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Synthesis of Alkynylthiopyridinium Salts and Their Use as Thioketene Equivalents

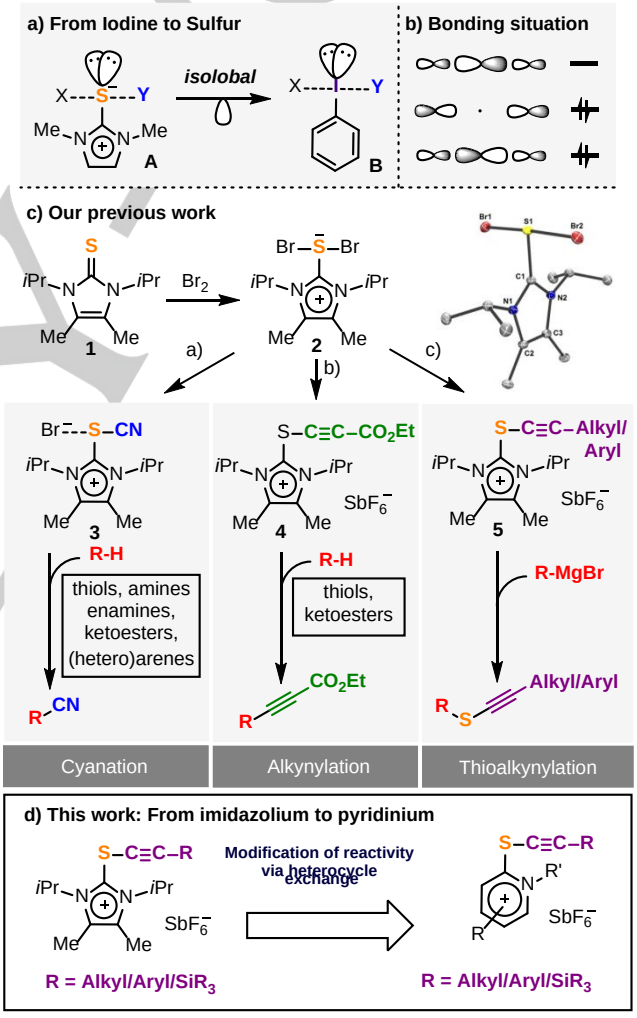
Kai F. G. Averesch, Henner Pesch, Christopher Golz and Manuel Alcarazo*[a]

Abstract: A synthetic method has been developed for the preparation of dihalo(pyridinium) sulfuranes and their transformation into alkynylthiopyridinium salts, starting from inexpensive thiopyridones. The reactivity of these salts toward different nucleophiles is evaluated. Most thiols and amines are converted into dithioesters and thioamides, respectively; while sterically demanding thiols delivered alkynylthioethers. These results, together with preliminary mechanistic studies reveal that alkynylthiopyridinium salts can be considered synthetic equivalents of unstable thioketenes.

Introduction

The unique ability of hypervalent I(III) compounds to invert the polarity of the groups coordinated to iodine and provide electrophilic synthons starting from classical nucleophiles; combined with the weakness of their three center-four electron X-I-Y bond, which allows the mild transfer of either X or Y to advanced organic intermediates, make I(III)-derived reagents extremely versatile tools for the synthetic practitioner.[1] Transformations which benefit from the use of I(III) platforms are, among others, electrophilic trifluoromethylations,[2] alkynylations,[3] (hetero)arylations,[4] aminations,[5] fluorinations[6] and cyanations.[7] Unfortunately, several hypervalent iodine reagents suffer from thermal instability, which reduces their range of practical application. In addition, Lewis acids, bases or even transition metal catalysts may promote their undesired decomposition. This problem has been in part alleviated by the employment of cyclic hypervalent iodine reagents, in particular benziodoxolones.[8]

Considering the tremendous synthetic utility of I(III)-based reagents, but also their limitations, our group recently started a research program focused on the identification of other structurally related scaffolds, yet not based in iodine, which could deliver similar reactivity. In this regard, we recently demonstrated that imidazolium sulfuranes **A**, which are isolobal to I(III) species and also depict the key three-center four-electron bond motive might be considered alternative platforms for this purpose (Scheme 1a-b). Specifically, a new electrophilic cyanation reagent **3** was developed, which was able to carry out the metal-free direct C-H cyanation of electron rich hetero- and polyaromatics in good to excellent yields.[9, 10] Unfortunately, the use of the imidazolium sulfurane platform **A** did not match the same level of success for the development of electrophilic alkynylation reagents. While the umpolung and transfer of alkynes decorated with electron withdrawing substituents such as **4** proceded satisfactorily; alkyl-, aryl- or silyl-substituted alkynylthioimidazolium salts **5** did not get involved in reaction with typical soft nucleophiles. Only strongly nucleophilic Grignard reagents are able to react with **5**, but in this case the attack takes place at the S-atom, providing the corresponding alkynyl thioethers (Scheme 1c).[11]



Scheme 1. Synthesis and reactivity of imidazolium thiocyanates and imidazolium thioalkynes. Reagents and conditions: a) TMSCN, CH_2Cl_2, r.t., 89%; b) AgC≡C-COOEt, CH_2Cl_2, r.t., and then $AgSbF_6$, CH_2Cl_2, r.t., 93%, two steps; c) RC≡C-ZnBr, THF, -78°C→r.t., and then $NaSbF_6$, 81-98%, two steps.

