Thiocarbonyl Elimination from Sulphenic Systems. Part II.[1] Elimination of Benzenethiol from Substituted Diphenylmethyl Phenyl Disulphides

By **U. Miotti,*** **U. Tonellato,** and **A. Ceccon,** Istituto di Chimica Organica, University of Padova, 35100, Italy

Aryl diphenylmethyl disulphides undergo elimination of arenethiol to give thiobenzophenones by the action of sodium isopropoxide in isopropyl alcohol. The yield of thiobenzophenones varies with the nature of the substituents both on the diphenylmethyl and on the aryl moiety, being higher in the case of electron-attracting substituents. The second-order elimination rate constants at 20° allow one to estimate an approximate Hammett ρ value of +4 for diphenylmethyl substituents and of +2 for aryl substituents. A kinetic isotope effect, k_H/k_D, of 6·1 at 30° was measured for α-biphenyl-4-ylbenzyl 4-tolyl disulphide. Tritium exchange experiments carried out on this material showed no appreciable tritium intake by the unchanged material.

A concerted elimination mechanism is suggested and the geometry of the transition state is discussed. The results of thiocarbonyl elimination from aryl diphenylmethyl disulphides are compared with those of hydrogen cyanide elmination from diphenylmethyl thiocyanates.

CONSIDERABLE attention has been devoted to the fission of the S–S bond by nucleophilic reagents.[2] When nucleophiles are 'thiophilic' in character, such as CN^-, SCN^-, RS^-, *etc.*, the mechanism is a bimolecular displacement on sulphur with a transition-state profile closely resembling that of an S_N2 displacement on carbon.[2e] On the other hand, the fission of the disulphide bond by 'basic' nucleophiles, such as metal hydroxides and alkoxides, has been interpreted on the basis of different mechanisms.

The alkaline cleavage of disulphide linkages in proteins and simpler aliphatic disulphides has been reviewed.[2b, 2d, 3] The following mechanisms have been suggested: (*a*) a direct nucleophilic attack on a sulphur atom with displacement of a thiolate ion and formation of sulphenic acid (or a derivative), as suggested by Schöberl[4] and later supported by Parker and Kharash[2b] [equation (1)];

$$R^1\text{–}S\text{–}S\text{–}R^1 + R^2\text{–}O^- \longrightarrow R^1\text{–}S^- + R^1\text{–}S\text{–}O\text{–}R^2 \quad (1)$$

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[1] Part I, A. Ceccon, U. Miotti, U. Tonellato, and M. Padovan, *J. Chem. Soc.* (*B*), 1969, 1084.

[2] For reviews, see (*a*) D. S. Tarbell and D. P. Harnish, *Chem. Rev.*, 1951, **49**, 11; (*b*) A. J. Parker and N. Kharasch, *ibid.*, 1959, **59**, 583; (*c*) O. Foss, in 'Organic Sulphur Compounds,' ed. N. Kharasch, Pergamon Press, Oxford, 1961, ch. 9; (*d*) J. P. Danehy, in 'The Chemistry of Organic Sulphur Compounds,' ed. N. Kharasch and C. Y. Meyers, Pergamon Press, Oxford, 1966, vol. 2, p. 337; (*e*) E. Ciuffarin and A. Fava, in 'Progress in Physical Organic Chemistry,' ed. A. Streitwieser, jun., and R. W. Taft, Interscience Publishers, New York, 1968, vol. 6, p. 81.

[3] A. Schöberl and A. Wagner, in 'Methoden der Organischen Chemie,' ed. Houben-Weyl, Thieme, Stuttgart, 1955, vol. 9, p. 75.

[4] A. Schöberl, *Annalen*, 1934, **507**, 111; A. Schöberl, E. Beringer, and F. Harren, *Ber.*, 1934, **67**, *B*, 1545.

(*b*) a β-elimination mechanism in which the initial step is the base-promoted ionization of a hydrogen from a carbon β to a sulphur atom with subsequent formation of an olefin and of a disulphide ion [equations (2) and (3)], as was suggested by Tarbell and Harnish[2a] and by Wallace and his co-workers;[5,6] (*c*) an α-elimination

$$\mathrm{R^1{-}S{-}S{-}CH_2{-}CH_2{-}R^2 + R{-}O^- \rightleftharpoons R^1{-}S{-}S{-}CH_2{-}\bar{C}H{-}R^2 + R^1{-}OH} \quad (2)$$

$$\mathrm{R^1{-}S{-}S{-}CH_2{-}\bar{C}H{-}R^2 \longrightarrow R^1{-}S{-}S^- + CH_2{=}CH{-}R^2} \quad (3)$$

mechanism initiated by dissociation of a hydrogen α to a sulphur atom followed by decomposition of the resulting carbanion to a thiolate ion and a thiocarbonyl compound [equations (4) and (5)] as suggested by Rosenthal and Oster.[7]

$$\mathrm{R^1{-}S{-}S{-}CH_2{-}R^2 + R^1{-}O^- \rightleftharpoons R^1{-}S{-}S{-}\bar{C}H{-}R^2 + R^1{-}OH} \quad (4)$$

$$\mathrm{R^1{-}S{-}S{-}\bar{C}H{-}R^2 \longrightarrow R^1{-}S^- + S{=}CH{-}R^2} \quad (5)$$

