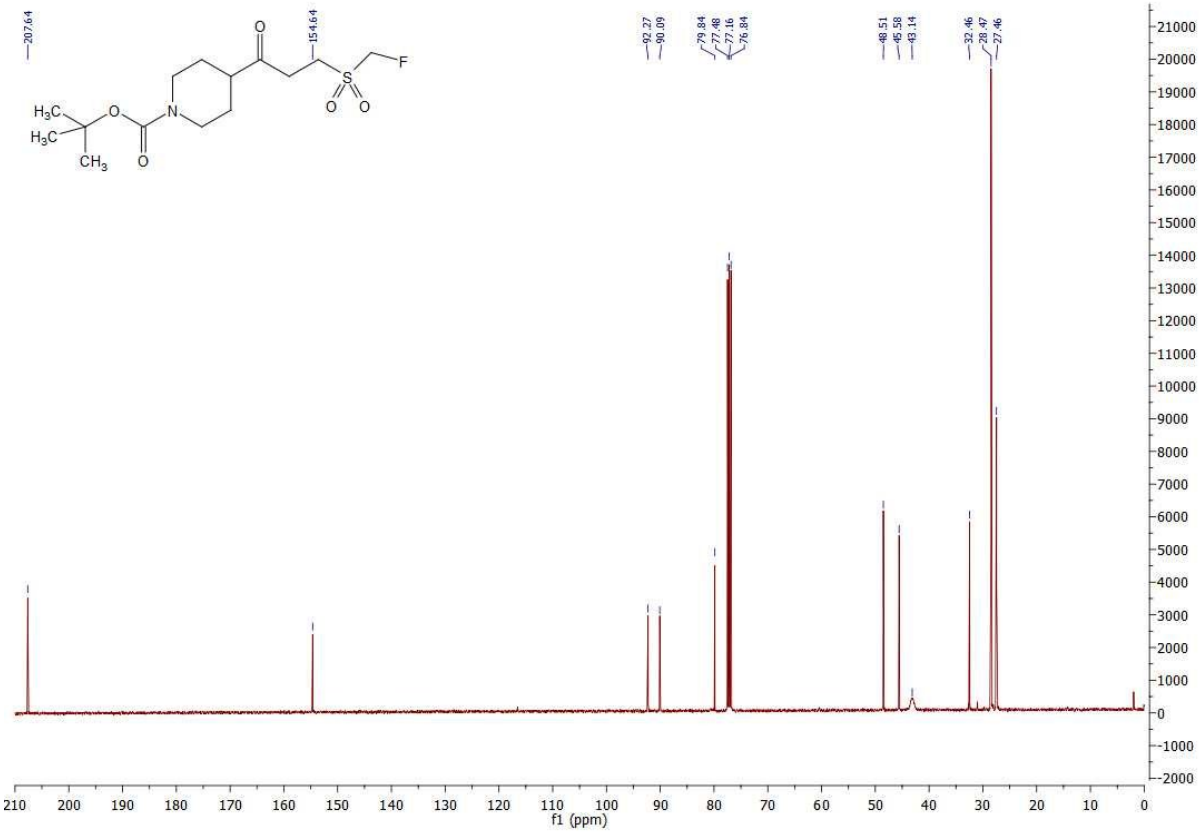
1.90
1.00
2.03
2.53
8.91
f1 (ppm)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154.64
92.27
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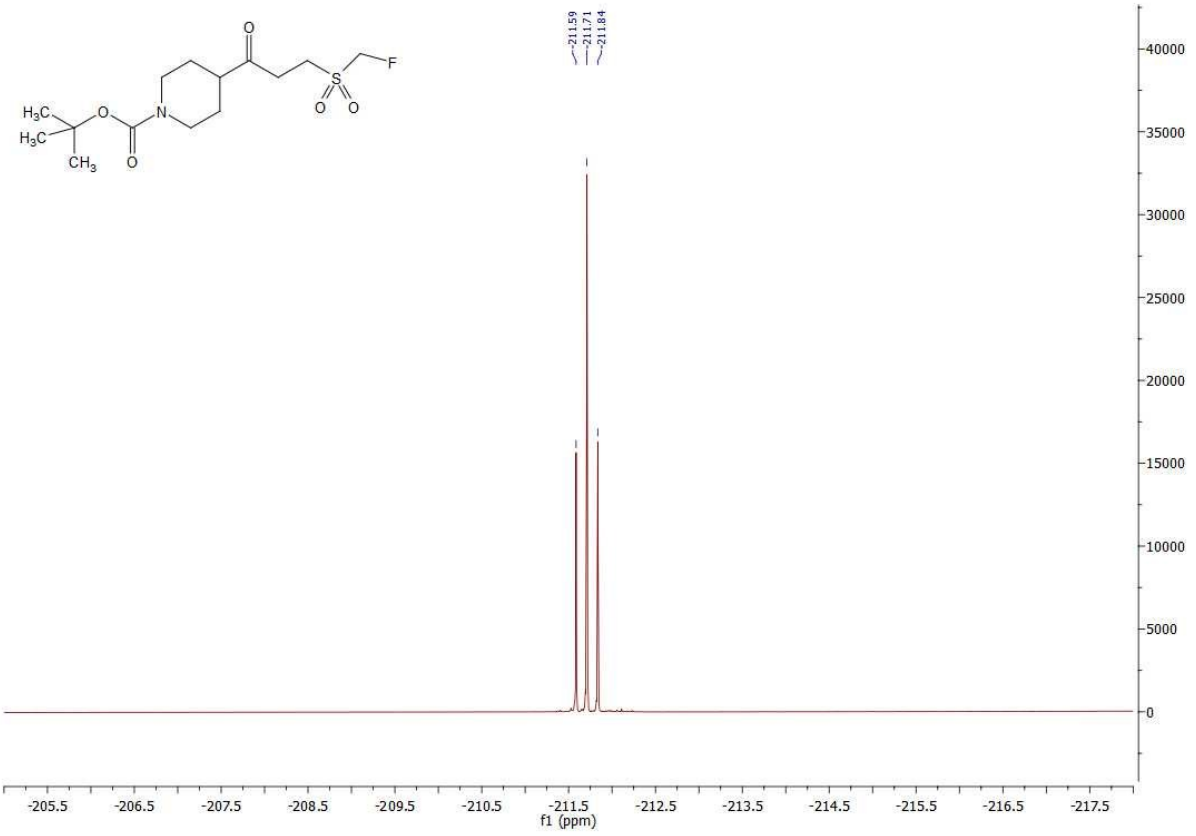
77.16
76.84
48.51
45.58
43.14
32.46
28.47
27.46
f1 (ppm)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-211.71
-211.84
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30000
25000
20000
15000
10000
5000
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-206.5
-207.5
-208.5
-209.5
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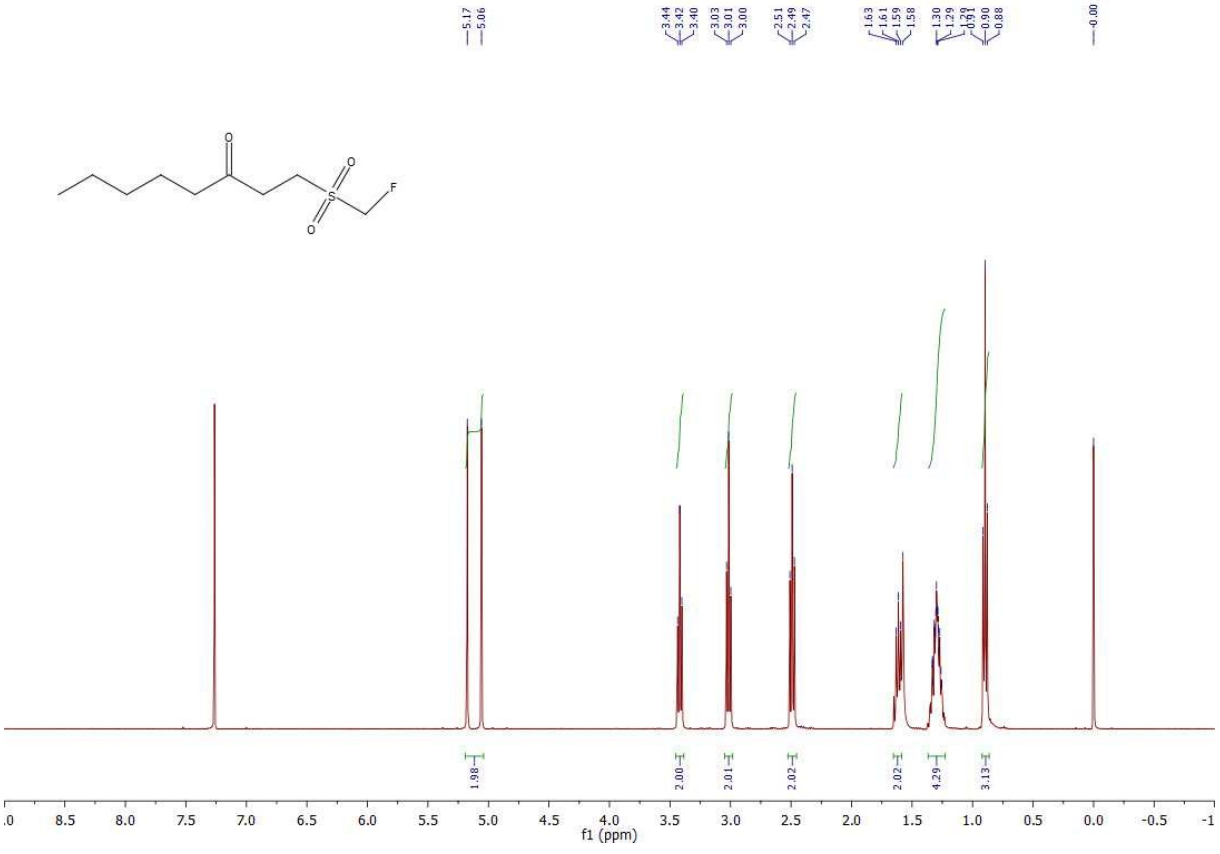
-214.5
-215.5
-216.5
-217.5
f1 (ppm)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3.03
3.01
3.00
2.51
2.49
2.47
1.63
1.61
1.59
1.58
1.30
1.29
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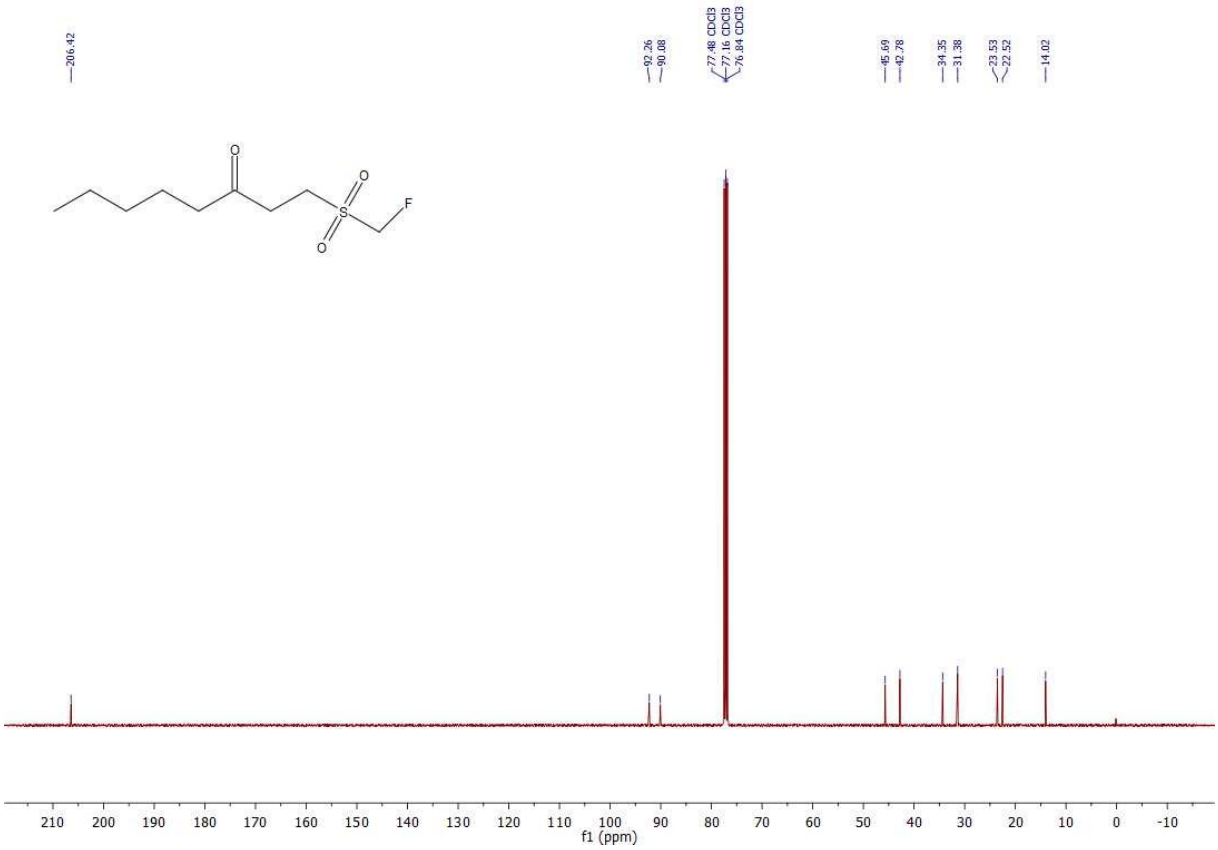
0.00
1.98
2.00
2.01
2.02
2.02
4.29
3.13
f1 (ppm)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90.08
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77.16 CDCl3
76.84 CDCl3
45.69
42.78
34.35
31.38
23.53
22.52
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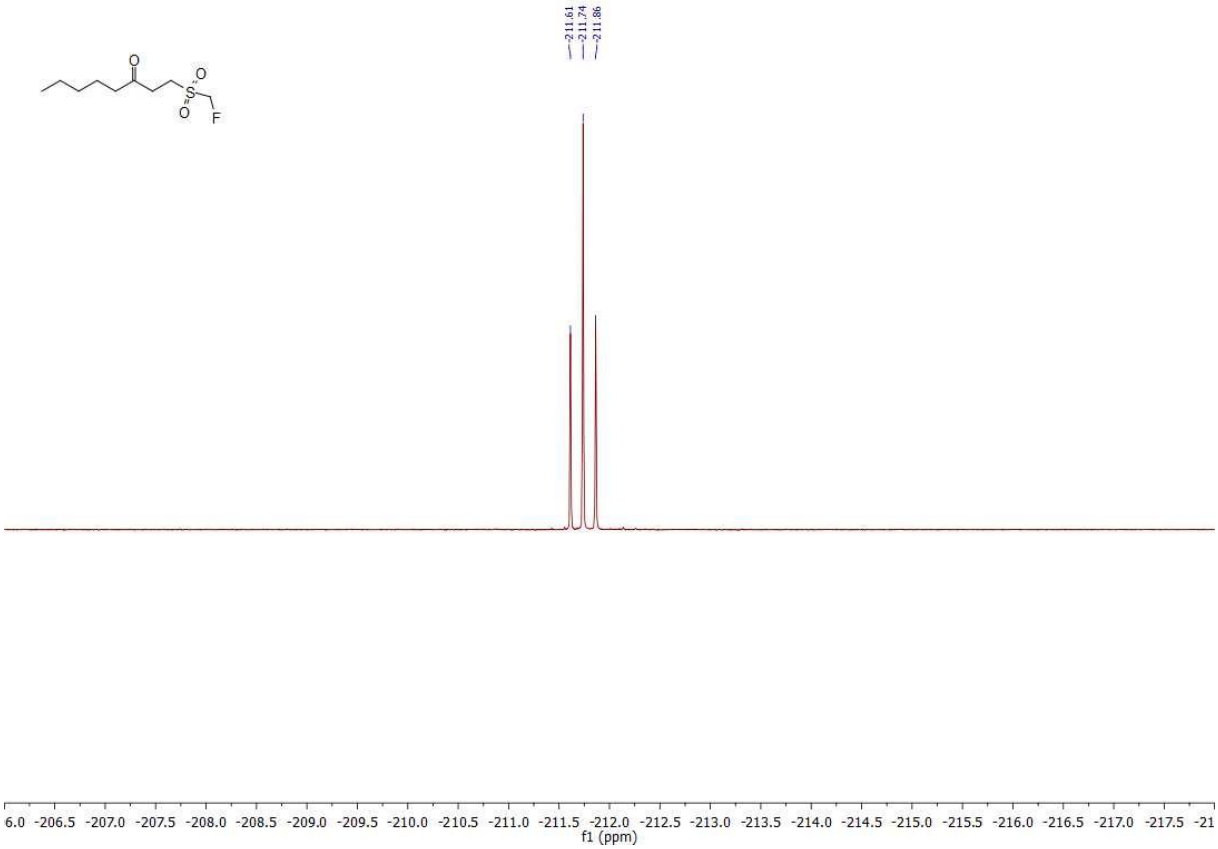
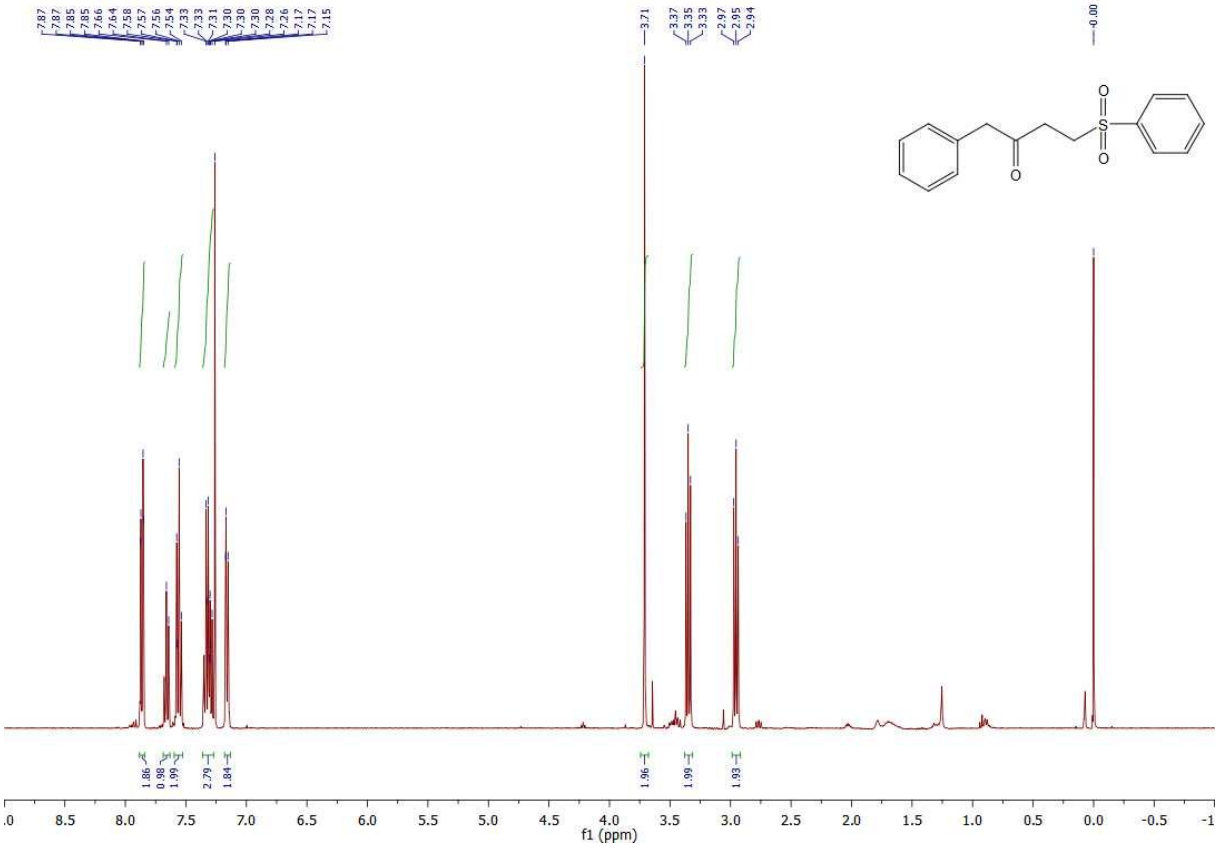
O
O
O
S
F
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


