

THE SYNTHESIS OF SOME UNSYMMETRICALLY SUBSTITUTED
THIIRANES AND AN INVESTIGATION OF THEIR REACTIONS
WITH VARIOUS NUCLEOPHILIC REAGENTS

By

Richard Lee Jacobs

A THESIS

Submitted to the School for Advanced Graduate Studies
of Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

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Department of Chemistry

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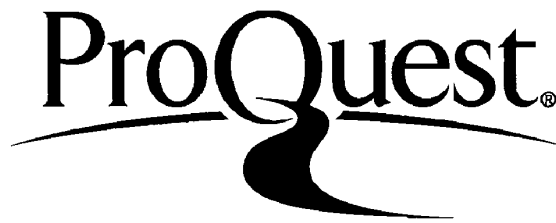
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To My Wife Wavalee

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837-840 (1956).

With Robert D. Schaeetz, "The Desulfurization of Thiiranes with
Triethyl Phosphite," J. Org. Chem., 23, 1799-1800 (1958).

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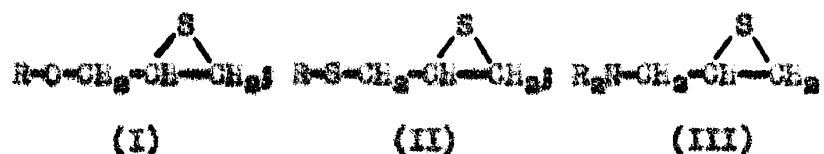
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ABSTRACT

The original purpose of this investigation was to develop suitable experimental conditions for promoting the condensation of alkene sulfides with active methylene compounds. However, even though a wide variety of experimental conditions was employed, little or no condensation occurred. In every instance tried, the major product was found to be polymeric alkene sulfide.

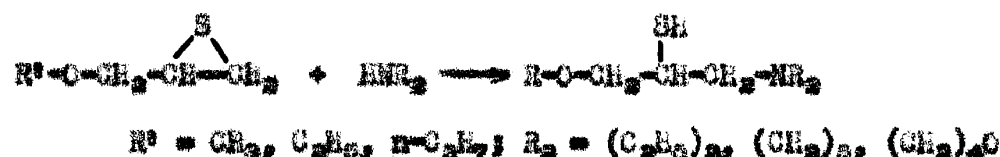
As a result of the failure of the above project, presumably due to the extreme ease with which simple olefin sulfides undergo self-polymerization, efforts were directed towards the synthesis of thiranes possessing a greater degree of stability. To this end, compounds having the following structures were prepared.



The 2-alkoxymethyl thiranes (I) were found to exhibit little tendency towards self-polymerization, as evidenced by the high yields of monomeric addition products obtained from reactions of these compounds with various nucleophilic reagents. The 2-alkylthiomethyl thiranes (II) were even less stable than the simple alkene sulfides, polymerizing upon attempted purification by distillation. Only one member of type (III) was

prepared, ($R = C_2H_5$), and although it was isolated as the monomer, it polymerized shortly after being isolated. As a consequence, only the 2-alkoxymethyl thiranes were employed in the following reactions.

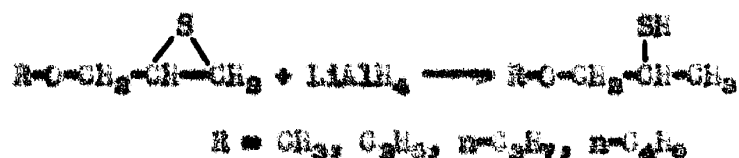
The action of secondary amines upon the 2-alkoxymethyl thiranes resulted in the formation of aminomercaptans.



The yield of ring fission product was observed to be quite sensitive to such factors as the mole ratio of amine to thirane, presence or absence of a solvent, type of solvent, and nature of the product formed.

Low molecular weight alcohols failed to yield simple addition products in base catalyzed condensations with 2-alkoxymethyl thiranes.

Lithium aluminum hydride reductions of these thiranes produced 1-alkoxy-2-mercaptoethanes.



In connection with the proof of structure work on the above reduction products, a study of the lithium aluminum hydride reduction of several glycidyl ethers was carried out.

Trimethylsulfonium iodide was obtained from the reaction of methyl iodide with the 2-alkoxymethyl thiranes.

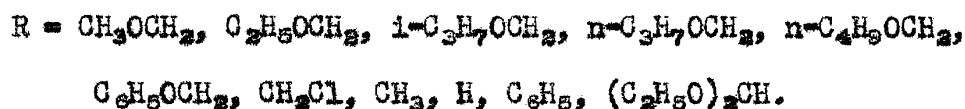
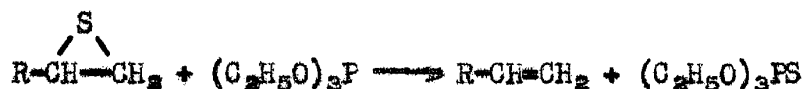


All efforts to isolate the 1-alkoxy-2,3-diiodopropanes failed.

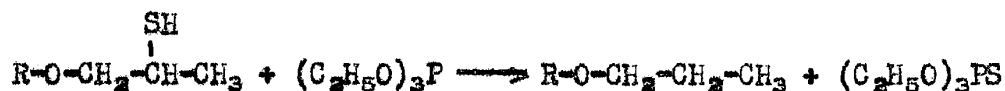
The reaction of 2-alkoxymethyl thiranes with organolithium compounds resulted in the formation of alkyl allyl ethers and lithium mercaptides.



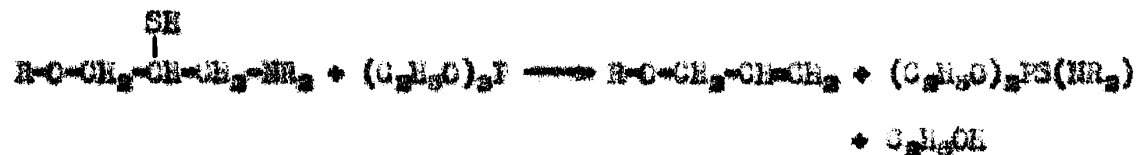
A desulfurization was also observed in the reaction of triethyl phosphite with the thiranes.



The reaction of triethyl phosphite with several 1-alkoxy-2-mercaptopropanes was also investigated and found to result in the production of alkyl propyl ethers and triethyl thionophosphate.



A brief study of the effect of triethyl phosphite upon the products of ring fission isolated from the reactions of amines with 2-alkoxymethyl thiranes was also carried out.



Alkyl allyl ethers and azidothionophosphates were formed.

The 2-alkoxymethyl thiranes were observed to react with bromine, but the products decomposed upon distillation.

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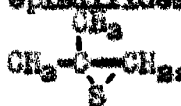
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I. INTRODUCTION

The structural similarity between cyclic ethers and cyclic sulfides is responsible for the present terminology associated with the latter compounds. Thus, the names oxirane, epoxide or alkene oxide, long associated with the cyclic ethers, becomes thirane, episulfide or alkene sulfide when applied to the corresponding sulfur compounds. The term thiacycloalkane is also frequently used to describe the simple aliphatic cyclic sulfides.

The nomenclature and numbering system employed in the present study is that used by Chemical Abstracts in which the hetero or sulfur atom in these cyclic sulfides is assigned number one and compounds are named as derivatives of a thirane. For example, the compound $\text{C}_6\text{H}_5\text{-O-CH}_2\text{-CH-CH}_2$  is referred to as 2-phenoxymethyl thirane. The simpler aliphatic episulfides, however, will be named as the alkene sulfide. For example, $\text{CH}_3\text{-C(CH}_3)_2\text{-CH}_2\text{-S-CH}_2\text{-CH(CH}_3)_2$ , is referred to as isobutylene sulfide.

The investigation initially undertaken involved a study of the reaction of aliphatic ethylene sulfides with labile or active hydrogen compounds such as, diethyl malonate and ethyl acetoacetate. The condensation of epoxides with the active methylene compounds, acetoacetic ester (1,2) and malonic ester (2,3,4,5) has become a valuable synthetic tool, and is of quite general application. The alkylation products, in many instances, themselves are of considerable chemical interest in their own right.

Snyder and Alexander (6) had previously reported that simple olefin sulfides condensed with ethyl cyanoacetate in the presence of sodium ethoxide, but not with ethyl malonate or ethyl acetoacetate. It was expected that by proper selection of reaction conditions, alkylation could be achieved using ethylene sulfides and diethyl malonate or ethyl acetoacetate. However, in the present study it was found that even though the condensing agents were widely varied and high dilution techniques employed, little or no alkylation occurred. The major product in all the cases examined was a polymeric sulfide. After additional variations in reaction media and experimental conditions failed to accomplish the desired condensation reaction this initial investigation was abandoned, and work was directed towards a study of the preparation and chemistry of unsymmetrically substituted thiranes.

A survey of the literature of ethylene oxides and sulfides revealed that while numerous references are available for the synthesis of unsymmetrically substituted ethylene oxides, (7,8) only a relatively few reports are to be found dealing with the preparation of ethylene sulfides (9,10). Further, while the reactions of epoxides with various nucleophilic reagents have been extensively treated (7,8), only a superficial study has been made of similar reactions of the corresponding sulfur compounds (9,10).

This situation, no doubt, is due in part to the fact that ethylene sulfides are not as readily accessible nor as stable as their oxygen analogues; they exhibit a much greater tendency towards self-polymerization. Ethylene sulfide polymerizes within a few hours after

preparation (11,12), even when stored at ice temperature unless a stabilizer such as hydrogen sulfide, an alkyl mercaptan, or an alkyl sulfide (13,14), is added to it. The polymerization of ethylene sulfides is effectively catalyzed by concentrated alkali, mineral acids, heavy metal salts, ammonia, pyridine and acetic acid (11,12).

Even though ethylene sulfides undergo many of the ring-opening reactions of ethylene oxides, polymerization inhibits the isolation of the initial product, unless special precautions are observed (15).

The literature search also revealed that although the alkene sulfides resemble the corresponding epoxides in many of their reactions where the same nucleophilic reagents were used with both (16,17,18), nearly as many cases can be cited in which the opposite is true (16,17,18). Therefore, the assumption that the reaction products obtained from an alkene sulfide with a given reagent may logically be deduced by formal analogy to the same reaction with alkene oxide can be quite misleading. This applies equally to studies (16,17,18) concerned with the direction of ring-opening of unsymmetrically substituted thiranes.

The work reported herein was undertaken with the intent of extending the list of known unsymmetrically substituted thiranes, and of expanding the literature dealing with reactions of such compounds with various nucleophilic reagents.

To obtain compounds possessing sufficient stability to permit a study of their reactions with fairly strong nucleophilic reagents, the synthesis of the following types of compounds, $R-C-CH_2-\overset{\text{S}}{\underset{\text{CH}_3}{\text{CH}}}-CH_2$

$R_2N-CH_2-\overset{\triangle}{\underset{S}{CH-CH_2}}$; $R-S-CH_2-\overset{\triangle}{\underset{S}{CH-CH_2}}$, was undertaken.

Of the methods (9,10) available for the preparation of thirane compounds, only those involving the conversion of an epoxide into the corresponding sulfur compound by alkali thiocyanates (14,19,20), or thiourea (21,22,23) were employed.



X = O, S, N

R = CH₃, C₂H₅, n-C₃H₇, i-C₃H₇, n-C₄H₉, C₆H₅



Only the ether thiranes exhibited little or no tendency towards polymerization. These compounds were obtained in excellent yields, by either method, and were quite stable at room temperature for several months. On the other hand, the thioether thiranes were very unstable and rapidly polymerized upon attempted purification by distillation, even at very low pressures. Only a single member of the amine thiranes was prepared, and although it could be obtained as the monomer, it polymerized in a few days at low temperature storage. Thus, only the ether thiranes, $R-O-CH_2-\overset{\triangle}{\underset{S}{CH-CH_2}}$, could be studied in their reactions with nucleophilic reagents.

The reagents selected for a study of their interaction with ether thiranes included lithium aluminum hydride, triethyl phosphite, methyl iodide, phenyl lithium, butyl lithium, secondary amines and primary alcohols.

In addition, several miscellaneous reactions of glycidyl ethers, secondary mercapto ethers and secondary mercapto amine ethers were investigated.

Some compounds heretofore prepared by reaction of ethylene sulfides with primary and secondary amines (23) and mercaptans (24) have received technical applications as starting materials for industrial preparation of dyes, textile aids, medicaments and vulcanization accelerators. The alkene sulfides themselves have recently found industrial use in the modification of wool fibers (25,26) and as synthetic polymers (27).

A timely use for compounds possessing the thirane ring system was published this year in a report (28) from the Stanford Research Institute, dealing with the synthesis of 2'-deoxynucleosides. This paper points out the value of the thirane ring system in permitting easy access to these potential anticancer agents. The need for further study concerning the ring-opening reactions of thiranes was emphasized by the fact that several of the proposed transformations involved attack by nucleophilic reagents on the episulfide linkage.

II. HISTORICAL

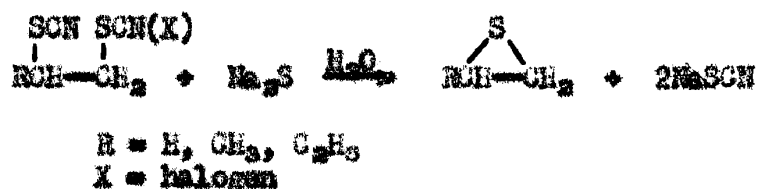
A. Methods of Preparation

As mentioned previously, ethylene sulfides may be considered the sulfur analogues of the ethylene oxides. In view of this relationship, it is perhaps surprising to find that an appreciable time interval elapsed following the discovery of ethylene oxide before the first successful synthesis of monomeric ethylene sulfide was reported.

Charles A. Wurtz (29,30) first described the preparation of ethylene oxide in 1859, but it was not until 1920 that the first authentic preparation of ethylene sulfide was reported by Marcel Delapine (11,12). It should, however, be mentioned that Troger and Hornung in 1897 (31), and Michael in 1895 (32), reported the preparation of derivatives of ethylene sulfide but recent work tends to disprove their claims (15).

Prior to the reports by Delapine (11,12) attempts to prepare ethylene sulfide, by procedures similar to those employed for the synthesis of alkene oxides, produced a substance which was first thought to be a monomeric sulfide, but was actually a mixture of diethylene disulfide $(C_2H_4S)_2$, and higher molecular weight material (33). Even as late as the year 1923 in one of the authoritative books (33) of that period on organic chemistry, the statement appears, "ethylene sulfide, $\begin{array}{c} \text{S} \\ \diagup \quad \diagdown \\ \text{CH}_2 \quad \text{CH}_2 \end{array}$, corresponding to ethylene oxide, is apparently not capable of existing. It is usually its polymerides which are obtained: $(C_2H_4S)_4$ and $(C_2H_4S)_2$ diethylene disulfide."

Despite the negative attitude which prevailed, concerning the stability of ethylene sulfides, it was in the period 1920-1923 that the French chemist Delepine and his collaborators (11,12,34,35,36) published the results of their studies on the synthesis of monomeric ethylene, propylene, and butylene sulfides. They observed that alkene sulfides were formed, in low yields, when an aqueous solution of sodium sulfide was allowed to react with either the alkene halothiocyanates or dithiocyanates.



This method has since been utilized by Youtz and Perkins (37) to prepare tetramethylethylene sulfide, and by Calingaert (38) for the synthesis of trimethylethylene sulfide.

Approximately fourteen years elapsed before a second and more suitable method for obtaining episulfides appeared in the literature. In 1934 Daublander and Jackel (39) described in patent form, a simple preparation of olefin sulfides from ethylene oxides. The latter were converted into the corresponding sulfur compounds by the action of aqueous thiourea at room temperature.



This procedure was later extended by Culvenor and his associates (21), and more recently by Bordwell and Andersen (22); it will be elaborated on in more detail in a subsequent section of this thesis.

In a second patent, issued two years later, Dachlauer and Jackel (19) described the transformation of epoxides into episulfides by the action of potassium thiocyanate in aqueous solution at room temperature.



This second general procedure has since been extended by Snyder and his collaborators (14), by Price and Kirk (40), and remains as one of the most convenient laboratory procedures available for the synthesis, in good yields, of the simple olefin sulfides. The reaction has proven to be quite general, provided there are no strongly polar groups, such as the carbonyl, alpha to the epoxide ring (21).

Some five years after the first report by Dachlauer and Jackel (39), an additional general preparative procedure for obtaining episulfides was described by Coltof (41). According to this method, ethylene sulfides were obtained by treating 2-chloroethylthiols with weak alkaline buffered solutions. The weak alkali avoids the formation of polymers, which earlier workers had found to be the major product with concentrated alkali. Coltof (41) claimed quantitative yields of the monomeric ethylene sulfide could be obtained by the dehydrochlorination of 2-chloroethanethiol.



It is important that sufficient alkali metal bicarbonate be used to neutralize the hydrogen chloride formed and still maintain the pH of the reaction mixture in the range of 7.5 to 9.5, to obtain high yields of monomer.

Jones and Reid (42), at about this same period, observed that when ethylene, propylene or cyclohexene was heated at 180° in a bomb with ethyl tetrasulfide (a liquid which decomposes on heating, releasing what may be considered to be atomic sulfur) for about ten hours, the corresponding alkene sulfide was obtained in very low yields. When ethylene was slowly bubbled through ethyl tetrasulfide at 150°, a small amount of ethylene sulfide was detected but the major product was ethyl mercaptan, and some ethyl sulfide. In addition, it was found that no cyclic sulfide formed when ethylene was passed over pyrites at 350° or when ethylene was bubbled through molten sulfur at 325°C.

A more recent investigation concerned with the direct addition of sulfur to an olefin, was carried out by Culvenor and his associates (15), who reported that cyclohexene is not converted into its sulfide when heated to 440° with molecular sulfur in Pyrex, or when heated in silicon in the range 440-630° with or without iron pyrites as catalyst.

Thus, it appears that the direct catalytic method of synthesis, so important with ethylene oxide, cannot be employed for the preparation of ethylene sulfides.

A procedure of still more recent origin, and doubtless capable of some extension, was reported in 1946 by Lazier and Signiago (27). They synthesized 2-mercaptomethyl thirane by the thermal dehydration of 1,2-dithioglycerol.



In the same year, Culvenor, Davies and Fausacker (21) described the results of their investigation on the conversion of ethylene oxides into ethylene sulfides by the action of thiourea, alkali thiocyanates, thiocarbonyl sulfide and xanthates. They found the reaction between simple ethylene oxides and the thio-reagents generally to be exothermic, and requiring external cooling, in order for the monomeric sulfide to be formed as the major product. It was also observed that as the reactions proceeded, the pH of the medium and the amount of polymeric material increased.

Although Bachlauer and Jackel (39) had stated that compounds like ethylene oxide, epichlorohydrin and propylene oxide gave good yields of the corresponding cyclic sulfide when treated with thiourea or potassium thiocyanate, Culvenor and his associates (21) were unable to isolate any of the monomeric 2-hydroxymethyl thirane in preparations utilizing glycidol. A similar situation was observed in attempts to prepare 2-phenyl thirane from styrene oxide. Even careful control of the temperature, acidity and reaction time resulted only in the production

of polymeric material. Recently, Jans and Chamberlain (13) have succeeded in isolating monomeric 2-phenyl thiirane by employing a modification of the general procedure of Culvenor and co-workers (21), which involved the use of 50% aqueous dioxane as a solvent media. In this manner, a 59% yield of the easily polymerized styrene sulfide was obtained. At present, the 2-hydroxymethyl thiirane is still unknown.

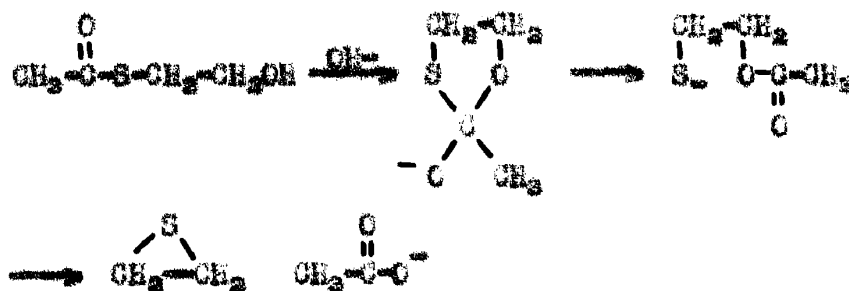
The nature of the product produced from the reaction of an alkene oxide with thiourea seems to depend mainly on the structure of the epoxide employed, as attested by the work of Bodfors (14), who found that 1-benzoyl-2-n-nitrophenyl-ethylene oxide reacts with thiourea to form 2-imino-4-benzoyl-5-n-nitrophenylthiazolidine or the isomeric 2-imino-5-benzoyl-4-n-nitrophenylthiazolidine. Likewise, Culvenor, Davies and Fausacker (21) observed that the ethyl ester of dimethyl glycidic acid, and benzylidenacetone oxide when treated with thiourea, yield compounds containing both nitrogen and sulfur.

Employing cyclohexene oxide in a series of comparative experiments, Culvenor (21) was able to demonstrate that potassium or ammonium thiocyanate tend to cause more polymerization, resulting in lower yields of the monomeric olefin sulfide than does thiourea. With thiocarbamide the above reaction is quite sluggish.

While investigating the reaction occurring when cyclohexene oxide or sulfide was treated with a metallic manganate, it was observed that cyclohexene trithiocarbonate was produced in each instance (21). Upon further study of the reaction, it was found that the epoxide is first

converted by the xanthate to the corresponding episulfide, which then reacts further. It is significant, that although Culvenor and his associates (21) were unable to obtain 2-phenyl thirane by the reaction of styrene oxide with aqueous thiourea or potassium thiocyanate, they were able to isolate styrene trithiocarbonate in 77% yield by treating the oxide with a xanthate. Their results indicate that a reaction may be expected to occur between xanthate and any compound with an epoxide structure. However, in certain instances the products are polymeric, as in the case with glycidol and epichlorohydrin.

A preliminary account of a new reaction useful in the synthesis of simple ethylene sulfides was published in 1951 by Harding, Owen and Miles (45), and followed a year later by a detailed description of the method (46). While investigating the alkaline hydrolysis of certain partly and fully acetylated vicinal hydroxy-thiols, they observed that the deacetylation reaction frequently proceeded abnormally, resulting in the formation of not only the parent hydroxythiols but also the corresponding ethylene sulfides, the latter often predominating. For example, deacetylation of either the S- or O-acetyl derivative as well as the diacetyl derivative of 2-mercaptoethanol with dilute aqueous alkali, resulted in the formation of ethylene sulfide in about 25% yield.



Similarly, either the S- or the O- acetyl derivative of trans-2-mercaptocyclohexanol produced cyclohexane sulfide in 55% yield. The O-acetate of 2,3-dimercaptopropanol gave 2-mercaptomethyl thirane whereas the triacetyl-2,3-dimercaptopropanol was converted into 3-acetylthiopropylene sulfide in 80% yield. The same compound was obtained when the di-S-acetyl derivative was used. It is noteworthy that no cyclic sulfide formation was observed when non-acetylated hydroxythiols were subjected to the same experimental conditions.

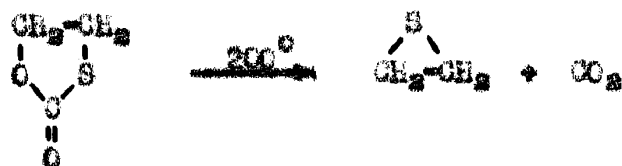
In 1953, Bordwell and Anderson (22) reported the results of their investigation of the transformation of ethylene oxides into olefin sulfides by the action of aqueous thiourea. They demonstrated that in the formation of propylene sulfide from propylene oxide a considerable reduction in the amount of polymeric material resulted by increasing the acidity of the reaction mixture. For example, by adding 2.5 mole per cent of acid (hydrochloric, sulfuric, acetic, perchloric, benzoic or p-toluenesulfonic) to the aqueous solution of thiourea, increased the yield of propylene sulfide by 20%. When an equimolar quantity of acid was employed, the yield of cyclic sulfide was increased by 50%.

When an equivalent amount of an acid is also employed, the reaction between an alkene oxide and thiourea produces a β -hydroxythiuronium salt. These salts may be made to yield alkene sulfides on alkaline hydrolysis. Actually, it was observed that the product formed on hydrolysis of the various salt, was entirely dependent upon the procedure used. If the acidic salt solutions were added to an excess of aqueous

alkali, the major product was found to be the 2-hydroxyalkane thiols, whereas the olefin sulfide was isolated in major amount if the reverse addition were used.

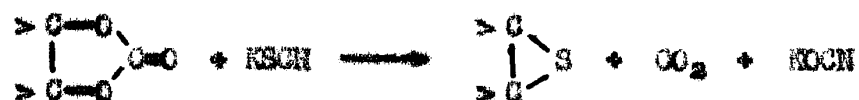
Further, it was observed that propylene sulfide could be obtained by heating either a dioxane solution of 2-hydroxy-1-propylthiuronium acetate, an aqueous solution of the acetate, or the dry benzoate, but not by heating aqueous solutions of the chloride or sulfate.

Recently, Reynolds (47) described a new method for the specific preparation of ethylene sulfide, which consisted of the pyrolysis of monothiolethylene carbonate in the presence of an alkaline catalyst such as sodium carbonate.



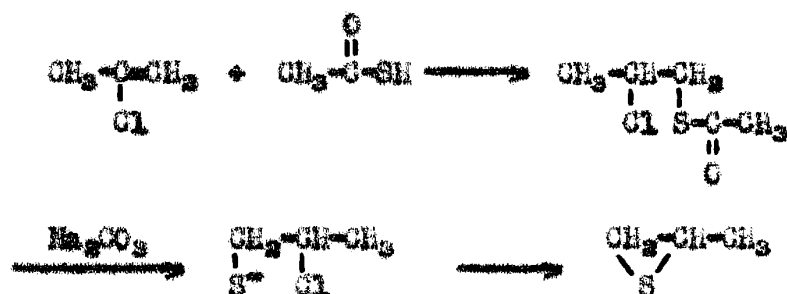
The reaction results in excellent yields of pure ethylene sulfide, with little or no occurrence of polymerization. A pure sulfide is obtained, since the only by-product is carbon dioxide. Since monothiolethylene carbonate is now commercially available, the synthesis has many advantages over the older methods of preparation.

A very recent method for preparing small ring cyclic sulfides was reported by Searles and Lutz (48) in 1958, and appears capable of extension. By this procedure, thiranes are produced when an equivalent mixture of potassium thiocyanate and the cyclic carbonate of a 1,2-diol are heated above the melting point of the carbonate.

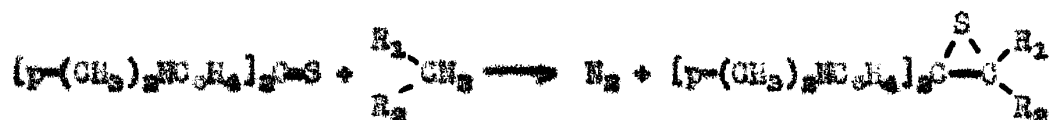


In the one instance reported, ethylene sulfide was obtained in 65% yield.

Bordwell and Lawett (19) have just reported the preparation of propylene sulfide by the following sequence of reactions.



In 1957, Schonberg and his co-workers (50) reported the preparation of a number of solid ethylene sulfides formed by the interaction of various diisocyanates with compounds such as Michler's thioketone.

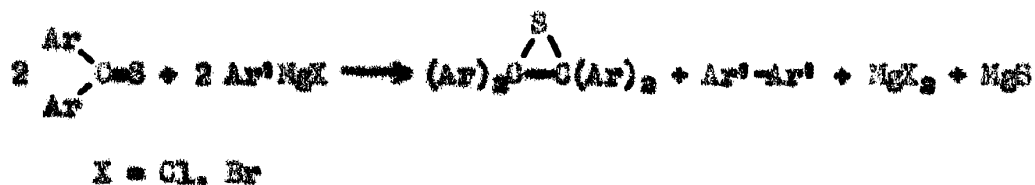


Historically, a number of other interesting and rather novel methods have been developed for the synthesis of tetra-arylethylene sulfides, and in view of the recent work by Schonberg and his associates (50), a brief review of these procedures seems of interest.

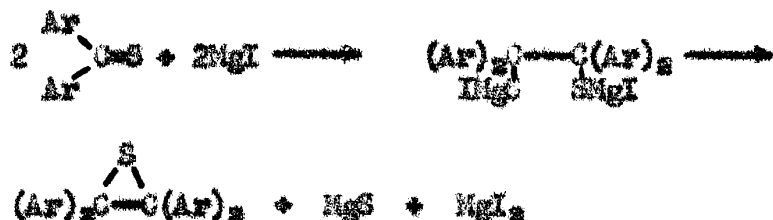
In the same year in which Delapine (11,12) reported the synthesis of ethylene sulfide, Staudinger and Siegart (51) described several

tetra-arylethylene sulfides which they had obtained from the reaction of diaryl thioesters with diaryl-diazomethanes. Thus, diphenyldiazomethane and Michler's thioester formed $[p-(CH_3)_2HC_6H_4]_2C(=S)C(C_6H_5)_2$ on reaction at room temperature. This procedure was later extended by Schonberg and Vargha (52), to include compounds of the type $R-C(=S)-R'$, where R and R' may be ArO, ArS or Cl.

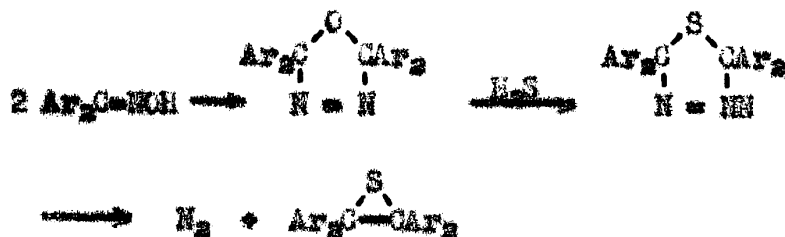
In 1927, Schonberg (53) reported that various aromatic Grignard reagents would react with diaryl thioesters to give tetra-arylethylene sulfides.



In the same year, Schonberg and Schutz (54) reported that the action of Mg + MgI₂ on aromatic thioesters produced the tetra-substituted ethylene sulfides.



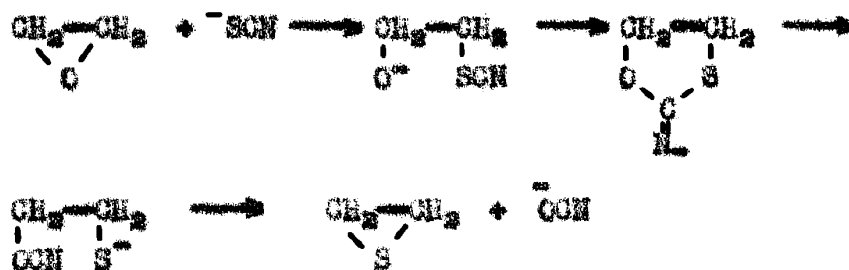
Still another method for obtaining aryl cyclic sulfides was introduced by Schonberg and Barakat (55) in 1939. According to this procedure, the desired compounds are obtained when diaryl ketoximes are treated successively with potassium ferricyanide and hydrogen sulfide.