No one mechanism operates in the alkaline cleavage of all disulphides though, depending on the structural features of the substrate, one may prevail. The concurrent operation of more than one mechanism in the same system should not be excluded. The difficulty in discriminating among the above alternatives and in particular between (*a*) and (*c*) is that the primary decomposition products are not easily isolated and identified and the final products can be usually accounted for by more than one mechanism.

We found[8] that aryl diphenylmethyl disulphides decompose by reaction with sodium isopropoxide in isopropyl alcohol to give mainly thiobenzophenones and benzenethiols [equation (6)]. This class of disulphide

$$\mathrm{Ar_2CH{-}S{-}S{-}Ar \xrightarrow{Pr^iO^-} Ar_2C{=}S + HS{-}Ar} \quad (6)$$

was suitable for a mechanistic study because (*a*) the α-elimination products, the thiobenzophenones, are relatively stable and their formation can be easily followed; (*b*) the presence of substituents on phenyl rings may alter the acidic character of the diphenylmethyl hydrogen and so modify the balance between possible concurrent mechanisms, such as the α-elimination process and a direct attack of the base on one of the sulphur atoms; and (*c*) a β-elimination is excluded.

This paper deals with a mechanistic study of the sodium isopropoxide-promoted elimination of benzenethiols from substituted aryl diphenylmethyl disulphides.

EXPERIMENTAL

Isopropyl alcohol was purified as previously reported.[1] Reagent grade benzene was refluxed over sodium–potassium alloy and distilled. Isopropyl [$^3H_1$]alcohol and the solutions of sodium isopropoxide in isopropyl alcohol were prepared as previously described.[1]

Phenylsulphenyl chloride,[9] 4-tolylsulphenyl chloride,[10] and 4-chlorophenylsulphenyl chloride[11] were obtained by chlorination of the corresponding benzenethiols.

Diphenylmethanethiol,[12] α-(4-chlorophenyl)toluene-α-thiol,[13] and α-biphenyl-4-yltoluene-α-thiol,[1] were prepared from the corresponding diphenylmethyl chlorides by the Klenk[12] method.

[α-^{2}H]-α-*Biphenyl-4-yltoluene-α-thiol*.—[α-^{2}H]-α-Biphenyl-4-ylbenzyl alcohol[1] (0·95 g.) was converted into the corresponding chloride by treatment with thionyl chloride (2·0 g.) at −30°. After 1 hr. at room temperature, the excess of thionyl chloride was pumped off and the crude product washed with light petroleum and dried under vacuum. The chloride (1 g.) was dissolved in anhydrous acetone (10 ml.) containing thiourea (0·39 g.) and refluxed for 4 hr. The solvent was then pumped off and the residue refluxed for 3 hr. under nitrogen with a solution of sodium hydroxide (0·39 g.) in ethanol–water (3 : 1 v/v) (8 ml.). The crude thiol obtained by dilution with water and acidification with sulphuric acid was chromatographed on silica gel (cyclohexane eluant): 0·65 g.; m.p. 87—89°.

The α-deuterium content was at least 97% by n.m.r. In deuteriochloroform (13% w/w) the product gave only bands at τ 2·40—2·60 (m) and τ 7·72 (s). No signal was observed at τ 4·48 (d) for the α-hydrogen atom.

Aryl Diphenylmethyl Disulphides.—Equimolar solutions of diphenylmethanethiols and arylsulphenyl chlorides in anhydrous ether were mixed at 0°. After 1 hr. each mixture was washed with water, dried (Na_2SO_4 and Drierite), and the solvent was removed under reduced pressure. The crude product, containing variable amounts of symmetrical disulphide was then purified as reported in Table 1.

Reaction Products.—In an experiment performed under preparative conditions, α-biphenyl-4-ylbenzyl 4-chlorophenyl disulphide (0·52 g., 1·24 mmoles) were dissolved in benzene (20 ml.) and treated with a solution (20 ml.) of sodium isopropoxide (2·46 mmoles) in isopropyl alcohol. After 30 min. the solution was extracted three times with water. The aqueous portions were acidified and twice extracted with cyclohexane. After the latter solvent was pumped off, the crude 4-chlorobenzenethiol was purified by sublimation under vacuum: 0·110 g. (60%); m.p. 50—52° (lit.,[14] 53—54°). The organic layer was dried (Na_2SO_4) and, after removal of the solvent, the residue, 4-phenyl(thiobenzophenone), was chromatographed on silica gel under nitrogen (eluant CCl_4). The product (0·170 g., 50%), m.p. 124—125° (lit.,[15] 125·7°), showed visible, u.v., and i.r. spectra superimposable on those of the authentic thioketone prepared from the oxygen analogue.

