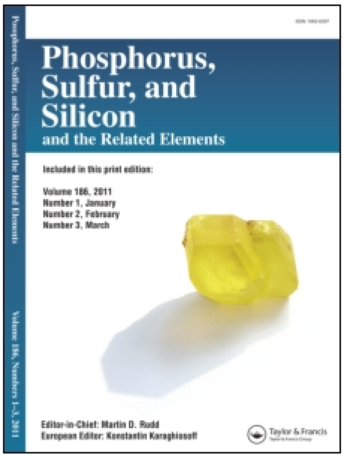
This article was downloaded by:
On: *27 January 2011*
Access details: *Access Details: Free Access*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Phosphorus, Sulfur, and Silicon and the Related Elements

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713618290

Trifluoromethylthiolation of 1,3-Dithiane

S. Munavalli[a]; D. K. Rohrbaugh[b]; L. L. Szafraniec[b]; H. D. Durst[b]
[a] Science Applications International Corporation, Gunpowder Branch, Aberdeen Proving Ground, Maryland [b] U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, Maryland

To cite this Article Munavalli, S. , Rohrbaugh, D. K. , Szafraniec, L. L. and Durst, H. D.(2006) 'Trifluoromethylthiolation of 1,3-Dithiane', Phosphorus, Sulfur, and Silicon and the Related Elements, 181: 2, 305 — 324
To link to this Article: DOI: 10.1080/104265090970377
URL: http://dx.doi.org/10.1080/104265090970377

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Phosphorus, Sulfur, and Silicon, 181:305–324, 2006
Copyright © Taylor & Francis Group, LLC
ISSN: 1042-6507 print / 1563-5325 online
DOI: 10.1080/104265090970377

Trifluoromethylthiolation of 1,3-Dithiane

S. Munavalli
Science Applications International Corporation, Gunpowder Branch,
Aberdeen Proving Ground, Maryland

D. K. Rohrbaugh
L. L. Szafraniec
H. D. Durst
U.S. Army Edgewood Chemical Biological Center,
Aberdeen Proving Ground, Maryland

*With a view to synthesize 2-(trifluoromethylthio)-1,3-dithiane (**1**), 1,3-dithiane (**2**) was reacted in dry pentane at −78°C under dry N_2 with trifluoromethylsulfenyl chloride (**3**) and was found to furnish the desired compound in poor yields along with ten other compounds. Under similar conditions, 2-lithio-1,3-dithiane on treatment with **2** and bis-(trifluoromethyl)disulfide (**4**) gave 8.0% and 10.0% yields of **1**, respectively. In connection with this study, (cholromethyl) propyl sulfide and bis-(propylthio)methane were synthesized. The reaction of the latter with **3** was also investigated. The characterization of the primary compound formed in the reaction of **2** with **3** using the 'INAPT'-NMR and GC-MS, the probable mechanism of the formation of the various compounds and their mass spectral identification are presented in this article.*

Keywords 1,3-dithiane; 1,3-dithiolane; bis-(trifluoromethyl)disulfide; bis-(propylthio)-methane; free radical; catalyzed cleavage products; (chloromethyl) propyl sulfide; INAPT'-NMR; GC-MS spectral data; lithio-dithiane; trifluoromethylsulfenyl chloride

Since the 1970s, 1,3-dithiane (**2**) has been extensively used as a building block in the preparation of a vast array of organic intermediates and synthons for the total synthesis of several scores of interesting organic compounds. The synthetic utility of 1,3-dithiane (**2**) rests squarely on the facile introduction of functional groups and the convenient removal of the masking moiety, namely the 1,3-propanedithiol fragment after the accomplishment of the stated objective. The pioneering work of Seebach and Corey[1] has demonstrated

Received January 18, 2005; accepted February 8, 2005.

Address correspondence to S. Munavalli, Science Applications International Corporation, P.O. Box 68, Gunpowder Branch, Aberdeen Proving Ground, Maryland 21010. E-mail: shekar.munavalli@us.army.mil

the synthetic usefulness and versatility of the dithiane synthons. The chemistry of dithiane and dithiolanes has been reviewed.[2] An excellent report on the synthetic applications of the anions derived from 1,3-dithiane (**2**) has been published.[2c] In this context, it should be mentioned that the dithiane ring system has been modified to 1,3-oxathiane and its synthetic applications have been described.[3]

The presence of fluorine, trifluoromethyl and trifluoromethylthio groups contributes significantly towards the enhancement of the biological potency and effectiveness of active compounds.[4,5] This observation has created considerable interest in the development of methodologies to incorporate the previously mentioned functional groups into the molecular architecture of biologically active compounds. In continuation of our interest in the chemistry of the trifluoromethylthio group,[6] attempts were made to synthesize new potential candidate compounds, in particular 2-(trifluoromethylthio)-1,3-dithiolane and -dithiane. This expectation was based on the use of N-(trifluoromethylthio)phthalimide in trifluoromethylthiolating carbonyl compounds.[7] These sulfur-stabilized trifluoromethylthiolated compounds were considered to be of particular interest and use as synthetic intermediates. The reaction of 1,3-dithiane (**2**) with trifluoromethylsulfenyl chloride (**3**) at −78°C was first examined. The GC-MS analysis of the reaction mixture enabled the characterization of eight compounds present in the reaction product. Thus, the structures of compounds **4** through **8** (Figure 1), have now been deduced from the examination of their mass spectral fragmentation behavior (Table I). The reaction of 2-lithio-1,3-dithiane (**12**) with trifluoromethylsulfenyl chloride (**3**) (Figure 2) and bis-(trifluoromethyl) disulfide (**4**, Figure 3) was also investigated in this context. A detailed NMR study of the primary product of the first reaction, namely of 1-(chloromethylthio)-

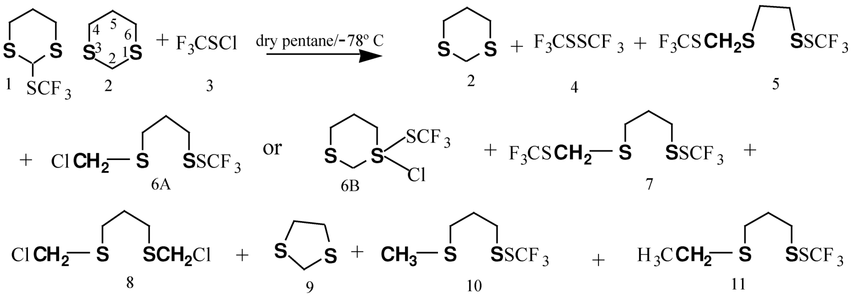


FIGURE 1 Products from the reaction of 1,3-dithiane with F$_3$CSCl.

TABLE I Mass Spectral Fragmentation of Compounds Cited in Figures 1 and 2

1. Bis-(trifluoromethyl)disulfide (4): $M^+ = 202$, (t = 1.26 min, 0.6%)
2. 1,3-dithialane (9): $M^+ = 106$, (r.t. = 4.20 min, 5.2%)
3. 1,3-dithialane (2): $M^+ = 120$, (r.t. = 5.47 min, 8.9%)
4. (Dichlorofluoromethyl)(trifluoromethyl)disulfide(**13**): $M^+ = 234$, (r.t. = 2.07 min, 0.2%)
5. Butyl(trifluoromethyl)disulfide (**14**): $M^+ = 190$, (r.t. = 234 min, 3.2%); 134(M-C_4H_8);114 (CF_2S_2); 89(SC_4H_9);78 (CH_2SS); 69(CF_3, 100%); 64 (SS); 61(SC_2H_5) and 60 (C_2H_4S)
6. 1-methylthio-3-(trifluoromethylperthiyl)propane (**10**): $M^+ = 222$ (not seen), (r.t. = 4.27 min, 0.5%); 121 (M-$SCF_{3'}$ 100%); 93(121-C_2H_4);78(93-CH_3); 73(SC_3H_5)· 69(CF_3); 59(C_3H_3S); 47(SCH_3) and 45(CSH)
7. 1-(trifluoromethylperthiyl)-2-[(trifluoromethylthio)methylthio]ethane (5): $M^+ = 308$, (r.t. = 729 min, 34.1%); 239 (M—CF_3); 207 (M-SCF_3, 100%); 147 (207-SC_2H_4); 133 (F_3CSS); 115 (CH_2SCF_3); 106 (C_3H_6SS);82 (CSF_2);78(CH_2SS); 73 (SC_3H_5); 69 (CF_3) and 64 (SS)
8. 1-ethylthio-3-(trifluoromethylperthiyl)propane (**11**): $M^+ = 236$ (not seen) (r.t. = 610 min, 0.3%); 207(M-C_2H_5); 136(M-SCF_3); 107(135-C_2H_4, 100%); 103(135-S); 78(CH_2SS);73(SC_3H_5); 69(CF_3) and 64(SS)
9. 1-(trifluoromethylperthiyl)-3-[(trifluoromethylthio)methylthio]propane(7): $M^+ = 322$, (r.t. = 829 min, 0.5%); 221(M-SCF_3, 100%); 147(SCH_2SCF_3 or CH_2SSCF_3);115(CH_2SCF_3); 106(C_3H_6SS); 78(CH_2SS); 73(SC_3H_5) and 69 (CF_3);64(SS), 61(C_2 H_5S);50(CF_2) and 45(CSH)
10. 1-chloromethylthio-3-(trifluoromethylperthiyl)propane (6**A**): $M^+ = 256$, (r.t = 9.53 min, 24.8%); 221(M-SCF_3); 207(M-CH_2Cl);175(207-S); 155(M-SCF_3, 100%); 147(CH_2SSCF_3); 106(C_3H_6SS); 101(SCF_3);95(CS_2F);82(CSF_2); 78(CH_2SS); 73(SC_3H_5);69(CF_3), 64(SS) and 61(C_2H_5S)
11. 2-(trifluoromethylthio)-1,3-dithiane(**1**): $M^+ = 220$(r.t. = 8.05 min, 0.7%); 151(M-CF_3);119 (M-SCF_3, 100%); 105(C_3H_5SS);85; 78(CH_2SS); 73(SC_3H_5); 69(CF_3);59(C_2H_3S) and 45 (CSH, 100%). 146(M-SC_3H_6);119(M-SCF_3' 100%);102(CF_3SH);91(119-C_2H_4);82(CSF_2); 75(C_3H_7S), 69(CF_3); 59(C_2H_3S) and (CSH)
12. Bis-1,3-(chloromethylthio)propane (**8**): $M^+ = 204$(r.t. = 10.37 min, 0.8%);169(M-Cl);155 (169-CH_2); 120(155-Cl);87(C_4H_7S); 73(SC_3H_5); 64(SS), 49(CH_2Cl) and 45(CSH)
13. (Trifluoromethylperthiyl)butylthione (**15**): $M^+ = 234$ (not seen) (r.t. = 3.35) min, 0.9%); 215 (M-F);183(215-S);133 (F_3CSS);69 (CF_3);64 (SS) and 57(C_4H_9, 100%)

