THE UNIVERSITY OF MANITOBA

A Study of the Reactions of Thiolchloroformates with Dimethyl Sulfoxide

by

Kenneth Robert Preston

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CHEMISTRY

WINNIPEG, MANITOBA

FEBRUARY, 1972

TO

MY WIFE

ACKNOWLEDGEMENT

I would like to thank Dr. Queen for his guidance and assistence during the past two years. I would also like to thank Dr. Paddon Row for his supervision and advice as well as providing a majority of the conclusions reached in this work.

ABSTRACT

A study of the reaction of alkyl and aryl thiolchloroformates with DMSO was initially undertaken with the hope that the corresponding alkyl or aryl dimethyl thiolsulfonium salts could be isolated. However the reaction led to the formation of the corresponding disulfide and/or the corresponding thiolsulfonate, dimethyl sulfide, carbon dioxide and dimethyl sulfur dichloride. A study of the reaction was undertaken and a mechanism has been proposed to account for the formation of these products.

A trapping agent, isopropyl mercaptan showed the initial formation of the corresponding alkyl (or aryl) dimethyl thiolsulfonium ion (32). Further reaction of this ion with thiolchloroformate and DMSO leads to the formation of dimethyl sulfur dichloride, dimethyl sulfide and the corresponding disulfide. The formation of the corresponding alkyl alkyl thiolsulfonates (R= n-propyl, ethyl, methyl) was shown to be the result of the oxidation of the initially formed disulfide by DMSO and dimethyl sulfur dichloride.

A study was also undertaken of dimethyl sulfur dichloride, which had not been isolated previously. Its potential synthetic use as an oxidizing agent in combination with DMSO was investigated. Phosphines, disulfides and thiols were oxidized rapidly at low temperatures with almost quantitative yields of the corresponding phosphine oxides, thiolsulfonates and disulfides.

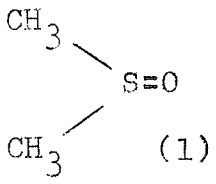
TABLE OF CONTENTS

INTRODUCTION

INTRODUCTION

General

Dimethyl sulfoxide (1) was first prepared by Saizew (1866). Although it attracted relatively little attention for a considerable length of time, it has in recent years been recognized as a remarkably useful dipolar aprotic solvent capable of accelerating a wide variety of chemical reactions. Moreover it has been found to participate in a wide range of useful chemical reactions. In subsequent discussions the compound will be referred to by the abbreviation, DMSO.

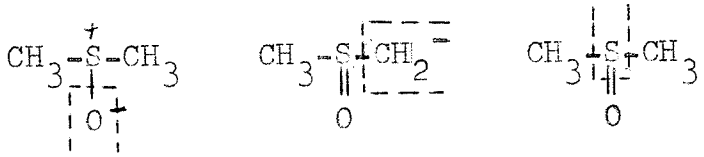


(1)

DMSO has a pyramidal structure with sulfur, oxygen and carbon atoms at each corner. The sulfoxide bond is highly polar, a feature that probably reflects the inefficiency of the d-p pi bonding (Crumper and Read: 1956). As a consequence, the oxygen atom remains electronegative compared to the sulfur atom. The major resonance structures of DMSO are shown below:

Chemical Features of DMSO

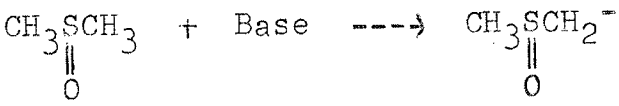
DMSO has three different reactive sites as shown below:



The polar sulfoxide group of DMSO is a highly versatile reaction site. Due to the intermediate oxidation state occupied by the sulfur atom, the group is easily oxidized or reduced. As a result of free electron pairs on both the sulfur and oxygen atoms, either atom may act as a basic or nucleophilic centre. The polar sulfoxide group also confers low but significant acidity on the methyl groups, Stewart and Jones (1967) reported a pK value for DMSO of 32.9.

Reaction at Carbon

In the presence of a strong base, DMSO is converted to the corresponding conjugate base (methyl sulfinyl carbanion) as shown below:



As expected the anion is strongly basic, a fact that has led to a wide variety of synthetic applications. For example, aromatic and aliphatic esters that do not undergo facile proton transfer react with the methylsulfinyl

carbanion to yield the corresponding β-keto sulfoxides as shown below:

$$RCO_2R' + 2CH_3\overset{\overset{O}{\|}}{S}CH_2^- \longrightarrow (RCOCHSOCH_3)^- + OR'^- + CH_3\overset{\overset{O}{\|}}{S}CH_3$$

$$(RCOCHSOCH_3)^- \longrightarrow RCOCH_2SOCH_3$$

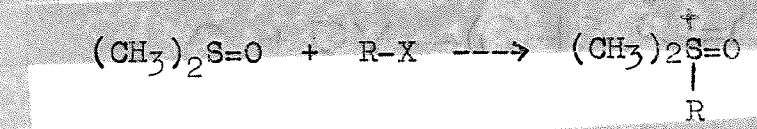
Since the methyl sulfinyl group is easily replaced by hydrogen in the presence of aluminum amalgam - water - tetrahydrofuran, these β-keto sulfoxides are valuable synthetic intermediates for the synthesis of ketones (Becker, Mikol and Russell; 1963).

Relatively inert halides also react rapidly with the methyl carbanion in DMSO. For example Corey and Chaykovsky (1965) found that chlorobenzene reacts with DMSO in the presence of an excess of base to give methyl benzyl sulfoxide. At lower base concentrations methyl benzhydrol sulfoxide was also isolated in considerable amounts.

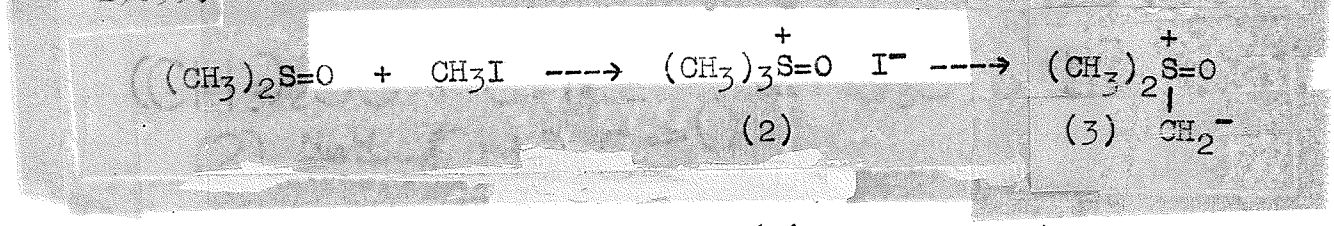
An important application of the methyl sulfinyl carbanion is the preparation of phosphonium ylides from phosphonium salts. The ylid can be generated very rapidly in DMSO in the presence of the carbanion. Furthermore it appears that in general Wittig reactions proceed more rapidly and with higher yields in DMSO than with customary solvents. By this method, Greenwald, Chaykovsky and Corey (1963) obtained an 86% yield of methylenecyclohexane from cyclohexanone.

Reaction at Sulfur

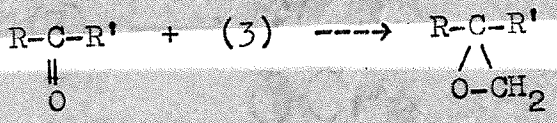
The reaction of DMSO with alkyl halides or arene-sulfonates leads to the corresponding S-alkyl derivitives (Smith and Winstein; 1958) as shown below:



In particular the trimethyl oxosulfonium ion (2) obtained from the reaction of DMSO and methyl iodide is of value since it can easily be converted to the corresponding ylid (3) in the presence of sodium hydride (Corey and Chaykovsky; 1965).



The dimethyloxosulfonium methylid (3) acts as a strong nucleophile and transfers methylene to unsaturated linkages including C=O, C=N, C=S and C=C. For example the ylid (3) reacts with ketones and aldehydes yielding epoxides as shown below:



Corey and Chaykovsky (1965) reported that the reaction of (3) with 4-t-butylcyclohexanone produced the corresponding oxirane which could be reduced to yield trans 4-t-butyl-1-

methylcyclohexanol, free of the cis isomer.

Reaction at Oxygen

The polarization of the oxygen-sulfur bond in DMSO effectively places a negative charge on the oxygen atom. Reaction of DMSO with a wide variety of electrophilic reagents leads initially to the di-methyl oxysulfonium ion (4).

$$(CH_3)_2SO + E \longrightarrow (CH_3)_2\overset{+}{S}OE$$
(4)

Depending on the nature of the electrophile (E) and the reaction conditions, the oxysulfonium ion (4) can undergo a variety of reactions. The oxysulfonium ion may be attacked by nucleophile at the sulfur displacing "OE" and forming another sulfonium ion (5) or a base may attack yielding the sulfur stabalized carbonium ion (6).

$$(CH_3)_2S\text{-}OE \xrightarrow{Nu} (CH_3)_2\overset{+}{S}\text{-}Nu + OE^-$$
(4) (5)

$$(CH_3)_2S\text{-}OE \xrightarrow{Base} CH_3\text{-}\overset{+}{S}{=}CH_2 + HOE$$
(4) (6)

The formation of these ions is usually followed by Pummerer type rearrangements yielding synthetically valuable sulfides. For example treatment of dimethyl methoxysulfonium fluroborate (7) with sodium acetate in DMSO yields

acetoxymethyl methyl sulfide. The mechanism proposed by Johnson and Phillips (1969) involves initial displacement of the methoxy group by acetate ion yielding the acetoxysulfonium salt (8) followed by a Pummerer type rearrangement yielding the sulfide product as shown below:

$$(CH_3)_2\overset{+}{S}\text{-}OCH_3 \; BF_4^- + NaOAc \longrightarrow (CH_3)_2\overset{+}{S}\text{-}OAc$$

(7) (8)

$$(8) \longrightarrow CH_3SCH_2\text{-}OAc$$

The reaction of DMSO and acetic anhydride also yields acetoxymethyl methyl sulfide. The mechanism proposed by Oae and Kise (1968) involves the initial formation of the acetoxysulfonium salt (8) followed by proton abstraction yielding the sulfur stabilized carbonium ion (10) via the ylid-ylene intermedite (9). Nucleophilic attack at α-carbon by acetate yields the product.

$$(CH_3)_2S{=}O + Ac_2O \longrightarrow (CH_3)_2\overset{+}{S}\text{-}OAc \; OAc^-$$

(8)

$$(8) \longrightarrow \left(CH_3\overset{+}{S}(OAc)CH_2^- \leftrightarrow CH_3S(OAc){=}CH_2 \right)$$

(9)

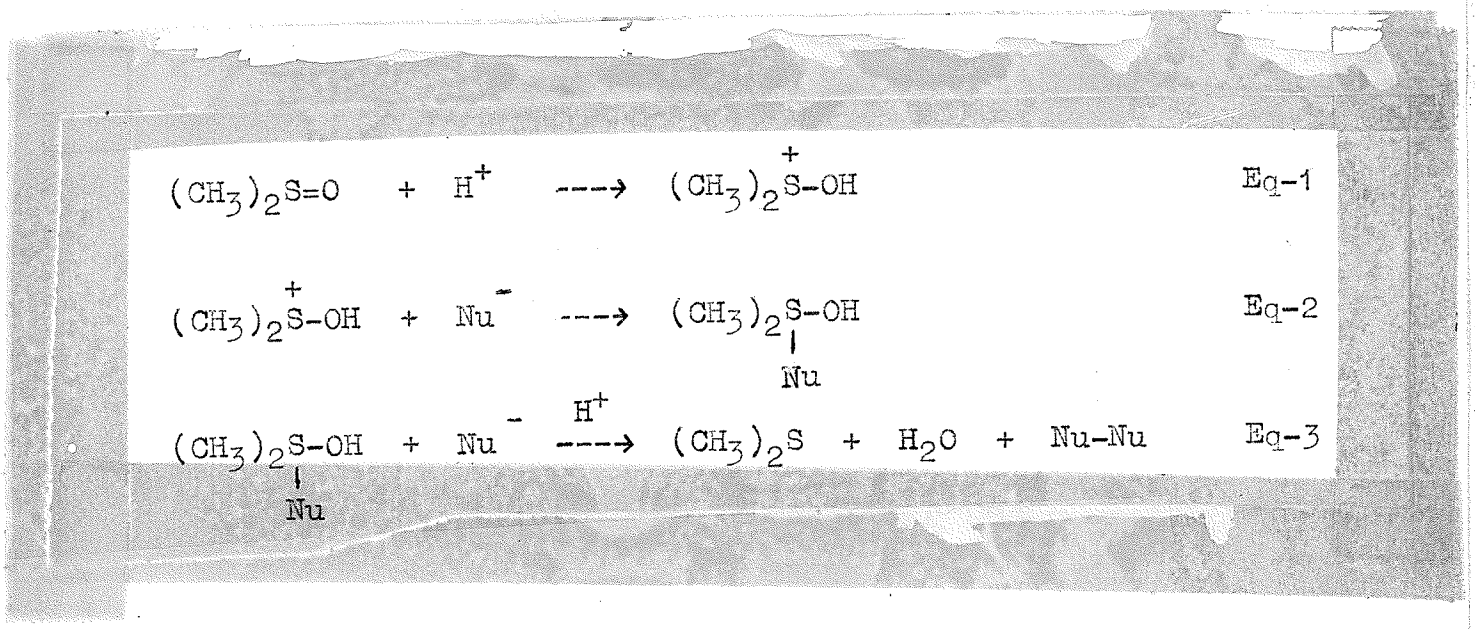
$$(9) \longrightarrow CH_3\overset{+}{S}{=}CH_2 \; OAc^- \longrightarrow CH_3SCH_2\text{-}OAc$$

(10)

Recently the ability of DMSO to yield sulfonium salts has been utilized for the oxidation of a wide variety of organic and inorganic compounds. For convenience these oxidations will be discussed in two sections, depending on whether the oxysulfonium salt is generated by protonation whereby DMSO acts primarily as a base or by a general Lewis acid in which case DMSO acts primarily as a nucleophile..

Oxidations Dependent on the Basic Properties of DMSO

In DMSO oxidations where the sulfoxide acts primarily as a base, the initial step involves the protonation of the basic oxygen atom (Eq-1) usually followed by the formation of a tetra-coordinated sulfur intermediate (Eq-2). Subsequent attack by a nucleophilic reagent (Nu) usually occurs at this stage (Eq-3).



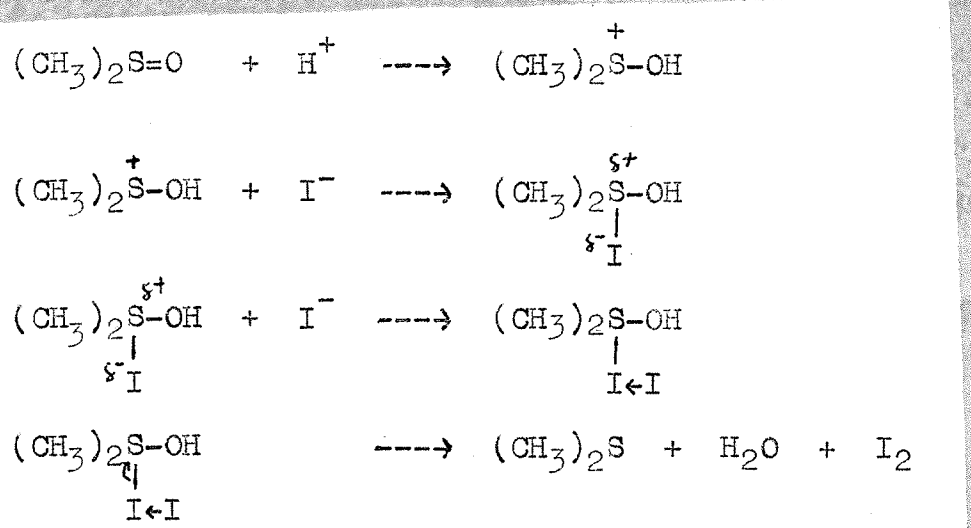
$$(CH_3)_2S{=}O + H^+ \longrightarrow (CH_3)_2\overset{+}{S}{-}OH \qquad \text{Eq-1}$$

$$(CH_3)_2\overset{+}{S}{-}OH + Nu^- \longrightarrow (CH_3)_2\underset{\displaystyle Nu}{\overset{|}{S}}{-}OH \qquad \text{Eq-2}$$

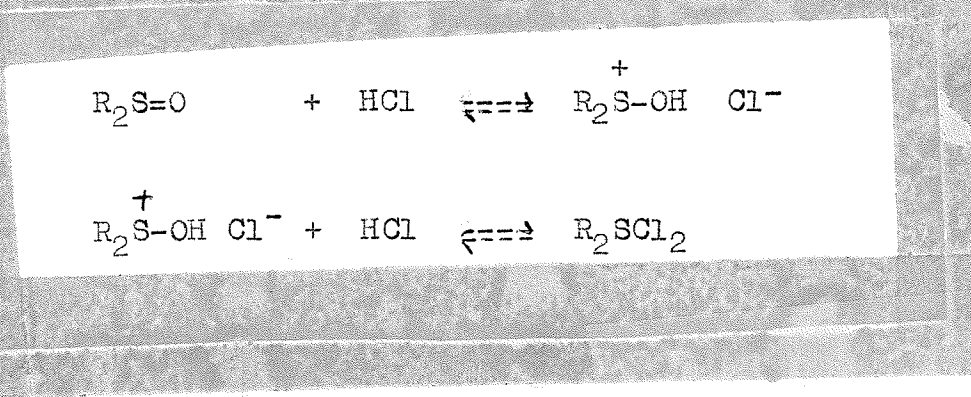
$$(CH_3)_2\underset{\displaystyle Nu}{\overset{|}{S}}{-}OH + Nu^- \xrightarrow{H^+} (CH_3)_2S + H_2O + Nu{-}Nu \qquad \text{Eq-3}$$

In all cases these oxidations are acid catalized, the rate of oxidation being dependent on both the stability of the tetra-coordinated intermediate and the nucleophilicity of the substrate. Either step may be rate determining.

For example DMSO is completely reduced to dimethyl sulfide in the presence of excess hydriodic acid. The mechanism for this reduction proposed by Landini and Montanari (1964) is shown below:



The rate determining step involves nucleophilic attack by iodide ion resulting in electron transfer from iodide to sulfur. However Mislow and co-workers (1964) found that optically active sulfoxides are rapidly racemized but not reduced by hydrochloric acid. The rate of racemization was shown to be sterically controlled. For example (+) phenyl p-tolyl methyl sulfoxide gave a rate constant at 25°C of 3.7×10^{5} sec^{-1} while replacement of the methyl group with t-butyl gave a rate constant of 1.05×10^{3} sec^{-1}.



With hydrobromic acid sulfoxides are both reduced and racemized (Landini and Montanari; 1964). These results agree with the fact that the reducing power of halide ions follow the order $I^- > Br^- > Cl^-$ while the stability of the sulfur-halide bond follows the order $Cl^- > Br^- > I^-$. Thus the weaker sulfur-iodide bond in the tetra co-ordinated intermediate and the greater reducing power of I^- enhances reduction while the stronger sulfur-chlorine bond and lower reducing ability of the chloride ion favors racemization. In other words chloride ion prefers attack at sulfur while iodide ion prefers attack at iodine.

A useful preparation of disulfides involving the oxidation of thiols by sulfoxides has been reported by Wallace (1964). The reactivity of the thiol depends upon its acidity ($ArSH > ArCH_2SH >$ alkyl) and the basicity of the sulfoxide ($TMSO > DMSO > Ar_2SO$). The oxidation mechanism proposed by Wallace and Mahon (1965; 1964) is analogous to the reduction of sulfoxides by hydriodic acid (Landini; 1964). Initial protonation of the sulfoxide is followed by the rate determining formation of the tetra co-ordinated sulfur intermediate (11). Reaction of (11) with another molecule of thiol leads to the formation of the disulfide.

$$(CH_3)_2S{=}O + RSH \longrightarrow (CH_3)_2\overset{+}{S}\text{-}OH \; SR^-$$

$$(CH_3)_2\overset{+}{S}\text{-}OH + SR^- \longrightarrow (CH_3)_2\underset{\underset{(11)}{|}}{S}\text{-}OH \quad SR$$

$$(11) + RSH \longrightarrow R_2S_2 + (CH_3)_2S + H_2O$$

These mechanistic proposals are similar to those proposed for the reaction of trimethylsulfoxonium iodide with thiols (Wallace; 1965) which yield the corresponding methyl aryl sulfides as shown below.

$$(CH_3)_3\overset{+}{S}O \; I^- + ArSH \xrightarrow{HI} (CH_3)_3\overset{+}{S}O \; SAr^-$$

$$(CH_3)_3\overset{+}{S}O + SAr^- \longrightarrow ArSCH_3 + (CH_3)_2S{=}O$$

In contrast to the example cited, the acid catalized oxidation of phosphines (Szmant and Cox; 1966) by DMSO is believed to be brought about by the rate determining nucleophilic attack of the phosphine upon the protonated sulfoxide (12) yielding the unstable phosphonium ion (13). Loss of a proton yields the corresponding phosphine oxide.

$$(CH_3)_2S{=}O + H^+ \longrightarrow (CH_3)_2\overset{+}{S}{-}OH \quad (12)$$

$$(12) + R_3P \longrightarrow R_3\overset{+}{P}{-}OH + (CH_3)_2S \quad (13)$$

$$(13) \longrightarrow R_3P{=}O + H^+$$

Oxidations Dependent on the Nucleophilic Properties of DMSO

One of the most useful applications of DMSO has been its use in oxidizing suitably activated organic compounds to the corresponding aldehyde or ketone. This class of reactions may be divided into two groups depending upon whether the oxygen of the resulting carbonyl group is derived from the compound being oxidized (Class-1) or from DMSO (Class-2). The first class as shown in Eq-4 involves reaction of DMSO with an intermediate activating electrophilic species (E) followed by displacement by substrate, usually an alcohol.

$$(CH_3)_2S{=}O + \overset{+}{E} \longrightarrow (CH_3)_2\overset{+}{S}{-}OE \qquad \text{Eq-4}$$

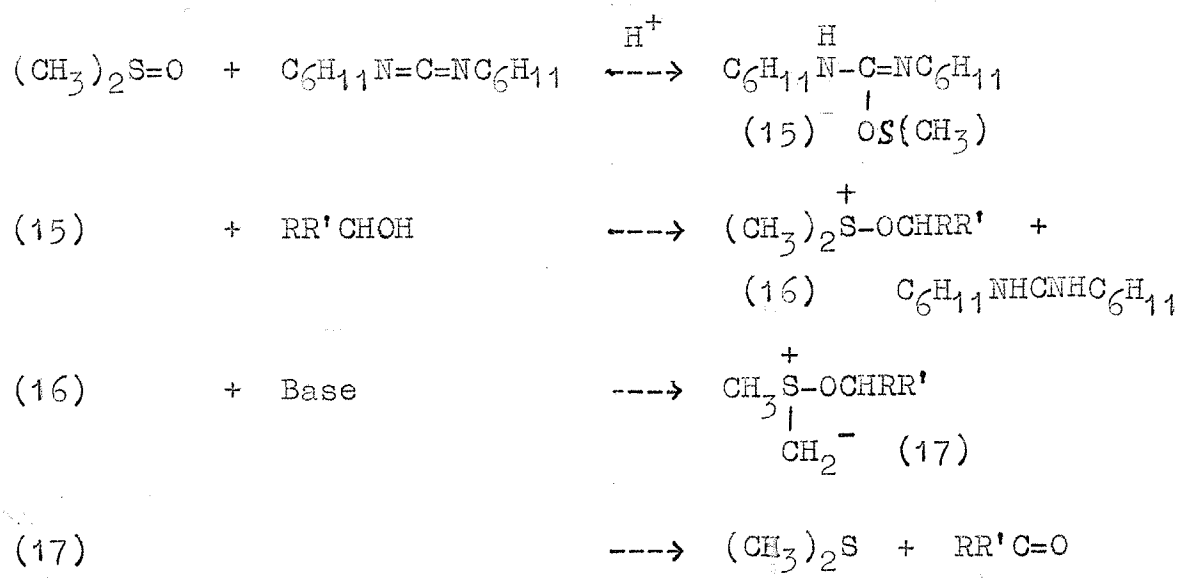
$$(CH_3)_2\overset{+}{S}{-}OE + R'RCHOH \longrightarrow (CH_3)_2\overset{+}{S}{-}OCHR'R \xrightarrow[(14)]{\text{Base}} (CH_3)_2S + R'RC{=}O$$

$$(CH_3)_2S{=}O + R'RCHX \longrightarrow (CH_3)_2\overset{+}{S}{-}OCHR'R \xleftarrow[(14)]{\text{Base}} \qquad \text{Eq-5}$$

The second class as shown in Eq-5 above, involves displacement of a leaving group (X=Cl,Br,I,SO etc.) by DMSO resulting in direct formation of the dimethyl oxysulfonium ion (14). In the presence of base (14) yields the corresponding carbonyl product and dimethyl sulfide.

