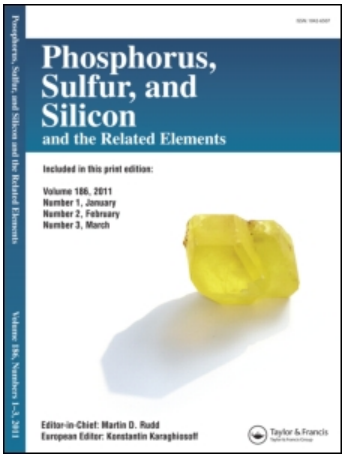

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Reactions of (1,3,3-Trichloro-2,2,4,4-tetramethylcyclobutyl)sulfenyl Chloride with Some *S*- and *O*-Nucleophiles

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*The sterically crowded 3,3-trichloro-2,2,4,4-tetramethylcyclobutanethione (**2c**) easily reacts with phosphorus pentachloride in CCl_4 yielding the relatively stable (1,3,3-trichloro-2,2,4,4-tetramethylcyclobutyl)sulfenyl chloride (**3c**). The reactions of **3c** with benzylsulfane (**4**) and thiocamphor (**5**) occur with elimination of HCl leading to the unsymmetrical disulfanes **6** and **9**. In the case of the sulfenates **10** and **12**, which are formed as intermediates in the reactions of **3c** with propargyl and allyl alcohol, respectively, the subsequent [2,3]-sigmatropic rearrangement yields the corresponding sulfoxides **11** and **13**.*

Keywords Diorganyldisulfanes; oxygen nucleophiles; sigmatropic rearrangements; sulfenyl chlorides; sulfur nucleophiles

INTRODUCTION

The synthesis and reactions of thiocarbonyl compounds, especially thioketones, is a significant topic in our ongoing research. In general, thioketones are rather unstable compounds,[1] and there is a limited number of aliphatic and cycloaliphatic representatives, which can be handled without special precautions. It is well documented that sterically crowded and non-enolizable thioketones are relatively

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Dedicated to Professor Marian Mikołajczyk, CBMiM PAN in Łódź, Poland, on the occasion of his 70th birthday.
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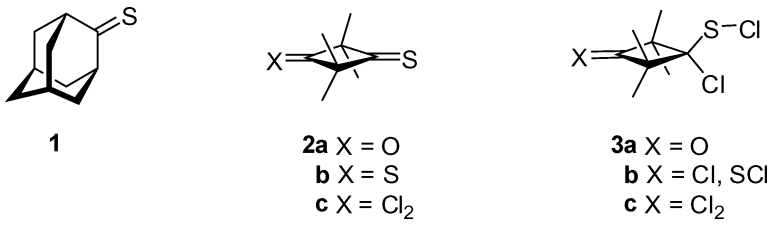


1 **2a** X = O **3a** X = O
b X = S **b** X = Cl, SCl
c X = Cl_2 **c** X = Cl_2

FIGURE 1 Nonenolizable, cycloaliphatic thioketones **1**, **2** and α-chlorosulfenyl chlorides **3**.

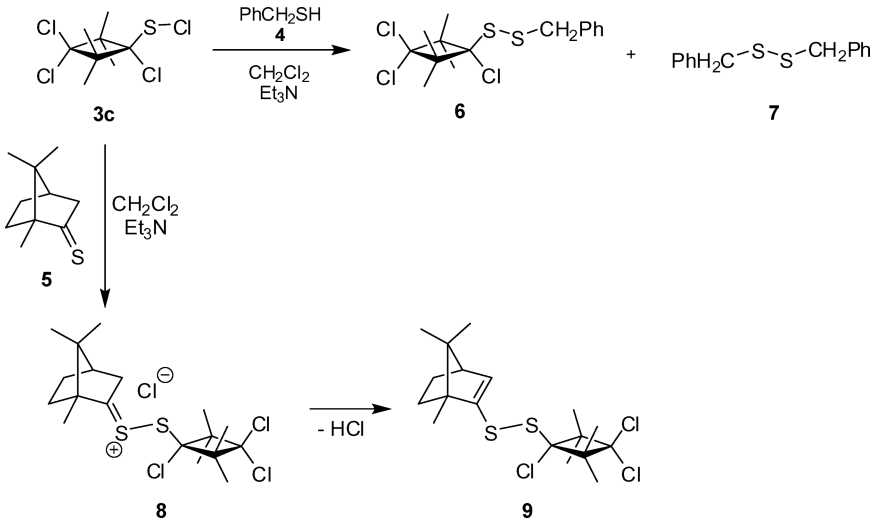
stable, and for this reason, adamantanethione (**1**)[2] and also 2,2,4,4-tetramethylcyclobutanethiones **2a**,**b**[3,4] are models of choice for studies on the reactivity of the C=S group (Figure 1).