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[5] J. E. Hofmann, T. J. Wallace, P. A. Argabright, and A. Schriesheim, *Chem. and Ind.*, 1963, 1243.

[6] T. J. Wallace, J. E. Hofmann, and A. Schriesheim, *J. Amer. Chem. Soc.*, 1963, **85**, 2739; J. E. Hofmann, T. J. Wallace, and A. Schriesheim, *ibid.*, 1964, **86**, 1561.

[7] N. A. Rosenthal and G. Oster, *J. Soc. Cosmetic Chemists*, 1954, **5**, 286; *J. Amer. Chem. Soc.*, 1961, **83**, 4445.

[8] U. Miotti, A. Sinico, and A. Ceccon, *Chem. Comm.*, 1968, 724.

[9] Ref. 4, p. 272.

[10] H. Lecher, F. Holschneider, K. Koberle, W. Speer, and P. Stöchlin, *Ber.*, 1925, **58**, 409.

[11] E. Gebauer-Fulnegg, *J. Amer. Chem. Soc.*, 1927, **49**, 2274.

[12] M. M. Klenk, C. M. Suter, and S. Archer, *J. Amer. Chem. Soc.*, 1948, **70**, 3846.

[13] Hiroichi Fukuda, *J. Pharm. Soc. Japan*, 1952, **72**, 1472 (*Chem. Abs.*, 1952, **47**, 8706).

[14] R. Otto and L. Brummer, *Annalen*, 1867, **143**, 109.

[15] R. W. Bost and B. O. Cosby, *J. Amer. Chem. Soc.*, 1935, **57**, 1404.

Thiobenzophenones were not usually isolated. Their identity was proved at the end of each kinetic run by comparison of the visible spectra, showing a characteristic bell-shaped absorption band centred at *ca.* 600 mμ, with those of authentic samples.

The determination of the benzenethiols was attempted by v.p.c. analysis. In an experiment under kinetic conditions in isopropyl alcohol–benzene (19 : 1) at 20°, a solution (20 ml.) $8{\cdot}86 \times 10^{-3}$M in α-biphenyl-4-ylbenzyl 4-chlorophenyl disulphide and $4{\cdot}70 \times 10^{-3}$M in sodium isopropoxide was set aside for *ca.* 60 min. 4-Phenyl(thiobenzophenone) (yield 76%) was determined spectrophotometrically from the known value of the extinction coefficient at 603 mμ. The mixture was mixed with a standard solution (25 ml.) of dodecane (0·335 mg./ml.) in benzene and the solution was washed with dilute hydrochloric acid and water and dried (Na_2SO_4). An aliquot portion (0·5 ml.) of this solution was frozen and sealed under vacuum in one arm of a U-tube. Solvent, dodecane, and 4-chlorobenzenethiol were then quantitatively sublimed into the second arm of the tube and analysed on an Aerograph model 1520 v.p. chromatograph with a 250 × 0·6 cm. column packed with 60—80 mesh Chromosorb W containing 5% SE30. The amount of 4-chlorobenzenethiol determined by this method corresponded to at least 90% of the theoretical yield based on the initial disulphide. A similar experiment was carried out on diphenylmethyl 4-tolyl disulphide. In a duplicate run, the 4-thiocresol recovered by sublimation from the reaction mixture and determined as described above corresponded to at least 80—85% of the theoretical yield.

TABLE 1

Aryl diphenylmethyl disulphides, $X{-}C_6H_4(Ph)CH{-}S{-}S{-}C_6H_4{-}Y$

				Found (%)				Required (%)			
X	Y	M.p.[a]	Yield (%)	C	H	S	Cl	C	H	S	Cl
H	H	Oil [b]		73·0	5·2	20·8		74·0	5·25	20·8	
4-Ph	H	88—89·5° [c]	31	77·75	5·2	16·55		78·1	5·25	16·65	
4-Cl	H	49—50 [d]	16	65·85	4·15	18·3	10·85	66·5	4·4	18·7	10·35
H	4-Me	75—76 [e]	15	73·0	5·85	20·2		74·5	5·65	19·9	
4-Ph	4-Me	110—111 [f]	30	78·15	5·8	16·1		78·35	5·8	15·95	
4-Ph [g]	4-Me	111—111·5 [f]									
H	Cl	58—59 [h]	53	65·8	4·35	18·75	10·35	66·55	4·4	18·7	10·35
4-Ph	Cl	106—107 [h]	85	68·0	4·35	15·3	8·3	71·5	4·8	15·25	8·45
4-Cl	H	Oil [b]	37	60·8	3·75	16·7	19·5	60·45	3·75	17·0	18·8