211.61
211.74
211.86
O
O
O
S
F
6.0 -206.5 -207.0 -207.5 -208.0 -208.5 -209.0 -209.5 -210.0 -210.5 -211.0 -211.5 -212.0 -212.5 -213.0 -213.5 -214.0 -214.5 -215.0 -215.5 -216.0 -216.5 -217.0 -217.5 -21
f1 (ppm)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7.87
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7.58
7.57
7.56
7.54
7.33
7.33
7.31
7.30
7.30
7.30
7.28
7.26
7.17
7.17
7.15
3.71
3.37
3.35
3.33
2.97
2.95
2.94
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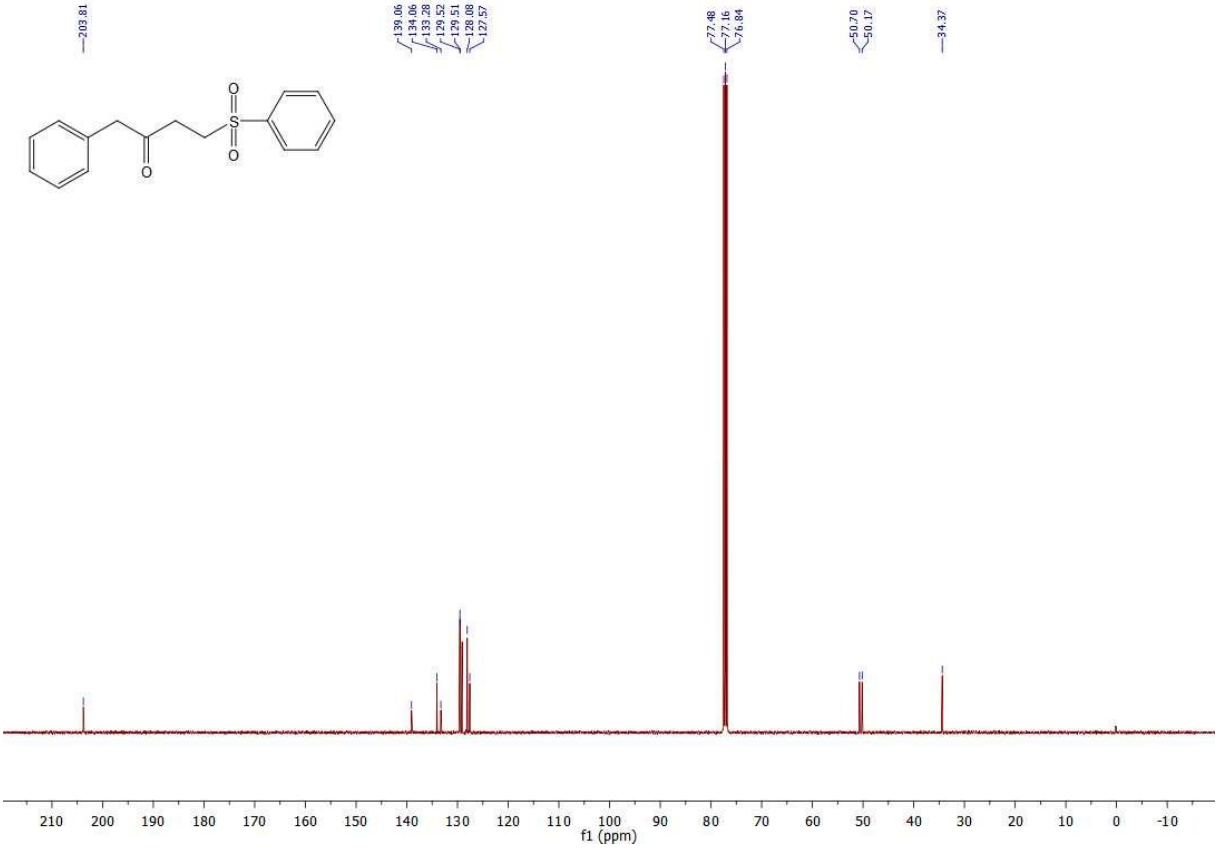
0.98
1.99
2.79
1.84
1.96
1.99
1.93
f1 (ppm)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139.06
134.06
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129.52
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127.57
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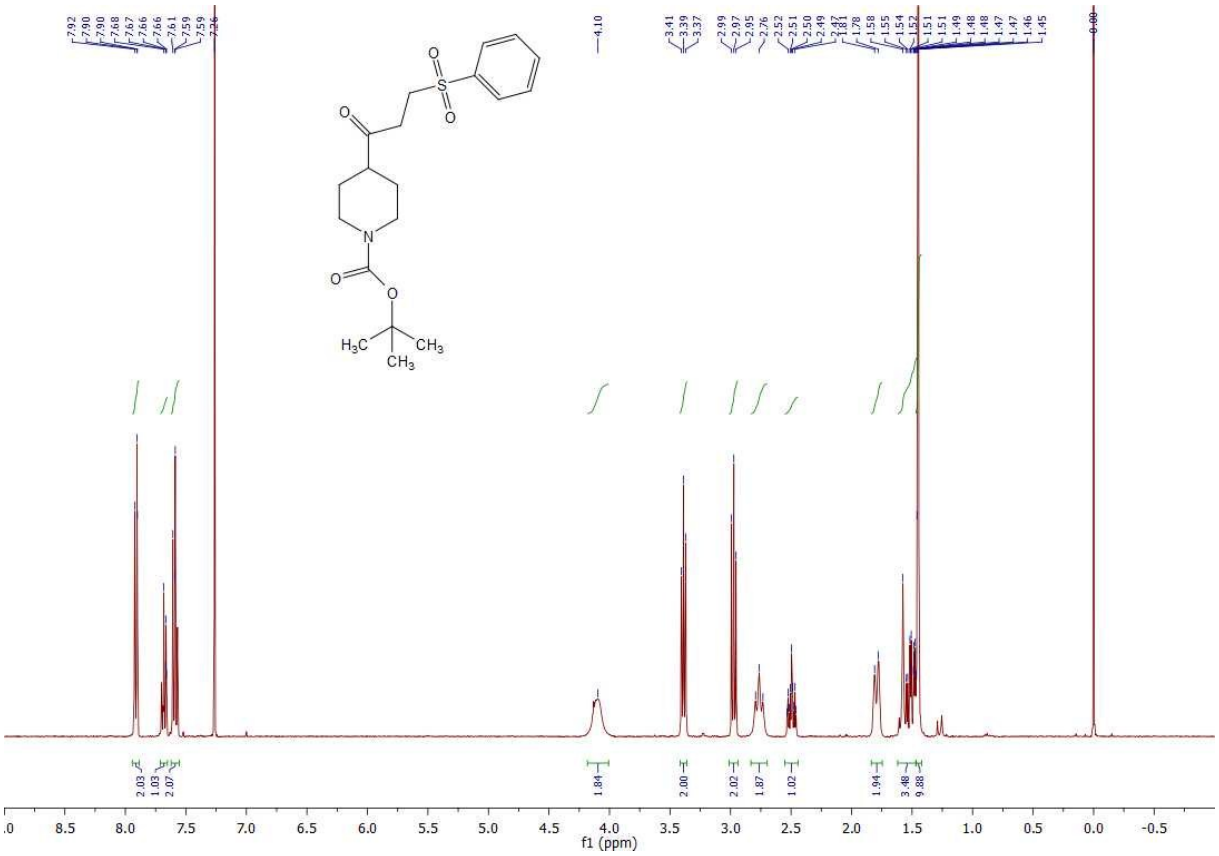
77.16
76.84
50.70
50.17
34.37
f1 (ppm)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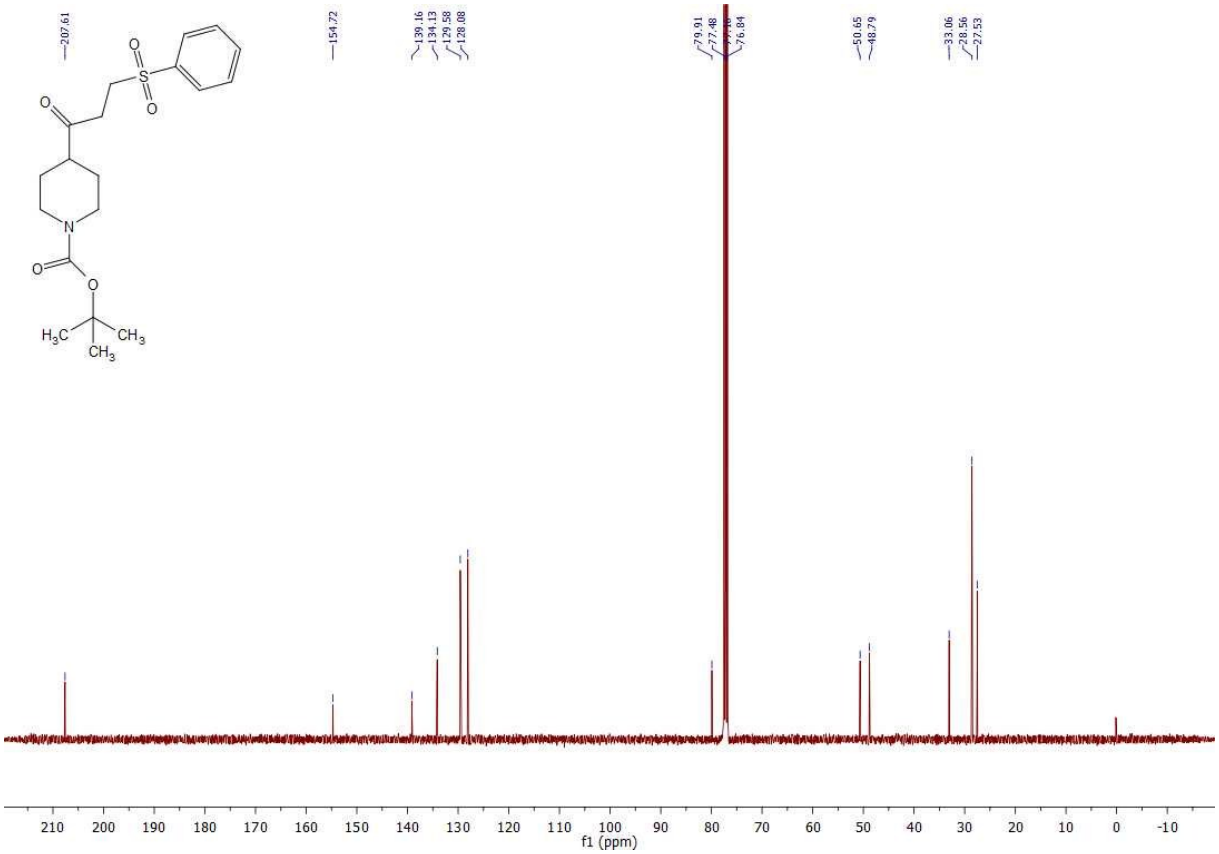
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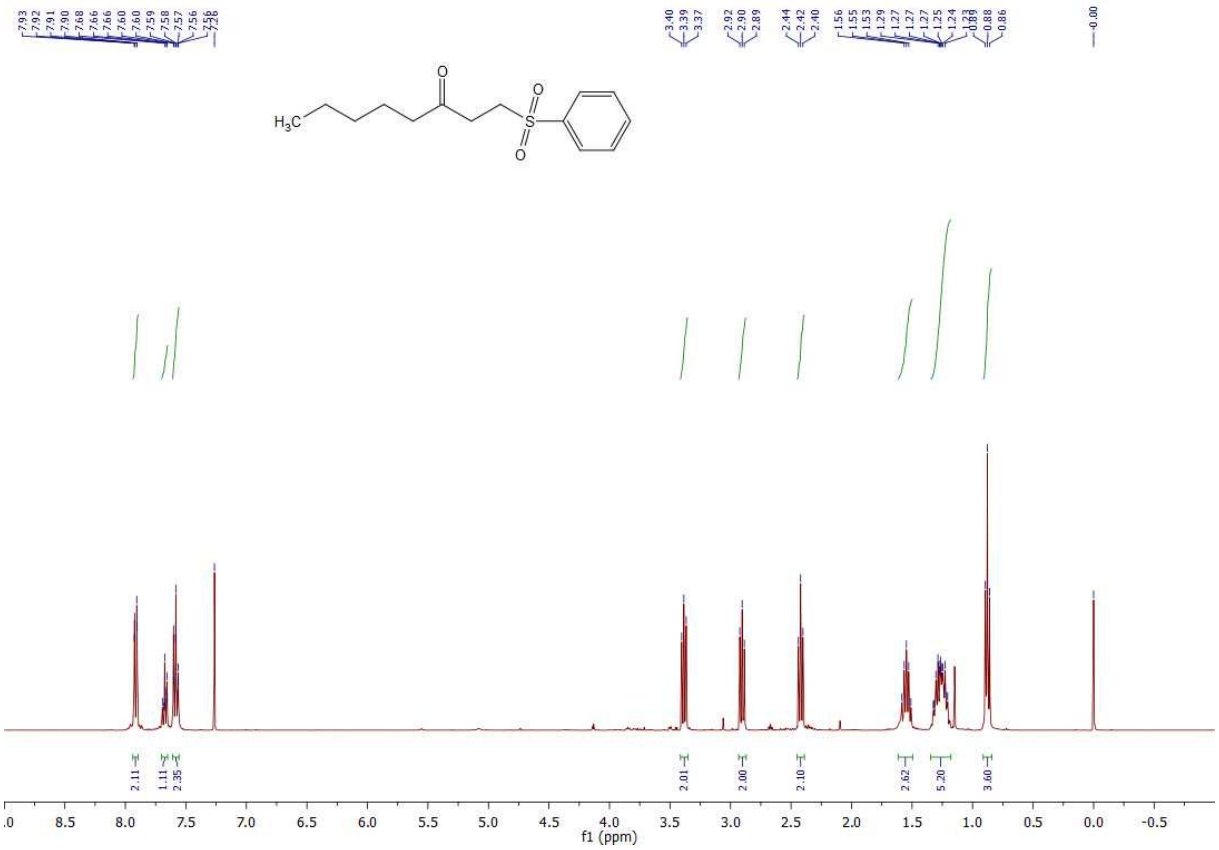
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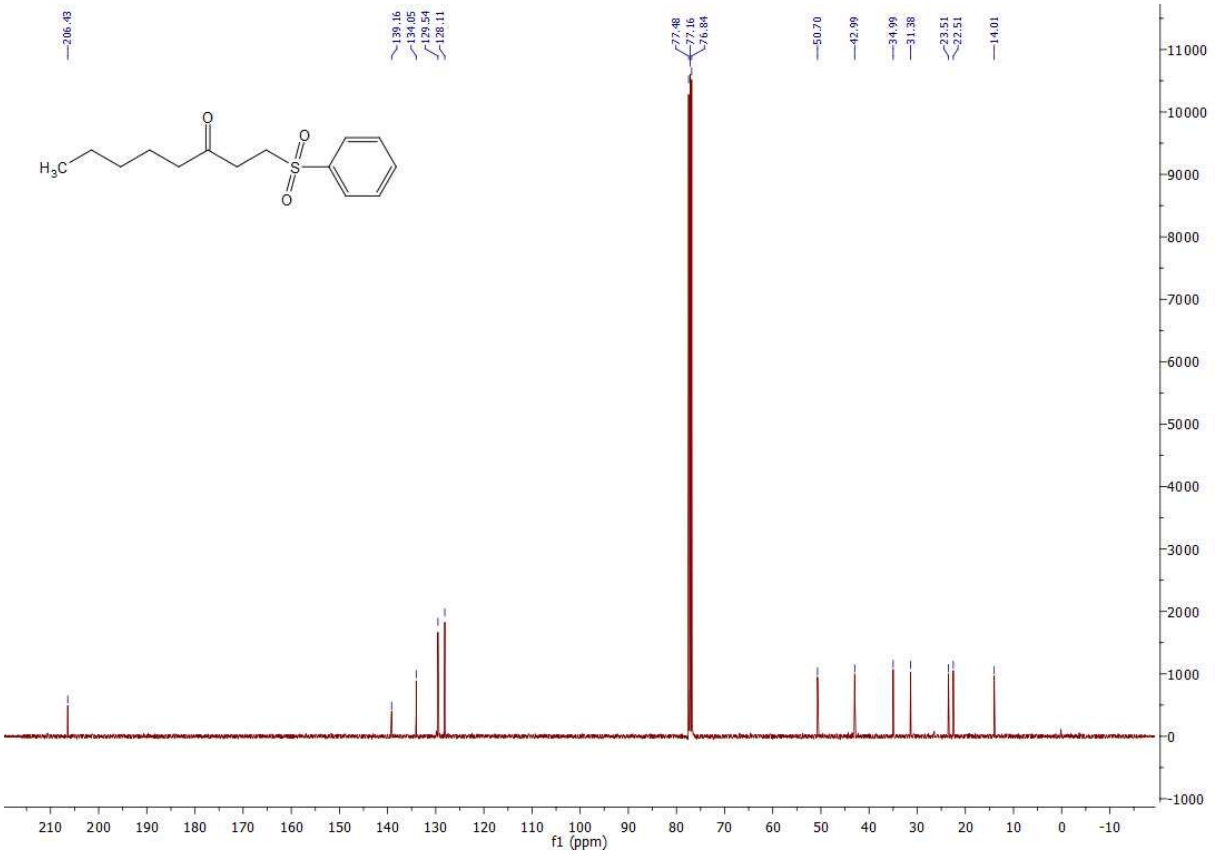
7.66
7.66
7.60
7.60
7.59
7.58
7.57
7.56
7.55
7.54
3.40
3.39
3.37
2.92
2.90
2.89
2.44
2.42
2.40
1.56
1.55
1.53
1.29
1.27
1.27
1.27
1.25
1.24
0.89
0.88
0.86
0.00
O
O
O
S
H3C
2.11
1.11
2.35
2.01
2.00
2.10
2.62
5.20
3.60
f1 (ppm)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134.05
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128.11
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77.16
76.84
50.70
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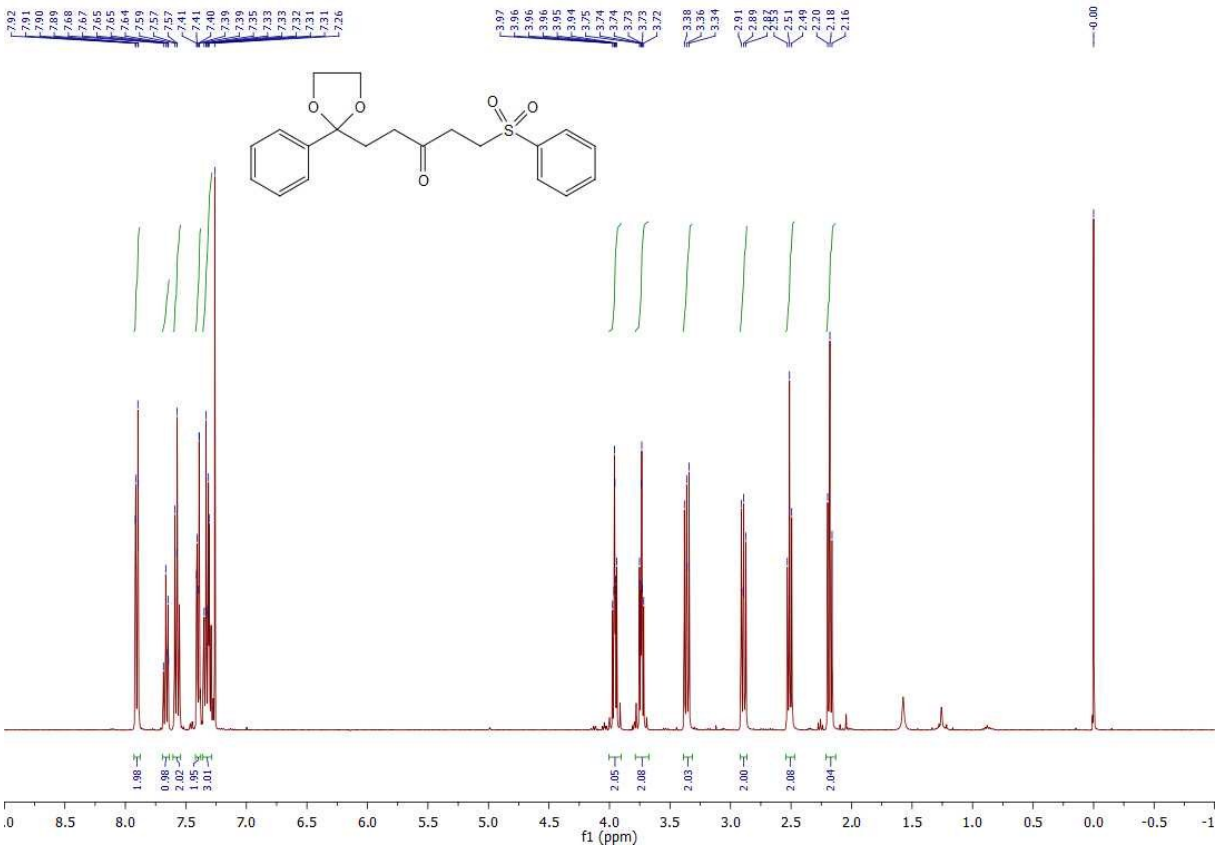
34.99
31.38
23.51
22.51
14.01
O
O
O
S
H3C
f1 (ppm)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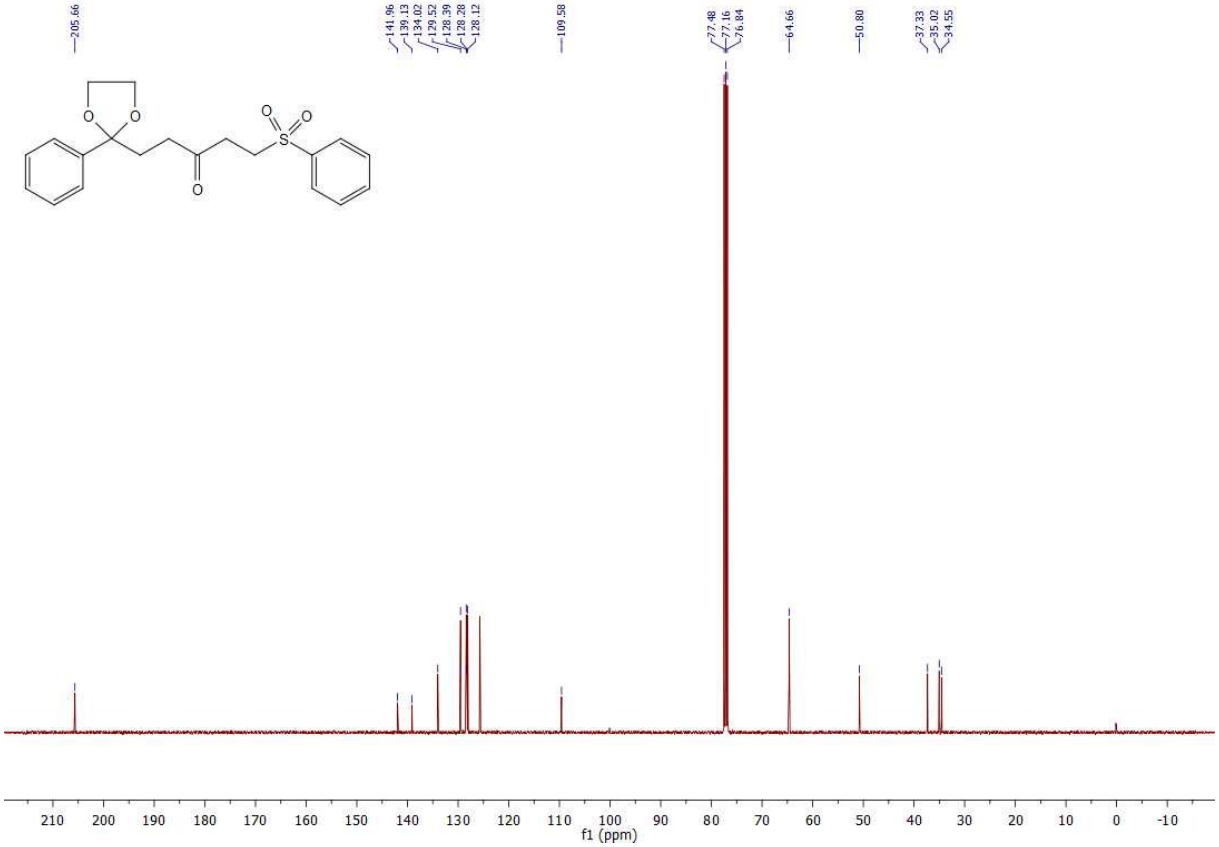
3.97 3.96 3.96 3.96 3.95 3.94 3.75 3.74 3.74 3.73 3.73 3.72
3.38 3.36 3.34
2.91 2.89 2.83 2.82 2.51 2.49 2.20 2.18 2.16
-0.00
1.98 0.98 2.02 1.95 3.01
2.05 2.08 2.03 2.00 2.08 2.04
f1 (ppm)


