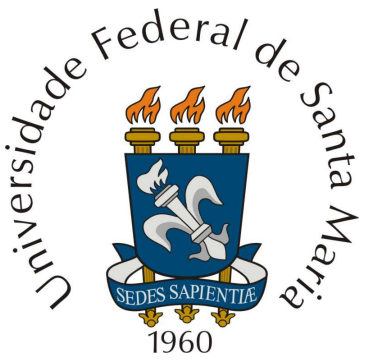

UFSM

PhD THESIS

IONIC LIQUID & ORGANOCHALCOGENOLATES: AN EFFICIENT REACTION MEDIA FOR THE SYNTHESIS OF ORGANOCHALCOGEN DERIVATIVES

By

SENTHIL NARAYANAPERUMAL

PPGQ

Santa Maria, RS, Brazil

2010

IONIC LIQUID & ORGANOCHALCOGENOLATES: AN EFFICIENT REACTION MEDIA FOR THE SYNTHESIS OF ORGANOCHALCOGEN DERIVATIVES

By

Senthil Narayanaperumal

SUPERVISORS

Prof. Dr. Oscar Endrigo Dorneles Rodrigues

Prof. Dr. Antonio Luiz Braga

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PPGQ-UFSM

In partial fulfillment of the requirements for the degree of

Doctor of Philosophy (PhD) in Chemistry

The Post Graduate Program in Chemistry

Federal University of Santa Maria

Santa Maria, RS, Brazil

2010

The Post Graduate Program in Chemistry
Federal University of Santa Maria
Santa Maria, RS, Brazil
15th December, 2010

The undersigned examining committee, approved the thesis entitled

"Ionic liquid and organochalcogenolates: An efficient reaction media for the synthesis of organochalcogen derivatives"

For the award of degree of Doctor of Philosophy (PhD) in Chemistry to

Senthil Narayanaperumal

EXAMINERS

Prof. Dr. Oscar Endrigo Dorneles Rodrigues - UFSM

Prof. Dr. Antonio Luiz Braga - UFSM

Prof. Dr. Luciano Dornelles – UFSM

Prof. Dr. Henri Stephan Schrekker – UFRGS

Prof. Helio Gauze Bonacorso - UFSM

DECLARATION

*I declare that this dissertation entitled "**Ionic liquid and Organochalcogenolates: An efficient reaction media for the synthesis of Organochalcogen derivatives"** is a original record of my doctoral thesis work at the Department of Organic Chemistry, **Federal University of Santa Maria- UFSM, Santa Maria, RS, Brazil** and the work has not been the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar like of this or any other University.*

Senthil Narayanaperumal

Dedicated

To

My Beloved Parents

Acknowledgement

This research work would not have been possible without the general support of the Academy of Sciences for Third World (TWAS) and Brazilian National Council for Scientific Development (CNPq) *i.e.* **TWAS-CNPq** for awarding me doctoral fellowship and I cordially acknowledge their financial support.

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Senthil Narayanaperumal

TITULO: Líquido iônico e organocalcogenolatos: um meio de reacional eficiente para a síntese de organocalcogenetos derivados.

Nós desenvolvemos uma metodologia para gerar espécies nucleofílicas de selênio em líquido iônico. Para isto, selecionamos sais de índio (I) como agentes redutores para promover a quebra da ligação Se-Se para preparar selenetos de diorganoíla assimétricos em curtos tempos de reação, condições brandas e excelentes rendimentos usando BMIM-BF_4 como solvente reciclável (Figura 1).

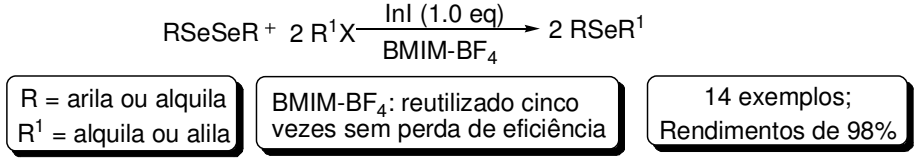

Figura 1: Síntese de selenetos de diorganoíla promovido por iodeto de índio (I) usando líquido iônico.

Em seguida, desenvolvemos um eficiente protocolo para a síntese de calcogenetos de diorganoíla e calcogenol ésteres usando Zn em pó comercialmente disponível e barato em líquido iônico como descrito na Figura 2. Interessantemente, as condições experimentais propostas para esta reação facilita o work-up da mistura de reação e isolamento dos produtos desejados em excelentes rendimentos.

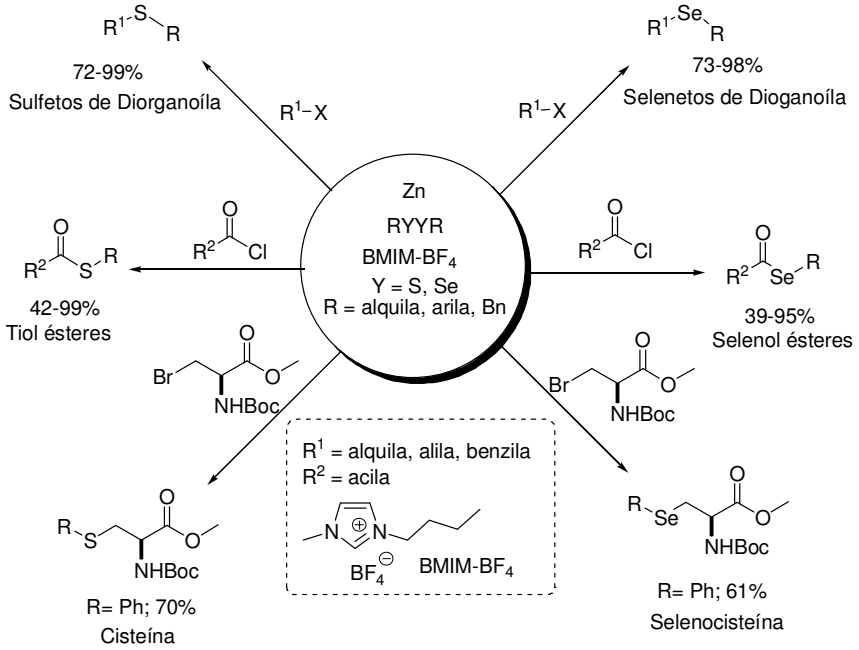

Figura 2: Síntese de derivados organocalcogenetos.

Empregando nossa metodologia, o potencial sintético e a importância biológica das β-calcogenoaminas e seus derivados, em particular, calcogenocisteína foi sintetizada com sucesso.

Title: Ionic liquid and Organochalcogenolates: An efficient reaction media for the synthesis of organochalcogen derivatives

This methodology provides to generate nucleophilic selenium species in ionic liquid. For this purpose, In(I) salts used as reducing agents to promote the Se–Se bond cleavage to prepare unsymmetrical diorganyl selenides in short reaction times, mild conditions and excellent yields using BMIM-BF_4 as a recyclable solvent (Figure 1).

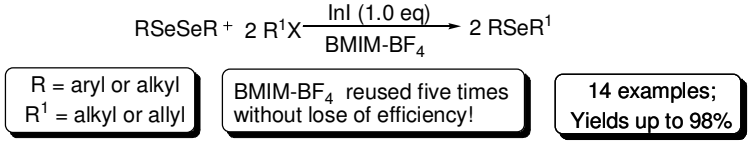

Figure 1: Synthesis of diorganyl selenides promoted by indium (I) iodide using ionic liquid

Next, an efficient protocol for the synthesis of diorganyl chalcogenides and chalcogen esters using commercially available less-expensive Zn dust in ionic liquid is developed as depicted in Figure 2. Interestingly, the experimental conditions proposed for this reaction facilitate the easy workup of the reaction mixtures and isolation of the desired product in excellent yield.

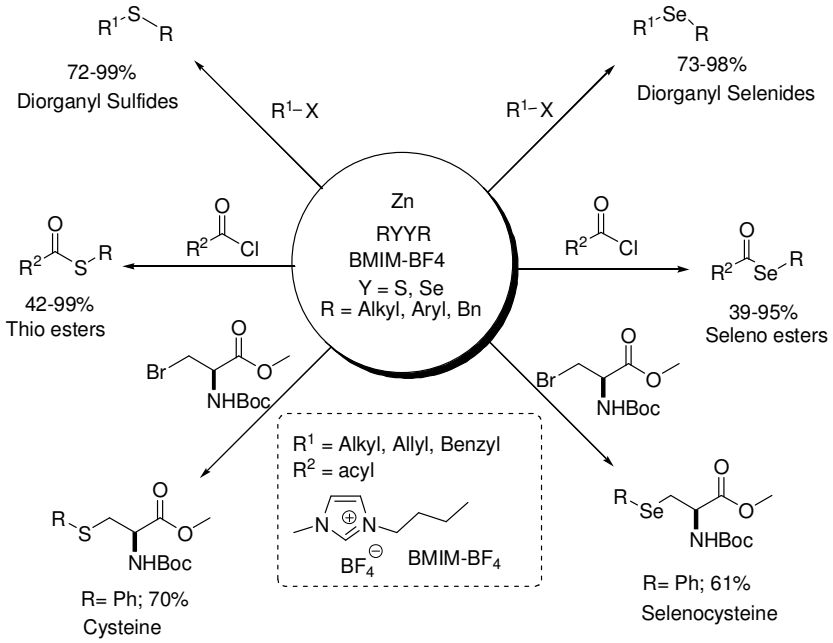

Figure 2: Synthesis of organochalcogen derivatives

To extend the scope of the developed methodology, the biologically importance of chiral β-chalcogen amines and their derivatives, in particular chalcogeno-cysteine was successfully synthesized.

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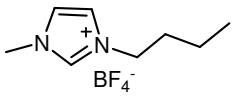
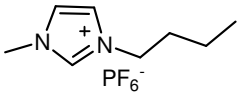
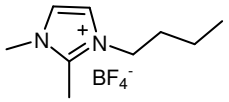
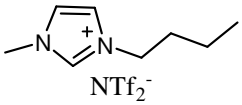
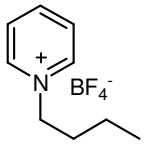
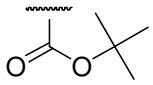
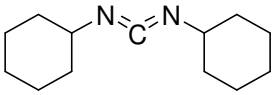
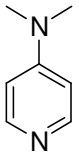
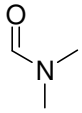
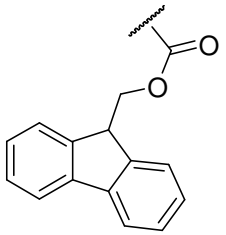
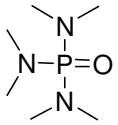
List of Symbols and Abbreviations

BMIM-BF_4	1-butyl-3-methylimidazolium tetrafluoroborate	
BMIM-PF_6	1-butyl-3-methylimidazolium hexafluorophosphate	
BMMIM-BF_4	1,2-dimethyl-3-butylimidazolium tetrafluoroborate	
BMIM-NTf_2	1-butyl-3-methylimidazolium bis(trifluoromethane)sulfonimidate	
Bpy-BF_4	1-butyl-pyridinium tetrafluoroborate	
Boc	tert-butyloxycarbonyl	
DCC	1,3-dicyclohexylcarbodiimide	
DMAP	4-dimethylamino pyridine	
DMF	dimethylformamide	
DMSO	dimethylsulfoxide	

Fmoc	9-fluorenylmethoxycarbonyl	
HMPA	hexamethylphosphoramide	

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Introduction and Objective

1. Introduction

1.1. Importance of Organochalcogenides

Organochalcogen compounds have become an attractive building block since selenium and sulfur-containing groups an important auxiliary function in many synthetic sequences.[1] They are of key interest to synthetic chemists due to the biological importance of organochalcogen compounds. In addition to the synthetic importance, simple organosulfur and organoselenium compounds exhibit many useful biological and medicinal properties. They are generally targeted as compounds with antioxidant, antitumor, and antimicrobial activity and many of these compounds are competitive inhibitors for target proteins.[2] Chiral diorganyl selenides are also employed as efficient ligands in asymmetric reactions affording the corresponding products with high selectivity.[3]

The synthesis of peptides containing selenocysteine is rapidly gaining interest with the discovery of an increasing number of proteins containing this amino acid. In addition, selenocysteine derivatives can serve as convenient precursors to dehydroamino acids, which are useful electrophilic handles for the chemoselective preparation of peptide conjugates.[4] More, synthetic methods for the preparation of selenium based peptides,[5] seleno-glycosides[6] and other important natural compound derivatives[7] is nowadays an area of intensive research. Specifically, synthetic routes to sulfur and selenium-substituted unnatural amino acids and its derivatives, which are the building blocks for the synthesis of modified

[1] (a) T. G. Back, Organoselenium Chemistry: A Practical Approach Oxford University Press, USA, **1999**. (b) F. A. Devillanova, Handbook of Chalcogen Chemistry: New Perspectives in S, Se and Te, Royal Society of Chemistry, **2006.** (c) E. Schaumann, *Top. Curr. Chem.* **2007***, 274*, 1. (d) E. M. McGarrigle, E. L. Myers, O. Illa, M. A. Shaw, S. L. Riches, V. K. Aggarwal, *Chem. Rev.* **2007**, *107*, 5841. (e) G. Perin, E. J. Lenardão, R. G. Jacob, R. B. Panatieri. *Chem. Rev.* **2009**, *109*, 3, 1277. (f) D. M. Freudendahl, S. Santoro, S. A. Shahzad, C. Santi, T. Wirth, *Angew. Chem. Int. Ed.* **2009**, *48*, 8409. (g) J. Voss, *J. Sulfur. Chem.* **2009**, 30, 167. (h) T. Toru, C. Bolm, *Angew. Chem. Int. Ed.* **2009**, 48, 2078.

[2] (a) G.Mugesh, H. Singh, *Chem. Soc. Rev.* **2000**, *29*, 347. (b) G. Mugesh, W.W. Du Mont, H. Sies, *Chem. Rev.* **2001**, *101*, 2125. (c) C.W. Nogueira, G. Zeni, J. B. T. Rocha, *Chem. Rev.* **2004**, *104*, 6255. (d) B. K. Sarma, G. Mugesh, *Org. Biomol. Chem.* **2008**, *6*, 965. (e) D. Das, G. Roy, and G. Mugesh, *J. Med. Chem.* **2008**, *51,*7313. (f) K. P. Bhabak, G. Mugesh *Chem. Eur. J.* **2009**, *15*, 9846.

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[4] (a) P. P. Phadnis, G. Mugesh, *Org. Biomol. Chem*. **2005**, *3*, 2476. (b) A. Schneider, O. E. D. Rodrigues, M. W. Paixão, H. R. Appelt, A. L. Braga, L. A. Wessjohann, *Tetrahedron Lett*. **2006**, *47,*1019.

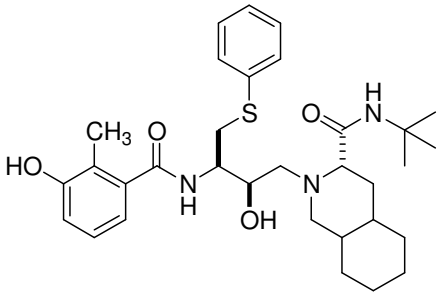
[5] (a) A. L. Braga, D. S. Lüdtke, M. W. Paixão, E. E. Alberto, H. A. Stefani, L. Juliano, *Eur. J. Org. Chem*. **2005**, *20*, 4260. (b) R. S. Schwab, F. Z. Galetto, J. B. Azeredo, A. L. Braga, D. S. Lüdtke, M. W. Paixão, *Tetrahedron Lett*. **2008**, *49*, 5094.

[6] (a) C. Mukherjee, P. Tiwari, A. K. Misra, *Tetrahedron Lett.* **2006**, *47*, 441. (b) P. Tiwari, A. K. Misra, *Tetrahedron Lett*. **2006**, *47*, 2345. (c) A. L. Braga, W. A. Severo Filho, R. S. Schwab, O. E. D. Rodrigues, L. Dornelles, H. C. Braga, D. S. Lüdtke, *Tetrahedron Lett.* **2009**, *50*, 3005.

[7] (a) R. Caputo, S. Capone, M. D. Greca, L. Longobardo, G. Pinto, *Tetrahedron Lett*. **2007**, *48*, 1425. (b) M. Abdo, S. Knapp, *J. Am. Chem. Soc.* **2008**, *130*, 9234. (c) O. E. D Rodrigues, D. de Souza, L. C Soares, L. Dornelles, L. A Burrow, H. R. Appelt, C. F. Alves, A. L. Braga, *Tetrahedron Lett.* **2010**, *51*, 2237.

thio- and seleno-proteins,[8] have attracted attention due to their interesting structural and biological properties. The seleno-proteins play an important role in metabolic processes, glutathione peroxidase (GPx) for *e.g.,* acts as a peroxide scavenger.[2b]

Application of organosulfur chemistry has increased due to the synthetic versatility of this class of compounds.[9] Significant attention has also been focused on sulfur-containing groups as model compounds of both active sites of natural enzymes and catalytic metal surfaces.[10] Also, the carbon–sulfur bond plays an important role in many molecules of biological and pharmaceutical interest for *e.g.,* nelfinavir (Figure 3), a potent inhibitor of HIV protease, shows the importance of organosulfur moiety.[11]



Nelfinavir

Figure 3. HIV protease inhibitor Nelfinavir.

1.2. Importance of Organochalcogen esters

Chalcogenoesters are important intermediates in several organic transformations. For instance, selenoester compounds have been used as precursors of acyl radicals and anions[12] and have attracted attention for the synthesis of new molecular materials, especially superconducting materials and liquid

[8] (a) R. J. Moroder, *J. Pept. Sci.* **2005**,*11*, 187. (b) S. Pegoraro, S. Fiori, J. Cramer, S. Rudolph-Böhner, L. Moroder, *Protein Sci.* **1999**, *8*, 1605. (c) S. Fiori, S. Pegoraro, S. Rudolph-Böhner, J. Cramer, L. Moroder, *Biopolymers* **2000**, *53*, 550.

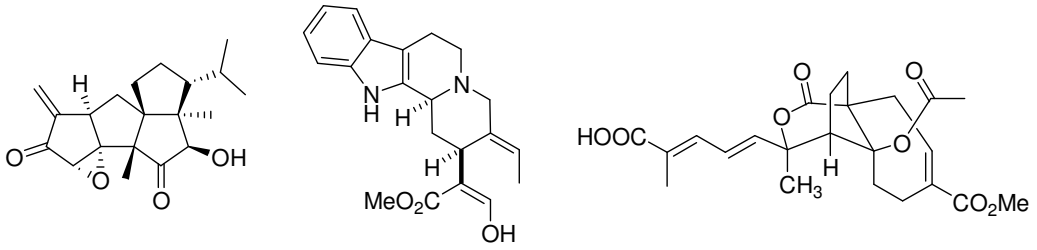
[9] (a) For general reviews on sulfides, see: D. N. Jones, In *Comprehensive Organic Chemistry*, Vol. 3; D.H.R. Barton, W.D. Ollis, Eds.; Pergamon Press: Oxford, **1979**, pp 33–103; (b) M. E. Peach, Thiols as Nucleophiles. In *The Chemistry of the Thiol Groups*, S. Patai, Ed.; John Wiley & Sons: London, **1979;** pp 721-756; (c) *Organic Sulfur Chemistry: Structure and Mechanism*; S. Oae, Ed.; CRC Press: Boca Raton, FL, **1991**; (d) R. J. Cremlyn, *An Introduction to Organo-sulfur Chemistry*; Wiley & Sons: New York, **1996**.

[10] R. J. Angelici, *Acc. Chem. Res*. **1988**, *21*, 387.

[11] P. S. Herradura, K. A. Pendola, R. K. Guy, *Org. Lett.* **2000**, *2*, 2019.

[12] (a) A. P. Kozikowski, A. Ames *J. Org. Chem.* **1978**, *43*, 2735. (b) D. L. Boger, R. J. Mathvink, *J. Org. Chem.* **1988**, *53*, 3377. (c) D. L. Boger, R. J. Mathvink, *J. Org. Chem.* **1989**, *54*, 1777. (d) D. L. Boger, R. J. Mathvink, *J. Org. Chem.* **1992**, *57*, 1429. (e) M. A. Lucas, C. H. Schiesser, *J. Org. Chem.* **1996**, *61*, 5754. (f) G. E. Keck, M. C. Grier, *Synlett.* **1999**, *10*, 1657. (g) G. Pattenden, D. A. Stoker, J. M. Winne, *Tetrahedron.* **2009**, *65*, 5767.

crystals.[13] Applications of selenoesters have been extended to the synthesis of proteins by chemical ligation of chalcogenol esters,[14] to the synthesis of substrates which undergo facile and efficient radical decarbonylation, and the same strategy was utilized for the synthesis of natural products *e.g.,* Crinipellin A, (+)-Geissoschizine, and (-)-Pseudolaric Acid B (Figure 4).[15]



Crinipellin A **(+)-Geissoschizine** **(-)-Pseudolaric Acid B**

Figure 4. Structure of natural products.

Additionally, thioesters are considerably important class of compounds in the medicinal area because of their broad range of biological activities *e.g., in vivo* tumor suppression and anti-HIV agents.[16] Also, they have found application in native chemical ligation for peptide bond formation,[17] and natural product synthesis.[18] Synthetic application of thioesters has also emerged as a crucial intermediate in a variety of organic transformations, such as C-C coupling,[19] synthesis of carbonyl compounds,[20]

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[13] (a) G. Heppke, J. Martens, K. Praefcke, H. Simon, *Angew. Chem. Int. Ed.* **1977**, *16*, 318. (b) J. Yamada, H. Akutsu, H. Nishikawa, K. Kikuchi, *Chem. Rev.* **2004**, *104,* 5057. (c) R. Cristiano, A. A. Vieira, F. Ely, H. Gallardo, *Liq. Cryst*. **2006**, *33*, 381.

[14] (a) M. Baca, T. Muir, M. Schonolzer, S. Kent, *J. Am. Chem. Soc.* **1995**, *117*, 1881. (b) M. Inoue, S. Yamahita, Y. Ishihara, M. Hirama, *Org. Lett.* **2006**, *8*, 5805.

[15] (a) C. E. Schwartz, D. P. Curran, *J. Am. Chem. Soc.* **1990**, *112*, 9272. (b) S. F. Martin, K. X. Chen, C. T. Eary, *Org. Lett*. **1999**, *1*, 79. (c) B. M. Trost, J. Waser, A. Meyer, *J. Am. Chem. Soc.* **2007**, *129*, 14556.

[16] (a) S.-S. Jew, B.-S. Park, D.-Y. Lim, M. G. Kim, I. K. Chung, J. H. Kim, C. II Hong, J.-K. Kim, H. J. Park, J.-H. Lee, H.-G. Park, *Bioorg. Med. Chem. Lett*. **2003**, *13*, 609. (b) J. A. Turpin, Y. Song, J. K. Inman, M. Huang, A. Wallqvist, A. Maynard, D. G. Covell, W. G. Rice, E. Appella, *J. Med. Chem*. **1999**, *42*, 67.

[17] a) P. E. Dawson, T. W. Muir, I. Clark-Lewis, S. B. H. Kent, *Science*. **1994**, *266*, 776. (b) D. Macmillan, *Angew. Chem. Int. Ed.* **2006**, *45*, 7668. (c) D. Crich, A. Banerjee, *J. Am. Chem. Soc*. **2007**, *129*, 10064. (d) K. S. A. Kumar, M. Haj-Yahya, D. Olschewski, H. A. Lashuel, A. Brik, *Angew. Chem. Int. Ed.* **2009**, *48*, 8090.

[18] (a) T. Fukuyama, S. C. Lin, L. Li, *J. Am. Chem. Soc*. **1990**, *112*, 7050. (b) R. J. Hondal, B. L. Nilsson, R. T. Raines, *J. Am. Chem. Soc*. **2001**, *123*, 5140. (c) M. D. Gieselman, L. Xie, , W. A. van der Donk *Org. Lett*. **2001**, *3*, 1331. (d) K. Agapiou, M. J. Krische, *Org. Lett*. **2003**, *5*, 1737.

[19] (a) J. Choi, E. Imai, M. Mihara, Y. Oderaotoshi, S. Minakata, M. Komatsu, *J. Org. Chem.* **2003**, *68*, 6164. (b) H. Prokopcová, C. O. Kappe, *Angew. Chem. Int. Ed.* **2008**, *47*, 3674.

[20] (a) T. Mukaiyama, M. Araki, H. Takei, *J. Am. Chem. Soc.* **1973**, *95*, 4763. (b) R. J. Anderson, C. A. Henrick, L. D. Rosenblum, *J. Am. Chem. Soc.* **1974**, *96*, 3654. (c) L. S. Liebeskind, J. Srogl, *J. Am. Chem. Soc.* **2000**, *122*, 11260. (d) S. Ozaki, H. Yoshinaga, E. Matsui, M. Adachi, *J. Org. Chem.* **2001**, *66*, 2503. (e) S. Ozaki, M. Adachi, S. Sekiya, R. Kamikawa, *J. Org. Chem.* **2003**, *68*, 4586.

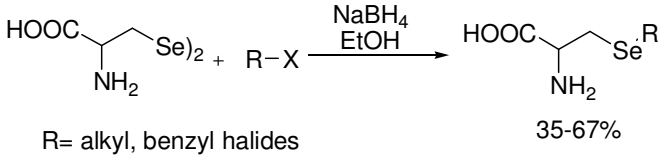
asymmetric aldol reactions[21] and asymmetric 1-4 additions.[22]

1.3. General methods for the preparation of organochalcogenides and chalcogen esters

The synthetic and biological importance of organochalcogenides and chalcogen esters discussed in the previous section 1.1 and 1.2. To give an insight, following section outlines the general methods for the synthesis of organochalcogenides and chalcogen esters. These compounds are generally prepared by reductive cleavage of dichalcogenide bonds, employing common reducing agents and expensive metal sources, as detailed in the following sections.

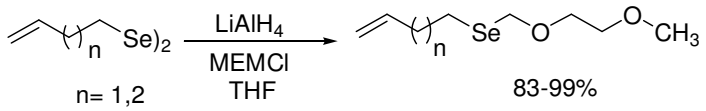
1.3.1. Reaction with Metal Hydrides ($NaBH_4$ and $LiAlH_4$)

The aliphatic and benzyl Se-substituents are introduced by reductive cleavage of Se-Se bond with $NaBH_4$ and subsequent reaction with the corresponding alkyl or benzyl halides affords the desired product in excellent yield (Scheme 1).[23]



Scheme 1

Also, various Se,O-heteroacetals were prepared by the reduction of diselenides with $LiAlH_4$ followed by alkylation with methoxymethyl chloride or (2-methoxyethoxy)methyl chloride (MEM-Cl) affording the corresponding product in excellent yield (Scheme 2).[24]



Scheme 2

[21] G. J. McGarvey, J. M. Williams, R. N. Hiner, Y. Matsubara, T. Oh, *J. Am. Chem. Soc*. **1986**, *108*, 4943.

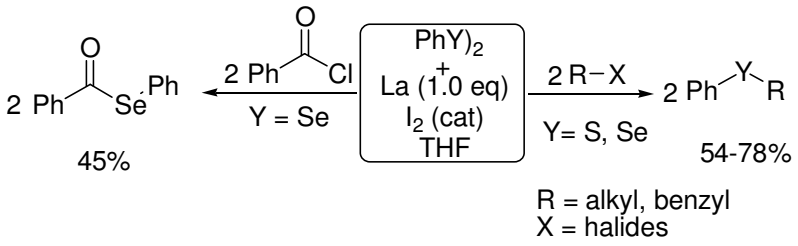
[22] (a) R. D. Mazery, M. Pullez, F. López, S. R. Harutyunyan, A. J. Minnaard, B. L. Feringa, *J. Am. Chem. Soc.* **2005**, *127*, 9966. (b) R. P. Summeren, D. B. Moody, B. L. Feringa, A. J. Minnaard, *J. Am. Chem. Soc*. **2006**, *128*, 4546. (c) G. P. Howell, S. P. Fletcher, K. Geurts, B. Horst, B. L. Feringa, *J. Am. Chem. Soc*. **2006**, *128*, 14977. (d) B. Horst, B. L. Feringa, A. J. Minnaard, *Chem. Commun*. **2007**, 489. (e) B. Horst, B. L. Feringa, A. J. Minnaard, *Org. Lett*. **2007**, *9*, 3013.

[23] I. Andreadou, W. M. P. B. Menge, J. N. M. Commandeur, E. A. Worthington, N. P. E. Vermeulen, *J. Med. Chem*. **1996**, *39*, 2040.

[24] M. Yoshimatsu, T. Sato, H. Shimizu, M. Hori, T. Kataoka, *J. Org.Chem*. **1994**, *59*, 1011.

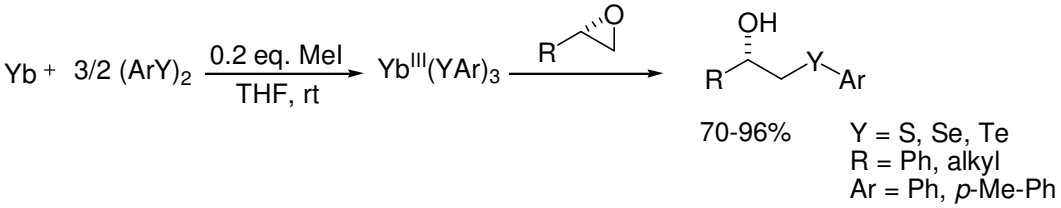
1.3.2. Reactions with Metals and Metal salts

When diphenyl diselenide/disulfide was allowed to react with two equimolar amounts of primary alkyl iodides and bromides in the presence of an equimolar amount of lanthanum metal, alkyl phenyl selenides were formed in moderate to good yields. A reaction pathway involving the generation of a lanthanum phenylselenolate/thiolate intermediate was suggested. The same methodology was employed for the synthesis of selenoester affording 45% yield. For the reaction of primary alkyl chlorides and secondary alkyl iodides, the yields of the selenides were low (Scheme 3).[25]



Scheme 3

Reaction with Yb metal and diaryl dichalcogenide, ytterbium (III) chalcogenolate complex was generated by insertion of ytterbium metal into the chalcogen-chalcogen bond. The resulting complexes have been found to transfer arylsulfanyl, -selenanyl, and -telluranyl groups to epoxides in a facile ring-opening reaction (Scheme 4).[26]



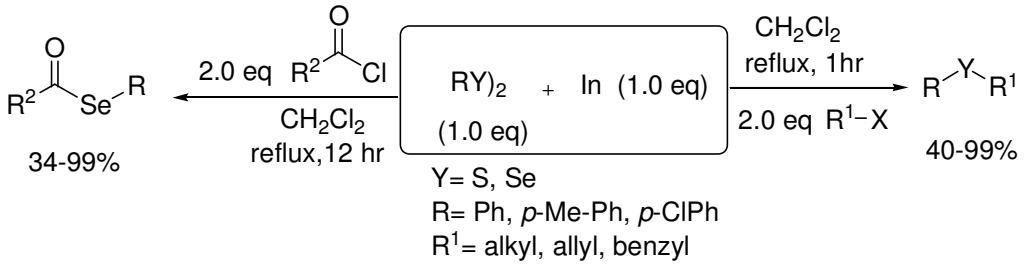
Scheme 4

A convenient and efficient method was developed for the synthesis of diorganyl chalcogenides in one-pot reaction by using indium metal. For the reaction of primary and secondary alkyl iodides and bromides, the yields of selenides were improved by the addition of a catalytic amount of iodine. The same methodology was utilized for the synthesis of a wide range of selenoesters from acyl chloride with diselenides in the presence of indium metal. A variety of functional groups can be tolerated within the

[25] T. Nishino, M. Okada, T. Kuroki, T. Watanabe, Y. Nishiyama, N. Sonoda, *J. Org. Chem.* **2002**, *67*, 8696.

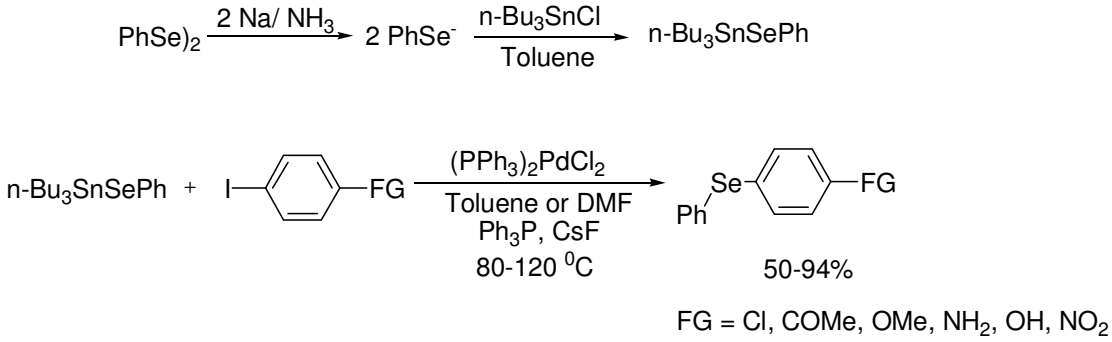
[26] J. Dowsland, F. McKerlie, D. J. Procter, *Tetrahedron Lett.* **2000**, *41*, 4923.

diorganyl diselenide and the acyl chloride coupling reaction affording the desired product in excellent yields (Scheme 5).[27]



Scheme 5

The Pd-catalyzed cross-coupling reaction of aryl and perfluoroalkyl iodides with n-$Bu_3SnSePh$ gave the desired selenylation product in good yield. The $PhSe)_2$ reacts with Na metal in liquid ammonia generate $PhSe^-$ ions. To this solution n-Bu_3SnCl was added to afford n-$Bu_3SnSePh$, which was introduced in the palladium-catalyzed coupling reaction without isolation. These reactions afford functionalized diarylselenides and phenylperfluroalkyl selenides as showed in Scheme 6.[28]



Scheme 6

Unsymmetrical diorganyl chalcogenides can be synthesized from aryl iodide and PhYYPh (Y= S, Se) with a copper catalyst (CuI or Cu_2O) and magnesium metal in one pot (Scheme 7). This reaction can be carried out under neutral conditions according to an addition of magnesium metal as the reductive reagent.[29]

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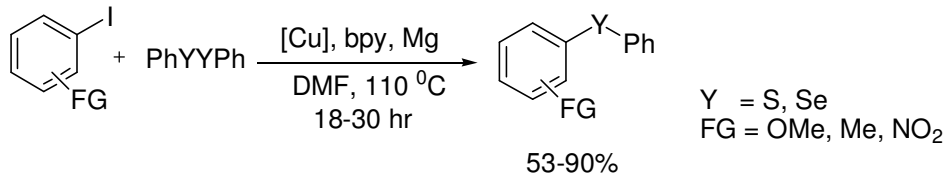
[27] (a) W. Munbunjong, E. H. Lee, P. Ngernmaneerat, S. J. Kim ,G. Singh, W. Chavasiri, D. O. Jang, *Tetrahedron.* **2009**, *65*, 2467. (b) G. Marin, A. L. Braga, A. S. Rosa, F. Z. Galetto, R. A. Burrow, H. Gallardo, M. W. Paixão, *Tetrahedron* **2009**, *65*, 4614.

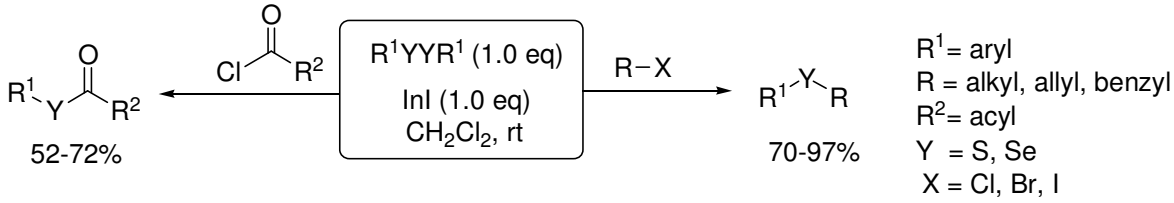
[28] M. Bonaterra, S. E. Martín, R. A. Rossi, *Tetrahedron Lett.* **2006**, *47*, 3511.

[29] N. Taniguchi, T. Onami, *J. Org. Chem.* **2004**, *69*, 915.



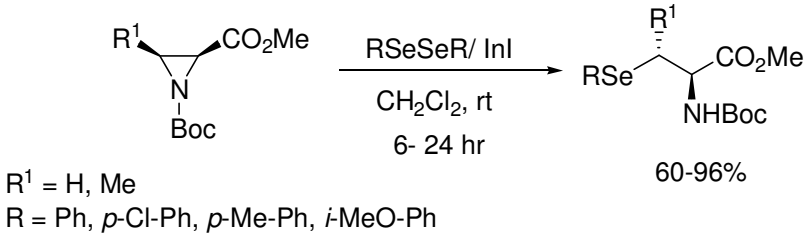
Scheme 7

Ranu *et al* has described a simple, efficient, and general procedure for the synthesis of unsymmetrical diorganyl selenides, sulfides, selenoesters, and thioesters using InI at room temperature (Scheme 8). Diphenyl diselenides and disulfides undergo facile cleavages by indium(I) iodide and the corresponding generated selenolate and thiolate anions condense in situ with alkyl or acyl halides present in the reaction mixture affording the corresponding product in good yields.[30]



Scheme 8

Our research group utilized the use of InI salts, for the synthesis of selenocysteine derivatives. The ring opening reaction of aziridine using Indium (III) chalcogenolate derivative generated from reactions with diaryl dichalcogenide and InI in CH_2Cl_2 under room temperature gave the chiral β-seleno-amines derivatives from a one-pot. The selenocysteine derivative was accomplished successfully in good to excellent yield (Scheme 9).[31]



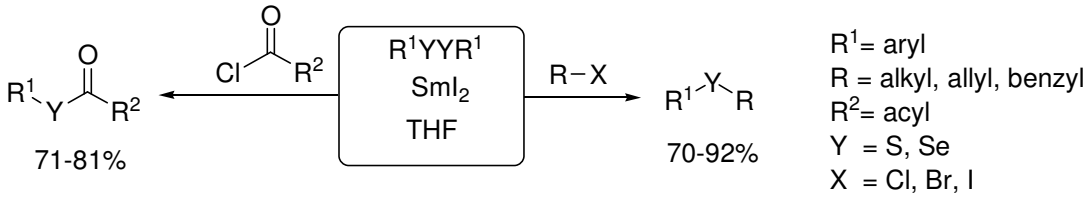
Scheme 9

Zhang *et al* developed a methodology for the synthesis of organochalcogen derivatives (Scheme 10). By using reducing agent (SmI_2) has been utilized for the reduction of diselenides led to samarium

[30] (a) B. C. Ranu, T. Mandal, S. Samanta, *Org. Lett.* **2003**, *5,* 1439. (b) B. C. Ranu, T. Mandal, *J. Org. Chem.* **2004**, *69*, 5793.

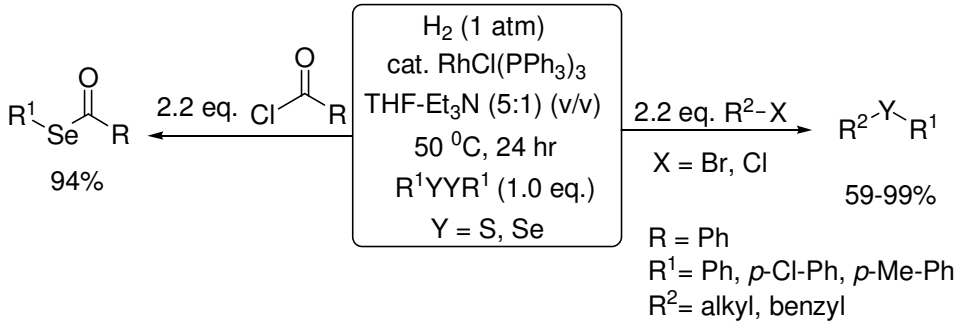
[31] A. L. Braga, P. H. Schneider, M. W. Paixão, A. M. Deobald, C. Peppe, D. P. Bottega, *J. Org. Chem.* **2006**, *71*, 4305.

selenolates. These species reacted with acyl chlorides and organic halides to give the consequent diorganyl chalcogenides and chalcogenesters in good yields under mild and neutral conditions.[32]



Scheme 10

In addition, the reductive cleavage of dichalcogenides was successfully achieved by hydrogenation method. The rhodium complex catalyzed reductive coupling of disulfides and diselenides with alkyl halides in the presence of triethylamine using hydrogen as a reducing agent (Scheme 11).[33] Also, the same methodology was used for the synthesis of seleno esters reacting with acyl chlorides. This reaction serves as a convenient method to produce unsymmetrical sulfides and selenides from disulfides and diselenides.



Scheme 11

1.3.3. Miscellaneous Reactions

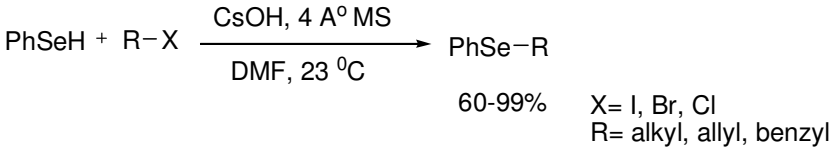
Diorganyl selenides was also synthesized starting from selenols instead of reductive cleavage of diselenides. In the presence of cesium hydroxide, molecular sieves, and DMF, benzeneselenol undergoes direct alkylation with various alkyl halides for the synthesis of alkyl phenyl selenides in moderate to excellent yields (Scheme 12).[34]

---

[32] (a) Y. Zhang, Y. Yu, R. Lin, *Synth. Commun.* **1993**, *23*, 189. (b) Y. M. Zhang, L. Wang, *Synth. Commun.* **1999**, *18*, 3107. (c) Y. M. Zhang, Y.K. Liu, *Synth. Commun.* **1999**, *22*, 4043. (d) W. Su, N. Gao, Y. Zhang, *J. Chem. Research Synopses.* **2002**, *4*, 168. (e) R. Chena, Y. Zhang, *Synth. Commun*, **2000**, *30***,** 1331.

[33] K. Ajiki, M. Hirano, K. Tanaka, *Org. Lett*. **2005**, *7*, 4193.

[34] R. J. Cohen, D. L. Fox, R. N. Salvatore, *J. Org. Chem*. **2004**, *69*, 4265.



Scheme 12

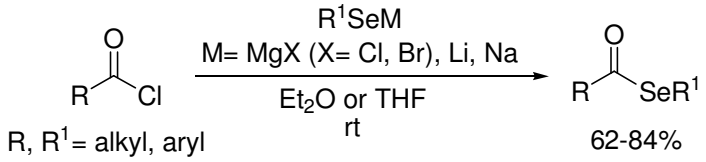
Also, benzyl triethylammonium tetrathiomolybdate $[BnEt_3N]_2MoS_4$ was utilized for the sulfur transfer reagent with symmetrical disulfides and aziridines leading to the formation of chiral β-chalcogen amine derivatives. Photochemical reactions were also reported for the diselenide bond cleavage.[35]

1.4. Synthesis of Chalcogen esters

Much effort has been devoted to the synthesis of chalcogen esters, and a substantial number of reports have been published. Some noteworthy synthetic methodologies were discussed in the following section.

1.4.1. From Acid Chlorides

A variety of methods for the synthesis of chalcogenoesters has been developed. Among these, the most general methods are the acylation of chalcogenols (RYH) and their metal salts with acyl chlorides. Using this strategy, selenoester was synthesized successfully by reactions with acyl chloride and selenol/and its metal salt gave the desired product in good yields as depicted Scheme 13.[36]



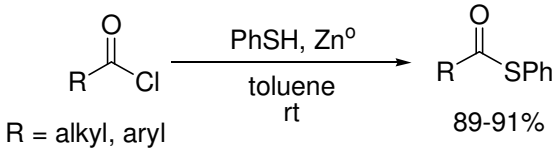
Scheme 13

Thioesters were obtained from the reaction with thiol and its appropriate acyl chloride in presence of zinc gave the corresponding thioesters in good yields (Scheme 14).[37]

[35] (a) A. Ouchi, S. Liu, Z, Li, S. A. Kumar, T. Suzuki, T. Hyugano, H. Kitahara, *J. Org. Chem.* **2007**, *72*, 8700. (b) D. Sureshkumar, V. Ganesh, R. S. Vidyarini, S. Chandrasekaran, *J. Org. Chem.* **2009,** *74*, 7958.

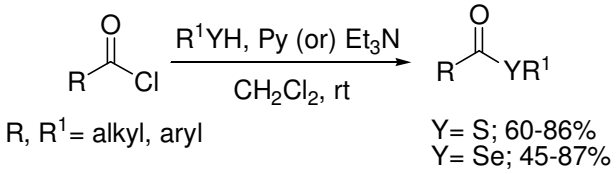
[36] L. H. Viana, M. J. Dabdoub, *Synth. Commun*. **1992**, *22*, 1619.

[37] H. M. Meshram, G. S. Reddy, K. H. Bindu, J. S. Yadav, *Synlett* **1998**, 877.



Scheme 14

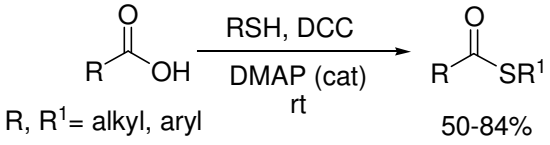
Alternatively, chalcogenolate species were generated *in situ* by using base such as Et_3N or pyridine which upon further reacts with appropriate acyl chloride gave the chalcogen esters in good yield (Scheme 15).[38]



Scheme 15

1.4.2. From Acids

By using DCC with the catalytic amount of DMAP promoted acylation of thiols with appropriate acid gave the thioester in moderate to good yield (Scheme 16).[39] Also reactions with thiol/selenol, imidazole or 1,2,4-triazole and acid leading to the chalcogen esters in good yield (Scheme 17).[40]

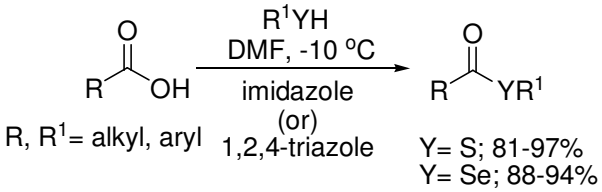


Scheme 16

[38] (a) T. Mukaiyama, M. Araki, H. Takei, *J. Am. Chem. Soc.* **1973**, *95*, 4763. (b) P. Wepplo, *Synth. Commun.* **1989**, **19**, 1533. (c) P. Coutrot, C. Charbonnier, C. Grisen, *Synthesis* **1991**, 23. (d) B.A. Kellogg, R. S. Brown, R. S. Donald, *J. Org. Chem.* **1994**, *59*, 4652.

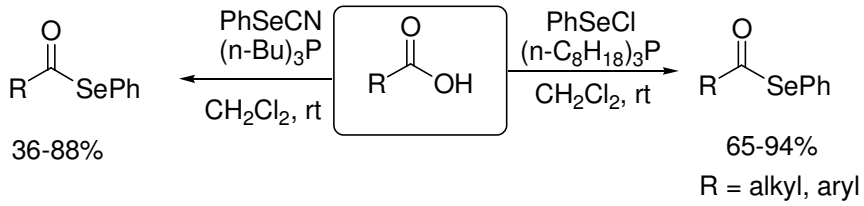
[39] J. R. Grunwell, D. L. Foerst, *Synth. Commun.* **1976**, 453.

[40] H. J. Gais, *Angew. Chem. Int. Ed. Engl.* **1977**, *16*, 244.



Scheme 17

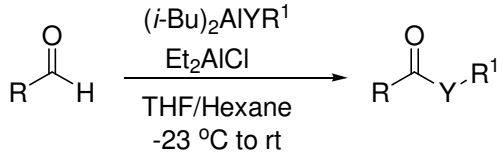
On the other hand, selenoesters were successfully accomplished by reaction with acid and phenylselenium chloride or phenyl selenium cyanide which was used as selenium source. The selenoester was obtained in good yield as depicted in Scheme 18.[41]



Scheme 18

1.4.3. From aldehydes

Chalcogenoesters were also synthesized from aldehydes using diisobutylaluminum chalcogenolate in THF/hexane affording the desired esters in good yields as depicted in Scheme 19.[42]



Y= S; R= alkyl, aryl; R^1= *n*-Bu, Ph, Bn; 46-96%

Y= Se; R= alkyl, aryl; R^1= *n*-Bu, Ph; 20-82%

Y= Te; R= alkyl, aryl; R^1= *n*-Bu; 27-73%

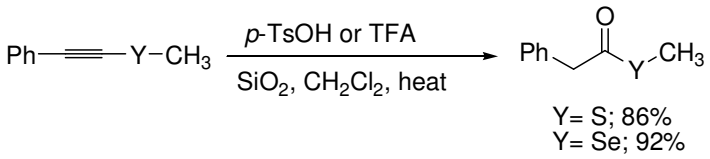
Scheme 19

[41] (a) S. Masamune, Y. Hayase, W. Schilling, W. K. Chang, G. S. Bates, *J. Am. Chem. Soc.* **1977**, *99*, 6756. (b) P. A. Grieco, Y. Yokoyama, E. Williams, *J. Org. Chem.* **1978**, *43*, 1283.

[42] T. Inoue, T. Takeda, N. Kambe, A. Ogawa, I. Ryu, N. Sonoda, *J. Org. Chem.* **1994**, *59*, 5824.

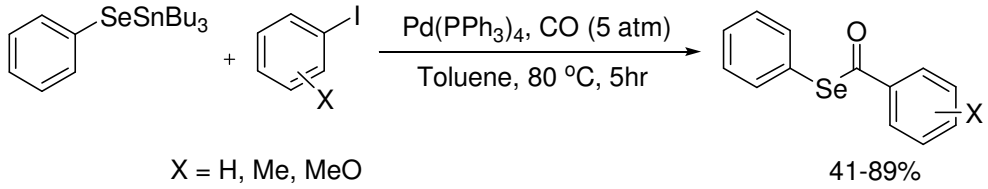
1.4.4. From Other Methods

Chalcogenoesters were conveniently prepared in good yields by reacting chalcogeno acetylenes with trifluoroacetic acid in dichloromethane in the presence of silica (Scheme 20).[43]



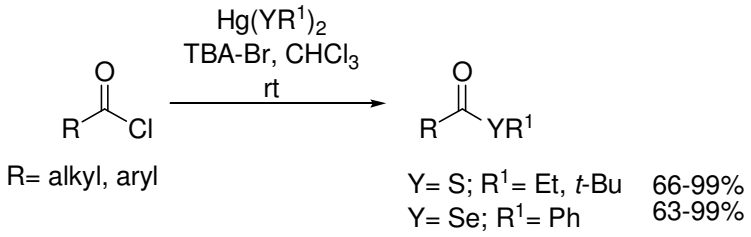
Scheme 20

Also, selenoesters have been successfully prepared by three-component coupling of aryl iodides with CO and $PhSeSnBu_3$ catalyzed by Pd, to afford the corresponding selenoesters in moderate to good yields (Scheme 21).[44]



Scheme 21

Most commonly, by the reaction of acyl chlorides with chalcogen nucleophilic species, such as $Hg(YPh)_2$ in the presence of tetrabutylammonium halides as catalysts gave the desired product in good to excellent yield (Scheme 22).[45]



Scheme 22

[43] A. L. Braga, T. L. C. Martins, C. C. Silveira, O. E. D. Rodrigues, *Tetrahedron.* **2001**, *57*, 3297.

[44] Y. Nishiyama, K. Tokunaga, H. Kawamatsu, N. Sonoda, *Tetrahedron Lett.* **2002**, *43*, 1507.

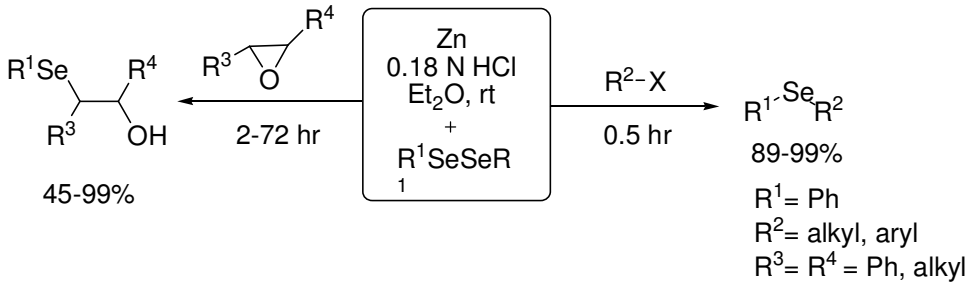
[45] C. C. Silveira, A. L. Braga, E. L. Larghi, *Organometallics.* **1999**, *18*, 5183.

1.5. Reactions with Zn and other catalysts

1.5.1. Reaction with Zn/HCl

Synthesis of diorganyl chalcogenides and chalcogen esters were prepared by the reductive cleavage of dichalcogenide bonds as detailed in the previous sections. In addition, Zn with other catalytic system involved for the synthesis of chalcogenides derivatives and discussed in the following section.

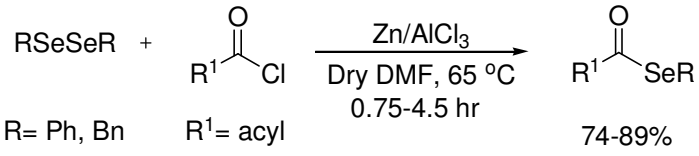
Reductive cleavage of the Se–Se bond mediated by zinc under acidic conditions to afford selenols, which can be either isolated or treated in situ with alkyl halides to produce alkyl selenides or with epoxides to give β-hydroxyselenides (Scheme 23).[46]



Scheme 23

1.5.2. Reaction with Zn/$AlCl_3$

Treatment of diphenyl and dibenzyl diselenides with aliphatic and aromatic acid chlorides in the presence of Zn/$AlCl_3$ system affords selenol esters in good yields (Scheme 24).[47]



Scheme 24

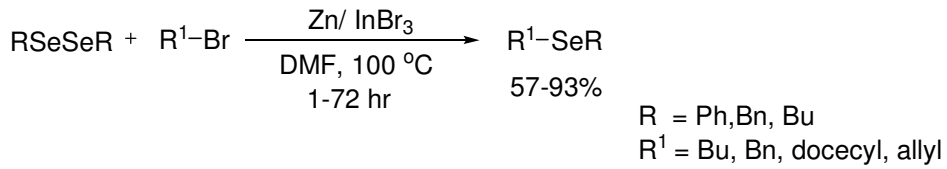
1.5.3. Reaction with Zn/$InBr_3$

Alternatively, unsymmetrical diorganyl selenides synthesized from an one-pot $InBr_3$ catalyzed, in

[46] C. Santi, S.Santoro, L. Testaferri andM. Tiecco, *Synlett.* **2008**, 1471

[47] (a) B. Movassagh, F. Mirshojaei, *Monatshefte für Chemie*. **2003**, *134*, 831. (b) B. Movassagh, M. shamsipoor, *Synlett*. **2005**, 121.

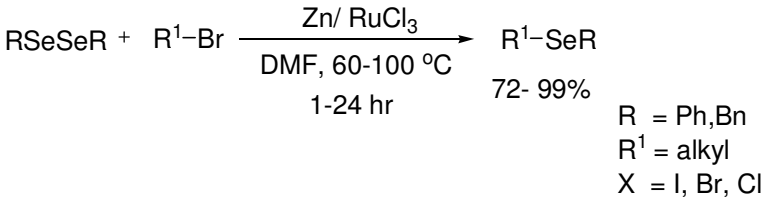
the presence of zinc, with diaryl diselenide and organic halides. Various organic halides underwent the coupling reaction affording the desired product in good yields (Scheme 25).[48]



Scheme 25

1.5.4. Reaction with Zn/$RuCl_3$

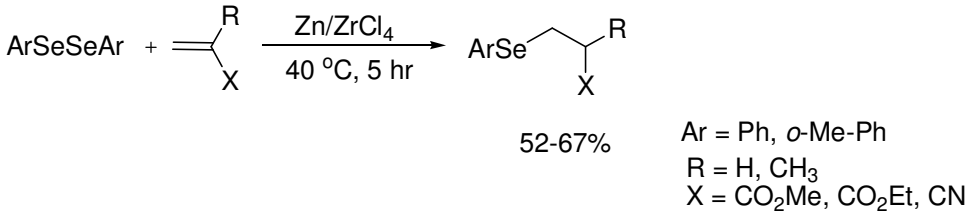
Ruthenium-(III) chloride catalyzed reactions of dibenzyl or diphenyl diselenides with alkyl halides in the presence of zinc gave the unsymmetrical diorganyl selenides. Organic iodides, bromides, and activated chlorides underwent the reactions efficiently (Scheme 26).[49]



Scheme 26

1.5.5. Reaction with Zn/$ZrCl_4$

The Se–Se bond in diselenides was reduced by Zn/$ZrCl_4$ to produce selenolate anions, which react with α,β-unsaturated esters or α,β-unsaturated nitriles to afford β-selenoesters and β-selenonitriles, respectively in good yield as depicted in Scheme 27.[50]



Scheme 27

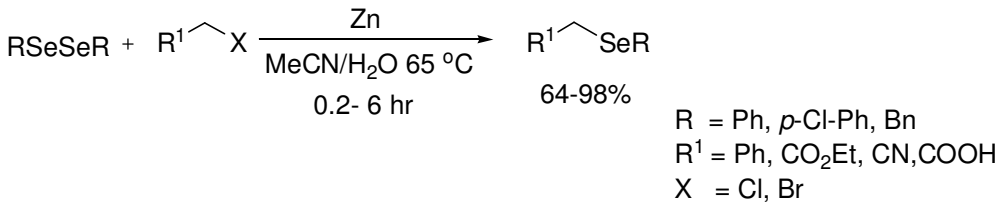
[48] A. L. Braga, P. H. Schneider, Marcio W. Paixão, A.M. Deobald, *Tetrahedron Lett.* **2006**, *47*, 7195.

[49] X. Zhao, Z. Yu, S. Yan, S. Wu, R. Liu, W. He, L. Wang, *J. Org. Chem.* **2005,** *70*, 7338.

[50] S. Zhang, F. Tian, T. *J. Chem. research (S).* **2001**, 198.

1.5.6. Reaction with Zn/H_2O

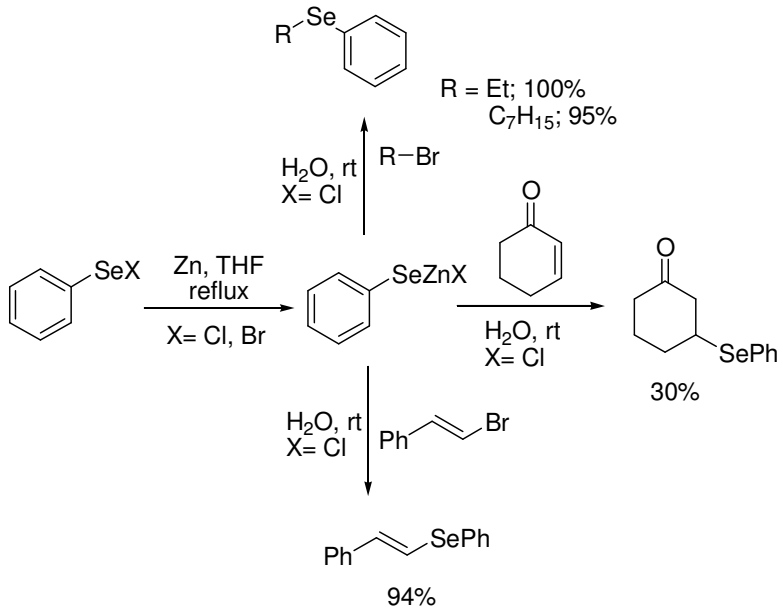
In the mixture of MeCN/water, zinc powder promotes cleavage of the Se-Se bond to form selenide anion (RSe^-). This species can then react with active organic halides such as benzyl halides, α-haloesters, α-haloacids, and chloroacetonitrile to afford unsymmetrical selenides in good to excellent yields (Scheme 28).[51]



Scheme 28

1.5.7. Reaction with PhSeZnBr

The air-stable selenolates were successfully achieved from commercially available phenyl-selenenyl halides and elemental zinc dust. These (PhSeZnX, X= Cl, Br) reagents were efficiently employed in nucleophilic substitution and addition reactions showing high yielding at room temperature in water (Scheme 29).[52]



Scheme 29

[51] B.Movassagh and M. Shamsipoor, *Synlett*. **2005**, 121

[52] C. Santi,S. Santoro, B. Battistelli, L. Testaferri and M. Tiecco, *Eur. J. Org.Chem*. **2008**, 5387.

A myriad of work has been devoted towards the synthesis of organochalcogen derivatives, and discussed in the introductory part. Moreover, most of the methods available to synthesize diorganyl chalcogenides and chalcogen esters are associated with any of the following disadvantages including:

i) The use of expensive metal sources and reagents such as La, Yb, In, InI, SmI_2 and $[BnEt_3N]_2MoS_4$ etc;

ii) Functional group incompatibility and handling of metal hydrides;

iii) Harsh reaction conditions, such as acidic or basic;

iv) Elevated temperature or long reaction time;

v) Hazardous solvents like HMPA;

vi) Use of odoriferous thiols and selenols.