[a] Melting points were determined with a Kofler apparatus; uncorrected. [b] Purified by chromatography on silica gel, light petroleum as eluant. [c] Purified by chromatography on silica gel, eluant cyclohexane, and crystallization from ether–light petroleum. [d] Purified by chromatography on silica gel, eluant light petroleum, and crystallization from ethanol. [e] Purified by chromatography on silica gel, eluant 19 : 1 cyclohexane–benzene, and crystallization from ethanol. [f] Washed with 2 : 1 light petroleum–ether and crystallized from ethanol. [g] [α-^{2}H]-α-Biphenyl-4-ylbenzyl 4-tolyl disulphide. The α-deuterium content was at least 97—98% by n.m.r. In deuteriochloroform (13% w/w) only signals at τ 2·5—2·9 (m) and at τ 7·68 (s) were observed. The α-hydrogen signal at τ 4·65 (s) was absent. [h] Crystallized from ethanol.

On the other hand, v.p.c. analysis of the unsublimed residue showed the same fragmentation pattern of the diphenylmethyl disulphide whose amount was estimated to be 30—45% of theoretical. The analysis showed also the absence of 4-tolyl disulphide in amounts higher than 5% relative to the starting material.

Hydrogen-exchange Test.—A solution of α-biphenyl-4-ylbenzyl 4-tolyl disulphide in 10 ml. of isopropyl [^{3}H]alcohol (0·34 mc/ml.) and 0·56 ml. of benzene was introduced into a 15 ml. cell equipped with a magnetic stirrer and fitted into a colorimeter. A solution of sodium isopropoxide in isopropyl alcohol (0·60 ml.) was then injected so that the initial concentration of the resulting solution was $4{\cdot}60 \times 10^{-3}$M in substrate and $7{\cdot}63 \times 10^{-3}$M in base. The reaction was allowed to proceed to about 50% completion (6 min.) and then quenched by injection of dichloroacetic acid. The mixture was added to a solution of 0·156 g. of carrier disulphide in ether and exhaustively washed with water until no activity was detected in the aqueous layer. After drying (Na_2SO_4) the solvent was removed with a nitrogen stream and the residue twice crystallized from ethanol: it had m.p. 111—112°, and i.r., u.v., and visible spectra superimposable on those of the starting disulphide. Activity was measured on a Beckman CPM-100 scintillation counter with samples dissolved in toluene solution containing POP (5%) and POPOP (0·5%). Corrections for quenching were made by use of the automatic external standardization mode of the counter and calibration curves determined with standard quenched solutions. The specific activity of the product was 1·55 ± 1·0 disintegrations min.$^{-1}$ mg.$^{-1}$.

Kinetic Measurements.—The experimental procedure and the calculation methods have been described.[1]

RESULTS

The thiocarbonyl elimination from diphenylmethyl phenyl disulphides bearing *para*-substituents both on one of the diphenylmethyl phenyl groups (X) and on the benzenethiol ring (Y) was studied for solutions in 19 : 1 isopropyl alcohol–benzene at 20° under nitrogen. Benzene was added because most disulphides are not soluble enough in pure isopropyl alcohol to reach the desired concentrations.

Thiobenzophenone yields were determined on the basis of the maximum value of optical density at about 600 mμ reached at the end of the reaction and of predetermined extinction coefficients.[1] The stability of the thiobenzophenones under the kinetic conditions was controlled in preliminary experiments with authentic samples. Only when relatively high isopropoxide concentrations were used did thio-ketones decompose at a significant rate. In each case, however, appropriate conditions were chosen to ensure stability of the thiobenzophenones at least for 4—5 half-lives. On the other hand, addition of benzenethiols did not appreciably affect the rate of decomposition.

The reproducibility of the yields of thio-ketone, in spite of substantial variations of base and substrate concentrations (Table 2) also indicates the stability of these products. The elimination fraction α (Table 2), based on the thiobenzophenone yields, varies from 86% when both X and Y

TABLE 2

Rate constants and elimination fractions (α) for the thiocarbonyl elimination from disulphides, $X-C_6H_4(Ph)-CH-S-S-C_6H_4-Y$, promoted by sodium isopropoxide in 19 : 1 isopropyl alcohol–benzene at 20° [a]

