tillation at reduced pressure, and the resulting brown, crystalline residue was washed with dilute sodium bicarbonate solution. Acidification of the bicarbonate washings yielded benzoic acid, m.p. 121°, the identity being confirmed in a mixture melting point with an authentic sample. The residue left after bicarbonate washing was extracted with 20 ml. of hot water, decolorized with Darco and concentrated by evaporation to a small volume. The crude solid so obtained was twice crystallized from small volumes of aqueous ethanol to yield 0.02 g. of **3,6-dimethyloxindole**, m.p. 137–138°. A mixture of this material and that obtained as described above under autohydrogenolysis of III (m.p. 139–140°) had m.p. 138–139°.

Preparation of Model Compounds. Preparation of VII.—VII was prepared according to the method of Woodward and Eastman.[3] The sample used for the ultraviolet absorption spectrum reported in Fig. 3 had m.p. 31–32°.

Preparation of VIII.—Seventy-five hundredths of a gram of VI[3] was heated with 0.70 g. of α-methylphenylhydrazine in a sealed tube filled with nitrogen at 140° for 16 hours. The mixture crystallized on being permitted to stand for two days at room temperature. The crystals were separated by filtration and washed with benzene to yield 0.65 g. of material, m.p. 108–109°. Crystallization from aqueous methanol gave 0.60 g. of white needles, m.p. 108–109.5°.

Anal. Calcd. for $C_{17}H_{22}O_2N_2$: C, 71.34; H, 7.68. Found: C, 71.14; H, 7.73.

VIII was soluble in warm 5% potassium hydroxide solution. Acidification of the alkaline solution with 3 *N* hydrochloric acid regenerated the compound in nearly quantitative yield. The compound VIII was also soluble in 6 *N* hydrochloric acid but not appreciably so in 3 *N* acid. Addition of excess sodium bicarbonate to the acid solution caused precipitation of VIII unchanged. The ultraviolet absorption spectrum is reported in Fig. 3.

Preparation of IX.—Two-tenths of a gram of VIII was heated with a tiny crystal of sodium bisulfate in a small distilling tube over a free flame while maintaining a pressure of 1 mm. Gas evolution commenced soon after the mixture melted and continued for 15 minutes of gentle heating. The product was finally distilled over an indentation in the distilling tube and after being cooled consisted of a greenish-yellow glass. This material was dissolved in purified ether and the solution was extracted three times with 3 *N* hydrochloric acid, three times with 5% sodium hydroxide and washed with water. Evaporation of the ether, finally at 1 mm., left a faintly yellow, very viscous oil. A sample was prepared for analysis by sublimation at 1 mm. and 130°.

Anal. Calcd. for $C_{17}H_{20}N_2O$: C, 76.1; H, 7.53; N, 10.30. Found: C, 75.72; H, 7.63; N, 10.30.

This material was insoluble in 6 *N* and 12 *N* hydrochloric acid, hot or cold, and insoluble in hot or cold 5% sodium hydroxide. The ultraviolet absorption spectrum is reported in Fig. 2.

Ultraviolet Absorption Spectra.—The ultraviolet absorption spectra were determined with a Beckman Model DU Quartz Spectrometer. The sensitivity knob was kept three and one-half turns from the extreme clockwise position and the instrument was balanced by varying the slit width from 0.3 to 2.0 mm. as necessary. Readings were taken at 5 mμ intervals.

STANFORD, CALIF. RECEIVED MARCH 27, 1951

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF NORTHWESTERN UNIVERSITY]

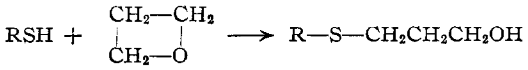
The Reactions of Trimethylene Oxide with Mercaptans, Thiophenol and Some Inorganic Sulfur Compounds[1]

BY SCOTT SEARLES

Trimethylene oxide is cleaved by sulfur anions in the same manner as is ethylene oxide although at a much slower rate. The reaction of thiophenol and aliphatic mercaptans proceeds smoothly in alkaline solution to give good yields of 3-hydroxypropyl sulfides, whereas no reaction occurs with tetrahydrofuran. The reactions of trimethylene oxide are strongly catalyzed by acids. A kinetic study of the reaction with aqueous sodium thiosulfate showed that acid catalysis is more effective with trimethylene oxide than with ethylene oxide in this reaction, as expected from the more basic nature of the four-membered cyclic ether.

