THE CHEMISTRY OF α-SULFENYL TRIMETHYLSILOXY DERIVATIVES

by

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ABSTRACT

This thesis reports the successful synthesis under mild conditions of a number of α-trimethylsiloxy sulfides, disulfides and thiols. In addition, appropriate experimental procedures have been developed for the desilylation of the α-trimethylsiloxy sulfides to give thiols. An investigation of the synthetic utility of these new compounds has been commenced. From the α-trimethylsiloxy sulfides a novel class of α-halosulfides, the α-bromosulfides, has been prepared. Other classes of compounds which have been synthesized from the α-trimethylsiloxy sulfides include unsymmetrical thioacetals, unsymmetrical sulfides and symmetrical disulfides.

RESUME

La présente thèse fait état de la synthèse sous conditions modérées, de certains α-trimethylsiloxy sulfides, disulfides et thiols. Des procédés expérimantaux adéquats ont été developpés et appliqués à la desilylation de α-trimethylsiloxy sulfides afin de produire des thiols.

L'étude des possibiltés synthétiques de ces nouveaux composés est actuellement en cours. Un nouveau genre d'α-halosulfides, les α-bromosulfides, ont été préparé à partir du α-trimethylsiloxy sulfides. Les autres formes de composés dont les synthèses ont été effectuées à partir du α-trimethylsiloxy sulfides sont les thioacetals assymétriques, les sulfides assymétriques et les disulfides symétriques.

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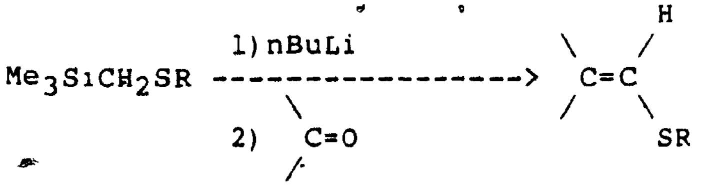
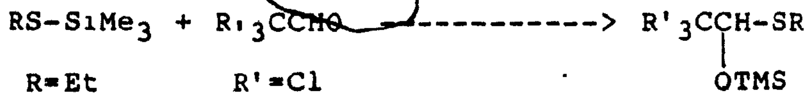
INTRODUCTION

Organic sulfur derivatives of silicon have been studied for many years[1-5]. One of the best known reactions using these elements is Peterson's olefin synthesis[6-8] illustrated below(eq.1).



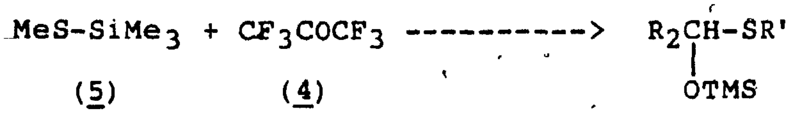
eq.1

The combination of a weak sulfur-silicon bond in the starting material coupled with a strong silicon-oxygen bond in the product can be used as a driving force in synthesis. This is illustrated by Hooten's preparation[9] of an α-siloxy sulfide(1) from trichloroacetoaldehyde(2) and trimethylsilyl ethyl sulfide(3); this reaction, however, requires harsh conditions (1.5 days at 80 °C)(eq.2).



$$\underset{\substack{R=Et\\(3)}}{RS{-}SiMe_3} + \underset{\substack{R'=Cl\\(2)}}{R'_3CCHO} \longrightarrow \underset{\substack{|\\OTMS\\(1)}}{R'_3CCH{-}SR} \qquad \text{eq.2}$$

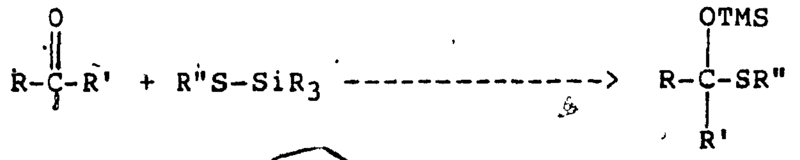
A similar example is the synthesis by Abel and co-workers[10] of an α-siloxy sulfide(1) from hexafluoroacetone (4) and trimethylsilyl methyl sulfide(5); this reaction also requires vigorous conditions (eq.3).



$$\underset{(5)}{MeS{-}SiMe_3} + \underset{(4)}{CF_3COCF_3} \longrightarrow \underset{\substack{|\\OTMS}}{R_2CH{-}SR'}\ (1) \qquad \text{eq.3}$$

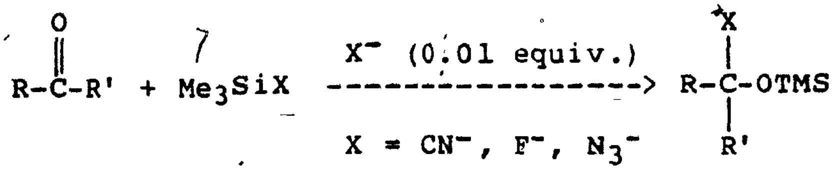
$R=CF_3;\ R'=Me$

A significant step forward was made by Evans[12] in 1974 when he discovered that the introduction of an anionic catalyst (potassium cyanide-crown ether complex or tetra-n-butylammonium fluoride) both increased the yield of siloxy sulfide and enabled the reaction to be carried out under mild conditions(eq.4). Interestingly, a very recent paper[13] on "anhydrous" tetrabutylammonium fluoride suggests that this compound may act as an enhanced silylation catalyst.

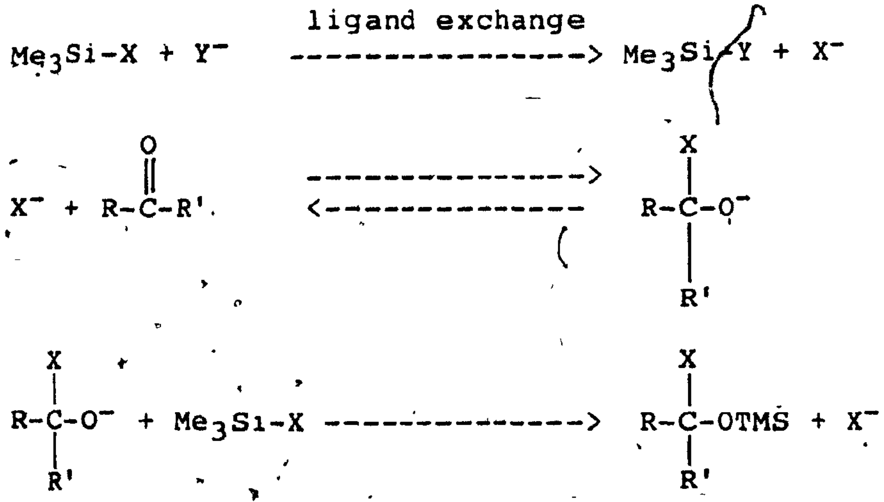


$$R-\overset{\displaystyle O}{\overset{\|}{C}}-R' + R''S-SiR_3 \longrightarrow R-\underset{\displaystyle R'}{\overset{\displaystyle OTMS}{C}}-SR''$$ eq.4

The type of transformation shown in eq.4 has been applied to reactions with other nucleophilic groups such as cyanide, fluoride and azide ions(eq.5). The mechanism proposed by Evans for these catalyzed reactions is shown in eq.6.



$$R-\overset{\displaystyle O}{\overset{\|}{C}}-R' + Me_3SiX \xrightarrow[X\ =\ CN^-,\ F^-,\ N_3^-]{X^-\ (0.01\ equiv.)} R-\underset{\displaystyle R'}{\overset{\displaystyle X}{C}}-OTMS$$ eq.5