X	Y	Disulphide (mmole $l.^{-1}$)	Base (mmole $l.^{-1}$)	k_{el} (l. $mole^{-1}$ $sec.^{-1}$)	α
4-Cl	4-Cl	3·85	7·75	0·72	0·856
		3·85	7·75	0·74	0·860
		3·85	15·4	0·69	0·867
		3·85	38·7	0·64	0·867
				Mean 0·70	Mean 0·862
H	4-Cl	5·25	10·5	0·077	0·755
		4·93	14·7	0·076	0·775
		4·93	25·0	0·072	0·772
				Mean 0·075	Mean 0·767
4-Ph	4-Cl	4·05	9·02	0·154	0·767
		4·05	9·02	0·153	0·763
		4·05	14·3	0·146	0·767
				Mean 0·151	Mean 0·766
4-Cl	H	3·74	7·47	0·229	0·685
		3·74	11·3	0·251	0·680
		3·74	18·0	0·210	0·710
				Mean 0·230	Mean 0·692
H	H	6·24	32·0	0·0194	0·565
		6·24	64·3	0·0189	0·540
				Mean 0·0192	Mean 0·552
4-Ph	H	3·81	28·5	0·0401	0·694
		3·81	28·5	0·0421	0·693
		3·81	57·2	0·0411	0·710
				Mean 0·041	Mean 0·699
H	4-Me	4·61	27·7	0·0119	0·526
		4·61	88·0	0·0126	0·505
				Mean 0·0109	Mean 0·516
4-Ph	4-Me	3·57	23·1	0·0232	0·666
		3·57	92·5	0·0231	0·683
				Mean 0·0231	Mean 0·673
		3·38	50·0	0·044 [b]	0·588
		3·38	50·0	0·044 [b]	0·582
		3·38	50·0	0·046 [b]	0·573
				Mean 0·045 [b]	Mean 0·581
		3·94	50·0	0·0074 [b]	0·311
		3·94	50·0	0·0075 [b]	0·313
				Mean 0·0075 [b,c]	Mean 0·31

[a] Some results have been previously reported.[8] [b] At 30°. [c] [α-^{2}H]-α-Biphenyl-4-ylbenzyl 4-tolyl disulphide.

are Cl to 52% when X is H and Y is CH_3. It clearly increases when both X and Y are electron-withdrawing substituents although the trend is apparently not strictly regular.

Benzenethiols were isolated and quantitatively determined only in a few cases. In one experiment carried out on α-biphenyl-4-ylbenzyl 4-chlorophenyl disulphide under preparative conditions 4-chlorobenzenethiol was isolated in 60% yield. A quantitative determination of benzenethiol produced under kinetic conditions was attempted by v.p.c. The yield of 4-chlorobenzenethiol was at least 90% and that of toluene-4-thiol from α-biphenyl-4-ylbenzyl 4-tolyl disulphide 80%: in both cases they are distinctly higher than those of the corresponding thiobenzophenones (77 and 52% respectively). This allows the conclusion that benzenethiols are not only the products of the thiocarbonyl elimination but are also produced in a concurrent irreversible fission reaction. This competing reaction was not investigated. Kinetics, however, show that it has to be an irreversible second-order process which, most likely, involves a direct nucleophilic displacement by the base on one of the sulphur atoms of the disulphide linkage. The excess of yield of benzenethiols determined in the cases reported above suggests that the nucleophilic attack occurs at the sulphur atom bound to the diphenylmethyl half of the molecule. This would agree with the finding [16] that the most stable anion is lost in displacement reactions on unsymmetrical disulphides and with recent results [17] on the alkaline decomposition of substituted aromatic disulphides.

V.p.c. analysis of the reaction mixture showed that diphenylmethyl disulphides are also formed among other by-products whose identity, however, has not yet been ascertained.

The second-order elimination rate constants for variously substituted disulphides, k_{el}, are in Table 2. Substantial variations of base and, in some cases, of substrate do not change the values of k_{el} appreciably. The rate increases when both X and Y are electron-withdrawing substituents, the effect of X being larger than that of Y. Changing of X from H to Cl increases k_{el} by a factor of *ca.* 9 whereas a similar variation of Y increases the rate about fourfold.

Substitution of the central hydrogen with deuterium decreases k_{el} rather notably, the ratio k_H/k_D being 6·1 at 30° in the case of α-biphenyl-4-ylbenzyl 4-tolyl disulphide.

To ascertain whether a carbanion intermediate is involved in the elimination a duplicate experiment was carried out on α-biphenyl-4-ylbenzyl 4-tolyl disulphide with isopropyl [^{3}H]alcohol as solvent. The reaction was allowed to proceed to about 50% completion and, after quenching, the unchanged disulphide was reisolated. The activity measured on the recovered material was just above the background level of the scintillation counter and probably within the experimental error. It corresponded to less than 0·014% of the activity expected if complete equilibration between the central hydrogen and solvent had occurred.

