material and then recrystallizing the residue from ligroin and from 85% aqueous ethanol[10] until the melting point of the white crystals was 115.5–116.5°. When pure butadiene was bubbled into a solution of bromine in chloroform, the recrystallized racemic form of 1,2,3,4-tetrabromobutane,[11] mp 115.5–116.5°, could be isolated in 59% yield. Accordingly, the yields of butadiene given in Table II in the column headed "bromine" were calculated by multiplying the yield of pure crystalline 1,2,3,4-tetrabromobutane product by 100/59.

---

(10) M. Lespieau and Ch. Prévost, *Bull. Soc. Chim. France*, [4] **37**, 704 (1925).

(11) W. M. Schubert and W. A. Lanka, *J. Am. Chem. Soc.*, **76**, 1956 (1954). Ya. M. Slobodin and S. A. Zaboev, *Chem. Abstr.*, **46**, 7433 (1952); *Zh. Obshch. Khim.*, **22**, 603 (1952).

Chlorination of Benzylic Sulfides with N-Chlorosuccinimide[1]

D. L. TULEEN AND V. C. MARCUM

Department of Chemistry, Vanderbilt University, Nashville, Tennessee 37203

Received August 8, 1966

The chlorination of benzylic sulfides by N-chlorosuccinimide has been investigated. The resulting α-chloro sulfides have been characterized by nmr and by conversion into the chloro sulfones. Mechanistic interpretation is offered for the results of competitive reactions of mixtures of sulfides, the directive effect in the chlorination of benzyl *p*-chlorobenzyl sulfide, and a large primary kinetic isotope effect in the chlorination of α-*d*-benzyl phenyl sulfide.

The two most generally applicable methods for the synthesis of α-chloro sulfides cited in the literature are the sulfuryl chloride chlorination of sulfides[2] and the condensation of aldehydes with mercaptans in the presence of hydrogen chloride.[3] The efficacy of N-chlorosuccinimide (NCS) for the conversion of sulfides into α-chloro sulfides has recently been reported.[4] This paper describes the reaction of NCS with benzylic sulfides.

Results

Chlorination of sulfides **1a–d** with NCS at room temperature in carbon tetrachloride afforded α-chloro sulfides **2a–d** with no detectable ring halogenation or chlorinolysis. The chloro sulfides were not isolated, but were identified by their nmr spectra (Table I) and by conversion on treatment with *m*-chloroperbenzoic acid[2d] into the corresponding sulfones (**3a–d**) (Scheme I).

TABLE I

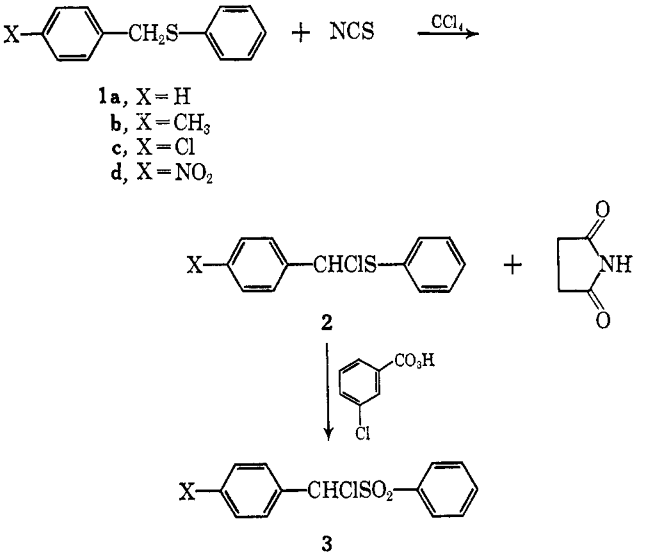
CHEMICAL SHIFTS[a] OF METHYLENE AND METHINE HYDROGENS IN COMPOUNDS 1 AND 2

X	CH_2S[b]	CHClS	Δ, ppm
H	4.00	6.15	2.15
CH_3	3.98	6.13	2.15
Cl	3.96	6.10	2.14
NO_2	4.09	6.20	2.11

[a] In parts per million downfield from internal tetramethylsilane. [b] 15% w/v solution in CCl_4.