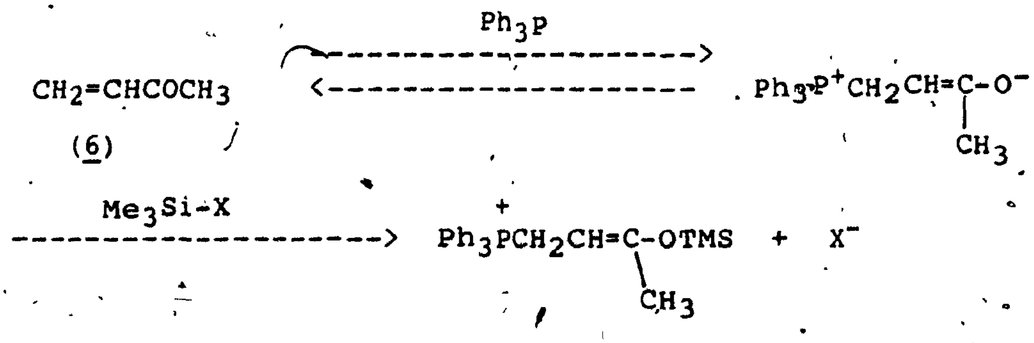


$$Me_3Si-X + Y^- \xrightarrow{\text{ligand exchange}} Me_3Si-Y + X^-$$ eq.6

$$X^- + R-\overset{\displaystyle O}{\overset{\|}{C}}-R' \rightleftarrows R-\underset{\displaystyle R'}{\overset{\displaystyle X}{C}}-O^-$$

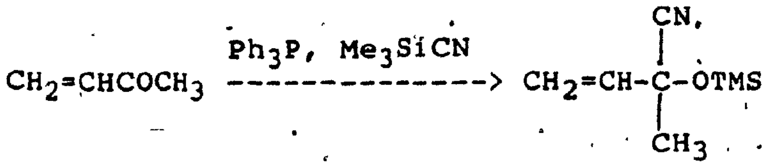
$$R-\underset{\displaystyle R'}{\overset{\displaystyle X}{C}}-O^- + Me_3Si-X \longrightarrow R-\underset{\displaystyle R'}{\overset{\displaystyle X}{C}}-OTMS + X^-$$

First, the nucleophilic catalyst attacks the carbonyl carbon. This is followed by reaction of the alkoxide oxygen with the silicon atom of Me_3SiX with concurrent displacement of X^-. When a catalyst which is different from the silicon counter ion is used, ligand exchange occurs first, and then the carbonyl carbon is attacked by the anion thus liberated. In the case of α,β-unsaturated carbonyl compounds(6), the addition reaction shown in eq.5 does not take place. Instead, a 1,4-addition occurs(eq.7). Triphenylphosphine is used as an initiator. It is of note that 1,2-addition occurs when cyanotrimethylsilane is used (eq.8).



$$\underset{(6)}{CH_2{=}CHCOCH_3} \overset{Ph_3P}{\rightleftharpoons} Ph_3P^+CH_2CH{=}\underset{\displaystyle CH_3}{\underset{|}{C}}{-}O^- \qquad eq.7$$

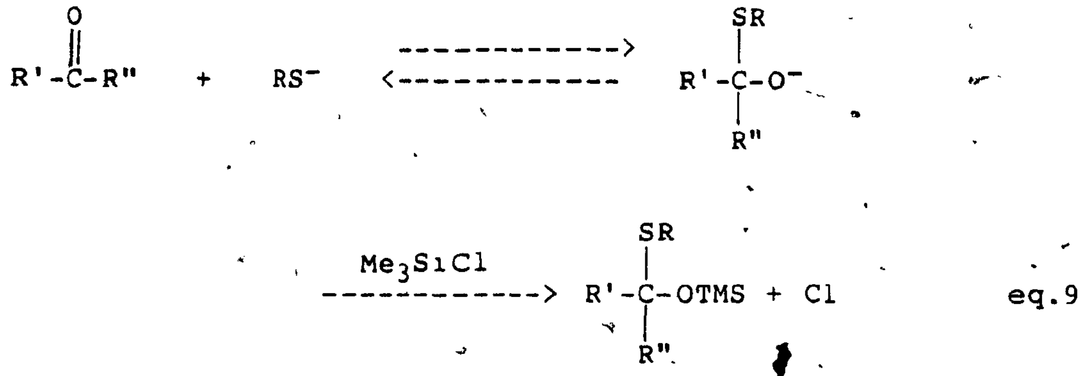
$$\xrightarrow{Me_3Si{-}X} Ph_3\overset{+}{P}CH_2CH{=}\underset{\displaystyle CH_3}{\underset{\backslash}{C}}{-}OTMS + X^-$$



$$CH_2{=}CHCOCH_3 \xrightarrow{Ph_3P,\ Me_3SiCN} CH_2{=}CH{-}\overset{\displaystyle CN}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}{-}OTMS \qquad eq.8$$

Chan and Ong[14] reported another preparation of α-siloxy sulfide compounds(1) from the corresponding carbonyl precursors, thiols, pyridine, and chlorotrimethylsilane (eq.9).

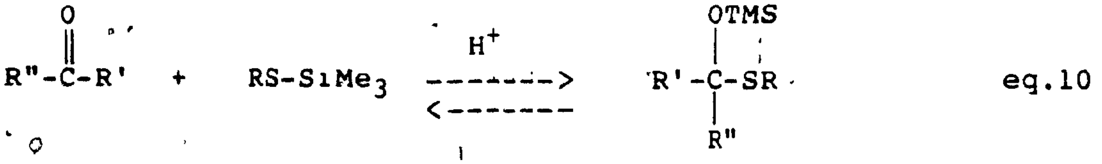
$$RSH + C_6H_5N \rightleftharpoons \underset{(7)}{RS^-} + C_5H_5NH^+$$



$$R'-\overset{\overset{O}{\|}}{C}-R'' + RS^- \rightleftharpoons R'-\underset{R''}{\overset{SR}{C}}-O^- \xrightarrow{Me_3SiCl} R'-\underset{R''}{\overset{SR}{C}}-OTMS + Cl \qquad \text{eq.9}$$

The mechanism of the reaction is thought to involve the formation of thiolate(<u>7</u>) from the thiol and pyridine. This anion then attacks the carbonyl carbon; this is followed by silylation on the acetal or ketal oxygen. In the absence of pyridine, thioketals or acetals are formed. Evans[12] proposed an alternate mechanism for Chan's reaction; this is formulated below(eq.10).

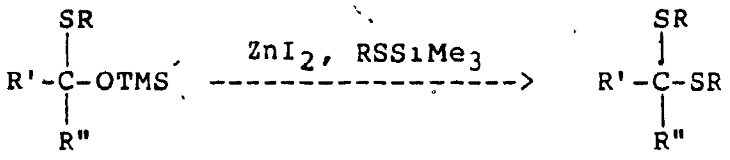
$$RSH + Me_3SiCl \overset{pyridine}{\rightleftharpoons} \underset{(\underline{8})}{RS-SiMe_3} + Py.HCl$$



$$R''-\overset{\overset{O}{\|}}{C}-R' + RS-SiMe_3 \overset{H^+}{\rightleftharpoons} R'-\underset{R''}{\overset{OTMS}{C}}-SR \qquad \text{eq.10}$$

(<u>8</u>) (<u>1</u>)

He suggested that the trimethylsilyl sulfide(<u>8</u>) could be formed from the thiol and chlorotrimethylsilane with pyridine. The trimethylsilyl sulfide would add to the carbonyl substrate since, under conditions of acid catalysis, ($ZnCl_2$, $AlCl_3$, anhydrous HCl in ether, $CHCl_3$, or acetonitrile) trimethylsilyl sulfides rapidly add to carbonyl substrates at room temperature. In the presence of another mole of compound <u>8</u> thioketals(<u>9</u>) are formed quantitatively(eq.11).



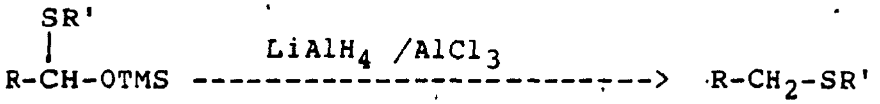
$$R'\text{-}\overset{SR}{\underset{R''}{C}}\text{-}OTMS \xrightarrow{ZnI_2,\ RSSiMe_3} R'\text{-}\overset{SR}{\underset{R''}{C}}\text{-}SR$$

eq.11

(9)

Evans rationalized the absence of thioketal in this instance on the basis of the acid strength of pyridinium hydrochloride. Chan[14] reported that the title compounds(1) are stable to heat, mild bases and alcohols.