Previous work has shown that trimethylene oxide is very similar to ethylene oxide in its reaction and reactivity with the Grignard reagent.[2] In order to obtain evidence on whether the four-membered cyclic ether is generally as reactive as the three-membered one, the reactions of the former with several mercaptans, thiophenol and certain inorganic sulfur anions have been investigated.

In contrast to the observations with the Grignard reaction, it is found that trimethylene oxide reacts with thiols much more slowly than does ethylene oxide; the course of the reaction, however, is analogous.



$$RSH + \begin{matrix} CH_2-CH_2 \\ | \quad\quad | \\ CH_2-O \end{matrix} \longrightarrow R-S-CH_2CH_2CH_2OH$$

The uncatalyzed reaction requires prolonged heating, and even when catalyzed with strong acids such as sulfuric acid or aluminum chloride the reaction gives poor yields. This is quite different from the easy reaction of mercaptans and thiophenol with ethylene oxide.[3]

The trimethylene oxide reaction proceeds smoothly in aqueous alkali, however, to give the expected sulfide alcohols in 60–75% yields (Table I). The faster reaction in the basic solution may be ascribed to the more nucleophilic character of the mercaptide anion, compared to the mercaptan.

The reaction of mercaptide ion, however, is much slower with trimethylene oxide than with ethylene oxide or propylene oxide, as shown by the time required and the products from competition experiments. Tetrahydrofuran, on the other hand, reacted much more slowly than trimethylene oxide, indicating that the ease of nucleophilic attack parallels the strain in the ring.

In view of the very easy reaction of thiosulfate,[4,5] bisulfite[6] and sulfide[5,7] ions with ethylene oxides, the reaction of these salts with trimethylene oxide was investigated. Trimethylene oxide reacted

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[1] Most of this material was presented before the Division of Organic Chemistry at the 118th Meeting of the American Chemical Society, Chicago, Ill., September 5, 1950.

[2] S. Searles, THIS JOURNAL, **73**, 124 (1951).

[3] C. D. Nenitzescu and N. Scarlatescu, *Ber.*, **68B**, 587 (1935).

[4] W. C. J. Ross, *J. Chem. Soc.*, 2257 (1950).

[5] C. C. J. Culvenor, W. Davies and N. S. Heath, *ibid.*, 278 (1949).

[6] W. M. Lauer and A. Hill, THIS JOURNAL, **58**, 1873 (1936).

[7] M. Mousseron, *Compt. rend.*, **216**, 812 (1943).

TABLE I

3-HYDROXYPROPYL SULFIDES, R–S–$CH_2CH_2CH_2OH$

R	Yield, %	B.p. °C.	B.p. Mm.	$n^{25}D$	Allophanates[a] M.p., °C.	Allophanates[a] Formula	Nitrogen, % Calcd.	Nitrogen, % Found
Phenyl[b,c]	76	134–5	2	1.5792	162–162.5	$C_{11}H_{14}O_3N_2S$	11.02	10.99
Benzyl[d]	63	185	22	1.5632	142–142.5	$C_{12}H_{16}O_3N_2S$	10.45	10.65
n-Butyl[e]	63	80	0.8	1.4782	134–134.5	$C_9H_{18}O_3N_2S$	11.96	11.78
n-Propyl[f]	64	118	23	1.4794	145–145.5	$C_8H_{16}O_3N_2S$	12.72	12.72

[a] Prepared by the method of Behal, *Bull. soc. chim.*, [4] **25**, 373 (1919). Melting points corrected. [b] W. R. Kirner and G. H. Richter, THIS JOURNAL, **51**, 3409 (1929). [c] Oxidation with hydrogen peroxide in glacial acetic acid gave phenyl 3-hydroxypropyl sulfone, b.p. 182–183° (0.3 mm.). *Anal.* Calcd. for $C_9H_{12}O_3S$: C, 53.98; H, 6.04. Found: C, 53.89; H, 5.87. [d] E. Rothstein, *J. Chem. Soc.*, 686 (1934). The sulfone was prepared by peroxide oxidation, m.p. 126–126.5°. [e] *Anal.* Calcd. for $C_7H_{16}OS$: C, 56.71; H, 10.88. Found: C, 57.04; H, 10.92. [f] G. M. Bennett and F. Heathcoat, *J. Chem. Soc.*, 268 (1929).

slowly with aqueous sodium sulfide to form 3,3′-dihydroxydipropyl sulfide. The isolation of this compound as the principal product even when sodium sulfide was used in considerable excess indicates that the intermediate 3-hydroxypropylmercaptide ion is more reactive than sulfide ion toward the cyclic ether.