205.66
141.96 139.13 134.02 129.52 128.39 128.28 128.12
109.58
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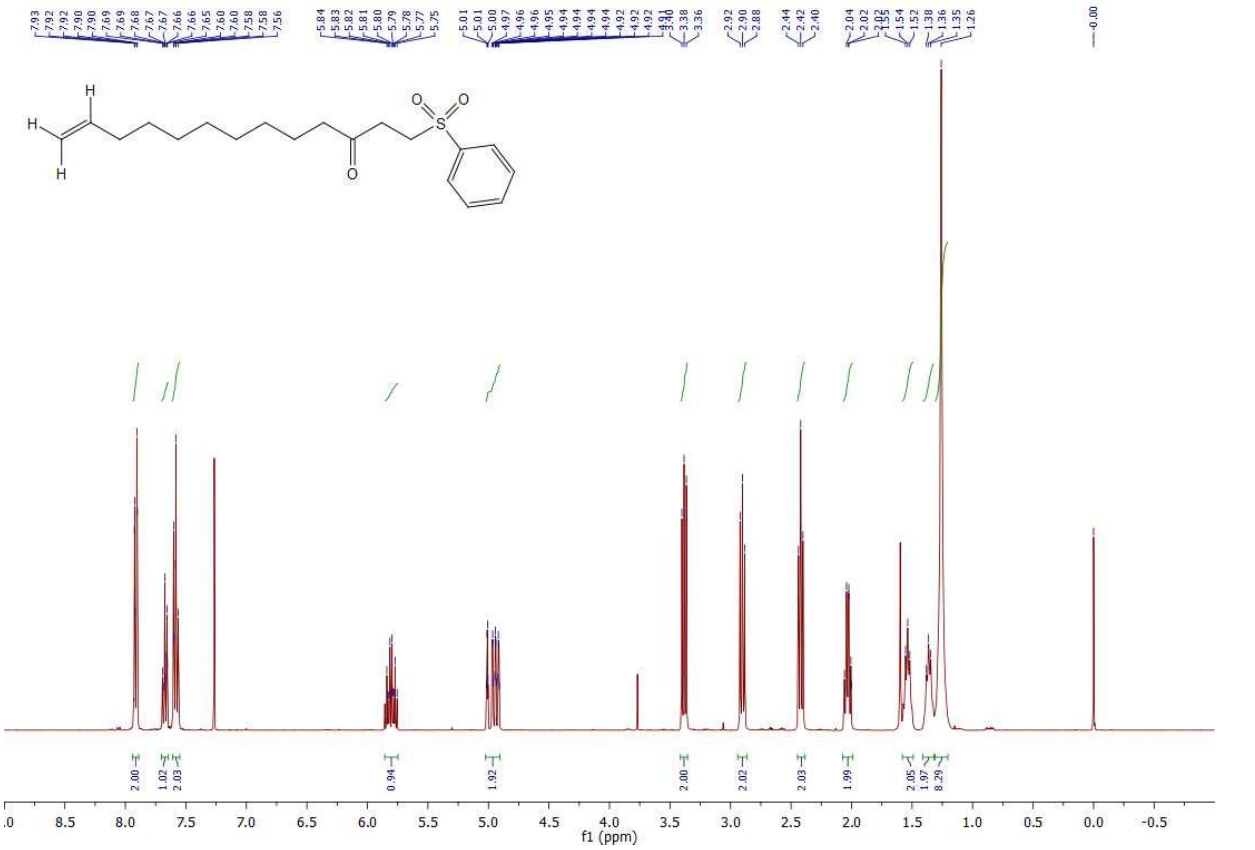
64.66
50.80
37.33 35.02 34.55
f1 (ppm)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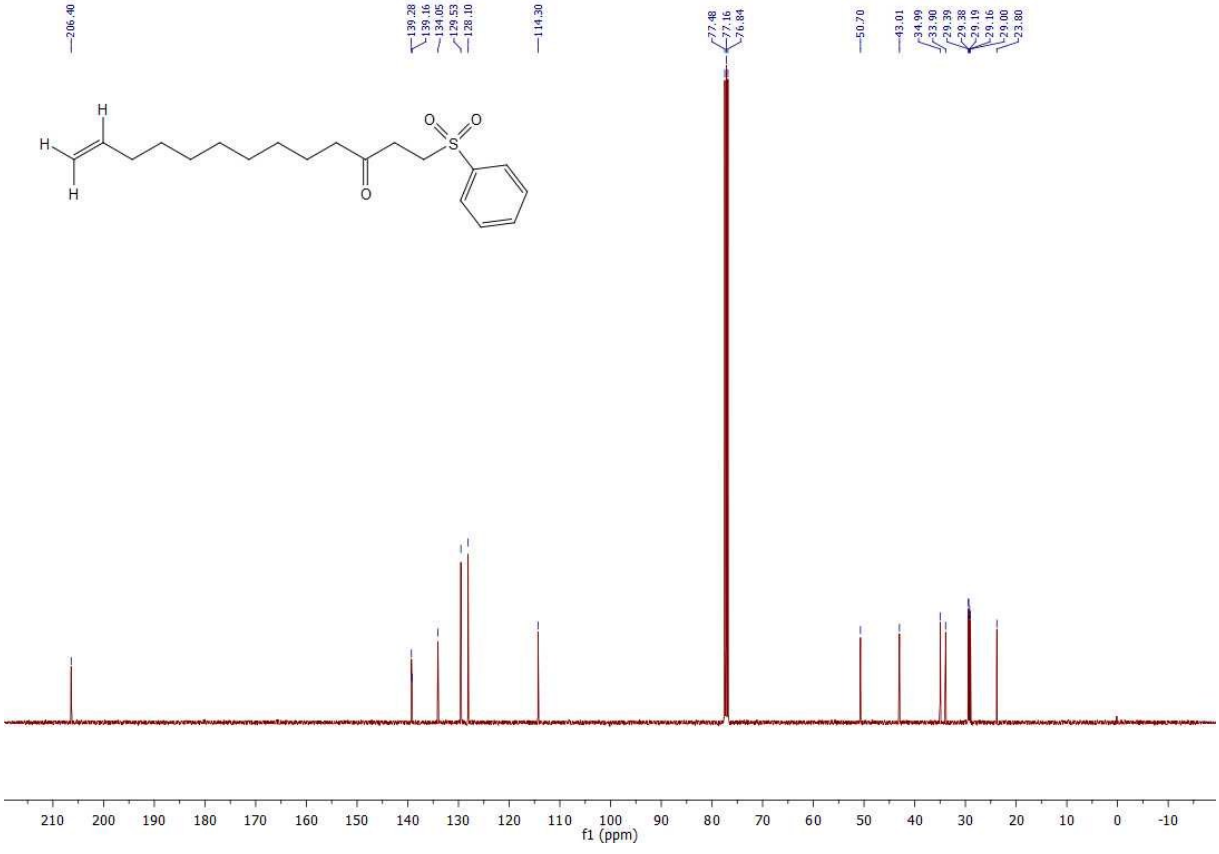
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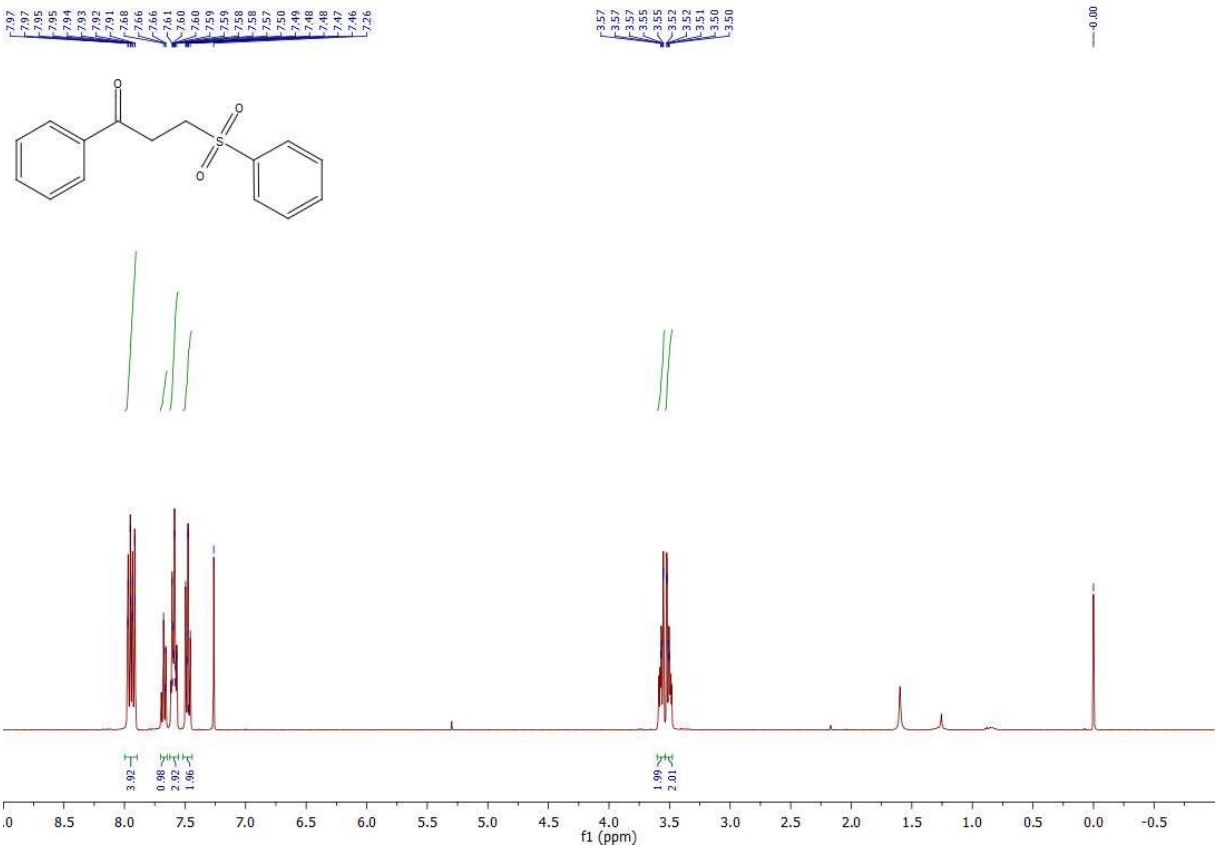
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3.57
3.55
3.55
3.52
3.52
3.51
3.50
3.50
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O
O
S
O
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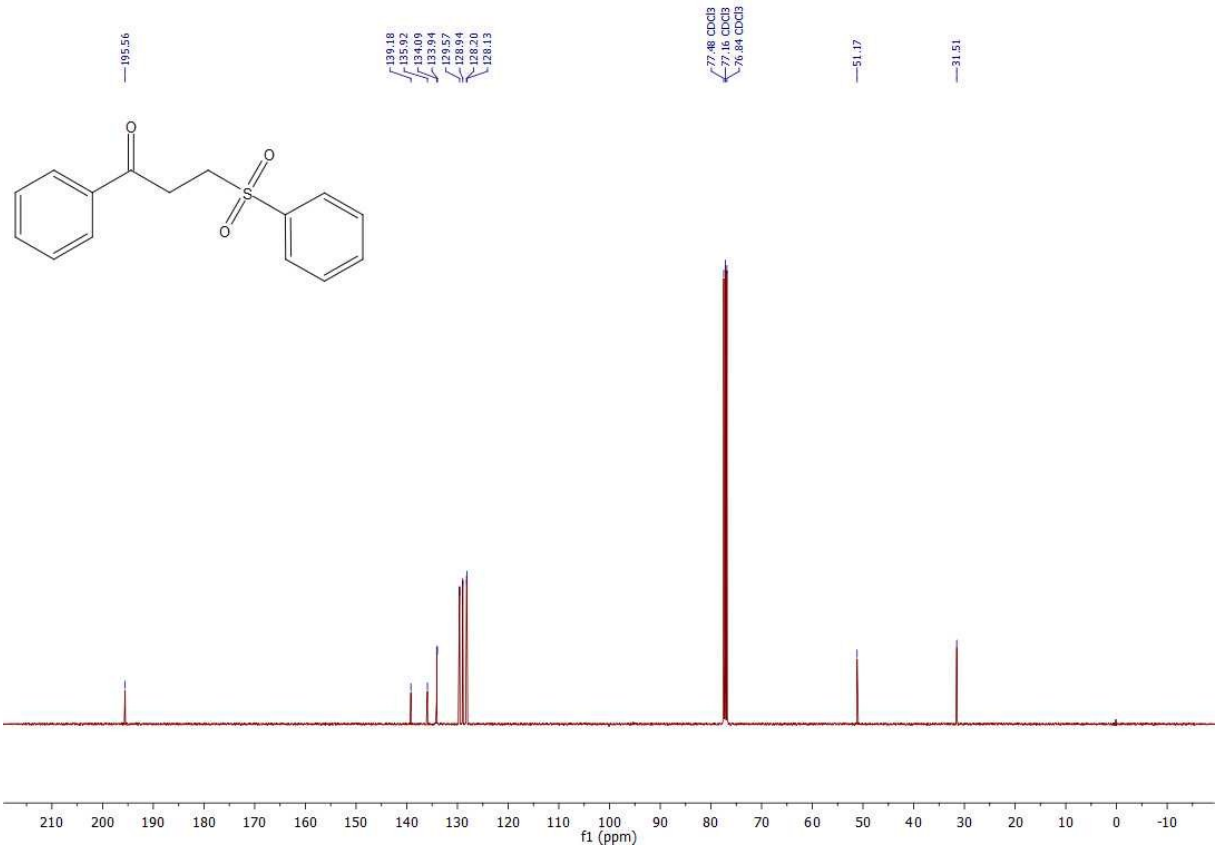
0.98
2.92
1.96
1.99
2.01
f1 (ppm)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133.94
129.57
128.94
128.20
128.13
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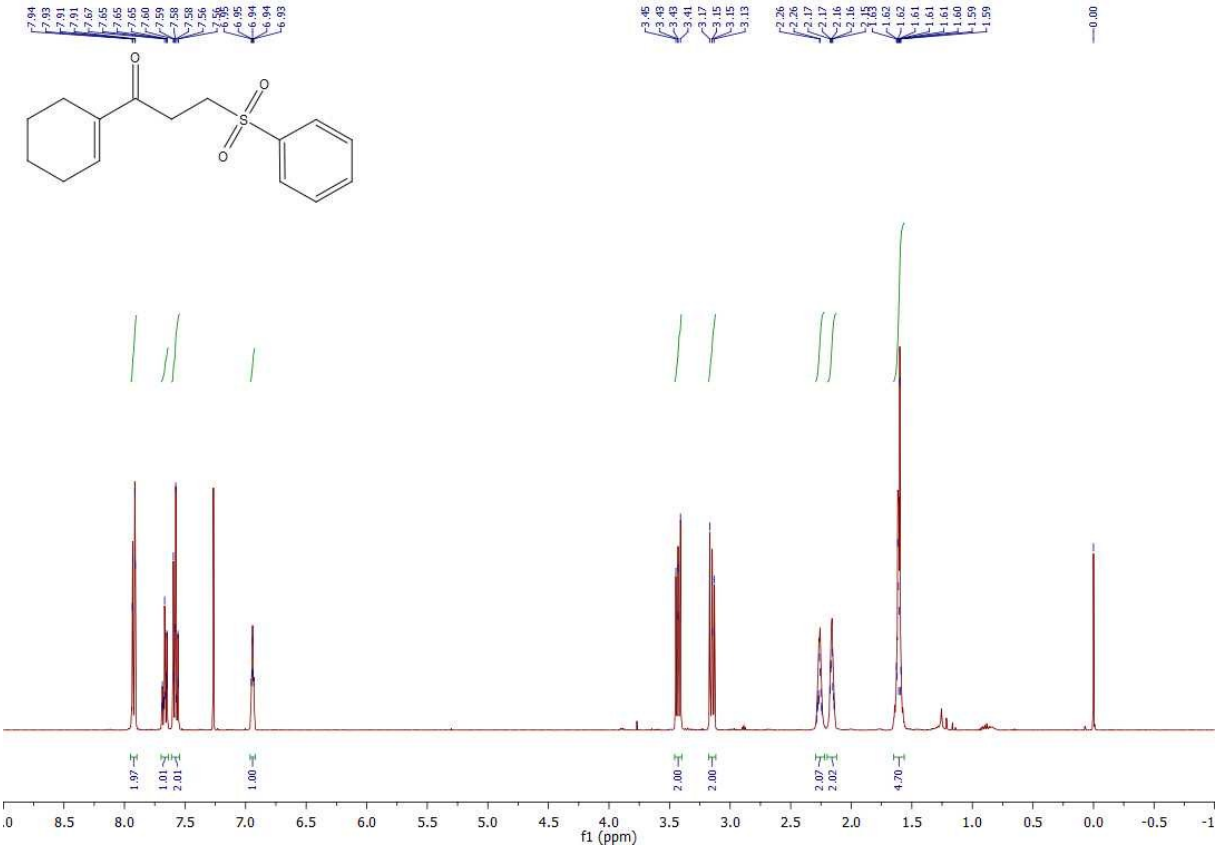
77.16 CDCl3
76.84 CDCl3
51.17
31.51
O
O
S
O
f1 (ppm)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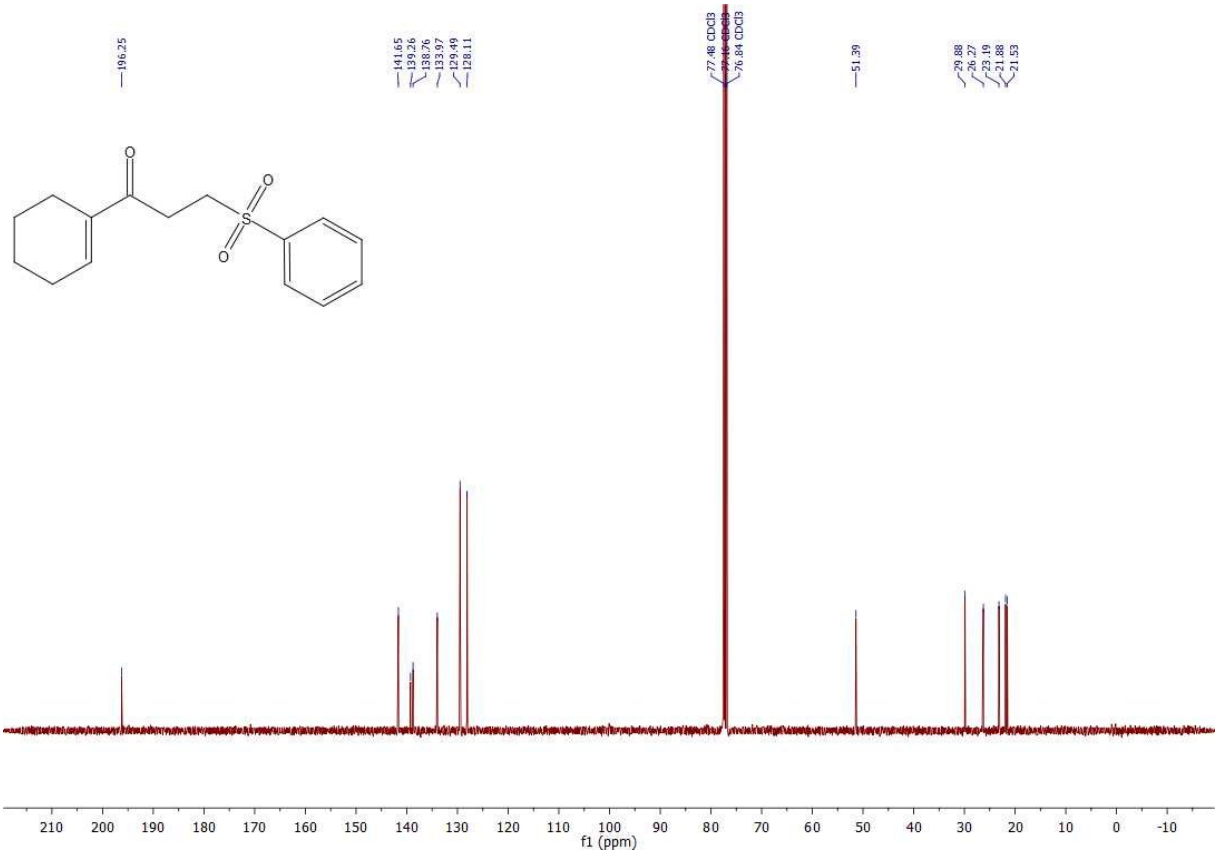
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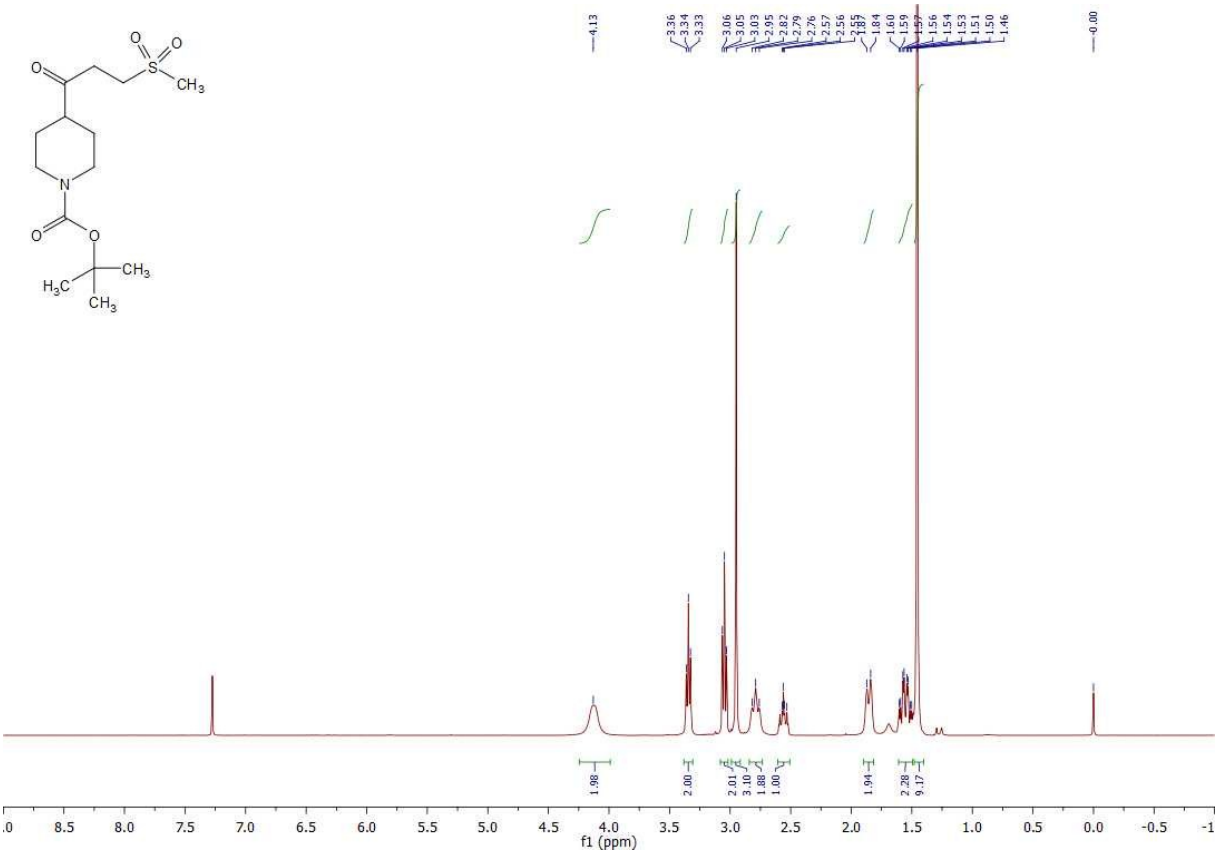
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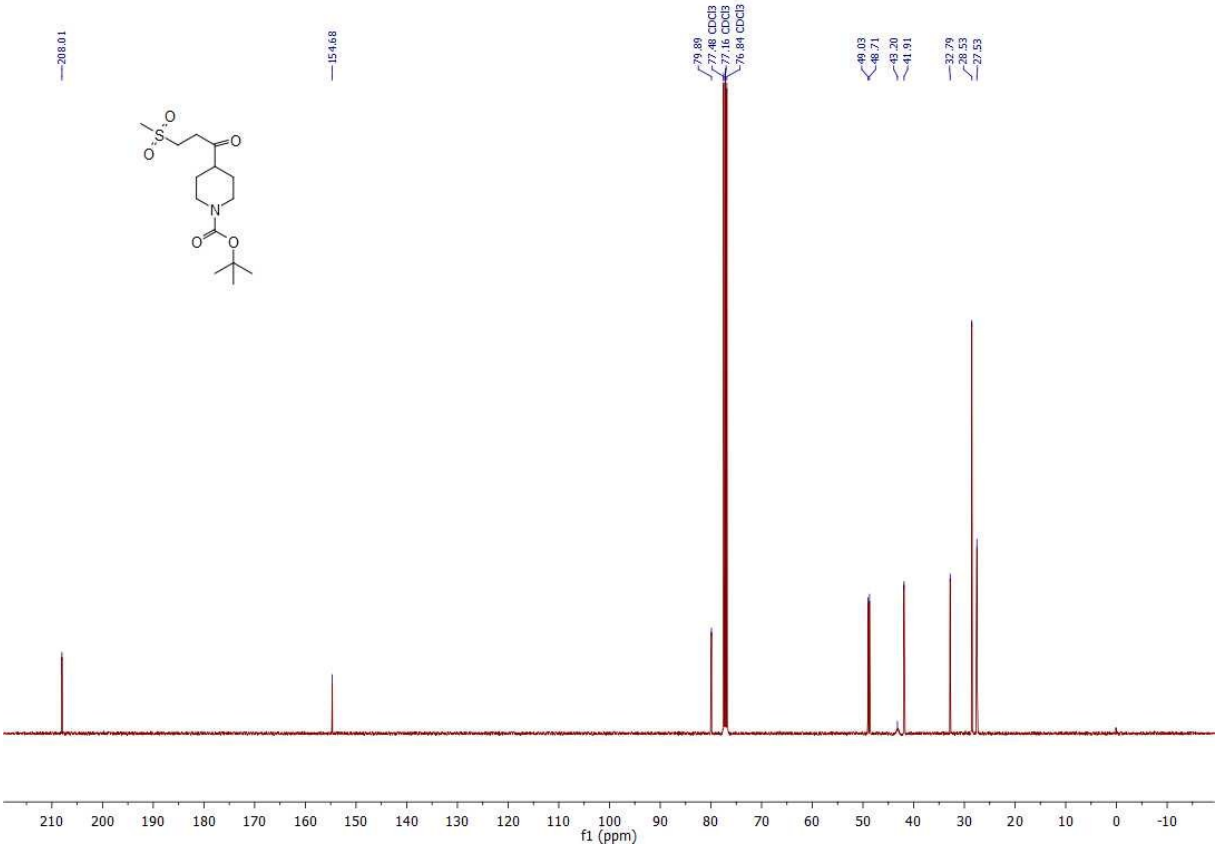
2.79
2.76
2.57
2.56
1.84
1.60
1.59
1.57
1.56
1.54
1.53
1.51
1.50
1.46
0.00
1.98
2.00
2.01
3.10
1.88
1.00
1.94
2.28
9.17
f1 (ppm)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154.68
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76.84 CDCl3
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48.71
43.20
41.91
32.79
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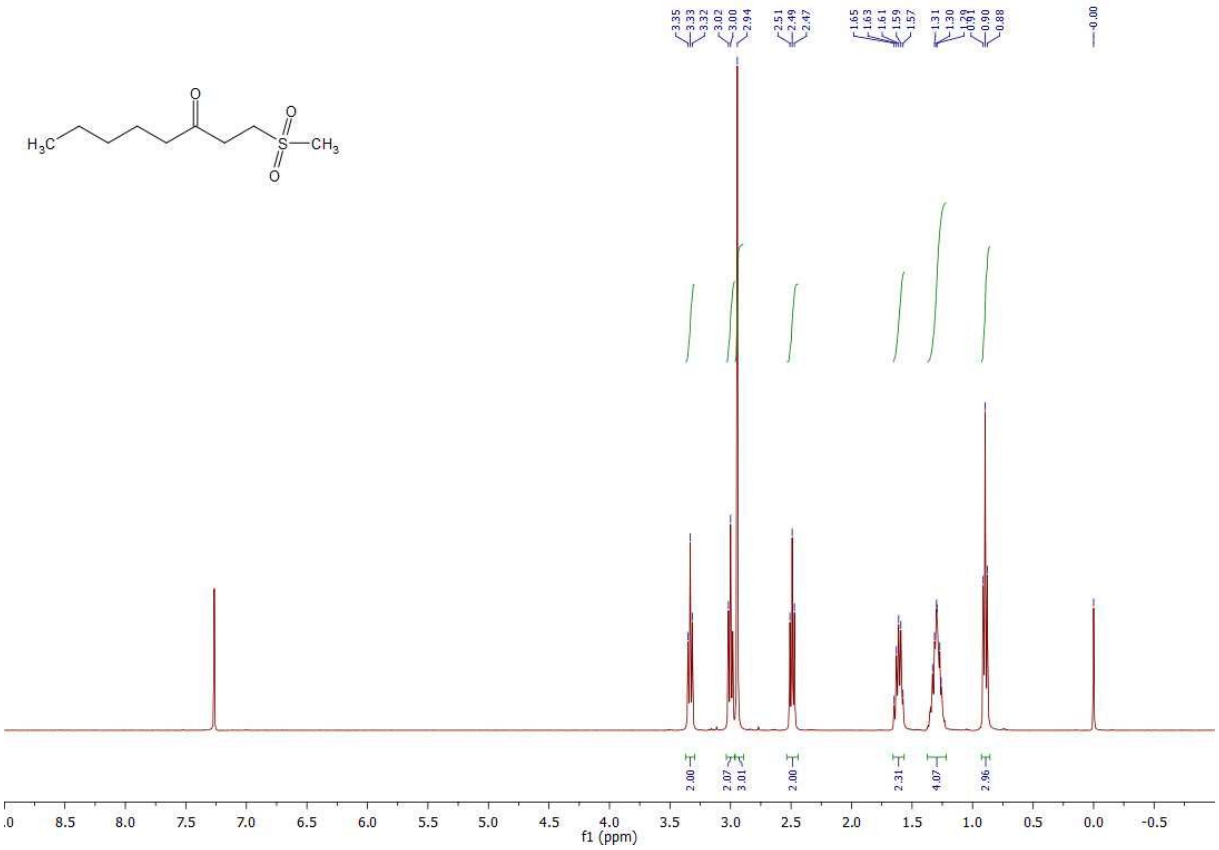
27.53
f1 (ppm)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1.65
1.63
1.61
1.59
1.57
1.31
1.30
0.93
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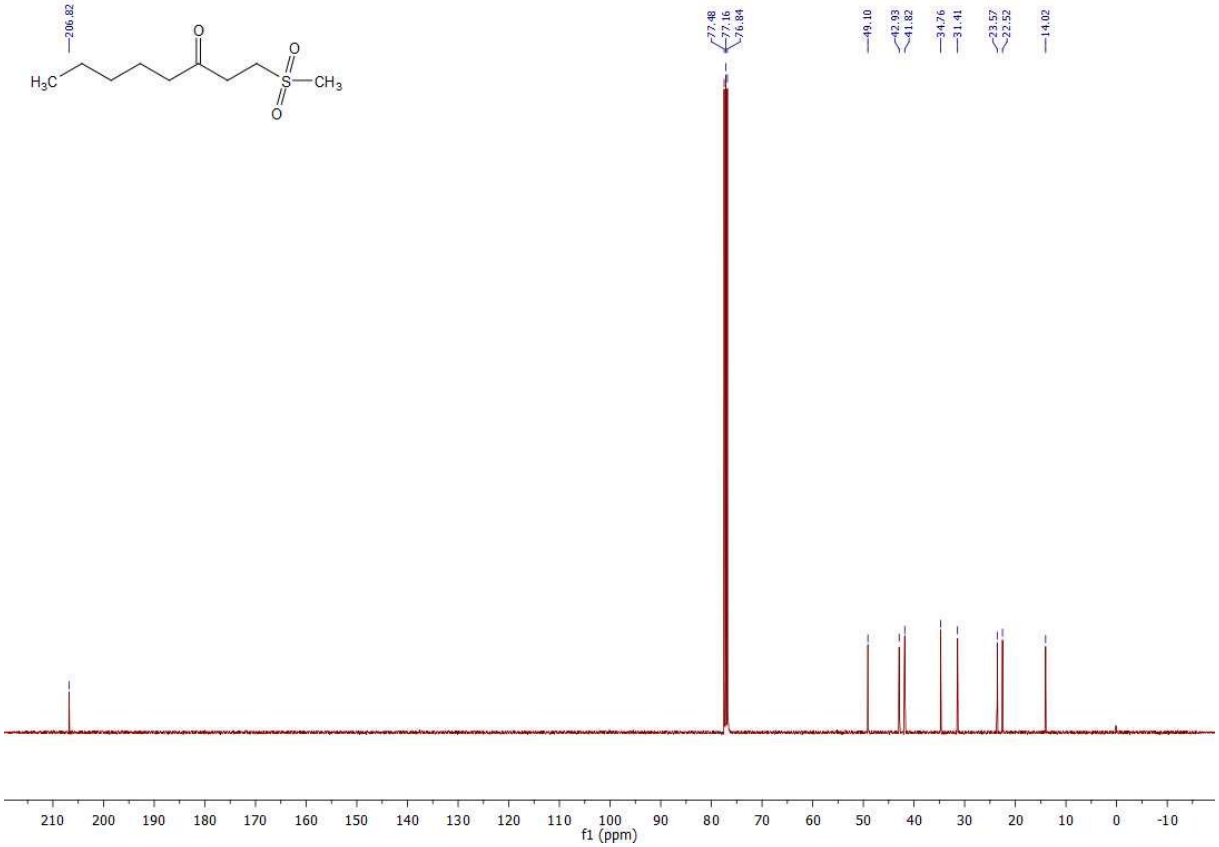
0.00
2.00
2.07
3.01
2.00
2.31
4.07
2.96
f1 (ppm)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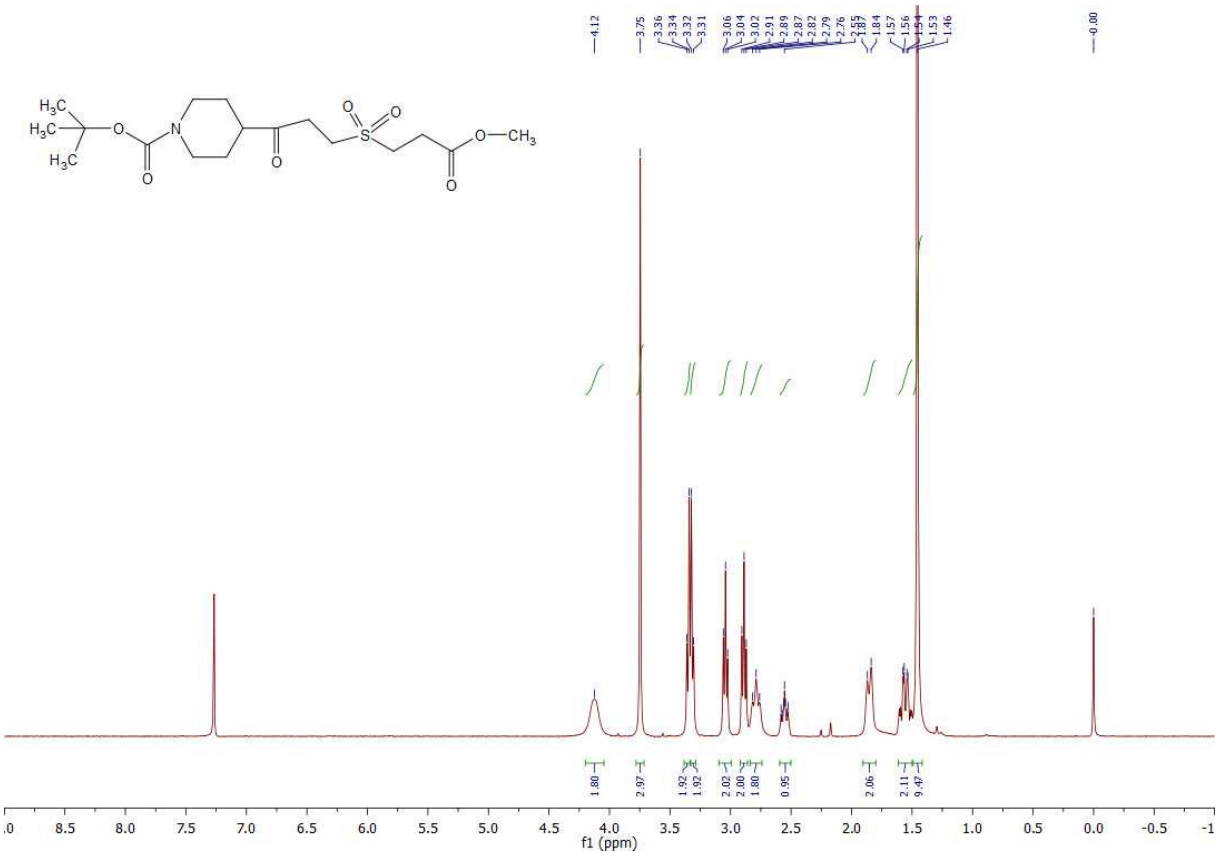
14.02
f1 (ppm)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2.89
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2.82
2.79
2.76
1.84
1.57
1.56
1.53
1.46
0.00
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1.92
2.02
2.00
1.80
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2.06