Once the significant influence on the reactivity of the terminal group at the alkyne was recognized, we wondered if the exchange of the imidazolium moiety by another cationic group might also be a method to efficiently modulate the reactivity of

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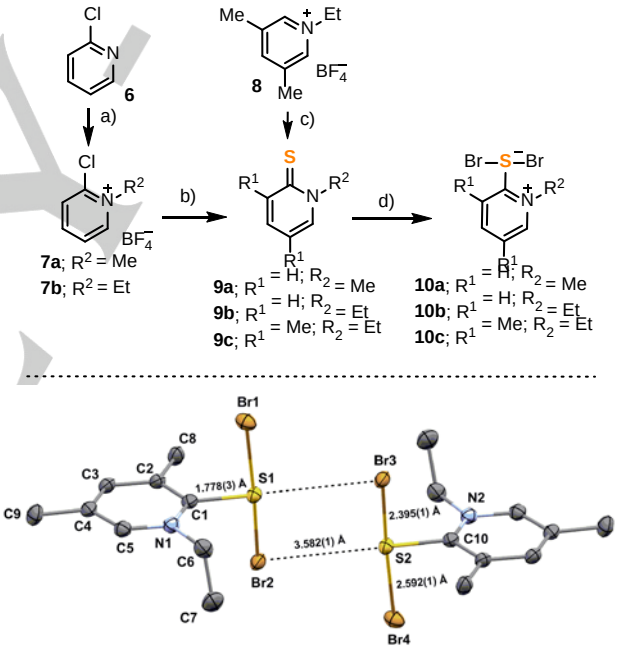
the resulting species. Specifically, pyridinium rests might be interesting alternatives because in these moieties the positive charge is less efficiently stabilized than in imidazolium ones. For this reason the pyridinium units are expected to deplete more electron density from the central S-atom and, as consequence, the corresponding cationic thioalkynes should depict enhanced reactivity towards nucleophiles (Scheme 1d).[12] In an attempt to bring this initial hypothesis into practice, we report herein the synthesis of dihalo(pyridinium) sulfuranes, their derivatization to the desired alkynylthiopyridinium salts and the reactivity of these towards typical S-, N-, and C-based nucleophiles. Interestingly, the alkyne transfer reaction was found not to be operative for most of the substrates. Instead, the prevalent reaction pathway found consists on the attack of the chosen nucleophile at the C1 atom of the pyridinium moiety following a nucleophilic aromatic substitution mechanism. This releases an aldothioketene, which further reacts with a second equivalent of the nucleophile to afford dithioesters or thioamides, when thiols and amines are used as nucleophiles, respectively. The scope of this transformation is presented together with insights supporting the proposed mechanism. Considering that the synthetic applications of aldothioketenes are often limited to their availability, due to their high tendency to oligo- or polymerize; the use of alkynylthiopyrydinium salts as easy-to-handle aldothioketene surrogates might actually broaden the range of applications of these compounds.[13]

Results and Discussion

Synthesis of dibromo(pyridinium)sulfurane precursors: While it is well established that both cyclic and acyclic thioureas react with elemental chlorine or bromine to form 1:1 adducts of sulfurane structure, little is known about the generality of this reaction.[14] In fact, we are not aware of any report describing the involvement of other structurally or electronically related species, such as for example thiolactams, in this transformation.[15] Considering the effectiveness of the syntheses of alkynylthioimidazolium salts by reaction of dihalo(imidazolium) sulfuranes with organozinc species, we were encouraged already at the earliest phase of this research project to evaluate whether dihalo(pyridinium) sulfuranes could be efficiently prepared. Hence, we first synthesized thiopyridones **9a-c** either from 2-chloropyridine **6** or from pyridinium salt **8** following reported procedures.[4a] The ethyl group in **9b-c** was used to improve the solubility of the corresponding derivatives, while the two additional methyl rests in **9c** where introduced to sterically protect the pyridine ring from the undesired attack of nucleophiles (Scheme 2).

Addition of one equivalent of bromine to solutions of **9a-c** in dichloromethane immediately caused the precipitation of intense orange powders, which were isolated in excellent yields after filtration. This reaction has been scaled up to multigram quantities with reproducible yields. Diagnostic spectroscopic features indicating the formation of sulfuranes **10a-c** are the ^{13}C-NMR signals for the carbon atoms directly attached to sulfur (C1; δ = 165-160 ppm.), which are significantly high field shifted if compared with those present in the parent thiolactam (C1; δ = 180-176 ppm.). This chemical shift is consistent with the disappearance of the C=S double bond from the original thiolactones **9a-c**, and the subsequent increase of the aromatic character at the pyridinium ring in **10a-c**.