In the last two decades, thioketones **1** and **2a**,**b** were extensively explored as dipolarophiles and as precursors of so called "sulfur-centered 1,3-dipoles," such as thiocarbonyl ylides,[5] *S*-sulfides,[6] *S*-imides,[7] and *S*-oxides.[8] In a recent article, the preparation of a new stable cycloaliphatic thioketone, **2c**, was described.[9] Thioketones **2a**,**b** easily add Cl_2 to yield stable α-chlorosulfenyl chlorides **3a**,**b**.[10] Similarly, treatment of thioketone **2c** with PCl_5 in CCl_4, gave the sulfenyl chloride **3c**.[9] In the same article, some reactions of **3c** with non-enolizable thioketones and selected nucleophiles such as diethyl phosphite and thioacetic acid were described. The present report is focused on the results obtained in reactions of **3c** with benzylsulfane (**4**), enolizable thiocamphor (**5**), and allyl as well as propargyl alcohol.

RESULTS AND DISCUSSION

The crude α-chlorosulfenyl chloride **3c** reacted with benzylsulfane (**4**) in the presence of Et_3N at room temperature within a few minutes to yield, unexpectedly, a mixture of the disulfane **6** and dibenzyldisulfane (**7**) (Scheme 1). Based on the intensities of the signals of the CH_2 groups in the ^1H NMR spectrum of the crude mixture located at 3.57 (**7**) and 4.15 ppm (**6**), the ratio was estimated to ca. 1:2. All attempts to separate this mixture chromatographically led to the decomposition of **6**, and only **7** could be isolated. In a second experiment, in the absence of Et_3N, the disulfane **7** was formed in small amount, and **6** could be isolated by crystallization of the mixture from petroleum ether. This result confirms that **3c**, in analogy to earlier published reactions with **3a**,**b**,[10,11] easily undergoes substitution with *S*-nucleophiles at the S-atom.

Under analogous reaction conditions, in the presence of Et_3N, the colored organic solution of thiocamphor (**5**) turned colorless after 10 min.

