mixture shaken at room temperature with hydrogen at 50 p.s.i. The theoretical amount of hydrogen was absorbed in about three days. Anhydrous magnesium sulfate was added to the reaction mixture and the solids were filtered. Dry benzene was added to the filtrate and the solution was concentrated; the last 50 ml. was removed at reduced pressure. Only a part of the total residue could be sublimed as a white crystalline substance. After two additional sublimations the product, 1,4 - dimethyl - 2,6,7 - trioxabicyclo[2.2.2]octane melted at 85–90°. This substance absorbed water rather quickly from the atmosphere to become a colorless viscous liquid. Even careful handling prior to analysis permitted the absorption of considerable water.

Anal. Calcd. for $C_7H_{12}O_3$: C, 58.31; H, 8.39. Calcd. for $C_7H_{12}O_3 \cdot {}^1/_2\,H_2O$: C, 54.89; H, 8.55. Found: C, 54.81, 54.94; H, 8.12, 8.31.

The reaction of trichloroacetic acid with glycerol. A mixture of trichloroacetic acid (33 g.), glycerol (18.4 g.), *p*-toluenesulfonic acid (2 g.), and xylene (350 ml.) was refluxed for 24 hr. with evolution of 6 ml. of water (two equivalents is 7.2 ml.). The solution was cooled, washed with sodium bicarbonate, and concentrated. The first fractions obtained on vacuum distillation boiled at 125–135°/3 mm. The infrared spectra of these fractions had strong carbonyl and hydroxyl absorption bands.

New Brunswick, N. J.

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Preparation of Thiols

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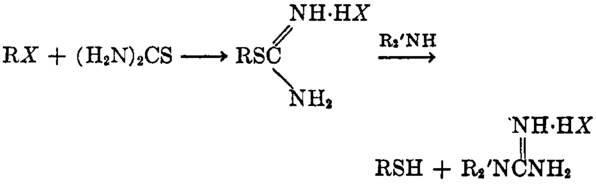
An improved method of preparing simple thiols is described. The steps involved are (1) preparation of an isothiuronium salt in a high-boiling solvent, followed by (2) cleavage of this salt with a high-boiling amine. The desired thiol is separated by distillation, leaving a guanidine salt by-product as residue. The process is not applicable to the preparation of 1,2-ethanedithiol. It is prepared by an alternate procedure involving the reaction of ethyl 2-mercaptoethylcarbonate with ammonium hydrosulfide.

During the one hundred twenty-five years since the discovery of the first mercaptan or thiol, preparation of the lower members has been unpleasant because of their inherent odors. The need for a variety of mono- and dithiols prompted a search for a more satisfactory method of preparation.

The method involving the action of aqueous alkali on isothiuronium salts has superseded most of the others used for laboratory-scale preparations.[1] Isolation usually involves either a steam distillation or an ether extraction, and in some instances both. During recent mercaptoethylation studies[2] an amine was used to cleave an isothiuronium salt to generate a thiol *in situ*. A similar reaction has been used by others for the synthesis of substituted guanidines[3] and for the preparation of mercaptoalkanesulfonic acids.[4] This type of reaction has now been adapted to the preparation of mono- and dithiols by a general method which eliminates handling operations.

The steps involved are the preparation of an isothiuronium salt in a high-boiling solvent, followed by cleavage of this salt by a high-boiling strong amine. The products are the desired thiol and a nonvolatile guanidine salt.



$$RX + (H_2N)_2CS \longrightarrow RSC(=NH\cdot HX)NH_2 \xrightarrow{R_2'NH} RSH + R_2'NC(=NH\cdot HX)NH_2$$

The solvent and the amine should be chosen so that their boiling points are well above that of the thiol being prepared. Triethylene glycol and tetraethylenepentamine have been used in the present study because of their low cost and ready availability. The over-all time required for a one-mole run is approximately one hour. The products prepared are listed in Tables I and II.

TABLE I

Thiols

RSH

R	B.P.	n_D^{25}	Purity, %	Yield, %
C_2H_5—	35	1.4269	99.7	68
n-C_3H_7—	65	1.4345	98.5	79
n-C_4H_9—	96–97	1.4407	99.5	77
n-C_5H_{11}—	123–124	1.4439	100.0	75
n-C_8H_{17}—	91–93/24 mm.	1.4518	97.7	84
n-$C_{10}H_{21}$—	94/5 mm.	1.4545	100.0	87

It was of interest to find that this synthesis could not be adapted to the preparation of 1,2-ethanedithiol. When the isothiuronium salt prepared from 1,2-dibromoethane was cleaved with tetraethylenepentamine, no product distilled below the boiling

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[1] E. E. Reid, *Organic Chemistry of Bivalent Sulfur*, Vol. I, Chemical Publishing Co., Inc., New York, 1958, p. 32.

