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The Reaction of Diaryl Disulfides with the Cyanide Ion

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The reaction of symmetrical disulfides with the cyanide ion in various solvents has been investigated. The reaction modes may be summarized as follows: (1) Dialkyl disulfides and diaryl disulfides with electron-withdrawing substituents react with the cyanide ion in DMSO or DMF to give the corresponding monosulfides. (2) Diaryl disulfides with electron-donating substituents react with DMSO to yield aryl methyl sulfides. (3) Diaryl disulfides are cleaved by the cyanide ion into thiolate anions and aryl thiocyanates, which then react with alcohol to afford alkyl aryl sulfides.

The scission of the sulfur-sulfur bond takes place when the attacking nucloeophile has a greater affinity for sulfur than the displaced group. This affinity for sulfur is called "*S*-nucleophilicity" or "thiophilicity".[1] The reaction of unsymmetrical disulfide with various *S*-nucleophiles was studied in detail by Parker and Kharasch.[2] The results indicate that the more stable (less basic) thiolate anion is displaced; the order of thiophilicity is found to be as follows:

$$C_2H_5S^- > C_6H_5S^- > CN^- > SO_3^{2-} > DNPS^- > N_3^- > SCN^-$$

The cyanide ion is a typical anthioanion which has a great affinity for sulfur to form thioanion (the thiocyanate ion).[3] The unsymmetrical disulfides with electron-withdrawing substituents on the aromatic nucleus were cleaved by the cyanide ion to displace thiolate anions at room temperature in aqueous alcohol.[2] Braun *et al.* found that bis(dialkylthiocarbamoyl) disulfides and bis(alkylarylthiocarbamoyl) disulfides react with potassium cyanide to give the corresponding monosulfides.[4] The analogous desulfurization of disulfides has been reported for dixanthyl disulfides,[5] bis(2-benzothiazolyl) disulfide, and dithiodiglycolic acid;[6] however, diphenyl disulfide,[5] bis(*p*-tolyl) disulfide,[6] and dibenzyl disulfide[6] do not react with the cyanide ion. We have previously found that dibenzyl disulfide reacts with the cyanide ion in dipolar aprotic solvents.[7] Therefore, we investigated the reaction of symmetrical disulfides with the cyanide ion in various solvents. We can now classify these reactions into three modes as follows:

$$\text{Mode A:}\quad RS\text{-}SR + CN^- \xrightarrow{\text{DMSO or DMF}} RSR + SCN^- \tag{1}$$

$$\text{Mode B:}\quad RS\text{-}SR + CN^- + DMSO \rightarrow RSCH_3 \tag{2}$$

$$\text{Mode C:}\quad RS\text{-}SR + CN^- + R'OH \rightarrow RSR' + RS^- \tag{3}$$

Results and Discussion

Reaction Mode A. It has been reported that dialkyl disulfide does not react with the cyanide ion in alcohol,[1] since the alkanethiolate anion is a more powerful *S*-nucleophile than is the cyanide ion—*i.e.*, the equilibrium shown in Equation (4) lies to the left:

$$RS\text{-}SR + CN^- \rightleftarrows RS^- + RSCN \tag{4}$$

$$RS^- + RSCN \rightarrow RSR + SCN^- \tag{5}$$

Since the cyanide ion reacts 5×10^5 times faster with methyl iodide in a dipolar aprotic solvent than in a protic solvent,[8] dialkyl disulfide can be expected to be cleaved by the cyanide ion in a dipolar aprotic solvent. Thus, dibenzyl sulfide was isolated in a 58% yield in the reaction of dibenzyl disulfide with the cyanide ion at room temperature in DMSO (Eq. (5)). This result shows that the cyanide ion is a more powerful *S*-nucleophile than is the alkanethiolate anion in the dipolar aprotic solvent. In a similar way, sulfides were obtained from disulfides in fairly good yields. The results are given in Table 1. Bis(*p*-nitrophenyl) and bis(*o*-nitrophenyl) disulfides were easily cleaved by the cyanide ion and gave the corresponding monosulfides in 60% and 76% yields respectively, while bis(*m*-nitrophenyl) and bis(*p*-tolyl) disulfides were not desulfurized to sulfides on treatment with the cyanide ion in DMSO.