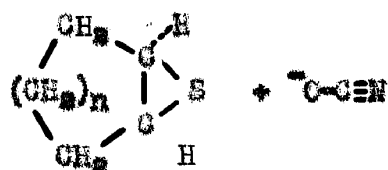
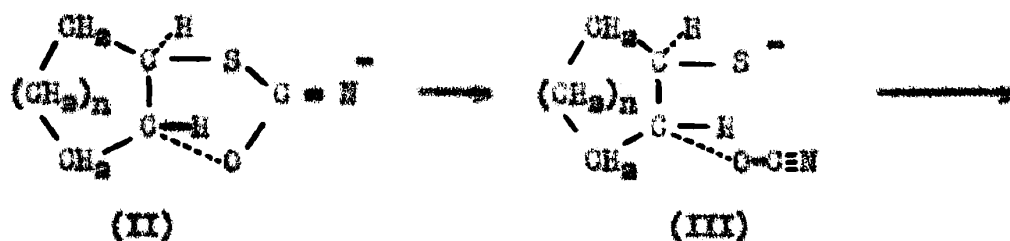
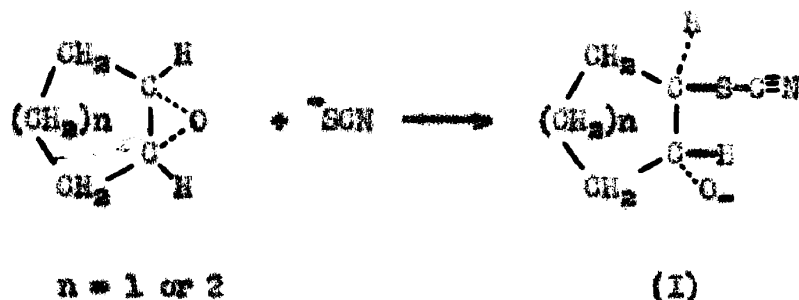
B. Reaction Mechanisms

Although the transformation of epoxides to cyclic sulfides by aqueous alkali thiocyanates was first described in 1936, it was some fifteen years later before serious efforts were directed toward elucidating the mechanism of this reaction (56).

Ettlinger (56) proposed the following as a possible mechanism for the conversion of ethylene oxide to its sulfide by the action of potassium thiocyanate, but offered no experimental evidence to support the mechanistic scheme.



A year after Ettlinger's report, van Tamelen (57) presented experimental evidence, obtained by his studies of the reaction of cyclic olefin oxides with thiocyanate ion, supporting such a mechanism.



The structures (I), (II), and (III), are presumed to be in equilibrium with the corresponding protonated forms.

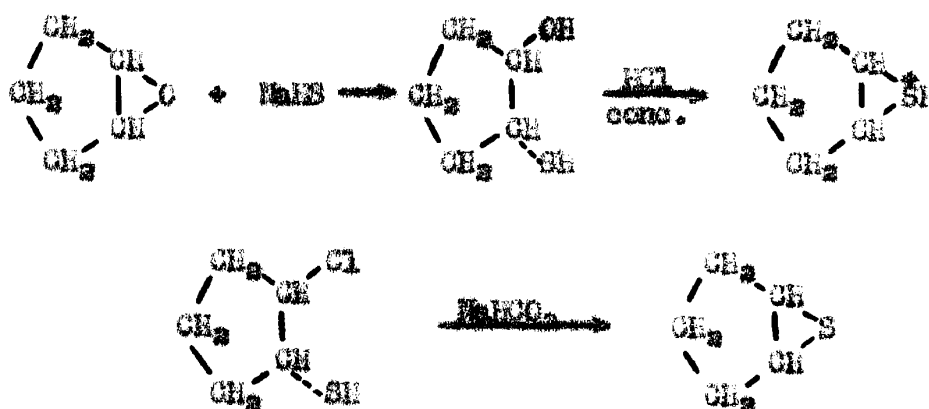
The above mechanistic scheme is plausible on a stereochemical basis. In the many ring opening reactions of cyclohexane oxide ($n = 2$), in acid, neutral or basic media, it has been amply demonstrated that the reactions proceed with a Walden inversion. In the present case, ring cleavage by thiocyanate ion would produce the anion of trans-2-hydroxycyclohexylthiocyanate. Migration of the cyano group from sulfur to oxygen via the cyclic intermediate (II), results in the formation of the anion of trans-2-mercaptocyclohexyl cyanate, which is favorably oriented for a trans ring-closure to yield the cyclic sulfide and cyanate ion.

The mechanism thus implies two Walden inversions, the first occurring in the trans opening of the oxirane ring, and the second in the trans closing of the thirane ring.

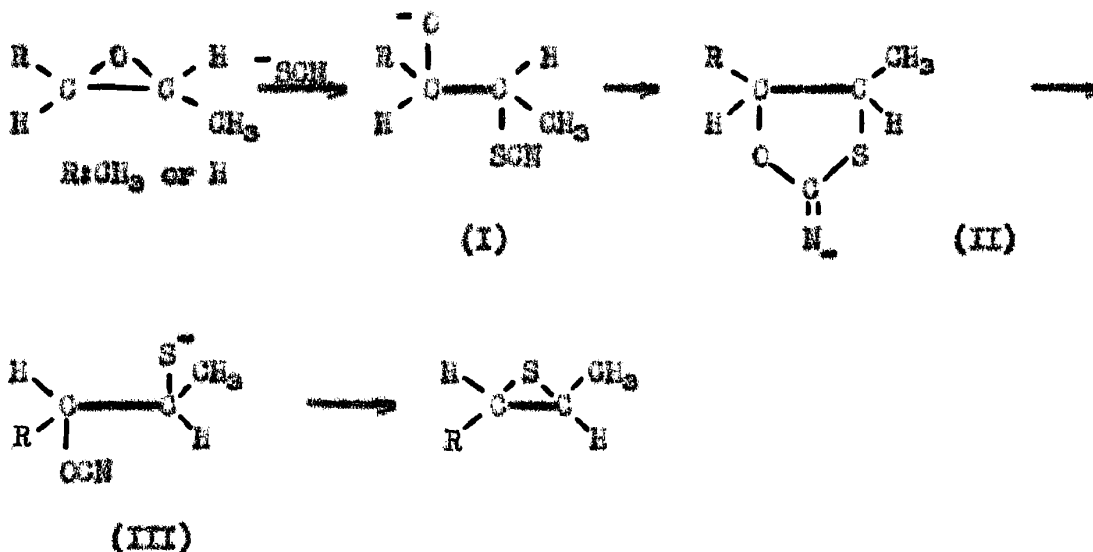
Further support for the mechanism was obtained from the attempted preparation of cyclopentene sulfide ($n = 1$), by treatment with alkali thiocyanates. In complete accord with the stereochemistry of the above mechanism it was found that no sulfide formation occurred, since the formation of an intermediate (II), where $n = 1$, would consist of two trans five-membered rings, a system involving considerable strain.

Additional evidence in support of this mechanism was gained from studies of the protonated derivatives corresponding in structure to anions (I) and (II). Both trans-2-hydroxycyclohexyl thiocyanate, and the trans-hydrochloride, of (II), gave high yields of cyclohexene sulfide. On the other hand, trans-2-hydroxycyclopentyl thiocyanate failed to yield cyclopentene sulfide when treated with a base. In addition, it failed to form the thiocarbonic acid-iminoester upon treatment with hydrogen chloride, again demonstrating that the formation of the ring system containing two five-membered rings fused trans is sterically prohibited.

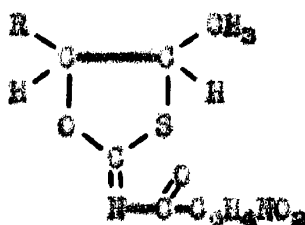
Cyclopentene sulfide was prepared by van Tamelen, by the following series of reactions, which also suggests that the reaction of cyclopentene oxide with thiocyanate ion would have led to the corresponding sulfide if the intermediate (III) had been formed.



In 1953, Price and Kirk (40) further substantiated the proposed mechanism from results obtained during the preparation of 2-methyl thiacyclopentane and 2,3-dimethyl thiacyclopentane.

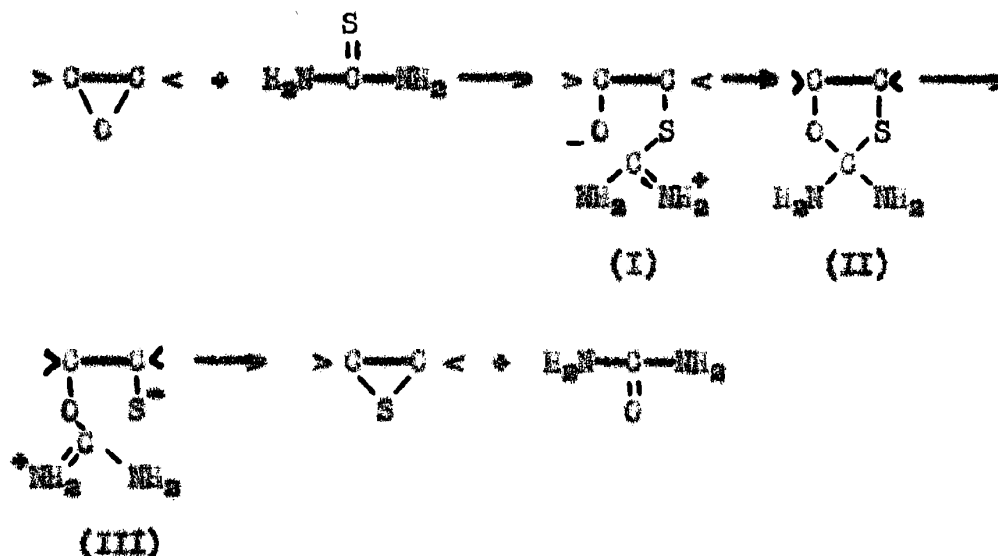


By adding p-nitrobenzoyl chloride to a partially reacted mixture of propylene oxide and aqueous potassium thiocyanate they were able to demonstrate the presence of the proposed intermediate (II), (R = H), by isolation of its N-(p-nitrobenzoyl) derivative.



Additional support for the mechanism was obtained from an investigation of the stereochemistry involved in the reaction. Price and Kirk observed that D(+)-2,3-butylene oxide gave L(-)-2,3-butylene sulfide when treated with aqueous alkali thiocyanates, indication that inversion had taken place at each asymmetric carbon atom. An independent synthesis of L(-)-2,3-dimethyl thirane was then carried out in a manner analogous to that used by van Tamelen for the preparation of cyclopentane sulfide. Further evidence in favor of the proposed mechanism was obtained through simultaneous measurements of acidity and $(\alpha)_D^{25}$, of an aqueous alcoholic solution of optically active 2,3-epoxybutene and potassium thiocyanate. It was found that the pH increased rapidly to 11-12 and remained fairly constant while the optical rotation fell evenly and slowly. These results indicated that the cyanate ion formed was hydrolyzed in the basic media to carbon dioxide and ammonia, the latter in an amount sufficient to maintain the high pH. The decrease in $(\alpha)_D^{25}$ suggested that the initial attack of the thiocyanate ion, which cleaves the ring, was quite fast. This was then followed by rapid ring closure to (II). The subsequent conversion of the cyclic intermediate, (II), to the thirane was relatively slow. The stability of (II) is in accord with its isolation as a p-nitrobenzoyl derivative.

Culvenor, Davies and Savige (58) have offered a similar mechanistic interpretation for the transformation of epoxides to episulfides by the action of aqueous thicurea.



The initial step involves a bimolecular nucleophilic attack by the zwitter-ion form of thiourea (59) on the epoxide ring to form the anion (I), which rearranges via the cyclic intermediate (II), into the anion (III), and the latter decomposes into the episulfide and urea.

A plausible driving force for the reaction is associated with the displacement of the urea grouping from carbon by the negatively charged sulfur, and unexplicable tendency for the formation of three-membered heterocycles.

The formation of cyclic sulfides by this method is therefore largely due to two favorable factors, first the ability of the urea grouping in (I) to migrate from sulfur to oxygen, and secondly, the facile displacement of this species by the negatively charged sulfur atom.

Comparable mechanisms may be written for the reactions of epoxides with thioamides, substituted thioureas and xanthates.

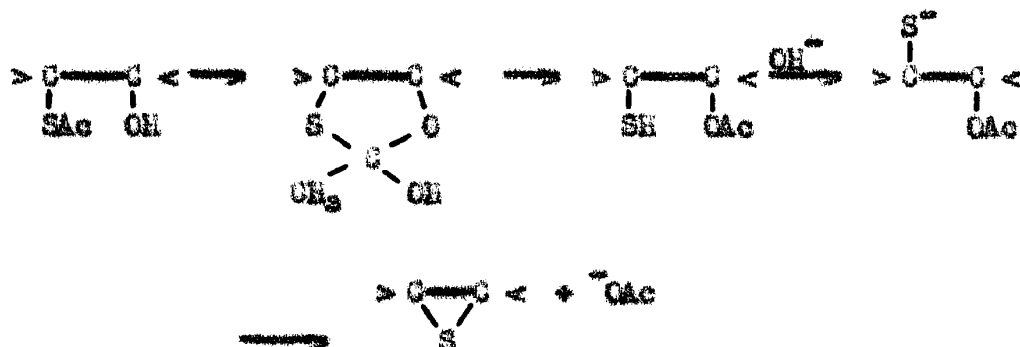
In the formation of olefin sulfides by intramolecular deacetylation of partially and completely acetylated vicinal hydroxy-thiols, originally described by Miles and Owen (46), it was suggested that the reaction proceeded by the following series of steps.



Even though ring formation occurred on alkaline hydrolysis of either the S- or O-acetyl derivatives, it was suggested that only the latter produced cyclic sulfide while the former underwent preliminary isomerization to the O-acetyl compound prior to ring closure. Ring formation was then due to the removal of the acetoxy group, which would involve the rare C-alkyl ester cleavage. This type of fission is favored by the presence of electron-donor groups in the "alkyl" portions of the molecule, and in the present case by the sulfur atom which functions as the electron-donating group.

Although the work of Miles and Owen (46) offered several suggestions as to the mechanistic scheme involved, it remained for Harding and Owen (60) to demonstrate that acetyl migration did actually occur, and to more fully elucidate the reaction mechanism. From studies involving alkaline hydrolysis of acetylated derivatives of 2-mercaptoethanol, trans-2-mercaptocyclohexanol, 2,3-dimercaptopropanol and trans-2-mercapto-cyclopentanol, it was found that ring formation was in each instance

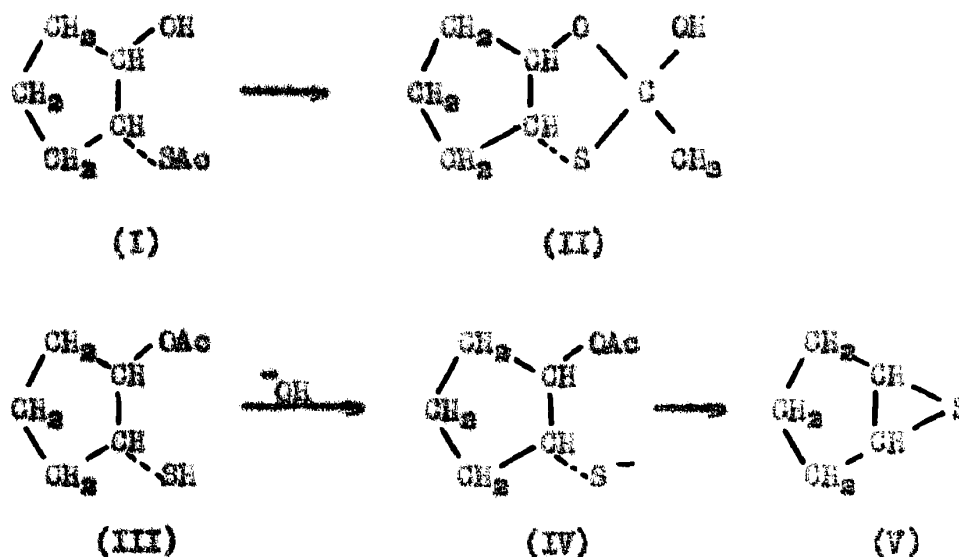
preceded by migration of acetyl from sulfur to oxygen.



Ring closure was depicted as proceeding by the intramolecular elimination of acetic acid, which requires the unusual displacement of an acetate ion by the strong nucleophile, mercaptide ion.

The claim that cyclopentane sulfide was formed from the S-acetyl derivative of trans-2-mercaptocyclopentanol is of especial interest, in view of the lack of success of previous investigators to obtain this compound.

According to the mechanistic interpretation advanced by Harding and Owen (60), the reaction sequence is as follows.



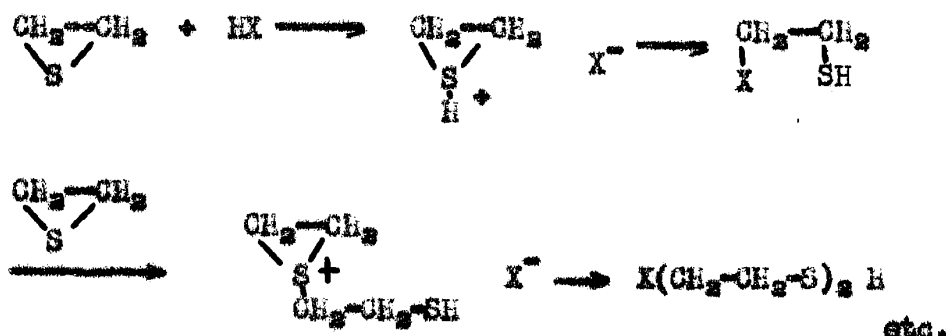
At the present time, only ethylene sulfide has been prepared by this method and therefore evidence for the existence of intermediates such as (III) is lacking.

C. The Properties and Reactions of Ethylene Sulfides

Probably the most characteristic property of the olefin sulfides is the ease with which they undergo self-polymerization. Thus, freshly distilled ethylene sulfide is completely polymerized within a few hours even when stored at 0°C. or in the dark. Delepine and his associates (11,12,34,35,36) were the first to show that with simple alkene sulfides the process is catalyzed by trace amounts of acid or base. Since then, a great variety of substances, including heavy metal salts, hydrazine, hydroxyl amines, guanidine and certain halogen compounds such as 3,5-dinitrobenzoyl chloride, benzoyl fluoride, triphenylmethyl chloride, p-toluene sulfonyl chloride and picryl chloride have been found to accelerate the polymerization process (15).

On the other hand, there are certain compounds which appear to have the reverse effect, namely the tendency to inhibit polymer formation. These include alkyl mercaptans, hydrogen sulfide and various alkyl sulfides (13). There appears to be very little known concerning the mechanism of polymer formation, although the proposal has been made that in the case of acid-catalysis, the reaction may proceed through the ethylenesulfonium ion, $\begin{array}{c} > \text{C}=\text{C} < \\ \diagdown \quad \diagup \\ \text{S}^+ \end{array}$, by a scheme similar to that

reported for the polymerization of ethyleneimine (142).



At present, it is believed that in the presence of basic reagents (NaX), polymerization is due to the transformation of a molecule of sulfide into $\text{NaS}-\text{CH}_2-\text{CH}_2-\text{X}$ which then attacks a second molecule of sulfide to form $\text{NaS}-\text{CH}_2-\text{CH}_2-\text{S}-\text{CH}_2-\text{CH}_2-\text{X}$, and so on, rapidly forming long chains (9).

A second notable feature of the thirane ring system is its inability to exist with the sulfur atom in the tri- or tetravalent state. Thus, all attempts to obtain sulfoxides and sulfones by the direct oxidation of the cyclic sulfides have resulted only in rupture of the ring. Delepine and Eschenbrenner (35) observed that the oxidation of ethylene sulfide with concentrated nitric acid produced $\text{HO}_2\text{S}-\text{CH}_2-\text{CO}_2\text{H}$ and products resulting from reaction of this material with more ethylene sulfide, but no sulfoxide or sulfone was isolated. More recently, Culvenor and his associates (15) have reported that neither aqueous hydrogen peroxide, nor permanganate interacts with ethylene sulfides to give sulfoxide or sulfone but instead, produces a variety of substances resulting from ring cleavage.

A few unstable sulfones of the tetra-arylethylene sulfide class have been described (61,62) but they were not prepared by direct oxidation of the corresponding cyclic sulfide.

In general, the alkane sulfides are colorless, volatile liquids with a strong garlic-like odor. They are water insoluble but quite miscible with common organic solvents. The tetra-arylethylene sulfides, on the other hand, are crystalline solids, possessing rather high melting points and tend to be more stable than the simple olefin sulfides.

With respect to the physical chemistry of cyclic sulfides, the majority of investigations have been carried out on ethylene sulfide itself, and are rather recent studies. The ultraviolet spectra of ethylene sulfide was first reported in 1958 (63), and the dipole moment was determined in 1950 (64). The recent work by Davis (63) on the ultraviolet spectra of ethylene, propylene and cyclohexane sulfides both in solution and in the gas phase indicate that a single band in the region of 2600 \AA (38460 cm.^{-1}) may be characteristic of the thirane ring system. A parallel study on the corresponding epoxides revealed that these compounds were transparent in the region above 2100 \AA .

The infrared spectrum of ethylene sulfide has received considerable comment, since the initial work by Thompson and Dupre (65), who determined both the Raman spectrum of the liquid and the infrared spectrum of the vapor. Recently, Guthrie, Scott and Waddington (66) described the infrared spectrum of liquid ethylene sulfide, and observed that certain of the bands reported earlier by Thompson and Dupre (65) were not

characteristic of monomeric ethylene sulfide, but rather were due to traces of polymerized sulfide and/or other impurities. At about the same time, Thompson and Cave (67) reinvestigated the infrared spectrum of the vapor and the Raman spectrum of the liquid, with the result that their observations confirm those of Guthrie and his co-workers (66).

Within the past year, Moore and Porter (68) have measured the infrared spectrum of n-hexyl thirane and have reported the principal bands observed.

In addition to studying the infrared spectrum, Guthrie and his collaborators (66) determined the vapor pressure and various thermodynamic functions for ethylene sulfide. Sumner (69) has also investigated the thermodynamic properties of ethylene sulfide, and from heats of combustion data, has calculated its heat of formation.

The dipole moment of ethylene sulfide has been determined by Gunthard and Gausmann (64), and the structures of ethylene sulfide and ethylene oxide have been compared on the basis of their microwave spectra (70).

Nelson and Jessup (71) have recently compared the heats of combustion of ethylene oxide, ethylenimine and ethylene sulfide in relation to the strain energies of their ring systems.

Investigations concerned with the ring opening reactions of cyclic sulfides have resulted in the observation that these compounds resemble the corresponding oxygen compounds in many respects (16,17,18). However, in contrast to the epoxides, very frequently the initial

products of ring fission are not isolated as such, due to further reaction of these initial products with cyclic sulfide or because of polymerization of the alkene sulfide (16,17,18).

In the following review, no attempt is made to maintain chronological order, as it appeared that a more useful discussion would be presented if all reports pertaining to the reactions of a particular reagent with alkene sulfides were grouped together.

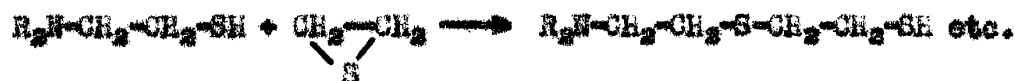
1. Ring Cleavage by Primary and Secondary Amines

Reppe and Nicolai (23) have described in patent form, the preparation of N-substitution products of $H_2N-CH_2-CH_2-SH$ and its homologs, by the interaction of ethylene or propylene sulfide with primary and secondary amines, at 100-200°C. in the presence of a substance capable of lowering the pH of the reaction mixture, such as phenol. The strong tendency of the primary addition product to react with additional sulfide was noted, especially when the mole ratio of sulfide to amine was greater than one. A slight modification of this procedure has recently been employed by Woodburn and Faulter (72), for the preparation of various N-substituted β -aminoethyl mercaptans from ethylene sulfide and various amino compounds. Prior to the report by Reppe and Nicolai (23), Delapine (11,35) had attempted the preparation of aminothiols by the action of aqueous ammonia on ethylene sulfide. However, he was able to isolate only solid polymers which contained little or no nitrogen, indicating that the reaction merely produced polymeric sulfide.

Several years later, Snyder and his associates (14) described the results of studies carried out with ethylene, propylene, isobutylene and cyclohexene sulfides and a variety of primary and secondary amines. The reactions were carried out at temperatures near 100°C., for periods of 10 to 20 hours without the benefit of catalysts or solvents. In contrast to the findings of Happe and Nicolai (23), they observed no beneficial effects when phenol or aluminum chloride was added, or when the sodium derivative of the amine was employed.



Only "normal" ring fission was observed by Snyder and co-workers. In all instances, more or less of the initially formed amino-mercaptan went on to form polymer, although, the use of excess amine suppressed this reaction.



An extensive investigation by the Russian chemist Braz (73), concerned with the reaction of ethylene sulfide with amines, has revealed several interesting facts. It was clearly demonstrated that the severe reaction conditions previously employed (23,24) in producing N-substituted β-aminoethane thiols were not indispensable, and very frequently were undesirable as they tend to favor the side reaction shown above, as well as sulfide polymerization. Moreover, it was

observed that when freshly prepared ethylene sulfide was added to a solution of the amine in an ionizing solvent, and allowed to stand at room temperature for a few hours, almost complete conversion of the sulfide to polymeric material occurred. In fact, the reaction of ethylene sulfide with alcoholic diethylamine was recommended as a method for the quantitative determination of ethylene sulfide. The above observations would appear to offer an explanation for the failure of Delepine to isolate any aminothiols from the reaction of ethylene sulfide with aqueous or alcoholic ammonia (11,35).

On the other hand, Bras (73) observed that when the reactions were carried out in a non-ionizing medium such as anhydrous ethyl ether or benzene, polymerization of the sulfide was almost completely suppressed. As a result, the amount of aminothiol isolated was substantially increased.

This procedure has recently been used by Schaefer and Spierri (74), to prepare 2-n-butylaminoethyl mercaptan from n-butylamine and ethylene sulfide.

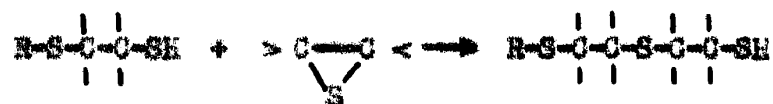
2. Ring Cleavage by Mercaptans

Several patents have been granted on the reaction of episulfides with mercaptans. A German patent issued in 1940 to Reppe and Freytag (24) described the synthesis of a number of compounds obtained by heating a mixture composed of an alkyl mercaptan with either ethylene or propylene sulfide, in an inert solvent at 100-200°C. until all of the sulfide had reacted.

Snyder and his co-workers (75) were unable to effect reaction under the above conditions, with either isobutylene or cyclohexene sulfide. Reactions did occur, however, when catalyst such as sodium ethoxide or boron trifluoride (added as the ether or acetic acid complex) were employed.



As in the reaction of alkene sulfides with primary and secondary amines, the initial product resulting from ring fission showed a marked tendency to react further, giving rise to products containing more than one thio-ether group.



Later work by Culvenor and his collaborators (15) on the reaction between ethylene sulfides and hydrogen sulfide or primary mercaptans, indicated that the free thiols do not readily bring about ring cleavage. In an experiment using cyclohexene sulfide and ethyl mercaptan, the reactants were heated in a sealed tube for six hours at 120°C. and recovered unchanged. When the alkali salts of the mercaptans were employed, reactions did occur in the expected manner, but in each instance considerable polymeric material was formed. Potassium hydrogen sulfide converted propylene and cyclohexene sulfides into the corresponding dithiols and with 2-chloroethyl thiolane produced trithioglycerol.

Attempts to bring about ring fission of tetramethylethylene sulfide in this way, have so far been unsuccessful (15).

Heade and Woodward (76) have carried out similar reactions on ethylene sulfide using hydrogen sulfide and alkali salts of aliphatic mercaptans.

The reaction of potassium hydrogen sulfide with 2-n-hexyl thirane has been reported to yield a small amount of 1,2-dimercaptocane along with considerable quantities of polymeric material (68).

3. Ring Cleavage by Alcohols

The preparation of β -alkoxy substituted mercaptans was first described by Snyder, Stewart and Ziegler (75). By employing boron trifluoride as catalyst, they were able to isolate small amounts of the alkoxy mercaptans from the reaction of isobutylene sulfide with primary saturated alcohols. Little or no reaction occurred between isobutylene sulfide and secondary alcohols, or between primary alcohols and either propylene or cyclohexene sulfide. No alcohols lower than butyl were studied. Once again, polymerization of the sulfide was observed.

Culverer and his associates (15) also studied the opening of alkene sulfides by hydroxy-compounds and found that at ordinary temperatures, the sulfides are fairly stable to neutral water and alcohols. When propylene sulfide and water were heated in a sealed tube for seventeen hours at 100°C., a mixture of cleavage products resulted, but individual compounds were not identified. Under the same conditions, absolute ethanol gave analogous results, but again, the individual structures were not determined.

4. Ring Cleavage by Acids

Although dilute mineral acids catalyze the polymerization of olefin sulfides, suitable control of the concentration can result in the formation of simple monomeric addition products. For example, Delapine (11,12,34,35,36) found that ethylene sulfide and concentrated hydrochloric acid produced 2-chloroethanethiol in 33% yield. Concentrated hydrobromic acid behaved similarly, to yield 2-bromoethanethiol.

Stewart (77) was able to isolate large quantities of chloropropenethiols from the reaction of excess concentrated hydrochloric acid with propylene sulfide.

Recently, Culvenor, Davies and Heath (15) have extended the reaction. When an excess of concentrated hydrochloric acid was employed with cyclohexene sulfide and 2-chloromethyl thirane, the 2-chlorothiols were formed in moderate to good yields. Best results were obtained by working at room temperature, and when the reaction mixture was kept well mixed by continuous shaking. Polymers were formed in major amounts when the following conditions were employed, (a) reaction carried out at reflux temperatures, (b) when reaction mixture was not thoroughly homogenized, and (c) bubbling hydrogen chloride gas into the sulfide.

Woodward and Meade (76) have produced substantial amounts of 2-chloroethanethiol by treating ethylene sulfide with dry hydrogen chloride gas.

Van Tassel (57) has recently shown that in the reaction of hydrochloric acid with cyclohexene sulfide, the 2-chlorocyclohexanethiol which is produced, exists entirely in the trans configuration.

When an excess of boiling glacial acetic acid was allowed to react with cyclohexane sulfide, Culvenor and his co-workers obtained low yields of 2-mercaptocyclohexyl acetate, along with large amounts of higher boiling material.

Stewart (77) has shown that the reaction of acetic acid with propylene sulfide gives a 15% yield of simple addition product, which is considered to be a mixture of $\text{CH}_3\text{-CH}(\text{SH})\text{-CH}_2\text{-O-C(=O)-CH}_3$ and $\text{HS-CH}_2\text{-CH}(\text{CH}_3)\text{-O-C(=O)-CH}_3$.

Apparently sulfuric acid whether concentrated or not, exerts only a polymerizing influence on olefin sulfides (15).

Delepine and Eschenbrenner (35) have reported that nitric acid oxidized ethylene sulfide to the acids $\text{HO}_3\text{S-CH}_2\text{-CO}_2\text{H}$ and $\text{HO}_3\text{S-CH}_2\text{-CH}_2\text{-S-CH}_2\text{-CO}_2\text{H}$.

5. Ring Cleavage by Acid Halides and Related Compounds

In 1940, a patent granted to Aldermann, Brubaker and Sanford (78) first described the conversion of ethylene sulfide into 2-chloroethyl thioacetate by the action of acetyl chloride. In addition, the synthesis of 2-acetoxyethyl thioacetate from ethylene sulfide and acetic anhydride with pyridine was described.

Several years later, Meade and Woodward (76) reported that treatment of ethylene sulfide with chloroacetyl chloride or bromide resulted in the formation of 2-chloroethyl thiochloroacetate and -bromoacetate respectively.

Ivin (79) has isolated 2-iodoethyl thioacetate from the reaction of ethylene sulfide with acetyl iodide.

Calverton, Davies and Heath (15) have reported that cyclohexane sulfide and acetyl chloride readily form 2-chlorocyclohexyl thioacetate in high yield. Propylene sulfide and 2-chloromethyl thiirane also reacted quite easily with acetyl chloride to form a chloropropyl thioacetate and a dichloropropyl thioacetate respectively. The absolute structure of the products was not determined.

