

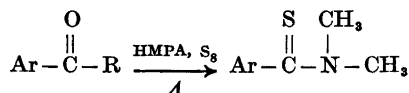
Studies on Organophosphorus Compounds. XII.* About Elemental Sulfur as a Reducing Agent in Hexamethylphosphoric Triamide (HMPA)

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Deoxybenzoin, benzoin, 1,2-diphenyl-1,2-ethanediol, 1,2-diphenylethanol, and benzil all give *E*-stilbene in fair to good yields, when reacted with S_8 in HMPA at elevated temperatures. Benzoin is first oxidized to benzil and then reduced to stilbene. 1,2-Diphenylethanol undergoes H_2O -elimination to deoxybenzoin and subsequent reduction to stilbene. Isolation of bis(diphenylethyl)polysulfide in the reactions of 1,2-diphenylethanol and 1,2-diphenyl-1,2-ethanediol and further thermal decomposition of the polysulphide to *E*-stilbene and S_8 , indicates this compound as a possible intermediate in these reactions. Oxidative degradation of the five substrates produces *N,N*-dimethylthiobenzamide, which partly undergoes demethylation to give *N*-methylthiobenzamide. Also the following heterocycles were isolated: 4,5-diphenyl-3*H*-1,2-dithiole-3-thione, 3-methyl-4,5-diphenyl-4-thiazoline-2-thione, 4,5-diphenyl-4-thiazoline-2-thione, and tetraphenylthiophene.

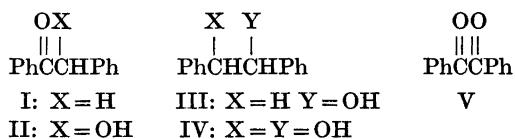
Recently it was shown¹ that elemental sulfur in HMPA smoothly oxidizes different substrates as aldehydes, ketones, alcohols, halides, and amines. The reaction times are short and generally the yields are very acceptable. Contrary to the well-known Willgerodt-Kindler reaction alkyl aryl ketones are oxidized and degraded to aromatic *N,N*-dimethylthiocarboxamides.



As a logical continuation of that investigation some other types of ketones and alcohols

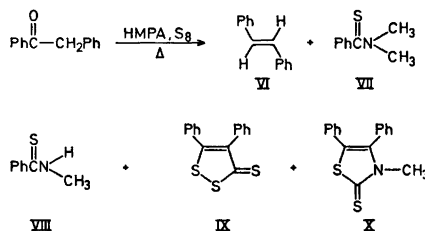
* Part XI see Ref. 1.

have been studied and this paper deals with the substrates I–V.



RESULTS AND DISCUSSION

The reason for investigating the substrates I–V was, that the ketone I when heated in HMPA at 205 °C with excess of sulfur gave as main product, *E*-stilbene, VI, and also the expected degradation products, *N,N*-dimethylthiobenzamide, VII, and *N*-methyl thiobenzamide, VIII, and two heterocycles, 4,5-diphenyl-3*H*-1,2-dithiole-3-thione, IX, and 3-methyl-4,5-diphenyl-4-thiazoline-2-thione, X (Scheme 1).



Scheme 1.

These results were not expected and to our knowledge not observed earlier. Some related substrates, II–V, with two terminal phenyl groups were then studied, and the intention

Table 1. Reaction conditions and product distribution from the reaction of elemental sulfur in HMPA with the substrates I–V.

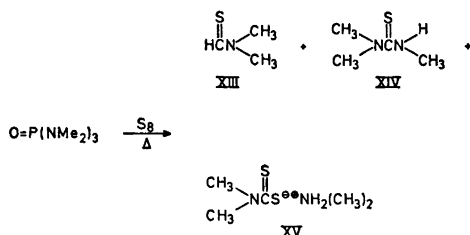
Substrate ^a	Reaction temp. (°C)	Reaction time (min)	Products (%)							
			VI	VII	VIII	IX	X	XI	XII	XVI
I	205	30	73	11	2	1	1			
II	205	120	65	14	4	2	2			
III	205	20	70	3	2	2	1			
IV	205	25	59	7	3	2	1			19
V	225	45	37	15	4	2	6	4	3	10

^a In all reactions were used 0.3 mol of S₈, 25 ml of HMPA, and 0.05 mol of substrate.

was to find out to what extent elemental sulfur would react as a reducing agent in HMPA. In literature very few reports have been given about sulfur as a reducing agent in the presence of amines. Staneck has reported that benzophenone and sulfur in morpholine give diphenylmethane and bis(diphenylmethyl)disulfide.^{2,3} Moreau reinvestigated this reaction⁴ and demonstrated that H₂S played a key-role. The same was the case with reduction of chalcone.⁵

In Table 1 are seen the reaction conditions and the product distribution.