The reactions of sodium and potassium bisulfite and sodium benzenesulfinate (which reacts with ethylene oxides to give sulfones[8]) in water were so slow that no definite reaction products could be isolated. In sulfurous acid solution, however, potassium bisulfite reacted to give a salt which may be formulated as potassium 3-hydroxypropylsulfonate by analogy to the ethylene oxide product.[6]

The reaction of aqueous sodium thiosulfate with ethylene oxides is quantitative and so rapid that Ross has used it for analysis of ethylene oxides. In the presence of a large excess of thiosulfate the reaction rate is first order with respect to oxide and can be followed by titrating the hydroxide formed.[4] The reaction with trimethylene oxide is similar except that the rate is slower and the reaction is more susceptible to acid catalysis.

TABLE II

RATE CONSTANTS FOR REACTION OF CYCLIC ETHERS IN 0.2 *M* SODIUM THIOSULFATE AT 35°

Oxide	k_w, min.$^{-1}$	k_a, min.$^{-1}$
Ethylene	0.20	380
Trimethylene	.013	400

As shown in Table II, the rate constant, k_w, for the "uncatalyzed" reaction of the four-membered cyclic ether is about one-tenth as large as that for the three-membered ether, but the rate constant, k_a, for the acid-catalyzed reaction is about the same for each. Since the kinetic similarity of the reactions with both ethers suggests that analogous mechanisms[4,9] are involved, the comparison of k_w values confirms in a more quantitative manner the previous conclusion that the four-membered ring is less susceptible to nucleophilic attack. In the acid-catalyzed reaction, however, this is compensated for by the greater basicity of the 4-membered ring ether,[10] so that the k_a values are about the same.

The previous observation that both oxides are of qualitatively the same reactivity in the Grignard reagent also may be explained by the lower strain of the four-membered ring being compensated for by its greater basicity, enabling it to form a more polarized complex with the reagent. The reason that acid catalysis of the addition of mercaptans to trimethylene oxide was not found more effective is probably the simultaneous polymerization of the oxide in the strongly acid medium.

Experimental

Sulfide Alcohols.—Method I (in alkaline solution) is illustrated by the following preparation of 3-phenylmercaptopropanol. To a mixture of 6.6 g. (0.06 mole) of thiophenol and 40 ml. of 10% sodium hydroxide 3.5 g. (0.06 mole) of trimethylene oxide was added. After the resulting homogeneous solution was allowed to stand overnight or was heated under reflux for 6 hours, an oily upper layer separated. This was removed, washed with 10% sodium hydroxide and with water and dried over potassium carbonate. Distillation gave 7.7 g. of the product, the physical constants of which are listed in Table I.

A solution of 10 g. of thiophenol and 10 g. of tetrahydrofuran in 60 ml. of 10% sodium hydroxide remained homogeneous after 24 hours of refluxing. Neutralization and ether extraction of the solution followed by drying and distillation of the extracts gave a practically quantitative recovery of thiophenol and tetrahydrofuran but no sulfide alcohol.

Method II (uncatalyzed reaction).—After a mixture of 9 g. (0.08 mole) of thiophenol and 6 g. (0.1 mole) of trimethylene oxide was heated in a sealed tube at 150° for 15 hours, distillation gave 3 g. of recovered trimethylene oxide, b.p. 47°, 6 g. of recovered thiophenol, b.p. 55–60° (8 mm.), and 2 g. (44% based on unrecovered thiophenol) of 3-phenylmercaptopropanol, b.p. 155–159° (8 mm.). When the initial mixture was merely refluxed for 10 hours, approximately one-half as much reaction occurred.

Method III (acid catalyst) (**A**).—A solution of 4 g. of trimethylene oxide, 11 g. of thiophenol and 0.2 g. of sulfuric acid in 50 ml. of glacial acetic acid was allowed to stand at room temperature 4 hours and then was heated under reflux for 4 hours. The reaction mixture was poured on ice, neutralized with potassium carbonate and extracted with ether. The dried ether extracts were distilled to give 6.7 g. of recovered thiophenol, 2.5 g. of diphenyl disulfide and 1.5 g. (10% based on trimethylene oxide or 55% based on unrecovered thiophenol) of 3-phenylmercaptopropanol.