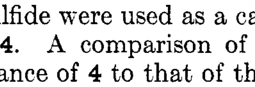
In Table I are collected the chemical shifts of the methylene and methinyl singlets observed in the nmr spectra of compounds **1** and **2**. The change in chemical shift brought about by chlorination appears reasonable when compared with a shielding constant of 2.53 for chlorine for disubstituted methylenes.[5]

SCHEME I



The relative reactivities of sulfides **1a–d** with NCS were determined. Samples of a carbon tetrachloride solution of two of the sulfides containing a few drops of cyclohexane as an internal standard were taken before the addition of NCS and after chlorination was complete. Quantitative nmr analysis indicated the relative amounts of the two sulfides before and after the reaction. The results of these competitions are summarized in Table II. The relative rates so obtained were correlated by the Hammett σ_p treatment (Figure 1) with a visually determined ρ value of -0.8.

The isotope effect in the chlorination of α-*d*-benzyl phenyl sulfide (**4**) was determined by quantitative nmr spectrometry. Data from the chlorination of benzyl phenyl sulfide were used as a calibration for the experiments on **4**. A comparison of the area of the methylene resonance of **4** to that of the methinyl peak



4

---

(1) Presented in part at the Southeastern Regional Meeting of the American Chemical Society, Louisville, Ky, Oct 1966.

(2) (a) W. E. Truce, G. H. Birum, and E. T. McBee, *J. Am. Chem. Soc.*, **74**, 3594 (1952); (b) F. G. Bordwell and B. M. Pitt, *ibid.*, **77**, 572 (1955); (c) F. G. Bordwell, G. D. Cooper, and H. Morita, *ibid.*, **79**, 376 (1957); (d) L. A. Paquette, *ibid.*, **86**, 4085, 4089 (1964).

(3) (a) H. Bohme, *Ber.*, **69**, 1612 (1936); (b) H. Bohme, H. Fischer, and R. Frank, *Ann.*, **563**, 54 (1949); (c) L. A. Walter, L. H. Goodson, and R. J. Fosbinder, *J. Am. Chem. Soc.*, **67**, 655, 657 (1945); (d) H. Bohme, L. Tils, and B. Unterhalt, *Chem. Ber.*, **97**, 179 (1964); (e) L. A. Paquette, *J. Am. Chem. Soc.*, **86**, 4383 (1964).

(4) D. L. Tuleen and T. B. Stephens, *Chem. Ind.* (London), 1555 (1966).

(5) R. M. Silverstein and G. C. Bassler, "Spectrometric Identification of Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 1964, p 87.

SCHEME II

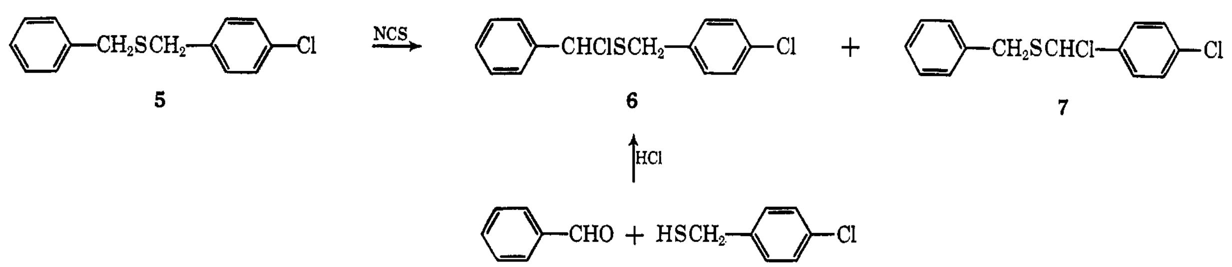


TABLE II

COMPETITIVE CHLORINATION OF BENZYLIC SULFIDES 1a–d BY NCS AT 20–25° IN CARBON TETRACHLORIDE[a]

