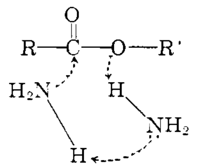
neutral water at the ester carbonyl group of phenyl acetates ρ is essentially zero due to a cancellation of electronic factors. The very small ρ for k_{NH_3} suggests the involvement of an acid-catalyzed mechanism. If the Bunnett mechanism were operative it might be anticipated that other nucleophilic displacements on the ester carbonyl group would be sensitive to general base catalysis. However, the reaction of tertiary amines with phenyl acetate is not subject to general base catalysis.[1,4,13] For these cases the amine cannot lose a proton upon nucleophilic attack but it should be able to partake in the Bunnett mechanism. Also, tertiary amines[4,5] are known to be unable to displace alkoxide ion from aliphatic esters (except in the instance of the more efficient intramolecular process and then only slowly[16]) which would be in accord with the inability to increase nucleophilicity *via* loss of a proton. The argument presented by Bunnett that the proton abstraction mechanism is improbable because general base catalysis is not observed in the nucleophilic displacement of Cl^- from 2,4-dinitrochlorobenzene by amines may be tenuous since the observance of general base catalysis depends on the magnitude of the non-catalyzed rate (as with the nitro esters of this study). On the other hand, the citation by Bunnett of the surprisingly low reactivity of carboxylic acid esters with alkali metal amides in liquid ammonia, due to the lack of suitable general acids in this medium, is compelling evidence for the need for protonation of the leaving group.

A mechanism which would appear to be in accord with all experimental results is that of (9).



(9)

In (9) the attack of NH_3 is assisted by proton abstraction while departure of $-OR'$ is assisted by proton transfer from the incipient ammonium ion. The value of ρ for this mechanism would certainly be quite small since electron attraction would affect the importance of the proton abstraction and donation in opposite sense. Also, the inability to observe general base catalysis in the reaction of tertiary amines with phenyl acetate is accommodated by (9) as is the observed low activity of esters toward amide ion in ammonia.

Acknowledgments.—This work was supported by grants from The National Science Foundation and from the Upjohn Co. We wish to thank Professors Bunnett and Jencks for preprints of their recently published aminolysis studies. Also, we are grateful to Professor Jencks for criticisms of this manuscript in its initial form.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF SOUTHERN CALIFORNIA]

Derivatives of Sulfenic Acids. XXXVI. The Ionic Scission of the Sulfur–Sulfur Bond.[1] Part 1

BY ALAN J. PARKER[2] AND NORMAN KHARASCH

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The cleavage of the S–S bond of nitro-substituted aromatic disulfides, R'SSR, by bases, *via* a nucleophilic displacement of mercaptide ion from divalent sulfur is reported. The reactions are equilibria, with the positions of equilibria determined by the nucleophilicity toward sulfur of the displaced mercaptides and displacing nucleophiles. The cleavage is controlled thermodynamically by the comparative nucleophilicities of the entering group, Y^-, and of the leaving mercaptide group, with the bond-breaking step, rather than the bond-making one, being the critical factor. The susceptibility to cleavage of disulfides becomes greater with increasing electron withdrawal by substituents. A spectroscopic method was used to estimate the rates of scission of selected disulfides by a series of nucleophiles. This indicated an order of S-nucleophilicity[4]: $CH_3CH_2S^- > C_6H_5S^- > CN^- > SO_3^{=} > OH^- > N_3^- > SCN^-, I^-$.

Introduction.—The literature on ionic scissions of sulfur–sulfur bonds has been reviewed recently in some detail.[3,4] Of particular interest are the bimolecular scissions of disulfides by nucleophiles, which with unsymmetrical disulfides R'–SS–R may occur as shown in (a) or as in (b).

$$R'S_aS_bR + Y^- \rightleftarrows R'S_aY + RS_b^- \qquad (a)$$

$$R'S_aS_bR + Y^- \rightleftarrows R'S_a^- + RS_bY \qquad (b)$$

The aim of the present study was to determine which sulfur—in selected unsymmetrical disulfides—serves as the electropositive center for attack by Y^-, and which sulfur is displaced as mercaptide (reactions a or b above). Incidentally, it was desired to obtain information as to the relative susceptibilities to nucleophilic cleavage when selected unsymmetrical disulfides were treated with a series of nucleophiles.