DISCUSSION

Elimination Mechanism.—Substituent effects. The small number of substituents X and Y considered prevents a critical evaluation of the correlation of the kinetic data with the Hammett equation. However, if it is assumed that this relationship is obeyed, a rough estimate of the sensitivity of the reaction to substituents is possible by calculating the ρ values for X (ρ_X) and Y (ρ_Y) based on a double and triple set of data, respectively. These values (Table 3) are *ca.* +4 for ρ_X and +2 for ρ_Y. Differences in ρ_X depending on the nature of the leaving group are not considered significant owing to the uncertainty of the determinations, although an increase of ρ_X on going from Y = Cl to Y = Me could be expected.[18] In concerted elimination reactions from β-phenylethyl systems, in fact, it has been regularly observed that the worse the leaving group the higher is ρ.

The effect of X substituents may be compared with that (ρ = +3·5) determined for the analogous thio-

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[16] A. J. Parker and N. Kharasch, *J. Amer. Chem. Soc.*, 1960, **82**, 3071.

[17] J. P. Danehy and K. N. Parameswaran, *J. Org. Chem.*, 1968, **33**, 568.

[18] J. F. Bunnett, *Angew. Chem.*, 1962, **74**, 731.

carbonyl elimination of hydrogen cyanide from diphenylmethyl thiocyanates in isopropyl alcohol,[1] with the effect found ($\rho = +3{\cdot}4$) for the carbonyl elimination of nitrous acid from benzyl nitrates,[19] and with the largest ones observed for olefin-forming eliminations from β-phenylethyl systems ($\rho = +3{\cdot}77$ for trimethylammonium salts[20] and $+4{\cdot}4$ for methyl sulphoxides[21]). The ρ_X value of $+4$ is therefore, apart from the strictly numerical value, quite large and indicates that the transition state of the elimination reaction of the diphenylmethyl phenyl disulphides has a rather advanced carbanionic character, a large negative charge residing on the central carbon atom.

The ρ_Y value of $+2$ is also large compared with that of $+2{\cdot}85$ determined for the dissociation process of substituted benzenethiols in 19 : 1 ethanol–water at 20°.[22] It suggests a relatively extended etherolytic rupture of the –S–S– bond in the transition state of the reaction and therefore a partial negative charge residing in the leaving sulphur atom. The effect of Y substituents could be alternatively interpreted in terms of stabilization of a negative charge on the central carbon atom. If this is the case, however, one should admit that the S–S bond is not extensively broken in the transition state and that polar effects can be transmitted quite effectively through a disulphide linkage.

Testing a Possible Intermediate.—The possibility of a mechanism involving formation of a carbanion seems *a priori* probable for the thiocarbonyl elimination of the aryl diphenylmethyl disulphides since their structure is particularly apt to stabilize a negative charge on the carbon atom. Moreover this point is of particular interest because the so-called α-elimination route for the alkaline cleavage suggested by earlier authors was formally defined as involving formation of an intermediate carbanion [equation (2)], although definite evidence of its existence was never presented.

TABLE 3

Approximate values of the Hammett reaction constants, ρ, calculated for the thiocarbonyl elimination from disulphides, $X{-}C_6H_4(Ph)CH{-}S{-}S{-}C_6H_4{-}Y$ in 19 : 1 isopropyl alcohol–benzene at 20°

4-Substituents				
X	Y	ρ_X [a]	ρ_Y [a]	Correl. coefft.[b]
(Cl,Ph,H)	Cl	+4·30		0·998
(Cl,Ph,H)	H	+4·72		0·999
H	(Cl,H,Me)		+2·02	0·980
Ph	(Cl,H,Me)		+2·05	0·999
Cl	(Cl,H)		(+2·12)	

[a] By use of Hammett's σ constants.[22] For the phenyl-substituted derivative a σ^- constant of $+0{\cdot}084$ was used. This value was obtained by interpolation of the kinetic data obtained for the thiocarbonyl elimination from diphenylmethyl thiocyanates.[1] [b] Ref. 22, p. 253.

The lack of tritium intake found in the unchanged α-biphenyl-4-ylbenzyl 4-tolyl disulphide after 50% reaction clearly rules out the possibility that a carbanion, if formed, returns to starting material at a rate comparable with that of its decomposition to products [equation (7)] ($k_{-1} \geqslant k_2$). Some results[23] for the

$$\mathrm{Ar_2CH{-}S{-}S{-}Ar + Pr^iO} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}}$$

$$\mathrm{Pr^iOH + Ar_2\bar{C}{-}S{-}S{-}Ar} \xrightarrow{k_2} \mathrm{Ar_2C{=}S + {}^-SAr} \quad (7)$$

hydrogen exchange of [α-$^2H_1$]diphenylmethyl phenyl sulphide in isopropyl alcohol with sodium isopropoxide are noteworthy. The rate of exchange is lower than the rate of elimination determined for the structurally analogous phenyl diphenylmethyl disulphide by a factor of about 10^3. Since, apart from the isotope effect, the acidity of the two substrates should be not appreciably different, this result confirms that a reversible *E*1c*B* mechanism does not govern the elimination.