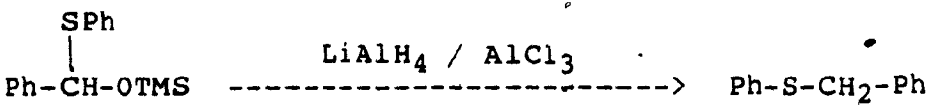
α-Siloxy sulfides(1) are among the most useful precursors of unsymmetrical sulfides(10). These may be obtained by hydride reduction of α-siloxy sulfides(1) using aluminium hydride and aluminium chloride[15](eq.12). For example, benzyl phenyl sulfide has been successfully prepared from α-siloxybenzyl phenyl sulfide(eq.13) following this method.



$$R\text{-}\overset{SR'}{CH}\text{-}OTMS \xrightarrow{LiAlH_4\ /AlCl_3} R\text{-}CH_2\text{-}SR'$$

eq.12

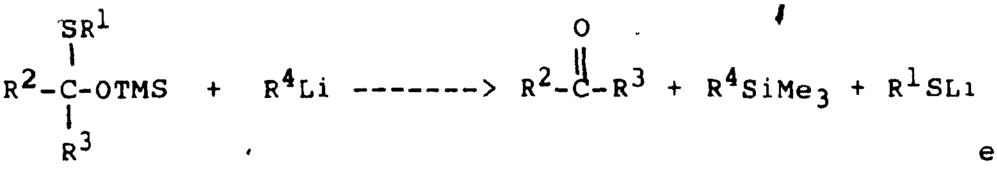
(1) (10)



$$Ph\text{-}\overset{SPh}{CH}\text{-}OTMS \xrightarrow{LiAlH_4\ /\ AlCl_3} Ph\text{-}S\text{-}CH_2\text{-}Ph$$

eq.13

Another interesting facet of the chemistry of α-siloxy sulfides has been reported by Chan and co-workers[14], who, in the course of their studies of desilylation methods, discovered that the latter compounds may be effectively desilylated by alkyllithiums(eq.14).

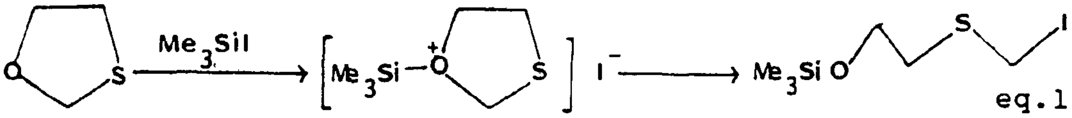


$$R^2\text{-}\overset{SR^1}{\underset{R^3}{C}}\text{-OTMS} + R^4Li \dashrightarrow R^2\text{-}\overset{O}{\overset{\|}{C}}\text{-}R^3 + R^4SiMe_3 + R^1SLi$$

eq.14

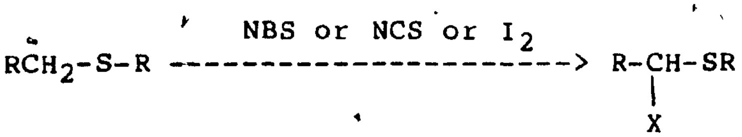
(1)

α-Siloxy sulfides(1) and related derivatives are useful starting materials for the preparation of α-iodosulfides(11). Keyser[16] has recently reported such a synthesis(eq.15).



eq.15

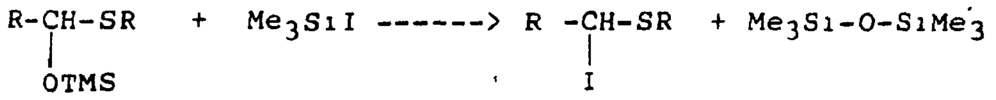
The cyclic ether(12) is treated with iodotrimethylsilane; ring opening occurs to give the α-iodosulfide(11). Clearly this method is limited to a small number of α-iodosulfides(11). Another α-iodosulfide preparation technique[17-27] involves the reaction of organic sulfides with iodine(eq.16). This method, however, has the disadvantage of introducing halogen into the reactive benzylic position.



$$RCH_2\text{-S-R} \xrightarrow{\text{NBS or NCS or } I_2} R\text{-}\underset{X}{\underset{|}{CH}}\text{-SR}$$

eq.16

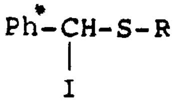
Recently, α-iodo sulfides(11) were synthesized in our laboratory(eq.17)[28]. The synthesis involves the reaction of an α-siloxy sulfide(1) with iodotrimethylsilane in $CHCl_3$ at -78 °C. The product is then purified by column chromatography or GLC.Theadvantage of this method is that the iodogroup is introduced specifically at the α-position of the sulfide.



$$\underset{\mathrm{OTMS}}{\mathrm{R{-}\overset{}{C}H{-}SR}} + \mathrm{Me_3SiI} \longrightarrow \mathrm{R} \; \underset{\mathrm{I}}{\mathrm{-CH{-}SR}} + \mathrm{Me_3Si{-}O{-}SiMe_3} \qquad \text{eq.17}$$

(1) (11)

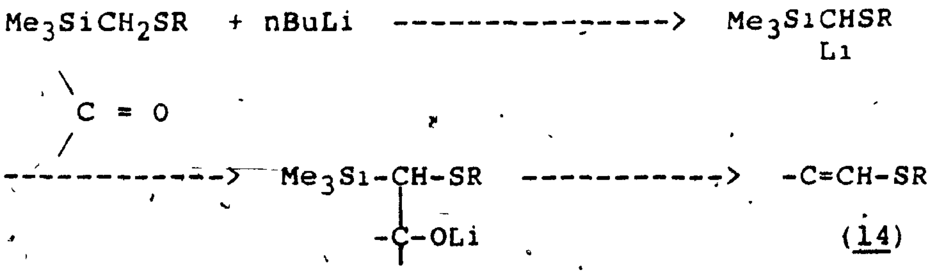
Most of the α-iodosulfides(11) prepared in this way were found to be stable in chloroform at room temperature for only about one hour, while those in which the α-iodo substituent was in a benzylic position (see structure 13 below) were found to decompose in about 20 minutes.



$$\mathrm{Ph{-}\underset{I}{C}H{-}S{-}R}$$

(13)

The preparation of vinyl sulfides(14) may also be effected using α-siloxy sulfides, although there are several well-known methods[29-32] which use different precursors. Of these, Peterson's method (mentioned at the beginning of the introduction) is one of the best known. It involves treatment of an α-trimethylsilyl sulfide with butyllithium followed by acetone. Vinyl sulfides(14) result by elimination of the trimethylsiloxy moiety(eq.18).

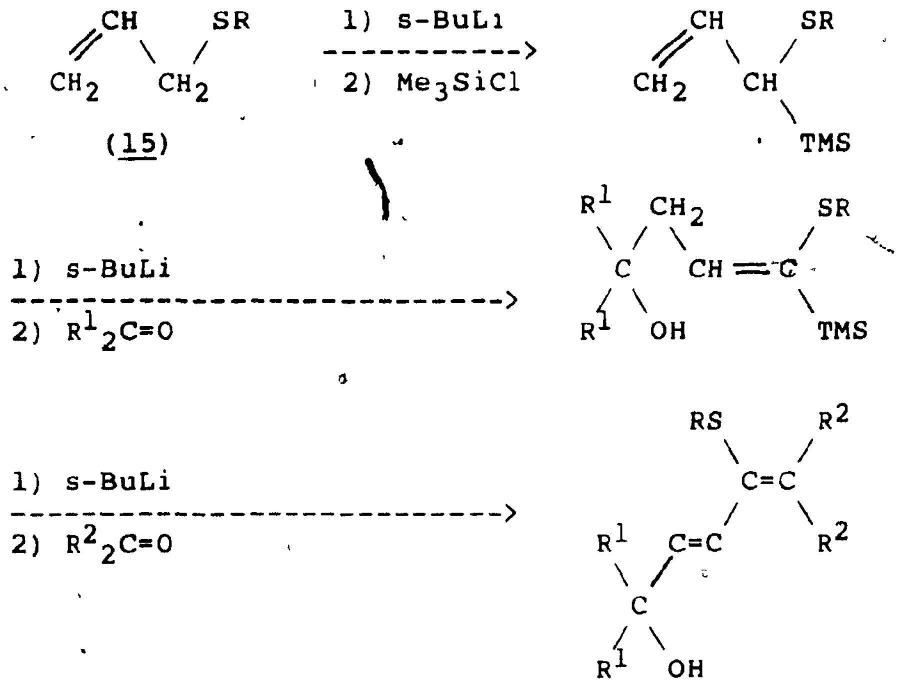


$$\mathrm{Me_3SiCH_2SR} + \mathrm{nBuLi} \longrightarrow \mathrm{Me_3Si\underset{Li}{C}HSR}$$

$$\xrightarrow{\;>C=O\;} \mathrm{Me_3Si{-}\underset{-\overset{|}{\underset{|}{C}}-OLi}{CH}{-}SR} \longrightarrow \mathrm{-C{=}CH{-}SR}$$

(14) eq.18

This concept has been extended by Watt[33] who recently reported the preparation of vinyl sulfides as illustrated in the following scheme,eq.19.