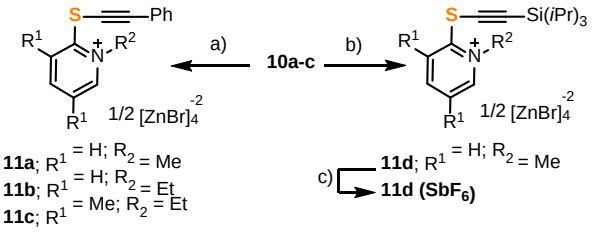
To our satisfaction, monocrystals of **10c** could be obtained and X -ray analysis confirmed its sulfurane structure. In the solid state **10c** adopts a slightly distorted T-shape with a nearly linear (177.50°(3)) Br1-S1-Br2 distribution. However, in sharp contrast with the situation observed in imidazolium sulfurane **2**, where both S-Br distances are identical (2.505(3)Å), the three center-four electron bond interaction in **10c** is not symmetrical. The Br1-S1 bond length is slightly elongated (2.5917(7)Å) from the average distance, while the Br2-S1 bond gets shortened in a similar magnitude (2.3947(7)Å) (Scheme 2). A closer inspection at the unit cell of this compound explains this asymmetry. Two secondary Br-S bonding interactions hold two molecules of **10c** together forming a face-to-face dimer. The two bromine atoms involved in these short contacts have shorten Br-S bonds, while the other two slightly elongate their S-Br distances.



Scheme 2. Synthesis of dibromo(pyridinium)sulfuranes. Reagents and conditions: a) Me_3OBF_4 or Et_3OBF_4, CH_2Cl_2, r.t., **7a**, 98%; **7b**, 98%; b) NaSH, MeOH/H_2O, 45 °C, **9a**, 92%; **9b**, 85%; c) LiHMDS (1 equiv.), THF, -100 °C, and then S_8 (excess); **9c**, 68%; d) Br_2, CH_2Cl_2, 0°C→r.t., **10a**, 98%; **10b**, 97%; **10c**, 98%. Molecular structure of compound **10c**. Anisotropic displacement parameter shown at 50% probability level, hydrogen atoms omitted for clarity. Selected bond lengths [Å] and angles [deg]: S1-Br1, 2.5917(7); S1-Br2, 2.3947(7); S1-C1, 1.778(3); Br1-S1-Br2, 177.50(3).[16]

Synthesis of alkynylthiopyridinium salts: Reaction of **10a-c** with alkynylzinc bromides, obtained by transmetallation of the corresponding organolithium species with $ZnBr_2$, cleanly provided the desired alkynylthiopyridinum salts as the corresponding tetrabromozincates **11a-d** in moderate to excellent yields. These conditions were applicable to both, aryl-

and silyl-substituted alkyne rests. All four compounds **11a-d** were isolated as crystalline materials and can be handled in air; for long time storage, the use of inert atmosphere is recommended. Subsequent treatment of **11d** with a saturated aqueous solution of $NaSbF_6$ allowed the exchange of the original tetrabromozincate anion by a more chemical inert hexafluoroantimonate in **11d(SbF$_6$)**. Contrarily, phenyl substituted salts **11a-c** decompose slowly in contact with water (Scheme 3). The preparation of **11d(SbF$_6$)** was scaled up to 16 grams (30 mmols) without compromising the yield of the product.



Scheme 3. Synthesis of alkynylthiopyridinium salts. Reagents and conditions: a) Phenylacetylene (1 equiv.), BuLi (1 equiv.), THF, -78°C→r.t., and then $ZnBr_2$, **11a**, 95%; **11b**, 87%; **11c**, 95%; b) TIPS-C≡CH (1 equiv.), BuLi (1 equiv.), THF, -78°C→r.t., then $ZnBr_2$, and finally aq. $NaSbF_6$, **11d(SbF$_6$)**, 65%, two steps.

Crystals suitable for X-ray analysis of **11b** and **11d(SbF$_6$)** were grown by slow diffusion of diethylether into saturated dichloromethane solution of the corresponding salts; their connectivity was thus unambiguously established (Figure 1). Similarly to imidazolium derivatives **4** and **5**, both **11b** and **11d(SbF$_6$)** adopt an angular geometry, with C1-S1-C7 angles of 101.2(2)° and 101.9(2)°, respectively; however, some differences are also evident when comparing the unit cells of the imidazolium and the pyridinium derivatives.[11] While short contacts are present in **4** and **5** between the anions and S1, these weak interactions are not observed neither in **11b** nor in **11d(SbF$_6$)**. On the other hand, short contacts appear between the counteranions and the pyridinium rings in **11b** and **11d(SbF$_6$)** (not shown in Figure 1; See the Supporting Information), which are not detectable in the imidazolium analogues. These interactions are probably a manifestation of the high electrophilicity at the pyridinium moiety and have, as it will be described in the next sections, a decisive influence on the reactivity of alkynylthiopyridinium salts.