3-(trifluoromethylperthiyl)propane (**6A**), was carried out to ascertain its structure. For the comparison of its NMR spectral characteristics and to examine the course of the reaction of **3** with 1,3-dithiane (**2**), (chloromethyl) propyl sulfide and bis-(propylthio)methane were synthesized. The NMR and GC-MS spectral identification of the various compounds and the probable mechanism of their formation are described in this article.

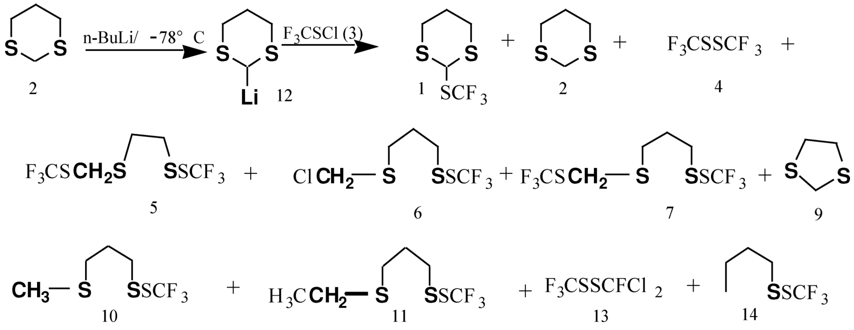


FIGURE 2 Products from the reaction of 2-lithio-1,3 dithiane with F_3CSCl.

RESULTS AND DISCUSSION

Simple *ab initio* calculations on the α-thio carbanions have shown the involvement and participation of the induced polarization.[8a] Later calculations have indicated significant contribution of the d-orbitals to the reactivity of the α-thio carbanions.[8b] The stability of the carbanions derived from dithiane has been examined in detail[9a] and the concept of the back donation of electrons into the vacant d-orbitals has been advanced to account for their observed unusual stability.[9b] The flanking sulfur atoms have been suggested to be responsible for the marked stabilizing effect on the carbanion.[9c]

2-chloro-1,3-dithiane has been prepared via the reaction of 1,3-dithiane (2) with N-chlorosuccinimide[10a] and sulfuryl chhloride,[10b] respectively, and its reactions have led to interesting compounds.[10b] The use of lithio-1,3-dithianes has been discussed in detail.[11] While the reaction of 2-lithio-1,3-ditihane (**12**) with nitriles furnishes carboxylic acid derivatives,[12a] the same reagent with nitrile oxides gives α-diketones.[12b] The reaction of 2-lithio-2-trimethylsilyl-, 2-lithio-2-trimethylstannyl-, and 2-lithio-2-trimethylgermanyl-1,3-dithianes

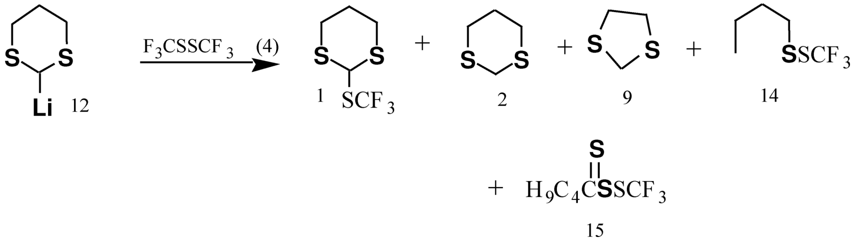


FIGURE 3 Reaction of lithio-dithiane with bis-(trifluoromethyl)disulfide.

with acylchloride has been reported to furnish, in addition to 2-acyl-1,3-dithianes, the thiane ring cleavage prodcuts, namely bis-1,3-dithia-acylpropane.[13] The reaction of 2-alkyl-2-lithio-1,3-dithiane with bis-(methyl)disulfide has been stated to yield 2-alkyl-2-methylthio-1,3-dithaine.[14] The treatment of 2, 2-diaryl-1,3-dithiolanes and -1,3-dithianes with n-BuLi has been observed to induce the cleavage of the heterocyclic ring.[15a] 1,3-dithiolane (**9**) has been employed in the preparation of secondary mercaptans and sulfides.[15b] However, the reaction of the thioketals with n-BuLi at 0°C has been reported to yield thioketones.[15c] Anion-induced gas phase deprotonation has also been described to result in the cleavage of the dithiane system and to form 1-allylthiomethylthiyl anion intermediate.[16] Thus, the facile fission of the ring and the ease of the formation of the products have contributed to the populairty of **2**.

With a view to synthesize 2-trifluoromethylthio-1,3-dithiane (1), dithiane (**2**) was reacted with trifluoromethylthiocopper and found to yield ring cleaavage products **7**, **17**, and **18** along with bis-(trifluoromethyl) disulfide (**4**, Figure 4).[17] In addition to the above, compound 2-methyl-1,3-dithiane (**16**) was also detected. Next, the reaction of dithiane (**2**) with with trifluoromethylsulfenyl chloride (**3**) was examined and the following compounds were characterized by GC-MS analysis: (1) 1,3-dithiane (**2**), (2) 2-(trifluoromethylthio)-1,3-dithiane (**1**), (3) 1,3-dithiolane (**9**), (4) bis-(trifluoromethyl)disulfide (**4**), (5) 1-(trifluoromethylperthiyl)-2-(trilfluoromethyl-thiomethylthio)-ethane (**5**), (6) 1-(trifluoromethylperthiyl)-3-(trifluoromethylthio-methylthio)propane (**7**), (7) 1-(chloromethylthio)-3-(trifluoromethyl-perthiyl)-propane (**6A**) or 1-chloro-1-(trifluoromethylthio)-1,3-dithiane **(6B)**, (8) bis-1,3-(chloromethylthio)propane (**8**), (9) 1-methylthio–3-(trifluoromethylperthiyl)propane (**10**), and (10) 1-ethylthio–3-(trifluoromethylperthiyl) propane (**11**). The major product (92.5%) of the reaction, based on the GC-MS analysis, was found to be either

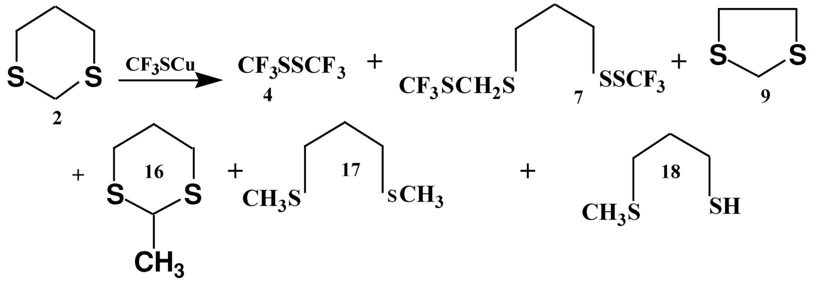


FIGURE 4 Compounds from the reaction of 1,3-dithiane and CF_3SCu.

6A or **6B** with $M^+ = 256$. The reaction mixture was then subjected to vacuum distillation to remove more volatile materials. The residue was then distilled under high vacuum and each fraction was carefully collected at every 2°C rise in the temperature. This furnished a highly pure fraction (95%) according its ^{13}C-NMR spectrum.