Van Tamelen (57) has shown that the interaction of cyclohexane sulfide with acetyl chloride results in the formation of trans- rather than cis-2-chlorocyclohexanethiol acetate.

Stewart (77) has reported that the reaction of propylene sulfide with acetyl chloride produces excellent yields of β -chloropropyl thioesters, $\text{CH}_3\text{-CH}(\text{Cl})\text{-CH}_2\text{-S-C(=O)-CH}_3$ and/or $\text{Cl-CH}(\text{CH}_3)\text{-CH-S-C(=O)-CH}_3$. The β -chloropropyl esters of thioacetic, thiobutyric and thiobenzoic acids were also prepared.

Benzoyl chloride has been found to react less readily with propylene sulfide than does acetyl chloride, but nevertheless gives large amounts of a chloropropyl thiobenzoate (15).

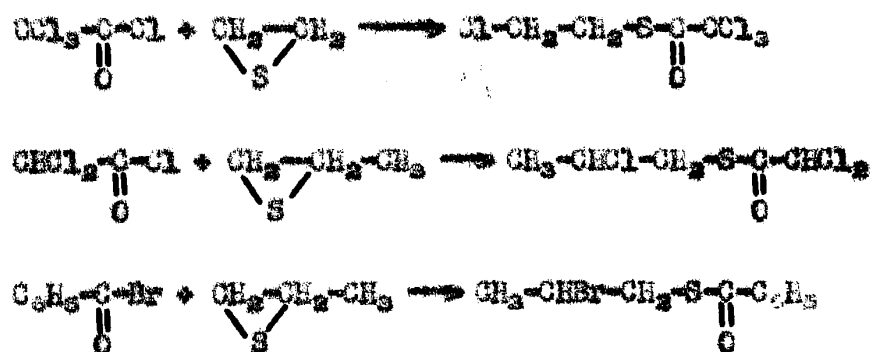
An intensive investigation of the reaction of propylene sulfide with acetyl chloride and related compounds was described in 1950 by Davies and Savige (17). The product formed in quantitative amount from the spontaneous reaction of acetyl chloride with propylene sulfide was shown to be 2-chloropropyl thioacetate. No indication of the presence of isomeric material was obtained. Likewise, propylene sulfide and acetyl bromide produced 2-bromopropyl thioacetate in theoretical amount.

The reaction of propylene sulfide with acetic anhydride in the presence of a small amount of pyridine was also investigated. The major product resulting from this reaction was found to be 2-acetylthio-propyl acetate.

Van Tamelen (57) has reported that cyclohexane sulfide and acetic anhydride produce the diacetate of 2-hydroxycyclohexanethiol.

Oulvenor and his associates (15) were unable to isolate any monomeric addition products from the reactions of olefin sulfides with the following halogen compounds: benzoyl fluoride, picryl chloride, 3,5-dinitrobenzoyl chloride, triphenylmethyl chloride and p-toluene sulfonyl chloride or fluoride.

Just recently, Ivin (79) has described the preparation of a number of simple addition compounds produced by the action of various acyl halides on ethylene and propylene sulfides. For example:



6. Ring Cleavage by Lithium Aluminum Hydride

Bordwell, Andersen and Pitt (16) first described the reduction of episulfides by lithium aluminum hydride, in 1953. The reagent was found to react quite smoothly with cyclohexene sulfide, propylene sulfide

and 2-n-butyl thirane, forming secondary mercaptans in each instance, in about 75% yield, with no indication of the presence of the isomeric primary thiols.



In contrast to these findings, Moore and Porter (68) found that reduction of 2-n-hexyl thirane by lithium aluminum hydride gave only a small percentage of the expected octane-2-thiol, and a rather large percentage of polymeric material.

7. Ring Cleavage with Organometallics

The preparation of β -diethylaminocethyl mercaptan, reported by Gilman and Woods (80) in 1945, appears to represent the first recorded instance in which an organometallic was employed to bring about ring cleavage of an olefin sulfide. A 48% yield of the amino-mercaptan was obtained by the action of lithium diethylamide on ethylene sulfide at low temperatures.

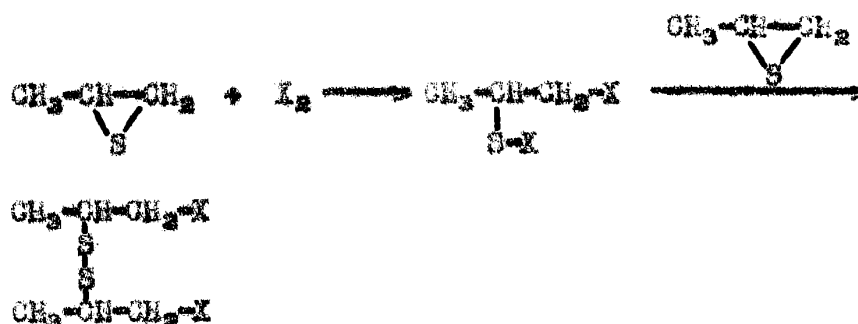
The reaction of ethylene sulfides with Grignard reagents has recently been studied by Borchwell and his associates (15). The action of phenyl magnesium bromide on cyclohexane sulfide produced cyclohexane in 87% yield, indicating that the Grignard reagent merely extracts sulfur from olefin sulfides, however, no thiophenol was isolated and the exact nature of the sulfur containing material is unknown. When butyl magnesium bromide was used, cyclohexane was obtained in 19% yield, and

1-butanethiol was obtained in 5% yield. Reaction of cyclohexene sulfide with benzyl magnesium chloride resulted in the production of 13% cyclohexene, 12% benzyl mercaptan and 5% benzyl disulfide.

Bortwell and collaborators (16) found that alkyl- and aryl-lithium compounds did not form simple mercaptans on reaction with alkene sulfides, but instead effected a 1,2-elimination reaction, giving rise to olefins and alkyl or aryl mercaptans. For example, phenyllithium with cyclohexene sulfide gave 60% of thiophenol and 52% of cyclohexene. Likewise, cyclohexene sulfide with butyllithium resulted in the formation of 67% cyclohexene and 63% of 1-butanethiol. Similar results were observed with propylene and ethylene sulfide, the alkyl or aryllithium compound appropriating the sulfur atom in each case.

8. Ring Cleavage with Halogens

Some interesting observations on the mode of reaction of propylene sulfide with chlorine and bromine have been reported recently by Stewart and Gordts (81).



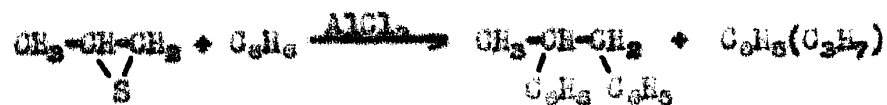
In an anhydrous medium, such as carbon tetrachloride or chloroform, the reaction was assumed to proceed in a step-wise manner, forming first

Delapins (11,12) was the first to study this particular reaction, and reported that the action of methyl iodide on ethylene sulfide produced a salt thought to be $(C_2H_4S)_2, CH_3I$. A similar situation was reported for the reaction of propylene sulfide with methyl iodide (34). These results have recently been questioned by Culvenor and co-workers (15).

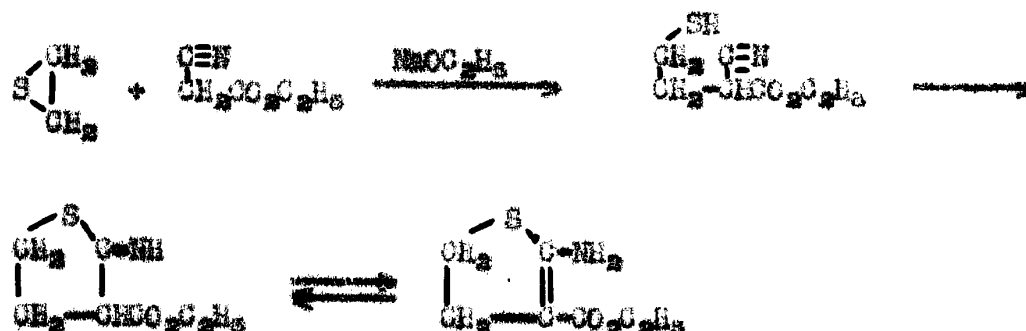
Culvenor and his co-workers (15) later extended this work by reacting, cyclohexene sulfide, 4-methylcyclohexene sulfide, and 2-chloromethyl thirane with methyl iodide and observed that trimethylsulfonium iodide was produced in each instance. The cyclopentene sulfide (57) undergoes decomposition into trimethylsulfonium iodide in the presence of methyl iodide, in a manner analogous to that of cyclohexene sulfide.

10. Alkylation Reactions

Stewart (77) has investigated the reaction of propylene sulfide with benzene in the presence of aluminum chloride. At ordinary temperatures, the reaction produces only propylene sulfide polymers. However, if the reaction mixture is then heated to reflux condensation products may be isolated. Although small quantities of monopropyl benzenes have been obtained, the reaction tends to give mainly the secondary condensation product, 1,2-diphenylpropane.



The alkylation of ethyl cyanacetate with alkene sulfides had previously been described by Snyder and Alexander (6).



Propylene sulfide and isobutylene sulfide behaved similarly, producing 2-imino-3-carbethoxy-5-methylthiophane and 2-imino-3-carbethoxy-5,5-dimethylthiophane, respectively. In addition, when the condensations were effected in methanol solution, ester interchange occurred and the methyl esters were obtained.

Recently, Gass (43) has reported the alkylation of ethyl cyanacetate by 2-phenyl thirane in the presence of sodium ethoxide. The structure of the condensation product, however, was not established.

11. Effect of Oxidizing Agents on Alkene Sulfides

As mentioned earlier, all attempts to prepare the sulfoxides and sulfones of the cyclic sulfides have failed. In every instance, the over-all effect is one of ring-fission followed by various secondary reactions such as polymerization.

Stewart and Cordts (81) found that chlorine and bromine would oxidize propylene sulfide very readily. If the oxidations were carried

out in anhydrous media, bis-(1-methyl-2-haloethyl) disulfides were formed whereas chlorine water produced 1-chloro-2-propane-sulfonyl chloride. Use of 30% hydrogen peroxide resulted in the formation of sulfuric acid and 2-hydroxy-1-propanesulfonic acid.

Prior to the above work, Culvenor and his associates (15) had reported that neither aqueous hydrogen peroxide nor permanganate would react with ethylene sulfides to form sulfoxides or sulfones. Instead, a variety of substances resulting from ring-opening were obtained. Delepine and Machenzbrenner (35) observed that the direct oxidation of ethylene sulfide with nitric acid produced $\text{HO}_2\text{S}-\text{CH}_2-\text{OC}_2\text{H}_5$ and higher molecular weight products resulting from further reaction of this acid with ethylene sulfide.

12. Miscellaneous Reactions

Ethylene, propylene, chloropropylene, isobutylene and cyclohexene sulfides are reported to undergo desulfurization with trivalent phosphorus compounds (15), such as triethylphosphine, at ordinary temperatures. Cyclohexene and propylene sulfides yield viscous liquids with methyl sulfate (15) and also with chloramine-T (15). Aqueous mercuric salts are found to react spontaneously with ethylene sulfide but the structure of the products are unknown (15). Ethylene sulfides instantly produce nitrogen when treated with aqueous sodium azide and iodine (15).

XII. EXPERIMENTAL

Preparation of Ethylene Sulfide

(Thiirane)



A solution containing 97 g. (1.0 mole) of potassium thiocyanate dissolved in an equal quantity of water was placed in a 350 ml. three-necked flask fitted with a thermometer, mechanical stirrer and a gas delivery tube. A constant stream of ethylene oxide was passed through the stirred reaction mixture, kept at -10 to -5° , until it had gained 70 g. in weight; which required five hours. After an additional three hours of stirring, at the same temperature, the transparent reaction mixture had begun to separate into two layers. A few drops of thiophenol were added to stabilize the ethylene sulfide (13) and the mixture was set aside overnight at $0-5^{\circ}\text{C}$. The liquid material was decanted from the precipitated potassium cyanate and the oily top layer, which had increased on standing, was separated and washed three times with 45 ml. portions of a 20% solution of sodium chloride. An additional few drops of thiophenol were added to the crude ethylene sulfide and it was dried over anhydrous calcium chloride. Fractionation at atmospheric pressure through a 2x30 cm. column packed with 3/16 inch glass helices gave 25.2 g. (0.42 mole), a 42% yield, of ethylene sulfide boiling at $54-55^{\circ}$ (747 mm.). The reported boiling point is $55-56^{\circ}$ (760 mm.), (73).

The ethylene sulfide prepared in this manner remained transparent for five to six days when stored at 0°C. The sulfide had a refractive index of n_D^{25} 1.4896. Reynolds (47) reports n_D^{25} 1.4898.

Preparation of Propylene Sulfide

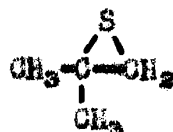
(2-Methyl Thirane)



Into a 2-l. three-necked flask provided with a sealed stirrer, dropping funnel and parallel side-arm fitted with a reflux condenser and thermometer, was charged 152 g. (2.0 moles) of thiourea, 700 ml. of water and 60 ml. (2.0 equivalents) of concentrated sulfuric acid. The flask was placed in an ice-bath and cooled to 10°C. A 116 g. (2.0 moles) quantity of propylene oxide was added dropwise to the vigorously stirred reaction mixture, in three hours. Following an additional fifteen minutes of stirring, the reaction mixture was allowed to warm to room temperature and neutralized by slowly adding 212 g. (2.0 moles) of sodium carbonate dissolved in 900 ml. of water. The oil layer was separated and the aqueous phase was extracted three times with 150 ml. portions of n-pentane. After standing overnight, additional oil had separated from the aqueous phase and the pentane extraction was repeated. The original oil and pentane extracts were combined and dried over anhydrous sodium sulfate. The pentane was removed and the residual liquid was fractionated at atmospheric pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The propylene sulfide

distilled at 73.8-74° (737 mm.), n_D^{25} 1.4732. The boiling point as reported by Bordwell and Andersen (22) is 72-75°. A 75%, 107 g. (0.72 mole), yield was obtained.

Preparation of Isobutylene Sulfide
(2,2-Dimethyl Thirane)



A solution containing 97 g. (1.0 mole) of potassium thiocyanate dissolved in 100 ml. of water was placed in a 500 ml. three-necked flask equipped with a mechanical stirrer, dropping funnel and parallel side-arm provided with a reflux condenser and thermometer. To the vigorously stirred solution was added dropwise, 72 g. (1.0 mole) of redistilled isobutylene oxide. The temperature was maintained at 25 to 30° throughout the addition of the epoxide, which required three hours. The reaction mixture was then stirred for an additional three hours. External cooling was required from time to time, in order to keep the reaction temperature below 30°C. The lower aqueous layer was removed by means of a pipet and the sulfide layer was stirred again, for five hours, with a fresh solution of potassium thiocyanate containing 50 g. of the salt in 100 ml. of water. The liquid material was decanted from the potassium cyanate precipitate and separated into two portions. The aqueous phase was extracted three times with 50 ml. portions of ether. The ether extracts were combined with the organic phase and

dried over anhydrous calcium chloride. The ether was removed and the crude sulfide was fractionated through a 2x30 cm. Fenske-type column packed with glass helices. A 71 g. (0.81 mole) quantity of isobutylene sulfide distilling at 83.5-84° (741 mm.), n_D^{25} 1.4640 was collected. This corresponded to an 80% yield based on the oxide. Snyder, Stewart and Ziegler (14) report these constants as: b. p. 84-86° and n_D^{25} 1.4641. Three additional preparations of this sulfide gave yields in the range 80-83%.

Preparation of Styrene Sulfide

(2-Phenyl Thirane)



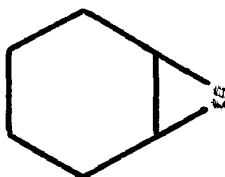
All apparatus was cleaned, rinsed with ammonium hydroxide solution and dried before use.

In a 500 ml. three-necked flask equipped with a sealed stirrer, reflux condenser and thermometer was placed a mixture containing 60 g. (0.50 mole) of redistilled styrene oxide, 50 g. (0.52 mole) of potassium thiocyanate, 100 ml. of dioxane and 100 ml. of water. The mixture was stirred at 60° for one hour, allowed to cool to room temperature and poured into a mixture of 200 g. of crushed ice and 400 ml. of water. The crude sulfide was extracted with three 100 ml. portions of ether and the combined ether extracts were washed twice with 150 ml. portions of water and dried over anhydrous potassium carbonate. The ether was

removed in vacuo and the residual solution was filtered through a sintered glass filter. The unreacted styrene oxide was removed by distillation at 1 mm. pressure through a 2x20 cm. column packed with 3/16 inch glass helices. When the temperature of the distillate reached 50° the remaining liquid was transferred to a short-path distillation apparatus and fractionated under reduced pressure. A 31 g. (0.23 mole) quantity of 2-phenyl thirane boiling at 28-30° (0.1 mm.), n_D^{20} 1.6015 was collected. The reported physical constants for this compound are: b.p. 25-28° (0.01 mm.), n_D^{20} 1.6015 (43). The yield of product was 45%, based on the oxide used. A second preparation gave a 47% yield. The sulfide was stored at 0°C.

Preparation of Cyclohexene Sulfide

(7-Thiabicyclo(4,1,0)heptane)



A 49 g. (0.50 mole) quantity of cyclohexene oxide was added in one portion to a solution of 121 g. (1.25 moles) of potassium thiocyanate dissolved in 100 ml. of water and 75 ml. of 95% ethanol, contained in a 1-l. two-necked flask equipped with a mechanical stirrer and reflux condenser. After allowing the reaction mixture to stand for about four hours, an additional 49 g. (0.50 mole) of cyclohexene oxide was added and the resulting solution was stirred vigorously for thirty-six hours. The supernatant layer and the aqueous phase were decanted from the

precipitated potassium cyanate into a 1-l. separatory funnel. The potassium cyanate was rinsed with two 50 ml. portions of ether, and these were added to the separatory funnel and used to extract the cyclohexene sulfide. The ether extract was washed twice with 50 ml. portions of saturated sodium chloride solution and dried over anhydrous sodium sulfate. The ether was removed on the steam bath and the residual liquid was distilled under reduced pressure through a 20 inch Vigreux column. The main fraction distilled at $70-72^{\circ}$ (20 mm.), n_D^{25} 1.5310. The yield of product was 67%. Physical constants reported by van Tamelen (11) for cyclohexene sulfide are: b. p. $71.5-73^{\circ}$ (21 mm.), $69-71^{\circ}$ (19 mm.), n_D^{25} 1.5306-1.5311.

Preparation of 2-Chloromethyl Thiirane
(Thioepichlorohydrin)

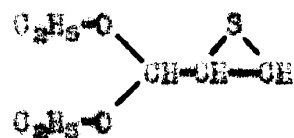


A 1-l. three-necked flask equipped with a sealed stirrer, dropping funnel, thermometer and reflux condenser was charged with 38 g. (0.5 mole) of thiourea, 175 ml. of water, and 15 ml. (0.5 equivalent) of concentrated sulfuric acid. The mixture was cooled to 0 to 5°C . Part of the thiourea was insoluble under these conditions, but it dissolved as the reaction proceeded. To the stirred solution, kept at 5° , was added 46 g. (0.5 mole) of epichlorohydrin, in an hour and a half. The reaction mixture was stirred an additional quarter of an hour, allowed to warm to room temperature and carefully neutralized with

53 g. (0.5 mole) of sodium carbonate dissolved in 250 ml. of water. The two layers were separated and the aqueous phase was extracted with two 50 ml. portions of n-pentane. After several hours of standing, additional oil had separated from the aqueous phase and the extraction was repeated. The organic fraction and pentane extracts were combined, dried over anhydrous sodium sulfate, and the pentane was removed in vacuo. The concentrated residue was fractionally distilled to yield pure 2-chloromethyl thirane boiling at 47-48° (23 mm.), n_D^{20} 1.5274. An 85.3% yield, 45.9 g. (0.43 mole), was obtained. The reported values are: b.p. 79-81° (114 mm.), n_D^{20} 1.5280, (15).

Preparation of Thioglycidaldehyde Diethylacetal

(2,2-Diethoxymethyl Thirane)



In a 500 ml. three-necked flask fitted with a sealed stirrer, reflux condenser and dropping funnel was placed a solution prepared from 97.0 g. (1.0 mole) of potassium thiocyanate and 100 ml. of water. To the vigorously stirred solution was added 146 g. (1.0 mole) of glycidaldehyde diethylacetal and 20 ml. of ethanol, over a two hour period. On continued stirring, the solution became turbid, with separation of two layers, and the temperature rose to 30°C. The reaction was allowed to continue for twenty-four hours. The two liquid layers were decanted from the small amount of solid present, saturated with sodium chloride

and extracted three times with 100 ml. portions of n-pentane. The pentane was removed by distillation through a twelve inch Vigreux column. The crude product was placed in a 300 ml. two-necked flask equipped with a mechanical stirrer and reflux condenser, and treated with a fresh solution of potassium thiocyanate containing 50 g. of the salt in 100 ml. of water. The resulting mixture was stirred vigorously for twenty-four hours and worked up as described above. The pentane extracts were dried over anhydrous sodium sulfate and the pentane was removed in vacuo. The concentrated residue was distilled under reduced pressure through a 2x30 cm. Fenske-type column. A yield of 67% of pure 2,2-diethoxymethyl thirane boiling at 80° (10 mm.), n_D^{20} 1.4615 was obtained. Physical constants as reported by Wright (90) for this material are: b.p. 84° (14 mm.), n_D^{20} 1.4613.

Preparation of 1-Methoxy-2-hydroxy-3-chloropropane



The halohydrin was prepared by reacting methanol with epichlorohydrin in the presence of an acid catalyst. A typical preparation follows:

In a 2-l. three-necked flask equipped with a sealed stirrer, dropping funnel and parallel side-arm fitted with a reflux condenser and thermometer, were placed 288 g. (9.0 moles) of methanol and 6.7 ml. of concentrated sulfuric acid. The stirred contents of the flask were heated to reflux and 277.5 g. (3.0 moles) of epichlorohydrin were added

dropwise in two hours. The resulting solution was stirred and refluxed for an additional four hours, and set aside overnight. A 30 g. (0.15 mole) quantity of barium carbonate was added and the mixture was stirred for four hours, filtered and the excess methanol was removed by distillation. The residue was fractionated under reduced pressure. A 232 g. (1.9 moles) quantity of material boiling at 68-70° (11-13 mm.), n_D^{25} 1.4450 was collected. Literature values for 1-methoxy-2-hydroxy-3-chloropropane are: b. p. 76.5° (20 mm.), n_D^{25} 1.4422, (112). A 62.4% yield was obtained based on epichlorohydrin. A second preparation gave a 67% yield.

By employing the following experimental modification, the yield was increased to 80%. The mole ratio of methanol to epichlorohydrin was raised from 3:1 to 4:1 and the reaction temperature was maintained at 25-30° while the epichlorohydrin was being added. The reaction mixture was stirred an additional fifteen hours at room temperature and after neutralization of the acid catalyst and filtration, the excess methanol was removed under reduced pressure.

Preparation of 1,2-Epoxy-3-methoxypropane



A solution of 231 g. (1.86 moles) of 1-methoxy-2-hydroxy-3-chloropropane in two liters of absolute ether was charged into a 3-l. three-necked flask equipped with a mechanical stirrer, addition flask for

solids and parallel side-arm fitted with a reflux condenser and thermometer. The flask was supported in an ice-bath and 120 g. (3.0 moles) of finely powdered sodium hydroxide were added in small portions, in one hour, while holding the temperature of the reaction mixture at 0-5°C. After an additional five hours of stirring at 5°C, the reaction mixture was set aside overnight. A 500 ml. quantity of water was added, and the ether layer was separated. The aqueous layer was extracted three times with 75 ml. portions of ether. The combined ether fractions were placed on the steam-bath and the ether was removed. The residue was distilled through a 2x30 cm. column packed with 3/16 inch glass helices. The 1,2-epoxy-3-methoxypropane distilled at 40-42°C (26-28 mm.), n_D^{25} 1.4019. This epoxide is reported to boil at 53.7°C (85 mm.), n_D^{25} 1.4012, (112). Four preparations gave yields of 81.6%, 80%, 83%, and 81.6% based on the 1-methoxy-2-hydroxy-3-chloropropane used. The highest yield reported by Flores-Gallardo and Pollard was 68% (112).

Preparation of 2-Methoxymethyl Thirane



The thirane was prepared from the corresponding oxirane and either aqueous potassium thiocyanate or thiourea. When employing potassium thiocyanate, the procedure of Snyder, Stewart and Ziegler (14) was utilized, while with thiourea the method developed by Bordwell and Andersen (22) was followed. A typical preparation utilizing potassium thiocyanate follows:

In a 500 ml. three-necked flask provided with a sealed stirrer, dropping funnel and parallel side-arm holding a reflux condenser and thermometer, were placed 97 g. (1.0 mole) of potassium thiocyanate and 100 ml. of water. To this vigorously stirred solution, kept at 20-30°, was added dropwise, 88 g. (1.0 mole) of 1,2-epoxy-3-methoxypropane, during an hour and three quarters. The turbid solution was stirred for an additional two hours and set aside overnight. The two phase system was separated and the organic phase was treated as described above with a fresh aqueous solution of potassium thiocyanate (fifty grams of the salt in 100 ml. of water), for five hours. The two phase system was again separated and the aqueous layer was combined with the first aqueous phase and extracted with three 25 ml. portions of ether. The combined ether extracts and organic phase were dried over anhydrous calcium chloride and the ether was removed. The crude product was distilled under diminished pressure, through a 2x60 cm. Fenske-type column packed with 3/16 inch glass helices. The major fraction distilled at 60.5-61° (16-17 mm.), n_D^{25} 1.4791. Two preparations gave yields of 93%, and 92%, based on the 1,2-epoxy-3-methoxypropane used.

When the conversion of an oxirane compound to the corresponding thirane was accomplished with thiourea, the following procedure was employed.

In a 1-l. three-necked flask equipped with a sealed stirrer, reflux condenser, dropping funnel and thermometer were placed 76 g. (1.0 mole) of thiourea and 30 ml. of a sulfuric acid solution (1.0 eq. of acid

in 350 ml. of water). The stirred contents of the flask were cooled to 5-10° and held in this range while 88 g. (1.0 mole) of 1,2-epoxy-3-methoxypropane was added dropwise in two hours. A quarter of an hour after the epoxide had been added, the reaction mixture was allowed to warm to room temperature and cautiously neutralized with 106 g. (1.0 mole) of sodium carbonate dissolved in 450 ml. of water. The aqueous phase was separated and extracted with two 25 ml. portions of ether. After standing several hours, additional oil had separated from the aqueous phase and the ether extraction was repeated. The ether extractions were combined with the organic layer and dried over anhydrous sodium sulfate. After removal of the ether, the residue was distilled under reduced pressure through a 2x60 cm. column packed with 3/16 inch glass helices. The major fraction distilled at 60° (16 mm.), n_D^{25} 1.4791 and corresponded to a 87% yield. A second preparation gave similar results. Elemental analysis for C_4H_8OS gave the following results. Calculated: C, 46.15; H, 7.69; S, 30.77. Found: C, 46.30; H, 7.94; S, 30.56.

Preparation of 1-Ethoxy-2-hydroxy-3-chloropropane



The halohydrin was obtained by two different methods, one utilizing anhydrous stannic chloride and the other concentrated sulfuric acid as the catalyst. When anhydrous stannic chloride was used, a slight modification of the procedure described by Van Zyl, *et al.* (2) was employed

and resulted in a 7-8% increase in yield. A typical synthesis follows.

In a 3-l. three-necked flask provided with a sealed stirrer, dropping funnel and parallel side-arm holding a reflux condenser and thermometer, were placed 5 ml. of anhydrous stannic chloride and 1104 g. (24 moles) of anhydrous ethanol. The reflux condenser and dropping funnel were protected with calcium chloride tubes. The reaction flask was placed in a water-bath initially at 20°C. A 555 g. (6.0 moles) quantity of epichlorohydrin was added dropwise over a period of two hours. The water-bath was replaced by a heating mantle and the reaction mixture was refluxed for an hour. After cooling, the solution was neutralized with ammonium hydroxide, and the excess ethanol was removed by vacuum distillation. The concentrated residue was distilled through a 2x30 cm. column packed with 3/16 inch glass helices, to give a 95.1% yield of product boiling at 74-75° (13-14 mm.), n_D^{25} 1.4425. A second preparation gave a 94.4% yield. The literature values for 1-ethoxy-2-hydroxy-3-chloropropane are: b. p. 80-81° (16 mm.), 71° (2 mm.), (2), n_D^{25} 1.4370 (112).

When concentrated sulfuric acid was employed as the catalyst, a modification of the method reported by Flores-Gallardo and Pollard (112) was used, and resulted in a 10% increase in yield. A typical preparation follows.

In a 2-l. three-necked flask equipped as described above, were placed 368 g. (8.0 moles) of anhydrous ethanol and 8.5 ml. of concentrated sulfuric acid (d. 1.84). To the vigorously stirred solution

was added dropwise, 372 g. (4.0 moles) of epichlorohydrin, in two and a half hours. The reaction temperature initially rose to 55° , but external heating was required to maintain the temperature during the final stages of the epichlorohydrin addition. The reaction mixture was refluxed for an additional four hours and allowed to cool to room temperature. After adding excess barium carbonate, (30 g.), the solution was stirred for several hours and then set aside overnight. The reaction mixture was filtered and the excess ethanol was removed in vacuo through a 30 cm. Vigreux column. The crude product was distilled through the packed column described above, under reduced pressure. The 1-ethoxy-2-hydroxy-3-chloropropene distilled at $72-73^{\circ}$ (11-12 mm.), n_D^{25} 1.4424. A 70% yield was obtained. The constants reported by Flores-Gallardo and Pollard for this material are: b. p. $80-82^{\circ}$ (20 mm.), n_D^{25} 1.4370, (112).

Preparation of 1,2-Epoxy-3-ethoxypropene



The epoxide was prepared from 1-ethoxy-2-hydroxy-3-chloropropene following the procedure of Flores-Gallardo and Pollard (112). In a 3-l. three-necked flask equipped with a sealed stirrer, solids addition flask and parallel side-arm holding a reflux condenser and thermometer, were placed two liters of absolute ether and 277 g. (2.0 moles) of 1-ethoxy-2-hydroxy-3-chloropropene. The flask was supported in an ice-bath and 120 g. (3.0 moles) of finely powdered sodium hydroxide was

added in small portions, via the solids addition flask, at a rate which maintained the reaction temperature at 0 to 5°C. The reaction mixture was stirred at 0 to 5°C for an additional five hours, and then at room temperature for another fifteen hours. A 500 ml. volume of water was added and the aqueous layer was separated and extracted with two 100 ml. portions of ether. The original ether layer and ether extracts were combined, and the ether was removed on the steam-bath using a two foot Vigreux column. Distillation of the residue through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices gave pure 1,2-epoxy-3-ethoxypropane boiling at 56-57° (54 mm.), n_D^{25} 1.4061. The yield was 91.8% of theoretical. A second similar preparation gave a 93% yield of the product. Flores-Gallardo and Pollard (112) obtained a 75% yield of this material and reported its physical constants as b. p. 61° (65 mm.), n_D^{25} 1.4046. Their reaction time was somewhat shorter than that used in the present work. Van Zyl, *et al.* (2) omitted the ether solvent, and used a larger molar ratio of sodium hydroxide to halohydrin to obtain a 73% yield of 1,2-epoxy-3-ethoxypropane boiling at 123-124° (745 mm.).

Preparation of 2-Ethoxymethyl Thirane



This compound was prepared by the two methods already described for 2-methoxymethyl thirane, with the results shown in Table I. In addition, the following procedure was used.