Reactivity towards nucleophiles and mechanistic insights: Once alkynylthioimidazolium salts **11** were completely characterized, we set up to preliminary explore their reactivity towards nucleophiles of different nature. For the initial studies the reaction of **11d(SbF$_6$)** with one equivalent of 4-(methoxyphenyl) methanethiol **12** was monitored. Interestingly, while the thiol substrate was found to be completely consumed after only five minutes, half equivalent of **11d(SbF$_6$)** was still present in the reaction mixture, together with similar amounts of two unidentified products. Careful optimization of the reaction conditions revealed that two equivalents of the thiol were necessary for the complete consumption of **11d(SbF$_6$)** and its quantitative transformation into a 1:1 mixture of the already mentioned products.

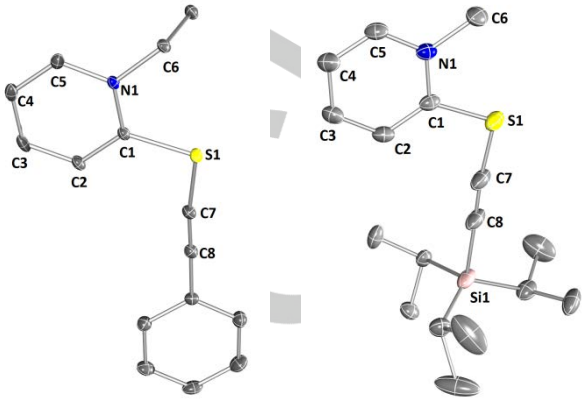
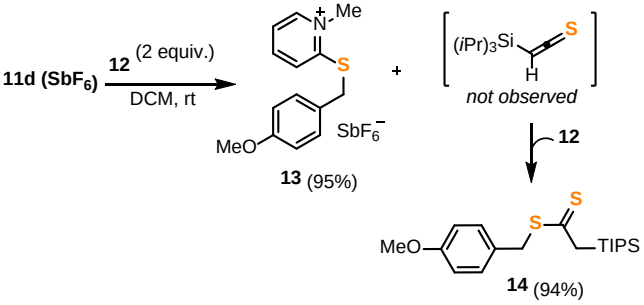


Figure 1. Molecular structures of compounds **11b** (left) and **11d(SbF$_6$)** (right). Anisotropic displacement parameter shown at 50% probability level, anions and hydrogen atoms omitted for clarity. Selected bond lengths [Å] and angles [deg] in **11b**, S1-C1, 1.769(3); S1-C7, 1.675(3); C1-S1-C7, 101.59(15); in **11a(SbF$_6$)**, S1-C1, 1.759(3); S1-C7, 1.693(4); C1-S1-C7, 101.17(17).[16]

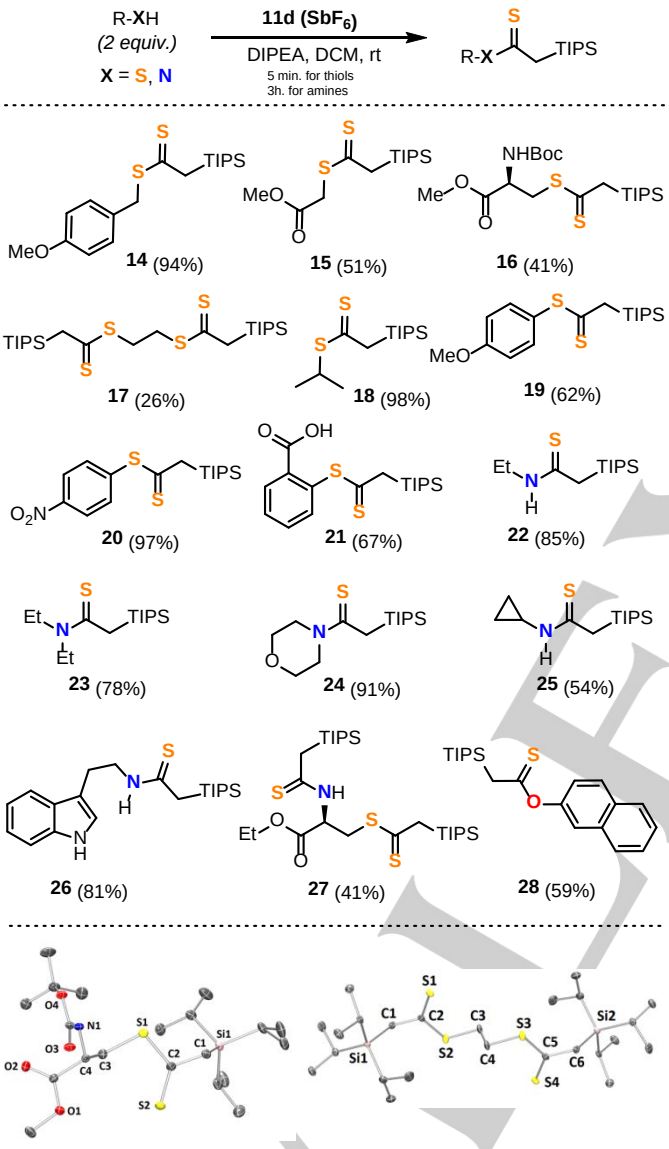
We also suspected from the differentiated retention factor on thin liquid chromatography that one of these products was a salt. Extraction of the reaction mixture with CH_2Cl_2 allowed the separation of both components and their complete characterization. The material insoluble in CH_2Cl_2 was found to be pyridinium salt **13**, the product of thiol attack at C1 of the pyridinium ring following a typical nucleophilic aromatic substitution pathway. The component soluble in CH_2Cl_2 was identified as dithioester **14**, which we assume results from the nucleophilic attack of the second equivalent of thiol **12** to the thioketene liberated as byproduct at the initial nucleophilic aromatic substitution (Scheme 4).



