Accepted Manuscript

Submission Date: 2023-09-27
Accepted Date: 2024-07-05
Accepted Manuscript online: 2024-07-16

SynOpen

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DOI: 10.1055/a-2360-9229

Please cite this article as: Gaikwad S, Chaturbhuj G U. Thiourea/NCBSI/HCl System: Telescoping alkyl halide to alkyl sulfonyl chloride by recyclable N-chloro-N-(phenylsulfonyl)benzene sulfonamide (NCBSI). SynOpen 2024. doi: 10.1055/a-2360-9229

Conflict of Interest: The authors declare that they have no conflict of interest.

This study was supported by Chhatrapati Shahu Maharaj Research, Training, and Human Development Institute Govt. of Maharashtra, India , CSMNRF-2022/2022-23/2341

Abstract:
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Thiourea/NCBSI/HCl System: Telescoping alkyl halide to alkyl sulfonyl chloride by recyclable *N*-chloro-*N*-(phenylsulfonyl)benzene sulfonamide (NCBSI)

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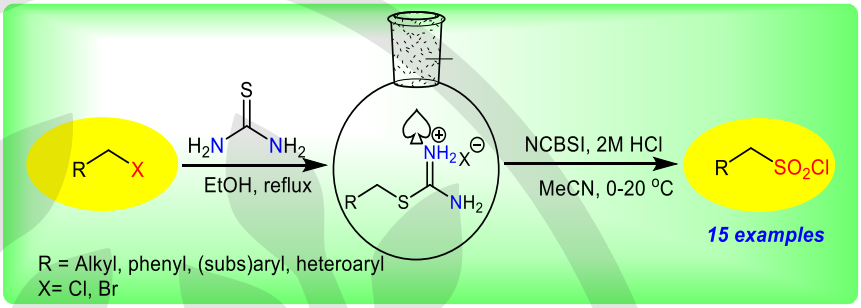
Click here to insert a dedication.



Received:
Accepted:
Published online:
DOI:

Abstract A convenient and efficient method to synthesize diverse alkyl sulfonyl chlorides through *N*-chloro-*N*-(phenylsulfonyl)benzene sulfonamide (NCBSI)-mediated oxidative chlorosulfonation of S-alkyl isothiouronium salts obtained from alkyl chlorides is presented. Synthesizing structurally diverse alkyl sulfonyl chloride in moderate to excellent yields up to 98% from alkyl halide *via* easy formation of S-alkyl isothiouronium salts using inexpensive thiourea. The mild reaction conditions and broad substrate scope make this method beneficial and advantageous to alkylsulfonyl chloride syntheses.

Keywords: Alkyl sulfonyl chlorides, *N*-chloro-*N*-(phenylsulfonyl)benzene sulfonamide, S-alkyl isothiouronium salts, alkyl halides, chlorosulfonation

Sulfonyl chlorides are essential synthetic intermediates widely used as building blocks in synthetic and medicinal chemistry.[1-2] Sulfonamides are the primary derivative of sulfonyl chloride, commonly featured in anticonvulsants, selective serotonin receptor agonists, and cytosolic phospholipase $A_2\alpha$ inhibitors.[3-4] Sulfonyl chlorides are frequently used as building blocks in medicinal chemistry because sulfonyl chloride reacts with heterocyclic amines to form complex sulfonamides.[5a-d] Concerning their significance, sulfonyl chlorides have received increasing interest in past centuries. Several research studies on the synthesis of sulfonyl chlorides from sulfides, [6] sulfonic acids, [7] or their sodium salts [7] or alkyl halides [8-9] have been reported using a variety of reaction procedures with different types of toxic and hazardous chlorinating reagents or by oxidative chlorination of sulfur-containing compounds such as thiols,[10-11] thioacetates,[11a] disulfides[11f-g] by oxidizing reagents.

Chlorine water[12] has been the most well-known method. However, handling chlorine is tedious. Although, many methodologies have been reported for synthesizing sulfonyl chlorides by the dehydration of sulfonic acids with highly corrosive and toxic reagents, such as $POCl_3$, PCl_5, and $SOCl_2$.[13b-c]

S-alkyl isothiouronium salts are readily synthesizable and inexpensive starting materials for converting into the subsequent alkyl sulfonyl chlorides *via* oxidative chlorosulfonation. HCl-treated silica gel and PhIO,[6] *t*-BuOCl-H_2O,[9] and $NaClO_2$/HCl,[10] chlorine gas,[12] *N*-chloro succinamide/HCl[14] have been applied in the oxidative chlorosulfonation. *N*-chloro succinamide/HCl generates water-soluble organic by-product succinimide, which creates the isolation problem.

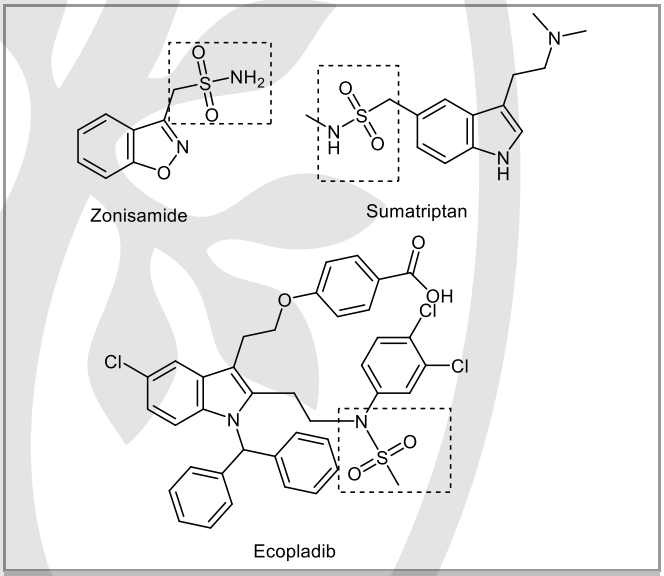


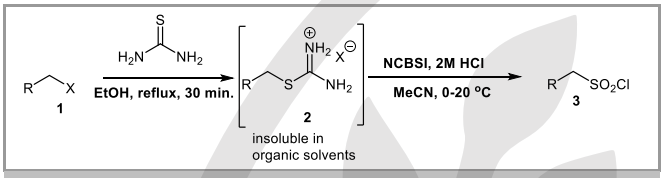
Figure 1 Structure of biologically active sulfonamide generated from sulfonyl chloride as building blocks

Recently, *N*-chloro-*N*-(phenylsulfonyl)benzene sulfonamide (NCBSI) was explored for chlorinating reactive aromatic compounds[15] and oxidation of alcohols and ethers.[15b] It is a recyclable, environment-friendly, and atom-economic recyclable reagent for chlorination and oxidation.

The reactivity and electrophilicity of NCBSI can be evident from its longer N-Cl bond length (1.848 Å) compared to other chlorinating reagents like NCS, TCCA, NCSAC, and *N*-chlorophthalimide. The longer bond length is due to a strong electron pull by the two neighboring sulfonyl groups, lowering the absolute charge density on the nitrogen atom. Therefore, nitrogen exerts a less electron pull effect towards chlorine atoms, which results in lowering the absolute charge density of chlorine, which in turn lowers BDE (40.36 kcal mol^{-1}).[15a] Based on the

earlier study[15] NCBSI is highly reactive and results in instantaneous reaction with the advantage of recyclability of by-product.

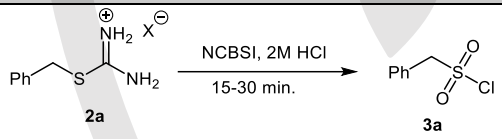
For the oxidative chlorosulfonation of S-alkyl isothiouronium salts, NCBSI should be an alternate atom-economic reagent. (Scheme 1). Thus, we herein report thiourea/ NCBSI/ HCl as a valuable reagent system for oxidative chlorosulfonation of alkyl halides into the corresponding sulfonyl chlorides *via* S-alkyl isothiouronium.



Scheme 1 Synthesis of alkane sulfonyl chlorides from S-alkyl isothiouronium salts via NCBSI oxidative chlorosulfonation

At the outset, we prepared S-benzyl isothiouronium chloride (**2a**) by reacting benzyl chloride **1a** with thiourea in ethanol for 30 minutes under reflux. (Table 1). Reaction optimization was commenced by reacting the model substrate S-benzyl isothiouronium chloride (**2a**) with NCBSI and 2M HCl. The oxidative chlorosulfonation was carried out in polar solvents to evaluate the solvent effect. Reacting S-benzyl isothiouronium chloride (**2a**) with the suspension of NCBSI (4 equiv) in 2M HCl with water as solvent resulted in an unsatisfactory yield (Table 1, entry 1). Reaction in EtOH showed no conversion (Table 1, entry 2). Furthermore, MeCN was used as a solvent, resulting in an improved yield of 42% (Table 1, entry 3). Further optimization by varying HCl concentrations yielded 96% yield (Table 1, entry 4). MeCN was found to be the most suitable solvent. To our delight, 96% yield was achieved for the desired product phenylmethanesulfonyl chloride (**3a**).

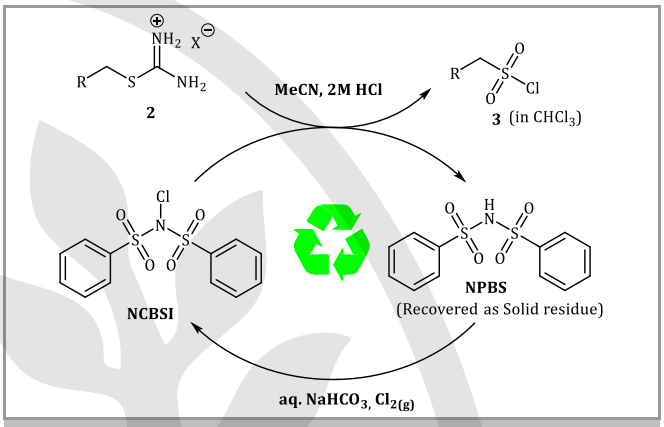
Table 1 Reaction Condition Optimization for chlorosulfonation[a]



Entry	NCBSI (equiv)	Solvent	HCl	Yield (%)[b]
1	4	H_2O	1M HCl	20[a]
2	4	EtOH	1M HCl	No Reaction[a]
3	4	MeCN	1M HCl	42
4	4	MeCN	2M HCl	96[b]

[a]Reaction conditions: S-benzyl isothiouronium salt **2a** (1.014 gm, 1 equiv.), solid NCBSI (4 equiv.), HCl, added to 10 mL solvent sequentially.
[b]S-benzyl isothiouronium salt added to a solution of NCBSI, 2M HCl, and MeCN (10 mL), r.t.
[c]Isolated yield.

Under optimized conditions, the starting material **2a** was consumed completely to produce **3a**. After the reaction, acetonitrile was evaporated to obtain a mixture of the desired compound and by-product. The chloroform was added to dissolve the desired compound and the by-product as residue, which was filtered. The filtrate-containing compound was washed with water and sodium bicarbonate to remove traces of the by-product, and the organic layer was dried and evaporated to obtain the desired products in high yield. The recovered by-product *N*-(phenylsulfonyl)benzene sulfonamide (NPBS) from residue can be recycled to NCBSI by treating it with sodium bicarbonate and chlorine gas in aqueous media (Scheme 2).[15a]



Scheme 2 Synthesis of alkyl sulfonyl chlorides by NCBSI chlorosulfonation

For the applicability of this procedure to prepare sulfonyl chlorides, it was decided to synthesize a series of sulfonyl chlorides.

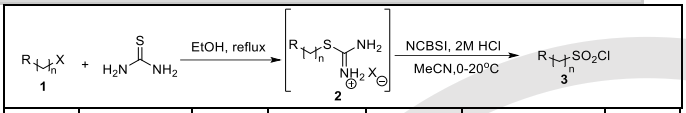
The monosubstituted S-benzyl isothiouronium salts (**2a-2h**) were prepared in 30 minutes, while the trisubstituted phenyl ring did not affect reaction time (**2i**). The phenyl propyl and heterocyclic ethyl chloride required 60 minutes to form S-alkyl isothiouronium salts (**2j and 2k**). The aliphatic primary alkyl chlorides converted to S-alkyl isothiouronium salt in 30 minutes (**2l-2n**), while secondary and tertiary alkyl chloride required 45 minutes for conversion (**2o-2p**).

The time needed to convert S-alkyl isothiouronium salts into alkanesulfonyl chlorides varies from 15 to 60 minutes, from good to excellent (**Table 2**). The unsubstituted and halo-substituted benzyl chlorides converted to corresponding sulfonyl chloride in an overall 45 minutes due to the inductive effect (-I) of phenyl ring (**3a-d, f**) with excellent yield 93 to 97% except *ortho* iodo substitution yielded 85 % product (**3e**). The substrate range was expanded by introducing an electron-donating or electron-withdrawing group on the phenyl ring of benzyl chloride. Electron-releasing methyl substituent on a phenyl ring required a longer reaction time with 97 % yield (**3g**). In contrast, the electron-withdrawing nitro-substituted phenyl ring resulted in a moderate yield of 86 % with extended reaction time (**3h**). The trimethyl phenyl ring (**3i**) and the phenylpropyl chloride (**3j**) required a little longer, although the yields were obtained at 90 % and 94 %, respectively.

Heterocyclic ethyl sulfonyl chlorides and fused ring sulfonyl chlorides were prepared to extend the substrate scope. The reaction time for the heterocyclic alkyl halide was longer, giving a moderate yield of 87 % (**3k**). Due to the inductive effect (+I), the alkyl substrates required a much longer time with a good yield of 95 to 98 % (**3l and 3n**), except **3m** gave a moderate yield of 77%. However, the secondary alkyl sulfonyl chloride required a slightly longer reaction time with a moderate yield of 78% (**3o**).

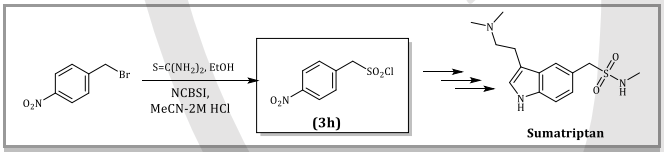
In comparison, tertiary alkyl sulfonyl chloride obtained an excellent yield of 96% with a shorter reaction time (**3p**).

Table 2 Synthesis of structurally diverse alkanesulfonyl chlorides[a]



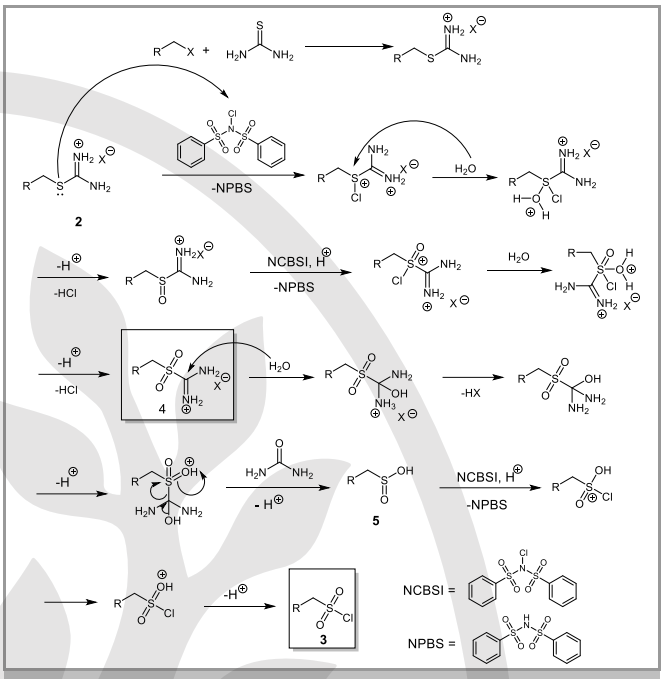
Entry	1	1	Time (min.)[b] 2a-p	Time (min.)[c]	3	Yield (%)[d]
1	C_6H_5	**1a**	30	15	$C_6H_5SO_2Cl$	97
2	4-F-C_6H_4	**1b**	30	15	4-F-$C_6H_4SO_2Cl$	94
3	4-Cl-C_6H_4	**1c**	30	15	4-Cl-$C_6H_4SO_2Cl$	96
4	4-Br-C_6H_4	**1d**	30	15	4-Br-$C_6H_4SO_2Cl$	94
5	2-I-C_6H_4	**1e**	30	15	2-I-C_6H_4 SO_2Cl	85
6	2-F-C_6H_4	**1f**	30	15	2-F-$C_6H_4SO_2Cl$	93
7	4-CH_3-C_6H_4	**1g**	30	30	4-CH_3-$C_6H_4SO_2Cl$	97
8	4-O_2N-C_6H_4	**1h**	30	25	4-O_2N-$C_6H_4SO_2Cl$	86
9	C_6H5-$(CH_2)_3$	**1i**	60	30	C_6H5-$(CH_2)_3SO_2Cl$	94
10		**1j**	60	45		87
11	*n*-C_3H_7	**1k**	30	60	$C_3H_7SO_2Cl$	95
12	*n*-C_4H_9	**1l**	30	60	$C_4H_9SO_2Cl$	77
13	*n*-C_5H_{11}	**1m**	30	60	$C_5H_{11}SO_2Cl$	98
14		**1n**	45	30		78
15	Ph_3C-	**1o**	45	20	Ph_3C-	96

[a] Reaction condition: Step 1: alkyl halide (1 equiv.) and thiourea (1 equiv.) in EtOH; Step 2: NCBSI (4 equiv.), 2M HCl, 10 mL MeCN, 0-20 °C.
[b] Reflux time
[c] Time for oxidative chlrosulfonation
[d] Isolated yield



Scheme 3 Application of (4-nitrophenyl)methanesulfonyl chloride in the synthesis of Sumatriptan

The proposed mechanism for synthesizing sulfonyl chloride from alkyl chloride *via* NCBSI-mediated oxidative chlorosulfonation is shown in Scheme 4. S-alkyl isothiouronium salts **2** prepared from alkyl halide and thiourea. HCl provides an aqueous acidic medium, and NCBSI is used to form alkyl sulfonyl methanimidamide salt 4, followed by oxidation steps. Intermediate **4** readily reacts with water because of the methanimidamide salt moiety's high electrophilicity in combination with an electron-withdrawing sulfonyl group. Accordingly, intermediate **4** is converted to corresponding sulfinic acid **5** by the water attack, elimination of halogen, proton transfer, and protonated urea elimination sequentially. Finally, sulfinic acid **5** undergoes chlorination and elimination of the hydroxyl group to give corresponding sulfonyl chloride **3**.