One of the tasks in striving for sustainable chemistry is the development of new methods that are efficient, inexpensive, high yielding, responsive to mild reaction conditions, reusable reaction media and byproduct-free. In this regard, ionic liquids have frequently been used in the last few years as alternative reaction media for a broad range of chemical transformations. Apart from direct replacement of organic solvents, ionic liquids have been shown to deliver improved yields in a number of chemical reactions and facilitate product recovery and have the potential for recyclability.

1.6. Ionic Liquid

Because the constraints of environment are becoming more and more stringent, organic transformations, catalytic processes and separation technologies require the development of alternative solvents and technologies. The ideal solvent should have a very low volatility, it should be chemically and physically stable, recyclable and reusable and eventually easy to handle. In addition, solvents that allow more selective and rapid transformations will have a significant impact. During these last 20 years, water has emerged as a new useful reaction media.[53] It has been successfully used in many organic reactions. However, its application is still limited due to the low miscibility of organic substrates in water. More, water is a protic coordinating solvent and probably it can react with organometallic compounds.

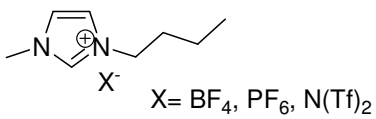


Figure 5. Frequently used ionic liquids.

[53] B. Cornils, W. A. Herrmann, in: B. Cornils, W. A. Herrmann (Eds.), Aqueous Phase Organometallic Catalysis - Concept and applications, Wiley-VCH, Weinheim, 1998.

Now-a-days, ionic liquids were utilized as an effective reaction media for many organic transformations and still it's emerging in trend. The spectrum of their physical and chemical properties is much larger than that of organic solvents. Most commonly used ionic liquids depicted in Figure 5. Initially ionic liquids developed by electrochemists who were looking for ideal electrolytes for batteries, they are now implied in a lot of applications. Some important characteristics of ionic liquids were discussed in the following section.

1.6.1. Chemical and physical properties of ionic liquids

Ionic liquids that are liquid at or below 25 °C and are referred to as room temperature ionic liquids (RTILs). In general, Ionic liquid consists of a large organic cation together with an organic or inorganic anion. Especially, an imidazolium cation-based ionic liquid has proven to be highly attractive and versatile. Frequently encountered favorable characteristics of imidazolium ionic liquids are, high thermal stability, being liquid over a wide temperature range, very low-vapor pressure, wide electrochemical window, high conductivity and ionic mobility, easy recycling, and being a good solvent for a wide range of organic and inorganic chemical compounds.[54] Besides, ionic liquids are "designable or tunable" because structural modifications in both the cation and anion permit the tuning of its physical properties[55] and this may influence the outcome of reaction yield.

As a result, applications of ionic liquids are numerous which continue to expand such as electrolytes for electrochemical devices and processes, solvents for organic and catalytic reactions, new material production, solvents for separation and extractions processes. They now find additional use in enzyme catalysis or in multiphase bio-process operations.

[54] (a) J. Dupont, R. F. Souza, P. A. Z. Suarez, *Chem. Rev*. **2002**, *102*, 3667. (b) C. C. Cassol, G. Ebeling, B. Ferrera, J. Dupont, *J. Adv. Synth. Catal.* **2006**, *348*, 243. (c) J. Ranke, S. Stolte, R. Störmann, J. Arning, B. Jastorff, *Chem. Rev*. **2007**, *107*, 2183. (d) P. Hapiot, C. Lagrost, *Chem. Rev*. **2008**, *108*, 2238.

[55] P. Wasserscheid, T. Welton, *Ionic Liquids in Synthesis*; VCH Wiley: Weinheim, Germany, **2002.**

1.7. Objective

The main objective of the present study,

1) To generate the nucleophilic selenium species ($PhSe^-$) in ionic liquid which upon further reaction with the organic halides to afford the corresponding products. Therefore, it is important and interesting to develop a simple and efficient synthetic route for the synthesis of diorganyl selenides from the reaction with diaryl diselenides using reducing agent such as indium (I) salts. Survey of literature showed that a very few methods are known for the efficient synthesis of diorganyl selenides mediated by ionic liquids. The use of indium (I) salts to promote the cleavage of the selenium-selenium bond in diaryl diselenides in ionic liquid has not been reported. Hence, we are interested to investigate the reactivity of indium (I) salts with diaryl diselenide and organic halide to synthesize the diorganyl selenide in ionic liquid under room temperature.
2) To reuse the ionic liquid.

Results and Discussion

Results and Discussion

The following are the systematic approach we followed to carry out the synthetic problem. In this view, we first synthesized ionic liquids by the available literature procedure and further it's used as a solvent for the synthesis of diorganyl selenides as explained in the following sections.

2.1. Room temperature ionic liquids (RTILs)

The ionic liquids (figure 6) were synthesized by the available literature procedure and the synthetic procedure is available in the experimental section.

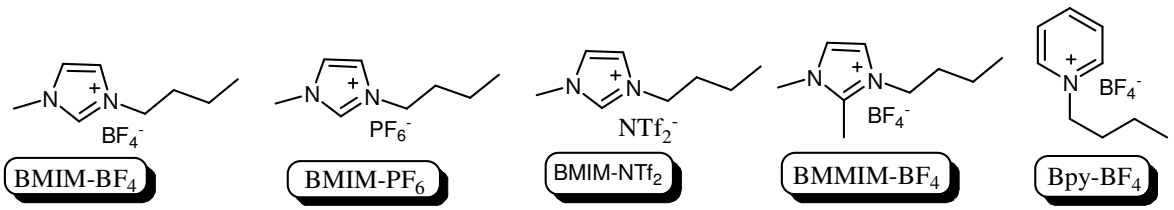
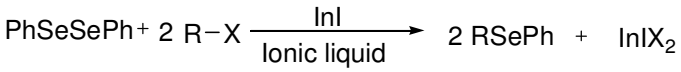


Figure 6

2.2. Preparation of diorganyl selenides

To resolve the first objective is to investigate the possibility to employ ionic liquids, which would function as a reaction medium, for the synthesis of unsymmetrical diorganyl selenides. For that purpose, we selected In(I) salts as reducing agents due to their well-known ability to promote the Se-Se bond cleavage as depicted in Scheme **30**. Although synthesis of unsymmetrical diorganyl selenides has been successfully accomplished by indium salts, it was undesirable from an environmental point of view, since organic solvents were used.[30]



Scheme 30

2.2.1. Screening of reaction conditions using In(I) salts

We first tested the reaction of diphenyl diselenide **1a** with benzyl halide and indium (I) salts using different ionic liquids (Figure 6) for the synthesis of desired product using the following procedure. To a stirred solution of ionic liquid (0.5 mL) was added indium (I) salt (0.5 mmol) and diphenyl diselenide **1a** (156 mg, 0.5 mmol) at room temperature under nitrogen. The mixture was allowed to stir for 5 min. Then benzyl halide (1 mmol) was slowly added. The reaction mixture was stirred for another 30 min (checked by TLC), the mixture was then extracted with ether (3 X 15 mL), and the combined ether extract was

washed with brine, dried ($MgSO_4$), and evaporated to leave the crude product **2a**. The results are summarized in Table 1.

The obtained product benzyl phenyl selenide (**2a**) was characterized by NMR spectrum. The ^1H NMR shows the $–CH_2$ protons in singlet at δ 4.10 (**H-1**). The eight aromatic protons appeared as a multiplet between δ 7.14 and 7.28 (**H-2**). The other two aromatic protons appeared as a multiplet between δ 7.42 and 7.50 (**H-2**). In ^{13}C NMR spectra, aromatic carbons appeared at δ 138.6, 133.5, 130.4, 128.9, 128.8, 128.4, 127.3 and 126.8 (**C-2**). The methylene carbon appeared at δ 32.2 (**C-1**). The ^1H and ^{13}C NMR spectral data of the compound **2a** confirmed that the formation of product was successfully accomplished. The spectra are presented in Figure 7 and 8.

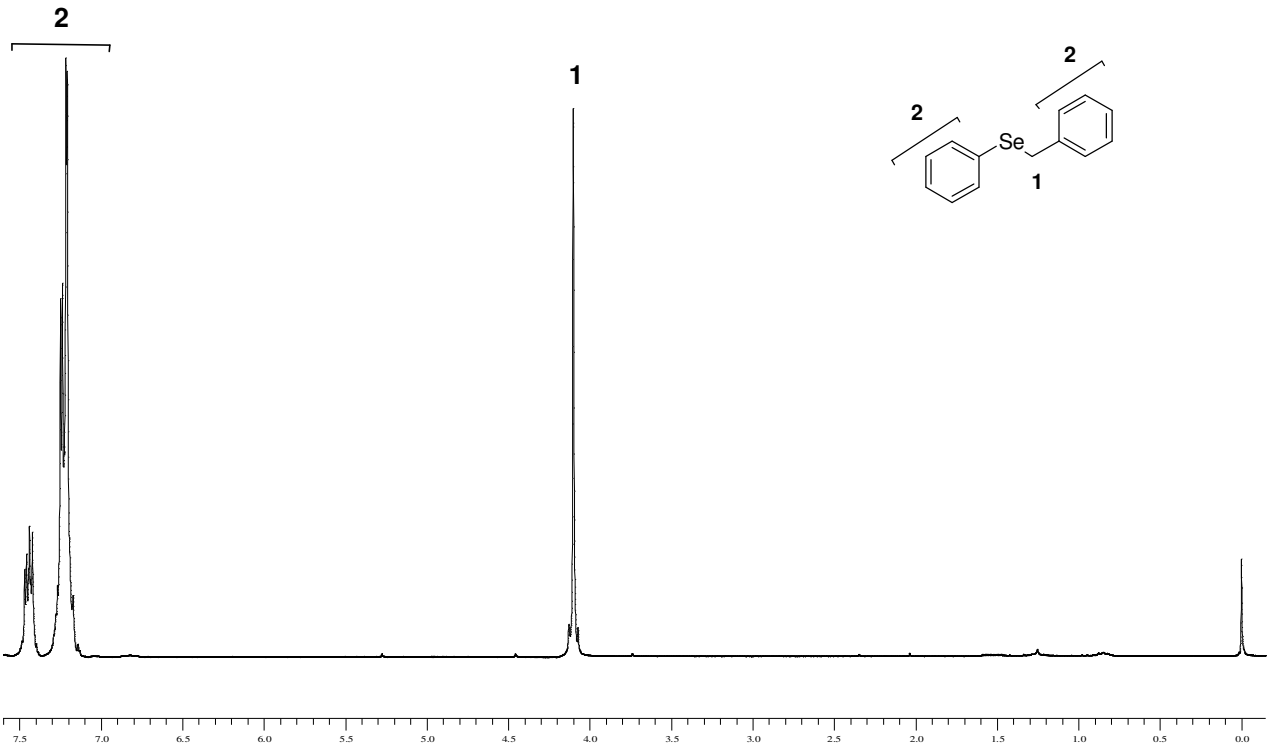


Figure 7. ^1H NMR (400 MHz, $CDCl_3$) Spectrum of **2a.**

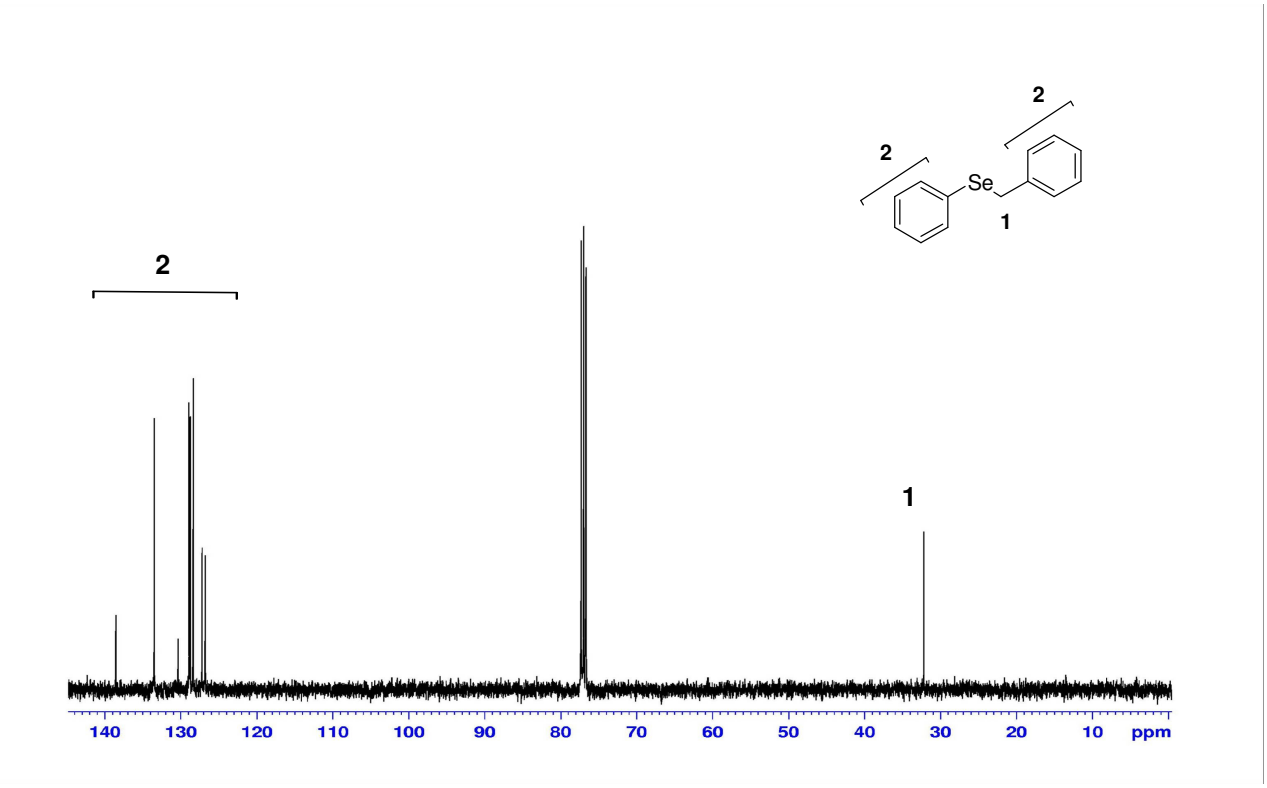
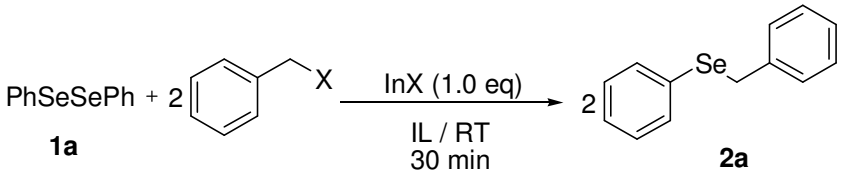


Figure 8. ^{13}C NMR (100 MHz, $CDCl_3$) Spectrum of **2a.**

During the optimization, we found that cationic and anionic changes in the ionic liquid display an important role in the formation of the product **2a** since the yield got varied using other ionic liquids. The origin of this effect is not studied using In(I) salts because during the initial course of our reaction we were focusing the generation of selenium nucleophilic species in ionic liquid and later on we investigated the fact behind the influence of ionic liquid using other reducing agent (*see* section 2. 3).

In BMIM-BF_4 and BMIM-PF_6, the products were achieved in the same range of yield (Table 1, entries 1 and 2), BMIM-NTf_2 and Bpy-BF_4 showed poorer results (Table 1, entries 3 and 4). With these results in hands, we next investigated the influence of the halide, both in the indium (I) salt and in the substrate. When we changed InI for InBr in the reaction using BMIM-BF_4 the product was formed in an appreciable yield, but which was lower than with InI (Table 1, entries 1 and 5). Better results were found for the use of different halides in the substrate, affording the benzyl phenyl selenide in near quantitative yield (Table 1, entries 6 and 7). This can be explained by the leaving group ability in the organic halide.

Table 1. Optimization of reaction conditions



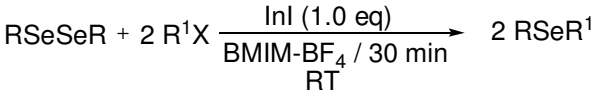
Entry	Ionic Liquid	InX	$PhCH_2X$	[a]Yield [%]
1	BMIM-BF_4	I	Cl	90
2	BMIM-PF_6	I	Cl	86
3	BMIM-$N(Tf)_2$	I	Cl	26
4	Bpy-BF_4	I	Cl	64
5	BMIM-BF_4	Br	Cl	84
6	BMIM-BF_4	I	Br	93
7	BMIM-BF_4	I	I	98

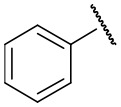
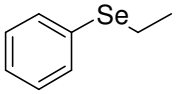
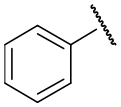
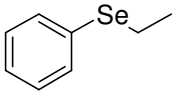
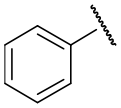
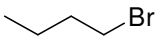
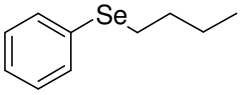
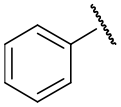
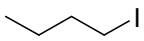
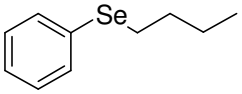
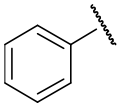
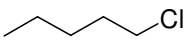
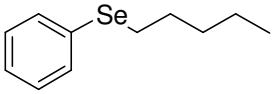
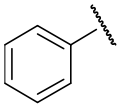
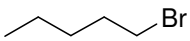
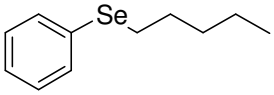
[a] Yields referent of pure isolated products, characterized by ^{1}H and ^{13}C NMR spectroscopic data.

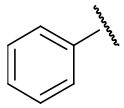
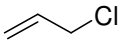
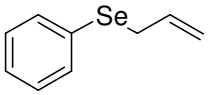
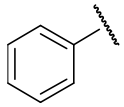
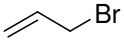
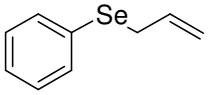
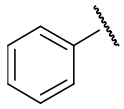
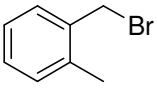
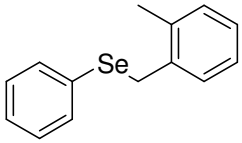
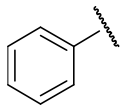
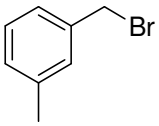
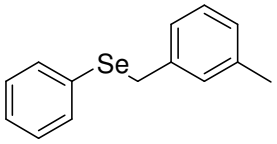
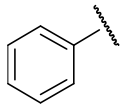
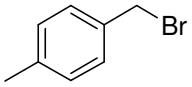
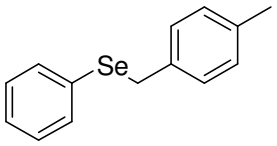
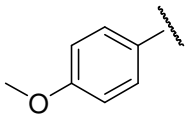
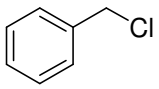
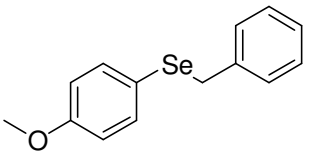
2.2.2. Synthesis of diorganyl selenides using InI in BMIM-BF_4

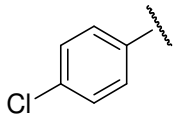
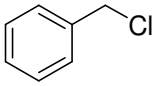
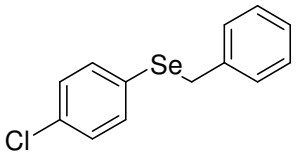
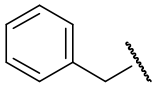
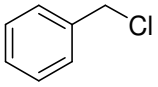
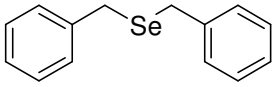
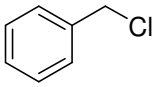
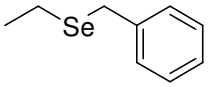
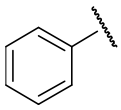
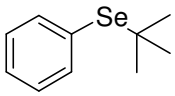
After optimization, we next prepared a series of unsymmetrical diorganyl selenides using aryl and alkyl diselenides, InI, and BMIM-BF_4. The results are summarized in Table 2. Initially the experiments were carried out with alkyl halides and PhSeSePh under standard reaction conditions. By using different alkyl halides reacts with diphenyl diselenide affording the respective products **2b-d** in good yields and indicate that the chain length has a positive effect on the reaction course, affording improved yields with substrates with longer chains (Table 2, entries 1–6) due to the volatile nature of the alkyl halides. The yields of the products were high, even for less reactive 1-chloropentane (Table 2, entry 5). The formation of the products was not strongly influenced by the nature of halide; in most cases the products were produced with just slight differences in the yields for the same alkyl chain. Employing more reactive allyl bromide, the conversion was almost quantitative (Table 2, entry 8), with a similar result found for allyl chloride (Table 2, entry 7).

Table 2. Synthesis of unsymmetrical diorganyl selenides promoted by InI



Entry	R	R^1X	Product	[a]Yield [%]
1	 **1a**		 **2b**	65
2	 **1a**		 **2b**	70
3	 **1a**		 **2c**	82
4	 **1a**		 **2c**	85
5	 **1a**		 **2d**	85
6	 **1a**		 **2d**	89

7	 **1a**		 **2e**	94
8	 **1a**		 **2e**	97
9	 **1a**		 **2f**	60
10	 **1a**		 **2g**	78
11	 **1a**		 **2h**	92
12	 **1b**		 **2i**	82

13	 **1c**		 **2j**	89
14	 **1d**		 **2k**	78
15	 **1e**		 **2l**	81
16	 **1a**		 **2m**	traces

[a] Yields referent of pure isolated products, characterized by ^{1}H and ^{13}C NMR spectroscopic data.

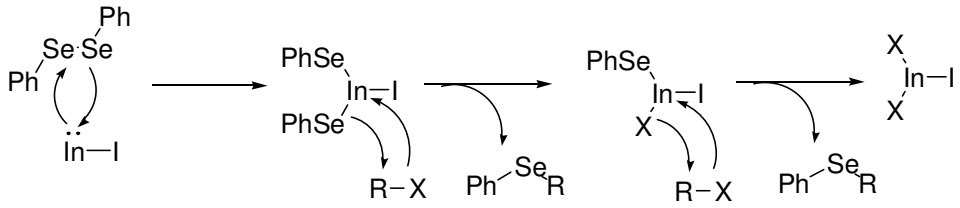
Substituted benzyl bromides were also employed, the most reactive one was the *para* substituted, followed by the *meta*- and *ortho*-methyl benzyl bromides which suggests that the steric influence of the organic substrates (Table 2, entries 9-11).

In a new set of experiments we screened substituted diaryl diselenides with the aim of checking the influence of electronic and steric hindrance effects. The reaction proceeded very well both for electron donating and for electron withdrawing groups attached at the *para* position of the diaryl diselenide (Table 2, entries 12–13). Finally we employed dibenzyl diselenide and diethyl diselenide as the source of selenium the desired diorganyl selenides were efficiently obtained in good yields (Table 2, entries 14 and 15). Trace amount of product formation was obtained using hindered *t*-butyl chloride as organic substrate (Table 2, entry 16).

All synthesized diorganyl selenides **2a-m** are characterized by ^{1}H and ^{13}C NMR and the characterization details available in the experimental section.

2.2.3. Plausible Reaction Pathway using InI

Based on the results obtained in Table 2, our protocol seems to follow a SN_2 type reaction, since good results were found for primary halides (Table 2, entries 1-6) and just traces of product were achieved for the hindered *t*-butyl chloride (Table 2, entry 16).



Scheme 31

In previous literature report[30] shows that the generation of indium selenolate and we speculate that the reaction is going through the alkylation pathway of bis(phenylseleno)-iodo-indium(III), formed readily by reacting equimolar quantities of InI and diphenyl diselenide with organic halides to give the corresponding diorganyl selenides.

2.2.4. Reason for the improvement of yield using ionic liquid as compared with organic solvents

At the present time, there is still an empirical knowledge of ionic liquid mainly developed on the basis of their solvent effect on organic reactions compared to that of well-know conventional solvents. The challenge would be able to predict their properties in order optimize the choice for a given application.

However, we may consider few important factors such as solvent polarity and type of the reaction has often a strong influence on the outcome of reactions. Concerning about polarity, it's even more complicated in the case of ionic solvents, as many interactions for *e.g*, characteristic of hydrogen bonding can be involved. In addition, reactions involving charged intermediates such as carbocations or carbanions which could become more long-lived in these media.

Therefore, in BMIM-BF_4 the alkylation of bis(phenylseleno)-iodo-indium(III), (formed readily by reacting equimolar quantities of InI and diphenyl diselenide) with organic halides occurs with similar reaction rates compared to organic polar solvents but with shorter reaction time in excellent yield.

2.2.5. Reuse of ionic liquid/ BMIM-BF_4

To further explore the scope of our method, and in an effort toward an industrial application, we examined the possibility of reusing the reaction media, Figure 9. Accordingly, after completion of the reaction, the reaction mixture was then extracted with ether (3 x 15 mL), and the combined ether extract was washed with brine, dried ($MgSO_4$), and evaporated to leave the crude product. The residual ionic liquid/BMIM-BF_4 was diluted in CH_2Cl_2 and filtered through a celite pad to remove the inorganic materials followed by concentration to remove the organic solvents and being subjected to vacuum for 1 hour to eliminate moisture and trace organic solvents to obtain the solvent and moisture free recovered ionic liquid.

After the recovery process, the same ionic liquid was reused for the following successive runs after addition of one equivalent of InI (121 mg, 0.5 mmol), diphenyl diselenide (156 mg, 0.5 mmol) and benzyl chloride (126 mg, 1 mmol). To our delight, the yield was found to be similar to that obtained in the first run (Figure 9, 2nd run). This operation was repeated three more times without appreciable loss of efficiency (Figure 9, runs 3–5).

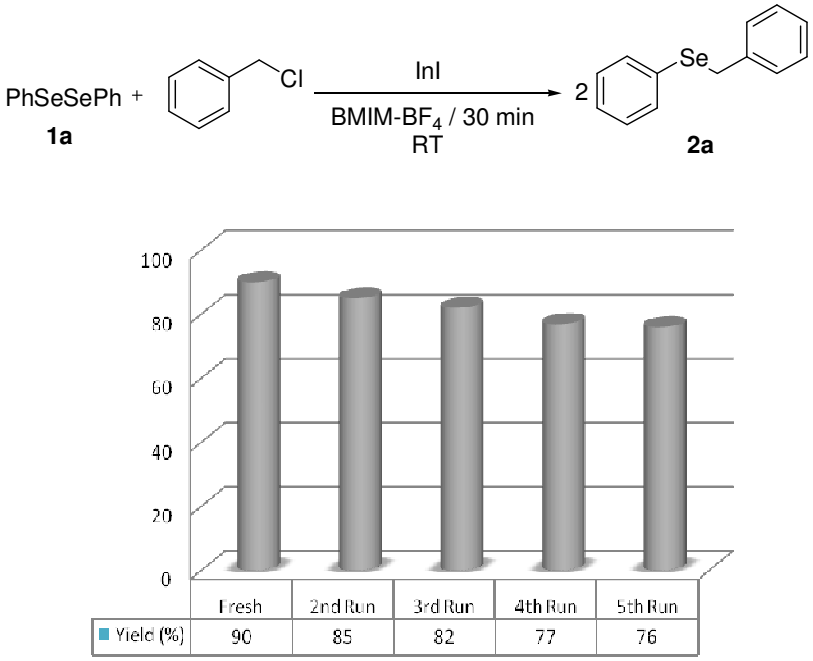


Figure 9

The above result describes a high yielding preparation of unsymmetrical diorganyl selenides, using very mild conditions and requiring a very short reaction time. Our approach employs InI as the reducing agent in BMIM-BF_4, and the ionic liquid which is suitable for further reuse without loss of

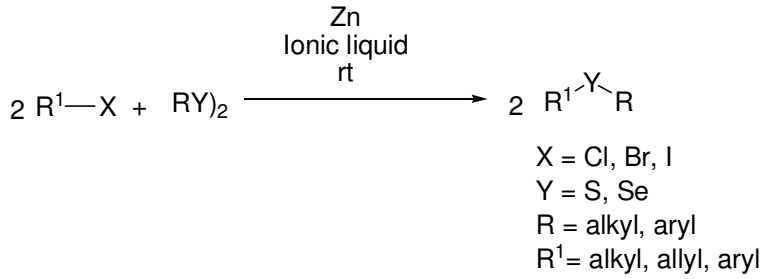
efficiency for at least five runs. Some important features of this method are the high reactivity, leading to the desired products in good to excellent yields and the readily commercial availability of the starting materials.

Motivated by the excellent results obtained using InI as a reducing agent to cleave the diaryl diselenide in BMIM-BF_4 which strongly support that the generation of selenium nucleophilic species in ionic liquid is possible. On the other hand, InI would function as an effective reducing agent in ionic liquid, it´s cost and hydrophobicity of some indium salts would hamper the reaction which suggests that still there is a need for more efficient, diversity-oriented and economically attractive method for the synthesis of this class of compounds. These limitations allowed us to find more efficient methodology and the results were discussed in the following section.

2.3. Synthesis of diorganyl chalcogenides using Zn in ionic liquid

It is well-recognized that the development of ionic liquid mediated organic transformations for the synthesis of diorganyl chalcogenides is an important pursuit from the viewpoints of operational simplicity, economic, and recyclability.

In our continuous efforts toward accessing privileged organochalcogenide compounds, we became interested in exploring the generation of organo chalcogenolates using inexpensive elemental zinc dust as a reducing agent to cleave the diaryl dichalcogenide which would further react with organic halide leading to the formation of diorganyl chalcogenides in ionic liquid at room temperature as depicted in Scheme 32. Interestingly, the experimental conditions proposed for this reaction facilitates the easy workup of the reaction mixtures and isolation of the desired product in excellent yield.



Scheme 32. Synthesis of diorganyl selenide and sulfide using Zn in ionic liquid

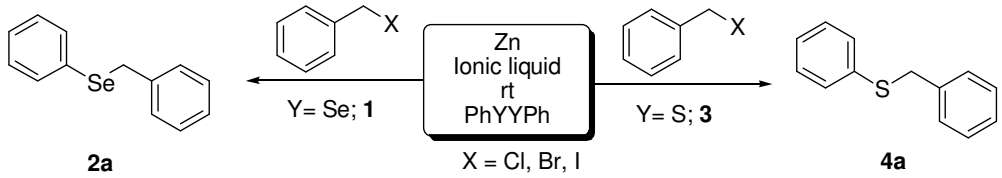
2.3.1. Optimization of reaction conditions using Zn in ionic liquid

To optimize the protocol, we performed the reaction of benzyl halide with diary dichalcogenide and 1.6 equiv of zinc dust with respect to diaryl dichalcogenide, in different ionic liquids (figure 6). The

results are summarized in Table 3. The cationic and anionic moieties present in the ionic liquid which really influenced the reaction outcome since the difference in yield was observed. The influence of ionic liquid and the side-by-side yield comparison with conventional organic solvent with ionic liquid were discussed in the following sections.

The reaction with benzyl chloride using PhSeSePh or PhSSPh and 1.6 equiv. of Zn dust was used to perform the initial reaction. The results driving to BMIM-BF_4 which showed better yield as compared with the other ionic liquids for the formation of desired products **2a** and **4a** (Table 3; entries 1-5). On the basis of these results, we investigated the influence of halide in the substrate. When benzyl iodide was used a higher yield was obtained as compared with that of benzyl bromide and chloride, which can be explained by the leaving group ability of the halogens (Table 3; entries 5-7). However, the difference was not significant and all the halogens afforded the desired product in excellent yields.

Table 3. Optimization of the reaction: ionic liquid and amount of Zn.



Entry	Ionic liquid[a]	X	Time [min]		Yield [%][b]	
			Y= S	Y= Se	Y= S	Y= Se
1	Bpy-BF_4	Cl	30	40	67	55
2	BMMIM-BF_4	Cl	30	40	78	65
3	BMIM-$N(Tf)_2$	Cl	30	40	46	29
4	BMIM-PF_6	Cl	30	35	89	86
5	BMIM-BF_4	Cl	15	30	92	93
6	BMIM-BF_4	Br	10	25	96	95
7	BMIM-BF_4	I	10	20	98	98
8[c]	BMIM-BF_4	Br	10	25	94	96
9[d]	BMIM-BF_4	Br	10	25	93	92

[a] Ionic liquids were subjected to vacuum before use. [b] Yields refer to pure isolated products; [c] 1.2 equiv. of zinc dust was used; [d] 1.0 equiv. of zinc dust was used.

The amount of zinc required to promote the completion of the reaction was also evaluated. Reactions with 1.2 and 1.0 equiv of zinc showed similar results, leading to the product **2a** and **4a** in excellent yields (Table 3, entries 8 and 9). Therefore, an optimum combination for the efficient reaction of diaryl dichalcogenide with organic halide was found employing 1.0 equiv of Zn related to dichalcogenide and 0.5 mL of BMIM-BF_4 at room temperature.

The formation product benzyl phenyl sulfide (**4a**) was characterized by NMR. The ^{1}H NMR shows the –CH_2 protons in singlet at δ 4.12. The ten aromatic protons appeared as a multiplet between δ 7.15 and 7.34. The other two aromatic protons appeared as a multiplet between δ 7.42 and 7.50. In ^{13}C NMR spectra, aromatic carbons appeared at δ 137.49, 136.32, 129.83, 129.79, 128.79, 128.45, 127.13, and 126.32. The methylene carbon appeared at δ 39.65. The ^{1}H and ^{13}C NMR spectral data of the compound **4a** are depicted in figure 10 and 11.

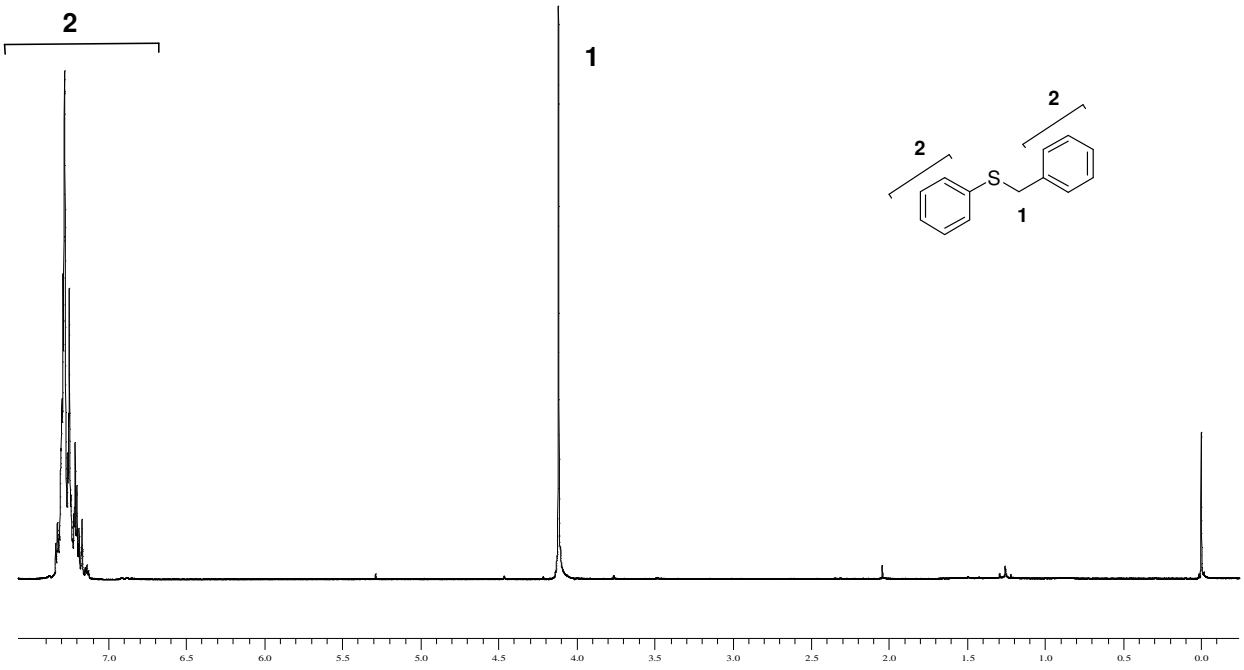


Figure 10. ^{1}H NMR (200 MHz, $CDCl_3$) spectrum of **4a**.

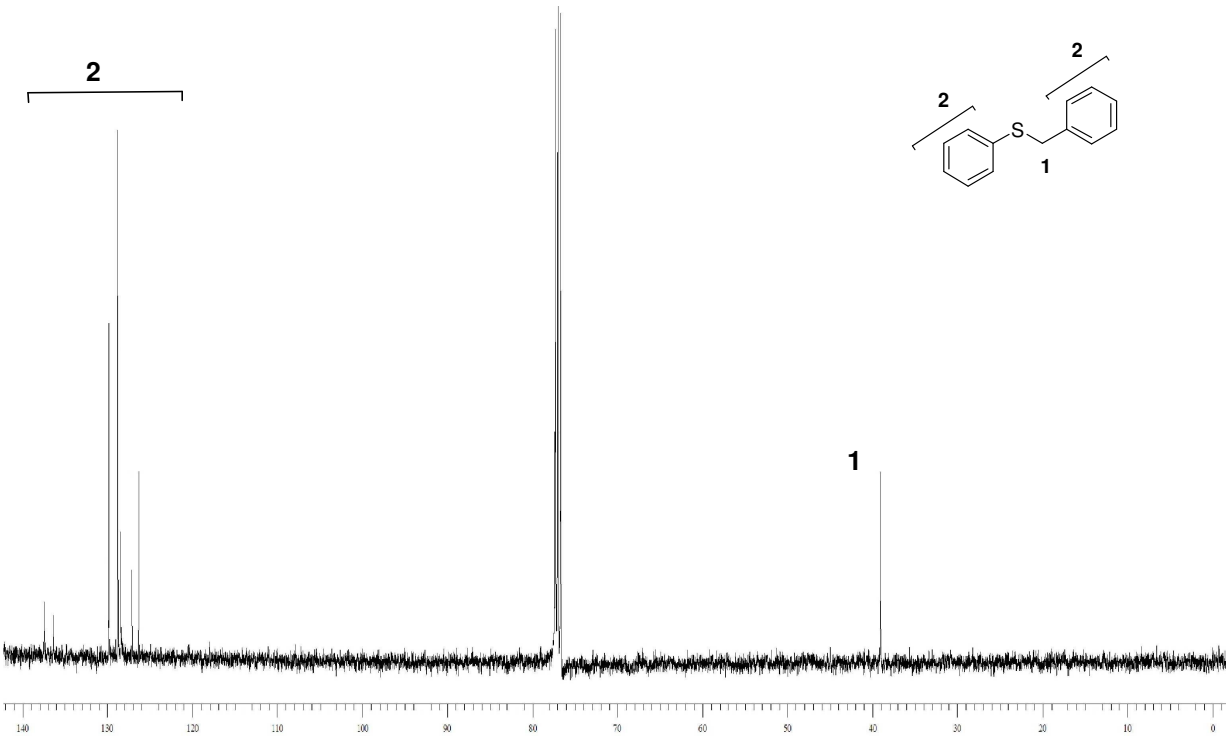


Figure 11. ^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **4a**.

2.3.2. Change of reaction color

Interestingly, the formation of the diorganyl selenides **(2a-l)** could be easily observed by the change of the reaction color from yellow to gray (Figure 12) whereas the change of the reaction color from gray to white was observed for the formation of diorganyl sulfides **(4a-l)** (Figure 13) also the reaction was monitored by TLC.

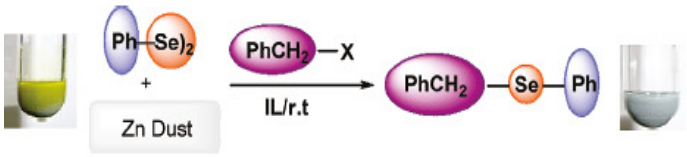


Figure 12. Change of color for the formation of diorganyl selenide.

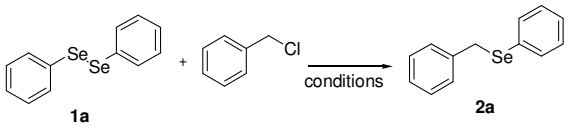
Figure 13. Change in reaction color for the formation of diorganyl sulfide.

Notably, after the change of color in the reaction assisted by visual observation (*see* reaction time in Table 3 and 4) there is no more improvement in the yield leaving to the long reaction time. The change of reaction color was captured before and after completion of the reaction and picturised in figure 12 and 13.

2.3.3. Comparison of ionic liquid mediated synthesis of 2a with conventional organic solvents:

To compare the efficiency of our protocol with the available literature reports using organic solvents we tabulated the results in Table 4. Similar protocols have appeared in the literature for reduction of PhSeSePh with zinc followed by reaction with benzyl chloride with use of other organic solvents such as MeCN and CH_2Cl_2. In a mixture of MeCN/H_2O at 65 ^{0}C the desired product **2a** was obtained in 64% yield after 3 hr, [47b] in CH_2Cl_2 at room temperature, 57 % of the yield was obtained after 5 hr[56] (Table 4, entries 1 and 2).

Table 4. Yield comparison.



Entry	Solvent	Reagents	Temp [^{0}C]	Time [hr]	Yield[%]
1	MeCN/H_2O	Zn	65	3	64
2	CH_2Cl_2	Zn	rt	5	57
3	DMF	Zn/$InBr_3$	100	1	93
4	DMF	Zn/$RuCl_3$	100	1	98
5	CH_3CN/H_2O	Zn/NaH_2PO_4	rt	1	45
6	BMIM-BF_4	Zn	rt	0.5	93

With bimetallic (In(III)/Zn) system,[48] at 100 ^{o}C the product **2a** was obtained in 93% of yield after 1hr using DMF as a solvent (Table 4, entry 3). The Zn/$RuCl_3$ system[49] in DMF gave the desired product **2a** in 98% yield at 100 ^{0}C (Table 4, entry 4). In a mixture of CH_3CN/H_2O the catalytic system

[56] A. Krief, M. Derock, D. Lacroixa, *Synlett.* **2005**, 2832.

Zn/NaH_2PO_4 gave the desired product in 45% yield with 1 hr reaction time (table 4, entry 5)[57]. These results proved that BMIM-BF_4 was found to be better reaction media than usual organic solvents (Table 4, entry 6). Therefore, we decide to analyze the influence of ionic liquid on the reaction course and it's discussed in the following section. In addition, S-S reductive cleavage involving elemental Zn dust using organic solvents was not available in the literature.

2.3.4. Effect of ionic liquid

Analyzing Table 4, it was possible to verify that the ionic liquid shows better yield as compared with the usual organic solvents. By modifying the structure of the cations or anions of ionic liquids, it has been shown that their properties can be altered in order to influence the outcomes of reactions and the reason was described in this section.

Although the improved capability of ionic liquid to accelerate many organic reactions compared to other organic solvents has been extensively reported, the origin of its behavior is still an intriguing subject of study. Properties such as strong dipolar and dispersion forces, hydrogen bond acidity (related to the cationic portion), and hydrogen bond basicity (related to the anionic portion) would account for the complex solvent interactions exhibited by ionic liquids.[58]

In previous reports hydrogen bonds have been evoked as a pivotal interaction in the formation of a given product in reactions performed in Ionic liquids.[59] Our experimental results (Table 3) suggest that perhaps the scale of hydrogen bond acidity of the tested ionic liquids may be a distinguished property for the formation of products. If one assumes that this characteristic would facilitate the reaction through the coordination of the acid hydrogen attached to C-2 in the imidazolium ring with the leaving group (chloride) in an SN_2 like reaction, the formation of products would be in the same range of yield for BMIM-BF_4, BMIM-PF_6, and BMIM-$N(Tf)_2$ due to the similarity of their hydrogen bound donor (HBD) parameters.[60] With the exception of BMIM-$N(Tf)_2$, 29% of yield for diorganyl selenide **2a** whereas 46% for diorganyl sulfide **4a** (Table 4, entry 3), BMIM-BF_4 and BMIM-PF_6 furnished the diorganyl selenide **2a** in 93% and 86% yields, respectively while 92% and 89% of yields obtained for the diorganyl sulfide

[57] L.W. Bieber, A. P. F. de Sa´, P. H. Menezes, S. M. C. Gonçalves *Tetrahedron Lett.* **2001**, *42*, 4597.

[58] M. A. P. Martins, C. P. Frizzo, D. N. Moreira, N. Zanatta, H. G. Bonacorso, *Chem. Rev.* **2008**, *108*, 2015.

[59] Selected examples: (a) T. Fischer, A. Sethi, T. Welton, J. Woolf, *Tetrahedron Lett.* **1999**, *40*, 793. (b) A. K. Chakraborti, S. R. Roy, *J. Am. Chem. Soc.* **2009**, *131*, 6902. (c) E. Baciocchi, C. Chiappe, T. D. Giacco, C. Fasciani, O. Lanzalunga, A. Lapi, B. Melai, *Org. Lett.* **2009**, *11*, 1413.

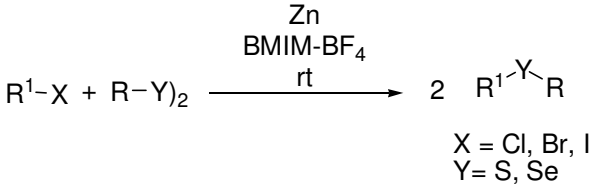
[60] (a) J. L. Anderson, J. Ding, T. Welton, D. W. Armstrong, *J. Am. Chem. Soc.* **2002**, *124*, 14247. (b) H. Tokuda, S. Tsuzuki, M. A. B. H. Susan, K. Hayamizu, M. Watanabe, *J. Phys. Chem. B.* **2006**, *110*, 19593. (c) R. Lungwitz, M. Friedrich, W. Linertc, S. Spange, *New J. Chem.* **2008**, *32*, 1493.

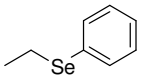
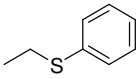
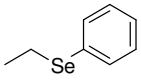
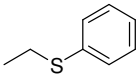
4a (Table 4, entries 5 and 4). Moreover, if the extent of hydrogen bond interactions really accounts for an effective formation of products, reactions carried in Bpy-BF_4 and BMMIM-BF_4 which have a much lower (HBD) value compared to the above-mentioned ionic liquids would result in the formation of products in lower yields. Actually, these ILs exhibited poorer activity compared to BMIM-BF_4 and BMIM-PF_6 (Table 3, entries 1 and 2). A reasonable explanation to the lower yield observed for BMIM-$N(Tf)_2$ is the influence of the anion $N(Tf)_2$.We speculate that it would interfere in the formation and/or in the reactivity of zinc selenolate, PhSeZnSePh.[61]

2.3.5. Synthesis of diorganyl chalcogenides using Zn in ionic liquid

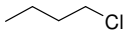
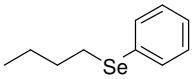
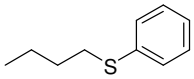
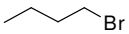
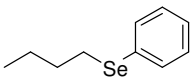
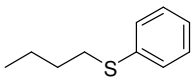
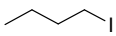
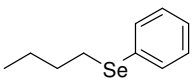
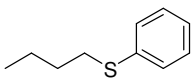
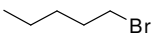
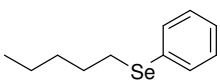
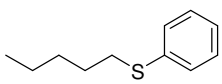
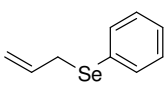
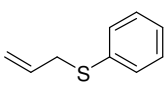
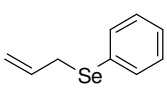
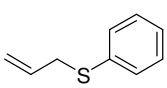
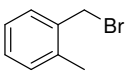
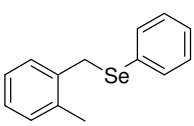
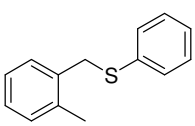
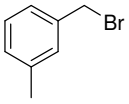
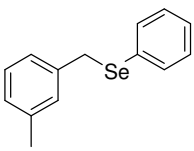
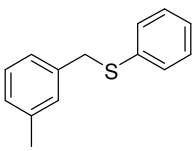
After optimization, the methodology was extended to diaryl diselenides and disulfides performing the coupling of different organic halides: alkyl, allyl, benzyl, and substituted aryl compounds were studied to check the versatility of the protocol. The results are summarized in table 5.

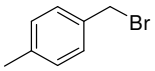
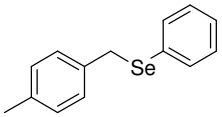
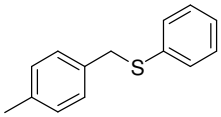
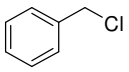
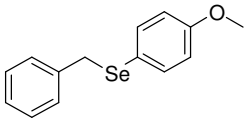
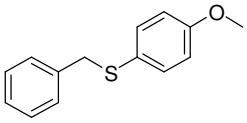
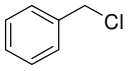
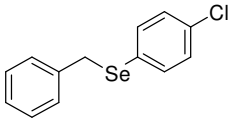
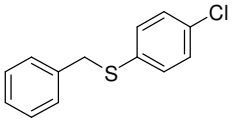
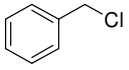
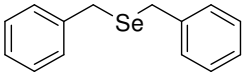
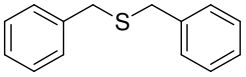
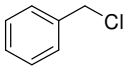
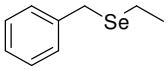
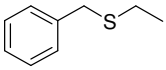
Table 5. Synthesis of diorganyl selenides and sulfides using Zn in ionic liquid.



Entry	R^1X	Product R^1YR Y= Se	Time [min] Y= Se	Yield R^1SeR [%]	Product R^1YR Y= S	Time [min] Y= S	Yield R^1SR [%]
1		 **2b**	30	80	 **4b**	20	78
2		 **2b**	35	73	 **4b**	20	72

[61] A previous report using task-specific ILs has shown that this anion is present in the coordination sphere of zinc salts: P. Nockemann, B. Thijs, K. V. Hecke, L. V. Meervelt, K. Binnemans, *Cryst. Growth Des*. **2008**, *8*, 1353.

3		 **2c**	20	82	 **4c**	20	87
4		 **2c**	20	84	 **4c**	20	93
5		 **2c**	15	89	 **4c**	20	96
6		 **2d**	25	92	 **4d**	25	97
7		 **2e**	30	94	 **4e**	5	96
8		 **2e**	20	98	 **4e**	5	99
9		 **2f**	20	79	 **4f**	10	92
10		 **2g**	25	85	 **4g**	15	95

11		 **2h**	25	98	 **4h**	15	99
12		 **2i**	40	88	 **4i**	20	92
13		 **2j**	30	82	 **4j**	20	97
14		 **2k**	35	80	 **4k**	30	83
15		 **2l**	40	77	 **4l**	30	>99

[a] Yields refer to pure isolated products characterized by ^{1}H and ^{13}C NMR.

A structurally diverse range of alkyl halides were reacted with diphenyl disulfide and diselenide under standard reaction conditions to provide the corresponding alkyl phenyl sulfides and selenides in excellent yields. By comparing the yields, diorganyl sulfides were obtained in better yield than the diorganyl selenides (Table 5; entries 1-6). These results may reflect the higher stability of zinc thiolate as compared with zinc selenolate. Alkyl halides substituted with long chain length gave better yields (Table 5; entries 2, 4, and 6).

With allylic halides the reaction was more effective and afforded the allyl phenyl sulfides **4e** in quantitative yields in a shorter reaction time as compared with the allyl phenylselenides **2e** (Table 5; entries 7 and 8). Moreover, the *ortho*, *meta*- and *para*-substituted benzyl bromides were also employed,

the highest reactivity being observed for the *para*-substituted followed by the *meta*- and *ortho*-methyl benzyl bromide (Table 5; entries 9-11) which suggests that the steric influence of the organic substrate.

Concerning the R group from the dichalcogenide, the influence of an electron-donating or an electron-withdrawing group, such as chloro and methoxy, in the aromatic rings of the diselenides and disulfides was investigated. Both diselenide and disulfide have no significant influence on the reactivity of the process, since the products were obtained in comparable yields (Table 5; entries 12 and 13).

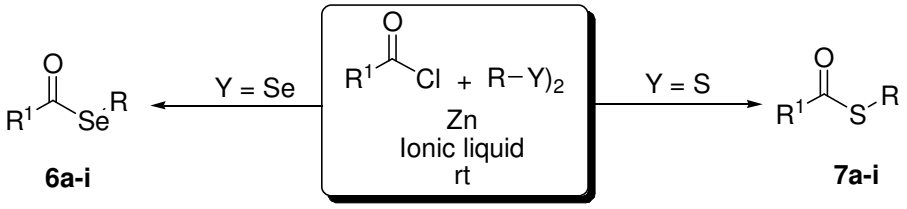
We also employed other dichalcogenide sources in this reaction, *e.g.* benzylic and alkylic. For instance, dibenzyl diselenide and dibenzyl disulfide were reacted with benzyl chloride, allowing the preparation of the desired products **2k** and **4k** in good yields (Table 5; entry 14).

Alkylic dichalcogenides were also investigated and for instance, when diethyl diselenide was reacted with benzyl chloride allowed the preparation of the desired product **2l** in 77% of yield (Table 5; entry 15). With diethyl disulfide and benzyl chloride, the product **4l** was obatined in quantitative (table 5; entry 15).

All synthesized diorganyl chalcogenides **2a-l** and **4a-l** were characterized by NMR and the analytical details available in experimental section.

2.4. Synthesis of Chalcogen esters

Based on our previous studies for the synthesis of diorganyl chalcogenides, it was observed that the zinc selenolate and zinc thiolate was generated *in situ* by using commercial available Zn dust with diphenyl diselenide/disulfide in ionic liquid. Extending the utility of our developed methodology by expanding the substrate scope such as the biological and synthetic importance of chalcogen esters is our next objective (Scheme 33).



Scheme 33

2.4.1. Optimization of reaction conditions

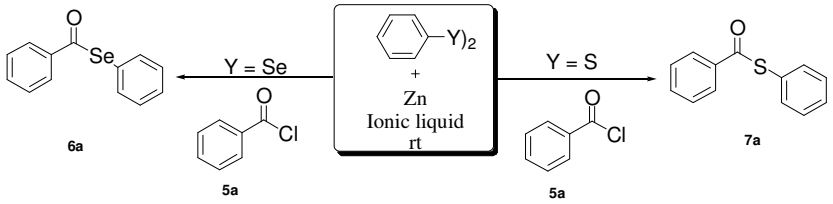
In order to identify the optimal reaction conditions, benzoyl chloride **5a** and diphenyl dichalcogenide was chosen as a test substrate. The optimization reaction was performed employing benzoyl chloride with diphenyl diselenide/disulfide and 1.6 equiv. of zinc dust with respect to dichalcogenide, in ionic liquid (0.5 mL) at room temperature. In the first set of experiments we studied the influence of different ionic liquids and the results are summarized in Table 6.

The seleno ester **6a** was obtained by reaction with diphenyl diselenide and benzoyl chloride **5a** using Zn in ionic liquid. The formation of product could be observed through change of reaction colour from yellow to gray whereas the formation of thioester **7a** was observed the colour change from gray to greyish white. In all ionic liquids the formation of chalcogen esters was observed with the different range of yield as tabulated in Table 6. By using BPy-BF_4, BMMIM-BF_4 and BMIM-$N(Tf)_2$ the formation of chalcogen ester **6a** and **7a** observed less yield as compared with BMIM-BF_4 and BMIM-PF_6 (Table 6, entries 1-5). A better conversion was obtained with BMIM-PF_6 in comparison to BMIM-BF_4 (Table 4, entries 4 and 5).

The influence of ionic liquid was already discussed in the previous section **2.3.4** during the formation of zinc chalcogenolates. A slight improvement in yield was observed using BMIM-PF_6 than BMIM-BF_4. This could be explained by the hydrophobicity of these ionic liquids.[62] In general, the BMIM-PF_6 is immiscible with water, whereas BMIM-BF_4 is water-soluble. This may lead to decrease the formation of chalcogen esters (Table 6, entries 4 and 5). Next we examined the amount of Zn required to cleave the Se-Se/S-S bond to afford the corresponding product. When 1.2 and 1.0 equiv. of Zn related to dichalcogenide moiety, the yields were quite similar and as a result we consider 1.0 equiv. Zn is enough to promote the reaction (Table 6, entries 6 and 7).

[62] J. H. Davis, P. A. Fox, *Chem. Comm.,* **2003**, *11*, 1209.

Table 6: Optimization for the synthesis of seleno- and thioesters.



Entry	Ionic Liquid[a]	Time (min) Y= S, Se		Yield [%][b] Y= S, Se	
		Y=S	Y=Se	Y=S	Y=Se
1	Bpy-BF_4	10	15	54	46
2	BMMIM-BF_4	10	15	77	69
3	BMIM-NTf_2	10	15	65	58
4	BMIM-PF_6	2	3	>99	97
5	BMIM-BF_4	2	3	92	95
6[c]	BMIM-PF_6	2	3	>99	97
7[d]	BMIM-PF_6	2	3	>99	95

[a] Ionic liquids were subjected to vacuum before use. [b] Yields refer to pure isolated products. [c] 1.2 equiv. of zinc dust was used. [d] 1.0 equiv. of zinc dust was used.

In general, our methodology provides the seleno- and thioesters in a short time, at room temperature, under neutral and mild conditions with good to excellent yields. Hence, the optimum conditions for the synthesis of seleno- and thioesters were 1.0 equiv. of acyl chloride, 0.5 equiv. of diaryl diselenide/disulfide, 0.5 equiv. of Zn dust and 0.5 mL of BMIM-PF_6, at room temperature in 2-3 min reaction time.

The seleno ester **6a** was characterized by NMR and its ^{1}H NMR (Figure 14) shows the two aromatic protons as a multiplet between δ 7.92 and 7.94. The three aromatic protons show as multiplet between δ 7.58 and 7.63. A multiplet between δ 7.42 and 7.50 belongs to the five aromatic protons. In ^{13}C NMR the carbonyl peak appeared at δ 193.7 and the other aromatic carbon peaks appeared at δ 138.9, 138.4, 136.7, 134.2, 129.7, 129.4, 129.3, 127.7, 126.1 depicted in Figure 15.

Also, the thioester **7a** was confirmed by NMR and its ^{1}H NMR shows a multiplet between δ 8.0–8.03 represents two aromatic protons. Followed by the other eight protons appeared as a multiplet between δ 7.41 and 7.59 as depicted in Figure 16. The ^{13}C NMR (Figure 17) shows the carbonyl peak at δ

189.9 while the rest of aromatic carbon peaks appeared at δ 136.5, 135.0, 133.5, 129.4, 129.1, 128.6, 127.3 and 127.2.

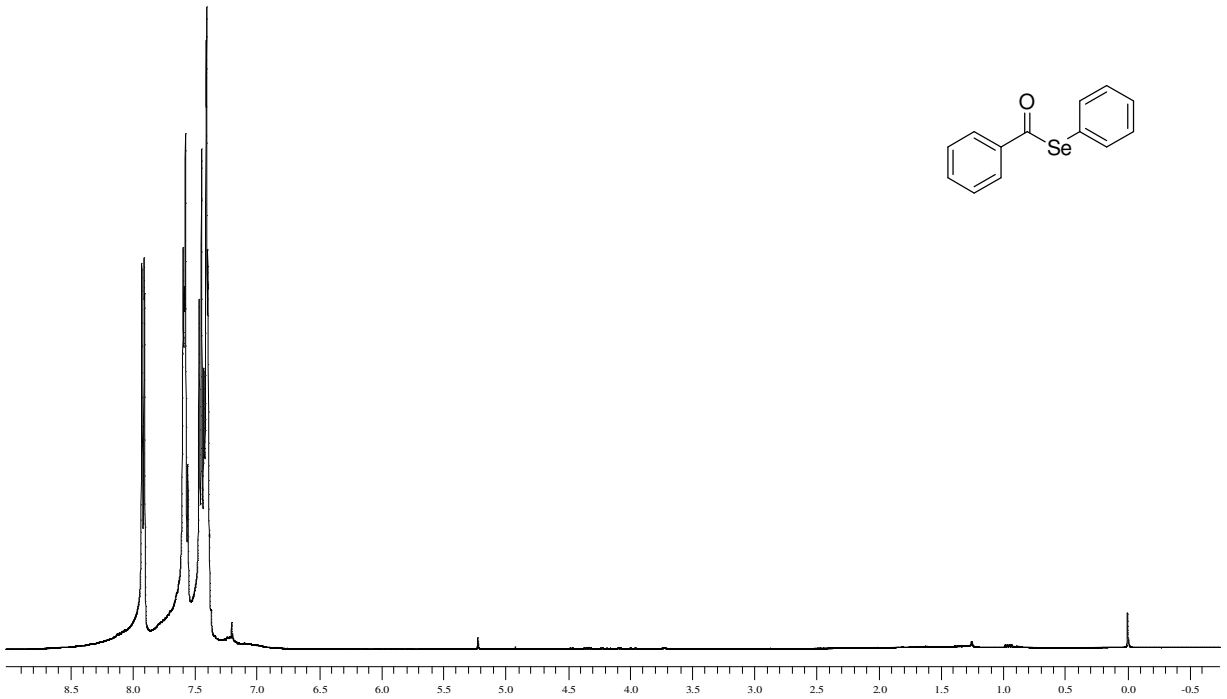


Figure 14. ^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6a**.