In a 1-l. three-necked flask provided with a sealed stirrer, reflux condenser and parallel side-arm holding a dropping funnel and thermometer, were placed 300 ml. of methanol and 84 g. (1.10 moles) of thiourea. The contents were cooled to 0-5° and maintained at this temperature while 118 g. (1.00 mole) of 1,2-epoxy-3-ethoxypropane was added dropwise in one hour. When all the epoxide had been added, the solution was allowed to warm to 20° over an hour and a half period. The stirred reaction mixture was kept at 20-25° for an additional four hours, poured into 800 ml. of water contained in a 2-l. separatory funnel, and extracted with several 50 ml. portions of chloroform. After drying over anhydrous sodium sulfate, the chloroform was removed and the concentrated residue was distilled under reduced pressure. A 71% yield of 2-ethoxymethyl thirane, distilling at 50° (11 mm.), n_D^{25} 1.4725 was obtained. Further use of this method was discontinued because of the lower yield obtained. Elemental analysis for C_3H_6OS gave the following results. Calculated: C, 50.84; H, 8.47; S, 27.12. Found: C, 51.05; H, 8.76; S, 27.32.

Preparation of 1-Propoxy-2-hydroxy-3-chloropropane



The halohydrin was prepared by the acid catalyzed reaction of propanol-1 with epichlorohydrin, according to the procedure already described for the synthesis of 1-ethoxy-2-hydroxy-3-chloropropane. When the ratio of propanol-1 to epichlorohydrin was 3:1, a 70% yield

was obtained. An 83% yield was realized when the ratio was 4:1. Pure 1-propoxy-2-hydroxy-3-chloropropane distilled at 86-88° (13-14 mm.), n_D^{25} 1.4425. The reported physical constants for this compound are: b.p. 97-98° (20 mm.), n_D^{25} 1.4378 (112).

Preparation of 1,2-Epoxy-3-propoxypropane



The glycidyl ether was prepared by dehydrohalogenation of 1-propoxy-2-hydroxy-3-chloropropane with sodium hydroxide according to the method already described for the synthesis of 1,2-epoxy-3-methoxypropane. A 90% yield was obtained in each of two preparations made. The product distilled at 48-49° (16-18 mm.), n_D^{25} 1.4115. Pure n-propyl glycidyl ether is reported to boil at 77.7° (65 mm.), n_D^{25} 1.4103 (112).

Preparation of 2-Propoxymethyl Thiirane



The cyclic sulfide was prepared from 1,2-epoxy-3-propoxypropane and either potassium thiocyanate or thiourea, employing the apparatus and procedures already described for the synthesis of 2-methoxymethyl thiirane. The 2-propoxymethyl thiirane distilled at 63° (11 mm.), n_D^{25} 1.4691. Elemental analysis for $\text{C}_6\text{H}_{12}\text{OS}$ gave the following results. Calculated: C, 54.54; H, 9.09; S, 24.24. Found: C, 54.21; H, 9.01; S, 23.95. When aqueous potassium thiocyanate was employed, a 59% yield

was obtained. The use of thiourea gave a 90% yield based on the 1,2-epoxy-3-propoxypropane used.

Preparation of 1-Isopropoxy-2-hydroxy-3-chloropropane



The halohydrin was prepared from propanol-2 and epichlorohydrin, according to the procedure described for the synthesis of 1-methoxy-2-hydroxy-3-chloropropane. The mole ratio of propanol-2 to epichlorohydrin was 4:1. Two preparations gave yields of 40% and 42% of 1-isopropoxy-2-hydroxy-3-chloropropane, boiling at 89-91° (24-25 mm.), n_D^{25} 1.4382. The reported constants are; b. p. 87-87.5° (20 mm.), n_D^{25} 1.4370 (112).

Preparation of 1,2-Epoxy-3-isopropoxypropane



The glycidyl ether was prepared by the dehydrohalogenation of 1-isopropoxy-2-hydroxy-3-chloropropane with sodium hydroxide. The procedure employed was similar to that described for 1,2-epoxy-3-methoxypropane. The isopropyl glycidyl ether used in the subsequent preparation of 2-isopropoxymethyl thirane distilled at 59-60° (41-43 mm.), n_D^{25} 1.4072. Literature values reported by Flores-Gallardo and Follard (112) are: b. p. 68° (65 mm.), n_D^{25} 1.4068. The yields from two preparations averaged 83%.

Preparation of 2-Isopropoxymethyl Thirane



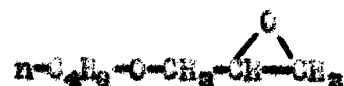
The thirane was formed by the action of aqueous potassium thiocyanate or thiourea on 1,2-epoxy-3-isopropoxypropane, employing the two methods already described for synthesizing 2-methoxymethyl thirane. The 2-isopropoxymethyl thirane distilled at 54° (11 mm.), n_D^{25} 1.4651. Elemental analysis for $\text{C}_6\text{H}_{12}\text{OS}$ gave the following results. Calculated: C, 54.54; H, 9.09; S, 24.24. Found: C, 54.49; H, 8.96; S, 24.07. A 36% yield of the thirane was obtained when potassium thiocyanate was used, while an 81% yield resulted when the thiourea procedure was employed.

Preparation of 1-Butoxy-2-hydroxy-3-chloropropane



The halohydrin was obtained from the reaction of butanol-1 with epichlorohydrin, employing sulfuric acid as the catalyst, according to the method described for the preparation of 1-methoxy-2-hydroxy-3-chloropropane. The material used in the subsequent preparation of 1,2-epoxy-3-butoxypropane distilled at $98-99^\circ$ (13-14 mm.), n_D^{25} 1.4450. Literature values for this compound are: b.p. 110-111 (20 mm.), n_D^{25} 1.4420 (112). A yield of 50% was obtained when the mole ratio of 1-butanol to epichlorohydrin was 3:1, whereas a 73% yield was realized when this ratio was 4:1.

Preparation of 1,2-Epoxy-3-butoxypropane



The butyl glycidyl ether was obtained in yields of 90-92%, from the sodium hydroxide dehydrohalogenation of 1-butoxy-2-hydroxy-3-chloropropane. The apparatus and procedure employed were similar to those described for the synthesis of 1,2-epoxy-3-methoxypropane. The butyl glycidyl ether boiled at 67-68° (16 mm.), n_D^{25} 1.4166. The physical constants reported for this glycidyl ether are: b. p. 69.7° (20 mm.), n_D^{25} 1.4150 (112).

Preparation of 2-Butoxymethyl Thirane



The thirane was prepared from the interaction of 1,2-epoxy-3-butoxypropane with either potassium thiocyanate or thicurea, according to the procedures already described for the synthesis of 2-methoxymethyl thirane. The 2-butoxymethyl thirane distilled at 80° (11 mm.), n_D^{25} 1.4679. Elemental analysis for $\text{C}_7\text{H}_{14}\text{S}$ gave the following results. Calculated: C, 56.70; H, 9.46; S, 21.70. Found: C, 56.90; H, 9.56; S, 21.90. A yield of 40% was realized when potassium thiocyanate was employed, and a 90% yield when the thicurea method was used.

Preparation of 1,2-Epoxy-3-phenoxypropane



In a 1-l. three-necked flask equipped with a Friedrichs condenser, mechanical stirrer, thermometer and dropping funnel were added, in order, the following: 95 g. (1.0 mole) of phenol dissolved in 100 ml. of dioxane, 40 g. (1.0 mole) of sodium hydride, and 185 g. (2.0 moles) of epichlorohydrin. The mixture was stirred overnight without heating and then at approximately 70-75° for eight hours. The reaction mixture was filtered, washed twice with dioxane and then distilled under reduced pressure through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices. A yield of 56.1% of phenyl glycidyl ether, distilling at 134-136° (20-22 mm.), n_D^{25} 1.5284, was obtained. In a second preparation, a 58.7% yield was realized. The literature values for this glycidyl ether are: b. p. 137-140° (23 mm.), n_D^{25} 1.5289, (2).

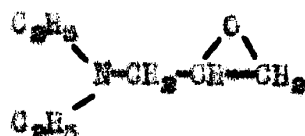
Preparation of 2-Phenoxymethyl Thiolane



The thiolane was prepared from 1,2-epoxy-3-phenoxypropane and potassium thiocyanate, utilizing the procedure previously described for the synthesis of 2-methoxymethyl thiolane. The cyclic sulfide could not be obtained by the thiourea method. The 2-phenoxyethyl thiolane distilled at 106° (1 mm.), n_D^{25} 1.5735. A yield of 61.0% was obtained.

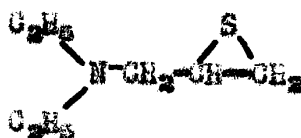
Elemental analysis for $C_9H_{15}OS$ gave the following results. Calculated: C, 65.11; H, 6.07; S, 19.31. Found: C, 65.16; H, 6.26; S, 19.33.

Preparation of 1,2-Epoxy-3-diethylaminopropane



In a 2-l. three-necked flask fitted with a sealed stirrer, dropping funnel and parallel side-arm equipped with a thermometer and dropping funnel, were placed 231 g. (2.5 moles) of commercial epichlorohydrin, 180.7 g. (2.47 moles) of redistilled diethyl amine (b. p. $55-56^\circ$), and 7.7 g. (0.43 mole) of water. The reaction mixture was stirred for five hours at $25-30^\circ$, then cooled to 20° and 120 g. (3.0 moles) of sodium hydroxide, dissolved in 200 ml. of water, was added in three quarters of an hour. The pasty solution was vigorously stirred for an additional forty minutes during which a yellow oil separated. The two layers were separated and the aqueous layer was extracted with two 100 ml. portions of ether. The organic fraction and ether extracts were combined, dried over anhydrous potassium hydroxide and the ether was removed. The crude product was fractionally distilled under reduced pressure through a 60 cm. Vigreux column. The 1,2-epoxy-3-diethylaminopropane distilled at $58-59^\circ$ (23 mm.), n_D^{20} 1.4337. A yield of 67.3% was obtained. Physical constants as reported by Gilman and Fullhart (113) for this material are: b. p. 69° (32 mm.), n_D^{20} 1.4362.

Preparation of 2-Diethylaminomethyl Thirane



In a 500 ml. three-necked flask equipped with a mechanical stirrer, dropping funnel and parallel side-arm fitted with a reflux condenser and thermometer, were placed 42 g. (0.55 mole) of thiourea and 140 ml. of methanol. The stirred contents in the reaction flask were cooled to 0-5°, and 65 g. (0.50 mole) of 1,2-epoxy-3-diethylaminopropane was added in an hour and a half. The reaction mixture was maintained at 0-5° during this period and for an additional half hour, after which it was allowed to warm, in three hours, to room temperature. The reaction mixture was poured into 300 ml. of water, and the product was extracted with four 50 ml. portions of chloroform. The combined chloroform extracts were dried over anhydrous sodium sulfate, filtered and the chloroform was removed. The residual liquid was distilled under reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The pure product distilled at 75° (11 mm.), n_D^{25} 1.4832. A yield of 60% was obtained. Elemental analysis for $C_7H_{13}NS$ gave the following results. Calculated: C, 57.93; H, 10.34; N, 10.00; S, 22.07. Found: C, 57.14; H, 10.45; N, 9.89; S, 21.96.

Preparation of 1-Ethylthiol-3-chloropropanol-2



The method used was essentially that described by Todeen, Pollard and Rietz (114). A 500 ml. three-necked flask equipped with a sealed stirrer, dropping funnel and parallel side-arm fitted with a thermometer and reflux condenser was charged with 100 ml. of anhydrous ether and 1.0 g. of fused zinc chloride. The ether was heated to reflux and a mixture composed of 31 g. (0.5 mole) of ethanethiol and 46 g. (0.5 mole) of epichlorohydrin was added dropwise to the vigorously stirred solution in a half hour. The reaction was continued for an additional nine hours. After cooling the reaction mixture to room temperature, the clear liquid was decanted from the white solid adhering to the sides of the flask and the ether was removed by simple distillation. The concentrated residue was then distilled through a 2x30 cm. column packed with 3/16 inch glass helices. A yield of 66.3%, 51 g. (0.33 mole), of product boiling at 80-82° (6-7 mm.), n_D^{25} 1.5049 was obtained. The reported physical constants for this chlorohydroxypropyl sulfide are: b. p. 69° (1.5 mm.), n_D^{25} 1.5047 (114).

Preparation of 1-Ethylthiol-2,3-epoxypropane



A modification of the procedure used by Manitzescu and Scarlatescu (115) was employed to obtain this material. In a 300 ml. three-necked

flask provided with a mechanical stirrer, reflux condenser and dropping funnel was placed 20 g. (0.36 mole) of potassium hydroxide dissolved in 50 ml. of water. To the vigorously stirred base was added dropwise, during a half hour, 34 g. (0.22 mole) of 1-ethylthiol-3-chloropropanol-2. After stirring another half hour the reaction was completed by adding 30 ml. of a 40% aqueous potassium hydroxide solution to the mixture and stirring it for another five hours. At this point, the reaction mixture consisted of two liquid phases and a small amount of solid. The desired reaction product was extracted with three 50 ml. portions of ether, dried over anhydrous sodium sulfate and the ether was removed in vacuo. The residual oil was distilled under reduced pressure through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices. A yield of 85%, 22 g. (0.19 mole), of product distilling at 60-63° (12-13 mm.), n_D^{25} 1.4771 was collected. The recorded physical constants for this compound are: b. p. 67° (15 mm.), 42° (3.5 mm.), n_D^{22} 1.4789 (115).

Attempted Preparation of 2-Ethylthiolmethyl Thiirane



The procedure used was similar to that described by Bordwell and Andersen (22) for the preparation of simple alkane sulfides. A 500 ml. three-necked flask equipped with a mechanical stirrer, dropping funnel and parallel side-arm provided with reflux condenser and thermometer, was charged with 175 ml. of water, 15 ml. (0.5 equivalent) of concentrated sulfuric acid and 40 g. (0.52 mole) of thiourea. The stirred

mixture was cooled to 0-10°, and held there while 59 g. (0.5 mole) of 1-ethylthiol-2,3-epoxypropane was added dropwise in an hour and a half. After another twenty minutes of stirring, the mixture was allowed, in three hours, to warm to room temperature. At this point a voluminous white solid had formed, which dissolved on careful neutralization of the reaction mixture with 53 g. (0.5 mole) of sodium carbonate dissolved in 250 ml. of water. The resulting solution was light pink in color, and on standing separated into two layers, which were separated. The aqueous phase was extracted with three 50 ml. portions of ether. The organic layer and combined ether extracts were dried over anhydrous sodium sulfate and the ether was removed with a water aspirator. The remaining viscous red oil when subjected to vacuum distillation, decomposed rapidly producing a black tarry mass.

Preparation of 1-Propylthiol-2,3-epoxypropane



A modification of the procedure of Nenitzescu and Scarlatescu (115) was used to obtain this material. In a 500 ml. three-necked round-bottomed flask equipped with a mechanical stirrer, reflux condenser and dropping funnel was placed a solution prepared from 34 g. (1.5 moles) of potassium hydroxide and 200 ml. of water. The stirred alkali solution was cooled to 0° and 100 g. (1.32 moles) of n-propanethiol was added dropwise to it, in forty-five minutes. After an additional hour of stirring, the solution of n-propyl mercaptide was allowed to warm to room temperature and employed in the following reaction.

In a 1-l. three-necked flask fitted with a sealed stirrer, dropping funnel and parallel side-arm holding a thermometer and reflux condenser, was placed 122.4 g. (1.32 moles) of epichlorohydrin. The n-propyl mercaptide was added dropwise to the stirred epoxide in six hours, during which the temperature of the reaction mixture was maintained at 30-40°. The mixture was stirred for an additional two hours, and then set aside overnight. The two layers which had formed were separated and the aqueous layer was extracted with three 50 ml. portions of ether. These were combined, dried over anhydrous sodium sulfate and the ether was removed by simple distillation. The residue was distilled through a two foot Vigreux column under reduced pressure, to obtain 113 g. (a 65% yield) of product having a boiling point of 78-79° (13-14 mm.), n_D^{25} 1.4745. The literature values for 1-propylthiol-2,3-epoxypropane are: b.p. 45° (2 mm.), n_D^{25} 1.4730 (114).

Attempted Preparations of 2-Propylthiolmethyl Thiirane



The following modifications of existing methods for the synthesis of thiiranes were employed without success.

A. The Method of Shrager, Stewart and Ziegler (14)

In a 500 ml. three-necked flask equipped with a mechanical stirrer, dropping funnel and parallel side-arm provided with a thermometer and reflux condenser, was placed an aqueous solution of potassium thiocyanate

(81 g., 0.83 mole in 85 ml. of water). To this vigorously stirred solution, held at 15-25°, was added dropwise, 110 g. (0.83 mole) of 1-propylthiol-2,3-epoxypropane, in an hour and a half. After stirring the reaction solution an additional five hours, the lower aqueous layer was removed by means of a pipet, and set aside. The organic layer was treated again, at room temperature, with a fresh potassium thiocyanate solution (40 g. in 85 ml. of water), for a second five hours. The two layers present, were separated and the aqueous layer was combined with the previous aqueous phase and extracted with ether. The ether extracts were combined with the organic phase, dried over anhydrous magnesium sulfate, and ether was removed in vacuo. The residue was distilled under reduced pressure through a 10 inch Vigreux column to recover 94% of the starting epoxide.

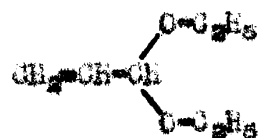
B. The Method of Culvenor, Davies and Pausacker (21)

In the apparatus described above, was placed 42 g. (0.55 mole) of thiourea and 140 cc. of methyl alcohol. The stirred mixture was cooled to 1-2° and held there while 66 g. (0.50 mole) of 1-propylthiol-2,3-epoxypropane was added dropwise to it, over the course of one hour. The reaction mixture was stirred a total of four hours after removal of the ice-bath. The reaction mixture was then poured into 300 ml. of water and the crude product extracted with three-75 ml. portions of chloroform. The extracts were dried over anhydrous sodium sulfate and the chloroform was removed in vacuo. Distillation of the viscous residue under reduced pressure was unsuccessful.

C. The Method of Borchell and Anderson (22)

In the apparatus mentioned above, were placed 175 ml. of water, 15 ml. (0.5 equiv.) of sulfuric acid and 40 g. (0.52 mole) of thiourea. The contents were cooled to 0°C. and held there, while 66 g. (0.5 mole) of 1-propylthiol-2,3-epoxypropane was added dropwise over a two hour period. The flask was kept in the ice-bath for an additional twenty minutes. At the end of this time the flask was filled with a voluminous white solid. The ice-bath was removed and the flask allowed to warm to room temperature in the course of three hours. An aqueous sodium carbonate solution (53 g., 0.5 mole in 250 ml. of water) was added over a thirty minute period. The solid dissolved, and the resulting liquid separated into two distinct layers. The layers were separated and the aqueous phase was extracted with three 50 ml. portions of ether. The combined organic phase and ether extracts were dried over anhydrous magnesium sulfate. Removal of the ether left a viscous brown residue which could not be distilled or further purified.

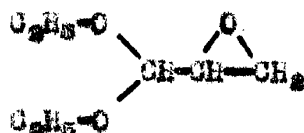
Preparation of Acrolein Diethylacetal



In a 500 ml. one-necked flask fitted with a reflux condenser, protected with a calcium chloride drying tube, were placed 44 g. (0.79 mole) of commercial acrolein and 444 g. (0.97 mole) of ethyl orthoformate. A warm solution of 3 g. of ammonium nitrate in 50 ml. of absolute

ethanol was added and the resulting solution was allowed to stand for eight hours. The reaction mixture was filtered, four grams of sodium carbonate were added to the filtrate and it was distilled directly from the sodium carbonate, through a 2x30 cm. column packed with 3/16 inch glass helices. The main fraction distilled at 120-124° (747 mm.), n_D^{25} 1.4001. A yield of 77% was realized. The literature values as reported by van Allen (117) for pure acrolein diethylacetal are: b. p. 120-125°, n_D^{25} 1.398-1.407.

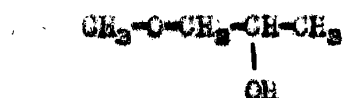
Preparation of Glycidaldehyde Diethylacetal



In a 1-l. three-necked flask equipped with a mechanical stirrer, reflux condenser, and parallel side-arm provided with a thermometer and dropping funnel, were placed 60.0 g. (0.46 mole) of acrolein diethylacetal and 200 ml. of water precooled to 0-2°C. To the vigorously stirred solution was added, in three portions, 740 ml. of hypochlorous acid solution (0.034 g./ml., 0.480 mole), prepared by the method of Wohl (130). The reaction mixture was stirred and cooled for an additional thirty minutes, and then made basic with 60.0 g. of sodium bicarbonate. The excess hypochlorous acid was destroyed with 5 ml. of 1-M sodium thiosulfate solution. The solution was saturated with sodium chloride and extracted three times with 75 ml. portions of benzene. The benzene extracts were dried over anhydrous sodium sulfate and 37 g.

(0.92 mole) of finely powdered sodium hydroxide were added. The resulting mixture was stirred for thirty minutes, heated to reflux and stirred an additional hour. The sodium chloride and sodium hydroxide were filtered out and the benzene was removed by distillation. The residual liquid was fractionated under reduced pressure, through a 2x30 cm. column packed with 3/16 inch glass helices. The product distilled at 60-62° (10 mm.), n_D^{25} 1.4125. A yield of 55% was realized. The physical constants for glycidaldehyde diethylacetal as reported by Weisblat, *et al.* (116) are: b. p. 60-64° (13 mm.), n_D^{25} 1.4128.

Preparation of 1-Methoxy-2-propanol



Into a 500 ml. three-necked flask provided with a sealed stirrer, reflux condenser and parallel side-arm fitted with a thermometer and dropping funnel, was charged 64 g. (2.0 moles) of methanol and 3 g. (0.13 g-at.) of sodium. A 69.7 g. (1.2 moles) quantity of propylene oxide was added and the reaction mixture heated until a constant reflux temperature was observed. The excess methanol was removed, and the residual liquid was distilled through a 2x40 cm. Fenske-type column packed with 3/16 inch glass helices. The pure product distilled at 118-119° (746 mm.), n_D^{25} 1.4010. Reeve and Sadle (99) reported the following physical constants for 1-methoxy-2-propanol, b. p. 118.5-119° (765 mm.), n_D^{25} 1.4017. Three separate preparations gave yields in the range 61-64%.

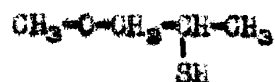
The α -naphthyl urethan was prepared and recrystallized from 60-80° petroleum ether, m. p. 71.5-73°. The reported melting point for this derivative is: 71-73° (99).

Preparation of 1-methoxy-2-bromopropane



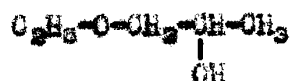
In a 250 ml. three-necked flask fitted with a mechanical stirrer, dropping funnel and parallel side-arm holding a reflux condenser and thermometer, were placed 116 g. (1.29 moles) of 1-methoxy-2-propanol. To the stirred solution was added, in two hours, 90 g. (0.33 mole) of freshly distilled phosphorous tribromide (b. p. 169-170°/742 mm.). The reaction mixture was stirred for an additional two hours and then distilled into 150 ml. of water. The oil layer was separated, washed with water until free of acid and dried over anhydrous calcium chloride. The crude product was fractionated through a 2x30 cm. column packed with 3/16 inch glass helices. The product boiled at 28-29° (20-21 mm.), 49-49.5° (60 mm.), n_D^{25} 1.4409. A yield of 13% was obtained. Elemental analysis for $\text{C}_4\text{H}_9\text{BrO}$ gave the following results. Calculated: C, 31.37; H, 6.00; Br, 52.30. Found: C, 31.57; H, 5.97; Br, 52.07.

Preparation of 1-Methoxy-2-mercapto propane



In a 250 ml. one-necked flask provided with a reflux condenser were placed 60 ml. of 95% ethanol, 12.9 g. (0.17 mole) of thiourea and 11.92 g. (0.17 mole) of 1-methoxy-2-bromopropane. The reaction mixture was refluxed for seven hours, allowed to cool to room temperature and 10 g. (0.25 mole) of sodium hydroxide dissolved in 100 ml. of water were added. The alkaline solution was refluxed for twelve hours, cooled and acidified with sulfuric acid (7 ml. of conc. in 50 ml. of water). The acid solution was washed with three 50 ml. portions of benzene. The combined benzene extracts were dried over anhydrous sodium sulfate and the benzene was removed in vacuo. The residual liquid was fractionated through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices. The product distilled at 26-27.6° (20-21 mm.), 43-43.5° (46 mm.), n_D^{25} 1.4412. The 2,4-dinitrophenyl thioether derivative melted at 79-80°. Elemental analysis for $\text{C}_{10}\text{H}_{13}\text{N}_2\text{O}_3\text{S}$ gave the following results. Calculated: C, 44.11; H, 4.41; N, 10.30; S, 11.80. Found: C, 43.91; H, 4.46; N, 10.26; S, 11.92.

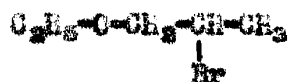
Preparation of 1-Ethoxy-2-propanol



In a 1-l. three-necked flask provided with a sealed stirrer, dropping funnel and parallel side-arm fitted with a reflux condenser

and thermometer, were placed 460 g. (10.0 moles) of absolute ethanol and 1.15 g. (0.05 g-at.) of sodium. To the stirred solution was added 116 g. (2.0 moles) of propylene oxide. The flask was heated until a constant reflux temperature was observed, allowed to cool, and the excess ethanol was then removed ~~in vacuo~~. The remaining liquid was distilled through a 240 cm. column packed with 3/16 inch glass helices. A yield of 80% of 1-ethoxy-2-propanol, distilling at 125-126° (735 mm.), n_D^{20} 1.4060, was obtained. The physical constants for this compound as reported by Chitwood and Freure (100) are: b. p. 130-130.8° (760 mm.), n_D^{20} 1.4058.

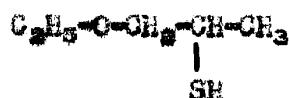
Preparation of 1-Ethoxy-2-bromopropane



In a 500 ml. three-necked flask provided with a sealed stirrer, reflux condenser and parallel side-arm holding a thermometer and dropping funnel were placed 41.6 g. (0.4 mole) of 1-ethoxy-2-propanol. The alkoxy ether was cooled to 0°C. and 108.4 g. (0.4 mole) of redistilled phosphorous tribromide were added dropwise in thirty minutes. The reaction mixture was allowed to warm to room temperature, poured onto 200 g. of ice, and the aqueous phase was separated and extracted twice with 50 ml portions of benzene. The organic layer and benzene extracts were combined, washed successively with water, 10% sodium carbonate, saturated sodium chloride solution and dried over anhydrous sodium sulfate. The benzene was removed and the residual liquid was distilled under

reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The 1-ethoxy-2-bromopropane distilled at 46-46.5° (28 mm.), n_D^{25} 1.4401, n_D^{20} 1.4419. A yield of 27% was obtained. Literature values (118), b. p. 32-34° (10-11 mm.), n_D^{20} 1.4410.

Preparation of 1-Ethoxy-2-mercaptopropane



The mercaptan was prepared in 47% yield, from the corresponding bromide, by the thiourea method, according to the procedure already described for obtaining 1-methoxy-2-mercaptopropane. The product distilled at 44° (24 mm.), n_D^{20} 1.4400. These constants are the same as those reported for the product obtained in the reduction of 2-ethoxymethyl thiazane with lithium aluminum hydride.

Preparation of 3-Ethoxypropanol-1



This compound was obtained by a modification of the procedure of Smith and Sprung (96). In a 500 ml. three-necked flask equipped with a mechanical stirrer, reflux condenser and parallel side-arm provided with a thermometer and dropping funnel, were placed 100 ml. of dry xylene and 250 g. (3.3 moles) of freshly distilled 1,3-propanediol. The solution was heated to 90° and 25 g. (1.08 g-at.) of sodium were added in small portions. Once the addition of sodium was begun, external heating was not necessary. When the sodium had reacted, the reaction

mixture was heated to reflux and 187.2 g. (1.2 moles) of redistilled ethyl iodide was added dropwise in one and a half hours. The resulting solution was reflux an additional hour, allowed to cool, and the precipitate of sodium iodide was removed by filtration. The filtrate was distilled under reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The 3-ethoxypropanol-1 distilled at 64-67° (14-16.5 mm.), n_D^{20} 1.4171. A yield of 57% was realized. The reported constants for this compound are: b. p. 155-163° (760 mm.), n_D^{20} 1.4175 (96). Anderson, *et al.* (119), report, b. p. 69-70° (22 mm.), 59-60° (12 mm.).

Preparation of 3-Ethoxy-1-bromopropane



In a 300 ml. three-necked flask provided with a sealed stirrer, reflux condenser and dropping funnel, were placed 54.2 g. (0.20 mole) of redistilled phosphorus tribromide. The reaction flask was cooled in an ice-bath and a solution of 69 g. (0.66 mole) of 3-ethoxypropanol-1 and 12 g. (0.15 mole) of pyridine was added dropwise in a half hour. The dropping funnel was replaced by a thermometer, and the reaction mixture heated to 60° for one and a quarter hours. After cooling, the liquid phase was decanted and the pyridine salts were washed several times with benzene. The benzene extracts and organic material were combined, washed successively with water, and saturated sodium bicarbonate solution and again with water. After drying over anhydrous sodium

sulfate the benzene was removed and the residual liquid was distilled under reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The 3-ethoxy-1-bromopropene distilled at 59-60.3° (30-31 mm.), n_D^{20} 1.4434. A yield of 71% was realized. The literature values for this compound are: b. p. 146-148° (760 mm.), n_D^{20} 1.4488 (120).

Preparation of 3-Ethoxy-1-mercaptopropane



The ether-mercaptan was obtained by the thiourea method, employing the following procedure. In a 500 ml. one-necked flask equipped with a reflux condenser were placed 120 ml. of 95% ethanol, 23.6 g. (0.31 mole) of thiourea and 52.3 g. (0.31 mole) of 3-ethoxy-1-bromopropene. The resulting solution was refluxed for twenty hours, allowed to cool and 20 g. (0.5 mole) of sodium hydroxide dissolved in 20 ml. of water was added. The reaction mixture was refluxed for an additional twelve hours, made acid with dilute sulfuric acid (14 ml. in 100 ml. of water) and the resulting layers were separated. The aqueous phase was washed three times with 50 ml. portions of benzene. The benzene extracts and organic layer were combined, dried over anhydrous sodium sulfate and the benzene was removed in vacuo. The residual liquid was distilled under reduced pressure through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices. The main fraction boiled at 54-56° (25-26 mm.). A yield of 47% was obtained. The boiling point of

3-ethoxy-1-mercaptopropane is reported by Gregg, Alderman and Mayo (122) to be: 55-57° (25 mm.).

Preparation of 1-Butoxy-2-propanol



In a 3-l. three-necked flask equipped with a sealed stirrer, reflux condenser and parallel side-arm provided with a thermometer and dropping funnel, with a stem extending to within a few centimeters of the stirrer, were placed 2035 g. (27.5 moles) of 1-butanol and 5 g. of sodium hydroxide. The solution was heated to 110-115° and 319 g. (5.5 moles) of propylene oxide was added dropwise in three hours. Heating of the reaction mixture was continued until a constant reflux temperature was observed. The reaction mixture was cooled to room temperature, the catalyst neutralized with dilute sulfuric acid and the excess alcohol was removed in vacuo. Fractionation of the concentrated residue under reduced pressure through a 2x60 cm. column packed with 3/16 inch glass helices afforded an 82% yield of material boiling at 73-74° (20 mm.), 60-61° (10 mm.), n_D^{20} 1.4169, n_D^{25} 1.4152. The physical constants reported for pure 1-butoxy-2-propanol are: b. p. 74-74.5° (20 mm.), n_D^{20} 1.4170 (100).

