8.41; N, 4.03. Found: C, 69.01; H, 8.37; N, 4.22.

Methyl 7-(5-Oxo-2-styryl-1-pyrrolidinyl)heptanoate (13). A solution of **7** (0.8 g, 2.3 mmol) in 20 mL of toluene containing a trace of *p*-toluensulfonic acid was refluxed for 8 h. The cooled reaction mixture was washed with water (40 mL), dried, and evaporated. The residue was chromatographed on Al_2O_3. Elution with (Et_2O–$CHCl_3$ 1:1) solution afforded 0.58 g (75%) of **13** as an oil: NMR ($CDCl_3$) δ 3.63 (s, 3 H), 4.17 (m, 1 H), 6.0 (dd, 1 H, J = 16, 8 Hz), 6.6 (d, 1 H, J = 16 Hz), and 7.34 (s, 5 H); IR (film) 1725, 1670, and 970 cm^{-1}. Anal. Calcd for $C_{20}H_{27}NO_3$: C, 72.95; H, 8.21; N, 4.25. Found: C, 73.21; H, 8.03; N, 4.42.

Methyl 7-(2-Formyl-5-oxo-1-pyrrolidinyl)heptanoate (14). Lemieux–Johnson oxidation of **13** (0.58 g, 1.76 mmol) was carried out as described above for **4**. Chromatography of the crude reaction mixture on silica gel and elution with Et_2O and then with MeOH afforded 0.35 g (77%) of the aldehydo ester **14**. Spectroscopic properties of **14** are in full accord with the reported ones.[2,3]

Registry No.—**2,** 69257-84-7; **3,** 69257-85-8; **4,** 69257-86-9; **5,** 69257-87-0; **6,** 69257-88-1; **7** isomer 1, 69257-89-2; **7** isomer 2, 69257-90-5; **8,** 34718-84-8; **9,** 3919-86-6; **10,** 69257-91-6; **11,** 69257-92-7; **12,** 69257-93-8; **13,** 69257-94-9; **14,** 60289-35-2; 7-aminoheptanoic acid hydrochloride, 62643-56-5; (*E*)-4-octenedioic acid, 48059-97-8; (*Z*)-4-octenedioic acid, 38561-68-1; methyl 7-amino heptanoate, 39979-08-3; dimethyl phenacylphosephonate, 1015-28-7; triphenylphenacylidenephosphorane, 859-65-4; phenylacetylene, 536-74-3; methyl 4-nitrobutyrate, 13013-02-0; methyl 7-iodoheptanoate, 38315-25-2.

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Use of Thionyl Chloride for Sulfurization of Active Methylene Compounds. Dechlorination of α-Chlorosulfenyl Chlorides

Kitaro Oka

Tokyo College of Pharmacy, Horinouchi 1432-1, Hachioji, Tokyo 192-03, Japan

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During our investigation of the reaction of α-chlorosulfenyl chlorides with various nucleophiles,[1,2] we found that some of the starting materials give thiocarbonyl derivatives under the action of triphenylphosphine. In the literature[3] there was only one example of a preparation of a thioketone from α-chlorosulfenyl chloride by the action of the anion of dipivaloylmethane, and its synthetic scope had not been investigated. Another sequence starting from active methylene compounds has been reported[4,5] in which the base-catalyzed decomposition of Bunte salts in an aqueous system includes some undesirable competitive reactions.[5] In this paper we report the results from our study on the conversion of α-chlorosulfenyl chlorides to the corresponding thioketones by simple treatment with triphenylphosphine.