A priori, there was no reason to consider **6A** as the primary candidate for this compound. The mass spectral fragmentation, although helpful in arriving at the molecular formula, did not lead to any definitive conclusion about its structure. During the past several years, many innovative modifications of the NMR have been fruitfully employed in deciphering the structure of complex organic molecules. In this context, it is worth mentioning that ^{13}C-NMR spectra have been found to be of considerable help in the study of conformational equilibiria of 1,3-dithiane derivatives.[18] Various polarization transfer NMR techniques such as Insensitive Nuclei Enhancement by Polarization Transfer (INEPT),[19a,b] Distortionless Enhancement by Polarization Transfer (DEPT),[19c] Attached Proton Test (APT),[19d] and two-dimensional ^{13}C—^{1}H polarization J transfer spectroscopy, etc. have been introduced to gain precise information on the structure and stereochemistry of complex organic molecules.

The last one is a modification of the clssical INEPT NMR procedure and permits the application of two-dimensional ^{13}C J spectroscopy to determine long range coupling.[19e] Another modifcation of the INEPT technique, called Insensitive Nuclei Attached Proton Test (INAPT), which makes use of soft pulses, has been stated to furnish useful information.[19e]

The probable mechanism of the formation of compounds **28**, **33**, **35–38** and **46** is given in Figure 10. Encouraged by the reported results of the INAPT techniques, it was considered interesting and useful to apply this technique to examine the structure of **6A** or **6B**. In fact we considered **6B** as our first choice for this compound. This assumption was based on the reported characterization of 9-chloro-9-methyl-9-thiabicyclo[6.1.0]nonane and σ-sulfurane (**48** and **49**, cf. Figure 11).[20] If this assumption was correct, then **6B** should exhibit "through space" ^{13}C- and ^{1}H-interactions and as such should show δ-vales resulting from the interactions between various carbon and hydrogen atoms. These changes should then be observable through the INAPT measurements. If the compound in question possessed the acyclic or linear structure, namely **6A**, then no such interactions should be observed. The INAPT measurements did not show any through-space interactions. This led us to assign structure **6A** to this compound. This inference stands supported by the following evidence: (i) The ^{1}H-chemical shifts of the $C\mathbf{H}_2Cl$ moieties of the **6A** and (chloromethyl)propyl sulfide (**28**, also cf. **6c** and **6d**, Figure 11) are almost identical; (ii) low temperature measurements showed no evidence of conformational isomers at −50°C and hence, no axial and equatorial type resonance "freeze out" was observed; (iii) long-range coupling experiment showed no coupling between carbon at δ 49.3 and protons at δ 2.96 nor any coupling between the protons at δ 4.71 and the carbon at δ 38.0; and (iv) all the couplings observed were found to be consistent with the acyclic structure, namely **6A**. The ^{1}H-chemical shift of S—CH$_2$—S of **2** appears at $\delta = 3.78$ ppm.[21a] Additional NMR support for **6A** compares very well with the reported ^{1}H-chemical shift of $-CH_2Cl$ of (chloromethyl)methyl sulfide ($\delta = 4.71$ ppm).[21b]

Because the reaction of 1,3-dithiane (**2**) in dry pentane at −78°C under dry N_2 with trifluoromethylsulfenyl chloride (**3**) furnished the desired compound, namely 2-(trifluoromethylthio)-1,3-dithiane (**1**), in poor yields, two additional approaches were explored. First, 2-lithio-1,3-dithiane (**12**) was prepared by reacting **2** with n-BuLi at −78°C and then reacted with bis-(trifluoromethyl)disulfide (**4**) sucked in via the vacuum line. The workup of the reaction mixture and the GC-MS analysis showed the presence of three main products: **2** (86.9%); 1,3-dithiolane (**9**), and **1** (8.2%). Second, the lithium-salt (**12**) was directly exposed to **3**, sucked in via the vacuum line at −78°C. The routine processing of the reaction mixture followed by the GC-MS analysis indicated the reaction mixture to consist of 11 components: (1) bis-(trifluoromethyl)disulfide (**4**, $M^+ = 202$, 0.4%), (2) 1,3-dithiolane (**9**, $M^+ = 106$, 2.5%), (3) 1,3-dithiane (**2**, $M^+ = 120$, 0.3%), (4) 1-[(trifluoromtheylthio)methylthio]-2-(trifluoromethylperthiyl)-ethane, (**5**, $M^+ = 308$, 36.2%), (5) 2-(trifluoromethylthio)-1,3-dithiane (**1**, $M^+ = 220$, 10.1%), (6) 1-ethylthio-3-(trifluoro -methylperthiyl)propane (**11**, $M^+ = 236$, 12.7%), (7) 1-[(trifluoromethylthio)methylthio]-3-(trifluoromethylperthiyl)propane (**7**, $M^+ = 322$, 0.5%); (8) 1-(methylthio)-3-(trifluoromethylperthiyl) propane, (**10**, $M^+ = 222$, 0.5%); (9) (dichlorofluoromethyl)(trifluor methyl)disulfide), (**13**, $M^+ = 234$, 0.2%), (10) butyl (trifluoromethyl)disulfide (**14**, $M^+ = 190$, 3.2%) and 1-(chloromethylthio)-1-3-(trifluoromethylperthiyl)propane (**6**, M^+-256, 0.4%).

Figure 1 describes the products formed from the reaction of **2** with **3**. Bis-(tri-fluoromethyl)disulfide (**4**) arises from the dimerization of the $F_3CS^{\cdot}$-radical (cf. Eq. (2) Figure 5) while **2** is the substrate itself. The origin of the ring contraction product, namely 1,3-dithiolane (**9**), has been rationalized.[17] The reaction of $F_3CS^{\cdot}$-radical with 1,3-dithiolane (**9**) gives intermediate **20**, which goes on to react with $F_3CS^{\cdot}$ to form compound **5**. The attack by the chloromethyl radical (cf. Eq. (7) Figure 5) on **2** results in the intermediate **21**, which joins up with $Cl^{\cdot}$ to give compound **8**. The abstraction of hydrogen from the C_2-position by $Cl^{\cdot}$ leads to **22**, which then reacts with $F_3CS^{\cdot}$ and furnishes 2-(trifluoromethylthio)-1,3-dithiane (**1**). If, on the other hand, $F_3CS^{\cdot}$ attacks the sulfur atom

$$F_3CSCl \rightleftharpoons F_3C\dot{S} + \dot{Cl} \qquad \text{Eq.(1)}$$

$$F_3C\dot{S} + \dot{S}CF_3 \longrightarrow F_3CSSCF_3\ (4) \qquad \text{Eq.(2)}$$

$$F_3CSSCF_3\ (13) \rightleftharpoons F_3CS\dot{S} + \dot{C}F_3 \qquad \text{Eq.(3)}$$

$$F_3CSCl \rightleftharpoons ClF_2C\dot{S} + \dot{F} \qquad \text{Eq.(4)}$$

$$ClF_2C\dot{S} + \dot{Cl} \longrightarrow Cl_2FC\dot{S} + \dot{F} \qquad \text{Eq.(5)}$$

$$Cl_2FC\dot{S} + F_3C\dot{S} \longrightarrow Cl_2FCSSCF_3\ (13) \qquad \text{Eq.(6)}$$

$$:CH_2 + \dot{Cl} \longrightarrow \dot{C}H_2Cl \qquad \text{Eq.(7)}$$

$$CH_3CH_2CH_2CH_2Li \rightleftharpoons CH_3CH_2CH_2\dot{C}H_2 + \dot{Li} \qquad \text{Eq.(8)}$$

$$CH_3CH_2CH_2\dot{C}H_2 + \dot{S}SCF_3 \longrightarrow CH_3CH_2CH_2CH_2SSCF_3(14) \qquad \text{Eq.(9)}$$

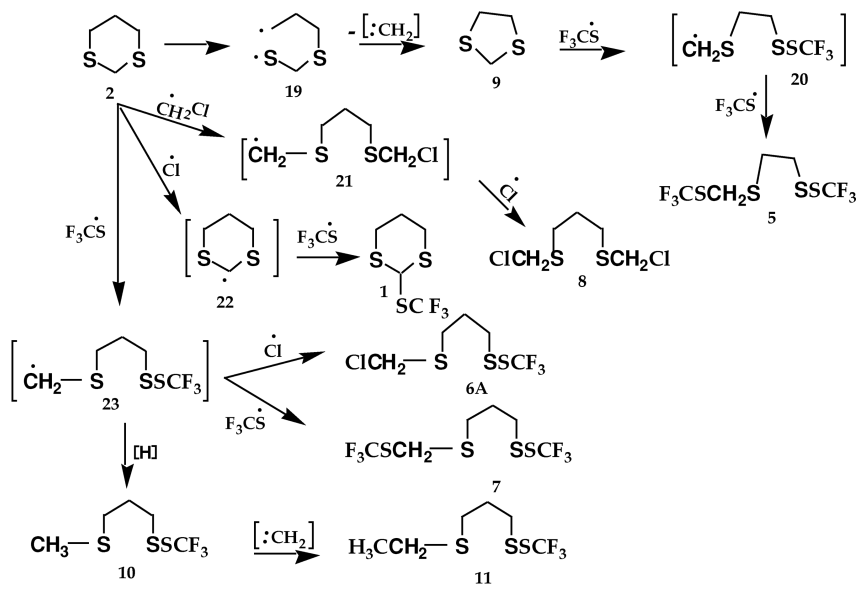


FIGURE 5 Mechanism of formation of compounds cited in Figures 1 and 2.

of **2**, then that would give intermediate **23**, which has three options open to it. First, it can simply react with Cl· to yield the primary product of the reaction, namely **6A**. Second, it can react with $F_3CS^{\cdot}$ to form compound **7**. Third, it can simply abstract hydrogen from the solvent to give 1-methylthio-3-(trifluoromethylperthiyl)propane (**10**). The methyelene insertion between the C—S bond of **10** gives 1-(ethylthio)-3-(trifluoromethylperthiyl)propane (**11**). All of the previously mentioned compounds have been characterized by their mass spectra (Table I).