Reaction Mode B. Diaryl disulfides, which have electron-donating substituents, were rapidly cleaved by the cyanide ion at room temperature; however, the corresponding monosulfides were not obtained, as has been cited above. When mixtures of diphenyl disulfide and sodium cyanide in DMSO were refluxed for 6 hr, a transparent oil was obtained in a 52% yield. The NMR spectra in CCl_4 exhibited singlet peaks at τ 7.63 (3H, S–CH_3) and at τ 2.66 (5H, aromatic), and the IR spectrum was identical with that of authentic methyl phenyl sulfide. The reaction process can reasonably be explained as follows; diphenyl disulfide was cleaved by the cyanide ion into phenyl thiocyanate and the benzenethiolate anion. Phenyl thiocyanate then reacts with the cyanide ion to afford the benzenethiolate

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

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

[3] R. E. Davis, "Survey of Progress in Chemistry," Vol. 2, ed. by A. Scott, Academic Press, New York (1964), p. 189.

[4] J. von Braun and F. Stechele, *Ber.*, **36**, 2275 (1903).

[5] G. S. Whitby and H. Greenberg, *Trans. Roy. Soc. Can.*, III, **23**, 21 (1929); *Chem. Abstr.*, **24**, 593 (1930).

[6] Y. Minoura, *Nippon Gomu Kyokai Shi*, **23**, 213 (1950).

[7] A part of this work was presented at the 21st Annual Meeting of the Chemical Society of Japan, Osaka, April, 1968 (See Abstracts of papers of the Meeting, Vol. 3, p. 1568).

[8] A. J. Parker, "Advances in Organic Chemistry *Methods and Results*," Vol. 5, ed. by R. A. Raphael, E. C. Taylor, and H. Wynberg, Interscience Publishers, New York, N. Y. (1965), p. 1.

TABLE 1. DESULFURIZATION OF DISULFIDES WITH THE CYANIDE ION

$$RS\text{-}SR + CN^- \rightarrow RSR + SCN^-$$

Disulfide R	Cyanide	Solvent	Reaction		Monosulfide yield %
			temp. (°C)	time (hr)	
n-$CH_3CH_2CH_2$-(Ia)	NaCN	DMSO	80	15	61(Ib)
-$(CH_2)_4$-(IIa)	NaCN	DMF	80	2	43(IIb)
$C_6H_5CH_2$-(IIIa)	NaCN	DMSO	r.t.	72	58(IIIb)
$C_6H_5CH_2$-(IIIa)	NaCN	DMF	60	14	36(IIIb)
p-$CH_3C_6H_4$-(Va)	NaCN	DMSO	65	6	(73)[a](Va)
o-$NO_2C_6H_4$-(VIIa)	NaCN	DMSO	60	3	76(VIIb)
m-$NO_2C_6H_4$-(VIIIa)	NaCN	DMSO	60	3	(36)[a](VIIIa)
p-$NO_2C_6H_4$-(IXa)	NaCN	DMSO	60	3	60(IXb)
3-NO_2-4-ClC_6H_3-(XIa)	NaCN	DMSO	80	9	36(XIb)

a) Recovered disulfide.

TABLE 2. FORMATION OF ALKYL ARYL SULFIDE IN THE REACTION OF DISULFIDE WITH THE CYANIDE ION IN DMSO

$$RS\text{-}SR + DMSO \xrightarrow{CN^-} RSCH_3$$

Disulfide R	Cyanide	Reaction		Yield of sulfide (%)
		temp. (°C)	time (hr)	
C_6H_5-(IVa)	NaCN (1 equiv.)	reflux	6	52(IVc)
C_6H_5-(IVa)	NaCN (2 equiv.)	reflux	6	66(IVc)
p-$CH_3C_6H_4$-(Va)	NaCN (1 equiv.)	reflux	6	63(Vc)