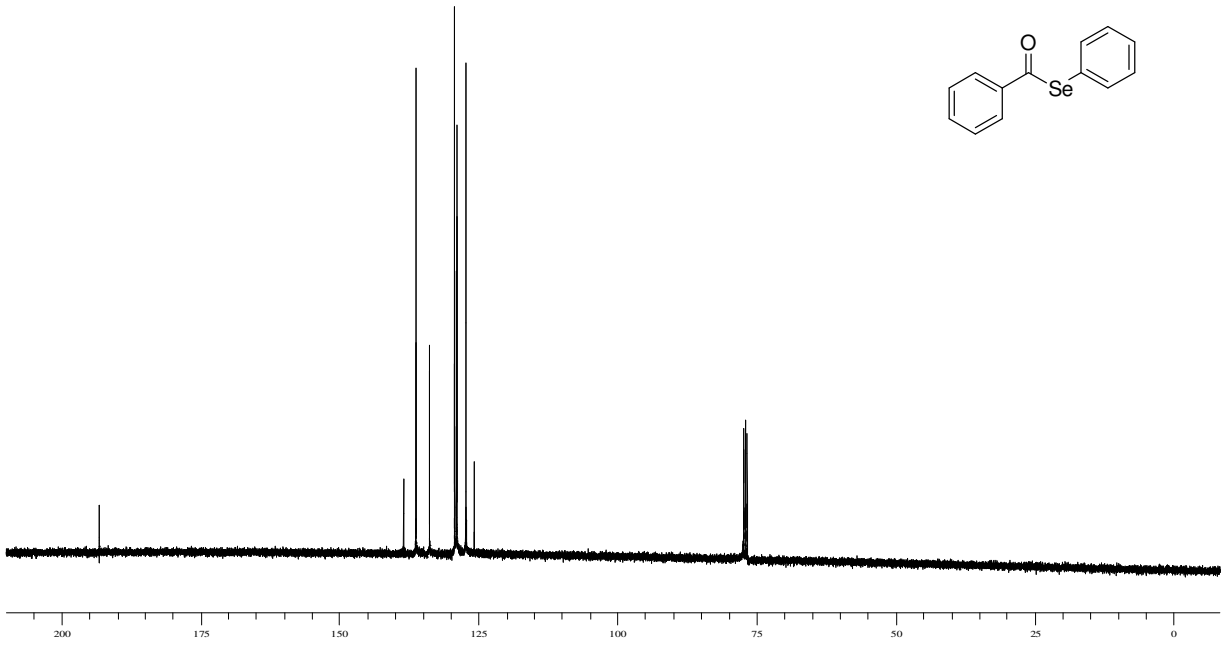


Figure 15. ^{13}C NMR ($CDCl_3$, 100 MHz) Spectrum of **6a**.

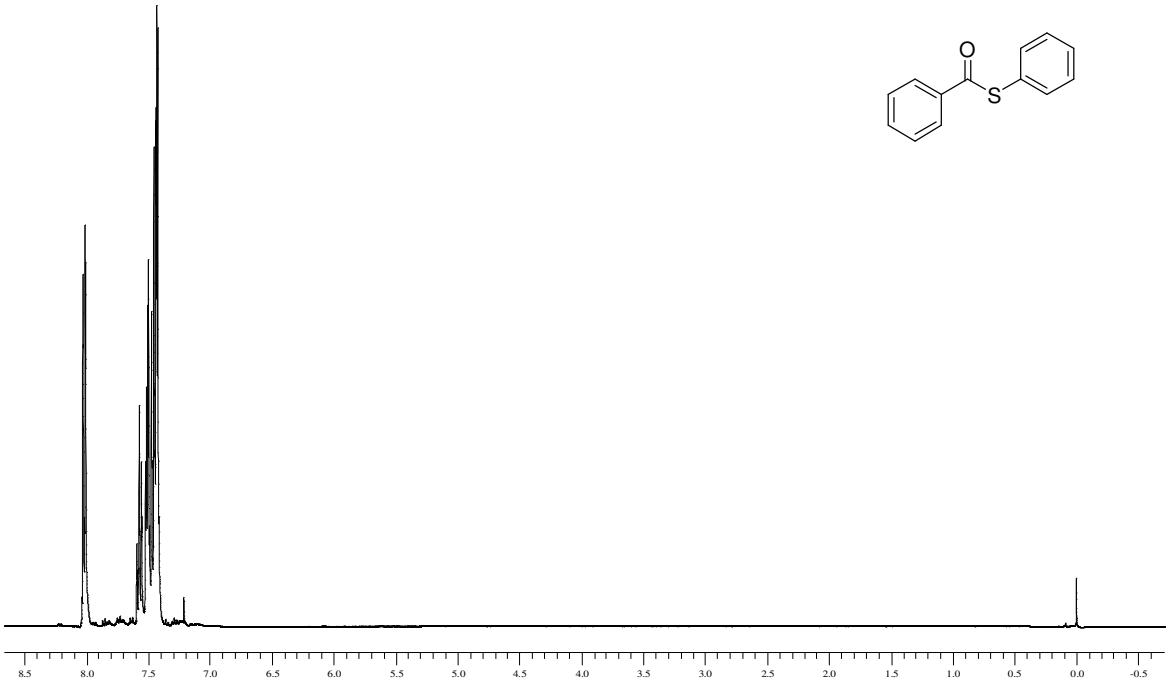


Figure 16. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7a**.

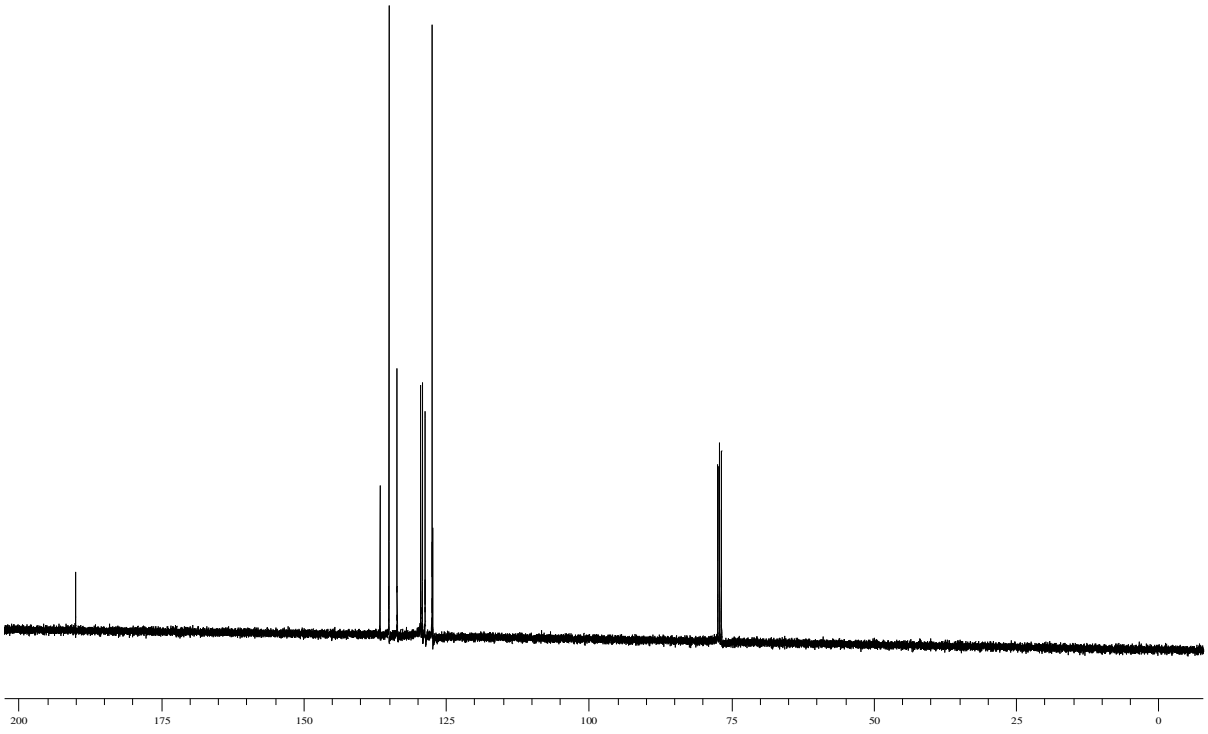
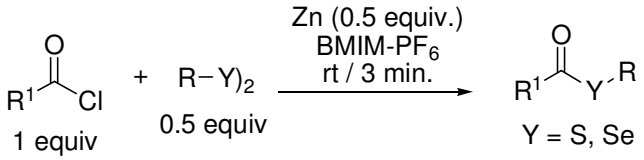


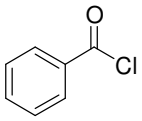
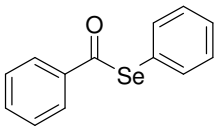
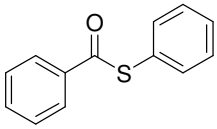
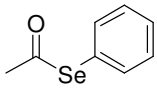
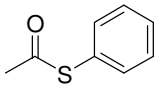
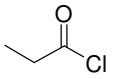
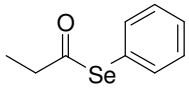
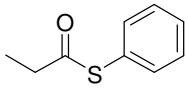
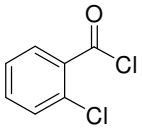
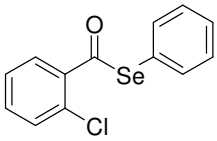
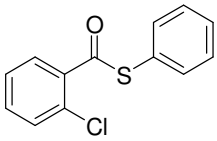
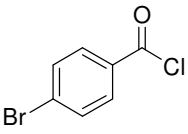
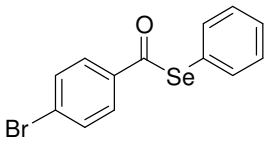
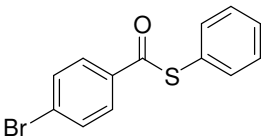
Figure 17. ^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7a**.

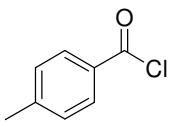
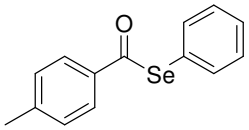
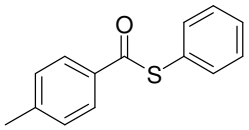
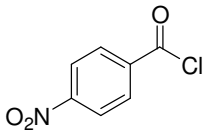
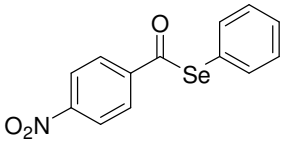
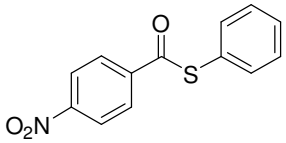
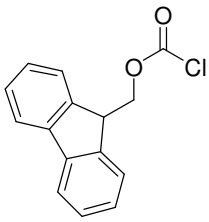
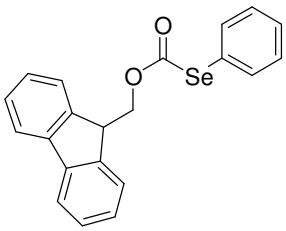
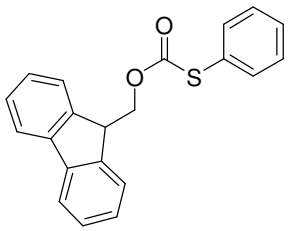
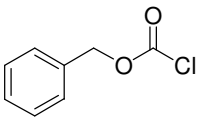
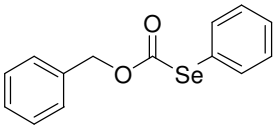
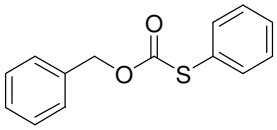
2.4.2. Synthesis of chalcogen esters using Zn in ionic liquid

After the optimization, we performed a series of reactions under standard conditions using different kinds of acyl chlorides with diaryl diselenides/ disulfides to synthesize the seleno- and thioesters in good to excellent yields, as depicted in Table 7.

Table 7. Synthesis of seleno- and thioesters.



Entry	Acyl halide	Product	Yield[%][a] Y= Se	Product	Yield[%][a] Y= S
1	 **5a**	 **6a**	95	 **7a**	>99
2	 **5b**	 **6b**	39	 **7b**	42
3	 **5c**	 **6c**	57	 **7c**	68
4	 **5d**	 **6d**	94	 **7d**	92
5	 **5e**	 **6e**	82	 **7e**	87

6	 **5f**	 **6f**	89	 **7f**	93
7	 **5g**	 **6g**	72	 **7g**	77
8	 **5h**	 **6h**	89	 **7h**	91
9	 **5i**	 **6i**	81	 **7i**	85

[a] Yields for pure isolated products characterized by ^{1}H and ^{13}C NMR.

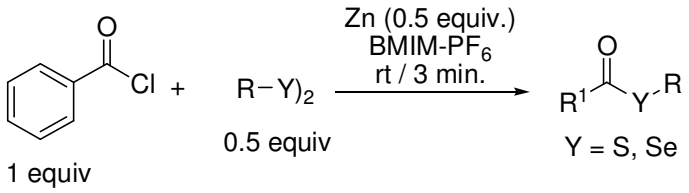
In general, employing our standard reaction conditions the thioesters were obtained in good yield as compared with selenoesters. Initially, aliphatic acyl chlorides were used in order to check the reaction course. The aliphatic acyl chlorides react with the dichalcogenide moiety affording alkylic selenoesters **6b-c** and thioesters **7b-c** in moderate yields (Table 7, entries 2 and 3).

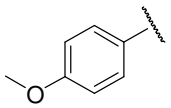
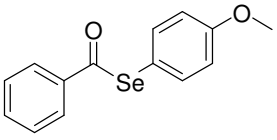
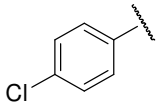
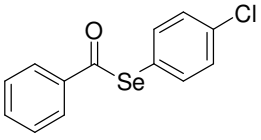
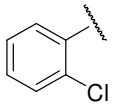
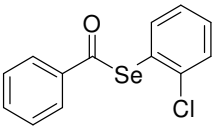
In terms of electronic effects, it was possible to verify that the reaction was more sensitive to the acid chloride than the dichalcogenide moiety. By using benzoyl chloride **5a** (without substituent) and *p*-methyl benzoyl chloride **5f** (electron donating group) the reaction proceeds efficiently and the chalcogenoesters were obtained in excellent yields (Table 7, entries 1 and 6). When electron withdrawing groups were attached to the acyl chloride **5d-e** the product (**6d-e; 7d-e**) was obtained in good yield (Table 7, entries 4 and 5). For instance, a strong electron withdrawing group, such as the nitro attached to acyl chloride **5g**, affords 77% of thioester **7g**, whereas 72% yield was obtained for selenoesters **6g** (Table 7, entry 7).

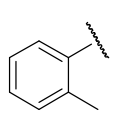
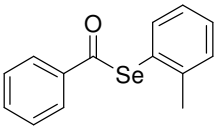
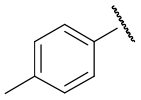
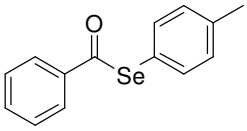
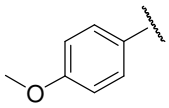
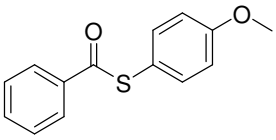
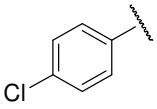
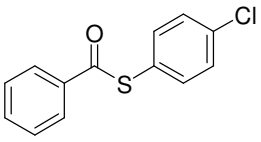
To improve the scope of our methodology, next we attempted to synthesize a seleno- and thiocarbonate bearing interesting functionalities, since they can act as a protecting group. In this context, when we used benzyl chloroformate **5i** and 9-fluorenylmethyl chloroformate **5h** the corresponding chalcogen esters **6h-i** and **7h-i** were obtained in good yields (Table 7, entries 8 and 9).

Inspired by the results obtained in Table 7, we focused reaction with benzoyl chloride **5a** and different dichalcogenide moieties for the synthesis of chalcogenoesters and the results were summarized in Table 8. In the diselenide moiety, a lower yield was observed by using *o*-chloro diphenyl diselenide **1d** as a selenium source compared with *p*-chloro diphenyl diselenide **1c** (Table 8, entries 2 and 3). These observations can be explained by electronic availability of dichalcogenide in this reaction, driving better yields for the less sterically hindered *para* substituted dichalcogenides. Good yields were obtained with electron donating groups attached to the dichalcogenides moiety, both in *ortho*- or *para*-positions (Table 8, entries 1, 4, 5 and 6). The reactions followed the same tendency observed in the organochalcogenide preparation allowing the synthesis of thioesters in slightly better yields than selenoesters. (Table 8, entries 1, 2 and 6, 7 respectively).

Table 8. Synthesis of chalcogenoesters using benzoyl chloride with different dichalcogenide moieties.

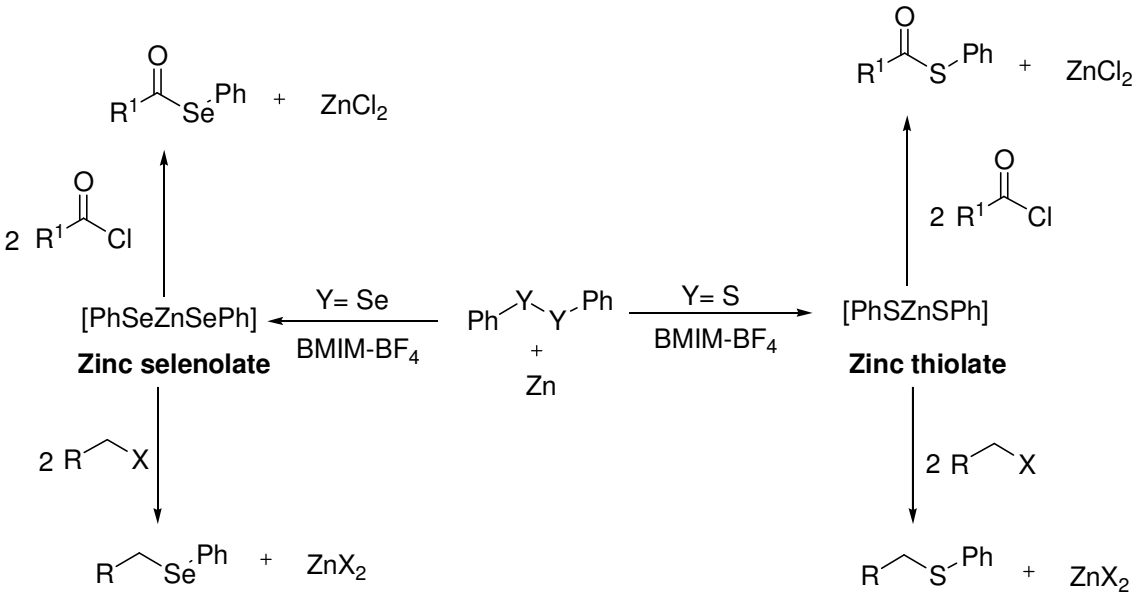


Entry	RY)$_2$	Product	Yield[%]
1	 **1b**	 **6j**	90
2	 **1c**	 **6k**	80
3	 **1d**	 **6l**	66

4	 **1e**	 **6m**	75
5	 **1f**	 **6n**	81
6	 **2b**	 **7j**	93
7	 **2c**	 **7k**	82

2.4.3. Mechanism for the preparation of diorganyl chalcogenides and chalcogen esters

To propose the plausible mechanism for the effective formation of diorganyl chalcogenides and chalcogen esters using Zn in ionic liquid we would account few aspects from the available literatures. [48] Recently, an elegant synthesis of stable PhSeZnX (X = Cl or Br) species prepared from PhSeX and Zn, which act as nucleophiles toward a series of electrophiles. However, we reasoned that for our purposes use of diselenides and elemental zinc would be more attractive since we would be able to prepare *in situ* a wide range of selenium species (zinc selenolate) that act exactly in the same way as those mentioned above.[46, 52] The same case was speculated for the generation of zinc thiolate from diphenyl disulfide. The effective zinc chalcogenolate intermediate would further react with the corresponding organic halide leading to the formation of diorganyl chalcogenides and chalcogen esters and the probable mechanism depicted in Scheme 34.



Scheme 34

In BMIM-PF_6, the selenoester **6a** was achieved 95% yield as compared reaction with Zn/$AlCl_3$ in DMF at 65 ^{0}C gave the desired product **6a** in 85% yield with 3 hr reaction time. The improved yield and efficiency of ionic liquid is better than organic solvents this could be explained reactions involving polar or charged intermediates such as zinc chalcogenolates which could become more long-lived in ionic liquid medium. This is the probable reason that the improved yield was obtained using ionic liquid as compared with the conventional organic solvents.

2.4.4. Reuse of reaction media

A great deal of interest has been laid in the application of ionic liquid especially its recyclability which is one of our objectives. For this reason, we continued our study by exploring the reusability of the reaction media.

After completion of the reaction (synthesis of diorganyl chalcogenides and chalcogen esters), the ionic liquids were partitioned with diethyl ether, and the crude products were extracted into the diethyl ether phase. The residual ionic liquid/BMIM-BF_4 was diluted in ethanol and filtered through a celite pad to remove the inorganic materials followed by concentration to remove the organic solvents and being subjected to vacuum for 1 hour to eliminate moisture and trace organic solvents to obtain the solvent and moisture free recovered ionic liquid. The same procedure was used for BMIM-PF_6 to recover the ionic

liquid. The recovered ionic liquid was used for the subsequent runs. As shown in Figure 18, for the following four runs the recovered ionic liquids showed similar efficiency.

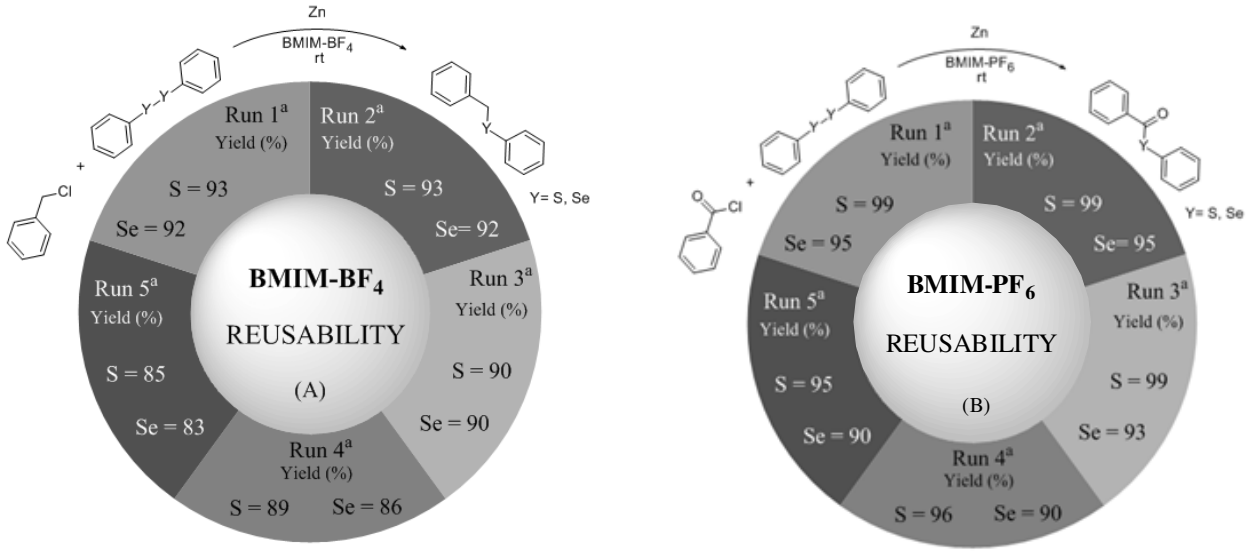


Figure 18. Reuse of ILs: (A) BMIM-BF_4; (B) BMIM-PF_6. [a] Yields refer to pure isolated products as characterized by ^1H and ^{13}C NMR

2.5. Application

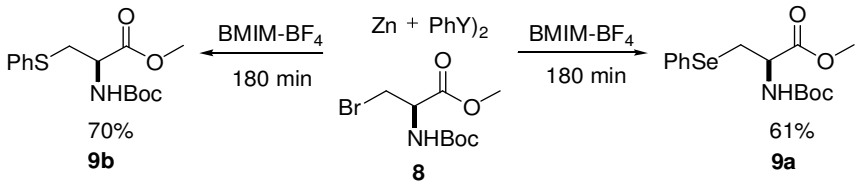
Expanding broader versatility of our methodology has been directed toward the development of a more complex functionality, such as biologically important cysteine[63, 64] and selenocysteine[4] derivatives. Moreover, the potential importance of selenocysteine, the 21st proteinogenic amino acid, which belongs to the active site in the enzymes such as glutathione peroxidase (GPx), iodothyronine deiodinase (ID) and thioredoxin reductase (TrxR).[2a] Thus, it is of high interest to develop novel routes for efficient synthesis of cysteine and selenocysteine. However, a tricky challenge still remains to develop novel synthetic methods that can permit the introduction of selenium and sulfur into optically active amino acids, which could be widely explored as building blocks for the synthesis of seleno and sulfur-peptides and derivatives. Hence, we used our methodology to synthesize such class of compounds and discussed in the following sections.

[63] M. D. Wendt, S. W. Elmore, *J. Med. Chem.* **2006,** *49,* 1165.

[64] For the synthesis of selenocysteine and their analogues, see: (a) H. J. Reich, C. P. Jasperse, J. M. Renga, *J. Org. Chem.* **1986**, *51*, 2981. (b) K. Hashimoto, M. Sakai, T. Okuno, H. Shirahama, *Chem. Commun*. **1996**, 1139. (c) N. M. Okeley, Y. Zhu, W. A. van der Donk, *Org. Lett*. **2000**, *2*, 3603. (d) M. D. Gielsman, L. Xie, W. A. van der Donk, *Org Lett*. **2001**, *3,* 1331. (e) S. V. Ley, A. Priour, C. Heusser, *Org. Lett.* **2002**, *4*, 711. (f) R. G. Bhat, E. Porhiel, V. Saravanan, S. Chandrasekaran, *Tetrahedron Lett.* **2003**, *44*, 5251. (g) A. H. G. Siebum, W. S. Woo, J. Raap, J. Lugtenburg, *Eur .J. Org. Chem*. **2004**, 2905.

2.5.1. Synthesis of cysteine and selenocysteine

The bromo aminoester (**8**) was prepared [65] and further used for the synthesis of chalcogeno–cysteine derivatives **9a-b.** Reaction with diphenyl diselenide and **8** gave the selenocysteine **9a** in 61% yield at room temperature. The cysteine derivative **9b** with a yield of 70% obtained from the reaction with diphenyl disulfide and **8** using Zn in ionic liquid at room temperature (Scheme 35). These reactions provide an efficient and powerful tool for chalcogeno–cysteine construction using simple starting materials.



Scheme 35

The compound **9a** was characterized by NMR and its ^{1}H NMR shows a multiplet appeared between δ 7.56 and 7.51 represents two aromatic protons (**H-1**) and another multiplet appeared between δ 7.23 and 7.28 belongs to three aromatic protons (**H-1**). A broad singlet from NH- proton appeared at δ 5.42 (**H-2**). The chiral single proton appeared as a multiplet in the region between δ 4.67 to 4.61(**H-3**).The singlet peak at δ 3.48 represents the methoxy protons (**H-5**). The methylene proton (**H-4**) appeared as a multiplet between δ 3.33 and 3.31. At δ 1.41 a singlet peak appeared which belongs to the nine protons from the Boc group (**H-6**). The spectrum is depicted in Figure 19.

In Figure 20, the ^{13}C NMR of **9a** shows the ester carbonyl peak at δ 170.90 and the ester from the Boc group appeared at δ 154.78. The aromatic carbons appeared at δ 133.52, 128.94 and 127.35.The tertiary carbon shows at δ 79.81. The rest of the carbons appeared at δ 53.07, 52.06, 30.48 and 28.07.

[65] E. M. Stocking, J. N. Schwarz, H. Senn, M. Salzmann, L. A. Silks, *J. Chem. Soc., Perkin Trans*. **1997**, *1*, 2443.

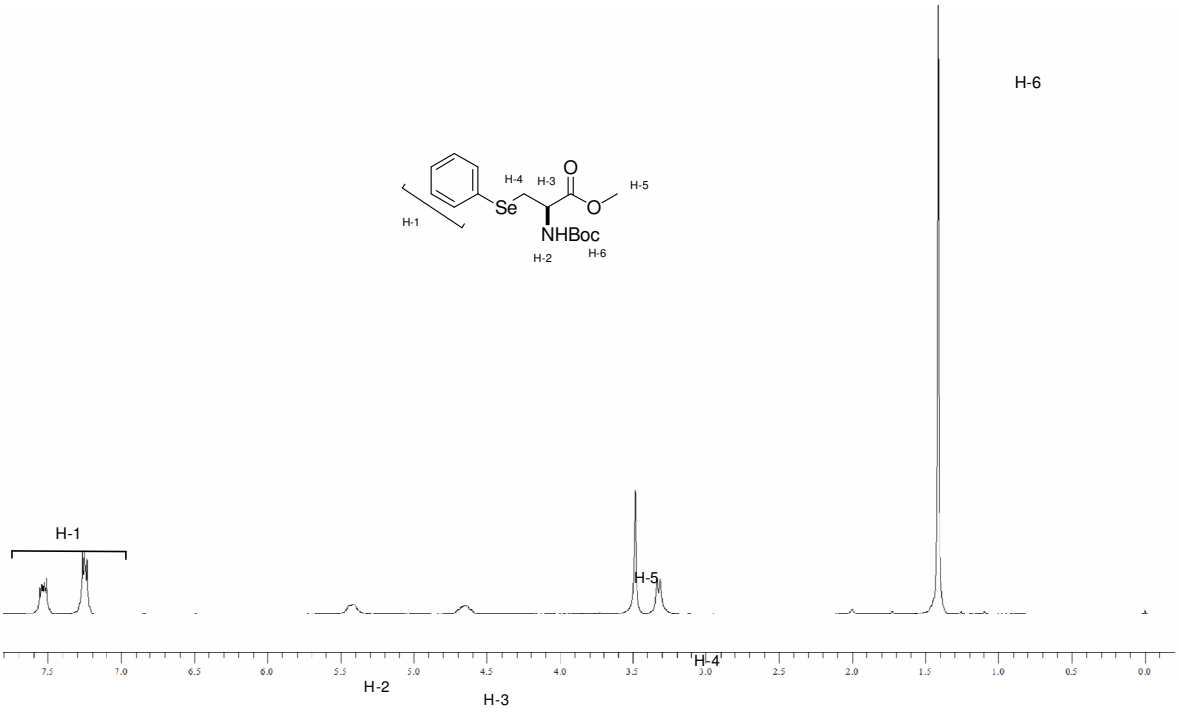


Figure 19. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **9a**.

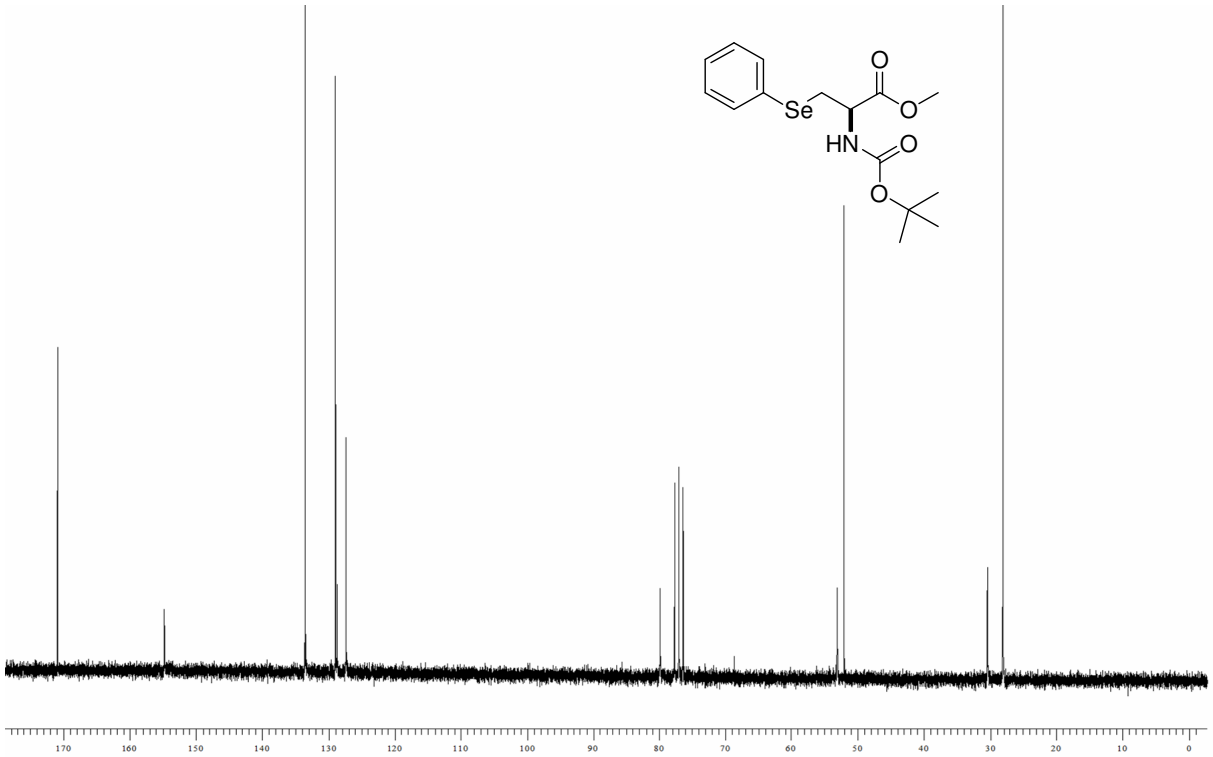


Figure 20. ^{1}H NMR (100 MHz, $CDCl_3$) spectrum of compound **9a**.

Conclusion

3. Conclusion

In conclusion, we have successfully accomplished our main objective to generate the chalcogen nucleophilic species using reducing agents in ionic liquid. In a first moment, we employed InI as a reducing agent to promote the cleavage of the Se-Se bond and satisfactory results were obtained.[66] These results drove us to find more efficient and economic methodology to generate chalcogenolate reactive species using Zn in ionic liquid. The zinc chalcogenolate which would further react with organic halides and acyl chlorides leading to the formation of diorganyl chalcogenides and chalcogen esters in excellent yield as compared to previously known approaches.[67] The main noteworthy features of the present method are the excellent yields obtained in a very short reaction time for the synthesis of diorganyl chalcogenides and chalcogenoesters. Other noteworthy features of this methodology are:

(1) Ease of handling and better safety aspects as compared with the metal hydrides.

(2) Neutral reaction conditions (room temperature as well).

(3) Easy access to check the formation of the product (*via* visual observation).

(4) From the industrial point of view the present method is less expensive, *e.g.,* it involves commercially available Zn which is comparatively costless than the La, In, InI, Yb and SmI_2 used in classical processes.

(5) Eliminate the use of unpleasant odor thiols and selenols.

(6) The solvent/ionic liquid offers better performance combined with reusability.

Also, our methodology has excellent generality, having been applied to the synthesis of chiral β–chalcogen amine derivatives, biologically active chalcogeno-cysteine derivatives displaying diverse functionalities of relevance to medicinal chemistry. These advantages make our procedure very attractive as compared with those previously reported in the literature.

On account of these findings, we believe that our protocol could find wide application in organic synthesis. Further investigations into the utility of this novel methodology are underway in our laboratory aiming at the synthesis of C-Y (Y= S, Se, Te) bond formation by transition-metal oxide nanoparticle catalyzed transformations, as well as extending their utility by expanding the substrate scope. Finally, this PhD thesis work results two international publications and few related articles are in progress for publications.

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[66] S. Narayanaperumal, E. E. Alberto, F. M. de Andrade, E. J. Lenardão, P. S. Taube, A. L. Braga, *Org. Biomol. Chem.* **2009**, *7*, 4647.

[67] S. Narayanaperumal, E. E. Alberto, K. Gul, O. E. D. Rodrigues, A. L. Braga, *J. Org. Chem.* **2010**, *75*, 3886.

Experimental Section

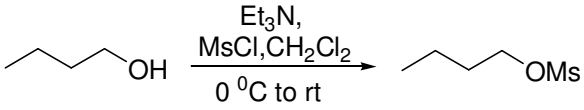
4.1. General

^{1}H and ^{13}C NMR spectra were recorded at 400 and 200 MHz respectively with tetramethylsilane as internal standard. Column chromatography was performed using Merck Silica Gel (230-400 mesh). Thin layer chromatography (TLC) was performed using Merck Silica Gel GF254, 0.25 mm thickness. For visualization, TLC plates were either placed under ultraviolet light, or stained with iodine vapor, or acidic vanillin. All solvents were used as purchased unless otherwise noted. The diselenides, disulfides, and halides were used as purchased.

4.2. Synthesis of Room temperature ionic liquids

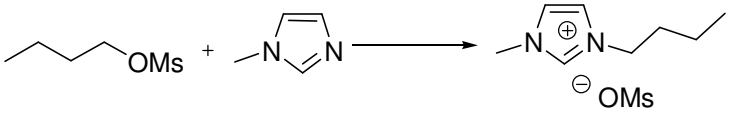
To synthesize the ionic liquids the following systematic procedure were used and discussed in the following section.

4.2.1. Synthesis of butyl methanesulfonate



Methanesulfonyl chloride (91.6 g, 0.8 mol) was added (over 45 min), with vigorous stirring, to a solution of n-butanol (59.2 g, 0.8 mol) and triethylamine (80.8 g, 0.8 mol) in dichloromethane (750 mL). An external water-ice bath was used to control the reaction mixture temperature between 10 –20 ^{0}C. After addition, stirring was continued for further 2 h. at room temperature. Water (300 mL) was added, the aqueous layer containing the triethyl ammonium chloride by-product was separated; the organic layer was washed with water (200 mL) and dried with sodium carbonate. Solvent evaporation followed by reduced pressure distillation of the residue afforded the desired butyl methanesulfonate, as a colorless liquid.

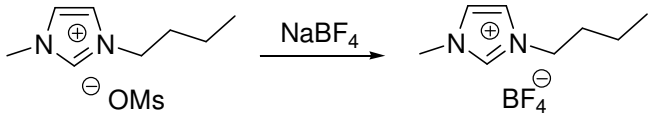
4.2.2. 1-Butyl-3-methylimidazolium Methanesulfonate



Butyl methanesulfonate (152.1 g, 1.0 mol) was mixed with 1-methyl imidazole (82.07 g, 1.0 mol) and the reaction mixture was kept at room temperature by means of an external water bath. After 24 h, one crystal of 1-butyl-3-methyl imidazolium methanesulfonate was added and the resulting crystalline reaction mass was kept at room temperature for a further 72 h. Recrystallization was performed twice using acetone as solvent (250 mL; from reflux temperature to freezer temperature overnight). After

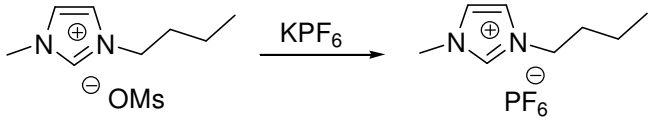
vacuum drying, colorless and very hygroscopic crystals of 1-butyl-3-methylimidazolium methanesulfonate were obtained.

4.2.3. 1-Butyl-3-methylimidazolium Tetrafluoroborate BMIM-BF_4



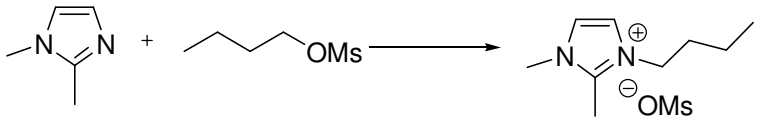
A mixture of 1-butyl-3-methylimidazolium methanesulfonate (41.0 g, 175 mmol), sodium tetrafluoroborate (21.25 g, 193.5 mmol) and distilled water (37 mL) was vigorously stirred for 30 min. The lower aqueous phase was separated and discarded and, to the remaining liquid, sodium tetrafluoroborate (1.5 g, 13.65 mmol) and distilled water (3 mL) were added. Stirring was continued for 15 min and dichloromethane (100 mL) was added. The organic phase was separated, dried with $MgSO_4$ and filtered. Solvent evaporation afforded the desired 1-butyl-3-methylimidazolium tetrafluoroborate as a pale amber liquid.

4.2.4. 1-Butyl-3-methylimidazolium Hexafluorophosphate BMIM-PF_6



A mixture of 1-butyl-3-methylimidazolium methanesulfonate (36.6 g, 157 mmol), potassium hexafluorophosphate (30.2 g, 164 mmol) and distilled water (83 mL) was vigorously stirred for 30 min. The upper aqueous phase was separated and discarded and, to the remaining liquid, potassium hexafluorophosphate (1.4 g, 7.7 mmol) and distilled water (13 mL) were added. Stirring was continued for 15 min and dichloromethane (83 mL) was added. The organic phase was separated, dried with sodium carbonate and filtered. Solvent evaporation afforded the desired 1-butyl-3-methylimidazolium hexafluorophosphate as a colorless liquid.

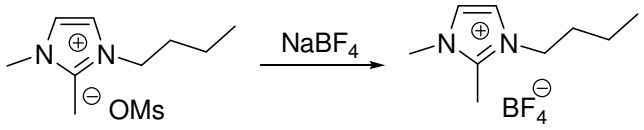
4.2.5. 1,2-Dimethyl-3-butylimidazolium Methanesulfonate



A mixture of 1,2-dimethylimidazole (96.02 g, 1.0 mol) and butyl methanesulfonate (152.05 g, 1.0 mol) was kept at room temperature for 96 h. The resulting crystalline mass was recrystallized twice with

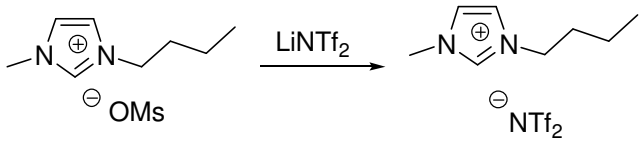
acetone (2.0 L), yielding hygroscopic colorless crystals of 1,2-dimethyl-3-butylimidazolium methanesulfonate.

4.2.6. 1,2-Dimethyl-3-butylimidazolium Tetrafluoroborate BMMIM-BF_4



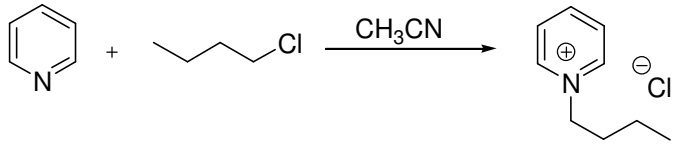
The same procedure discussed in section 4.2.3 was followed to exchange the counter ion.

4.2.7. 1-Butyl-3-methylimidazolium bis(trifluoromethane)sulfonimidate BMIM-NTf_2



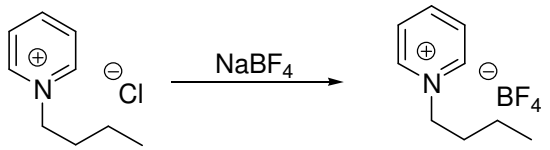
N-Lithium bis(trifluoromethane)sulfonimide salt (25 g, 87 mmol) was dissolved in water (13 mL) and 1-butyl-3-methylimidazolium methanesulfonate (19.3 g, 82.5 mmol) was also dissolved in water (32 mL). Both solutions were mixed, vigorously stirred for 30 min and dichloromethane (100 mL) was added. The organic phase was separated, washed with water (15 mL) and dried with sodium carbonate. Solvent evaporation afforded the desired 1-butyl-3-methylimidazolium bis (trifluoromethane) sulfonimidate as a colorless liquid.

4.2.8. 1-Butyl-pyridinium chloride



Pyridine (91.6 g, 200 mmol) was added (over 45 min), to a solution of n-chloro butane (59.2 g, 200 mmol) in acetonitrile (75 mL). This mixture is allowed to stir 12 hr at 75 0C. After that, acetonitrile was evaporated using roto evaporator followed by washing with ether to remove the unreactive starting materials followed by reduced pressure under vacuum afforded the desired butyl pyridinium chloride, as a turbid crystals .

4.2.9. 1-Butyl-pyridinium Tetrafluoroborate Py-BF_4



The same procedure discussed in section 4.2.3 was used to exchange the counter ion.

4.3. Preparation of diorganyl selenides (2a-l) promoted by InI:

In a schlenk tube, to a stirred solution of BMIM-BF_4 (0.5 mL) was added indium (I) iodide (121 mg, 0.5 mmol) and diphenyl diselenide (156 mg, 0.5 mmol) at room temperature under nitrogen. The mixture was allowed to stir for 5 min. Then organic halide (1 mmol) was slowly added. The reaction mixture was stirred for another 30 min (checked by TLC), the mixture was then extracted with ether (3 x 15 mL), and the combined ether extract was washed with brine, dried ($MgSO_4$), and evaporated to leave the crude product. Following purification by column chromatography over silica gel (hexane/ether 95:5) furnished the corresponding products (**2a-l**).

4.4. General procedure for the synthesis of diorganyl selenides (2a-l) and sulfides (4a-l):

Commercially available Zn dust (33 mg, 0.5 mmol) and PhSeSePh/PhSSPh (0.5 mmol) were added to BMIM-BF_4 (0.5 mL) at room temperature under nitrogen. The mixture was allowed to stir for 2-3 min. Then corresponding organic halides (1 mmol) was slowly added. The reaction mixture was allowed to stir until the color change (monitored by TLC and assisted by visual observation). The mixture was then extracted with ether (3 x 15 mL), and the combined ether extract was washed with brine, dried ($MgSO_4$), and evaporated to leave the crude product. Purification by column chromatography over silica gel (hexane/ethyl acetate 98:2) furnished the corresponding products.

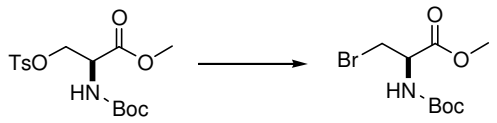
4.5. General procedure for the synthesis of selenoester (6a-n) and thioesters (7a-k):

Commercially available Zn dust (0.5 mmol) and PhSeSePh or PhSSPh (0.5 mmol) were added to BMIM-PF_6 (0.5 mL) at room temperature under nitrogen. Followed by the addition of acyl chloride (1 mmol) was slowly added. The reaction mixture was stirred for another 2-3 min (monitored by TLC and assisted by visual observation). The mixture was then extracted with ether (3 ×15 mL), and the combined ether extract was washed with brine, dried ($MgSO_4$) and evaporated to leave the crude product. Purification by column chromatography over silica gel (hexane/ethyl acetate 90:10), furnished the pure product.

4.6. Representative Experimental Procedure To Reuse BMIM-BF_4 and BMIM-PF_6:

After the workup of the first run, BMIM-BF_4/BMIM-PF_6 is diluted in ethanol, filtered through a celite pad, and then subjected to the vacuum for 1 h. For the following run the recovered ionic liquid was used after addition of 1 equiv of Zn (33 mg, 0.5 mmol), diphenyl diselenide/disulfide (0.5 mmol), and organic halide (1 mmol) followed by the procedure described in section 4.3 and 4.4.

4.7. Synthetic procedure for the preparation bromo amino ester (8)



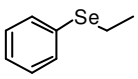
8

In a round-bottom flask, Ts-protected amino ester (2.5 g, 6.7 mmol), 4.0 equiv. of NaBr (2.76, 26.77 mmol) in dry acetone (125 mL) was added. The mixture was refluxed, under N_2, for 12 h (monitored by TLC analysis; 30% ethyl acetate–hexanes, v/v). The reaction mixture was cooled to ambient temperature. Filtration, followed by removal of the volatiles *in vacuo*, gave rise to a yellow–white solid. Ethyl acetate (3 x 25 mL) was added and the solution was washed with saturated aqueous $Na_2S_2O_3$. The ethyl acetate solution was dried over $MgSO_4$. The resulting solution was then filtered and reduced to give the crude product **8**. Purification of **8** by column chromatography afforded the starting material **8**.

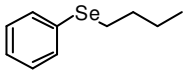
4.8. Synthetic procedure for the preparation of chalcogeno-cysteine (9a-b)

In a schlenk tube, under argon atmosphere bromo amino ester **8** (1.0 mmol) and diphenyl diselenide/disulfide (0.5 mmol) , Zn (0.5 mmol) were stirred in BMIM-BF_4 (0.5 mL) at room temperature. After completion of reaction (assisted by visual observation & monitored by TLC), the mixture was extracted from BMIM-BF_4 with Et_2O (3x 15 mL) and dried over $MgSO_4$. The solvent was then removed, yielding the crude products **9a-b**. Purification of by column chromatography afforded the pure products **9a-b.**

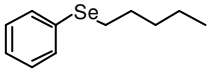
4.9. Spectral details



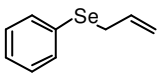
(2b) ethyl phenyl selenide 80% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.50-7.45 (m, 2H), 7.27-7.20 (m, 3H), 2.91 (q, *J*= 7.6 Hz, 2H), 1.43 (t, *J*= 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.6, 130.3, 129.0, 126.7, 21.3, 15.5



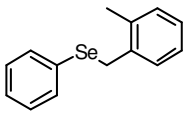
(2c) butyl phenyl selenide 89% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ= 7.49-7.45(m, 2H), 7.26-7.18(m, 3H), 2.90 (t, *J*= 7.6 Hz, 2H), 1.71-1.64 (m, 2H), 1.46-1.37 (m, 2H), 0.90 (t, *J*= 7.2Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.4, 130.8, 129.0, 126.6, 32.3, 27.7, 23.0, 13.6.



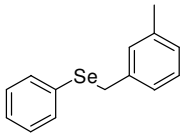
(2d) pentyl phenyl selenide 89% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47-7.44 (m, 2H), 7.22-7.14 (m, 3H), 2.87 (t, *J* = 7.6 Hz, 2H), 1.68 (m, 2H), 1.39-1.24 (m, 4H), 0.86 (t, *J* = 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.4, 130.9, 129.0, 126.6, 32.1, 30.5, 28.3, 22.3, 14.1



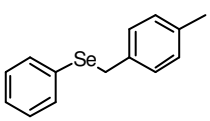
(2e) allyl phenyl selenide 98% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.63-7.58 (m, 2H), 7.27-7.23 (m, 3H), 6.05-5.84 (m, 1H), 5.02-4.92 (m, 2H), 3.52 (d, J= 7.6 Hz, 2H); **^{13}C ($CDCl_3$, 100 MHz) δ =** 134.4, 133.3, 131.5, 128.9, 127.1, 116.8, 30.6



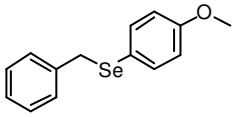
(2f) *o*-[(phenylseleno)methyl]toluene 79% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47-7.45 (m, 2H), 7.26-7.20 (m, 3H), 7.13-7.11 (m, 2H), 7.06-7.01 (m, 2H), 4.10 (s, 2H), 2.35 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.5, 136.2, 134.3, 130.5, 129.6, 128.9, 127.32, 127.20, 125.9, 30.46, 19.1.



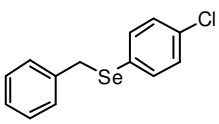
(2g) *m*-[(phenylseleno)methyl]toluene 85 % Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.46-7.43 (m, 2H), 7.26-7.21 (m, 3H), 7.15-7.11 (m, 1H), 7.01-6.99 (m,3H), 4.07 (s, 2H), 2.28 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 138.38, 138.02, 133.45, 130.61, 129.59, 128.92, 128.30, 127.63, 127.21, 125.84, 32.23, 21.29.



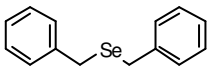
(2h) *p*-[(phenylseleno)methyl]toluene 98% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47-7.44 (m, 2H), 7.25-7.23 (m, 3H), 7.11 (d, *J*= 8 Hz, 2H), 7.05 (d, *J*= 8.4 Hz, 2H), 4.09 (s, 2H), 2.30 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.3, 135.4, 133.2, 130.7, 129.0, 128.8, 128.6, 127.0, 31.8, 21.0



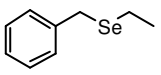
(2i) benzyl 4-methoxyphenyl selenide 82% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.36 (d, *J*= 8.6 Hz, 2H), 7.26-7.10 (m, 5H), 6.77 (d, *J*= 8.6 Hz, 2H), 4.0 (s, 2H), 3.79 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 159.5, 139.1, 136.5, 128.7, 128.3, 126.6, 120.0, 114.6, 55.2, 33.1



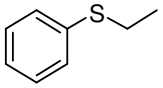
(2j) benzyl(4-chlorophenyl) selenide 88% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.35-7.33 (m, 2H), 7.26-7.16 (m, 7H), 4.07 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 140.0, 138.4, 135.1, 130.8, 129.9, 129.4, 127.8, 126.6, 32.2



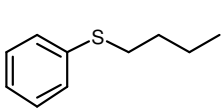
(2k) dibenzyl selenide 80% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.31-7.25 (m, 8H), 7.23-7.19 (m, 2H), 3.72 (s, 4H); ^{13}C ($CDCl_3$, 100 MHz) δ = 139.3, 129.0, 128.1, 126.7, 27.2



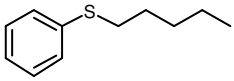
(2l) benzyl ethyl selenide 77% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.29-7.25 (m, 4H), 7.23-7.18 (m, 1H), 3.79 (s, 2H), 2.50 (q, *J*= 7.6 Hz, 2H), 1.37 (t, *J*= 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100MHz) δ = 132.4, 130.8, 128.9, 126.3, 27.0, 17.8, 15.9.



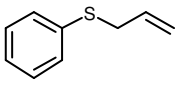
(4b) n-ethyl phenyl sulphide 78% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.34-7.25 (m, 5H), 2.94 (q, *J*= 7.6 Hz, 2H), 1.31 (t, *J*= 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.65, 129.02, 128.79, 125.74, 27.67, 14.42 ppm.



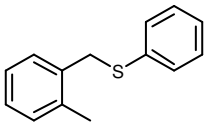
(4c) n-butyl phenyl sulphide 96% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.33-7.25 (m, 4H), 7.17-7.13 (m, 1H), 2.92 (t, *J*= 7.2 Hz, 2H), 1.67-1.60 (m, 2H), 1.49-1.40 (m, 2H), 0.92 (t, *J*= 7.6 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 137.03, 128.83, 128.77, 125.59, 33.25, 31.21, 21.94, 13.60.



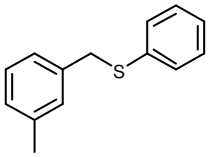
(4d) n-pentyl phenyl sulphide 97% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.35-7.23 (m, 4H), 7.19-7.11 (m, 1H), 2.91 (t, *J*= 7.2 Hz, 2H), 1.72-1.58 (m, 2H), 1.48-1.23 (m, 4H), 0.89 (t, *J*= 6.6 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.98, 128.73, 127.98, 125.51, 36.71, 30.72, 29.98, 22.17, 13.90 ppm.



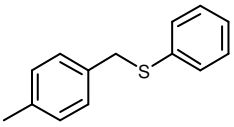
(4e) allyl phenyl sulphide 99% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.51-7.16 (m, 5H), 5.93-5.82 (m, 1H), 5.19-5.06 (m, 2H), 3.55 (d, *J*= 6.8 Hz, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.08, 133.09, 129.10, 126.8, 125.2, 117.20, 37.10 ppm.



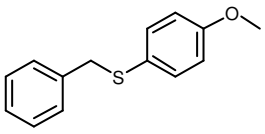
(4f) 2-methyl benzyl phenyl sulphide 92% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.33-7.09 (m, 9H), 4.09 (s, 2H), 2.38 (s, 3H); ^{13}C ($CDCl_3$, 50 MHz) δ= 136.66, 136.59, 134.99, 130.41, 130.14, 129.72, 128.77, 127.45, 126.38, 125.95, 37.34, 19.12 ppm.



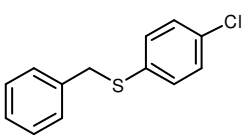
(4g) 3-methyl benzyl phenyl sulfide 95% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.33-7.02 (m, 9H), 4.08 (s, 2H), 2.30 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 138.09, 137.21, 136.58, 129.62, 129.52, 128.76, 128.32, 127.91, 126.19, 125.81, 38.94, 21.29 ppm.



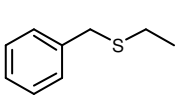
(4h) 4-methyl benzyl phenyl sulphide 99% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz)δ= 7.33-7.06 (m, 9H), 4.08 (s, 2H), 2.31 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.78, 136.61, 134.27, 129.58, 129.15, 128.76, 128.66, 126.15, 38.65, 21.06 ppm.



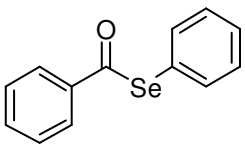
(4i) 4-Benzylsulfanylanisole 97% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.27-7.20 (m, 7H), 6.82-6.76 (m, 2H), 3.98 (s, 2H), 3.78 (s, 3H); ^{13}C ($CDCl_3$, 50 MHz) δ = 159.31, 138.29, 134.32, 129.09, 128.50, 127.21, 126.19, 125.6, 56.51, 41.55.



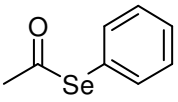
(4j) benzyl 4-chloro phenyl sulphide 92% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.28-7.21 (m, 9H), 4.06 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.60, 135.74, 133.29, 130.57, 130.22, 128.87, 128.58, 126.98, 42.39 ppm.



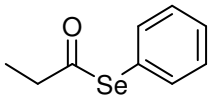
(4l) Benzyl ethyl sulfide 99% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.31-7.17 (m, 5H), 3.71 (s, 2H), 2.42 (q, *J*= 7.4 Hz, 2H), 1.22 (t, *J*= 7.4 Hz, 3H);); ^{13}C ($CDCl_3$, 50 MHz) δ = 138.51, 128.70, 128.34, 126.75, 35.78, 25.10, 14.28 ppm.



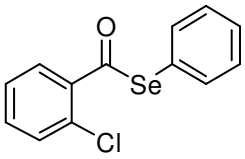
(6a) *Se*-phenyl selenobenzoate 95% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.94 - 7.92 (m, 2H), 7.63 - 7.58 (m, 3H) 7.50 - 7.42 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 193.7, 138.9, 138.4, 136.7, 134.2, 129.7, 129.4 , 129.3, 127.7, 126.1.



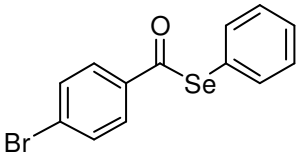
(6b) *Se*-phenyl ethaneselenoate 39% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.54 – 7.25 (m, 5H), 2.46 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 196.4, 135.7, 131.4, 129.1, 127.7, 68.8.



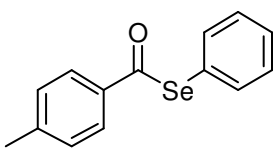
(6c) *Se*-phenyl propaneselenoate 57% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ= 1.20 (t, *J*= 7.2 Hz, 3H), 2.77 (q, *J*= 7.2 Hz, 2H), 7.36-7.70 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 197.6, 135.6, 130.9, 129.10, 128.7, 41.90, 10.58.



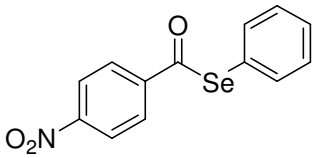
(6d) *Se*-phenyl-2-chlorobenzoselenoate 94% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.65 - 7.59 (m, 4H), 7.37 - 7.18 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 190.1, 136.3, 135.7, 135.0, 132.3, 131.5, 130.9, 129.1, 128.6, 127.7, 126.5.



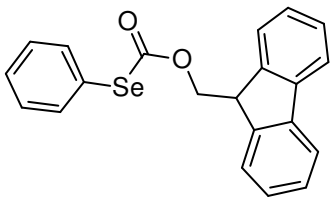
(6e) *Se*-phenyl-4-bromoselenobenzoate 82% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.92 (d, *J*= 8.8 Hz, 2H), 7.60 (d, *J*= 8 Hz, 1H), 7.48 (d, *J*= 8.4 Hz, 2H), 7.29-7.17 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 167.5, 136.9, 132.4, 132.2, 131.9, 131.0, 128.9, 127.4, 127.0 ppm.



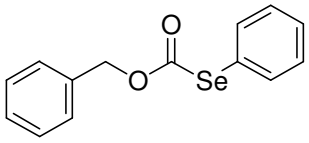
(6f) *Se*-phenyl-4-methylselenobenzoate 89% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.80 (d, *J*= 8.4 Hz, 2H), 7.58 – 7.55 (m, 2H), 7.38 - 7.36 (m, 3H), 7.20 (d, *J*= 8.0 Hz, 2H), 2.34 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 192.4, 144.7, 136.1, 135.8, 129.4, 129.1, 128.7, 127.2, 125.8, 21.5.