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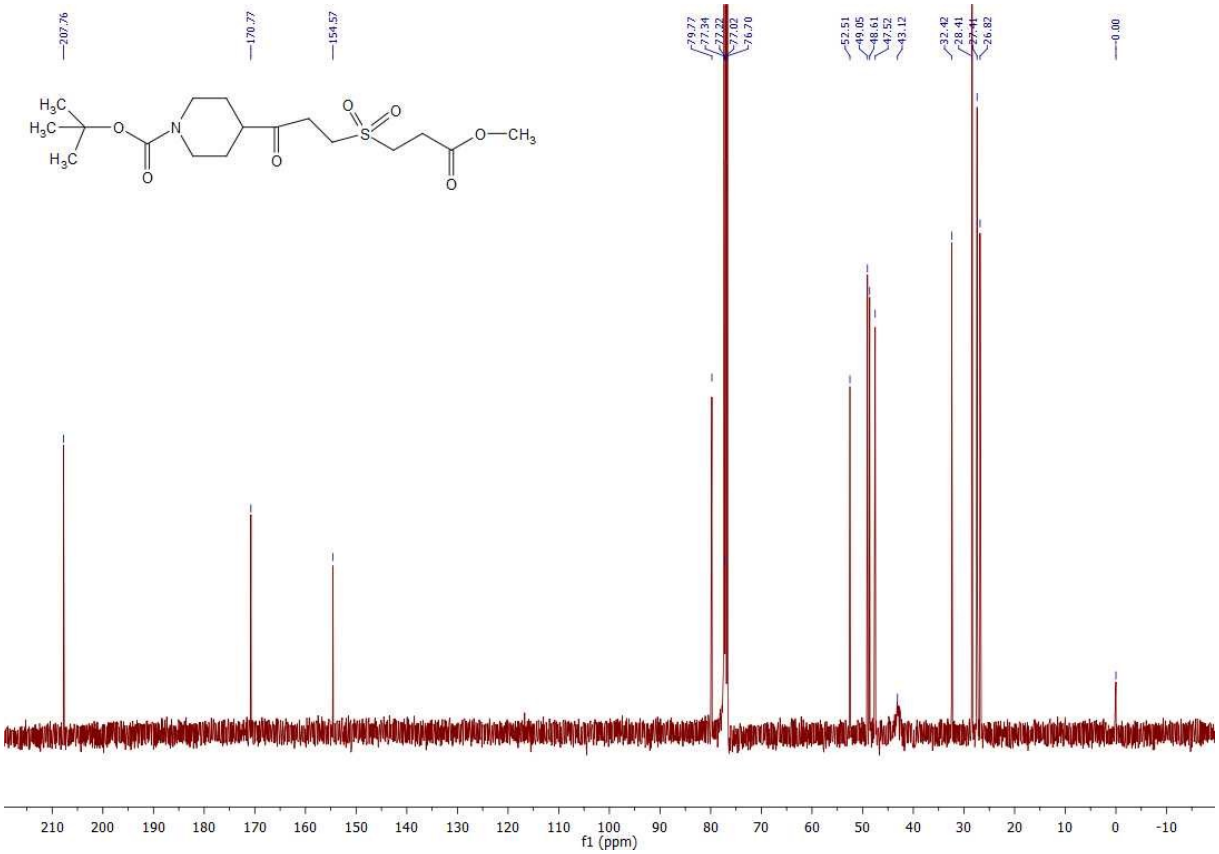
9.47
f1 (ppm)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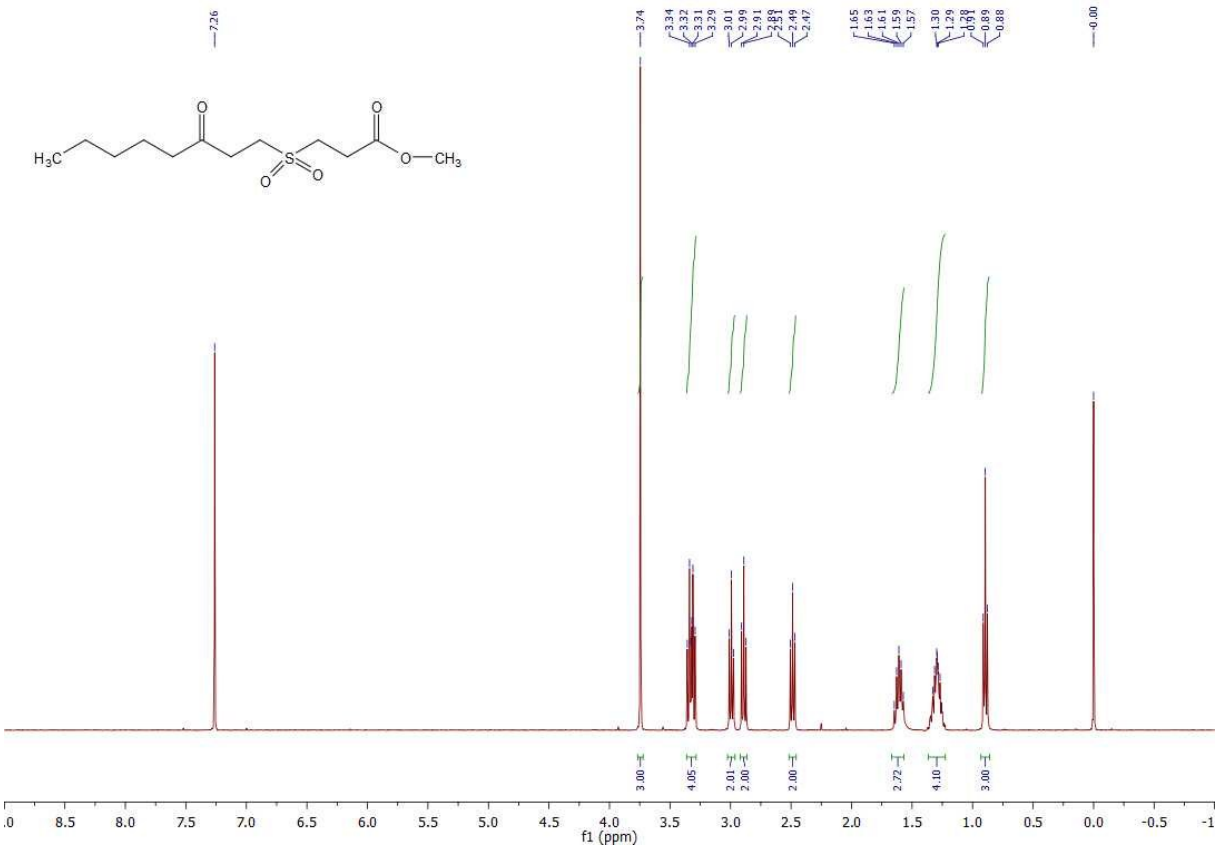
22.41
26.82
0.00
f1 (ppm)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2.47
1.65
1.63
1.61
1.59
1.57
1.30
1.29
0.91
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4.05
2.01
2.00
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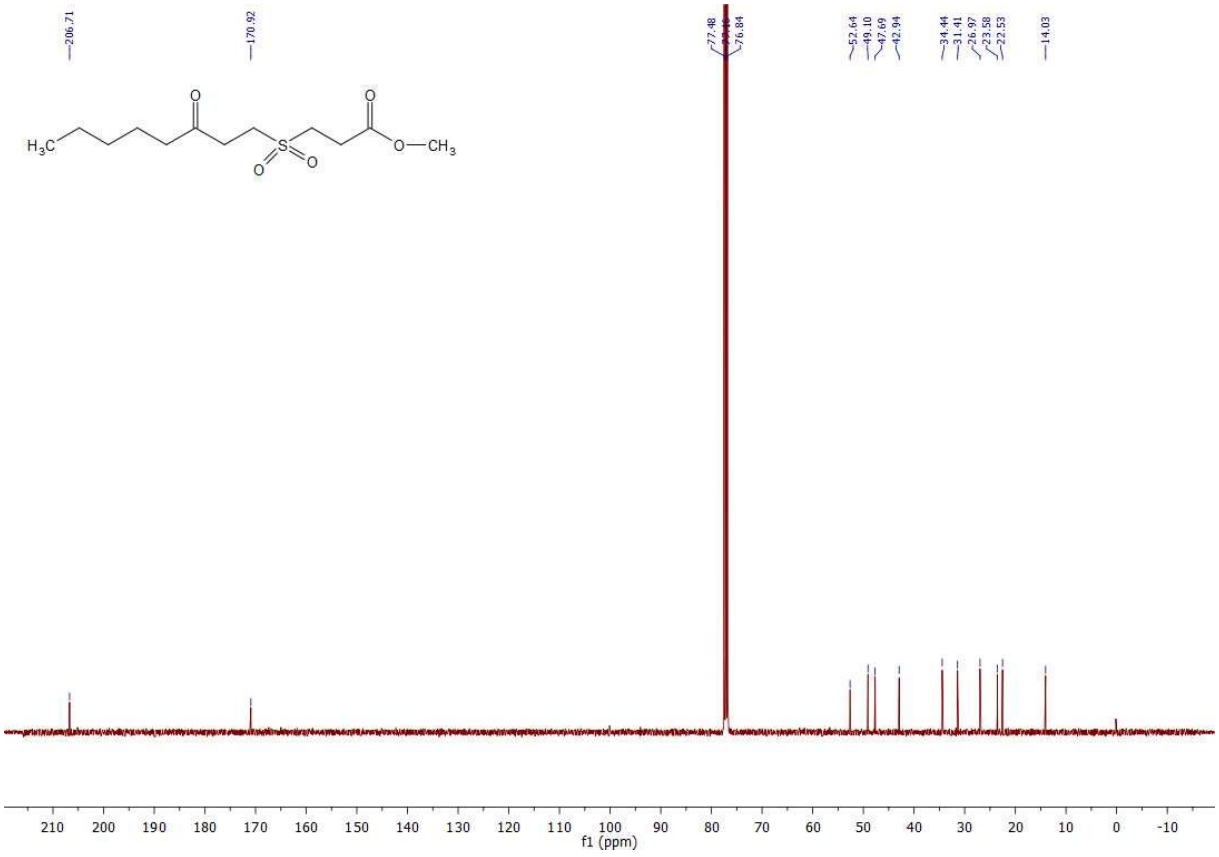
3.00
f1 (ppm)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23.58
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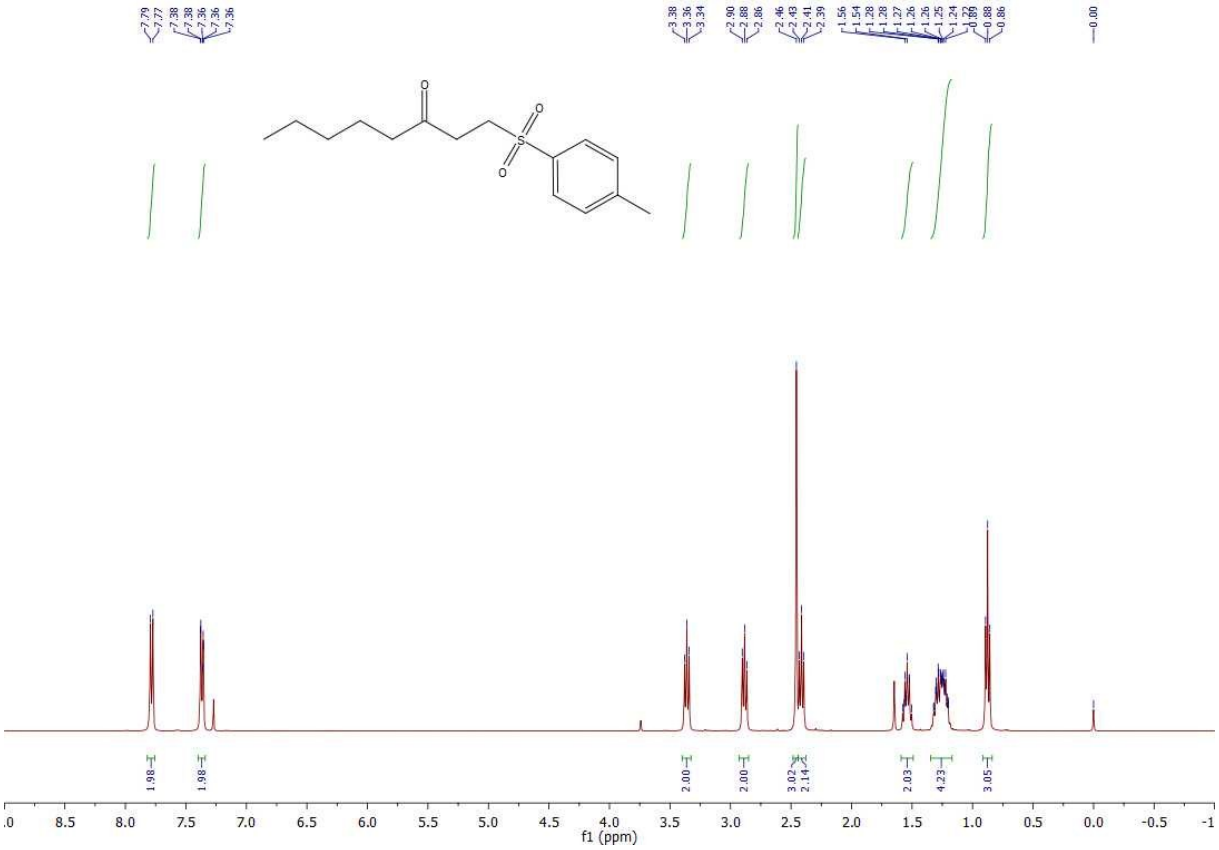
f1 (ppm)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2.46
2.43
2.41
2.39
1.56
1.54
1.28
1.28
1.27
1.26
1.25
1.24
0.89
0.88
0.86
0.00
O
O
S
O
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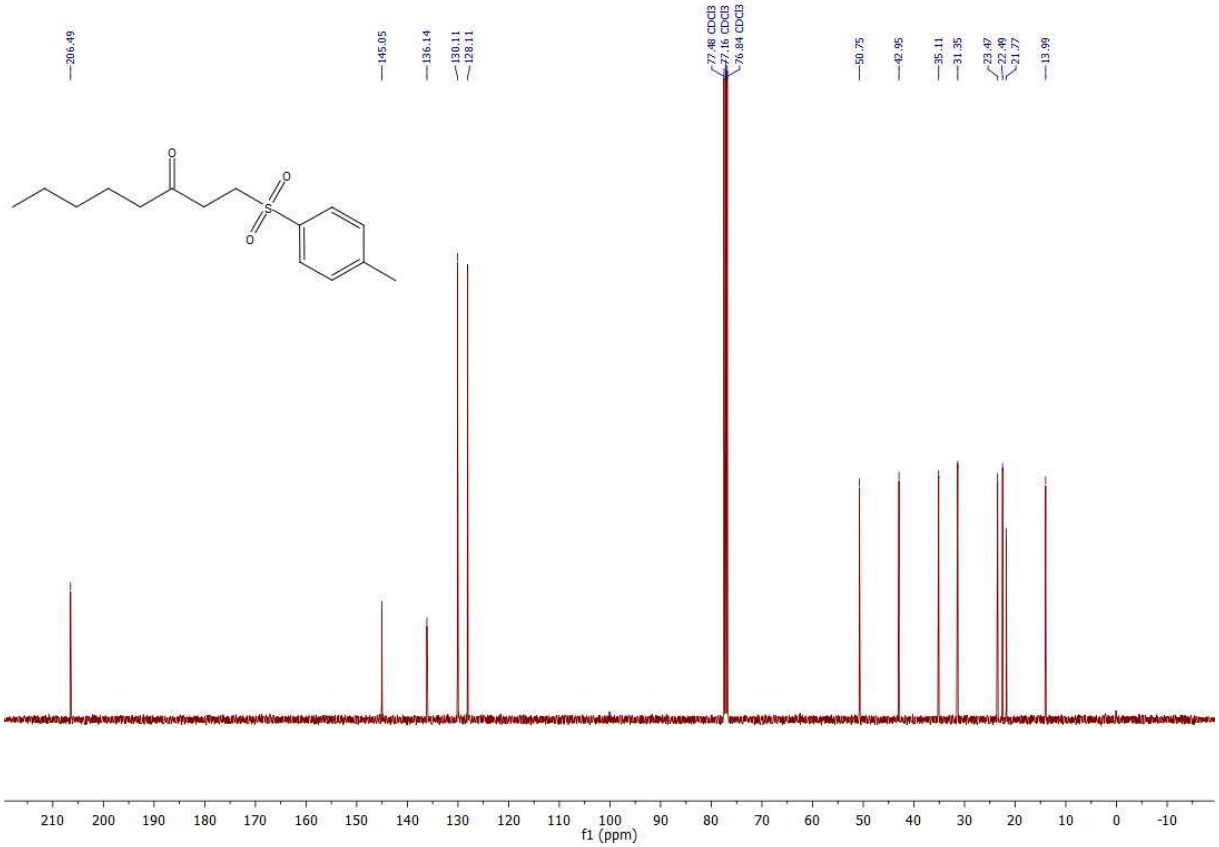
1.98
2.00
2.00
3.02
2.14
2.03
4.23
3.05
f1 (ppm)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77.16 CDCl3
76.84 CDCl3
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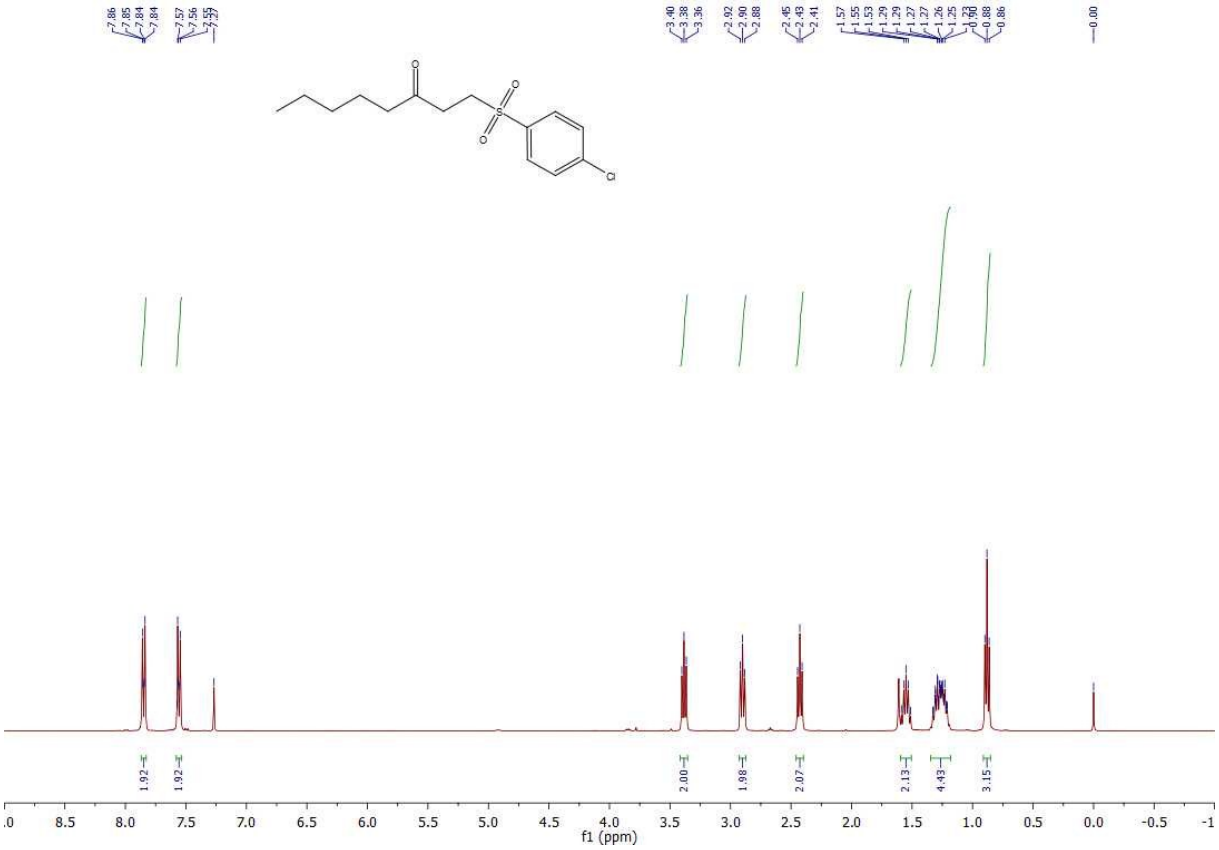
31.35
23.47
22.49
21.77
13.99
O
O
S
O
f1 (ppm)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2.45
2.43
2.41
1.57
1.55
1.53
1.29
1.29
1.27
1.27
1.26
1.25
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1.92
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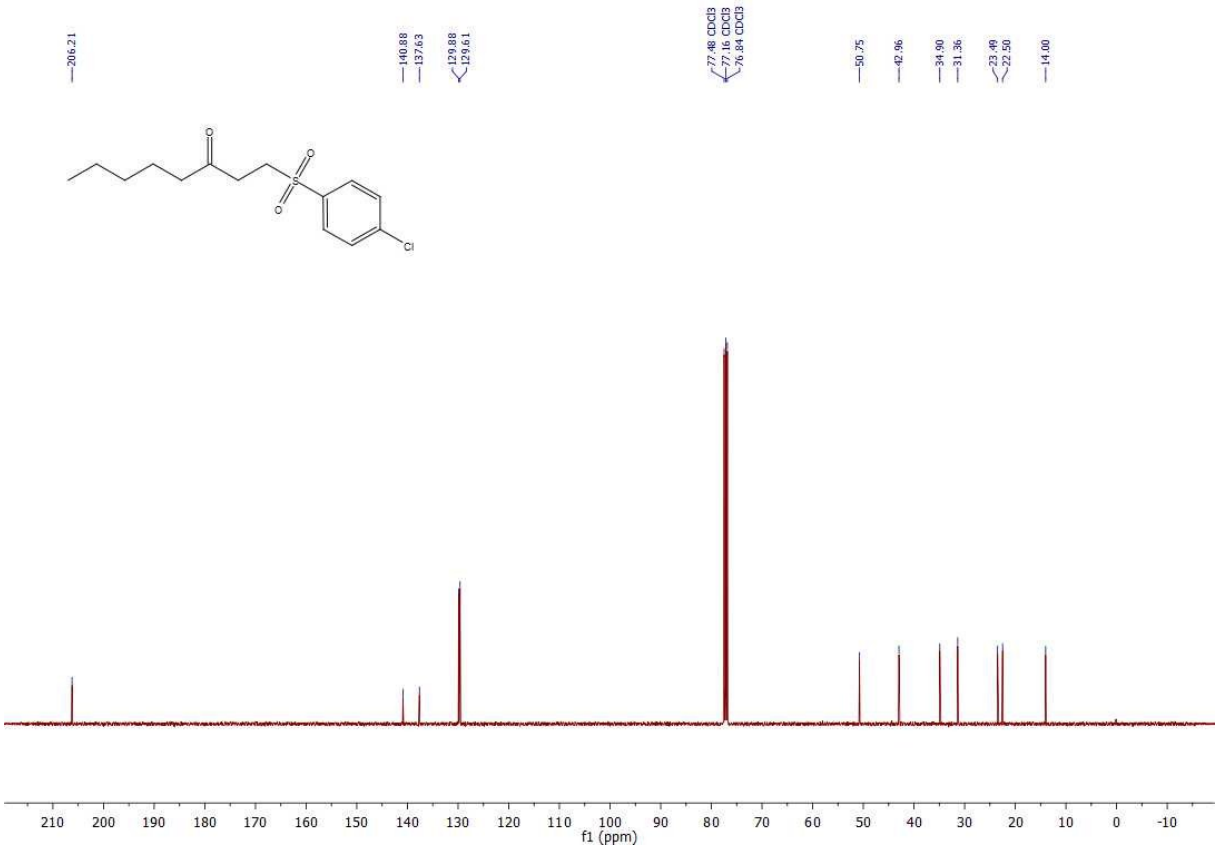
1.98
2.07
2.13
4.43
3.15
f1 (ppm)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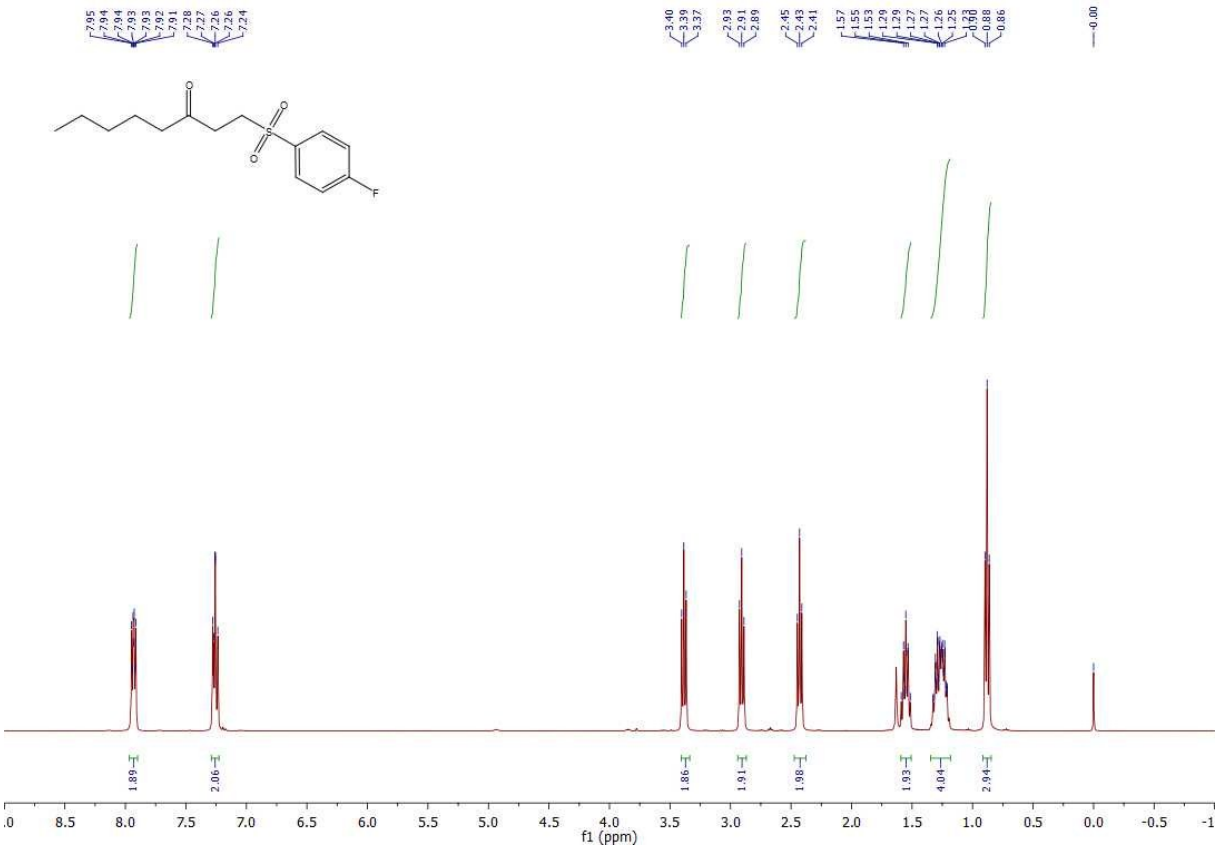
23.49
22.50
14.00
f1 (ppm)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3.37
2.93
2.91
2.89
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2.43
2.41
1.57
1.55
1.53
1.29
1.29
1.27
1.27
1.26
1.25
0.93
0.90
0.88
0.86
-0.00
O
O
S
O
F
1.89
2.06
1.86
1.91
1.98
1.93
4.04
2.94
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
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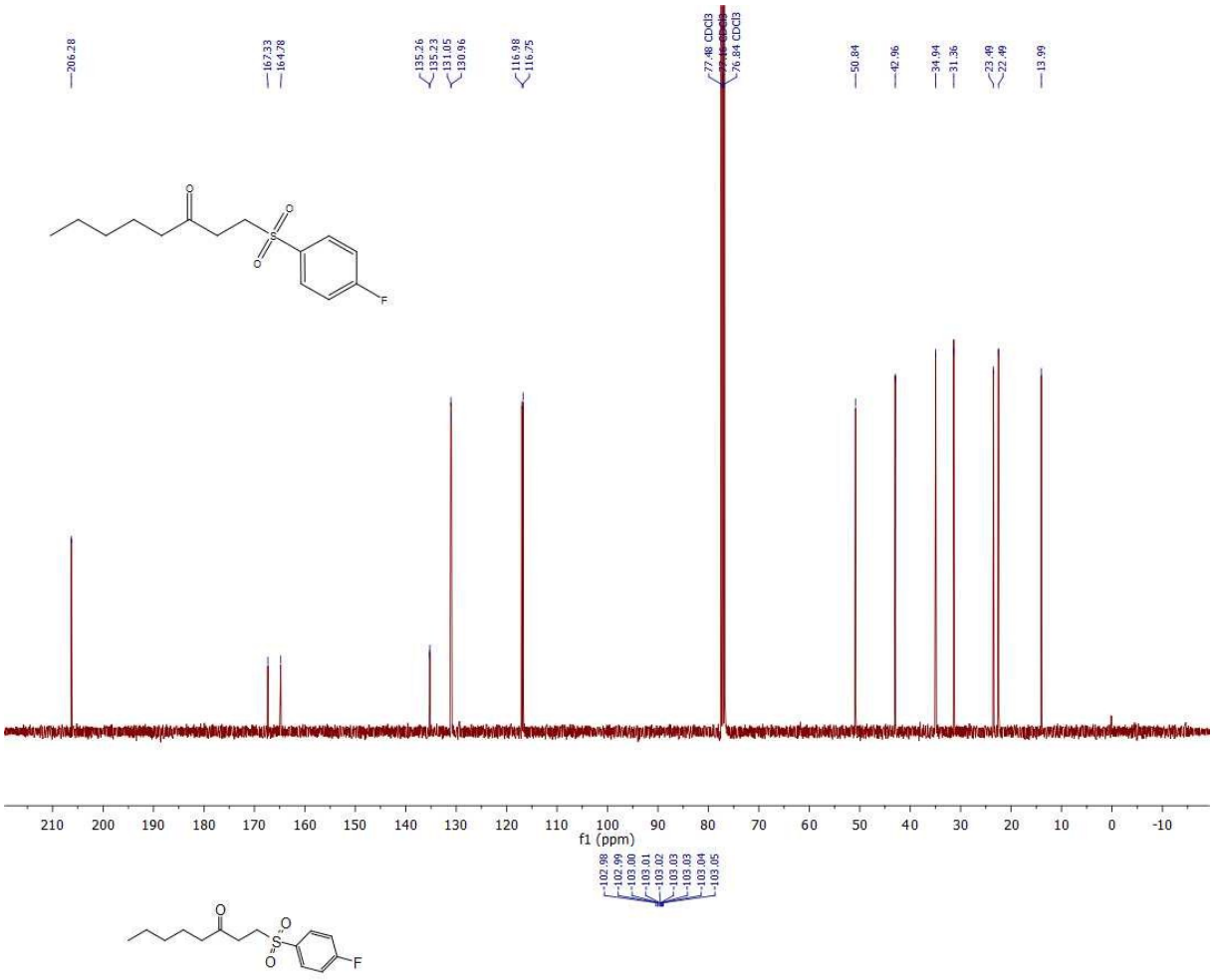
-1
f1 (ppm)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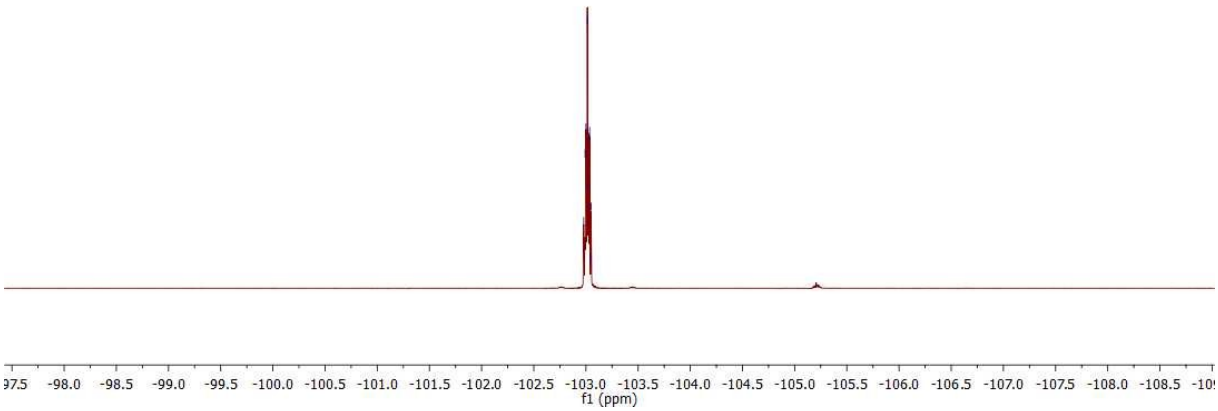
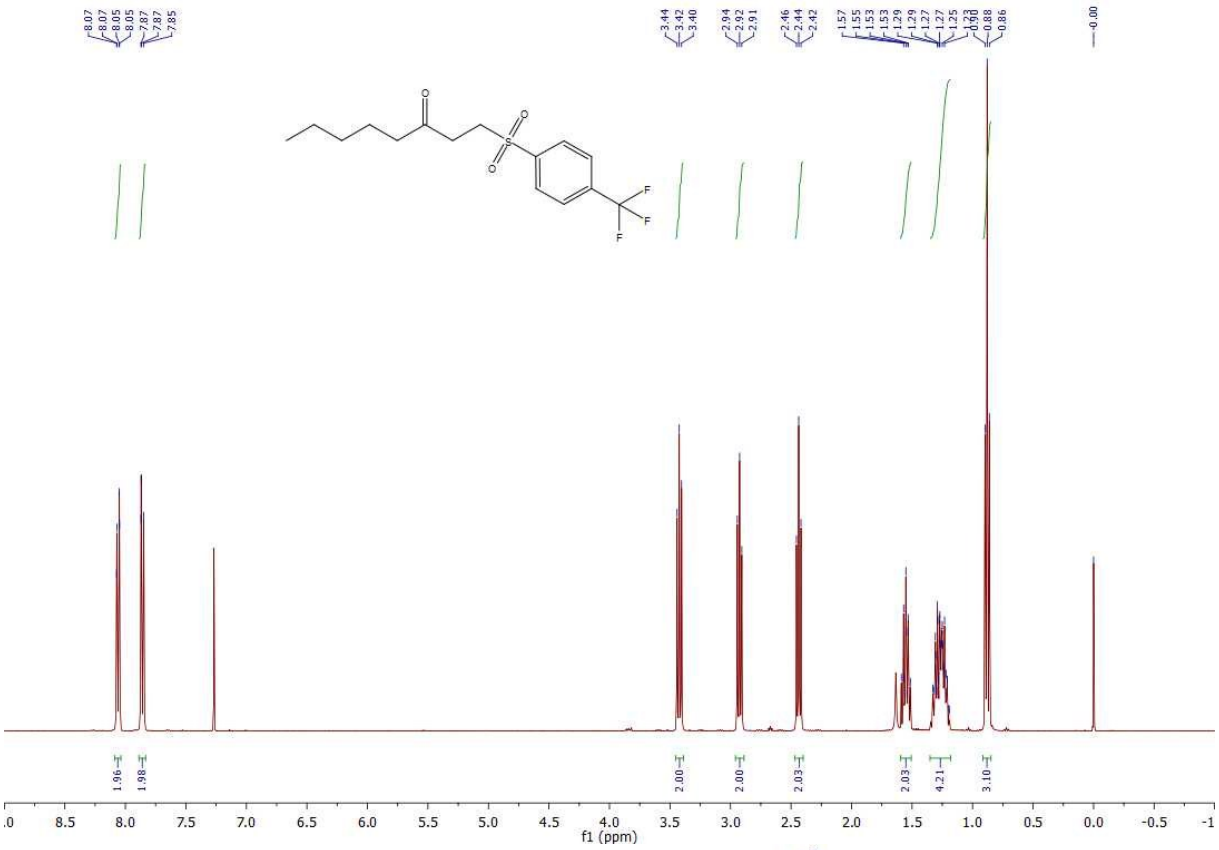
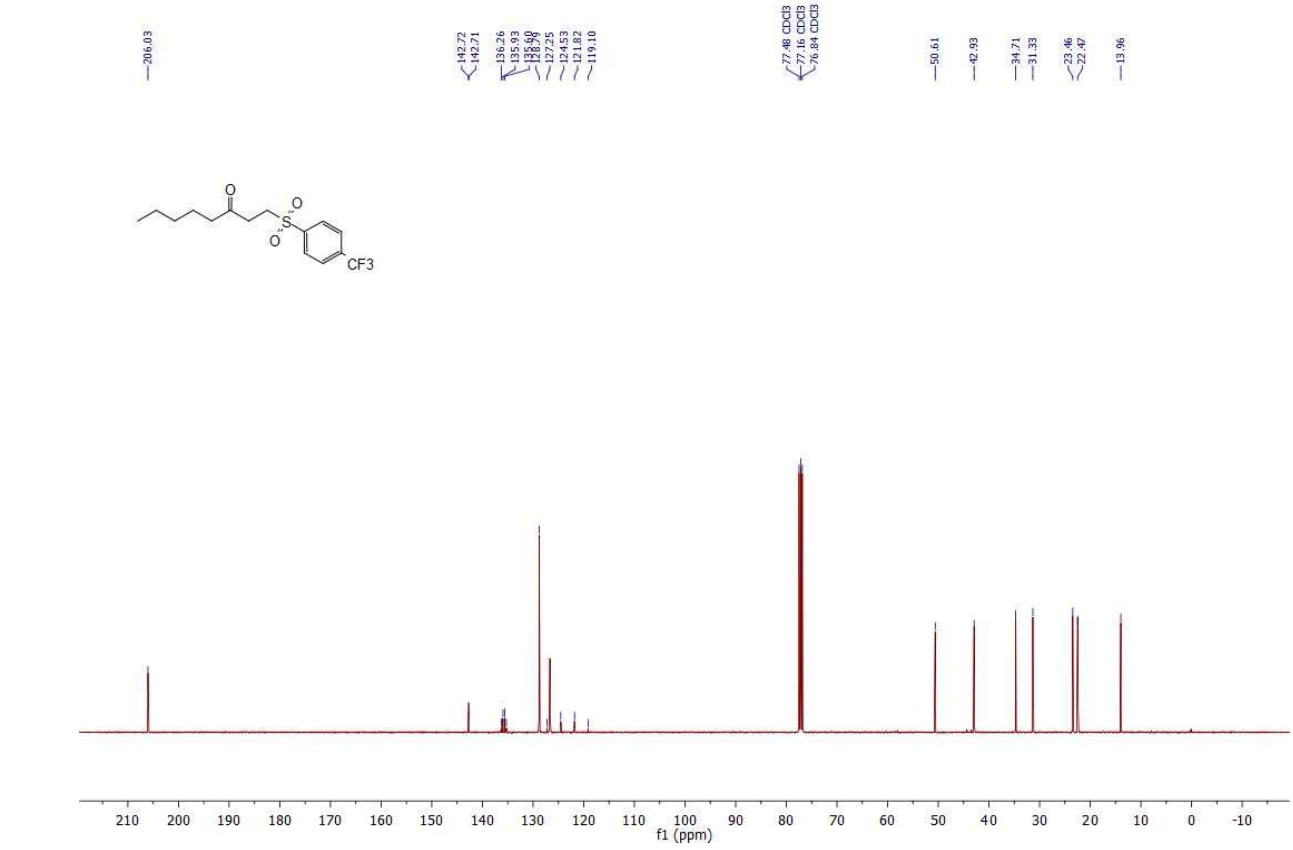
164.78
135.26
135.23
131.05
130.96
116.98
116.75
77.48 CDCl3
76.84 CDCl3
50.84
42.96
34.94
31.36
23.49
22.49
13.99
f1 (ppm)