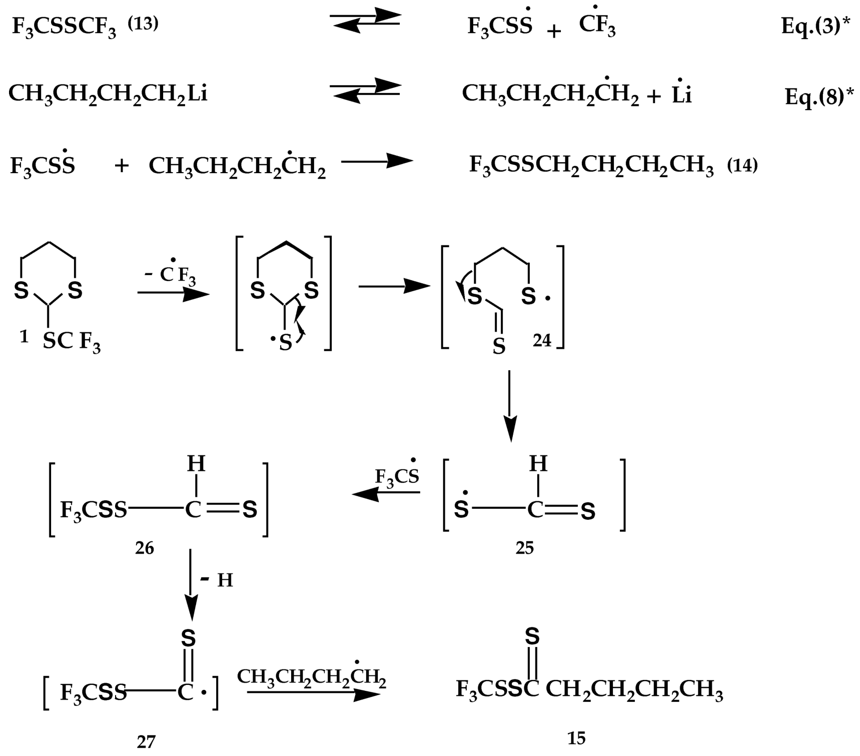
It was surprising to see a similar distribution pattern of products arising from the reaction of 2-lithio-1,3-dithiane (**12**) with

3. It is interesting to note that two more compounds, namely (dichlorofluoromethyl)(trifluoromethyl)disulfide (**13**) and butyl (trifluoromethyl)disulfide (**14**), are formed in this reaction. The formation of **13** from **3** has been previously described,[6d] while Eqn. 9 (Figure 5) explains the formation of compound **14**.

In view of the reported facile formation of 2-methyl-1,3-dithiane (**16**) from the reaction of 2-lithio-1,3-dithiane (**12**) with dimethyl disulfide,[22] it was hoped that the reaction of **12** with **4** would lead to satisfactory yields of **1**. Accordingly, the reaction was carried out and the partial results thus obtained from this reaction are shown in Figure 3. Three more compounds present in the reaction product could not be identified as they undergo extensive degradation in the mass spectrometer without recording their M^+-ion peaks. However their partial mass spectra show the presence of the $C_4H_9$and F_3CS groups. The formation of compound **14** has already been discussed. The source of the butyl moiety is the butyl lithium used to generate the lithio-derivative (**12**) of **2**. Figure 6 attempts to explain the probable mechanism of the formation of compounds **14** and **15**. Compound **14** is also formed in the reaction of **12** with **3** (cf. Figure 2). Compound **16** owes its origin to compound **1** and its formation appears to be somewhat much more involved. Loss of the $F_3C^{\cdot}$-radical from **1** gives the sulfur radical intermediate (cf. Figure 6), which undergoes the thiane ring cleavage to form intermediate **24** and fragments off the C_3H_6S moiety to furnish radical 25, which in turn reacts with $F_3CS^{\cdot}$ to give intermediate **26**. The latter splits off hydrogen to form **27**, which joins up with the $^{\cdot}C_4H_9$ radical to give **15**.

While preparing (chloromethyl)propyl sulfide (**28**), bis-(propylthio) methane (**29**) was formed as a major product, about 66.0% (cf. Figure 7). A couple of vacuum distillation gave a highly pure product by G.C., which was found by GC-MS to be more than 99.0% pure. It was considered interesting to examine whether its reaction with **3** would lead to compounds containing the 'trifluoroperthiyl' ($F_3CSS^{\cdot}$) moiety. Accordingly the reaction was conducted under similar conditions as used in the reaction of **2** with **3** except that anhydrous diethyl ether was used as a solvent, instead of pentane. The GC-MS analysis of the reaction mixture showed the presence of 8 compounds including the substrate (Figure 8): (1) (chloromethyl)propyl sulfide (**28**), (2) bis-(propylthio)methane (**29**), (3) bis-(propyl)disulfide (**33**), (4) (2-chloroethyl) ethyl ether (**35**), (5) [(propylthio)methyl](trifluoromethyl)disulfide (**36**), (6) (dichlorofluoromethyl)(trifluoromethyl)disulfide (**13**), (7) (propyl)(trifluoromethyl) disulfide (**37**), and (8) (chloromethyl)(propenyl)disulfide (**38**).

Figure 9 explains the formation of 7 compounds formed during the preparation of bis-(propylthio)methane (**29**). To begin with, (chloromethyl)propyl sulfide (**28**) undergoes free radical dissociation to



* cf. Fig. 5

FIGURE 6 Formation of products from reaction of lithio-dithiane with F_3CSSCF_3.

form three pairs of radicals: (i) propyl and chloromethylthiyl, (ii) propylthiyl and chloromethyl, and (iii) propylthiomethyl and chlorine radicals. The combination of propylthiomethyl and propylthiyl would result in bis-(propylthiyl)methane (**29**). When propylthiyl radical dimerizes, it yields bis-(propyl)disilfide (**33**). When it simply abstracts hydrogen, it forms propyl mercaptol (**30**). This can also arise from the hydrolysis of

$$\underset{28}{{}^{*}C_3H_7SCH_2Cl} \xrightarrow{C_3H_7SNa} \underset{28}{C_3H_7SCH_2Cl} + \underset{29}{C_3H_7SCH_2S\,C_3H_7} + \underset{30}{C_3H_7SH} + \underset{31}{C_4H_9SH}$$

$$+ \underset{32}{C_4H_9SCH_3} + \underset{33}{C_3H_7SS\,C_3H_7} + \underset{34}{C_4H_9SCH_2S\,C_3H_7}$$

$^{*}C_3H_7$= n-propyl

FIGURE 7 Preparation of bis-(propylthio) methane.

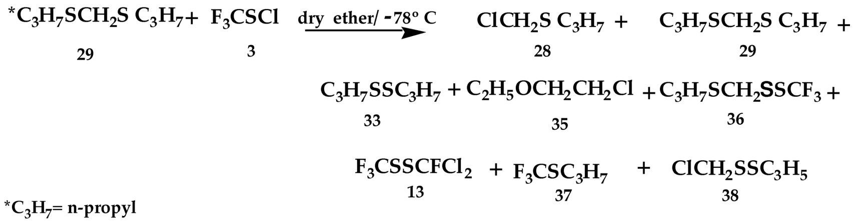


FIGURE 8 Products from the reaction of bis-(propylthio)methane with F_3CSCI.

the sodium salt of propyl mercaptol (**30**) used as reagent in the reaction. Abstraction of hydrogen by a Cl$\cdot$ radical from **29** leads to intermediate **39**, which can also be formed by the abstraction of the α-hydrogen, followed by successive hydrogen migrations to form **39**. Whether the initial abstraction of hydrogen occurs at the α-methylene moiety of **29** or γ-methylene group cannot be definitely stated. In this context it has been said that the "consideration of the acidity of α-hydrogens does not, however, explain the directive effects in the chlorination of aikyl sulfides.[23a] In addition, "internal competition of hydrogen abstraction"