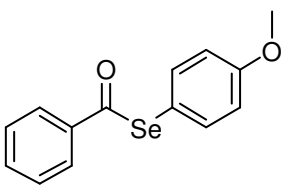
(6g) *Se*-phenyl 4-nitroselenobenzoate 72% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.35–8.33 (m, 2H), 8.17–8.00 (m, 2H), 7.66–7.40 (m, 2H), 7.30–7.23 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 192.5, 150.6, 143.0, 136.1, 131.5, 129.6, 128.1, 124.9, 124.2.



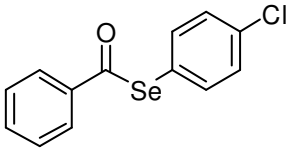
(6h) *O*-(9H-fluoren-9-yl) methyl *Se*-phenylcarbonoselenoate 89% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.78 - 7.26 (m, 13H), 4.53 (d, *J*= 7.6 Hz, 2H), 4.12 (t, *J*= 7.2 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 166.5, 134.8, 129.3, 128.1, 127.4, 126.9, 124.9, 119.9, 64.9, 50.2.



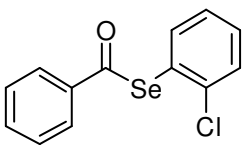
(6i) *Se*-phenyl Benzyl formate 81% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.53-7.49 (m, 2H), 7.10-6.95 (m, 8H), 4.89 (s, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ= 166.20, 136, 135.39, 129.30, 129.0, 128.67, 128.59, 127.90, 126.51, 69.60.



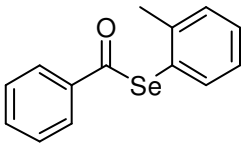
(6j) *Se*-4-methoxyphenyl selenobenzoate 90% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.93 - 7.90 (m, 2H), 7.59 - 7.37 (m, 3H), 6.96 - 6.94 (m, 2H), 6.80 - 6.78 (d, *J*= 8.8 Hz, 2H), 3.82 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 194.2, 160.4, 137.8, 135.4, 134.5, 133.7, 128.9, 127.3, 114.3, 55.7.



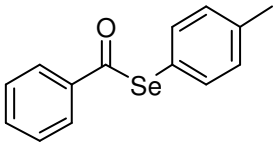
(6k) *Se*-4-chlorophenyl selenobenzoate 80% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.90 - 7.87 (m, 2H), 7.58 (t, *J*= 7.6 Hz, 1H), 7.49 - 7.42 (m, 4H), 7.35 (d, *J*= 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 192.4, 138.2, 137.9, 136.4, 133.7, 129.2, 128.6, 127.0, 123.6.



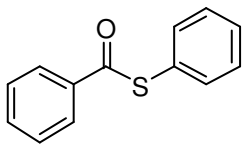
(6l) *Se*-2-chlorophenyl selenobenzoate 66% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.93–7.24 (m, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 191.4, 138.7, 137.8, 133.6, 130.8, 130.3, 129.9, 129.3, 129.1, 128.9,127.4.



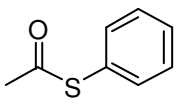
(6m) *Se-2*-tolyl selenobenzoate 75% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.96 - 7.80 (m, 2H), 7.50 - 7.20 (m, 7H), 2.35 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 192.7, 142.5, 138.6, 137.7, 133.7, 130.4, 129.8, 128.8, 127.2, 127.2, 126.5, 22.9.



(6n) *Se-4*-tolyl selenobenzoate 81% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.96 - 7.80 (m, 2H), 7.54 - 7.38 (m, 5H), 7.18 (d, *J*= 8.0 Hz, 2H), 2.35 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 192.7, 142.5, 138.6, 137.7, 133.7, 130.4, 129.8, 128.8, 127.2, 127.2, 126.5, 22.9.

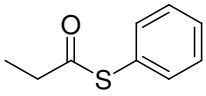


(7a) *S*-phenyl benzothioate >99% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 8.03 – 8.00 (m, 2H), 7.59 - 7.41 (m, 8H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 189.9, 136.5, 135.0, 133.5, 129.4, 129.1, 128.6, 127.3, 127.2.

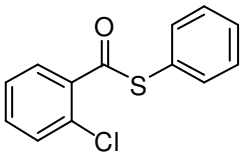


(7b) *S*-phenyl ethanethioate 42% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.41 – 7.37 (m, 5H), 2.38 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 193.8, 134.3, 129.3, 129.0,

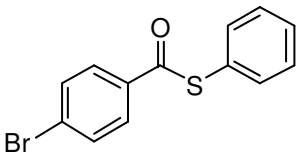
127.8, 30.0.



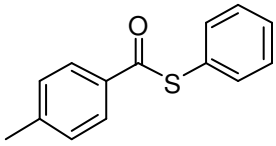
(7c) *S*-phenyl propanethioate 68% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.42-7.35 (m, 5H), 2.59 (q, *J*= 6.4 Hz, 2H), 1.19 (t, *J*= 6.3 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 193.34, 134.45, 129.68, 129.32, 127.34, 37.11, 9.44.



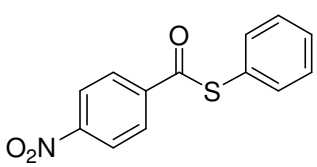
(7d) *S*-phenyl 2-chlorobenzothioate 92% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.74 - 7.27 (m, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 189.9, 136.8, 134.4, 132.2, 130.7, 129.5, 129.1, 128.9, 127.2, 126.6, 125.6.



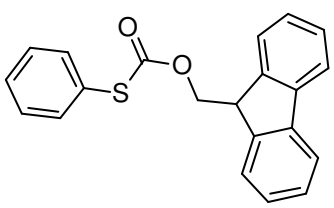
(7e) *S*-phenyl 4-bromobenzothioate 87% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.92 (d, *J*= 8.8 Hz, 2H), 7.60 (d, *J*= 8 Hz, 1H), 7.48 (d, *J*= 8.4, 2H), 7.29 - 7.17 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 167.5, 136.9, 132.4, 132.2, 131.9, 131.0, 128.9, 127.4, 127.0.



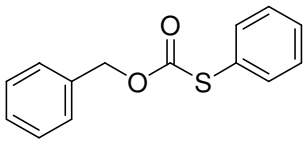
(7f) *S*-phenyl 4-methylbenzothioate 93% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.91 (d, *J*= 8.8 Hz, 2H), 7.51 – 7.48 (m, 2H), 7.43 - 7.40 (m, 3H), 7.24 (d, *J*= 8.4 Hz, 2H), 2.39 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 189.5, 144.4, 135.0, 134.0, 129.3, 129.1, 127.5, 127.4, 21.6.



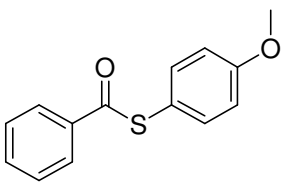
(7g) *S*-phenyl 4-nitrobenzothioate 77% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 8.31(d, *J*= 8.6 Hz, 2H), 8.15 (d, *J*= 8.6 Hz, 2H), 7.49-7.28 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 188.71, 151.6, 141.76, 135.6, 132.10, 129.5, 128.45, 125.11, 124.19.



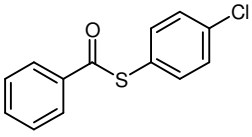
(7h) *O*-(9H-fluoren-9-yl)methyl-*S*-phenylcarbonothioate 91% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.70 - 7.67 (d, *J*= 7.6, 2H), 7.51 (d, *J*= 7.2, 2H), 7.38 – 7.32 (m, 4H), 7.29 – 7.23 (m, 5H), 4.45 (d, *J* = 7.6 Hz, 2H), 4.18 (t, *J* = 7.6 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 169.5, 150.5, 143.1, 142.2, 141.1, 134.8, 129.1, 128.0, 127.2, 124.9, 120.1, 73.3, 46.0.



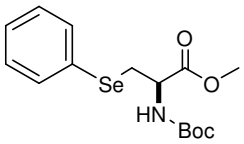
(7i) *S*-phenylcarbonothioate 85% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.48-7.39 (m, 2H), 7.05-6.86 (m, 8H), 4.78 (s, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 159.2, 135.6, 133.118, 128.6, 128.3, 127.61, 127, 125.1, 67.18.



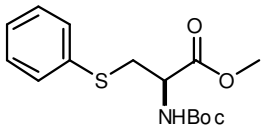
(7j) *S*-4-methoxyphenyl benzothioate 93% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 8.08-7.78 (m, 4H), 7.39-7.03 (m, 5H), 3.81 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 191.38, 161.19, 136.10, 135.78, 134.6, 129.18, 127.78, 118.28, 115.4, 56.08.



(7k) *S*-4-chlorophenyl benzothioate 82% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 8.05-7.90 (m, 2H), 7.72-7.61 (m, 2H), 7.34-7.09 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ = 190.06, 136.76, 136.39, 135.09, 134.30, 129.78, 129.19, 127.78, 126.21.



(9a) (*R*)-methyl 2-(*tert*butoxycarbonylamino)-3-(phenylselanyl) propanoate 61% Yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.56-7.51 (m, 2H), 7.28-7.23 (m, 3H), 5.42 (br s, 1H), 4.67-4.61 (m, 1H), 3.48 (s, 3H), 3.33-3.31 (m, 2H), 1.41 (s,9H); ^{13}C ($CDCl_3$, 100 MHz) δ = 170.9, 154.8, 133.5, 128.9, 127.4, 79.8, 53.1, 52.1, 30.5, 28.1.



(9b) (R)-methyl-2-(tertbutoxycarbonylamino)-3-(phenylselanyl) propanoate 70% Yield; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.43-7.38 (m, 2H), 7.37-7.21 (m, 3H), 5.38 (br s, 1H), 4.61-4.49 (m, 1H), 3.53 (s, 3H), 3.38-3.36 (m, 2H), 1.42 (s, 9H); ^{13}C ($CDCl_3$, 50 MHz) δ = 170.98, 154.95, 134.68, 131.02, 128.99, 127.02, 80.10, 53.21, 52.30, 37.21, 28.23 ppm.

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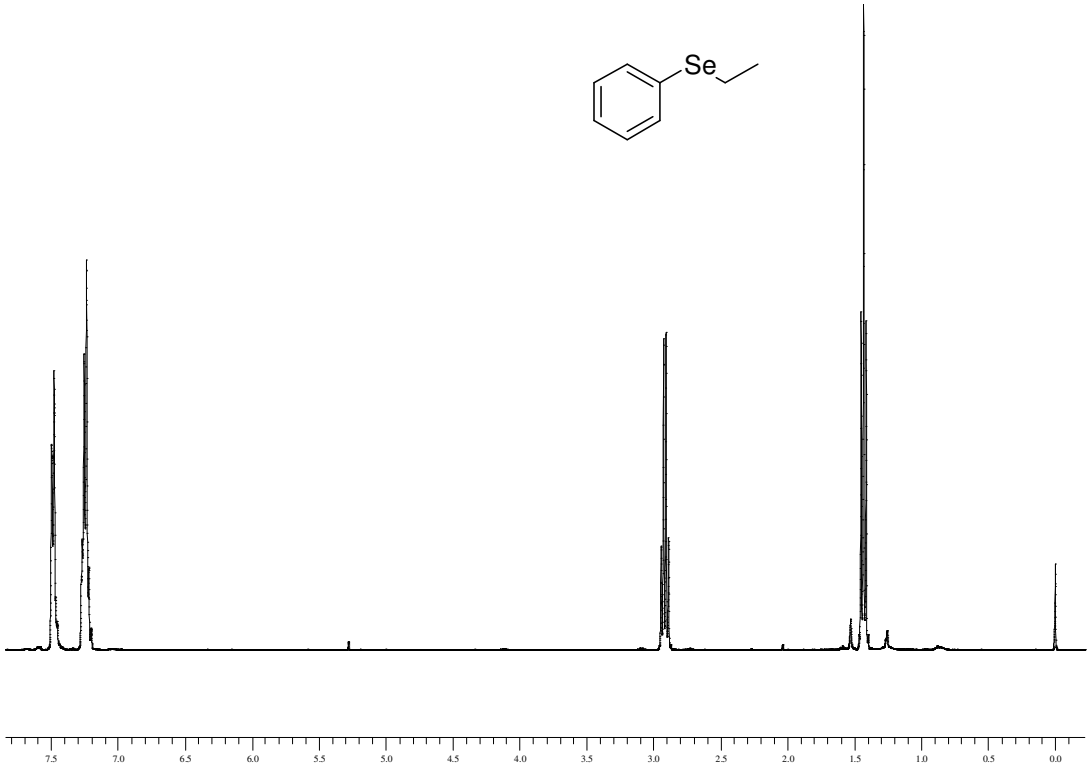
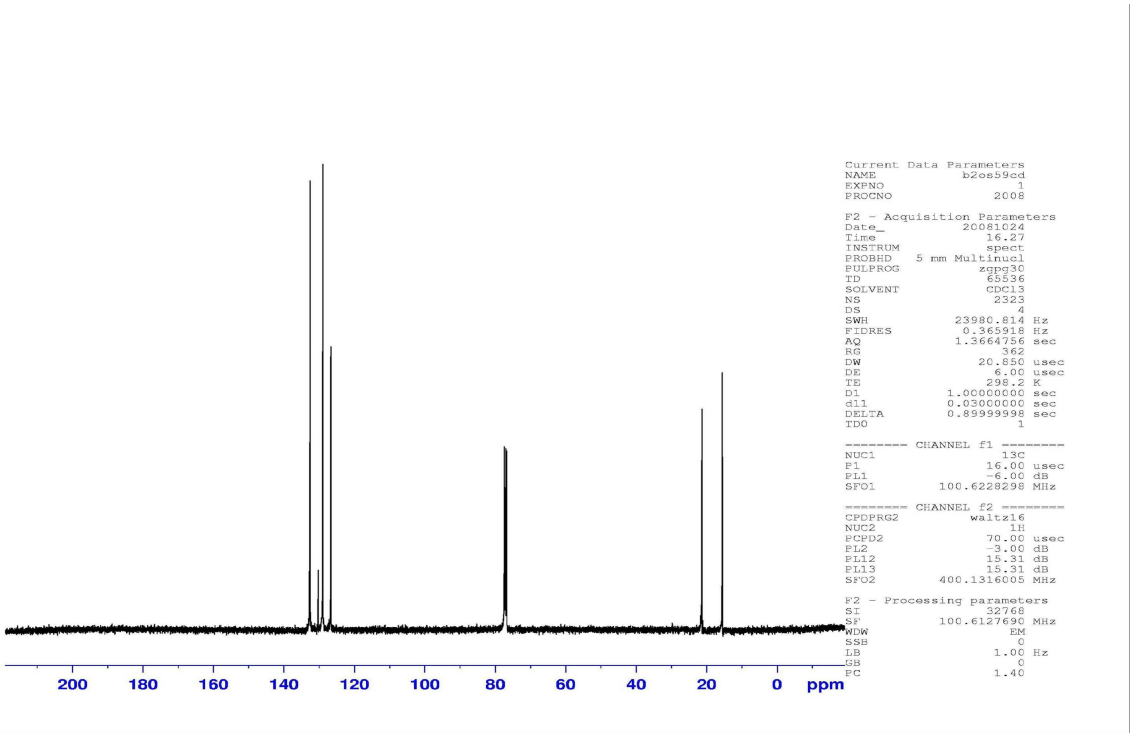
Reproduced Spectra



^{1}H NMR (400 MHz, $CDCl_3$) Spectrum of **2b**



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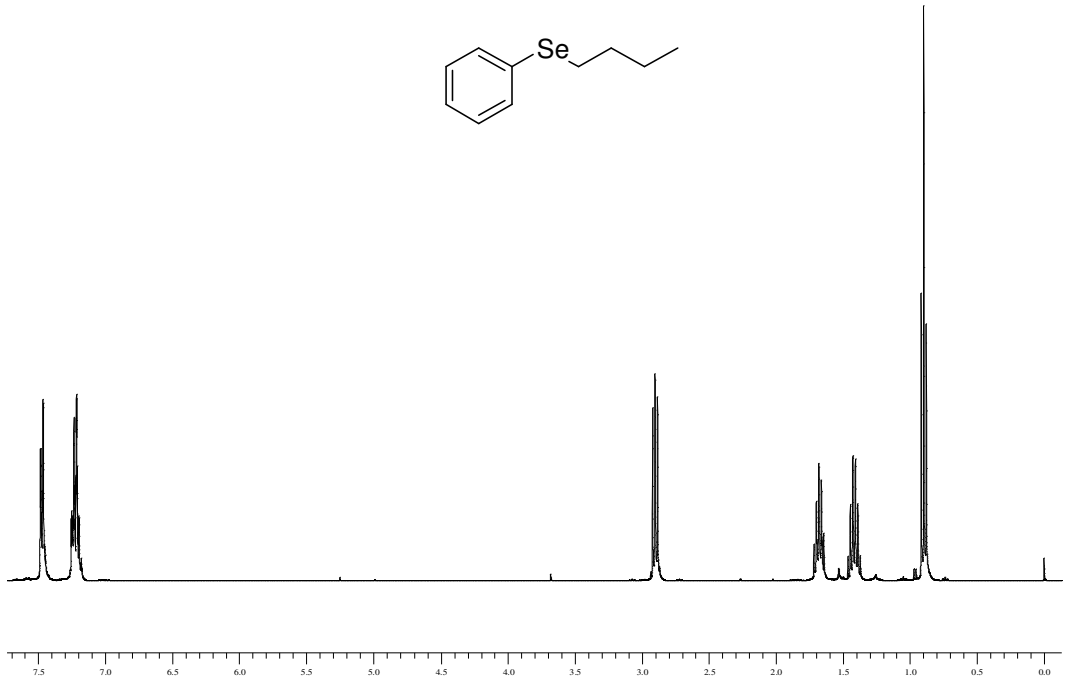

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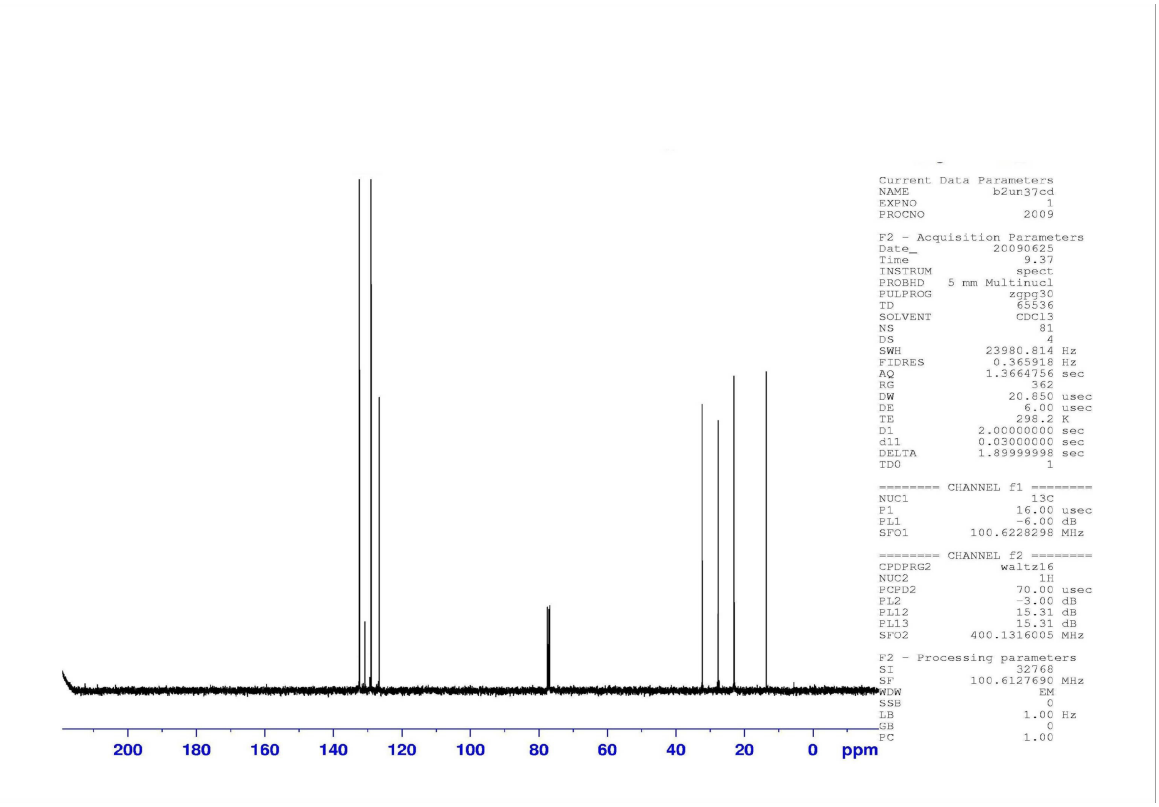

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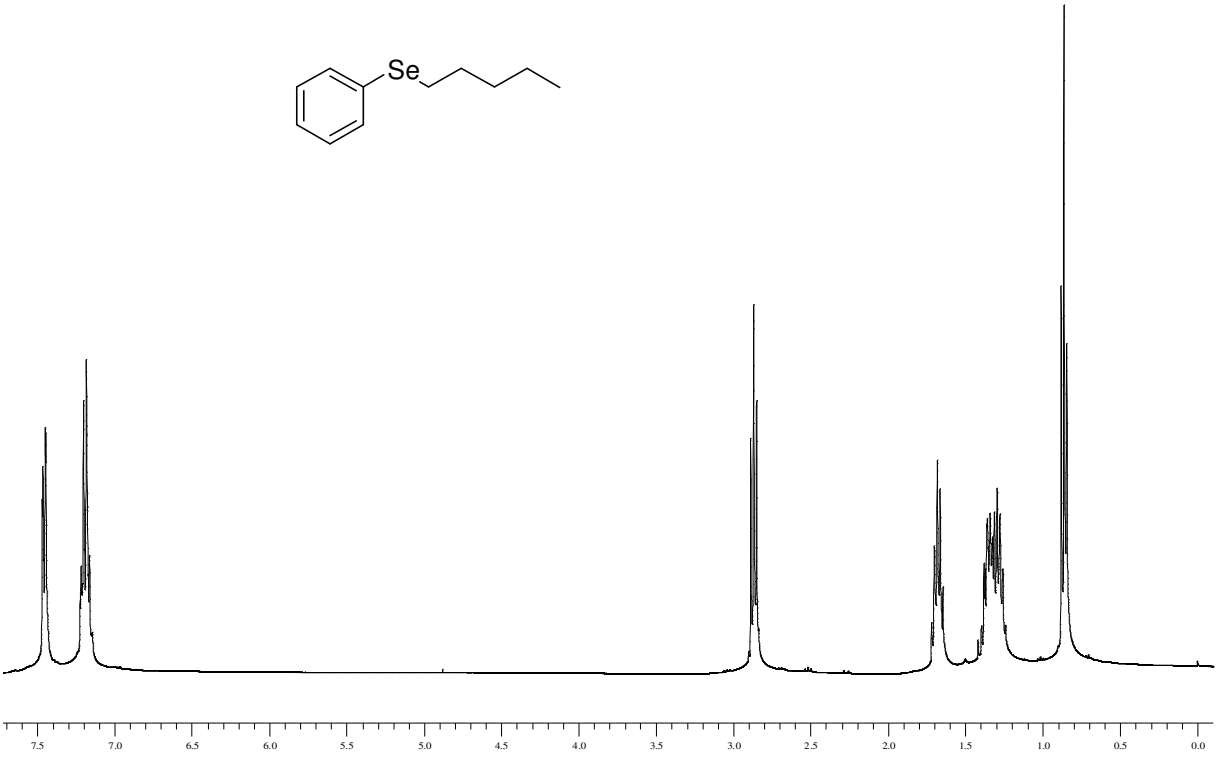

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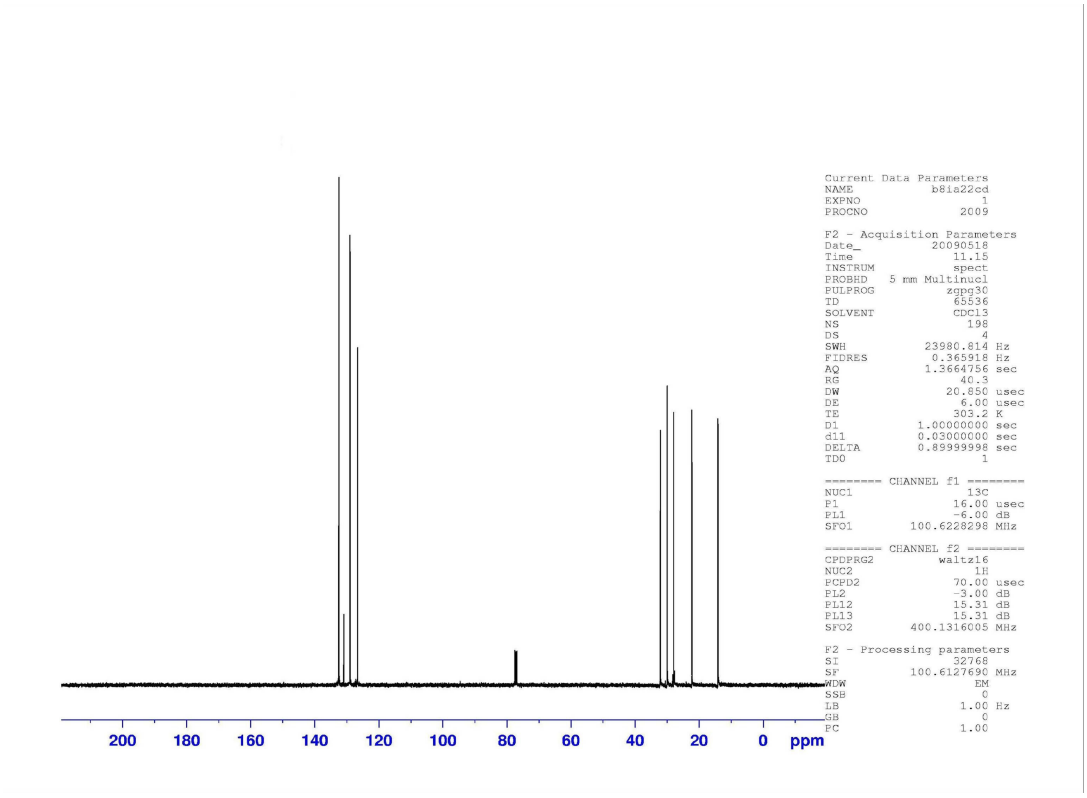

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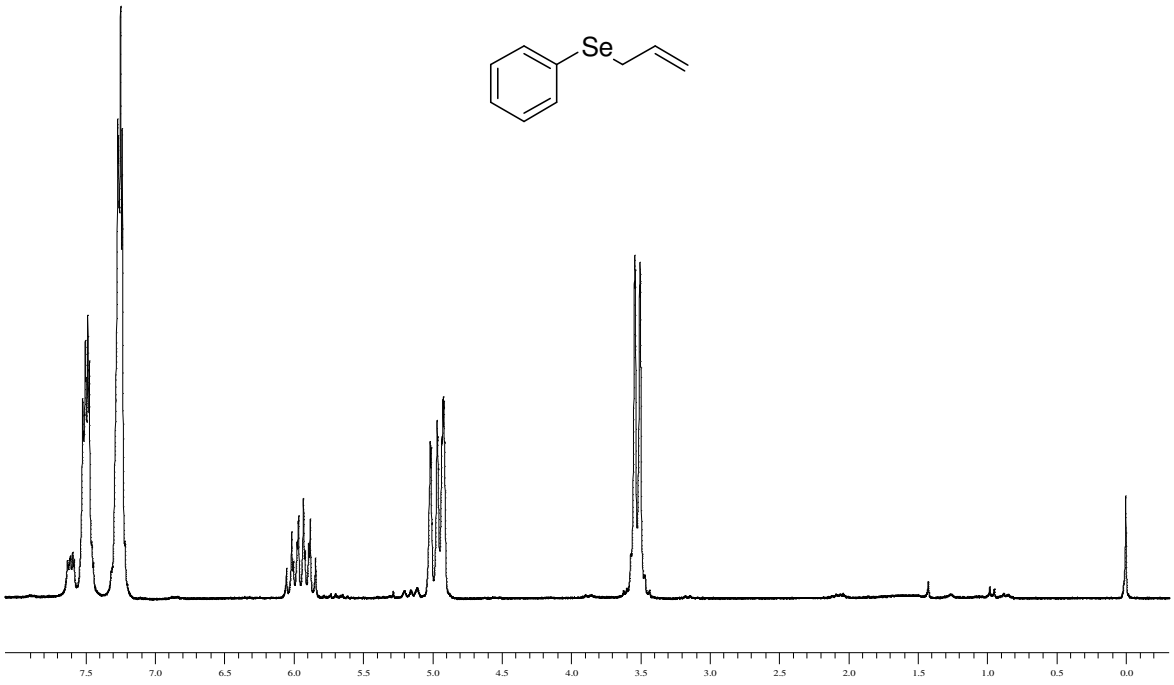

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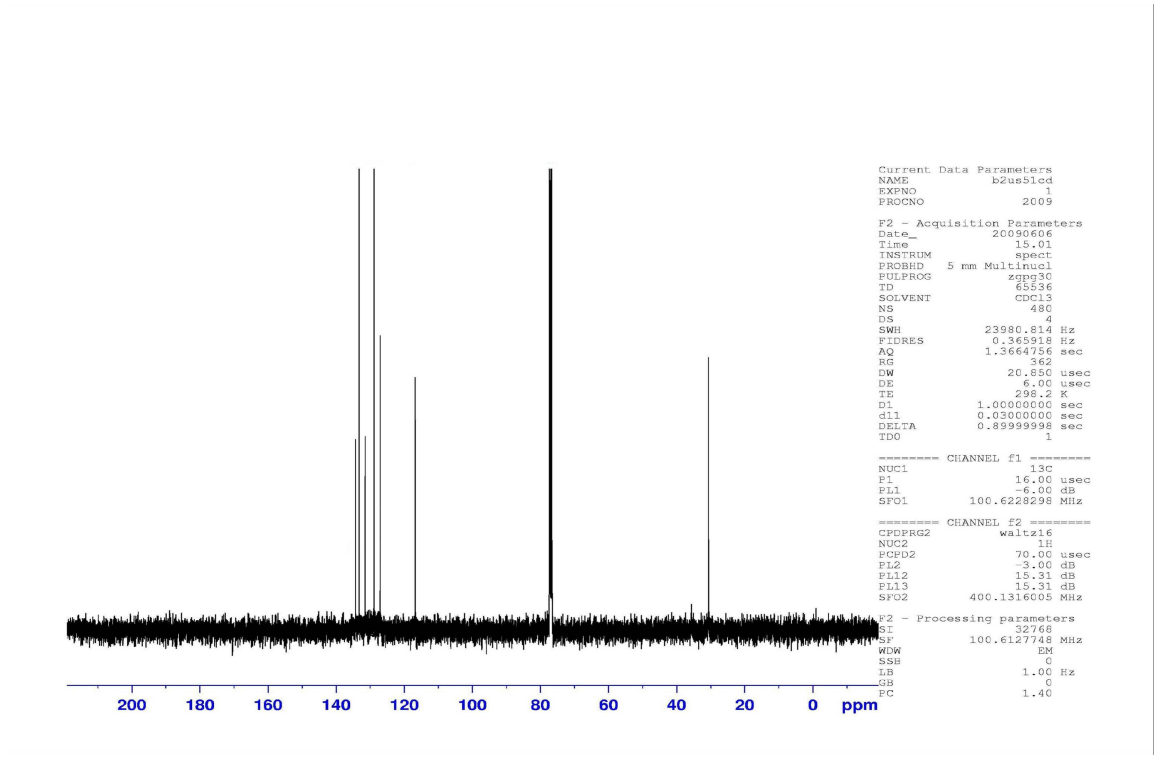

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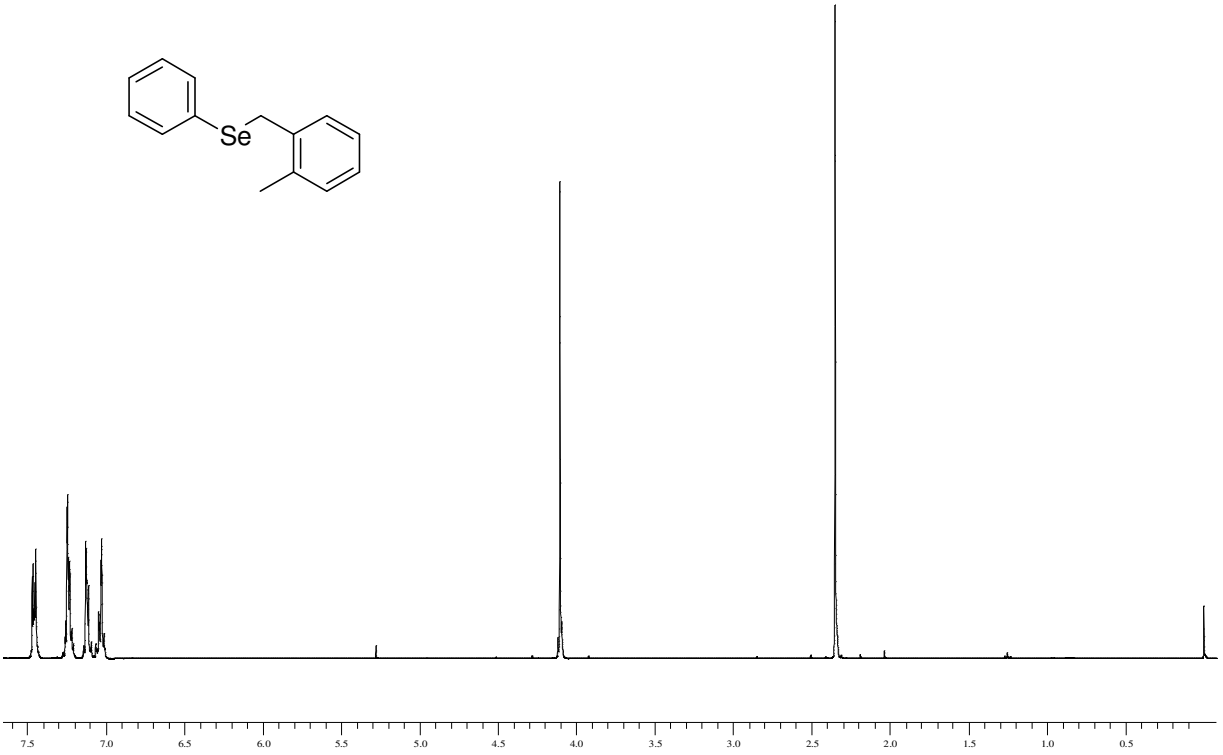

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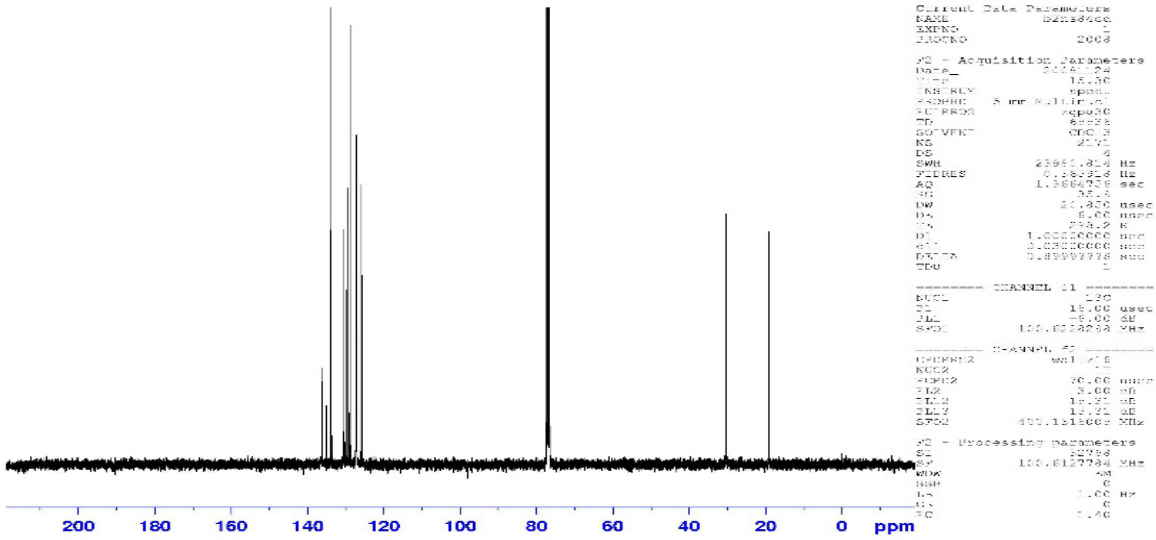

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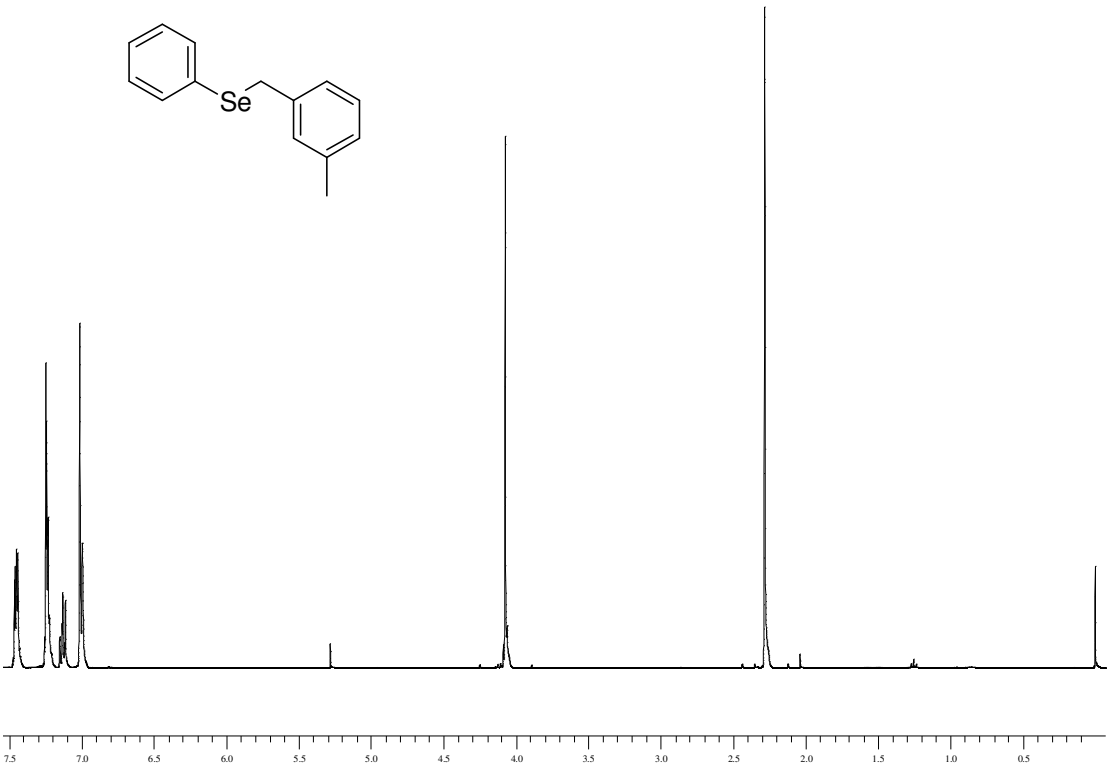

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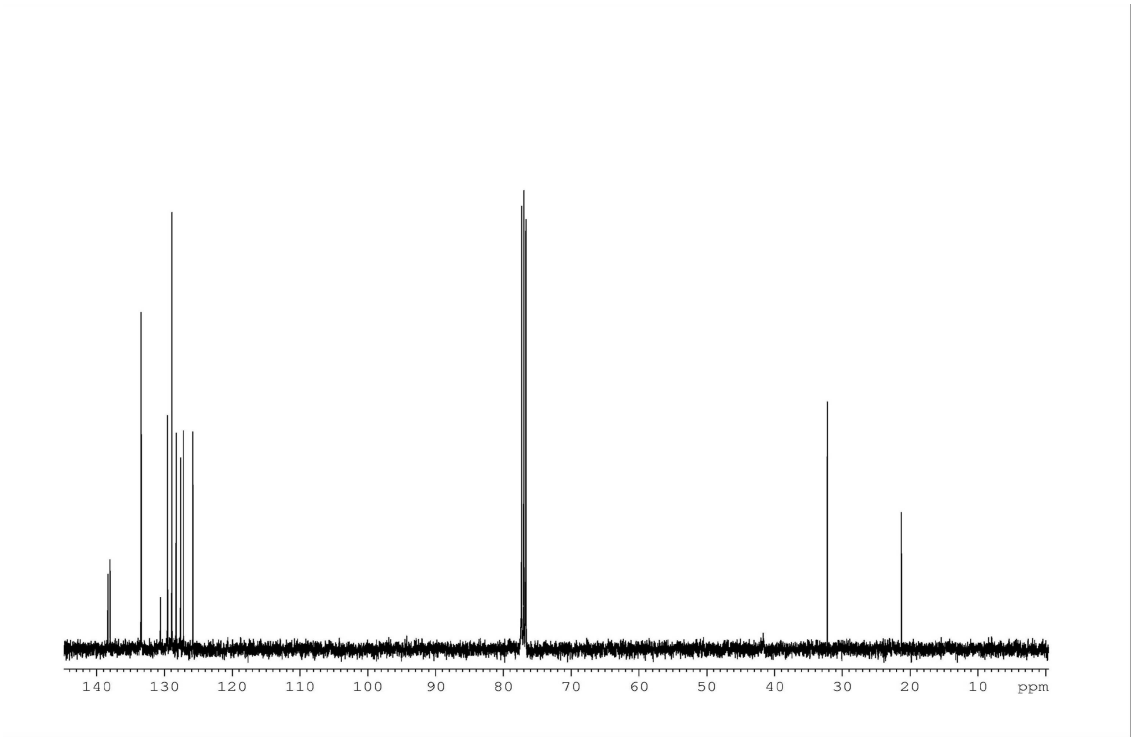

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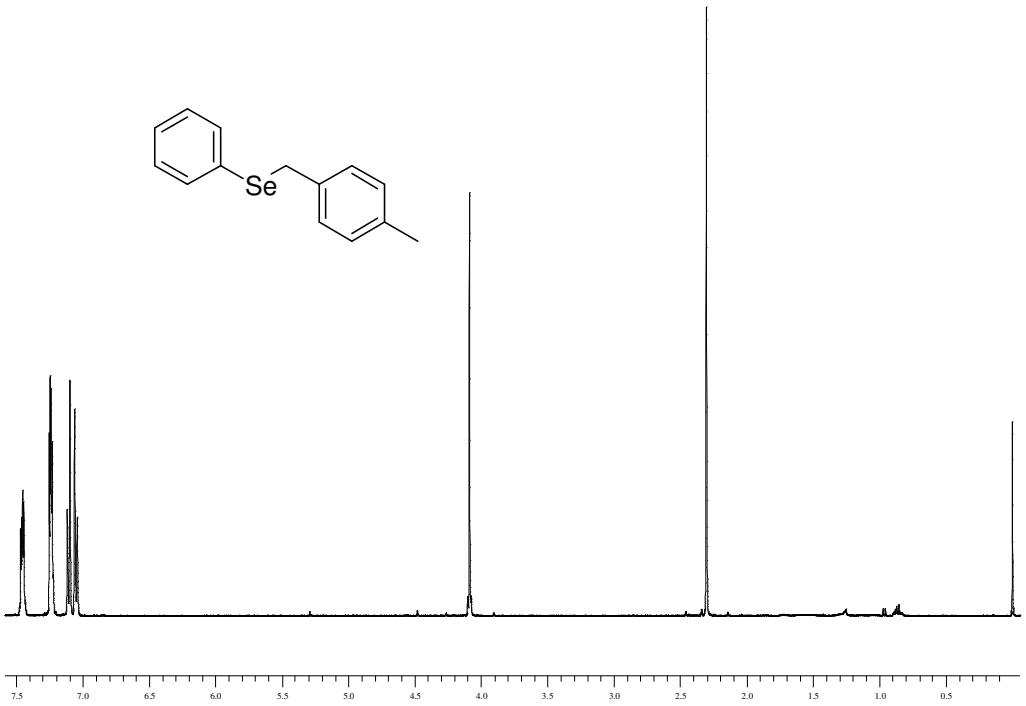

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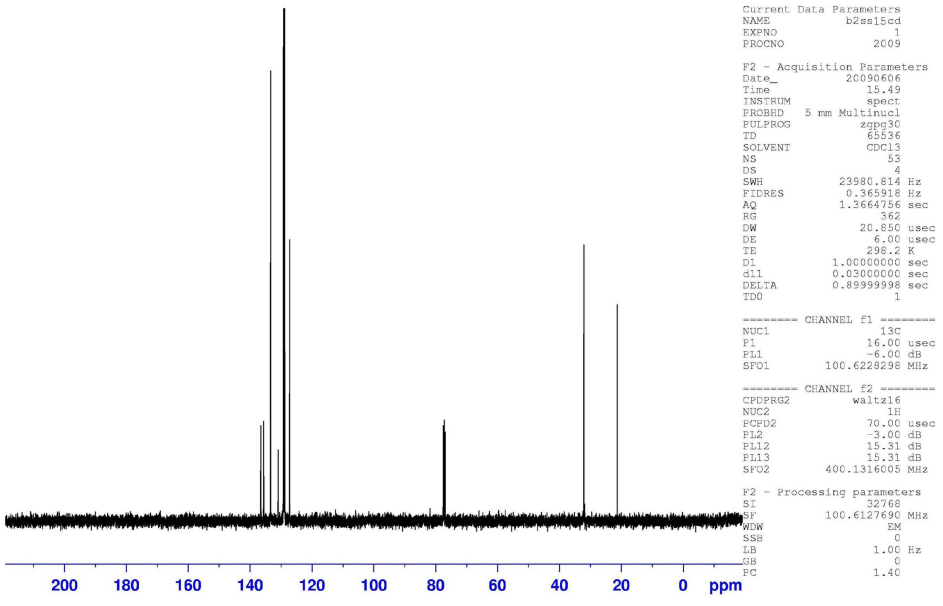

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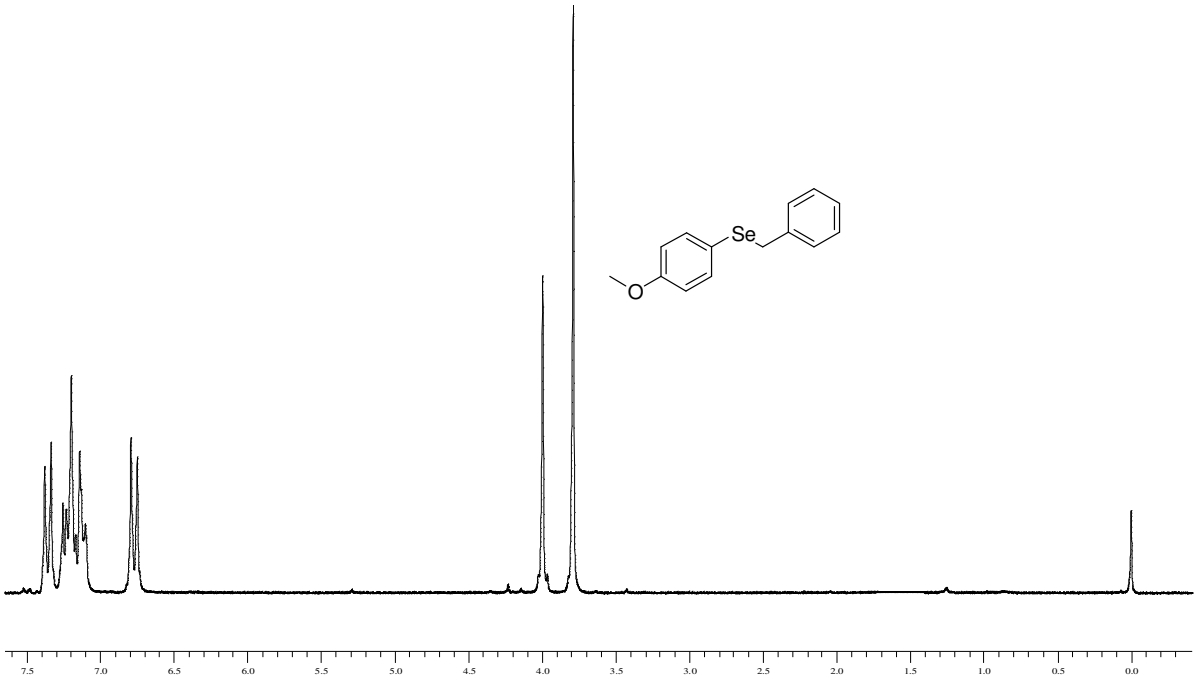

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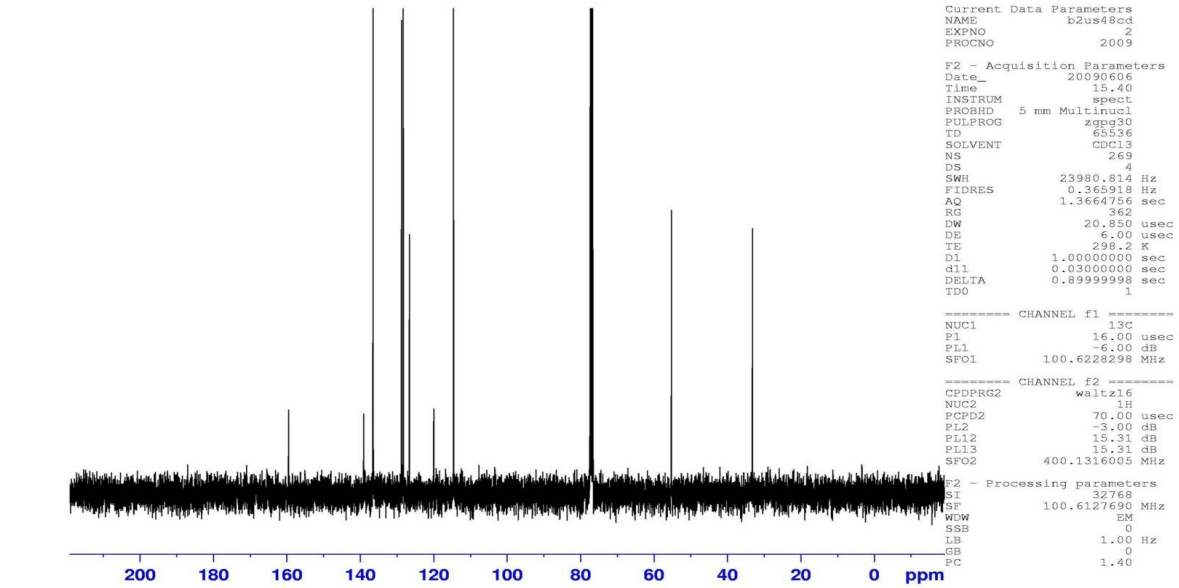

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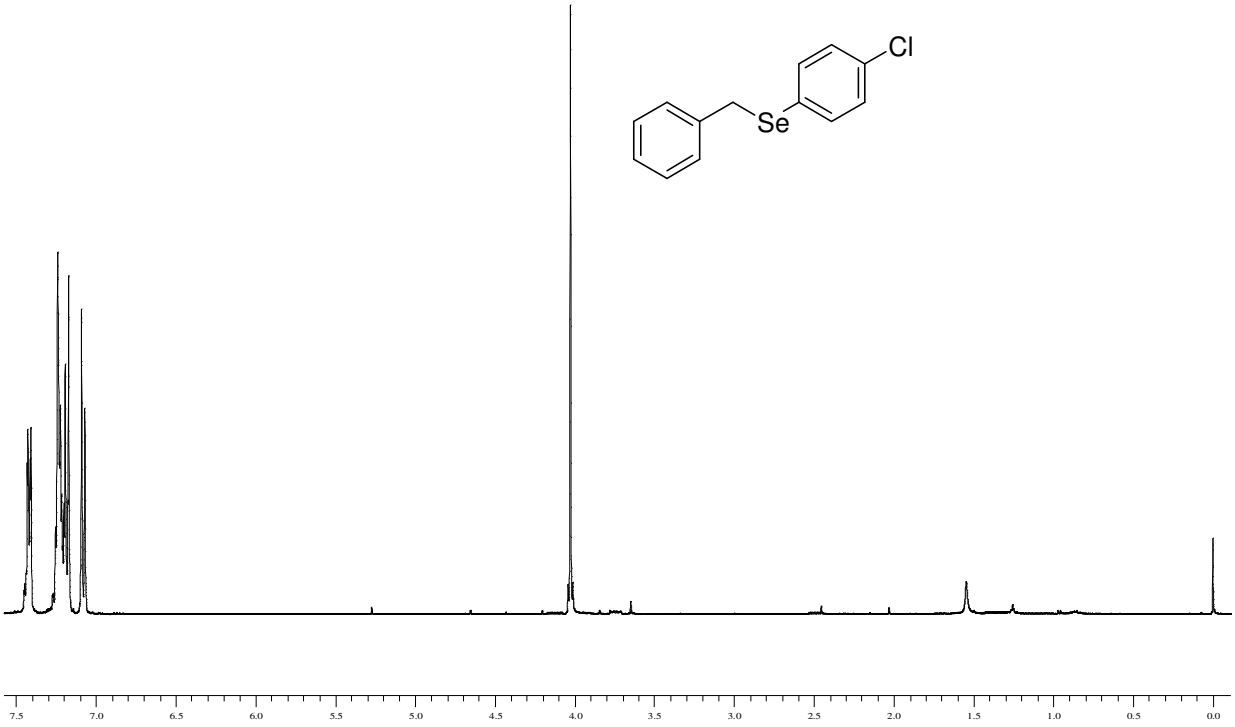

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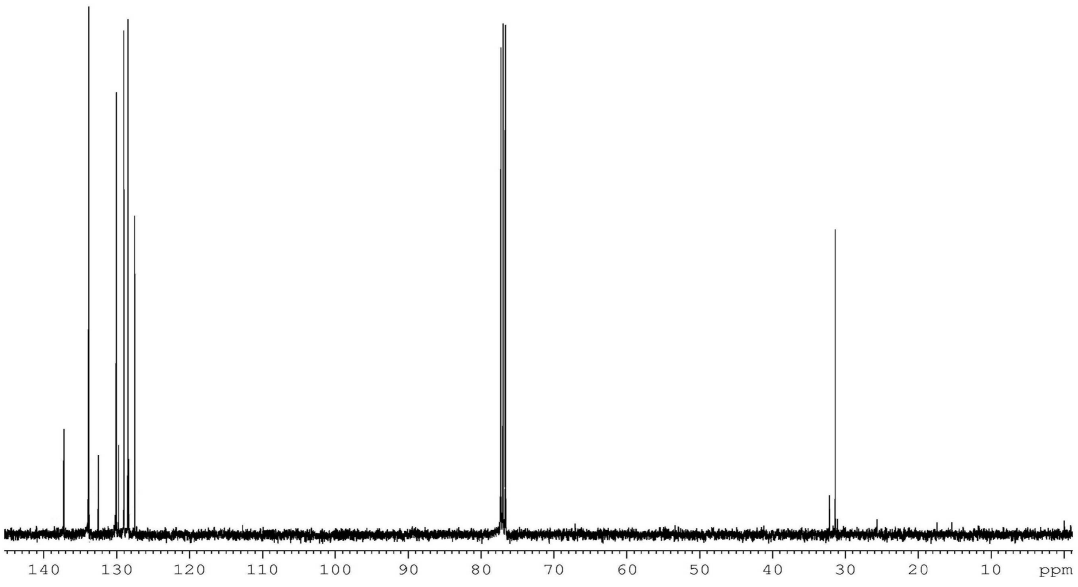

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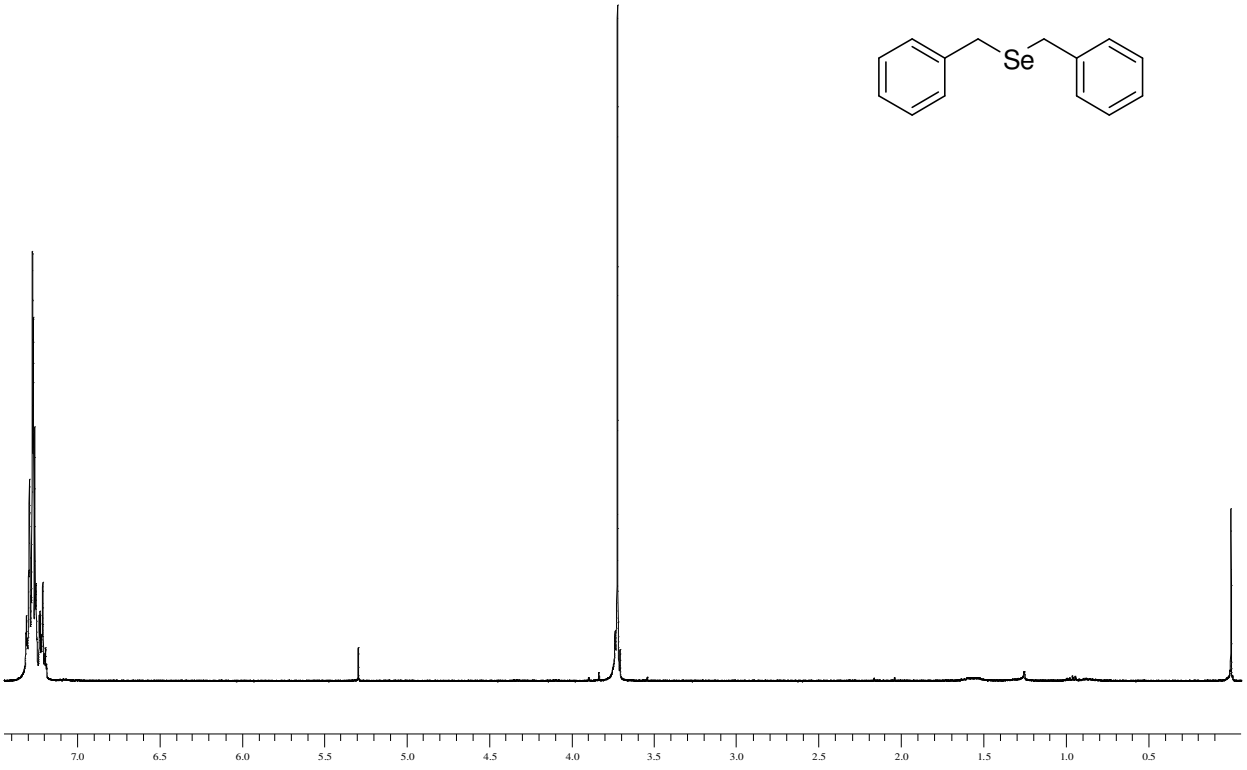

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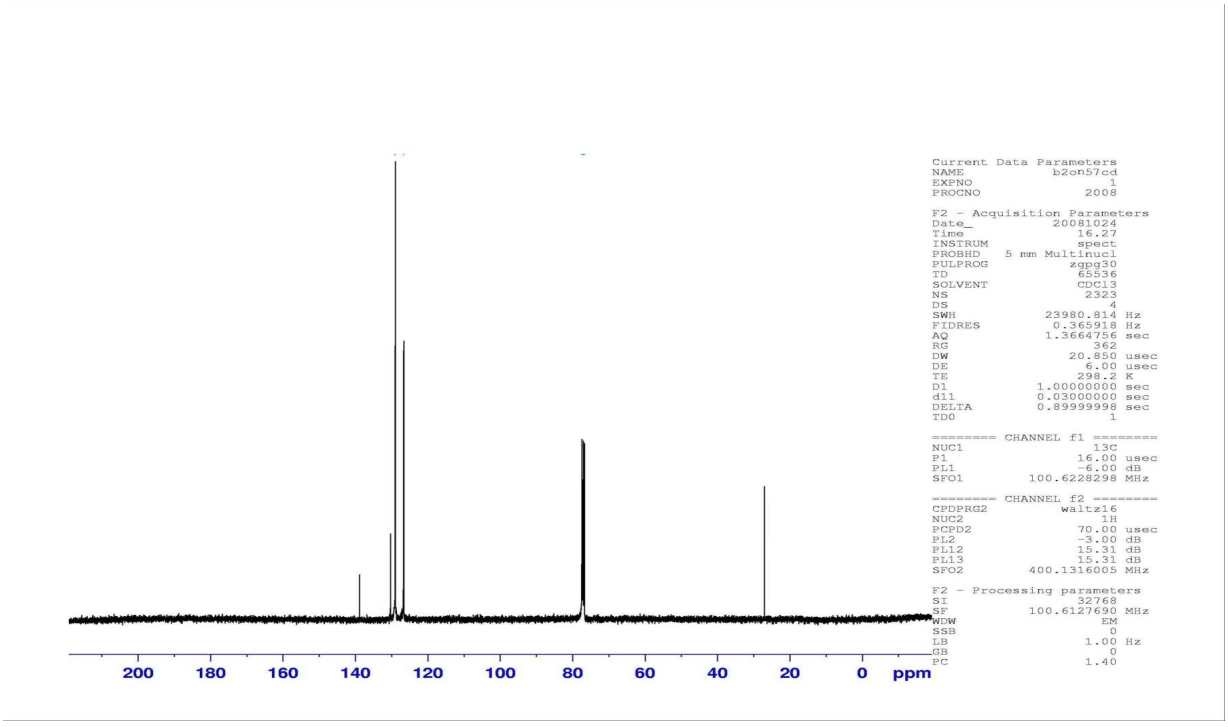