The possibility still exists that the ionization step is irreversible[24] [$k_2 \gg k_{-1}$ of equation (7)]. This possibility can be excluded on the basis of (*a*) the deuterium kinetic isotope effects and (*b*) the value of ρ_Y. The deuterium kinetic isotope effect, $k_H/k_D = 6{\cdot}1$, measured on the α-biphenyl-4-ylbenzyl 4-tolyl disulphide at 30°, is only slightly lower than the maximum theoretical value, 6·6, calculated for an intermediate proton transfer between oxygen and carbon at 30°.[25] The observed value is not consistent with the possibility of an irreversible carbanion mechanism: in the few cases in which such a scheme was suggested values of the isotope effect close to unity were determined.[26]

Moreover, an irreversible carbanionic mechanism does not imply a strong dependence of rate on leaving group goodness, as the relatively high positive ρ_Y indicates.

In conclusion our data do not support the existence of a carbanion in the base-promoted elimination of diphenylmethyl disulphides despite their favourable structure. It seems obvious that less favoured structures such as those of most aliphatic disulphides will be even more unlikely to react *via* a carbanion intermediate.

A Hybrid E1–E1cB Transition-state Model.—The mechanistic information so far examined does not allow us to draw a transition-state picture based on classical models[18,27] entirely consistent in any respect. On one hand, the absence of hydrogen exchange and in particular the magnitude of the isotope effect suggest a balanced situation consistent with a synchronous process. On the other the very large effect of substituents on both halves of the molecule implies a rather pronounced unbalance of the transition-state geometry.

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[19] J. W. Baker and T. G. Heggs, *J. Chem. Soc.*, 1955, 616; E. Buncel and A. N. Bourns, *Canad. J. Chem.*, 1960, **38**, 2457.

[20] W. H. Saunders, jun., D. G. Busham, and A. F. Cockerill, *J. Amer. Chem. Soc.*, 1968, **90**, 1775.

[21] R. Baker and M. J. Spillett, *J. Chem. Soc.* (*B*), 1969, 482.

[22] H. H. Jaffé, *Chem. Rev.*, 1953, **53**, 191.

[23] A. Ceccon, unpublished results.

[24] D. J. McLennan, *Quart. Rev.*, 1967, 490.

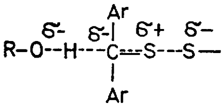
[25] F. H. Westheimer, *Chem. Rev.*, 1961, **61**, 265.

[26] D. J. Cram and A. S. Wingrove, *J. Amer. Chem. Soc.*, 1964, **86**, 3590; J. Crosby and C. J. M. Stirling, *ibid.*, 1968, **90**, 6869; Z. Rappoport and E. Shohamy, *Israel J. Chem.*, 1968, **6**, 15P.

[27] D. V. Banthorpe, 'Elimination Reactions,' Elsevier, Amsterdam, 1963.

However, there is no reason why the heteroeliminations and in particular the thiocarbonyl eliminations must fit exactly the same mechanistic patterns and the same transition-state models suggested for olefin-forming eliminations. Sulphur, for instance, is well known to form double bonds with carbon with reluctance as compared with a carbon–carbon system. The low effectiveness of π-type overlap involving $3p$ orbitals in the case of carbon–sulphur systems may be a barrier to the neutralization of developing opposite charges on the carbon and sulphur atoms. In the present case, this should imply very little double-bond character in the transition state in spite of a relatively extended C–H and S–S bond rupture.

Most reasonably, the transition-state picture which evolves from the mechanistic responses and from the above considerations is the one represented in (I). In terms of classical geometries it could be defined as a hybrid $E1$–$E1cB$-like, a transition state earlier suggested by Banthorpe,[28] with different arguments, for the elimination from some β-phenylated toluene-p-sulphonates.



$$\mathrm{R{-}\overset{\delta-}{O}\cdots H\cdots\underset{Ar}{\overset{\delta-\ \ Ar}{C}}\overset{\cdots}{=}\overset{\delta+}{S}\cdots\overset{\delta-}{S}{-}Ar}$$

(I)

Comparison with the Thiocarbonyl Elimination from Diphenylmethyl Thiocyanates.—The thiocarbonyl elimination from disulphides can be most directly compared with the analogous elimination (8) of hydrogen cyanide from diphenylmethyl thiocyanates recently investigated.[1]

$$\mathrm{Ar_2CH{-}S{-}CN}\xrightarrow[\mathrm{Pr^iOH}]{\mathrm{Pr^iONa}}\mathrm{Ar_2C{=}S + HCN}\qquad(8)$$

Both disulphides and thiocyanates are diphenylmethyl sulphenic systems, $\mathrm{Ar_2CH{-}S{-}Z}$, differing only in the nature of the leaving group, Z. The elimination from the two systems has been investigated in similar conditions and the results can be directly compared if one neglects the possible solvent effect of 5% benzene added to isopropyl alcohol in the case of the disulphides. The kinetic effect of added benzene should not exceed a 10% variation on the elimination rate constants, as was determined in preliminary kinetic runs carried out on α-biphenyl-4-ylbenzyl phenyl disulphide in pure isopropyl alcohol and in isopropyl alcohol–benzene (19 : 1).

