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LETTERS

Sulfur ylides generated from the reaction of arylchlorocarbenes with trimethylenesulfide: determination of rate parameters by laser flash photolysis

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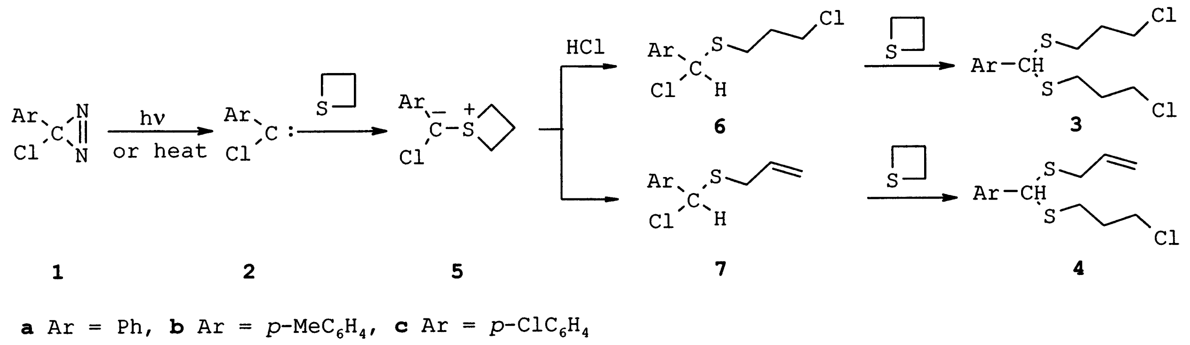
Abstract—Reaction of arylchlorodiazirines with trimethylenesulfide gives a mixture of aryldi(3-chloropropyl)thioacetal and aryl(2-propenyl)(3-chloropropyl)thioacetal in a good yield. The reaction goes through a formation of a sulfur ylide as an intermediate. Rate constants have been determined using laser flash photolytic techniques. © 2000 Elsevier Science Ltd. All rights reserved.

Sulfur ylides are becoming increasingly useful intermediates in synthetic organic chemistry,[1] which has been thoroughly reviewed in a number of monographs and reviews.[2] They have been successfully utilized for the synthesis of β-lactams antibiotics, pyrrolizidine alkaloids, and other natural products. Some evidence also suggests the involvement of sulfur ylides in biochemical processes.[1] The generation of sulfur ylides from carbenes and sulfur containing organic compounds is a useful alternative to the widely employed base-promoted methodology.[1,2] Higher reactivity of thiiranes, thietanes, and tetrahydrothiophenes compared to the open-chain sulfides makes this group of compounds more attractive for this purpose, as well as for theoretical studies. The number of publications on their synthetic applications, including kinetics studies of such reactions, is limited.[3–7]

We are continuing our studies of ylides, obtained from the reaction of arylchlorocarbenes with heteroatom containing compounds. We now report the formation of di(3-chloropropyl)- and (3-chloropropyl)(2-propenyl)-thioacetals of arylaldehydes in the reaction of arylchlorodiazirines with trimethylene sulfide (TMSF) under photolytic and thermal conditions. We also conducted kinetics studies of the reaction using laser flash photolytic (LFP) techniques in order to prove that the reaction involves the formation of sulfur ylide as an intermediate (Scheme 1).



Scheme 1.

Keywords: diazirine; carbene; sulfur ylide; trimethylene sulfide; thioacetal; kinetics; laser flash photolysis.

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We prepared the arylchlorodiazirines **1a**–**c** by Graham oxidation of amidines,[8] and we generated the arylchlorocarbenes **2a**–**c** from arylchlorodiazirines **1a**–**c** by photolysis or thermolysis. We carried out photolyses by irradiation (350 nm) of solutions of diazirines **1a**–**c** (1 mmol) and TMSF (2.5 mmol) in hexane (50 ml) at 25°C for 24 h. For the thermolysis reactions solutions of diazirines **1a**–**c** (1 mmol) and TMSF (2.5 mmol) in absolute benzene (10 mL) were refluxed under Argon for 18 h. After the workup, we isolated the aryldi(3-chloropropyl)thioacetals **3a**–**c** and aryl(3-chloropropyl)(2-propenyl)thioacetals **4a**–**c** by column chromatography on silica gel with eluent hexane/ether = 9:1. The yields of the obtained thioacetals **3a**–**c** and **4a**–**c** are presented in the Table 1 and their selected physical data are given in Ref. 9. NMR data compare well with the authentic sample **3a** prepared from benzaldehyde and 3-chloropropanethiol.[10]