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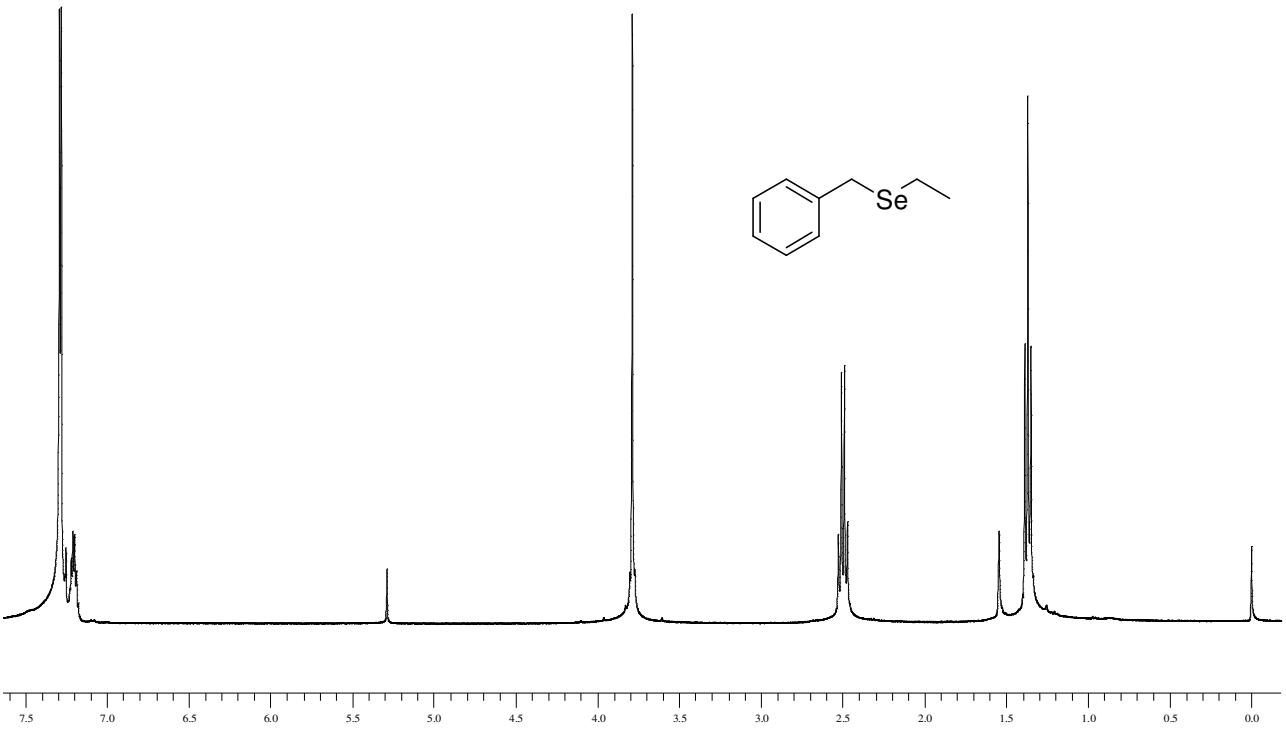

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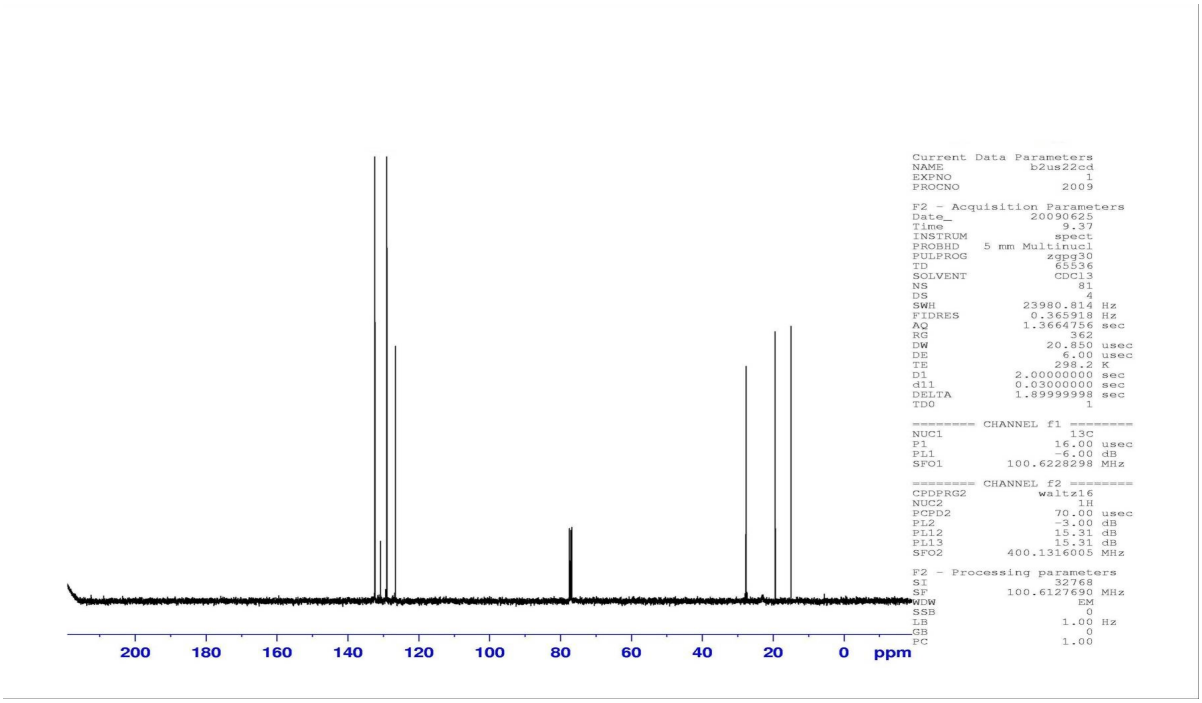

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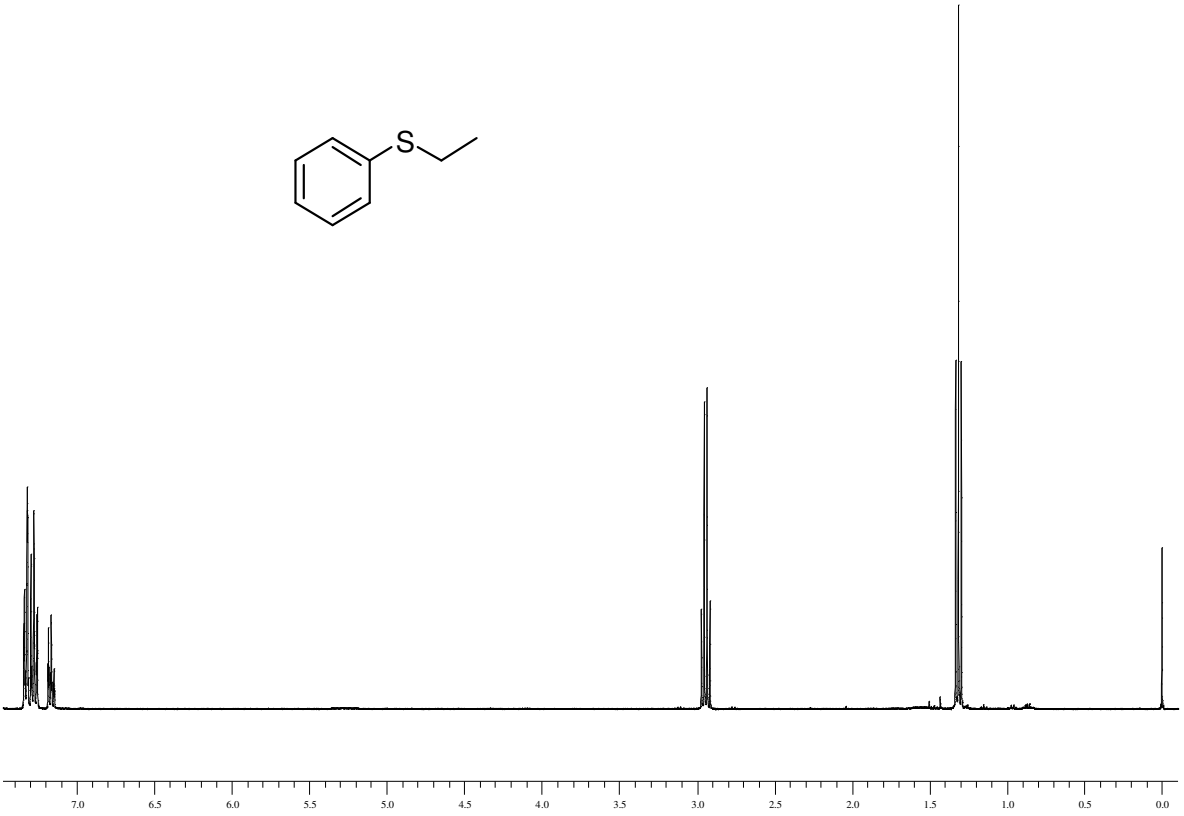

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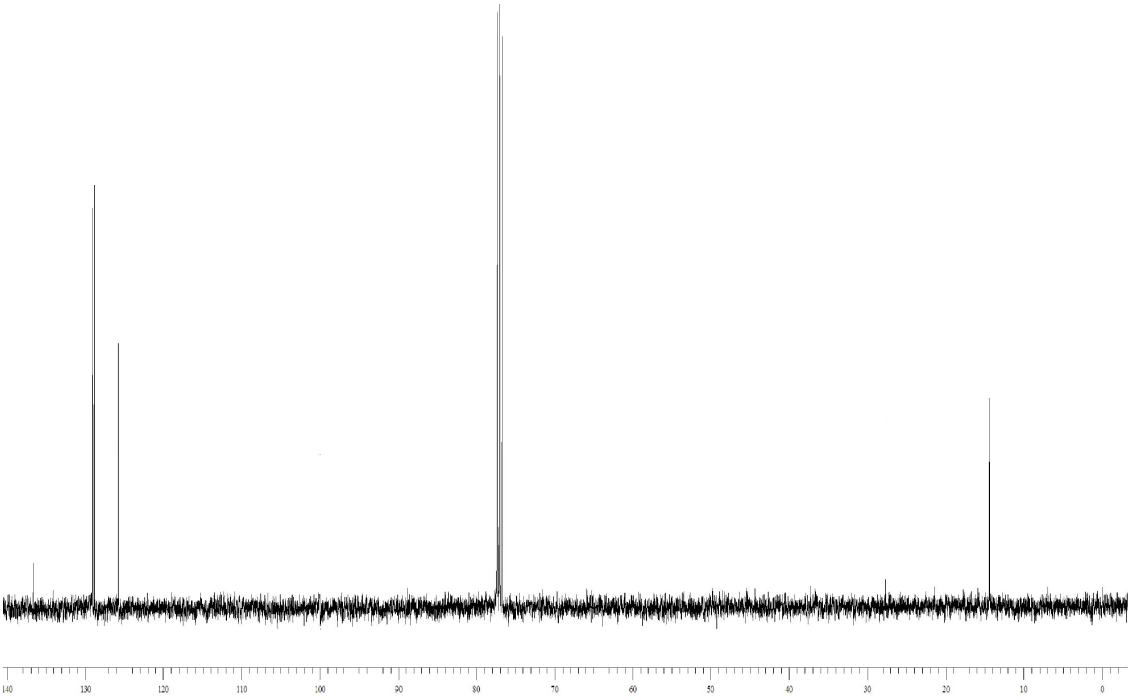

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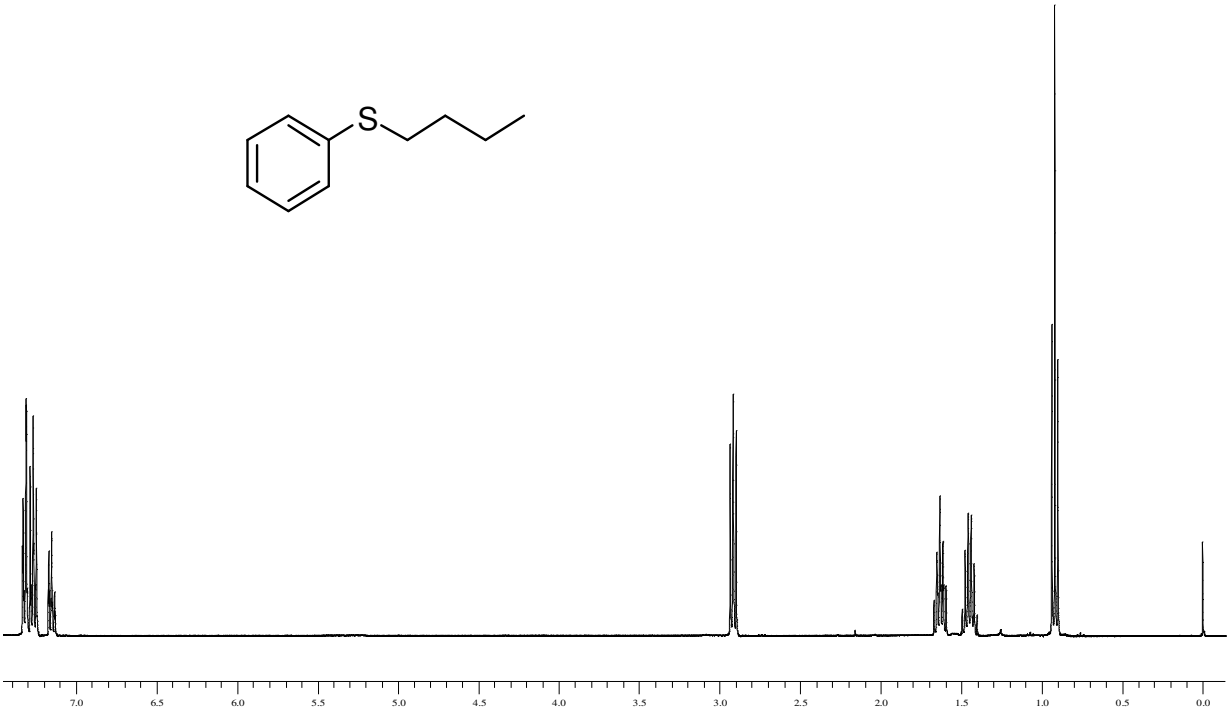

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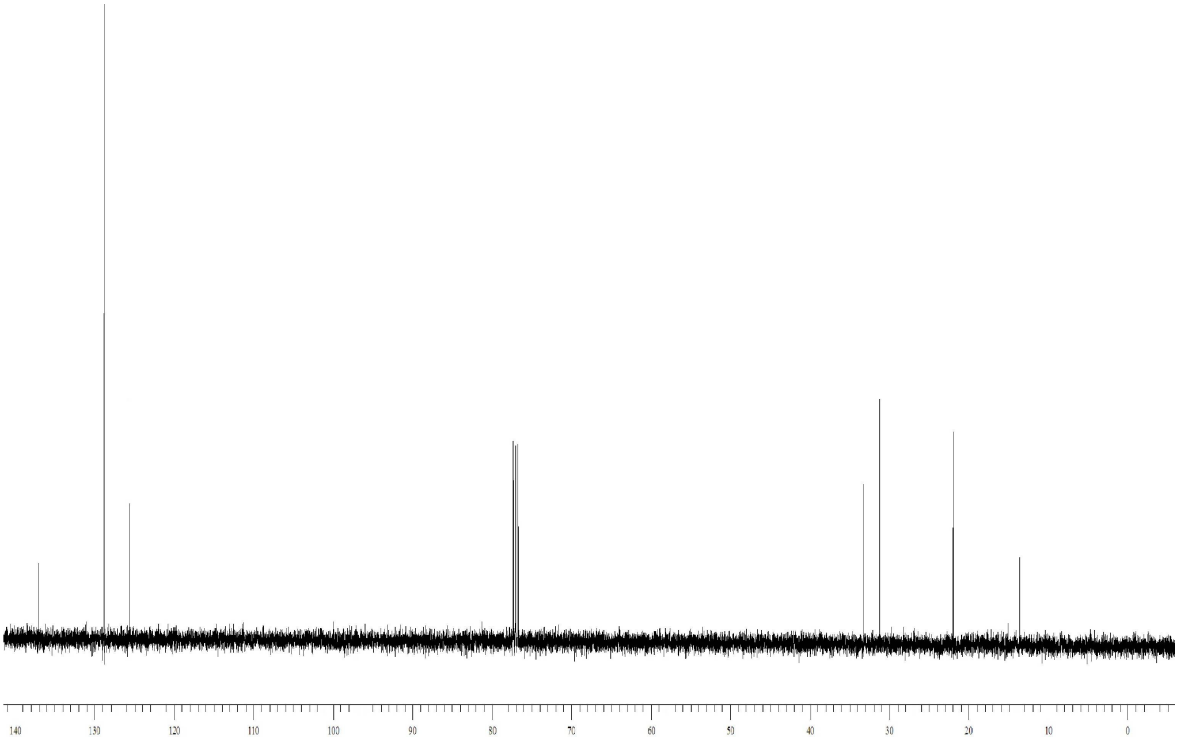

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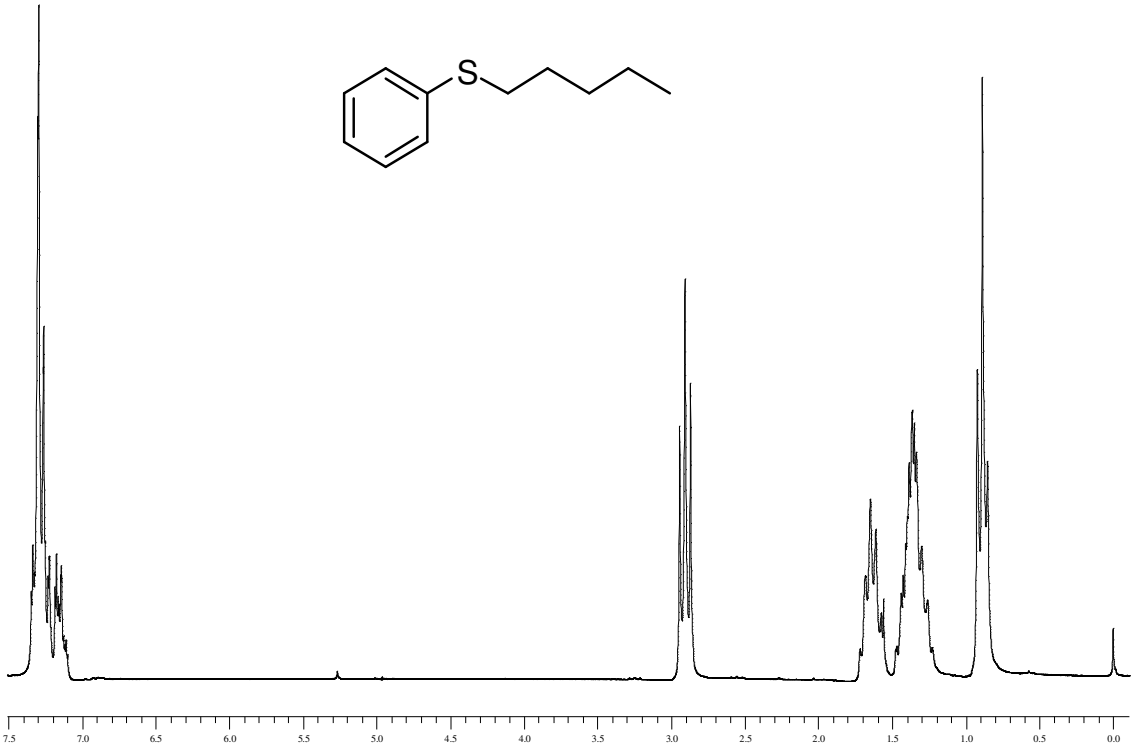

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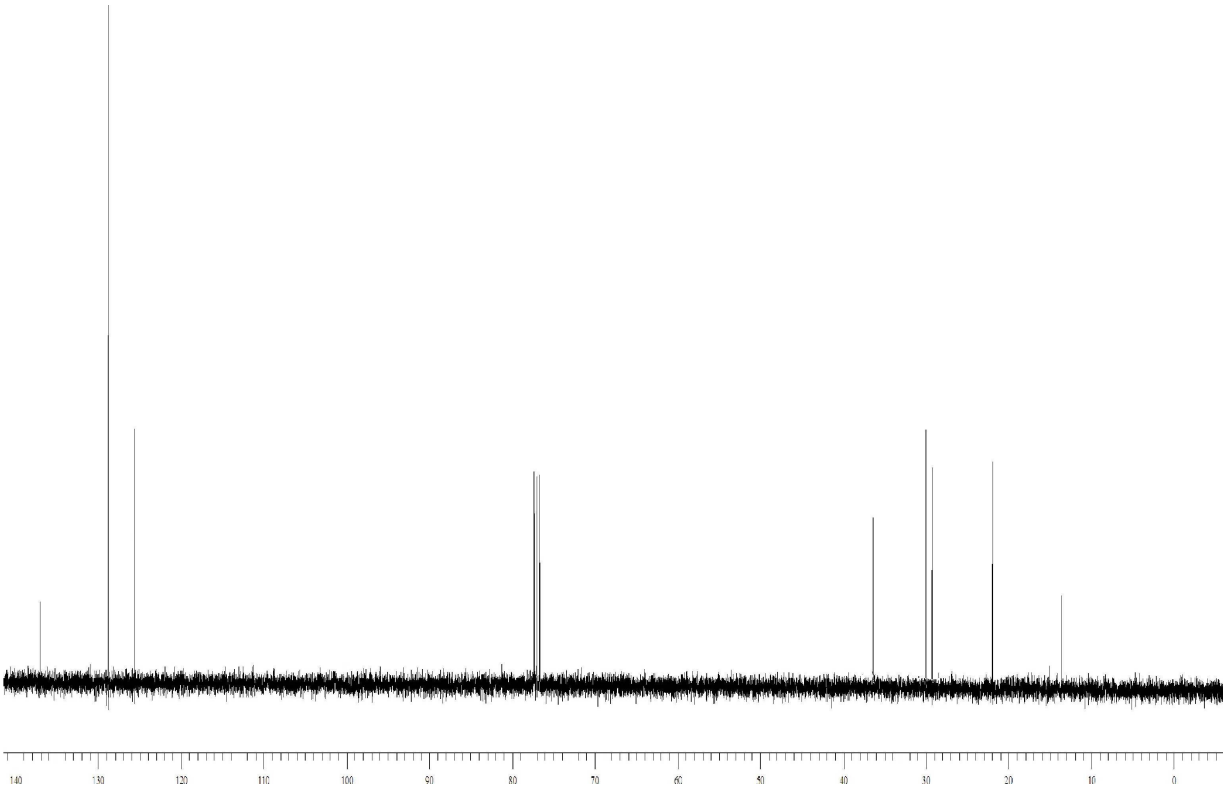

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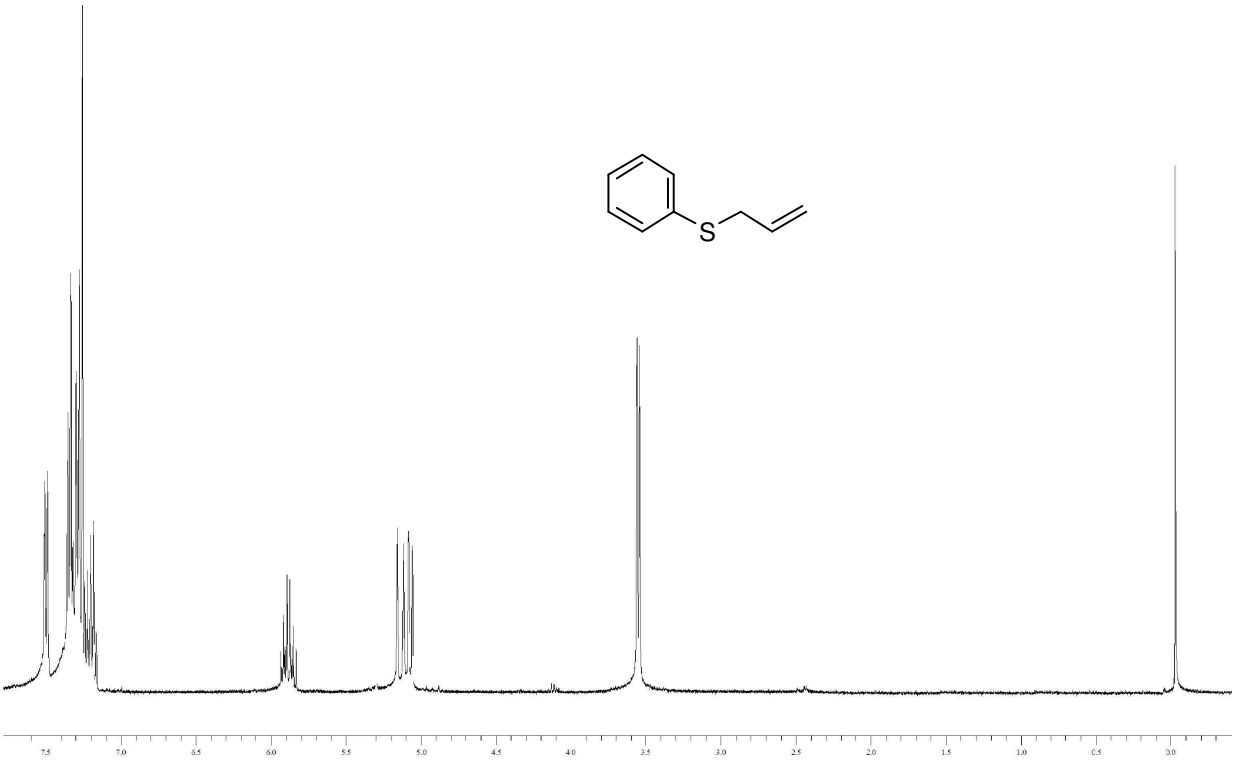

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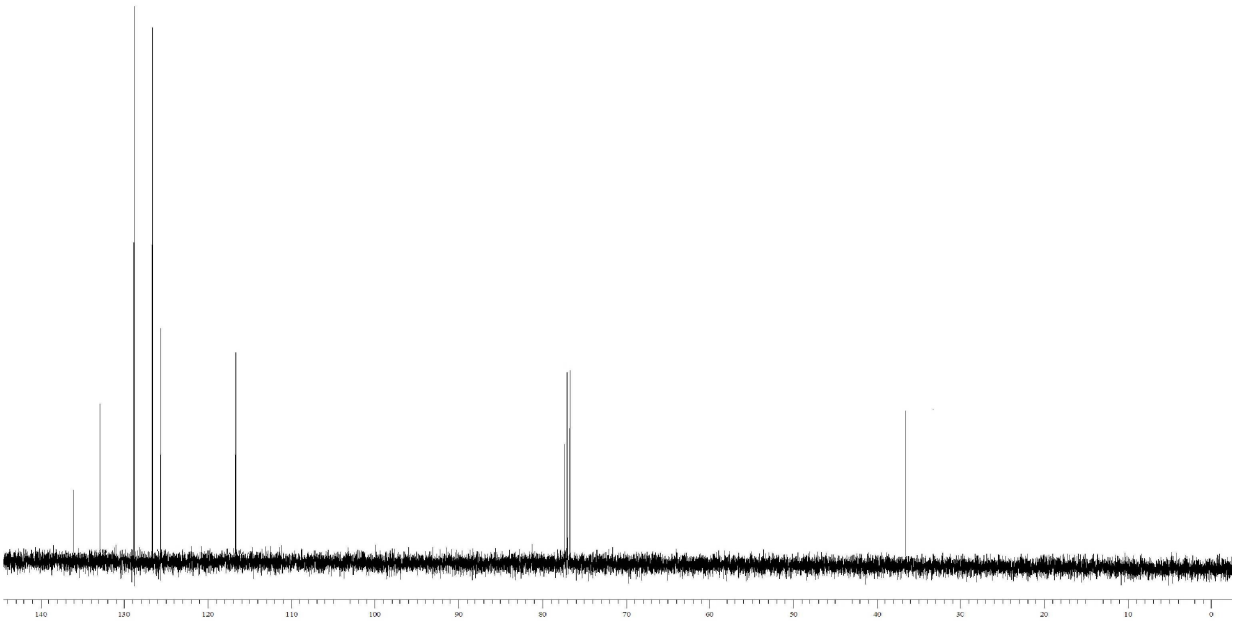

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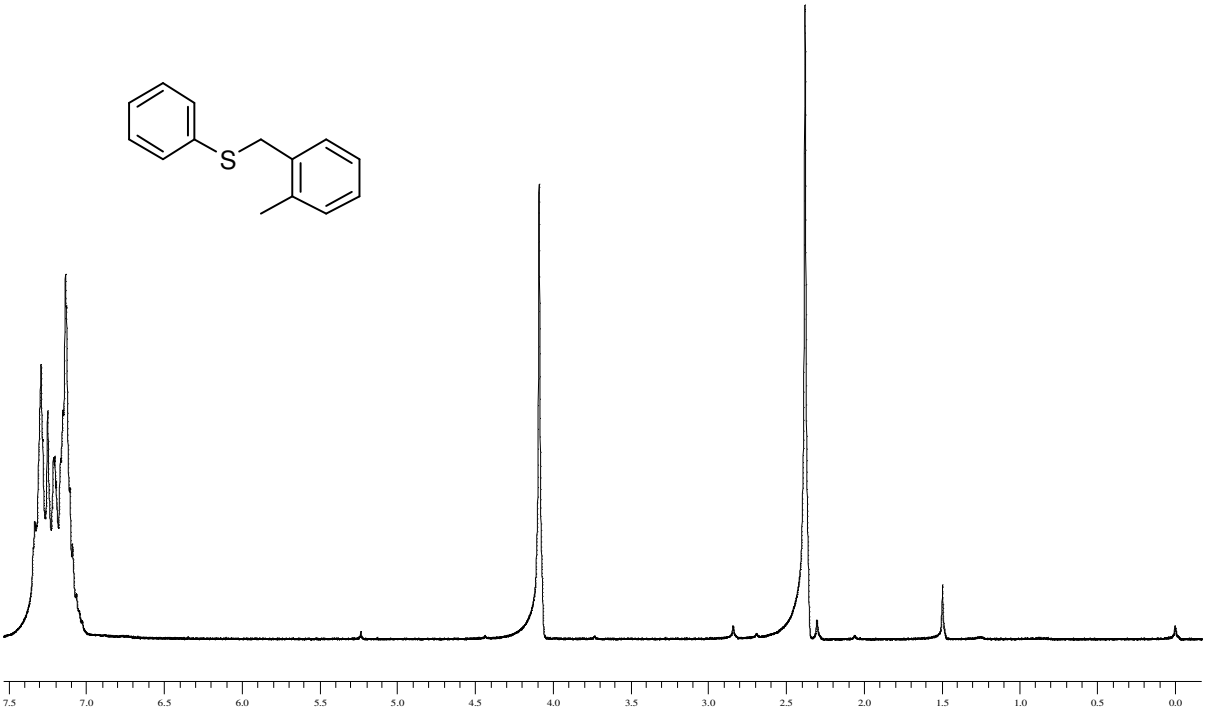

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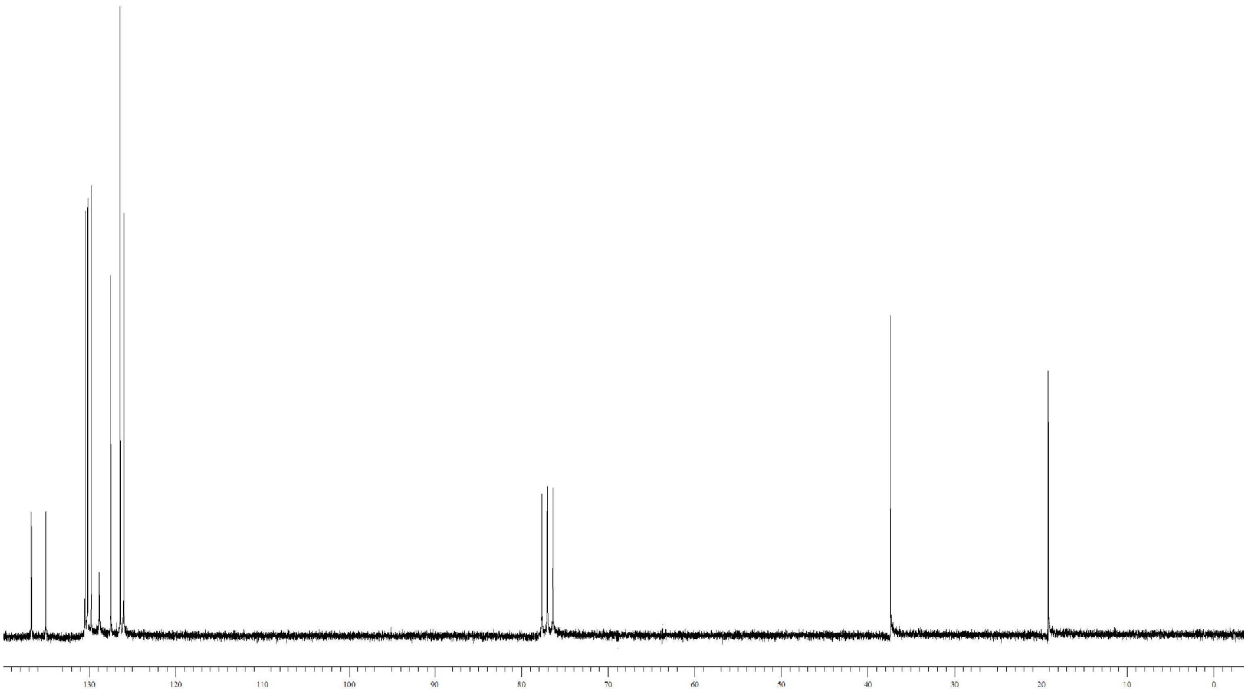

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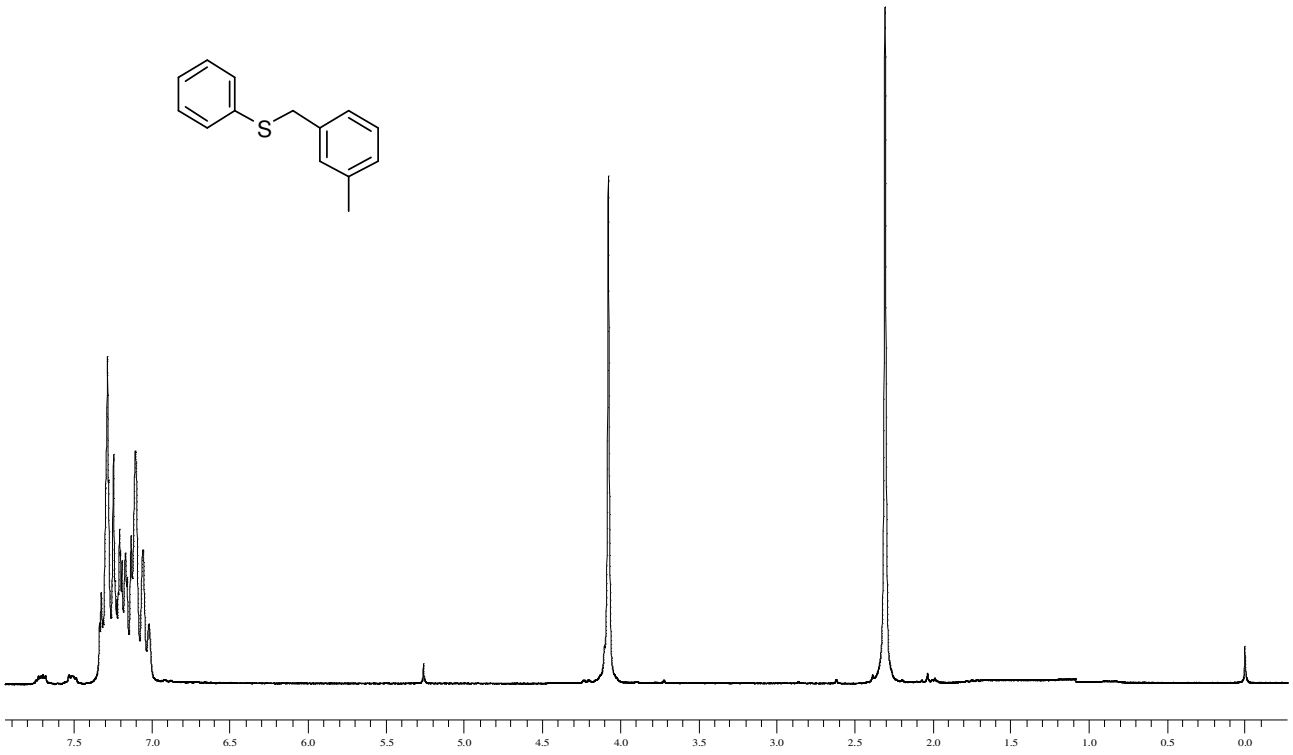

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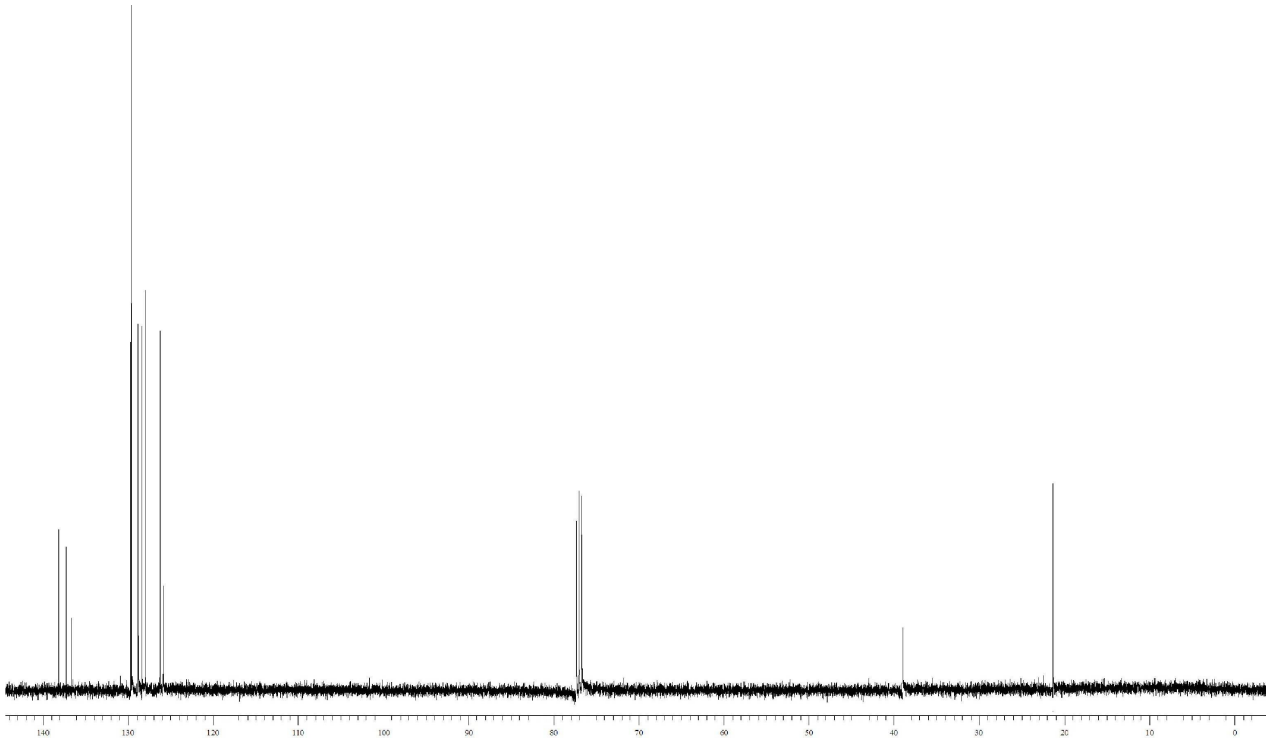

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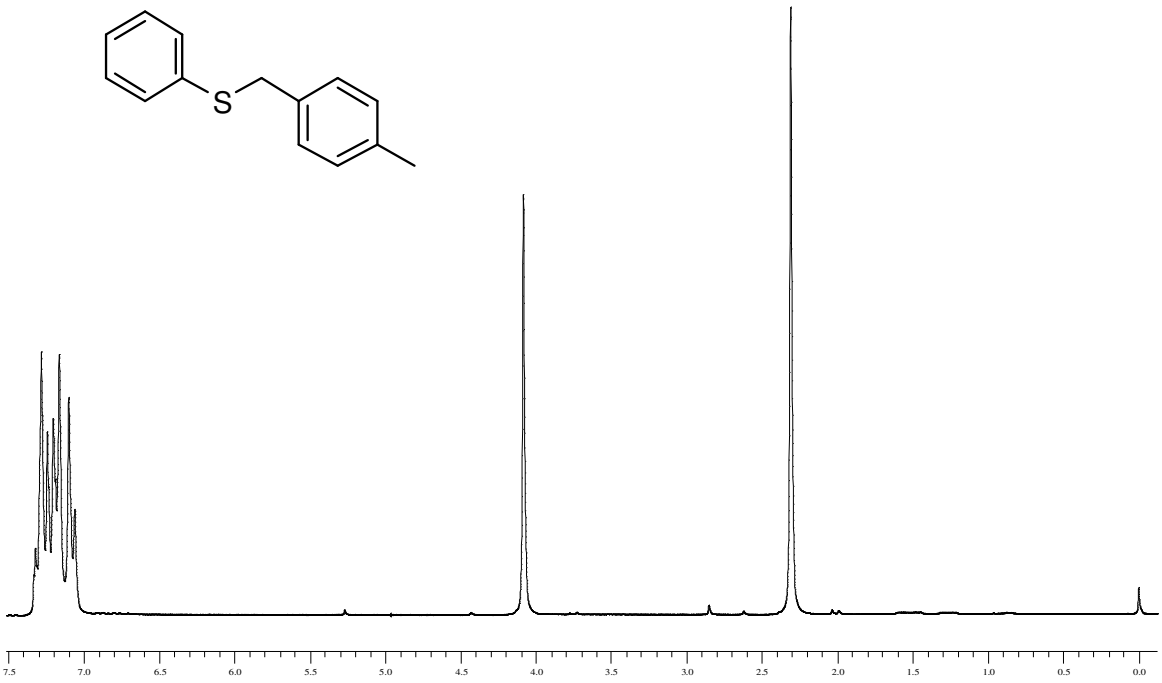

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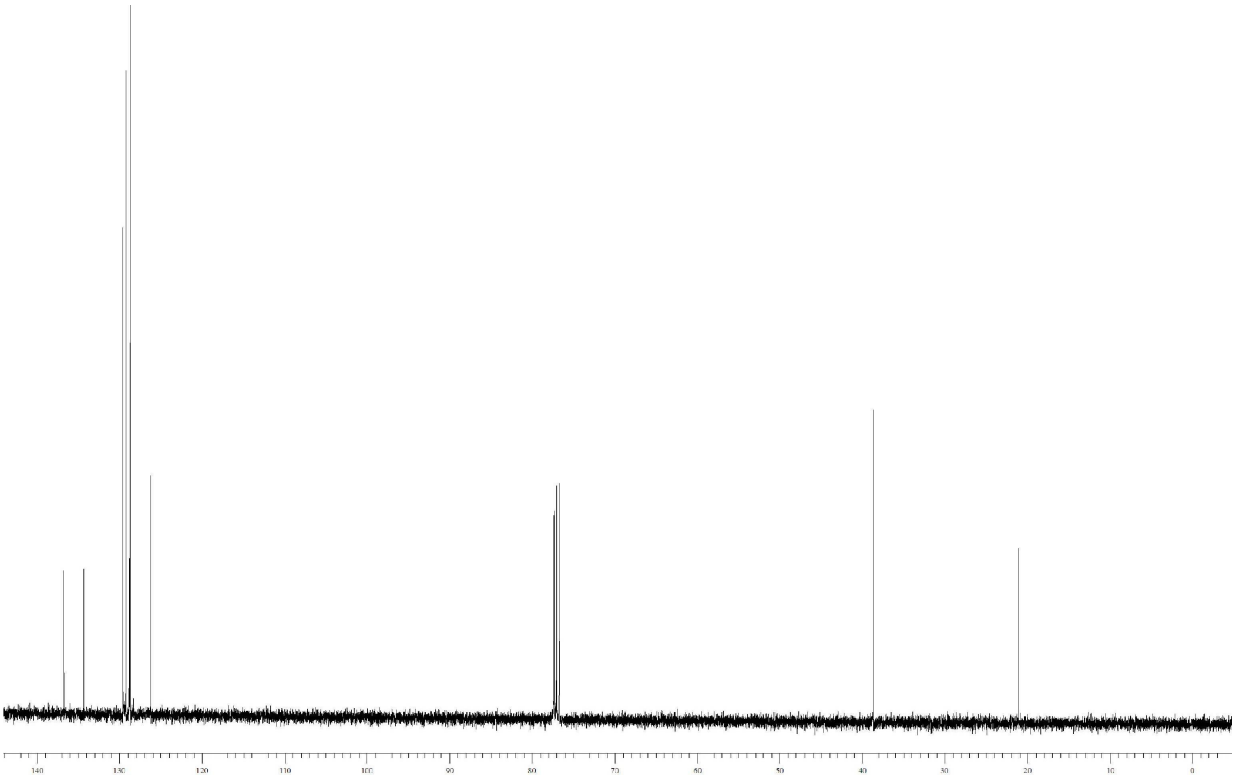

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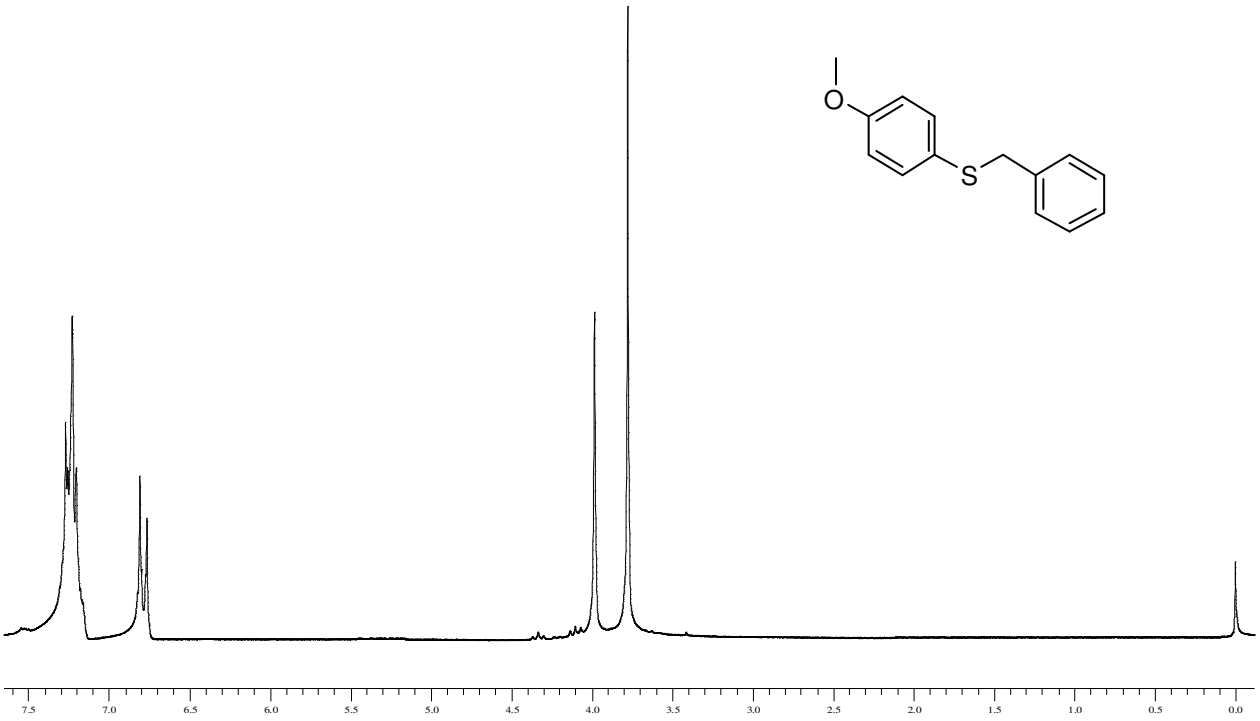

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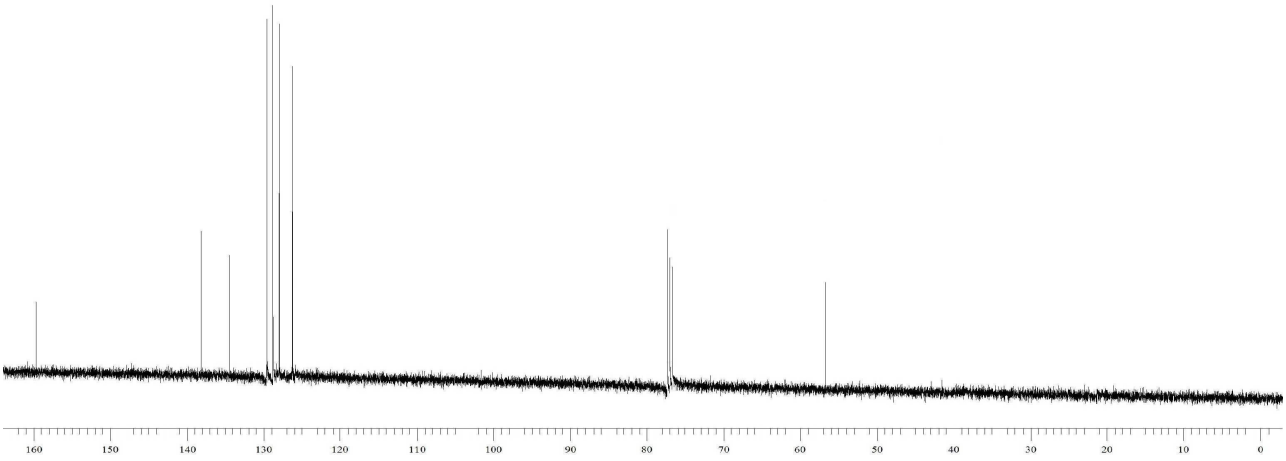

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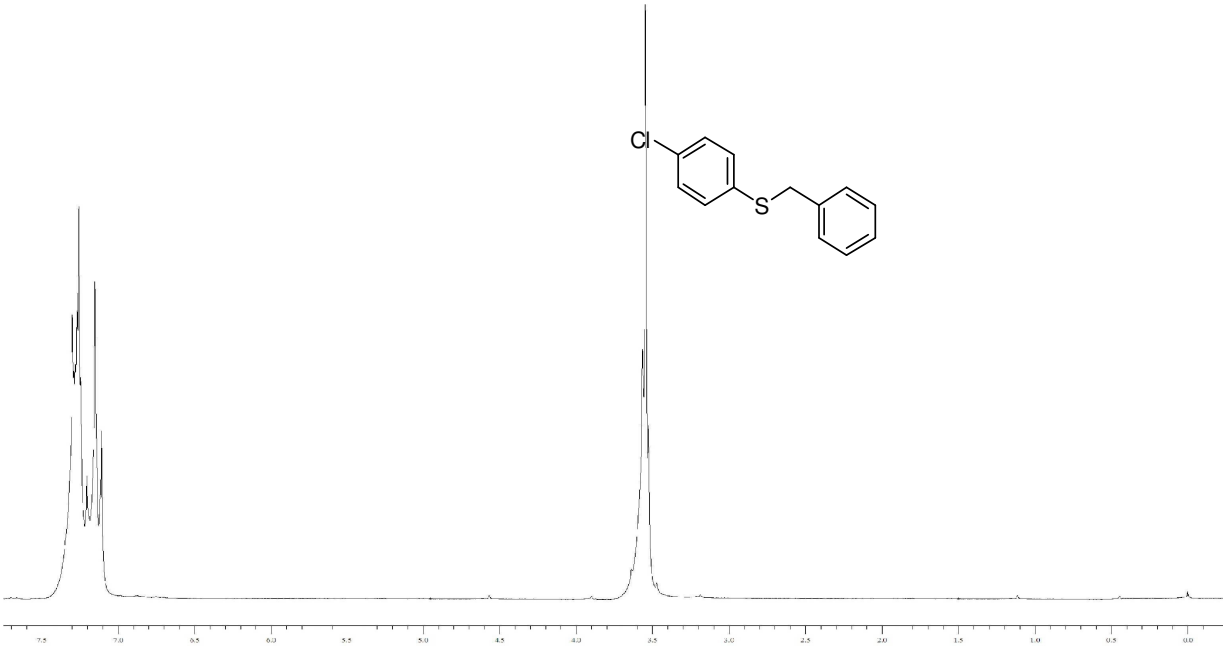
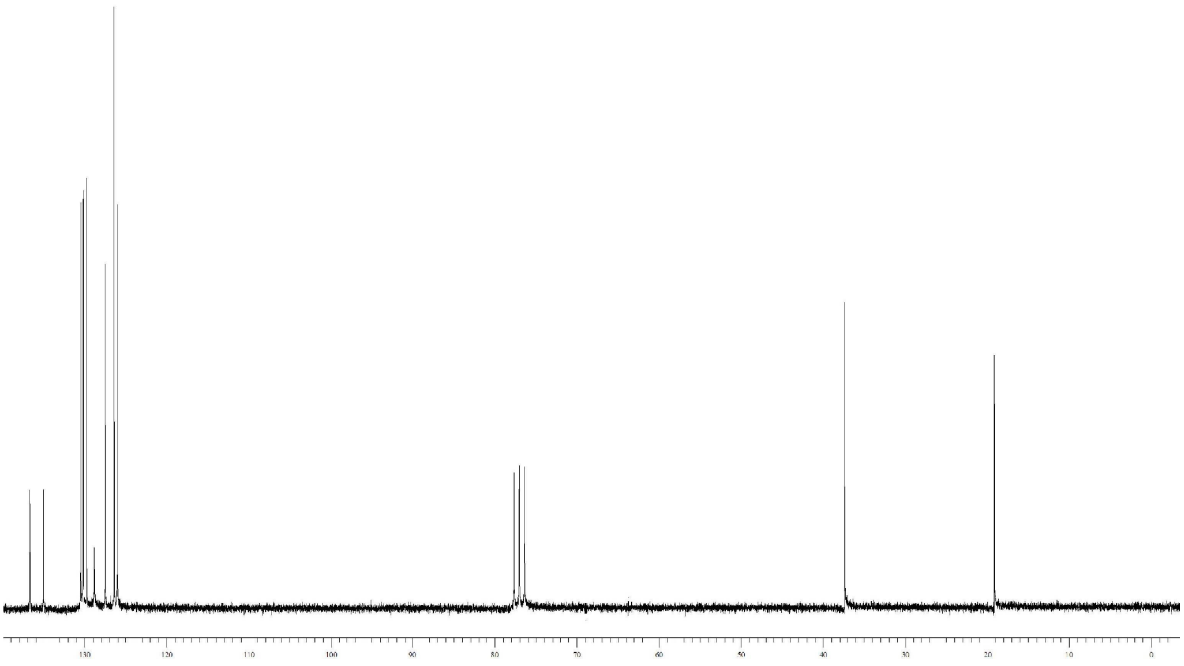
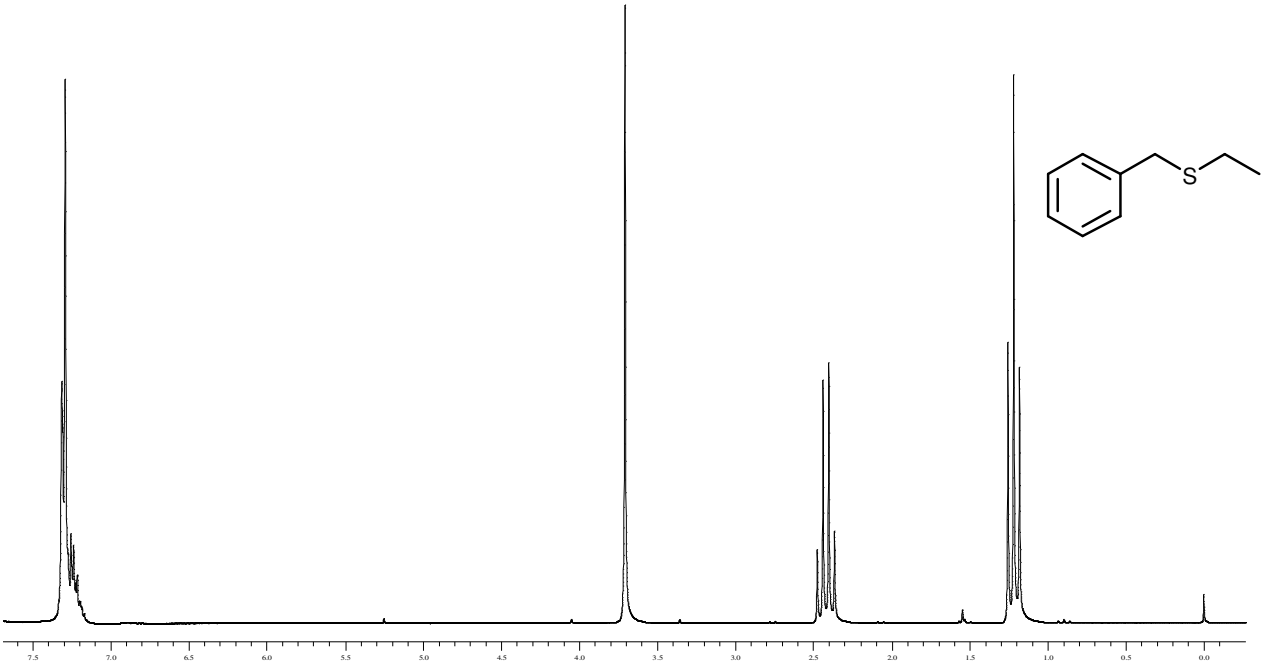


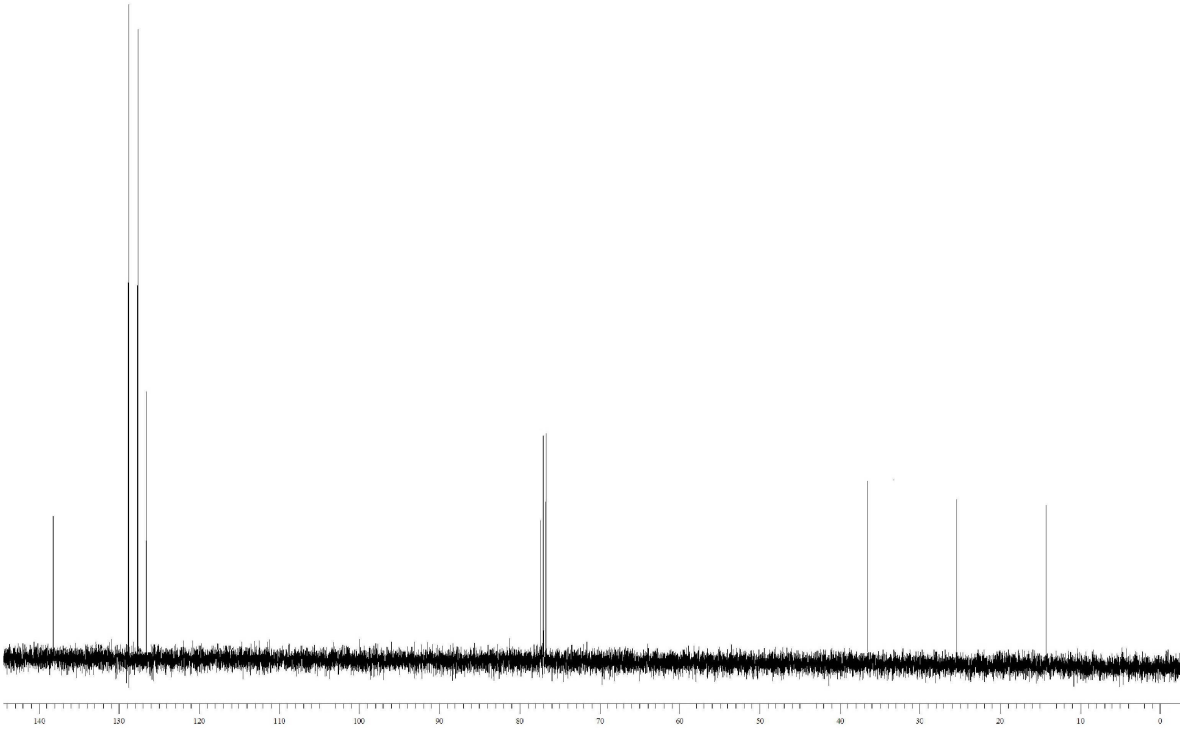
^{13}CNMR (100 MHz, $CDCl_3$) spectrum of **4j**



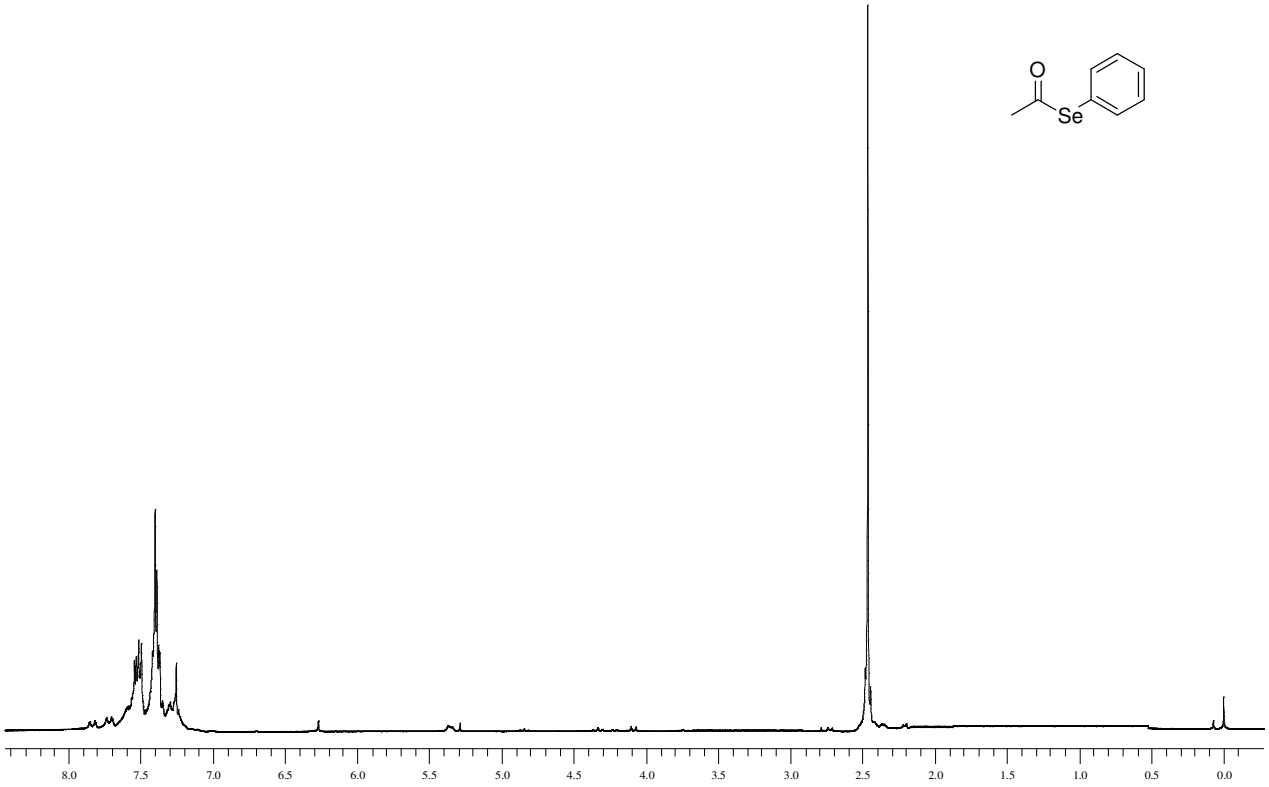
^{13}CNMR (100 MHz, $CDCl_3$) spectrum of **4j**



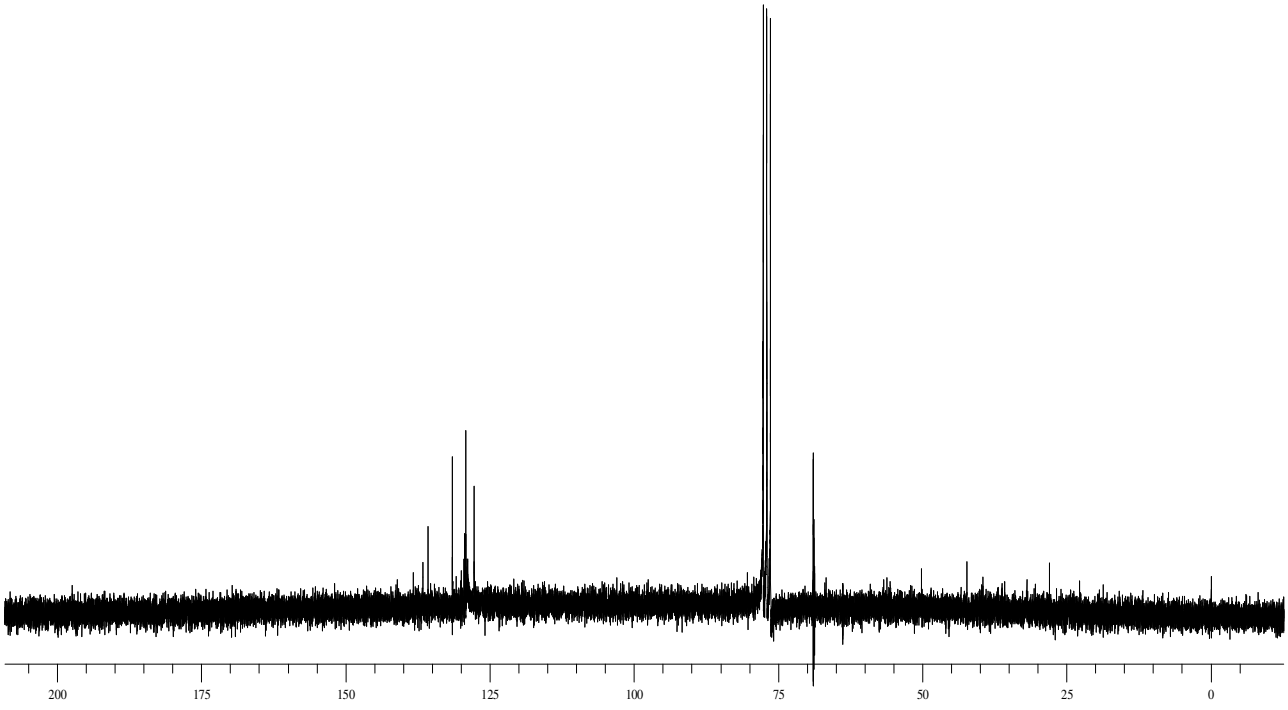
^{1}H NMR (200 MHz, $CDCl_3$) spectrum of **4l**.