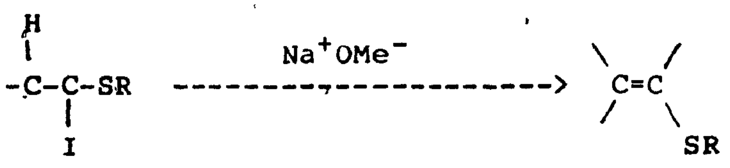


(15)

eq.19

Allyl sulfide(15) is treated with sec-butyllithium followed by chlorotrimethylsilane. The product from this step, in turn, is reacted with sec-butyllithium and ketone followed by another mole of sec-butyllithium and another mole of ketone to finally give the vinyl sulfide.

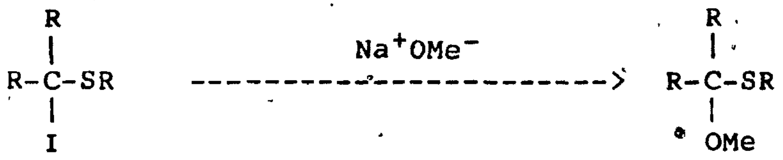
α-Iodosulfides(11) with β-hydrogens to iodine are very effective compounds for the preparation of vinyl sulfides(14)(eq.20). Preparation of the required α-iodo sulfides has been effected *via* α-siloxy sulfides[28].



(11) (14)

eq.20

To synthesize vinyl sulfides(14) in this way requires the use of either iodotrimethylsilane in aqueous sodium hydroxide under phase transfer conditions, or an anion exchange resin to bring about the elimination of hydrogen iodide. The vinyl sulfides thus prepared have the E configuration. Under the same reaction conditions, α-iodosulfides(11) without hydrogens β to iodine undergo the reaction shown in eq.21.

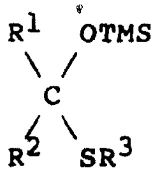


$$\mathrm{R_2C(I){-}SR} \xrightarrow{\mathrm{Na^+OMe^-}} \mathrm{R_2C(OMe){-}SR}$$

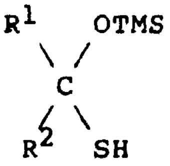
eq.21

(11)

Studies on the synthetic utility of α-siloxy sulfides(1) have recently been extended to include a method for the synthesis of α-siloxy thiols(16)[36].

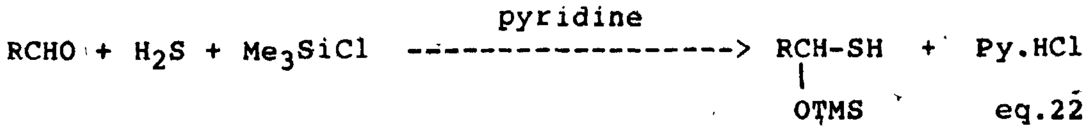


(1)



(16)

The latter compounds are synthesized from aldehydes, chlorotrimethylsilane, hydrogen sulfide and pyridine in ether(eq.22).

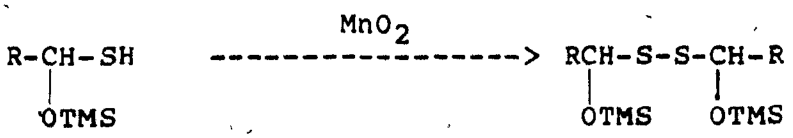


$$\mathrm{RCHO + H_2S + Me_3SiCl} \xrightarrow{\text{pyridine}} \mathrm{RCH(OTMS){-}SH + Py.HCl}$$

eq.22

(16)

This class of compounds is stable and its members possess a very strong, unpleasant odor. They are oxidized by MnO_2 like more simple thiols to give α,α-disiloxy disulfides(<u>17</u>); the meso/dl ratio is reported as 1:1(eq.23)[36].

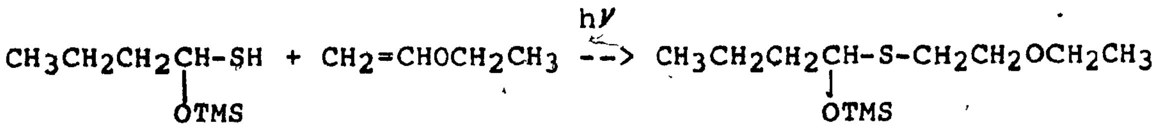


$$\underset{\text{OTMS}}{\text{R-CH-SH}} \xrightarrow{MnO_2} \underset{\text{OTMS}\quad\;\;\text{OTMS}}{\text{RCH-S-S-CH-R}}$$

eq.23

(<u>16</u>) (<u>17</u>)

Another reaction of α-siloxy thiols(<u>16</u>) is photochemical addition to olefins to give α-siloxy sulfides(eq.24).

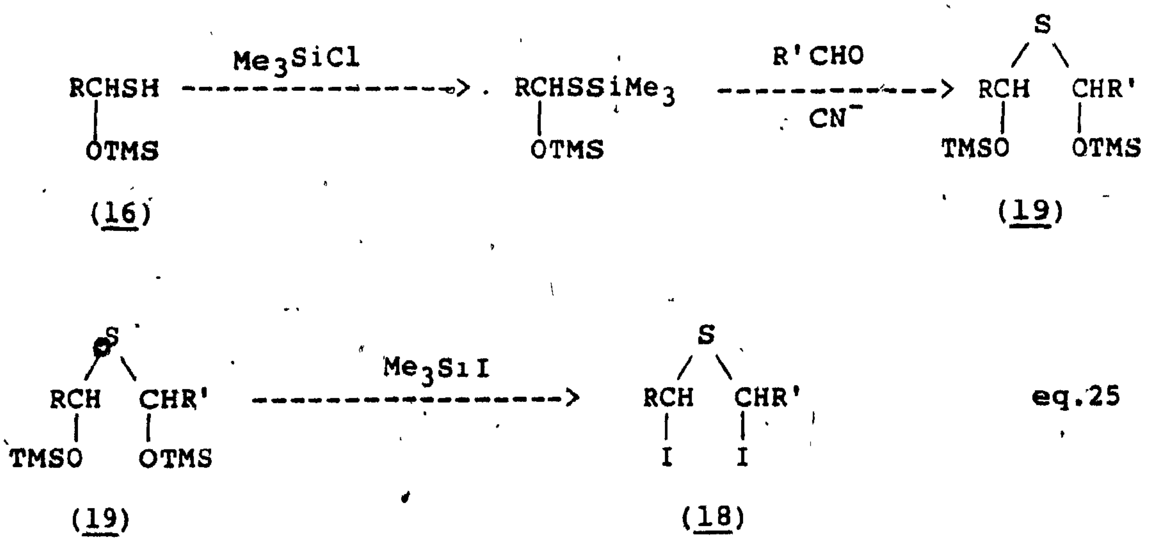


$$\underset{\text{OTMS}}{CH_3CH_2CH_2CH\text{-}SH} + CH_2{=}CHOCH_2CH_3 \xrightarrow{h\nu} \underset{\text{OTMS}}{CH_3CH_2CH_2CH\text{-}S\text{-}CH_2CH_2OCH_2CH_3}$$

eq.24

(<u>16</u>)

The chemistry of α-trimethylsiloxy thiols has been studied extensively in our lab[37a]; they may be used as precursors to diiodosulfides(<u>18</u>)(eq.25).