f1 (ppm)


8.07
8.07
8.05
8.05
7.87
7.87
7.85
3.44
3.42
3.40
2.94
2.92
2.91
2.46
2.44
2.42
1.57
1.55
1.53
1.53
1.29
1.27
1.27
1.25
0.90
0.88
0.86
0.00
1.96
1.98
2.00
2.00
2.03
2.03
4.21
3.10
f1 (ppm)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142.71
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128.50
127.25
124.53
121.82
119.10
77.48 CDCl3
77.16 CDCl3
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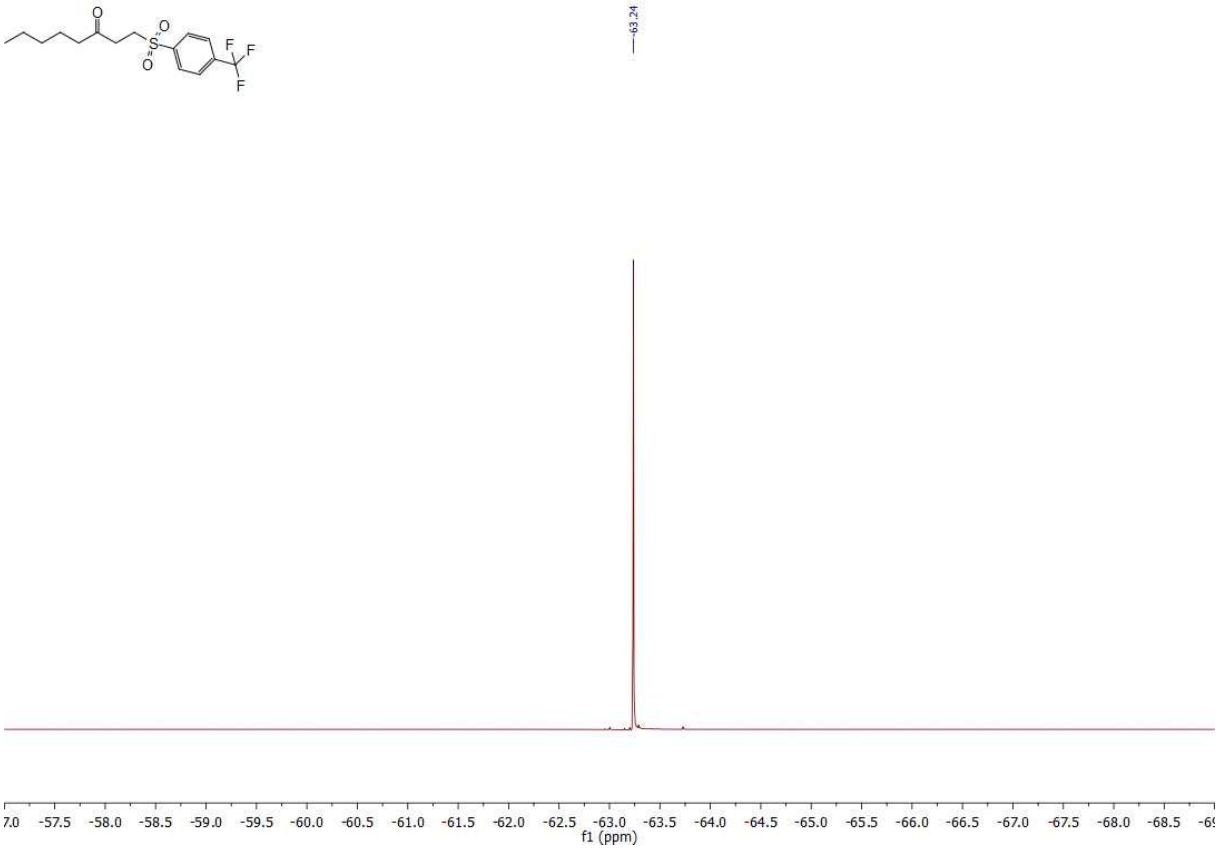
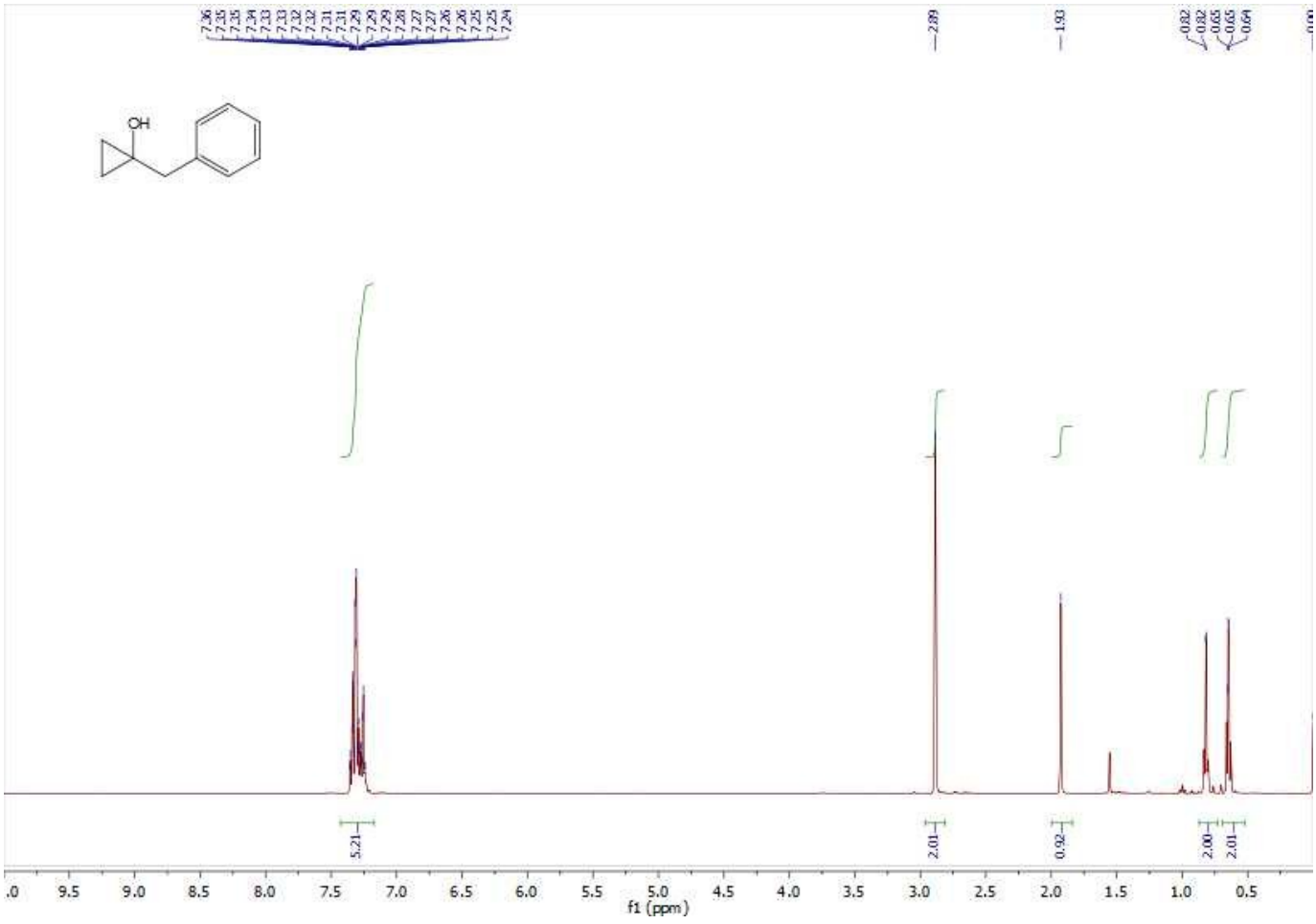
50.61
42.93
34.71
31.33
23.46
22.47
13.96
CF3
f1 (ppm)