Scheme 4. Reactivity of alkynylthiopyridinium salts towards thiols.

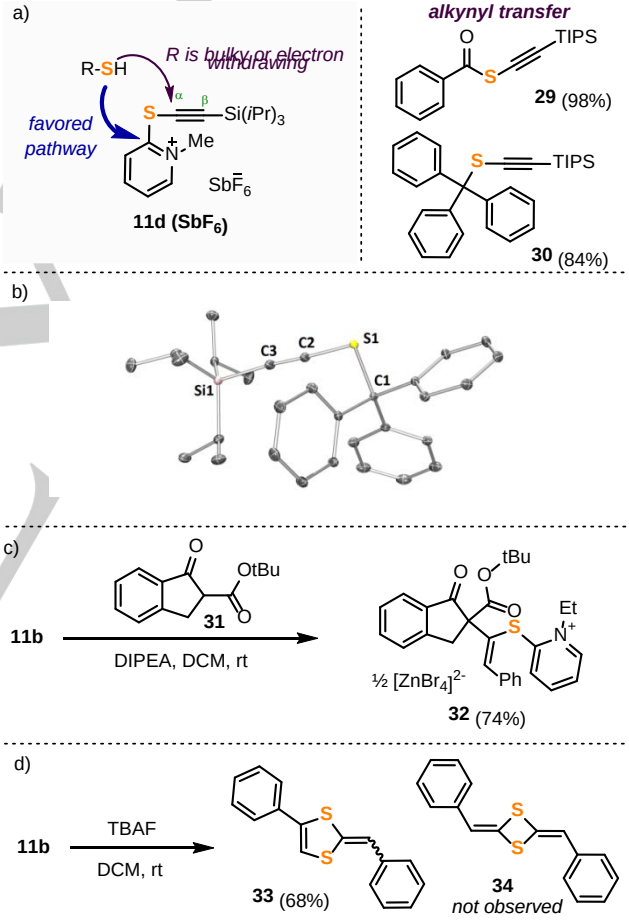
The reaction just described seems to be general for both, aliphatic and aromatic thiols, and can be used for preparative purposes provided that the starting thiol is available in sufficient quantities; note however, that two equivalents are to be consumed to produce only one of the dithioester **14-21** (Scheme 5).[17] The transformation has been be extended to primary and

secondary amines and phenols to afford the corresponding thiolactams and thioesters **22-26**, respectively. Aminothiols can be used as substrates as well; in that case both basic functionalities react to afford product **27**. 2-Naphtol is transformed into the corresponding thioester **28** as well. [18] From the results compiled in Scheme 5 it can be concluded that alkynylthiopyridinium salts efficiently behave as synthetic equivalents of aldothioketenes, which are notoriously unstable members of the heterocumulene family.[19]



Scheme 5. Reactivity of **11d(SbF$_6$)** with thiols, amines and phenols: Substrate scope. Molecular structures of compounds **16** and **17**. Anisotropic displacement parameters shown at 50% probability level and hydrogen atoms omitted for clarity. Selected bond lengths [Å] and angles [deg] for **16**: S2-C2, 1.644(3); C2-S1, 1.7434(19); S1-C3, 1.799(2); C1-C2-S1, 125.06(13); C1-C2-S2, 111.32(14), C2-S2-C3, 103.21(10); for **17**: S1-C2, 1.644(3); C2-S2, 1.758(3); S2-C3, 1.820(3); C1-C2-S1, 123.9(3); C1-C2-S2, 111.2(2), C2-S2-C3, 104.17(16).[16]