Class 1 Reactions

Activating agents that have been used to great advantage are dicyclohexylcarbodiimide (DCC) and acetic anhydride. With mixtures of DMSO and DCC, commonly referred to as the Pfitzer-Moffatt reagent, a wide variety of hydroxyl compounds are readily converted to the corresponding carbonyl products. The proposed mechanism for the Pfitzer-Moffatt oxidation is shown below:



Acid catalized nucleophilic attack by DMSO on DCC leads to the adduct (15). The activated sulfur of (15) then enhances the following displacement reaction with a suitable hydroxyl compound leading to the dimethyl oxysulfonium salt (16). Reaction of the dimethyl oxysulfonium salt (16) with base (NN'dicyclohexylurea) yields the corresponding carbonyl

product and dimethyl sulfide. In the presence of deuterium labelled alcohols, labelled dimethyl sulfide was detected (Fenselau and Moffatt; 1966). This evidence supports the intermediate formation of the sulfur ylid (17) followed by intra molecular hydrogen transfer yielding the products.

Compounds that have been oxidized by this method include alcohols, nucleosides, nucleotides and carbohydrates. For example the oxidation of p-nitrobenzyl alcohol by this method gave a 92% yield of p-nitrobenzaldehyde (Pfitzer and Moffatt; 1965) while 1-octanol yielded 100% octanal. Nucleotides possessing a free 3' hydroxyl group react with DMSO and DCC resulting in the cleavage of the glycosidic and the 5' phosphate bond (Pfitzer and Moffatt; 1965). However in the absence of a 3' hydroxyl or in the case of the 3' O-acetyl derivative the 5' position of the nucleoside is oxidized to the 5'aldehyde. The importance of this product is the fact that other oxidative methods lead to the corresponding 5' acid (Moss et.al; 1963). The high yields under mild conditions with this technique has also been found useful for the oxidation of carbohydrates and steroids to the corresponding carbonyl compounds. For example cholestanol is converted to 3-cholestanone in 80% yield with mixtures of DMSO and DCC (Pfitzer and Moffatt; 1965).

The acetic anhydride method developed by Albright and Goldman; (1965) utilizes mixtures of DMSO and acetic anhydride to oxidize primary and secondary alcohols. Yields of the corresponding carbonyl products with this method are generally

lower than those obtained using DMSO and DCC but are superior when the reaction site is subject to marked steric hindrance. The mechanism for the oxidation using DMSO-acetic anhydride is shown below:

$$(CH_3)_2SO + (CH_3CO)_2O \longrightarrow (CH_3)_2\overset{+}{S}-$$

$$(CH_3)_2S{=}O + (CH_3C{=}O)_2O \longrightarrow \underset{(18)}{(CH_3)_2\overset{+}{S}OCCH_3\ O^-} + OAc^-$$

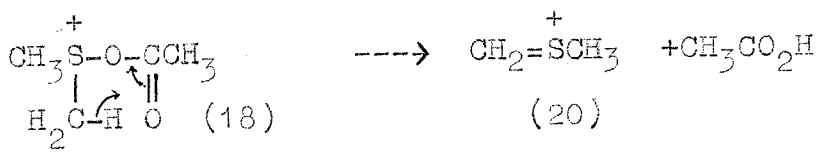
$$(18) + RR'CHOH \longrightarrow \underset{(19)}{(CH_3)_2\overset{+}{S}OCRR'\ H}$$

$$(19) + Base \longrightarrow RR'C{=}O + (CH_3)_2S$$

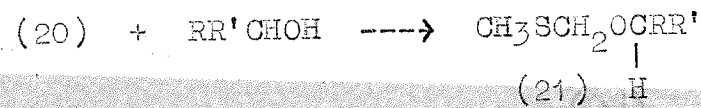
The initial step involves the reaction of DMSO and acetic anhydride to yield the adduct (18), followed by a displacement reaction with alcohol leading to the corresponding dimethyl oxysulfonium salt (19). Reaction of (19) with base leads to the products as shown. For example the reaction of α or β yohimbine with DMSO and acetic anhydride leads to an 85% yield of yohimbinone while a 75% yield of p-nitrobenaldehyde is obtained with p-nitrobenzyl alcohol (Albright and Goldman; 1965).

A major disadvantage of this method however is the formation of methyl thiol methyl ether (21) as a side product

via a Pummerer type rearrangement as shown below:



(18) (20)

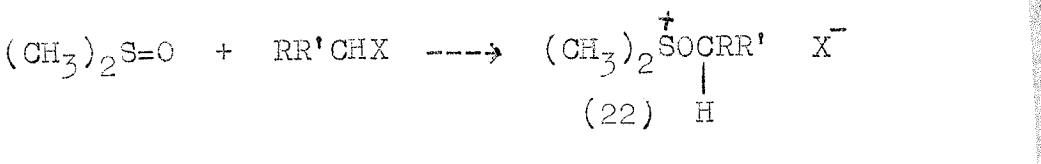


(21)

The DMSO-acetic anhydride adduct (18) loses acetate giving the sulfonium ylid (20) which can also react with the alcohol substrate yielding the corresponding ether (21).

Class 2 Reactions

Displacement of a suitable leaving group by DMSO usually leads directly to the formation of the dimethyloxysulfonium salt (22). Treatment of the salt with base then yields the corresponding carbonyl product and dimethyl sulfide.

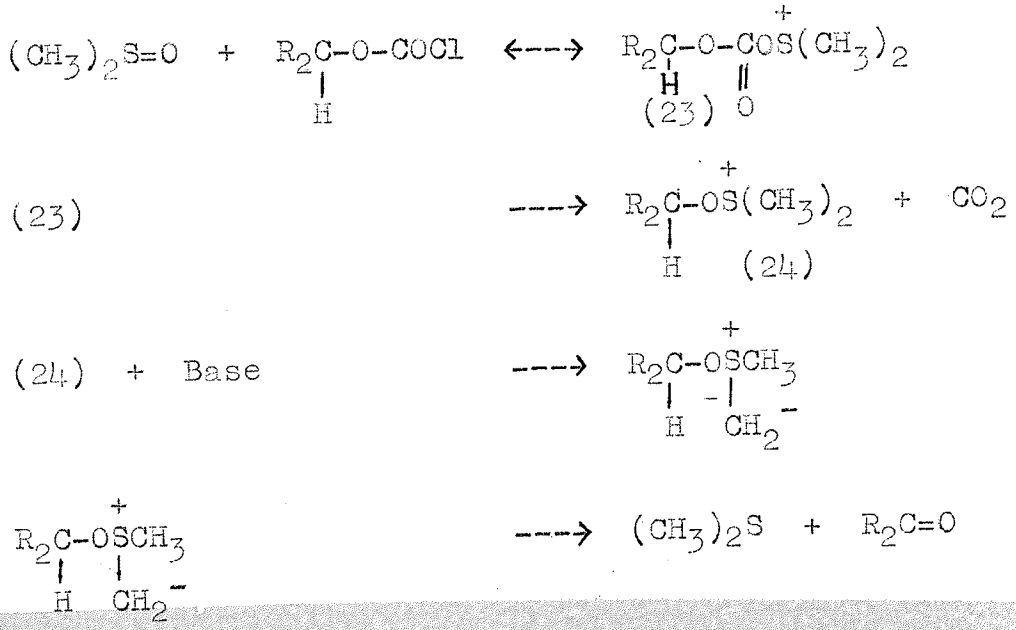


(22)

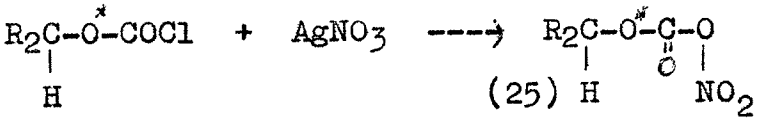
This technique has been found synthetically useful for a variety of organic halides and tosylates since oxidation yields only the carbonyl product, while other functional groups generally remain inert. The order of reactivity toward oxidation follows the order $TsO^- > I^- > Br^- > Cl^-$ so that in general chlorides and bromides are converted to the corresponding tosylates in situ and then oxidized. The most common application of this technique is the oxidation of α-halo esters (Hunsberger and Tien; 1959), phenacyl halides (Major and Hess; 1958), benzyl halides (Nace and Monagle; 1959), primary sulfonates (Nace and Monagle; 1959) and primary iodides (Johnson and Pelter; 1964). For example octyl iodide is oxidized by DMSO in the presence of sodium carbonate giving a 77% yield of octanal (Johnson and Pelter; 1964), while p-bromobenzyl bromide gives a 76% yield of p-bromobenzaldehyde. In comparison to the above, octyl tosylate yields 74% octanal (Kornblum et.al; 1959) while p-bromobenzyl tosylate gives a 65% yield of p-bromobenzaldehyde.

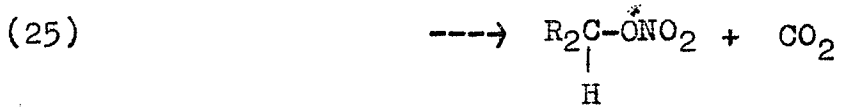
Alkyl chloroformates react rapidly at room temperature in neutral solution, yielding the corresponding di-methyl oxysulfonium salts. Addition of triethyl amine then yields the corresponding aldehydes or ketones. The mechanism proposed by Barton, Garner and Wightman (1964) involves initial displacement of chlorine by DMSO yielding the unstable adduct (23). Rapid collapse of (23) with extrusion of carbon dioxide leads to the di-methyl oxysulfonium salt

(24). Under basic conditions (24) decomposes via the ylid to give the final product as shown below:



The formation of the dimethyl oxysulfonium salt is analogous to the formation of nitrate esters from the reactionof alkyl chloroformates with silver nitrate (Boshan; 1959) and the formation of nitramines from dimethyl carbamyl chlorides and silver nitrate (Norris; 1959). By labelling the chloroformate with O^{18} oxygen, Boshan demonstrated the collapse of the adduct (25) to occur with cleavage of the unlabelled carbon-oxygen bond.





DISCUSSION

DISCUSSION

THE REACTION OF ARYL THIOLCHLOROFORMATES WITH DMSO

Introduction

Dialkylalkyl thiosulfonium ions, $R_2\overset{+}{S}SR'$, are thought to be important intermediates in a number of alkyl sulfide catalized reactions of disulfides and thiolsulfinates (Kice and Large; 1968). The preparation of dimethyl methyl thiolsulfonium 2,4,6 trinitrobenzene sulfonate (26) by the treatment of tri-methyloxonium 2,4,6 trinitrobenzenesulfonate with methyl disulfide (Helmkamp et.al; 1965) has made it possible to study these important intermediates.

$$(CH_3)_2\overset{+}{S}\text{-}SCH_3 \quad SO_2^{-}C_6H_2(NO_2)_2$$

(26)

However the difficulty in the preparation of trimethyloxonium 2,4,6 trinitrobenzenesulfonate is a disadvantage in the procedure. Since Barton, Garner and Wightman (1964) have previously shown that the reaction of alkyl chloroformates and DMSO lead to the corresponding dimethyl alkyl oxysulfonium salt (27), it was thought that the reaction of thiochloroformates with DMSO might lead in an analogous manner to the corresponding dimethyl alkyl or aryl thiolsulfonium salts (28) as shown:

$$R\text{-}X\text{-}COCl + (CH_3)_2S{=}O \longrightarrow (CH_3)_2\overset{+}{S}\text{-}XR \quad Cl^{-} + CO_2$$

(27) X=S

(28) X=O

However the corresponding thiolsulfonium salts could not be isolated and this led to an investigation of the reaction more fully.

Reaction of DMSO with Phenyl Thiolchloroformate

When phenyl thiochloroformate and excess DMSO were mixed at room temperature in carbon tetrachloride, a vigorous exothermic reaction took place with evolution of carbon dioxide and dimethyl sulfide. An extremely hygroscopic white solid and a yellow solution resulted and were separated by filtration and separately investigated.

The yellow solution was evaporated to dryness and the resulting solid purified by column chromotography and recrystallized from methanol. The white crystalline product was identified as phenyl disulfide by its melting point (59°C) and by comparison of its infra red and nmr spectra with those of an authentic sample of phenyl disulfide.

The white hygroscopic solid was insoluble in a variety of organic solvents including carbon tetrachloride, methylene chloride, ether and cold methanol. However addition of water to the solid resulted in a strongly acidic solution. Furthermore hydrolysis of the white solid in deuterium oxide resulted in the formation of an oily organic liquid identified as DMSO by comparison of its nmr and infra red spectrum with an authentic sample.

The mass spectrum of the white solid is shown in Table 1.

Table 1

The Mass Spectrum of Dimethyl Sulfur Dichloride

m/e	Peak Intensity	Proposed Ion
62	100	$(CH_3)_2S$
63	77	
48	71	CH_3Cl
46	67	CH_2S
97	49	$(CH_3)_2SCl$
47	43	CH_3S
36	38	
28	30	
99	19	$(CH_3)_2SCl$
45	8	

The splitting pattern obtained for the solid is similar to the splitting pattern of dimethyl sulfide (Cornu and Bassol; 1966) which has intense peaks at m/e 62,46 and 47. Therefore the peak m/e 62 was attributed to the dimethyl sulfide ion. The peaks at m/e 99 and m/e 97 were then assigned to the dimethyl sulfur chloride ion on the basis that the ratio of the peak intensities (m/e 99 vs m/e 97) were in the correct ratio considering natural isotopes where:

m/e = 97 = $C_2H_6S^{32}Cl^{35}$

m/e = 99 = $C_2H_6S^{34}Cl^{35}$; $C_2H_6S^{32}Cl^{37}$

Furthermore the loss of a chlorine atom from the dimethyl sulfur chloride ion is consistant with the formation of the dimethyl sulfide ion. On the basis of the evidence presented the white solid was tentatively identified as dimethyl sulfur dichloride (26).

$$(CH_3)_2\overset{+}{S}\text{-}Cl \quad Cl^-$$

(26)

The mass spectrum of the solid can be easily explained on the basis of the proposed structure since loss of a chlorine would result in the dimethyl sulfur chloride ion. The absence of a parent peak would probably reflect the low bond dissociation energy of the sulfur-chlorine bond. The formation of DMSO and an acidic solution on hydrolysis of the solid is also consistant with the proposed structure. Hydrolysis of dimethyl sulfur dichloride would conceivibly lead to the formation of DMSO and hydrochloric acid as shown:

$$(CH_3)_2SCl_2 + H_2O \longrightarrow DMSO + 2HCl$$

Hydrolysis of a weighed sample of the solid followed by titration for hydrochloric acid using standardized sodium hydroxide led to an equivalent weight of 65 per chloride ion in agreement with the proposed structure of the solid ($C_2H_6SCl_2$ = 132). Infra red and nmr spectra of the solid were also consistant with the proposed structure (dimethyl sulfur dichloride). The infra red spectrum gave a strong absorption at 880 cm^{-1}, characteristic of sulfur-chlorine stretching vibrations. The nmr spectrum of the solid in a mixture of deutero-chloroform and methyl methyl thiolsulfonate (3:1 v/v) gave a single peak at 3.1 P.P.M. The low field absorption of the methyl groups is consistant with the expected deshielding effects of the electronegative chlorine atoms.

Although an elemental analysis of the solid could not be obtained due to its instability, conclusive proof for the proposed structure (dimethyl sulfur dichloride) was obtained by the synthesis of dimethyl sulfur dichloride by an alternate route. Slow addition of excess thiophosgene to DMSO in ether at 0°C in an inert atmosphere of nitrogen resulted in the formation of a hygroscopic white solid with identical properties to the white hygroscopic solid isolated from the reaction of phenyl thiochloroformate and DMSO. The infra red of the solid gave a strong absorption at 880 cm^{-1} while the nmr spectrum gave a singlet at 3.1 P.P.M. The mass spectrum of the product shown in Table 2 was also identical with the solid isolated in the DMSO-thiolchloroformate reaction.

Table 2

The Mass Spectrum of Dimethyl Sulfur Dichloride

m/e	Peak Intensity
62	100
63	73
48	70
46	61
97	46
47	46
36	36
28	28
99	18
45	12

Although dimethyl sulfur dichloride has previously been postulated an intermediate in a number of reactions (Truce,Biran and McBee; 1952,Mislow et al; 1964, Tsuchiya et al; 1964, Lampert and Smith; 1964), its isolation has heretofore not been reported. The synthesis of dimethyl sulfur dichloride from thio phosgene and DMSO now makes it possible to undertake studies with this compound. Due to its potential importance as a facile oxidant in combination with DMSO a discussion of the studies undertaken with this compound has been placed in a separate section.

In order to determine the stoichiometry of the reaction of phenyl thiolchloroformate and DMSO, various ratios of the reactants were mixed and the resulting products analyzed. Table 3 shows yields of phenyl disulfide obtained when phenyl thiolchloroformate and DMSO were mixed in various ratios. Two methods, shown as A and B in Table 3, were employed to isolate the disulfide product. In method A, DMSO and phenyl thiolchloroformate were allowed to react in carbon tetrachloride at $0^{o}C$ and the resulting solution was neutralized with aqueous sodium bicarbonate followed by removal of volatile products and solvent under vacuum. The resulting yellow solid containing phenyl disulfide was purified by column chromatography and weighed. In method B DMSO and phenyl thiolcholoroformate were allowed to react as in method A and the resulting solution was neutralized and the volatile products and solvent were removed. The resulting product was then redissolved in carbon tetrachloride and excess di-isopropyl amine was added in order

to convert unreacted phenyl thiolchloroformate to the less reactive amide derivative, N-di-isopropyl-S-phenyl thiolcarbamate ($(iC_3H_7)_2NCOSC_6H_5$). Attempts to separate the disulfide and thiolcarbonate quantitatively were unsuccessful. However it was found that the ratios of disulfide to thiolcarbamate could be estimated accurately from the nmr spectrum of the mixture by integration of the peaks. This procedure was tested by treating known amounts of phenyl disulfide and phenyl thiolchloroformate with excess di-isopropyl amine and isolating the product as in method B. The nmr method gave excellent results in comparison to the expected product ratios while separation of the products by column chromotography gave poor results as shown in Table 4.

Table 3

Isolation of Phenyl Disulfide from the Reaction of DMSO and Phenyl Thiolchloroformate

PhSCOCl*	DMSO*	Ph_2S_2*	PhSCON(iPr)2*	Method
0.02	0.03	0.0089(89%)		A
0.028	0.10	0.012 (86%)		A
0.02	0.10	0.0097(97%)		A
0.02	0.04	0.0085(85%)		A
0.02	0.02	0.0076(76%)		A
0.02	0.02	0.0078(78%)	0.0022(11%)	B
0.02	0.01	0.0048(48%)	0.010 (50%)	B
0.04	0.01	0.0038(19%)	0.032 (80%)	B

* gram moles

Table 4

Comparison of nmr vs Chromotography Method for Disulfide-Thiolcarbonate Product Ratios

PhSCOCl*	Ph_2S_2*	$PhSCON(iPr)_2$*	Ph_2S_2*	Method
0.0064	0.0052	0.0061(98%)	0.0052(100%)	nmr
0.0064	0.0052	0.0038(62%)	0.0048(94%)	column chrom.

* gram moles

The results from Table 3 clearly indicate that the formation of 1 mole of phenyl disulfide resulted from the reaction of 2 moles of phenyl thiolchloroformate and 2 moles of DMSO.

In order to identify the volatile products from the reaction, phenyl thiolchloroformate was allowed to react with an excess of DMSO at 40°C in carbon tetrachloride and the volatile products were trapped in an acetone-dry ice bath followed by a liquid nitrogen trap. The product obtained from the liquid nitrogen trap was identified as carbon dioxide by its characteristic absorption at 2350 cm^{-1}. The product obtained from the acetone-dry ice bath was identified as dimethyl sulfide by its boiling point (38°C) and comparison of its infra red and nmr spectra with those of an authentic sample. On the basis of the yields of dimethyl sulfide shown in Table 5 it appears that 1 mole of dimethyl sulfide is produced by the reaction of 2 moles of phenyl thiolchloroformate with an excess of DMSO.

Table 5

Isolation of Dimethyl Sulfide from the Reaction of DMSO and Phenyl Thiolchloroformate

PhSCOCl*	DMSO*	$(CH_3)_2S$*
0.02	0.10	0.0097(97%)
0.02	0.10	0.0096(96%)

* moles

Yields of the hygroscopic white solid, dimethyl sulfur dichloride, obtained by rapid filtration following reaction of equimolar amounts of phenyl thiolchloroformate and DMSO are shown in Table 6,

Table 6

Isolation of Dimethyl Sulfur Dichloride from the Reaction of DMSO and Phenyl Thiolchloroformate

PhSCOCl*	DMSO*	$(CH_3)_2SCl_2$*
0.02	0.02	0.0056(56%)
0.02	0.02	0.0059(59%)

* moles

Due to the instability of the dichloride it was assumed that a large percentage of this product was lost. However the fact that only four products, phenyl disulfide, dimethyl sulfide, carbon dioxide and dimethyl sulfur dichloride, were isolated from the reaction of phenyl thiolchloroformate with DMSO and that 2 moles of phenyl thiolchloroformate were shown to react with 2 moles of DMSO yielding 1 mole of phenyl disulfide (Table 3) and 1 mole of dimethyl sulfide (Table 5), led us to the conclusion that 1 mole of dimethyl sulfur dichloride must

also be formed. This conclusion is consistant with the results shown in Table 6 if the instability of the dichloride is considered. In order to balance the reaction 2 moles of carbon dioxide must also be produced. From the data presented the stoichiometry of the reaction of phenyl thiolchloroformate with DMSO was determined as:

$$2\ PhS\text{-}COCl + 2DMSO \longrightarrow Ph_2S_2 + (CH_3)_2S + (CH_3)_2SCl_2 + 2\ CO_2$$

Reaction of DMSO with p-Chlorophenyl Thiolchloroformate

The reaction of p-chlorophenyl thiolchloroformate with DMSO gave products similar to those obtained from the reaction of phenyl thiolchloroformate and DMSO. Reaction of p-chlorophenyl thiolchloroformate with DMSO in carbon tetrachloride led to the evolution of carbon dioxide and dimethyl sulfide. An extremely hygroscopic white solid and a yellow solution also resulted. The white solid was identified as dimethyl sulfur dichloride by comparison of its infra red and nmr spectra with those of an authentic sample prepared by the action of thiolphosgene on DMSO. The yellow solution was evaporated to dryness and the solid product was purified by column chromotography. The white crystalline product, recrystallized from methanol, was identified as p-chlorophenyl disulfide by its melting point (72°C), by comparison of its infra red spectrum with published values and elemental analysis. Yields of p-chlorophenyl disulfide obtainted when various ratios of DMSO and

p-chlorophenyl disulfide were mixed as shown in Table 7.