Isolation of thioacetals **3** and **4** rather than tetrahydrothiophenes[4,11] can be explained in terms of the mechanism similar to the one described by Wenkert and co-workers[12] for the reaction of thiochromane and ethyl diazoacetate leading to the formation of ethyl *o*-allylphenylthioacetate. We suggest that the reaction of arylchlorocarbene **2a**–**c** with TMSF includes a formation of sulfur ylide **5a**–**c** followed by ring opening to form 3-chloropropylsulfide **6a**–**c** and allylsulfide **7a**–**c**. Further reaction with second molecule of TMSF yields the final products **3a**–**c** and **4a**–**c**. The latter ring-cleavage process is promoted by coordination of an electrophile at sulfur atom of TMSF[3,13] similar to the reaction of TMSF with allyl bromide.[13a] The formation of thioacetals **3a**–**c** is due to the presence of HCl in the reaction mixture, which forms as a by-product of the decomposition of arylchlorodiazirines **1a**–**c**.[14] The proposed mechanism is supported by the results obtained from the photolysis of a mixture of diazirines **1b**,**c** and TMSF in hexane solution in presence of HCl, as well as in the presence of diisopropylethylamine. When the mixture of chloro(*p*-chlorophenyl)diazirine **1c** and TMSF in hexane was photolyzed in the presence of HCl, we obtained the thioacetal **3c** as a major product (ratio **3c**/**4c** was 97:3 after 3 hours and 91:9 after 24 hours of photolysis). When the mixture of chloro(*p*-methylphenyl)diazirine **1b** and TMSF in hexane was photolyzed in the presence of diisopropylethylamine, we isolated thioacetal **4b** as a major product (ratio **3b**/**4b** was 26:74 after 24 hours of photolysis). This also explains the formation of thioacetals **4a**–**c** as a major product in thermolysis, when the reaction is accomplished with less HCl formation than in photolysis.[14]

Table 1. Isolated yields of thioacetals **3a**–**c** and **4a**–**c**

Product	Ar	Method	Yield (%)	
			Thioacetal **3**	Thioacetal **4**
a	Ph	*hv*	34	23
b	*p*-MeC_6H_4	*hv*	36	21
b	*p*-MeC_6H_4	heat	16	27
c	*p*-ClC_6H_4	*hv*	38	18
c	*p*-ClC_6H_4	heat	25	35

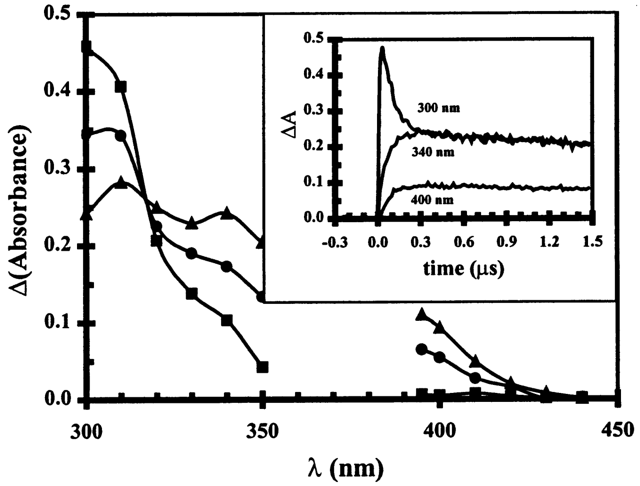

Figure 1. Transient absorption spectra at $t = 16$ (■), 90 (●), and 300 ns (▲) after excitation. Inset: Kinetic traces at 300, 340 and 400 nm.

LFP[15] at 355 nm of a solution of chlorophenyldiazirine **1a** in isooctane at 25°C produces a transient absorption at 300 nm, due to the formation of the chlorophenylcarbene **2a**, whose decay rate constant is 3.8×10^5 s^{-1}. In the presence of TMSF, a new transient, attributed to the *S*-ylide, **5a**, grows in at 340 and 400 nm (Fig. 1) at a rate equal to that of the decay of the carbene measured at 300 nm. The absorption spectrum of *S*-ylide, **5a**, is similar to that observed by Moss and co-workers[16] in the reaction of chlorophenylcarbene with allylphenylsulfide. The plot of the observed pseudo-first-order rate constants, k_{obs}, versus the concentration of TMSF is linear (Fig. 2); the rate constant for the reaction of chlorophenylcarbene **2a** with TMSF is $k_{yl} = 8.87\times10^9$ M^{-1} s^{-1}. The *S*-ylide, **5a**, at 400 nm decays with a lifetime equal to 25 μs at 25°C, independent of the concentration of TMSF, so that the rate constant reflects the first-order disappearance of the ylide **5a**, $k_d = 4\times10^4$ s^{-1}. The temperature dependence (15–42°C) of the decay of the ylide **5a**, yielded the following