-63.24
7.0 -57.5 -58.0 -58.5 -59.0 -59.5 -60.0 -60.5 -61.0 -61.5 -62.0 -62.5 -63.0 -63.5 -64.0 -64.5 -65.0 -65.5 -66.0 -66.5 -67.0 -67.5 -68.0 -68.5 -6
f1 (ppm)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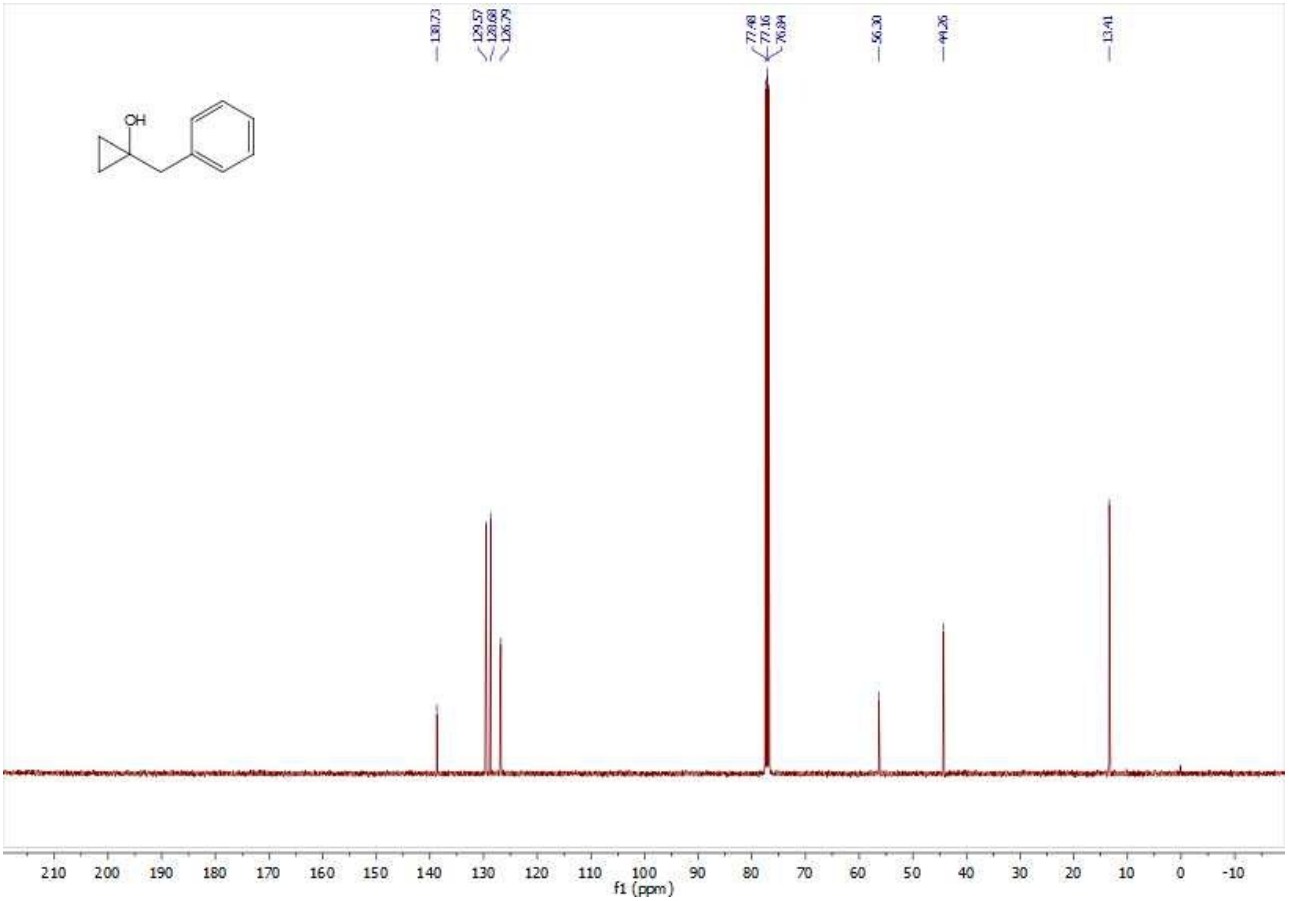
7.36
7.35
7.35
7.34
7.33
7.33
7.32
7.32
7.31
7.31
7.29
7.29
7.29
7.28
7.27
7.27
7.26
7.26
7.25
7.24
2.89
1.93
0.82
0.82
0.65
0.65
0.64
5.21
2.01
0.92
2.00
2.01
f1 (ppm)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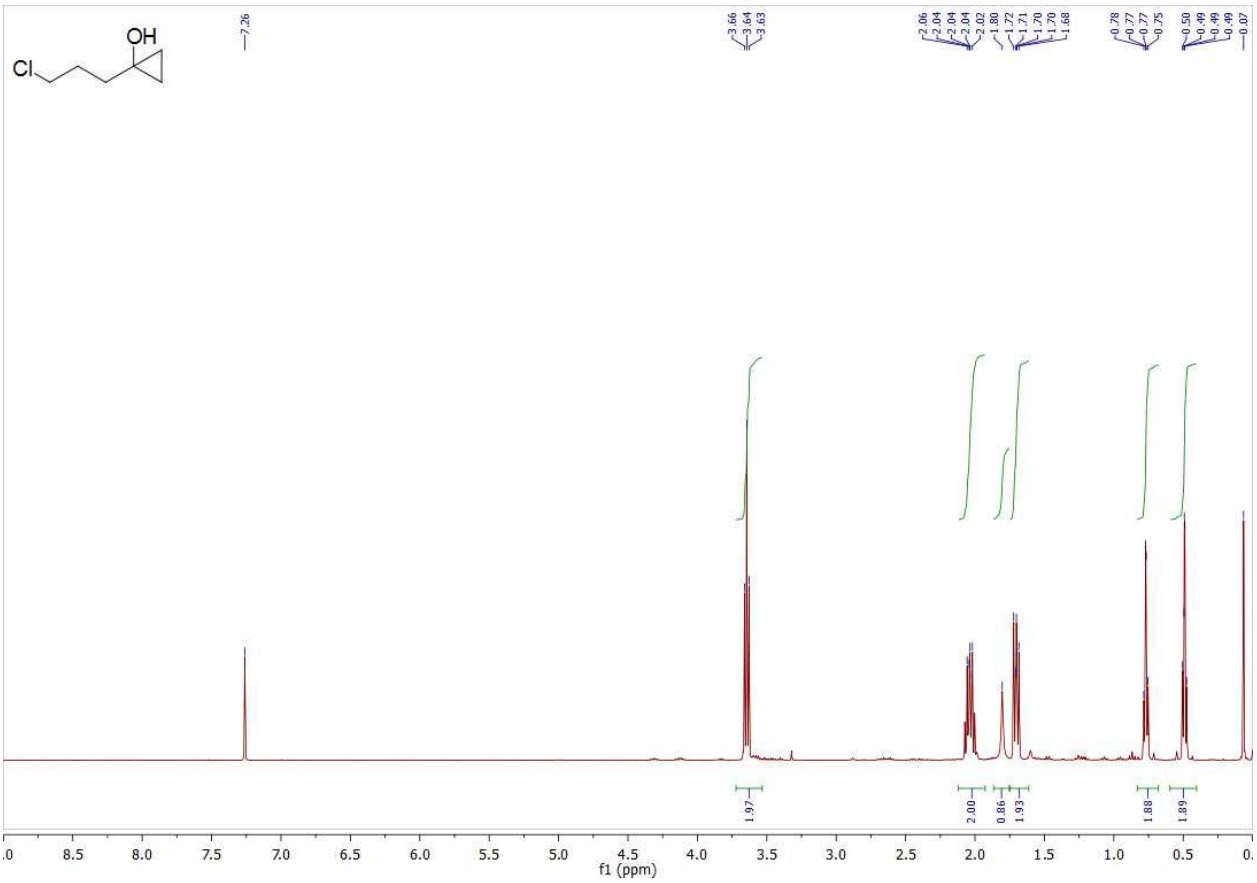
126.79
77.48
77.16
76.84
56.30
44.26
13.41
f1 (ppm)