Compd A	Compd B	$[A]_0$	$[B]_0$	$[A]_f$	$[B]_f$	k_A/k_B[b]
1a	1b	0.89	1.00	0.312	0.457	0.75[c]
1a	1b	0.88	1.00	0.326	0.507	0.69[c]
1a	1c	1.00	1.00	0.293	0.466	1.06
1a	1c	1.00	0.96	0.298	0.473	1.71
1b	1c	1.00	0.96	0.251	0.523	2.27
1d	1c	1.00	0.97	0.597	0.302	0.44
1d	1c	1.00	0.94	0.581	0.297	0.47
1d	1c	1.00	0.97	0.510	0.222	0.45

[a] Analyzed by quantitative nmr employing electronic integration by a Varian A-60 spectrometer. [b] Calculated by the equation $k_A/k_B = \log([A]_f/[A]_0)/\log([B]_f/[B]_0)$. [c] Analyzed using a Keuffel and Esser planimeter, Model 620005.

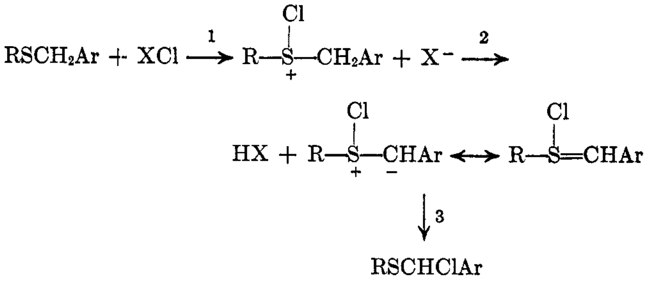
of α-chlorobenzyl phenyl sulfide in the products gave values of k_h/k_d of 5.9, 5.3, and 5.8.[6] Although inaccuracies inherent in this method preclude exact measurement of k_h/k_d, it is evident that there is a large primary kinetic isotope effect in this chlorination.

An internal directive competition was effected by the chlorination of benzyl *p*-chlorobenzyl sulfide (**5**). Chlorinated isomers **6** and **7** were formed in the ratio 1:1.6. Identification of **6** as the minor component of the mixture was made by augmentation of the mixture with an authentic sample prepared by the condensation of benzaldehyde with *p*-chlorobenzyl mercaptan.[3] In addition, hydrolysis of the crude products yielded more *p*-chlorobenzaldehyde than benzaldehyde. The methylene protons in **6** and **7** are rendered nonequivalent by the asymmetric site in the molecules; they appear in the spectrum of the mixture of **6** and **7** as two doublets of doublets (J = 14 cps) centered at about 4.9 ppm. (See Scheme II.)

Discussion

Although Price and Oae[7] have noted that the chlorination of sulfides by sulfuryl chloride may be a free-radical chain reaction in which an intermediate radical is stabilized by expansion of the valence octet of the adjacent sulfur, the directive effects in polyhalogenation of dimethyl sulfide[2a] and the occasional observation of a transitory intermediate[2b] militate in favor of the ionic pathway originally proposed.[2a,b] The data presented here are consistent with a mechanism (Scheme III) analogous to that proposed for the sulfuryl chloride chlorination of sulfides (X = Cl).

SCHEME III



$$\mathrm{RSCH_2Ar} + \mathrm{XCl} \xrightarrow{1} \mathrm{R}\!-\!\overset{\mathrm{Cl}}{\underset{+}{\mathrm{S}}}\!-\!\mathrm{CH_2Ar} + \mathrm{X}^- \xrightarrow{2}$$

$$\mathrm{HX} + \mathrm{R}\!-\!\overset{\mathrm{Cl}}{\underset{+}{\mathrm{S}}}\!-\!\underset{-}{\mathrm{C}}\mathrm{HAr} \longleftrightarrow \mathrm{R}\!-\!\overset{\mathrm{Cl}}{\mathrm{S}}\!=\!\mathrm{CHAr} \xrightarrow{3} \mathrm{RSCHClAr}$$