Non-expected reactivities were found in particular cases as well. For example, when the nucleophilicity of the thiol is severely reduced by conjugation, as in the case of thiobenzoic acid, or the thiol unit is embedded in a sterically very demanding environment such as in tritylthiol, then the already described nucleophilic aromatic substitution at the pyridine moiety gets disfavored. These nucleophiles preferentially attack **11a-d** at the much more accessible and softer α-position of the alkyne moiety, allowing the isolation of the products of electrophilic alkynylation **29** and **30**, which are formed after elimination of the thiopyridone fragment (Scheme 6a-b). Very similar reactivity, although applicable to a much larger scope of substrates, has been recently described for the reaction of 5-(alkynyl) dibenzothiophenium triflates with S-, N-, and even C-based nucleophiles.[20]



Scheme 6. Reactivity of **11d(SbF$_6$)** and **11b** towards selected nucleophiles. Molecular structure of compound **30**. Anisotropic displacement parameters shown at 50% probability level and hydrogen atoms omitted for clarity. Selected bond lengths [Å] and angles [deg]: S1-C1, 1.8949(8); S1-C2, 1.6804(9); C2-C3, 1.2130(13); Si1-C3, 1.8398(10); C1-S1-C2, 103.35(4).[16]

Also interesting is the isolation of compound **32** after reaction of cyclic ketoester **31** with **11b** under basic conditions. In this case the sterically quite demanding enolate attacks again at the α-position of the alkyne moiety, but instead of eliminating

the thiopyridone moiety, the intermediate has been trapped by protonation (Scheme 6c). The formation of **32** still puzzle us since for the analogue 5-(alkynyl)dibenzothiophenium salts of similar substitution pattern, the attack takes place at the β-position.[21] Finally, we also decided to collect additional evidence for the proposed mechanistic picture trying to demonstrate the formation of thioketenes under the reaction conditions. Aldothioketenes are known to dimerize either to 2,4-dimethylene-1,3-dithietanes **34** or to the corresponding 1,3-dithiafulvenes **33** in the absence of a trapping nucleophile.[22, 23] Thus, we treated **11b** with $(Bu)_4NF$; the fluoride anion should be strong enough to promote the nucleophilic substitution at the pyridinium ring, but unable to react with the nascent thioketene. From this reaction dithiafulvene **33** was isolated in good yield as a mixture of the *cis*- and *trans*-isomers, additionally supporting the mechanistic picture proposed (Scheme 6).[24]

Conclusions

We describe here for the first time a synthetic method for the preparation of dihalo(pyridinium) sulfuranes starting from inexpensive thiopyridones. Subsequently, alkynylthiopyrydinium salts were also prepared by reaction of the corresponding sulfuranes with organozinc species, and their reactivity was evaluated towards a series of thiols and amines. Alkynylthiopyrydinium salts only transfer the alkynyl group to sterically hindered nucleophiles; otherwise, they preferentially react via aromatic substitution at the pyridinium ring with concomitant elimination a thioketene, which can further trap a second equivalent of the nucleophile. This makes alkynylthiopyridinium salts synthetic equivalents of thioketenes and useful precursors for the preparation of dithioesters or thiolactams.

Experimental Section

Synthesis and characterization of representative products

Synthesis of 10a: Bromine (1 equiv, 365 µL, 7.1 mmol) was added slowly to a solution of **9a** (893 mg, 7.1 mmol) in dry CH_2Cl_2 (20 mL) at 0 ºC, and the reaction mixture was stirred for 2 hours. After removal of all volatiles in vacuo, **10a** was obtained as a bright orange solid (2 g, 7.1 mmol, 99%). ^{1}H NMR (500 MHz, $C_2D_2Cl_4$) δ= 8.39 (d, *J* = 7.9 Hz, 1H), 8.28 (d, *J* = 6.2 Hz, 1H), 8.17 (t, *J* = 7.8 Hz, 1H), 7.69 (ddd, *J* = 7.7, 6.2, 1.6 Hz, 1H), 4.44 (s, 3H). ^{13}C NMR (126 MHz, $C_2D_2Cl_4$) δ = 163.5, 145.5, 144.6, 137.5, 125.8, 48.9 ppm. HRMS (ESI) calcd. for $[C_6H_7BrNS]^+$: 203.9477; found: 203.9475.