Scheme 4 Possible mechanism for oxidative chlorosulfonation of S-alkyl isothiouronium salts mediated by NCBSI

In conclusion, a method was developed to synthesize alkanesulfonyl chlorides from alkyl halide through a one-pot, two-step reaction with thiourea and NCBSI. Furthermore, a one-pot conversion of alkanesulfonyl chlorides from alkyl halide has been developed. Various alkyl sulfonyl chlorides with aryl, heterocyclic, and aliphatic straight-chain compounds were synthesized in good to excellent yields by this procedure. The key advantages of this method are the economical and readily available reagents, mild reaction condition, excellent yields, ease of workup, and recyclability of the reagent by-product.

All solvents and reagents were obtained from Avra Synthesis, Spectrochem, and SD Fine Chemicals and were utilized without purification. All reactions were carried out in an oven-dried glassware fuming hood, magnetically agitated, and heated in an oil bath. The reactions were monitored by TLC on Merck silica gel G F254 plates. Melting points were recorded on the Analab ThermoCal instrument in open glass capillaries and were uncorrected. ^1H and $^{13}C\{^1H\}$ NMR spectra are recorded on MR500 NMR spectrometer, Agilent Technologies $CDCl_3$ and DMSO-d6 with tetramethylsilane (TMS) as the internal standard. Chemical shifts are reported in delta (δ) units in parts per million (ppm). The peak patterns are indicated as s, singlet; d, doublet; t, triplet; m, multiplet; q, quartet.

Sulfonyl chlorides 3; General procedure

An equimolar quantity of alkyl halide and thiourea were heated at 80 °C in EtOH (5 mL). EtOH was evaporated under vacuum; the obtained solid or viscous liquid was gradually added to a mixture of NCBSI (4 equiv.), 2 M HCl (2 mL), and MeCN (10 mL) at 0-10 °C in an ice bath. The progress of the reaction was monitored by TLC. After the reaction completion, MeCN was evaporated under a vacuum. Chloroform (15 mL) was added to the resultant solid or suspension. The mixture was filtered, and the filtrate was washed with water (15 mL) and sat. $NaHCO_3$ solution (5 mL). The organic layer was dried over Na_2SO_4 and concentrated under reduced pressure. The residue was subjected to short-column filtration (silica gel; chloroform) to get the desired products.

All the synthesized products were characterized by melting point and NMR spectroscopy.

Phenylmethanesulfonyl Chloride (3a)

Colorless crystals; yield: 0.92 g (97%); mp 92-96 °C (Lit. 91-93 °C).[17]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 – 7.35 (m, 5H), 4.80 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 131.30, 129.14, 126.12, 70.90.

(4-Fluorophenyl)methanesulfonyl chloride (3b)

Colorless crystals; yield: 0.98 g (94%); mp 66-68 °C (Lit. 68-69 °C).[9]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 (dd, *J* = 8.5, 5.2 Hz, 2H), 7.15 (t, *J* = 8.5 Hz, 2H), 4.84 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 164.88, 162.88, 133.43, 122.07, 116.46, 69.97.

Anal. Calcd: C, 40.30; H, 2.90; S, 15.37. Found: C, 41.56; H, 3.12; S, 15.31

(4-Chlorophenyl)methanesulfonyl chloride (3c)

Colorless crystals; yield: 1.08 g (96%); mp 92-93 °C (Lit. 88-91 °C).[18]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.33 (m, 4H), 4.76 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 136.74, 132.63, 129.53, 124.59, 69.97.

(4-Bromophenyl)methanesulfonyl chloride (3d)

Colorless crystals; yield: 1.27 g (94%); mp 114-118 °C (Lit. 116-118 °C).[19]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.40 (m, 2H), 7.20 (d, *J* = 2.5 Hz, 1H), 7.18 (d, *J* = 1.7 Hz, 1H), 4.46 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 136.76, 136.42, 131.88, 130.39, 129.77, 122.45, 45.38.

(2-Iodophenyl)methanesulfonyl chloride (3e)

Yellowish liquid; yield: 1.35 g (85%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87 (d, *J* = 7.9 Hz, 1H), 7.48 (d, *J* = 6.1 Hz, 1H), 7.36 (t, *J* = 7.4 Hz, 1H), 7.01 (t, *J* = 8.6 Hz, 1H), 4.68 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 139.88, 130.23, 128.93, 99.71, 51.15.

Anal. Calcd: C, 26.56; H, 1.91; S, 10.13. Found: C, 27.71; H, 2.33; S, 11.94

(2-Fluorophenyl)methanesulfonyl chloride (3f) [20]

Colorless crystals; yield: 0.97 g (93%); mp 52-54 °C (Lit. 52-53.5 °C)

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.44 (dt, *J* = 21.5, 6.6 Hz, 2H), 7.16 (dt, *J* = 18.1, 8.2 Hz, 2H), 4.89 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 162.44, 133.03, 132.57, 124.87, 116.31, 116.14, 63.82.

Anal. Calcd: C, 40.30; H, 2.90; S, 15.37. Found: C, 40.65; H, 2.93; S, 14.89

(4-Methylphenyl)methanesulfonyl chloride (3g)

Colorless crystals; yield: 0.99 g (97%); mp 79-81 °C (Lit. 73-75 °C)[18]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.31 (d, *J* = 7.9 Hz, 2H), 7.20 (t, *J* = 3.9 Hz, 2H), 4.77 (s, 2H), 2.34 (s, 3H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 137.89, 137.35, 129.22, 127.10, 65.20, 21.12.

(4-Nitrophenyl)methanesulfonyl chloride (3h)

Off-white crystals; yield: 1.01 g (86%); mp 84-86 °C (Lit. 92-93 °C).[21]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.7 Hz, 2H), 7.47 (d, *J* = 8.7 Hz, 2H), 4.55 (s, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 147.73, 144.28, 129.32, 123.96, 44.50.

3-Phenylpropane-1-sulfonyl chloride (3i)

Clear viscous liquid; yield: 1.09 g (94%)[22]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.31 – 7.07 (m, 5H), 3.52 – 3.44 (m, 2H), 2.88 – 2.68 (m, 2H), 2.07 – 1.99 (m, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 141.88, 128.43, 125.87, 62.13, 34.22, 32.10.

2-(4-methylthiazol-5-yl)ethane-1-sulfonyl chloride (3j) CAS No. 1342688-76-9

Dark Yellow Liquid; Yield: 0.98 g (87%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.85 (s, 1H), 3.61 (t, *J* = 6.8 Hz, 2H), 3.17 (t, *J* = 6.8 Hz, 2H), 2.39 (s, 3H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 149.98, 147.63, 127.22, 43.08, 28.52, 13.38.

Anal. Calcd: C, 31.93; H, 3.57; S, 28.41; N, 6.21. Found: C, 34.24; H, 3.94; S, 29.57; 7.12

Propane-1-sulfonyl chloride (3k)

Light Yellow Liquid; yield: 0.68 g (95%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 3.63 – 3.54 (m, 2H), 2.02 (tt, *J* = 14.4, 7.2 Hz, 2H), 1.08 (t, *J* = 7.5 Hz, 3H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 66.95, 18.19, 12.26.

Butane-1-sulfonyl chloride (3l)

Light orange liquid; yield: 0.60 g (77%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 3.64 – 3.57 (m, 2H), 2.00 – 1.93 (m, 2H), 1.52 – 1.43 (m, 2H), 0.94 (t, *J* = 7.4 Hz, 3H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 65.22, 26.18, 20.90, 13.39.

Pentane-1-sulfonyl chloride (3m)

Light Yellow Liquid; yield: 0.84 g (98%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 3.63 – 3.56 (m, 2H), 2.02 – 1.92 (m, 2H), 1.46 – 1.38 (m, 2H), 1.37 – 1.29 (m, 2H), 0.88 (t, *J* = 7.2 Hz, 3H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 65.43, 29.59, 23.96, 22.00, 13.62.

2,3-dihydro-1*H*-indene-2-sulfonyl chloride (3n)

Colorless oil; yield: 0.84g (78%)[23]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.23 – 7.10 (m, 4H), 4.71 – 4.66 (m, 1H), 3.38 (dt, *J* = 31.8, 15.9 Hz, 2H), 3.21 – 3.10 (m, 2H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 140.82, 126.65, 124.99, 73.15, 42.62.

Anal. Calcd: C, 49.89; H, 4.19; S, 14.80. Found: C, 47.96; H, 4.36; S, 13.53

Triphenylmethanesulfonyl chloride (3o)

Colorless crystals; yield:1.65 g (96%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37 – 7.24 (m, 15H).

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 146.85, 127.94, 127.26, 82.04.

Anal. Calcd: C, 66.56; H, 4.41; S, 9.35. Found: C, 62.32; H, 4.36; S, 8.52

Recovery of Reagent:

To find the recovery of the *N*-(phenylsulfonyl)benzene sulfonamide, a starting material of NCBSI, a gram-scale model reaction was performed. The residue from the reaction was collected and washed with ice-cold water and dried in an oven at 65 °C to afford 77.8 % of *N*-(phenylsulfonyl)benzene sulfonamide, This can be reused for the preparation of NCBSI. The recovered compound may contain a mixture of *N*-(phenylsulfonyl)benzene sulfonamide and NCBSI. The *N*-(phenylsulfonyl)benzene sulfonamide was purified by recrystallization and confirmed by NMR.

Funding Information

Financial support was provided by Chhatrapati Shahu Maharaj Research, Training, and Human Development Institute, Govt. of Maharashtra, India (CSMNRF-2022/2022-23/2341).

Acknowledgment

The authors thank Chhatrapati Shahu Maharaj Research, Training, and Human Development Institute, Govt of Maharashtra, India. for awarding a Chhatrapati Shahu Maharaj National Research Fellowship.

Supporting Information

YES (This text will be updated with links prior to publication)

Primary Data

NO.

Conflict of Interest

The authors declare no conflict of interest.

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Supporting information

Thiourea/NCBSI/HCl System: Telescoping alkyl halide to alkyl sulfonyl chloride by recyclable *N*-chloro-*N*-(phenylsulfonyl)benzene sulfonamide (NCBSI)

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Table of Contents

1. General information

All solvents and reagents were obtained from Avra Synthesis, Spectrochem, and SD Fine Chemicals and were utilized without purification. All reactions were carried out in an oven-dried glassware fuming hood, magnetically agitated, and heated in an oil bath. The reactions were monitored by TLC on Merck silica gel G F254 plates. Melting points were recorded on Analab ThermoCal instrument in open glass capillaries and were uncorrected. ^{1}H and $^{13}C\{^{1}H\}$ NMR spectra are recorded on MR500 NMR spectrometer, Agilent Technologies $CDCl_3$ and DMSO-d6 with tetramethylsilane (TMS) as the internal standard. Chemical shifts are reported in delta (δ) units in parts per million (ppm). The peak patterns are indicated as s, singlet; d, doublet; t, triplet; m, multiplet; q, quartet.

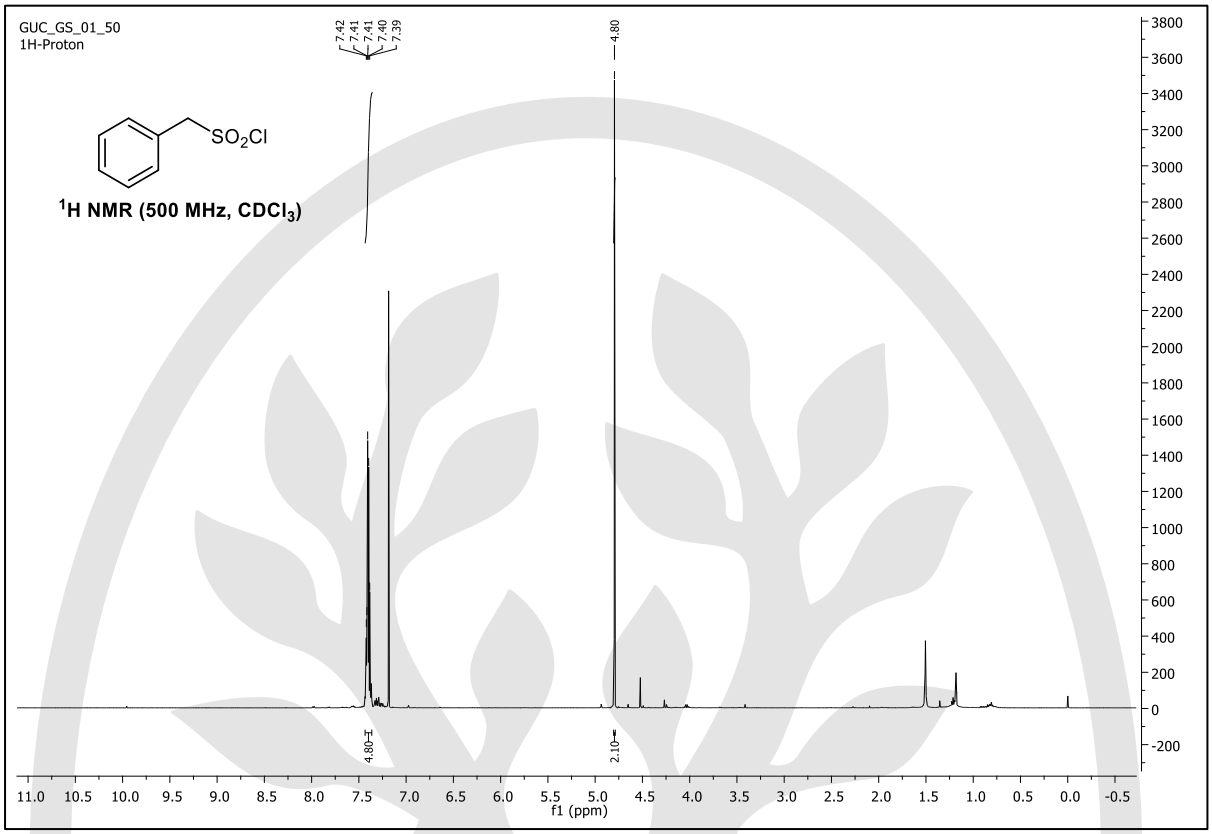
2. General procedure for the synthesis of Alkyl sulfonyl chloride