Earlier it has been shown that sulfur oxidizes HMPA under similar conditions as used here. The products found resulted from oxidation or oxidative degradation of the dimethylamino groups of HMPA and were the expected products XIII–XV (Scheme 2).



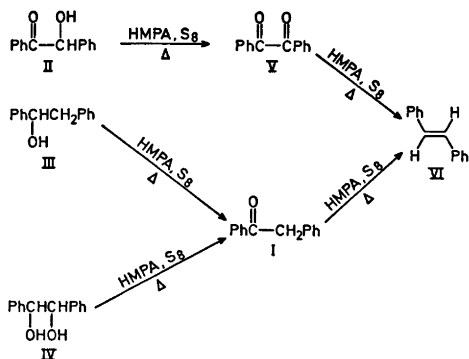
Scheme 2.

E-Stilbene is the main product isolated from all five reactions (Table 1). However, it is not known, if *Z*-stilbene is first formed, as it smoothly and completely is converted into *E*-stilbene by heating with S₈ in HMPA at 200 °C for 1.5 h. Based on the present results it is premature at this stage of the investigation to suggest a mechanism for the formation of stilbene. However, a few features should be

noted: The reaction between benzoin, II, and S₈ produces benzil, V, in 86 % yield, when the reaction time is short (a few minutes) (Scheme 3). Benzoin, fused with sulfur, also gives benzil.⁶ The reduction of benzoin produces a considerably higher yield of stilbene than benzil does which would indicate that H₂S plays a keyrole in the reaction. It is also observed that H₂S is immediately formed in the reaction of II with S₈, while the detection of H₂S in the reaction of V with S₈ is slow. It is suggested that the formation of H₂S in the last reaction results from oxidation of the dimethylamino groups of HMPA. A search in literature shows that benzoin has not been reacted with H₂S alone, but with HCl present to give 2,3,5,6-tetraphenyl-1,4-dithiacyclohexadiene as the main product and *E*-stilbene in minor amounts (5 %).⁷ Also benzil was only reduced to deoxybenzoin or benzoin under basic conditions,⁸ so probably the reduction under our conditions goes through other intermediates.

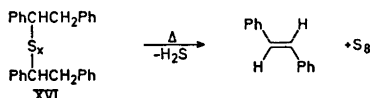
In the reaction of 1,2-diphenylethanol, III, deoxybenzoin, I, could be isolated when the reaction was interrupted before total conversion had occurred. However, as I does react very fast with S₈ to give VI only small amounts of I could be isolated. Also in the reaction of 1,2-diphenyl-1,2-ethanediol, IV, with S₈, I was isolated as an intermediate, formed by H₂O-elimination from IV (Scheme 3).

1,2-Diphenylethanol, III, and 1,2-diphenyl-1,2-ethanediol, IV, both produce bis(1,2-diphenylethyl)polysulfides, XVI, as minor products. According to a microanalysis XVI had an average content of sulfur atoms of 3.2. A disulfide has earlier been reported as intermediate in the reduction of benzophenone with sulfur in



Scheme 3.

boiling morpholine.⁴ Thiobenzophenone was suggested to be first formed and then reduced to the disulfide. So probably under our conditions the initially formed deoxybenzoin, I, reacts further, possibly *via* the corresponding thioketone, to XVI, which finally decomposes to *E*-stilbene. In fact, attempts to distill XVI under reduced pressure gave *E*-stilbene and sulfur:



Reduction of XVI with Zn and HCl produces 1,2-diphenylethylmercaptan, XVII. The same reduction of the corresponding disulfide is known.⁶ A very small fraction possibly containing the polysulfane, XVIII, was isolated in the reaction of IV.

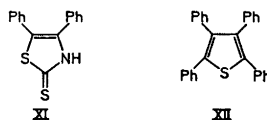


TLC (*R_F*-values) of XVII and XVIII were identical and the NMR-spectra were similar. However, the SH-proton in XVII was found as a doublet at δ 1.9, while the S_xH-proton of XVIII was found as a singlet at δ 2.0. Further, signals in the NMR-spectrum of XVIII at δ 2.4 and 2.5 were probably due to impurities as repeated purification (column chromatography) changed the ratios of these signals to the other signals in the spectrum.