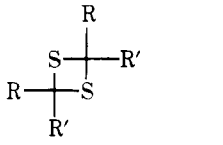
Attempts have been made to explain the highly exothermic reaction of simple sulfenyl chlorides with phosphites or

RR′CClSCl

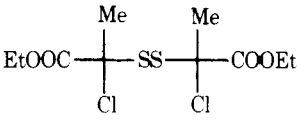
1a, R,R′ = COOEt
b, R = PhCO; R′ = Ph
c, R = Ph; R′ = COCl
d, R = Me; R′ = COCl
e, R = Ph; R′ = COOEt
f, R = Me; R′ = COOEt

RR′C=S

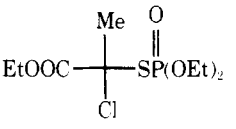
2a, R,R′ = COOEt
b, R = PhCO; R′ = Ph
c, R = Ph; R′ = COOEt



3a, R,R′ = COOEt
b, R = Ph; R′ = COOEt



4



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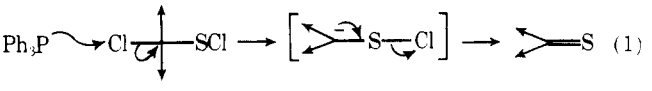
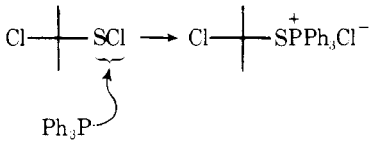


(1)



(2)

phosphines using "hard and soft acids and bases theory",[6] but the site of initial attack (S or Cl) has not been determined. In the present case, the problem seems to be more difficult owing to the substitution of another chlorine and strong π-electron acceptor(s) on the central carbon atom. The starting materials **1a** and **1b** were prepared from diethyl malonate and benzyl phenyl ketone, respectively, by treatment with thionyl chloride as described in our previous paper.[2] The sulfenyl chloride **1e** was synthesized from the corresponding acyl chloride **1c**[2,7] under the action of an equimolar amount of sodium ethoxide. This esterification was regiospecific as suggested by HSAB theory.[6] Chlorosulfenyl derivatives of monocarboxylic esters have not been reported so far. Compound **1e** showed two strong carbonyl-stretching bands at 1742 and 1715 cm^{-1}, as previously reported with other analogous derivatives of acyl chlorides[7] and ketones.[2] Two single peaks in the ^{13}C NMR spectrum at 166.5 and 83.8 ppm representing the carbonyl carbon and sulfur-substituted carbon, respectively, assured the purity of the material. The sulfenyl chloride **1f** was also prepared from the acyl chloride **1d,** which was derived from propionic acid. Since direct chlorosulfenylation of carboxylic esters, except diethyl malonate, failed, these esterifications of acyl chlorides provide a convenient synthetic method.

The sulfenyl chloride **1a** was treated with triphenylphosphine to give 1,3-dithietane **3a** in excellent yield. Intermediacy of the thioketone **2a** in this reaction was expected from the following results. When the sulfenyl chloride **1b** was treated similarly, the initial formation of monothiobenzil (**2b**) was detected by the appearance of 608-nm blue color.[5] Isolation of this material failed because of its facile polymerization to give a slightly green oil as the solvent was removed.[5] The sulfenyl chloride **1e** was also treated with triphenylphosphine to give thiobenzoyl formate **2c,** whose blue color completely disappeared during addition of the reagent. The product was assigned as the 1,3-dithietane **3b.**

We also applied the reaction to the aliphatic acid derivative **1f.** However, the formation of dichloro disulfide **4** occurred predominantly.[8] When triethyl phosphite was used as reagent,

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the diethyl phosphate **5** was isolated in agreement with the known reactions of simple sulfenyl chlorides.[9]

Consequently, we would like to propose that the initial attack of triphenylphosphine in the synthesis of the thioketones occurs at the *C*-chlorine atom to form a carbanion stabilized by the strong π-electron acceptors (eq. 1). Alternatively, the formation of the dichloro disulfide might be a result of another attack on the sulfur or *S*-chlorine atom and subsequent intermolecular reaction in the case of comparatively weak π-electron accepting substituents. The fact that the reverse addition of the reagent or the dilution technique did not affect the experimental results suggests that disulfide formation may be very facile and occur through an *S*-phosphonium chloride as a possible intermediate (eq 2).

Experimental Section

IR spectra were obtained using a Hitachi Model 215. ^{1}H NMR and ^{13}C NMR spectra were determined on JNM-PS-100 and JNM-FX-100, respectively. Mass spectra were obtained using a Hitachi RMU-7L. The unstable sulfenyl chlorides were applied to the TLC plates made of Wako-Gel B5-FM (Wako Pure Chem. Co., Osaka, Japan) and silica gel columns made of Wako-Gel C-100.