Table 7

Reaction of p-Chlorophenyl Thiolchloroformate with DMSO

p-ClPhSCOCl*	DMSO*	p-$ClPh_2S_2$
0.012	0.015	0.0098(82%)
0.0102	0.020	0.0042(85%)

* moles

Although a stoichiometric study of the reaction of DMSO and p-chlorophenyl thiolchloroformate was not undertaken, the fact that the reaction yielded the same products (dimethyl sulfide, dimethyl sulfur dichloride, carbon dioxide and the corresponding disulfide) as the reaction of DMSO with phenyl thiolchloroformate indicates that the stoichiometry of the two reactions are identical;

$$2\ p\text{-ClPhS-COCl} + 2DMSO \longrightarrow p\text{-}ClPh_2S_2 + (CH_3)_2S + (CH_3)_2SCl_2 + 2CO_2$$

$$2\ PhS\text{-}COCl + 2DMSO \longrightarrow Ph_2S_2 + (CH_3)_2S + (CH_3)_2SCl_2 + 2CO_2$$

Results in table 7 also support this conclusion, since 1 moles of p-chlorophenyl disulfide are produced by the reaction of 2 moles of p-chlorophenyl thiolchloroformate with DMSO.

Summary

From the data presented the stoichiometry of the reaction of p-chlorophenyl thiolchloroformate or phenyl thiolchloroformate with DMSO can be summarized as;

$$2\ RS\text{-}COCl + 2DMSO \longrightarrow R_2S_2 + (CH_3)_2SCl_2 + (CH_3)_2S + 2CO_2$$

Although the reaction of a wide variety of aryl thiolchloroformates with DMSO was not attempted, there appears to be no reason why the analogous reactions should not proceed. If this is true then the reaction of aryl thiolchloroformates with DMSO should prove a valuable synthetic route to a variety of aryl disulfides.

The reaction of DMSO with aryl thiolchloroformates or the action of thio phosgene on DMSO have also been found to be easy routes to the synthesis of dimethyl sulfur dichloride, an important intermediate in a number of reactions. Thus a direct study of the compound can now be undertaken since previous workers were unable to isolate it.

DISCUSSION

THE REACTION OF ALKYL THIOLCHLOROFORMATES WITH DMSO

Results

As in the case of the aryl thiolchloroformates, the reaction of alkyl thiolchloroformates with DMSO were expected to yield similar products (dimethyl sulfide, dimethyl sulfur dichloride, carbon dioxide and the corresponding disulfide). In all cases studied the addition of DMSO to an alkyl thiolchloroformate (alkyl= CH_3, C_2H_5, n-C_3H_7, i-C_3H_7, t-C_4H_9) led to a vigorous exothermic reaction with the evolution of carbon dioxide and dimethyl sulfide. In all cases the hygroscopic white salt, dimethyl sulfur dichloride, could also be isolated,

As in the case of the aryl thiolchloroformates, the reaction of t-butyl thiolchloroformate or i-propyl thiolchloroformate with excess DMSO in methylene chloride at room temperature led to the formation of the corresponding disulfide, The corresponding disulfide products were identified by comparison of their boiling points, infra red and nmr spectra and their refractive indexes with authentic samples prepared by the method of Vogel and Conan (1943). Yields of the corresponding disulfides obtained from the reaction of t-butyl and i-propyl thiolchloroformate with DMSO are given in Table 8.

Table 8

Reaction of t-Butyl and i-Propyl Thiolchloroformate with DMSO. Isolation of Disulfides

R	RSCOCl	DMSO	R_2S_2	Time (hr.)
t-C_4H_9	.03	.05	.013 (84%)	3.0
i-C_3H_7	.1	.2	.041 (82%)	10.0
i-C_3H_7	.1	.2	.038 (76%)	3.0

* moles

The yields of disulfide shown in Table 8 and the fact that carbon dioxide, dimethyl sulfur dichloride and dimethyl sulfide were isolated from the reaction of t-butyl or i-propyl thiolchloroformate and DMSO indicates that the stoichiometry of these reactions are the same as the corresponding aryl thiolchloroformates:

$$2\ RS\text{-}COCl + 2DMSO \longrightarrow R_2S_2 + 2CO_2 + (CH_3)_2SCl_2 + (CH_3)_2S$$

Variation of the reaction time as shown in Table 8 did not have any effect on the reaction products.

When n-propyl thiolchloroformate and excess DMSO were mixed in methylene chloride, vacuum distillation of the resulting solution yielded two higher boiling products. The lower boiling product (bp=40°C/0.4mmHg)was identified as i-propyl disulfide by comparison of its infra red spectrum, nmr spectrum, boiling point and refractive index with an authentic sample prepared by the method of Vogel and Conan (1943).

The infra red spectrum of the higher boiling component (bp=96°C/0.4mmHg) showed characteristic sulfone

absorptions at 1140 and 1350 cm^{-1} while the refractive index and boiling point were consistant with those obtained by Boldyrev, Litkovets and Trofimora (1956) for n-propyl n-propyl thiolsulfonate. Although evolution of carbon dioxide subsided after 15 minutes, leaving the reaction for longer periods of time resulted in higher yields of n-propyl n-propyl thiolsulfonate and lower yields of n-propyl disulfide as shown in Table 9.

Table 9

Reaction of n-Propyl Thiolchloroformate with DMSO. Isolation of Higher Boiling Products

$n\text{-}C_3H_7SCOCl$*	DMSO*	$(n\text{-}C_3H_7)_2S_2$*	$(n\text{-}C_3H_7)_2SO_2S$*	Time (hr.)
0.1	0.2	.013 (25%)	.031 (61%)	1.0
0.1	0.2	.0054(12%)	.036 (78%)	10.0

These results indicated that n-propyl disulfide was being converted to the corresponding thiolsulfonate, probably by a slow oxidative process in the presence of DMSO.

When ethyl thiolchloroformate and excess DMSO were reacted in methylene chloride, ethyl ethyl thiolsulfonate was the only higher boiling product isolated as shown in Table 10. Examination of the products by vapor phase chromatography did not indicate the presence of ethyl disulfide.

Table 10

Reaction of Ethyl Thiolchloroformate with DMSO. Isolation of Higher Boiling Products

C_2H_5SCOCl*	DMSO*	$(C_2H_5)_2S_2$*	$C_2H_5SO_2SC_2H_5$*	$C_2H_5SCON(i\text{-}C_3H_7)_2$*
.0415	.0830	.015 (72%)	-	-
.1	.2	.035 (70%)	-	-
.075	.15	.038(100%)	-	-
.1	.1	.0136(28%)	.0107 (22%)	.0262 (26%)

* moles

When equimolar quantities of DMSO and ethyl thiolchloroformate were mixed (see Table 10), both ethyl ethyl thiolsulfonate and ethyl disulfide were isolated. Unreacted ethyl thiolchloroformate was converted to N-di-i-propyl-S-ethyl thiolcarbamate by treatment with di-i-propyl amine in the same manner as was done in the reaction of phenyl thiolchloroformate and DMSO.

The reaction of methyl thiolchloroformate with excess DMSO yielded methyl methyl thiolsulfonate as the only high boiling product. When equimolar amounts of methyl thiolchloroformate and DMSO were reacted, methyl methyl thiolsulfonate and unreacted methyl thiolchloroformate were isolated. No methyl disulfide could be detected in the product by means of vapor phase chromotography. Results are shown in Table 11.

Table 11

Reaction of Methyl Thiolchloroformate with DMSO. Isolation of Higher Boiling Products

CH_3SCOCl *	DMSO *	$CH_3SO_2SCH_3$ *	CH_3SCOCl *
0.1	0.2	.047 (94%)	-
0.1	0.13	.031 (62%)	.030 (30%)
0.1	0.1	.018 (36%)	.048 (48%)

* moles

Studies were initiated to determine the stoichiometry of the reaction of methyl thiolchloroformate and DMSO. Results in Table 11 indicate that 2 moles of DMSO react with 1 mole of methyl thiolchloroformate, yielding 0.5 moles of methyl methyl thiolsulfonate. Yields of dimethyl sulfide and dimethyl sulfur dichloride are shown in Table 12.

Table 12

Reaction of Methyl Thiolchloroformate with DMSO. Isolation of Dimethyl Sulfide and Dimethyl Sulfur Dichloride

CH_3SCOCl *	DMSO *	$(CH_3)_2S$ *	$(CH_3)_2SCl_2$ *
.017	.036		.006 (75%)
.01	.02	.013(87%)	

* moles

From the data obtained the stoichiometry of the reaction of DMSO and methyl thiolchloroformate was determined as;

$$2(CH_3)_2S{=}O + 2CH_3SCOCl \longrightarrow CH_3SO_2SCH_3 + (CH_3)_2SCl_2 + 2(CH_3)_2S + 2CO_2$$

Discussion

It is possible that the products of the present reactions (disulfide or thiolsulfonate) are formed by two separate pathways. However it is significant that in the case where n-propyl thiolchloroformate was reacted with DMSO (Table 9), the ratio of n-propyl n-propyl thiolsulfonate to n-propyl disulfide increases with time. This suggests that the thiolsulfonate is formed from the disulfide by an oxidative process that releases dimethyl sulfide. The isolation of ethyl disulfide when equimolar amounts of ethyl thiolchloroformate and DMSO are reacted further supports the hypothesis. The fact that only methyl methyl thiolsulfonate is isolated when methyl thiolchloroformate and DMSO were reacted suggests that the rate of oxidation of methyl disulfide is much faster than its rate of formation. If the oxidation of the disulfide to the thiolsulfonate is a sterically controlled process as the results above would appear to indicate, the relative rates of oxidation would follow the order shown below:

$$CH_3 > C_2H_5 > n\text{-}C_3H_7 \gg i\text{-}C_3H_7 = t\text{-}C_4H_9$$

DISCUSSION

MECHANISTIC STUDIES OF THE REACTION OF THIOLCHLOROFORMATES WITH DMSO

Introduction

Thiolsulfonium ions are believed to be important intermediates in a number of alkyl sulfide catalized reactions of disulfides and thiolsulfinates (Kice and Markved, 1964; Kice and Large, 1968a). Studies by Kice,

$R_2\overset{+}{S}-SR$	RSSR	RSOSR	RSO_2SR
Thiolsulfonium Ion	Disulfide	Thiolsulfinate	Thiolsulfonate

Vernier and Heasley (1967) have shown that the rate of reaction of thiolsulfinates with sulfonic acids is dramatically increased by the addition of small amounts (10^{-5}M) of n-alkyl sulfides. The catalytic effect of the sulfide is believed to be the result of the formation of the di-alkyl aryl thiolsulfonium intermediate (29) as shown below:

$$C_6H_5\overset{\overset{O}{\|}}{S}-SC_6H_5 + H^+ \longrightarrow C_6H_5\overset{\overset{OH}{|}}{\overset{+}{S}}-SC_6H_5$$

$$C_6H_5\overset{\overset{OH}{|}}{\overset{+}{S}}-SC_6H_5 + R_2S \longrightarrow R_2\overset{+}{S}-SC_6H_5 + C_6H_5SOH$$

(29)

$$(29) + ArSO_2H \longrightarrow ArSO_2-SC_6H_5 + R_2S + H^+$$

Intermediates such as (29) are known to undergo

extremely rapid nucleophilic substitution at sulfenyl sulfur. This point was dramatically demonstrated by Kice and Favstritsky (1969). The rate of exchange of dimethyl sulfide with the dimethyl methyl thiolsulfonium ion (30) was shown to be approximately $10^5 M^{-1}sec^{-1}$ at 0°C in acetonitrile.

$$(CH_3)_2S + CH_3S\text{-}\overset{+}{S}(CH_3)_2 \rightleftharpoons (CH_3)_2\overset{+}{S}\text{-}SCH_3 + (CH_3)_2S$$

(30)

Mechanistic Studies of the Reaction of Thiolchloroformates with DMSO. Formation of Disulfides

In the present studies the formation of the disulfide products from the reaction of aryl (or alkyl) thiolchloroformates with DMSO can be rationalized by proposing the initial formation of the corresponding dimethyl alkyl (or aryl) thiolsulfonium intermediates. Initial nucleophilic displacement of chloride by DMSO would result in the formation of the unstable intermediate (31). Extrusion of carbon dioxide would then yield the corresponding dimethyl thiolsulfonium ion (32), as shown in Scheme 1. The thiolsulfonium intermediate (32) would then be expected to undergo rapid nucleophilic substitution with another molecule of thiolchloroformate, yielding the unstable intermediate (33). The formation of (33) could conceivably involve either direct attack by the lone pair electrons on the sulfur atom of the thiolchloroformate with extrusion of dimethyl sulfide

Scheme 1

$$(CH_3)_2S{=}O + RSCOCl \longleftrightarrow RSC(=O)-O-\overset{+}{S}(CH_3)_2 \quad (31)$$

$$(31) \longrightarrow RS-\overset{+}{S}(CH_3)_2 + CO_2 \quad (32)$$

$$(32) + RSCOCl \xrightarrow{a} RS\overset{+}{S}(R)-COCl\ Cl^- + (CH_3)_2S \quad (33)$$

$$(32) + RSCOCl \xrightarrow{b} RS-S(CH_3)_2 \text{ (on } RSCOCl) \quad (33)$$

$$(33) + (CH_3)_2S{=}O \longrightarrow RSSR + (CH_3)_2\overset{+}{S}OCOCl\ Cl^- \longrightarrow RSSR + CO_2 + (CH_3)_2SCl_2$$

Scheme 2

$$(CH_3)_2S{=}O + CH_3SCOCl \longrightarrow CH_3S\overset{+}{S}(CH_3)_2\ Cl^- + CO_2 \quad (34)$$

$$(34) + i\text{-}C_3H_7SH \longrightarrow CH_3SSi\text{-}C_3H_7 + (CH_3)_2S + HCl$$

$$(34) + CH_3SCOCl \xrightarrow{DMSO} (CH_3)_2S_2 + CH_3SO_2SCH_3 + CO_2 + (CH_3)_2SCl_2 + (CH_3)_2S$$

$$(CH_3)_2SCl_2 + i\text{-}C_3H_7SH \longrightarrow (CH_3)_2\overset{+}{S}Si\text{-}C_3H_7\ Cl^- + HCl \quad (35)$$

$$(35) + i\text{-}C_3H_7SH \longrightarrow (i\text{-}C_3H_7)_2S_2 + HCl + (CH_3)_2S$$

(pathway a) or a cyclic pathway involving initial nucleophilic attack by carbonyl oxygen followed by an intra molecular rearrangement (pathway b) as shown. Either pathway would be equally favored by the ability of dimethyl sulfide to act as a facile leaving group. Nucleophilic attack by DMSO on (33) would lead to the products as indicated.

This mechanism is consistent with the stoichiometry of the reaction of phenyl thiolchloroformate with DMSO as shown on page 31.

Although the dimethyl thiolsulfonium intermediates could not be isolated, Kice and Large (1968b) have previously shown that di-alkyl aryl thiolsulfonium ions are "trapped" by n-alkyl mercaptans, yielding the corresponding n-alkyl aryl disulfide. In the present studies, when DMSO and methyl thiolchloroformate were mixed in the presence of i-propyl mercaptan, the products obtained were i-propyl methyl disulfide, methyl disulfide, i-propyl disulfide and methyl methyl thiolsulfonate. The formation of i-propyl methyl disulfide strongly suggested the presence of the dimethyl methyl thiolsulfonium ion (34). It is suggested that these products arise as shown in Scheme 2.

The dimethyl methyl thiolsulfonium ion (34) formed by the reaction of DMSO and methyl thiolchloroformate can react with either i-propyl mercaptan or can further react with methyl thiolchloroformate and DMSO yielding the product as indicated. In a separate experiment it was shown that the reaction of i-propyl mercaptan and methyl sulfur dichloride

yielded i-propyl disulfide. This reaction probably involves initial nucleophilic attack by mercaptan resulting in the formation of the dimethyl i-propyl thiolsulfonium ion (35) which reacts with another molecule of mercaptan to yield i-propyl disulfide as shown in Scheme 2.

Mechanistic Studies of the Reaction of Thiolchloroformates with DMSO. Formation of Thiolsulfonates

It was suggested previously that disulfides are precursors of the thiolsulfonates that are formed when primary alkyl thiolchloroformates react with DMSO. Depending on the reaction conditions used, mixtures of the corresponding disulfides and thiolsulfonates were obtained from the reaction of DMSO with ethyl or n-propyl thiolchloroformate, but no direct evidence for the formation of methyl disulfide was obtained when DMSO and methyl thiolchloroformate were reacted. However methyl disulfide was obtained at the expense of methyl methyl thiolsulfonate when i-propyl mercaptan was introduced. Since dimethyl sulfur dichloride is also formed as a product of these reactions and since i-propyl mercaptan reacts rapidly with dimethyl sulfur dichloride, it seems likely that the thiolsulfonates were produced by an oxidative process dependant on the intervention of dimethyl sulfur dichloride. Further evidence for this view will now be presented.

It was demonstrated experimentally that in the presence of dimethyl sulfur dichloride, methyl disulfide was oxidized rapidly by DMSO to methyl methyl thiolsulfonate at room

temperature. It was also found that no appreciable change in the concentration of dimethyl sulfur dichloride occurred during the oxidation. However in the absence of dimethyl sulfur dichloride the oxidation did not take place under similar conditions. In fact oxidation of methyl disulfide by DMSO did not take place at 80°C.

Three methods were used to generate dimethyl sulfur dichloride. In the first method, excess DMSO was added to a solution of methyl disulfide containing small amounts of methyl or i-propyl thiolchloroformate. Results are shown in Table 13. The second method involved the isolation of dimethyl sulfur dichloride from the reaction of phenyl or methyl thiolchloroformate and DMSO. The isolated salt was then added to a solution of DMSO and methyl disulfide in methylene chloride. Results are shown in Table 14. In the last method the salt was generated by the action of excess thiophosgene on DMSO and added to a solution of methyl disulfide and DMSO. Results are shown in Table 14.

It was also found that when methyl disulfide was added to a solution of DMSO and anhydrous hydrogen chloride in methylene chloride, methyl methyl thiolsulfonate was produced as shown in Table 15. This is not surprising since Tsuchiya, Iriyama and Umezama (1964) have proposed the formation of dimethyl sulfur dichloride from solutions of DMSO and hydrochloric acid as shown below:

$$(CH_3)_2S{=}O + HCl \longleftrightarrow CH_3\overset{+}{S}(OH)CH_3\ Cl^- \overset{HCl}{\rightleftharpoons} CH_3\overset{+}{S}(Cl)CH_3\ Cl^- + H_2O$$

Table 13

Oxidation of Methyl Disulfide by DMSO in the presence of Thiolchloroformate

RSCOCl	R	DMSO	$(CH_3)_2S_2$	$CH_3SO_2SCH_3$
.065	$i\text{-}C_3H_7$	.265	0.1	.098 (96%)
.02	CH_3	.22	0.1	.103 (94%)
.01	CH_3	.22	0.1	.101 (91%)

* moles

Table 14

Oxidation of Methyl Disulfide by DMSO in the presence of Dimethyl Sulfur Dichloride

DMSO	$(CH_3)_2S_2$	$(CH_3)_2SCl_2$	$CH_3SO_2SCH_3$
.21	0.1	.0060	.096 (96%)
.21	0.1	.0064	.094 (94%)
.10	0.05	.0136	.046 (92%)
.21	0.1	.0057	.092 (92%)

* moles

Table 15

Oxidation of Methyl Disulfide by DMSO in the presence of Hydrochloric Acid

$(CH_3)_2S_2$	DMSO	HCl	$CH_3SO_2SCH_3$
.05	.11	trace	.048(96%)
.05	.10	.014	.049 (98%)

* moles

In the absence of DMSO, dimethyl sulfur dichloride was found to react rapidly with methyl disulfide in methylene chloride at room temperature. The reaction was characterized by the formation of a white insoluble solid, with extrusion of methyl sulfide. Attempts to characterize the solid were unsuccessful. However addition of DMSO to the solid followed by immediate neutralization of the solution with aqueous sodium bicarbonate resulted in the isolation of equal amounts of methyl methyl thiolsulfonate and methyl disulfide. Results are shown in Table 16.

Table 16

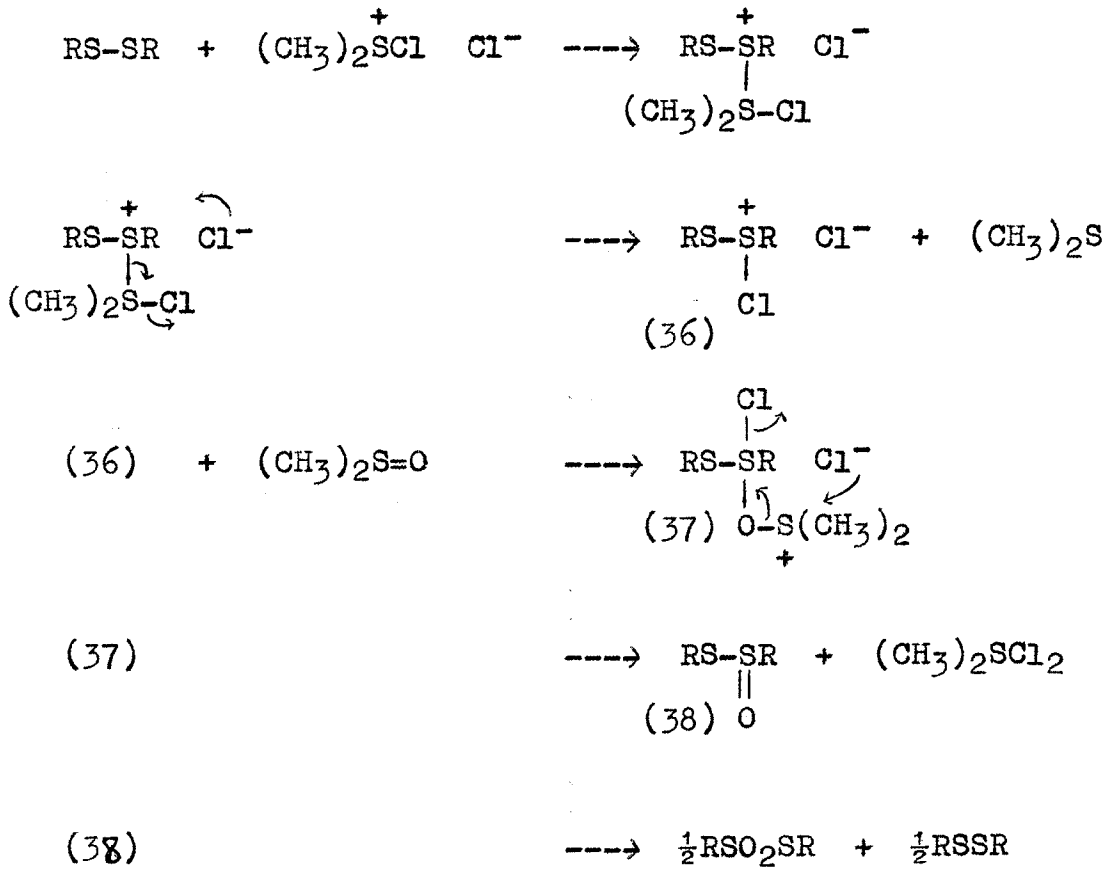
Reaction of Dimethyl Sulfur Dichloride and Methyl Disulfide

$(CH_3)_2SCl_2$*	$(CH_3)_2S$*	DMSO*	$(CH_3)_2S_2$*	$CH_3SO_2SCH_3$*
.015	.015	.05	.0048 (32%)	.0049 (33%)

* moles

On the basis of the evidence presented, a mechanism for the oxidation of disulfide by DMSO in the presence of dimethyl sulfur dichloride is proposed as shown on the following page (Scheme 3). The initail step involves nucleophilic attack by disulfide on dimethyl sulfur dichloride, leading to the disulfide dichloride adduct (36). Attack by DMSO on the adduct (36) could lead to the unstable oxysulfonium intermediate (37) which would then decompose resulting in the regeneration of dimethyl sulfur dichloride and formation of the corresponding thiolsulfinate ester (38) as shown.