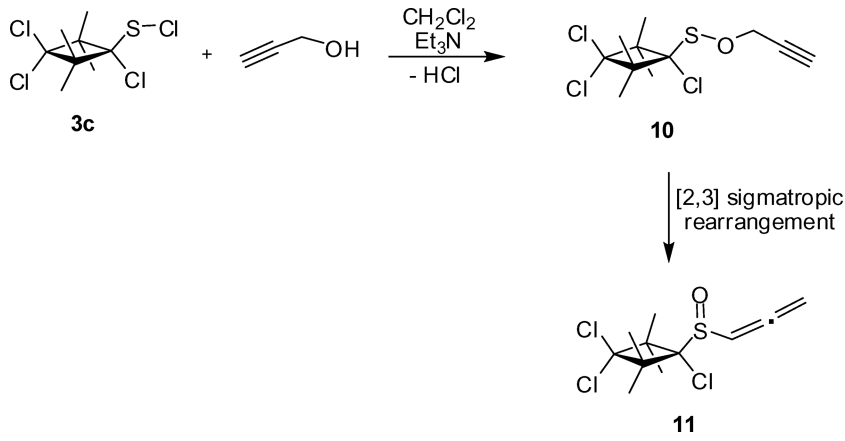


SCHEME 1

The typical workup by crystallization led to colorless crystals. The ^{1}H NMR spectrum of this material showed a doublet at 6.18 ppm, which is characteristic for camphen-2-yl sulfides (see, e.g.[12,13]). In addition, the ^{13}C NMR spectrum revealed the presence of two sp^2-C atoms (*d* at 135.1 and *s* at 141.5 ppm). The spectroscopic data fit well with structure **9** (Scheme 1). It is likely that the mechanism of the formation of **9** involves the initial formation of the ion pair **8** via nucleophilic substitution of Cl^- at the S-atom, followed by deprotonation. On the other hand, involvement of the enol of **5** can also be taken into account.

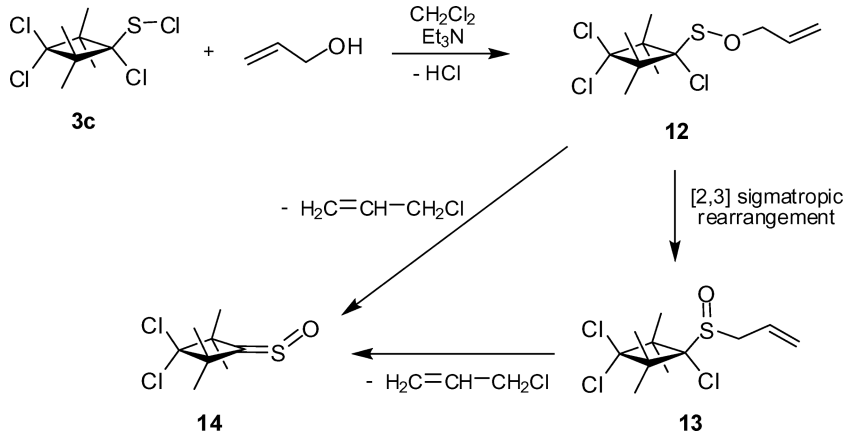
The reaction of **3c** with propargyl alcohol was carried out at ca. 5°C in the presence of Et_3N. After ca. 1 h, the conversion was complete, and the product was isolated as a colorless solid. The ^{1}H NMR spectrum indicated that the molecule contains an allenyl fragment. Furthermore, the presence of four signals for methyl groups is evidence that the molecule is no more symmetric. These data point out that the isolated product is an isomer of the expected propargyl sulfenate. Based on the spectroscopic data, the structure of the allenyl *S*-oxide **11** was confirmed (Scheme 2).

We propose that the nucleophilic substitution leads to the propargyl sulfenate **10**, which spontaneously undergoes a [2,3]-sigmatropic rearrangement to give **11**. This type of rearrangement was previously reported for reactions of propargyl alcohol with variably substituted halomethyl sulfenyl chlorides (e.g.[14]) and for the reaction with **3a**.[11]



SCHEME 2

In the case of the reaction of **3c** with allyl alcohol under the same conditions (CH_2Cl_2, Et_3N, 5°C), the ^1H NMR spectrum of the crude mixture evidenced the presence of two products. One of them, showing four signals for methyl groups located between 1.40 and 1.95 ppm and the characteristic pattern of multiplets for an allyl residue, was the expected allyl sulfoxide **13** (Scheme 3). The second product was identified as the known thiocarbonyl *S*-oxide (sulfine) **14**.[9] Both products were isolated as pure substances after chromatographic separation (TLC, ratio ca. 2:1).