Ethyl α-Chloro-α-(chlorosulfenyl)phenylacetate (1e). To a solution of 9 g of the sulfenyl chloride **1c** in 50 mL of absolute benzene was added 2.65 g of NaOEt. The mixture was stirred at room temperature overnight. The solvent was evaporated in vacuo, and the resulting oil was purified on a silica gel column (200 g) using a mixture of EtOAc–*n*-hexane (1:50) as the solvent system. Evaporation of the first eluate gave 5.4 g (58%) of slightly yellow oil: IR (neat) 1742, 1715 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.29 (t, 3 H), 4.34 (q, 2 H), 7.26–7.50 (m, 3 H), 7.56–7.76 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 166.5 (C=O), 134.0, 130.1, 128.6, 127.5 (Ph), 83.8 (C–S), 64.1, 13.9 (Et); MS *m/e* 264 (M, 3), 229 (M − Cl, 3), 197 (M − SCl, 81), 194 (M − Cl_2, 14), 191 (M − COOEt, 14), 121 (PhCS, 100).

Ethyl α-Chloro-α-(chlorosulfenyl)propionate (1f). A mixture of 5 g of propionic acid, 0.15 mL of pyridine, and 50 mL of thionyl chloride was refluxed for 72 h. The NMR spectrum of the resulting solution exhibited a single peak at δ 2.18 which was attributed to methyl hydrogens of the sulfenyl chloride **1d.** Excess thionyl chloride was evaporated in vacuo, and the resulting material was triturated with *n*-hexane. Precipitated pyridinium salts were filtered off. The filtrate was concentrated to dryness, and the residue was dissolved in 100 mL of absolute benzene. The solution was treated with 5.05 g of NaOEt at room temperature overnight. The solvent was evaporated, and the residue was purified on a silica gel column (150 g) using 1.5% EtOAc in *n*-hexane as the solvent system. Evaporation of the first eluate gave 5.8 g (43%) of slightly yellow oil: IR (neat) 2976, 1745, 1732 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.34 (t, 3 H), 2.16 (s, 3 H), 4.32 (q, 2 H); ^{13}C NMR ($CDCl_3$) δ 166.8 (C=O), 75.0 (C–S), 63.7, 14.0 (Et), 28.0 (Me); MS *m/e* 202 (M, 44), 135 (M − SCl, 9), 132 (M − Cl_2, 9), 129 (M − COOEt, 64).

2,2,4,4-Tetrakis(ethoxycarbonyl)-1,3-dithietane (3a). To a solution of 2.015 g (7.69 mmol) of Ph_3P in 20 mL of absolute benzene was added a solution of 2.0 g (7.69 mmol) of the sulfenyl chloride **1a** in absolute benzene at 5–10 °C. The resulting mixture was stirred for 10 min and then evaporated to dryness. The residue was triturated with 20 mL of absolute ether and 0.15 mL (~8 mmol) of water. After the evolution of HCl gas, the resulting Ph_3PO (1.55 g, 72%) was filtered off and the filtrate was evaporated to dryness. The residue was further triturated with 30 mL of *n*-hexane to remove another crop of Ph_3PO (0.48 g, 22%). Complete removal of Ph_3PO was accomplished by LC using 30 g of 50-μm irregular shaped silica gel and a 4% EtOAc–*n*-hexane mixture as the solvent system. The eluate was evaporated to give 1.35 g (93%) of crystals which was further recrystallized from *n*-hexane to afford plates: mp (uncorrected) 51–51.5 °C (lit.[10] mp 59.5–60 °C); IR and NMR spectra were identical with reported ones.[10] Anal. Calcd for $C_{14}H_{20}O_8S_2$: C, 44.20; H, 5.30; S, 16.85. Found: C, 44.11; H, 5.35; S, 16.85.