TABLE 3. METHYLATION OF THIOPHENOLS AND THIOCYANATES WITH DMSO IN THE PRESENCE OF THE CYANIDE ION

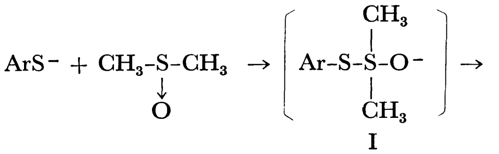
Starting material	Cyanide	Reaction		Product (Yield %)
		temp. (°C)	time (hr)	
C_6H_5SH	NaCN (1 equiv.)	reflux	24	$C_6H_5SCH_3$(65)
o-$CH_3C_6H_4SH$	NaCN (1 equiv.)	reflux	19	o-$CH_3C_6H_4SCH_3$(73)
m-$CH_3C_6H_4SH$	NaCN (1 equiv.)	reflux	14	m-$CH_3C_6H_4SCH_3$(73)
p-$CH_3C_6H_4SH$	none	reflux	6	(p-$CH_3C_6H_4S$-)-$_2$(86)
p-$CH_3C_6H_4SH$	NaCN (1 equiv.)	reflux	8	p-$CH_3C_6H_4SCH_3$(86)
p-$CH_3C_6H_4SH$	NaCN (1 equiv.)	reflux	24	p-$CH_3C_6H_4SCH_3$(92)
p-$CH_3C_6H_4SH$	NaCN (0.2 equiv.)	reflux	24	p-$CH_3C_6H_4SCH_3$(70)
p-$CH_3C_6H_4SH$	NaOH (1 equiv.)	reflux	7	p-$CH_3C_6H_4SCH_3$(74)
p-$CH_3C_6H_4SNa$	none	reflux	6	p-$CH_3C_6H_4SCH_3$(80)
p-$CH_3C_6H_4SH$	NaCN (1 equiv.)	170	6	p-$CH_3C_6H_4SC_2H_5$(46)[a]
C_6H_5SCN	NaCN (1 equiv.)	reflux	6	$C_6H_5SCH_3$(63)
p-$CH_3C_6H_4SCN$	NaCN (1 equiv.)	reflux	6	p-$CH_3C_6H_4SCH_3$(58)

a) Diethyl sulfoxide was used instead of DMSO.

anion and cyanogen:[9]

$$ArSCN + CN^- \rightarrow ArS^- + (CN)_2 \qquad (6)$$

Thus, when mixtures of phenyl thiocyanate and sodium cyanide in DMSO were refluxed for 6 hr, methyl phenyl sulfide was isolated in a 63% yield. The above data show that the thiolate anion, once formed, should react with DMSO to give aryl methyl sulfide. Thus, sodium p-toluenethiolate was treated with DMSO to afford methyl p-tolyl sulfide in an 80% yield. The results are shown in Table 3. The reaction of the thiolate anion with DMSO would form the I adduct, which might then thermally rearrange to aryl methyl sulfide.



$$ArS^- + CH_3\text{-}\underset{\downarrow \atop O}{S}\text{-}CH_3 \rightarrow \left[Ar\text{-}S\text{-}\overset{CH_3}{\underset{CH_3}{S}}\text{-}O^- \right] \rightarrow$$

I

$$Ar\text{-}S\text{-}CH_3 + [CH_3SO^-]^{10)} \qquad (7)$$

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[9] Cyanogen was hydrolyzed by introducing into an aqueous solution of sodium hydroxide and the resulting cyanate ion was detected by cobalt ion. See G. J. Jang, "Inorganic Syntheses," Vol. 5, p. 47 (1957); A. Scattergood, *ibid.*, Vol. 2, p. 89 (1946); W. T. Hall, "Analytical Chemistry," Vol. 1, p. 360 (1955).