Scheme 3


RS-SR + (CH3)2SCl Cl−
RS-SR Cl−
(CH3)2S-Cl
RS-SR Cl−
(CH3)2S-Cl
RS-SR Cl− + (CH3)2S
Cl
(36)
(36) + (CH3)2S=O
Cl
RS-SR Cl−
O-S(CH3)2
(37)
(37)
RS-SR + (CH3)2SCl2
O
(38)
(38)
½RSO2SR + ½RSSR

Disproportionation of the thiolsulfinate ester results in the formation of the corresponding thiolsulfonate ester and disulfide.

Methyl disulfide dichloride (36) has previously been prepared by Schneider (1951) by slow addition of a cold solution of chlorine in carbon tetrachloride to methyl mercaptan in carbon tetrachloride at -15°C. Initial oxidation of the mercaptan to methyl disulfide followed by chlorination was proposed for the formation of the salt. When excess DMSO was added to freshly prepared methyl disulfide dichloride (prepared by the method of Schneider) in methylene chloride at 0°C, a violent reaction took place with the evolution of methyl sulfide. The product was identified as methyl methyl thiolsulfonate. In a separate experiment the regeneration of dimethyl sulfur dichloride was also demonstrated. When DMSO in anhydrous ether was added slowly to methyl disulfide dichloride at 0°C and the solution left for 10 hours at -10°C, a large percentage of dimethyl sulfur dichloride could be isolated. Results are shown in Table 17.

Table 17

DMSO*	$(CH_3)_2S_2Cl_2$*	$CH_3SO_2SCH_3$*	$(CH_3)_2SCl_2$*
.01	.02	.017 (85%)	
.05	.025		.014 (56%)

* moles

These results suggest that the initial formation of the disulfide dichloride adduct (36) is rate determining. On formation, methyl disulfide dichloride reacts rapidly with DMSO giving the products. These results are also consistent with the fact that the concentration of dimethyl sulfur dichloride is constant. The dimethyl sulfur dichloride reacts initially with the disulfide with formation of methyl disulfide dichloride (36). Reaction of (36) with DMSO followed by decomposition of the adduct (37) leads to regeneration of dimethyl sulfur dichloride.

When reactions of methyl disulfide, DMSO and dimethyl sulfur dichloride were monitored by nmr, no absorptions corresponding to methyl methyl thiolsulfinate (CH_3SOSCH_3) could be detected. This evidence suggests that the dispropriation of methyl methyl thiolsulfinate is rapid. Several workers (Kice, Venier and Heasley, 1967; Barnard, 1957) have shown that in the presence of acid, aryl thiolsulfinates rapidly disproprionate to the corresponding disulfide and thiolsulfonate as shown.

$$ArSOSAr \xrightarrow{H^+} ArSO_2SAr + ArSSAr$$

Catalytic amounts of methyl disulfide dichloride, dimethyl sulfur dichloride or hydrogen chloride added to solutions of methyl methyl thiolsulfinate caused violent reactions at room temperature in methylene chloride. Equimolar amounts of methyl methyl thiolsulfonate and methyl disulfide were isolated as shown in Table 18. Methyl methyl

thiolsulfinate was prepared by the slow addition of an equimolar amount of MCPA (meta-chloroperbenzoic acid) in chloroform to methyl disulfide in chloroform at 0°C.

Table 18

Dispropriation of Methyl Methyl Thiolsulfinate

CH_3SOCH_3*	Catalyst	$CH_3SO_2SCH_3$*	$(CH_3)_2S_2$*
.038	$(CH_3)_2S_2Cl_2$	.014	.015
.05	HCl	.023	.022
.05	$(CH_3)_2SCl_2$	.022	.023
.05	DMSO	no reaction	
.05	$CH_3SO_2SCH_3$	no reaction	

* moles

Kinetics of the Oxidation of Methyl Disulfide

Kinetic studies of the system methyl disulfide-DMSO-dimethyl sulfur dichloride were chosen as a model system for the oxidation of disulfides to thiolsulfonates by DMSO in the presence of dimethyl sulfur dichloride. Rates were measured by following the rate of disappearance of methyl disulfide and the rate of appearance of methyl methyl thiolsulfonate by nmr as a function of peak height. Results in Table 19 show that under the conditions, the rate of disappearance of methyl disulfide and the rate of appearance of methyl methyl thiolsulfonate yield first order kinetics. Furthermore the rates of formation of methyl methyl thiolsulfonate and disappearance of methyl disulfide within experimental error are identical. This fact implies that the initial step is rate determining. That the reaction is first order in

disulfide is evident by the fact that the rate constant does not vary with changes in DMSO concentration. The kinetic order of dimethyl sulfur dichloride must be zero since it is conserved during the reaction. However changes in initial concentrations of dimethyl sulfur dichloride do effect the rate (Table 19) and must therefore take part in the rate determining step. The experimental first order rate constant (k_1) therefore must contain a term for the concentration of dimethyl sulfur dichloride. The true rate constant (k_t) then is the experimental rate constant (k_1) divided by the concentration of dimethyl sulfur dichloride as derived below.

$$\text{rate} = -\frac{d\,[(CH_3)_2S_2]}{dt} = k_1[(CH_3)_2S_2]$$
$$= k_t[(CH_3)_2S_2].[(CH_3)_2SCl_2]$$

Attempts to determine the true rate constant however, were unsuccessful. This was probably due to the fact that the salt, dimethyl sulfur dichloride, was decomposing slowly during the reaction in methylene chloride. Attempts to find better solvent systems were hindered by the fact that dimethyl sulfur dichloride was unstable in most polar solvents.

The kinetics of the reaction of methyl disulfide and dimethyl sulfur dichloride show second order kinetics in the absence of DMSO as shown in Table 20. These results are consistent since in the presence of DMSO, di-methyl sulfur dichloride is regenerated as in the proposed mechanism (Scheme 3). In the absence of DMSO the kinetic order of

Table 19

Kinetics of the Reaction of Methyl Disulfide with DMSO in the Presence of Dimethyl Sulfur Dichloride at 40°C.

$(CH_3)_2S_2$*	$(CH_3)_2SCl_2$*	DMSO*	k_1[a] (min^{-1})	k_1[b] (min^{-1})	k_T ($min^{-1}M^{-1}$)
.0043	.0043	.0086	.013 ± .003	.016 ± .002	37
.0043	.0062	.0086	.072 ± .003	.070 ± .002	11
.0043	.0073	.0086	.11 ± .02	.12 ± .02	16

[a] rate of disappearance of methyl disulfide

[b] rate of appearance of methyl methyl thiolsulfonate

Table 20

Kinetics of the Reaction of Methyl Disulfide with Dimethyl Sulfur Dichloride at 40°C.

$(CH_3)_2S_2$*	$(CH_3)_2SCl_2$*	k_2[c] (1 M^{-1} min^{-1})
.015	.015	65 ± 5
.005	.0076	219 ± 14

[c] rate of disappearance of methyl disulfide

* moles

dimethyl sulfur dichloride must change from zero to first order.

Summary

A mechanism has been proposed to account for the formation of disulfides from the reaction of the corresponding thiolchloroformates with DMSO as shown in Scheme 1. The proposed mechanism involves initial nucleophilic attack by DMSO on the thiolchloroformate leading to the corresponding dimethyl alkyl (or aryl) thiolsulfonium ion (32), which undergoes further attack by thiolchloroformate and DMSO yielding the corresponding alkyl (or aryl) disulfide. Support for the proposed mechanism was obtained by "trapping" out the dimethyl methyl thiolsulfonium ion with i-propyl mercaptan. Futhermore the stoichiometry of the reaction of phenyl thiolchloroformate with DMSO was consistant.

A mechanism has also been proposed to account for the formation of the corresponding alkyl alkyl thiolchloroformates from the reaction of less sterically hindered alkyl thiolchloroformates with DMSO involving the oxidation of initially formed disulfide by DMSO in the presence of dimethyl sulfur dichloride. The proposed mechanism involves initial attack by disulfide on dimethyl sulfur dichloride leading to the formation of the di-alkyl disulfide dichloride adduct (36). Replacement of chloride ion by DMSO followed by decomposition of the adduct leads to the corresponding thiolsulfinate and dimethyl sulfur dichloride. Dispropriation of the thiolsulfinate then leads to equimolar quantities of the corres-

ponding thiolsulfonate and disulfide. Evidence supporting this mechanism is listed below:

(1) The stoichiometry of the reaction of methyl thiolchloroformate and DMSO was consistant with the proposed mechanism.

(2) Methyl disulfide was rapidly oxidized by DMSO to methyl methyl thiolsulfonate in the presence of dimethyl sulfur dichloride. In the absence of the dichloride no oxidation took place.

(3) Dimethyl sulfur dichloride and methyl disulfide reacted rapidly to yield a white solid. Addition of DMSO to the solid followed by immediate neutralization of the solution yielded equimolar amounts of methyl methyl thiolsulfonate and methyl disulfide.

(4) Methyl methyl thiolsulfinate in the presence of acid, yielded equimolar amounts of methyl disulfide and methyl methyl thiolsulfonate.

(5) Addition of DMSO to methyl disulfide dichloride resulted in the formation of methyl methyl thiolsulfonate and dimethyl sulfur dichloride.

DISCUSSION

Studies with Dimethyl Sulfur Dichloride

Indroduction

The presence of dimethyl sulfur dichloride as an intermediate in a number of reactions has been postulated. For example Truce, Birum and McBee (1952) postulated the presence of dimethyl sulfur dichloride as an intermediate in the chlorination of dimethyl sulfide with sulfuryl and thionyl chloride. The racemization of sulfoxides in the presence of hydrochloric acid is also believed to involve initial formation of the corresponding sulfur dichloride intermediate (40) (Mislow et al, 1964; Tsuchiya et al, 1964).

$$R_2S + HCl \rightleftharpoons R_2SCl_2 + H_2O$$

(40)

Lampert and Smith (1964) indicated that the reaction of sulfoxides with group 3 and 4 halides leads to the corresponding sulfur dihalide product while Copley et al (1964) indicated the formation of dimethyl sulfur dichloride from the reaction of niobium pentaflouride and DMSO. However neither of these workers attempted to isolate the products.

Preparation of Dimethyl Sulfur Dichloride

Although dimethyl sulfur dichloride could be isolated from the reaction of alkyl or aryl thiolchloroformates and DMSO, the method of choice for the preparation of the compound was by the slow addition of excess thiolphosgene to DMSO in anhydrous ether under a nitrogen atmosphere as previously

described. Yields of dimethyl sulfur dichloride by this method were of the order of 75%.

Exchange Reaction of DMSO and Dimethyl Sulfur Dichloride

Nmr studies showed that the addition of dimethyl sulfur dichloride to DMSO in a solution of deutero-chloroform and methyl methyl thiolsulfonate led to the collapse of the separate resonances of the methyl protons of DMSO and dimethyl sulfur dichloride into a sharp singlet. Further studies showed that the position of the singlet was directly proportional to the ratio of DMSO and dimethyl sulfur dichloride. This fact indicated a rapid exchange reaction rather than the formation of a complex was taking place between the two species. Low temperature nmr studies were undertaken (37°C to -60°C) and it was found that no peak splitting took place even at -60°C. Results are shown in Table 21. From the data the rate of exchange of DMSO and dimethyl sulfur dichloride must be at least $3X10^{-2}$ sec^{-1} under these conditions. This figure was obtained from the equation shown below where τ is the exchange rate and V_a-V_b is the difference in chemical shift between the two species at the coalescence temperature. Since the coalescence temperature was below -60°C, a minimum exchange rate could be obtained by using values obtained at -60°C.

$$\tau = \frac{\sqrt{2}}{2\pi(V_a-V_b)}$$

The mechanism of the exchange reaction probably involves nucleophilic displacement of chloride by DMSO followed by

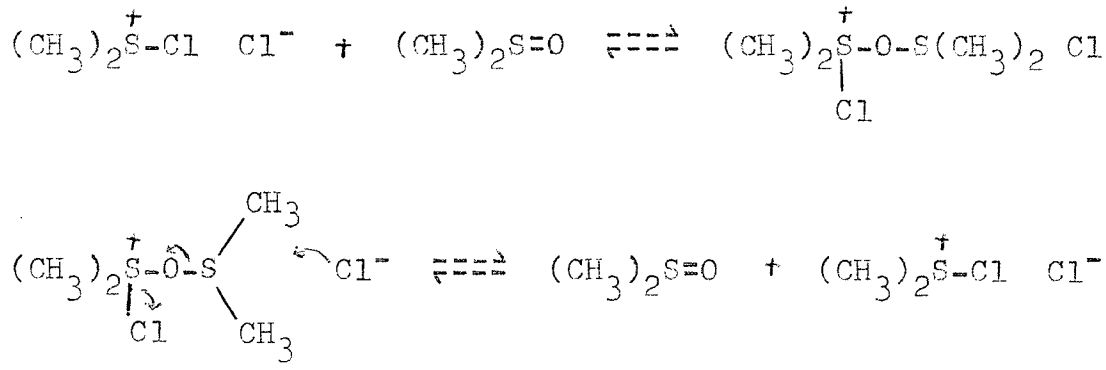
Table 21

Low Temperature nmr Study of Exchange of DMSO and Dimethyl Sulfur Dichloride

Temp (°C)	$(CH_3)_2SCl_2$*	DMSO*	Chemical Shift (c.p.s. from CH_2Cl_2)
37	.0204	--	137
0	"	--	134
-20	"	--	133
-40	"	--	132
-60	"	--	128
37	.0204	.0102	146
0	"	"	143
-20	"	"	142
-40	"	"	140
-60	"	"	139
37	.0204	.0204	152
0	"	"	151
-20	"	"	149
-40	"	"	149
-60	"	"	149
37	.0204	.0306	158
0	"	"	157
-20	"	"	156
-40	"	"	156
-60	"	"	155
37	--	.0204	166
0	--	"	166
-20	--	"	166
-40	--	"	166
-60	--	"	168

* moles

backside attack by chloride on the intermediate as shown below.



Synthesis of Deuterated Dimethyl Sulfide

The prohibative cost of producing deuterated dimethyl sulfide is probably the major factor in preventing this compound from becoming both a useful nmr solvent and a precurser for related deuterated compounds. The present work suggested a relatively inexpensive and rapid method for the preparation of this compound.

Deuterated dimethyl sulfide was prepared from the reaction of deuterated DMSO (Merck, Sharp and Dohme Canada Limited) and methyl disulfide in the presence of dimethyl sulfur dichloride. The sulfide was trapped in an acetone-dry ice bath and purified by distillation (bp=38°C) through a column containing glass beads. The infra red spectrum showed absorptions at 2240 and 2140 cm^{-1} charactoristic of carbon-deuterium stretching vibrations while the mass spectrum gave a splitting pattern similar to dimethyl sulfide considering the difference in mass between hydrogen and deuterium with m/e = 68(100), 50(85), 51(32), 45(29), 42(27), 30(19) and 15(9).

Exchange with Deuterated Dimethyl Sulfide

When deuterated dimethyl sulfide and dimethyl sulfur dichloride were mixed in equimolar quantities in methylene chloride and methyl methyl thiolsulfonate, after five minutes only one peak was visible at 3.2 PPM correspdonding to the methyl protons of dimethyl sulfur dichloride. After one hour two peaks were visible in a 1:1 ratio at 3.2 PPM and 2.1 PPM corresponding to the methyl protons of dimethyl sulfur dichloride and dimethyl sulfide. The ratio of the peaks did not change thereafter. From this data it appears that a very slow exchange reaction is taking place between the two species.

The mechanism for this exchange reaction probably involves initial nucleophilic attack on deuterated dimethyl sulfide by dimethyl sulfur dichloride resulting in the formation of the intermediate thiolsulfonium ion. Attack on this intermediate by chloride ion would them be expected to yield deuterated dimethyl sulfur dichloride and dimethyl sulfide as shown below:

$$(CH_3)_2\overset{+}{S}\text{-}Cl\ \ Cl^- + (CD_3)_2S \rightleftharpoons (CH_3)_2S(Cl)\text{-}\overset{+}{S}(CD_3)_2\ \ Cl^-$$

$$(CH_3)_2S(Cl)\text{-}\overset{+}{S}(CD_3)_2\ \ Cl^- \rightleftharpoons (CH_3)_2S + (CD_3)_2\overset{+}{S}\text{-}Cl\ \ Cl^-$$

Oxidation of Phosphines

Szmant and Cox (1966) have reported that triphenylphosphine is oxidized to triphenylphosphine oxide at 100°C in the presence of glacial acetic acid. In our laboratory it was found that addition of dimethyl sulfur dichloride to a solution of triphenylphosphine and DMSO in anhydrous ether gave high yields of triphenylphosphine oxide at room temperature as shown in Table 22.

Table 22

Oxidation of Triphenylphosphine by DMSO and Dimethyl Sulfur Dichloride

DMSO*	$(CH_3)_2SCl_2$*	$(C_6H_5)_3P$*	$(C_6H_5)_3P{=}O$*
.025	.025	.02	.018(92%)

* moles

Conceivably this technique could be useful for the facile oxidation of phosphines at low temperatures.

Attempted oxidation of Alcohols

Kornblum et al (1957) showed that dimethyloxysulfonium salts (43) decompose into a carbonyl compound and dimethyl sulfide under basic conditions. The possibility that the

$$R_2\underset{\underset{H}{|}}{C}\text{-}O\text{-}\overset{+}{S}(CH_3)_2 \xrightarrow{\text{base}} R_2C{=}O + (CH_3)_2S$$

(43)

reaction of dimethyl sulfur dichloride with an alcohol could lead to the formation of the corresponding dimethyloxysulfonium

salt (44) was investigated. However no reaction took place

$$(CH_3)_2SCl_2 + \underset{\underset{H}{|}}{R_2C}\text{-OH} \text{ ---- } \underset{\underset{H}{|}}{R_2C}\text{-O-}\overset{+}{S}(CH_3)_2 \; Cl^- + HCl$$
(44)

when dimethyl sulfur dichloride was mixed with isopropyl alcohol, anisyl alcohol or 2-hydroxy methyl-5-norbornene under a variety of conditions.

Oxidation of Thiols

Addition of thiols (R=C_2H_5, CH_3, i-C_3H_7, C_4H_9) to dimethyl sulfur dichloride in anhydrous ether resulted in the oxidation of the thiols to the corresponding disulfides. Complete reaction was over in fifteen minutes at 0°C. The mechanism probably involves initial nucleophilic attack by thiol on the dichloride yielding the dimethyl alkyl thiolsulfonium intermediate (45) which rapidly reacts with another mole of thiol yielding the corresponding disulfide.

$$(CH_3)_2\overset{+}{S}\text{-Cl} \; Cl^- + RSH \longrightarrow \underset{(45)}{(CH_3)_2\overset{+}{S}\text{-S-R}} \; Cl^- + HCl$$

$$(45) + RSH \longrightarrow (CH_3)_2S + HCl + R_2S_2$$

Results are shown in Table 23.

Table 23

Oxidation of Thiols by Dimethyl Sulfur Dichloride at 0°C

R	RSH*	$(CH_3)_2SCl_2$*	R_2S_2*
CH_3	.051	.025	.011 (65%)
C_2H_5	.05	.025	.014 (75%)
$i\text{-}C_3H_7$	.05	.025	.021 (79%)
C_4H_9	.05	.025	.20 (80%)

* moles

EXPERIMENTAL

All melting points given were determined on a Fisher-Johns melting point apparatus and are corrected.

Infrared spectra were obtained on a Perkin-Elmer Model 337 Grating Infrared Spectrometer.

Ultra violet spectra were obtained on a Perkin-Elmer Model 450 UV-Visible - NIR Spectrometer.

N.m.r. spectra were obtained on a Varian A-56/60A Spectrometer. All solutions or neat liquids contained tetramethylsilane as the internal standard.

Mass spectra were performed by Mr. D. Lin on a Hitachi Perkin-Elmer RMU-6D Mass Spectrometer.

Vapour Phase Chromatography was performed on a Varian Aerograph Series 1520 Gas Chromatograph.

Silica gel used in Column Chromatography was supplied by Fisher Scientific Company, 60-200 mesh for gas chromatography, Grade 950.

Thin layer Chromatography was performed on silica gel DSF-5, made by Camag, obtained from Mondray Ltd., 4180 de Courtrai, Montreal.

Elemental analyses were performed by A. Bernhardt, Microanalytical Laboratory, 5251 Elback über Engelakirchen, W. Germany.

Reaction of Phenyl Thiolchloroformate and DMSO: Method A

In a typical example 0.1 moles of dry DMSO in 5 ml of carbontetrachloride was added slowly (5 min.) to 0.02 moles of phenyl thiolchloroformate (K and K) in 10 ml of carbontetrachloride at 0°C. The reaction was stirred at room temperature for 0.5 hours and the resulting yellow solution was neutralized with aqueous sodium bicarbonate. The products were extracted with carbontetrachloride and the extract was washed with aqueous sodium chloride and dried over sodium sulfate. Removal of the solvent under vacuo gave a yellow solid. The solid was passed thru a 1 ft. silica gel column (95% petroleum ether/5% chloroform) yielding 2.12g of a white solid with a melting point of 59°C. The infra red spectrum of the product in nujal gave absorptions at 2950,1460,1370, 740 and 680cm^{-1}. The nmr spectrum of the product in carbontetrachloride showed peaks at 7.5 P.P.M. in the aromatic region. The compound was identified as phenyl disulfide (yield=96%) by comparison with results obtained by Cymerman and Willis (1951).

Reaction of Phenyl Thiolchloroformate and DMSO: Method B

In a typical example 0.01 moles of dry DMSO in 5 ml of carbon tetrachloride was added slowly to 0.02 moles of phenyl thiolchloroformate in 5 ml of carbon tetrachloride at 0°C. The reaction was stirred for 1 hour at room temperature and then filtered to yield 0.416g of a hygroscopic white salt. The salt was identified as dimethyl sulfur dichloride (yield=70%) by its mass spectrum (m/e=62,63,48,97,47,36, 28,99,45), by the strong absorption at 880 cm^{-1} characteristic

of sulfur-chlorine stretching vibrations, and by the nmr which gave one absorption at 3.2 P.P.M. when disolved in a mixture of methyl methyl thiolsulfonate and deuterated chloroform (1:3 v/v).