[2] D. D. Reynolds, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5116 (1961).

[3] M. Schenk and H. Kerchhof, *Z. physiol. Chem.*, **158**, 90 (1926); R. Phillips and H. T. Clark, *J. Am. Chem. Soc.*, **45**, 1755 (1923).

[4] C. Schramm, H. Lemaire, and R. Karlson, *J. Am. Chem. Soc.*, **77**, 6231 (1955).

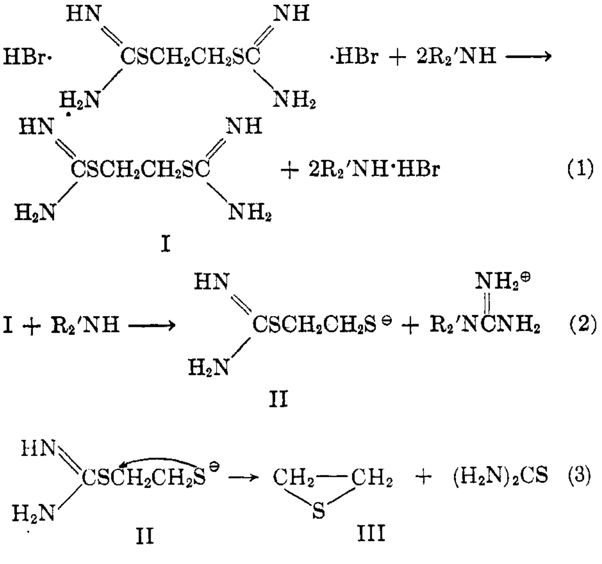
TABLE II

DITHIOLS

$HS(CH_2)_nSH$

n	B.P	n_D^{25}	Purity, %	Yield, %
2	—	—	—	0
3	69–69/18 mm.	1.5374	98.3	58
4	75/18 mm.	1.5270	97.7	78
5	103/20 mm.	1.5174	99.4	80

point of triethylene glycol. However, when the isothiuronium salt was allowed to react with morpholine, a 62% yield of 2-morpholinoethanethiol was obtained. In like manner, di-*n*-butylamine gave a 22% yield of di-*n*-butylaminoethanethiol, along with some polyethylene sulfide. These results may be interpreted as follows. Ethylenebisisothiourea (I) is formed in the presence of base, as shown in Equation 1. It is then converted to the intermediate 2-mercaptoethylisothiourea (II) (Equation 2), which, in the presence of the amine, undergoes an intradisplacement reaction to yield ethylene sulfide (III). This reacts, in turn, with the amine to form an aminoethanethiol (IV) and higher mercaptoethylated derivatives which have been designated as polyethylene sulfides (V).



$$n\text{III} + 2R_2'NH \longrightarrow R_2'NCH_2CH_2SH + R_2'N(CH_2CH_2S)_{n-1}H \quad (4)$$

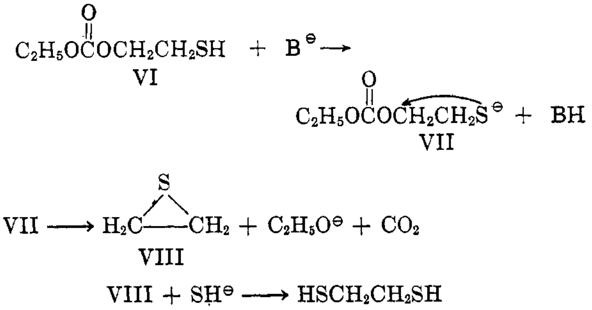
IV V

When tetraethylenepentamine was used as just cited, IV and V were not distillable.

In an attempt to fill the void left in the general procedure by 1,2-ethanedithiol, attention was directed to an investigation of the reaction of hydrosulfides with some recently developed mercaptoethylating agents.[2,5-8] These agents were ethyl 2-mercaptoethylcarbonate, ethylene monothiolcarbonate, ethyl 2-hydroxyethylthiolcarbonate, 2-mercaptoethyl acetate, and 2-mercaptoethyl *n*-butylcarbamate.

As a result of this study, ethyl 2-mercaptoethylcarbonate (VI) was found to be the best precursor for the 1,2-ethanedithiol. It reacts in the presence of ammonium hydrosulfide to yield (70–80%) pure (>99% by iodometric titration) 1,2-ethanedithiol.