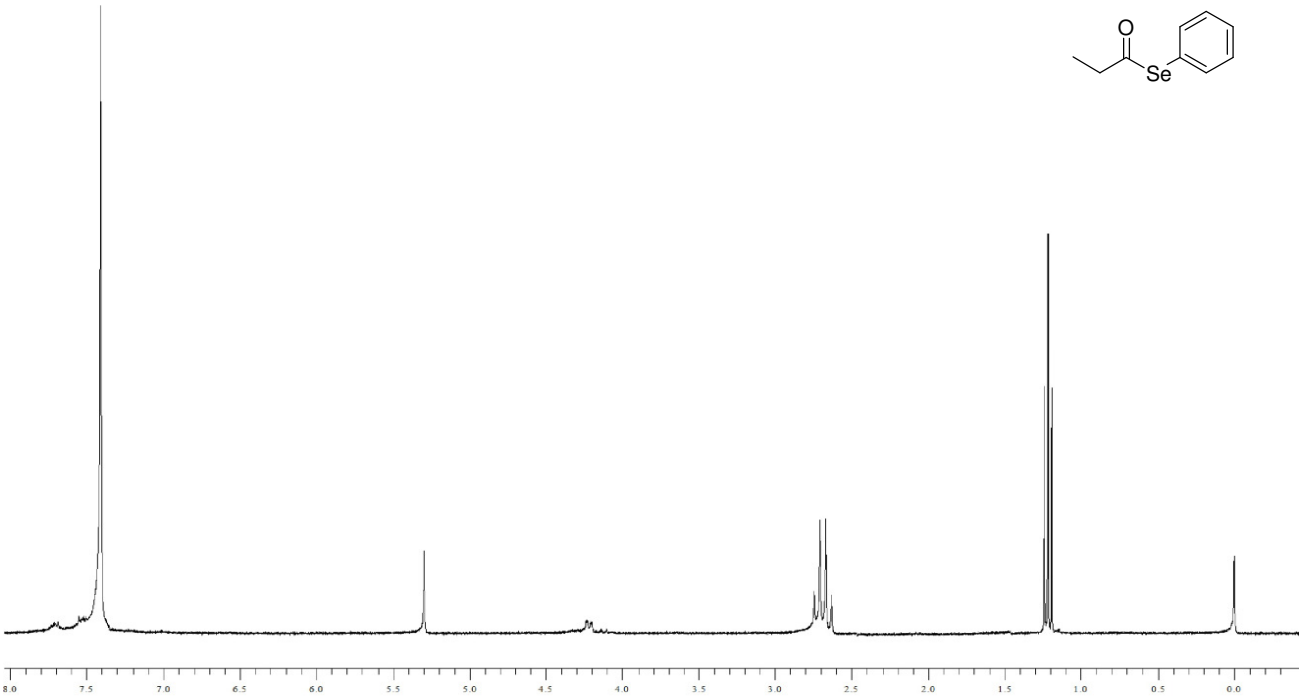
^{13}C NMR (50 MHz, $CDCl_3$) spectrum of **4l**.



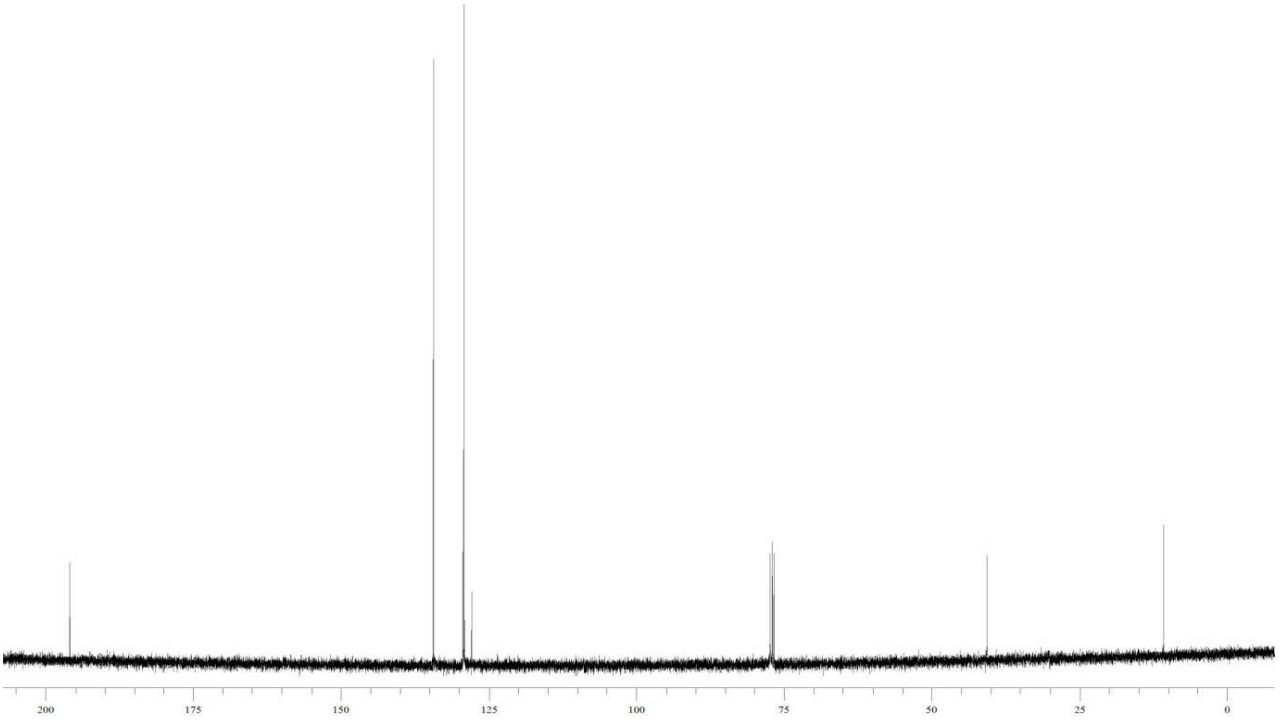
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of ***6b***.



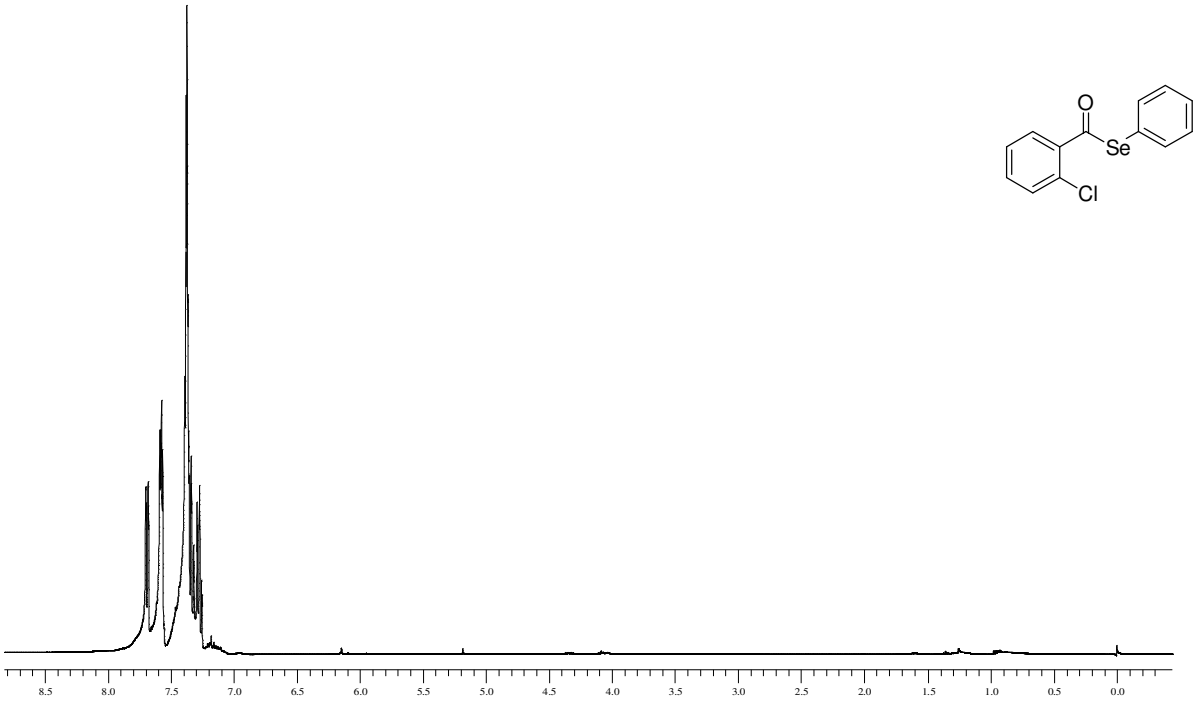
^{13}C NMR ($CDCl_3$, 100 MHz) Spectrum of **6b**.



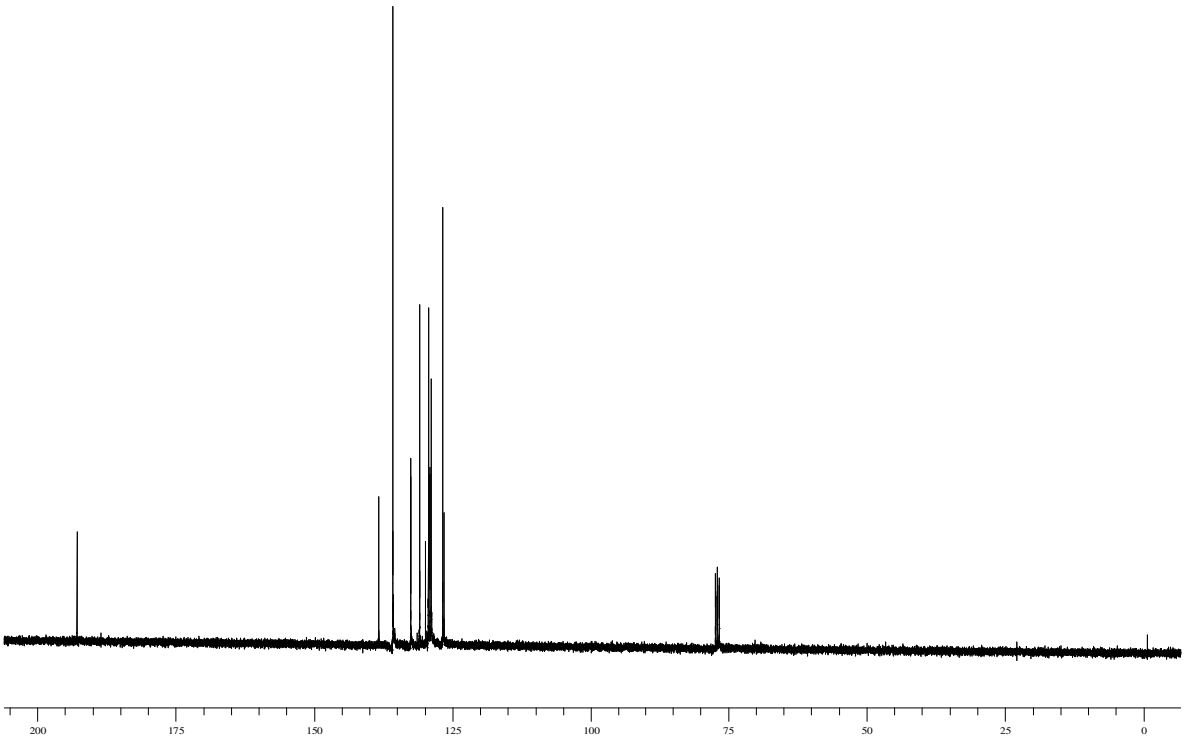
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6c**.



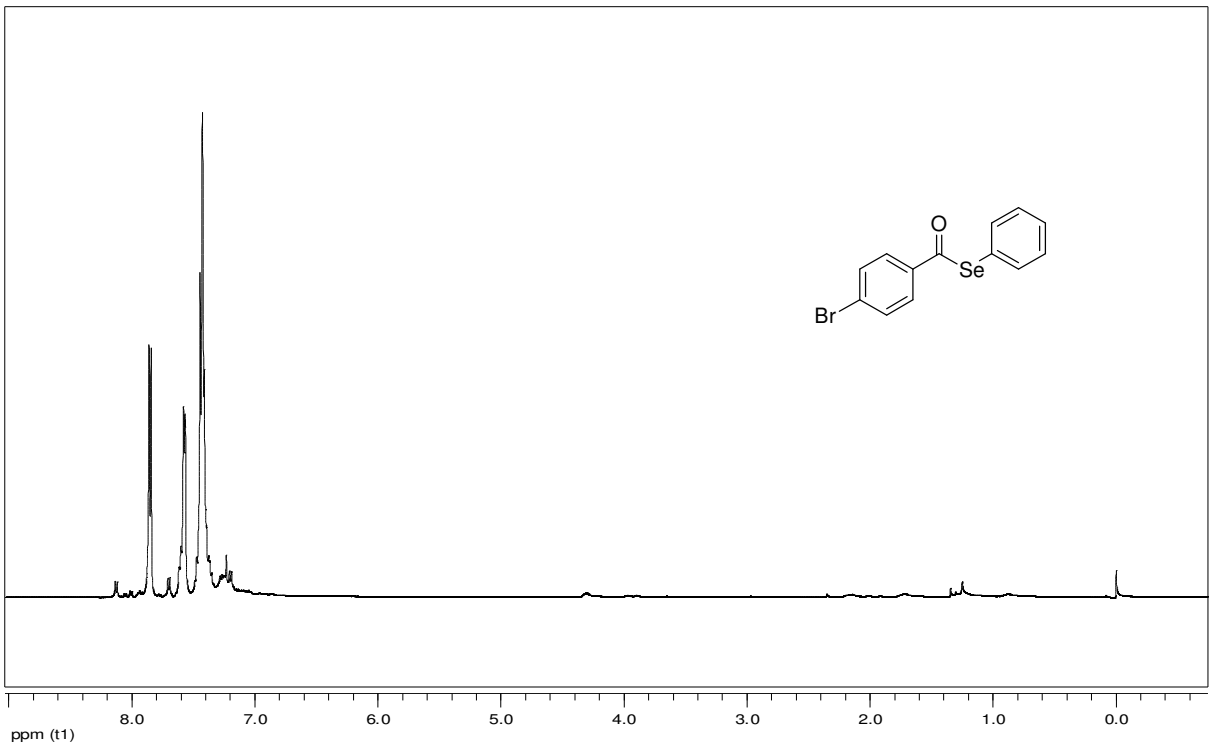
^{13}C NMR ($CDCl_3$, 100 MHz) Spectrum of **6b**.



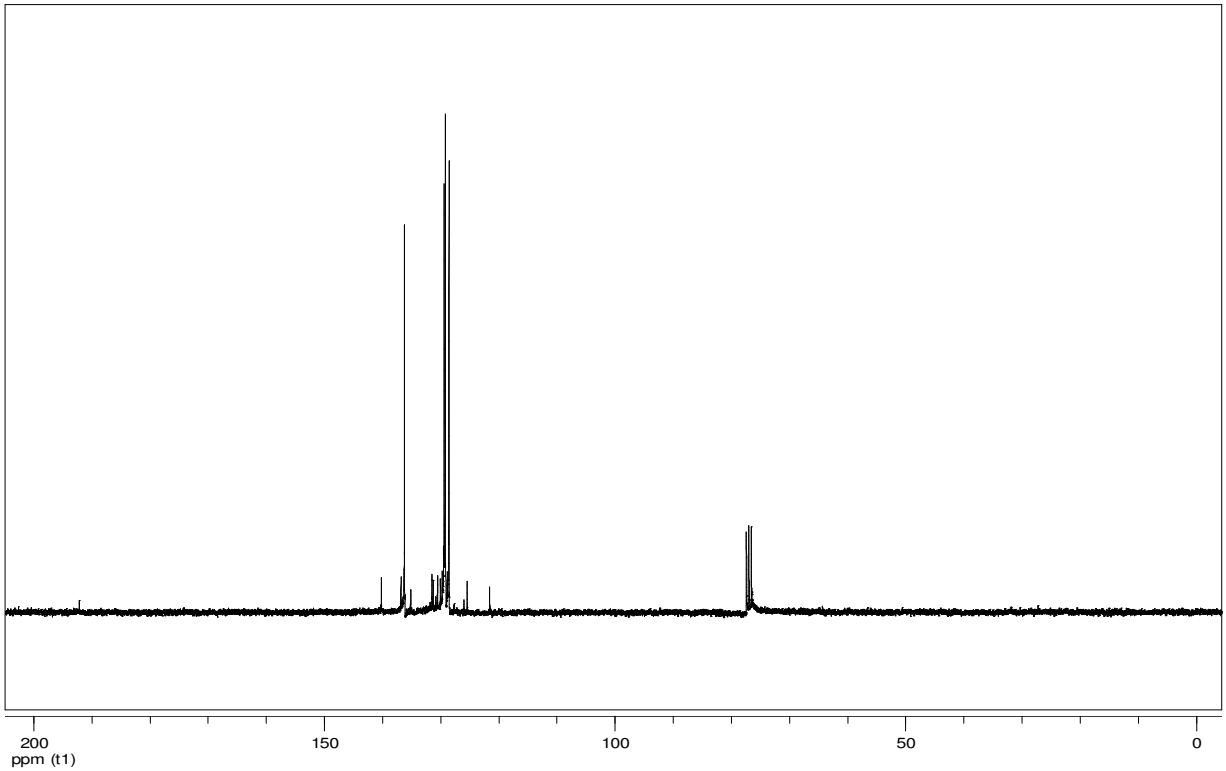
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6d**.



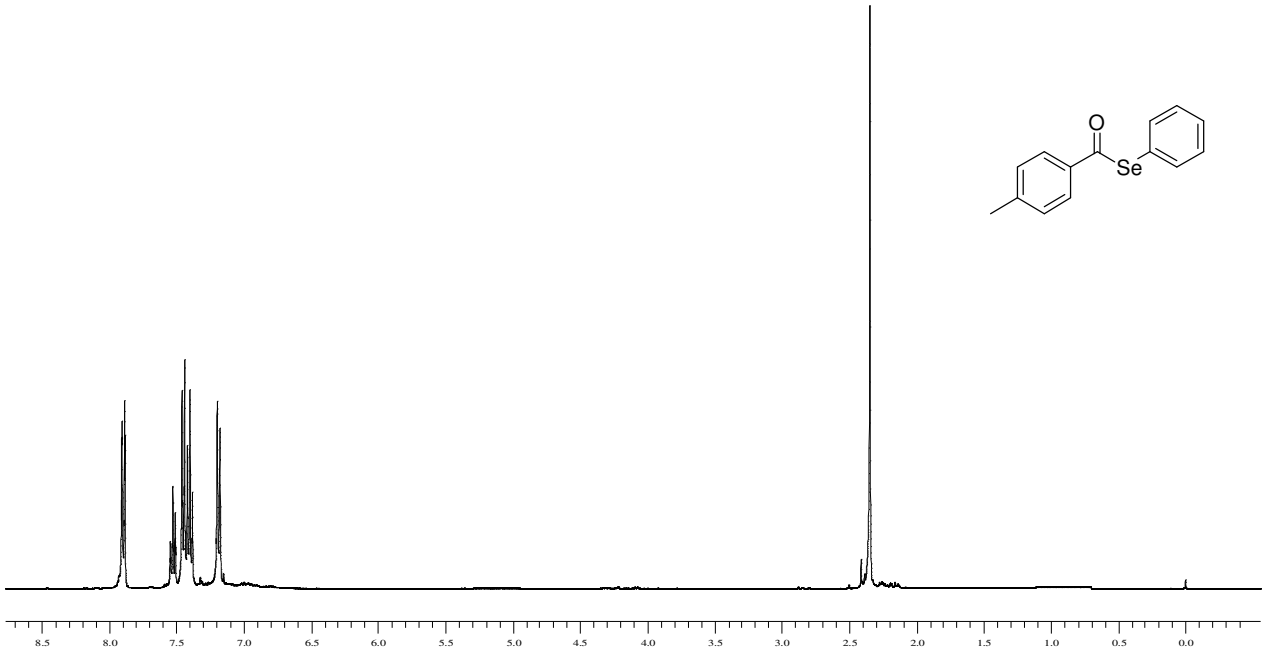
^{13}C NMR ($CDCl_3$, 100 MHz) Spectrum of **6d**.



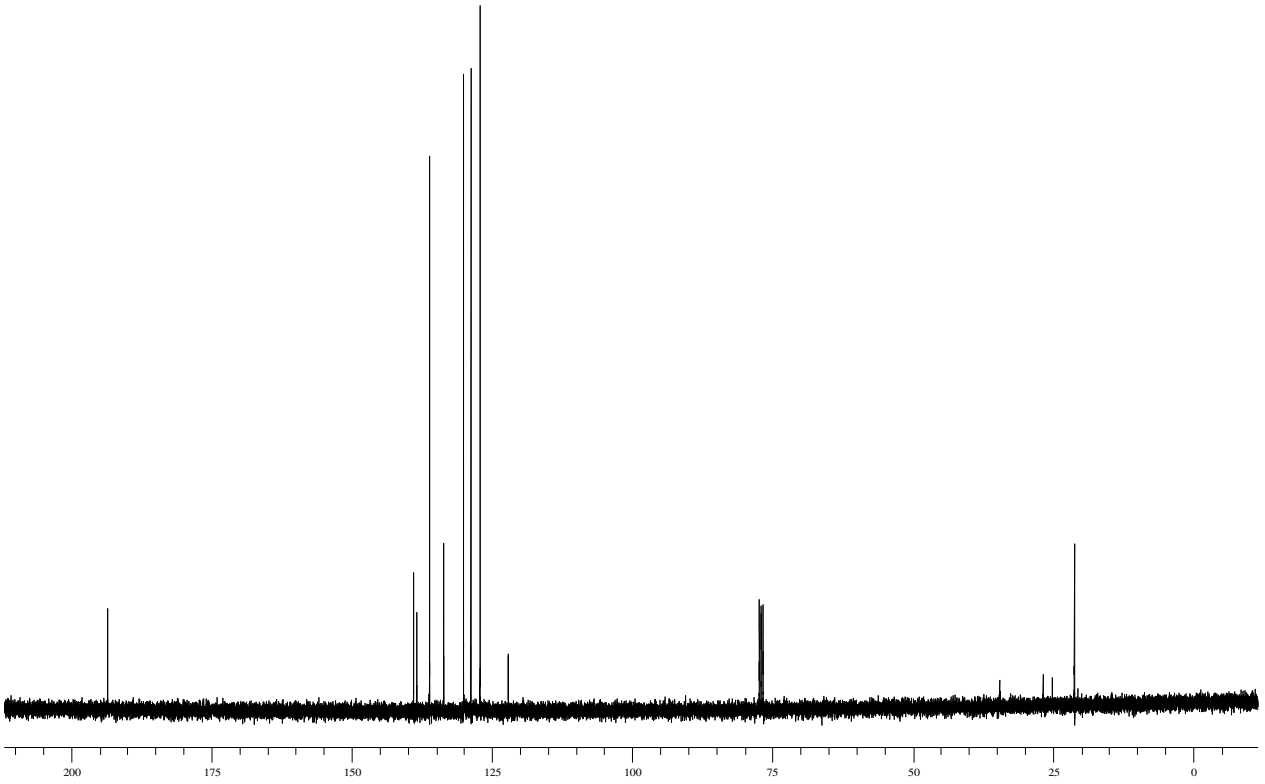
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6e**.



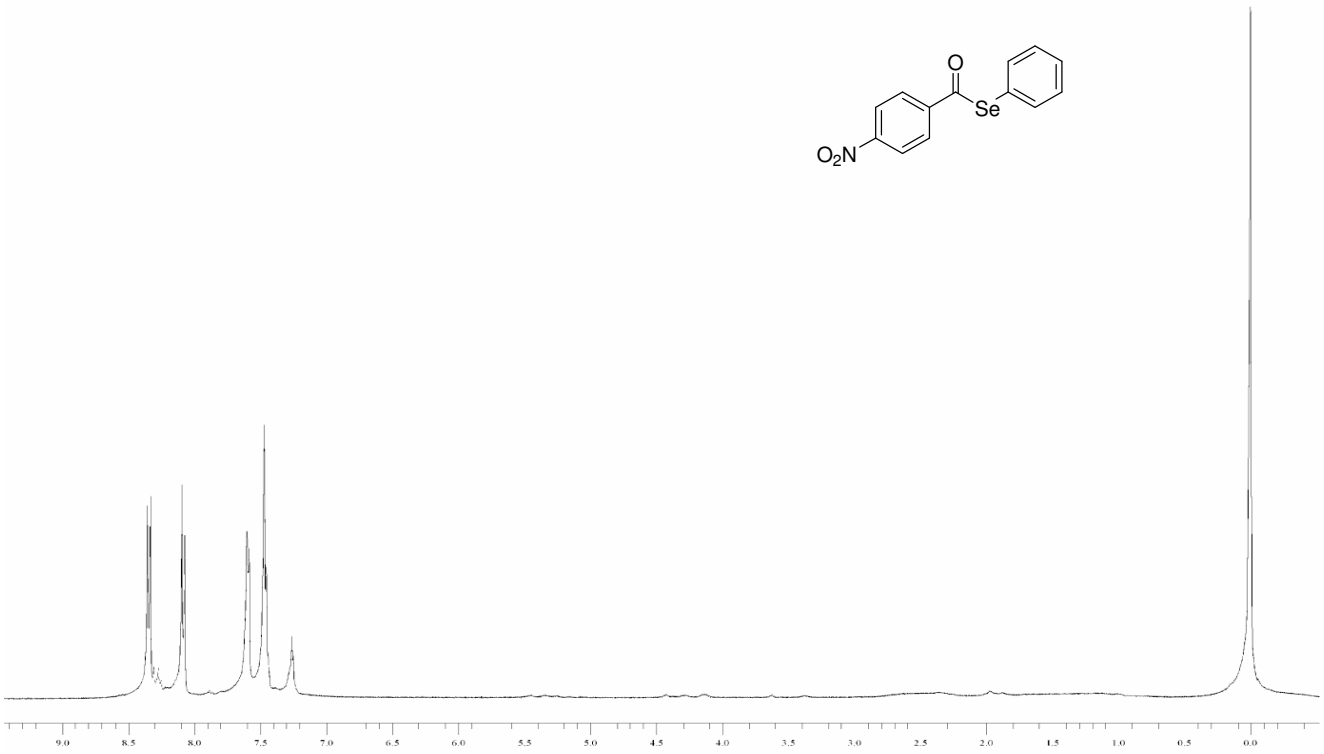
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **6e**.



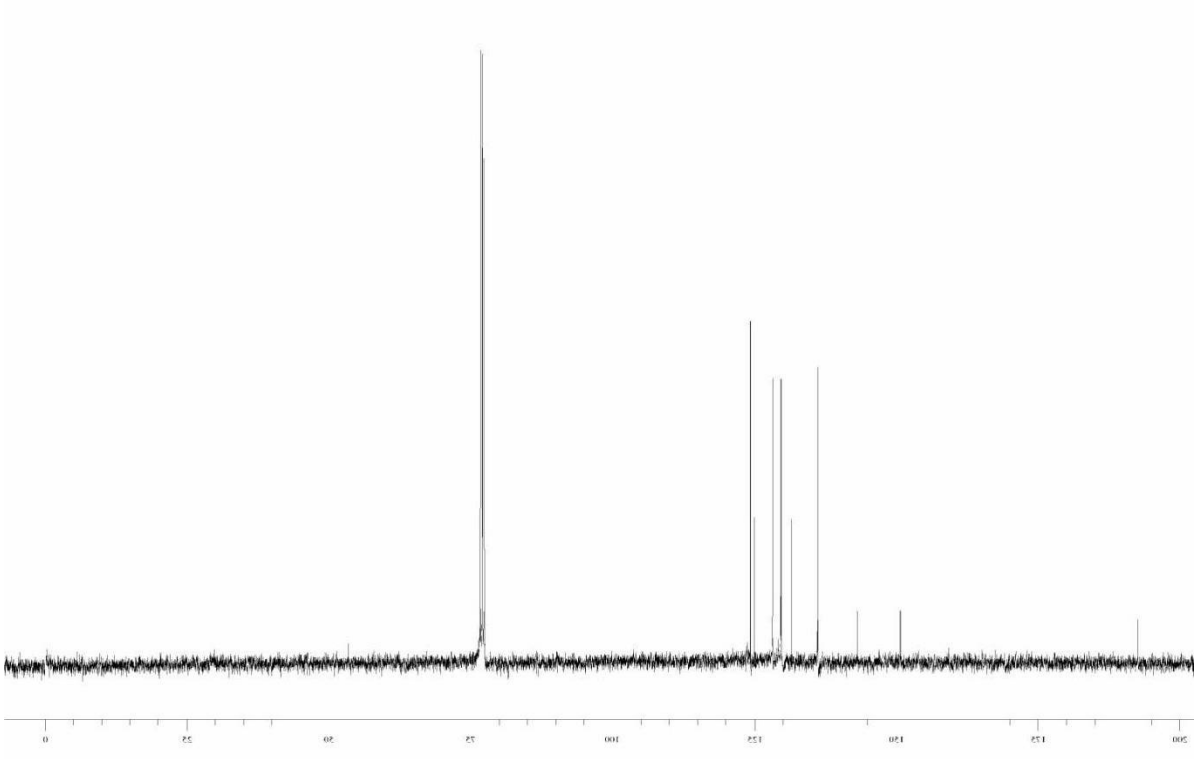
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6f**.



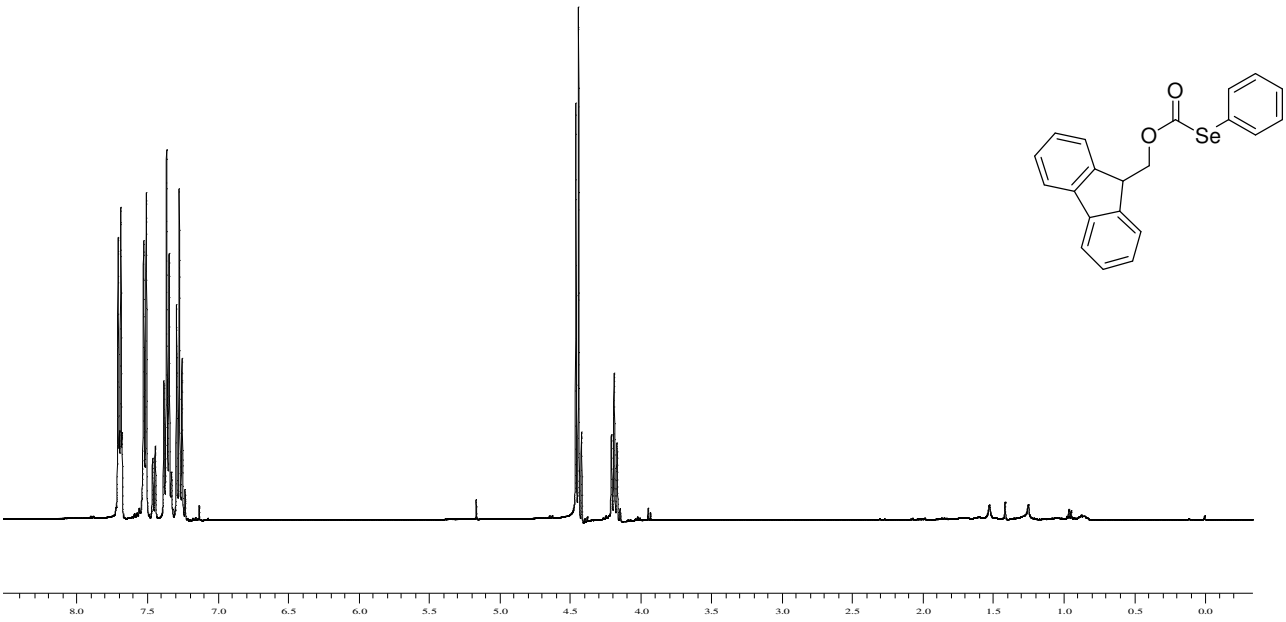
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **6f**.



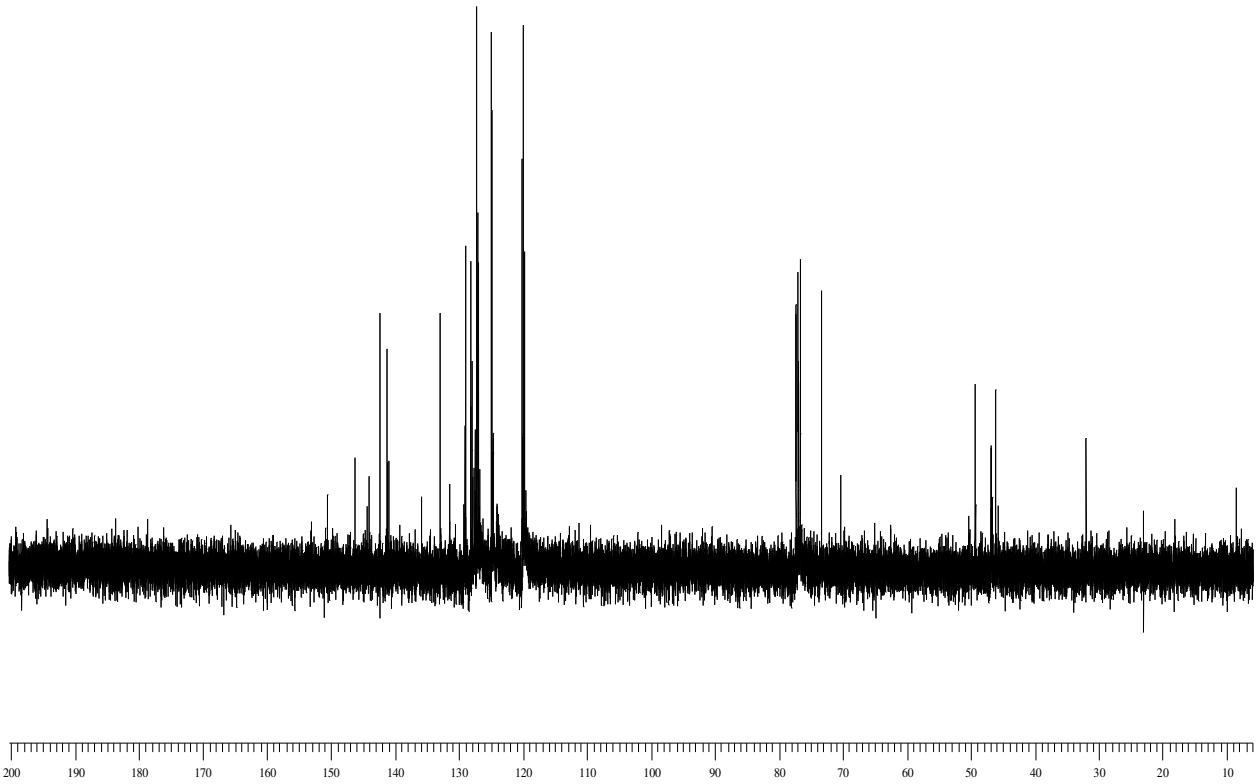
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6g**.



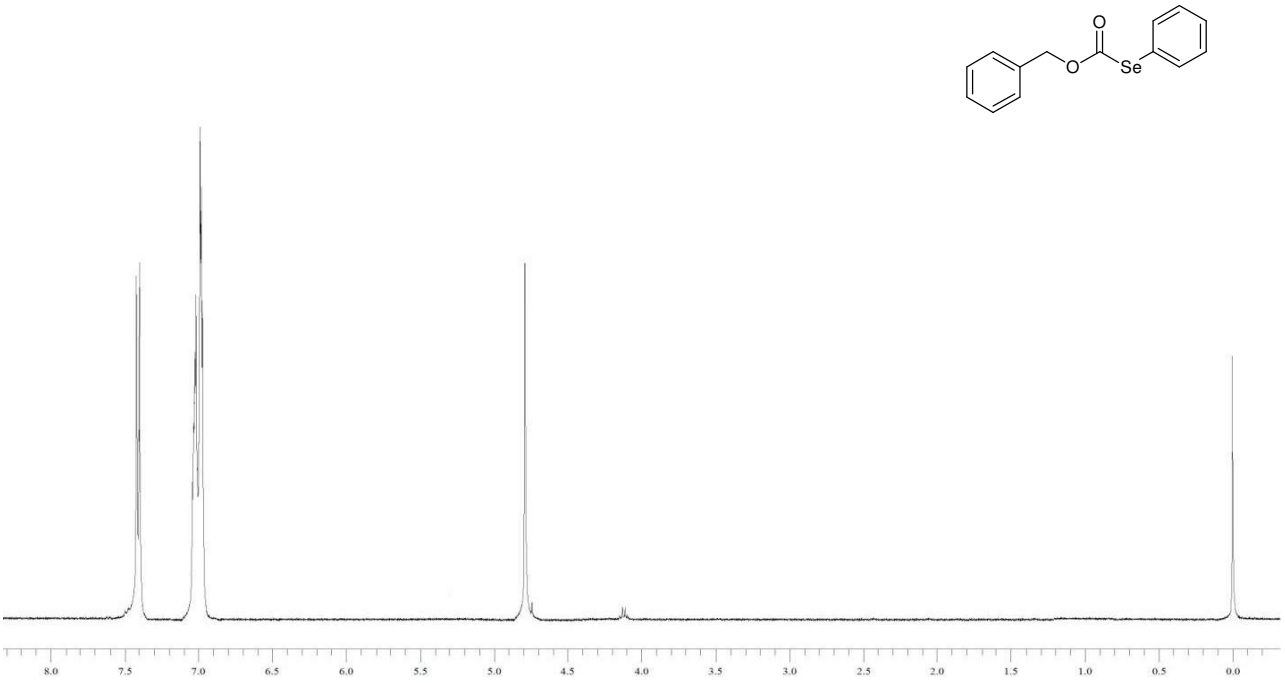
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **6g**.



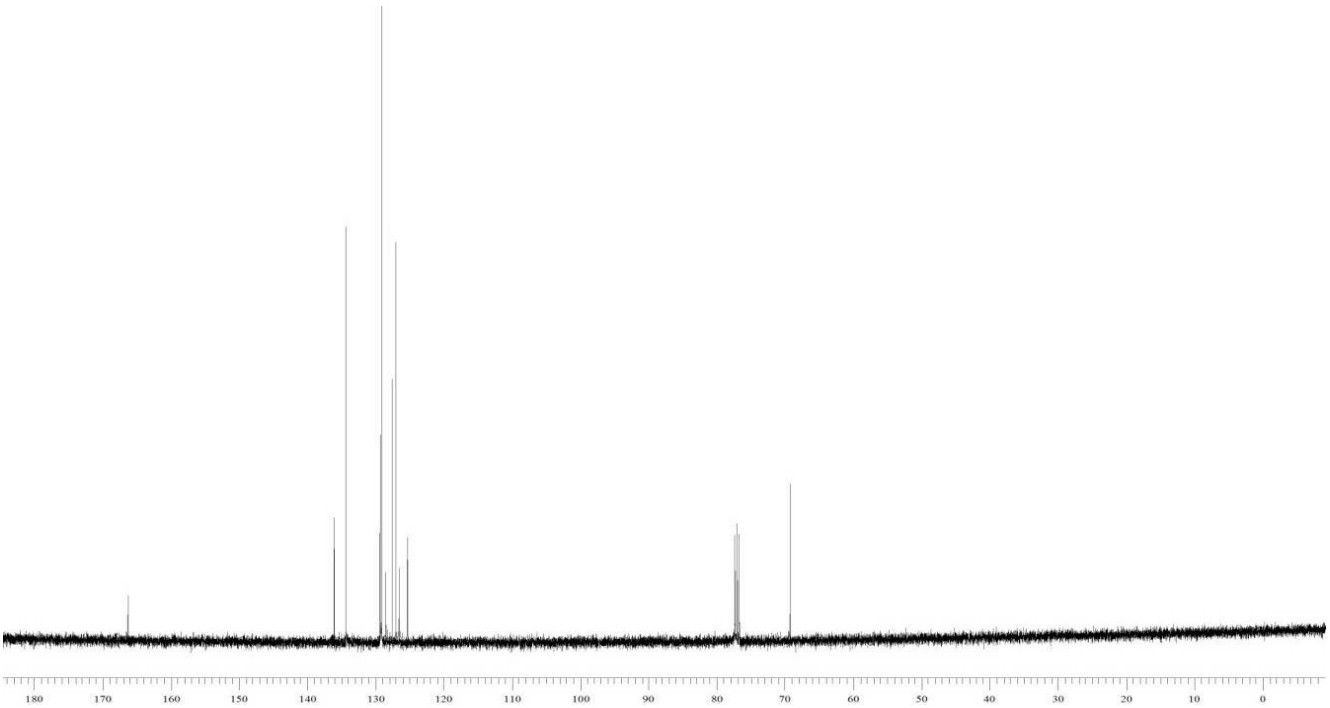
^{1}H NMR($CDCl_3$, 400 MHz) Spectrum of **6h**.



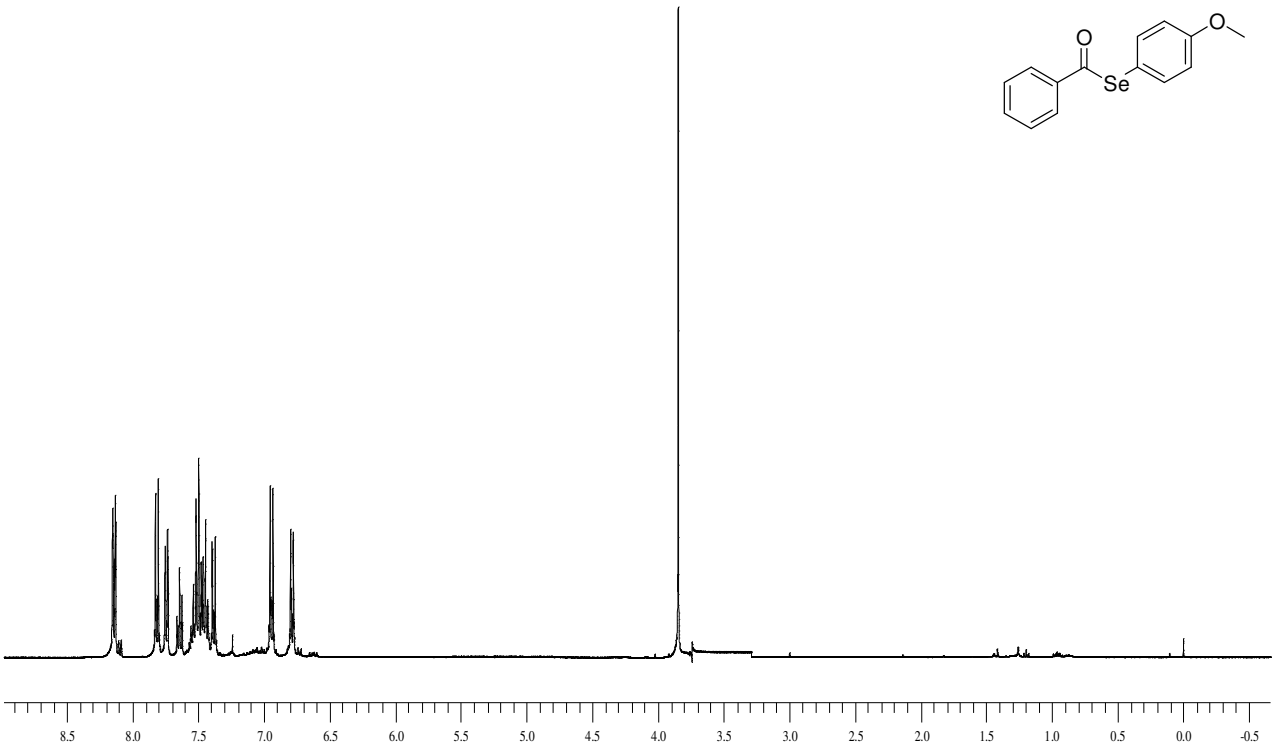
^{13}C NMR(100MHz, $CDCl_3$) Spectrum of **6h**.



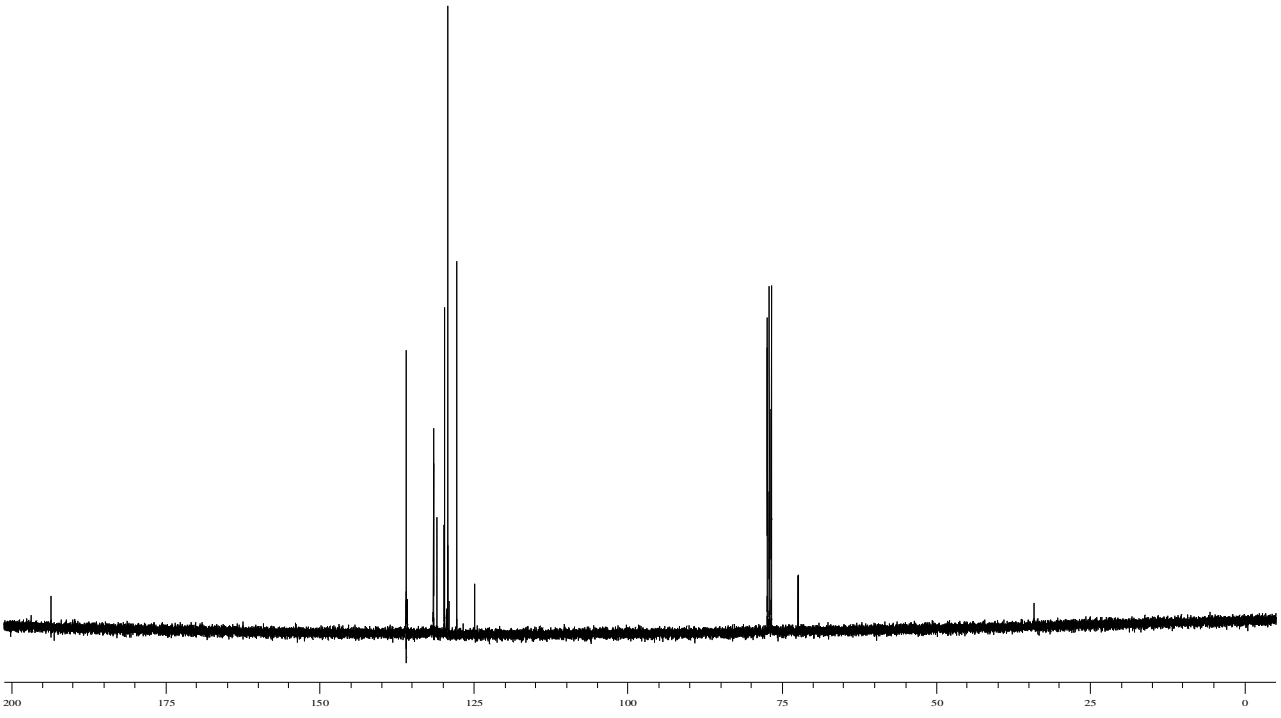
^{1}H NMR($CDCl_3$, 400 MHz) Spectrum of **6i**.



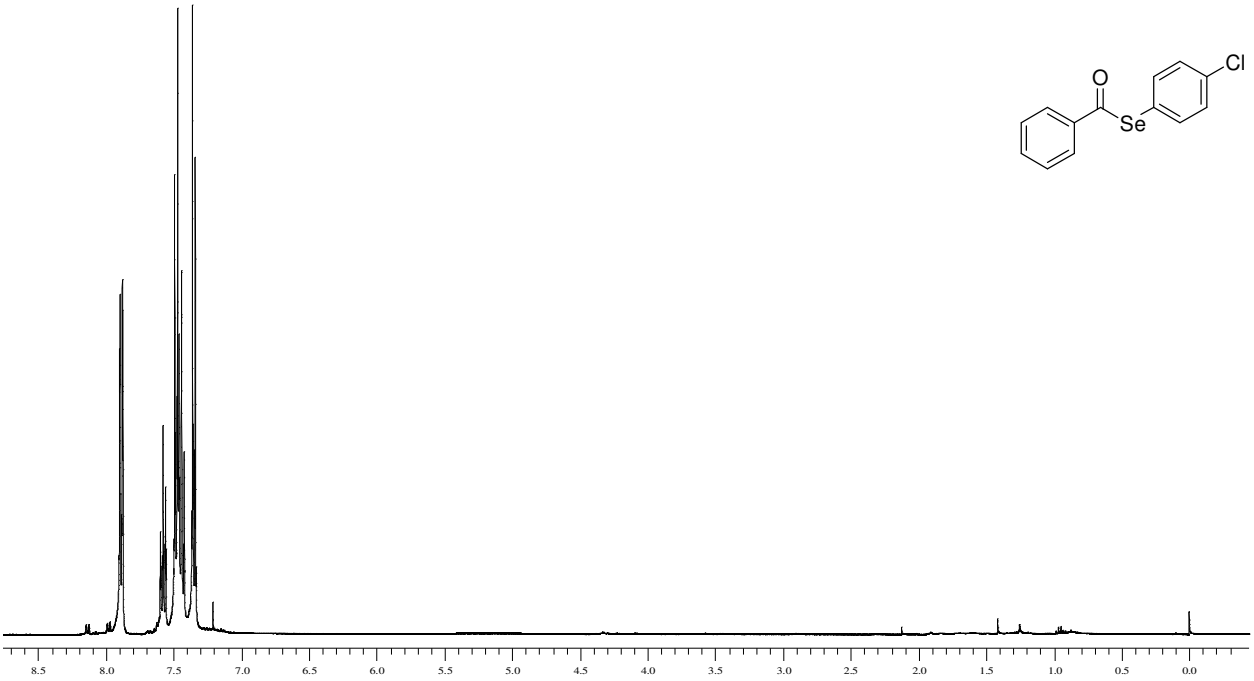
^{13}C NMR(100MHz, $CDCl_3$) Spectrum of **6i**.



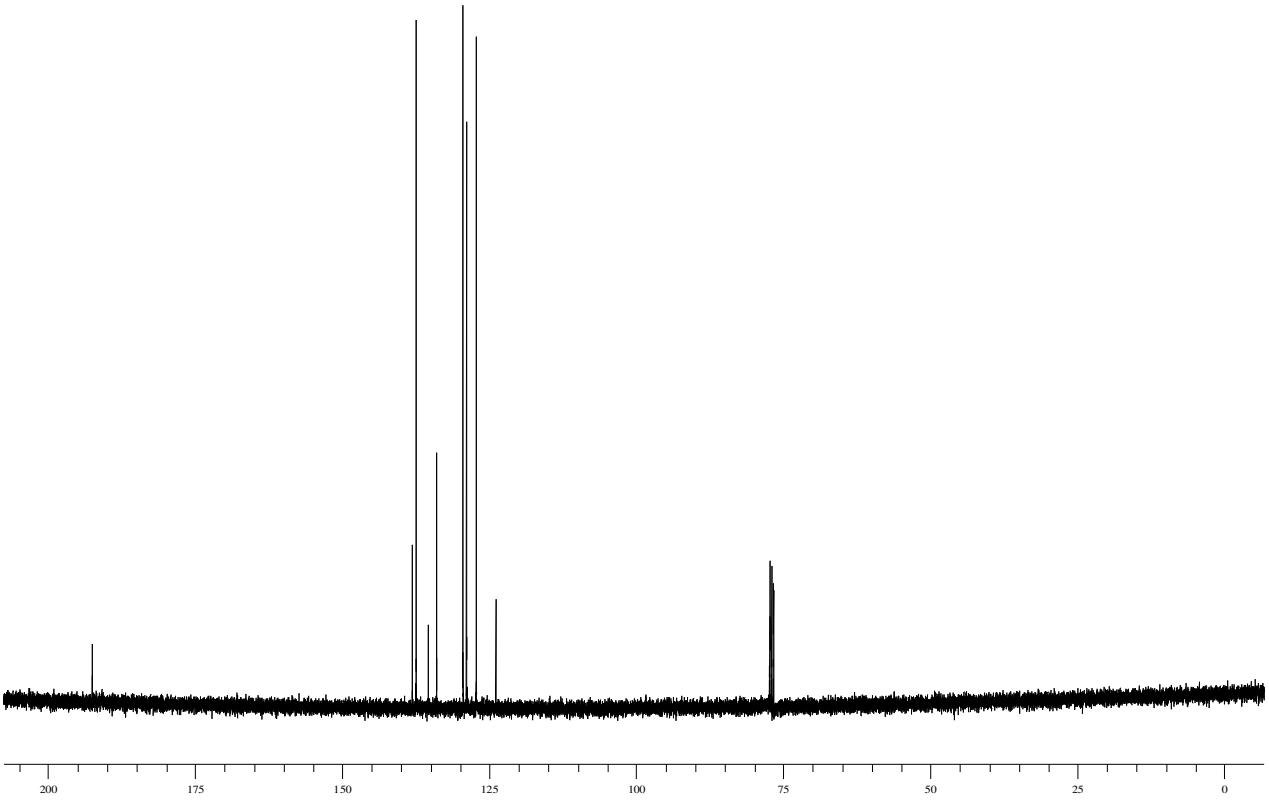
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6j**.



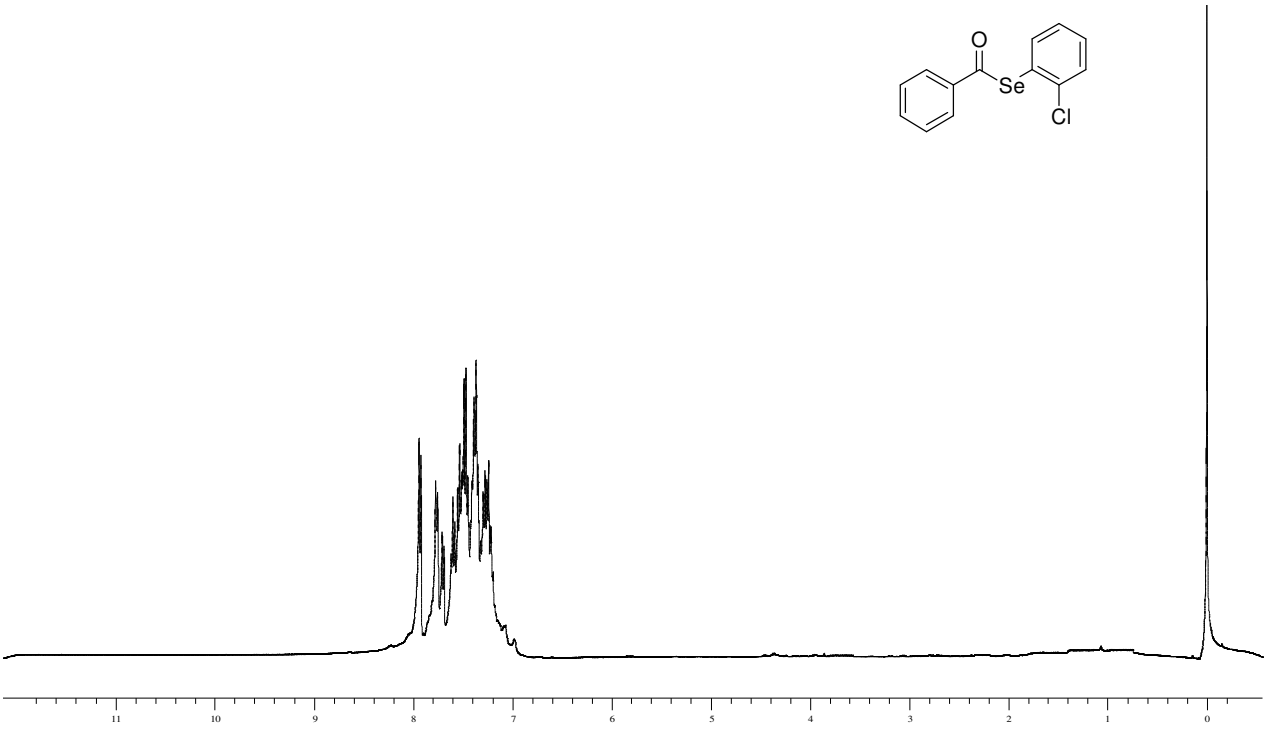
^{13}C NMR (100MHz, $CDCl_3$) Spectrum of **6j**.