SCHEME 3

The formation of **13** results from a [2,3]-sigmatropic rearrangement of the initially formed allyl sulfenate **12**. The precursor of the unexpected **14** is either **12** or **13**, which, by elimination of allyl chloride, can be transformed into the sulfine **14**. However, the isolated sulfoxide **13** is a stable compound, and, therefore, it is more likely that the elimination of the allyl cation from **12** leads to **14**. The different results obtained with propargyl alcohol can be explained by the enhanced stability of the allyl cation in comparison with the propargyl cation. The thereby formed sulfenate ion stabilizes by elimination of Cl^-.

CONCLUSIONS

The present study showed that α-chlorosulfenyl chloride **3c** easily reacts with *S*- and *O*-nucleophiles such as benzylsulfane (**4**), thiocamphor (**5**), propargyl, and allyl alcohol. The reactions with the *S*-nucleophiles **4** and **5** occur with elimination of HCl and lead to disulfanes **6** and **7**, respectively. We propose that these reactions are initiated by the nucleophilic attack of the *S*-nucleophile at the S-atom of the sulfenyl chloride group by substitution of chloride. In an analogous manner, the reactions of **3c** with propargyl and ally alcohol gives the sulfenates **10** and **12**, respectively, which, under the reaction conditions, spontaneously rearrange to give the corresponding sulfoxides **11** and **13**. The proposed mechanism of these transformations is a [2,3]-sigmatropic rearrangement, which, in the case of the allyl derivative **12**, is accompanied by the competitive elimination of the allyl cation.

EXPERIMENTAL

General

Melting points (mp) were determined in capillary using a Meltemp 2 apparatus and are uncorrected. ^{1}H and ^{13}C NMR spectra were obtained with a Tesla BS 687 (80 and 20 MHz, respectively) or a Bruker 300 (300 and 75 MHz, respectively) spectrometer using TMS ($\delta_{TMS} = 0$) as internal standard. The multiplicity of the ^{13}C signals was elucidated based on the DEPT experiments. IR spectra were registered with a Nexus spectrophotometer (in KBr). MS (EI or CI) were recorded using a Finnigan-Mat-90 or Finnigan-SSQ-700 spectrometer. Elemental analyses were performed by the Analytical Laboratory of the Polish Academy of Sciences (CBMiM) in Łódź.

Starting Materials

(1,3,3-Trichloro-2,2,4,4-tetramethylcyclobutyl)sulfenyl chloride (**3c**) was prepared from 3,3-dichloro-2,2,4,4-tetramethylcyclobutanethione (**2c**) by chlorination using PCl_5 in CCl_4 solution following a protocol in the literature.[9] Benzylsulfane (**4**), thiocamphor (**5**), propargyl alcohol, and allyl alcohol were used as trade reagents. Propargyl alcohol and allyl alcohol were dried by azeotropic distillation with CH_2Cl_2 prior to usage.

Reaction of 3c with Benzylsulfane (4)

A solution of **3c** (282 mg, 1 mmol) and **4** (124 mg, 1 mmol) in CH_2Cl_2 (2 mL) was stirred magnetically at room temperature for 24 h. Then, the solvent was evaporated and pure product **6** was obtained after crystallization from petroleum ether.

(Benzyl)(1,3,3-trichloro-2,2,4,4-tetramethylcyclobutyl)disulfide (6)

Yield: 164 mg (44%), colorless crystals, mp 62–64°C (petroleum ether, −20°C). IR (KBr): 3002 *m*, 2981 *m*, 1495 *m*, 1469 *s*, 1454 *s*, 1440 *m*, 1384 *m*, 1200 *m*, 942 *m*, 865 *s*, 828 *s*, 801 *m*, 704*vs*, 559 *m*. ^{1}H NMR ($CDCl_3$): $\delta =$ 1.55 (s, 6H, Me), 1.56 (s, 6H, Me), 4.15 (s, 2H, CH_2), 7.28 (s, 5H, arom. H). ^{13}C NMR ($CDCl_3$): $\delta = 26.2$ (Me), 27.2 (Me), 59.9 (C_q), 92.0 (C_qCl_2), 98.7 ($C_qS(Cl)$), 127.6 (arom. CH), 128.6 (arom. CH), 129.4 (arom. CH), 136.5 (arom. C_q). CI-MS (isobutan): 373 (7), 371 (20, $[M+1]^+$), 335 (75), 333 (100), 123 (10, $[C_6H_5CH_2S]^+$), 91 (5, $[C_6H_5CH_2]^+$). Anal. Calcd. for $C_{15}H_{19}Cl_3S_2$ (369.81): C 48.72, H 5.18, S 17.34. Found: C 48.61, H 5.35, S 17.43.