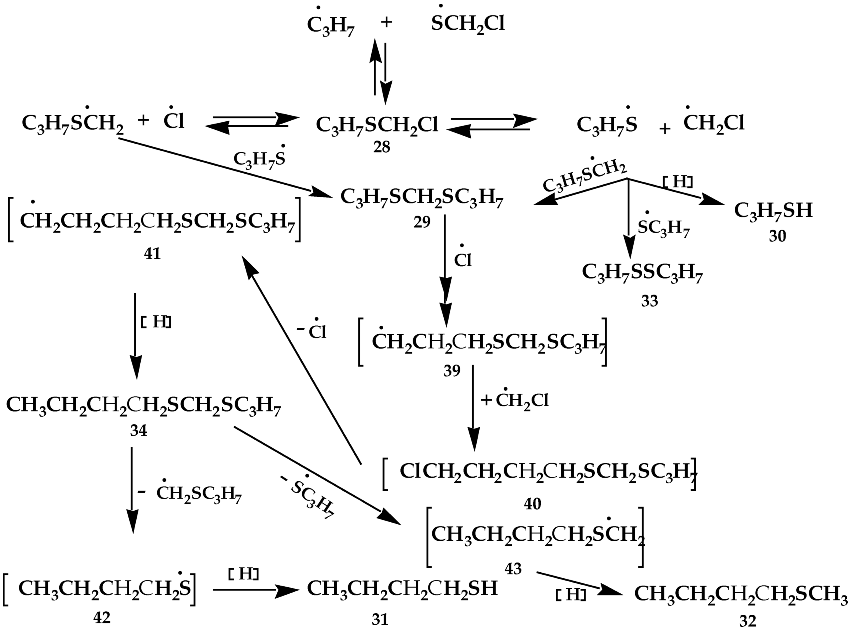


FIGURE 9 Compounds from the reaction of $H_7C_3SCH_2SC_3H_7$ with F_3CSCIl.

may be playing some part in the chlorination of unsymmetrical alkyl sulfides.[23b] As stated earlier, it is also possible that the initially formed radical may undergo successive hydrogen migrations before forming the final product.

The intermediate **39**, on reacting with $\cdot CH_2Cl$, forms (4-chloro butylthio)(propylthio)methane (**40**), which fragments off $Cl\cdot$ and gives intermediate **41**. This intermediate simply abstracts hydrogen to furnish (butylthio)(propylthio)methane (**34**). This has two options open to it. First, **34** splits off (propylthio)methyl moiety and forms butylthiyl radical (**42**), which goes on to abstract hydrogen and to yield butyl mercaptol (**31**). Second, **34** can fragment off the propylthio entity to generate intermediate **43**, which after abstraction of hydrogen gives butyl methyl sulfide (**32**). The GC-MS identification of the compounds previously described lends credence to the proposed mechanism (cf. Table II).

Figure 10 endeavors to rationalize the formation of the compounds formed during the reaction of bis-(propylthio)methane (**29**) with F_3CSCl (**3**) (cf. **Figure** 8). Bis-(propylyhio)methane (**29**) undergoes free radical fragmentation to $H_7C_3S\dot{C}H_2$ and $\dot{S}C_3H_7$ radicals. The latter reacts with $F_3C\dot{S}$, which is itself formed from the free radical dissociation of F_3CSCl (**3**) and gives (propyl)(trifluoromethyl) disulfide (**44**), which extrudes sulfur to form (propyl)(trifluoromethyl)sulfide (**37**), while $H_7C_3S\dot{C}H_2$radical has two options available to it. Firsty, it can react with $Cl\cdot$ to give (chloromethyl)propyl)sulfide (**28**). Second, the (propylthio)methyl radical can react with tirlluoroperthiyl ($F_3CSS\cdot$) [cf. **Eq(3)**] to form (propylthio)-(trifluoromethylperthiyl)methane (**36**). That (chloromethyl)propyl sulfide (**28**) is a product of the reaction was confirmed by its absence in the substrate (**29**) via GC-MS analysis.

Compound **28** dissociates to generate the propylthiyl radical and chloromethyl radicals, respectively. The propylthiyl radical simply dimerizes to form the di-sulfide (**33**). Bis-(propyl)disilfide (**33**) again has two options open to it. First, it can slit off a propyl radical to form propylperthiyl radical (**47**), which joins up with $\dot{C}H_2Cl$ and gives (chloromethyl)(propyl)disulfide (**38**). Second, **33** can undergo hydrogen abstraction by $Cl\cdot$ to form intermediate **45**, which after losing hydrogen, forms (propenyl)(propyl) disulfide (**46**). Finally, it remains to explain the origin of (chloroethyl) ethyl ether (**35**). The primary source for this compound is the solvent, diethyl ether, used in this reaction. Two possible pathways from diethyl ether to **35** are shown in **Eq. (7)** (**Figure 10**). The first one envisages the abstraction of hydrogen α to the oxygen to give a radical intermediate, which undergoes hydrogen migration to form the β-radical, which in turn links up with a $Cl\cdot$ radical to give compound

TABLE II Mass Spectral Fragmentation of Compounds Cited in Figures 7 and 8

1. Propylmercaptol (30): $M^+ = 76$ (r.t. = 0.33 min, 0.1%); 75 (M-H); 73 (75-2H); 70 (C_2H_4S); 61 (SC_2H_5); 58 (SC_2H_2); 48 (CH_4S); 47 (CH_3S, 100%), 46 (CSH_2) and 45 (CSH)
2. Butyl mercaptol (31); $M^+ = 90$ (r.t. = 0.42 min, 0.7%); 75 (M-CH_3); 62 (M-C_2H_4); 61 (M-SC_2H_5, 100%); 59 (SC_2H_3); 57 (C_4H_9); 48 (CH_4S); 47 (SCH_3); 46 (CSH_2) and 45(CSH)
3. Butyl methyl sulfide (32); $M^+ = 104$ (r.t. = 1.06 min, 0.1%); 90(M-CH_2); 75 (M-C_2H_5); 71 (86-CH_3); 63 (C_2H_7S); 61 (SC_2H_5); 60 (C_2H_4S); 59 (SC_2H_3); 58 (C_4H_{10}); 57 (C_4H_9); 48 (CSH_4); 47 (SCH_3 100%); 46 (SCH_2) and 45 (CSH)
4. (Chloromethyl) propyl sulfide (28): $M^+ = 124$ (r.t. = 1.55 min, 326%); 95(M-C_2H_5); 89 (M-C1, 100%); 82 (M-C_3H_5); 75 (89-CH_2);73 (C_3H_5S); 61 (SC_2H_5); 59 (SC_2H_3); 49 (CH_2Cl); and 45 (CSH)
5. Bis-(propyl)disulfide (33):$M^+ = 150$ (100%); (r.t. = 3.41 min, 0.3%); 108 (M-C_3H_6); 79(108-C_2H_5); 73 (C_3H_5S);66 (H_2S_2);64 (SS); 59(C_2H_3S); 47 (SCH_3) and 45 (CSH)
6. Bis-(prpopylthio)methane (29); $M^+ = 164$: (r.t. = 5.46 min, 66.2%), 122 (M-C_3H_6); 117 (M-SCH_3); 89 (M-SC_3H_7, 100%); 79 (CH_3S_2); 76 (CS_2 or C_3H_7SH); 61 (SC_2H_5); 55 (C_4H_7); 49 (C_2H_3S); 47 (SCH_3,) and 45 (CSH)
7. (Butylthio)(propylthio)methane (**34**):$M^+ = 178$; (r.t. = 7.27 min, 0.1%);136 (M-C_3H_6); 103 (M-SC_3H_7);94 (136-C_3H_6); 89(C_4H_9S);74 (89- CH_3);61 (SC_2H_5, 100%); 47 (SCH_3,); and 45 (CSH)
8. $C_2H_5OCH_2CH_2Cl$(35): $M^+ = 108$;r.t. = 0.3 min, 0.4%); 93 (M-CH_3); 79(M- C_2H_5);63 (CH_2CH_2Cl); 59($C_2H_5OCH_2$, 100%); and 49 (CH_2Cl)
9. (Dichlorofluoromethyl)(trifluoromethyl)disulfide (**13**); $M^+ = 234$; r.t. = 1.20 min, 6.2%)
10. (Trifluoromethyl) propyl sulfide (37) : $M^+ = 176$; r.t. = 2.06 min, 48.6%) ; 157 (M-F); 147 (M-C_2H_5); 133 (F_3CSS or M-C_3H_7); 114 (133-F); 101 (F_3CS); 82 (CSF_2); 78 (C_2H_3SF); 75(SC_3; 69 (CF_3, 100%); 64 (CHSF); 50(CF_2) and 45 (CSH)
11. (Chloromethyl) propenyl disulfide (38): $M^+ = 156$; r.t. = 2.59 min, 0.4%); 119 (M-Cl); 95 (C_2H_4ClS); 89 (C_2HS_2);81 (CSCl), 79 ($C_2H_2S_2$, 100%); 73 (C_3H_5S); 61 (C_2H_5S); 49 (CH_2Cl) and 46 (CSH_2)
12. [(Propylthio) methyl](trifluoromethyl)disulfide (36): M+ = 222; r.t. = 3.10 min, 1.1%; 193 (M-C_2H_5); 153 (M-CF_3); 89 ($C_3H_7SCH_2$, 100%); 73 (C_3H_5S); 69 (CF_3); 61(C_2H_5S) and 47 (SCH_3)

35. The formation of such a free radical α to oxygen of the ethers has previously been suggested.[24] An alternate possibility involves the free radical cleavage of ether into ethyl and ethoxy radicals. The latter would then react with a chlormethyl radical to yield chloromethyl ethyl ether as an intermediate, which undergoes methylene insertion between C—Cl to form **35**. There is precedence for the suggested methyelene insertion.[25] That this compound is (2-chloroethyl) ethyl ether (**35**) is confirmed by the presence of the molecular ion, the chlorine isotope peaks and the ion m/e = 49 (CH_2Cl) in its mass spectrum (cf. Table II).

