J. Org. Chem. **1995**, 60, 7142–7143

Reductive Dimerization of Organic Thiocyanates to Disulfides Mediated by Tetrathiomolybdate

Kandikere R. Prabhu, A. R. Ramesha, and Srinivasan Chandrasekaran*

Department of Organic Chemistry, Indian Institute of Science, Bangalore 560 012, India

Received June 1, 1995[®]

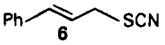
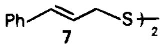
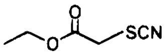
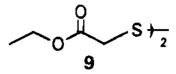
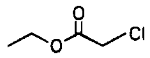
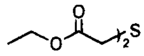
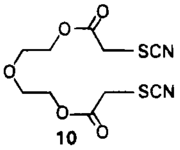
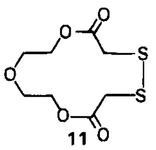
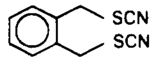
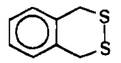
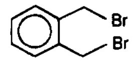
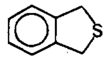
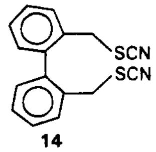
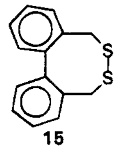
An interesting reductive dimerization of organic thiocyanates assisted by benzyltriethylammonium tetrathiomolybdate, [$(\text{PhCH}_2\text{NEt}_3)_2\text{MoS}_4$], **1**, leads to the formation of the corresponding disulfides in high yields.

Earlier work from our laboratory has shown that benzyltriethylammonium tetrathiomolybdate, [$(\text{PhCH}_2\text{NEt}_3)_2\text{MoS}_4$], **1**, is a useful sulfur transfer reagent which can be used for the synthesis of disulfides from alkyl halides in both intermolecular and intramolecular reactions.[1] Disulfides[2] are useful synthetic intermediates in a variety of chemical transformations, and many methods have been developed for the preparation of disulfides.[3] Here we wish to report a novel synthetic approach to disulfides from thiocyanates mediated by tetrathiomolybdate **1**. This reaction is novel in that it does not involve sulfur transfer from tetrathiomolybdate **1** to the organic thiocyanate (RSCN) as in the case of alkyl halides[1] but goes through a process of reductive dimerization mediated by tetrathiomolybdate **1**.

The thiocyanates used as starting materials were synthesized by the reaction of alkyl bromides with potassium thiocyanate in refluxing ethanol.[4] In general, when organic thiocyanates were treated with 1.1 mol equiv of tetrathiomolybdate **1** in CH_3CN (25 °C; 0.5–15 h), the corresponding disulfides were formed in very high yields. The results of this reductive dimerization are summarized in Table 1. As can be seen from Table 1, benzyl thiocyanate (**2**) reacted with tetrathiomolybdate **1** to form the disulfide **3** in 88% yield. Thiocyanates, having a hydroxyl group or a carbon–carbon double bond, **4** and **6**, respectively, also gave the corresponding disulfides without any complication. The reaction of thiocyanate **8** containing a carbonyl group at the α-carbon is worth mentioning. Earlier attempts at sulfur transfer reaction of tetrathiomolybdate **1** with ethyl α-chloroacetate (**8a**) yielded a mixture of the corresponding mono- and disulfides **9b** and **9**, respectively.[1a] However, in the present case thiocyanate **8** yielded exclusively the disulfide **9** in excellent yield.

A novel application of this reductive dimerization in an intramolecular reaction to form a macrocyclic system is illustrated in entry 5. Reaction of tetrathiomolybdate **1** with dithiocyanate **10** containing ester functionality afforded the macrocyclic disulfide **11** as the only product in near quantitative yield. Similar intramolecular cyclizations of **12** and **14** mediated by tetrathiomolybdate **1** also yielded cyclic disulfides **13** and **15**, respectively, in high yields. The facility of this reaction is in contrast to our earlier observation on the sulfur transfer reaction of tetrathiomolybdate **1** with the dibromide **12a** which resulted in the formation of a mixture of disulfide **13** and monosulfide **13b** in poor yields.[5]

Table 1. Reductive Dimerization of Thiocyanates with Tetrathiomolybdate 1

Entry	Substrate	Time(h)	Product[a]	Yield[b] (%)
1	PhCH_2SCN **2**	6	$\text{PhCH}_2\text{S}\!-\!)_2$ **3**	88
2	$\text{HO(CH}_2)_6\text{SCN}$ **4**	15	$\text{HO(CH}_2)_6\text{S}\!-\!)_2$ **5**	85
3	 **6**	3	 **7**	85
4	 **8**	6	 **9**	92
4a	 **8a**	6	 + **9** **9b**	85[c]
5	 **10**	15	 **11**	94
6	 **12**	0.5	 **13**	73
6a	 **12a**	1	 + **13** **13b**	20[d]
7	 **14**	2	 **15**	85
8	PhSCN **16**	1	PhSSPh **17**	73
8a	PhBr **16a**	12	**17**	33[c]
9	$p\text{-Me}_2\text{NC}_6\text{H}_4\text{SCN}$ **18**	15	$p\text{-Me}_2\text{NC}_6\text{H}_4\text{S}\!-\!)_2$ **19**	97

[a] The products exhibited expected spectral data and were compared with authentic samples. [b] Yields refer to pure, isolated products. [c] Reference 1a. [d] Reference 5.