Monothiobenzil (2b). A solution of 1.5 g of the sulfenyl chloride **1b** in 10 mL of absolute benzene was treated with 1.33 g of Ph_3P in the same manner as described above to give 1.15 g (72%) of the product as a glassy polymer: IR spectrum was identical with reported one;[11] MS *m/e* 226 (M, 58), 121 (PhCS, 89), 105 (PhCO, 100). When this polymer was dissolved in dichloromethane, absorption of the solution at 608 nm, identical with that of **2b,** was observed as described in the literature.[5]

2,4-Bis(ethoxycarbonyl)-2,4-diphenyl-1,3-dithietane (3b). A solution of 1 g of the sulfenyl chloride **1e** in 10 mL of absolute benzene was treated with 993 mg of Ph_3P in the same manner as described above. The resulting crystals (610 mg, 83%), obtained after column chromatography using 30 g of silica gel and a mixture of EtOAc–*n*-hexane (1:30) as the solvent system, were recrystallized from *n*-hexane as needles: mp 103–103.5 °C (lit.[4] mp 89–91 °C); IR (KBr) 1725, 1715, 1221, 1019 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.25 (t, 6 H), 4.26 (q, 4 H), 7.18–7.35 (m, 6 H), 7.41–7.58 (m, 4 H); MS *m/e* 388 (M, 1.2), 355 (M − SH, 1.4), 324 (M − S_2, 1.8), 315 (M − COOEt, 51), 194 (M/2, 10), 121 (PhCS, 100). Anal. Calcd for $C_{20}H_{20}O_4S_2$: C, 61.83; H, 5.19; S, 16.50. Found: C, 62.10; H, 5.24; S, 16.51.

Bis[1-chloro-1-(ethoxycarbonyl)ethyl] Disulfide (4). A solution of 500 mg of the sulfenyl chloride **1f** in 10 mL of absolute benzene was also treated with 649 mg of Ph_3P. The crude product was purified on a silica gel column (20 g) using a mixture of *n*-hexane and EtOAc (100:1) as the solvent system. Evaporation of the solvent from the first eluate gave 269 mg (65%) of colorless oil: IR (neat) 1730 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.35 (t, 6 H), 2.12 (s, 6 H), 4.28 (q, 4 H); MS *m/e* 334 (M, 16).

Diethyl *S*-[1-Chloro-1-(ethoxycarbonyl)ethyl] Thiolphosphate (5). To a solution of 400 mg of the sulfenyl chloride **1f** was added 600 mg of $(EtO)_3P$. Evaporation of the solvent and column chromatography of the resulting oil on 20 g of silica gel using a mixture of *n*-hexane–EtOAc (10:1) gave 289 mg (48%) of colorless oil: IR (neat) 1739 cm^{-1}; ^{1}H NMR (CCl_4) δ 1.37 (t, 9 H), 2.27 (s, 3 H), 4.02–4.43 (m, 6 H); MS *m/e* 304 (M, 7).

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Registry No.—**1a,** 51270-73-6; **1b,** 63369-91-5; **1c,** 31076-68-3; **1d,** 69439-77-6; **1e,** 69439-78-7; **1f,** 52414-78-0; **2b,** 16939-18-7; **2b** polymer, 69439-74-3; **3a,** 17239-56-4; **3b,** 55970-45-1; **4,** 69439-79-8; **5,** 69439-80-1; propionic acid, 79-09-4; thionyl chloride, 7719-09-7.

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Synthesis of 5-(Methylthio)-, 5-(Methanesulfinyl)-, and 5-(Methanesulfonyl)uracil and Reaction of the Methyl Hypobromite Adduct of 5-Bromouracil with Carbonylmethylene Compounds

Kentaro Anzai

The Institute of Physical and Chemical Research, Wako-Shi, Saitama 351, Japan

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The reaction of dimethyl sulfoxide with chloromethyl methyl ether or acetyl chloride has been shown to give methylal, dimethyl sulfide, dimethyl disulfide, methyl methanethiolsulfonate, methyl chloride, and paraformaldehyde.[1] When uracil was present in the reaction mixture, it was converted to 5-(methylthio)uracil (**1**) in good yield. However, on treatment with a mixture of dimethyl sulfoxide and acetic anhydride,[2] uracil was found to be stable. Few papers on using dimethyl sulfoxide as a methylthiation reagent have appeared,[3] and a mixture of dimethyl sulfoxide and

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