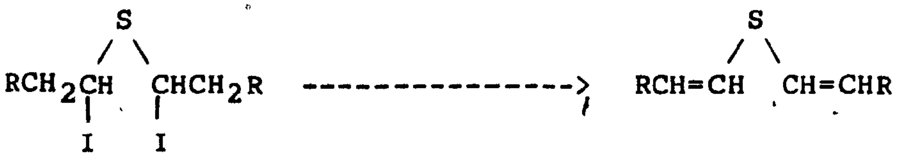


(<u>16</u>) (<u>19</u>) (<u>19</u>) (<u>18</u>)

eq.25

First, the thiol group of the α-siloxy thiol(16) is silylated using chlorotrimethylsilane in the presence of pyridine. Addition of an aldehyde to the silylated α-siloxy thiol in the presence of cyanide ion forms the α,α′-disiloxy sulfide(19) which is treated with iodotrimethylsilane. Siloxy-iodo group exchange gives the desired α,α′-diiodosulfide(18).

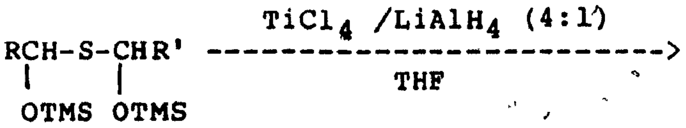
α,α′-Diiodosulfides(18) with hydrogens to iodine can be used to prepare divinyl sulfides(20)[37b] by elimination of two moles of hydrogen iodide(eq.26).



eq.26

(18) (20)

The intermediates, α,α′-disiloxy sulfides(19)(eq.25), are also synthetically useful for preparing olefins[38](eq.27).

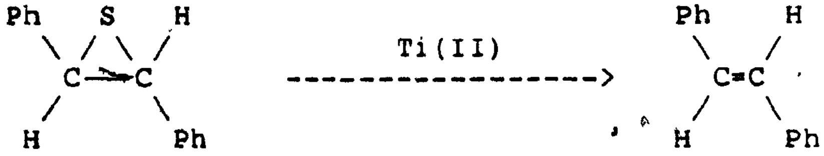


$$\underset{\text{OTMS}}{\text{RCH}}\text{-S-}\underset{\text{OTMS}}{\text{CHR}'} \xrightarrow[\text{THF}]{\text{TiCl}_4\ /\text{LiAlH}_4\ (4:1)} \text{RCH=CHR}'$$

eq. 27

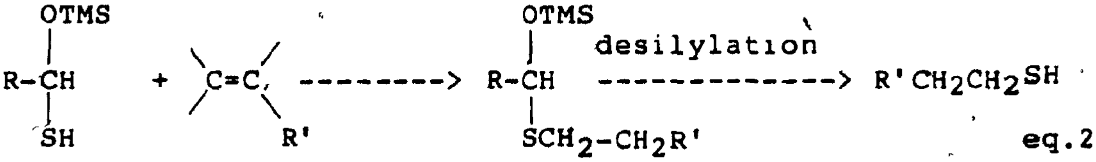
(19)

In the presence of titanium(II) derived from a 4:1 mixture of $TiCl_4$ and $LiAlH_4$, reductive deoxygenation occurs to give the product olefin. The authors suggest an episulfide as an intermediate for the reaction because trans 1,2-diphenylepisulfide reacted under identical conditions with the titanium reagent to give trans stilbene quantitatively(eq.27a).



eq.27a

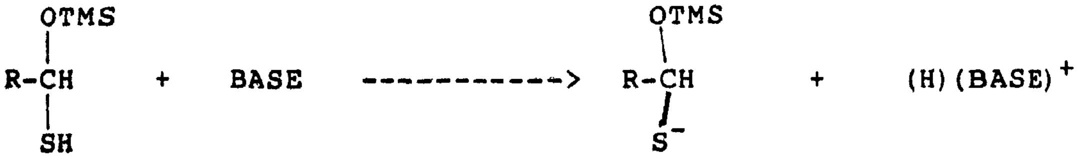
In the present work, it was of interest to further explore the synthetic applications of α-siloxy thiols(16). We expected these compounds to be of general use as thiol synthesis reagents because α-siloxy thiol groups can react with suitable reagents (e.g. an olefin (eq.28) or an alkyl halide) to give siloxy sulfides which in turn can be converted to new thiols after a final desilylation step, thus transforming the siloxy SH group.



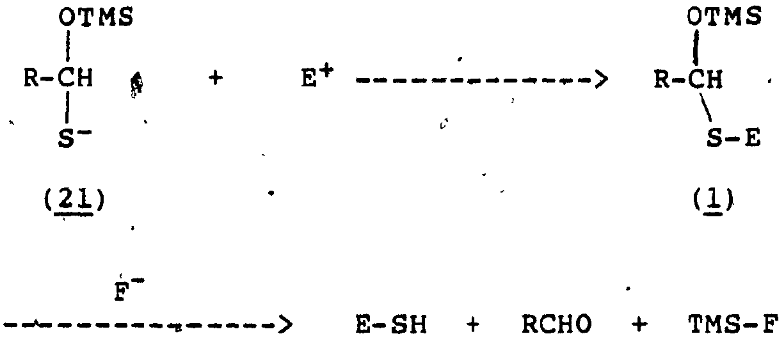
(16)

eq.28

Previous work in our lab[67] showed that α-siloxy thiolates(21) may be effectively generated using sodium hydride in dimethylformamide at -10 °C (this is a specific example of the first step in the general reaction sequence which appears below). Alkylation would provide the desired siloxy sulfide.



(16) (21)



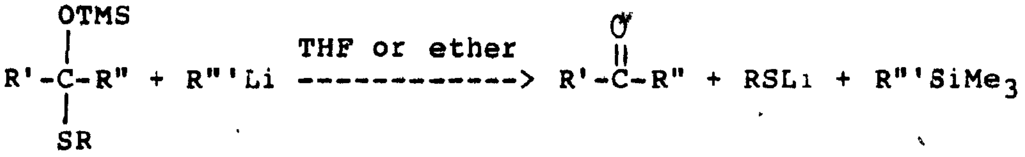
$$\underset{(\underline{21})}{\mathrm{R{-}}\overset{\mathrm{OTMS}}{\underset{\mathrm{S^-}}{\mathrm{CH}}}} + \mathrm{E^+} \longrightarrow \underset{(\underline{1})}{\mathrm{R{-}}\overset{\mathrm{OTMS}}{\underset{\mathrm{S{-}E}}{\mathrm{CH}}}} \xrightarrow{\mathrm{F^-}} \mathrm{E{-}SH} + \mathrm{RCHO} + \mathrm{TMS{-}F} \qquad \text{eq.29}$$

The final (and crucial) step in the reaction sequence shown in eq.29 above involves desilylation of the α-siloxy sulfide($\underline{1}$) to give the target thiol. A brief discussion of desilylation methods follows.

Desilylation of silyl ethers may be effected in several ways. Mineral or organic acids under aqueous conditions often give good results[39-41](eq.30).