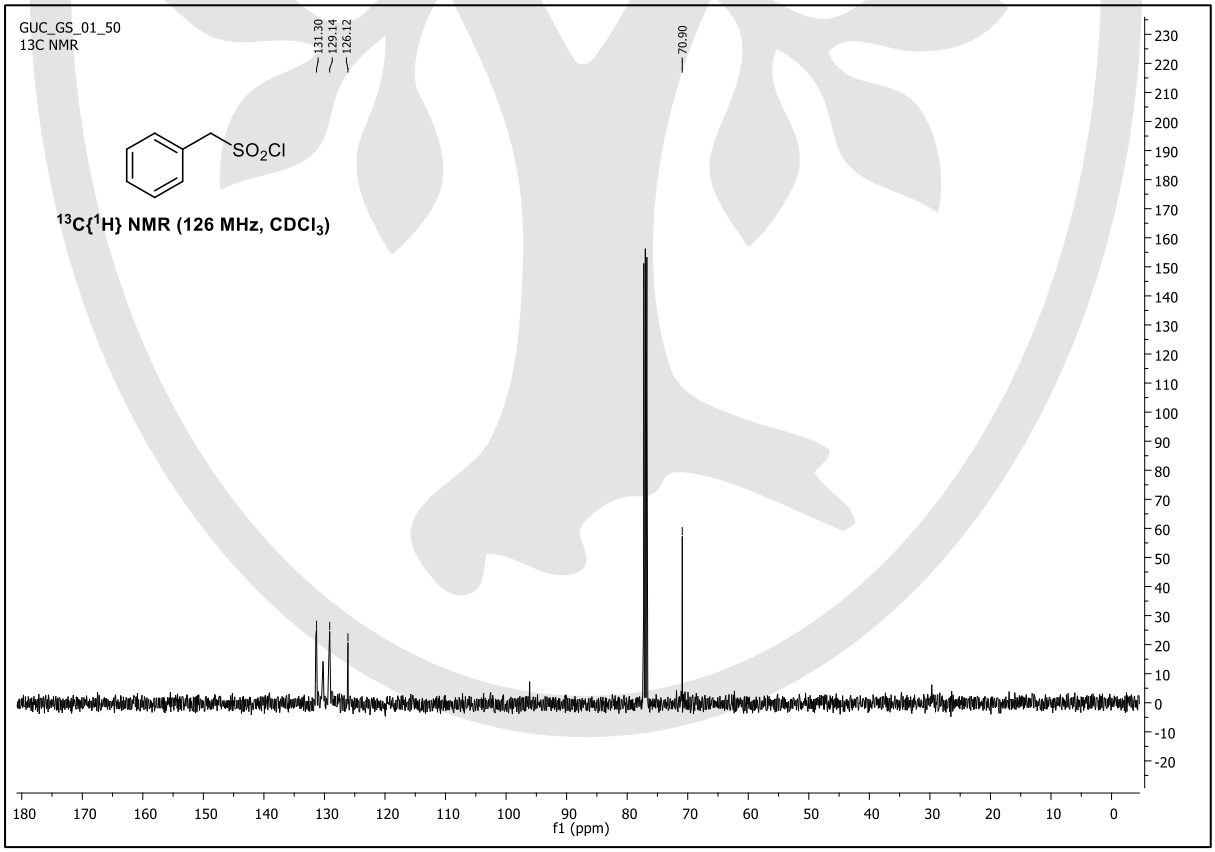
An equimolar quantity of alkyl halide and thiourea were refluxed in EtOH (5 mL) for the time indicated in Table 2. After removal of EtOH at reduced pressure, the obtained solid or sticky oil was slowly added to a mixture of NCBSI (4 equiv.), 2 M HCl (2mL), and MeCN (10 mL) at 0-10 °C in ice bath. The progress of the reaction was monitored by TLC. After the reaction completion, acetonitrile was evaporated under a vacuum. To the resultant solid or liquid with suspension of BBI chloroform (15 mL) was added. The reaction mixture was filtered, and the filtrate was washed with water (15 mL) and sat. $NaHCO_3$ solution (10 mL). The organic layer was separated, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was subjected to short-column filtration (silica gel; chloroform) to afford the desired products.

All the synthesized products were characterized by melting point and NMR spectroscopy.

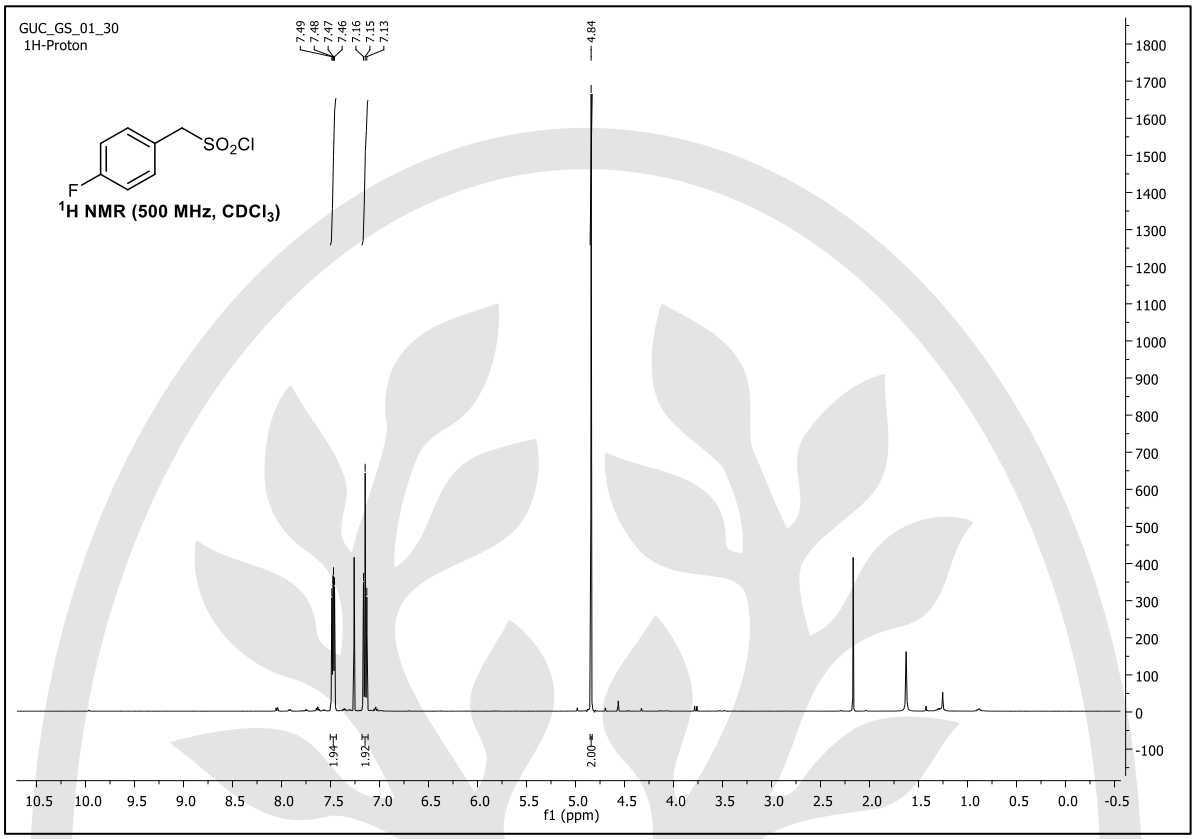
3. Copies of NMR spectra of synthesized compounds

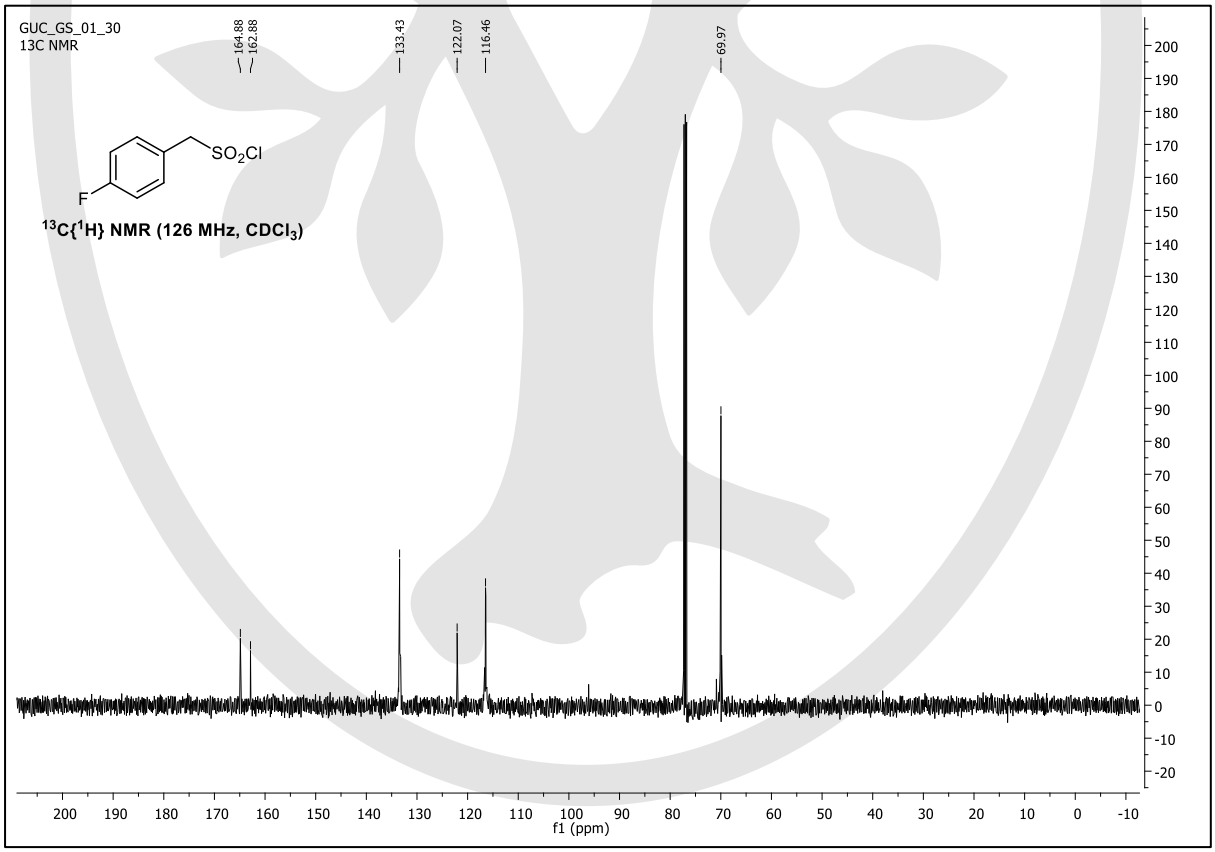
1. Phenylmethanesulfonyl Chloride (3a)[1]



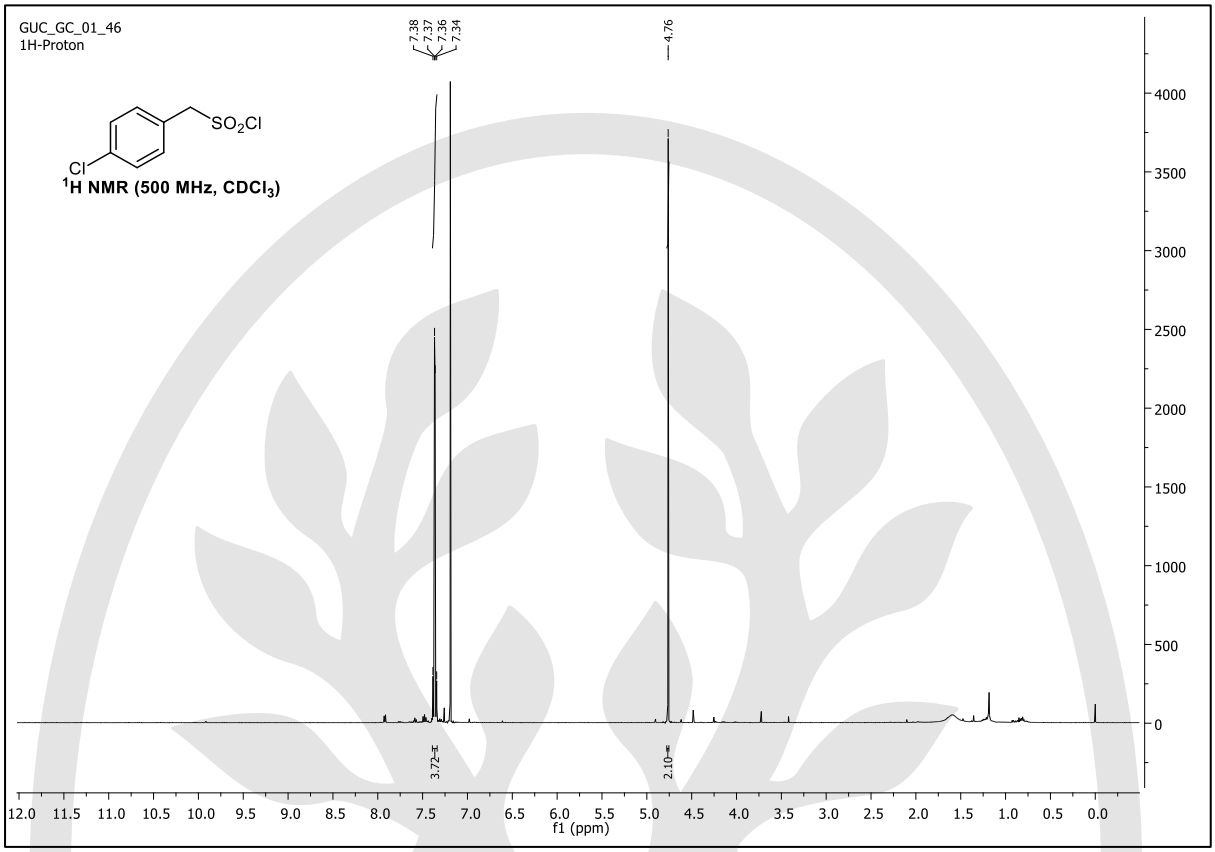


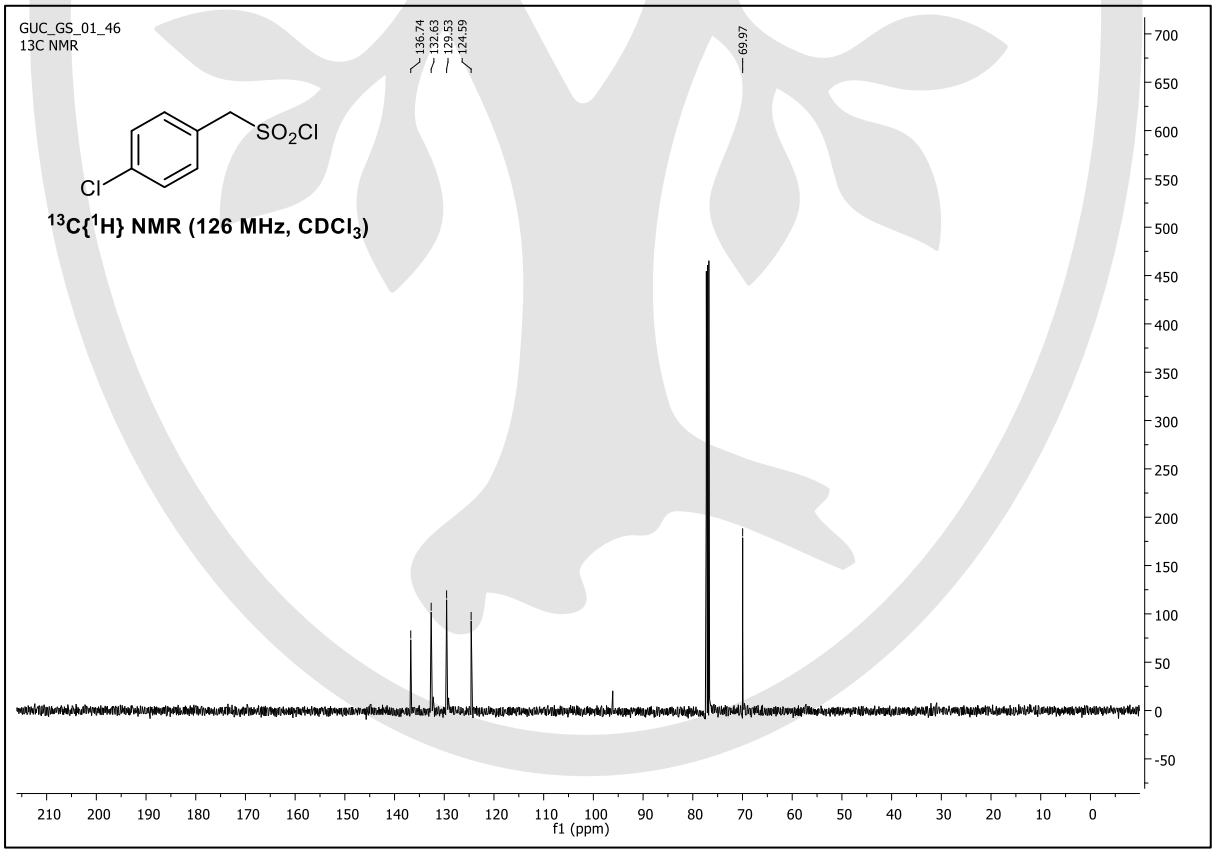
2. (4-Fluorophenyl)methanesulfonyl chloride (3b)[1]