Reaction of 3c with Thiocamphor (5)

To a magnetically stirred solution of **3c** (282 mg, 1 mmol) in CH_2Cl_2 (4 mL) at room temperature, a solution of **5** (168 mg, 1 mmol) and triethylamine (101 mg, 1 mmol) in CH_2Cl_2 (4 mL) was added, and stirring was continued for 10 min. Then, the solvent was evaporated, and the residue was washed with diethyl ether (for the purpose to remove inorganic salts). The product was purified by repeated crystallization from diethyl ether.

((1*R*,4*R*)-1,7,7-Trimethylbicyclo[2.2.1]hept-2-en-2-yl)(1,3,3-trichloro-2,2,4,4-tetramethylcyclobutyl)disulfide (9)

Yield: 210 mg (51%), colorless crystals, m.p 123–127°C (diethyl ether, −70°C). IR (KBr): 2953 *s*, 2870 *m*, 1470 *m*, 1451 *m*, 1441 *m*, 1385 *m*, 870 *m*, 830 *m*. ^{1}H NMR ($CDCl_3$): $\delta = 0.78$ (s, 3H, Me), 0.82 (s, 3H, Me), 1.06 (s, 3H, Me), 1.53 (s, 3H, Me), 1.54 (s, 3H, Me), 1.56 (s, 3H, Me), 1.59 (s, 3H, Me), 0.87–1.94 (m, 4H, CH_2), 2.38 (t, $J_{H,H} = 3.6$ Hz, 1H, CH), 6.18 (d, $J_{H,H} = 3.4$ Hz, 1H, C=CH). ^{13}C NMR ($CDCl_3$): $\delta = 11.4$ (Me), 19.3 (Me), 19.5 (Me), 25.5 (CH_2), 26.1 (Me), 26.3 (Me), 26.9 (Me), 27.1 (Me), 31.5 (CH_2), 52.4 (CH), 56.7 (C_q), 57.6 (C_q), 60.0 (C_q), 60.1 (C_q), 90.7 (C_qS), 98.8 (C_qCl_2), 135.1 (C=*C*H), 141.5 (C=*C*H). CI-MS (isobutan): 417 (20), 415 (40, $[M+1]^+$), 413 (38), 379 (75), 377 (100), 252 (10), 167 (15). Anal. Calcd. for $C_{18}H_{27}Cl_3S_2$ (413.90): C 52.23, H 6.58, S 15.49. Found: C 51.94, H 6.53, S 15.37.

Reaction of 3c with Propargyl Alcohol

To a magnetically stirred and cooled (ice-water bath) solution of **3c** (282 mg, 1 mmol) in CH_2Cl_2 (2 mL), propargyl alcohol (56 mg, 1 mmol) dissolved in CH_2Cl_2 (2 mL) was added. After 10 min, a solution of triethylamine (101 mg, 1 mmol) in CH_2Cl_2 (2 mL) was added in small portions. Stirring was continued at room temperature for 1 h, and the solvent was evaporated. The oily residue was treated with diethyl ether, the organic layer was separated, and the solvent was evaporated to dryness. An analytically pure sample was obtained after crystallization from petroleum ether.