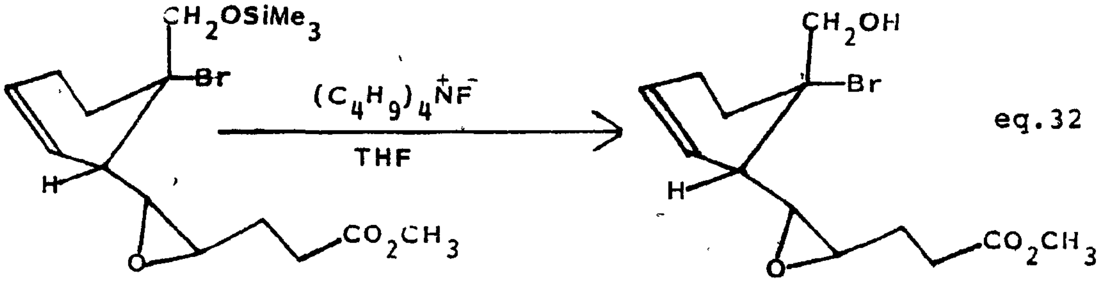
$$\rangle\mathrm{C{-}OSiMe_3} \xrightarrow{\mathrm{H^+},\ \mathrm{H_2O}} \rangle\mathrm{C{-}OH} + \mathrm{HOSiMe_3} \qquad \text{eq.30}$$

Alkyllithiums have also been employed successfully[14](eq.31).



$$\mathrm{R'{-}}\overset{\mathrm{OTMS}}{\underset{\mathrm{SR}}{\mathrm{C}}}\mathrm{{-}R''} + \mathrm{R'''Li} \xrightarrow{\text{THF or ether}} \mathrm{R'{-}}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{{-}R''} + \mathrm{RSLi} + \mathrm{R'''SiMe_3} \qquad \text{eq.31}$$

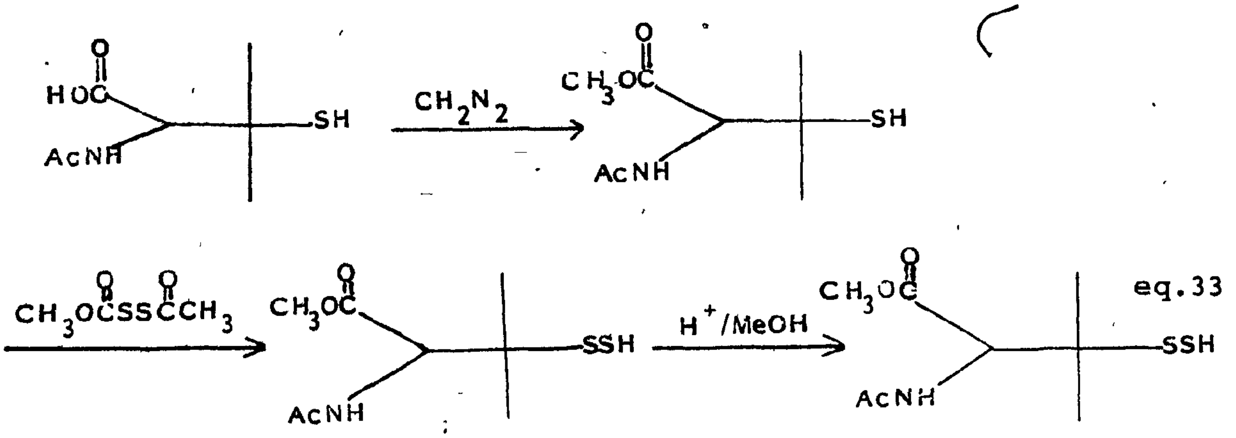
The high affinity of the fluoride anion toward the silicon atom is well known[42]; this tendency has been exploited for desilylation. Cleavage of the silicon-oxygen bond (128 kcal/mol) followed by formation of the stronger silicon-fluoride bond (160 kcal/mol) is an energetically favourable process. This property was effectively demonstrated by Corey and co-workers [43] for the system shown in eq.32.



eq.32

Salts can be used as fluoride anion sources. Since the fluoride anion is a hard base, large, soft cations are effective counter ions[44]. Tetrabutylammonium fluoride and benzyltrimethylammonium fluoride are often used for desilylation[45,46]. Metal salts of the fluoride ion also give successful results; potassium fluoride and cesium fluoride are most commonly used[47,48].

Following the principles discussed above for the preparation of thiols from α-siloxy thiols (_via_ α-siloxy sulfides), it should be possible to synthesize hydrodisulfides _via_ α-siloxy disulfides. Hydrodisulfides have been proposed in several significant biological systems as products from the reactions of cysteine or cystine[49-52]. From a chemical viewpoint, they are important precursors of unsymmetrical trisulfides[53], and also find applications in other areas of synthetic chemistry[54-62]. For example, Field and co-workers[63] have recently developed a synthetic route to a hydrodisulfide derivative of DL N-acetylpenicillamine(_24_) (eq.33).



eq.33

We plan to investigate some of the substitution reactions of α-siloxysulfides(1) and intend to construct α-substituted derivatives as well as to develop a general synthesis of thiols and hydrodisulfides(RSSH)(22).

RESULTS AND DISCUSSION

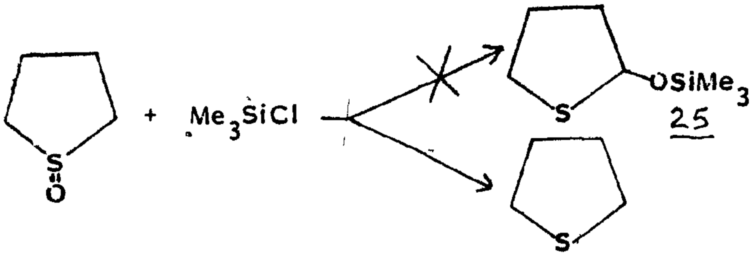
As has been pointed out in the previous section, techniques exist for the synthesis of α-siloxy sulfides($\underline{1}$) based on nucleophilic attack by thiolate anion on a carbonyl carbon[11,12,14]. Of these,the Evans[12] method requires the relatively expensive KCN-18-crown-6 complex, and a longer reaction time than Chan's method[14] at the same reaction temperature. For this reason, a modified version of Chan's method was employed to prepare the starting materials for the present study.

α-Siloxy sulfides($\underline{1}$) were synthesized from the corresponding aldehydes, thiols, chlorotrimethylsilane and pyridine with ether as a solvent. All syntheses were carried out under dry nitrogen. The reactions were exothermic, but not sufficiently so to require the use of a cooling bath. Freshly distilled chlorotrimethylsilane was used as a reactant; it was subsequently found that it was unnecessary to distill the reagent immediately before use and that chlorotrimethylsilane stored under a nitrogen atmosphere gave satisfactory results. In this case, however, an extra 0.2-0.5 equiv.of chlorotrimethylsilane was required to obtain a yield comparable to that obtained by using freshly distilled chlorotrimethylsilane.

Although Chan and co-workers[14] used pyridine as a solvent,it was found to be better to use only 1.1-1.5 equiv. of pyridine so that the pyridinum salt formed in the reaction could be effectively removed. Usually this is difficult, but the problem was overcome by using a solvent exchange technique. After the reaction, changing the solvent from ether to hexane caused the pyridinium salt to precipitate. It could then be easily removed by filtration. Ether was the solvent of choice for the reaction because of its low boiling point. If low boiling aldehydes are used, exposure of the reaction mixture to vacuum also removes any unreacted starting materials. If unreacted thiol was detected in the reaction mixture, it was washed with 5% $NaHCO_3$ solution until no thiol was detectable by TLC.

Using the procedure outlined above pure (GLC analysis) products were obtained. Yields and spectral data are collected in Tables 1a and 1b respectively.

One example of a cyclic α-siloxy sulfide(25) was prepared. Initially, the strategy shown in eq.34 was tried[64-66]; however, it gave a cyclic sulfide instead of an α-siloxy sulfide.

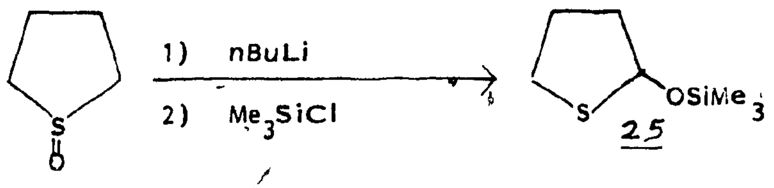


eq.34

Deoxygenation of sulfoxides by bromotrimethylsilane or iodotrimethylsilane has been reported (eq.34a)[110a]. In a later paper [110b] the same authors report the deoxygenation of a sulfoxide by chlorotrimethylsilane in the presence of sodium iodide. The deoxygenation of a sulfoxide by chlorotrimethylsilane, however, is a new reaction.

$$R\text{-}S(O)\text{-}R' \xrightarrow[CCl_4]{TMSBr\ \text{or}\ TMSI} R\text{-}S\text{-}R' \qquad \text{eq.34a}$$

Another attempt was made which utilized a sulfur to carbon transfer of the trimethylsiloxy group (eq.35).