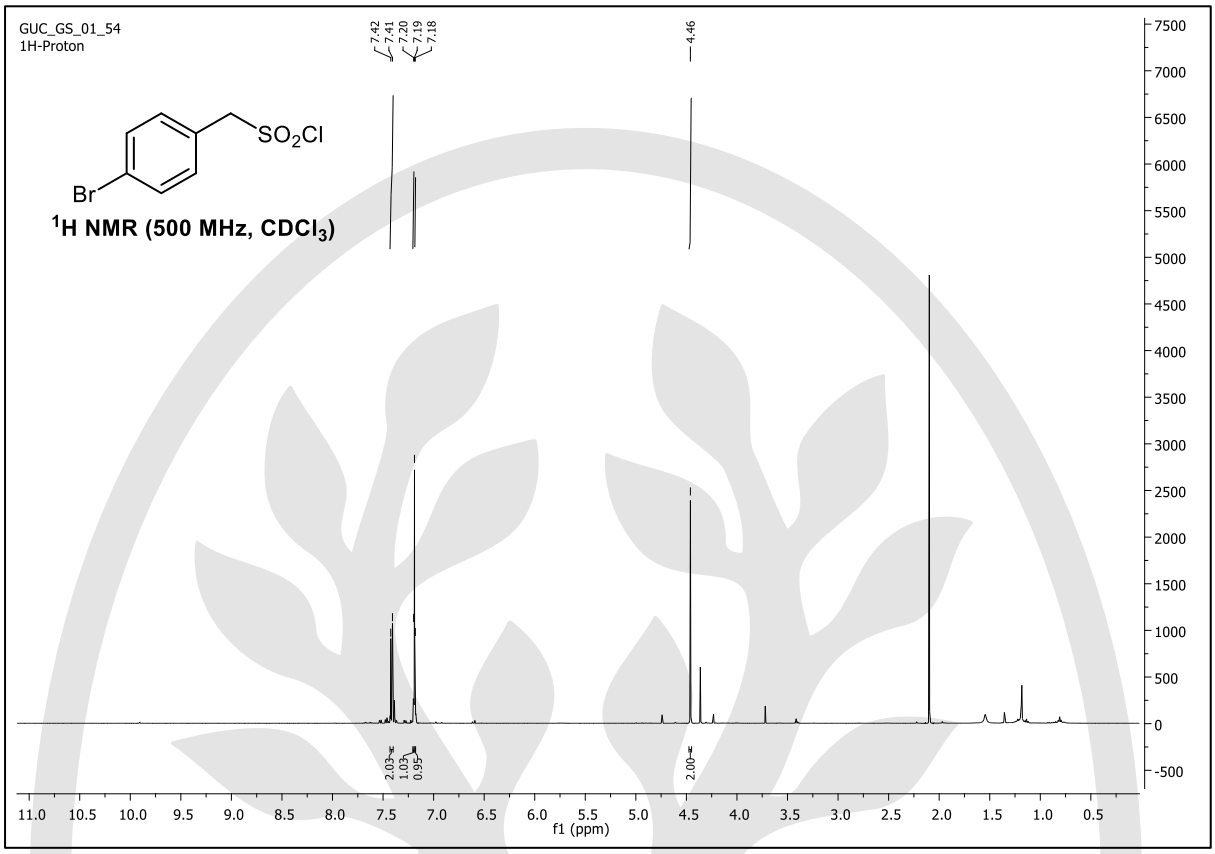


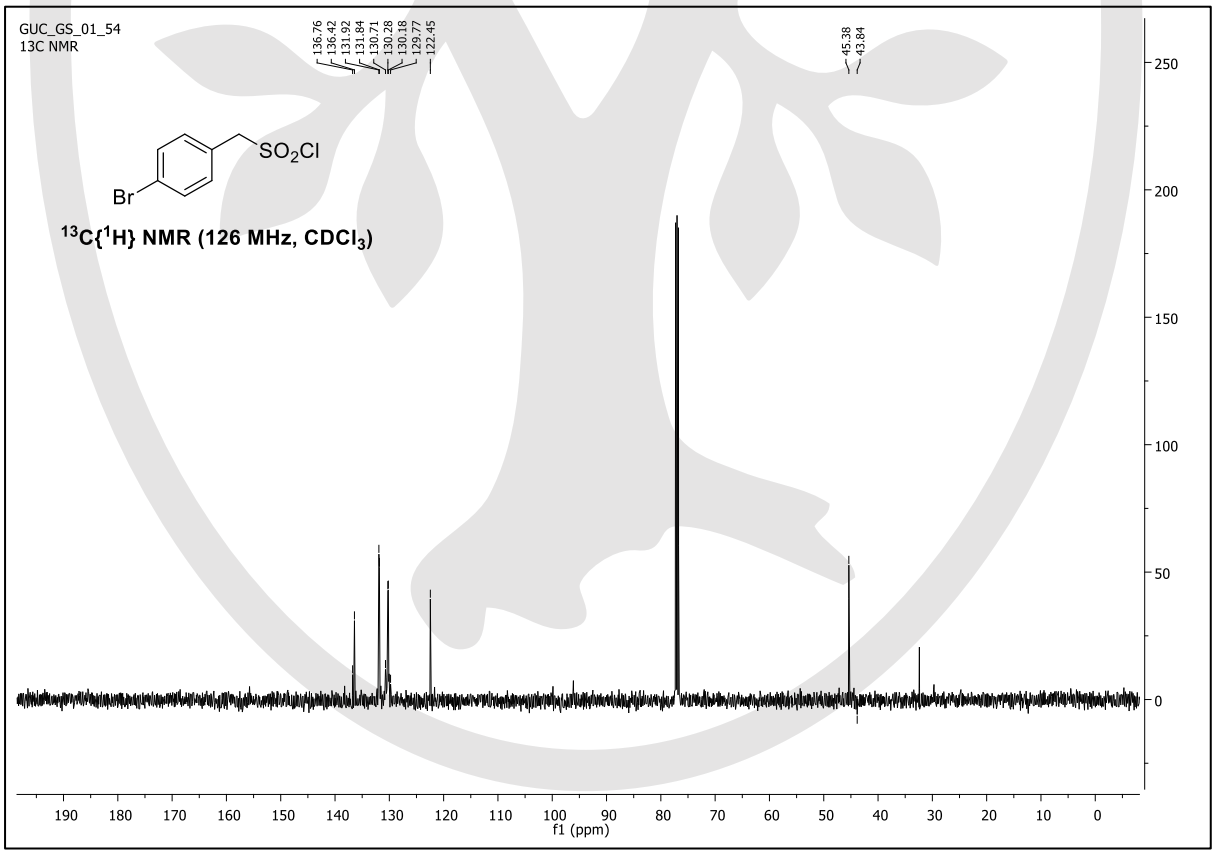
3. **(4-Chlorophenyl)methanesulfonyl chloride (3c)[1]**



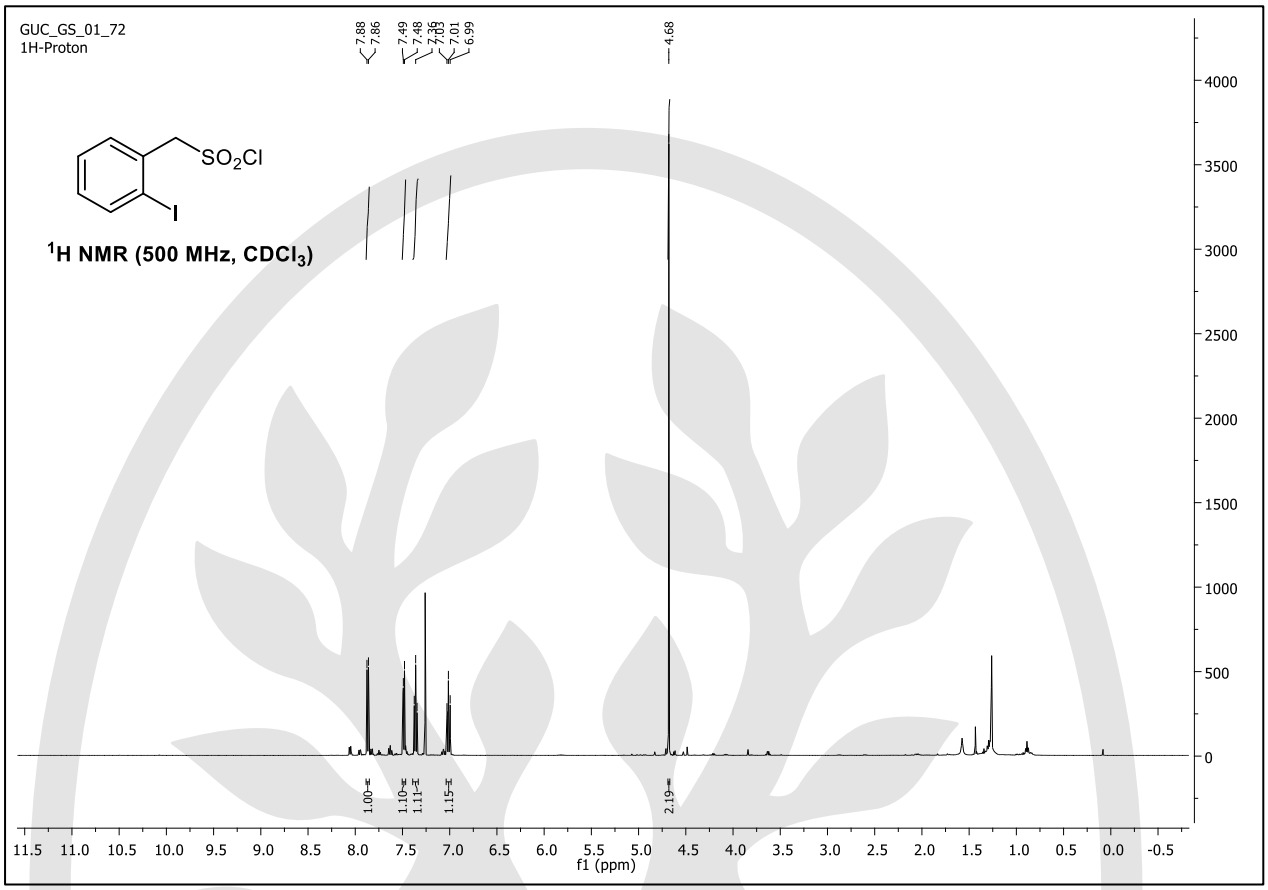


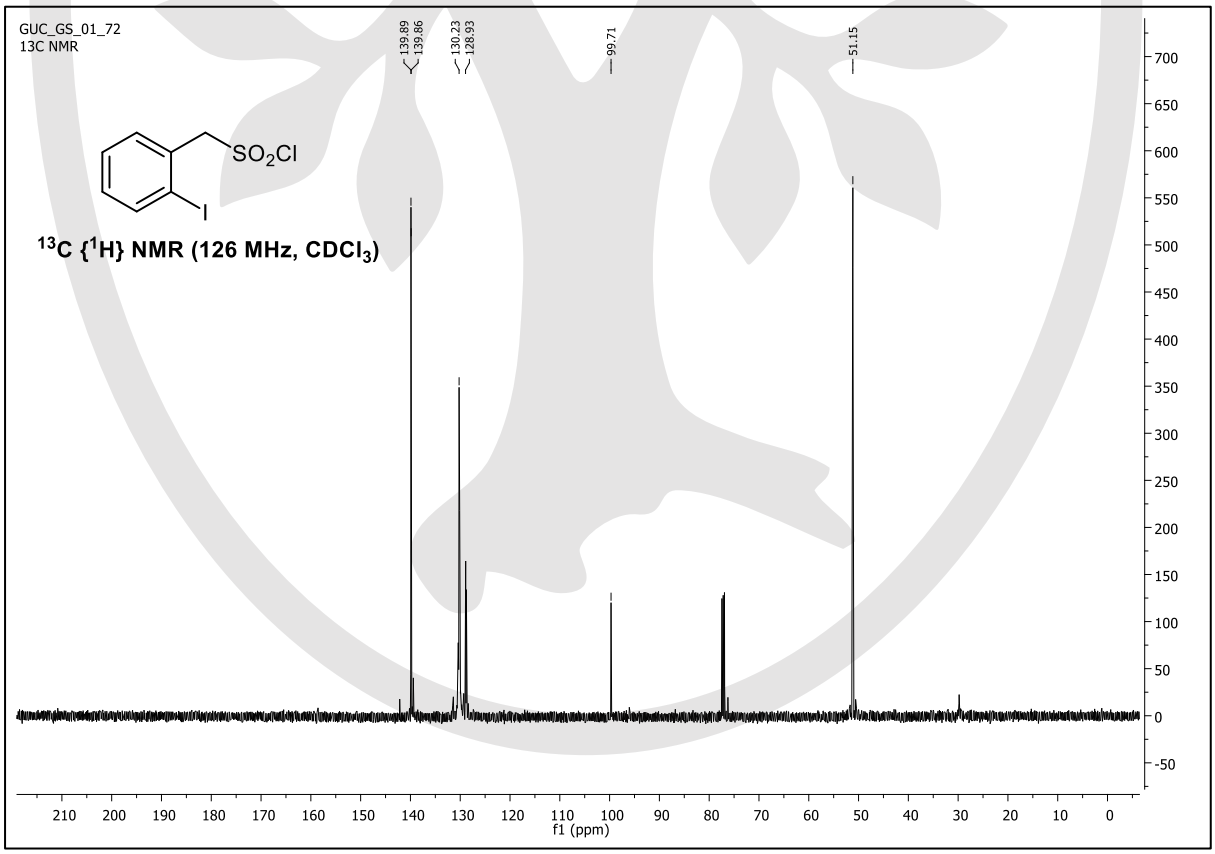
4. (4-Bromophenyl)methanesulfonyl chloride (3d)[2,4]