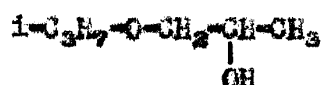
Preparation of 1-Propoxy-2-propanol



The reaction and subsequent isolation of the product were performed in the same way as previously described for the preparation of

1-ethoxy-2-propanol, except that 600 g. (10.0 moles) of 1-propanol were employed. A 78% yield of 1-propoxy-2-propanol, boiling at 148.5-150° (744 mm.), n_D^{20} 1.4132 was obtained. Literature values: b. p. 148.5-149° (730 mm.) (104), n_D^{20} 1.4130 (105).

Preparation of 1-Isopropoxy-2-propanol



The preparation of 1-isopropoxy-2-propanol was carried out by the procedure previously described for 1-butoxy-2-propanol, except that 1650 g. (27.5 moles) of 2-propanol were used, and the reaction temperature was 75-78° C. Heating of the reaction mixture was continued for twelve hours after the addition of propylene oxide was completed. A 43% yield of 1-isopropoxy-2-propanol, distilling at 135-137° (737 mm.), n_D^{20} 1.4068 was obtained. Literature values (100), b. p. 137-138° (760 mm.), n_D^{20} 1.4070.

Preparation of Butyllithium



Butyllithium was prepared just prior to use, according to the following procedure (121). In a 500 ml. three-necked flask provided with a sealed stirrer, dropping funnel and low temperature thermometer, was placed 200 ml. of anhydrous ether. After sweeping the apparatus with dry, oxygen-free nitrogen, 8.6 g. (1.23 g-at.) of lithium was cut into small pieces, rinsed with ether and added to the reaction flask.

The reaction flask and its contents were cooled to -10°C . (Dry Ice-acetone trap) and 30 to 40 drops of a solution composed of 60.5 g. (0.44 mole) of n-butyl bromide dissolved in 100 ml. of dry ether was added to initiate the reaction. This was indicated by the solution becoming turbid, and the remainder of the n-butyl bromide solution was then added dropwise in thirty minutes. The reaction mixture was allowed to warm up to $0-10^{\circ}$ in two hours and filtered by decantation through a narrow glass tube plugged with glass wool, directly into the flask, (previously flushed with dry nitrogen), used in the reactions of 2-alkoxymethyl thiiranes with n-butyllithium.

Preparation of Phenyllithium



In a 500 ml. three-necked flask provided with a dropping funnel, thermometer, mechanical stirrer and reflux condenser protected from moisture (apparatus flushed with dry oxygen-free nitrogen), were placed 3.5 g. (0.5 g-at.) of lithium metal and 100 ml. of anhydrous ether. To the stirred metal-ether suspension was added, rapidly, approximately 20 ml. of a mixture of 40 g. (0.25 mole) of redistilled bromobenzene in 50 ml. of dry ether. The reaction mixture became turbid and commenced to reflux. The remainder of the bromobenzene-ether solution was added, in an hour, and stirring was continued for another two hours to allow complete reaction of the lithium. The mixture was filtered by decantation through a narrow glass tube packed with glass wool, directly into the flask, (previously flushed with nitrogen), used in the reactions of

2-alkoxymethyl thiranes with phenyllithium. This procedure is reported to give a 95-99% yield of phenyllithium (123).

Purification of Commercial Triethyl Phosphite



Commercial triethyl phosphite was placed in a 500 ml. one-necked flask equipped with a reflux condenser protected by a calcium chloride drying tube. Several grams of sodium were added to the phosphite and it was set aside overnight. The phosphite and sodium were heated to 100° , cooled to room temperature, and the triethyl phosphite was decanted into a clean 500 ml. flask. After repeating the treatment with sodium the material was distilled under reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. Pure triethyl phosphite distilled at 57.5° (20 mm.), 55° (17 mm.). Scott (106) reports a boiling point of $54-58^\circ$ (20 mm.) for this compound.

Attempted Condensations of Alkene Sulfides with Malonic and Acetoacetic Esters

Numerous attempts were made to bring about the "alkylation" of malonic and acetoacetic ester by propylene and isobutylene sulfides. However, in all cases tried no simple monomeric addition product was isolated and only the polymerization of the sulfide was observed. The following procedures were employed.

A. In a 500 ml. three-necked flask provided with a sealed stirrer, reflux condenser and dropping funnel were placed 300 ml. of absolute

ethanol and 2.3 g. (0.1 g.-at.) of metallic sodium. After all the sodium had dissolved, 24 g. (0.15 mole) of malonic ester was added and this mixture was heated to reflux. To the vigorously stirred solution was added dropwise, 10 g. (0.12 mole) of propylene sulfide. The addition was completed in ten minutes and caused the solution to become turbid. The resulting solution was refluxed for one hour and then concentrated to about 50 ml. The concentrated solution was filtered and the filtrate poured into ice-water. No precipitate was formed. The aqueous phase was neutralized with dilute hydrochloric acid and washed with ether. The ether fraction was dried over anhydrous sodium sulfate and distilled. Diethyl malonate was the only product obtained. Similar results were obtained with malonic ester and isobutylene sulfide. When acetoacetic ester and propylene sulfide were employed in the above procedure, only polymeric propylene sulfide and recovered acetoacetic ester were obtained.

B. In a one-liter, three-necked flask equipped with a sealed stirrer and two side-arm adapters, one of which was fitted with a reflux condenser and thermometer while the other held a dropping funnel and nitrogen-inlet tube, were placed 8.6 g. (0.35 mole) of sodium hydride and 300 ml. of anhydrous ether. A slow stream of nitrogen was passed over the solution throughout the entire reaction period. To the vigorously stirred suspension of sodium hydride was added, over the course of one and a half hours, 56 g. (0.35 mole) of diethyl malonate. A gray spongy mass soon filled the one-liter flask. After an additional

twenty-five minutes of vigorous stirring, 30.8 g. (0.35 mole) of isobutylene sulfide in 100 ml. of anhydrous ether was added dropwise over a three hour period. No temperature rise was observed during this addition period, but the formation of a white solid material was observed. After all the isobutylene sulfide had been added, the nitrogen inlet tube was replaced by a ground glass stopper and the reaction mixture refluxed with stirring for four and a half hours. Fifty ml. of ethyl alcohol was added and the mixture stirred until the evolution of hydrogen had ceased. The slurry was poured onto 500 grams of ice and filtered. The filtrate was transferred to a separatory funnel and the two layers separated. The ether layer was dried over anhydrous calcium chloride, the ether removed and the concentrated residue distilled under reduced pressure. Only unreacted diethyl malonate was recovered. The water layer was made acid with dilute hydrochloric acid and extracted with ether. Evaporation of the ether left only a very small amount of a yellow oil. Isobutylene sulfide was recovered as a solid polymeric material. A second run, in which the ratio of isobutylene sulfide to malonic ester and sodium hydride was 1:2, gave similar results. Likewise, a run in which sodium hydride was slowly added to an equimolar mixture of isobutylene sulfide and malonic ester gave only polymeric isobutylene sulfide and unreacted malonic ester. The use of p-dioxane, n-butyl ether, or tetrahydrofuran as solvents also failed to promote the desired condensation reaction, and only polymeric isobutylene sulfide was isolated.

C. In a 2-l, three-necked flask equipped as above, were placed 400 ml. of "super-dry" ethanol and 13.8 g. (0.6 g.-at.) of metallic sodium added in small pieces. After all the sodium had reacted, and the flask had cooled to room temperature, 96 g. (0.6 mole) of diethyl malonate were added dropwise. Next, 17.6 g. (0.2 mole) of isobutylene sulfide in 500 ml. of "super-dry" alcohol was added. The rate of addition of the sulfide was approximately a milliliter per minute. Vigorous stirring was provided throughout the addition period. After stirring the reaction mixture for 25 hours, the apparatus was so altered that direct removal of the ethanol from the reaction flask was made possible. Subsequent work-up of the reaction mixture gave only unreacted diethyl malonate (90%) and polymerized isobutylene sulfide.

A second run carried out at the reflux temperature of ethanol also failed to yield a condensation product.

Similar results were obtained with acetoacetic ester and propylene sulfide or isobutylene sulfide.

D. A run utilizing anhydrous aluminum trichloride as the condensing agent also failed to promote the alkylation of malonic ester by isobutylene sulfide. Similarly no condensation occurred between propylene sulfide and acetoacetic ester. Once again only polymeric sulfide was isolated.

Reaction of 2-Alkoxyethyl Thiranes with Piperidine

The following experimental procedure resulted in the highest yield of monomeric addition product. In a 500 ml. two-necked flask equipped

with a reflux condenser and dropping funnel were placed 85 g. (1.0 mole) of redistilled piperidine (b. p. 104-104.5°/728 mm., n_D^{20} 1.4526) and 75 ml. of benzene. The amine solution was cooled to 0° and a chilled solution of the 2-alkoxymethyl thirane, 0.5 mole, dissolved in 75 ml. of benzene, was added in ten minutes. The reaction mixture was held at 0° for an additional hour, warmed to room temperature and was refluxed for two hours. The excess piperidine and benzene were removed in vacuo and the concentrated residue was fractionated under reduced pressure through a 40 cm. Vigreux column.

A. 2-Methoxymethyl Thirane

From 52 g. (0.5 mole) of 2-methoxymethyl thirane and 85 g. (1.0 mole) of piperidine there was obtained a 92% yield of 1-methoxy-2-mercapto-3-piperidinopropane distilling at 88-90° (2-3mm.), n_D^{20} 1.4891. Elemental analysis for $C_9H_{13}NOS$ gave the following results. Calculated: C, 57.10; H, 10.11; N, 7.40; S, 16.94. Found: C, 57.01; H, 10.03; N, 7.63; S, 16.70.

The hydrochloride was prepared by bubbling dry hydrogen chloride into an ethereal solution of the compound. The derivative was quite hygroscopic but appeared to melt at 130-132°C. Elemental analysis for $C_9H_{13}NOS \cdot HCl$ gave the following results. Calculated: C, 48.87; H, 9.00; N, 6.20; S, 14.20. Found: C, 48.02; H, 8.83; N, 6.24; S, 14.30.

Several additional preparations were carried out with 2-methoxymethyl thirane and piperidine, in which the mole ratio of reactants, time and reaction solvent were varied. The results are tabulated in Table V.

B. 2-Ethoxymethyl Thiirane

From 59 g. (0.5 mole) of 2-ethoxymethyl thiirane and 85 g. (1.0 mole) of piperidine there was obtained a 90.6% yield of 1-ethoxy-2-mercapto-3-piperidinopropane boiling at 129-131°, (20 mm.), n_D^{25} 1.4819. Elemental analysis for $C_{10}H_{21}NO_2S$ gave the following results. Calculated: C, 60.00; H, 10.34; N, 7.00; S, 16.00. Found: C, 59.98; H, 10.33; N, 7.10; S, 15.95. Yields and reaction conditions for several other preparations are listed in Table V.

Reaction of 2-Alkoxymethyl Thiiranes with Morpholine

A. 2-Methoxymethyl Thiirane

The apparatus and procedure followed were similar to those described previously for the reaction of 2-alkoxymethyl thiiranes with piperidine. The morpholine employed boiled at 126° (747 mm.). Careful fractionation of the material formed by the action of morpholine on 2-methoxymethyl thiirane gave an 80.2% yield of 1-methoxy-2-mercapto-3-morpholinopropane distilling at 35-36° (12 mm.), n_D^{25} 1.4909. Elemental analysis for $C_6H_{17}NO_2S$ gave the following results. Calculated: C, 50.21; H, 8.90; N, 7.33; S, 16.75. Found: C, 50.52; H, 8.86; N, 7.60; S, 16.41. The results of other reactions of this thiirane and morpholine are shown in Table V, along with the reaction conditions employed.

B. 2-Ethoxymethyl Thiirane

The product formed by the reaction of 59 g. (0.5 mole) of 2-ethoxymethyl thiirane with one mole of morpholine had a boiling point of 66-68°

at 15 mm., n_D^{25} 1.4838. An 81.3% yield was obtained. Elemental analysis for $C_9H_{19}N_2OS$ gave the following results. Calculated: C, 52.68; H, 9.27; S, 15.61. Found: C, 52.89; H, 9.27; S, 15.65. The yields and reaction conditions employed in other reactions of 2-ethoxymethyl thirane and morpholine are tabulated in Table V.

Reaction of 2-Ethoxymethyl Thirane with Diethylamine

This reaction was carried out in the same way as described for the reaction of 2-alkoxymethyl thiranes with piperidine. Fifty-nine grams (0.5 mole) of 2-ethoxymethyl thirane and 170 g. (2.0 moles) of redistilled diethylamine were employed. Subsequent work-up of the reaction mixture resulted in the recovery of both components, unchanged and in nearly quantitative amounts. Once again the evolution of heat was observed on mixing the two reagents, indicating that reaction did occur.

Reaction of 2-Propoxymethyl Thirane with Diethylamine

The following procedure was patterned after that employed by Ponomarev (125), for reacting methyl and ethyl glycidyl ethers with diethylamine. A 200 ml. one-necked flask fitted with a reflux condenser was charged with 37 g. (0.5 mole) of freshly distilled diethylamine and 75 ml. of water. A 20 g. (0.15 mole) quantity of 2-propoxymethyl thirane was slowly added, with frequent agitation. No temperature rise was observed. The non-homogenous reaction mixture was refluxed

for fifteen hours, transferred to a separatory funnel and potassium hydroxide pellets added. After several minutes, the layers were separated and the oil layer dried over solid potassium hydroxide. Distillation of the material through a 2x30 cm. column packed with 3/16 inch glass helices afforded 36.6 g. of recovered diethylamine and left a viscous yellow residue which could not be distilled at reduced pressures.

A second attempt was carried out, according to the above general procedure except that the use of water was omitted. In this preparation, heat was liberated on mixing the two reagents, but upon subsequent fractionation of the reaction mixture, most of the diethylamine and thiirane were recovered unchanged. A similar situation was observed by Wright (90), who allowed thioglycidaldehyde diethylacetal to react with diethylamine and reported that distillation of the reaction product resulted in recovery of the two starting materials, indicating that the amino-mercaptan readily splits out diethylamine.

Reaction of 1-Methoxy-2-mercapto-3-piperidinopropane
with Triethyl Phosphite

In a 200 ml. one-necked flask provided with a thermometer well and equipped with a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices and a variable take-off distilling head, were placed 33.2 g. (0.2 mole) of purified triethyl phosphite and 18.93 g. (0.1 mole) of 1-methoxy-2-mercapto-3-piperidinopropane. The reaction mixture was gradually heated until it reached 150°, the boiling point of triethyl

phosphite. Soon after heating was begun, low boiling material began to collect in the distilling head. Distillate was collected at such a rate that the distillate temperature remained in the range $40-44^{\circ}$. On redistillation, all of this material distilled at $41.2-41.8^{\circ}$ (739 mm.), n_D^{20} 1.3791, n_D^{25} 1.3755. The physical constants reported for methyl allyl ether are: b. p. $42.5-43^{\circ}$ (757 mm.), n_D^{20} 1.3778-1.3803 (132). A yield of 60% was obtained. The original distillation residue was fractionated under reduced pressure through the packed column. After recovery of excess triethyl phosphite, a small amount of material boiling at 135° (10 mm.) was obtained. The amidothionophosphate, $(C_2H_5O)_2PS(NEt_3)$, is reported to boil at 138° (10 mm.) (138). The majority of material could not be purified by vacuum distillation and remained in the distillation flask as a semi-solid, which was readily soluble in the common organic solvents.

Reaction of 1-Methoxy-2-mercapto-3-morpholinopropane
with Triethyl Phosphite

This reaction was conducted in the same manner as already described for 1-methoxy-2-mercapto-3-piperidinopropane and triethyl phosphite, except that equimolar quantities of triethyl phosphite and 1-methoxy-2-mercapto-3-morpholinopropane were employed, and the pot temperature was allowed to reach $173^{\circ}C$. A yield of 57% of methyl allyl ether was obtained. The thick brown pot residue could not be distilled under vacuum.

Reaction of 1-Ethoxy-2-mercapto-3-piperidinopropane
with Triethyl Phosphite

This reaction and subsequent work-up were carried out according to experimental procedures already described. From an equimolar mixture of 1-ethoxy-2-mercapto-3-piperidinopropane and triethyl phosphite there was obtained a 53% yield of ethyl allyl ether boiling at 65-66° (739 mm.), n_D^{25} 1.3887. The reported constants for this ether are: b. p. 66-67° at 743 mm. (128), n_D^{25} 1.3892 (131). The viscous semi-solid pot residue could not be distilled under reduced pressure.

Reaction of 1-Ethoxy-2-mercapto-3-morpholinopropane
with Triethyl Phosphite

An equimolar mixture of 1-ethoxy-2-mercapto-3-morpholinopropane and triethyl phosphite was distilled employing the experimental procedure described above. A yield of 47% of ethyl allyl ether boiling at 65-66° (741 mm.), n_D^{25} 1.3889 was obtained. Literature values, b. p. 66-67° at 743 mm. (128), n_D^{25} 1.3892 (131). Attempted distillation of the viscous brown colored residue under vacuum was unsuccessful.

Reaction of 2-Methoxymethyl Thiirane
with Bromine

This reaction was carried out according to the method developed by Stewart and Cordts (81). In a 200 ml. three-necked flask equipped with a sealed stirrer, reflux condenser and dropping funnel was placed 10.4 g. (0.10 mole) of 2-methoxymethyl thiirane dissolved in 25 ml. of carbon

tetrachloride. To the chilled solution was added, in one hour, 8 g. (0.1 gram.) of bromine dissolved in 25 ml. of carbon tetrachloride. The reaction mixture was transferred to a separatory funnel and washed twice with 100 ml. portions of 5% sodium carbonate solution and once with water. After drying over anhydrous calcium chloride, the carbon tetrachloride was removed in vacuo and the concentrated residue was subjected to vacuum distillation, whereupon the material rapidly decomposed. A similar situation has recently been reported by Stewart and Burnside (92), who observed that the product resulting from the action of bromine on trimethylene sulfide decomposed upon attempted purification by vacuum distillation.

Reaction of 2-Ethoxymethyl Thiirane with Bromine

A solution containing 20 g. (0.17 mole) of 2-ethoxymethyl thiirane dissolved in 50 ml. of chloroform was placed in a 250 ml. three-necked flask equipped with a reflux condenser, sealed stirrer and dropping funnel. To the vigorously stirred solution was added, at 0°C., in one and a half hours, 13.6 g. (0.17 mole) of bromine dissolved in 50 ml. of chloroform. The reaction mixture was stirred for an additional two hours and worked-up as described previously for the reaction of 2-methoxymethyl thiirane with bromine. Attempted purification of the crude reaction product, by vacuum distillation resulted in decomposition of this material.

Reaction of 2-Methoxymethyl Thiirane with Lithium Aluminum
Hydride--Preparation of 1-Methoxy-2-mercapto propane

The procedure employed for the reduction of 2-alkoxymethyl thiiranes by lithium aluminum hydride was patterned after that of Bordwell, Andersen and Pitt (16). A typical preparation follows. In a 1-l. three-necked flask fitted with a mechanical stirrer, dropping funnel and parallel side-arm equipped with a reflux condenser and thermometer, were placed 5.7 g. (0.15 mole) of lithium aluminum hydride and 200 ml. of anhydrous ether. To the vigorously stirred suspension was added, in one hour, a solution of 31.2 g. (0.30 mole) of 2-methoxymethyl thiirane in 70 ml. of anhydrous ether. The stirred reaction mixture was held at its reflux temperature for an additional two hours, cooled to room temperature and 300 ml. of water carefully added. A 150 ml. quantity of 10% sulfuric acid was then added to dissolve the aluminum hydroxide. The ether layer was separated and the aqueous layer was extracted twice with 75 ml. portions of ether. The ether fractions were combined, washed with small portions of water until neutral, dried over anhydrous sodium sulfate and the ether was removed in vacuo. The residual liquid was distilled under reduced pressure through a 2x30 cm. column packed with 3/16 inch glass helices. The main fraction distilled at 32-33° (27 mm.), n_D^{25} 1.4411. The yield was 85%, based on the thiirane used. A second preparation afforded an 87% yield. Elemental analysis for $C_4H_{10}OS$ gave the following results. Calculated: C, 45.28; H, 9.43; S, 30.18. Found: C, 45.40; H, 9.63; S, 30.38. A small amount of solid polymeric material, and higher boiling liquid were also produced in this

reaction. A molecular weight determination on the high boiling liquid indicated a value of 224.

**Reaction of 2-Ethoxymethyl Thirane with Lithium Aluminum
Hydride--Preparation of 1-Ethoxy-2-mercapto propane**

The experimental procedure employed in the reduction of 2-ethoxymethyl thirane, was the same as that already described for the reduction of 2-methoxymethyl thirane. A 35.4 g. (0.30 mole) quantity of 2-ethoxymethyl thirane and 5.7 g. (0.15 mole) of lithium aluminum ²⁵hydride were employed. The reduction product distilled at 45-46° (25 mm.), ²⁵ n_D^{25} 1.4379. A 77% yield of 1-ethoxy-2-mercapto propane was obtained. Elemental analysis for C_3H_7OS gave the following results. Calculated: C, 50.00; H, 10.00; S, 26.50. Found: C, 49.95; H, 9.92; S, 26.43. A somewhat greater amount of higher boiling material was produced in this reaction. Some solid polymeric material was also observed.

**Reaction of 2-Propoxymethyl Thirane with Lithium Aluminum
Hydride--Preparation of 1-Propoxy-2-mercapto propane**

In a 300 ml. three-necked flask, equipped as previously described, were placed 100 ml. of absolute ether and 2.3 g. (0.06 mole) of lithium aluminum hydride. A 17 g. (0.12 mole) quantity of 2-propoxymethyl thirane dissolved in 30 ml. of anhydrous ether was added, in forty minutes, to the metal hydride suspension. The reaction mixture was heated under reflux for an additional two hours, cooled to room temperature and 200 ml. of water carefully added. A 200 ml. quantity of 10% sulfuric acid

was then added and the organic layer was separated. The aqueous phase was extracted with three 25 ml. portions of ether. The ether extracts and organic layer were combined, dried over anhydrous sodium sulfate, and the ether was removed *in vacuo*. The 1-propoxy-2-mercaptopropane distilled at 49° (13 mm.), n_D^{25} 1.4390. A yield of 78% was realized. Elemental analysis for $C_5H_{10}OS$ gave the following results. Calculated: C, 53.77; H, 10.53; S, 23.88. Found: C, 53.75; H, 10.54; S, 23.81.

Reaction of 2-Butoxymethyl Thirane with Lithium Aluminum
Hydride--Preparation of 1-Butoxy-2-mercaptopropane

Reduction of 25 g. (0.17 mole) of 2-butoxymethyl thirane with 3.4 g. (0.09 mole) of lithium aluminum hydride, by experimental techniques already described, resulted in the formation of 1-butoxy-2-mercaptopropane in 74% yield. The reduction product distilled at 66° (13 mm.), n_D^{25} 1.4415. Elemental analysis for $C_7H_{14}OS$ gave the following results. Calculated: C, 57.00; H, 10.81; S, 21.70. Found: C, 56.95; H, 10.92; S, 21.88. Several grams of a high boiling liquid were also produced.

Reaction of 1-Alkoxy-2-mercaptopropanes
with 2,4-Dinitrochlorobenzene

The reaction was carried out according to the procedure of Best, Turner and Norton (101). Only 1-methoxy-2-mercaptopropane yielded a crystalline compound. A typical preparation follows. To 30 ml. of absolute ethanol in a 100 ml. flask was added a 0.01 mole quantity of

the liquid mercaptan and 0.4 g. (0.01 mole) of sodium hydroxide dissolved in 3 ml. of water. In a second 100 ml. flask, containing 10 ml. of absolute ethanol, was placed 2.02 g. (0.01 mole) of 2,4-dinitrochlorobenzene. The two alcoholic solutions were combined and the resulting solution was heated under reflux for fifteen minutes, filtered hot and the filtrate was reduced in volume. After cooling, the yellow crystals were collected on a filter and recrystallized from absolute ethanol. The solid derivative of 1-methoxy-2-mercaptopropane melted at 79-80°C. Elemental analysis for $C_{10}H_{13}N_2O_5S$ gave the following results. Calculated: C, 44.11; H, 4.41; S, 11.80; N, 10.30. Found: C, 43.91; H, 4.46; S, 11.92; N, 10.26. Similar treatment of 1-ethoxy, 1-propoxy and 1-butoxy-2-mercaptopropanes resulted in the formation of orange colored oils which could not be induced to crystallize.

Attempts to React 1-Alkoxy-2-mercaptopropanes with 3-Nitrophthalic Anhydride

In a Pyrex test tube were placed 1.93 g. (0.01 mole) of 3-nitrophthalic anhydride and 0.015 mole of the 1-alkoxy-2-mercaptopropane. The reaction mixture was heated over a free flame for about 30 seconds and allowed to cool. Twenty drops of a 10% solution of sodium hydroxide were added in small portions. The tube was shaken vigorously between additions of the base and subsequently. The reaction mixture quickly assumed an oily consistency. Ten drops of a 5% hydrochloric acid solution were added and the test tube was shaken vigorously. The semi-solid material was dried on a porous plate. Attempted crystallizations from

aqueous acetone or dilute acetic acid, according to the directions of Wertheim (102), failed. The following 1-alkoxy-2-mercaptopropanes were employed: 1-ethoxy, 1-propoxy and 1-butoxy-2-mercaptopropanes.

Attempts to React 1-alkoxy-2-mercaptopropanes
with 3,5-Dinitrobenzoyl Chloride

In a Pyrex test tube were placed 2.3 g. (0.01 mole) of 3,5-dinitrobenzoyl chloride and 0.015 mole of the 1-alkoxy-2-mercaptopropane. Four drops of pyridine were added to catalyze the reaction. The test tube was gently heated from time to time, until the fumes of hydrogen chloride ceased to appear (about fifteen minutes). Five drops of water were added to the test tube, and then pyridine was added dropwise until the odor indicated an excess of this reagent. Upon vigorous stirring, the reaction mixture became viscous but did not solidify. The material was placed on a filter, washed with water and was transferred to a porous plate. The product failed to crystallize. Several attempts to bring about crystallization from dilute ethanol or dilute acetic acid, according to the procedure of Wertheim (102), also failed. The following 1-alkoxy-2-mercaptopropanes were employed: 1-ethoxy, 1-propoxy and 1-butoxy-2-mercaptopropanes.

Attempts to Prepare the Mercaptoacetaldehyde Dinitrophenyl-
hydrazones of the 1-alkoxy-2-mercaptopropanes

The following procedure is patterned after that of Snyder, Stewart and Ziegler (14). In a 100 ml. one-necked flask equipped with a reflux condenser, were placed 20 ml. of absolute ethanol and 0.023 g. (0.01 mole)

of sodium. To this solution was added 0.01 mole of the 1-alkoxy-2-mercaptopropane followed by 1.5 g. (0.01 mole) of diethyl monochloroacetal. The reaction mixture was heated under reflux for four to five hours. The end of the reaction was indicated by the clarification of the solution, which remained cloudy during the precipitation of sodium chloride. The precipitated salt was collected on a Hirsch funnel and was washed several times with small portions of absolute ethanol. The combined filtrate and washings were treated with 10 ml. of water and acidified to congo-red paper with concentrated hydrochloric acid. The acidified solution was evaporated on the steam-bath, to obtain an orange-red oil. This oil was taken up in ether and washed with water and sodium bicarbonate solution. After removal of the ether, the crude mercaptoacetaldehyde was obtained as an orange-red oil. An attempt to prepare the 2,4-dinitrophenylhydrazone, by means of the procedure of Shriner and Fuson (126), failed to yield a crystalline product. The following 1-alkoxy-2-mercaptopropanes were used: 1-ethoxy-2-mercaptopropane, 1-propoxy-2-mercaptopropane and 1-butoxy-2-mercaptopropane.

Reaction of 1,2-Epoxy-3-methoxypropane with Lithium Aluminum
Hydride--Preparation of 1-Methoxy-2-propanol

In a 500 ml. three-necked flask provided with a sealed stirrer, reflux condenser and dropping funnel were placed 4 g. (0.1 mole) of lithium aluminum hydride and 100 ml. of anhydrous ether. A solution of 26.4 g. (0.3 mole) of 1,2-epoxy-3-methoxypropane dissolved in 60 ml. of absolute ether was added in three-quarters of an hour. Vigorous

refluxing was observed throughout the addition period. The reaction mixture was stirred and refluxed for an additional three hours, and then 25 ml. of water was carefully added. The resulting liquid was decanted and the solid material was washed three times with 30 ml. portions of ether. The original liquid and ether extracts were combined, dried over anhydrous sodium sulfate and the ether was removed in vacuo. The concentrated residue was distilled through a 2x40 cm. Fenske-type column packed with 3/16 inch glass helices. A 74% yield of material boiling at 118-118.5° (747 mm.), n_D^{25} 1.4010 was obtained. The reported values for 1-methoxy-2-propanol are: b. p. 118.5-119° (765 mm.) n_D^{25} 1.4017 (99). The α -naphthyl urethan was prepared and recrystallized from 60-80° petroleum ether, m. p. 71.5-73°C. The mixed melting point with the α -naphthyl urethan of the known 2-methoxy-2-propanol obtained from the alkaline catalyzed condensation of methanol and propylene oxide showed no depression.

Reaction of 1,2-Epoxy-3-ethoxypropane with Lithium Aluminum
Hydride--Preparation of 1-Ethoxy-2-propanol

This reduction was carried out in the same manner as described for the reaction of 1,2-epoxy-3-methoxypropane and lithium aluminum hydride, except that 5.7 g. (0.15 mole) of the hydride and 30.6 g. (0.30 mole) of 1,2-epoxy-3-ethoxypropane were employed. A 78.3% yield of 1-ethoxy-2-propanol was obtained, b. p. 128-129° (735 mm.), n_D^{25} 1.4041, n_D^{20} 1.4060. The physical constants reported for this compound are: b. p. 130-130.8°, n_D^{20} 1.4058 (100). The infrared spectrum of the

reduction product and that of the condensation product from the alkaline catalyzed reaction of ethanol with propylene oxide were identical.

Reaction of 1,2-Epoxy-3-propoxypropane with Lithium Aluminum Hydride--Preparation of 1-Propoxy-2-propanol

This reaction was carried out as previously described except that 39.1 g. (0.3 mole) of 1,2-epoxy-3-propoxypropane were employed. A 70.5% yield of the reduction product, boiling at 147-148° (747 mm.), n_D^{20} 1.4128, was obtained. The reported physical constants for 1-propoxy-2-propanol are: b. p. 148.5-149° at 730 mm. (104), n_D^{20} 1.4130 (105). The infrared spectrum of this material and that for the product isolated from the alkaline catalyzed condensation of 1-propanol with propylene oxide were identical.

Reaction of 1,2-Epoxy-3-isopropoxypropane with Lithium Aluminum Hydride--Preparation of 1-Isopropoxy-2-propanol

From the reduction of 39.6 g. (0.30 mole) of 1,2-epoxy-3-isopropoxypropane with 5.7 g. (0.15 mole) of lithium aluminum hydride, by experimental procedures already described, there was obtained a 57% yield of 1-isopropoxy-2-propanol, boiling at 135-137° (741 mm), n_D^{20} 1.4067. The reported values for these constants are: b. p. 137-138° (760 mm.), n_D^{20} 1.4070 (100). The infrared spectrum of this material and that for the product isolated from the alkaline catalyzed condensation of 2-propanol with propylene oxide were identical. A considerable amount of viscous high boiling material was also formed in this reaction.