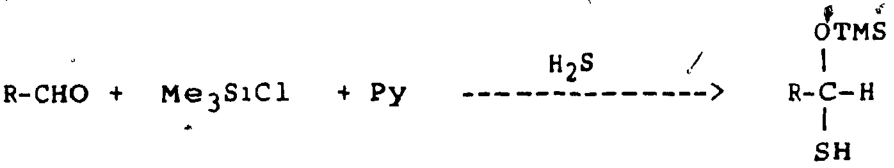


25

eq.35

This route gave the cyclic α-siloxy sulfide in 50 % yield. Full preparative details are given in the experimental section.

α-Siloxy sulfides(1) were also prepared by alkylation of the corresponding α-siloxy thiols(16). These were synthesized from the aldehydes, hydrogen sulfide and chlorotrimethylsilane in ether at $-10^{\circ}C$(eq.36).



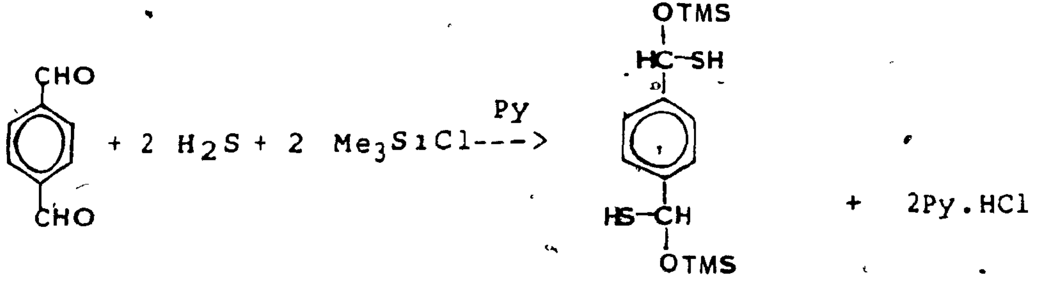
$$R\text{-}CHO + Me_3SiCl + Py \xrightarrow{H_2S} R\text{-}\overset{\overset{OTMS}{|}}{\underset{\underset{SH}{|}}{C}}\text{-}H \qquad \text{eq.36}$$

(16)

Hydrogen sulfide was introduced by bubbling it directly into the reaction mixture. Trapping of excess escaping hydrogen sulfide and/or formed thiol from the reaction mixture was effected by using, in series, 2 traps containing saturated potassium hydroxide solution, and a final one containing lead acetate solution to indicate the presence of H_2S.

As Table 5 indicates, yields of α-alkyl α-siloxy thiols were quite good. All product thiols(16) were liquids and had distinctive, unpleasant odors.

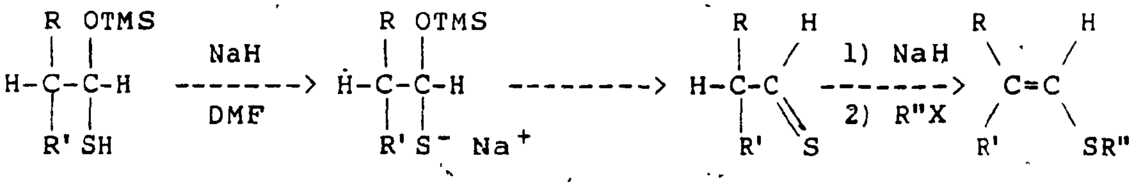
A solid α-siloxy thiol(16) would be expected to be less volatile and hence to have a weaker odor than than a liquid one. For this reason, efforts were made to prepare such a compound so that it could act as a "template" for the transfer of the sulfur atom to the desired substrate. These, however, were unsuccessful, or gave unacceptably low yields. An example appears below (eq.37).



2% yield and at least 10 other products

eq.37

The α-siloxy thiols(16) were used to synthesize α-siloxy sulfides(1). Treatment of the substrate in DMF at -60°C with n-butyl lithium gave the siloxy thiolate, which was then reacted with an alkyl halide. Temperature control of this reaction was critical. A cooling bath prepared from chloroform and dry ice was used to keep the temperature at ca -60°C. The solution was colourless during the reaction. After stirring the reaction mixture for 1h at -60 °C, the thiolate was trapped with an alkyl halide to give the appropriate α-siloxy sulfide(1). This type of reaction is closely related to recent unpublished work carried out in our lab[67], which is summarized in eq.38.

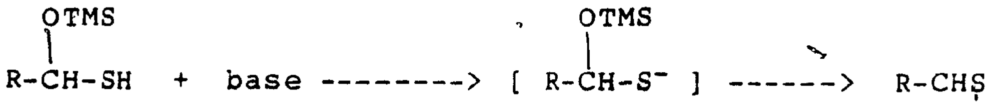


(16) (26) (14)

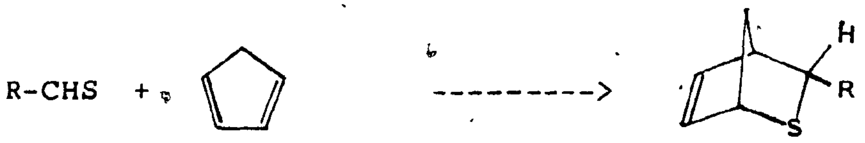
eq.38

The reaction of an α-siloxy thiol(16) with sodium hydride in DMF at -10 °C gives a slightly greenish coloured solution. Addition of an alkyl halide to this solution gives a vinyl sulfide(14). One working hypothesis for the mechanism of this reaction is as follows. First, the thiolate ion is formed with sodium hydride. The siloxy group then leaves forming an unstable thioaldehyde(26) with α-hydrogens, which reacts with alkyl halide to form the vinyl sulfide(14). It is also possible that elimination of the siloxy group takes place immediately after thiolate formation, directly forming the enethiolate.

In the light of the results discussed in the preceding paragraph, it was of interest in the present work to attempt to trap the thioaldehyde(26) possibly generated from an α-siloxy thiolate. In this experiment, an α-siloxy thiol(16) was treated with sodium hydride in THF at -70 °C. Cyclopentadiene was used as a trapping agent; the procedure is summarized in eq.39 and eq.40 below.



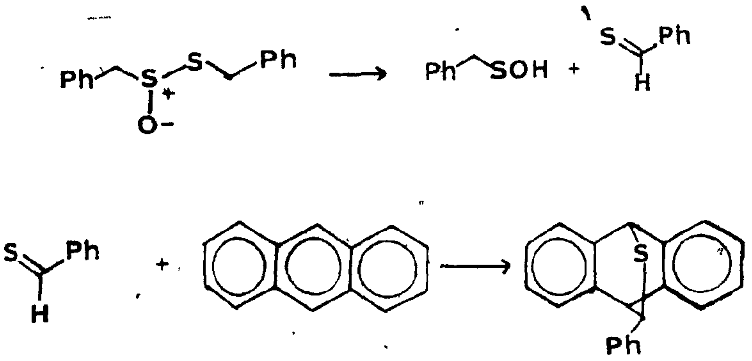
$$\text{R-}\overset{\text{OTMS}}{\overset{|}{\text{C}}}\text{H-SH} + \text{base} \dashrightarrow [\,\text{R-}\overset{\text{OTMS}}{\overset{|}{\text{C}}}\text{H-S}^-\,] \dashrightarrow \text{R-CHS} \quad \text{eq.39}$$



eq.40

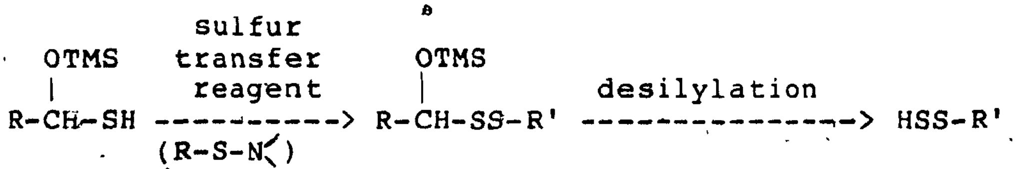
After chromatography, a very small quantity of product was obtained. From the ^{1}Hnmr spectrum, it was not possible to determine the nature of the compound isolated from the trapping experiment.