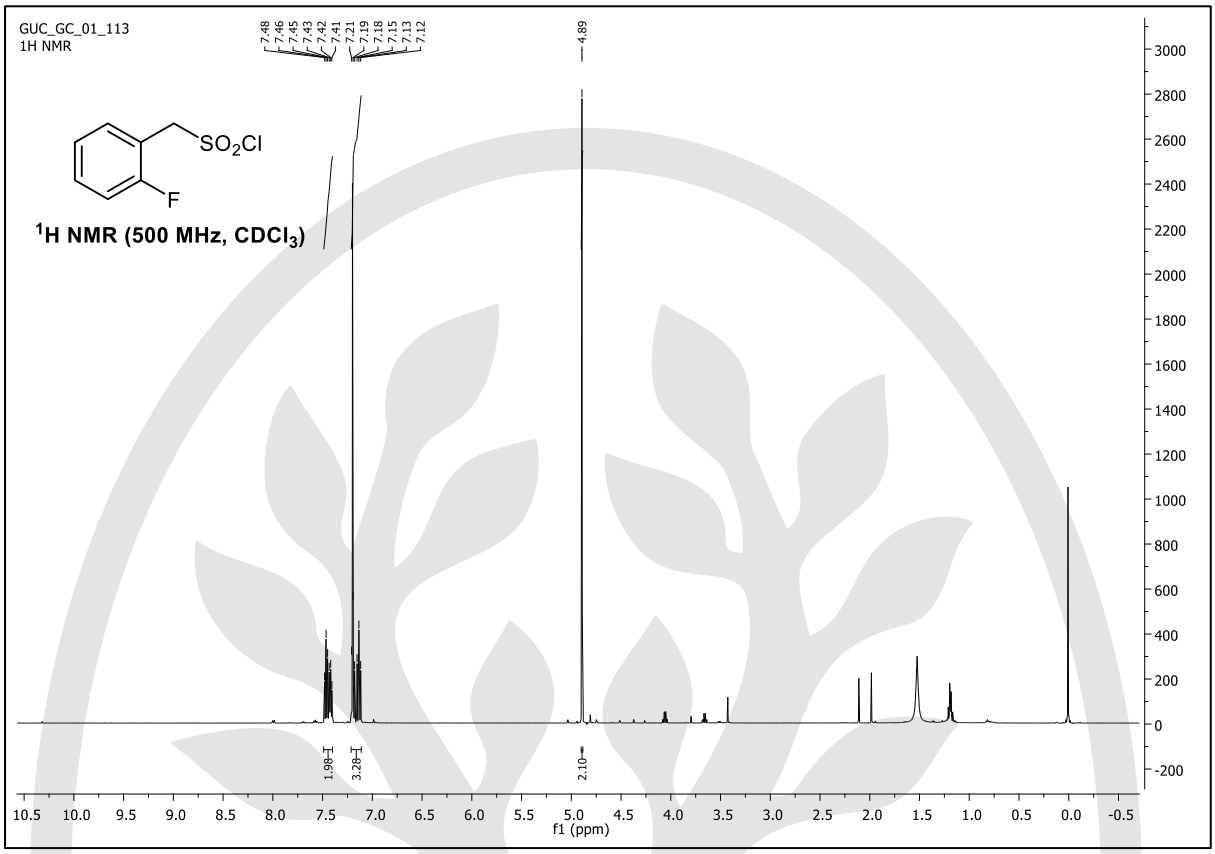


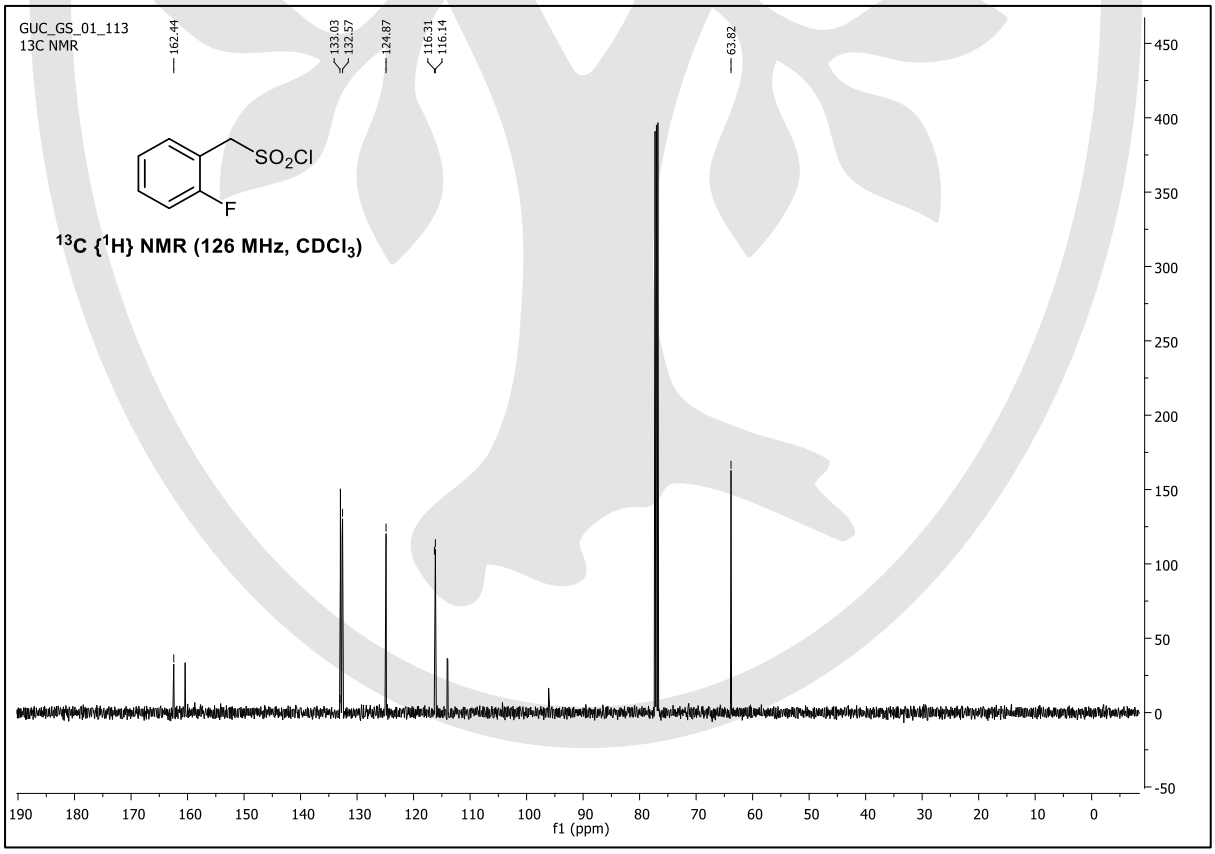
5. (2-Iodophenyl)methanesulfonyl chloride (3e)



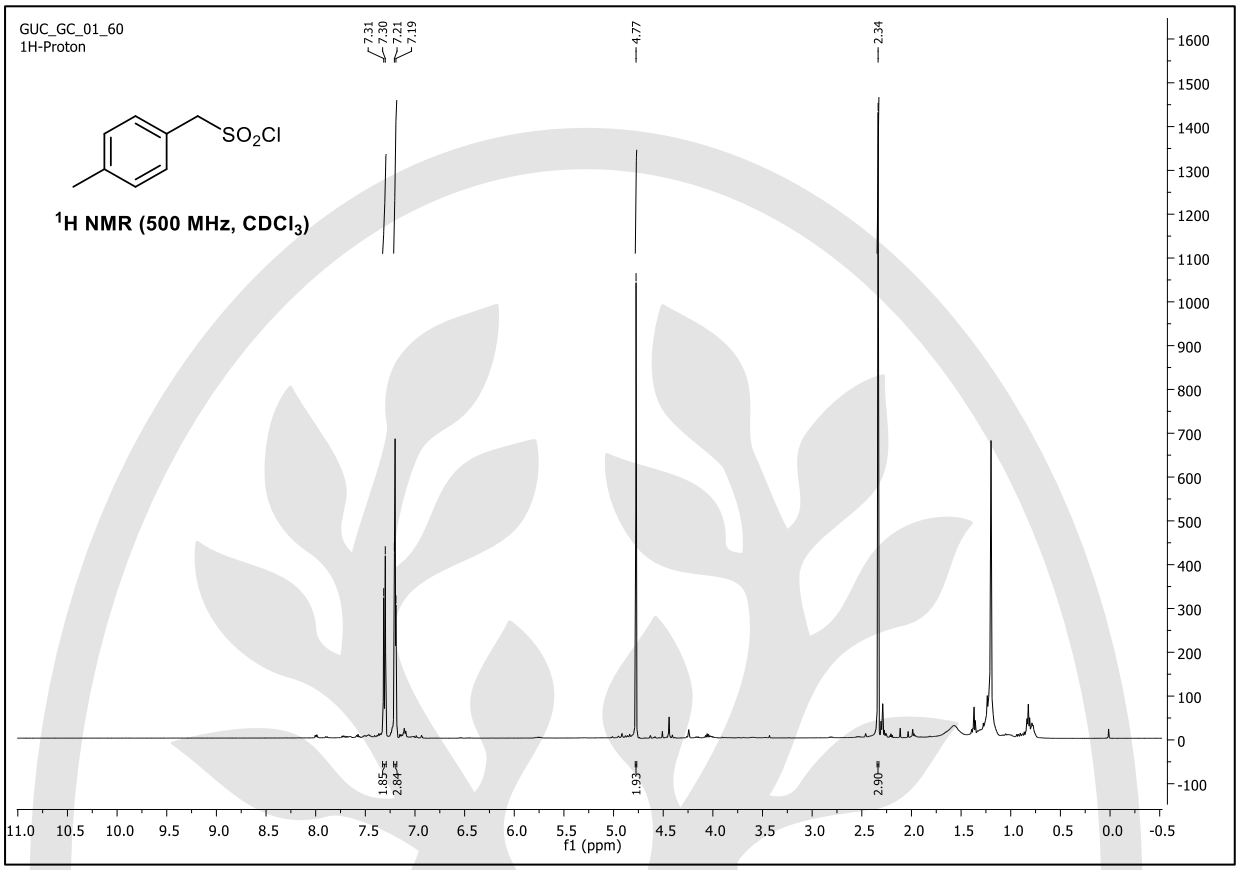


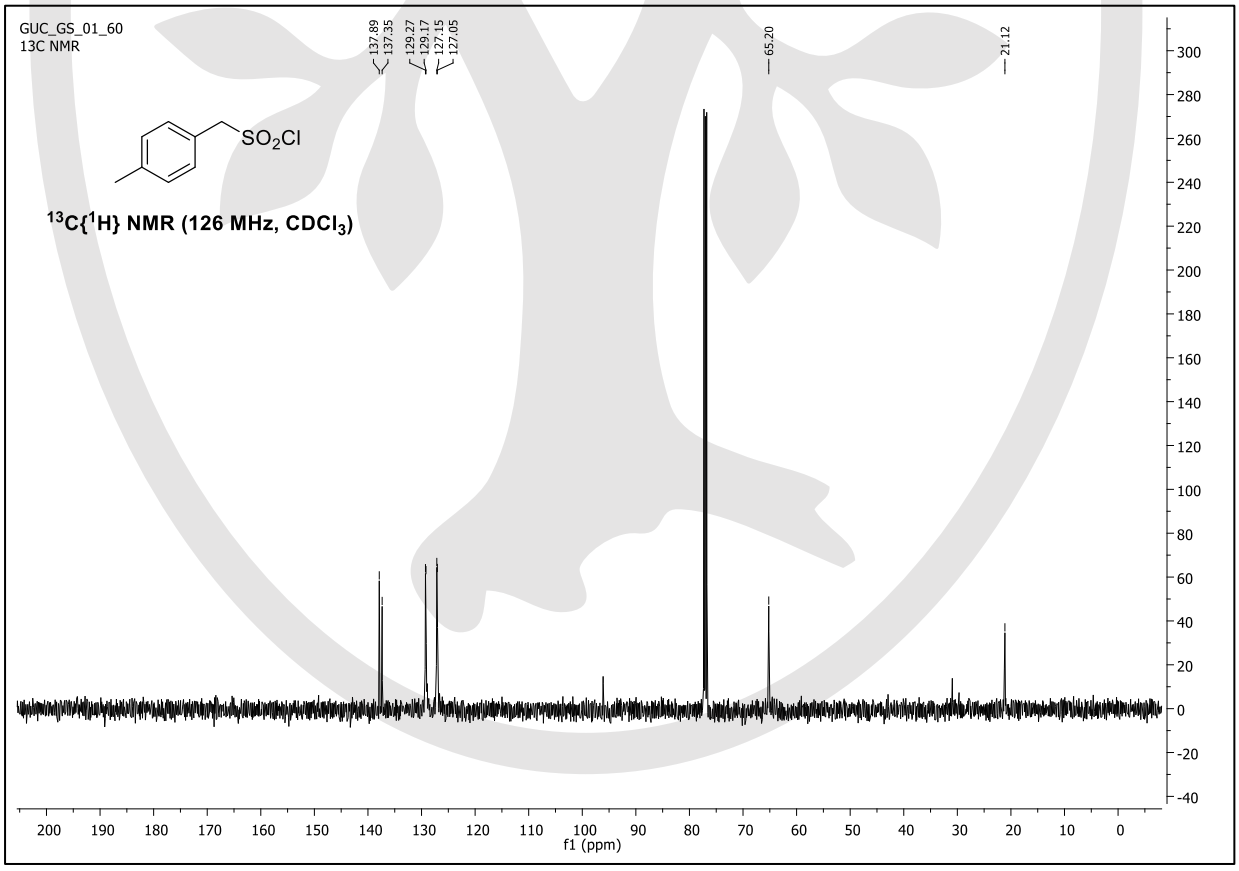
6. (2-Fluorophenyl)methanesulfonyl chloride (3f)



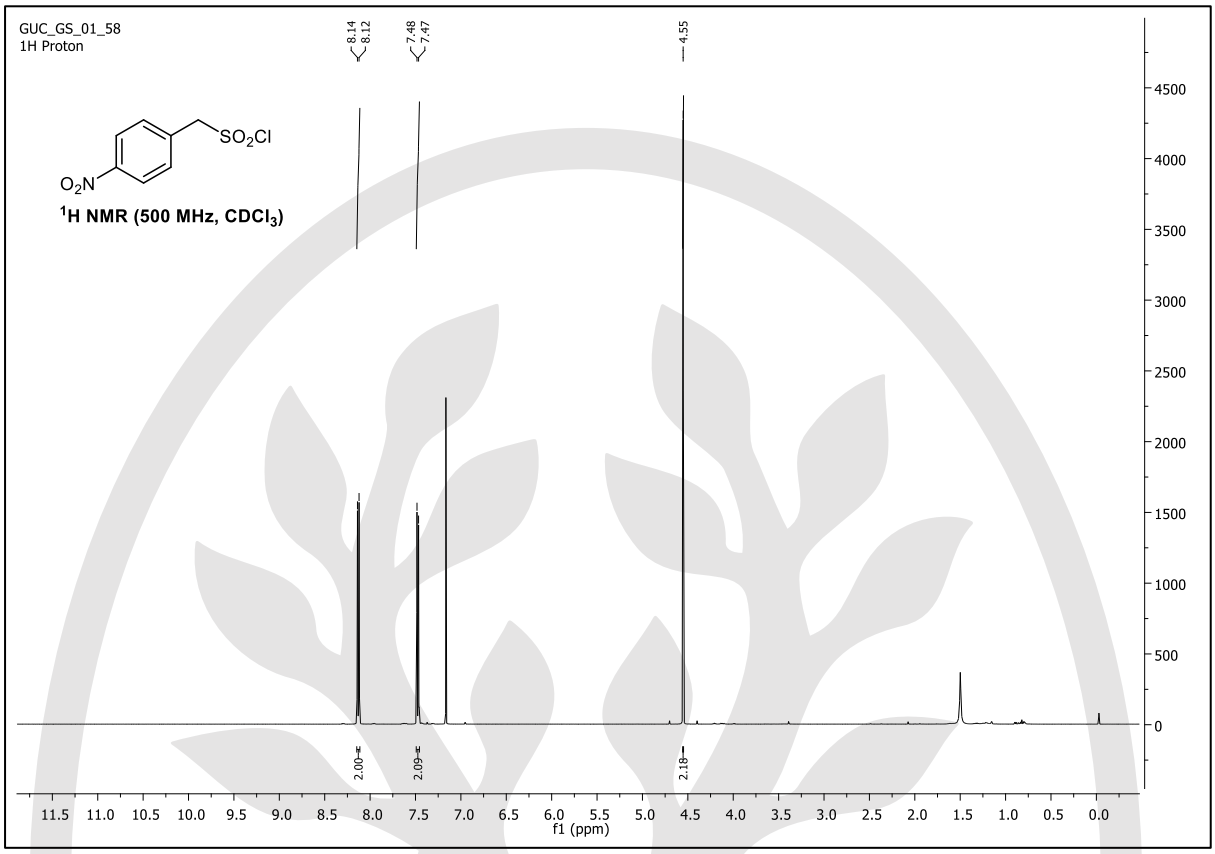


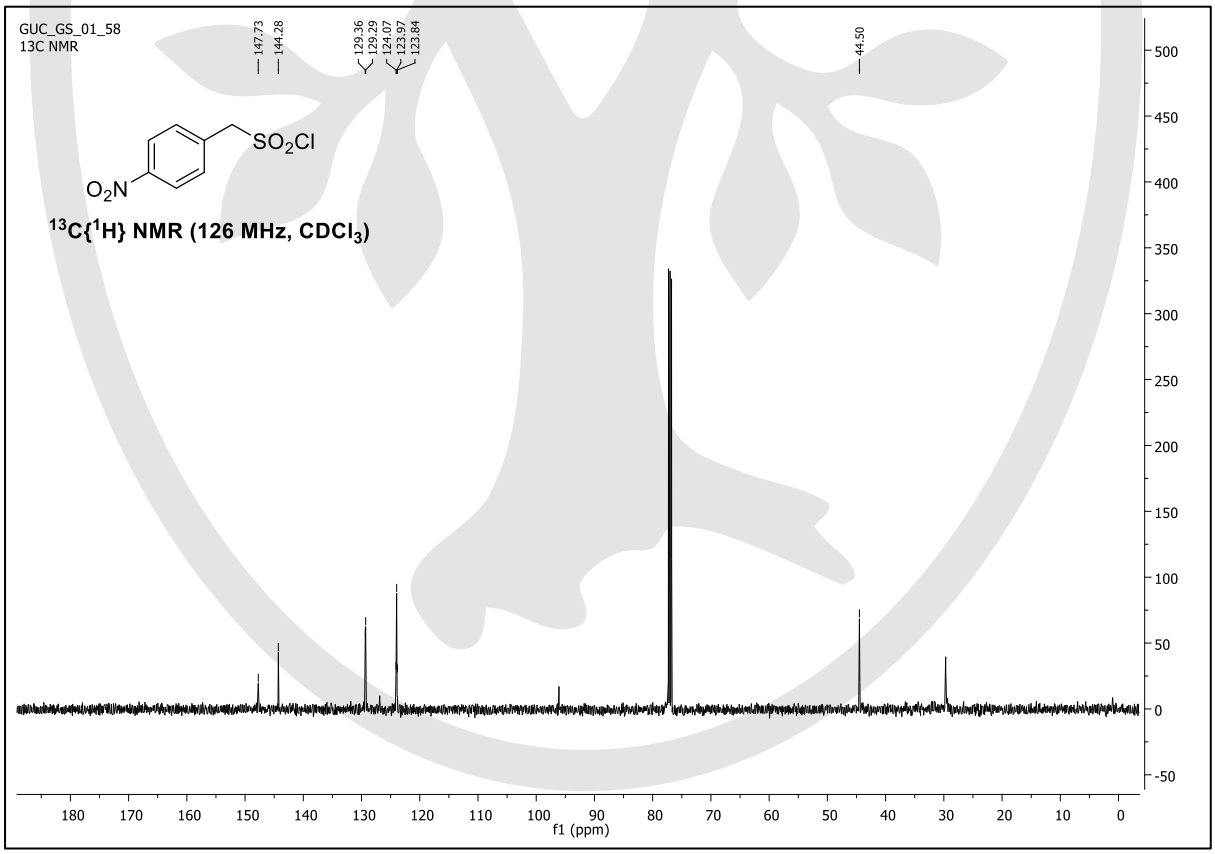
7. (4-Methylphenyl)methanesulfonyl chloride (3g)[1]