Reaction of 1,2-Epoxy-3-butoxypropane with Lithium Aluminum
Hydride--Preparation of 1-Butoxy-2-propanol

The reduction of 13.7 g. (0.30 mole) of 1,2-epoxy-3-butoxypropane with 5.7 g. (0.15 mole) of lithium aluminum hydride, by experimental techniques previously described, resulted in the formation of 1-butoxy-2-propanol in 80.1% yield. The compound distilled at 73-75° (20 mm.), n_D^{20} 1.4169, n_D^{25} 1.4152. The physical constants reported for 1-butoxy-2-propanol are: b. p. 74-74.5° (20 mm.), n_D^{20} 1.4170 (100). The infrared spectrum of this material and that for the product obtained from the alkaline catalyzed condensation of 1-butanol with propylene oxide were identical.

Reaction of 2-alkoxymethyl Thiiranes
with Methyl Iodide

The most satisfactory results were obtained when the following procedure was utilized. In a 300 ml. one-necked flask equipped with a reflux condenser and calcium chloride drying tube, were placed 0.05 mole of the 2-alkoxymethyl thiirane and 1.5 moles of freshly distilled methyl iodide. Mild agitation was provided from time to time by a magnetic stirrer. The reaction mixture was allowed to stand for two weeks, filtered and the residue washed several times with acetone. After one recrystallization from absolute ethanol, the material melted at 215°C. The melting point reported for trimethylsulfonium iodide is: 215°C. (15). No success met attempts to isolate the 1,2-diiodo-3-alkoxypropane, which presumably is the other product formed in this reaction. In each

case, after removal of the excess methyl iodide, distillation of the residual liquid under reduced pressures resulted in rapid and extensive decomposition.

A. 2-Methoxymethyl Thirane

A 71% yield of trimethylsulfonium iodide was isolated from the reaction of 5.2 g. (0.05 mole) of 2-methoxymethyl thirane and 213 g. (1.5 moles) of methyl iodide. When the reaction time was limited to one week, a 57% yield was obtained. Employing a mole ratio of 3.5 of methyl iodide to 2-methoxymethyl thirane, and a two week reaction period gave only a 23% yield of the trimethylsulfonium iodide.

B. 2-Ethoxymethyl Thirane

In a similar fashion, a 72% yield of trimethylsulfonium iodide was obtained from the reaction of 5.9 g. (0.05 mole) of 2-ethoxymethyl thirane and 213 g. (1.5 moles) of methyl iodide. A second preparation, employing the same quantities of reagents, resulted in a 56% yield of the iodide, when the reaction mixture was worked-up at the end of one week. By employing a two week reaction period and a mole ratio of 3.0 of methyl iodide to 2-ethoxymethyl thirane lowered the yield to 18% of theory. A 22% yield of trimethylsulfonium iodide was obtained from a reaction using a mole ratio of 3.5 and a reaction period of one week.

C. 2-Propoxymethyl Thirane

From 6.6 g. (0.05 mole) of 2-propoxymethyl thirane and 213 g. (1.5 moles) of methyl iodide there was obtained a 66% yield of

trimethylsulfonium iodide. When the mole ratio of methyl iodide to 2-propoxymethyl thirane was decreased to 3.5, and the reaction time to one week, the yield of the iodide fell to 22% of theory.

D. 2-Isopropoxymethyl Thirane

From 6.6 g. (0.05 mole) of 2-isopropoxymethyl thirane and 213 g. (1.5 moles) of methyl iodide there was obtained a 67% yield of trimethylsulfonium iodide. Lowering the mole ratio of methyl iodide to 2-isopropoxymethyl thirane to 3.5, lowered the yield of trimethylsulfonium iodide to 20% of theory.

E. 2-Butoxymethyl Thirane

From 7.3 g. (0.05 mole) of 2-butoxymethyl thirane and 213 g. (1.5 moles) of methyl iodide there was formed a 65% yield of trimethylsulfonium iodide. A mole ratio of 3.5 of methyl iodide to 2-butoxymethyl thirane resulted in an 18% yield of the sulfonium iodide.

Reaction of 2-Butoxymethyl Thirane with Butyllithium

In a 500 ml. three-necked flask equipped with a sealed stirrer, reflux condenser and dropping funnel, was placed an ether solution of *n*-butyllithium, prepared by the method of Gilman, *et al.* (124), from 60.0 g. (0.44 mole) of *n*-butyl bromide and 8.6 g. (1.23 g-at.) of lithium. To the stirred solution was added, in forty minutes, 26.28 g. (0.18 mole) of 2-butoxymethyl thirane dissolved in 30 ml. of anhydrous ether. The reaction mixture was stirred an additional three

hours, set aside overnight and then poured into an equal volume of ice-water and the ether layer separated. The ether layer was washed twice with 50 ml. portions of 2-N sodium hydroxide solution and the washings were combined with the aqueous phase. The ether phase was then washed with small portions of water, till neutral, dried over Drierite and the ether was removed. The residual liquid was fractionated under reduced pressure through a 2x30 cm. Fenske-type column packed with 3/16 inch glass helices. The main fraction distilled at 114-116° (741 mm.), n_D^{20} 1.4053. The physical constants reported for butyl allyl ether are: b.p. 117.8-118° (763 mm.), n_D^{20} 1.4057 (124). A yield of 77% was realized.

The aqueous phase was acidified with concentrated hydrochloric acid to precipitate 1-butanethiol as an oil, which was separated. The aqueous phase was washed three times with 25 ml. portions of pentane, the pentane extracts combined with the oil and dried over Drierite. Subsequent distillation through an 18 inch Vigreux column afforded an 81% yield of 1-butanethiol, boiling at 94-96° (747 mm.). The latter was characterized as n-butyl-2,4-dinitrophenyl sulfide, m.p. 66-67.5°. The reported boiling point of 1-butanethiol is, 95-97° at 760 mm. (16). The melting point of the above derivative is reported to be, 66-68° (16).

Reaction of 2-Butoxyethyl Thirane with Phenyllithium

This reaction and the subsequent work-up were performed in a manner identical to that described above for the reaction of n-butyllithium

with 2-butoxymethyl thirane, except that 40.0 g. (0.25 mole) of bromobenzene and 3.5 g. (0.50 g.-at.) of lithium were used to prepare the required phenyllithium. Butyl allyl ether, b. p. 114-116° (741 mm.), n_D^{20} 1.4054, was obtained in 74% yield. The other product of this reaction, thiophenol, was obtained in 83% yield, b. p. 70-73° (33 mm.), and was characterized as the 2,4-dinitrophenyl phenyl sulfide, m.p. 119-121°. The reported melting point for this derivative is 119-121° (16).

Reaction of 2-Isopropoxymethyl Thirane with Butyllithium

This reaction and the subsequent product isolation were carried out according to the experimental procedure previously described for 2-butoxymethyl thirane and butyllithium. From 23.76 g. (0.18 mole) of 2-isopropoxymethyl thirane and an ether solution of butyllithium, prepared from 60 g. (0.44 mole) of n-butyl bromide and 8.6 g. (1.23 g.-at.) of lithium, there was obtained a 53% yield of isopropyl allyl ether, boiling at 80-82° (741 mm.). This ether is reported to distill at 82-83° (730 mm.) (130). The other reaction product, 1-butanethiol, was obtained in a 74% yield.

Reaction of 2-Isopropoxymethyl Thirane and Phenyllithium

The reaction of 23.76 g. (0.18 mole) of 2-isopropoxymethyl thirane with a phenyllithium solution, prepared from 40 g. (0.25 mole) of bromobenzene and 3.5 g. (0.50 g.-at.) of lithium, resulted in a 53%

yield of isopropyl ether and a 71% yield of thiophenol. The isopropyl allyl ether distilled at 82-84° (741 mm.). The reported boiling point is 82-83° at 730 mm. (130).

Reaction of 2-Propoxymethyl Thirane with Butyllithium

A 67% yield of n-propyl allyl ether and a 78% yield of 1-butane-thiol were obtained from the reaction of 23.76 g. (0.18 mole) of 2-propoxymethyl thirane with n-butyllithium, prepared from 60 g. (0.44 mole) of n-butyl bromide and 8.6 g. (1.23 g.-at.) of lithium, employing experimental techniques already described. The n-propyl allyl ether distilled at 90-91° (743 mm.), n_D^{20} 1.3917. The literature values for this ether are: b. p. 90-92° (760 mm.), n_D^{20} 1.3919 (129).

Reaction of 2-Propoxymethyl Thirane with Phenyllithium

Reaction of 23.76 g. (0.18 mole) of 2-propoxymethyl thirane with an ether solution of phenyllithium, prepared from 40.0 g. (0.25 mole) of bromobenzene and 3.5 g. (0.5 g.-at.) of lithium, employing experimental techniques already described, resulted in the formation of n-propyl allyl ether in 70% yield. The ether distilled at 89-91° (737 mm.), n_D^{20} 1.3920. This compound is reported to boil at 90-92° (760 mm.), n_D^{20} 1.3919 (129). The other product from this reaction, thiophenol, was obtained in an 86% yield.

Reaction of 2-Ethoxymethyl Thirane
with Butyllithium

From 21.24 g. (0.18 mole) of 2-ethoxymethyl thirane and an ether solution of butyllithium, prepared from 60 g. (0.44 mole) of n-butyl bromide and 8.6 g. (1.23 g.-at.) of lithium there was isolated a 47% yield of ethyl allyl ether and an 84% yield of 1-butanethiol. The ethyl allyl ether distilled at 66-67° (747 mm.), n_D^{25} 1.3892. The reported values for ethyl allyl ether are b. p. 66-67° at 743 mm. (128), n_D^{25} 1.3892 (131).

Reaction of 2-Ethoxymethyl Thirane
with Phenyllithium

The reaction of 21.24 g. (0.18 mole) of 2-ethoxymethyl thirane with an ether solution of phenyllithium, obtained from 40 g. (0.25 mole) of bromobenzene and 3.5 g. (0.50 g.-at.) of lithium, resulted in a 42% yield of ethyl allyl ether and an 81% yield of thiophenol. The ethyl allyl ether distilled at 66-67° (745.3 mm.).

Reaction of 2-Methoxymethyl Thirane
with Butyllithium

A 70% yield of 1-butanethiol was isolated from the reaction of 20.8 g. (0.20 mole) of 2-methoxymethyl thirane with an ether solution of butyllithium, obtained from 60 g. (0.44 mole) of n-butyl bromide and 8.6 g. (1.23 g.-at.) of lithium. Due to the low boiling point of the methyl allyl ether, and the experimental procedure employed, only a

trace of methyl allyl ether was isolated, b. p. 42° (746.5 mm.), n_D^{20} 1.3786. The literature values for this ether are reported as: b. p. $42.5-43^{\circ}$ at 757 mm., n_D^{20} 1.3778-1.3803 (132).

Reaction of 2-Methoxymethyl Thiirane
with Phenyllithium

From the reaction of 20.8 g. (0.20 mole) of 2-methoxymethyl thiirane with an ether solution of phenyllithium, prepared from 40 g. (0.25 mole) of bromobenzene and 3.5 g. (0.5 g.-at.) of lithium, there was obtained a 74% yield of thiophenol. Due to the high volatility of methyl allyl ether, and the experimental procedure employed, no methyl allyl ether was actually isolated.

Reaction of 2-Chloromethyl Thiirane
with Triethyl Phosphite

In a 150 ml. one-necked flask equipped with a thermometer well, was placed a mixture composed of 33.2 g. (0.20 mole) of purified triethyl phosphite and 21.6 g. (0.20 mole) of 2-chloromethyl thiirane. The flask was fitted with a 1x30 cm. Fenske-type column packed with 3/16 inch glass helices, and a variable reflux distilling head. The reaction mixture was slowly distilled at atmospheric pressure, removing distillate at such a rate that the distillate temperature remained in the range $45-46^{\circ}\text{C}$. At the end of a five hour period, the temperature of the residual material remaining in the distillation flask had reached 130°C . At this point 14.8 g. (0.195 mole) of allyl chloride had been obtained

as distillate. Redistillation of the chloride gave 14.6 g. (0.19 mole), a 95% yield, of pure allyl chloride, b. p. 44.8-45° (741.4 mm.), n_D^{25} 1.4116. The literature values for this chloride are: b. p. 44.7-44.8° (760 mm.), n_D^{25} 1.4116, (133). Distillation of the colorless liquid residue in the distillation flask, under reduced pressure, afforded 39.6 g. (0.20 mole) of triethyl thionophosphate distilling at 82-83° (5 mm.), n_D^{25} 1.4460, n_D^{20} 1.4481. The reported physical constants of this thionophosphate are: b. p. 45° (0.5 mm.), 105-106° (20 mm.), n_D^{25} 1.4461, n_D^{20} 1.4480, (108). Thus a quantitative yield of triethyl thionophosphate was obtained. When the original distillation residue was heated above 180°, or kept at about that temperature for long periods of time, the liquid became dark colored and subsequent distillation failed to give quantitative yields of triethyl thionophosphate. The best results were obtained when triethyl phosphite was employed in excess. A possible explanation of this result is found in the work of Emmett and Jones (110), who observed that thionophosphates readily undergo thermal isomerization to phosphorothiolates.

Reaction of 2-Methyl Thirane with Triethyl Phosphite

A mixture composed of 14.8 g. (0.20 mole) of 2-methyl thirane and 33.2 g. (0.20 mole) of triethyl phosphite was distilled, employing the apparatus and experimental procedure described for the reaction of 2-chloromethyl thirane with triethyl phosphite, except that bromine-carbon tetrachloride trays (two) were installed to collect any propylene

gas liberated. At the end of three hours of distillation, the temperature of the residue had reached $180^{\circ}\text{C}.$, at which point heating was discontinued. Vacuum distillation of the liquid residue gave 39.2 g. (0.199 mole), a 99% yield, of pure triethyl thionophosphate. Treatment of the material in the bromine-carbon tetrachloride traps, following standard procedures, afforded a 97% yield of 1,2-dibromopropane, b. p. 137° (734.6 mm.), n_{D}^{20} 1.5193. The literature values for this dibromide are: b. p. $139-142^{\circ}$ (760 mm.), n_{D}^{20} 1.5194 (134).

Reaction of Thirane (Ethylene Sulfide)
with Triethyl Phosphite

The experimental procedure followed in this reaction was the same in every respect as that followed in the desulfurization of 2-methyl thirane (propylene sulfide). A 24 g. (0.40 mole) quantity of ethylene sulfide and 66.4 g. (0.40 mole) of triethyl phosphite were employed. Triethyl thionophosphate was isolated in 94% yield. Treatment of the material in the bromine-carbon tetrachloride traps, following standard procedures, afforded a 91% yield of ethylene dibromide, b. p. $30-32^{\circ}$ (10-11 mm.), n_{D}^{20} 1.5380. The recorded values for this dibromide are: b. p. 34° (14 mm.), n_{D}^{20} 1.53789 (135).

Reaction of 2-Methoxymethyl Thirane
with Triethyl Phosphite

Distillation of a mixture containing 20.8 g. (0.20 mole) of 2-methoxymethyl thirane and 33.2 g. (0.20 mole) of triethyl phosphite, by experimental techniques already described, gave a 94% yield of methyl

allyl ether, b. p. 42° at 746.5 mm., n_D^{20} 1.3786. The reported physical constants for methyl allyl ether are: b. p. $42.5-43^{\circ}$ at 757 mm., n_D^{20} 1.3778-1.3803 (132). The other product in this reaction, triethyl thionophosphate, was obtained in 96% yield.

Reaction of 2-Ethoxymethyl Thiirane with Triethyl Phosphite

Distillation of a mixture composed of 23.6 g. (0.2 mole) of 2-ethoxymethyl thiirane and 33.2 g. (0.2 mole) of triethyl phosphite, by experimental techniques already described, resulted in the formation of ethyl allyl ether, b. p. 67° at 742 mm., n_D^{25} 1.3892. The literature values for this ether are: b. p. 66.67° at 743 mm. (128), n_D^{25} 1.3892 (131). A 96% yield was obtained. The other product in this reaction, triethyl thionophosphate was isolated in 98% yield.

Reaction of 2-Propoxymethyl Thiirane with Triethyl Phosphite

Distillation of a mixture composed of 26.4 g. (0.2 mole) of 2-propoxymethyl thiirane and 33.2 g. (0.2 mole) of triethyl phosphite, by experimental techniques previously described, gave a 93% yield of propyl allyl ether, b. p. 90° at 739.8 mm., n_D^{25} 1.3941, n_D^{20} 1.3968. The reported constants are: b. p. $90-92^{\circ}$, n_D^{20} 1.3919 (129). Triethyl thionophosphate was isolated in 97% yield.

Reaction of 2-Isopropoxymethyl Thiirane
with Triethyl Phosphite

A mixture composed of 26.4 g. (0.2 mole) of 2-isopropoxymethyl thiirane and 33.2 g. (0.2 mole) of redistilled triethyl phosphite was distilled according to the experimental procedure described for 2-propoxymethyl thiirane. A 91% yield of isopropyl allyl ether was obtained, b. p. 81-83° at 741 mm. The boiling point of this ether is reported as 82-83° at 730 mm., (130). Triethyl thionophosphate was obtained in 95% yield.

Reaction of 2-Butoxymethyl Thiirane
with Triethyl Phosphite

Distillation of a mixture composed of 29.2 g. (0.2 mole) of 2-butoxymethyl thiirane and 33.2 g. (0.2 mole) of redistilled triethyl phosphite, by previously described procedures, resulted in the formation of n-butyl allyl ether b. p. 116° at 740 mm., n_D^{20} 1.4053. A 97% yield of the ether was realized. The literature values for this ether are: b. p. 117.8-118° at 763 mm., n_D^{20} 1.4057 (124). The other product of this reaction, triethyl thionophosphate was obtained in 100% yield.

Reaction of 2-Phenoxymethyl Thiirane
with Triethyl Phosphite

The procedure followed in this reaction was similar to that described for 2-methoxymethyl thiirane and triethyl phosphite, except that the distillation was run at 20-22 mm. pressure. A 16.6 g. (0.1 mole) quantity of 2-phenoxymethyl thiirane and 16.6 g. (0.1 mole) of

triethyl phosphite were employed. Phenyl allyl ether, b. p. 89° at 22 mm. was isolated in 73% yield. The recorded boiling point is 85° at 19 mm. (142). The other product of this reaction, triethyl thionophosphate was obtained in 77% yield. A considerable amount of polymeric material was also formed in the reaction.

Reaction of Cyclohexane Sulfide with Triethyl Phosphite

A solution of 51 g. (0.5 mole) of cyclohexane sulfide and 116.2 g. (0.7 mole) of redistilled triethyl phosphite was charged into a 250 ml. one-necked flask equipped as previously described. The mixture was distilled at atmospheric pressure, collecting distillate at such a rate that the distillate temperature remained at $79-82^{\circ}\text{C}$. In about five hours there was collected an 88% yield of cyclohexane, b. p. $81-82^{\circ}$ at 747 mm., n_D^{20} 1.4530. These values are reported for this cycloalkane, b. p. $83-84^{\circ}$, $n_D^{19.5}$ 1.4533 (137). After removal of the excess triethyl phosphite at reduced pressure, triethyl thionophosphate was obtained in 91% yield. When a similar reaction was carried out using equimolar proportions of phosphite and sulfide, the residue in the distilling pot became slightly colored before the evolution of cyclohexane was complete, and triethyl thionophosphate was isolated in only 70% yield.

Reaction of 2-Phenyl Thiirane with Triethyl Phosphite

A 27.2 g. (0.2 mole) quantity of 2-phenyl thiirane and 33.2 g. (0.2 mole) of triethyl phosphite were mixed together and distilled under

reduced pressure, employing the procedure described for 2-chloromethyl thiirane. A 57% yield of styrene was isolated, b. p. 53-55° at 30 mm., n_D^{20} 1.5466. The recorded values for this alkene are: b. p. 52-53° at 28 mm., n_D^{20} 1.5462 (136). Triethyl thionophosphate was formed in 60% yield. A rather large amount of solid polymeric material was produced in this reaction.

Reaction of 2,2-Diethoxymethyl Thiirane with Triethyl Phosphite

When a mixture of 16.2 g. (0.1 mole) of 2,2-diethoxymethyl thiirane and 16.6 g. (0.1 mole) of redistilled triethyl phosphite was distilled according to experimental techniques already described, an 87% yield of acrolein diethylacetal was obtained, b. p. 121-123° at 743 mm., n_D^{25} 1.3985. The literature values are: b. p. 120-124° at 747 mm., n_D^{25} 1.3983 (116). Triethyl thionophosphate was isolated in 93% yield.

Reaction of 1-Methoxy-2-mercapto-*propane* with Triethyl Phosphite

A 100 ml. one-necked flask, equipped with a thermometer well, and provided with a 10 inch Vigreux column and variable take-off distillation head, was charged with 12.4 g. (0.12 mole) of 1-methoxy-2-mercapto-*propane* and 19.4 g. (0.12 mole) of purified triethyl phosphite. The reaction mixture was allowed to stand for twenty-four hours, and then was slowly heated. Distillate was collected in the range 38-40°C. An 8.4 g. quantity of distillate was collected. Redistillation of this material through a short packed column gave only one fraction, boiling

at 38-39° (741.7 mm.), n_D^{20} 1.3563, corresponding to a 94% yield of methyl propyl ether. This ether is reported to boil at 38.3-39° (140). Fractionation of the liquid residue in the distillation flask, under reduced pressure, afforded 19 g. of a material boiling at 80° (4.5 mm.), n_D^{20} 1.4481, n_D^{25} 1.4460. Triethyl thionophosphite is reported to boil at 45° (0.5 mm.), 105-106° (20 mm.), n_D^{20} 1.4480, n_D^{25} 1.4461 (108). Thus an 89% yield of this compound was obtained. A considerably longer distilling period (twenty-five hours) was required in this reaction, as compared to that required in the reaction of 1-methoxymethyl thirane with triethyl phosphite.

Reaction of 1-Ethoxy-2-mercaptopropane with Triethyl Phosphite

Distillation of a mixture composed of 24.0 g. (0.2 mole) of 1-ethoxy-2-mercaptopropane and 33.2 g. (0.2 mole) of purified triethyl phosphite, by experimental techniques previously described, gave a 91% yield of ethyl propyl ether, b. p. 62-63 (747 mm.). The reported boiling point for this ether is: b. p. 63-63.4° (760 mm.), (140). The other product of this reaction, triethyl thionophosphate, was obtained in 83% yield. A twenty-seven hour heating period was employed in this reaction.

Reaction of 1-Propoxy-2-mercaptopropane with Triethyl Phosphite

Distillation of mixture composed of 26.8 g. (0.2 mole) of 1-propoxy-2-mercaptopropane and 33.2 g. (0.2 mole) of triethyl phosphite, employing

the experimental procedure described above, gave a 65% yield of dipropyl ether, b. p. 89-90° (742 mm.), n_D^{20} 1.3801. The physical constants reported for this ether are: b. p. 90-90.5° (768 mm.), n_D^{20} 1.3808 (139). The other reaction product, triethyl thionophosphate was obtained in 72% yield. A fifteen hour distillation period was employed in this reaction. The reaction was carried out a second time, and after thirty hours of heating, an 87.6% yield of the ether was isolated and an 85% yield of the triethyl thionophosphate.

Attempted Reactions of Thiiranes with Primary Alcohols

Several attempts were made to bring about the condensation of simple olefin sulfides and 2-alkoxymethyl thiiranes, with low molecular weight primary alcohols, employing sodium alkoxides as catalysts. However, no simple monomeric addition products were isolated. In each instance, polymerization of the cyclic sulfide was the only reaction observed. The following procedures were utilized:

In a 500 ml. three-necked flask fitted with a sealed stirrer, reflux condenser and parallel side-arm provided with a thermometer and dropping funnel, were placed 64 g. (2.0 moles) of methanol and 1.6 g. (0.07 g.-at.) of sodium. To this vigorously stirred solution was added, in thirty minutes, 18.5 g. (0.25 mole) of propylene sulfide. No temperature change was observed during the first half of the addition period; however, during the latter stages considerable heat was evolved and the solution became quite turbid. The reaction mixture was refluxed

for an additional three hours, and neutralized with 6-N sulfuric acid. A 5 g. quantity of potassium carbonate was added to the solution and it was set aside overnight. After removal of the excess methanol, only a viscous semi-solid material remained, which could not be further purified. A second preparation, employing the above quantities of reagents, but with the reaction temperature held at 0°C., was carried out. Subsequent work-up of the reaction mixture gave only the above mentioned semi-solid material. Similar results were observed with isobutylene sulfide and methanol, with 2-methoxymethyl thiirane and methanol, and with 2-ethoxymethyl thiirane and ethanol respectively.

A further method was tried, in which a mole ratio of 1:10 of propylene sulfide to ethyl alcohol was used and the alkoxide catalysis omitted. The sulfide was added to a refluxing solution of the alcohol. Towards the end of the sulfide addition, the reaction mixture became turbid. Removal of the excess ethanol left a thick polymeric material which could not be distilled under reduced pressure. Similar results were obtained with 2-ethoxymethyl thiirane and ethanol.

IV. DISCUSSION AND RESULTS

A general survey of the literature reveals numerous references dealing with the addition to alkene oxides of such nucleophilic reagents as the anions of malonic ester, (2,3,4,5) acetoacetic ester (1,2) and cyanoacetic ester (2,82,83).

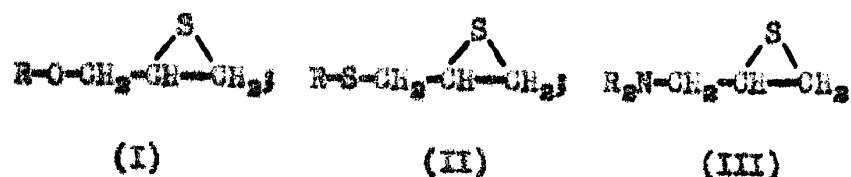
The initial aim of the present work was to discover suitable procedures which could be used to bring about the condensation of thiiranes with active methylene compounds such as malonic ester and acetoacetic ester, thereby extending a very useful synthetic approach to organic sulfur compounds.

Snyder and Alexander (6) had reported that simple olefin sulfides would readily condense with ethyl cyanoacetate, in the presence of sodium ethoxide, but not with ethyl malonate or ethyl acetoacetate. However, it was felt that perhaps by proper selection of reaction conditions, "alkylations" could be achieved with the latter two labile hydrogen compounds. Thus, the "alkylation" of diethyl malonate and acetoacetic ester by propylene and isobutylene sulfides was investigated. A variety of solvents were employed, including anhydrous ethyl ether, p-dioxane, n-butyl ether, chloroform, and tetrahydrofuran, but regardless of whether malonic ester or acetoacetic ester was used, the only reaction product isolated was polymeric propylene or isobutylene sulfide. In most instances, the ester component was recovered unchanged, and in nearly quantitative amount. No matter whether the reactions were carried out

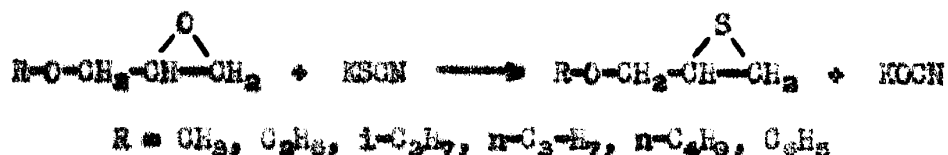
at room temperature or below, or at the reflux temperatures of the solvent used, only polymeric sulfide was obtained. Variation of the reaction time from one or two hours to several days failed to change the course of the reaction, the major products still being sulfide polymers. The utilization of high dilution techniques as well as changing the mode of addition also failed to keep the polymerization reaction from being predominate. Even varying the condensing agent from basic, C_2H_5ONa or NaH , to no catalyst, to the acidic condensing agent, $AlCl_3$, did not promote condensations, only polymer formation being observed.

The attempted alkylation catalyzed by anhydrous aluminum trichloride requires additional comment. Raha (84) had reported that malonic ester could be readily alkylated by ethylene oxide using anhydrous aluminum trichloride, to give γ -butyrolactone in nearly quantitative amount. However, repetition of this work by Hart and Curtis (85) indicated that the reaction products described by Raha (84) were actually the ester-interchange product β -chloroethyl ethyl malonate, bis- β -chloroethyl malonate and recovered malonic ester with no γ -butyrolactone being detected. Our own observations are in accord with those of Hart and Curtis (85).

As a result of the failure of "alkylation" to occur in the above studies, apparently because of the ease with which the olefin sulfides undergo self-polymerization, our attention was directed towards the preparation of thiranes possessing a higher degree of stability. To this end, the following three types, alkoxymethyl, thioalkylmethyl and dialkylaminomethyl thiranes were investigated.

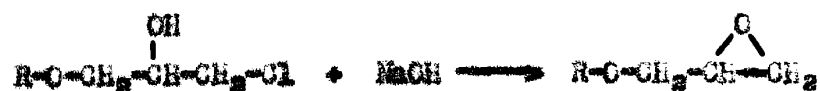


Only the compounds of type (I) exhibited little tendency towards polymerization, and could be kept at room temperature for some time without showing appreciable deterioration. These compounds were obtained in good yields by either of the following general methods; 1) by treatment of the corresponding glycidyl ethers with aqueous potassium thiocyanate at room temperature or below,



or 2) by treatment of the corresponding glycidyl ether with aqueous thiourea, in the presence of an equivalent amount of an acid. The β-hydroxy thiuronium salts which formed were hydrolyzed to the thiiranes upon treatment with excess aqueous sodium carbonate. The yields of 2-alkoxymethyl thiiranes are summarized in Table I, and the analytical data in Table II.

The 1,2-epoxy-3-alkoxypropanes required in the above reactions, were prepared from the halohydrins by treatment with sodium hydroxide.



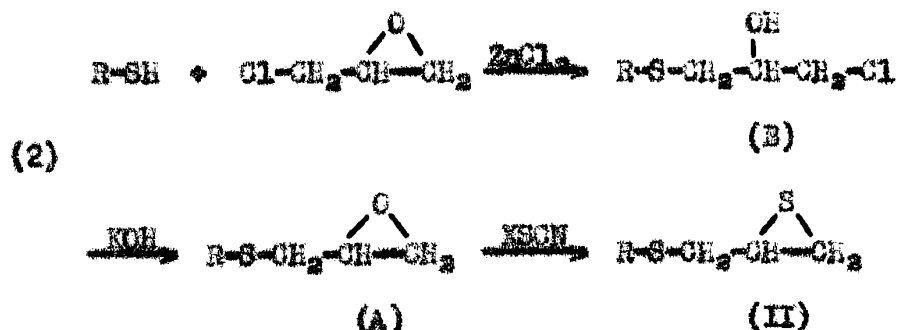
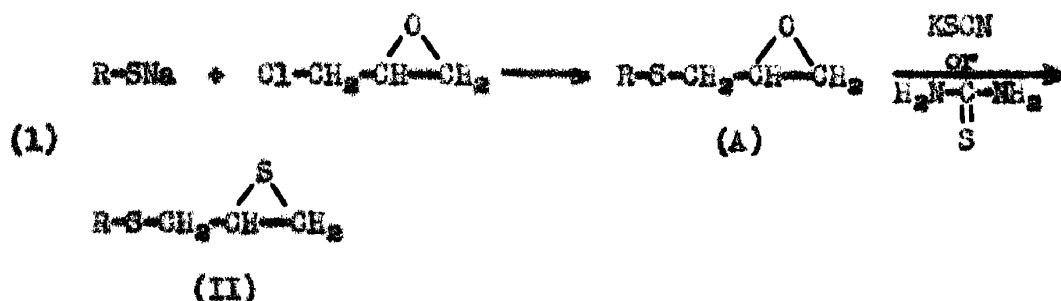
The yields of glycidyl ethers are recorded in Table III.

The 1-alkoxy-2-hydroxy-3-chloropropanes were prepared by the following scheme.



The yields of halohydrins are given in Table IV.

With respect to compounds of type II, the following preparative schemes were utilized.