[10] Methanesulfenate anion was not isolated because of its facile disproportionation. See N. Kharasch, S. J. Potempa, and H. L. Wehrmeister, *Chem. Rev.*, **39**, 269 (1946); M. Chaykovsky and E. J. Corey, *J. Org. Chem.*, **28**, 254 (1963); C. Walling and L. Bollyky, *ibid.*, **28**, 256 (1963); D. R. Hogg and P. W. Vipond, *J. Chem. Soc., B*, **1970**, 1242; D. J. Pasto and C. R. Johnson, "Organic Structure Determination," Prentice-Hall, Canada (1969), p. 456.

TABLE 4. FORMATION OF ALKYL ARYL SULFIDE IN THE REACTION OF DISULFIDE WITH THE CYANIDE ION IN ALCOHOL

$$\text{ArS-SAr} + \text{ROH} \xrightarrow{\text{CN}^-} \text{ArSR} + \text{HCN} + \text{OCN}^-$$

Disulfide Ar	Cyanide	Alcohol	Reaction[a] time (hr)	Yield of sulfide (%)
C_6H_5-(IVa)	NaCN (2.7 equiv.)	CH_3OH	3	66(IVc)
p-$CH_3C_6H_4$-(Va)	NaCN (2.7 equiv.)	CH_3OH	3	67(Vc)
p-ClC_6H_4-(VIa)	NaCN (2.7 equiv.)	CH_3OH	3	60(VIc)
o-$NO_2C_6H_4$-(VIIa)	NaCN (2.7 equiv.)	CH_3OH	3	81(VIIc)
m-$NO_2C_6H_4$-(VIIIa)	NaCN (2.7 equiv.)	CH_3OH	3	81(VIIIc)
p-$NO_2C_6H_4$-(IXa)	NaCN (2.7 equiv.)	CH_3OH	3	79(IXc)
3-NO_2-4-ClC_6H_3-(XIa)	NaCN (1.2 equiv.)	CH_3OH	5	55(XIc)
2-Cl-5-$NO_2C_6H_3$-(XIIa)	KCN (2.5 equiv.)	CH_3OH	4	78(XIIc)
2-Cl-5-$NO_2C_6H_3$-(XIIa)	NaCN (1.7 equiv.)	C_2H_5OH	4	48(XIId)
2-Br-5-$NO_2C_6H_3$-(XIIIa)	NaCN (1.4 equiv.)	CH_3OH	2	55(XIIIc)

a) Refluxing in alcohol.

Although the mechanism of this novel reaction is not yet clear, the *S*-methylation of thiols with DMSO is a useful method for preparing aryl methyl sulfides.

Reaction Mode C. Parker and Kharasch isolated phenyl thiocyanate in the reaction of 2,4-dinitrophenyl phenyl disulfide with sodium cyanide in the presence of 2,4-dinitrochlorobenzene.[2] We found that symmetrical diaryl disulfides were rapidly cleaved by the cyanide ion under refluxing in methanol, and that aryl methyl sulfides were isolated in high yields, as is shown in Table 4. The reaction can be explained by considering the initial formation of *O*-alkyl *S*-aryl thioiminocarbonate (II) from aryl thiocyanate and alcohol.[11] The intermediate (II) is in turn decomposed into the thiolate anion and alkyl cyanate. The nucleophilic attack of the thiolate anion on alkyl cyanate gave alkyl aryl sulfide, with the elimination of the cyanate ion.

The mechanism of the addition of alcohol to thiocyanate in the presence of the cyanide ion and the decomposition of the resulting *O*-alkyl *S*-aryl thioiminocarbonate will be described in detail elsewhere.

Conclusion

The reaction of disulfides with the cyanide ion may be summarized as follows:

i) Dialkyl disulfides and diaryl disulfides with electron-withdrawing substituents in the *ortho*- and *para*-positions give the corresponding monosulfides in dipolar aprotic solvents.

ii) Diaryl disulfides with electron-donating substituents react with DMSO to afford aryl methyl sulfides.

iii) Diaryl disulfides react with alcohol to give alkyl aryl sulfides.

Experimental

The melting points were determined on a hot-stage apparatus and were uncorrected. The NMR spectra were obtained in carbon tetrachloride with a JEOLCO 3H-60 spectrometer against internal TMS. The IR spectra were recorded with JASCO IR-S and DS-402G spectrophotometers, and glc was carried out using a Yanagimoto GCG-5DH gaschromatograph (Silicone DC-550, 3 m).