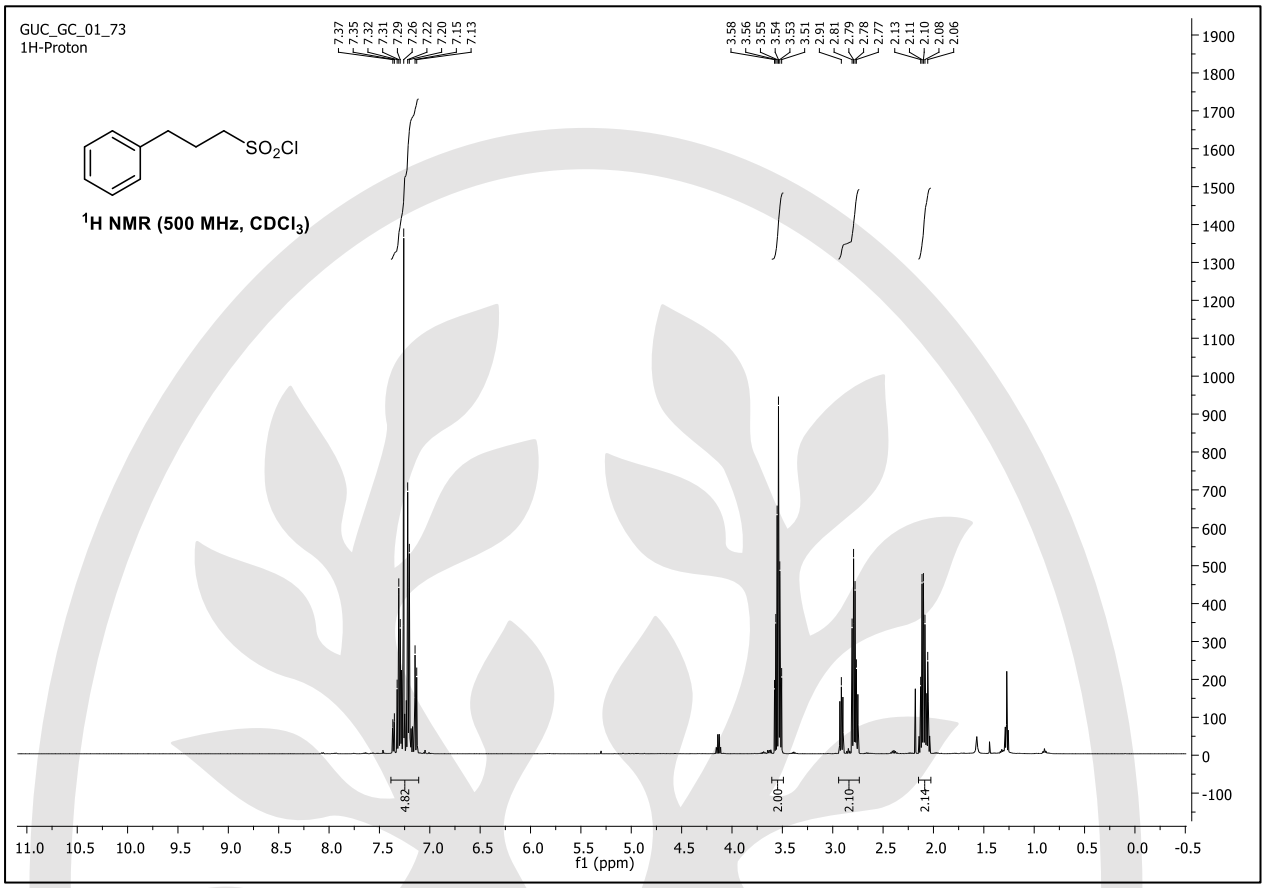


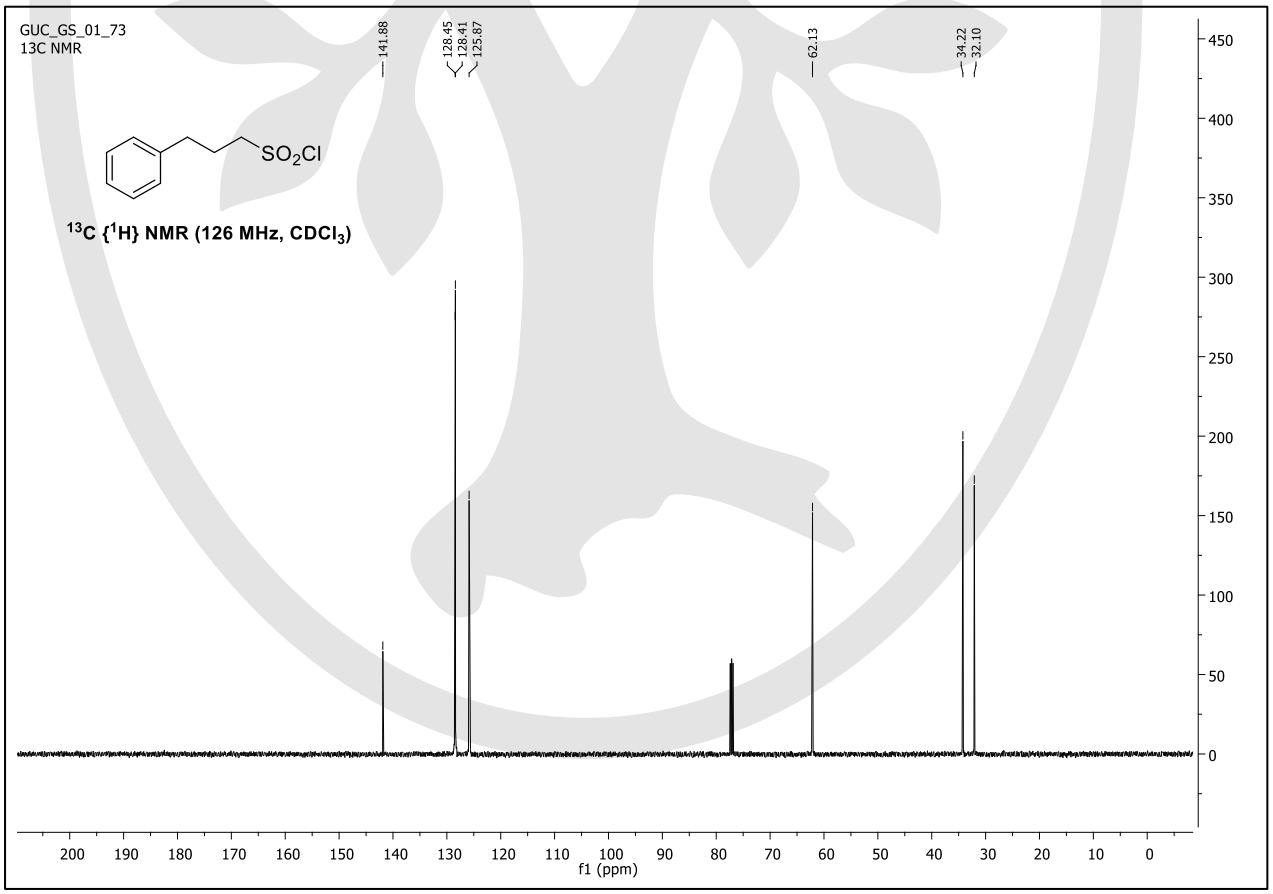
8. (4-Nitrophenyl)methanesulfonyl chloride (3h)[1]



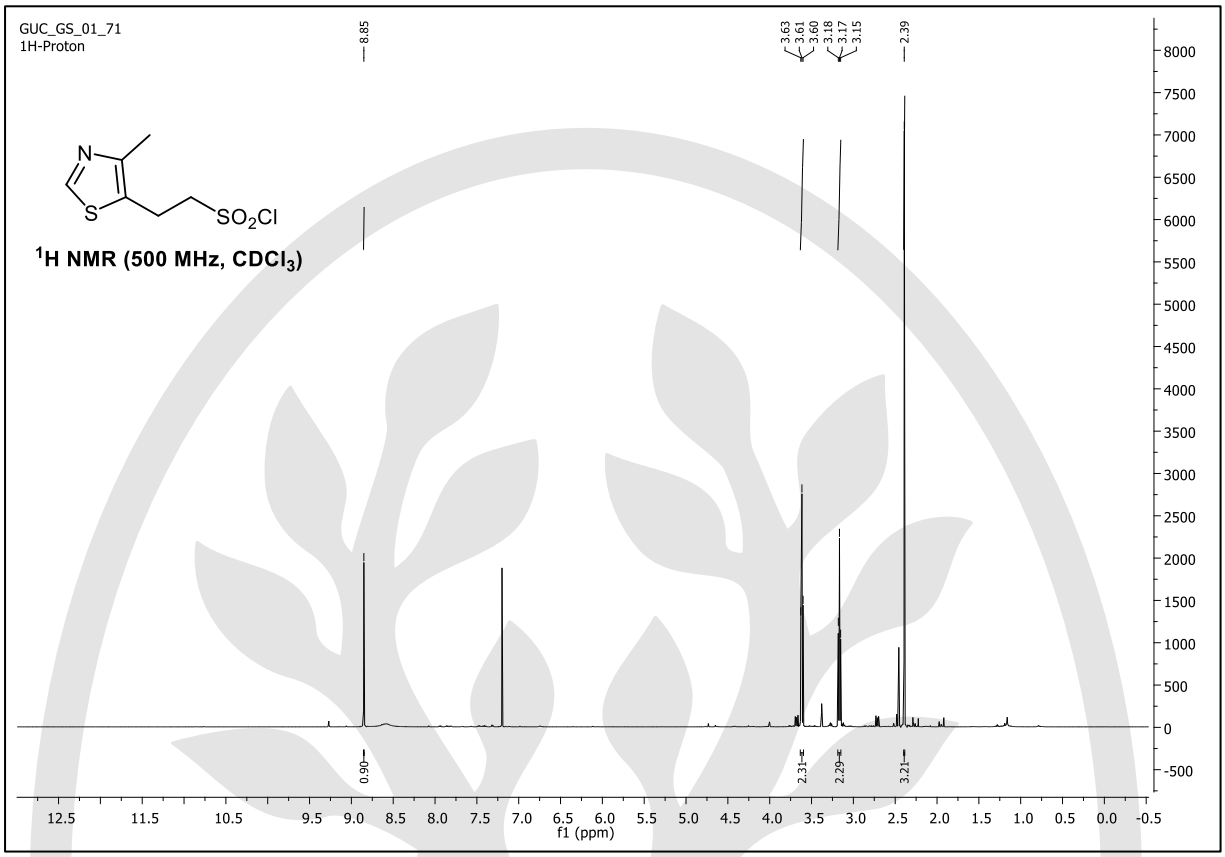


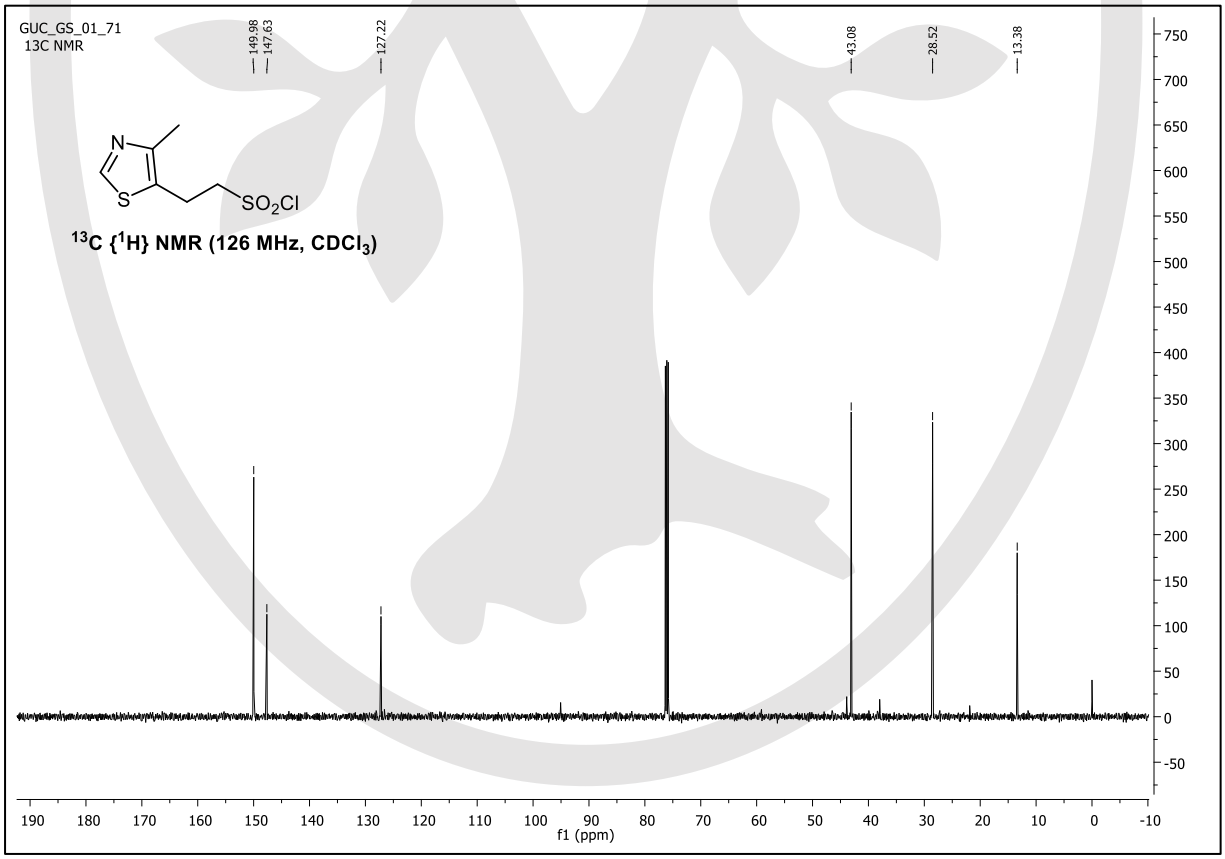
9. 3-Phenylpropane-1-sulfonyl chloride (3i)[3]