Although the 1-thioalkyl-2-hydroxy-3-chloropropanes (B) and glycidyl thioethers (A) were isolated, the thioalkylmethyl thiranes (II) were quite unstable, polymerizing upon attempted purification by distillation, even at pressures as low as one millimeter.

TABLE I
YIELDS OF 2-ALKOXYMETHYL THIIRANES



Number	Compound	Formula	Preparation	Percent Yield	
				A ¹	B ²
I	2-Methoxymethyl Thiirane	C ₄ H ₈ OS	1	92	—
			2	93	—
			3	—	87
			4	—	84
II	2-Ethoxymethyl Thiirane	C ₆ H ₁₀ OS	1	90	—
			2	—	83
III	2-Propoxymethyl Thiirane	C ₇ H ₁₂ OS	1	59	—
			2	—	90
IV	2-Isopropoxymethyl Thiirane	C ₈ H ₁₄ OS	1	38	—
			2	—	81
V	2-Butoxymethyl Thiirane	C ₉ H ₁₆ OS	1	40	—
			2	—	90
VI	2-Phenoxymethyl Thiirane	C ₉ H ₁₀ OS	1	61	—
			2	—	C ³

¹Potassium Thiocyanate procedure.

²Thiourea and Acid procedure.

³Thiouronium salt formed but failed to hydrolyze.

TABLE II

ANALYTICAL DATA FOR 2-ALKOXYMETHYL THIIRANES



Compound	Formula	C. °C.	B. P. mm.	n _D ²⁵	Percent Carbon		Percent Hydrogen		Percent Sulfur	
					Calc'd	Found	Calc'd	Found	Calc'd	Found
2-Ethoxymethyl Thiirane	C ₄ H ₈ O ₃	60-61	16-17	1.4791	46.15	46.30	7.69	7.94	30.77	30.56
2-Ethoxymethyl Thiirane	C ₆ H ₁₂ O ₃	50	11	1.4725	50.84	51.05	8.47	8.76	27.12	27.32
2-Propoxymethyl Thiirane	C ₅ H ₁₀ O ₃	63	11	1.4691	54.54	54.21	9.09	9.01	24.24	23.95
2-Isopropoxymethyl Thiirane	C ₆ H ₁₂ O ₃	54	11	1.4651	54.54	54.49	9.09	8.96	24.24	24.07
2-Butoxymethyl Thiirane	C ₇ H ₁₄ O ₃	80	11	1.4679	56.70	56.90	9.46	9.56	21.70	21.90
2-Phenoxymethyl Thiirane	C ₉ H ₁₀ O ₃	106	1	1.5735	65.11	65.16	6.07	6.26	19.31	19.33

TABLE III
YIELDS OF GLYCIDYL ETHERS



Number	Compound	Formula	Preparation	Percent Yield	B. P.	
					°C.	mm.
I	Methyl Glycidyl Ether	$\text{C}_4\text{H}_8\text{O}_2$	1	80	40-42	26-28
			2	81.6		
			3	81.6		
			4	83		
II	Ethyl Glycidyl Ether	$\text{C}_6\text{H}_{10}\text{O}_2$	1	91.8	57	54
			2	93		
III	n-Propyl Glycidyl Ether	$\text{C}_8\text{H}_{12}\text{O}_2$	1	90	48	16-18
			2	90		
IV	i-Propyl Glycidyl Ether	$\text{C}_8\text{H}_{12}\text{O}_2$	1	83.4	59	41-43
			2	82.3		
V	n-Butyl Glycidyl Ether	$\text{C}_9\text{H}_{14}\text{O}_2$	1	92.3	67	16
			2	90.7		
VI	Phenyl Glycidyl Ether	$\text{C}_9\text{H}_{10}\text{O}_2$	1	56.1	134-136	20-22
			2	58.7		

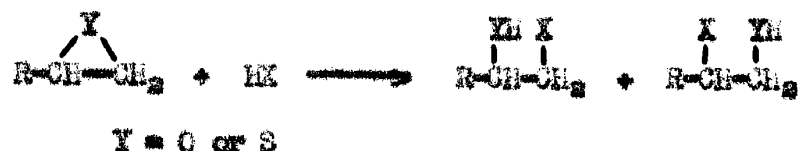
TABLE IV
YIELDS OF 1-ALKOXY-2-HYDROXY-3-CHLOROPROPANES



Number	Compound	Formula	Preparation	Percent Yield	Mole Ratio of Alcohol to Epichlorohydrin
I	1-Methoxy-2-hydroxy-3-chloropropane	$\text{C}_3\text{H}_5\text{ClO}_2$	1	62.4	3:1
			2	67.3	3:1
			3	80	4:1
II	1-Ethoxy-2-hydroxy-3-chloropropane	$\text{C}_5\text{H}_{11}\text{ClO}_2$	1	70	2:1
			2	94.4*	4:1
			3	95.1	4:1
III	1-Propoxy-2-hydroxy-3-chloropropane	$\text{C}_6\text{H}_{13}\text{ClO}_2$	1	70	3:1
			2	85	4:1
IV	1-Isopropoxy-2-hydroxy-3-chloropropane	$\text{C}_6\text{H}_{13}\text{ClO}_2$	1	40	4:1
			2	42	4:1
V	1-Butoxy-2-hydroxy-3-chloropropane	$\text{C}_7\text{H}_{15}\text{ClO}_2$	1	50	3:1
			2	73	4:1

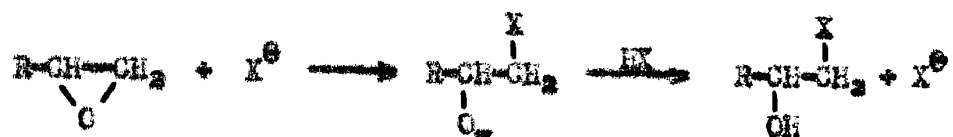
* Reaction catalyzed by anhydrous SnCl_4 , all others shown catalyzed by H_2SO_4 .

carbon atoms may in effect be measured simply by a determination of the ratio in which the two isomeric products are formed. A similar situation holds for the unsymmetrically substituted thiranes.

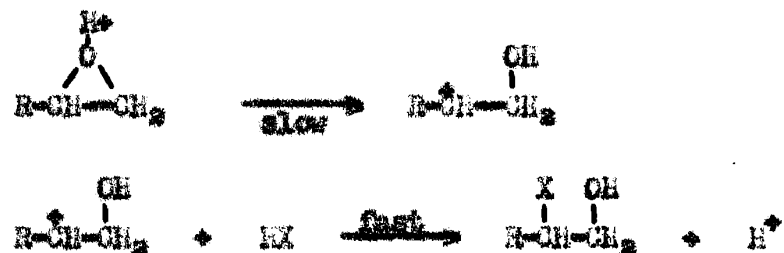


With respect to ethylene oxides, it has been observed (7,86,87) that a variety of substances of the type K^+X^- ($\text{X} = \text{Cl}^-, \text{Br}^-, \text{I}^-, \text{OH}^-, \text{SCN}^-, \text{S}_2\text{O}_3^{2-}$), phenoxide ion, alkoxide ion, the anion of malonic, acetoacetic, and cyanoacetic esters, and reactive molecules with an unshared pair of electrons (primary, and secondary amine, ammonia, hydrogen sulfide, mercaptans), generally react in such a manner as to give the alcohol with maximum branching at the carbinol carbon. This has been termed the "normal" cleavage reaction (87), and is equivalent to stating that in a higher homolog of ethylene oxide, the nucleophilic reagent will attack a primary carbon atom in preference to a secondary, and secondary in preference to a tertiary.

The agreement of these results with the order primary > secondary > tertiary, established for the rate in the S_{N}^2 substitutions of alkyl halides (86), as well as the second order kinetics (88), and inversion of configuration (3,87) which have been observed, support the theory that these reactions are bimolecular nucleophilic displacements on carbon.

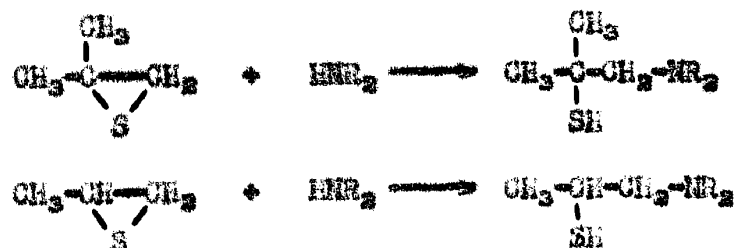


A few exceptions to these generalizations have been reported, and it is noteworthy that in these instances, the reactions were acid catalyzed (87). The proposal has been advanced that these so-called "abnormal" reactions involve a unimolecular ring opening of the conjugate acid of the epoxide (87).



In like manner, the terms "normal" and "abnormal" cleavage have carried over into discussions of the ring opening reactions of ethylene sulfides.

Thus, in the reaction of unsymmetrically substituted alkene sulfides with both primary and secondary amines, the so-called "normal" fission process occurs, since the aminomercaptans which are produced have the sulfur atom attached to the more highly substituted carbon atom (14).



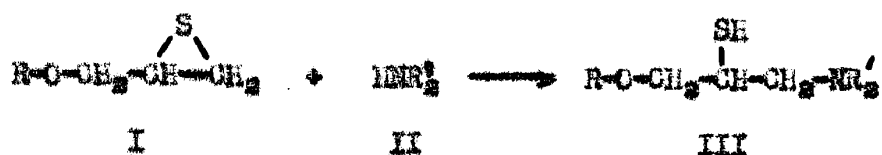
Snyder and co-workers (14) were unable to detect the presence of any isomeric primary mercaptans or the formation of isomeric mixtures in these reactions, which were run without catalyst or solvent, at temperatures near 100° for periods of ten to twenty hours. The yield of amino-mercaptan resulting from the initial ring opening reaction was rather low in several instances, presumably due to side reactions such as sulfide polymerization and reaction of the amino-mercaptan with another molecule of the sulfide to produce higher molecular weight compounds. Although these side reactions may be inhibited by employing a large excess of the amine, Snyder (14) in general used equimolar mixtures of the amine and cyclic sulfide. In addition, the yield of amino-mercaptan was found to be adversely affected by the presence of bulky substituents on the nitrogen atom, and by increasing degree of substitution in the sulfide ring.

The formation of an "abnormal" addition product has been reported by Reppe and Nicolai (23), who stated that $n\text{-C}_4\text{H}_9\text{N}[\text{CH}(\text{CH}_3)\text{CH}_2\text{SE}]_2$ was produced in the reaction of *n*-butyl amine with two molecules of propylene sulfide. However, recent studies (14,18) indicate that the compound was actually $n\text{-C}_4\text{H}_9\text{N}[\text{CH}_2\text{CH}(\text{SE})\text{CH}_2]_2$, the "normal" addition product.

In the present investigation, the reactions of 2-alkoxymethyl thiranes with the secondary amines piperidine, morpholine, and diethylamine were studied. Careful control of the reaction conditions gave excellent yields of substituted amino-mercaptans (Table V).

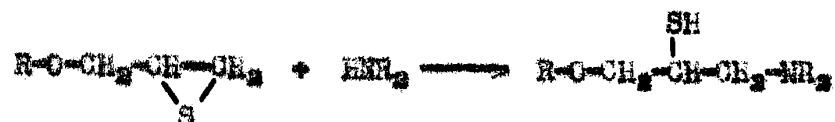
TABLE V

INFLUENCE OF SOLVENTS AND MOLE RATIO OF REACTANTS ON YIELDS OF AMINO-MERCAPTANS



Preparation	II	Mole Ratio I:II	Solvent	Percent III	R
1	HN(CH ₂) ₃	1:1	none	23.1	CH ₃
2	HN(CH ₂) ₃	1:2	none	57.7	CH ₃
3	HN(CH ₂) ₃	1:5	none	70.4	CH ₃
4	HN(CH ₂) ₃	1:1	ether	73.2	CH ₃
5	HN(CH ₂) ₃	1:2	ether	91.0	CH ₃
6	HN(CH ₂) ₃	1:2	benzene	92.1	CH ₃
1	HN(CH ₂) ₄ O	1:2	none	16.3	CH ₃
2	HN(CH ₂) ₄ O	1:1	none	17.1	CH ₃
3	HN(CH ₂) ₄ O	1:2	benzene	80.2	CH ₃
1	HN(CH ₂) ₃	1:1	none	21.4	C ₂ H ₅
2	HN(CH ₂) ₃	1:2	none	60.6	C ₂ H ₅
3	HN(CH ₂) ₃	1:5	none	67.8	C ₂ H ₅
4	HN(CH ₂) ₃	1:1	ether	71.3	C ₂ H ₅
5	HN(CH ₂) ₃	1:2	ether	83.2	C ₂ H ₅
6	HN(CH ₂) ₃	1:2	benzene	90.6	C ₂ H ₅
1	HN(CH ₂) ₄ O	1:2	none	34.0	C ₂ H ₅
2	HN(CH ₂) ₄ O	1:2	ether	81.3	C ₂ H ₅
3	HN(CH ₂) ₄ O	1:5	none	53.7	C ₂ H ₅

By analogy to the findings of Snyder and associates (14), the compounds are assumed to consist largely, if not solely, of the secondary mercaptan structure.



No evidence that would indicate the formation of an isomeric mixture was obtained.

The yield of substituted amino-mercaptan was found to be quite sensitive to such factors as the mole ratio of amine to thirane, presence or absence of a solvent, type of solvent, and nature of the product formed. Thus, it was observed that heating an equimolar mixture of piperidine and 2-ethoxymethyl thirane at reflux for twenty hours, in the absence of any solvent, gave only 21.4% of the amino-mercaptan. When the heating period was limited to ten hours, the yield increased to 31.3%. When a twofold excess of piperidine was employed, and the reaction mixture refluxed for ten hours, a 60.6% yield was realized. When the reaction was carried out in a non-ionizing medium such as anhydrous ether or benzene, an equimolar mixture of the above reagents gave a 71.3% yield of the amino-mercaptan. By employing a 2:1 ratio of piperidine to 2-ethoxymethyl thirane, the yield was increased to 90%. The length of the reflux period had little or no effect upon the yield,

in those preparations utilizing a non-ionizing solvent. Similar results were obtained with 2-methoxymethyl thirane (Table V).

Yields in the reactions of morpholine with 2-methoxymethyl and 2-ethoxymethyl thirane were likewise effected by the above factors. To illustrate, yields were in the neighborhood of 80% in those preparations utilizing a 2:1 ratio of amine to thirane and either anhydrous ether or benzene as solvent, whereas the yield dropped to about 40% when the solvent was omitted. Although some polymer formation accompanied all of the preparations, the proportion was far less in those preparations employing a solvent and a mole ratio of amine to thirane greater than one.

The above observations are similar to those reported by Braz (73), for the reaction of ethylene sulfide with a variety of amines.

The reaction of diethylamine with 2-alkoxymethyl thiranes requires special consideration, in view of the erratic results observed. A recent article by Ponomarev (89) described the reaction of methyl and ethyl glycidyl ethers with diethylamine. It was reported that no noticeable reaction occurred at ordinary or elevated temperatures, even when the amine was used in a two to threefold excess. However, when aqueous solutions of the amine were employed, substantial amounts of the expected ethers of diethylaminopropanediol were isolated. Prior to learning about the above work by Ponomarev (89), we had attempted the reactions of 2-ethoxymethyl thirane and 2-propoxymethyl thirane with diethyl amine using procedures identical to those employed with piperidine and morpholine. When the excess diethylamine had been removed,

the concentrated reaction product was subjected to distillation at reduced pressure. However, instead of isolating an amino-mercaptan, either 2-propoxymethyl thirane or 2-ethoxymethyl thirane was recovered in almost quantitative amount. After learning of the above work by Ponomarev, it was felt that the two reagents had merely failed to react and that the presence of water would be required to bring about reaction. In a preparation using aqueous diethylamine and 2-propoxymethyl thirane, according to the procedure of Ponomarev, a nearly complete polymerization of the thirane occurred, and the amine component was recovered unchanged. The explanation for the latter result would appear to be the observation by Bras (73), that ionizing solvents readily promote the polymerization of ethylene sulfide in the presence of amines. This coupled with the fact that ethylene sulfides are much more susceptible to self-polymerization than the corresponding oxides, may explain why Ponomarev (89) was able to effect a reaction whereas we obtained only polymer formation.

An indication that reaction had occurred, in the absence of water, is found in the recent work by Wright (90), who reported a similar situation in the reaction of thioglycidaldehyde diethyl acetal with non-aqueous diethyl amines. The reaction was thought to give the amino-mercaptan $(C_2H_5)_2N-CH_2-\overset{SH}{\underset{|}{CH}}-CH(OC_2H_5)_2$. However, when excess amine had been removed and the remaining material subjected to vacuum distillation, only the starting thirane $CH_2-\overset{S}{\underset{|}{CH}}-CH(OC_2H_5)_2$ was obtained, indicating that diethylamine is probably split out readily from the above amino-mercaptan. Such an explanation could apply equally as well in our case.

In further support of this contention, the study by Snyder and associates (14) may be cited. They observed that the higher-boiling amino-mercaptans derived from either ethylene or isobutylene sulfide and amines could not be obtained pure by distillation under reduced pressure. In most instances, successive redistillations gave distillates of successively lower mercaptan sulfur content. They suggested that the explanation for these observations is that the amino-mercaptans are subject to thermal decomposition, according to either or both of the following reactions.



The study by Wright (90) and our own observations strongly suggest that the second reaction is in the main, responsible for the results observed.

Some rather interesting results were obtained from an investigation of the reaction occurring between triethyl phosphite and the products of ring fission isolated from the reactions of 2-alkoxymethyl thiranes with secondary amines. The study was initially carried out with the aim of removing the mercapto-group, and thereby producing compounds such as $R-O-CH_2-CH_2-CH_2-NR_2$ or $R-O-CH_2-\overset{NR_2}{\underset{|}{CH}}-CH_3$. By unequivocal synthesis of these structures, and comparison of their properties, the question of the direction of ring opening caused by attack of secondary amines upon 2-alkoxymethyl thiranes could be determined. It was felt that the

preparation of structures of the above two types would be easier and less subject to question than those containing a mercapto-group in addition to the ether and amino linkages. However, the reactions failed to proceed as expected. For example, from the reaction of triethyl phosphite and 1-methoxy-2-mercapto-3-N-substituted aminopropanes there was isolated a 60% yield of methyl allyl ether and a viscous material which when subjected to distillation failed to give any appreciable amount of low boiling material.

Trialkyl phosphites are known to remove sulfur from a great variety of organosulfur compounds (91) and also to be capable of forming compounds with phosphorous to nitrogen bonds (91) by reaction with amines, nitriles, etc. In addition, a rather extensive list of compounds known as aridothionophosphates $(R_2N)PS(OR)_2$, $(RNE)PS(OR)_2$ have been prepared (91).

In view of these facts, the nature of the reaction which occurs when 1-alkoxy-2-mercapto-3-N-substituted aminopropanes are treated with triethyl phosphite becomes more obvious. That is to say, it becomes more apparent as to why an allyl ether should result, and why the removal of both the amino- and mercapto-group is not unexpected. Considering once again the case of 1-methoxy-2-mercapto-3-piperidinopropane,

$$CH_3-O-CH_2-\overset{SH}{\underset{|}{CH}}-CH_2-N(CH_2)_5 + (EtO)_3P \longrightarrow CH_3-O-CH_2-CH=CH_2 + (C_5H_{10}N)PS(OEt)_2 + EtOH,$$

it is not possible at the present time to say which occurs first, the removal of the mercapto- or amino-function or whether the processes occur simultaneously. The aridothionophosphate, $(C_5H_{10}N)PS(OEt)_2$, is a

known compound (91), and was obtained in small amounts in the present work. The low yields are presumably due to the high temperatures and long heating periods which were employed in the above reaction. In support of this contention, it has been shown that amidithionophosphates undergo several secondary reactions. For example, they undergo a more or less ready oxidation to the $R_2NPO(OR')_2$ analogs during purification operations such as distillations and crystallization (1). Little precise information is available about reaction of this type. In addition, amidithionophosphates are subject to thermal decompositions and various disproportionations during attempted distillations (91).

The reaction of triethyl phosphite with the product isolated from the reaction of 2-methoxymethyl thirane with morpholine likewise produced methyl allyl ether and an unidentified amidithionophosphate or derivative thereof. Similarly, the products isolated from the reaction of 2-ethoxymethyl thirane with both piperidine and morpholine, produced ethyl allyl ether and presumably amidithionophosphates.

Propylene sulfide in anhydrous solvents cleaves at the primary-carbon sulfur bond in reactions with chlorine or bromine, forming bis-(halopropyl) disulfides in quantitative amounts (81).

In the present investigation, the action of bromine on 2-methoxymethyl and 2-ethoxymethyl thirane in anhydrous solvents was investigated. The reaction presumably occurs by a step-wise process similar to that proposed by Stewart and Cordts (81), for the reaction of propylene sulfide with halogens.

from the cleavage of the secondary carbon-sulfur bond, was noted. The exclusive production of secondary mercaptans in these reactions was interpreted as involving initial attack by aluminohydride ion (AlH_4^-) on either the primary carbon atom or on sulfur, with the resultant fission of the primary carbon-sulfur bond. In the only other study so far reported, Moore and Porter (68) observed that reduction of n-hexylthiacyclopropane resulted in the formation of 2-octanethiol, with none of the isomeric 1-octanethiol being reported.

In the present work, the lithium aluminum hydride reduction of several 2-alkoxymethyl thiranes was investigated.



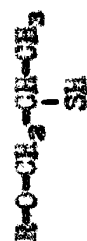
the results of this study are shown in Table VI.

In complete accord with the results of previous investigators (16,68), no evidence to indicate the formation of any primary thiols in these reactions was obtained. Further, no indication was noted that any of the reactions produced isomeric mixtures of ether-thiols.

Yields were in the range of 75-85%, except in the case of 2-phenoxy-methyl thirane. Some solid polymeric sulfide was produced in all of the reactions, but was especially prominent in the reaction of 2-phenoxy-methyl thirane with lithium aluminum hydride. The observation of polymer formation, although not mentioned by Bordwell and his associates (16), is in agreement with the recent work by Moore and Porter (68), who reported that n-hexylthiacyclopropane produced only small amounts

TABLE VI

ANALYTICAL DATA FOR THE 1-ALKOXY-2-MERCAPTOPROPANES

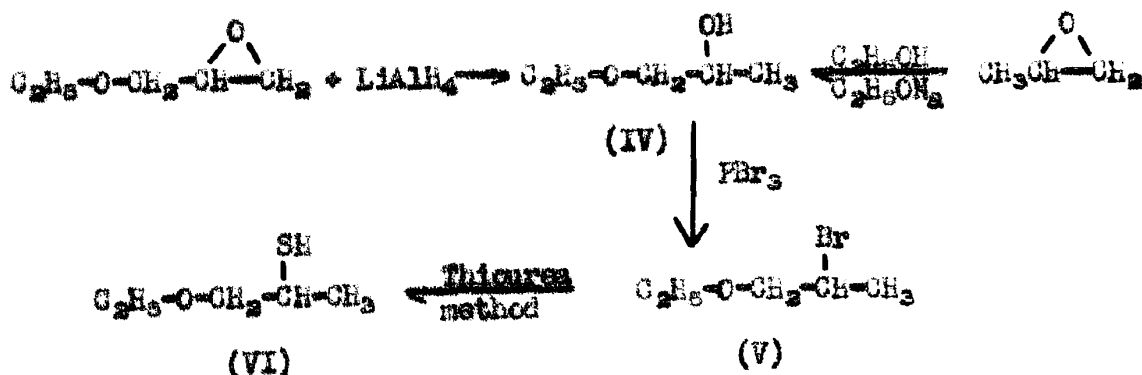
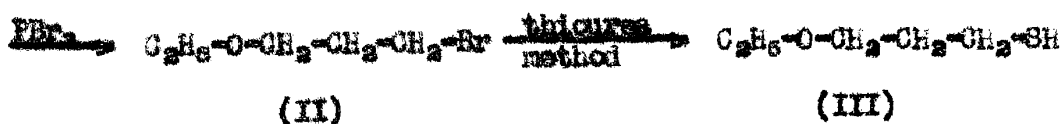
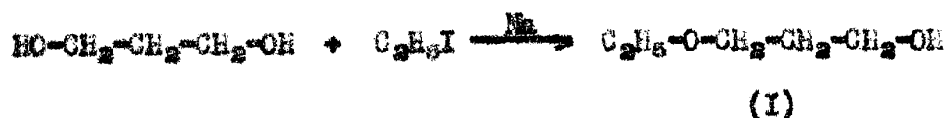


Compound	Formula	B. P. °C.	n _D ²⁵	Percent Carbon		Percent Hydrogen		Percent Sulfur	
				Calc'd	Found	Calc'd	Found	Calc'd	Found
1-Methoxy-2-mercaptopropane	C ₄ H ₁₀ OS	32-33	1.4411	45.28	45.40	9.43	9.63	30.18	30.38
1-Ethoxy-2-mercaptopropane	C ₆ H ₁₂ OS	45-46	1.4379	50.00	49.95	10.00	9.92	26.50	26.43
1-Propoxy-2-mercaptopropane	C ₇ H ₁₄ OS	49	1.4390	53.77	53.75	10.53	10.54	23.88	23.81
1-Butoxy-2-mercaptopropane	C ₇ H ₁₆ OS	66	1.4415	57.00	56.95	10.81	10.92	21.70	21.88

Although primary and secondary alcohols may be differentiated by a simple qualitative test (94), no such simple means is available for determining whether a compound contains a primary or a secondary mercapto-group. A color test (95) has been devised for distinguishing between tertiary and primary or secondary thiols, but obviously is of no value in the present study.

Thus, in the present problem any proof of structures had to be based strictly upon unequivocal synthesis of the two possible alkoxypropylmercaptans, and a comparison made between their properties and those of the reduction product obtained.

The reduction of 2-ethoxymethyl thirane could give rise to $\text{C}_2\text{H}_5\text{-O-CH}_2\text{-CH}(\text{SH})\text{-CH}_3$ or $\text{C}_2\text{H}_5\text{-O-CH}_2\text{-CH}_2\text{-CH}_2\text{-SH}$, depending upon the direction of ring-opening, therefore these two isomers were prepared by independent reactions and compared with the isolated reduction product. The following preparative reaction schemes were employed.



Reaction of the mono-sodium derivative of 1,3-propanediol with ethyl iodide gave I in 56% yield (96). Treatment of I with phosphorous tribromide produced II in 63% yield (97). 3-Ethoxy-1-mercaptopropane was subsequently obtained in 52% yield from II via the thiourea method (98). Comparison of the physical properties of this thiol with those of the reduction product from 2-ethoxymethyl thirane showed no similarity.

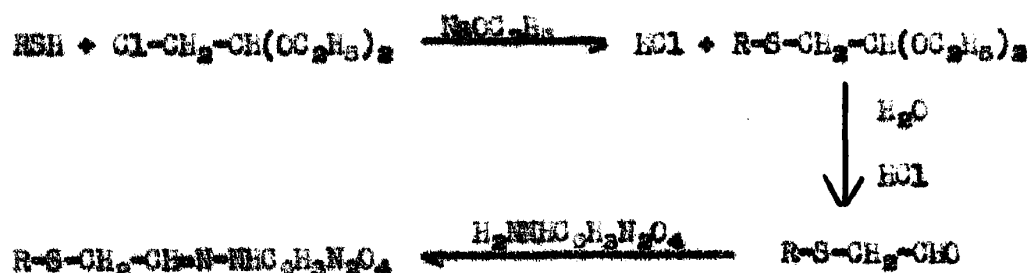
The exact course of the reaction of propylene oxide with alcohols (99,100) has been established for sometime. All available evidence indicates that the acid-catalyzed reaction leads to a mixture of the two possible ring fission products, 2-alkoxypropanol-1 and 1-alkoxypropanol-2. On the other hand, the alkaline catalyzed reaction leads to formation of only one isomer, namely the 1-alkoxypropanol-2.

As illustrated above, 1-ethoxypropanol-2 was prepared by the base catalyzed reaction of propylene oxide with ethanol. This same compound was also obtained from the reduction of ethyl glycidyl ether by lithium aluminum hydride. The preparation of IV by this latter procedure has not previously been described. Conversion of IV into the corresponding bromide V, was accomplished in 17% yield, using phosphorous tribromide. Again, the thiourea method was employed for the synthesis of VI from V. A 47% yield of VI was realized. A comparison of the properties of this material with those of the reduction product obtained from 2-ethoxymethyl thirane showed the two to be identical.

The common reagents employed for the conversion of thiols to solid derivatives, such as 2,4-dinitrochlorobenzene (101), 3,5-dinitrobenzoyl

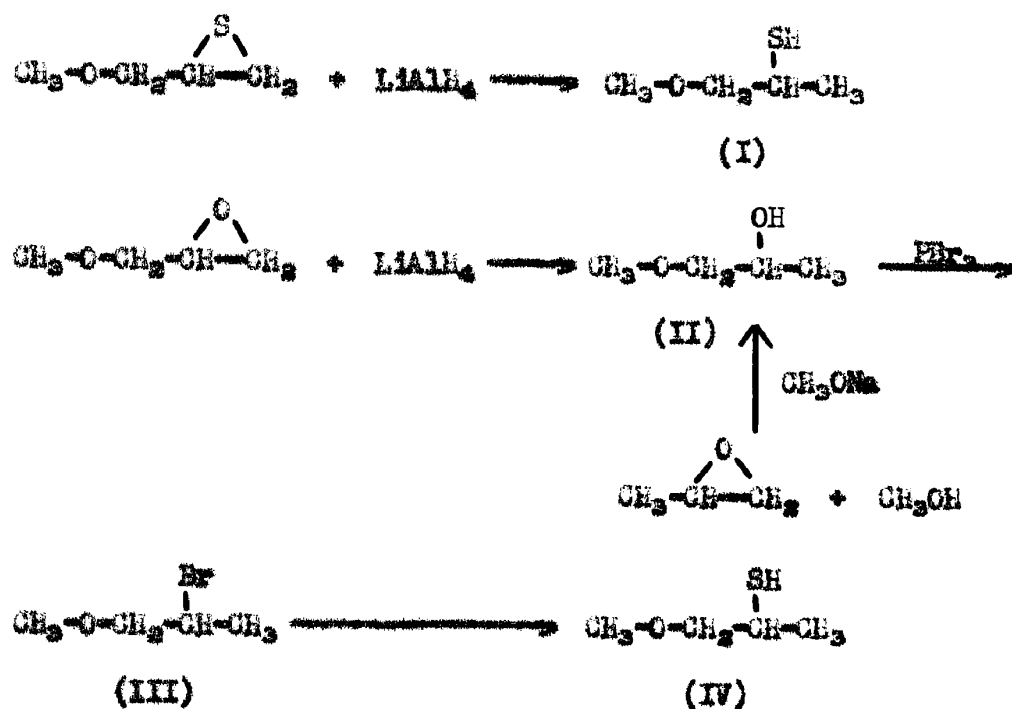
chloride (102) and 3-nitrophthalic anhydride (102), produced only viscous liquids or oils when applied to the alkoxy-mercaptans prepared in the present study. 1-Methoxy-2-mercaptopropane did yield a solid 2,4-dinitrophenyl thio-ether when treated with 2,4-dinitrochlorobenzene but the higher members of the series gave only thick orange colored oils which could not be induced to crystallize.

This phenomenon has also been observed by Swallen and Boord (103), who noted that β -ethoxy-alkylmercaptans would not form crystalline mercury or lead salts, and by Snyder and his associates (75), who were unable to obtain the usual solid derivatives of alkoxythiols prepared by the reaction of alkene sulfides with various alcohols. Snyder (75) was able to obtain several solid derivatives by transforming the mercaptans into mercaptoacetaldehyde dinitrophenylhydroses.



Application of this procedure to the alkoxymercaptans prepared in the present work, however, failed to produce any solid derivatives.