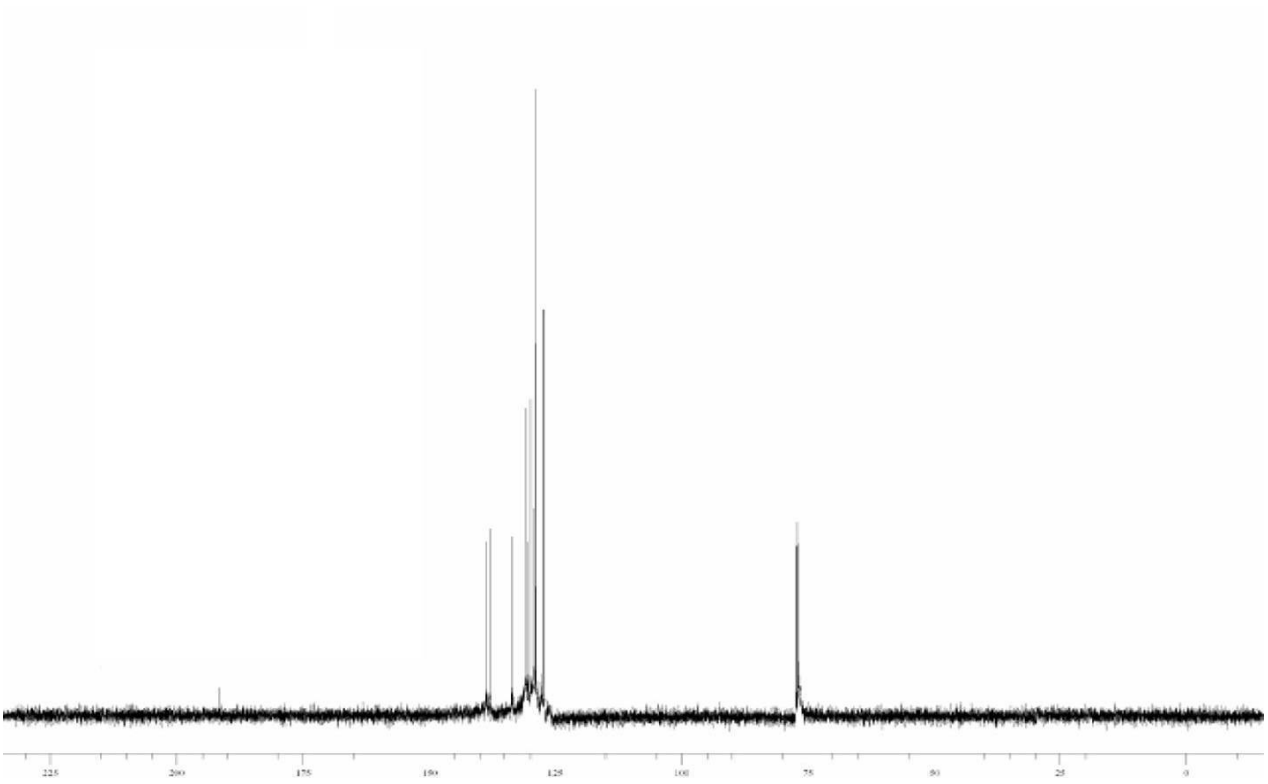
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6k**.



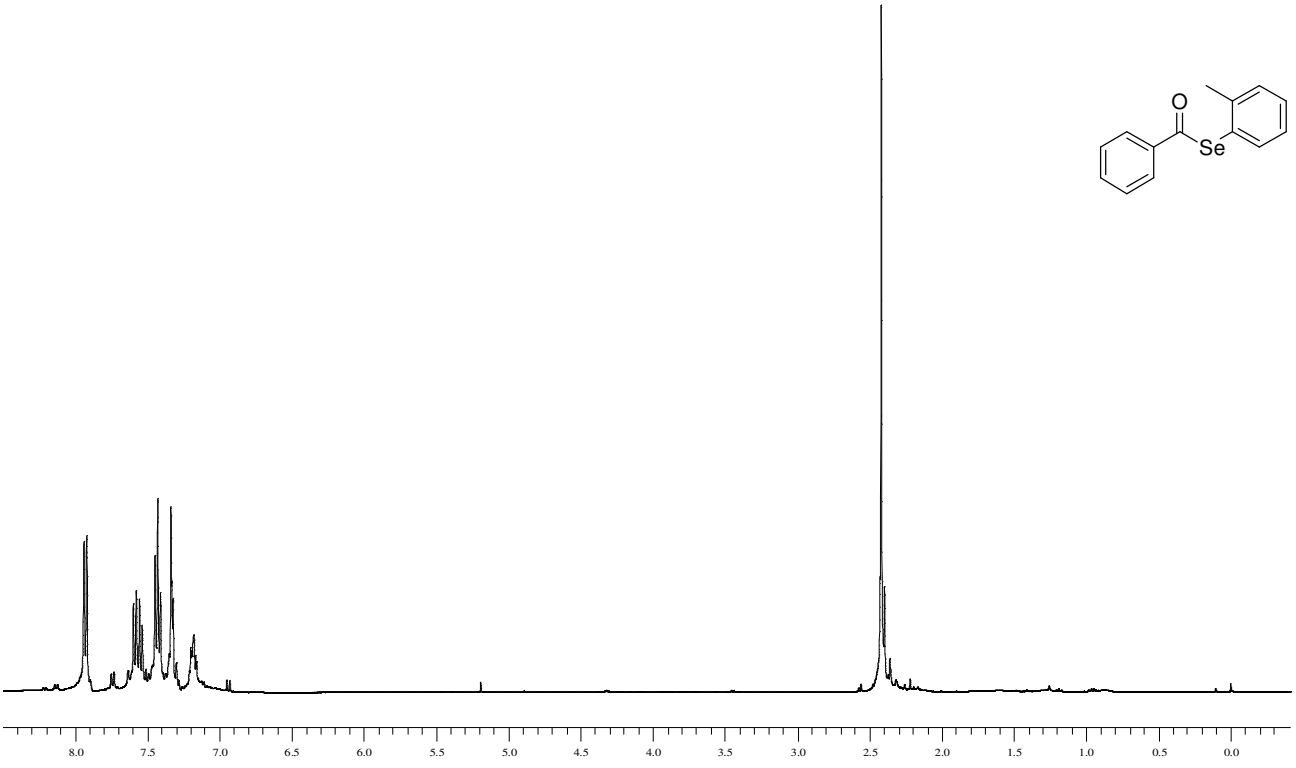
^{13}C NMR (100MHz, $CDCl_3$) Spectrum of **6k**.



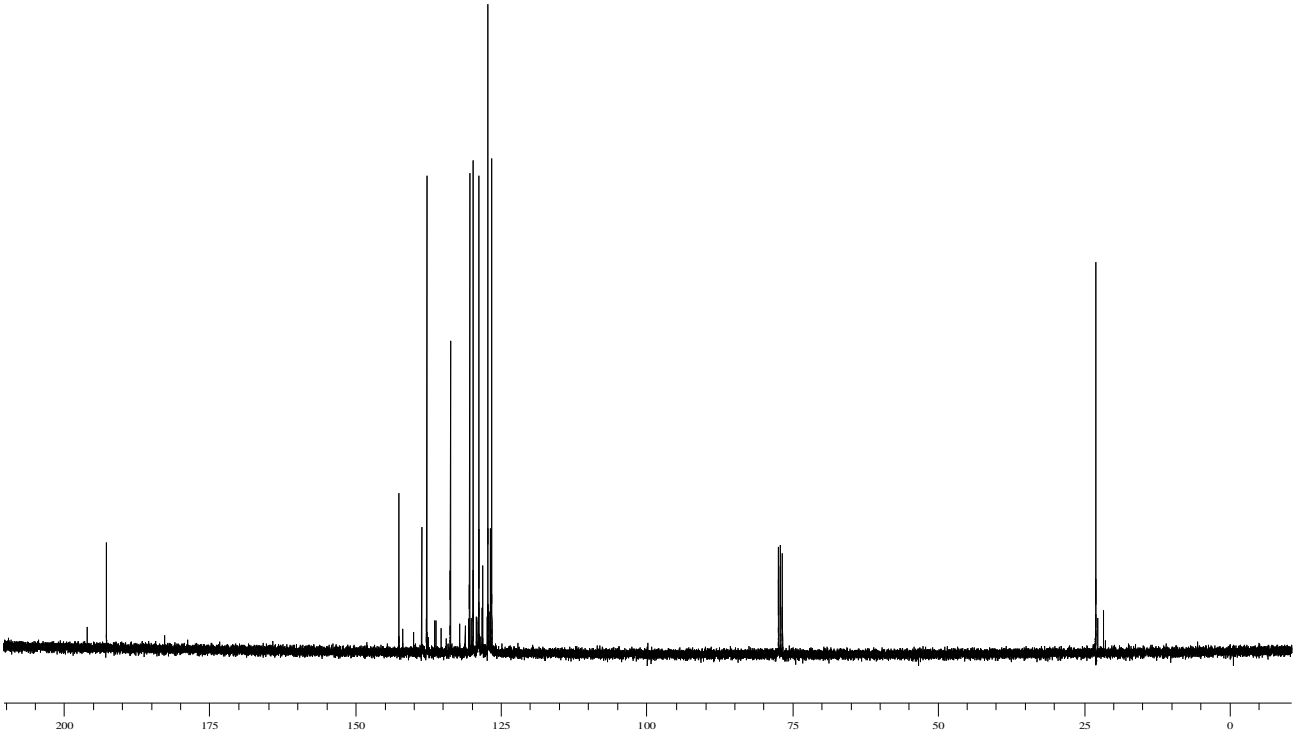
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6l**.



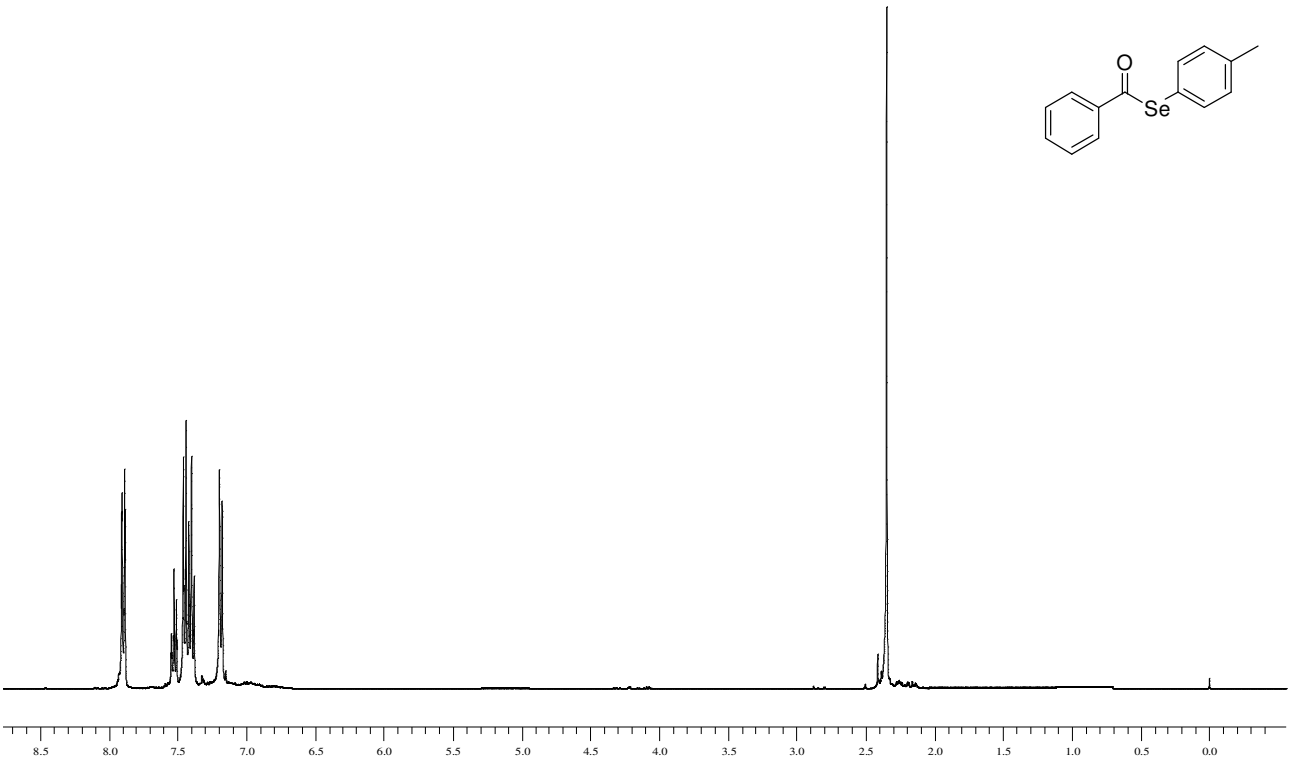
^{13}C NMR (100MHz, $CDCl_3$) Spectrum of **6l**.



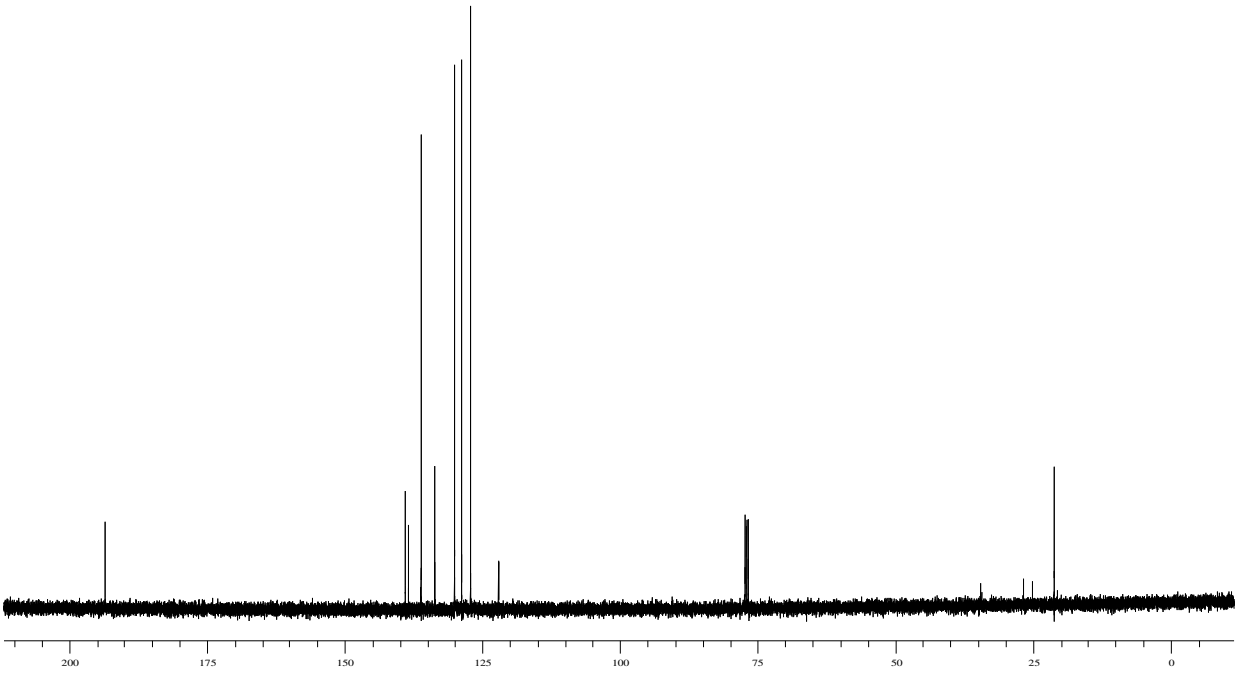
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6m**.



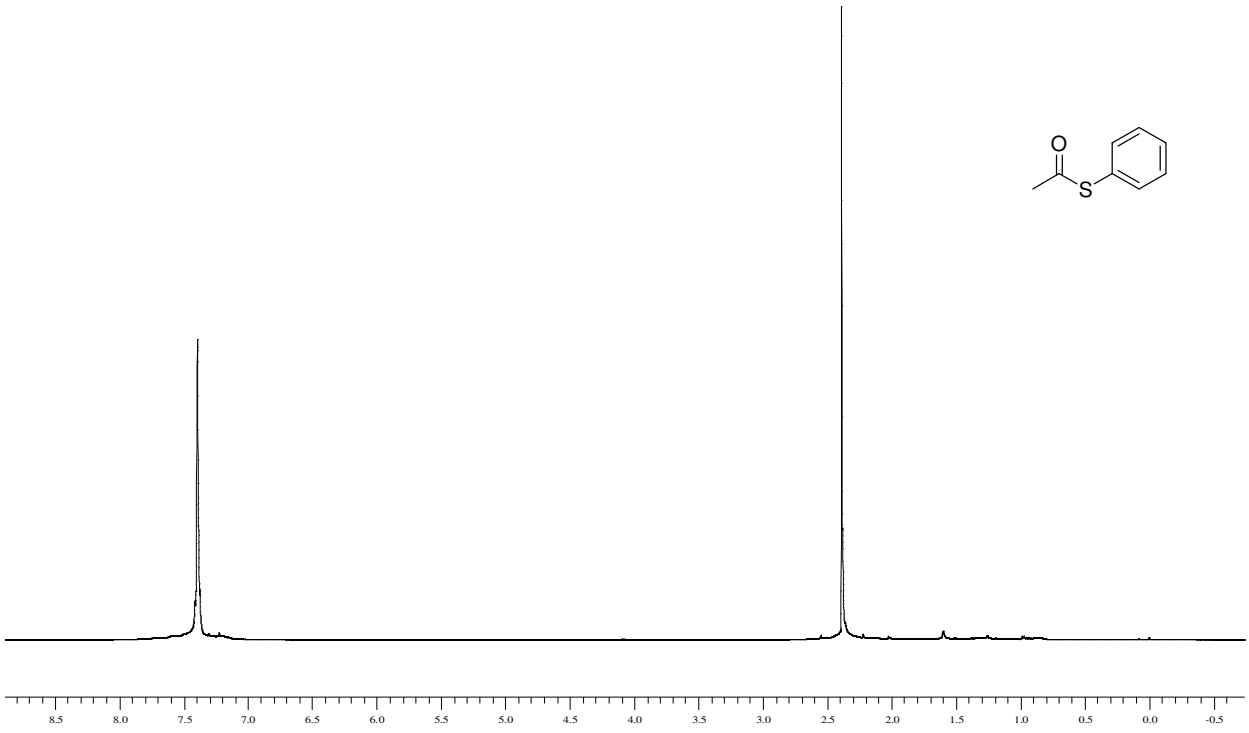
^{13}C NMR (100MHz, $CDCl_3$) Spectrum of **6m**.



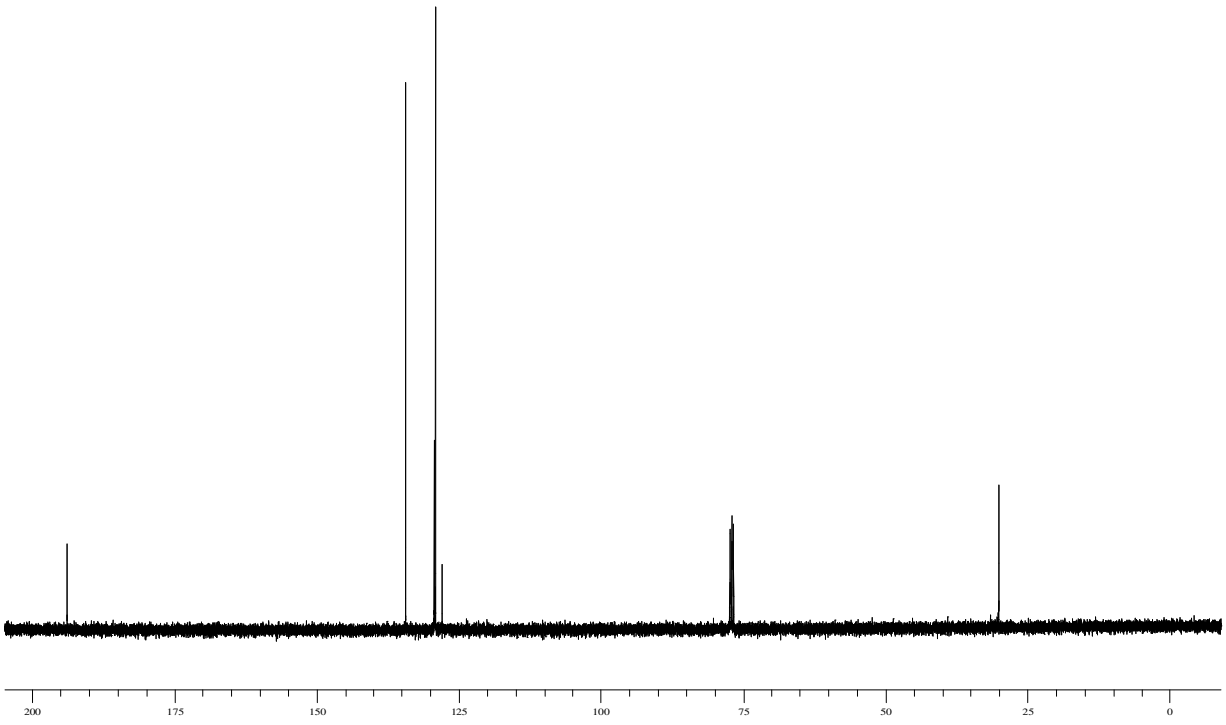
^{1}H NMR ($CDCl_3$, 400 MHz) Spectrum of **6n**.



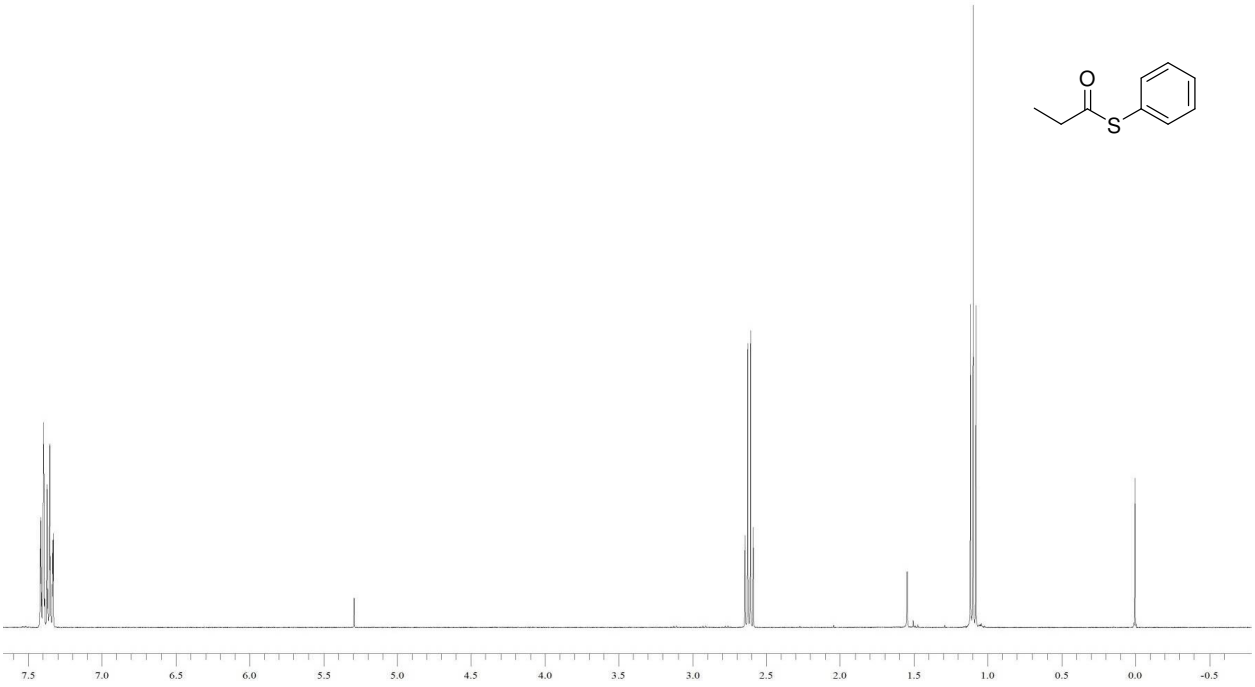
^{3}C NMR (100MHz, $CDCl_3$) Spectrum of **6n**.



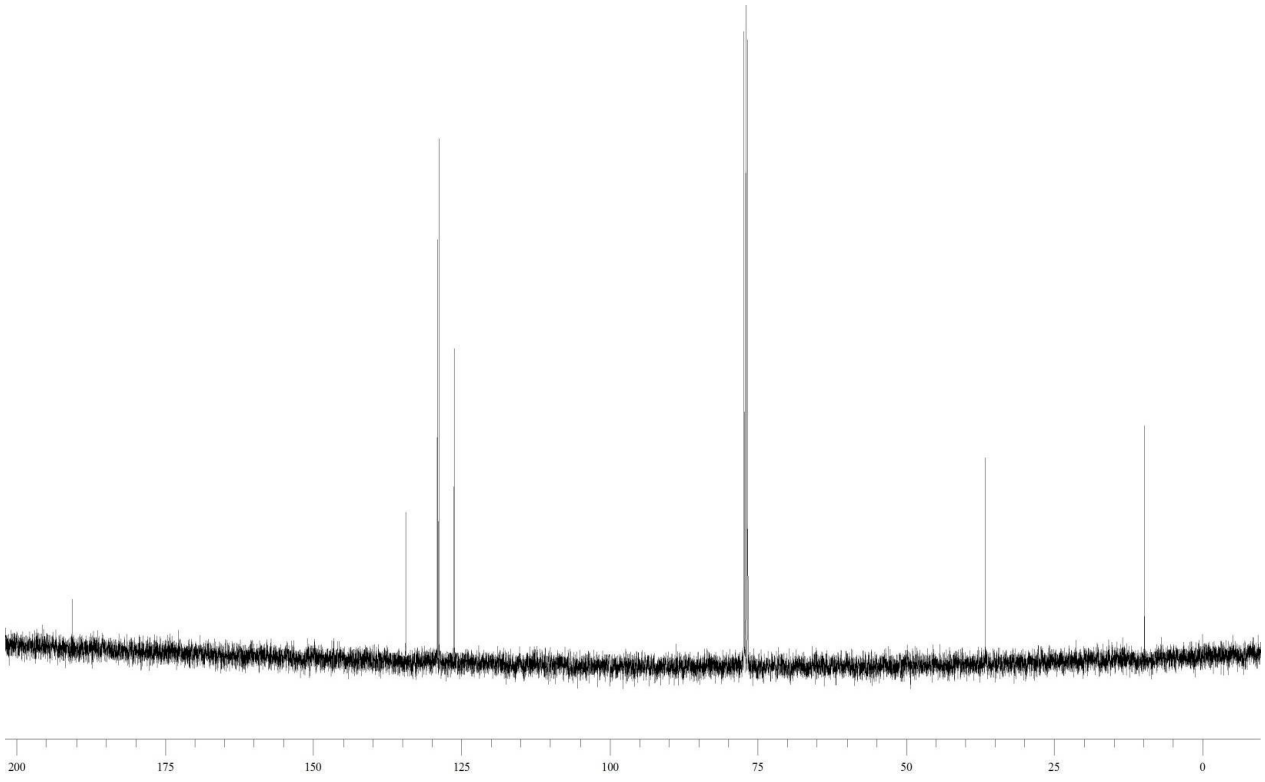
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7b**.



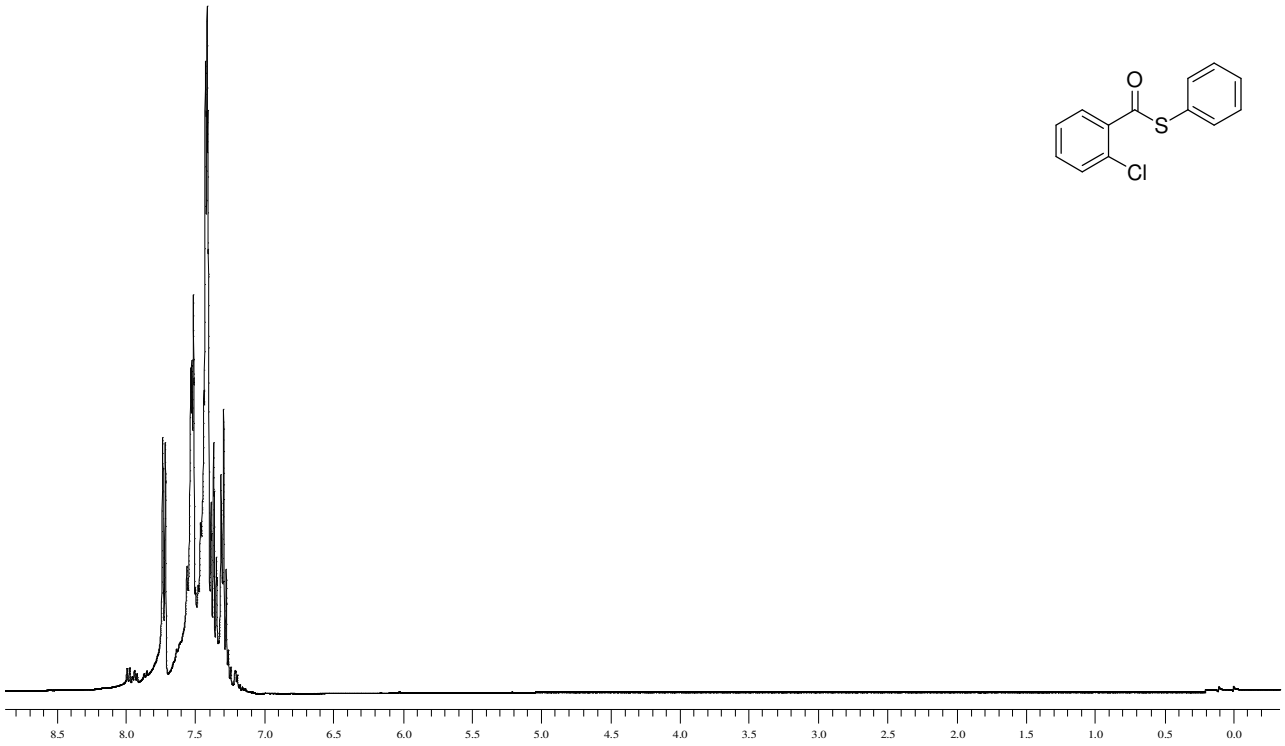
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7b**.



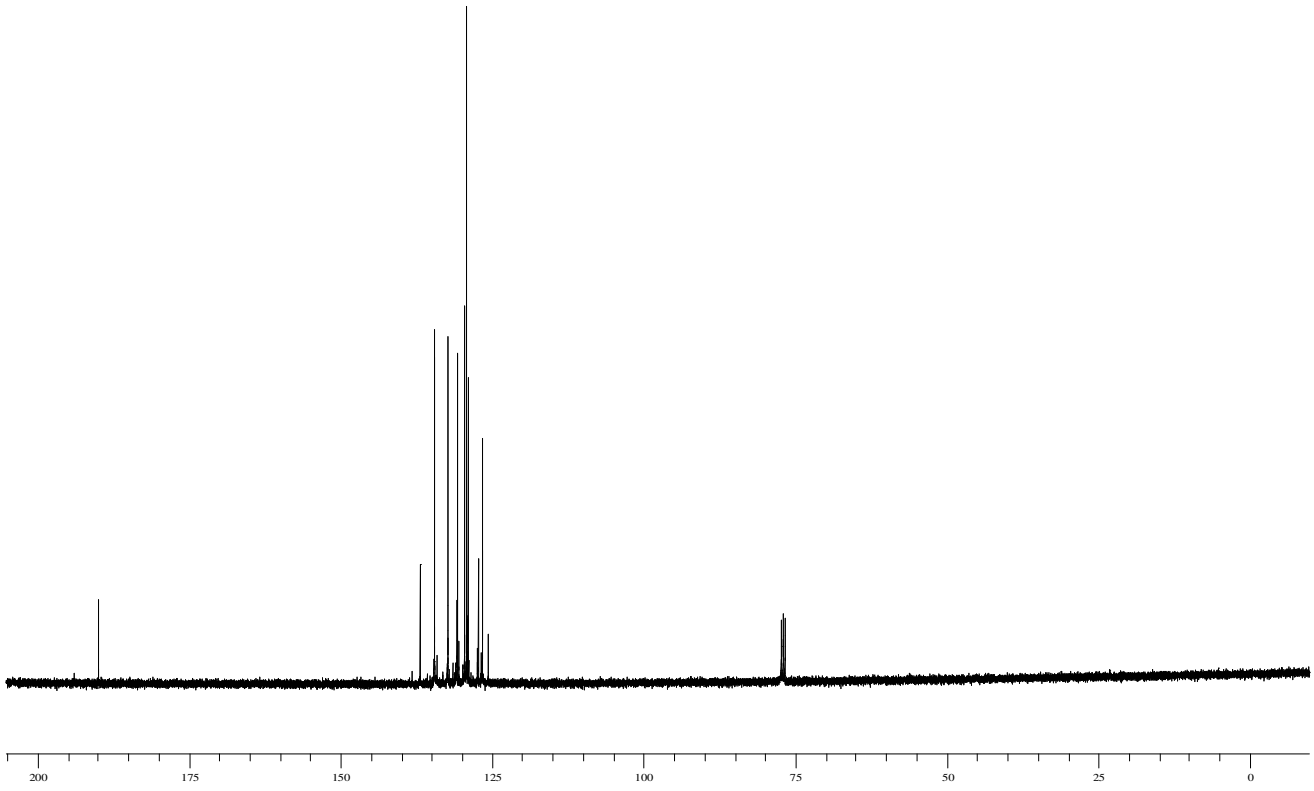
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7c**.



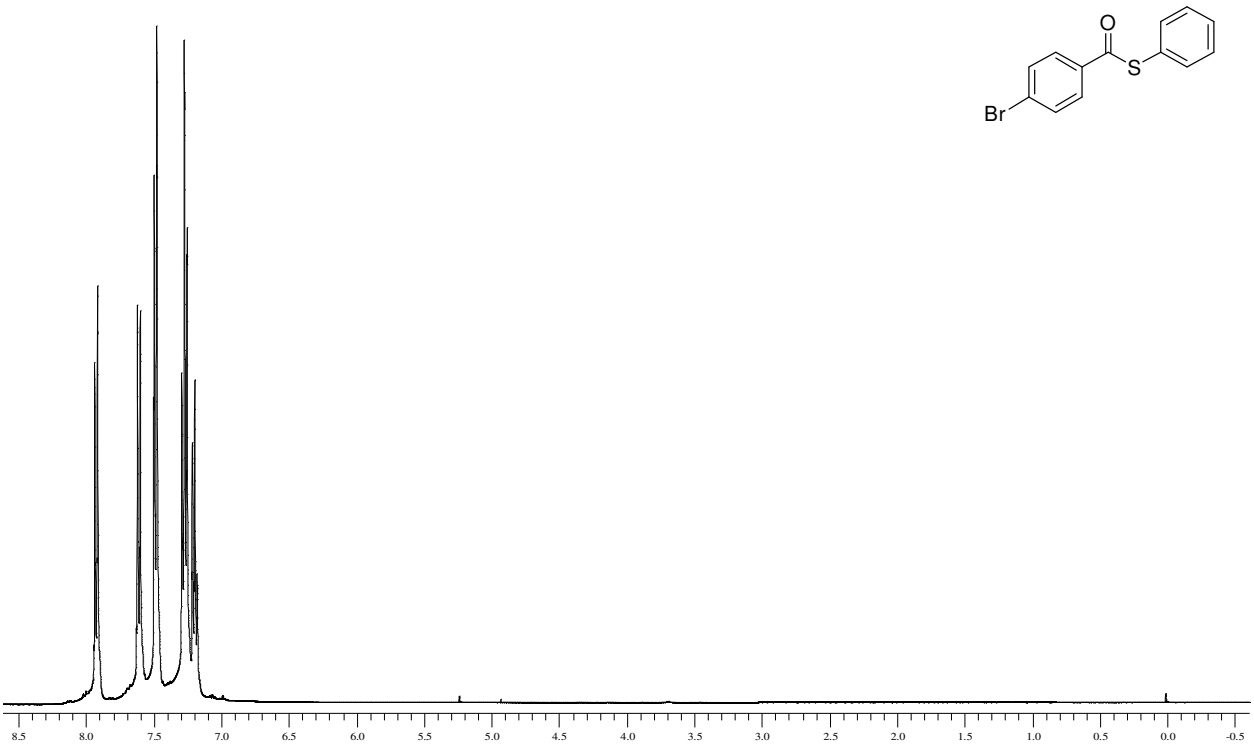
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7c**.



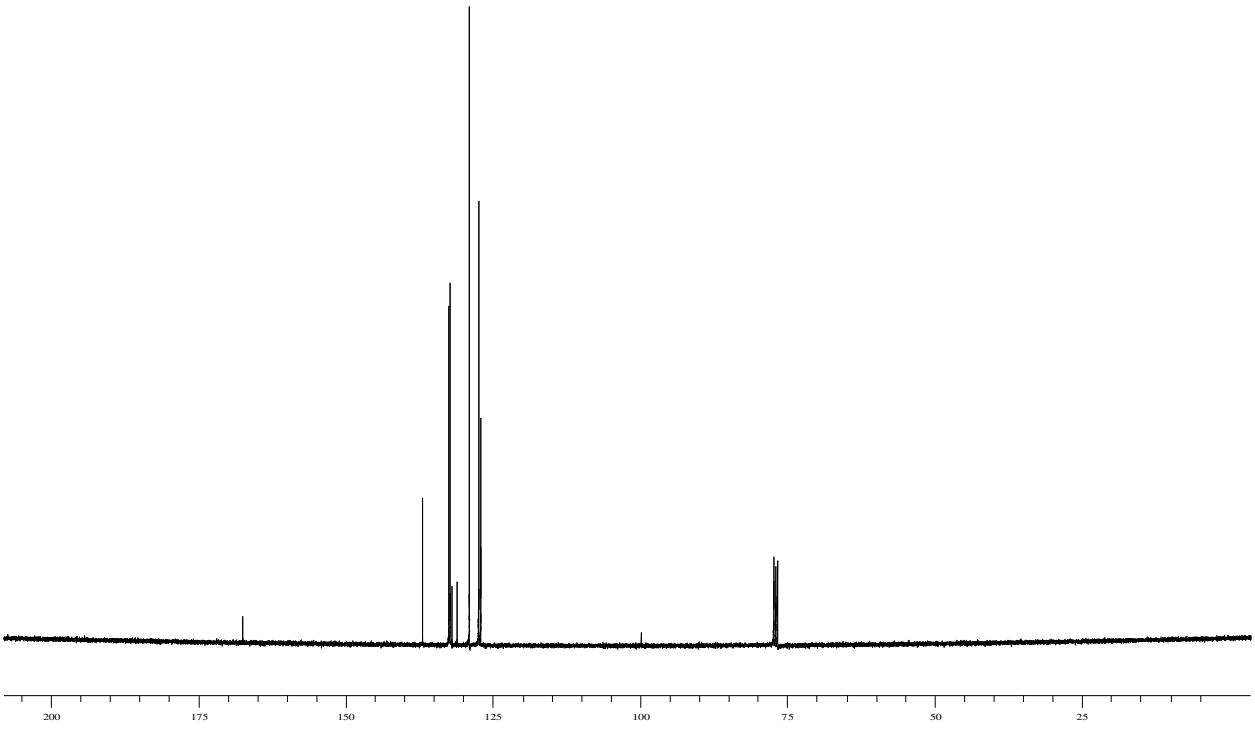
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7d**.



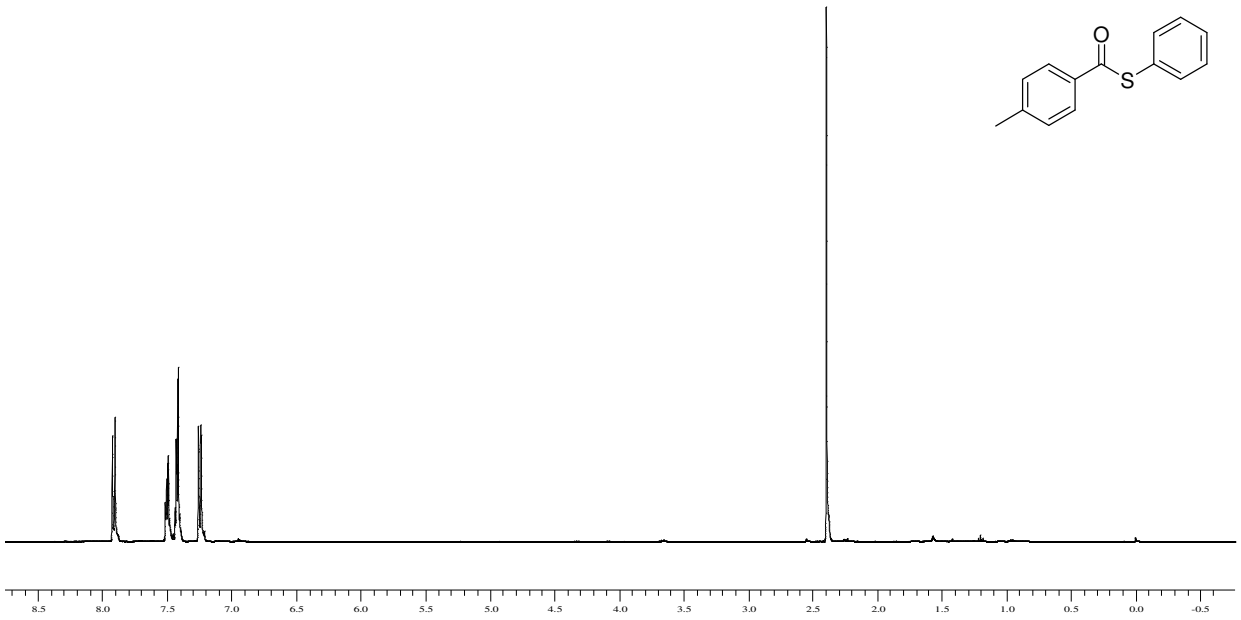
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7d**.



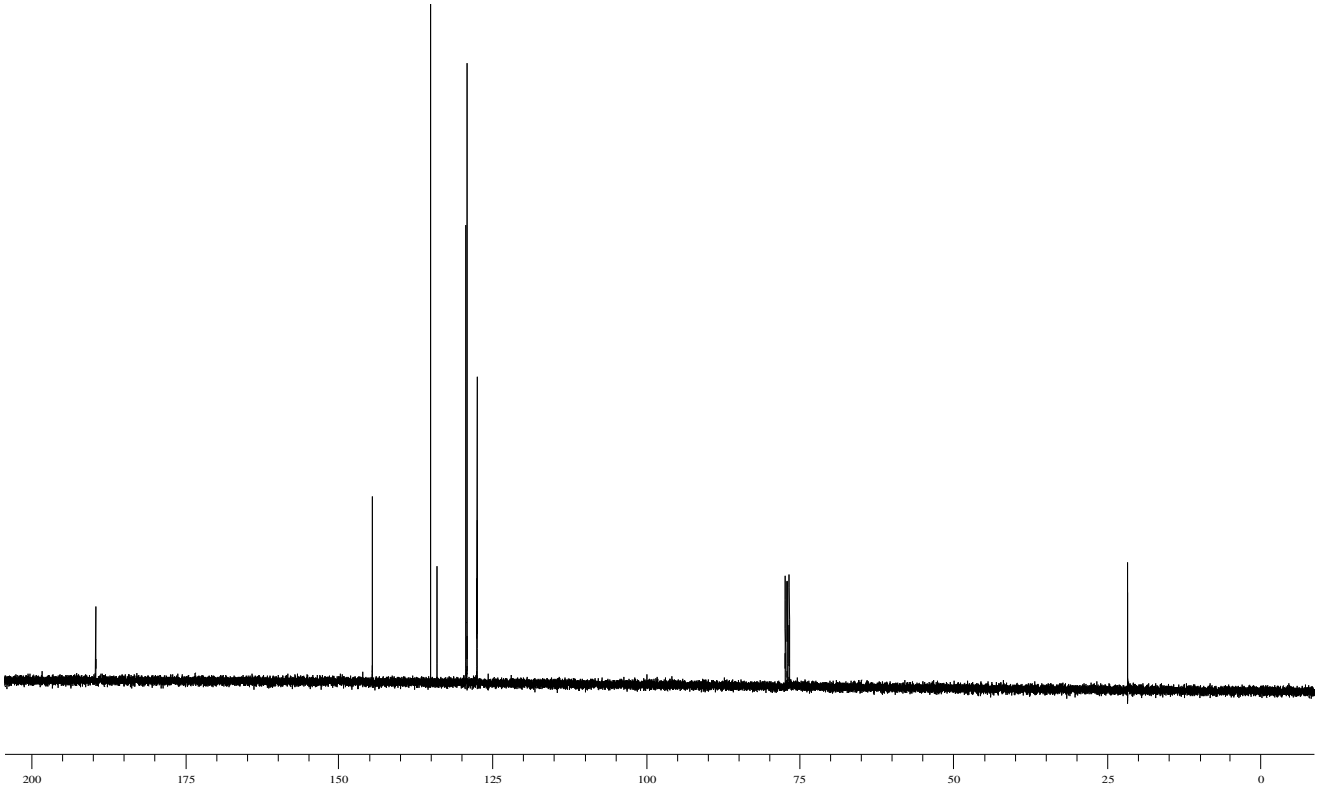
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7e**.



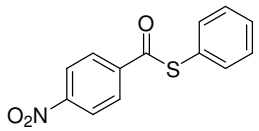
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7e**.

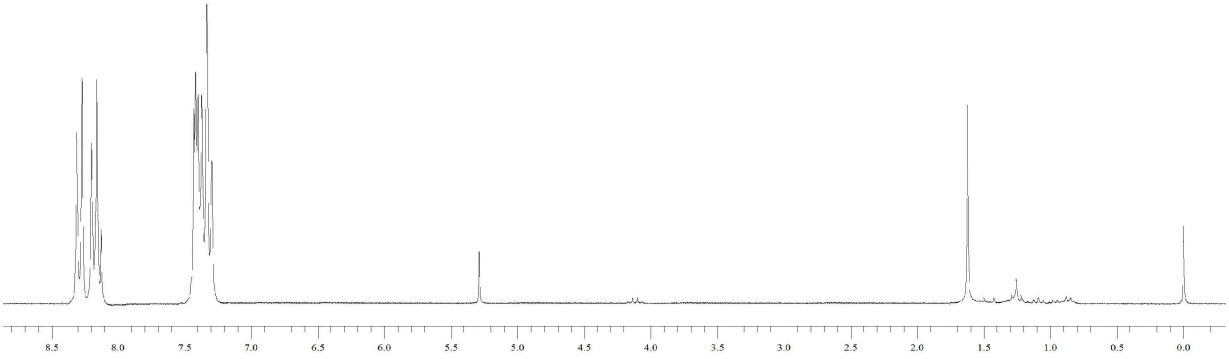


^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7f**.

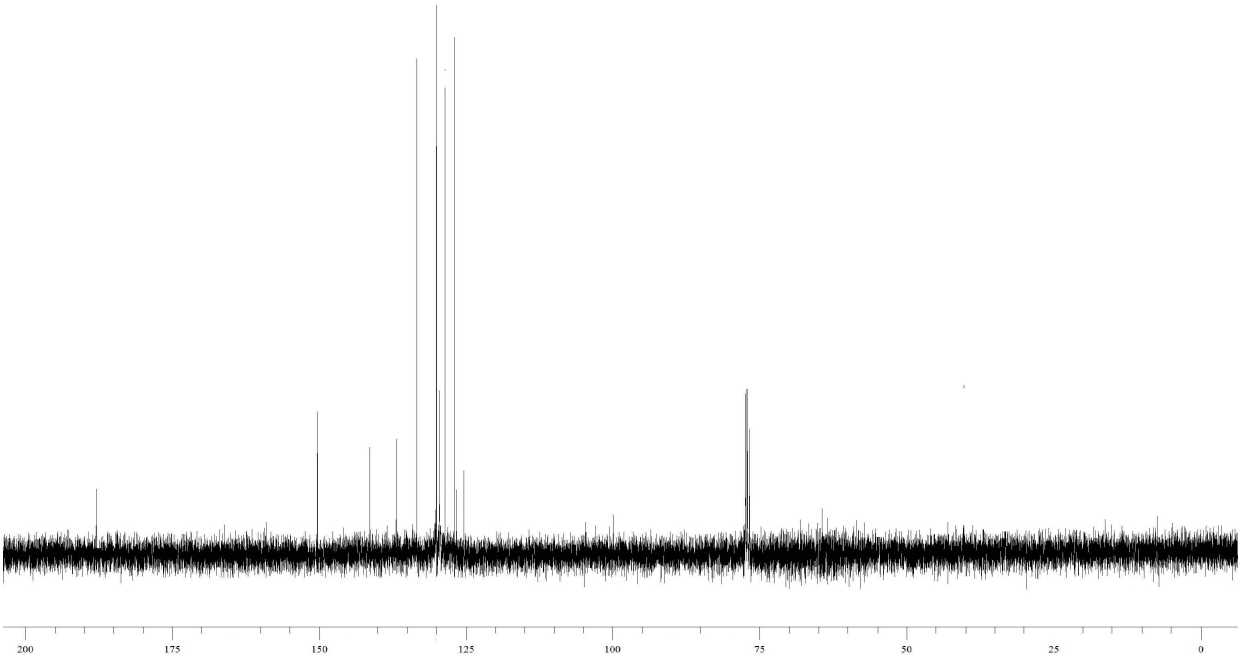


^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7f**.

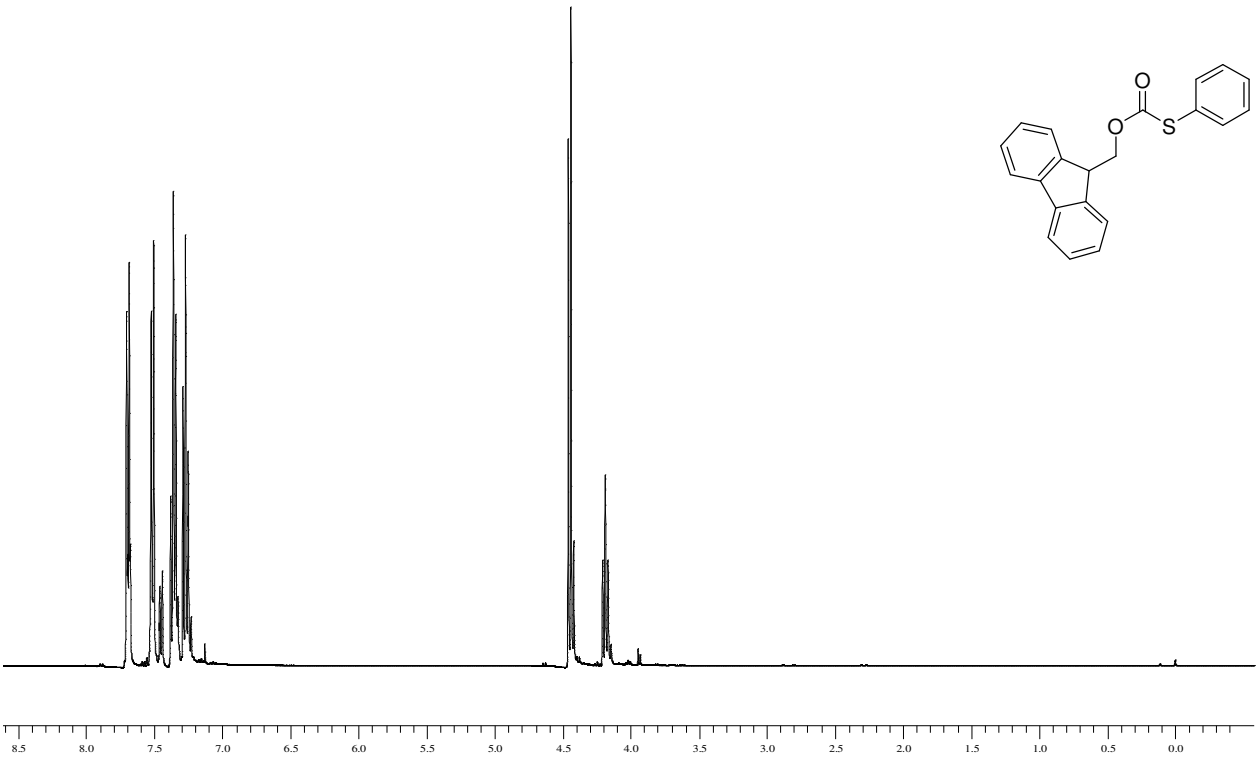




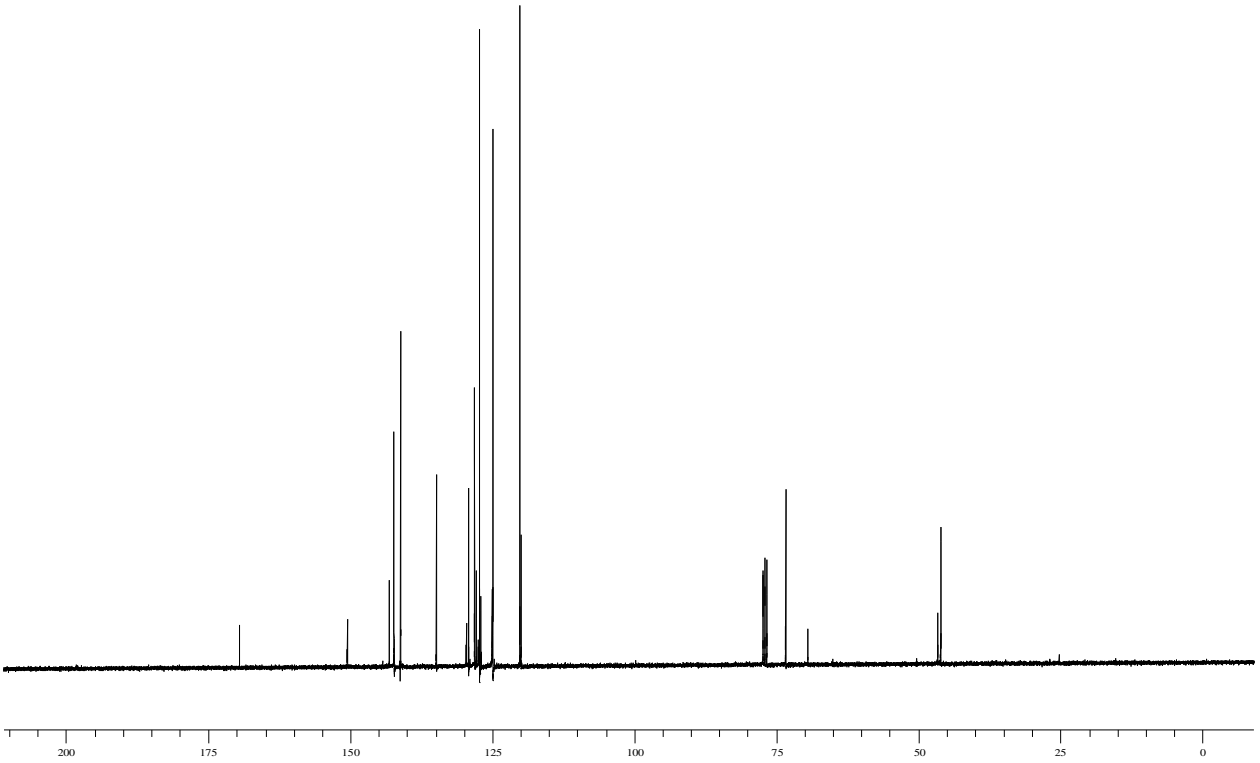
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7g**.



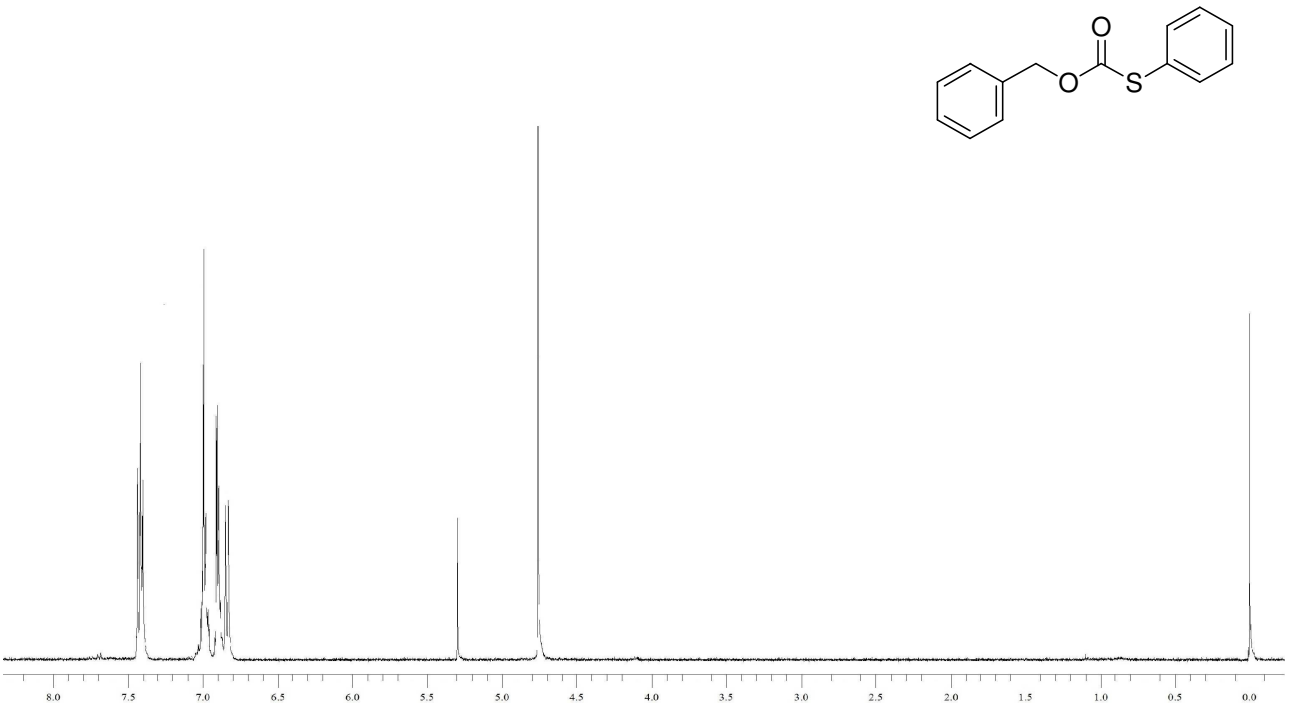
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7g**.



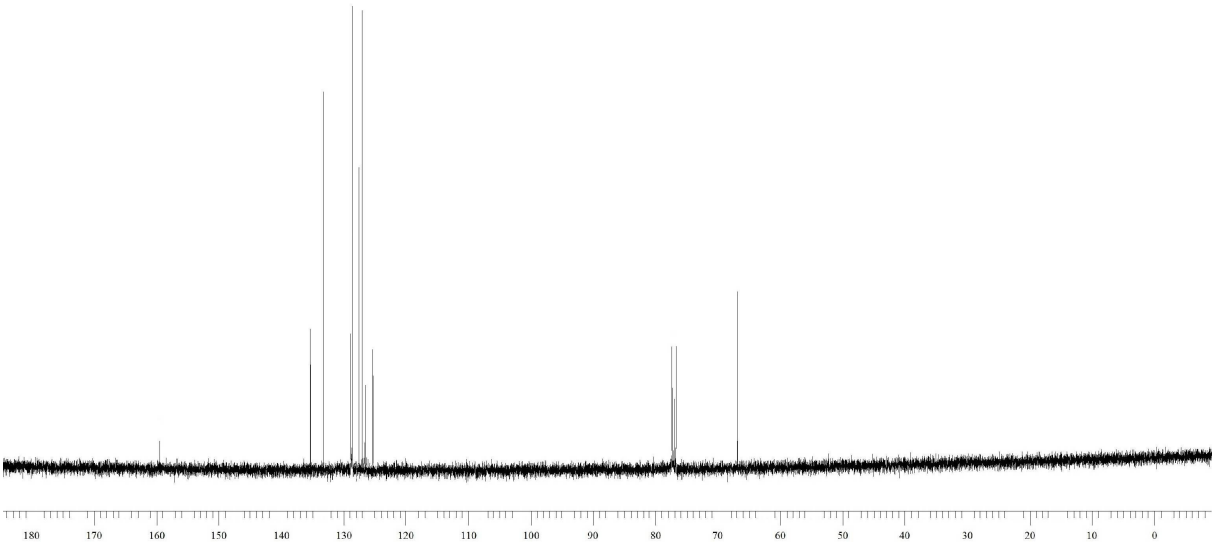
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7h**.