Earlier studies[5,6] have shown, for a few cases, that in unsymmetrical disulfides, R'SSR, where large differences exist in the electronegativities of R' and R, *electrophilic* attack occurs at the sulfur further from the more electronegative group. Thus, in R'S–SR, where R' is very strongly electron withdrawing and R is not, both peracid oxida-

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[2] William Ramsay and Ralph Forster Laboratories, University College, London W. C. 1. Australian Commonwealth Scientific and Industrial Research Organization post-doctoral fellow at the University of Southern California, 1958–1959.

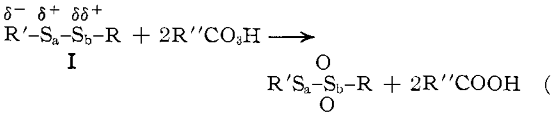
[3] O. Foss, "Organic Sulfur Compounds," Vol. 1, Pergamon Press, London, England, 1960.

[4] A. J. Parker and N. Kharasch, *Chem. Revs.*, **59**, 583 (1959).

[5] G. Leandri and A. Tundo, *Ann. Chim. (Rome)*, **44**, 74 (1954).

[6] C. G. Moore and M. Porter, *J. Chem. Soc.*, 2890 (1958).

tion to thiosulfonates[5] (equation c) which does not involve S–S bond scission and the reaction of a sulfenyl chloride with disulfides[6] (equation d) which does, proceed by attack of the electrophiles (RCO_3H and RSCl) on the sulfur further removed from the strongly electronegative substituent R′. This suggests that the more distant sulfur, S_b, has a higher electron density about it than S_a, the sulfur attached to R′. The disulfide, R′SSR, may therefore be considered to be polarizable as in I, where $\delta\delta+$ represents a smaller positive polarization than $\delta+$



$$\overset{\delta^-}{R'}\text{–}\overset{\delta^+}{S_a}\text{–}\overset{\delta\delta^+}{S_b}\text{–}R + 2R''CO_3H \longrightarrow R'S_a\text{–}\overset{O}{\underset{O}{S_b}}\text{–}R + 2R''COOH \quad (c)$$

I

$$R'\text{–}S_a\text{–}S_b\text{–}R + R''\overset{\delta^+}{S}\text{—}\overset{\delta^-}{Cl} \longrightarrow R'\overset{\delta^+}{S}\text{—}\overset{\delta^-}{Cl_a} + R''SS_bR \quad (d)$$

For the reaction of disulfides with nucleophiles if the charge distribution on the sulfur atoms is as in I, Y^- might in a *nucleophilic* displacement, be expected to form a bond with S_a more readily than with S_b, thus displacing RS_b^- as in reaction a. On the other hand, $R'S_a^-$ (where R′ = 2,4-dinitrophenyl, 4-nitrophenyl, etc.) has a greater anionic stability, and will thus be a better leaving group than RS_b^-, so that scission as in (b) may be favored. To demonstrate which factor—bond forming or bond breaking—determines the orientation of scission, we prepared a number of disulfides, R′S–SR, by the convenient reaction of a mercaptan and a sulfenyl chloride[7] (equation e)

$$R'SCl + RSH \longrightarrow R'S\text{–}S\text{–}R + HCl \qquad (e)$$

Again, R′ is a substituted phenyl group (such as 4-nitrophenyl 2,4-dinitrophenyl, etc.) and R(C_2H_5 or C_6H_5) is far less electron-withdrawing, so that the predicted polarization of R′SSR is as in I.

Results and Discussion.—The disulfides were all stable in hot ethanol or aqueous acetone, were unchanged when irradiated with light of wave length longer than 2500 Å. at room temperature, or when refluxed with 2,4-dinitrochlorobenzene in ethanol. This showed that SN1 type fission,[8] homolysis[9] or nucleophilicity of the disulfides[10] toward dinitrochlorobenzene would not complicate the present study.

Three methods were used to identify the mercaptide displaced from R′SSR and to estimate the percentage cleavage. The first (A) was used in reactions where the mercaptans could be easily separated from other fission products by acidification and filtration of the aqueous reaction mixture. The yield of mercaptan was estimated, and its identity established by mixture melting point with an authentic sample. The results are given in Table I. Atmospheric oxidation of the mercaptide produced some symmetrical disulfide R′SSR′ but this was not serious, under a nitrogen atmosphere, since—as shown[7]—the procedure can be used to synthesize thiophenols, R′SH, from selected disulfides (R′SSR).