It is pertinent to point out that this methodology is also

[®] Abstract published in *Advance ACS Abstracts*, September 15, 1995.

(1) (a) Ramesha, A. R.; Chandrasekaran, S. *Synth. Commun.* **1992**, *22*(22), 3277. (b) Ramesha, A. R.; Chandrasekaran, S. *J. Org. Chem.* **1994**, *59* (6), 1354.

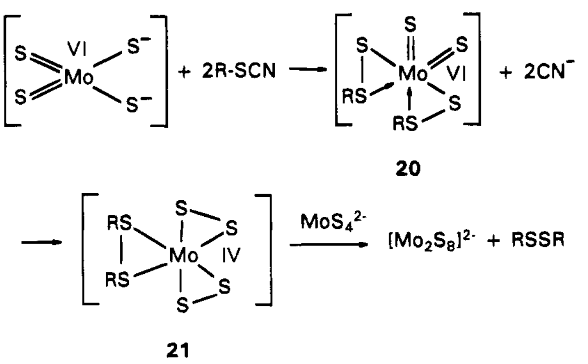
(2) (a) Ogawa, A.; Nishiyama, Y.; Kambe, N.; Murai, S.; Sonoda, N. *Tetrahedron Lett.* **1987**, *28* (28), 3271–3274. (b) Antebi, S.; Alper, H. *Tetrahedron Lett.* **1985**, *26* (22), 2609.

(3) (a) Jia, X.; Zhang, Y.; Zhou, X. *Tetrahedron Lett.* **1994**, *35*, (47), 8833. (b) McKillop, A.; Koyuncu, D.; Krief, A.; Dumont, W.; Renier, P.; Trabelsi, M. *Tetrahedron Lett.* **1990**, *31* (35), 5007. (c) Oae, S.; Togo, H. *Synthesis* **1982**, 152. (d) Ogura, F.; Yamaguchi, H.; Otsubo, T.; Tanaka, H. *Bull. Chem. Soc. Jpn.* **1982**, *55* (2), 641.

(4) Allen, P., Jr. *J. Am. Chem. Soc.* **1935**, *57* (1), 198.

0022-3263/95/1960-7142$09.00/0

Scheme 1

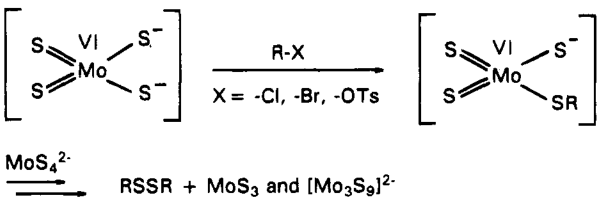


applicable to the synthesis of aryl disulfides. Accordingly, when phenyl thiocyanate (**16**) was treated with tetrathiomolybdate **1**, diphenyl disulfide (**17**) was formed readily (25 °C, 1 h). Reaction of bromobenzene with **1**, however, had to be done in DMF at 70 °C to obtain the disulfide **17** in poor yield.[1a] Although the reaction of **1** with aryl thiocyanate **18** containing an electron releasing substituent was slow, the product could be isolated in excellent yield. Similar reaction of *N,N*-dimethyl-*p*-bromoaniline with **1** even at high temperature failed to produce any significant product.

All the above mentioned transformations clearly indicate that in the reaction of organic thiocyanates, tetrathiomolybdate **1** does not act as a sulfur transfer reagent but rather as a reagent which mediates reductive dimerization. Although a cursory glance indicates that molybdenum in tetrathiomolybdate **1** is in the highest oxidation state (VI) and cannot act as a reducing agent, induced internal redox processes have been reported with tetrathiomolybdate **1** where reduced molybdenum(V) and (IV) complexes have been prepared in the presence of electron acceptors.[6] It is very likely that in the reaction of organic thiocyanates, the attack of $[MoS_4]^{2-}$ on the sulfur of thiocyanate can lead to mononuclear molybdenum species of the type **20** with two sulfide ligands. The second stage of the reaction can be viewed as an induced internal electron transfer from S^{2-} to Mo(VI) to produce Mo(IV) species, **21**. Further reaction of **21** with **1** leads to the formation of organic disulfides and $[Mo_2S_8]^{2-}$ (Scheme 1).[7] The process thus involves a net two electron oxidation with no overall gain or loss of sulfur atom.