The directive effect in the chlorination of benzyl *p*-chlorobenzyl sulfide and the observed isotope effect implicate step 2 as the rate-determining step. Apparently, the base (X^-) preferentially abstracts the more acidic α hydrogen. A negative slope was observed in the Hammett correlation of the competitive chlorinations of mixtures of benzylic sulfides. We feel that this indicates that step 1 represents product-determining sulfonium salt formation. If this step is product determining, the relative rates obtained would represent a determination of the relative basicities of benzylic sulfides toward the chloronium donor, XCl. The magnitude of ρ for such a process would not be expected to be large; the effect on basicity exerted by the substituent is attenuated by the intervening methylene group.[8]

The identity of the chloronium donor (XCl) in this process is undetermined. It may be either NCS or molecular chlorine, continuously regenerated by the rapid reaction of NCS with HCl.[9]

Experimental Section[10]

Reagents.—N-Chlorosuccinimide, obtained from Aldrich, was purified by recrystallization from eight times its weight of hot water, followed by filtration. It was allowed to dry in air for two days. Spectrograde carbon tetrachloride, obtained from Matheson Coleman and Bell, was used without further purification. FMC Corp. *m*-chloroperbenzoic acid was used without purification. The thiols and benzylic halides were all commercially available, and were used as received.

Sulfides 1a–d.—To 0.5 mole each of potassium hydroxide and thiophenol dissolved in 95% ethanol was added slowly an ethanolic solution of 0.5 mole of benzyl chloride. After the addition was complete the reaction mixture was refluxed for 3 hr and poured into water, and the sulfide was extracted into ether. The ether solution was washed once with aqueous potassium hydroxide solution and several times with water. The solution was dried over sodium sulfate and the ether was distilled. Three recrystallizations of the resultant solid from methanol–water

---

[6] $k_h/k_d = (1 - r)/r$, where r = area ratio of methinyl of product to methylene of starting material.

[7] C. C. Price and S. Oae, "Sulfur Bonding," The Ronald Press Co., New York, N. Y., 1962, p 59.

[8] A Hammett correlation of relative reactivities of substituted thioanisoles has a ρ value of approximately −3.0: D. L. Tuleen and T. B. Stephens, unpublished results.

[9] J. Adams, P. A. Gosselain, and P. Goldfinger, *Bull. Soc. Chim. Belges*, **65**, 523 (1956).

[10] Melting points are corrected. Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn. Infrared spectra were obtained with a Beckman IR-10 spectrophotometer. Nmr spectra were recorded on a Varian Associates A-60 spectrometer, employing tetramethylsilane as an internal reference. The nmr spectrometer was purchased with a grant from the National Science Foundation (GP 1683).

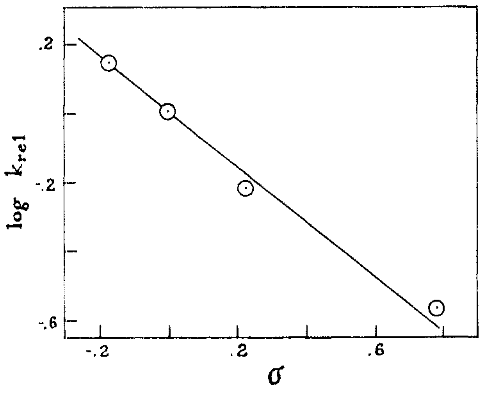


Figure 1.—Correlation of log k_{rel} for chlorination of benzylic sulfides with NCS *vs.* σ. The ρ value is −0.8.

afforded 63 g (63%) of benzyl phenyl sulfide, mp 41–42° (lit.[11] mp 44.5°). Sulfides **1b–d** were obtained in an analogous manner.

p-Chlorobenzyl phenyl sulfide was obtained from thiophenol and *p*-chlorobenzyl chloride. Three recrystallizations from methanol–water afforded the sulfide (65%), mp 78–78.5° (lit.[12] mp 77.5–78°).

p-Methylbenzyl phenyl sulfide was synthesized from thiophenol and *p*-methylbenzyl chloride. Three recrystallizaions from methanol–water afforded the sulfide (69%), mp 69–70° (lit.[13] mp 69–70°).

p-Nitrobenzyl phenyl sulfide was obtained from thiophenol and *p*-nitrobenzyl bromide. The benzylic bromide, which is relatively insoluble in ethanol, was added in portions to the ethanolic potassium thiophenolate. Three recrystallizations from methanol–water afforded the sulfide (47%), mp 76–77°.