The reaction path is believed to involve the generation of ethylene sulfide in the presence of base ($B^{\ominus}$), followed by its reaction with hydrosulfide ion to form the dithiol.



$$C_2H_5O\overset{O}{\overset{\|}{C}}OCH_2CH_2SH + B^{\ominus} \rightarrow C_2H_5O\overset{O}{\overset{\|}{C}}OCH_2CH_2S^{\ominus} + BH$$

VI VII

$$\text{VII} \longrightarrow H_2C\overset{S}{—}CH_2 + C_2H_5O^{\ominus} + CO_2$$

VIII

$$\text{VIII} + SH^{\ominus} \longrightarrow HSCH_2CH_2SH$$

A satisfactory process is dependent upon the formation of ethylene sulfide. When the other mercaptoethylating agents were used as the starting material, this step was incomplete under the reaction conditions involving ammonium hydrosulfide. The yields of 1,2-ethanedithiol were therefore low.

EXPERIMENTAL

Materials. Practical-grade triethylene glycol, practical-grade thiourea, Eastman-grade alkyl bromides, and technical-grade tetraethylenepentamine were obtained from Distillation Products Industries, Rochester, N.Y. The glycol and tetraethylenepentamine were heated under vacuum to remove materials which boiled below 150° (1.0 mm.).

General procedure for preparing alkanethiols which boil below 130° (760 mm.). A mixture of 125 ml. of triethylene glycol and 83.6 g. (1.1 moles) of thiourea was stirred in a 1-l. flask equipped with a magnetic stirrer, a thermometer, a dropping funnel, and a 14-in., glass-helices-packed column having a variable reflux ratio still-head. The pot temperature was raised to 75° and 1 mole of alkyl bromide added through the dropping funnel. The reaction temperature was kept below 130°. External cooling was applied when necessary. After the reaction mixture became homogeneous, it was allowed to proceed for an additional 15 min., and 94.6 g. (1 mole) of tetraethylenepentamine was added *via* the dropping funnel. The exothermic reaction caused the lower-boiling thiols to reflux. Heat was applied to the reaction flask and total reflux continued until the head temperature became constant. Distillation was begun and the thiol collected.

General procedure for the preparation of mono- and dithiols having boiling points above 130° (760 mm.). The apparatus just described was used and the distillations were carried out under reduced pressure. A mixture of 250 ml. of triethylene glycol and 167.4 g. (2.2 moles) of thiourea was stirred at

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(5) D. D. Reynolds, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5111 (1961).

(6) D. D. Reynolds, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5119 (1961).

(7) D. D. Reynolds, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5125 (1961).

(8) D. D. Reynolds, M. K. Massad, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5109 (1961).

75°. One mole of dibromoalkane (or 2 moles of alkyl bromide for the preparation of monothiols) was added. The mixture was stirred until it became homogeneous. The temperature was kept below 130°. After an additional 15 min. of stirring, a vacuum pump was attached to the system. Tetraethylenepentamine (189.3 g.; 1 mole) was added at a rate which prevented foaming or too rapid reaction. Heat was applied and total reflux continued until the head temperature became constant. Distillation was then begun and the product collected.

Reaction of morpholine with ethane-1,2-bisisothiuronium bromide. One mole (340 g.) of ethane-1,2-bisisothiuronium bromide was mixed with 4 moles (348.5 g.) of morpholine in a flask equipped with a stirrer, a thermometer, and an efficient condenser. The exothermic reaction raised the temperature to 90°. The viscous solution was heated on a steam bath and stirred for 18 hr. It was cooled and poured into 1 l. of rapidly stirred benzene. A crystalline product separated. It was completely water-soluble. The benzene layer was separated and distilled. 2-Morpholinoethanethiol, 92.5 g. (63%), b.p. 93°/12 mm., n_D^{25} 1.5028 (lit.[8] b.p. 83°/11 mm., n_D^{25} 1.5000), was collected. It was 98.5% pure, as shown by iodometric titration.

Reaction of di-n-butylamine with ethane-1,2-bisisothiuronium bromide. One mole (340 g.) of ethane-1,2-bisisothiuronium bromide was stirred into 4 moles of di-*n*-butylamine. There was no apparent heat of reaction. This mixture was stirred under a reflux condenser for 18 hr. at 90°. The resulting white slurry was cooled and added to 1 l. of rapidly stirred benzene. One liter of water was added and stirring continued for 10 min. The mixture was filtered by suction. The benzene layer from the filtrate was separated and distilled to yield 42 g. (22.2%) of 2-di-*n*-butylaminoethanethiol (b.p. 99°/8 mm.; n_D^{25} 1.4632) (lit.[5] b.p. 66°/0.7 mm.; n_D^{25} 1.4622) and 23 g. of higher-boiling residue. The insoluble residue which remained on the funnel was dried to yield 33 g. of a polyethylene sulfide. This was dissolved in hot dimethyl sulfoxide, filtered, cooled, and stirred into 500 ml. of benzene. The white product was then extracted in a Soxhlet extractor with benzene and dried.