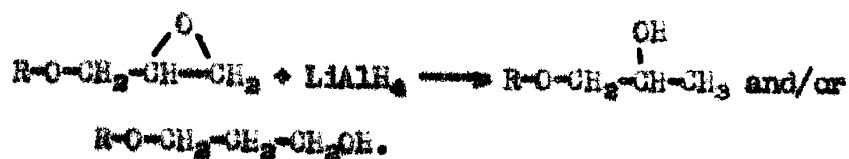
Further evidence in regards to the direction of ring-opening produced by the nucleophilic attack of AlH_4^- on 2-alkoxymethyl thiiranes was obtained by a study involving 2-methoxymethyl thiirane. In this case, the following procedures were involved.



The physical properties of I and IV were found to be in complete accord. Moreover, the solid 2,4-dinitrophenyl thioethers of I and IV were prepared and a mixed melting point determination showed no depression.

In light of the above evidence, there would appear to be little doubt as to the actual direction of ring-fission to be expected in the reduction of 2-alkoxymethyl thiranes by lithium aluminum hydride.

As mentioned previously, the synthesis of glycol monoethers by the reduction of glycidyl ethers with lithium aluminum hydride had not previously been reported. In view of this situation, a brief study of this particular reaction was carried out.



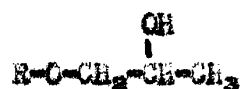
In each instance, only a secondary alcohol-ether was isolated. The structure proof of the products were based on a comparison of the physical properties and infrared spectra (99,100,105) of the compounds obtained in these reductions, and those obtained from the alkaline catalyzed condensation of propylene oxide with alcohols. The latter reaction is known to involve a nucleophilic attack of alkoxyl ion, preferentially at the primary carbon atom of propylene oxide, giving rise to 1-alkoxy-2-propanols. The data is summarized in Table VII.

A comparison of the products of ring-opening formed by the action of methyl iodide upon ethylene sulfides and epoxides reveals little or no similarity. For example, 2-iodocyclohexyl methyl ether was obtained from cyclohexene oxide (15), whereas trimethylsulfonium iodide was isolated from cyclohexene sulfide and methyl iodide (15).

The reaction between methyl iodide and alkene sulfides was first observed by Dalepine (11,12,34,36), who obtained a complex mixture of salts from ethylene and propylene sulfides and methyl iodide. By employing a large excess of methyl iodide, Culvenor and co-workers (15) were able to isolate trimethyl sulfonium iodide, using the latter two sulfides. These reactions are thought to involve the following steps (15).

TABLE VII

COMPARISON OF THE PHYSICAL PROPERTIES OF THE 1-ALKOXY-2-PROPANOLS
OBTAINED BY THE LiAlH_4 REDUCTION OF GLYCIDYL ETHERS AND BY
THE ALKALINE CATALYZED CONDENSATION OF
PROPYLENE OXIDE WITH ALCOHOLS



Reaction	R	B. P.		n_D^{20}	Percent Yield	Reference
		$^{\circ}\text{C.}$	mm.			
A	CH_3	118-118.5	747	1.4010 ^f	74	
B	CH_3^a	118.5-119	765	1.4017 ^f	63.1	99
A	C_2H_5	128-129	735	1.4060	78.3	
B	C_2H_5^b	130-130.8	760	1.4058	81.4	100
A	$n\text{-C}_3\text{H}_7$	147-148	747	1.4128	70.5	
B	$n\text{-C}_3\text{H}_7^c$	148.5-149	730	1.4130	58.7	104, 105
A	$i\text{-C}_3\text{H}_7$	135-137	741	1.4067	57	
B	$i\text{-C}_3\text{H}_7^d$	137-138	760	1.4070	53.2	100
A	$n\text{-C}_4\text{H}_9$	73-75	20	1.4169	80.1	
B	$n\text{-C}_4\text{H}_9^e$	74-74.5	20	1.4170	80.3	100

A = LiAlH_4 reduction of glycidyl ether.

B = Alkaline catalyzed condensation of propylene oxide with an alcohol.

Physical properties (for comparison) of 2-alkoxy-2-propanols:

^a 2-Methoxy-1-propanol, b. p. 130-130.2 $^{\circ}$ /758 mm., n_D^{20} 1.4070 (99);

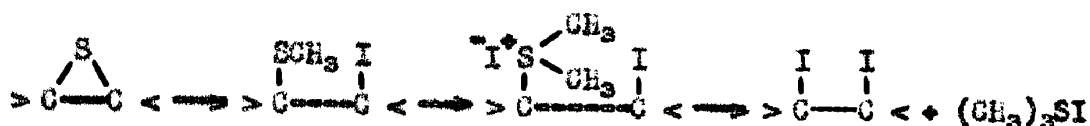
^b 2-Ethoxy-1-propanol, b. p. 137.5-138 $^{\circ}$ /760 mm., n_D^{20} 1.4100 (100);

^c 2-Propoxy-1-propanol, b. p. 150.5-151 $^{\circ}$ /730 mm., (104);

^d 2-Isopropoxy-1-propanol, b. p. 143-144 $^{\circ}$ /760 mm., n_D^{20} 1.4094, (100);

^e 2-Butoxy-1-propanol, b. p. 78-78.5 $^{\circ}$ /20 mm., n_D^{20} 1.4192, (100);

^f n_D^{25} .



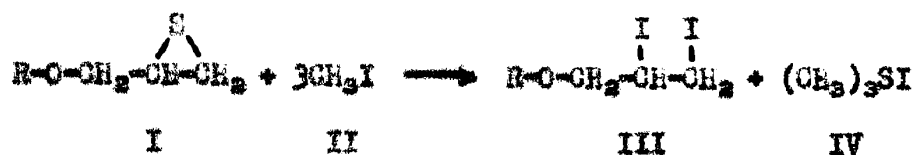
In the present investigation, a study was made of the effect of methyl iodide upon the 2-alkoxymethyl thiranes. In general, a tenfold excess of methyl iodide was employed and the reactants were allowed to stand at room temperature for a one to two week period. In each instance, (Table VIII), trimethylsulfonium iodide was the only solid material produced. All efforts to isolate the 1-alkoxy-2,3-di-iodopropanes were without success. Little or no polymer formation was detected, and yields of trimethylsulfonium iodide were in the neighborhood of 65-70%. When an excess of methyl iodide was not employed, yields averaged only 23-17% of theory.

Likewise, a comparison of the products formed by the action of organolithium compounds upon thiranes and oxiranes reveals little or no similarity. Thus, the reaction of alkyl- or aryllithium compounds with ethylene oxides results in the formation of alcohols, whereas these same reagents bring about the desulfurization of ethylene sulfides (16). For example, the action of phenyllithium upon cyclohexene sulfide results in the formation of cyclohexene and thiophenol (as the lithium salt). Similarly, cyclohexene and 1-butanethiol are obtained from cyclohexene sulfide and butyllithium (16). Comparable results were obtained with ethylene and propylene sulfide.

The appropriation of sulfur from olefin sulfides by organolithium compounds has been interpreted (16) as involving an initial attack by

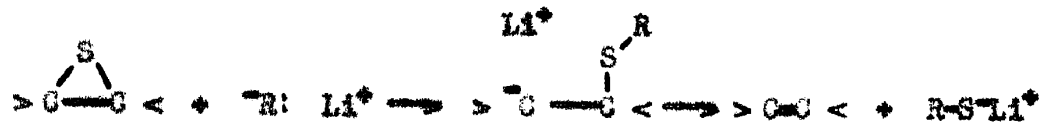
TABLE VIII

YIELDS OF TRIMETHYLSULFONIUM IODIDE FROM DECOMPOSITION
OF THE 2-ALKOXYMETHYL THIRANES BY METHYL IODIDE



Reaction	R	Mole Ratio II/I	Reaction Time	Percent Yield of IV
1	CH ₃	3.5	two weeks	23
2	CH ₃	30.0	two weeks	71
3	CH ₃	30.0	one week	57
1	C ₂ H ₅	3.0	two weeks	18
2	C ₂ H ₅	3.5	one week	22
3	C ₂ H ₅	30.0	two weeks	72
4	C ₂ H ₅	30.0	one week	56
1	n-C ₃ H ₇	3.5	one week	22
2	n-C ₃ H ₇	30.0	two weeks	66
1	i-C ₃ H ₇	3.5	one week	20
2	i-C ₃ H ₇	30.0	two weeks	67
1	n-C ₄ H ₉	3.5	two weeks	18
2	n-C ₄ H ₉	30.0	two weeks	65

the nucleophilic reagent directly on sulfur, followed by cleavage of a carbon-sulfur bond giving rise to an electron pair which then simultaneously or subsequently initiates a 1,2-elimination reaction to form the olefin and lithium mercaptide.



The removal of sulfur from organosulfur compounds by phenyllithium has previously been observed by Schonberg, *et al.* (93), who found that diphenyl disulfide and phenyllithium produced diphenyl sulfide and thiophenol (as the lithium salt).

In the present investigation, the reaction of 2-alkoxymethyl thiranes with phenyllithium and butyllithium was investigated. It was observed that both organolithium compounds caused a 1,2-elimination reaction to occur, giving rise to alkyl allyl ethers and lithium mercaptides. Thus, the reaction of 2-butoxymethyl thirane with phenyllithium gave 74% of butyl allyl ether and 83% of thiophenol. Butyllithium gave 77% of butyl allyl ether and 81% of 1-butanethiol. From the reaction of 2-propoxymethyl thirane with phenyllithium there was isolated a 70% yield of n-propyl-allyl ether and 86% of thiophenol. Butyllithium gave 67% of n-propyl allyl ether and 78% of 1-butanethiol. The reaction of 2-isopropoxymethyl thirane with phenyllithium produced isopropyl allyl ether in 53% yield and thiophenol in 71% yield. When butyllithium was employed, isopropyl allyl ether was obtained in 58% yield and 1-butanethiol in 74% yield. Similarly, a 42% yield of ethyl allyl ether and

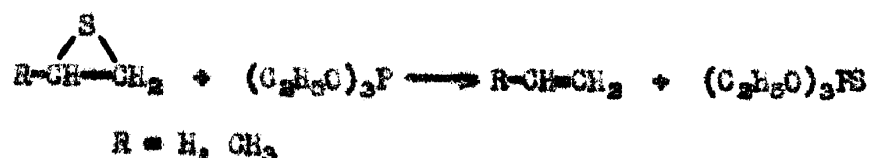
an 81% yield of thiophenol was obtained from the reaction of 2-ethoxymethyl thiirane and phenyllithium. Butyllithium gave a 47% yield of ethyl allyl ether and an 84% yield of 1-butanethiol. From comparable experiments using 2-methoxymethyl thiirane. A 70% yield of 1-butanethiol and a 74% yield of thiophenol were obtained.

An explanation as to why attack occurs on sulfur in ethylene sulfides, and on carbon in ethylene oxides has been presented by Bordwell and his associates (16), who suggest that the difference in the mode of attack is due 1) to sulfur being more electropositive and polarizable than oxygen, 2) the small carbon-sulfur dipole, and 3) the fact that divalent sulfur in disulfides, sulfonyl halides, etc. is known to be susceptible to attack by nucleophilic agents in displacement type reactions.

Recently Scott (106) has reported that the reaction of simple ethylene oxides with triethyl phosphite results in the reduction of the epoxide to the corresponding olefin and oxidation of the phosphite to triethyl phosphate. For example, when equivalent amounts of triethyl phosphite and either ethylene or propylene oxide were heated in a stainless steel bomb at 150-175°C for several hours, high yields of the corresponding olefin and triethyl phosphate were obtained.

In the present investigation, it was observed that merely heating an equimolar mixture of triethyl phosphite and ethylene or propylene sulfide at its reflux temperature for a short period of time resulted in the formation of triethyl thionophosphate with the simultaneous

conversion of the thirane to the corresponding unsaturated compounds.

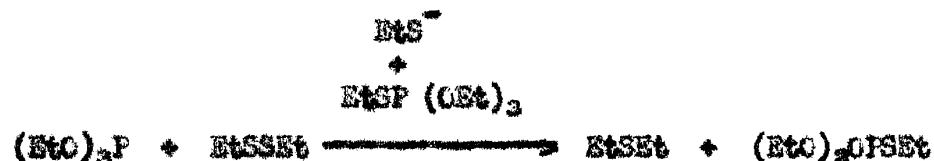


In each instance, the reaction produced, within experimental limits, quantitative amounts of triethyl thionophosphate and the unsaturate (isolated as the dibromide) under much milder conditions than those employed with the corresponding oxygen analogs. In general, the best results were obtained when a slight excess of triethyl phosphite was employed and the reaction halted as soon as the temperature of the reaction mixture reached the boiling point of triethyl thionophosphate.

Some indication of the scope of this desulfurization process was gained from studies with other thiranes. The over-all results are summarized in Table II. In addition, several of the corresponding oxiranes were subjected to the action of triethyl phosphite under comparable experimental conditions. For example, when 2-chloromethyl thirane was refluxed with triethyl phosphite, excellent yields of allyl chloride and triethyl thionophosphate were isolated, however, when epichlorohydrin was similarly treated, a quantitative recovery of starting materials was obtained. Likewise, 2-methoxymethyl thirane and 2-butoxymethyl thirane gave high yields of the corresponding alkyl allyl ethers whereas the corresponding methyl and butyl glycidyl ethers under identical conditions failed to react with triethyl phosphite.

The lowest yields in the desulfurization reactions were obtained when the thirane component contained a phenyl or phenoxy group (Table IX). This decrease in yield parallels the lower stability of the 2-phenyl thirane and 2-phenoxyethyl thirane as compared with 2-alkyl or 2-alkoxymethyl thiranes.

Several related desulfurizations initiated by triethyl phosphite have recently been described. Jacobsen, Harvey and Jensen (107) reported that upon refluxing a mixture of diethyl disulfide and triethyl phosphite for several hours, good yields of triethyl monothio phosphate and diethyl sulfide were obtained.



The mechanistic scheme was considered to involve a nucleophilic displacement of the substituent group by the triethyl phosphite moiety, coupled with the cleavage of the ethoxy linkage by the displaced anionic species.

In an attempt to extend the transesterification of triethyl phosphite with aliphatic alcohols to mercaptans, Hoffman (108) and his associates observed that the mercaptans were converted to the corresponding alkanes and the triethyl phosphite to triethyl thio phosphate as illustrated by the following equation.



TABLE IX

DESULFURIZATION OF THIIRANES BY TRIETHYL PHOSPHITE



I II

Number	Compound	Formula	Percent I	Percent II	R
1	ethylene sulfide	$\text{C}_2\text{H}_4\text{S}$	91 ^a	94	H
2	propylene sulfide	$\text{C}_3\text{H}_6\text{S}$	97 ^a	99	CH_3
3	cyclohexane sulfide	$\text{C}_6\text{H}_{10}\text{S}$	88	91	C_6H_5
4	styrene sulfide	$\text{C}_8\text{H}_8\text{S}$	57 ^b	66	C_6H_5
5	2-chloromethyl thiirane	$\text{C}_3\text{H}_5\text{ClS}$	95	100	ClCH_2
6	2-methoxymethyl thiirane	$\text{C}_4\text{H}_8\text{OS}$	94	96	CH_3OCH_2
7	2-ethoxymethyl thiirane	$\text{C}_5\text{H}_{10}\text{OS}$	96	98	$\text{C}_2\text{H}_5\text{OCH}_2$
8	2-propoxymethyl thiirane	$\text{C}_6\text{H}_{12}\text{OS}$	93	97	$n\text{-C}_3\text{H}_7\text{OCH}_2$
9	2-isopropoxymethyl thiirane	$\text{C}_7\text{H}_{14}\text{OS}$	91	95	$i\text{-C}_3\text{H}_7\text{OCH}_2$
10	2-butoxymethyl thiirane	$\text{C}_7\text{H}_{14}\text{OS}$	97 ^b	100	$n\text{-C}_4\text{H}_9\text{OCH}_2$
11	2-phenoxymethyl thiirane	$\text{C}_9\text{H}_{10}\text{OS}$	73 ^b	77	$\text{C}_6\text{H}_5\text{OCH}_2$
12	2,2-diethoxymethyl thiirane	$\text{C}_8\text{H}_{16}\text{O}_2\text{S}$	87	93	$\text{C}_2\text{H}_5\text{H}_2\text{C}_2$

^a Isolated as the dibromide.^b Polymer formation observed.

This unique desulfurization reaction occurred when a mixture of equimolar amounts of the mercaptan and triethyl phosphite was kept at its reflux temperature for several hours, or at room temperature when the mixture was irradiated with ultraviolet light. No suggestion as to the probable mechanism was given, although the catalytic effect of ultraviolet irradiation suggests a free radical process.

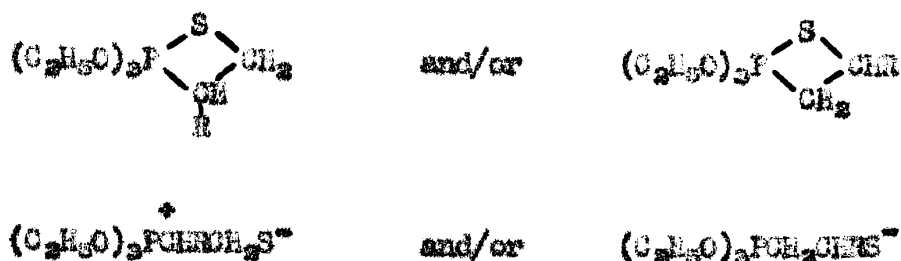
More recently, Walling and Rabinowitz (109) have shown that other free radical sources, such as azobisisobutyronitrile or di-*t*-butyl peroxide, initiate the above reaction of triethyl phosphite with mercaptans. It was further observed that an analogous radical reaction occurred when disulfides were treated with trialkyl phosphites in the presence of free radical sources.

The following chain processes were proposed, with



step (C) and (D) signifying the usual chain transfer reactions of mercaptans and disulfides respectively.

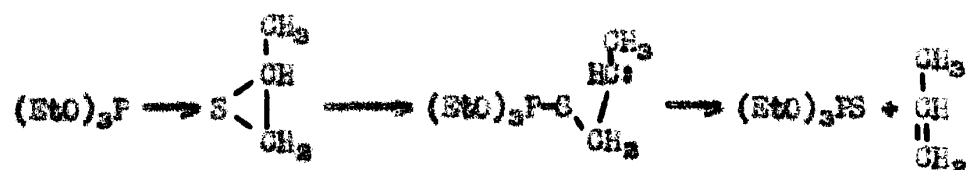
With regard to the desulfurization of thiranes by triethyl phosphite, a mechanistic interpretation similar to that offered by Scott (106) may be applicable. Thus, a nucleophilic attack by phosphite on either ring carbon atom could produce intermediates such as the following.



a subsequent rearrangement of such intermediates could then account for the observed products.



However, while the above mechanism would satisfactorily account for the observed products, the recent work of Bordwell and collaborators (16) on 1,2-elimination reactions of thiocyclopropanes with organolithium compounds giving rise to olefins, would suggest an alternative mechanism in which direct attack by phosphite on sulfur occurs. This mechanism can be formulated as,



The first step in the reaction is facilitated by coordination of sulfur with phosphite and breaking of the carbon-sulfur bond. This yields a pair of electrons which could initiate a 1,2-elimination reaction resulting in the simultaneous formation of olefin and thiophosphite.

Since the lithium aluminum hydride reduction of 2-alkoxymethyl thiranes had resulted in the formation of several 1-alkoxy-2-mercapto-propanes, a limited study of their reaction with triethyl phosphite was carried out.

Prior to the present study, only three mercaptans had been desulfurized by this process and in each case, the mercapto-group was primary. Hoffmann and collaborators (108) had discovered that triethyl phosphite removed the sulfur atom from n-octyl mercaptan and also from benzyl mercaptan, thereby forming the corresponding saturated hydrocarbon and triethyl thionophosphate. Later work by Walling and Rabinowitz (109), employing isobutyl mercaptan indicated that the reaction proceeded by a free radical chain process.

The use of 1-alkoxy-2-mercapto-propanes in the present investigation appears to be the first recorded instance in which secondary mercaptans have been desulfurized by the action of triethyl phosphite. When 1-methoxy-2-mercapto-propane was heated with an equimolar amount of triethyl phosphite, for twenty-five hours, there was isolated a 9½% yield of methyl propyl ether and an 88.3% yield of triethyl thionophosphate. A possible explanation for the lower yield of thionophosphate is found in the work of Emmett and Jones (110), who observed that thionophosphates readily undergo thermal isomerization to phosphorothiolates. Thus, the prolonged heating period required to bring about the above desulfurization process, may well have caused a partial isomerization of the thionophosphate. A similar situation, lower yields of triethyl

thionophosphate, was observed in the other cases studied, and also with the thiranes, if the temperature of the reaction mixture was allowed to remain at about 180° for prolonged periods of time.

In the case of 1-propoxy-2-mercapto propane, a 65% yield of di-n-propyl ether was isolated after fifteen hours of heating, while a 72% yield of thionophosphate was obtained. The reaction was carried out a second time and after thirty hours an 87.6% yield of the ether was isolated and 85% of triethyl thionophosphate. 1-Ethoxy-2-mercapto propane furnished a 91% yield of ethyl propyl ether and an 83% of the thionophosphate after a twenty-seven hour heating period.

Several attempts were made to bring about the condensation of methanol and ethanol with unsymmetrically substituted thiranes. However, the major or sole product in every instance was polymeric sulfide. For example, the reaction of propylene sulfide with methanol or ethanol, catalysed by the corresponding sodium alkoxide, gave only a trace of the monomeric product, the major product being a white semi-solid substance.



In the case of 2-methoxymethyl thirane and 2-ethoxymethyl thirane, only the polymeric material was obtained.

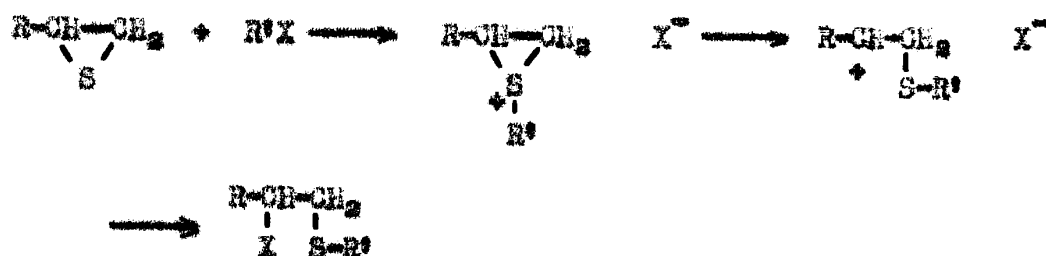
While the present investigation did not include any reactions in which "abnormal" ring-fissions were involved, it seems worth-while to

discuss briefly, this mode of ring-fission in order to have a brief but complete review of thiirane chemistry.

An example of this phenomena is found in the reaction of propylene sulfide with acetyl chloride. Culvenor and his collaborators (15) had observed that in this reaction a chloropropyl thioacetate was formed in nearly theoretical amount, but were unable to assign a definite structure. Later work by Davies and Savige (17) established the structure as 2-chloropropyl thioacetate, the isomer in which the sulfur atom retains its linkage with the least substituted carbon atom. No indication of the presence of a "normal" product was obtained. Acetyl bromide was also shown to yield the "abnormal" addition product, 2-bromopropyl thioacetate, and by analogy the product from benzoyl chloride was assumed to be 2-chloropropyl thiobenzoate. 2-Chloromethyl thiirane and acetyl chloride also form the "abnormal" addition product.

In a like manner, the action of concentrated hydrochloric acid on both propylene sulfide (17) and 2-chloromethyl thiirane (18) resulted in the formation of "abnormal" products, 2-chloropropene-1-thiol and 2,3-dichloropropene-1-thiol respectively.

These "abnormal" ring-fissions have been ascribed to the formation of an intermediary ethylene sulfonium ion, which allows the formation of the secondary carbonium ion by cleavage (18).



In such instances, the nature of the R-group should influence the direction of ring-opening of the "onium"-type ion. However, little information is available on this particular point.

In the reactions of episulfides and epoxides, which result in the formation of "abnormal" product, the relative amounts obtained from the epoxide are small in comparison with the amounts produced from episulfides. This has been attributed to the lesser tendency of oxygen, as compared to sulfur, to form "onium" ion intermediates (18).

The observation by Snyder, Stewart and Zeigler (75), that the interaction of aliphatic thiols with isobutylene sulfide, in the presence of the acid-catalyst boron trifluoride, produces mainly "abnormal" products, is in complete accord with the above mechanistic interpretation. A major discrepancy would appear to be their observation that "abnormal" products are also formed when basic-catalyst are employed in the above reactions. However, since only trace amounts of catalyst were used, and the thiol was employed in several fold excess, it may be that the large proportion of free thiol functioning as an acid

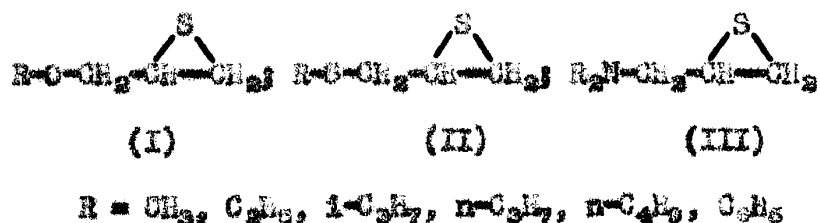
environment is responsible for the isolation of "abnormal" product.

Alcohols have also been reported to yield mainly primary mercaptans by interaction with isobutylene sulfide (75). The isolation of chiefly "abnormal" product is accounted for by the fact that the reactions are acid catalyzed (boron trifluoride). Basic catalysts fail to promote this reaction.

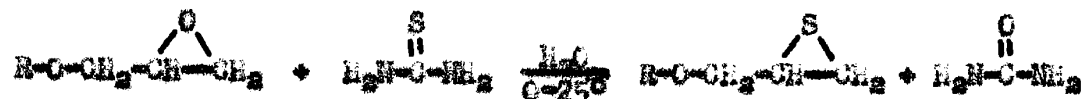
V. SUMMARY

A number of attempts were made to promote the condensation of propylene and isobutylene sulfides with diethyl malonate and ethyl acetoacetate. However, even though a variety of experimental conditions were employed, little or no "alkylation" occurred. In each instance, the major product was found to be polymeric propylene or isobutylene sulfide.

As a result of the failure of the above project, presumably due to the extreme ease with which the simple olefin sulfides undergo self-polymerization, efforts were directed towards the synthesis of thiranes possessing a greater degree of stability. To this end, the preparation of molecules having structures of the following three types was investigated.

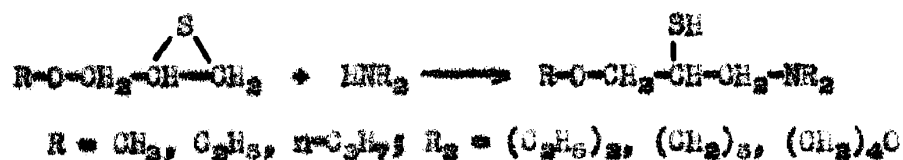


Of the various methods now available for the production of thiranes, only those utilizing the transformation of an epoxide into the corresponding sulfur compound, by reaction with either alkali thiocyanates or thiourea, were employed.



Only compounds of type I exhibited little tendency towards polymerisation. Compounds of type II were even less stable than the simple alkane sulfides, polymerising upon attempted purification by distillation. Only one member of type III was prepared, ($R = C_2H_5$), and although it was isolated as the monomer, it polymerised within a few days after preparation. As a consequence, only compounds of type I were employed in the following reactions with nucleophilic reagents.

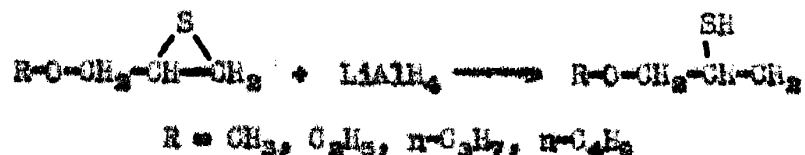
The reaction of 2-alkoxymethyl thiranes with the secondary amines; piperidine, morpholine and diethylamine gave excellent yields of substituted amino-mercaptans.



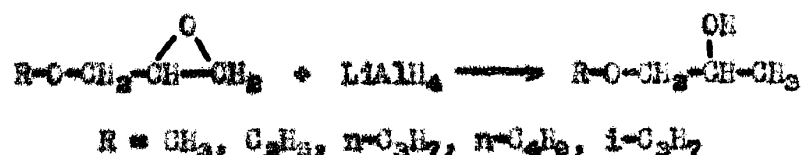
By analogy to the findings of previous investigators, the products are assumed to consist largely if not solely of the secondary mercaptan structure. The yield of ring fission product was found to be quite sensitive to such factors as the mole ratio of amine to thirane, presence or absence of a solvent, type of solvent, and nature of the product formed.

Low molecular weight primary alcohols, on the other hand, did not yield simple addition products, only polymeric sulfides being isolated.

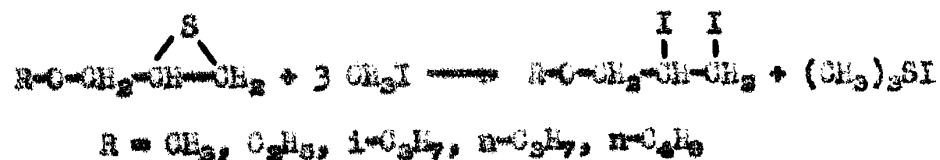
The reaction of 2-alkoxymethyl thiranes with lithium aluminum hydride produced 1-alkoxy-2-mercaptopropanes.



In connection with the proof of structure of these reduction products, a study of the lithium aluminum hydride reduction of several glycidyl ethers was carried out and found to yield only 1-alkoxy-2-propanols.



Trimethylsulfonium iodide was obtained from the reaction of methyl iodide with 2-alkoxymethyl thiranes.



All efforts to isolate the 1-alkoxy-2,3-diiodopropanes were without success.

The 2-alkoxymethyl thiranes were observed to react with bromine, but the reaction products decomposed upon attempted distillation.

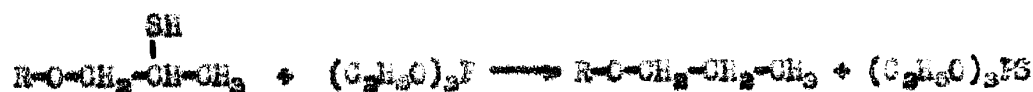
Phenyllithium and butyllithium appropriated the sulfur atom from 2-alkoxymethyl thiranes, resulting in the formation of alkyl allyl ethers and lithium mercaptides.



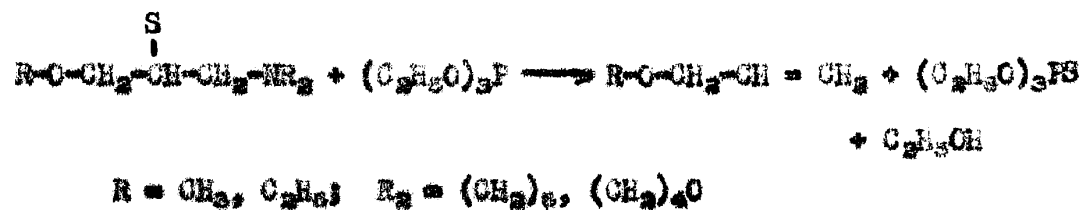
An investigation of the reaction of triethyl phosphite with a variety of thiranes was carried out and observed to result in the desulfurization of the thiranes, with the formation of an olefinic compound and triethyl thionophosphate.



The reaction of triethyl phosphite with several 1-alkoxy-2-mercapto-
propanes was also investigated and found to result in the formation of
alkyl propyl ethers and triethyl thionophosphate.



A brief study of the effect of triethyl phosphite upon the products isolated from the reactions of amines with 2-alkoxymethyl thiiranes was also carried out.



Alkyl allyl ethers and amidotidionophosphates were obtained in this reaction.

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