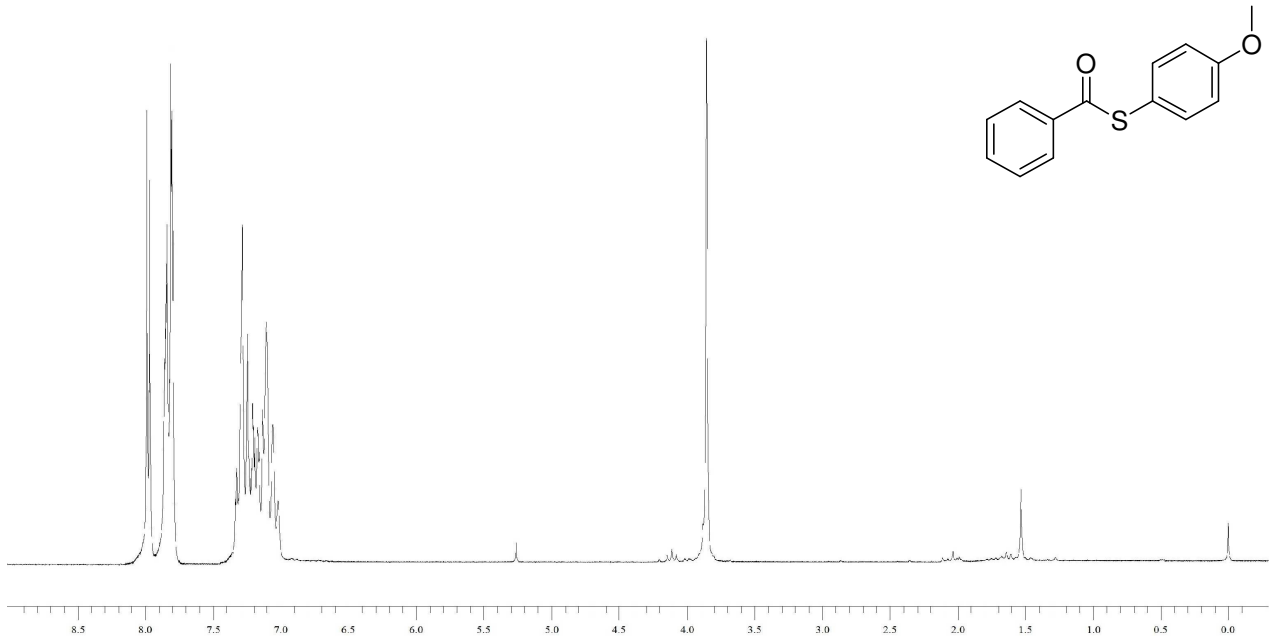
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7h**.



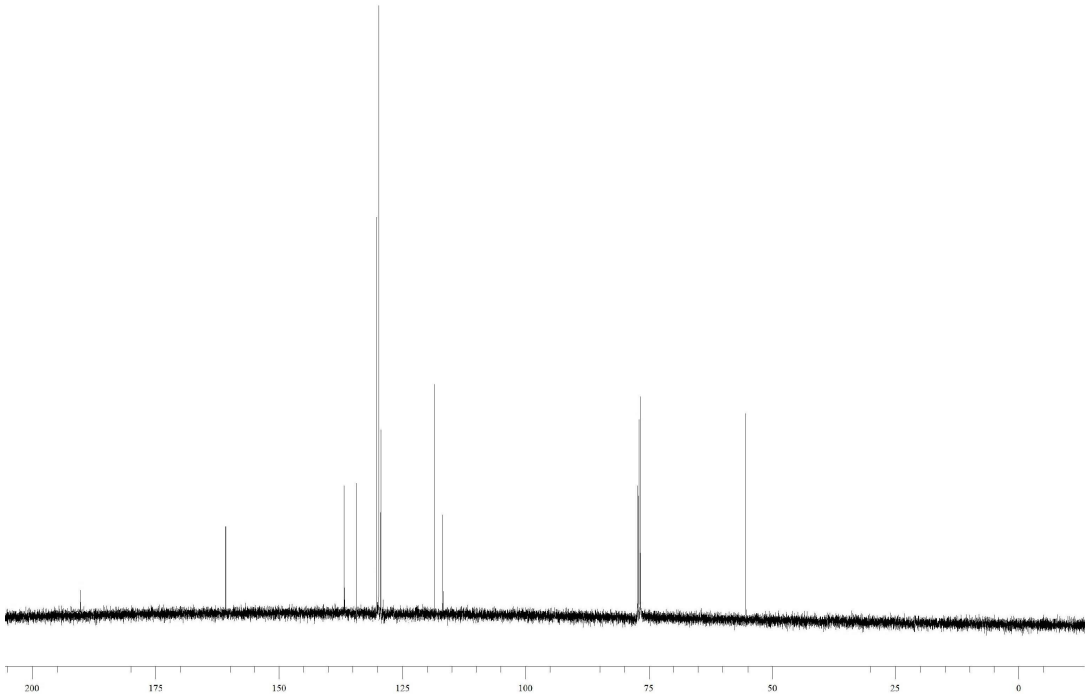
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7i**.



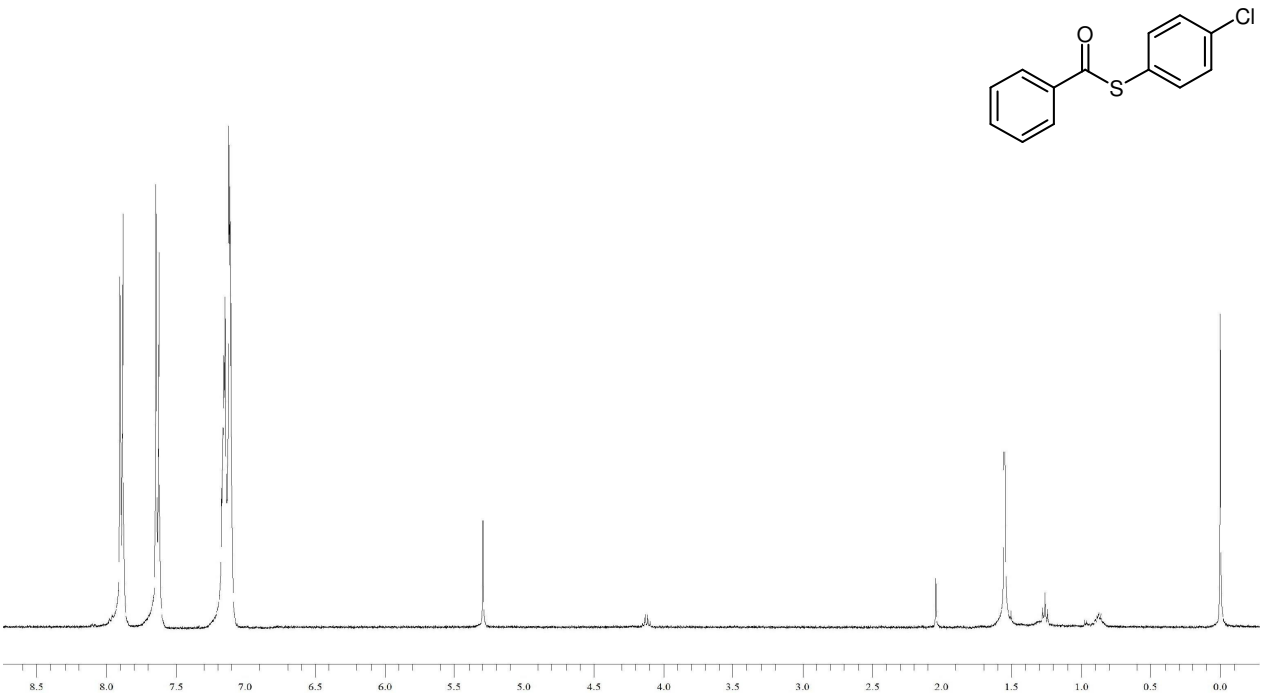
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7i**.



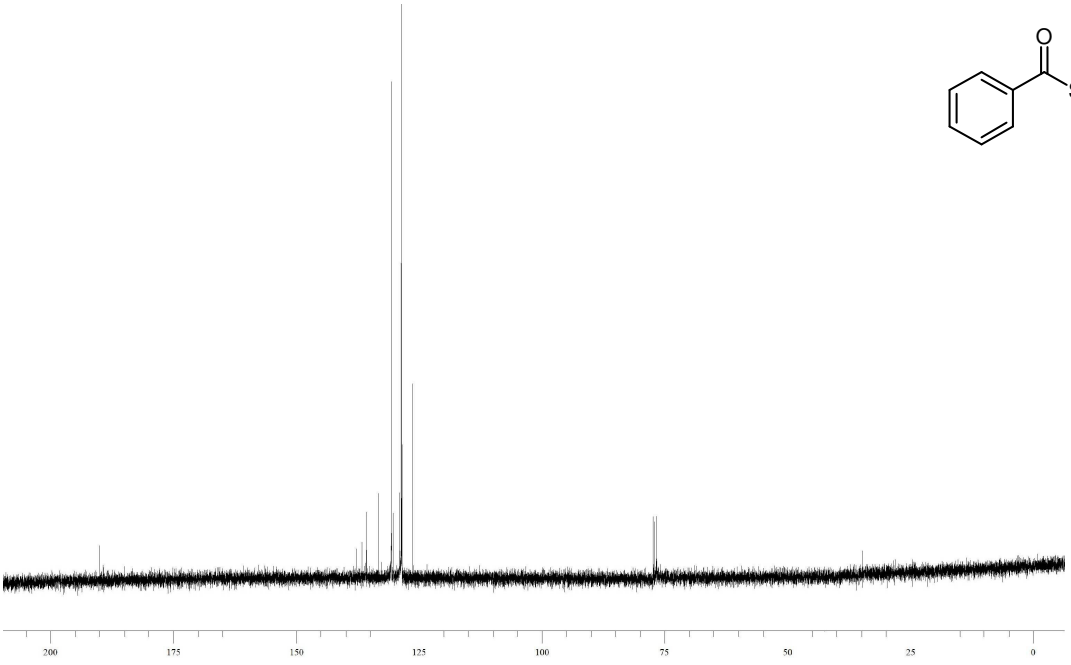
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7j**.



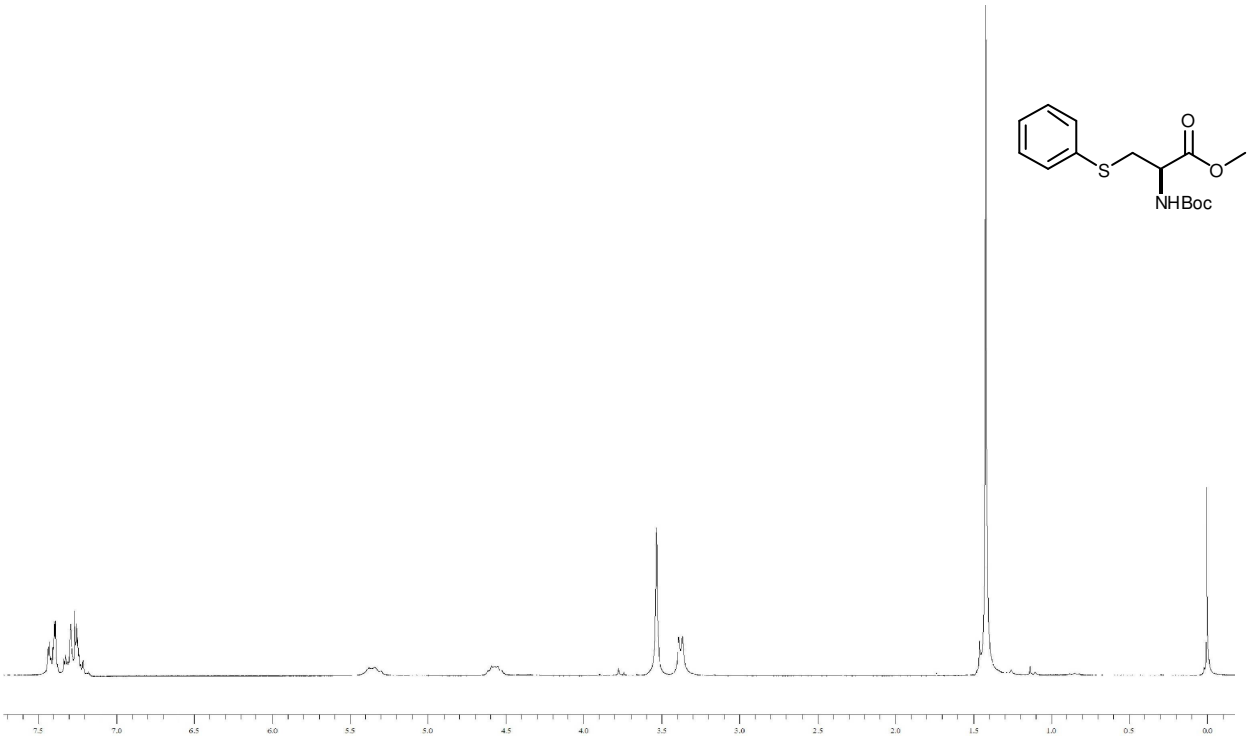
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7j**.



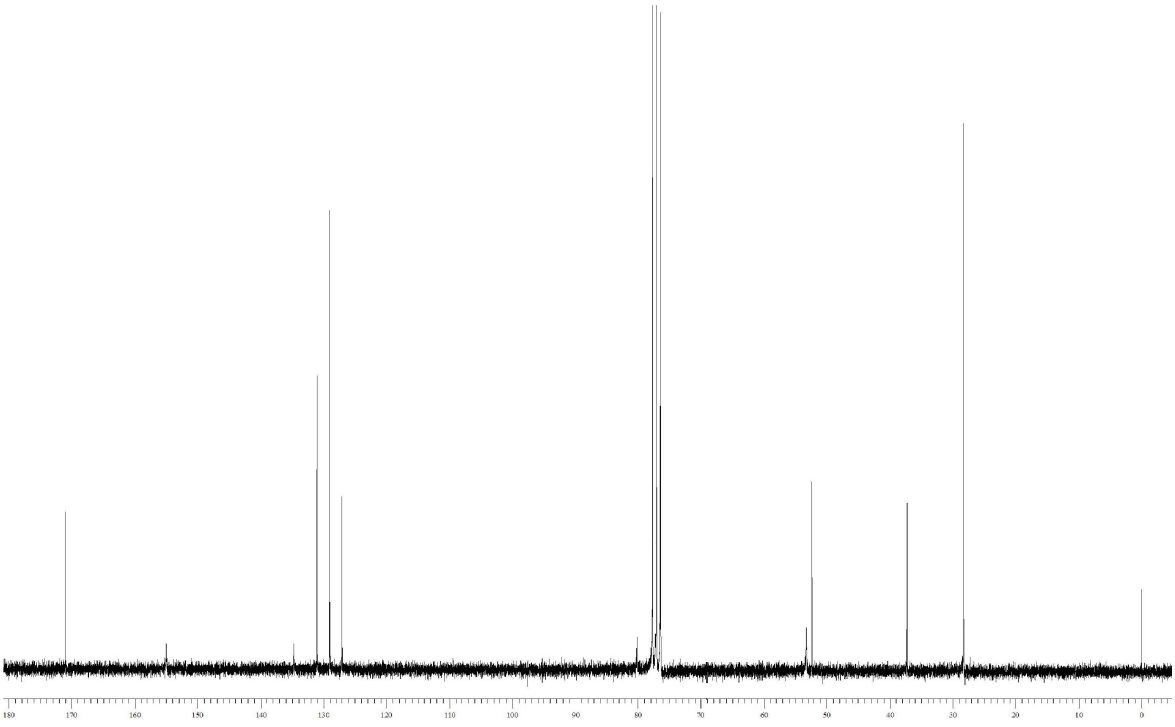
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **7k**.



^{13}C NMR (100 MHz, $CDCl_3$) spectrum of **7k**.



^{1}H NMR (200 MHz, $CDCl_3$) spectrum of **9b**.



^{13}C NMR (50 MHz, $CDCl_3$) spectrum of **9b**.

Curriculum Vitae

Senthil Narayanaperumal

Laboratório de Organocalcogenetos Quirais
Departamento de Química- DQ
Universidade Federal de Santa Maria- UFSM
CEP-97105 900; RS- Brazil.

Mobile : + 55 55 8138 8951
Office : + 55 55 3220 8669
E-Mail : senthil_nitt@yahoo.com

ACADEMIC PROFILE

2008-2010	**Doctorate in Organic Chemistry** Universidade Federal de Santa Maria – (**UFSM**), Santa Maria- RS, 97105 900 Brazil	
2003-2005.	**M.Sc**., in **Applied Chemistry** from National Institute of Technology (**NIT**) (Formerly Regional Engineering College), Tiruchirappalli-620 015, India	**8.11/10 CGPA**
1999-2002	**B.Sc**., in **Chemistry** from Pioneer Kumaraswamy College, Nager coil- 629 003, India	**85.38%**
1997-1999	**HSC** S.M.R.V Higher Secondary School, Nager Coil- 629 001, India	**71.92%**
1997	**SSLC** S.M.R.V Higher Secondary School, Nager Coil- 629 001, India	**86.80%**

AWARDS AND HONOURS

- International research fellowship awarded by Conselho Nacional de Desenvolvimento Scientific e Technologico (**CNPq**), Brazil and the Academy of Sciences for the Developing World (**TWAS**), Trieste, Italy to pursue PhD (2008-2010).
- Summer project fellowship from Tamil Nadu state council for science and Technology **(TNSCST),** India during 2004-2005.
- Secured **5th Rank** in all India Entrance Examination Conducted by National Institute of Technology, Tiruchirappalli, India in July 2003.

ACADEMIC PROJECTS

Doctoral Thesis Ionic liquid and Organochalcogenolates: an efficient recyclable reaction media for the synthesis of organochalcogen derivatives.

Description **:** A new eco-fashion method to the synthesis of organochalcogen derivatives is described. The biological and medicinal properties of organochalcogen compounds is also increasingly appreciated, mainly due to their antioxidant, antitumor, antimicrobial, and antiviral properties. By using less-expensive zinc dust in ionic liquid, a series of diorganylchalcogenides, chalcogenesters, chiral β-chalcogen amino acid derivatives and biologically important unnatural cysteine & selenocystines were efficiently achieved in excellent yields, in neutral reaction condition. The ionic liquid was recyclable up to five successive runs, which really makes our procedure eco-friendly.

Master´s Thesis

Title of the Project : "A Novel Ring Opening Reaction of Epoxides With 1,3- Dipoles"
Research Institute : Regional Research Laboratory (CSIR), Trivandrum, Kerala, India.
Duration **:** January 2005-June 2005 (six months)

Description : The ring opening of epoxy alcohol using 1, 3-dipolar species derived from sugar moieties and dimethyl acetylene dicarboxylate with triphenyl phosphine furnished substituted bicyclic nonone and dihydro pyranone moieties respectively.

Title of the Project : "A facile and mild regioselective ring opening of epoxides to halohydrins with silica chloride-MX"
Research Institute : Regional Research Laboratory (CSIR), Trivandrum, Kerala, India.
Duration : September 2006 to March 2007 (six months)
Description : To explore the ring opening reaction of epoxides with new reagent system SiO_2.Cl-MX was developed. This project was sponsored by the **Department of Science and Technology (DST),** India.

Summer Project

Title of the Project : "*Optical nanofillers synthesis, characterization and testing"* in the sector chemical engineering under student projects scheme sponsored by the **Tamil Nadu state council for science and Technology (TNSCST)** during the academic year 2004-2005.
Institute : **National Institute of Technology (**Formerly **REC),** Tiruchirappalli, Tamil Nadu, India.

PROFESSIONAL EXPERIENCE

From April 2007-January 2008	Worked as a **Scientist** in **Biocon Limited,** Bangalore, India.
From Sep. 2006-March 2007	Worked as a **Project Assistant** in **Regional Research Laboratory (CSIR),** Trivandrum, Kerala, India.
From Aug-2005-Aug 2006	Worked as a **Research Associate** in **Molecular Connections Pvt Ltd,** Bangalore, India.
From Jan. 2005-June 2005	Worked as a Project Student in **Regional Research Laboratory (CSIR),** Trivandrum, Kerala, India.

CONFERENCE PAPERS & POSTERS

- Participated in the seminar on **"Emerging Trends in Chemistry"** held at department of Chemistry, National College, Tiruchirappalli, India on 24.01.2004.
- Participated and Presented a Paper in the two day national seminar on "**Frontiers in Organic Chemistry 2007**" organized by the Department of chemistry University of Calicut, Kerala, India during 11 &12 -01-2007.
- Presented a paper in **"Materials for the millennium-2007"** a international conference held at Department of chemistry, University of science and Technology, Kochi, India during march1-3; 2007.
- Participated in the DST sponsored national workshop on **"One and two dimensional NMR spectroscopy Theory and Applications"** organized by the school of chemistry, Madurai Kamaraj university, Madurai, India during 22, 23-03-2007.
- Delivered a lecture titled **"A Novel Ring Opening Reaction of Epoxides With 1,3- Dipoles"** organized by the Department of chemistry, Universidade Federal de Pelotas – (UFPel), Pelotas, Brazil during 1st August 2008
- Senthil Narayanaperumal, E. E. Alberto, K. Gul, F. M. de Andrade, E. J. Lenardão, P. S. Taube, A. L. Braga,* "Ionic Liquid: an Efficient and Recyclable Media for Synthesis of Unsymmetrical Diorganyl Selenides Promoted by InI" page no. 163, 2009. Presented a Poster in the **"13th Brazilian Meeting on Organic Synthesis 2009"** organized by the Department of chemistry, University of Sao Paulo, Sao Pedro, Brazil during 31st August-4th Sep 2009.
- F. Z. Galetto, A. L. Braga,* Senthil Narayanaperumal and E. J. Lenardão,* Efficient Synthesis of Selenolanthionines: LiAlHSeH as Selenating Reagent in Aziridine Ring Opening Reactions." page no. 270, 2009. Presented a Poster in the **"13th Brazilian Meeting on Organic Synthesis 2009"** organized by the Department of chemistry, University of Sao Paulo, Sao Pedro, Brazil during 31st August-4th Sep 2009.
- O. E. D. Rodrigues,* A. L. Braga,* C. Y. Kawasoko, Senthil Narayanaperumal, P. Foletto, "Transition metal oxide Nanopowder Catalyzed Efficient Cross-Coupling Reaction of Diaryl Diselenides with Aryl Halides using Zn in Ionic Liquid".

Presented a Poster in the "33[a] **Reunião Annual da Sociedade Brasileira de Quimica**" organized by the Department of chemistry, University of Sao Paulo, Brazil during May 28-31, 2010.

- O. E. D. Rodrigues,* A. L. Braga,* C. Y. Kawasoko, Senthil Narayanaperumal, P. Foletto "Synthesis of Organochalcogen derivatives mediated by ionic liquid". Presented a Poster in the "***III Encontro sobre Selênio e Telúrio – Brasil (III ESeTe–Brasil)***" organized by the Department of chemistry, Federal University of Santa Catrina- UFSC, Brazil during Nov 29 to 02 December, 2010.
- A. L. Braga,* O. E. D. Rodrigues,* L. Dornelles,* Senthil Narayanaperumal, E. E. Alberto, K. Gul, E. F. Heck. "Synthesis of diorganyl selenides mediated by Zn in ionic liquid". Presented a Poster in the "***III Encontro sobre Selênio e Telúrio – Brasil (III ESeTe–Brasil)***" organized by the Department of chemistry, Federal University of Santa Catrina- UFSC, Brazil during Nov 29 to 02 December, 2010.
- A. L. Braga,* O. E. D. Rodrigues,* L. Dornelles,* J. Vargas, D. Singh, Senthil Narayanaperumal, M. Godoi, K. Gul, B. S. Martins. "Synthesis of Selenoesters from Acyl Chlorides Mediated by CuO Nanopowder in Ionic Liquid ". Presented a Poster in the "***III Encontro sobre Selênio e Telúrio – Brasil (III ESeTe–Brasil)***" organized by the Department of chemistry, Federal University of Santa Catrina- UFSC, Brazil during Nov 29 to 02 December, 2010.
- A. L. Braga*, S. M. Salman, Senthil Narayanaperumal, O. E. D. Rodrigues, L. Dornelles, D. de Souza, C. R. Bender. "Synthesis of chiral β-Seleno amino derivatives using Zn in Ionic Liquid". Presented a Poster in the "***III Encontro sobre Selênio e Telúrio – Brasil (III ESeTe–Brasil)***" organized by the Department of chemistry, Federal University of Santa Catrina- UFSC, Brazil during Nov 29 to 02 December, 2010.

CO-CURRICULAR ACTIVITIES

- Active class representative in B.Sc (1999-2000).
- Active secretary of the Chemistry Department in the year 2001-2002.
- Organizer of a national level technical symposium "HORIZON – 2003" in National Institute of Technology, Tiruchirappalli, India.
- Organizer of a national level technical symposium "HORIZON – 2004" in National Institute of Technology, Tiruchirappalli, India.
- Won Second prize in Dr. Sivaramakrishnan Nagarajan endowment inter college quiz contest conducted at Bishop Heber College, Tiruchirappalli, India.

LIST OF PUBLICATIONS

1. Ionic liquid: an efficient and recyclable medium for synthesis of unsymmetrical diorganyl selenides promoted by InI
   Senthil Narayanaperumal, E. E. Alberto, F. Molinos de Andrade, E.J. Lenardão, P. S. Taube and A. L. Braga* ***Organic & Biomolecular Chemistry***, **2009**, 7, 4647–4650.
2. Synthesis of Diorganyl Selenides Mediated by Zinc in Ionic Liquid
   Senthil Narayanaperumal, E. E. Alberto, K. Gul, O. E. D. Rodrigues* and A. L. Braga* ***Journal of Organic Chemistry***, **2010**, 75, 3886–3889.
3. Efficient Synthesis of Selenoesters from Acyl Chlorides Mediated by CuO Nanopowder in Ionic Liquid
   D. Singh, Senthil Narayanaperumal, K. Gul, M. Godoi, O. E. D. Rodrigues,* and A. L. Braga* ***Green Chemistry***, **2010**, 12, 957–960
4. Transition-metal oxide nanopowder and ionic liquid: an efficient system for the synthesis of diorganyl selenides and β-seleno amines
   Senthil Narayanaperumal, K. Gul, C. Y. Kawasoko, L. Dornelles, O. E. D. Rodrigues* and A. L. Braga ***Journal of Brazilian Chemical Society***, **2010,** 21, 2079-2087.

Ionic liquid: an efficient and recyclable medium for synthesis of unsymmetrical diorganyl selenides promoted by InI†

Senthil Narayanaperumal,[a] Eduardo E. Alberto,[a] Fabiano Molinos de Andrade,[a] Eder J. Lenardão,[c] Paulo S. Taube[b] and Antonio L. Braga*[a,b]

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In an environmentally friendly protocol, InI was used as a reducing agent for the Se–Se bond to prepare unsymmetrical diorganyl selenides with very short reaction times, mild conditions and excellent yields using (bmim)BF_4 as a recyclable solvent.

Introduction

Interest in organochalcogen compounds has been growing since the 1970s, when selenium based methods became a useful tool in the hands of organic chemists.[1] Organoselenium compounds have found such wide utility because of their effects on an extraordinary number of very different reactions, including many asymmetric transformations.[2] Furthermore, organoselenium compounds have been attracting considerable attention, especially for their biological and medicinal proprieties, due to their ability to mimic natural compounds with important biological properties (*e.g.*, antioxidant, antitumor, anti-inflammatory, and anti-infective activities).[3] Investigation of synthetic methods for the preparation of selenocysteine,[4] selenium-based peptides,[5] selenoglycosides[6] and other important natural compounds[7] is nowadays an area of intensive research.

Recently, many reports have appeared in the literature describing the preparation of diorganyl selenides. In general, to avoid handling unstable reagents, such as selenols, diorganyl diselenides are used as starting materials and the selenium anion is generated *in situ*. Most of these procedures employed $NaBH_4$,[8] Zn,[9] Zn/In(III),[10] In,[11] InI,[12] Sn/Pd,[13] $RhCl(PPh_3)/H_2$,[14] $RuCl_3$/Zn,[15] La/I_2,[16] Cu[17] and others[18] as reducing agents. In general, most procedures often require drastic reaction conditions and/or expensive routes, which compromise any possibility of industrial development.

Although synthesis of unsymmetrical diorganyl selenides has been successfully accomplished by indium salts, it was undesirable from an environmental point of view, since organic solvents were used.

In a sustainable chemistry context, there is a need for new methods which are not only very efficient, but also eco-friendly and inexpensive. In this respect, ionic liquids seem to be a promising choice for the development of "green" chemical protocols.[19] So, this prompted us to investigate the possibility of employing ionic liquids, which would function as a mild and recyclable medium, for the synthesis of unsymmetrical diorganyl selenides. Advantages such as high reactivity, their ready commercial availability, ease of preparation and handling as well the environmental aspects all justified our choice to employ them in our work.[19] We selected In(I) salts as reducing agents due to their well-known ability to promote the Se–Se bond cleavage.[12,20]

Accordingly, and in connection with our ongoing interest in the synthesis and evaluation of organochalcogen derivatives as ligands in asymmetric transformations[21] as well as biological screening,[22] we wish to highlight in this report our results on the preparation of unsymmetrical diorganyl selenides promoted by InI in ionic liquids. The desired products were obtained in high yields, in a very short time and with the advantage of being able to recycle the reaction media, which represents an environmentally benign approach.

Results

Firstly, we investigated the effect of four different ionic liquids (Chart 1) for the synthesis of the desired products using PhSeSePh/InI and benzyl chloride as the substrate, at room temperature and with a reaction time of 30 minutes, Table 1. Commercially available (bmim)BF_4, (bmim)PF_6, (bmim)NTf_2 and (bpy)BF_4 were used. We found that cationic and anionic changes in the ionic liquid display an important role in the formation of the product. While in (bmim)BF_4 and (bmim)PF_6 the products were achieved in the same range of yield (entries 1 and 2), (bmim)NTf_2 and (bpy)BF_4 showed poorer results (entries 3 and 4).

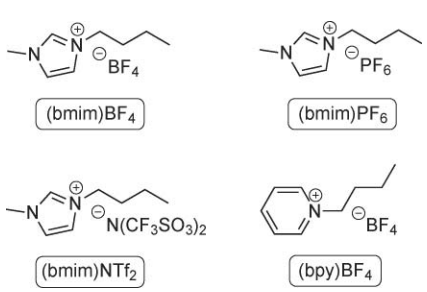
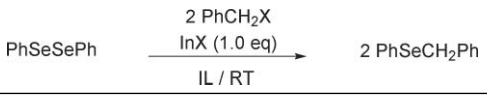


Chart 1 Room temperature ionic liquids (RTILs).

[a]*Departamento de Química, Universidade Federal de Santa Maria, 97105-900, Santa Maria, Brazil; Fax: +55 55 3220 8798. E-mail: albraga@qmc.ufsc.br*
[b]*Departamento de Química, Universidade Federal de Santa Catarina, Florianópolis, Brazil*
[c]*Instituto de Química e Geociências, Universidade Federal de Pelotas, Pelotas, Brazil*

† Electronic supplementary information (ESI) available: ^{1}H and ^{13}C NMR spectra of all compounds. See DOI: 10.1039/b910699e

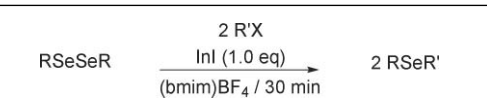
Table 1 Optimization of reaction conditions



#	Ionic Liquid	InX	$PhCH_2X$	Time (min)	Yield (%)[a]
1	$(bmim)BF_4$	I	Cl	30	90
2	$(bmim)PF_6$	I	Cl	30	86
3	$(bmim)NTf_2$	I	Cl	30	26
4	$(bpy)BF_4$	I	Cl	30	64
5	$(bmim)BF_4$	Br	Cl	30	84
6	$(bmim)BF_4$	I	Br	30	93
7	$(bmim)BF_4$	I	I	30	98

[a] Yields referent of pure isolated products, characterized by ^1H and ^{13}C NMR spectroscopic data.

Table 2 Synthesis of unsymmetrical diorganyl selenides



#	R	R′	X	Yield (%)[a]	Ref.
1	Ph	Et	Br	65	9a
2	Ph	Et	I	70	9a
3	Ph	Bu	Br	82	17
4	Ph	Bu	I	85	17
5	Ph	*t*-Bu	Cl	traces	12
6	Ph	Pentyl	Cl	85	10
7	Ph	Pentyl	Br	89	10
8	Ph	Allyl	Br	97	15
9	Ph	Allyl	Cl	94	15
10	Ph	*p*-Cl-$PhCH_2$	Cl	89	12
11	*p*-MeC_6H_4	$PhCH_2$	Cl	89	8c
12	*p*-$MeOC_6H_4$	$PhCH_2$	Cl	82	8c
13	*p*-ClC_6H_4	$PhCH_2$	Cl	89	10
14	*o*-$MeOC_6H_4$	$PhCH_2$	Cl	52	8c
15	Ph	*o*-$MeC_6H_4CH_2$	Br	60	18d
16	Ph	*m*-$MeC_6H_4CH_2$	Br	78	18d
17	Ph	*p*-$MeC_6H_4CH_2$	Br	92	18d
18	Bn	$PhCH_2$	Cl	78	15
19	Et	$PhCH_2$	Cl	81	10

[a] Yields referent of pure isolated products, characterized by ^1H and ^{13}C NMR spectroscopic data.

With these results in hands, we next investigated the influence of the halide, both in the indium salt and in the substrate. When we changed InI for InBr in the reaction using $(bmim)BF_4$ the product was formed in an appreciable yield, but which was lower than with InI (entries 1 and 5). Better results were found for the use of different halides in the substrate, affording the selenide in near quantitative yield (entries 6 and 7). Encouraged by our results, we next prepared a wide range of unsymmetrical diorganyl selenides using aryl or alkyl diselenides, InI, and $(bmim)BF_4$. The results are summarized in Table 2.

Initially the experiments were carried out with alkyl or allyl halides (entries 1–9) and PhSeSePh. The yields of the products were high, even for less reactive 1-chloropentane (entries 6 and 7). Based on the results, our protocol seems to follow a S_N2 type reaction, since good results were found for primary halides and just traces of product were achieved for the hindered *t*-butyl chloride (entry 5). The formation of the products was not strongly influenced by the nature of halide; in most cases the products were produced with just slight differences in the yields for the same alkyl chain. Employing more reactive allyl bromide, the conversion was almost quantitative (entry 8), with a similar result found for allyl chloride (entry 9). A good result was also found for *p*-chlorobenzyl chloride, with the selenide being obtained in 89% yield (entry 10). In a new set of experiments we screened substituted diaryl diselenides with the aim of checking the influence of electronic and hindrance effects (entries 11–14). The reaction proceeded very well both for electron donating and for electron withdrawing groups attached at the *para* position of the diaryl diselenide (entries 11–13). A significant decrease in the yield was achieved by using $(o\text{-}MeOC_6H_4Se)_2$ (entry 14). Substituted benzyl bromides were also employed, the most reactive one was the *para* substituted, followed by the *meta*- and *ortho*-methyl benzyl bromides (entries 15–17). Finally we employed dibenzyl diselenide and diethyl diselenide as the source of selenium (entries 18 and 19). Once again, the desired diorganyl selenides were efficiently obtained in good yields.

Table 3 Reuse of the reaction media

Entry	Run	InI (eq)	Yield (%)[a]
1	1	1.0	90
2	2	1.0	85
3	3	1.0	82
4	4	1.0	77
5	5	1.0	76

[a] Isolated yields.

To further explore the scope of our method, and in an effort toward an environmentally benign protocol, we examined the possibility of reusing the reaction media, Table 3. Accordingly, after the work-up (see ESI†) the ionic liquid was recovered.

The recovered ionic liquid was then used in another run after the addition of one equivalent of InI. To our delight, the yield was found to be similar to that obtained in the first run (entry 2). This operation was repeated three more times without appreciable loss of efficiency (entries 3–5).

Conclusions

In summary, the present report describes a high yielding preparation of unsymmetrical diorganyl selenides, using very mild conditions and requiring a very short reaction time. Our approach employs InI as the reducing agent in $(bmim)BF_4$, which is suitable for further reuse without loss of efficiency for at least five runs. Some important features of this method are the high reactivity, leading to the desired products in good to excellent yields, the ready commercial availability of the starting materials, as well as its environmentally benign nature. We are currently pursuing further applications of this procedure as well as investigating the use of other reducing agents.

Experimental

General

^{1}H and ^{13}C NMR spectra were recorded at 400 and 100 MHz respectively with tetramethylsilane as internal standard. Column chromatography was performed using Merck Silica Gel (230-400 mesh). Thin layer chromatography (TLC) was performed using Merck Silica Gel GF_{254}, 0.25 mm thickness. For visualization, TLC plates were either placed under ultraviolet light, or stained with iodine vapor, or acidic vanillin. All solvents were used as purchased unless otherwise noted. The diselenides, ionic liquids and halides were used as purchased. ^{1}H and ^{13}C NMR spectral data of the compounds are identical to those reported.

Representative experimental procedure to prepare unsymmetrical diorganyl selenides

In a schlenk tube, to a stirred solution of (bmim)BF_4 (0.5 mL) was added indium(I) iodide (121 mg, 0.5 mmol) and diphenyl diselenide (156 mg, 0.5 mmol) at room temperature under nitrogen. The mixture was allowed to stir for 5 min. Then benzyl bromide (171 mg, 1 mmol) was slowly added. The reaction mixture was stirred for another 30 min (checked by TLC), the mixture was then extracted with ether (3 × 15 mL), and the combined ether extract was washed with brine, dried (Mg_2SO_4), and evaporated to leave the crude product. Following purification by column chromatography over silica gel (hexane/ether 95:5) the pure benzyl phenyl selenide was obtained as a yellow liquid (224 mg, 93%).

Representative experimental procedure to reuse (bmim)BF_4

After the work-up of the first run, (bmim)BF_4 was diluted in dichloromethane and filtered through a celite pad to remove the inorganic materials followed by concentration to remove the organic solvents and being subjected to vacuum for 1 hour to eliminate moisture and trace organic solvents. For the following runs the recovered ionic liquid was used after addition of one equivalent of InI (121 mg, 0.5 mmol), diphenyl diselenide (156 mg, 0.5 mmol) and benzyl bromide (171 mg, 1 mmol).

Ethyl phenyl selenide[9a]

Yield: 70%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.50–7.45 (m, 2H), 7.27–7.20 (m, 3H), 2.91 (q, J = 7.6 Hz, 2H), 1.43 (t, J = 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.57, 130.32, 129.0, 126.71, 21.26, 15.51.

Butyl phenyl selenide[17]

Yield: 85%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.49–7.45(m, 2H), 7.26–7.18(m, 3H), 2.90 (t, J = 7.6 Hz, 2H), 1.71–1.64 (m, 2H), 1.46–1.37 (m, 2H), 0.90 (t, J = 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.42, 130.82, 129.02, 126.62, 32.32, 27.66, 23.02, 13.64.

Pentyl phenyl selenide[10]

Yield: 89%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47–7.44 (m, 2H), 7.22–7.14 (m, 3H), 2.87 (t, J = 7.6 Hz, 2H), 1.68 (m, 2H), 1.39–1.24 (m, 4H), 0.86 (t, J = 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 132.43, 130.94, 129.02, 126.61, 32.11, 30.50, 28.28, 22.27, 14.05.

Allyl phenyl selenide[15]

Yield: 97%; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.63–7.58 (m, 2H), 7.27–7.23 (m, 3H), 6.05–5.84 (m, 1H), 5.02–4.92 (m, 2H), 3.52 (d, J = 7.6 Hz, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 134.37, 133.32, 131.51, 128.91, 127.11, 116.81, 30.65.

(4-Chlorophenyl) methyl phenyl selenide[12]

Yield: 89%; ^{1}H NMR ($CDCl_3$, 00 MHz) δ = 7.45–7.41 (m, 2H), 7.25–7.11 (m, 5H), 7.09–7.07 (m, 2H), 4.03 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 137.32, 133.38, 132.5, 130.08, 129.80, 129.04, 128.48, 127.54, 31.45.

Benzyl 4-tolyl selenide[8c]

Yield: 89%; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.33 (d, J = 8 Hz, 2H), 7.30–7.16 (m, 5H), 7.04 (d, J = 7.8 Hz, 2H), 4.05 (s, 2H), 2.31 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 138.83, 137.27, 133.93, 129.71, 128.75, 128.29, 126.68, 126.49, 32.45, 21.06.

Benzyl 4-methoxyphenyl selenide[8c]

Yield: 82%; ^{1}H NMR ($CDCl_3$, 200 MHz) δ = 7.36 (d, J = 8.6 Hz, 2H), 7.26–7.10 (m, 5H), 6.77 (d, J = 8.6 Hz, 2H), 4.0 (s, 2H), 3.79 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 159.55, 139.08, 136.51, 128.78, 128.29, 126.64, 120.02, 114.58, 55.22, 33.15.

Benzyl (4-chlorophenyl) selenide[10]

Yield: 89%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.35–7.33 (m, 2H), 7.26–7.16 (m, 7H), 4.07 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ = 140.01, 138.42, 135.09, 130.86, 129.90, 129.45, 127.82, 126.65, 32.18.

Benzyl 2-methoxyphenyl selenide[8c]

Yield: 52%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.35 (m, 1H), 7.29–7.15 (m, 6H), 6.87–6.81 (m, 2H), 4.10 (s, 2H), 3.84 (s, 3H); ^{13}C ($CDCl_3$, 50 MHz) δ = 157.64, 138.14, 131.98, 128.83, 128.31, 127.99, 126.71, 121.24, 120.10, 110.26, 55.69, 29.43.

2-[(phenylseleno)methyl]toluene[18d]

Yield: 60%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47–7.45 (m, 2H), 7.26–7.20 (m, 3H), 7.13–7.11 (m, 2H), 7.06–7.01 (m, 2H), 4.10 (s, 2H), 2.35 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 133.86, 130.47, 129.76, 128.92, 127.40, 127.21, 125.91, 30.53, 19.20.

3-[(phenylseleno)methyl]toluene[18d]

Yield: 78%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.46–7.43 (m, 2H), 7.26–7.21 (m, 3H), 7.15–7.11 (m, 1H), 7.01–6.99 (m,3H), 4.07 (s, 2H), 2.28 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 138.38, 138.02, 133.45, 130.61, 129.59, 128.92, 128.30, 127.63, 127.21, 125.84, 32.23, 21.29.

4-[(phenylseleno)methyl]toluene[18d]

Yield: 92%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.47–7.44 (m, 2H), 7.25–7.23 (m, 3H), 7.11 (d, J = 8 Hz, 2H), 7.05 (d, J = 8.4 Hz, 2H), 4.09 (s, 2H), 2.30 (s, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ = 136.34, 135.37, 133.20, 130.67, 129.02, 128.84, 128.62, 127.01, 31.84, 21.01.

Dibenzyl selenide[15]

Yield: 78%; ^{1}H NMR ($CDCl_3$, 400 MHz) $\delta = 7.31$-7.25 (m, 8H), 7.23-7.19 (m, 2H), 3.72 (s, 4H); ^{13}C ($CDCl_3$, 100 MHz) $\delta = 139.26$, 129.01, 128.07, 126.71, 27.16.

Benzyl ethyl selenide[10]

Yield: 81%; ^{1}H NMR ($CDCl_3$, 400 MHz) $\delta = 7.29$–7.25 (m, 4H), 7.23–7.18 (m, 1H), 3.79 (s, 2H), 2.50 (q, $J = 7.6$ Hz, 2H), 1.37 (t, $J = 7.2$ Hz, 3H); ^{13}C ($CDCl_3$, MHz) $\delta = 132.42$, 130.80, 128.90, 126.31, 27.01, 17.8, 15.9.

Benzyl phenyl selenide[12]

Yield: 98%; ^{1}H NMR ($CDCl_3$, 400 MHz) $\delta = 7.50$–7.42 (m, 2H), 7.28–7.14 (m, 8H), 4.10 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) $\delta = 138.60$, 133.53, 130.40, 128.94, 128.82, 128.39, 127.26, 126.82, 32.21.

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Synthesis of Diorganyl Selenides Mediated by Zinc in Ionic Liquid

Senthil Narayanaperumal,[†] Eduardo E. Alberto,[†] Kashif Gul,[†] Oscar E. D. Rodrigues,*[,†] and Antonio L. Braga*[,‡]

[†]*Departamento de Química, Universidade Federal de Santa Maria, 97105-900, Santa Maria, Brazil, and* [‡]*Departamento de Química, Universidade Federal de Santa Catarina, 88040-900, Florianópolis, Brazil*

albraga@qmc.ufsc.br; rodriguesoed@smail.ufsm.br

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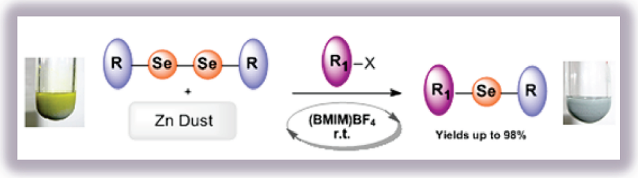

A new approach for the synthesis of diorganyl selenides is described. By using economically attractive zinc dust in BMIM-BF_4, a series of diorganyl selenides were efficiently achieved in excellent yields, under neutral reaction conditions. Compared to the usual organic solvents, BMIM-BF_4 exhibited higher performance with the advantage to be reused up to five successive runs.

Research on organoselenides has been driven by the potential applications of selenium compounds in modern organic synthesis and catalysis.[1] The biological and medicinal properties of selenium and organoselenium compounds are also becoming increasingly appreciated, mainly due to their antioxidant, antitumor, antimicrobial, and antiviral properties.[2] Also, the synthesis of peptides containing selenocysteine is rapidly gaining interest with the discovery of an increasing number of proteins containing this amino acid.[3]

Diorganyl selenides are versatile tools in organic chemistry, and have found wide application as radical precursors, in elimination reactions, and as selenium-stabilized carbanions.[4] Chiral diorganyl selenides are also used as efficient ligands in asymmetric reactions.[5]

These compounds are generally prepared by reductive cleavage of Se−Se bonds, employing common reducing agents such as $NaBH_4$, $LiAlH_4$, and other expensive metal sources such as La, In, Yb, Sm, etc.[6,7] Most of the procedures require handling of unstable reagents, strongly acidic or basic conditions, or two-step procedures. Thus, there is still considerable interest in the development of highly efficient methods for this transformation.[8]

Ionic liquids are versatile and novel reaction media, for organic transformations, and have also found application as flexible "platforms" to establish highly effective and easily separable systems.[9] Room temperature ionic liquids, especially those based on the 1,3-dialkylimidazolium cation, have attracted considerable attention due to their negligible vapor

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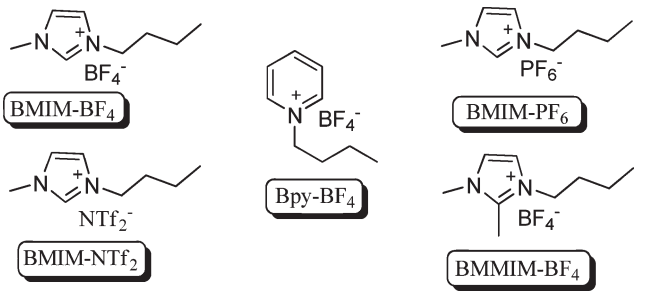


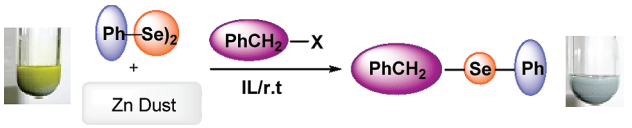
FIGURE 1. Room temperature ionic liquids.

pressure, nonflammability, reasonable thermal stability, ease of handling, and potential for recycling.[10] Ionic liquids were used as solvent in many organic transformations and have shown enhanced reaction rates when compared with conventional organic solvents. Thus, development of ionic liquid mediated organic transformation is gaining prominence.[11]

In connection with our insights about the synthesis of diorganyl selenides and their application in biological and asymmetric transformations,[12,13] we describe herein a simple, efficient, and versatile approach to the preparation of diorganyl selenides. Employing zinc dust and ionic liquid, to promote the direct coupling of diselenides and organic halides, the respective selenides were achieved in good to excellent yields in a short time at room temperature. To optimize the protocol, we performed the reaction of benzyl chloride with PhSeSePh and 1.6 equiv of zinc dust with respect to diselenide, in five different ionic liquids (Figure 1). The formation of the product could be easily observed by the change of the reaction color from yellow to gray.

The results for BMIM-BF_4 were found to be better than those for the other ionic liquids (Table 1, entries 1−5). Similar protocols have appeared in the literature for reduction of PhSeSePh with zinc followed by reaction with benzyl chloride with use of other organic solvents. In a mixture of MeCN/H_2O at 65 °C the desired product was obtained in 64% yield after 3 h,[7h] in CH_2Cl_2 at rt, 57% of the yield was obtained after 5 h.[7j] Although the improved capability of ionic liquid to accelerate many organic reactions compared to other organic solvents has been extensively reported, the origin of its behavior is still an intriguing subject of study. Properties such as strong dipolar and dispersion forces,

TABLE 1. Reaction Optimization



entry	ionic liquid[a]	X	time (min)	yield (%)[b]
1	Bpy-BF_4	Cl	40	55
2	BMMIM-BF_4	Cl	40	65
3	BMIM-NTf_2	Cl	40	29
4	BMIM-PF_6	Cl	35	86
5	BMIM-BF_4	Cl	30	93
6	BMIM-BF_4	Br	25	95
7	BMIM-BF_4	I	20	98
8[c]	BMIM-BF_4	Br	25	96
9[d]	BMIM-BF_4	Br	25	92

[a]Prepared according literature procedure.[10e] [b]Yields refer to pure isolated products. [c]1.2 equiv of zinc dust. [d]1.0 equiv of zinc dust.

hydrogen bond acidity (related to the cationic portion), and hydrogen bond basicity (related to the anionic portion) would account for the complex solvent interactions exhibited by ILs.[14] In previous reports hydrogen bonds have been evoked as a pivotal interaction in the formation of a given product in reactions performed in ILs.[15] Our experimental results (Table 1) suggest that perhaps the scale of hydrogen bond acidity of the tested ILs may be a distinguished property for the formation of products. If one assumes that this characteristic would facilitate the reaction through the coordination of the acid hydrogen attached to C-2 in the imidazolium ring with the leaving group (chloride) in an S_N2 like reaction, the formation of products would be in the same range of yield for BMIM-BF_4, BMIM-PF_6, and BMIM-N-$(Tf)_2$ due to the similarity of their hydrogen bound donor (HBD) parameters.[16] With the exception of BMIM-$N(Tf)_2$, 29% yield (entry 3), BMIM-BF_4 and BMIM-PF_6 furnished the desired product in 93% and 86% yields, respectively (entries 5 and 4). Moreover, if the extent of hydrogen bond interactions really accounts for an effective formation of products, reactions carried in Bpy-BF_4 and BMMIM-BF_4 which have a much lower (HBD) value compared to the above-mentioned ionic liquids would result in the formation of products in lower yields. Actually, these ILs exhibited poorer activity compared to BMIM-BF_4 and BMIM-PF_6 (entries 1 and 2). A reasonable explanation to the lower yield observed for BMIM-$N(Tf)_2$ is the influence of the anion $N(Tf)_2$. We speculate that it would interfere in the formation and/or in the reactivity of zinc selenolate, PhSeZnSePh.[17] On the basis of these results, we investigated the influence of halide in the substrate. When benzyl iodide was used a higher

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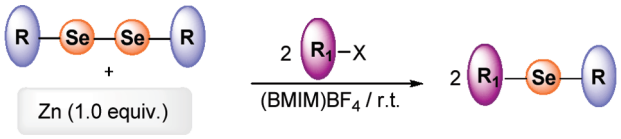
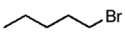
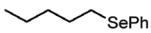
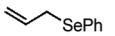
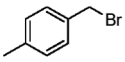
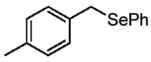
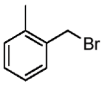
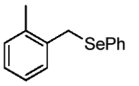
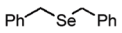
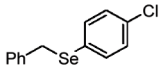
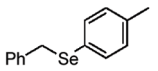
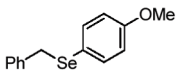
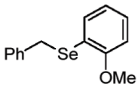
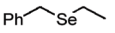
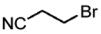
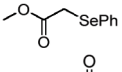
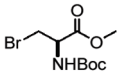
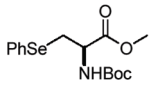
TABLE 2. Synthesis of Diorganyl Selenides



	Halide	Product	Time (min)	Yield (%)[a]
1			30	80
2			35	73
3			20	82
4			20	84
5			15	89
6			25	92
7			30	94
8			20	98
9			20	98
10			25	79
11			35	80
12			40	88
13			35	89
14			30	82
15			45	52
16			40	77
17			10	89
18			20	84
19[b]			180	61

[a]Yields refer to pure isolated products. [b]Bromo ester (1 equiv), Zn (0.6 equiv), $PhSe)_2$ (0.6 equiv), BMIM-BF_4 (1 mL).

yield was obtained as compared with that of benzyl bromide and chloride, which can be explained by the leaving group ability of the halogens (entries 5−7). However, the difference was not significant and all the halogens afforded the desired product in excellent yields. The amount of zinc required to promote the completion of the reaction was also evaluated. Reactions with 1.2 and 1.0 equiv of zinc showed similar results, leading to the product in excellent yields (entries 8 and 9).

After optimization, the coupling of different substrates and diselenides was applied to check the versatility of the protocol. A diverse range of alkyl halides were reacted with diphenyl diselenide under standard reaction conditions to provide the corresponding alkyl phenyl selenides in excellent yields. The results are summarized in Table 2 (entries 1−6) and indicate that the chain length has a positive effect on the reaction course, affording improved yields in longer chains (entries 2, 4, and 6). Reactive allylic halides allowed the corresponding allyl phenylselenide in near quantitative yields, for both allyl chloride and iodide (entries 7 and 8). Substituted benzylic halides and diaryl diselenides were also applied to this protocol in order to check the steric and electronic effects in the course of the reaction. When 4-methylbenzyl bromide was applied, the product was achieved in 98% yield, while 2-methylbenzyl bromide gave the selenide in 79% yield (entries 9 and 10). In the diselenide moiety, a lower yield was observed by using 2-methoxy diphenyl diselenide as a selenium source compared with 4-methoxy diphenyl diselenide (entries 14 and 15). These observations can be explained by the steric dependence in this coupling reaction, driving better yields to the less sterically hindered para-substituted aryl halides and diselenides.

Electronic effects had no significant influence on the reaction course and the coupling of diaryl diselenides, with electron-donating or electron-withdrawing groups attached to the aromatic ring, afforded the products with a similar level of efficiency (entries 12−14). We also employed other diselenide sources in this reaction, e.g. benzylic and alkylic. For instance, dibenzyl diselenide and diethyl diselenide were reacted with benzyl chloride, allowing the preparation of the desired products in good yields (entries 11 and 16).

An important feature of our methodology is the tolerance of different functional groups, such as protected aminoester, ester, and nitrile, giving the corresponding products in good yields (entries 17, 18, and 19). Exploiting the versatility of our current methodology, the synthesis of the biologically important selenocysteine[2,3,18] derivative was accomplished from the corresponding bromo amino ester derivative[19] in 61% yield, employing our standard reaction conditions (entry 19). This result demonstrates the potential wide-ranging utility of this methodology by the preparation of various chiral organoselenium compounds.

Furthermore, our approach allows the preparation of the desired products in really smooth reaction conditions in a shorter time. Although in the other related procedures with Zn the products were successfully obtained,[7h−k,8] these protocols require severe reaction conditions such as long reaction time under higher temperature. It is noteworthy to highlight that, when the solvent for the synthesis of diorganyl selenides was changed from conventional organic solvents to ionic liquid (BMIM-BF_4) excellent conversion rates and yields were obtained under room temperature with very short reaction times and mild conditions with BMIM-BF_4 as a reusable solvent.

After completion of the reaction, the desired products can be conveniently obtained by extraction with diethyl ether (3 × 15 mL). After the workup of the first run, the remaining ionic liquid (BMIM-BF_4) was diluted in ethanol, filtered through a Celite pad to remove inorganic materials, followed by concentration to remove the organic solvents. Then, it was subjected to the vacuum for 1 h to eliminate the moisture and trace organic solvents. For the following runs, the recovered ionic liquid was used after addition of 1 equiv of Zn (33 mg, 0.5 mmol), diphenyl diselenide (156 mg, 0.5 mmol), and benzyl chloride (127 mg, 1 mmol) for each run (Figure 2). The yields were almost constant for the first three runs, followed by a slight decrease for the following two runs.

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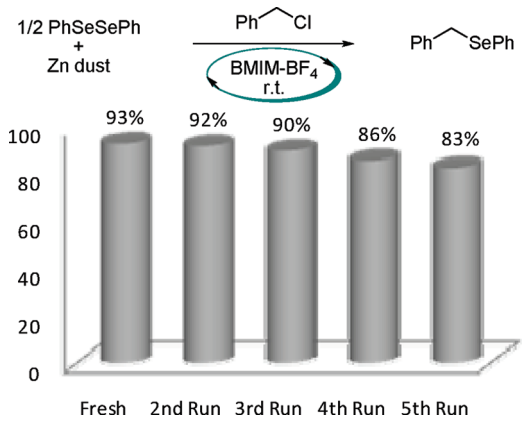

FIGURE 2. Reuse of BMIM-BF_4.

In conclusion, the present method has the following noteworthy features: (1) good to excellent yields were obtained in a short time; (2) ease of handling and better safety aspects as compared with metal hydrides; (3) neutral reaction conditions; (4) from an industrial point of view, the use of commercially available and inexpensive Zn is an interesting option to processes which use La, Yb, Sm, or In salts to promote the reduction of selenium−selenium bound; and (5) the solvent/ionic liquid is reused in up to five successive runs without loss of its efficiency and when compared to usual organic solvents, BMIM-BF_4 exhibited higher performance. Continued investigations into the utility of this novel methodology are underway in our laboratory aiming at the synthesis of seleno aminoacids and derivatives.

Experimental Section

Typical Procedure. Commercially available Zn dust (33 mg, 0.5 mmol) and PhSeSePh (156 mg, 0.5 mmol) were added to BMIM-BF_4 (0.5 mL) at room temperature under nitrogen. The mixture was allowed to stir for 2−3 min. Then benzyl bromide (171 mg, 1 mmol) was slowly added. The reaction mixture was stirred for another 25 min (monitored by TLC and assisted by visual observation). The mixture was then extracted with ether (3 × 15 mL), and the combined ether extract was washed with brine, dried ($MgSO_4$), and evaporated to leave the crude product. Purification by column chromatography over silica gel (hexane/ethyl acetate 98:2) furnished the pure benzyl phenyl selenide as a yellow oil (231 mg, 92%).

Benzyl phenyl selenide:[6f] 92% yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.50−7.42 (m, 2H), 7.28−7.14 (m, 8H), 4.10 (s, 2H); ^{13}C ($CDCl_3$, 100 MHz) δ 138.6, 133.5, 130.4, 128.9, 128.8, 128.4, 127.3, 126.8, 32.2.

Ethyl phenyl selenide:[6h] 80% yield; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.50−7.45 (m, 2H), 7.27−7.20 (m, 3H), 2.91 (q, J = 7.6 Hz, 2H), 1.43 (t, J = 7.2 Hz, 3H); ^{13}C ($CDCl_3$, 100 MHz) δ 132.6, 130.3, 129.0, 126.7, 21.3, 15.5.

Representative Experimental Procedure To Reuse BMIM-BF_4. After the workup of the first run, BMIM-BF_4 is diluted in ethanol, filtered through a Celite pad, and then subjected to the vacuum for 1 h. For the following run the recovered ionic liquid was used after addition of 1 equiv of Zn (33 mg, 0.5 mmol), diphenyl diselenide (156 mg, 0.5 mmol), and benzyl chloride (127 mg, 1 mmol) followed by the procedure described above.

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Supporting Information Available: Synthetic procedures and compound characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

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Baixar livros de Educação - Trânsito
Baixar livros de Educação Física
Baixar livros de Engenharia Aeroespacial
Baixar livros de Farmácia
Baixar livros de Filosofia
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Baixar livros de Geociências
Baixar livros de Geografia
Baixar livros de História
Baixar livros de Línguas

Baixar livros de Literatura
Baixar livros de Literatura de Cordel
Baixar livros de Literatura Infantil
Baixar livros de Matemática
Baixar livros de Medicina
Baixar livros de Medicina Veterinária
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Baixar livros de Saúde Coletiva
Baixar livros de Serviço Social
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