(Propa-1,2-dienyl)(1,3,3-trichloro-2,2,4,4-tetramethylcyclobutyl)sulfoxide (11)

Yield: 88 mg (29%), colorless crystals, mp 110–112°C (petroleum ether). IR (KBr): 3058 *m*, 2991 *m*, 2972 *m*, 1935 *m*, 1053 *s*, 881 *m*, 841 *m*. ^{1}H NMR ($CDCl_3$): $\delta = 1.43$ (s, 3H, Me), 1.48 (s, 3H, Me), 1.56 (s, 3H, Me), 1.88 (s, 3H, Me), 5.28 (dd, $^4J_{H,H} = 6.2$ Hz, $^2J_{H,H} = 14.0$ Hz, 1H, =C(H)*H*), 5.36 (dd, $^4J_{H,H} = 6.5$ Hz, $^2J_{H,H} = 14.0$ Hz, 1H, =C(*H*)H), 6.19 (dd, $^4J_{H,H} = 6.5$ Hz, $^4J_{H,H} = 6.2$ Hz, 1H, −C*H*=). ^{13}C NMR ($CDCl_3$): $\delta = 24.9$ (Me), 25.3 (Me), 25.4 (Me), 26.1 (Me), 56.7 (C_q), 59.0 (C_q), 81.8 (CH_2), 94.0 (C_qS), 96.4 (CH), 98.2 (C_qCl_2), 209.3 (CH=*C*=CH_2). CI-MS (NH_3): 320 (17), 318 (16, $[M+NH_4]^+$), 305 (32), 304 (12), 303 (98), 302 (12), 301 (100, $[M+1]^+$). Anal. Calcd. for $C_{11}H_{15}Cl_3OS$ (301.66): C 43.80, H 5.01, S 10.63. Found: C 43.38, H 4.74, S 10.44.

Reaction of 3c with Allyl Alcohol

A solution of **3c** (282 mg, 1 mmol) in CH_2Cl_2 (2 mL) was stirred magnetically and cooled in an ice-water bath. Anhydrous allyl alcohol (116 mg, 2 mmol) dissolved in CH_2Cl_2 (2 mL) was added first, and after 10 min, a solution of triethylamine (101 mg, 1 mmol) in CH_2Cl_2 (2 mL) was added dropwise. Stirring was continued for 1 h at room temperature, and the solvent was evaporated. The residue was washed with diethyl ether (to remove inorganic salts), and product **13** was separated from the sulfine **14**[9] [isolated as the less polar fraction, 53 mg (23%)] using preparative layer chromatography and CH_2Cl_2/petroleum ether 1:1 as the eluent. An analytically pure sample of **13** was obtained after crystallization from petroleum ether.

(Prop-2-en-1-yl)(1,3,3-trichloro-2,2,4,4-tetramethylcyclobutyl)sulfoxide (13)

Yield: 80 mg (46%), colorless crystals, mp 66–70°C (petroleum ether, −20°C). IR (KBr): 2981 *m*, 1471 *m*, 1387 *m*, 1082 *m*, 1047 *s*, 995 *m*, 880 *m*, 838 *m*, 798 *m*. ^{1}H NMR ($CDCl_3$): $\delta = 1.47$ (s, 3H, Me), 1.49 (s, 3H, Me), 1.58 (s, 3H, Me), 1.90 (s, 3H, Me), 3.26–3.33, 3.54–3.62 (2m, 2H, CH_2), 5.42–5.49 (m, 2H, CH=CH_2), 5.89–6.01 (m, 1H, C*H*=CH_2). ^{13}C NMR ($CDCl_3$): $\delta = 25.1$ (Me), 25.3 (Me), 25.4 (Me), 26.1 (Me), 55.3 (CH_2), 56.5 (C_q), 58.9 (C_q), 92.6 (C_qS), 98.2 (C_qCl_2), 124.0 (CH=*C*H_2), 126.2 (*C*H=CH_2). CI-MS (NH_3): 307 (37), 305 (99), 303 (100, $[M+1]^+$), 246 (43), 244 (60). Anal. Calcd. for $C_{11}H_{17}Cl_3OS$ (303.68): C 43.51, H 5.64, S 10.56. Found: C 43.29, H 5.62, S 10.42.

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