Elemental analysis, iodometric titration, and infrared spectra indicate that this is a polymer having the structure $(n\text{-}C_4H_9)_2N(CH_2CH_2S)_nH$.

General preparative procedure for 1,2-ethanedithiol using ammonium hydrosulfide. A 2-l., three necked, round bottomed flask, immersed in an ice-salt bath, was fitted with a stirrer, a gas inlet tube extending below the surface of the liquid, and a connecting tube with a parallel sidearm fitted with a thermometer and an addition funnel.

In the flask were placed 350 ml. of methanol and 350 ml. (4.6 moles) of concd. ammonium hydroxide. The solution was cooled to −5° and saturated with hydrogen sulfide at −5° to +5°. While hydrogen sulfide continued to pass slowly into the solution, 2 moles of the mercaptoethylating agent was added in small portions over a 30-min. period. During the addition, the temperature was maintained at 5–10°. Hydrogen sulfide was passed into the mixture for 2 hr. after the addition was complete. The mixture was stirred for 20 hr. at 25–30°.

The mixture was cooled to 0° and made acid to Congo red paper with concentrated hydrochloric acid. The product was extracted with four 250-ml. portions of chloroform, which were combined and dried over anhydrous magnesium sulfate. After filtration, the chloroform was removed by distillation. The reaction product was distilled through a 2.5 × 16-cm. column packed with glass helices, at reduced pressure, using a Dry Ice trap. When the mercaptoethylating agent was ethyl 2-mercaptoethylcarbonate (VI), 1,2-ethanedithiol was obtained in 70–80% yields. B.p. 73°/62 mm.; n_D^{25} 1.5562.

Anal. Calcd. for $C_2H_6S_2$: C, 25.5; H, 6.4; S, 68.1. Found: C, 25.4; H, 6.2; S, 68.3.

ROCHESTER, N. Y.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, VIRGINIA POLYTECHNIC INSTITUTE]

Unsaturated Cyclic Sulfones. V. 3-Methyl-2,3-dihydrothiophene 1,1-Dioxide

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The synthesis of 3-methyl-2,3-dihydrothiophene 1,1-dioxide is described, and the base-catalyzed isomerization of this compound gave 18% 3-methyl-4,5-dihydrothiophene 1,1-dioxide, and 55% 4-hydroxy-3-methyltetrahydrothiophene 1,1-dioxide.

Of the three 3-methyldihydrothiophene 1,1-dioxides only the 2,3-dihydro isomer was unknown. Böeseken and van Zuydewijn[2] suggested that the action of an aqueous solution of potassium hydroxide on 3-methyl-2,5-dihydrothiophene 1,1-dioxide (I) should give rise to the 2,3-dihydro (VI) and the 4,5-dihydro isomers (VII); however, only VII was isolated. Ozonolysis of the reaction product and the analysis of the resulting sulfonic acids indeed indicated that a very small amount of VI was probably in the product. Thus, the isomerization of I as a synthetic route to VI did not appear attractive.

The synthesis of VI *via* 4-hydroxy-3-methyltetrahydrothiophene 1,1-dioxide (II) from I appeared to be particularly attractive using the novel hydroboration technique of Brown and Subba Rao.[3] The hydroboration of I at 0° was not successful; however, the initiation of reaction at room temperature with subsequent control of the temperature between 25–50° during reaction gave II in 63% yield. The structure of II was confirmed as shown in the formula sequence compounds I → VII.

The oxime (III) and the unsaturated ketone (IV) were reported previously,[4] and the reduction of IV gave II.

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[1] Taken from the M.S. thesis of Donald E. Boswell, November 1960.

[2] J. Böeseken and E. de Roy van Zuydewijn, *Proc. Acad. (Amsterdam)*, **37**, 760 (1934).

[3] H. C. Brown and B. C. Subba Rao, *J. Am. Chem. Soc.*, **81**, 6423, 6428 (1959).

[4] R. C. Krug, G. R. Tichelaar, and F. E. Didot, *J. Org. Chem.*, **23**, 212 (1958).