OH
Cl
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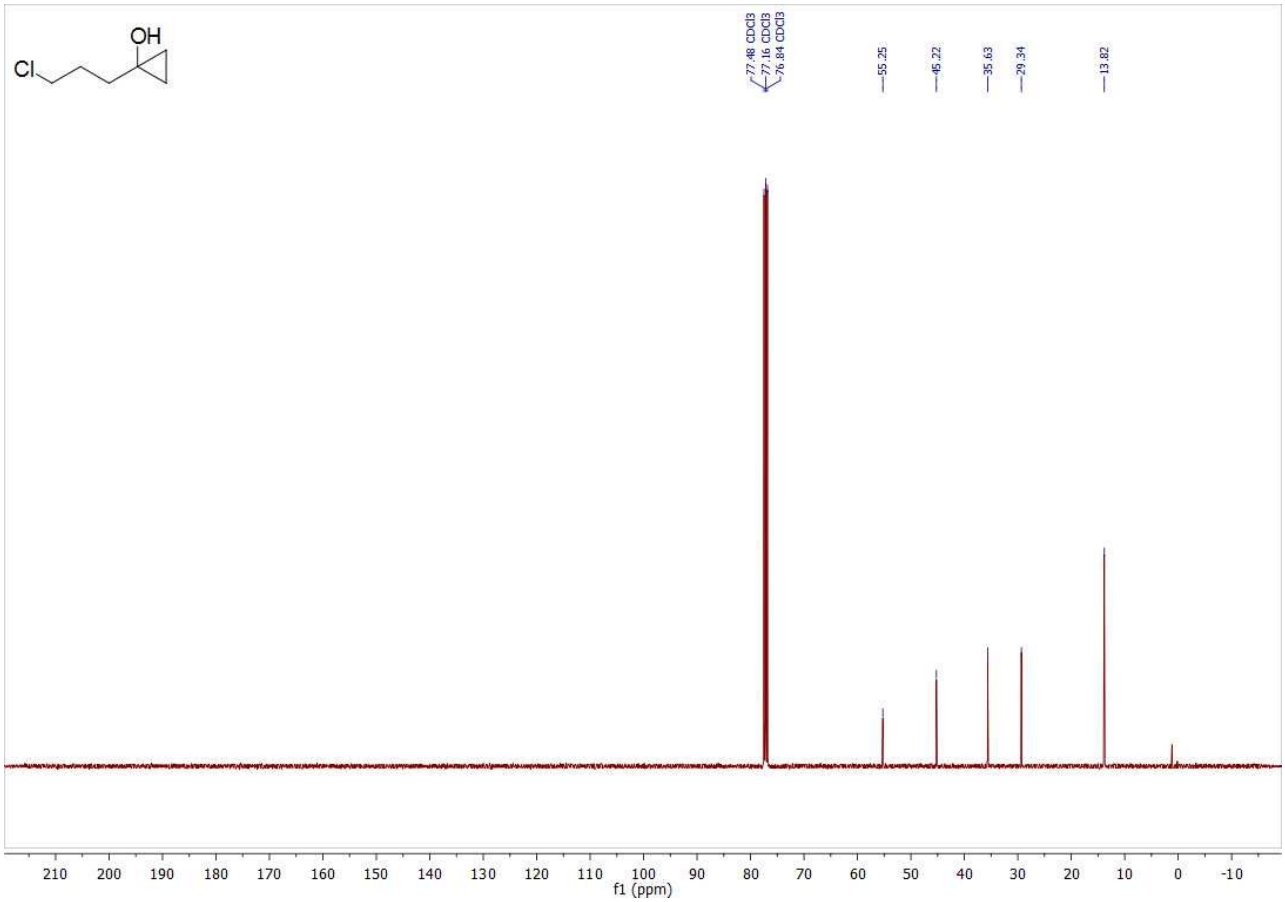
3.66
3.64
3.63
2.06
2.04
2.04
2.04
2.02
1.80
1.72
1.71
1.70
1.70
1.68
0.78
0.77
0.77
0.75
0.50
0.49
0.49
0.49
0.07
1.97
2.00
0.86
1.93
1.88
1.89
f1 (ppm)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Cl
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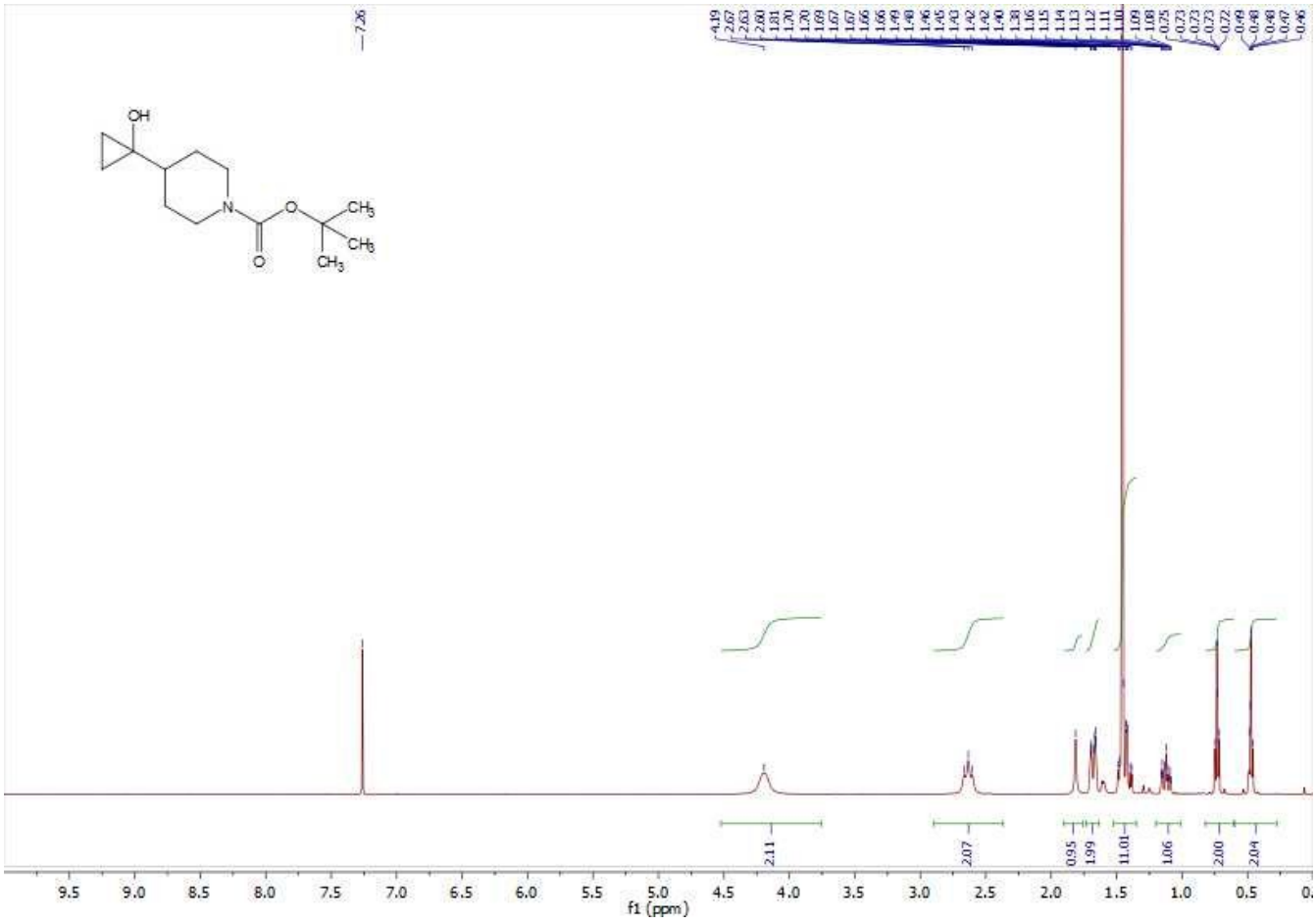
77.16 CDCl3
76.84 CDCl3
55.25
45.22
35.63
29.34
13.82
f1 (ppm)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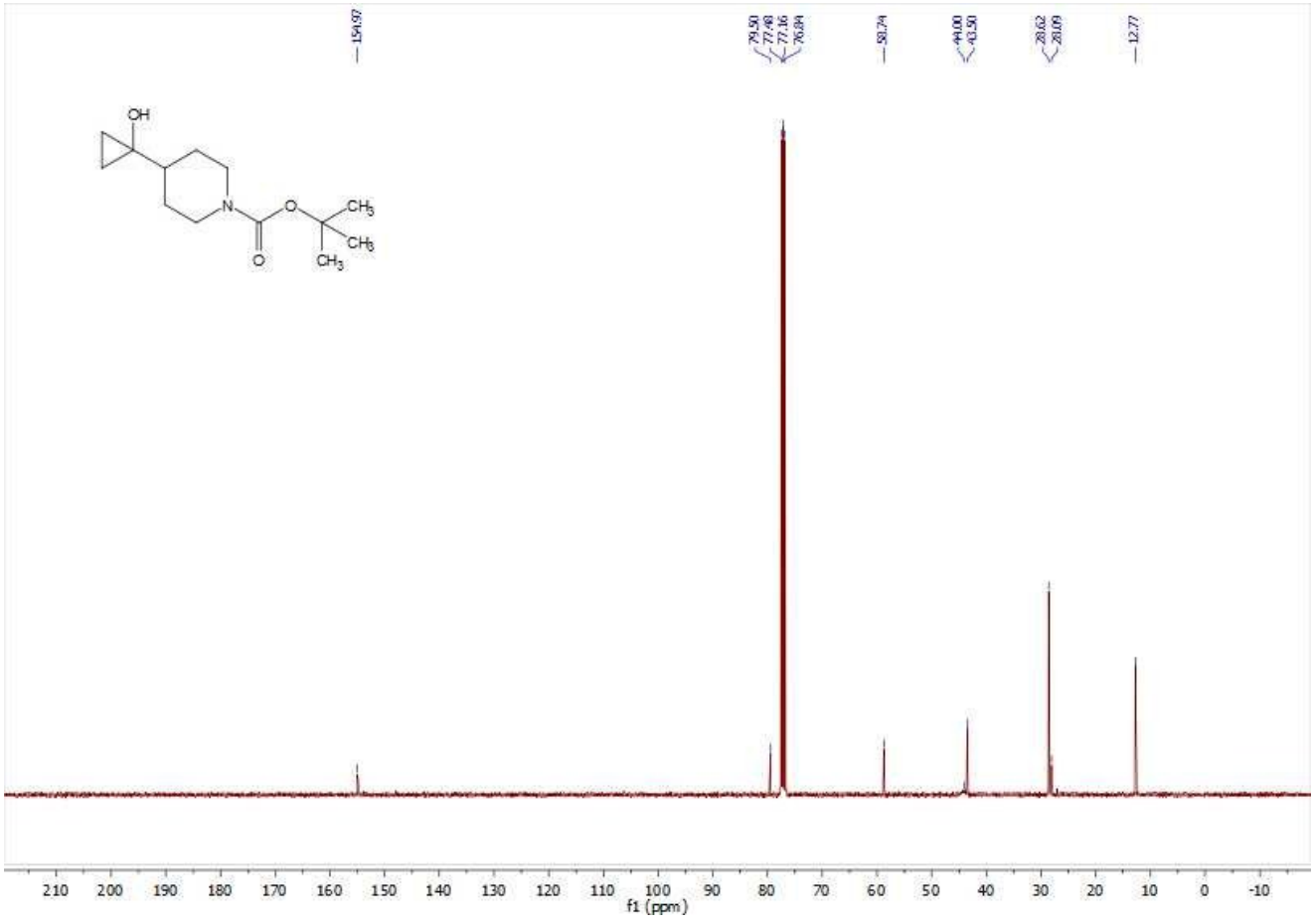
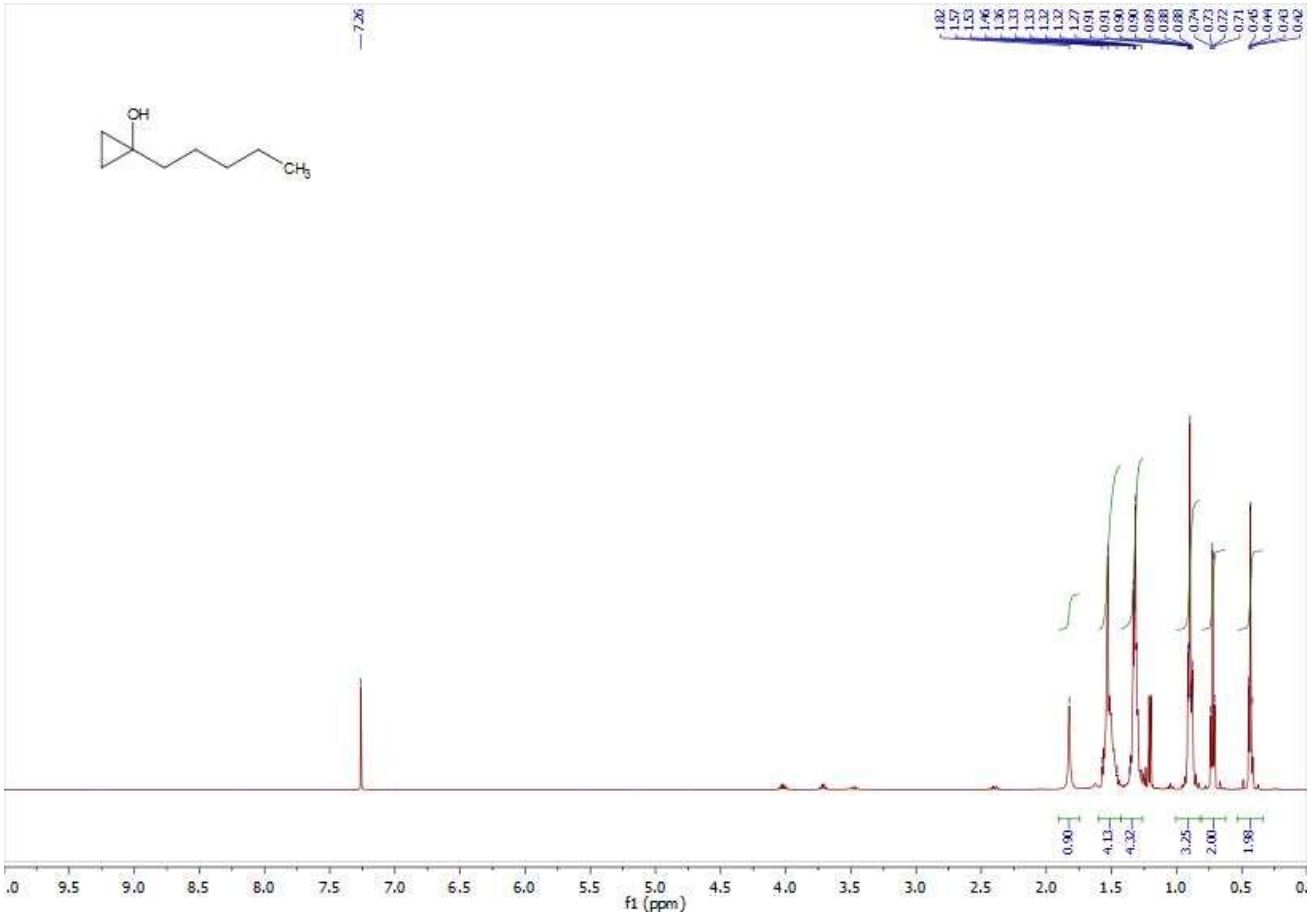
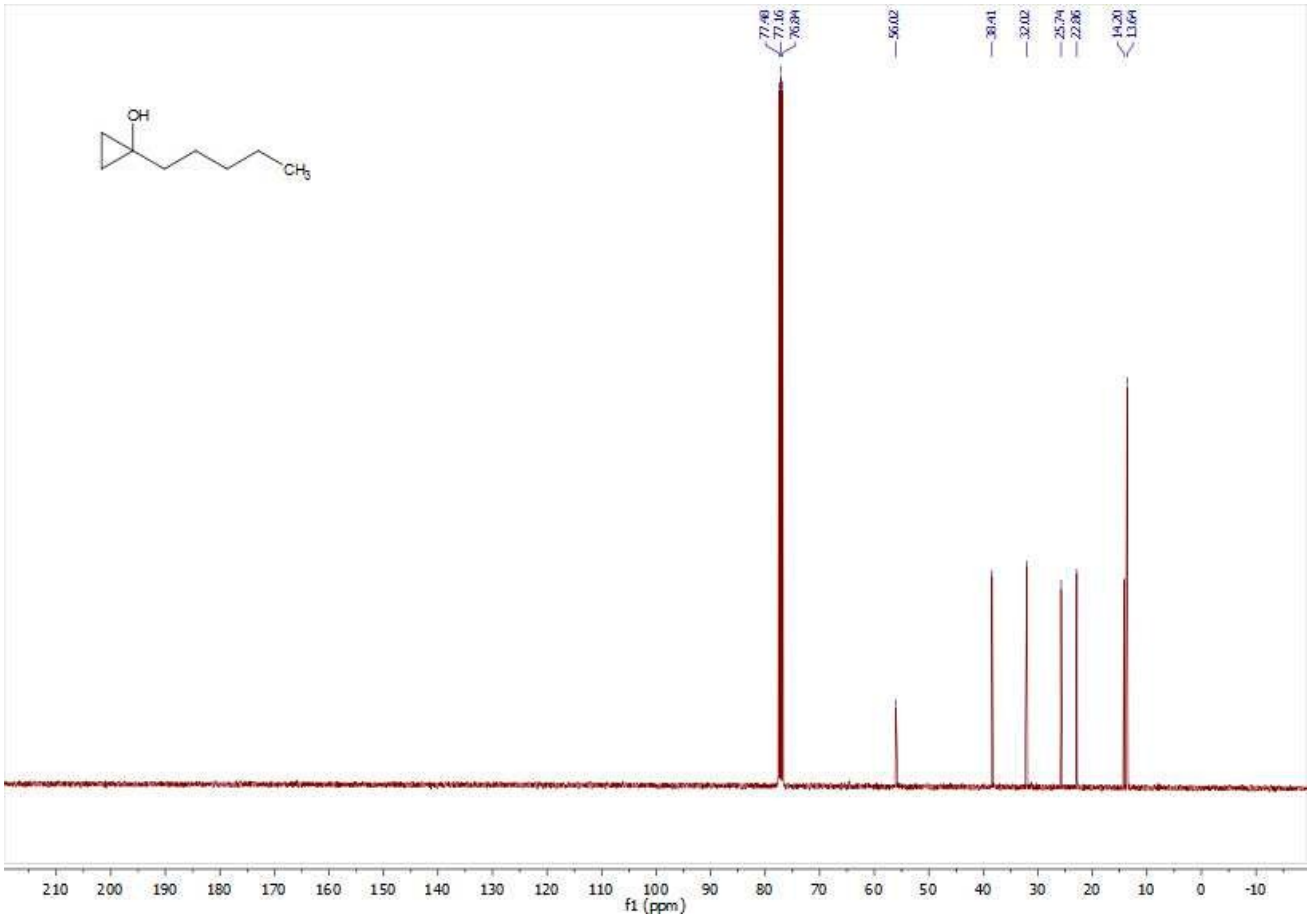
N
O
O
CH3
CH3
CH3
f1 (ppm)


OH
N
O
O
CH3
CH3
CH3
f1 (ppm)


OH
CH3
7.26
1.82
1.57
1.53
1.46
1.36
1.33
1.32
1.32
1.27
0.91
0.91
0.90
0.90
0.89
0.88
0.88
0.74
0.73
0.72
0.71
0.45
0.44
0.43
0.42
0.90
4.13
4.32
3.25
2.00
1.98
f1 (ppm)


OH
CH3
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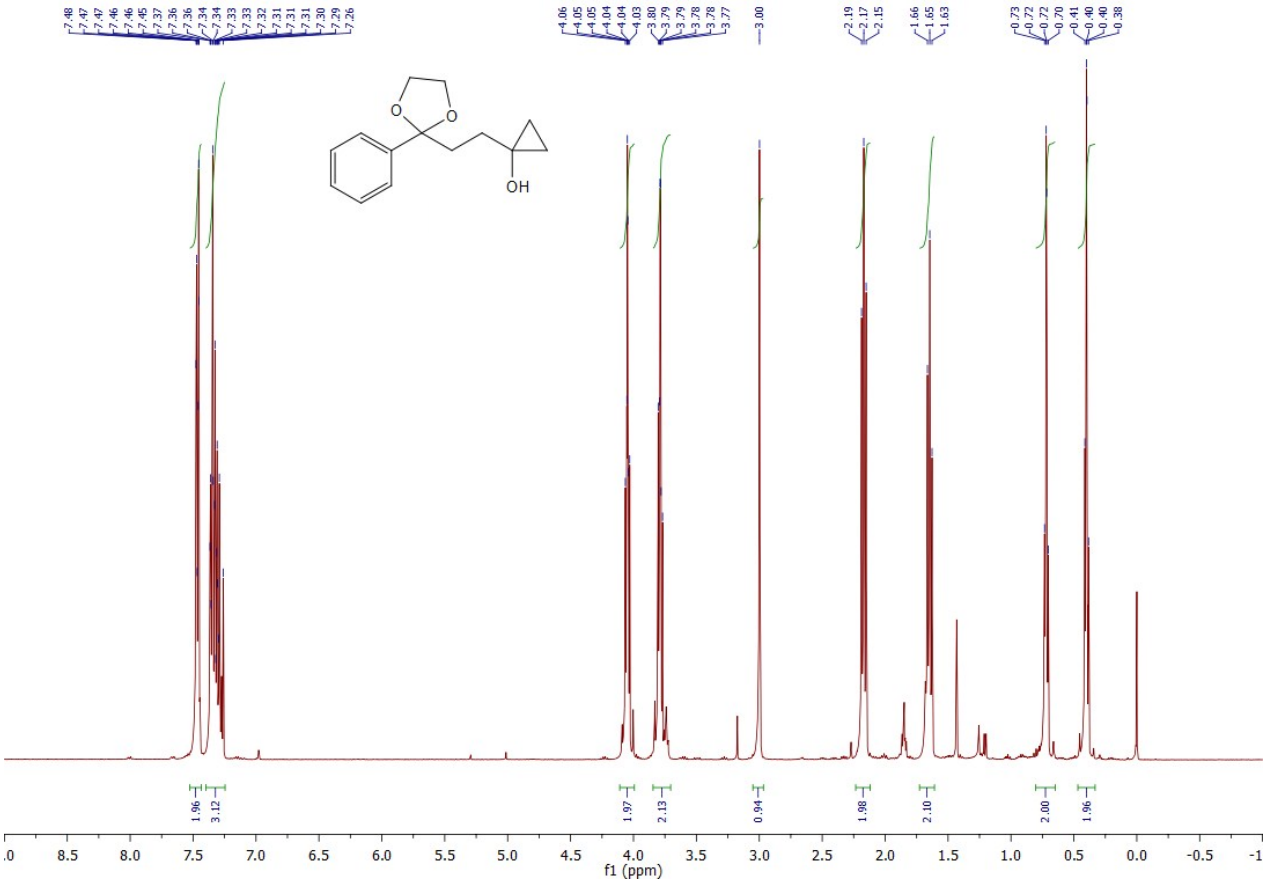
77.16
76.84
56.02
30.41
32.02
25.74
22.86
14.20
13.64
f1 (ppm)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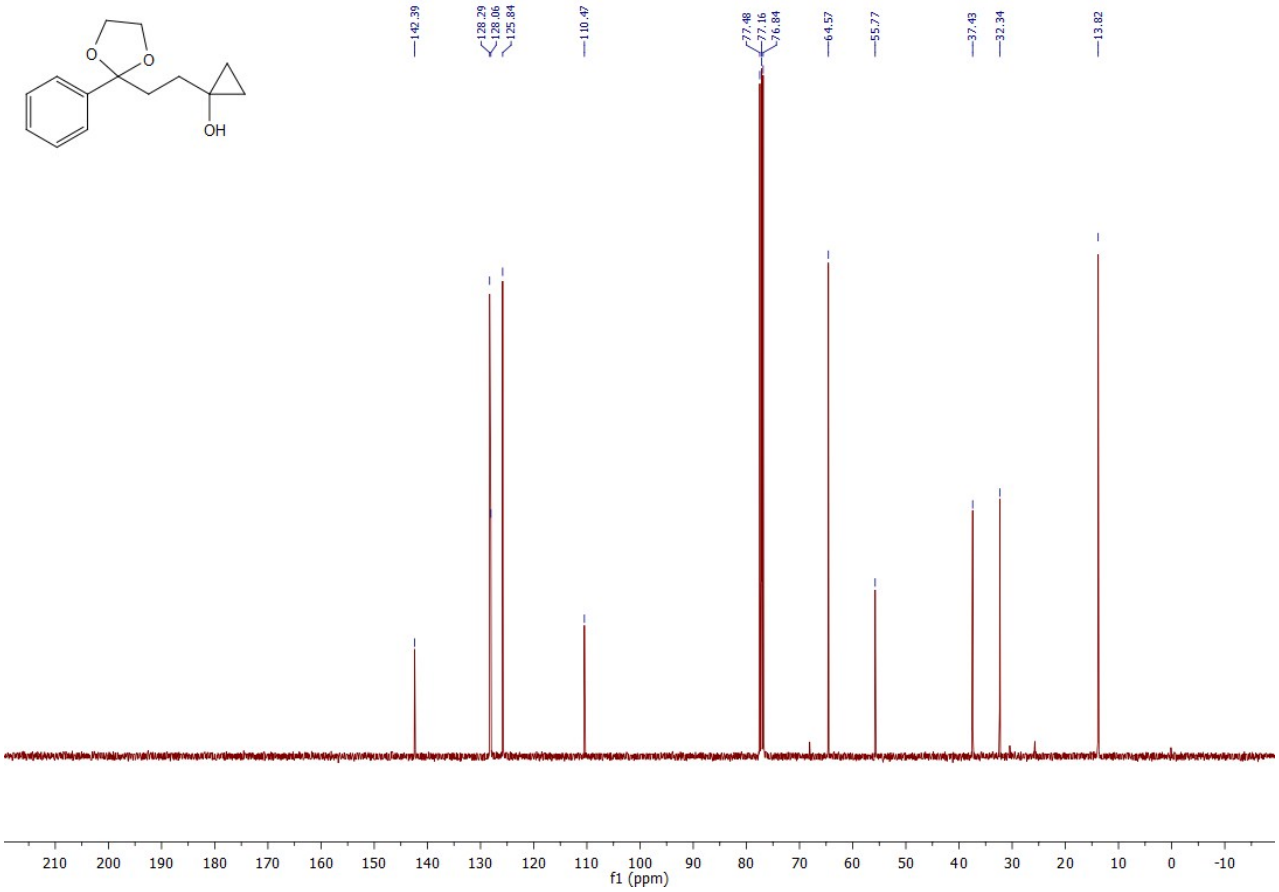
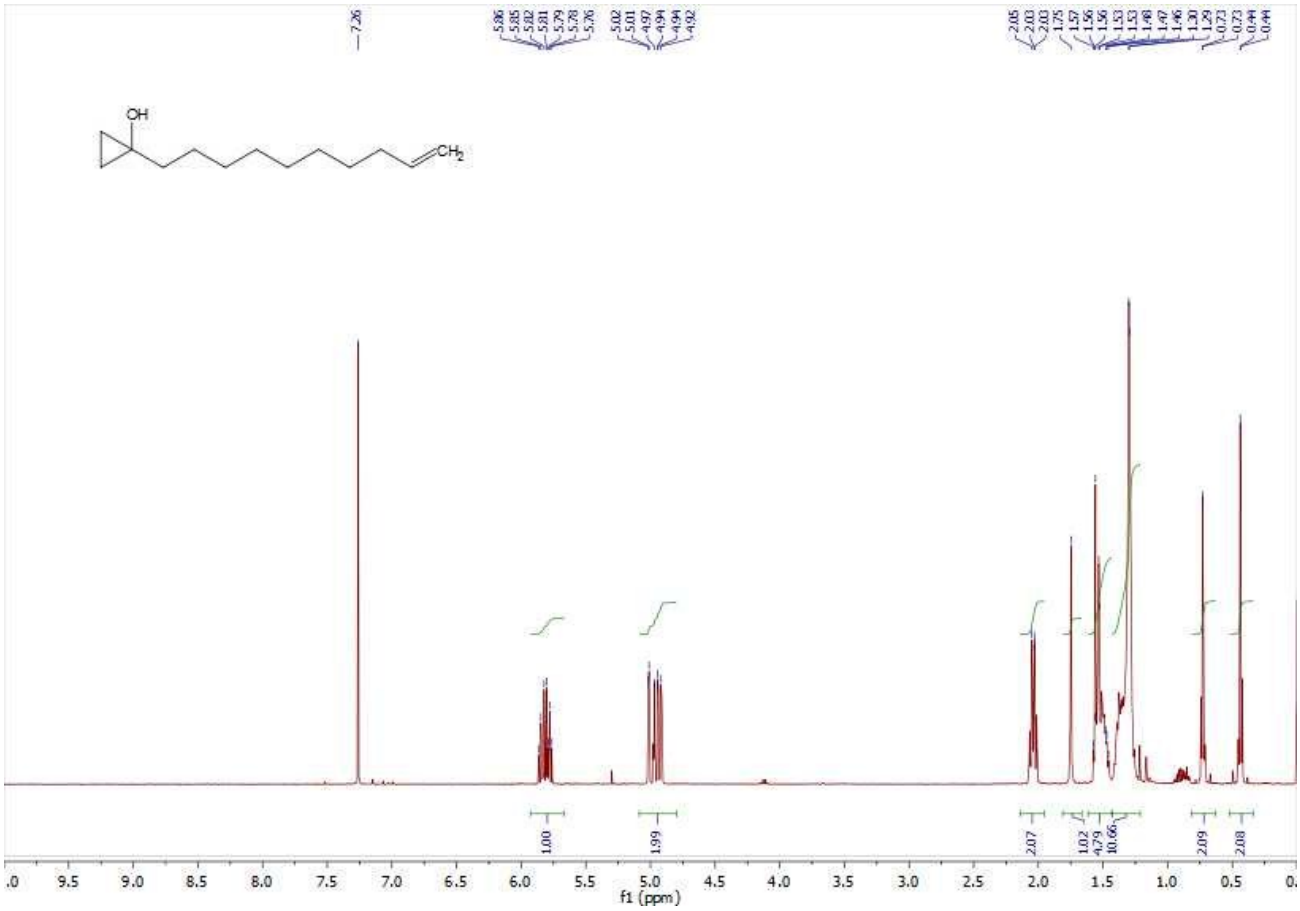
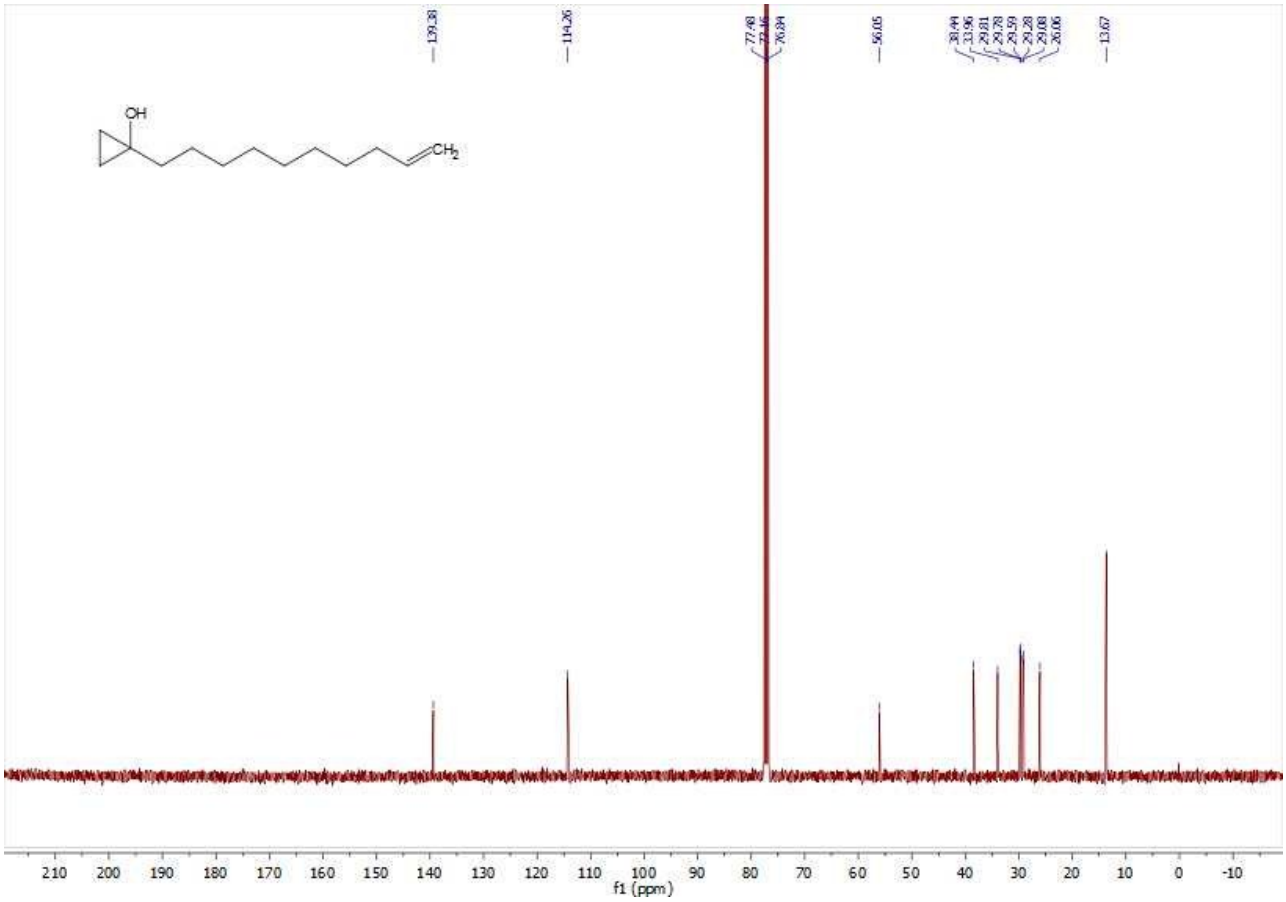
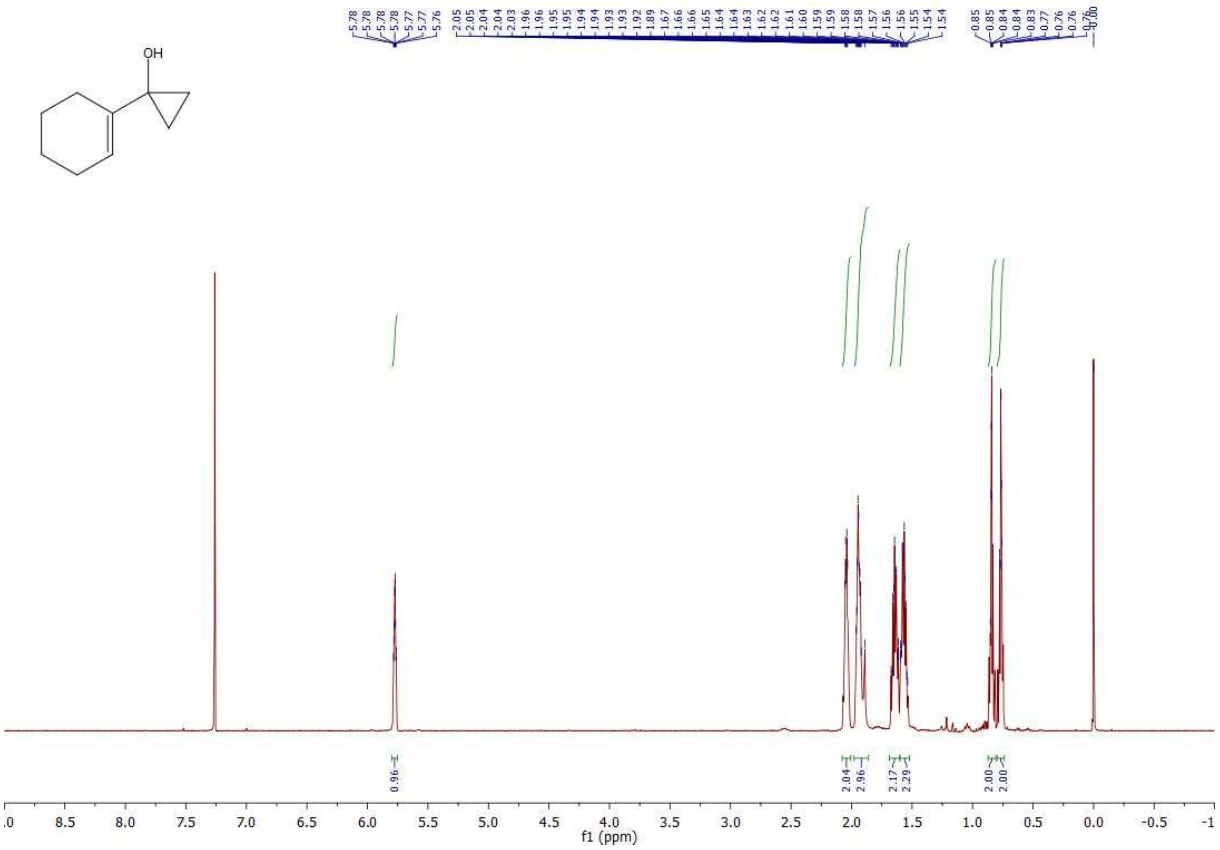
4.06 4.05 4.05 4.04 4.04 4.03 3.80 3.79 3.79 3.78 3.78 3.77
3.00
2.19 2.17 2.15
1.66 1.65 1.63
0.73 0.72 0.72 0.70 0.41 0.40 0.40 0.38
O
O
OH
1.96 3.12 1.97 2.13 0.94 1.98 2.10 2.00 1.96
f1 (ppm)