TABLE I

REACTIONS OF NUCLEOPHILES WITH DISULFIDES IN 85% AQUEOUS ACETONE AT 25–30°

Disulfide R′SSR (0.1 *M*)	Nucleophile Y^- (0.1 *M*)	Yield R′SH, %	Yield R′SSR′, %
$DNPSSCH_2CH_3$	CN^-	70[b]	. .
	OH^-	85	10
	N_3^-	0[c]	15
DNPSSDNP[a]	OH^-	30	. .
$DNPSSCH_2CH_2OH$	OH^-	50	35
$DNPSSCH_2C_6H_5$	OH^-	Impure[d]	98[e]
o-NO_2-p-$ClC_6H_3SSCH_2CH_3$	OH^-	50	25
o-$NO_2C_6H_4SSCH_2CH_3$	OH^-	15[f]	64
o-$NO_2C_6H_4SSCH_2CH_3$	CN^-	70[g]	15
$C_6H_5SSCH_2CH_3$	OH^-	10[h]	. .

[a] This disulfide is very insoluble in most common solvents, but is slightly soluble in dioxane which was used as the solvent in this case. In unpublished work, in this Laboratory, T. C. Bruice reported yields of the thiophenol of over 50% and concluded that some of the thiol must come from disproportionation of the intermediate sulfenic acid, formed in the reaction: $RSSR + OH^- \rightleftarrows RSOH + RS^-$. [b] 10% of R′SSR was recovered unchanged. [c] 65% of R′SSR was recovered. [d] Probably contaminated with products of decomposition of $C_6H_5CH_2SOH$. [e] After oxidation to ArSSAr with iodine. [f] Refluxed for 15 minutes. [g] Rapid reaction at 25°. [h] Yield is based on amount of 2,4-dinitrophenyl phenyl sulfide isolated by reaction with 2,4-dinitrochlorobenzene. [i] DNP = 2,4-dinitrophenyl.

While the data of Table I are only roughly quantitative (*ca.* ±5%) they clearly show that if in R′SSR R′ is much more electronegative than R, effective attack by Y^- occurs preferentially at the sulfur atom more distant from R′. Thus the cleavage of the disulfide is controlled thermodynamically, *i.e.*, by the anionic stability of the leaving mercaptide group, $R'S^-$ It may also be noted that cyanide ion is a more effective S-nucleophile than hydroxide ion, while azide ion causes little or no displacement of mercaptides.

Method A does not exclude the possibility that some RS^- is also formed since, in the examples studied, it would not be isolated. A second method (B) suggested by the work of Leandri and Tundo,[10] was used to demonstrate that $R'S^-$ was, essentially, the only mercaptide formed during the nucleophilic cleavage of R′–S–S–R. If equimolar amounts of 2,4-dinitrochlorobenzene, nucleophile and disulfide are mixed, any mercaptides formed will react rapidly to give 2,4-dinitrophenyl sulfide derivatives, which can be isolated, and which allow the mercaptides to be identified. The method requires that the nucleophile should cleave the disulfide more readily than it displaces Cl^- from 2,4-dinitrochlorobenzene, and should not subsequently react with the 2,4-dinitrophenyl sulfide. These requirements are fulfilled in the cleavage of disulfides, DNP–S–S–R (where DNP = 2,4-dinitrophenyl and R = a less electron-withdrawing group) since these disulfides are cleaved very rapidly by many S-nucleophiles to give $DNPS^-$ (*cf.* Table I) which reacts immediately with 2,4-dinitrochlorobenzene in ethanol to form the very insoluble[11] $(DNP)_2S$.

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[7] N. Kharasch and A. J. Parker, *J. Org. Chem.*, **24**, 1029 (1959).

[8] A. Schöberl and A. Wagner, in Houben-Weyl, "Methoden der Organischen Chemie," 4th Ed., Vol. IX, F. Thieme, Stuttgart, 1955, pp. 45–82.

[9] G. Leandri and A. Tundo, *Ann. Chim. (Rome)*, **44**, 63 (1954).

[10] G. Leandri and A. Tundo, *ibid.*, **44**, 512 (1954); **45**, 842 (1955).

[11] One gram of bis-(2,4-dinitrophenyl) sulfide, $(DNP)_2S$, was recovered without loss of weight after refluxing with 100 ml. of ethanol.

Some reactions of nucleophiles with DNP–S–SR in the presence of equimolar amounts of dinitrochlorobenzene, are summarized in Table II. It can be seen that, for the cases where reaction takes place readily, 85% yields, or higher, of $(DNP)_2S$ are obtained, suggesting that DNP–SSR cleaves almost entirely as in equation b.[12] If appreciable RS^- were formed in the cleavage (equation a) the yield of $(DNP)_2S$ would fall significantly, for it is known, from competitive reactions of aromatic mercaptides, $R'S^-$, with dinitrochlorobenzene,[13] that the nucleophilicity of $R'S^-$ becomes less with greater electron withdrawal by R′; hence the unsubstituted RS^- would compete favorably with $R'S^-$ for dinitrochlorobenzene.