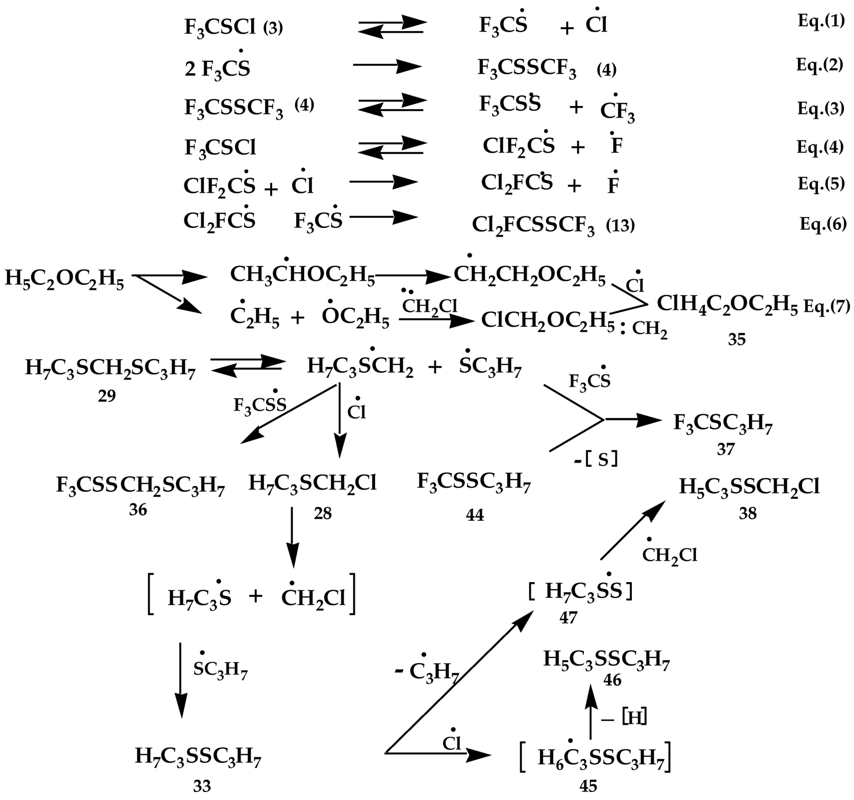


FIGURE 10 Compounds from the reaction of $H_7C_3SCH_2SC_3H_7$ with F_3CSCl.

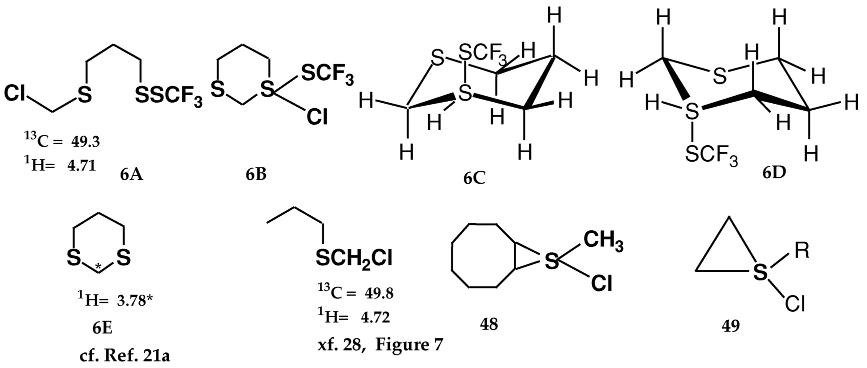


FIGURE 11 Structure of the primary product of the reaction of dithiane with F_3CSCl.

The results described in Figures. 1, 2, 3, and 4 clearly demonstrate the cleavage of the heterocyclic ring system of 1,3-dithiane (**2**) under mild experimental conditions. It should be stated here that there are not too many examples of the cleavage of the 1,3-dithiane ring system.[13,15,24] Although the reaction of 1,3-dithiane with $SOCl_2$ leaves intact the ring system, its reaction with SO_2Cl_2 has been reported to give an acyclic product.[24] The reaction of 2,2-disubstituted-1,3-dithiolane with Py-$(HF)_x$ in the presence of dibromodimethylhydantoin has been reported to cleave the dithialane ring and to yield ethyl 1,2-sulfenyl dibromide and difluoroalkanes.[25] The reaction has been suggested to proceed via the initial attack on sulfur, followed by the cleavage of the dithiolane ring.

The mass spectra of sulfides show interesting behavior. For example, the molecular ion of di-i-propyl sulfide has been described to form dimeric species with its own precursor[26] and the formation of a two-center three-electron S—S bond.[26] The loss of the CH_3, SH, CH_2S, CH_3S, and C_3H_7S moieties from the molecular ion was seen in the mass spectral breakdown of 1,3-dithiane. The expulsion of these entities involves a variety of cleavages and hydrogen migrations. A detailed examination of the mass spectral breakdown of 1,3-dithiane using labeled substrates has appeared.[26] FAB and CI-induced as well as collision-induced dissociation of dithiane fragmentation has also been investigated.[14] The mass spectral breakdown behavior of 1,3-dithiane (**2**) and 2-methyl-1,3-dithiane (**16**) has been investigated with deuterium labeling in various positions.[26] 1,3-dithiane on ionic impact produces ions with m/e = 105, 87, 74, 55, 46 and 45. On the other hand, 2-methyl-1,3-dithiane (**16**) furnishes peaks at m/e = 119, 105, 87, 74 and 60, corresponding to the loss of the CH_3, C_2H_5, SCH_3, C_2H_4S and C_3H_6S moieties respectively. Also observed is the loss of S_2H and SH fragments.

The most prominent peak (m/e = 155) in the mass spectrum of 6A arises from the loss of the SCF_3-fragment ($M—SCF_3$). The presence of chlorine in the molecule can be inferred by the presence of the chlorine isotope peaks with intensities in proportion to their natural abundance. This was seen in all compounds containing chlorine. Other interesting peaks occurred at m/e = 106, 95, 82 (CSF_2), 73, 69 (CF_3); 64 (SS), 61 (C_2H_5S), and 45 (CSH). The mass spectral breakdown of bis(trifluoromethyl)disulfide (4) and (dichlorofluoromethyl)(trifluoromethyl)disulfide has been previously discussed.[4a,6d] The mass spectral fragmentation of the compounds cited in the narrative is described in Tables I and II.

Experimental

Mass spectra were obtained using a Finnigan TSQ-7000 GC/MS/MS equipped with a 30 m × 0.25 mm. i.d. DB-5 capillary column (J and W Scientific, Folsom, CA) or a Finnigan 5100 GC/MS equipped with a 15 m × 0.25 mm. i.d. Rtx-5 capillary column (Restek, Bellefonte, PA). The conditions on 5100 were as follows oven temperature, 60–270° C at 10°C/min; injection temperature, 210°C, interface temperature 230°C; electron energy 70 eV; emission current, 500 μ A; and scan time, 1 s. The conditions on the TSQ-7000 were as follows: oven temperature, 60–270°C at 15°C/min, injection temperature, 220°C, interface temperature, 250°C; source temperature, 150°C, electron energy, 70 eV (EI) or 200 eV (CI); emission current, 400 μA (EI) or 300 μA (CI); and scan time, 0.7 s. Data was obtained in both the electron ionization mode (range 45–450 da) and chemical ionization mode (mass range 60–450 da). Ultrahigh-purity methane was used as the CI agent gas with a source pressure of 0.5 Torr (5100) or 4 Torr (TSQ-7100). Routine GC analyses were accomplished with a Hewlett-Packard 5890A gas chromatograph equipped with a J and W Scientific 30 m × 0.53 mm i.d. DB-5 column (J and W Scientific, Folsom, CA). NMR spectra (^{13}C and ^{19}F) were recorded in $CDCl_3$ on a Varian VXR spectrometer at 100 MHz and 376 MHz, respectively. The external reference for ^{19}F spectra was $CFCl_3$.