The carbon tetrachloride layer was washed with aqueous sodium chloride and dried over sodium sulfate. 0.13 moles of di-i-propyl amine was then added to the carbon tetrachloride solution and the solution was stirred for 0.5 hours at room temperature. The solution was filtered and the solvent was removed under vacuo yielding 3.51 grams of a grey solid. The solid was passed thru a one foot silica gel column (100% chloroform) yielding 3.49 grams of a white solid. Nmr integration of a solution of the products (identified as phenyl disulfide and N-di-i-propyl -S-phenyl thiolcarbamate) showed the products to be 0.0048 moles (48%) phenyl disulfide and 0.01 moles (50%) N-di-i-propyl-S-phenyl thiolcarbamate.

For identification the products were separated on a one foot silica gel column (85% petroleum ether/15% chloroform) yielding 1.041 grams phenyl disulfide and 1.041 grams N-di-i-propyl-S-phenyl thiolcarbamate. The thiolcarbamate in nujol showed infra red absorptions at 3000,1660,1300,1040, 820,700 and 640 cm^{-1} and melting point of 93°C after recrystallization from methonal. Analysis showed: %C= 65.99 %H = 8.07, %N= 5.71, %S =13.53,

C13H19NSO requires: %C = 65.77, %H = 8.08, %N= 5.71, %S = 13.53.

Criteria for nmr Intergration Technique to Identify Ratio of Phenyl Disulfide and N-di-i-propyl-S-phenyl Thiolcarbamate

1.1g phenyl thiolchloroformate and 1.13g phenyl disulfide were disolved in 15ml of carbon tetrachloride and 4g of di-i-propyl amine was added slowly (10 min.) at 0°C and the solution was left stirring for 0.5 hours at room temperature. The solution was filtered and the filtrate was evaporated down to give 2.61g of a grey solid. The solid was put thru a 1 ft. silica gel column (100% chloroform) yielding 2.55g of a white solid. Nmr integration of a solution of the products in carbon tetrachloride gave values of 1.1g (100%) phenyl disulfide and 1.43g (96%) N-di-i-propyl S-phenyl thiolcarbamate.

The products were separated on a 1 ft. silica gel column (85% petroleum ether/15% chloroform) yielding 1.04g (94%) phenyl disulfide and 0.89g (61%) N-di-i-propyl S-phenyl thiolcarbamate.

Analysis for Volatile Products from the Reaction of Phenyl Thiolchloroformate and DMSO

0.1 moles of dry DMSO was added slowly (5 min,) to 0.02 moles phenyl thiolchloroformate in 10ml carbon tetrachloride at 0°C and the reaction stirred for 1 hour at room temperature. Volatile products were trapped in an acetone-dry ice bath followed by a liquid nitrogen trap. An infra red spectrum of the gases trapped in the liquid nitrogen trap showed the characteristic absorption for carbon dioxide at 2350cm^{-1}. The product from the acetone-dry ice bath was distilled thru a 1 ft. column packed with helical glass beads

yielding .0097 moles (97%) methyl disulfide.

Preparation of Dimethyl Sulfur Dichloride

0.026 moles of thiolphosgene in 10ml of anhydrous ether was added slowly (15 min.) to 0.013 moles of dry DMSO in 10ml of anydrous ether at 0°C. The reaction was left stirring for 0.5 hours at 0°C. The solvent was removed with a filter stick and the white salt was washed 3 times with anhydrous ether under a stream of dry nitrogen. The hygroscopic white salt was dried under vacuo yielding .01 moles (76%) of dimethyl sulfur dichloride. The infra red spectrum of the salt in Kel-F grease #90 (3M Company) showed a strong chlorine absorption at 870 cm^{-1}. The mass spectrum of the salt showed peaks and relative intensities at 62(100), 63(73), 48(70), 46(61), 97(46), 47(46), 36(36), 28(28), 99(18) and 45(12). The instability of the salt at room temperature prevented an elemental analysis.

Hydrolysis of Dimethyl Sulfur Dichloride

0.0012 moles of freshly prepared dimethyl sulfur dichloride was added to 25ml of water and the solution stirred at room temperature for 0.25 hours. The solution was titrated for acid using 0.001 molar standardized sodium hydroxide. The titration showed 0.0023 moles of chloride ion present.

Hydrolysis of Dimethyl Sulfur Dichloride in Deuterium Oxide

0.0041 moles of freshly prepared dimethyl sulfur dichloride was added to 1ml of deuterium oxide in an nmr tube. The nmr spectrum showed a singlet at 2.6 P.P.M. Addition of DMSO to the sample still showed a singlet indicating the presence of DMSO. The infra red showed characteristic sulfone

absorptions at 1330 and 1135cm^{-1}.

Reaction of p-Chlorophenyl Thiolchloroformate and DMSO

0.02 moles of dry DMSO in 5ml carbon tetrachloride was added to 0.0102 moles of p-chlorophenyl thiolchloroformate (K&K Laboratories) in 5ml of carbon tetrachloride at 0°C. The reaction was stirred for 0.5 hours at room temperature. A white solid product was obtained using the same method used to isolate phenyl disulfide from the reaction of phenyl thiolchloroformate and DMSO (Method A). The product was identified as p-chlorophenyl disulfide (yield =.0042 moles (85%)). The product gave a melting point of 72°C and the infra red spectrum in nujol showed absorptions at 2980, 1480, 1400, 1090, 1010, and 830cm^{-1}.

Reaction of t-Butyl Thiolchloroformate and DMSO

0.05 moles of dry DMSO in 2ml of methylene chloride was added over 5 min. to o.03 moles of t-butyl thiolchloroformate in 3 ml of methylene chloride at 0°C. The reaction was stirred for 3 hours at room temperature. The solution was neutralized with aqueous sodium bicarbonate and the products were extracted with methylene chloride and dried over sodium sulfate. Removal of the solvent under vacuo yielded 2.8g of a yellow liquid. The liquid product was purified by vacuum distillation (bp=130°/150mmHg) yielding 2.24g (0.013 moles; 87%) of t-butyl disulfide. Refractive index (n_D^{20}=1.4901), infra red absorptions at 2960, 1450, 1350 and 1160$cm^{-1}$and nmr in carbon tetrachloride gave a singlet at 1.3 P.P.M. were consistant with an authentic sample of t-butyl disulfide.

Preparation of Authentic t-Butyl Disulfide

t-Butyl disulfide was prepared by the method of Vogel and Conan (1943). Distillation of the product gave a boiling point at 139°/150mmHg, infra red absorptions at 2960, 1455, 1345 and 1165cm^{-1}, n_D^{20} at 1.4900 and nmr singlet at 1.3 P.P.M.

Reaction of i-Propyl Thiolchloroformate and DMSO

The reaction of i-propyl thiolchloroformate and DMSO was carried out under the same conditions as the corresponding reaction with t-butyl thiolchloroformate. The crude product from the reaction was distilled yielding i-propyl disulfide (bp=174°/750mmHg). The product gave infra red absorptions at 2900, 1450, 1350, 1240, 1160, 1050 and 870cm^{-1}, n_D^{20}=1.4904 and nmr peaks at 1.2 and 2.9 P.P.M. in a 6:1 ratio. Vapor phase chromotography of the crude product showed the absence of any other high boiling products.

Preparation of Authentic i-Propyl Disulfide

i-Propyl disulfide was prepared by the method of Vogel and Conan (1943). Distillation of the product gave a boiling point of 123°/150mmHg, infra red absorptions at 2900, 1450, 1150, 1240, 1155, 1050 and 865cm^{-1} and n_D^{20}= 1.4912.

Reaction of n-Propyl Thiolchloroformate and DMSO

In a typical example 0.1 moles of dry DMSO in 5ml of methylene chloride was added to 0.1 moles of n-propyl thiolchloroformate (K & K Laboratories) at 0°C. The reaction was stirred at room temperature for 1 hour and the crude liquid product (6.45 grams) obtained using the same method as in the case of the reaction of t-butyl thiolchloroformate and DMSO. Vacuum distillation gave 5.95 grams of n-propyl n-propyl

thiolsulfonate (bp=96°C/0.4mmHg) and 1.87 grams of n-propyl disulfide (bp=192°C/750mmHg). The thiolsulfonate showed infra red absorptions at 299, 1750, 1140 and 960 cm^{-1}. n_D^{20}=1.4943 and nmr peaks in deuterated chloroform at 1.1, 1.8, 2.3, and 3.3 P.P.M. in the ratios 3:2: 1:1. Boldyrev (1956) gives values for n-propyl n-propyl thiolsulfonate of n_D^{20}=1.4935 and bp=112°C/2mmHg. The disulfide showed infra red absorptions at 2960, 1480, 1300 and 1240 cm^{-1}, n_D^{20}=1.4973 and nmr absorptions at 0.9, 1.6 and 2.5 P.P.M. in ratios 3:2:2.

Preparation of Authentic n-propyl Disulfide

n-Propyl disulfide was prepared by the method of Vogel and Conan (1943). Distillation of the crude product gave a boiling point of 123°C/150mmHg, n_D^{20}=1.4981 and infra red absorptions at 2960, 1480, 1305 and 1240 cm^{-1}.

Reaction of Ethyl Thiolchloroformate and DMSO Method A

0.2 moles of dry DMSO in 5ml of methylene chloride was added over 10 mins. to 0.1 moles of ethyl thiolchloroformate (K & K Laboratories) at 0°C. The reaction was left at 0°C for 0.5 hours then at room temperature for 1 hour. The reaction was worked up as in the case of the reaction of t-butyl thiolchloroformate and DMSO. The crude liquid product was distilled yielding .035moles of ethyl ethyl thiolsulfonate (bp=83°C/0.3mmHg).The product showed infra red absorptions at 1140, 1320, 780 and 2950cm^{-1}, ultra violet absorption with max in 100% methanol at 240mu and n_D^{20}=1.4974. No ethyl disulfide was detected by vapor phase chromotography.

Reaction of Ethyl Thiolchloroformate and DMSO Method B

0.1 moles of dry DMSO and 0.1 moles of ethyl thiolchloro-

formate in 5ml of methylene chloride were reacted as in Method A. Distillation of the crude liquid product yielded .0136 moles (27%) ethyl ethyl thiolsulfonate (bp=82°C/0.3mmHg) and a lower boiling fraction trapped in liquid nitrogen during the distillation. 15g of di-i-propyl amine in 50ml methylene chloride was added to the lower boiling fraction and the reaction stirred for 0.5 hours at room temperature. Following filtration and removal of solvent and excess di-i-propyl amine by vacuum distillation, the crude products (5.28g) were put thru a 1 ft. silica gel column (100% chloroform) yielding 5.18g of a liquid product. By nmr integration, yields of .0107 moles (26%) ethyl disulfide and .0262 moles (26%) N-di-i-propyl-S-ethyl thiolcarbamate were obtained. For identification the products were separated on a 1 ft silica gel column (85% petroleum ether/15% chloroform) yielding 1.2g ethyl disulfide and 3.8g N-di-i-propyl-S-ethyl thiolcarbamate. The disulfide gave infra red absorptions at 3000, 1450, 1380, 1200, 980 and 760 cm^{-1}, n_D^{20}= 1.4916 and bp=176°C/757mmHg. The thiolcarbamate showed infra red absorptions at 3000, 1450, 1380, 1260, 980 and 760 cm^{-1}, bp=152°C/757mmHg, n_D^{20}=1.8069 and nmr peaks in deuterated chloroform at 1.3 and 2.6 P.P.M. in a 3:2 ratio. Elemental analysis showed: %C=57.22, %H=10.25 %N=7.57, %S=16.95.

$C_{10}H_{19}SON$ requires: %C=57.10, %H=10.14, %N=7.40, %S=16.91.

Preparation of Methyl Thiolchloroformate

Methyl thiolchloroformate was prepared from methyl mercaptan and phosgene by the method of Reinschneider and Lorentz (1953).

Reaction of Methyl Thiolchloroformate and DMSO

A typical example is as follows: 0.1 moles of dry DMSO in 2ml of methylene chloride was added over 10 mins. to 0.1 mole of methyl thiolchloroformate in 8ml methylene chloride at 0°C. The reaction was left stirring for 1 hour. Workup as in the case of the reaction of t-butyl thiolchlorformate and DMSO gave a yellow liquid. Distillation yielded .048 moles (48%) methyl methyl thiolsulfonate. The thiolsulfonate gave bp=74°C/0.4mmHg, infra red absorptions at 3010, 2940, 1300, 1135 and 955 cm^{-1}, λmax=240mu in 100% methanol, nmr peaks in deuterated chloroform at 2.6 and 3.3 P.P.M. in a 1:1 ratio and N_D^{20}=1.5121. No methyl disulfide was detected by vapor phase chromotography.

Preparation of Authentic Methyl Methyl Thiolsulfonate

Methyl methyl thiolsulfonate was prepared by the method of Douglas et al (1959). The product gave bp=73°C/0.4mmHg, infra red absorption at 3010, 2940, 1300, 1135 and 955 cm^{-1}, max=240mu in 100% methanol, n_D^{20}=1.5112 and nmr peaks in deuterated chloroform at 2.7 and 3.3 P.P.M. in a 1:1 ratio.

Reaction of Methyl Thiolchloroformate, DMSO and i-Propyl Mercaptan

0.2 moles of dry DMSO in 5ml of methylene chloride was added over one hour to 0.1 moles of i-propyl mercaptan and 0.05 moles methyl thiolchloroformate in 5ml methylene chloride at 0°C. The reaction was stirred for 2 hours at room temperature and then neutralized with aqueous sodium bicarbonate. The products were extracted with methylene chloride and dried over sodium sulfate. The solvent was taken off in vacuo

and the product distilled to give .005 moles methyl methyl thiolsulfonate (bp=70°C/0.2mmHg) and 5.8g of lower boiling product. The lower boiling products were separated by vapor phase chromotography on a 5 ft. x 0.5 in. 20% carbowax M on chromosorb W column at 160°C. Ratios of products were obtained by peak areas. Results showed 0.0042 moles of methyl disulfide (ret. time =4.60 min. at 60cc He/min.), .0173 moles of i-propyl disulfide (ret. time=9.44 min.) and .0233 moles i-propyl methyl disulfide (ret. time=6.73 min.). Methyl disulfide was identified by its infra red absorptions at 2900, 1400, 1350 and 970 cm^{-1} and n_D^{20}=1.5092. I-propyl disulfide gave infra red absorptions at 2900, 1445, 1350, 1240, 1160 1,050 and 870 cm^{-1} and n_D^{20}=1.4906. I-propyl methyl disulfide gave infra red absorptions at 2970, 1420, 1370 and 1020 cm^{-1} and n_D^{20}=1.5049.

Preparation of Authentic i-Propyl Methyl Disulfide

0.02 moles of i-propyl mercaptan and 0.02 moles of methyl mercaptan were dissolved in 50ml of 15% aqueous sodium hydroxide. 0.035 moles of iodine was added over 0.5 hours at 0°C to the solution, and the solution was stirred for 1 hour. The products were extracted with benzene and the organic layer washed with aqueous sodium chloride and dried over sodium sulfate. The solvent was removed and the crude products were separated by vapor phase chromotography using the same conditions as previously described. The retention times of the products were 4.88 min. (60cc He/min.) for methyl disulfide, 9.48 min. for i-propyl disulfide and 6.78 min. for i-propyl methyl disulfide. I-propyl methyl disulfide gave infra red

absorptions at 2970, 1415, 1370 and 1020 cm^{-1} and n_D^{20}=1.5047.

Reaction of Dimethyl Sulfur Dichloride and i-Propyl Mercaptan in the Presence of Methyl Thiolchloroformate

0.05 methyl thiolchloroformate and 0.05 moles i-propyl mercaptan in 10ml methylene chloride was added over 10 min. to 0.025 moles of freshly prepared dimethyl sulfur dichloride. The reaction was stirred for 1 hour at room temperature and then neutralized with aqueous sodium bicarbonate. The products were extracted with methylene cloride and the organic layer washed with aqueous sodium chloride and dried over sodium sulfate. The solvent was removed under vacuo and the crude liquid products distilled to yield .046 moles methyl thiolchloroformate (bp=48°C/150mmHg) and .021 moles (84%) i-propyl disulfide (bp=25°C/150mmHg).

i-Propyl Mercaptan and Methyl Methyl Thiolsulfonate

0.05 moles i-propyl mercaptan and 0.05 moles methyl methyl thiolsulfonate in 15ml methylene chloride refluxed for 2 hours. No reaction took place.

i-Propyl Disulfide and Methyl Methyl Thiolsulfonate

0.1 moles of i-propyl disulfide and 0.1 moles methyl methyl thiolsulfonate in 10ml methylene chloride were refluxed for 2 hours. No reaction took place.

Methyl Disulfide and DMSO

0.1 moles of dry DMSO was added to 0.05 moles of methyl disulfide and the solution left at 80°C for 3 hours. No reaction took place.

Reaction of Methyl Disulfide, DMSO and i-Propyl Thiolchloroformate

0.065 moles of i-propyl thiolchloroformate in 5ml of methylene chloride was added over 10 min. to a solution containing 0.265 moles DMSO and 0.1 moles of methyl disulfide in 10ml of methylene chloride. The reaction was stirred for 3 hours at room temperature and then neutralized with aqueous sodium bicarbonate. The products were extracted with methylene chloride and the organic layer washed with aqueous sodium chloride and dried over sodium sulfate. The solvent was removed under vacuo and the crude liquid produce distilled yielding 0.098 (98%) methyl methyl thiolsulfonate and 0.025 moles (78%) of i-propyl disulfide.

Reaction of Methyl Disulfide, DMSO and Methyl Thiolchloroformate

0.22 moles of dry DMSO in 5ml methylene chloride was added over 10 mins. to 0.1 moles of methyl disulfide and 0.02 moles methyl thiolchloroformate in 5ml methylene chloride at 0°C. The reaction was stirred for 3 hours at room temperature. The products were isolated as in the reaction of methyl disulfide, DMSO and i-propyl thiolchloroformate to yield 0.103 moles (94%) methyl methyl thiolsufonate.

Reaction of Methyl Disulfide, DMSO and Dimethyl Sulfur Dichloride Method A

Dimethyl sulfur dichloride was isolated from the reaction of an alkyl or aryl thiolchloroformate and DMSO as previously described. 0.036 moles of dry DMSO in 2ml methylene chloride was added to 0.017 moles methyl thiolchloroformate in 5ml methylene chloride at 0°C. The reaction was left 1 hour at 0°C

and then 10 hours at -10°C. The solution was filtered yielding 0.8g (72%) dimethyl sulfur dichloride. The dichloride was added to 0.1 moles of methyl disulfide and 0.21 moles of DMSO in 15ml methylene chloride and the reaction left at room temperature for 3 hours. The solution was neutralized with aqueous sodium bicarbonate and the products extracted with methylene chloride. The aqueous layer was washed with aqueous sodium chloride and dried over sodium sulfate. Removal of the solvent in vacuo and distillation of the crude liquid product yielded .096 moles (96%) methyl methyl thiolsulfonate.

Reaction of Methyl Disulfide, DMSO and Dimethyl Sulfur Dichloride Method B

Dimethyl sulfur dichloride was prepared by the action of thiophosgene on DMSO as previously described. 0.0057 moles of freshly prepared dimethyl sulfur dichloride was added to 0.1 moles of methyl disulfide and 0.21 moles of dry DMSO. The reaction was stirred for 1 hour at 80°C and the products extracted as described in Method A, yielding 0.101 moles (91%) methyl methyl thiolsulfonate.

Reaction of Methyl Disulfide, DMSO and Hydrogen Chloride

0.014 moles anhydrous hydrogen chloride was dissolved in 0.1 moles of dry DMSO in 5ml methylene chloride at 0°C. The exothermic reaction was cooled at 0°C for .05 hours and then 0.05 moles of methyl disulfide in 5ml methylene chloride was added to the solution. The reaction was left 3 hours at room temperature but no reaction took place. The solution was heated to 80°C for 1 hour and the products extracted as in

Method A, yielding .049 moles (96%) methyl methyl thiolsulfonate.

Reaction of Methyl Disulfide and Dimethyl Sulfur Dichloride

.015 moles of freshly prepared dimethyl sulfur dichloride and .015 moles of methyl disulfide were dissolved in 8g of methyl methyl thiolsulfonate and 8g deuterated chloroform and stirred 15 min. at room temperature. A white unstable precipitate was isolated but could not be characterized. Addition of .05 moles of DMSO to the precipitate in 10ml methylene chloride resulted in a vigorous reaction which was immediately neutralized with aqueous sodium bicarbonate. The products were extracted with methylene chloride and the organic layer washed with aqueous sodium chloride and dried over sodium sulfate. Distillation of the crude liquid product yielded .0049 moles (32%) methyl methyl thiolsulfonate and .0048 moles (31%) methyl disulfide.

Preparation of Methyl Disulfide Dichloride

Methyl disulfide dichloride was prepared by the method of Schneider (1951). Yield was 14.9g (91%).

Reaction of Methyl Disulfide Dichloride and DMSO

0.1 moles of dry DMSO in 10ml of methylene chloride was added over 10 min. to 0.02 moles of freshly prepared methyl disulfide dichloride in 5ml methylene chloride over 10 min. A vigorous reaction took place immediately. The products were extracted by the same method as the reaction of methyl disulfide and dimethyl sulfur dichloride to yield 0.017 moles (85%) methyl methyl thiolsulfonate.

Isolation of Dimethyl Sulfur Dichloride from Methyl Disulfide Dichloride and DMSO

0.05 moles of dry DMSO in 15ml anhydrous ether was added over 15 min. to 0.025 moles methyl disulfide dichloride at 0°C. The reaction was left .05 hour at 0°C and 10 hours at -10°C. The solution was filtered and the filtrate was distilled to yield .024 moles (97%) methyl methyl thiolsulfonate. The precipitate from the reaction was identified as dimethyl sulfur dichloride with a yield of .014 moles (57%).

Preparation of Methyl Methyl Thiolsulfinate

0.2 moles of meta-chloroperbenzoic acid (MCPA) in 200ml of chloroform was added over 15 min. to 0.2 moles methyl disulfide in 100ml chloroform at 0°C. The reaction was left at room temperature for 5 min. and the solution filtered. The filtrate was neutralized with aqueous sodium bicarbonate, washed with aqueous sodium chloride and dried over sodium sulfate. The solvent was removed in vacuo to yield 10g of liquid. The liquid product was distilled, yielding .086 moles (43%) methyl methyl thiolsulfinate (bp=58°C/1mmHg). The product gave infra red absorptions at 3000, 1400, 1250, 1080 and 770 cm^{-1} n_D^{20}=1.5557 and λmax=250mu in 100% ethanol. Small, Bailey and Corallito (1947) list values of methyl methyl thiolsulfinate of :n_D^{25}=1.5481, λmax=248mu in 100% ethanol and bp=64°C/0.5mmHg.

Reaction of Methyl Methyl Thiolsulfinate and Dimethyl Sulfur Dichloride

A catalytic amount (0.1g) of dimethyl sulfur dichloride

was added to 0.05 moles of methyl methyl thiolsulfinate in 10ml of methylene chloride at 0°C. A violent reaction took place. The reaction was immediately neutralized with aqueous sodium bicarbonate, and the products extracted with methylene chloride. The organic layer was washed with aqueous sodium chloride and dried over sodium sulfate. Removal of the solvent followed by distillation of the crude liquid product yielded 0.023 moles (45%) methyl disulfide and 0.22 moles (44%) methyl methyl thiolsulfonate.

Reaction of Methyl Methyl Thiolsulfinate and Methyl Disulfide Dichloride

A catalytic amount (0.1g) of methyl disulfide dichloride was added to 0.038 moles of methyl methyl thiolsulfinate in 5ml methylene chloride at room temperature. A violent reaction took place. The products were isolated as in the reaction of methyl methyl thiolsulfinate and dimethyl sulfur dichloride yielding 0.015 moles (44%) methyl disulfide and 0.014 moles (43%) methyl methyl thiolsulfonate.