TABLE II

IDENTIFICATION AND ESTIMATION OF MERCAPTIDE FORMED BY REACTION OF Y^- WITH DNP–S–SR IN THE PRESENCE OF 0.01 MOLE OF DNPCl, IN 95% ETHANOL

Nucleophile Y^- (0.01 mole)	Yield, %[b] $(DNP)_2S$	DNPSSR recovd.	Conditions
$DNPSSCH_2CH_3$[a]			
CN^-	93	..	5 min. at 30°
OH^-	92	..	5 min. at 30°
$SO_3^=$	82	..	5 min. at 30°
SCN^-	0	90	5 hr. reflux
I^-	0	84	5 hr. reflux
$C_6H_5NH_2$	0	92	5 hr. reflux
N_3^-	0	45[d]	5 hr. reflux
CN^-	97	..	At *p*H 7, 5 min. at 30°
OH^-	5	0[e]	With excess Y^- 5 min. at 30°
$DNPSSC_6H_5$[a]			
CN^-	95[h]	..	5 min. at 20°
OH^-	86	..	5 min. at 20°
$SO_3^=$	78[f]	..	5 min. at 20°
N_3^-[c]	0	80[c]	5 hr. reflux
SCN^-	0	95	5 hr. reflux
$DNPSSCH_2C_6H_5$[a]			
CN^-	92	..	5 min. at 20°
OH^-	41[g]	..	10 min. at 30° 2-fold excess alk.
N_3^-[c]	0	75[c]	5 hr. reflux
SCN^-	0	87	5 hr. reflux

[a] DNP = 2,4-dinitrophenyl (0.01 mole). [b] Calculated as % of the theoretical amount (0.01 mole). [c] Attacks DNPCl preferentially. [d] 10% DNP–SS–DNP was also obtained. [e] 6% DNP–SS–DNP was also obtained. [f] Reduction of nitro groups may also be involved. [g] Together with 26% DNP–SS–DNP. [h] Also isolated 55% impure C_6H_5SCN.

It should be noted that in the presence of the nucleophiles, SCN^-, I^-, N_3^- and $C_6H_5NH_2$, DNP–S–S–R was recovered unchanged—showing that even reactive disulfides were not cleaved by these relatively powerful carbon nucleophiles[16] under normal conditions. Apparently nucleophilicity toward sulfur, just like basicity toward protons, does not parallel nucleophilicity toward carbon.

With sulfite ions as nucleophiles, yields of bis-(2,4-dinitrophenyl) sulfide were lower than expected. This may be related to the possible reduction of the nitro groups by sulfite, but the exact reason was not established.

In strongly alkaline solution the product, $(DNP)_2S$, is cleaved by excess hydroxide ions,[17] resulting in low yields. However with equimolar proportions of OH^- and disulfide or with bicarbonate as nucleophile,[9] high yields of $(DNP)_2S$ are obtained.

Attempts to extend procedure B to less-highly substituted disulfides, such as 2-nitrophenyl phenyl disulfide, failed because Y^- preferentially attacks the 2,4-dinitrochlorobenzene rather than the disulfide, R′SSR.

In method B, the equilibrium b is disturbed by the removal of mercaptide ions from the system. For this reason a roughly quantitative, spectrophotometric examination of reaction b was made (method C). Nitro-substituted aromatic mercaptides, $R'S^-$, absorb in the visible region of the spectrum (350 to 450 mμ), but the other components of reaction b (*i.e.*, RSY, Y^- and RSSR′; R is phenyl or ethyl and Y^- are the nucleophiles of Table IV) do not absorb appreciably in this region at the concentrations used (*ca.* 10^{-4} *M*). Thus, by measuring the maximum optical density of the reaction mixture at 350 to 450 mμ at selected time intervals and known temperatures, an estimate of the concentration of $R'S^-$ at equilibrium, and the rate of approach to equilibrium, as R, R′ and Y^- change in b, can be made.