Reaction of 1,3-dithiane (2) with trifluoromethylsulfenyl chloride (3)

A stirred solution of 1,3-dithiane (**2**) in dry pentane was treated at −78°C under argon with stoichiometric amounts of trifluoromethylsuflenyl chloride (**3**) sucked in through the vacuum line. The reaction mixture was stirred for 2 h at −78°C. The usual processing of the reaction mixture gave a colorless homogeneous liquid. Because its gas chromatograhic analysis showed the presence of a complex mixture of several components, it was analyzed via GC-MS and found to contain the following compounds: (1) 1,3-dithiane (**2**), (2) 2-(trifluoromethylthio)-1,3-dithiane (**1**), (3) 1,3-dithiolane (**9**), (4) bis(trifluoromethyl)disulfide (**4**), (5) 1-(trifluoromethylperthiyl)-2-(trifluoromethylthiomethylthio)ethane (**5**), (6) 1-(trifluoromethylperthiyl)-3-(trifluoromethylthiomethylthio)propane (**7**), (7) 1-(chloromethylthio) 3-(trifluoromethylperthiyl)propane (**6A**) or 1-chloro-1-(tri-fluoromethylthio)-1,3-dithiane (**6B**), (8) bis-1,3-chloromethylthio)propane (**8**), (9) 1-methylthio-3-(trifluoromethylperthiyl)propane (**10**), and (10) 1-ethylthio-3-(trifluoromethylperthiyl)propane (**11**). The major product (92.5%) of the reaction based on the GC-MS analysis was found to be **6A** with $M^+ = 256$. The reaction mixture was then subjected to vacuum distillation to remove volatile materials. The residue was then distilled under high vacuum and each fraction was carefully collected at every 2°C rise in the temperature. This furnished a highly pure fraction (96% according to NMR): δ-values of **6A**: ^{13}C—NMR: S**C**F_3 [129.3; (J_{CF} = 314 Hz); —**C**H_2SSCF_3 (38.0); —SCH_2**C**H_2—(27.3); —S**C**$H_2CH_2CH_2SSCF_3$ (29.8); and S**C**H_2Cl (49.3). ^{1}H: -C**H**$_2SSCF_3$(2.96) [t, J_{HH} = 7.0 Hz, J_{HF} = < 0.6 Hz]; -SCH_2 C**H**$_2CH_2$— [2.07 (m, 2H)]; —SC**H**$_2CH_2CH_2SS$**C**F_3 [2.84 (t, J_{HH} = 7.2 Hz) and —SC**H**$_2Cl$ (s, 4.71).

Reaction of 2-lithio-1,3-dithiane (12) with trifluoromethylsulfenyl chloride (3)

To a suspension of 1,3-dithiane (**2**, 1.2 g, 0.0l mole) in freshly distilled dry tetrahydrofurane (15 mL) cooled to −78°C, a solution of n-BuLi in pentane (6.8 mL, 2M) under nitrogen was added dropwise over 30 min and the mixture was stirred for 2 h at −78°C. To this cold solution, was added stoichiometric amounts of trifluoromethylsulfenyl chloride (**3**) sucked in through the vacuum lime. The whole was stirred for 2 h at −78°C. It was allowed to come to an ambient temperature. After the routine processing of the reaction mixture and its GC-MS analyis, the presence of the following compounds was detected: (1) 1,3-dithiane (**2**), (2) 1,3-dithiolane (**9**), (3) bis-(trifluoromethyl)disulfide (**4**), (4) 2-(trifluoromethylthio)-1,3-dithiane (**1**), (5) 1-ethylthio-3-trifluoromethylperthiyl)-propane (**11**), (6) 1-methythio-3-trifluoromethylperthiyl)propane (**10**), and (7) 1-(chloromethylthio)-3-trifluoromethylperthiyl)propane (**6A**) (Figure 2).

Synthesis of (Chloromethyl) Propyl Sulfide (28, Figure 7)

Dry hydrogen chloride gas was bubbled through a solution of propyl mercaptol and paraformaldehyde in dry methylene chloride at −78°C until all the paraformaldehyde got dissolved. The reaction mixture was stirred for an additional hour and left aside for 24 h. The organic layer separated, and the usual processing of the reaction mixture and evaporation of the solvent furnished the desired product (**28**, 32.00 %)[29] and bis-(propylthio)methane (**29**, 66.00%). A gas chromatographically homogeneous sample of **28** was obtained after two vacuum distillations. It gave the following NMR-data: ^{13}C-NMR: **C**H_3 (13.3), **C**H_2 (21.9), **C**H_2(33.6) and CH_2Cl (49.8), and ^{1}H-NMR: C**H**$_3$ (1.00), C**H**$_2$ (1.66), C**H**$_2$ (2.31), and C**H**$_2Cl$ (4.72).

Preparation of bis-(propylthio)methane (29)

Stoichiometric amounts of the sodium salt of propyl mercaptol reacted with (chloromethyl)propyl sulfide (**28**) in a mixture of i–propanol and benzene (1:3) at r.t. for 2 h with stirring under nitrogen, then refluxed for 2 h and stirred over night at ambient temperature. The reaction mixture was treated with cold water and extracted with benzene. The organic layer was washed with water, followed by saturated solution of brine dried over anhydrous sodium sulfate and the solvent evaporated under reduced pressure. The GC analysis of the residue showed it to consist of at least seven components. However, its GC-MS analysis permitted the identification of the following compounds: (1) (chloromethyl) propyl sulfide (**28**; (32.3%), (2) bis-(propylthio)methane (**29**, 66.2%), (3) propylmercaptol (**30**, 0.1%), (4) butylmercaptol (**31**, 0.2%), (5) butyl methyl sulfide (**32**, 0.1%), (6) butyl disulfide (0.**2**%), (7) (buylthio) (propylthio)sulfide (0.2%), (8) bis-(propyl)sulfide (03%) and bis-(chloromethylthio)methane (0.1%). After several vacuum distillations, a highly purified sample of bis-(propylthio)methane (**29**) was obtained (> 98%) and used in the reaction with F_3CSCl. The NMR δ-values are ^1H: $SC\mathbf{H}_2S$ (s, 3.81), $-C\mathbf{H}_2S$ (2.76) and $CH_2{-}C\mathbf{H}_2S$ (1.97) and $C\mathbf{H}_3{-}CH_2S$ (1.16). ^{13}C: $S\mathbf{C}H_2S$ (38. 4), $-\mathbf{C}H_2S$ (35.6), and $-\mathbf{C}H_2{-}CH_2S$ (25.5) and $\mathbf{C}H_3{-}CH_2S$ (16.5).

Reaction of bis-(propylthio)methane (29) with trifluoromethylsulfenyl chloride (3)

To a soltuion of bis-(propylthio)methane (**29**) in freshly distilled dry anhydrous ether (20 mL) contained in a three-necked flask carrying a reflux condenser, dry-ice attachment, and nitrogen outlet and cooled to −78°C was added stoichiometric amounts of trifluoromethylsulfenyl chloride (**3**) sucked in via the vacuum lime. The whole was stirred for 4 h at −78°C. It was allowed to come to ambient temperature. The routine processing of the reaction mixture, and its GC-MS analyis, led to the identification of the following compounds: (1) (chloromethyl) propyl sulfide (**28**), (2) bis-(propylthio)methane (**29**), (3) bis-(propyl)disulfide (**33**), (4) (2-chloroethyl) ethyl ether (**35**), (5) (propylthiomethyl)- (trifluoro-methyl)disulfide (**36**), (6) (dichlorofluoro methyl)(trifluoromethyl)-disulfide (**13**), (7) prpopyl (trifluoromethyl) sulfide (**37**), and (8) (chloromethyl)-propenyldisulfide (**38**, cf. Figure 8).

REFERENCES

[1] D. Seebach and E. J. Corey, *J. Org. Chem.*, **40,** 231 (1975) and references. cited therein.

[2] (a) B. T. Grobel and D. Seebach, *Synthesis*, (1977) 357, (b) L. Field, *Synthesis* 101 (1972); (c) Comprehensive Heterocyclic Chemistry, Vol. 3, ch. 2.26; A. Katritzky and C.W. Rees (Eds.), (Pergamon Press, New York 1984), pp. 943–994; (d) P. C. Bulman Page, M. B. van Niel, and P. C. Prodger, *Tetrahedron*, **45,** 7643 (1989); (e) L. F. Tietze, B. Weiga, and C. Wulff, *Synthesis*, 69 (2000).

[3] (a) K. Fuji, M. Ueda, K. Sumi, and E. Fujita, *J. Org. Chem.*, **50,** 662 (1985); (b) K. Fuji, M. Ueda, K. Sumi, K. Kajiwara, E. Fujita, T. Iwashi, and T. Miura, *J. Org. Chem.*, **50,** 657(1985).

[4] (a) S. Munavalli, D. I. Rossman, J. W. King, L. L. Szafraniec, W. T. Beaudry and C. P. Ferguson, Proc. ERDEC Scientific Conf. on Chemical Defense, 1993; (b) S. Munavalli, D. I. Rossman, D. K. Rohrbaugh, C. P. Ferguson, and L. C. Buettner, *J. Fluorine Chem.*, **65,** 15 (1993).