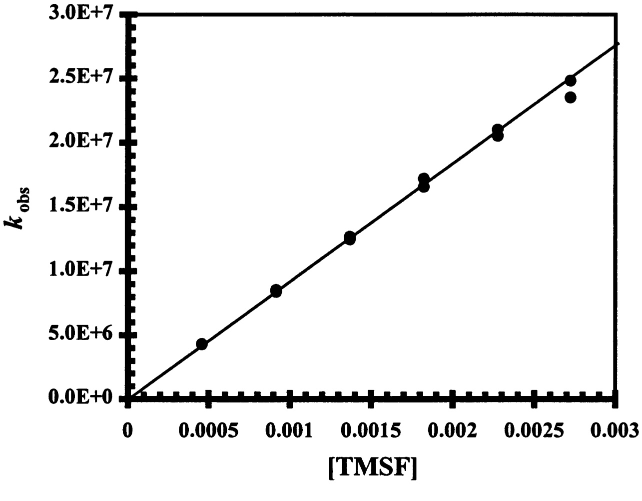

Figure 2. Rate of formation of the chlorophenylcarbene–TMSF ylide, **5c**, monitored at 340 nm. $k_{yl} = 8.87\times10^9$ M^{-1} s^{-1}.

Arrhenius parameters for this rearrangement: $E_a = 14.8 \pm 2$ kcal mol^{-1} and $\log A = 15.4 \pm 1.4$. The errors on the E_a and $\log A$ are relatively large because the investigated temperature range was limited.

In summary, the reaction of arylchlorodiazirines with TMSF yielded aryldi(3-chloropropyl)thioacetals and aryl(2-propenyl)(3-chloropropyl)thioacetals as the only products. No tetrahydrothiophene derivatives have been detected. Laser flash photolysis experiments have also demonstrated the existence of sulfur ylides as intermediates in these reactions.

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9. For **3a**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (4H, m), 2.6–2.8 (4H, m), 3.61 (4H, t, $J = 6$ Hz), 4.89 (1H, s), 7.2–7.5 (5H, m); ^{13}C NMR (300 MHz, CDCl$_3$): 29.344, 31.886, 43.382, 53.599, 127.629, 128.151, 128.679, 139.879. For **4a**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (2H, m), 2.6–2.8 (2H, m), 2.9–3.1 (1H, m), 3.2–3.4 (1H, m), 3.58 (2H, t, $J = 6$ Hz), 4.80 (1H, s), 5.1–5.2 (2H, m), 5.7–5.9 (1H, m), 7.2–7.5 (5H, m). For **3b**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (4H, m), 2.34 (3H, s), 2.6–2.8 (4H, m), 3.60 (4H, t, $J = 6$ Hz), 4.89 (1H, s), 7.0–7.2 (2H, m), 7.2–7.4 (2H, m); ^{13}C NMR (300 MHz, CDCl$_3$): 21.209, 29.423, 31.990, 43.478, 53.407, 127.562, 129.394, 136.881, 138.005. For **4b**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (2H, m), 2.34 (3H, s), 2.6–2.8 (2H, m), 2.9–3.1 (1H, m), 3.2–3.4 (1H, m), 3.59 (2H, t, $J = 6$ Hz), 4.78 (1H, s), 5.1–5.2 (2H, m), 5.7–5.9 (1H, m), 7.0–7.2 (2H, m), 7.2–7.4 (2H, m); ^{13}C NMR (300 MHz, CDCl$_3$): 21.132, 29.161, 31.969, 35.281, 43.434, 51.473, 117.581, 127.697, 129.291, 133.659, 136.781. For **3c**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (4H, m), 2.6–2.8 (4H, m), 3.61 (4H, t, $J = 6$ Hz), 4.86 (1H, s), 7.2–7.4 (4H, m). For **4c**: ^{1}H NMR (300 MHz, CDCl$_3$): δ 1.9–2.1 (2H, m), 2.6–2.8 (2H, m), 2.9–3.1 (1H, m), 3.2–3.4 (1H, m), 3.58 (2H, t, $J = 6$ Hz), 4.77 (1H, s), 5.0–5.2 (2H, m), 5.7–5.9 (1H, m), 7.2–7.4 (4H, m).
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15. LFP setup uses a crossed-beam arrangement. The sample in a 10×10 mm cell was excited at 355 nm by single light pulses (200 ps; 5–30 mJ) provided by a frequency tripled mode-locked Nd-YAG laser (Quantel). The detection system (pulsed Xe-arc, monochromator, photomultiplier, and Tektronix 7912 transient recorder) has a response time of approximately 4 ns.
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