The absorptions in 95% ethanol of the disulfides R′S–SR and the mercaptides $R'S^-$, considered in this study, are shown in Table III. The solutions all obeyed Beer's law and the spectra of $R'S^-$ in the

TABLE III

SPECTRA OF DISULFIDES AND MERCAPTIDES IN 95% ETHANOL AT 25°

Compound[a] R′SSR and $R'S^-$	λ_{max}, mμ	log ε[b]	log ε[c]
$DNPSSC_6H_5$	309	3.99	2.30
$DNPSSC_2H_5$	328	3.97	2.60
$2\text{-}NO_2C_6H_4SSC_6H_5$	351	3.52	2.30
$2\text{-}NO_2C_6H_4SSC_2H_5$	356	3.48	2.30
$4\text{-}NO_2C_6H_4SSC_6H_5$	318	4.10	<2
$C_6H_5SSC_6H_5$	239	4.23	3.26
$C_6H_5SSC_2H_5$	240	3.95	3.28
$DNPS^-$	418	3.28	..
$2\text{-}NO_2C_6H_4S^-$	420	3.20	..
$4\text{-}NO_2C_6H_4S^-$	425	4.32	..
$C_6H_5S^-$	269	4.16	..

[a] DNP = 2,4-dinitrophenyl. [b] Measured at λ_{max}. [c] Measured at the wave length where $R'S^-$ has λ_{max}.

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(12) DNP = 2,4-dinitrophenyl and is the more electron withdrawing group R′ in the formula R'S–SR; see also ref. 26.

(13) G. Leandri and A. Tundo, *Ann. Chim.* (*Rome*), **45**, 832 (1955), established the reactivity series toward DNPCl shown below and in this study we have extended the series to include ethyl and benzyl mercaptides, which are more reactive than phenyl mercaptide toward DNPCl: $C_2H_6S^- > C_6H_5CH_2S^-, CH_3C_6H_4S^- > C_6H_5S^- > p\text{-}NO_2C_6H_4S^- > DNPS^-$. The series parallels the known base strengths of these anions[14] and agrees with the kinetic results of Miller, *et al.*,[15] for the reactions of alkoxides with dinitrochlorobenzene, where the nucleophilicity and the base strengths of alkoxides were in the order: $C_2H_5O^- > C_6H_6O^- > p\text{-}NO_2C_6H_4O^- > 2,4,6\text{-}(NO_2)_3C_6H_2O^-$.

(14) F. G. Bordwell and H. M. Anderson, THIS JOURNAL, **75**, 6019 (1953).

(15) G. D. Leahy, M. Liveris, J. Miller and A. J. Parker, *Austral. J. Chem.*, **9**, 382 (1956).

(16) C. G. Swain and C. B. Scott, THIS JOURNAL, **75**, 141 (1953).

(17) N. Kharasch and R. S. Swidler, *J. Org. Chem.*, **19**, 1704 (1954).

TABLE IV

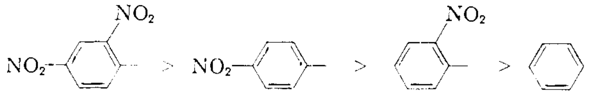
SPECTROPHOTOMETRIC EXAMINATION OF THE REACTION RS–S–R′ + Y^- ⇄ RSY + $R'S^-$ IN 95% ETHANOL AT 20–22°

Disulfide R′S–SR (10^{-4} M)	Nucleophile Y^- (10^{-3} M)	Optical density[a] at λmax of $R'S^-$ A	B	C	D	E	Forward reacn.,[d] %	Max. time to attain equil. at 20–22°, min.
$DNPSSCH_2CH_3$	OH^-	1.90	1.60	1.72	1.72	..	90	5–10
	CN^-	1.90	1.72	1.75	1.70	..	92	5
	$CH_3CH_2S^-$	1.90	1.80	1.70	1.50	..	94	5
	N_3^-	1.90	0.03	0.04	0.20	0.46	0	..
	SCN^-	1.90	0.02	0.03	0.03	0.03	0	..
	$DNPS^{-i}$	1.90	1.90	1.80	1.00	..	..	..
	$DNPS^{-i}$	0.98	0.98	0.98	0.96[b]	..	[h]	..
	$DNPS^{-c,i}$	1.90	1.86	1.80	1.00	..	..	..
		0.10	0.10	0.10	0.10[b]	..	..	..
$DNPSSC_6H_5$	CN^-	1.90	1.73	1.73	1.70	..	90	5
	$C_6H_5S^-$	1.90	1.74	1.74	1.68	..	92	5
	OH^-	1.90	1.50	1.69	1.74	1.70	92	30
o-$NO_2C_6H_4SSCH_2CH_3$	CN^-	0.80	0.65	0.66	0.68	..	85	5–30
	$C_6H_5S^-$	.80	.63	.63	.60	..	80	5
	OH^-	.80	.15	.17	.20	..	15	>100
o-$NO_2C_6H_4SSC_6H_5$	CN^-	.80	.58	.62	.64	..	80	30
	$C_6H_5S^-$	.80	.67	.67	.66	..	85	5
	OH^-	.80	.12	.14	.36	0.44	50	>100
p-$NO_2C_6H_4SSC_6H_5$	CN^-	2.15	1.54	1.38	1.36	..	70	5
	$C_6H_5S^-$	2.15	1.71	1.70	1.68	..	80	5
	OH^-	2.15	0.23	0.83	1.08	1.18	50	>100
	4-$NO_2C_6H_4S^{-j}$	1.07	1.23	1.22	..	..	[h]	..
$C_6H_5SSC_6H_5$	CN^-	1.46	0.30	0.49	0.58	0.73	[g]	>100
	OH^-	1.46	0.15	0.15	0.18	0.26	[g]	>100
	4-$NO_2C_6H_4S^{-j}$	1.07	1.07	1.07[f]	..	..	[g]	..
$C_6H_5SSCH_2CH_3$	CN^-	1.46	0.19	0.41	1.32	..	[g]	>100