Reaction of Methyl Methyl Thiolsulfinate and Hydrogen Chloride

A catalytic amount of anhydrous hydrogen chloride was bubbled into a solution containing 0.05 moles methyl methyl thiolsulfinate in 10ml methylene chloride at room temperature. A violent reaction took place. The products were isolated as in the reaction of methyl methyl thiolsulfinate and dimethyl sulfur dichloride yielding 0.022 moles (44%) methyl disulfide and 0.023 moles (45%) methyl methyl thiolsulfonate.

Methyl Methyl Thiolsulfinate and DMSO

0.1 moles dry DMSO in 5ml methylene chloride was added to 0.05 moles methyl methyl thiolsulfinate in 5ml methylene chloride. The solution was left at room temperature for 3 hours and at 80°C for 3 hours. No reaction took place.

Methyl Methyl Thiolsulfinate and Methyl Methyl Thiolsulfonate

0.05 moles methyl methyl thiolsulfonate in 5ml methylene chloride was added to 0.05 moles methyl methyl thiolsulfinate in 5ml methylene chloride. The solution was left at room temperature for 3 hours and then at 80°C for 3 hours. No reaction took place.

Kinetic Studies of Methyl Disulfide, DMSO and Dimethyl Sulfur Dichloride

In a typical example 0.0043 moles of dimethyl sulfur dichloride was added to 0.0086 moles dry DMSO and 0.0043 moles methyl disulfide in 3ml methylene chloride. The rate of disappearance of methyl disulfide and the rate of formation of methyl methyl thiolsulfonate was followed at 40°C by nmr by measuring their respective peak heights as a function of time. The reaction showed 1st order kinetics calculated from the equation:

$$k = \frac{2.303}{T} \log \frac{(\text{peak height})^{t=o}}{(\text{peak height})^{t=x}}$$

The rate constant for the disappearance of methyl disulfide was $0.013 \pm .003$ min^{-1} at 40°C while the rate constant for the appearance of methyl methyl thiolsulfonate was $0.016 \pm .002$ min^{-1}.

Exchange Reaction of DMSO and Dimethyl Sulfur Dichloride

2.70g (.020 moles) dimethyl sulfur dichloride was dissolved in 10.5g deuterated chloroform and 10.5g methyl methyl thiolsulfonate. A few drops of methylene chloride were added and some of the solution was put in an nmr tube. The solution showed a single peak of 137 cps from the standard methylene chloride at 37°C. The peak position at 37°, 0°, -20°, -40° and -60°C were determined. Similar experiments were run at the same concentration of dimethyl sulfur dichloride with the addition of .795g (.010 moles), 1.590g (.020 moles) and 2.385g (.030 moles) DMSO at the above temperatures.

Reaction of Dimethyl Sulfur Dichloride and i-Propyl Mercaptan

3.3g (0.025 moles) dimethyl sulfur dichloride was put in a 100ml flask in 25ml anhydrous ether with drying tubes and stirrer. 3.8g (0.05 moles) i-propyl mercaptan in 10ml anhydrous ether was added over 15 min. at 0°C and the reaction was then stirred for 1 hour at room temperature. The solution was neutralized with aqueous sodium bicarbonate and the products extracted with ether. The organic layer was washed with aqueous sodium chloride and dried over sodium sulfate. The ether was removed under vacuo and the crdue liquid product distilled yielding .021 moles (79%) i-propyl disulfide.

Reaction of Dimethyl Sulfur Dichloride and t-Butyl Mercaptan

Using the same method as above, 0.05 moles of t-butyl mercaptan and 0.025 moles dimethyl sulfur dichloride yielded 0.20 moles (78%) t-butyl disulfide.

Reaction of Dimethyl Sulfur Dichloride and Ethyl Mercaptan

Using the same method as above, 0.05 moles of ethyl mercaptan and 0.025 moles dimethyl sulfur dichloride yielded .014 moles (75%) ethyl disulfide.

Reaction of Dimethyl Sulfur Dichloride and Methyl Mercaptan

Using the same method as above, 0.05 moles methyl mercaptan and 0.025 moles dimethyl sulfur dichloride yielded .011 moles (65%) methyl disulfide.

Reaction of Triphenyl Phosphine and DMSO in the Presence of Dimethyl Sulfur Dichloride

5.24g (0.02 moles) triphenyl phosphine was added to 3.3g (0.025 moles) dimethyl sulfur dichloride and 1.95g (0.025 moles) dry DMSO in 25ml anhydrous ether. The reaction was stirred for 10 min. at room temperature with formation of an oily precipitate. The solvent was evaporated off under vacuo leaving a yellow oil. The oil was shaken with 50ml of cold water and a white solid precipitate appeared. The solution was filtered and the solid washed several times with cold water yielding 5.12g (92%) triphenyl phosphine oxide. The product had M.P.=185°C, infra red absorptions of 1200, 750, 710 and 695 cm^{-1} and the nmr showed peaks at 7.7 PPM in the aromatic region. Geddes (1957) found M.P. = 156°C and infra red absorptions at 1200, 755, 710 and 700 cm^{-1} for triphenyl phosphine oxide.

Triphenyl Phosphine and DMSO

5.24g (0.02 moles) triphenyl phosphine and 1.95g (0.025 moles) dry DMSO were heated at 80°C for 2 hours. No reaction took place.

Dimethyl Sulfur Dichloride and i-Propanol

3.0g (0.05 moles) of dry i-proponal was added to 6.1g (0.05 moles) dimethyl sulfur dichloride in 30ml of anhydrous ether. The solution was left for 1 hour at room temperature then refluxed for 1 hour. No reaction took place.

Dimethyl Sulfur Dichloride and Anisyl Alcohol

6.9g (0.05 moles) anisyl alcohol was added to 6.1g (0.05 moles) dimethyl sulfur dichloride in 30ml anhydrous ether. The solution was stirred for 3 hours at room temperature. No reaction took place.

Dimethyl Sulfur Dichloride and 2-Hydroxymethyl-5-norborene

6.2g (0.05 moles) 2-hydroxymethyl-5-norbornene was added to 6.1g (0.05 moles) dimethyl sulfur dichloride in 20ml anhydrous ether. The solution was stirred at room temperature for 1 hour then refluxed for 3 hours. No reaction took place.

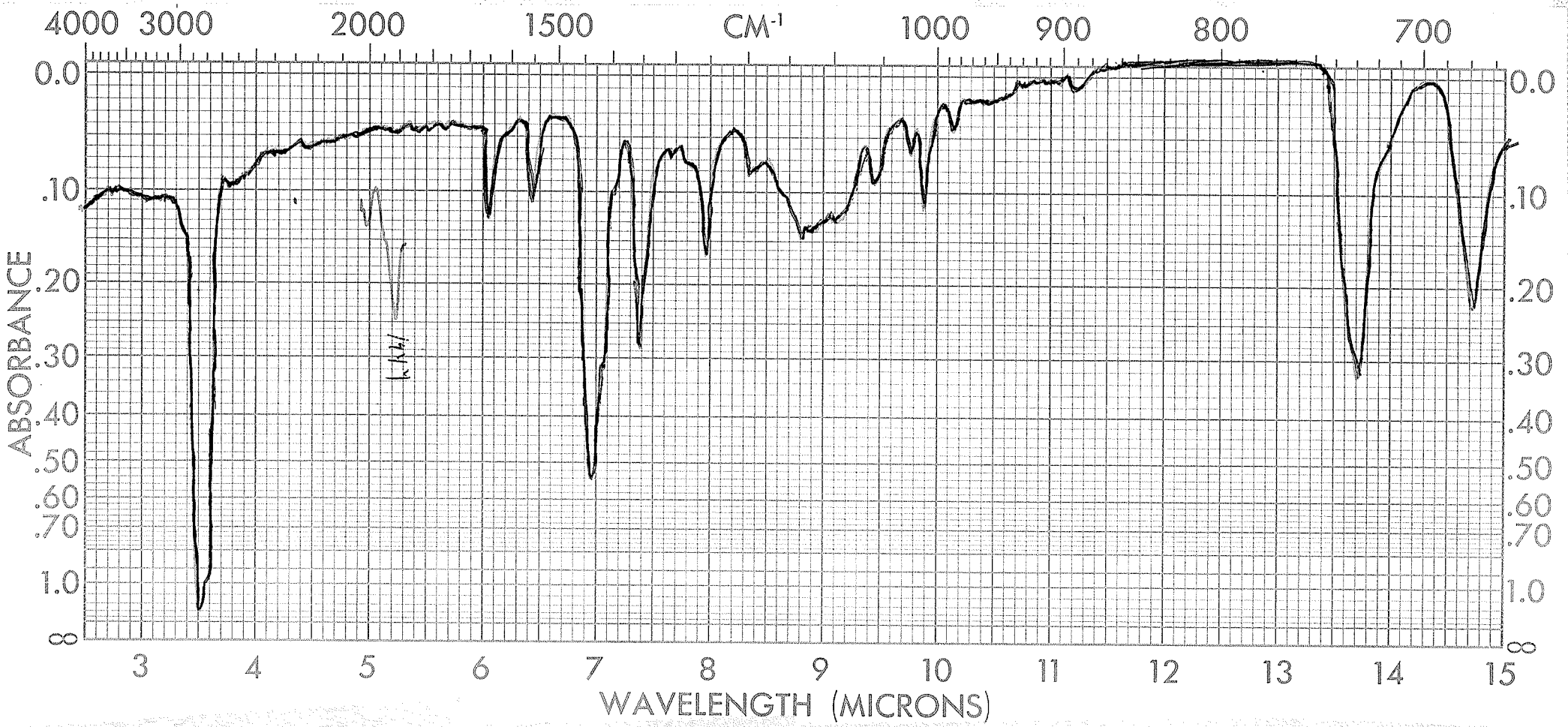
Preparation of Deuterated d_6-Dimethyl Sulfide

16.5g (0.205 moles) dry deuterated d_6-DMSO was added to 10.4g (0.11 moles) of methyl disulfide and 0.6g (.005 moles) methyl thiolchloroformate at 0°C. The solution was heated to 80°C for 1 hour and the volatile products trapped in an acetone-dry ice bath. The trap products were distilled thru a 1 ft. column packed with glass beads yielding 9.22g(0.12moles, 60%) deuterated d_6-dimethyl sulfide(bp=38°C). The infra red spectrum of the product gave absorptions at 2240, 2140, 1040, 840, 750 and 650 cm^{-1} while the mass spectrum gave peaks m/e = 68 (100), 50 (85), 51 (32), 45 (29), 42 (27), 30 (19), 15 (9).

Exchange of Deuterated d_6-Dimethyl Sulfide and Dimethyl Sulfur Dichloride

1.6g (0.025 moles) deuterated d_6-dimethyl sulfide was added to 3.3g (0.025 moles) dimethyl sulfur dichloride in 4.0g methyl methyl thiolsulfonate and 10g methylene chloride. The solution was monitored by nmr at 40°C. After 5 min. only one peak was visible at 3.2 P.P.M. After 1 hour 2 peaks at 3.2 and 2.1 P.P.M. in a 1:1 ratio were visible. After 2 hours the peak ratios remained unchanged.

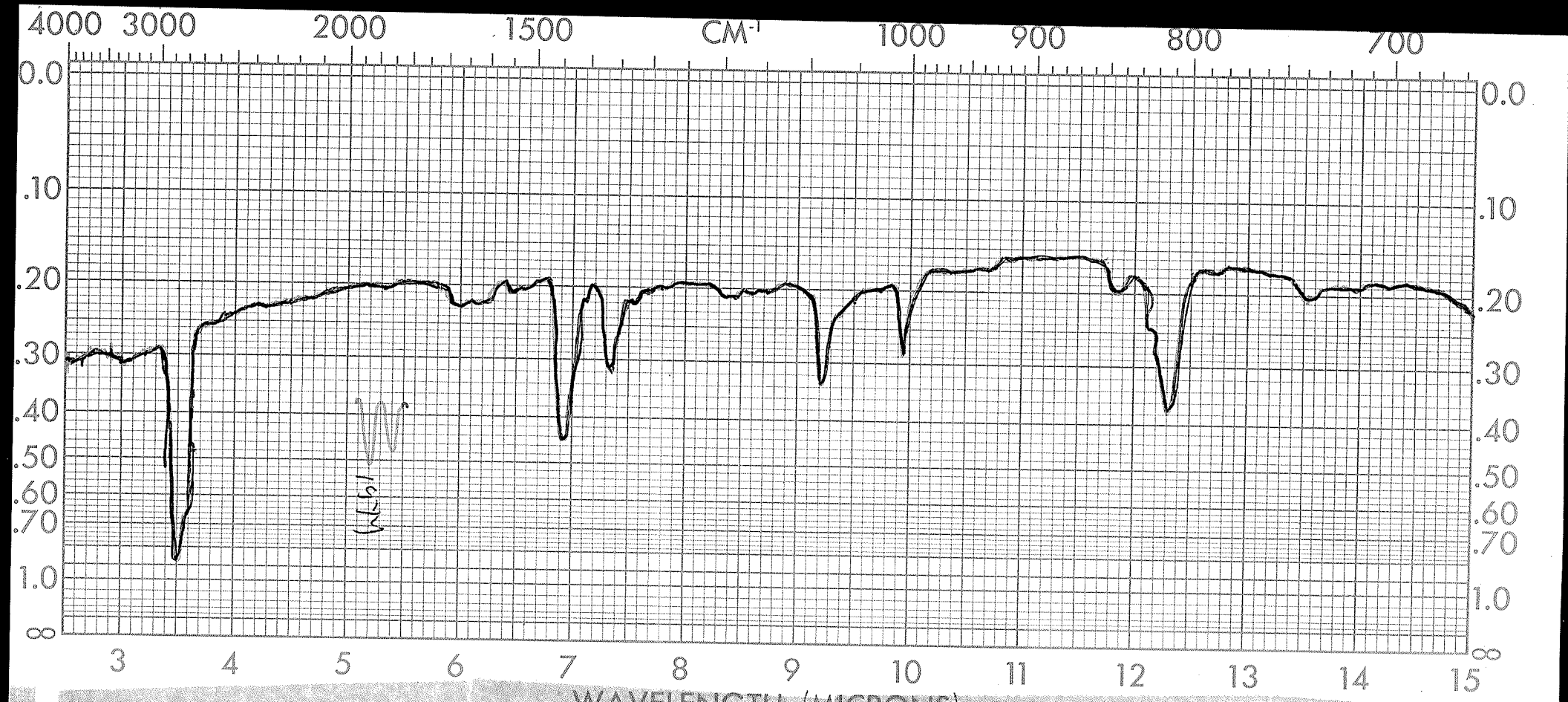
INFRARED SPECTRA



Phenyl Disulfide

$(C_6H_5)_2S_2$

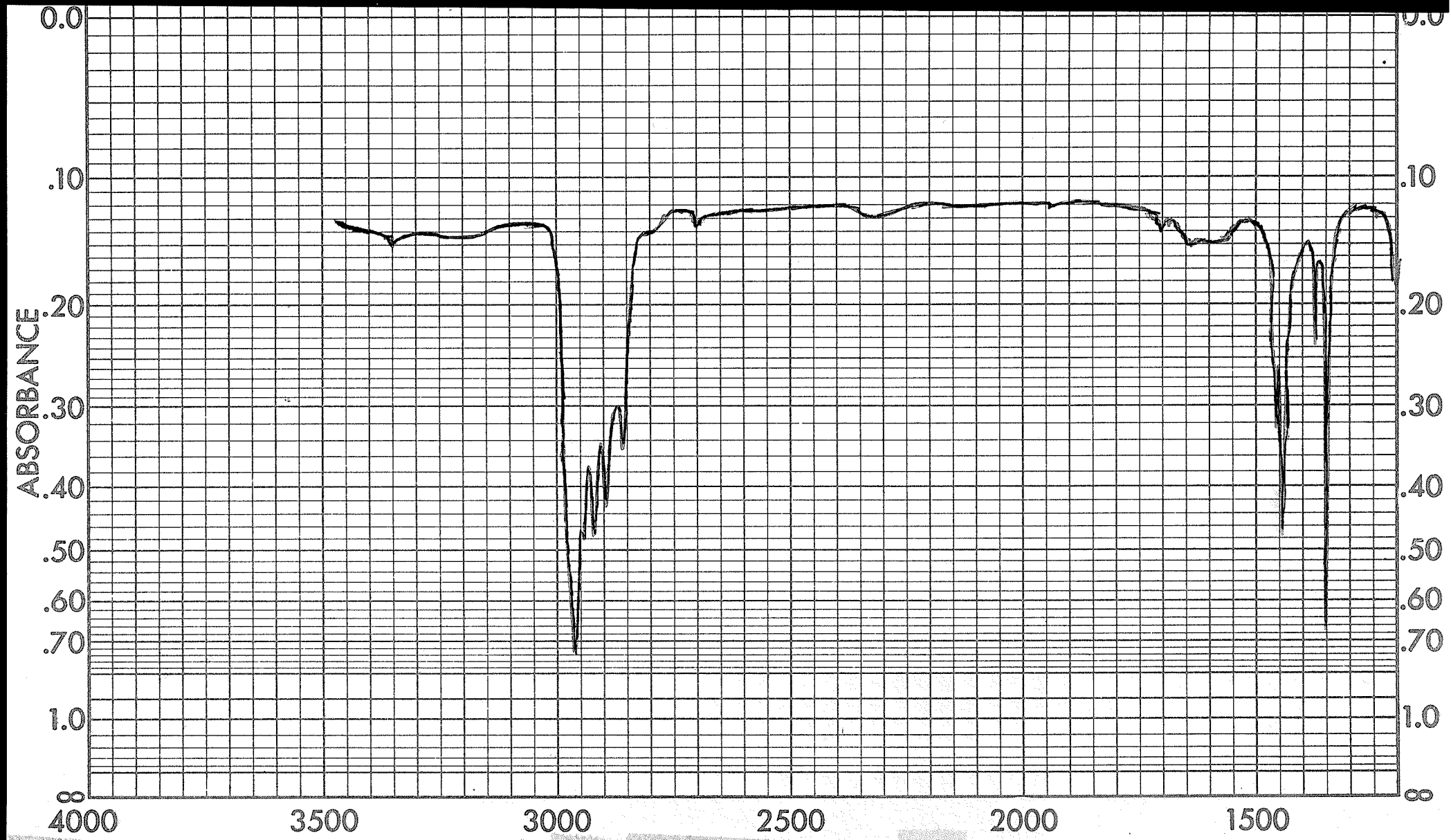
85.



p-Chlorophenyl Disulfide

$(p\text{-}ClC_6H_5)_2S_2$

86.



t-Butyl Disulfide

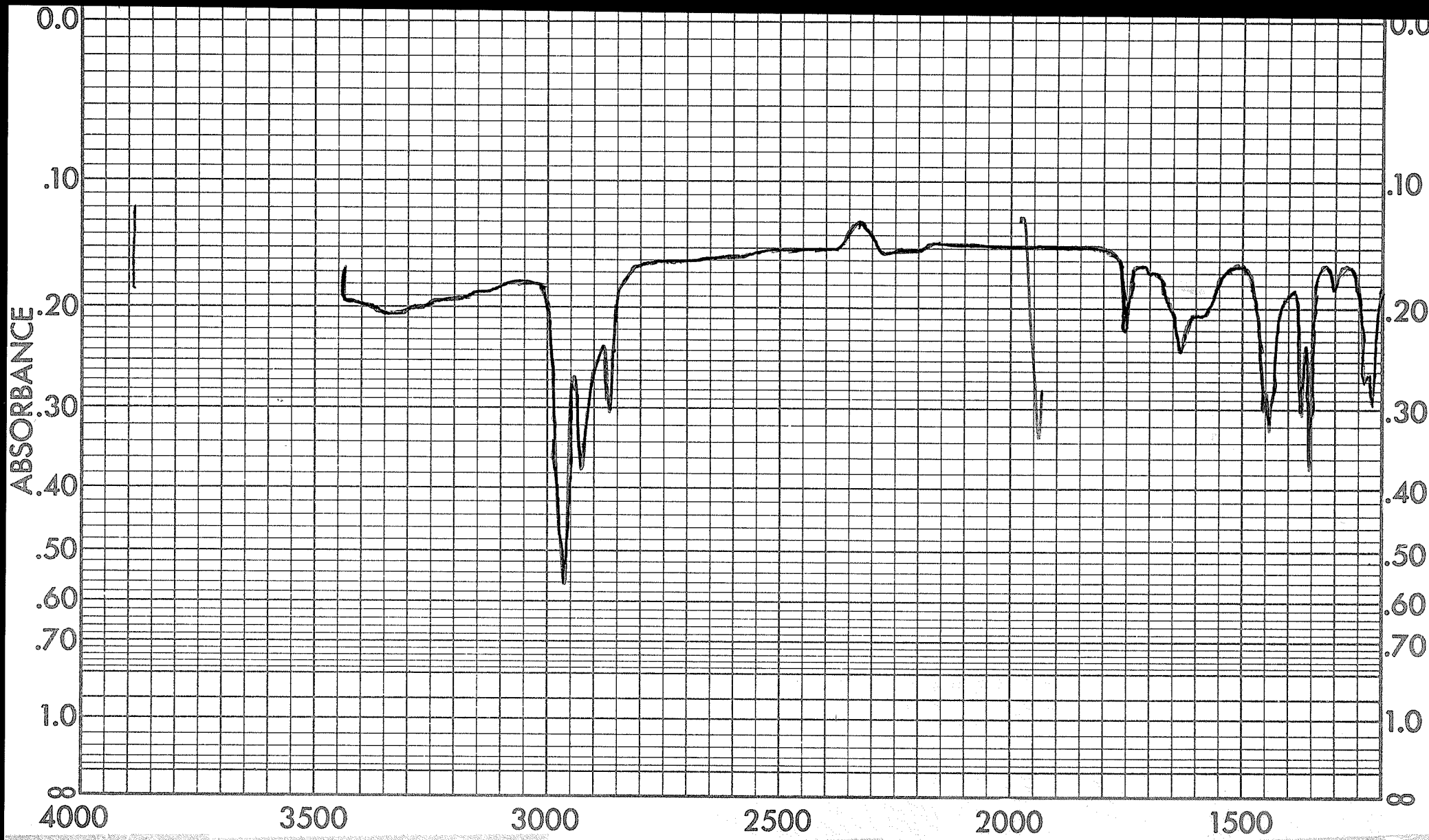
$(t\text{-}C_4H_9)_2S_2$

87.