Material. The disulfides were prepared as has been described in the literature. The physical constants and the results of the elemental analysis of disulfides are listed in Table 5.

TABLE 5. MELTING POINTS AND ANALYTICAL DATA OF DISULFIDES

Disulfide	Mp °C (lit.)	Analysis Found (Calcd) C%	H%	S%
IIIa	69—70 (71[12])	68.31 (68.25)	5.72 (5.73)	25.92 (26.03)
IVa	59.1—60 (62.5—63.5[13])	65.94 (66.01)	4.54 (4.62)	29.30 (29.37)
Va	43.5—44 (48—49[13])	68.49 (68.25)	5.51 (5.73)	25.97 (26.03)
VIIa	198.5—200.5 (195[14])	46.82 (46.72)	2.49 (2.61)	20.88 (20.80)
VIIIa	82—83 (82—83[15])	46.50 (46.74)	2.43 (2.61)	20.93 (20.80)
IXa	186—188 (181[16])	46.89 (46.74)	2.67 (2.61)	20.55 (20.80)
Xa	212—213 (212.8[17])	38.47 (38.21)	1.90 (1.60)	16.99 (17.00)
XIa	115.5—116.5 (116—117[18])	37.96 (38.21)	1.57 (1.60)	17.10 (17.00)
XIIa	145—147 (143—143.5[18])	38.19 (38.21)	1.39 (1.60)	17.09 (17.00)
XIIIa	159—161	30.74 (30.92)	1.49 (1.30)	13.94 (13.76)

Xa: 2-NO_2-4-ClC_6H_3-

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[11] K. Tanaka, J. Hayami, and A. Kaji, This Bulletin, **44**, 2815 (1971).

[12] Y. Minoura, *Nippon Kagaku Zasshi*, **73**, 131 (1952).

[13] E. Campaigne, J. Tsurugi, and W. W. Meyer, *J. Org. Chem.*, **26**, 2486 (1961).

[14] M. T. Bogert and A. Stull, "Organic Syntheses," Coll. Vol. I, p. 220 (1956).

[15] W. A. Sheppard, *ibid.*, Vol. 40, p. 80 (1960).

[16] Th. Zincke and S. Lenhardt, *Ann. Chem.*, **400**, 2 (1913).

[17] J. N. Elgersma, *Rec. Trav. Chim. Pays-Bas*, **48**, 752 (1929).

[18] V. O. Lukashevich, *Dokl. Akad. Nauk SSSR*, **103**, 627 (1955); *Chem. Abstr.*, **50**, 5557a (1956).

Reaction Mode A. General Procedure: Disulfide (0.05 mol) was dissolved in dry DMSO (100 m*l*) or dry DMF (100 m*l*) under stirring, and then powdered sodium cyanide (0.051 mol) was added. After a definite period (see Table 1), the colored solution (red to yellow) was poured into ice-cooled water. The resulting monosulfide was filtered (if solid), dried *in vacuo*, and then recrystallized. If the monosulfide was a liquid, the organic layer was extracted with ether three times, washed with water, and dried with anhydrous sodium sulfate. Distillation gave monosulfide as a transparent liquid. The physical data and the results of the analysis of the monosulfide which was formed by desulfurization are given in Table 6.

TABLE 6. MELTING POINTS AND ANALYTICAL DATA OF MONOSULFIDES

Monosulfide	Mp °C (lit.)	Analysis Found (Calcd)		
		C%	H%	S%
IIIb	46.5—47.5 (48.5[12])	78.72 (78.45)	6.60 (6.58)	14.68 (14.96)
VIIb	122—124 (122—123[19])	52.20 (52.17)	3.20 (2.92)	11.35 (11.61)
IXb	162.5—163.5 (160—161[20])	51.87 (52.17)	2.83 (2.92)	11.55 (11.61)
Xb	156.5—158.0 (149—150[21])	41.84 (41.76)	1.96 (1.75)	9.47 (9.29)