The parameters determined for the two systems are summarized in Table 4.

It appears that while both systems are affected by comparable effects of substituents in the diphenylmethyl moiety and do not exchange hydrogen with the solvent, they markedly differ (*a*) in the magnitude of the deuterium isotope effect and (*b*) in absolute rate, the unsubstituted thiocyanate being more than 300 times faster than the analogous disulphide.

The difference in reactivity could be rationalized in terms of different leaving group goodness. However since cyanide ion and mercaptide ion do not differ appreciably in thionucleophilicity[29] this factor is unlikely to be responsible for the reactivity ratio of more than 300. We think that it is the acidity of the central hydrogen which plays the fundamental role in determining the different behaviour of the two systems. In fact, apart from the two phenyl groups present in both cases, in one an SCN group and in the other a S–S–Ar group are directly bound to the central carbon. There is little doubt that thiocyanate is a rather strong electron-attracting group capable of stabilizing a negative charge on an adjacent carbon atom mainly by the inductive effect. On the other hand, although strictly pertinent data are not available, polar effects due to the aryl disulphide group should be reasonably weak or at least much weaker than those attributable to the thiocyanate. Available Hammett substituent constants[30] show that alkylthio-groups are capable of weak electron-donating effects through resonance and of weak electron-accepting inductive effects which however just balance ($\sigma = 0{\cdot}00$ for p-$\mathrm{SCH_3}$). If polar effects due to an arylthio-group are assumed to be not very different from those of a simple alkylthio-group and the insertion of a bivalent sulphur atom is taken into account (*e.g.*, by considering the following σ-*para* values: 0·66 for CN, 0·52 for SCN, and 0·502 for $\mathrm{CO_2Me}$ and 0·44 for S–COMe) the ineffectiveness of the phenyl disulphide group relative to the thiocyano-group as an electron-attracting substituent can be safely inferred.

TABLE 4

Mechanistic parameters determined for the thiocarbonyl elimination from diphenylmethyl thiocyanates and from diphenylmethyl phenyl disulphides

Sulphenic system $\mathrm{X{-}C_6H_4(Ph)CH{\cdot}SZ}$	k_0 [a] (l. mole^{-1} sec.$^{-1}$)	ρ_X	k_H/k_D [b]	Hydrogen exchange
Z = CN	6·24	+3·4	3·0	Negative
$\mathrm{Z = S{-}C_6H_4{-}Y}$	0·019	+4	6·1 [c]	Negative

[a] Second-order elimination rate constants for the unsubstituted terms (Y = H) at 20°. [b] Determined on the 4-phenyl derivatives (Y = Me). [c] At 30°.

On this basis, the observed values of the deuterium kinetic effect can also be interpreted. The lower k_H/k_D ratio determined in the case of the thiocyanates is consistent with a transition state[31] in which the hydrogen is more extensively transferred to the base than in the case of the disulphides. An extensive rupture of the C–H bond for the former compounds implies a pronounced unbalance of the transition-state geometry and presumably a scarcely advanced etherolysis of the S–CN bond. Although no direct evidence is available, the

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[28] Ref. 27, p. 63.

[29] W. A. Pryor, 'Mechanisms of Sulphur Reactions,' McGraw-Hill Co. Inc., New York, 1962, p. 60 and references therein. See also R. G. Hiskey, W. H. Bowers, and D. N. Harpp, *J. Amer. Chem. Soc.*, 1964, **86**, 2010.

[30] J. E. Leffler and E. Grunwald, 'Rates and Equilibria of Organic Reactions,' J. Wiley and Sons, New York, 1963.

[31] See, for discussion, U. Miotti and A. Ceccon, *Ricerca Sci.*, 1968, **38**, 824.

lower ρ_X, +3·5, observed for the thiocyanates than for the disulphides may suggest that the negative charge developed on the central carbon atom in the transition state of the thiocyanates, although greater in magnitude, is effectively delocalized also toward the SCN group. This requires that the S–CN bond is not extensively broken.

In conclusion, the mechanistic responses of the thiocarbonyl elimination in the two systems are consistent with a shift in the spectrum of transition states from a balanced concerted geometry for the disulphides toward a *ElcB*-like structure in the case of the more acidic diphenylmethyl thiocyanates.

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