[a] A = calculated optical density at λ_{max}R′S^- at 10^{-4} M (Table III); B = after 5 min. at 20–22°; C = after 30 min. at 20–22°; D = after 2 hours at 20–22°; E = D + 10 min. at reflux (60–70°). [b] At λ_{max} for R′S-SR. [c] A blank in the absence of disulfide to show extent of oxidation of $DNPS^-$. [d] From maximum optical density recorded. [f] At λ_{max} of Y^-. [g] Interference by other bands prevents calculation. [h] Apparently R′SSR is unchanged. [i] At 10^{-4} M. [j] At 5 × 10^{-5} M.

region 350 to 450 mμ were unchanged in the presence of the nucleophiles of Table IV.

Reaction b was followed using the procedure outlined above (*cf.* Experimental). While this gives only an approximate estimate of rate, the gross differences of reactivity are seen easily. The percentage of $R'S^-$ displaced from R′S-SR at equilibrium, can be estimated by comparison of the optical density at λ_{max} ($R'S^-$) of the reaction mixture with that of $R'S^-$ at the concentration expected if reaction b proceeded exclusively in the forward direction. The results, which are summarized in Table IV, also confirm the conclusions suggested by Table I. The greater the anionic stability of the displaced mercaptide ion, the more susceptible to scission is the parent disulfide. Thus, reactivity toward cyanide, sulfite, hydroxide and mercaptide ions decreases in the order of R′ in R′SSR, as



Although phenyl mercaptide apparently is a stronger S-nucleophile than cyanide ion, excess cyanide ion slowly displaces some phenyl mercaptide from diphenyl disulfide, despite reports to the contrary.[18] It is difficult to estimate the percentage of phenyl mercaptide displaced because absorption by phenyl thiocyanate[19] and by unchanged phenyl disulfide (Table III) interferes with the absorption at 269 mμ. Since it is known that phenyl mercaptide will displace cyanide ion from phenyl thiocyanate,[20] we conclude that phenyl mercaptide is a slightly more powerful nucleophile toward divalent sulfur than is cyanide ion.

Table IV suggests the following order of nucleophilicity for displacement of mercaptides from divalent sulfur[4]: $C_2H_5S^- > C_6H_5S^- > CN^- > OH^- > DNPS^- > N_3^- > SCN^-$. The thiocyanate ion has not been shown to cleave any disulfides[4] despite its nucleophilicity in displacements at carbon.[16]

Reactions such as h and i also were studied spectrophotometrically. Within experimental error, largely due to oxidation, the initial mercaptide concentration, as shown by the optical density of the solution, did not change. Thus in h and i displacement of $CH_3CH_2S^-$ or $C_6H_5S^-$ by a considerably weaker S-nucleophile[4] does not occur. Even the extreme insolubility of bis-(2,4-dinitrophenyl) disulfide in ethanol cannot force reaction h in the direction shown by (h-1). Presumably, the exchanges h and i do occur, although there is no direct evidence for this as yet.[21]

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[18] G. S. Whitby and H. Greenberg, *Trans. Roy. Soc. Can.*, **3**, 21 (1929).

[19] F. G. Bordwell and P. J. Boutan, THIS JOURNAL, **78**, 854 (1956).

[20] H. Lecher and M. Wittwer, *Ber.*, **55**, 1474 (1922).