The mechanism proposed in Scheme 1 is essentially similar to the one enunciated by Stiefel[8] in his pioneering work on induced internal redox reactions of tetrathiomolybdate. It is interesting to note that the reaction of thiocyanate with tetrathiomolybdate **1** does not involve the formation of thiol and a subsequent oxidation to disulfide.[9] More experiments are needed to substantiate the mechanistic pathway involved in this reductive dimerization mediated by tetrathiomolybdate **1**.

Scheme 2



In contrast, in the reaction of alkyl halides and tosylates with tetrathiomolybdate **1**, the mechanism of sulfur transfer is not fully understood. It is believed that the alkylation of metal−sulfur bond is the key step which triggers an internal redox reaction with sulfur transfer leading to the formation of alkyl disulfide and sulfide clusters of higher nuclearity[10,11] (Scheme 2).

In summary, this methodology involving the reaction of tetrathiomolybdate **1** with organic thiocyanates having different functional groups like hydroxyl, ester, carbon−carbon double bond turns out to be a mild, clean and efficient procedure for the synthesis of a variety of disulfides without the formation of competing side products. This method is particularly useful for the synthesis of disulfides with α-carbonyl functionality where all other methods are inefficient. Further synthetic and mechanistic studies involving the use of organic thiocyanates and other tetrathiometalates are under investigation in our laboratory.

Experimental Section

^1H and ^{13}C NMR spectra were recorded in $CDCl_3$. TLC was performed on 0.25 mm precoated silica plates (60F-254). The mp's and bp's reported are uncorrected. Benzyltriethylammonium tetrathiomolybdate (**1**) was prepared as described earlier.[1a] Thiocyanates were prepared according to the literature procedure.[4]

General Procedure: Reaction of Dithiocyanate 10 with Tetrathiomolybdate 1. To a solution of **1** (1.74 g, 2.86 mmol) in CH_3CN (10 mL) was added dithiocyanate **10** (0.394 g, 1.3 mmol), and it was stirred at room temperature (25 °C) for 15 h. Most of the solvent was evaporated under reduced pressure, and the black residue was slurried with CH_2Cl_2 (2 mL) and ether (10 mL). It was then filtered through a pad of Celite, and washed with ether (3 × 20 mL). The combined filtrate on removal of solvent yielded the crude product which on flash chromatography on silica gel [CH_2Cl_2:hexanes (60−80 °C), 1:9] afforded the pure disulfide **11** (0.308 g, 94%) as a viscous liquid. IR (neat): 2920, 1745, 1450, 1400, 1300, 1130, 1040, 960, 750 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$): δ 4.28 (t, 4H, J = 4.7 Hz), 3.71 (t, 4H, J = 4.7 Hz), 3.61 (s, 4H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 169.3 (s), 68.9 (t), 64.6 (t), 41.3 (s); MS (m/z) 252 (M^+). Anal. Calcd for $C_8H_{12}O_5S_2$: C, 38.08; H, 4.79. Found: C, 38.09; H, 4.80.

Acknowledgment. We are grateful to the Department of Science and Technology, New Delhi, for financial support of this investigation.

Supporting Information Available: Physical and spectral data of compounds **5**, **7**, **9**, **13**, **15**, and **19** (5 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from ACS; see any current masthead page for ordering information.

JO951003A

---

(5) Ramesha, A. R. Organosulfur Reactions in organic Synthesis with Tetrathiomolybdates. Ph.D. Thesis, Indian Institute of Science, 1994.

(6) (a) Simhon, E. D.; Baenziger, N. C.; Kanatzidis, M.; Draganjac, M.; Coucouvanis, D. *J. Am. Chem. Soc.* **1981**, *103* (5), 1218. (b) Stiefel, E. I. *Proceedings of the Climax Fourth International Conference on the Chemistry and the Uses of Molybdenum*; Barry, H. F., Mitchel, P. C. H., Eds.; Climax Molybdenum Company: Ann Arbor, MI, 1982; pp 56−66. (c) Müller, A.; Jaegermann, W.; Enemark, J. H. *Coord. Chem. Rev.* **1982**, *46*, 245.

(7) Infrared spectrum in KBr of the molybdenum byproduct shows bands at 516, 532, and 460 cm^{-1} assignable to molybdenum−sulfur vibrational modes.

(8) Coyle, C. L.; Harmer, M. A.; George, G. N.; Daage, M.; Stiefel, E. I. *Inorg. Chem.* **1990**, *29* (1), 14.

(9) Even traces of thiol could not be detected in the reaction mixture and tetrathiomolybdate **1** does not convert thiols to disulfides.

(10) Dhar, P.; Chandrasekaran, S. *J. Org. Chem.* **1989**, *54* (13), 2998.

(11) Boorman, P. M.; Wang, M.; Parvez, M. *J. Chem. Soc., Chem. Commun.* **1995**, 999.