142.39
128.29 128.06 125.84
110.47
77.48 77.16 76.84
64.57
55.77
37.43
32.34
13.82
O
O
OH
f1 (ppm)


OH
CH2
f1 (ppm)


OH
CH2
f1 (ppm)


OH
5.78
5.78
5.78
5.77
5.77
5.76
2.05
2.05
2.04
2.04
2.03
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1.95
1.94
1.94
1.93
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1.62
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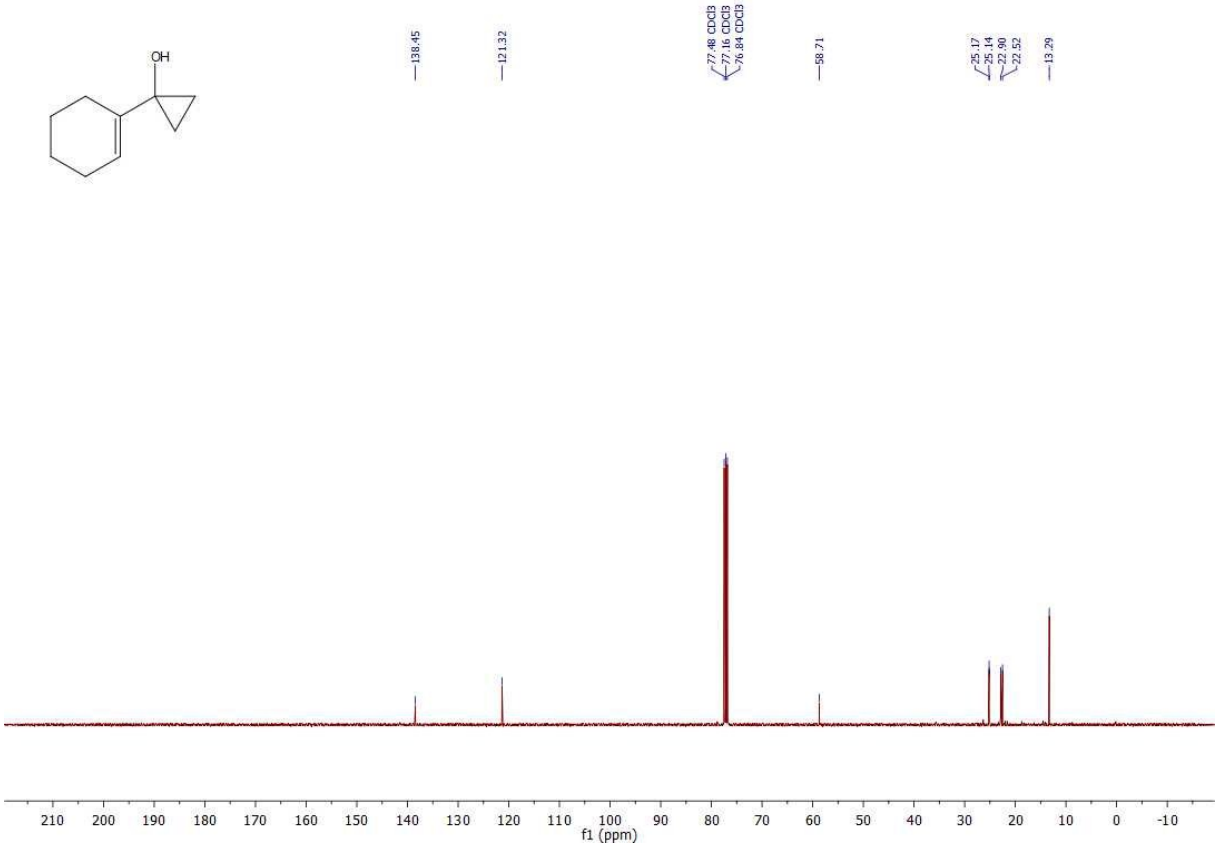
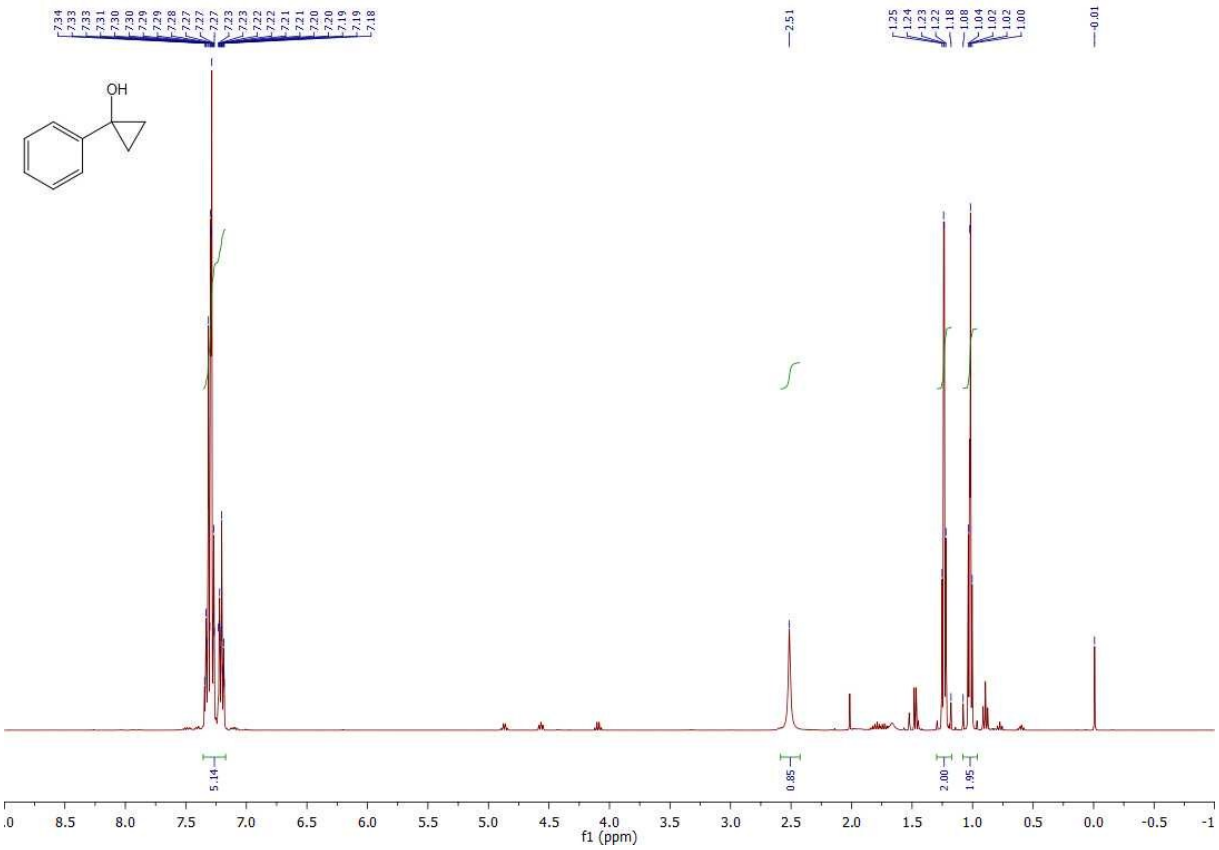
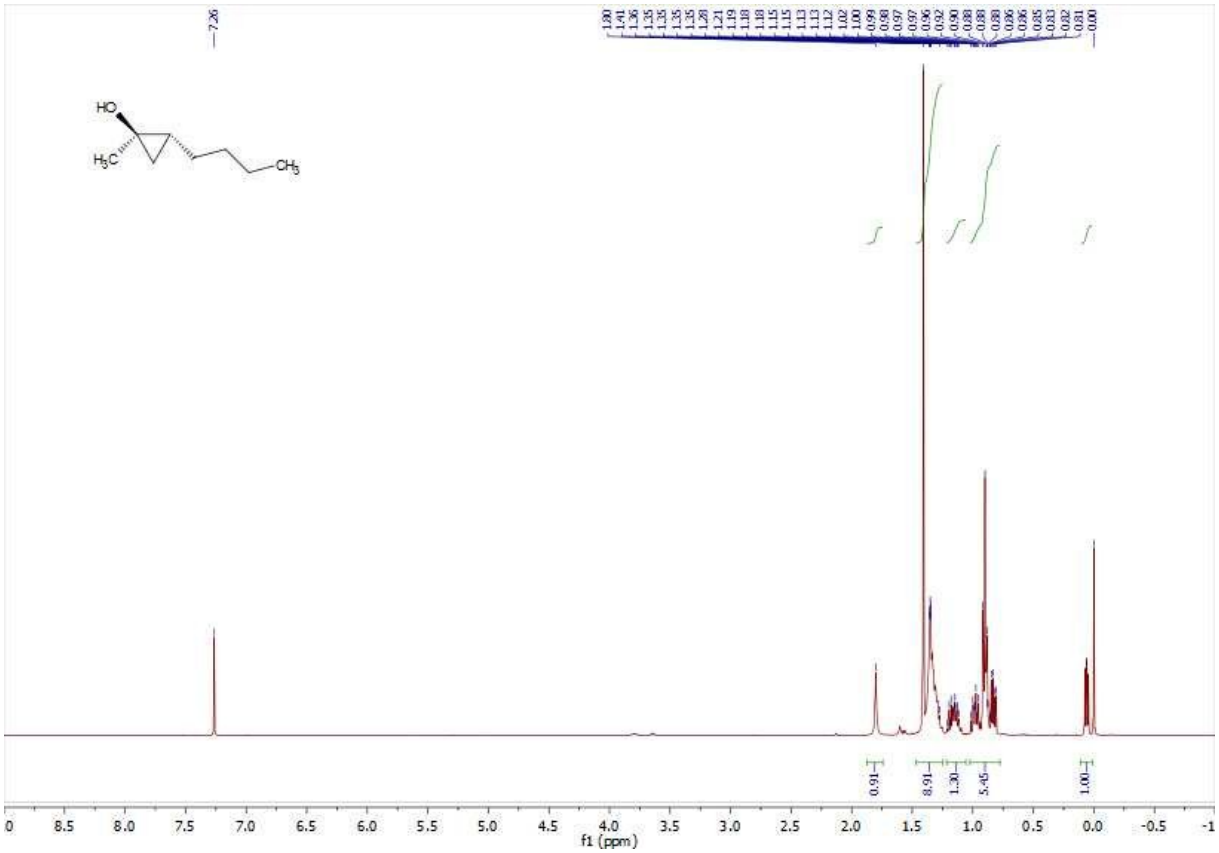
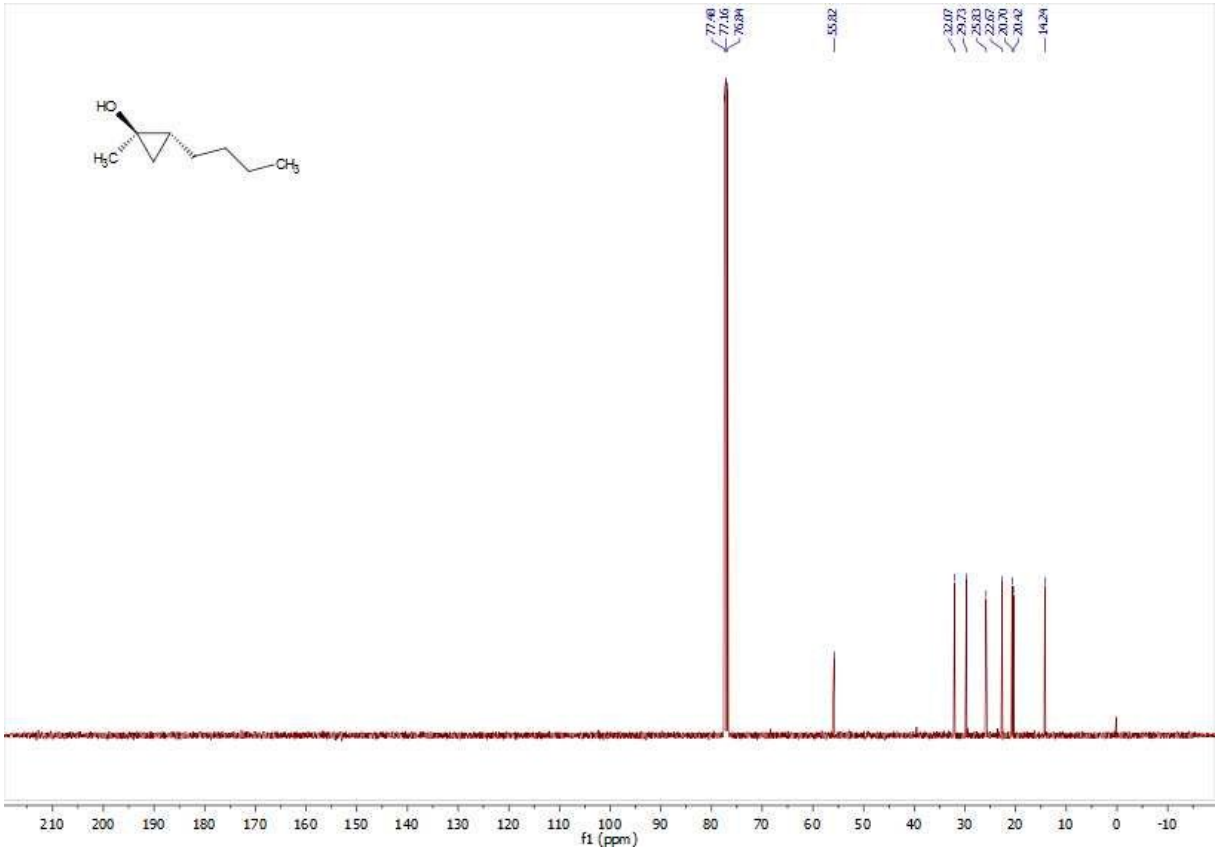
1.61
1.60
1.59
1.59
1.58
1.58
1.57
1.56
1.56
1.55
1.54
1.54
0.85
0.85
0.84
0.84
0.84
0.83
0.77
0.76
0.76
0.76
0.00
0.96
2.04
2.96
2.17
2.29
2.00
2.00
f1 (ppm)


OH
138.45
121.32
77.48 CDCl3
77.16 CDCl3
76.84 CDCl3
58.71
25.17
25.14
22.90
22.52
13.29
f1 (ppm)


OH
f1 (ppm)


HO
H3C
CH3
f1 (ppm)


77.40
77.16
76.84
55.82
32.07
29.73
25.83
22.67
20.70
20.42
14.24
HO
H3C
CH3
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)

VI. Single crystal X-ray diffraction analysis

Crystal data for **4a:**

$C_{11}H_{13}FO_3S$, M_r =244.27 g/mol, monoclinic, $P2_1/c$ (no. 14), a = 15.2903(14) Å, b = 5.0921(4) Å, c = 16.0912(14) Å, β = 115.067(11)°, V = 1134.85(19) Å^3, Z = 4, Cu-$K\alpha$ radiation (λ = 1.54184 Å) at T = 123.0 K, μ(CuKα) = 2.600 mm^{-1}, *Dcalc* = 1.430 g/cm^3, 9604 reflections measured (6.382° ≤ 2Θ ≤ 134.804°) of which 2005 unique (R_{int} = 0.0878, R_{sigma} = 0.0529), final R_1 [$F^2>2\sigma(F^2)$] = 0.0562, wR_2 (all data) = 0.1565. The crystallographic data is deposited with the Cambridge Crystallographic Data Centre (CCDC 1533651) and can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

Single crystals of the compound **4a** were obtained by slow diffusion of pentane into a solution of **4a** in chloroform. Thin needle-like colourless crystals were obtained. Single crystal X-ray diffraction data was collected at 123.0 K on a Rigaku Compact HomeLab diffractometer, equipped with a Saturn 944 HG CCD detector and Oxford Cryostream cooling system using monochromatic Cu-$K\alpha$ radiation (1.54178 Å) from a MicroMax^{TM}-003 sealed tube microfocus X-ray source. The strategy of data collection was calculated using Rigaku *CollectionStrategy* [1]. Data was collected using ω-scans. CrysAlisPro [2] was used for data reduction and empirical absorption correction using spherical harmonics implemented in *SCALE3 ABSPACK* scaling algorithm [3]. The structure was solved using *SHELXT* [4] and refined by full-matrix least-squares method against F^2 with *SHELXL-2014* [4] through *OLEX2* [5] program package. All non-hydrogen atoms were refined with anisotropic atomic displacement parameters. Hydrogen atoms were treated as riding atoms, using isotropic displacement parameters U_{iso}(H) = 1.2U_{iso}(C) for CH and CH_2. The compound was found to crystallize in a centrosymmetric space group $P2_1/c$, with four molecules of **4a** in the unit cell. The figure was drawn using the program Mercury CSD 3.9 [6] and POV-Ray 3.7 [7].

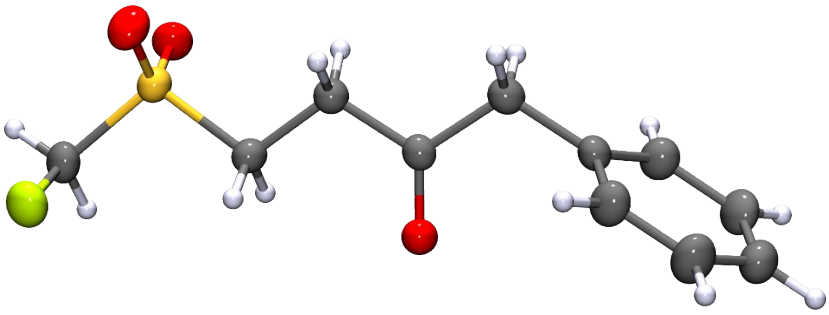


Figure S1 The asymmetric unit in the crystal structure of **4a**. The atomic displacement ellipsoids are drawn at 50% probability level.

1. L. M. Daniels, *Acta Cryst.*, 2011, **A67**, C143.
2. *CrysAlisPro*, 2014, Agilent Technologies Ltd, Yarnton, Oxfordshire, UK. Version 1.171.36.35
3. R. C. *Clark* and J. S. *Reid*, *Acta Cryst.*, 1995, **A51**, 887-897.
4. G. M. Sheldrick, *Acta Cryst.*, 2015, **A71**, 3-8.
5. O.V. Dolomanov, L.J. Bourhis, R.J. Gildea, J.A.K. Howard and H. Puschmann, *J. Appl. Cryst.,* 2009, **42**, 339-341.
6. Mercury CSD 2.0 - new features for the visualization and investigation of crystal structures, C. F. Macrae, I. J. Bruno, J. A. Chisholm, P. R. Edgington, P. McCabe, E.

Pidcock, L. Rodriguez-Monge, R. Taylor, J. van de Streek and P. A. Wood, *J. Appl. Cryst.*, **41**, 466-470, 2008.
7. Persistence of Vision Pty. Ltd. (2004) Persistence of Vision Raytracer (Version 3.7) [Computer software]. Retrieved from http://www.povray.org/download/