PART NO. 337-1207

PERKIN-ELMER ®

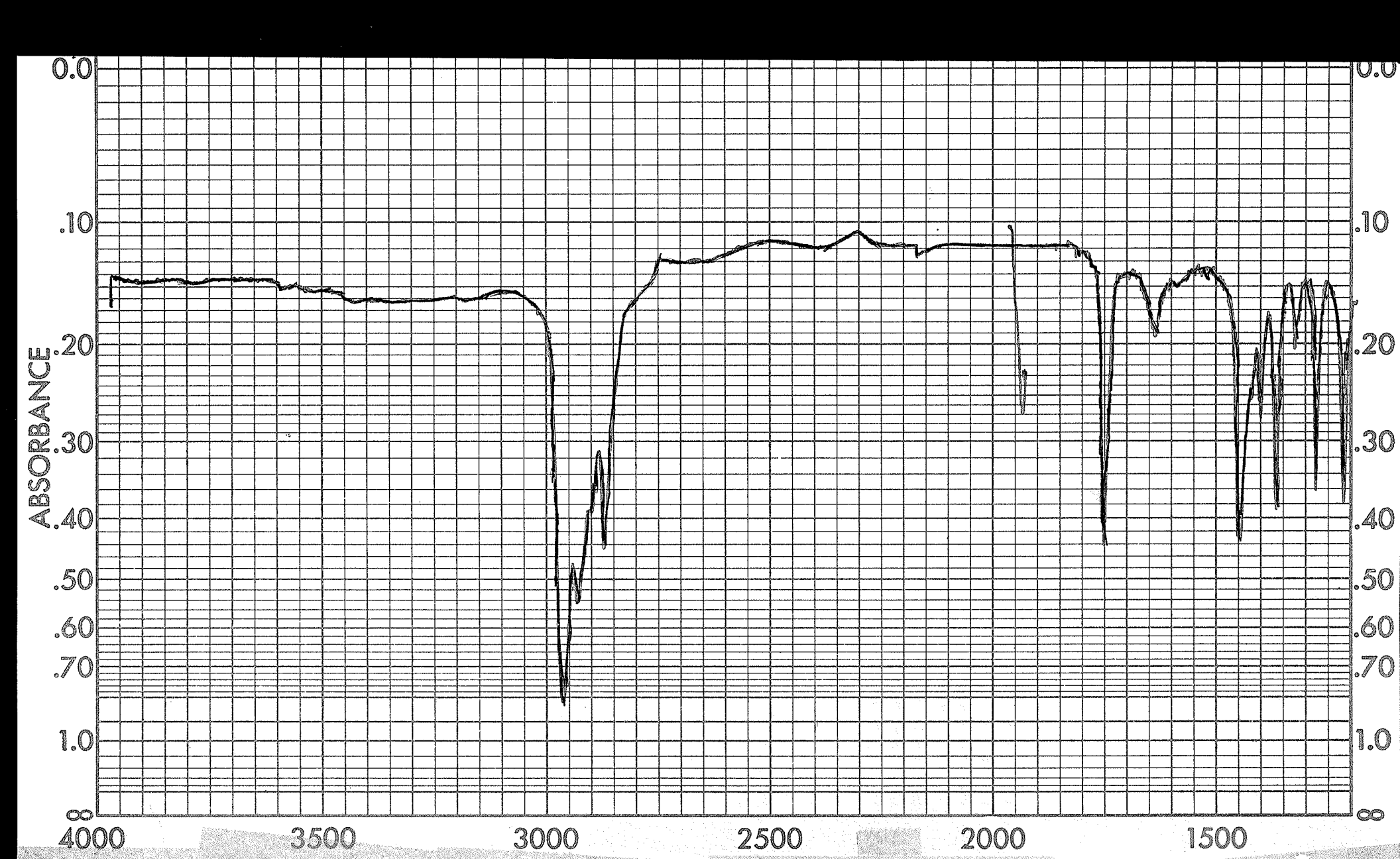
88.



i-Propyl Disulfide

$(i\text{-}C_3H_7)_2S_2$

TRANSMITTANCE (%)
100
80
60
40
20
0
FREQUENCY (CM⁻¹)
400
500
600
700
800
900
1000
1100
1200
1300
926

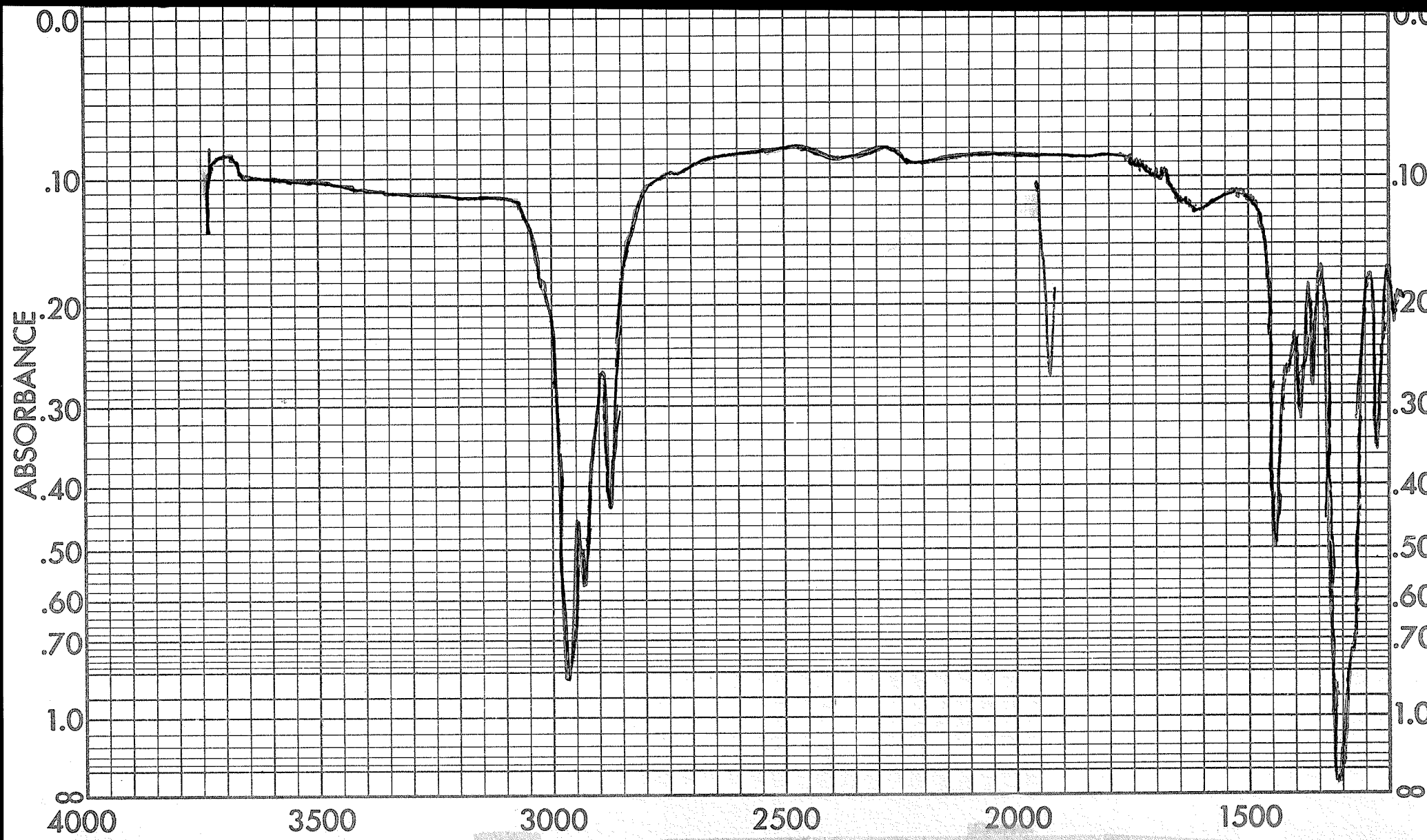


n-Propyl Disulfide

$(n\text{-}C_3H_7)_2S_2$

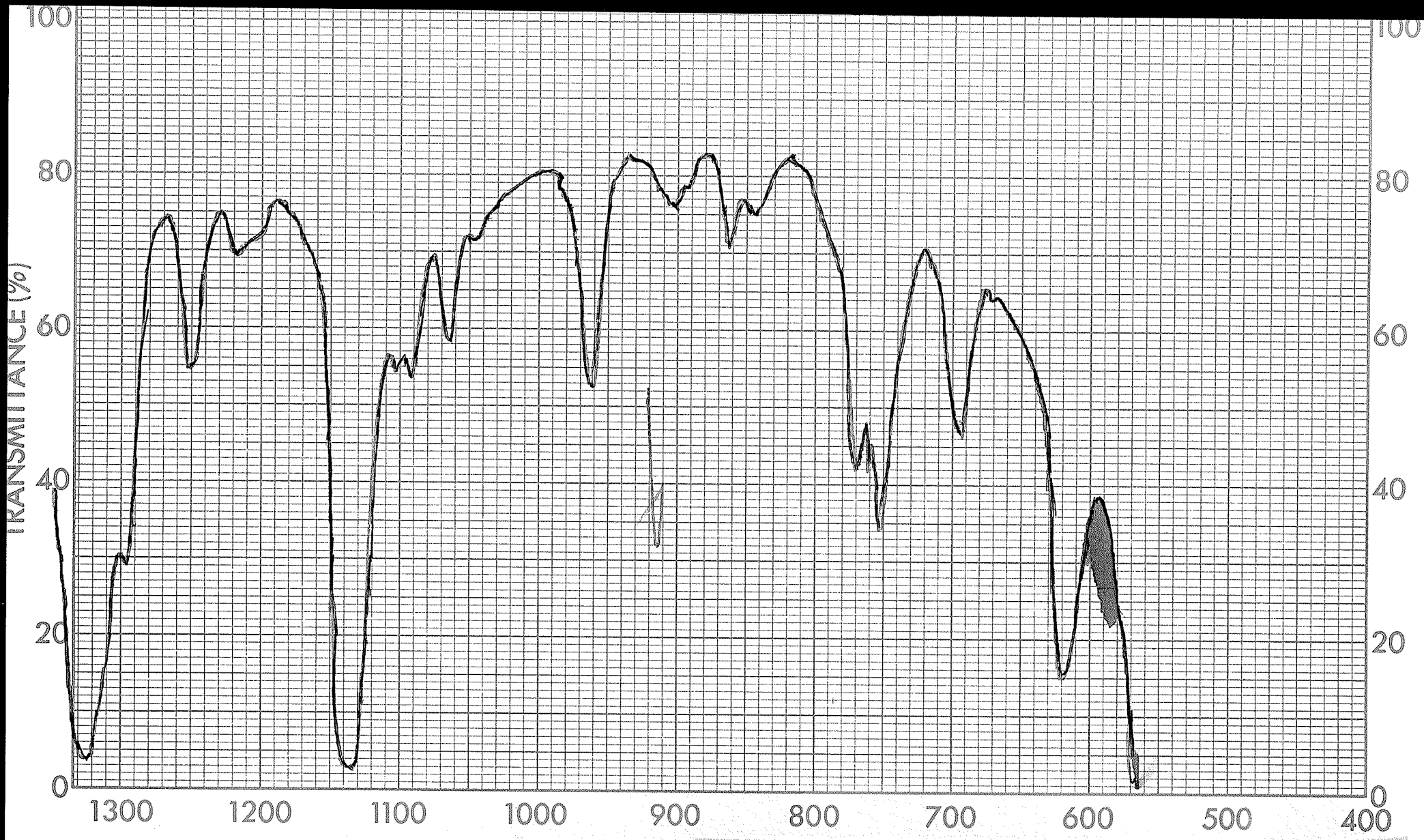

100
80
60
40
20
0
TRANSMITTANCE (%)
1300
1200
1100
1000
900
800
700
600
500
400
FREQUENCY (CM⁻¹)

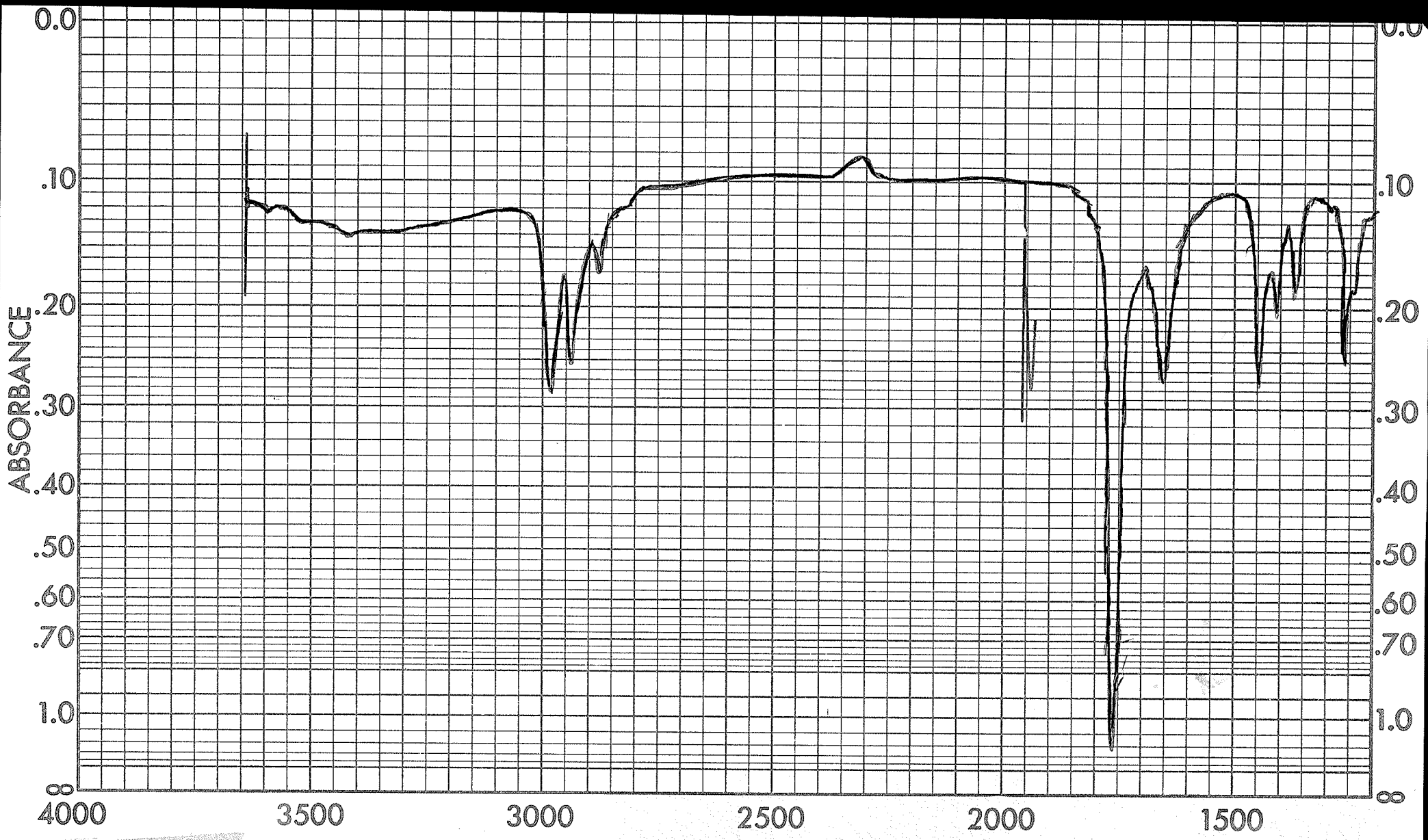
92.



n-Propyl n-Propyl Thiolsulfonate

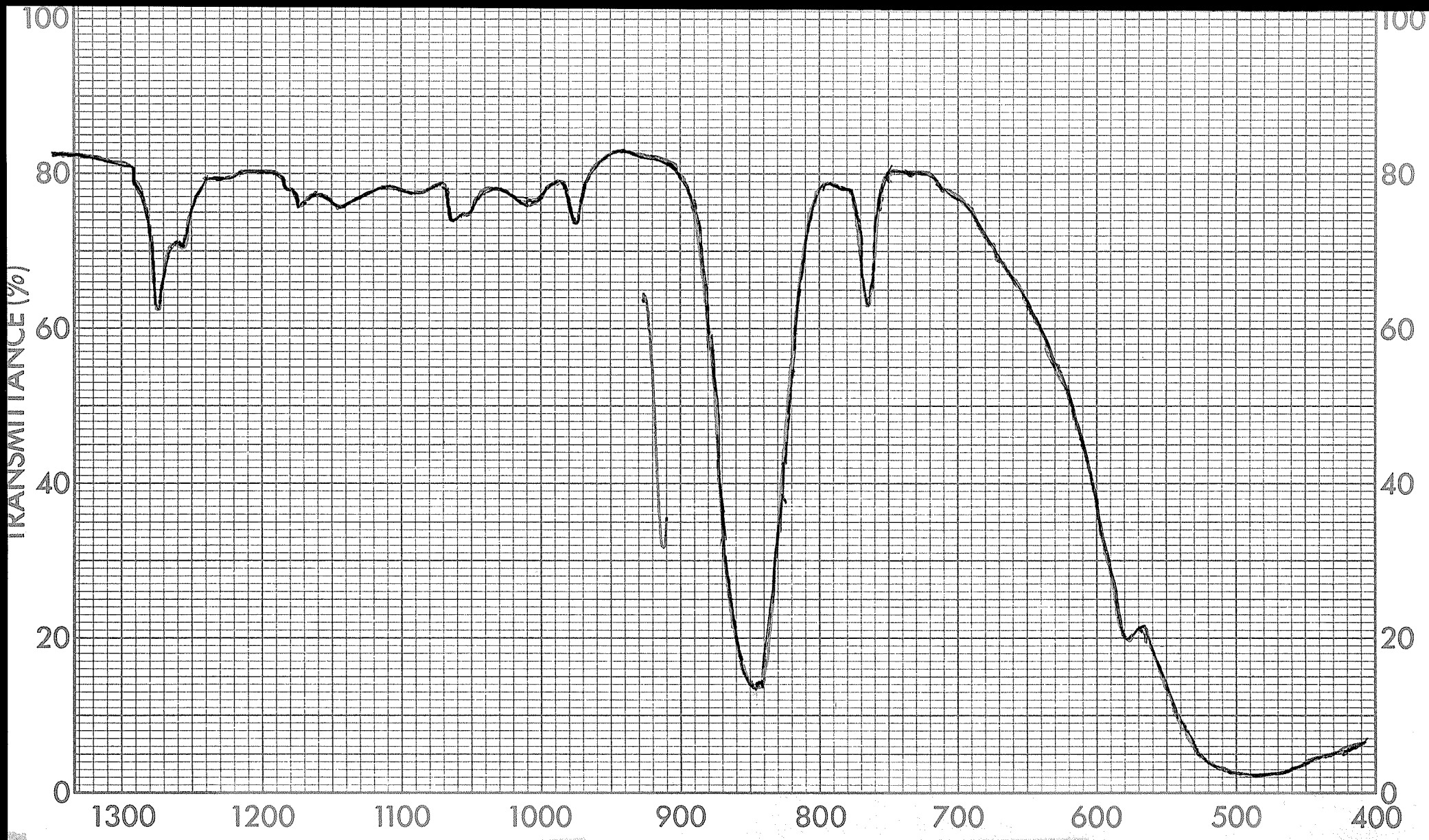
$n\text{-}C_3H_7SO_2Sn\text{-}C_3H_7$

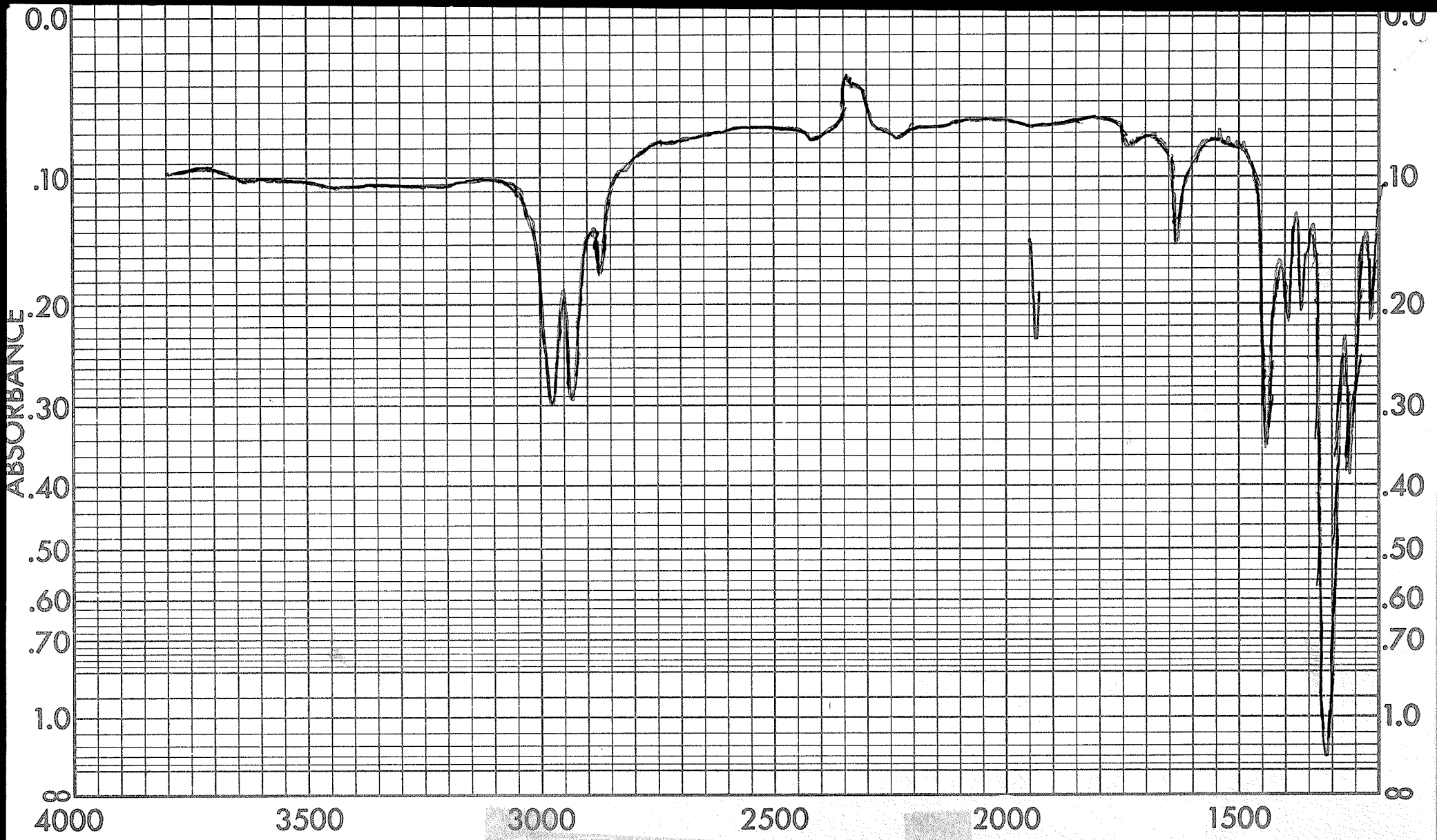

100
80
60
40
20
0
TRANSMITTANCE (%)
1300
1200
1100
1000
900
800
700
600
500
400
FREQUENCY (CM⁻¹)