Reaction Mode B. General Procedure: A mixture of disulfide and sodium cyanide in DMSO was refluxed for 6 hr. After being cooled to room temperature, the reaction mixture was steam-distilled. The organic layer was extracted with *n*-hexane four times, washed with water, and then dried over anhydrous sodium sulfate. The evaporation of the solvent gave an oil, which was then distilled *in vacuo*. Methyl phenyl sulfide, by 86—87.5°C/20 mmHg (lit,[13] bp 84°C/18 mmHg); methyl *p*-tolyl sulfide, bp 100.8—103°C/19 mmHg (lit,[13] bp 104—105°C/20 mmHg). The NMR and IR spectra and the glc retention time of aryl methyl sulfide were identical with those of authentic samples.

TABLE 7. MELTING POINTS AND NMR DATA OF ALKYL ARYL SULFIDES

Alkyl aryl sulfide	Mp °C or bp °C/mmHg (lit.)	τ(*S*-Alkyl)
$C_6H_5SCH_3$ (IVc)	90/22 (84/18[13])	7.63(3H, s)
p-$CH_3C_6H_4SCH_3$ (Vc)	105—106/23 (104—105/20[13])	7.65(3H, s)
p-$CH_3C_6H_4SC_2H_5$ (Vd)	114—117/27 (122—125/20[22])	7.20(2H, q) 8.76(3H, t)
p-$ClC_6H_4SCH_3$ (VIc)	120/23 (170—108/15[23])	7.64(3H, s)
o-$NO_2C_6H_4SCH_3$ (VIIc)	59—60 (60—61[11])	7.53(3H, s)
m-$NO_2C_6H_4SCH_3$ (VIIIc)	125/3 (119—124/1.5[24])	7.44(3H, s)
p-$NO_2C_6H_4SCH_3$ (IXc)	69—70 (69—70[11])	7.45(3H, s)
3-NO_2-4-$ClC_6H_3SCH_3$ (XIc)	70—71.5 (70—72[25])	7.47(3H, s)
2-Cl-5-$NO_2C_6H_3SCH_3$ (XIIc)	98—99[a]	7.47(3H, s)
2-Cl-5-$NO_2C_6H_3SC_2H_5$ (XIId)	68—69.5[b]	6.94(2H, q) 8.54(3H, t)
2-Br-5-$NO_2C_6H_3SCH_3$ (XIIIc)	145—146[c]	7.42(3H, s)

a) Found: C, 41.19; H, 2.90; S, 15.76%. Calcd for $C_7H_6ClNO_2S$: C, 41.28; H, 2.97; S, 15.74%.

b) Found: C, 44.24; H, 3.71; S, 14.62%.. Calcd for $C_8H_8ClNO_2S$: C, 44.14; H, 3.70; S, 14.73%.

c) Found: C, 33.83; H, 2.38; S, 13.05%. Calcd. for $C_7H_6BrNO_2S$: C, 33.89; H, 2.44; S, 12.92%.

Reaction Mode C. General Procedure: A mixture of disulfide and sodium cyanide in alcohol was refluxed under stirring. The solvent was evaporated under reduced pressure, and the residue was crystallized or distilled. The physical constants and NMR data of alkyl aryl sulfides are reported in Table 7.

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19) R. Nietzki and H. Bothof, *Ber.*, **29**, 2774 (1896).

20) C. C. Price and G. W. Stacy, "Organic Syntheses," Coll. Vol. III, p. 667 (1955).

21) F. Beilstein and A. Kurbatow, *Ann. Chem.*, **197**, 75 (1879).

22) H. Gilman and N. J. Beaber, *J. Amer. Chem. Soc.*, **47**, 1449 (1925).

23) J. van der Veen and W. Stevens, *Rec. Trav. Chim. Pays-Bas*, **82**, 287 (1963).

24) A. H. Goldkamp, *J. Org. Chem.*, **34**, 1780 (1969).

25) R. C. Elderfield and F. W. Short, *J. Org. Chem.*, **17**, 758 (1952).