Anal. Calcd for $C_{13}H_{11}NO_2S$: C, 63.65; H. 4.52. Found: C, 63.56; H, 4.46.

Chloro Sulfides 2a–d.[14]—To a solution of benzyl phenyl sulfide (1.09 g, 0.005 mole) in carbon tetrachloride was added N-chlorosuccinimide (0.61 g, 0.005 mole). The mixture was stirred magnetically for 30 min at 20–25°. Succinimide was removed by filtration. An nmr spectrum of the filtrate displayed, in addition to the aromatic multiplet, a singlet at 6.15 ppm which was assigned to the methinyl proton of α-chlorobenzyl phenyl sulfide (**2a**). Chloro sulfides **2b–d** were prepared by this method; the chemical shifts of the methinyl protons are listed in Table I.

Chloro Sulfones 3a–d.—Carbon tetrachloride was removed at reduced pressure from the solution of α-chlorobenzyl phenyl sulfide. The residue was dissolved in 25 ml of chloroform. Oxidation with *m*-chloroperbenzoic acid by the method of Paquette[2d] gave the crude α-chloro sulfone (**3a**). Two recrystallizations from benzene–hexane afforded 0.83 g (62%) of α-chlorobenzyl phenyl sulfone: mp 185–186°; $\nu_{max}^{CHCl_3}$ 1335 and 1155 cm^{-1} (SO_2); nmr ($CDCl_3$) 7.25–7.7 (multiplet) and 5.67 ppm (singlet).

Anal. Calcd for $C_{13}H_{11}ClO_2S$: C, 59.54; H, 4.13. Found: C, 59.34; H, 4.26.

p-Methyl-α-chlorobenzyl phenyl sulfone (**3b**) was prepared (70%) analogously: mp 184–185°; $\nu_{max}^{CHCl_3}$ 1330 and 1155 cm^{-1}; nmr ($CDCl_3$) 7.2–7.8 and 5.67 ppm.

Anal. Calcd for $C_{14}H_{13}ClO_2S$: C, 59.89; H, 4.63. Found: C, 59.76; H, 4.68.

α-*p*-Dichlorobenzyl phenyl sulfone (**3c**) was similarly prepared (72%): mp 148–149°; $\nu_{max}^{CHCl_3}$ 1335 and 1155 cm^{-1}; nmr ($CDCl_3$) 7.3–7.8 and 5.69 ppm.

Anal. Calcd for $C_{13}H_{10}Cl_2O_2S$: C, 51.83; H, 3.32. Found: C, 51.98; H, 3.43.

α-Chloro-*p*-nitrobenzyl phenyl sulfone (**3d**) was similarly prepared (47%): mp 168–169°; $\nu_{max}^{CHCl_3}$ 1350 and 1157 cm^{-1}; nmr ($CDCl_3$) 7.5–8.4 and 5.80 ppm.

Anal. Calcd for $C_{13}H_{10}ClNO_4S$: C, 50.08; H, 3.21. Found: C, 49.94; H, 3.16.

Procedure for Competitive Chlorination.—Weighed amounts of pairs of the sulfides **1a–d** were dissolved in 10 ml of carbon tetrachloride containing a small amount of cyclohexane. A sample was withdrawn for nmr analysis and an amount of NCS sufficient to react with about 50–60% of the total amount of sulfide present was added. The mixture was stirred magnetically at 20–25° until the reaction was complete; a sample was removed for nmr analysis. The areas of the methylene proton resonances of the two sulfides were measured, compared with the standard, before and after reaction. The spectra were run with minimum sweep width (50 cps). Low radiofrequency field was employed to minimize saturation. Experimentation with known samples established that electronic integration and planimetry gave equally valid results for the relative areas.