[21] Mercaptide–disulfide exchanges have been studied by L. Eldjarn and A. Pihl, THIS JOURNAL, **79**, 4589 (1957), with S^{35}-labeled mercaptides. Their method should be applicable here.

$$\text{DNPS}^- + \text{DNPSSCH}_2\text{CH}_3 \rightleftarrows \text{DNPSSCH}_2\text{CH}_3 + \text{DNPS}^- \quad \text{(h)}$$

$$\text{DNPS}^- + \text{DNPSSCH}_2\text{CH}_3 \rightleftarrows \text{DNPSSDNP} + \text{CH}_3\text{CH}_2\text{S}^- \quad \text{(h-1)}$$

$$p\text{-NO}_2\text{C}_6\text{H}_4\text{S}^- + p\text{-NO}_2\text{C}_6\text{H}_4\text{SSC}_6\text{H}_5 \rightleftarrows p\text{-NO}_2\text{C}_6\text{H}_4\text{SSC}_6\text{H}_5 + p\text{-NO}_2\text{C}_6\text{H}_4\text{S}^- \quad \text{(i)}$$

Experimental

Synthesis of Unsymmetrical Disulfides, R'SSR.—The sulfenyl chloride (R'SCl) was dissolved in hot dry acetic acid and the solution filtered to remove disulfide (R'SSR'). To this was added an equimolar amount of the thiol, RSH, in dry acetic acid. The solution was warmed for 30 minutes, when the disulfide either crystallized from the reaction mixture, was precipitated by adding water, or was isolated by removing acetic acid under reduced pressure. Recrystallization from acetic acid, then ethanol, gave the disulfide, R'SSR, in high yield (80–100%).

In this way were prepared, from 2,4-dinitrobenzensulfenyl chloride and the appropriate thiol: 2,4-dinitrophenyl phenyl disulfide, m.p. 88°,[22a] in 90% yield; 2,4-dinitrophenyl benzyl disulfide, m.p. 144°,[22b] in 90% yield; 2,4-dinitrophenyl ethyl disulfide, m.p. 87°, 95% yield (*Anal.* Calcd. for $C_8H_8N_2O_4S_2$: C, 36.92; H, 3.10; S, 24.61. Found: C, 37.04; H, 3.41; S, 24.41); 2,4-dinitrophenyl ethyl disulfide, m.p. 109–110°,[23] 80% yield; and 2,4-dinitrophenyl 4'-nitrophenyl disulfide, m.p. 178°, 94% yield (*Anal.* Calcd. for $C_{12}H_7N_3O_6S_2$: C, 40.82; H, 2.00; N, 11.89. Found: C, 41.02; H, 2.13; N, 11.81). The same method was used to prepare 4-chloro-2-nitrophenylethyl disulfide, m.p. 68.5° in 85% yield (*Anal.* Calcd. for $C_8H_8NO_2\,ClS_2$: C, 38.40; H, 3.20; S, 25.65. Found: C, 38.41; H, 3.32; N, 25.63); 2-nitrophenyl ethyl disulfide, m.p. 30–31°, in 70% yield (*Anal.* Calcd. for $C_8H_9NO_2S_2$: C, 44.86; H, 4.20; S, 29.90. Found: C, 44.78; H, 4.32; S, 29.73); and phenyl ethyl disulfide,[24] b.p. 92–93° (5 mm.), in 40% yield (*Anal.* Calcd. for $C_8H_{10}S_2$: C, 56.41; H, 5.93; S, 37.65. Found: C, 56.37; H, 6.10; S, 37.42) from ethyl mercaptan and the appropriate sulfenyl chloride.[25] 4-Nitrophenyl-phenyl disulfide, m.p. 58°,[22a] in 40% yield from benzenesulfenyl chloride and 4-nitrothiophenol; 2-nitrophenyl phenyl disulfide, m.p. 48°,[22a] in 80% yield from 2-nitrobenzenesulfenyl chloride and thiophenol, were similarly prepared.

All of the above disulfides were recovered unchanged after refluxing in ethanol or aqueous acetone, or after irradiation with ultraviolet light at room temperature in a quartz cell.

Identification and Isolation of Mercaptans (Method A).—The disulfide (0.01 mole) was dissolved in 100 ml. of acetone and 20 ml. of 0.05 *N* aqueous solution of the nucleophile. After 5 hours at 25–30° under nitrogen, 30 ml. of water was added and the solution was concentrated under reduced pressure. The residue (30 ml.) was filtered, the filtrate acidified and the precipitated thiol weighed and identified by a mixture melting point with an authentic sample.