It has recently been shown,¹⁰ that deoxybenzoin when heated in HMPA yields 13 % of

N,N-dimethylbenzamide. It is also known that carboxamides are easily converted to thio-carboxamides by reaction with S₈ in HMPA and by reaction with dithiophosphoric acids.¹¹ The formation of *N,N*-dimethylthiobenzamide, VII, (Table 1) can thus be accounted for in several ways.¹ That VII undergoes demethylation at elevated temperatures in HMPA with S₈ present is also since recently a known reaction.¹

In the reaction of benzil, V, a higher temperature (225 °C) is needed to get fair yields of products. Small yields of tetraphenylthiophene, XII, are also isolated, maybe due to the known reaction of stilbene with S₈ at 240–250 °C to give XII.¹² Also in this reaction three other products were isolated, *viz* IX, X, and 4,5-diphenyl-4-thiazoline-2-thione, XI.



EXPERIMENTAL

NMR-spectra were recorded at 60 MHz on a Varian A-60 spectrometer. TMS was used as internal reference standard. The chemical shifts are expressed in δ-values (s=singlet, d=doublet, m=multiplet). IR-spectra were recorded on a Beckman IR-18 spectrophotometer. Mass-spectra were recorded on a CEC 21-104 operating at 70 eV, using direct inlet. Direct inlet temperature 180–190 °C, ion source temperature 250 °C. Column chromatography was carried out with Silica gel 60 (Merck) *R_F*-values on TLC are given with Silica gel as supporting material and elution with light petroleum-CH₂Cl₂ (1:1). Commercial HMPA dried over molecular-sieves was used. Elemental analyses were performed by Novo Industry A/S, Copenhagen. M.p.'s are uncorrected.

General procedure. 0.05 mol of substrates were heated under vigorous stirring with 0.3 mol of S₈ in 25 ml of HMPA until the substrate was consumed (followed on TLC) (in the reaction of benzoin until benzil was used up). After cooling to room temperature 250 ml of water and 100 ml of ether were added, and non-reacted sulfur was filtered off. After ether extraction (3 × 100 ml) and washing with 2 × 50 ml of H₂O the combined ether phases were dried (CaSO₄) and the ether evaporated. The mixture was then dissolved in hot CCl₄. *E*-Stilbene crystallized from the solution on cooling and was filtered off. After evaporation of CCl₄ the remaining mixture was column chromatographed. Mixtures of CH₂Cl₂ and light petroleum were used as eluent, starting with light

petroleum and raising the polarity. Most, but not all of the compounds in the mixtures could be purified and characterized in this way. The yields of the compounds thus isolated are given in Table 1, and the physical properties are as follows:

E-Stilbene (VI): M.p. 122–123 °C (CCl₄) (lit.¹ m.p. = 122 °C). *R_F*-value: 0.82. Spectral evidence was in accordance with an authentic sample.¹

N,N-Dimethylthiobenzamide (VII): M.p. 67 °C (EtOH) (lit.¹ n.p. 67 °C). *R_F*-value: 0.25. Spectral evidence was in accordance with an authentic sample.¹

N-Methylthiobenzamide (VIII): M.p. 77–78 °C (EtOH) (lit.¹ m.p. 77–78 °C). *R_F*-value: 0.15. Spectral evidence was in accordance with an authentic sample.¹

4,5-Diphenyl-3H-1,2-dithiole-3-thione (IX): M.p. 159 °C (CHCl₃) (lit.¹ m.p. 159 °C). *R_F*-value: 0.42. Spectral evidence was in accordance with an authentic sample.¹

3-Methyl-4,5-diphenyl-4-thiazoline-2-thione (X): M.p. 199 °C (ether–CHCl₃) (lit.¹³ m.p. 201–202 °C). *R_F*-value: 0.43. (Found: C 67.40; H 4.62; N 5.16; S 22.62. C₂₀H₁₃NS₂ requires: C 67.81; H 4.62; N 4.94; S 22.63). NMR (CDCl₃): 3.5(s,3H); 7.2(m,10H). IR (CHCl₃): 1100, 1435, 1480, 1580 and 2950 cm⁻¹. MS: *m/e* 283 (M⁺, 100 %), 267(M–CH₃, 30 %), 210(M–CH₂NCS, 19 %), 178(PhCCPh, 33 %), 165(M–PhCNCH₂, 71 %), 121(PhCS⁺, 23 %), 118(PhCNCH₂⁺, 28 %), 89 (27 %), 77 (52 %).