α-*d*-Benzyl Phenyl Sulfide (4).—Benzyl phenyl sulfide (15 g, 0.075 mole) was dissolved in 150 ml of dry ether and flushed with nitrogen. A solution of a slight excess of butyllithium in hexane (Foote Mineral Co.) was added over a 20-min period; the resulting yellow solution was refluxed for 3 hr and cooled. Excess D_2O was slowly added and the mixture was stirred until the color had disappeared. Water was added; the layers were separated. The organic phase was washed once with water and dried over sodium sulfate. The solvent was removed and the resulting deuterated sulfide was recrystallized several times from 95% ethanol to give material, mp 41–42°.

Determination of the Isotope Effect.—Benzyl phenyl sulfide (0.50 g, 0.0025 mole) was dissolved in 5.0 ml of carbon tetrachloride containing 4 drops of cyclohexane. A 0.5-ml sample was taken for analysis and NCS (0.30 g, 0.00225 mole) was added. The mixture was stirred at 20–25° for 2 hr and a sample of the product was taken for analysis. The ratio of the areas of the α-chlorobenzyl phenyl sulfide product methinyl singlet to the starting methylene resonance was obtained by means of the cyclohexane standard, and found to be 0.47. There was no evidence of residual starting material in the nmr spectrum after the reaction. The experiment was performed three times on α-*d*-benzyl phenyl sulfide. The ratios of product methinyl to starting methylene protons were 0.153, 0.168, and 0.155. Employing the chlorination of the unlabeled sulfide as a calibration, these ratios were multiplied by 0.94 to give corrected ratios of 0.144, 0.158, and 0.146. Utilization of the equation in footnote 6 gave values for k_h/k_d of 5.9, 5.3, and 5.8.

Benzyl *p*-Chlorobenzyl Sulfide (5).—Benzyl mercaptan (37.2 g, 0.3 mole) was dissolved in ethanolic sodium ethoxide prepared by dissolving sodium (6.9 g, 0.3 g-atom) in 100 ml of ethanol. A solution of *p*-chlorobenzyl chloride (48.3 g, 0.3 mole) in 50 ml of ethanol was added dropwise with stirring. After the addition was complete, the mixture was refluxed for 1 hr before it was cooled; the sodium chloride was removed by filtration. The filtrate was diluted with water and extracted with ether, and the organic phase was dried over sodium sulfate. The ether was removed and the product was distilled: 44 g (60%); bp 185–187° (3.5 mm); nmr (CCl_4) 7.1–7.3 (9 H), 3.49 (2 H), and 3.46 ppm (2 H).

α-Chlorobenzyl *p*-Chlorobenzyl Sulfide (6).—*p*-Chlorobenzyl mercaptan (7.9 g, 0.05 mole) in 25 ml of benzene cooled in an ice bath was saturated with dry hydrogen chloride as benzaldehyde (5.3 g, 0.05 mole) in 25 ml of benzene was slowly added. The layers were separated; the organic layer was dried over sodium sulfate. Distillation of the benzene left the crude product a yellow oil.

Chlorination of Benzyl *p*-Chlorobenzyl Sulfide.—Reaction with equimolar NCS in carbon tetrachloride was carried out as described for the preparation of chloro sulfides **2a–d**. The nmr spectrum after reaction revealed two singlets at 5.66 and 5.62 ppm in the ratio 1:1.6. In addition, there were two doublets of doublets (J = 14 cps for each) centered about 4.9 ppm. Augmentation of this product mixture with authentic α-chlorobenzyl-*p*-chlorobenzyl sulfide gave an increase in the lower field methinyl singlet. The crude reaction mixture was diluted to twice its volume with water and stirred for 6 hr. Analysis of the aldehydic region of the nmr spectrum of the products of hydrolysis showed that *p*-chlorobenzaldehyde was more prominent than benzaldehyde.

---

[11] R. Pummerer, *Ber.*, **43**, 1406 (1910).

[12] A. Jumar and W. Schulze, *J. Prakt. Chem.*, **5**, 83 (1957).

[13] R. F. Brookes, J. E. Cranham, D. Greenwood, and H. A. Stevenson, *J. Sci. Food Agr.*, **9**, 141 (1958); *Chem. Abstr.*, **52**, 11773 (1958).

[14] Caution! These compounds are irritating to the skin and should be handled with care.