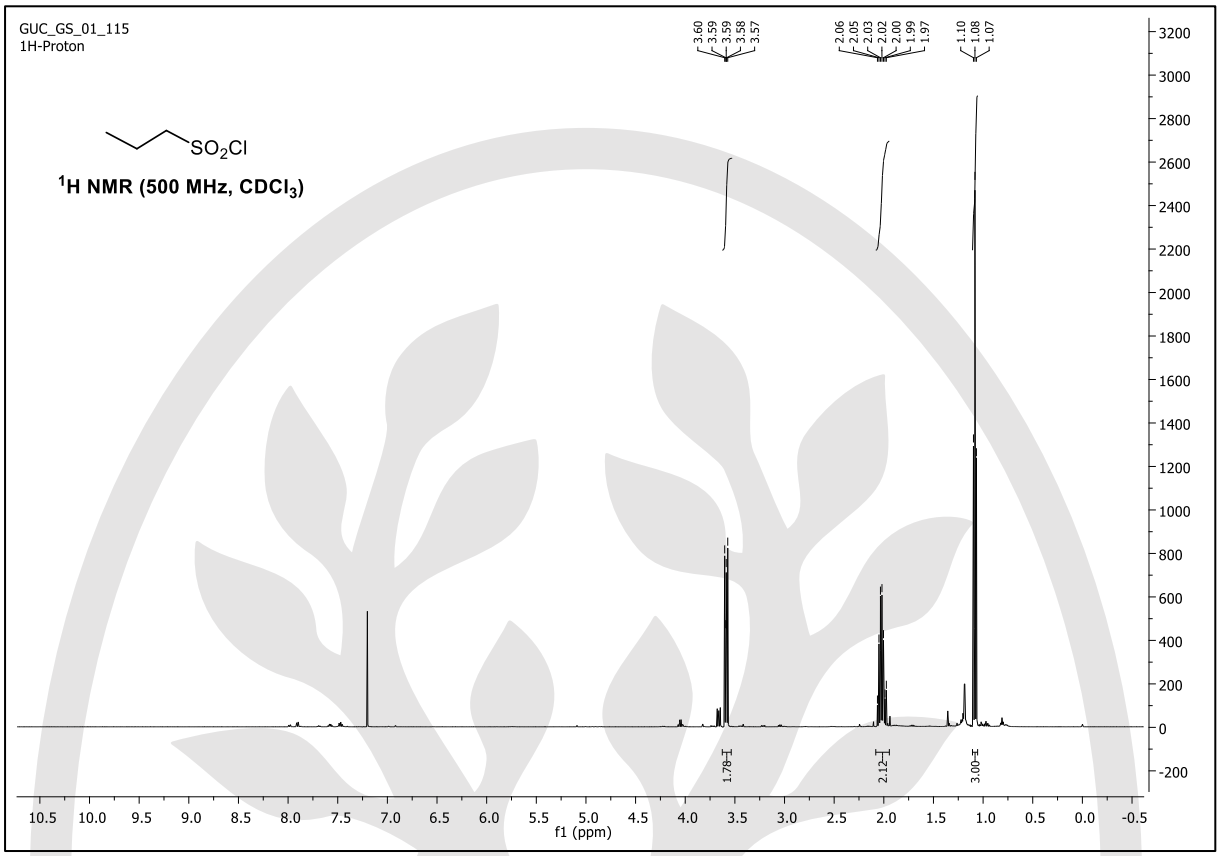


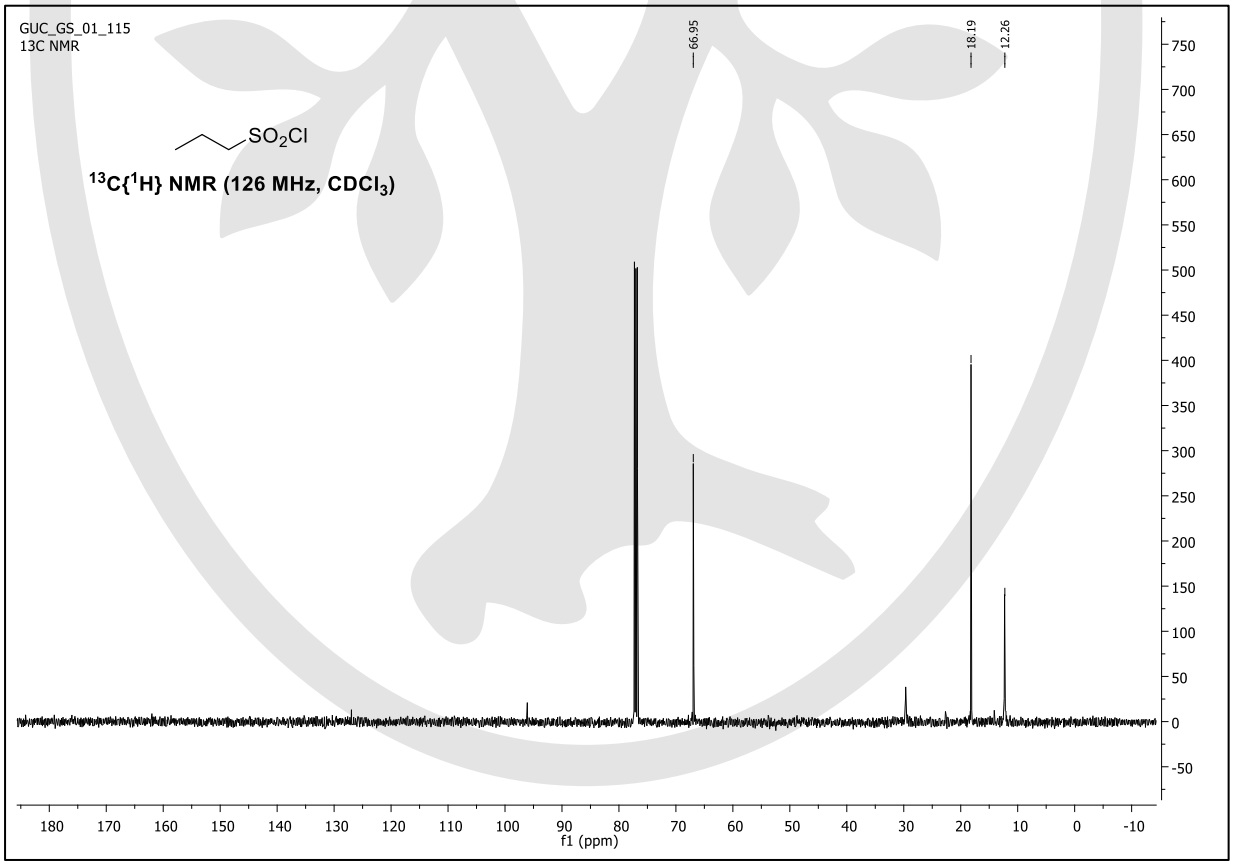
10. 2-(4-methylthiazol-5-yl)ethane-1-sulfonyl chloride (3j)



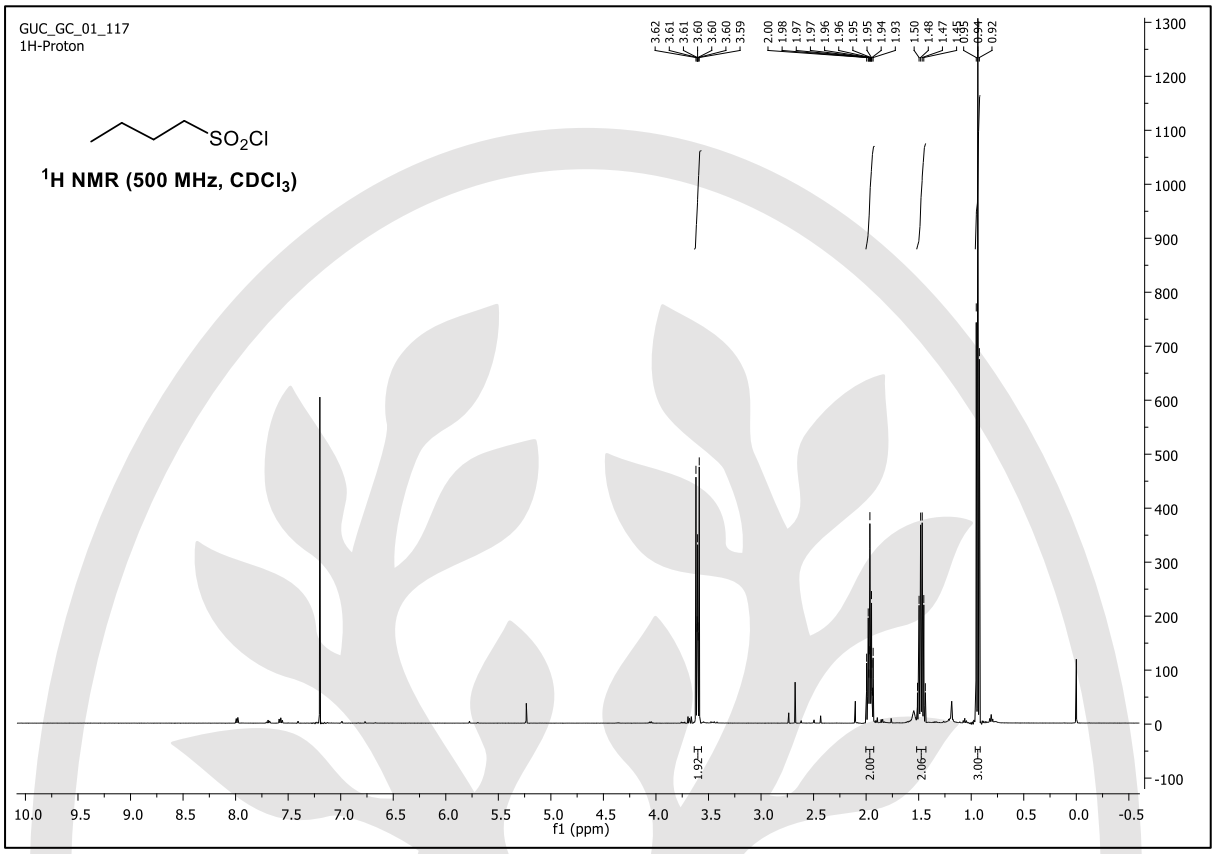


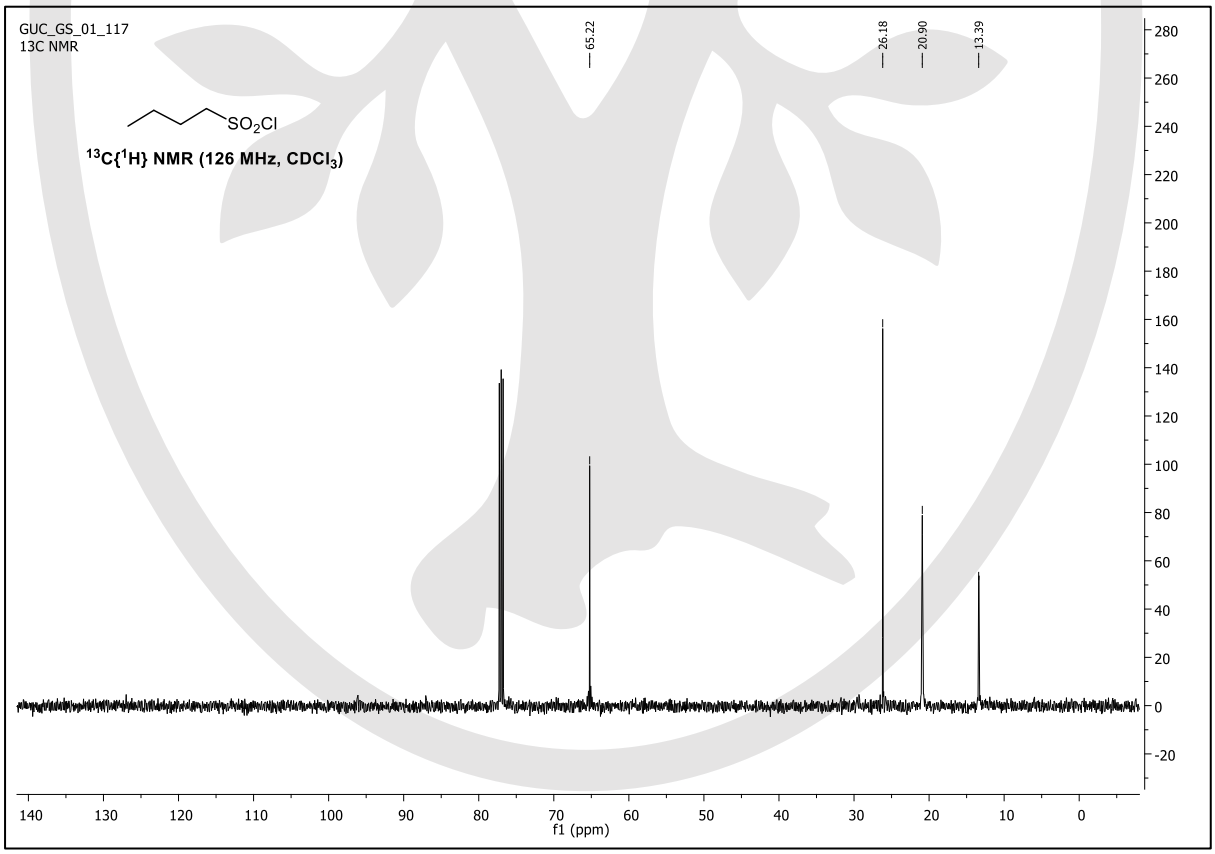
11. Propane-1-sulfonyl chloride (3k)



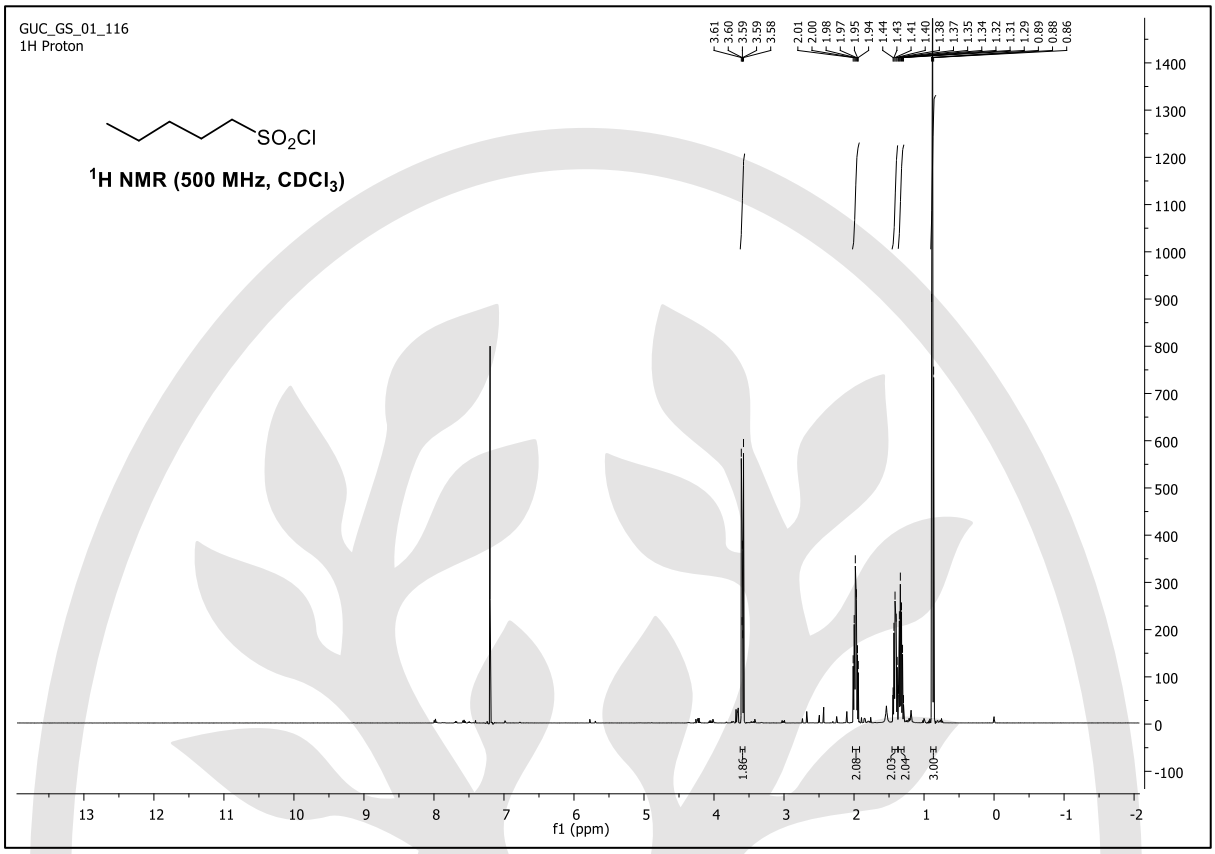


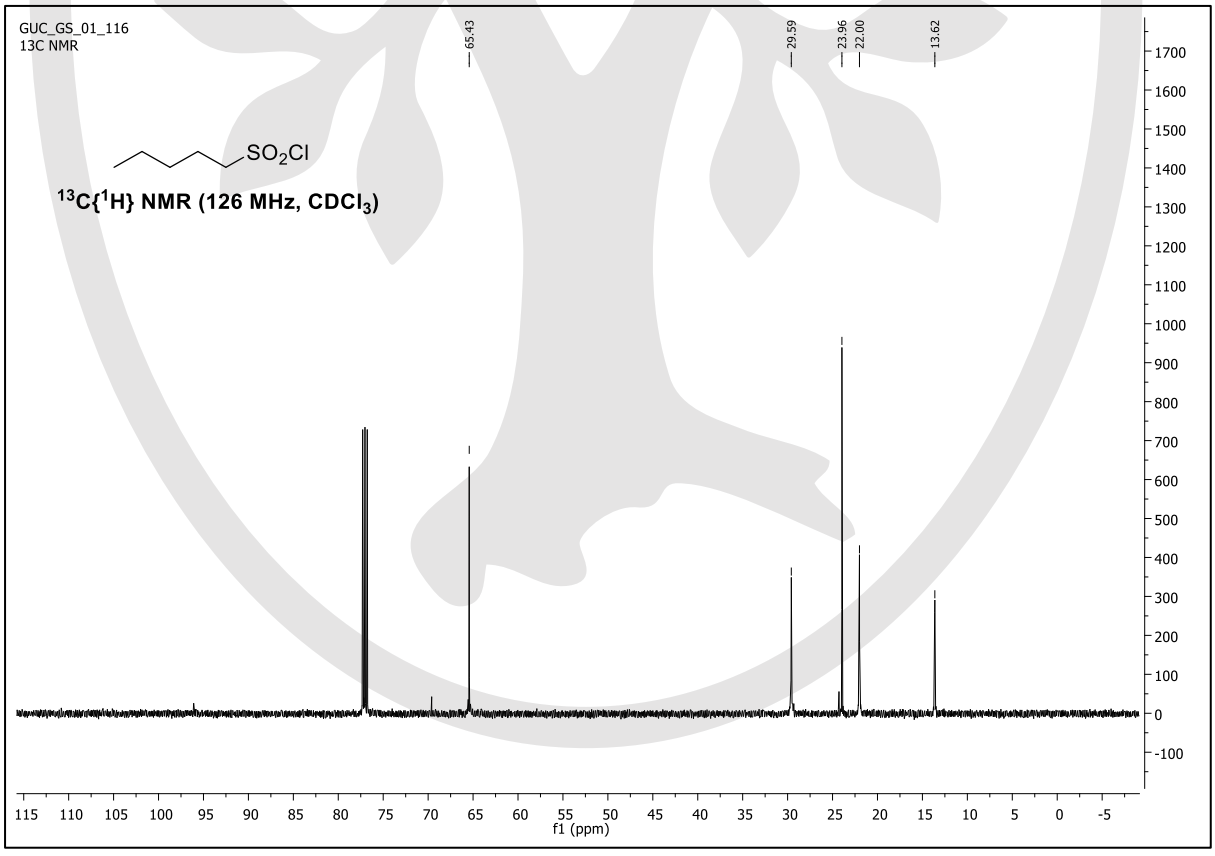
12. Butane-1-sulfonyl chloride (3l)[1]