4,5-Diphenyl-4-thiazoline-2-thione (XI): M.p. 223–224 °C (MeOH–CHCl₃) (lit.¹⁴ m.p. 224 °C). *R_F*-value: 0.40. (Found: C 66.37; H 4.08; N 5.18; S 23.76. C₁₅H₁₁NS₂ requires: C 66.88; H 4.12; N 5.20; S 23.80). NMR (CF₃COOH): 7.4(m). IR (KBr): 1110, 1480, 1590, 3050 and 3400 cm⁻¹. MS: *m/e* 269 (M⁺, 100 %), 210 (M–CSNH, 40 %), 178 (PhCCPh, 21 %), 165 (M–PhCNH, 68 %), 121 (PhCS⁺, 40 %), 89 (20 %), 77 (25 %).

Tetraphenylthiophene (XII): M.p. 184 °C (ether–CHCl₃) (lit.¹ m.p. 181–183 °C). *R_F*-value: 0.81. Spectral evidence was in accordance with an authentic sample.¹

Bis(1,2-diphenylethyl)polysulfide (XVI): A viscous liquid with *R_F*-value (on silica gel eluted with 10 % CH₂Cl₂ in light petroleum): 0.26. (Found: C 72.44; H 5.68; S 22.21, which gives C₂₈H_{26.8}S_{3.2}). NMR (CDCl₃): 3.3(m, 4 H), 4.4(m, 2 H), 7.2(m, 20 H). IR (CCl₄): 1070, 1440, 1485, 2900 and 3050 cm⁻¹.

Reduction of XVI. To 200 mg of XVI and 2 g of Zn-powder in 10 ml of EtOH were dropwise added 10 ml of 4 N HCl, during 30 min under stirring. Addition of H₂O (50 ml) followed by ether extraction (2 × 25 ml), drying (CaSO₄), and evaporation of the ether gave a mixture which was column chromatographed to yield 120 mg of *1,2-diphenylethylmercaptan*, m.p. 37–38 °C (lit.⁹ m.p. 41 °C). *R_F*-value (on silica gel eluted with 10 % CH₂Cl₂ in light petroleum): 0.34. NMR (CDCl₃): 1.9 (d, 1 H), 3.2 (m, 2 H), 4.3 (m, 1 H), 7.2 (m, 10 H).

1,2-Diphenylethylpolysulfane (XVIII): *R_F*-value (on silica gel eluted with 10 % CH₂Cl₂ in light petroleum): 0.34. NMR (CDCl₃): 2.0 (s, 1 H), 3.4 (m, 2 H), 4.3 (m, 1 H), 7.2 (m, 10 H).

Isolation of intermediates

Benzoin (10.6 g) was heated for 5 min at 190 °C with 9.6 g of S₈ in 25 ml of HMPA. The above described working-up procedure was used. Recrystallization from MeOH of the obtained product yielded 9.0 g (86 %) of *benzil*, m.p. 95 °C (lit.¹⁵ m.p. 95 °C). IR (CCl₄): 865, 1170, 1200, 1440, 1590, 1670 and 3050 cm⁻¹ which was identical with an IR-spectrum of a commercially available compound.

I. 1,2-Diphenyl-1,2-ethanediol (5.4 g) was heated for 40 min at 185 °C with 4.8 g of S₈ and 12.5 ml of HMPA. The same working-up procedure as above and column chromatography with CH₂Cl₂–light petroleum (1:1) yielded first a mixture of products and then 290 mg of *deoxybenzoin*, m.p. 58 °C (lit.¹⁶ m.p. 60 °C). NMR (CDCl₃): 4.3 (s, 2 H); 7.4 (m, 8 H); 8.0 (m, 2 H). IR (CCl₄): 990, 1270, 1450, 1500, 1590, 1600, 1690, 3040 cm⁻¹. These spectra were identical with spectra of a commercially available compound. Finally 3.8 g of starting material was eluted with CH₂Cl₂–ether (1:1).

II. 1,2-Diphenylethanol (9.9 g) was heated for 12 min at 204 °C with 9.6 g of S₈ in 25 ml of HMPA. The same working-up procedure as for 1,2-diphenyl-1,2-ethanediol yielded 180 mg of *deoxybenzoin*, characterized as above, and 4.5 g of starting material.

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