Ethyl Disulfide

$(C_2H_5)_2S_2$

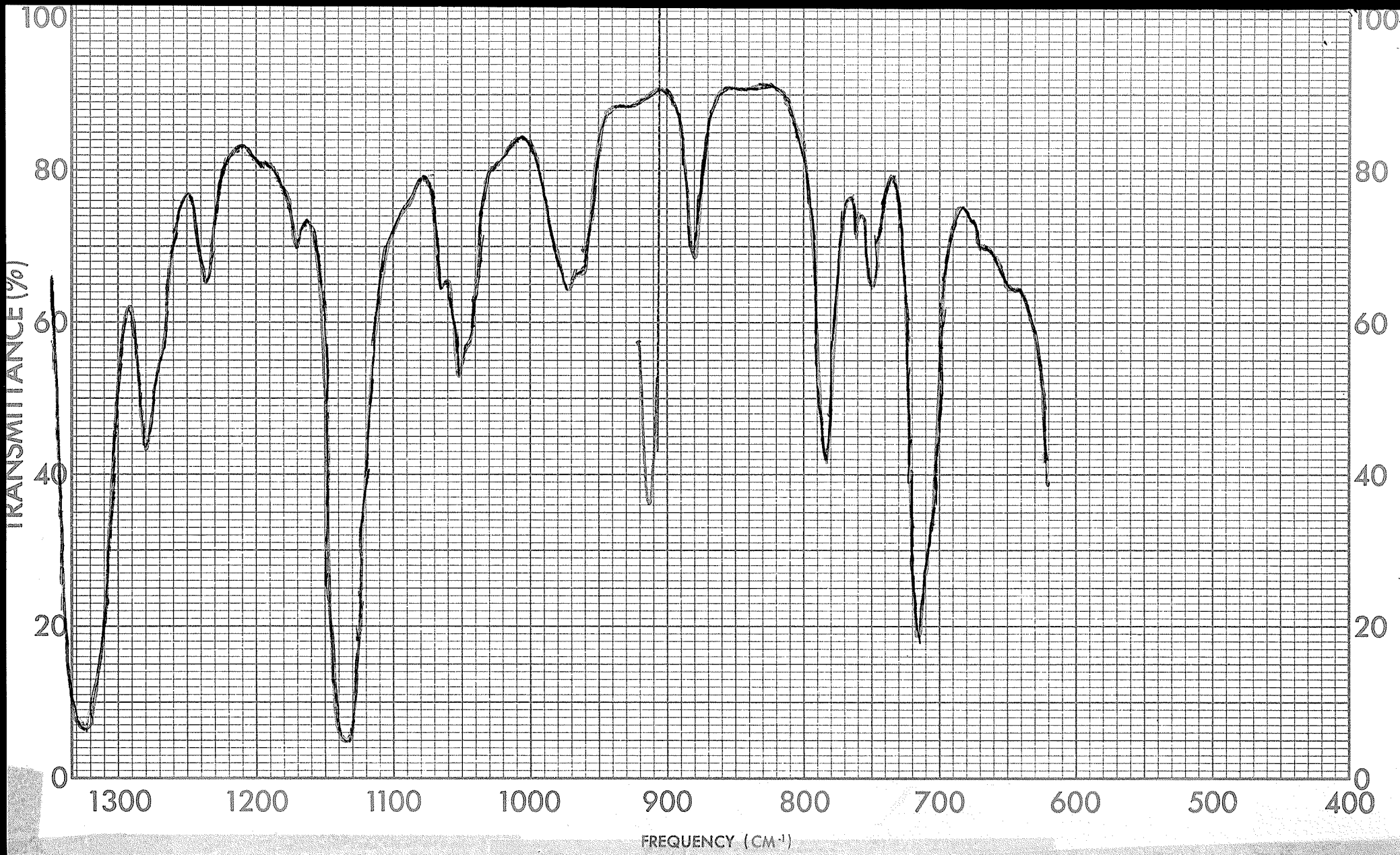

100
80
60
40
20
0
TRANSMITTANCE (%)
1300
1200
1100
1000
900
800
700
600
500
400
FREQUENCY (CM⁻¹)

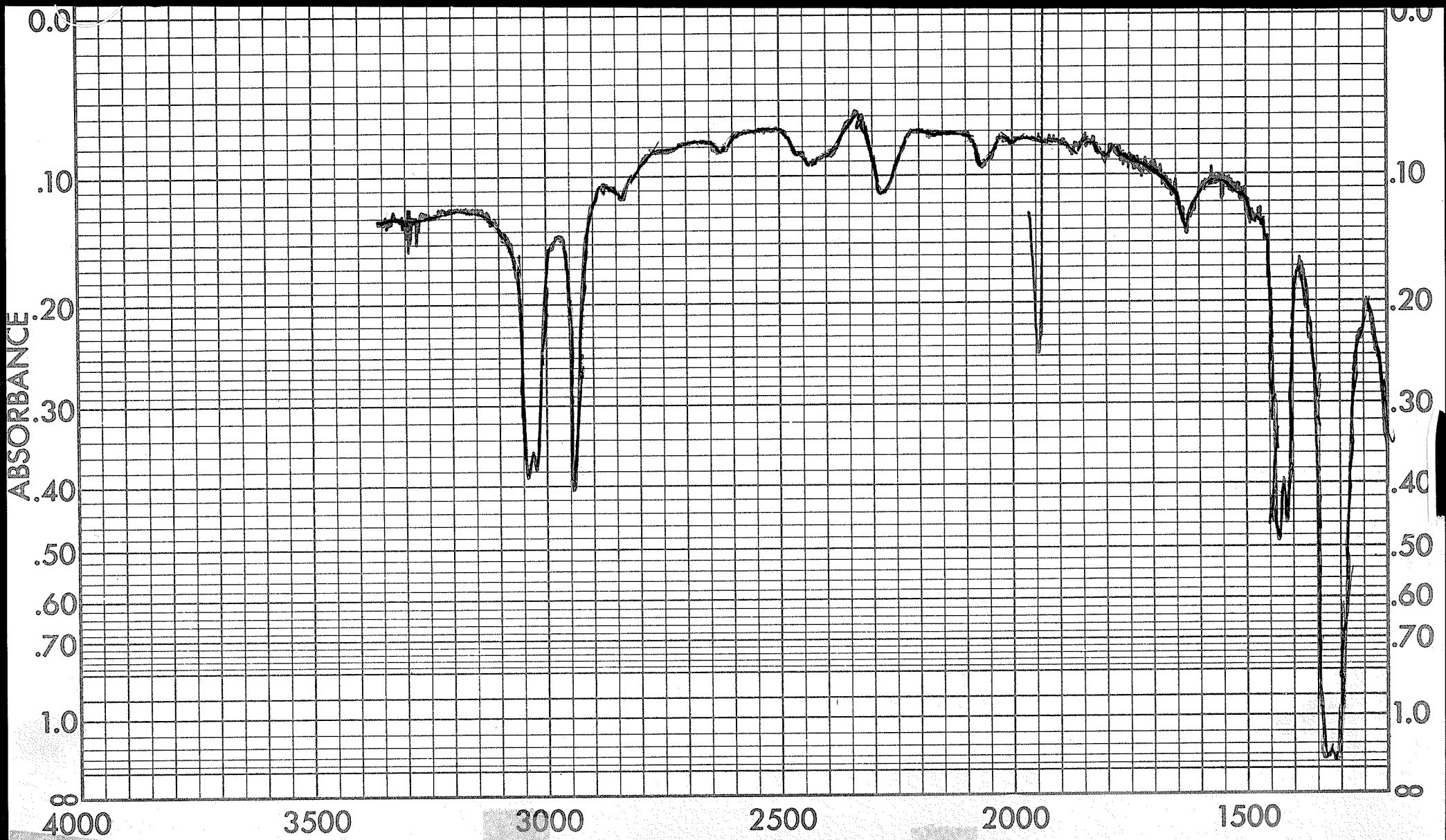


Ethyl Ethyl Thiolsulfonate

$C_2H_5SO_2SC_2H_5$

97.

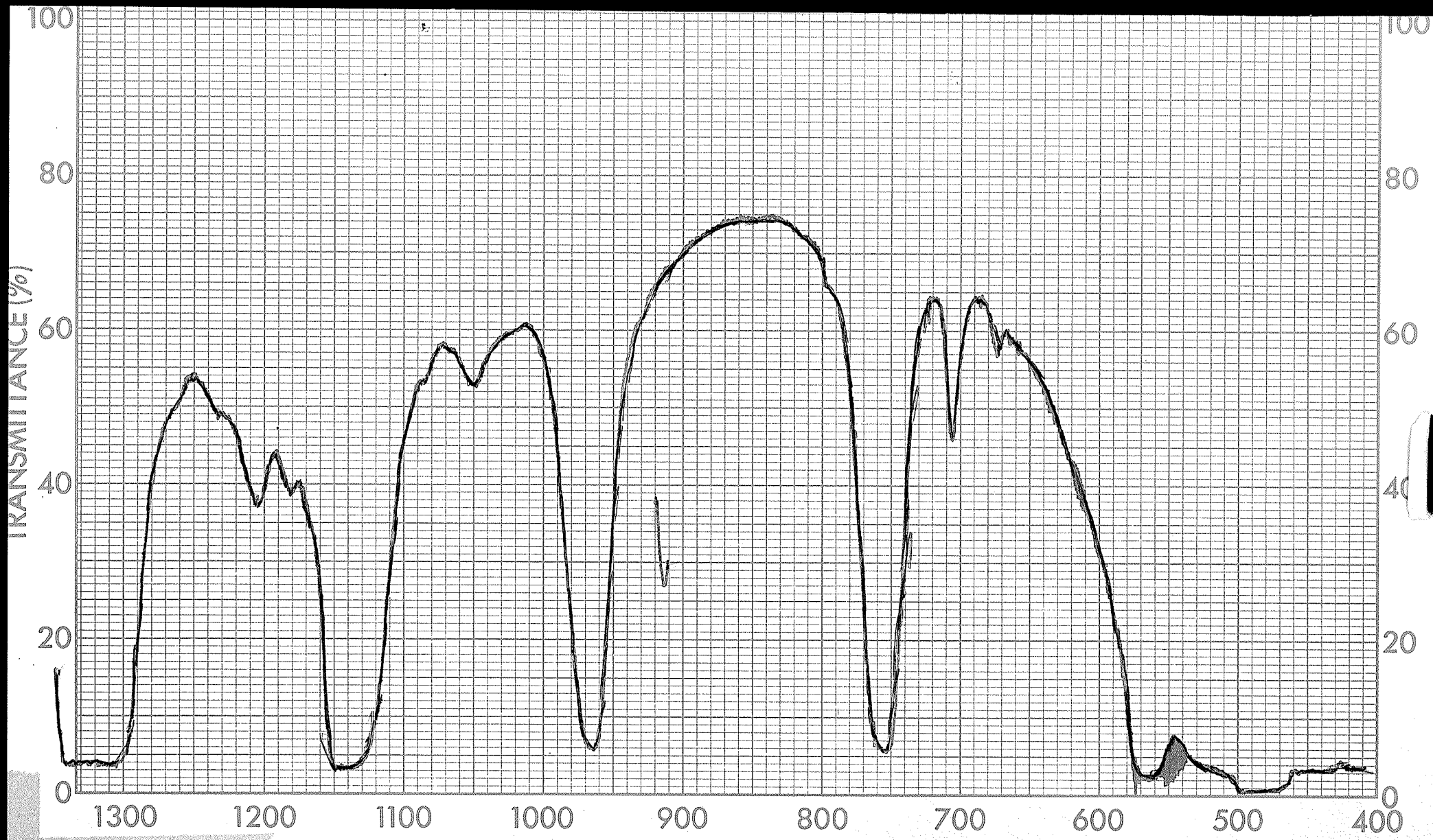




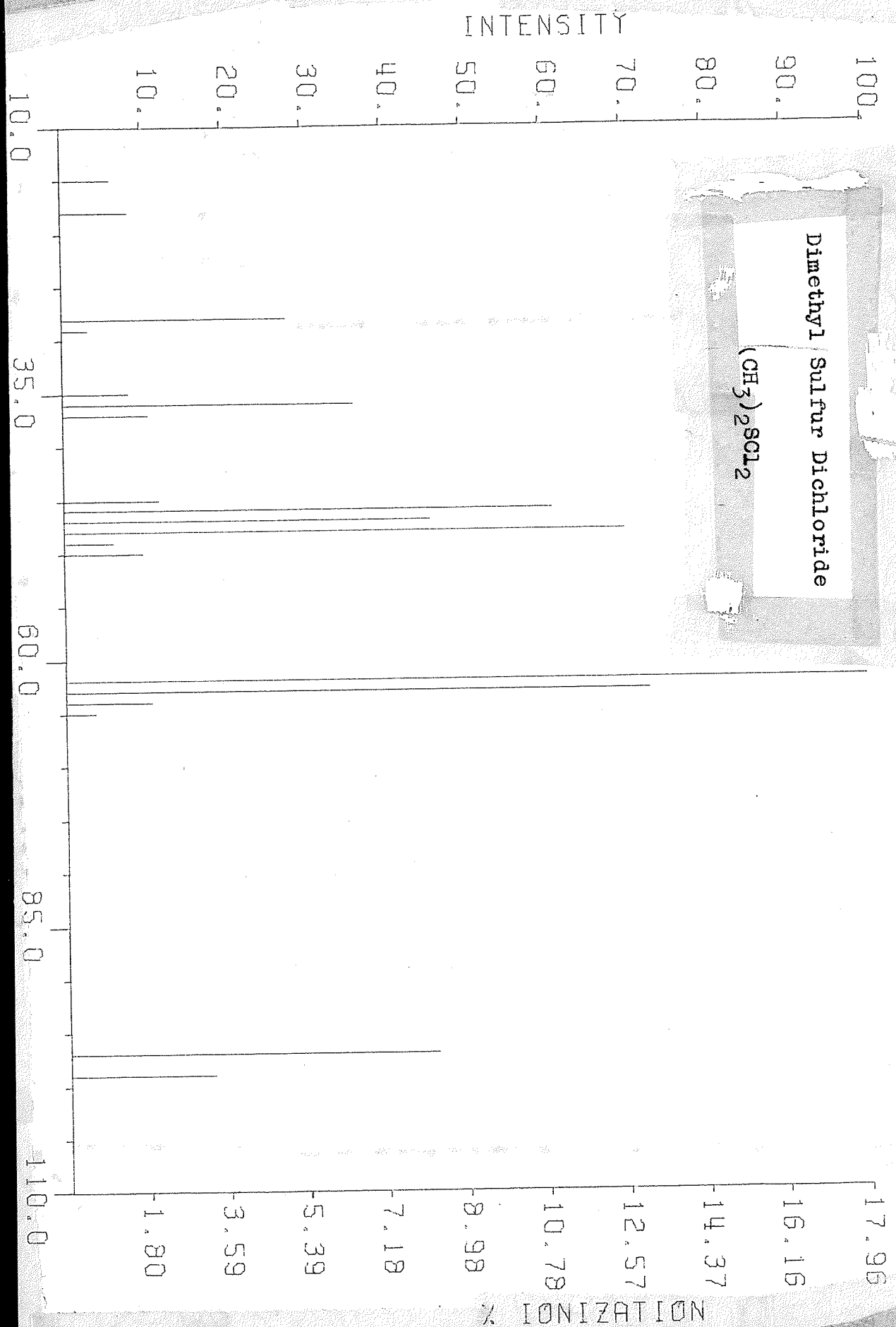
Methyl Methyl Thiolsulfonate

$CH_3SO_2SCH_3$

99.

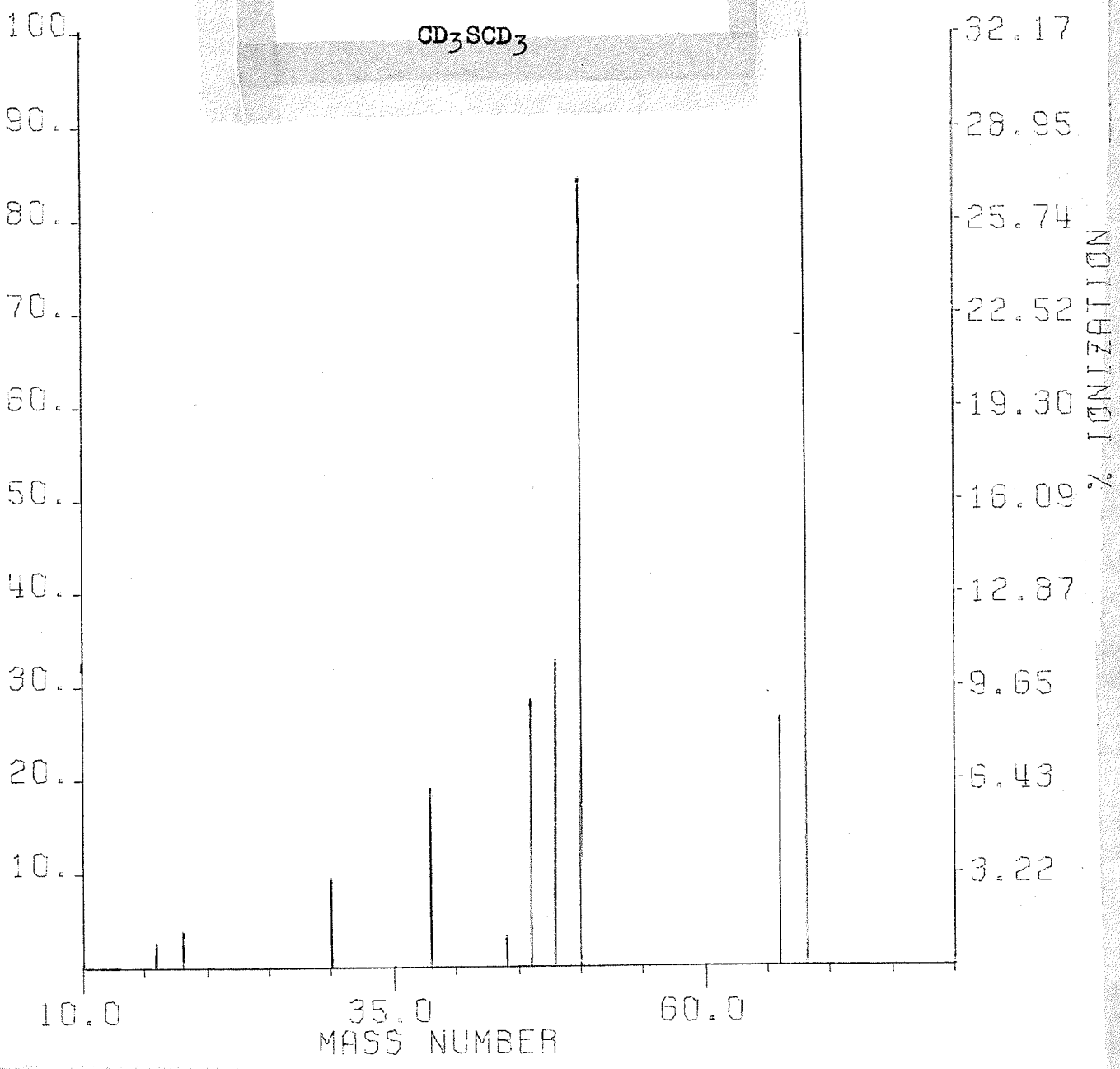

100
80
60
40
20
0
TRANSMITTANCE (%)
1300
1200
1100
1000
900
800
700
600
500
400
FREQUENCY (CM⁻¹)

Mass Spectra


INTENSITY
10.0
20.
30.
40.
50.
60.
70.
80.
90.
100.
Dimethyl Sulfur Dichloride
$(CH_3)_2SCl_2$
35.0
60.0
85.0
110.0
1.80
3.59
5.39
7.18
8.98
10.78
12.57
14.37
16.16
17.96
% IONIZATION

Deutero-Dimethyl Sulfide

CD_3SCD_3



REFERENCES

J. Albright, L. Goldman J.O.C. 30, 1107(1965)

J.Albright, L.Goldman J.A.C.S. 87, 4214(1965)

E. Amonoo-Neizer, S. Ray, R. Shaw, M. Smith J.C.S. 6250 (1965)

B. Baker, D. Buss J.O.C. 30, 2304(1965)

D. Barnard J.C.S. 4547(1957)

D. Barnard J.C.S. 4675(1957)

D. Barton, G.Garner, R. Wightman J.C.S. 1855(1965)

H. Becker, G. Mikol, G. Russel J.A.C.S. 85, 3410(1963)

H. Bohme, H.Fisher, R. Frank Ann. 563, 54(1949)

B. Boldyrev, A. Litkovets, T. Trofimora Doklody Akad. Naok. SSSR 107, 697(1956)

B. Boldyrev, A. Litkovets, T. Trofimora Zhur. Obshechei Khim. 26, 3360(1956)

F. Bordwell, B. Pitt J.A.C.S. 77, 572(1955)

R. Bosham J.A.C.S. 81, 3341(1959)

D. Copley, F. Fairbrother, K. Grundy, A. Thompson J. Less Common Metals 6, 407(1964)

E. Corey, M. Chaykovsky J.A.C.S. 87, 1363(1965)

A. Cornu, R. Bassol "Compilation of Mass Spectral Data" Heyden & Sons Ltd (1966)

C. Crumper, T. Reed J.C.S. 5323(1965)

J. Cymmerman, J. Willis J.C.S. 1332(1951)

I. Douglas J.O.C. 24, 2004(1959)

I. Douglas, B. Farah J.O.C. 24, 973(1959)

A. Fenselau, J. Moffatt J.A.C.S. 88, 1762(1966)

E. Fromm Ann. 396, 75(1913)

A. Geddes J.Phy. Chem. 58, 1062(1954)

M. Gumbmann, H. Burr J. Agr. Food Chem. 12, 404(1964)

A. Greenwald, M. Chaykovsky, E. Corey J.O.C. 28, 1128(1963)

G. Helmkamp, H. Cussey, B. Olson, D. Pettitt J.O.C. 30, 933(1965)

I. Hunsberger, J. Tien Chem. Ind. (London) 88(1959)

C. Johnson, M. Jones J.O.C. 32, 2014(1967)

A.Johnson, A. Pelter J.C.S. 520(1964)

C. Johnson, W. Phillips J.A.C.S. 91, 682(1969)

J. Kice, N. Favstritsky J.A.C.S. 91, 1751(1969)

J. Kice, G. Large J.A.C.S. 90, 4069(1968a)

J. Kice, G. Large J.O.C. 33, 1940(1968b)

J. Kice, G. Vernier, L. Heasley J.A.C.S. 91, 1751(1969)

N. Kornblum, W. Jones, C. Anderson J.A.C.S. 79, 6562(1959)

N. Kornblum, T. Powers, C. Anderson, W. Jones, H. Larson, O.Levand, W. Weaver J.A.C.S. 79 6562(1957)

M. Lamport, J. Smith J.C.S. 3224(1961)

D. Landini, F. Montanari Tet. Let. 38, 2691(1964)

R. Major, H. Hess J.O.C. 23, 1563(1958)

M. Meerwein Org. Syn. 46, 113

K. Mislow, T. Simmons, J. Melillo, A. Ternay J.A.C.S. 86, 1452(1964)

G. Moss, G. Reese, K. Schofield, R. Shapiro, L. Todd J.C.S. 1149(1963)

H. Nace, J. Monagle J.O.C. 24, 1792(1959)

W. Norris J.A.C.S. 81, 3346(1959)

S. Oae, M. Kice Tet. Let. 2261(1968)

K. Pfitzner, J. Moffatt J.A.C.S. 87, 5661(1965a)

K. Pfitzner, J. Moffatt J.A.C.S. 87, 5670(1965b)

R. Riemschneider, O. Lorentz Monatsh Chem. 84, 518(1953)

H. Reinboltd, E. Giesbrecht, M. Perrier, B. Cecchini Quimica 3, 172(1951)

A. Saizew Ann. Physik 139, 354(1866)

E. Schneider Chem. Ber. 911(1951)

L. Small, J. Bailey, C. Corallito J.A.C.S. 69, 1710(1947)

S. Smith, S. Winstien Tetrahedron 3, 317(1958)

R. Stewart, J. Jones J.A.C.S. 89, 5069(1967)

H. Szmant, O. Cox J.O.C. 31, 1595(1966)

W. Truce, G. Birum, E. McBee J.A.C.S. 74, 3594(1952)

T. Tsuchiya, S. Iriyama, S. Umezawa Bull. Chem. Soc. Japan 37, 286(1964)

D. Tuleen, T. Stephens J.O.C. 34 31(1969)

A. Vogel, M. Conan J.C.S. 16(1943)

T Wallace Chem. & Ind. 501(1964)

T. Wallace Chem. & Ind. 765(1965)

T. Wallace, J. Mahon J.A.C.S. 80, 4099(1964)

T. Wallace, J. Mahon J.O.C. 30, 1502(1965)

J. Kice, E. Markved J.A.C.S. 86, 2270(1964)