Identification of Mercaptides Displaced (Method B).—The disulfide (0.01 mole) and 2,4-dinitrochlorobenzene (0.01 mole) were dissolved in 100 ml. of 95% ethanol.[26] The nucleophile (0.01 mole in 50 ml. of 50% ethanol) was then added and the solution warmed for a period of time determined by the S-nucleophilicity[4] of the displacing anion. Where $DNPS^-$ was displaced from the disulfide a precipitate of the very insoluble[11] bis-(2,4-dinitrophenyl) sulfide, m.p. 194–195°, was formed. This was collected, washed with hot ethanol, and the yield of $DNPS^-$ calculated from the yield of $(DNP)_2S$ (Table II).

Spectrophotometric Measurements (Method C).—The spectra of disulfides and mercaptides (Table III) were measured in 95% ethanol on a Cary recording spectrophotometer.

The disulfide or freshly purified mercaptan (0.001 mole) was dissolved in 100 ml. of 95% ethanol. The solution was diluted to an appropriate concentration (10^{-4}–10^{-5} *M*) and examined in the region 250–500 mμ. With the mercaptans, the solution was flushed with nitrogen when prepared, made alkaline with sodium hydroxide and the spectra measured without delay under nitrogen. In all cases Beer's law was obeyed in the range 10^{-4}–10^{-5} *M* and disulfide spectra were unchanged after warming, standing for 24 hr., or exposure to light of wave length 300 mμ at 25°. Mercaptide spectra were unchanged 15 minutes after preparation at 25°, but the optical density of λ_{max} slowly diminished after this, due no doubt to oxidation to disulfide.

The Reaction between Disulfides and S-Nucleophiles, (Table IV).—The mercaptide spectra of Table III were unchanged by the presence of $10^{-4}M$ sodium cyanide, sodium hydroxide, potassium thiocyanate, sodium azide and sodium iodide. Sodium sulfite caused a lowering and broadening of the major peak of nitrosubstituted mercaptides, due no doubt to reduction of nitro groups. Phenyl thiocyanate at $10^{-4}M$ did not interfere with the spectra of nitro-substituted mercaptides in the region 375–450 mμ nor did a freshly prepared 10^{-4} *M* solution of benzenesulfenyl chloride in 95% ethanol.[27] The unsymmetrical disulfides, R'SSR, do not interfere with $R'S^-$ absorption at λ_{max} in the region 350–450 mμ (Table III). Thus neither the S-nucleophiles Y^-, the neutral product RSY, nor the reacting disulfide R'SSR, in the reaction $R'SSR + Y^- \rightarrow R'S^- + RSY$ interfere with the absorption of $R'S^-$.

A 10^{-4} to 5×10^{-4} *M* disulfide solution in 95% ethanol was mixed with a tenfold excess of γ^- at 20–22° under nitrogen. The maximum optical density in the region 350–450 mμ was measured at standard time intervals from the time of mixing; after two hours the solution was warmed to 60° to complete reaction.

Identification of Phenyl Thiocyanate.—Equimolar quantities (0.01 mole) of DNP^- phenyl disulfide and sodium cyanide were dissolved in aqueous ethanol and 0.10 mole of DNP Cl added. $(DNP)_2S$ in quantitative yield was precipitated and removed by filtration. Solvent was removed from the filtrate leaving a red oil which was washed with water and steam distilled. A yellow oil ($n^{25}{}_D$ 1.5540) was obtained and distilled, to give a fraction, b.p. 69–72° (6 mm.), $n^{25}{}_D$ 1.5565 (lit. C_6H_5SCN,[19] 1.5712), which analyzed for nitrogen as 11.2% (C_6H_5SCN requires N: 10.34%); yield was 30% calculated as C_6H_5SCN. The liquid absorbed at 2170 cm.$^{-1}$ suggesting that the –SCN grouping was present.[19] Further attempts to purify the product resulted in decomposition.

Competitive Reaction between Ethyl, Phenyl and Benzyl Mercaptides.—Equimolar quantities of phenyl and benzyl mercaptans in ethanol were converted to mercaptide with two moles of alkali. One mole of DNPCl was added, the solution was warmed and diluted with water. An 83% yield of $DNP–SCH_2C_6H_5$, m. 130°, was isolated. A mixture of ethyl and phenyl mercaptans gave 76% yield of $DNP–S–CH_2CH_3$, m.p. 115°, by this procedure.

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[26] A test for chloride ion was negative and no material was precipitated when DNP Cl and DNP SSR were refluxed together in aqueous ethanol for 1 hour, showing that disulfides alone do not display appreciable nucleophilic reactivity toward DNPCl.

[27] The reaction $C_6H_5SCl + H_2O \rightarrow C_6H_5SOH + HCl$ would give products corresponding to alkaline cleavage of $R'SSC_6H_5$.