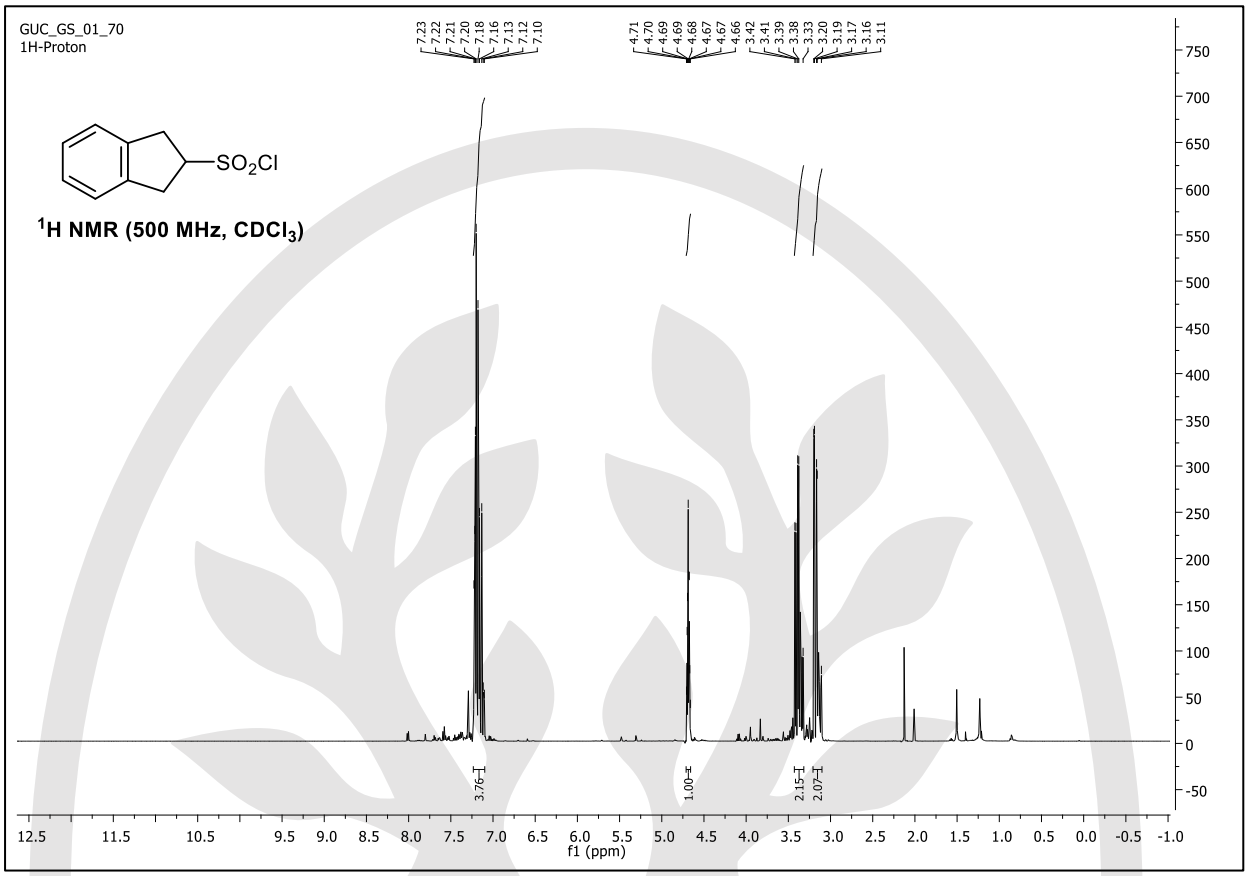


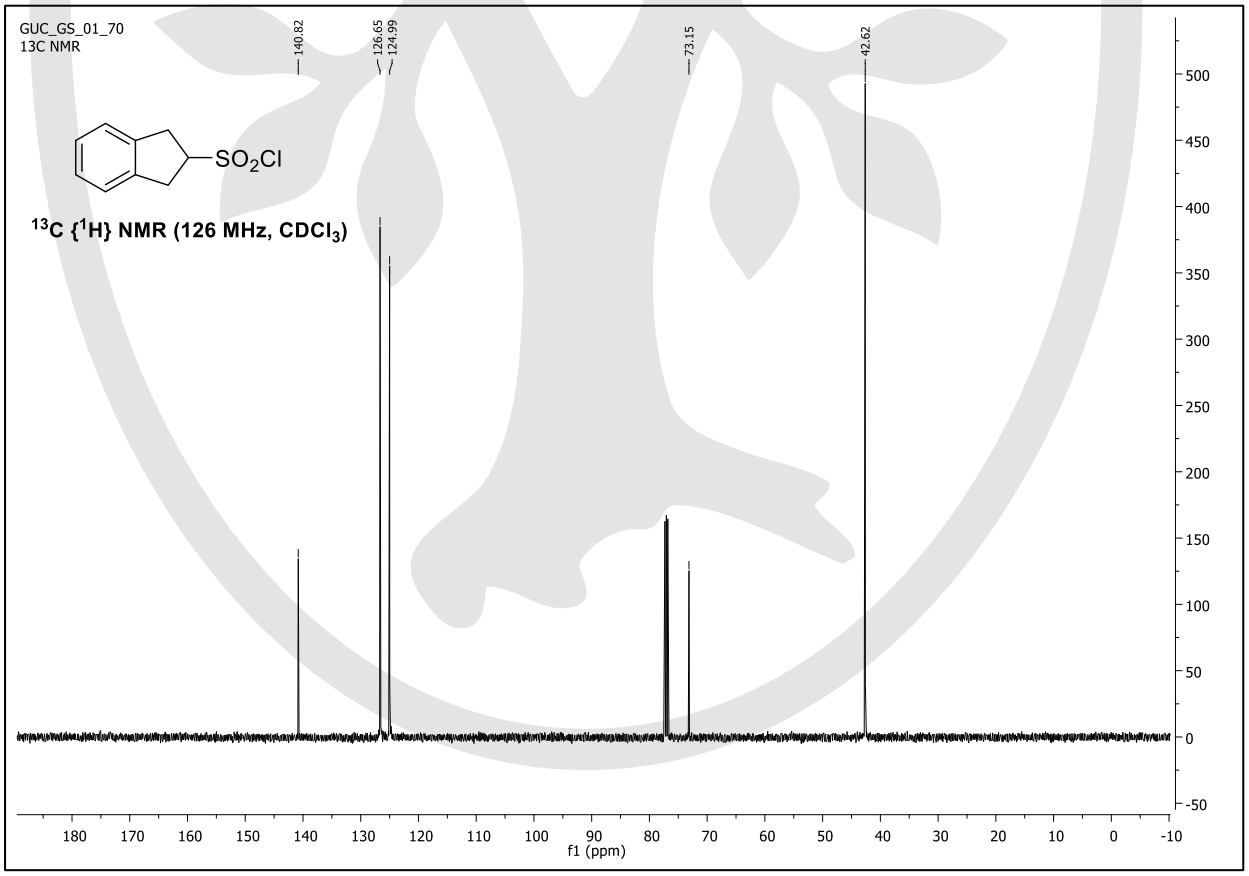
13. Pentane-1-sulfonyl chloride (3m)



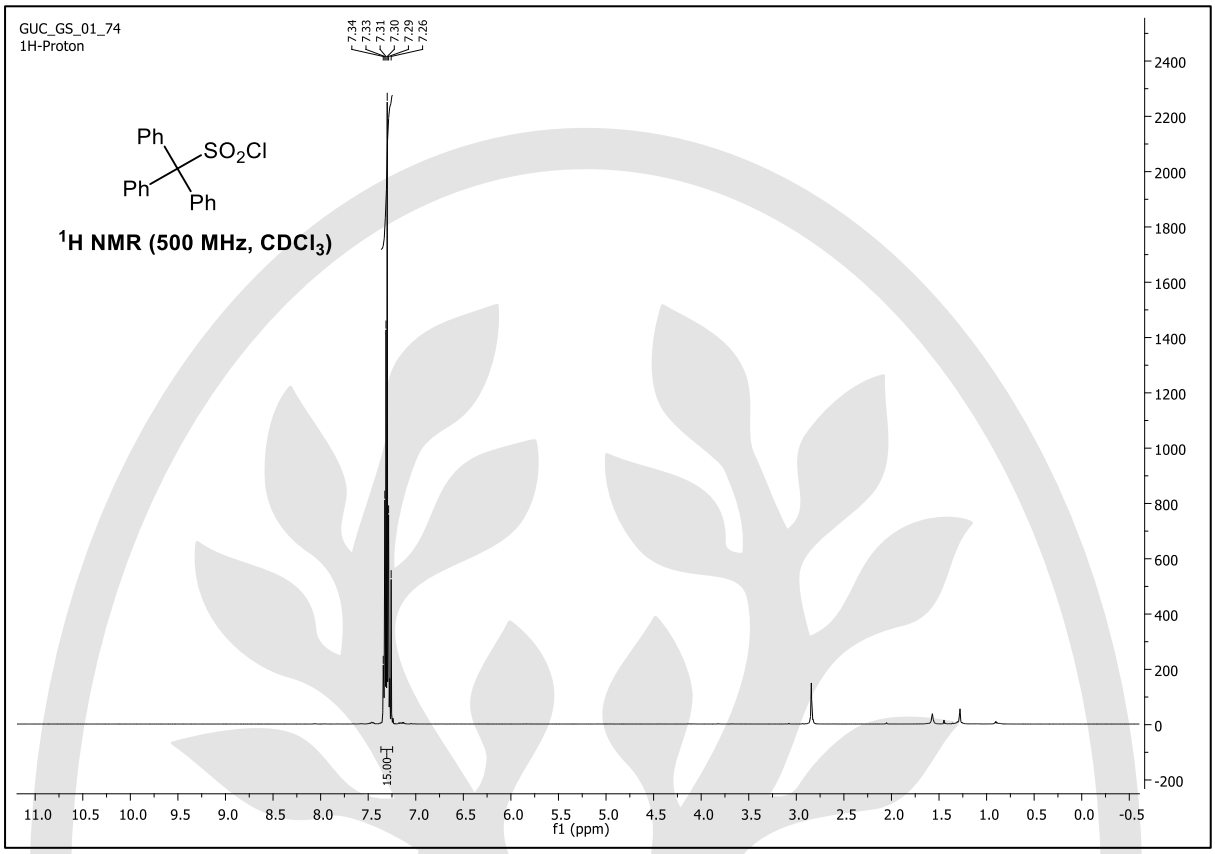


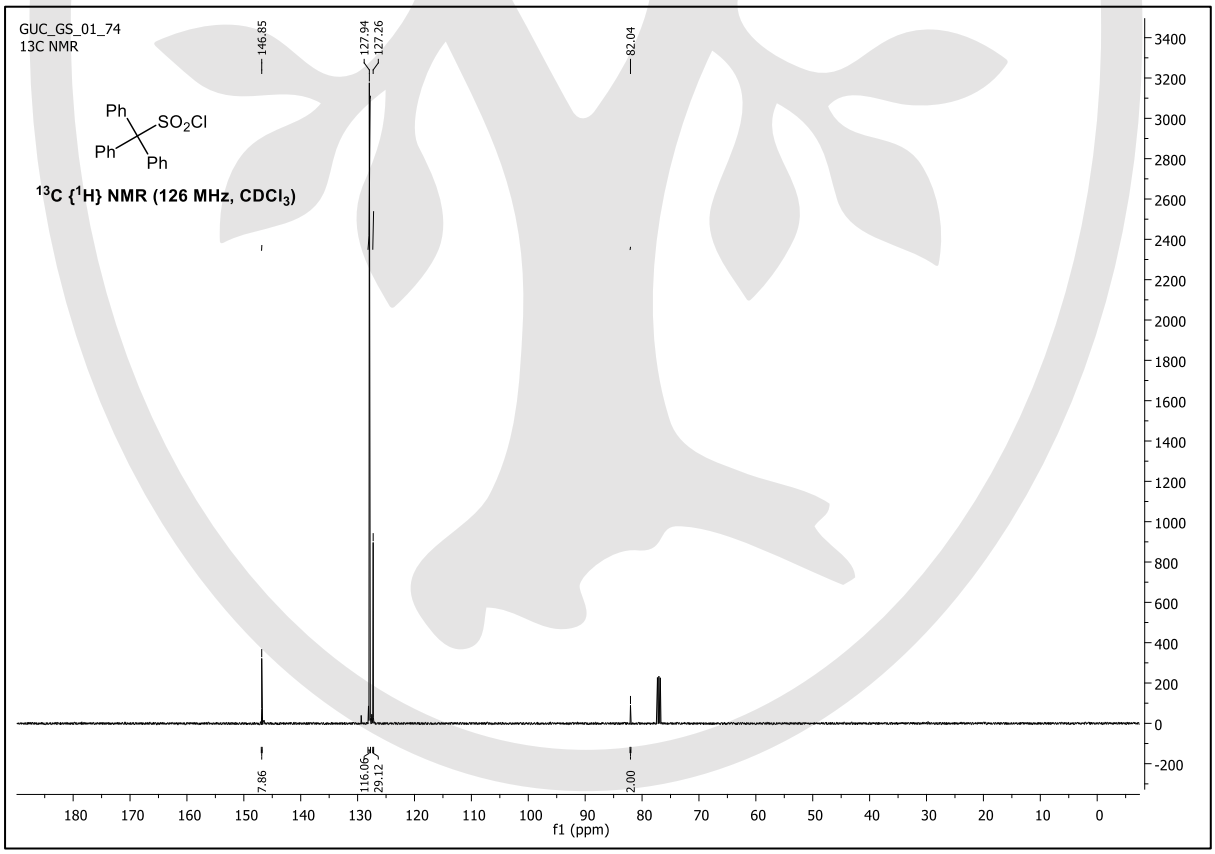
14. 2,3-dihydro-1*H*-indene-2-sulfonyl chloride (3n)



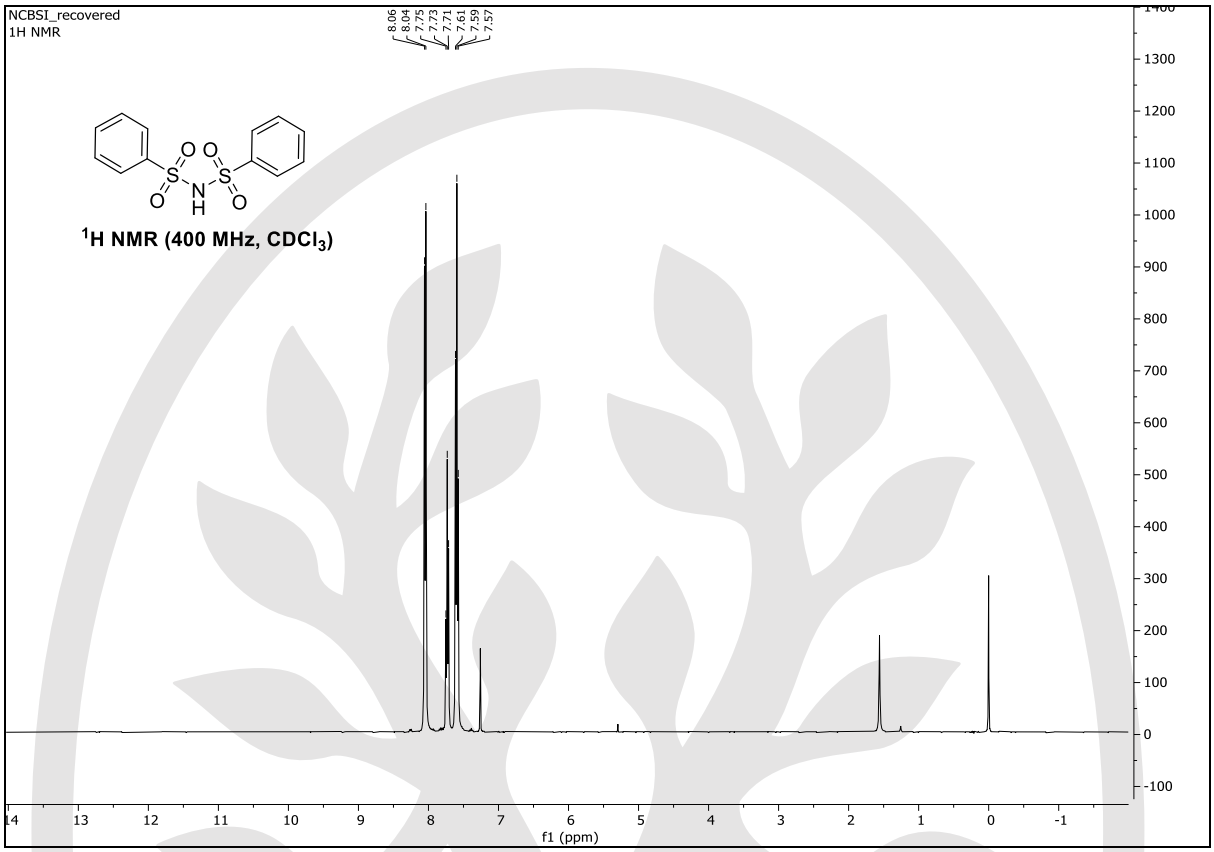


15. Triphenylmethanesulfonyl chloride (3o)





^{1}H NMR for recovered N-(phenylsulfonyl)benzene sulphonamide



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