(**B**).—To a suspension of 20 g. of anhydrous aluminum chloride in 75 ml. of dry hexane at 0–5°, a solution of 5.8 g. of trimethylene oxide and 8.0 g. of *n*-propyl mercaptan was added. After standing at room temperature for 2 hours and being heated under reflux one hour, the mixture was processed in the usual manner to give 2.5 g. (19%) of 3-propylmercaptopropanol.

Competition Experiments (**A**).—Addition of a solution of 11.6 g. (0.2 mole) of trimethylene oxide and 8.8 g. of ethylene oxide in 20 ml. of water to a cooled mixture of 22 g. (0.2 mole) of thiophenol in 100 ml. of 10% sodium hydroxide caused a rapid, exothermic reaction. The oily layer which separated was processed as described in Method I to give 26.4 g. (86%) of 2-phenylmercaptoethanol, b.p. 136–137° (9 mm.), $n^{25}D$ 1.5892, as the only observed product. The allophanate melted at 179–179.5°.

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(8) W. Hentrich and W. Gundel, U. S. Patent 2,378,551 (1945); *C. A.*, **39**, 4081 (1945).

(9) J. N. Bronsted, M. Kilpatrick and M. Kilpatrick, THIS JOURNAL, **51**, 428 (1929).

(10) S. Searles and M. Tamres, *ibid.*, **73**, 3704 (1951).

Anal. Calcd. for $C_{10}H_{12}O_3N_2S$: N, 11.7. Found: N, 11.8.

(**B**).—When the ethylene oxide in the above experiment was replaced by an equivalent of propylene oxide, 27.7 g. (83%) of 3-phenylmercaptopropanol-2, b.p. 133° (9 mm.), n^{25}D 1.5715, was the only product obtained. The melting points of the *p*-nitrobenzoate (64–65°) and sulfone *p*-nitrobenzoate (164°) agree closely with values reported by Fuson and Koehnecke,[11] who used an unambiguous synthesis. Thus the direction of cleavage of propylene oxide by this reagent is determined.[12]

3,3′-Dihydroxydipropyl Sulfide.—A solution of 6 g. of trimethylene oxide, 25 g. of sodium sulfide nonahydrate and 25 ml. of water was allowed to stand 3 days at about 30°. After the reaction mixture was acidified and concentrated *in vacuo*, the precipitated sodium chloride was filtered and washed with alcohol. Evaporation of the solvent then gave 8.2 g. (95%) of a pale yellow, viscous, non-distillable oil. The phenylurethan melted at 120° (from alcohol).[13]

The use of twice as much sodium sulfide led to the same result, and an attempt to isolate 3-hydroxypropylmercaptan by steam distillation of the reaction mixture was unsuccessful.

Reaction of Potassium Bisulfite with Trimethylene Oxide. A solution of 5 g. of the oxide with 10 g. of potassium metabisulfite in 15 ml. of water previously saturated with sulfur dioxide was allowed to stand 3 days at about 30°. After removal of the solvent *in vacuo* the white residue was extracted with 95% alcohol in a Soxhlet apparatus. White platelets separated from the alcoholic extract, m.p. 195–198° dec.

Anal. Calcd. for $C_3H_7O_4SK$: K, 22.4. Found: K, 23.1, 23.2.

Reaction of Sodium Thiosulfate with Ethylene and Trimethylene Oxides.—The Ross procedure[4] for following the reaction kinetically was modified to reduce the extent of evaporation of these volatile oxides: The oxide (0.002 mole) was added to 50 ml. of aqueous 0.1 *M* sodium thiosulfate, well stirred and thermostated at 35°, and 0.1 *N* hydrochloric acid was added from a microburet at a rate such that the *p*H of the solution remained constant (within ± 0.2 *p*H, as determined by a Beckman model H *p*H meter).

The data gave a linear relationship between the time and log $(V_\infty)/(V_\infty - V)$, where V and V_∞ are the volumes of acid added at time t and t_∞, in agreement with the first order rate law, and the first order rate constant, k, was evaluated graphically. The theoretical volume of acid was used in the reaction of ethylene oxide but not in that of the slower reacting trimethylene oxide. Since the direct reaction of this compound with water is extremely slow and since its odor was quite discernible over the solution, it seems likely that the difference was caused by evaporation. This was taken into consideration by treating the data as a case of two simultaneous first order equations. The constant k evaluated graphically thus is k_{thio} plus $k_{\text{evap.}}$, and k_{thio} was evaluated by solving[14]

$$\frac{V \times k}{[A]_0 \times k_{\text{thio}}} = 1 - e^{-kt}$$

(where $[A]_0$ is the initial oxide concentration) for individual sets of V and t values and then averaged.