Synthesis of 11d(SbF$_6$): *n*-BuLi (1.1 equiv, 2.5 M, 20.5 mL, 51.3 mmol) was slowly added to a solution of tri(isopropyl)silylacetylene (1.1 equiv, 11.5 mL, 51.3 mmol) in THF (10 mL) at -78 ºC and the reaction mixture thus obtained was allowed to warm up to room temperature over 2 hours. After this, the flask was again cooled down to -78°C, and then $ZnBr_2$ (1.1 equiv., 11.5 g, 51.3 mmol) in THF (1 M) was added and stirred for an additional hour. The solution thus obtained was then added drop wise to a solution of **10**a (1.0 equiv., 13.3 g, 46.6 mmol) in THF at -78 °C and 30 minutes after the addition was finished, the suspension was let to warm up to room temperature by removing the cooling bath. Finally, an aqueous solution of $NaSbF_6$ (3 equiv., 36.2 g, 139.8 mmol) was added under vigorous stirring, and successively, the two phases were transferred to a separatory funnel. After drying the organic phase with Na_2SO_4 the solvents were removed in vacuo affording **11d(SbF$_6$)** as a beige solid (16.3 g, 30.0 mmol, 65%). ^{1}H NMR: (300 MHz, CD_3CN) δ = 8.64 – 8.56 (m, 1H), 8.44 (td, *J* = 8.0, 7.6, 1.5 Hz, 1H), 8.31 (dd, *J* = 8.5, 1.4 Hz, 1H), 7.78 (ddd, *J* = 7.6, 6.2, 1.5 Hz, 1H), 4.09 (s, 3H), 1.32 – 1.07 (m, 21H) ppm. ^{13}C NMR: (75 MHz, CD_3CN) δ = 148.4, 146.0, 127.0, 125.5, 113.6, 82.7, 46.9, 18.8, 11.9 ppm. IR: (ATR, cm^{-1}) 3516, 3140, 2943, 2867, 2104, 1617, 1571, 1489, 1456, 1282, 1168, 1110, 993, 878, 851, 767, 656, 625, 595. HRMS(ESI) calcd. for $[C_{17}H_{28}NSSi]^+$: 306.1706 ; found: 306.1707.

Synthesis of 15: (4-methoxyphenyl)methanethiol (2 equiv, 83.6 µL, 0.6 mmol) and DIPEA (2 equiv, 104.5 µL, 0.6 mmol) were added to a dichloromethane solution (4 mL) of **11d(SbF$_6$)** (1 equiv, 162.7 mg, 0.3 mmol). After completion of the reaction, the solvent was removed in vacuo and the products separated by column chromatography (Hexanes/Ethyl Acetate, 20:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ = 7.25 – 7.20 (m, 2H), 6.87 – 6.80 (m, 2H), 4.39 (s, 2H), 3.79 (s, 3H), 3.16 (s, 2H), 1.32 – 1.17 (m, 3H), 1.16 – 1.05 (m, 18H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ = 236.1, 159.2, 130.5, 127.5, 114.2, 55.4, 42.5, 41.8, 18.7, 11.6 ppm. IR (ATR, cm^{-1}): 2940, 2864, 1610, 1510, 1462, 1301, 1248, 1174, 1102, 1036, 911, 880, 830, 658, 510. HRMS calcd. for $[C_{19}H_{34}OS_2Si]^+$: 369.1737; found = 369.1736.

Acknowledgments

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Keywords: sulfuranes • pyridinium salts • thioketenes •dithioesters • thioamides.

[1] V. V. Zhdankin in *Hypervalent Iodine Chemistry*, John Wiley & Sons, **2014**.

[2] J. Charpentier, N. Früh, A. Togni, *Chem. Rev.* **2015**, *115*, 650-682.

[3] D. P. Hari, P. Caramenti, J. Waser, *Acc. Chem. Res.* **2018**, *51*, 3212-3225.

[4] P. Caramenti, S. Nicolai, J. Waser, *Chem. Eur. J.* **2017**, *23*, 14702−14706.

[5] J. A. Souto, C. Martínez, I. Velilla, K. Muñiz, *Angew. Chem. Int. Ed.* **2013***, 52*, 1324-1328.

[6] G. C. Geary, E. G. Hope, K. Singh, A. M. Stuart, *Chem. Commun.* **2013**, *49*, 9263-9265.

[7] R. Frei, T. Courant, M. D. Wodrich, J. Waser, *Chem. Eur. J.* **2015**, *21*, 2662 – 2668.

[8] a) V. V. Zhdankin, Curr. *Org. Synth.* **2005**, *2*, 121−145; b) T.-Y. Sun, X. Wang, H. Geng, Y. Xie, Y.-D. Wu, X. Zhang, H. F. Schaefer III, *Chem. Commun*. **2016**, *52*, 5371−5374.

[9] For the synthesis of dihalo(imidazolium)sulfuranes see: A. J. Arduengo, E. M. Burgess, *J. Am. Chem. Soc.* **1977**, *99,* 2376-2378.

[10] G. Talavera, J. Peña, M. Alcarazo, *J. Am. Chem. Soc.* **2015**, *137*, 8704-8707.

[11] J. Peña, G. Talavera, B. Waldecker, M. Alcarazo, *Chem. Eur. J.* **2017**, *23*, 75-78.