[5] (a) R. Filler and Y. Kobayashi (Eds.), Biomedicinal Aspects of Fluorine Chemistry, (Kodash/Elsevier, New York 1982); (b) W. C. Randall, P. S. Anderson, E. A. Cresson, C. A. Hunt, T. F. Lyon, K. Hoogsteen, M. Williams, E. A. Risley and J. A. Totaro, *J. Med. Chem.*, **22,** 1222 (1979) and references cited there; (c) E. A. Nodiff, S. Lipschutz, and M. Gordon, *J. Org. Chem.*, **25,** 60 (1960); (d) J-P. Belgue and D. Bonnet-Delpon, *Tetrahedron*, **47,** 3207 (1991); (e) D. J. Burton and Z-Y. Yang, *Tetrahedron*, **48,** 189 (1992); (f) G. A. McClinton, Tetrahedron, **48,** 6555 (1992).

[6] (a) S. Munavalli, D. I. Rossman, D. K. Rohrbaugh, C. P. Ferguson and L. J. Szafraniec, *J. Fluorine Chem.*, **59,** 91 1992; (b) S. Munavalli, D. I. Rossman, D. K. Rohrbaugh, and H. D. Durst, *J. Organometal. Chem.*, **587,** 160 (1999); (c) S. Munavalli, A. Hassner, D. I. Rossman, S. Singh, D. K. Rohrbaugh, and C.P. Ferguson, J. Fluorine Chem.,**73,** 7 (1995); (d) S. Munavalli, D. I. Rossman, D. K. Rohrbaugh, C.P. Ferguson, and H. D. Durst, *J. Fluorine Chem.*, **76,** 7 (1996); (e) S. Munavalli, D.K. Rohrbaugh, D. I. Rossman, and H. D. Durst, *J. Flourine Chem.*, **89,** 189 (1998); (f) S. Munavalli, G. W. Wagner, A. Bashir-Hashemi, D. K. Rohrbaugh and H. D. Durst, *Synthetic Comm.*, **27,** 2847 (1997); (g) S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, W. G. Wagner, and H.D. Durst, *Phosphorus, Sulfur, and Silicon*, **177,** 1021 (2002); (h) S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, W. G. Wagner, and H. D. Durst, **177,** 1073 (2002); (i) S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, H. D. Durst and A. Dondoni, **177,** 2465 (2002); (j) S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, W. G. Wagner, and H. D. Durst, *Phosphorus, Sulfur and Silicon*, **107,** 1073 (2003); (k). S. Munavalli, D. K. Rohrbaugh, H. D. Durst, and D. I. Rossman, in Recent Developments in Organometallic Chemistry, Vol. 5, (2003), pp 15; (l) S. Munavalli, D. K. Rohrbaugh, W.G. Wagner H.D. Durst, and F.R. Longo, *Phosphorus, Sulfur and Silicon*, **179,** 1635 (2004); (m) S. Munavalli, D.K. Rohrbaugh, D. I. Rossman, F. J. Berg, and H. D. Durst, *Phosphorus, Sulfur and Silicon*, **179,** 1645 (2004); (n) S. Munavalli, D. K. Rohrbaugh, and H. D. Durst, *Phosphorus, Sulfur, and Silicon*, **179,** 1657 (2004).

[7] S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, F. J. Berg, G. W. Wagner, and H. D. Durst, *Synthetic Comm.*, **30,** 2847 (2000).

[8] (a) A. Streitwieser and S. P. Ewing, *J. Am. Chem. Soc.*, **97,** 190 (1975), (b) S. Wolfe, S. Stowlow, and L. A. LaJohn, *Tetrahedron Lett.*, **24,** 4071 (1983) and references cited therein.

[9] (a) J.-M. Lehn and G. Wipff, *J. Am. Chem. Soc.*, **98,** 7498 (1976); (b) A. Krief, *Tetrahedron* **36,** 2531 (1980); (c) E. Block, in Reactions of Organosulfur Compounds, (Academic Press, New York, 1978), pp. 42.

[10] (a) K. Arai and K. Oki, *Bull. Chem. Soc.* (*Japan*), **49,** 553 (1976); (b) C.G. Kruse, N. L. J. M. Broekhof, A. Wijaman and A. van der Gen, *Tetrahedron Lett.*, 885 (1977).

[11] (a) W. D. Wessner, *Chem. Lett.*, 43 (1976); (b) D. Seebach, *Angew. Chem. Int. Ed.*, **18,** 239 (1979); (c) A. Katritzsky and C. W. Rees, Comprehensive Heterocyclic Chemistry, Vol. 3, (Pergamon Press, New York 1984), pp. 943.

[12] (a) P. C. Bullman Page, M. B. van Niel, and D. Westwood, *J. Chem. Soc., Perkin Trans.*, **1,** 269 (1988); (b) T. Yamamori and I. Adachi, *Tetrahedron Lett.*, **21,** 1747 (1980).

[13] P. Jutzi and O. Lorey, *Phosphorus and Sulfur*, **5,** 203 (1979).

[14] R. A. Elison, W. D. Waesner, and C. C. Willimas, *J. Org. Chem.*, **37,** 2767 (1992).

[15] (a) Y. Kamitori, M. Hoja, R. Matsuda, T. Kimura, and T. Yoshida, *J. Org. Chem.*, **51,** 4427 (1986); (b) S. R. Wilson, G. M. Georgiadus, H. N. Khatri, and J. E. Bartness, *J. Am. Chem. Soc.*, **102,** 3577 (1980); (c) S. R. Wilson, P. Caldera, and M. A. Jester, *J. Org. Chem.*, **47,** 3319 (1982).

[16] (a) N. M. M. Nibbering, S. Ingemann, and L. J. de Koning in Supplement S, The Chemistry of Sulfur Containing Functional Groups, S. Patai and Z. Rappoport (Eds.), (Wiley and Sons, New York 1993), pp. 310; (b) J. E. Bartness, R. L. Hayes, H. N. Khatri, R. N. Misra, and S. R. Wilson, *J. Am. Chem. Soc.*, **103,** 4746 (1991).

[17] S. Munavalli, D. K. Rohrbaugh, D. I. Rossman, and H. D. Durst (in press).

[18] (a) E. L. Eliel, V. S. Rao, and F. G. Riddell, *J. Am. Chem. Soc.*, **98,** 3583 (1976); (b) K. Pihlaja and B. Bjorkqvist, *Org. Magn. Reson.*, **9,** 533 (1977).

[19] (a) P. H. Bolton, *J. Magn. Reson.*, **41,** 287 (1980); (b) D. M. Doddrell and D. T. Pegg, *J Am. Chem. Soc.*, *102,* 6388 (1980); (c) J. K. M. Sanders and B. K. Hunters, Modern NMR Spectroscopy, (Oxford Umiversity Press, New York, 1993); (d) S. L. Patt and J. N. Shoolery, *J. Magn. Reson.*, **46,** 535 (1982); (e) D. M. Thomas, M. R. Bendall, D. T. Pegg, D. M. Doddrell, and J. Field, *J. Magn. Reson.*, **42,** 298 (1981).

[20] (a) G. K. Helmkamp, D. C. Owley; D. M. Barness, and H. J. N. Cassey, *J. Am. Chem. Soc.*, **90,** 1635 (1968); (b) D. C. Owley, G. K. Helmkamp, and M. F. Retting, *J. Am. Chem. Soc.*, **91,** 5239 (1969).

[21] Aldrich NMR Catalog, (a) **1** (1); (b) **1** (1) 439B.

[22] R. A. Ellison, W. D. Woessner, and C. C. Williams, *J. Org. Chem.*, **37,** 2757 (1972).

[23] (a) D. L. Tuleen and T. B. Stephens, *J. Org. Chem.*, **34,** 31 (1969); (b) D. L. Tuleen, *J. Org. Chem.*, **32,** 4006 (1967).

[24] J. Fossey, D. Lefort, and J. Sorba, Free Radicals in Organic Chemistry, (Wiley and Sons, New York, 1995), pp. 132; (b) J.M. Tedder, *Tetrahedron*, **38,** 313 (1982).

[25] (a) M. Jones, Jr, and R. A. Moss (Eds.), Carbenes, Vol. 1, (Wiley and Sons, New York 1973); (b) S. Munavalli, R. K. Rohrbaugh, and H. D. Durst, *Phosphorus, Sulfur, and Silicon*, **180,** 2179 (2005).

[26] C. G. Kruse, N. L. J. M. Broekhof, A. Wijman, and A. Vna der Gen, *Tetrahedron Lett.*, 885 (1977).

[27] S. C. Sondej and J. A. Katzenellenbogen, *J. Org. Chem.*, **51,** 3508 (1986).

[28] (a) J. K. Kim, J. Bonicamp, and M. C. Caserio, *J. Org. Chem.*, **46,** 4230 (1981) and references cited therein; (b) T. Clark, *J. Am. Chem. Soc.*, **110,** 1672 (1988); (c) P. M. W. Gill and L. Radom, *J. Am. Chem. Soc.*, **110,** 49312 (1988); (d) J.H. Bowie and P.Y. White, Org. Mass Spectrom., **6,** 317 (1972).

[29] (a) D. L. Tuleen and T. B. Stephens, *J. Org. Chem.*, **34,** 31 (1969); H. Bohme, H. Fischer, and R. Frank, *Ber.*, **81,** 54 (1948).