TABLE III

FIRST ORDER RATE CONSTANTS FOR REACTION OF OXIDES IN 0.2 *M* THIOSULFATE AT 35°

*p*H	Ethylene oxide, min.$^{-1}$	Trimethylene oxide, min.$^{-1}$
8	0.20	0.013
5.0		.017
4.5	.22	.025
3.4	.35	

From the specific rate constants observed at three *p*H values (Table III) the constants k_w and k_a, for the "uncatalyzed" and acid-catalyzed reactions, respectively, were evaluated from the relation

$$k = k_w + k_a/[H^+]$$

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(11) Fuson and Koehnecke, *J. Org. Chem.*, **14**, 706 (1949).

(12) NOTE ADDED IN PROOF.—The same conclusion was reported recently by R. D. Schuetz, THIS JOURNAL, **73**, 1881 (1951).

(13) McGinnis and Robinson, *J. Chem. Soc.*, 406 (1941), reported m.p. 122–123°.

(14) F. H. MacDougall, "Physical Chemistry," revised ed., The Macmillan Co., New York, N. Y., 1943, p. 425, eq. 51.

EVANSTON, ILL. RECEIVED APRIL 16, 1951

[CONTRIBUTION FROM THE SCHOOL OF CHEMISTRY OF THE UNIVERSITY OF MINNESOTA]

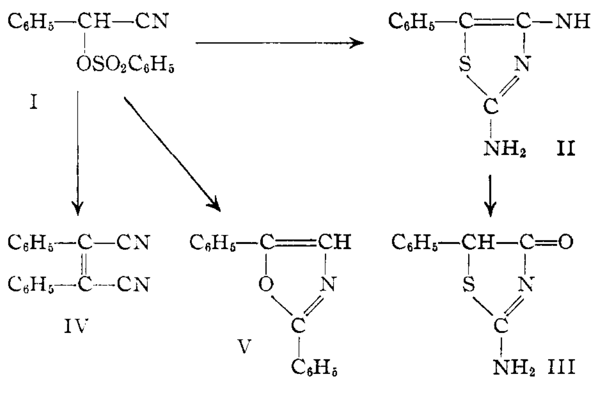
α-Cyanoalkyl Sulfonates. I. The Reactions of α-Cyanobenzyl Benzenesulfonate

BY R. M. DODSON AND HARRY W. TURNER[1]

2,4-Diamino-5-phenylthiazole benzenesulfonate was prepared in excellent yield by the reaction of α-cyanobenzyl benzenesulfonate with thiourea. The structure of the 2,4-diamino-5-phenylthiazole was established by its hydrolysis to the known 2-amino-5-phenyl-4(5)-thiazolone. Treatment of α-cyanobenzyl benzenesulfonate with a suspension of potassium cyanide in alcohol yielded α,α¹-dicyanostilbene. When the α-cyanobenzyl benzenesulfonate was treated with benzaldehyde and sodium cyanide in dilute dioxane, 2,5-diphenyloxazole was obtained.

Even though the chemistry of cyanohydrins has been extensively studied, the α-cyanoalkyl sulfonates have been neglected. Because of the similarity of alkyl sulfonates and alkyl halides in chemical reactions, one would expect the α-cyanoalkyl sulfonates to be similar to the α-halonitriles in their reactions. In the work reported in this paper, this has been found to be true.

α-Cyanobenzyl benzenesulfonate (I) was prepared in 84% yield by the reaction of sodium cyanide and benzenesulfonyl chloride with benzaldehyde.[2] The compound is rather unstable; it slowly decomposes at room temperature but can be stored at 0°. When an acetone solution of α-cyanobenzyl benzenesulfonate was treated at room temperature with an equivalent amount of thiourea and then diluted with water until cloudy, the



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[1] Abstracted from the Ph.D. thesis of Harry W. Turner.

[2] F. Francis and O. C. M. Davis, *J. Chem. Soc.*, **95**, 1403 (1909).