[12] The effect of pyridinium substituents on phosphines is reported in: a) H. Tinnermann, C. Wille, M. Alcarazo, *Angew. Chem. Int. Ed.* **2014**, *53*, 8732-8736; b) H. Tinnermann, L. D. M. Nicholls, T. Johannsen, C. Wille, C. Golz, R. Goddard, M. Alcarazo, *ACS Catal.* **2018**, *8*, 10457-10463; c) L. D. M. Nicholls, M. Alcarazo, *Chem. Lett.* **2019**, *48*, 1-13.

[13] E. Schaumann, *Comp. Org. Chem.*, **1991,** 6, 419-434.

[14] H. W. Roesky, U. N. Hehete, S. Singh, H. G. Schmidt, Y. G. Shermolovich, *Main Group Chemistry*, **2005***, 4,* 11-21.

[15] Lewis adducts formed by reaction of thiolactames and I_2 are known, see: M. Tretiakov, Y. G. Shermolovich, A. P. Singh, P. P. Samuel, H. W. Roesky, B. Niepötter, A. Visscheraand, D. Stalke, *Dalton Trans* **2013***, 42*, 12940-12946.

[16] CCDC 1905834- 1905839, 1907719, 1907720 and 1907737 contain the supplementary crystallographic data for this paper. These data are provided free of charge by The Cambridge Crystallographic Data Centre.

[17] For the synthesis of dithioesters see: a) J. Houben. *Berichte der Dtsch. Chem. Gesellschaft* **1906**, *39*, 3219-3233; b) J. Houben; K. M. L. Schultze, *Berichte der Dtsch. Chem. Gesellschaft* **1910**, *43*, 2481-2485; c) E. J. Hedgley, H. G. Fletcher, *J. Org. Chem.* **1965**, *30*, 1282-1283; d) P. J. W. Schuijl, L. Brandsma, J. F. Arens, *Recl. des Trav. Chim. des Pays-Bas* **1966**, *85*, 889-894; e) J. Meijer, P. Vermeer, L. Brandsma, *Recl. des Trav. Chim. des Pays-Bas* **1973**, *92*, 601-604; f) H. Westmijze, H. Kleijn, J. Meijer, P. Vermeer, *Synthesis* **1979**, 432-434; g) R. Hoffmann, K. Hartke, *Chem. Ber.* **1980**, *113*, 919-933; h) A. C. Worth, C. E. Needham, D. B. Franklin, A. J. Lampkins, *Synth. Commun*. **2012**, *42*, 2694-2706.

[18] For the synthesis of thioamides see: a) K. A. Petrov, L. N. Andreev, *Russ. Chem. Rev.* **1969**, *38*, 21-36; b) E. V. Brown, *Synthesis*, **1975**, 358-375; c) A. B. Charette, M. Grenon, *J. Org. Chem.* **2003**, *68*, 5792-5794.

[19] C. Spanka, E. Schaumann, *Synlett*, **2014**, *25*, 2415-2428.

[20] B. Waldecker, F. Kraft, C. Golz, M. Alcarazo, *Angew. Chem. Int. Ed.* **2018**, *57*, 12538-12542.

[21] No switching of the selectivity towards alkynylation was observed with compound **11c**.

[22] E. Schaumann, *Tetrahedron*, **1988**, *44*, 1827-1871.

[23] B. F. Bonini, M. C. Franchini, M. Fochi, S. Mangini, G. Mazzanti, A. Ricci, *Eur. J. Org. Chem.* **2000**, 2391-2399.

[24] An alternative mechanism may be simultaneously operative. The incoming thiol may attack the α-position of the alkyne affording an alkene such as **32**. Attack of a second equivalent of thiol on the pyridinium ring following a nucleophilic aromatic substitution should liberate the corresponding dithioester. This mechanism however, does not explain the formation of dimer **33** as byproduct.

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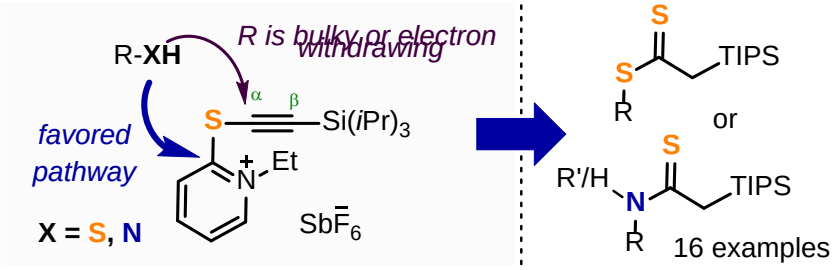

Synthesis of Alkynylthiopyridinium Salts and Their Use as Thioketene Equivalents

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New reactivity was found when changing the imidazolium group in alkynylthioimidazolium salts by pyridinium ones. While the formers react with Grignards to afford the corresponding thioethers, pyridinium-based salts behave as thioketene equivalents and produce dithioesters and thioamides by reaction with thiols or amines respectively.