Although in the present work no thioaldehyde was isolated, this has recently been achieved by several groups[68-73]. They were successful in synthesizing and isolating various stabilized thioaldehydes. One example is shown in eq.41.



eq.41

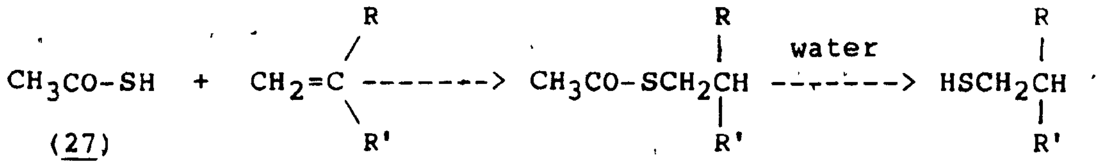
α-Siloxy thiols were used in an attempt to synthesize hydrodisulfides(22). The synthetic strategy adopted is shown in eq.42 below.



$$\text{R-}\overset{\text{OTMS}}{\overset{|}{\text{C}}}\text{H-SH} \xrightarrow[\text{(R-S-N}\langle\,)]{\text{sulfur transfer reagent}} \text{R-}\overset{\text{OTMS}}{\overset{|}{\text{C}}}\text{H-SS-R}' \xrightarrow{\text{desilylation}} \text{HSS-R}' \quad \text{eq.42}$$

(16) (23) (22)

In order to confirm the identity of the product, an authentic sample of hydrodisulfide was prepared by an independent route. The method chosen was a modification of Bordwell's thiol synthesis[113] (eq.43).

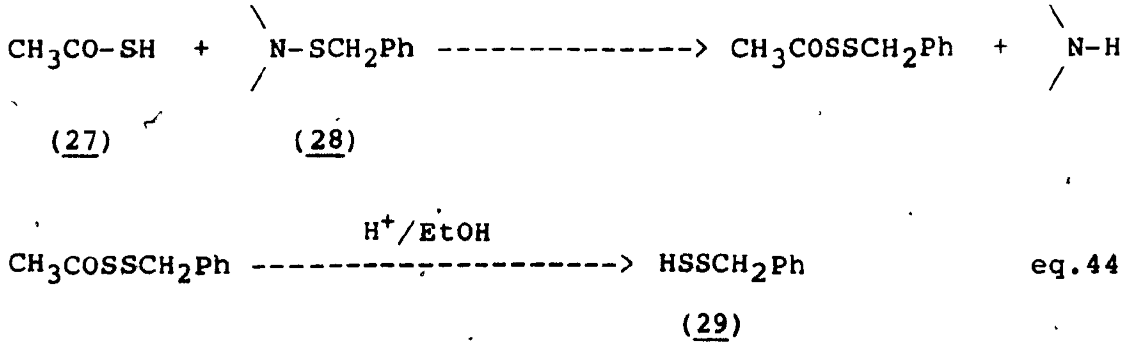


$$CH_3CO\text{-}SH + CH_2{=}C(R)(R') \longrightarrow CH_3CO\text{-}SCH_2CH(R)(R') \xrightarrow{\text{water}} HSCH_2CH(R)(R')$$

(27)

eq.43

This reaction involves a radical addition of thioacetic acid to an olefin, followed by hydrolysis. It was modified by reacting thioacetic acid with a sulfur transfer reagent in place of the olefin (eq.44).



$$CH_3CO\text{-}SH + {>}N\text{-}SCH_2Ph \longrightarrow CH_3COSSCH_2Ph + {>}N\text{-}H$$

(27) (28)

$$CH_3COSSCH_2Ph \xrightarrow{H^+/EtOH} HSSCH_2Ph$$

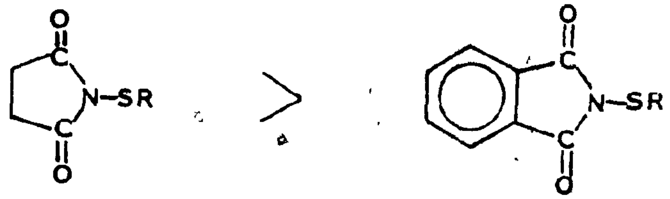
eq.44

(29)

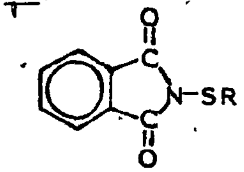
Using this procedure, benzyl hydrodisulfide(29) was prepared successfully in 82 % yield.

To follow the synthetic strategy outlined in eq.42 above, an efficient sulfur transfer reagent which can be used under very mild conditions was required. Convenient (stable and solid) sulfur transfer reagents have been extensively studied[74-83].

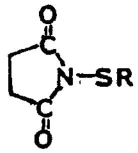
The reactivity order of these compounds towards nucleophiles is shown below.



In the present work, two types of sulfur transfer reagents were used (30,31).



(30)



(31)

Synthesis of these interesting reagents requires several steps. First, a sulfenyl chloride(32) is prepared. There are several ways of doing this[84-89](eq.45-47).

$2RSH + Cl_2 \longrightarrow 2RSCl$ eq.45

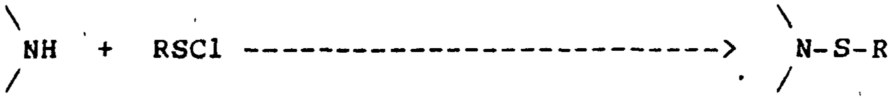
(32)

$RS\text{-}SR + Cl_2 \longrightarrow 2RSCl$ eq.46

$RS\text{-}SR + SO_2Cl_2 \longrightarrow 2RSCl$ eq.47

The major disadvantage of the first method (eq.45) is that it necessitates the handling of thiols with strong, unpleasant odors. Using disulfides instead of thiols (eq.46) is better, but measuring a precise amount of chlorine is not easy. This problem is overcome in the third method (eq.47) by using sulfuryl chloride (a liquid). There was no carbon-sulfur bond cleavage. In the present work, the third method was used.

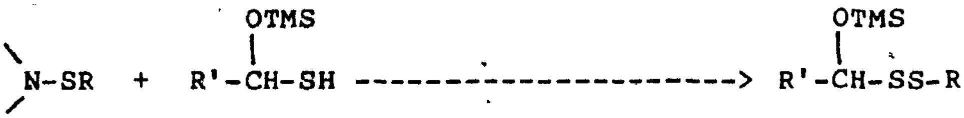
The sulfenyl chloride(32) was then used to prepare the sulfur transfer reagent. As an example, the N-thiophthalimides(30) will be discussed in detail. In principle, these compounds may be prepared from either phthalimide(33) or potassium phthalimide(34). In practice, because the potassium salt requires DMF as a solvent (which leads to a work-up procedure with more steps, and consequently a lower overall recovery), it was found to be preferable to use phthalimide(33) itself (eq.48).



$$\rangle\mathrm{NH} + \mathrm{RSCl} \longrightarrow \rangle\mathrm{N{-}S{-}R} \qquad \text{eq.48}$$

(33) [R = Me, t-Bu, Ph, CH_2Ph] (30)

The N-thiophthalimide(30) was reacted with an α-siloxy thiol(16) to give an α-siloxy disulfide(23) (eq.49).



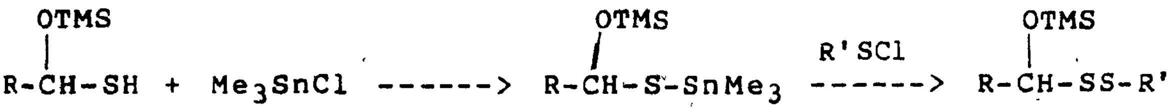
$$\rangle\mathrm{N{-}SR} + \mathrm{R'{-}\overset{OTMS}{CH}{-}SH} \longrightarrow \mathrm{R'{-}\overset{OTMS}{CH}{-}SS{-}R} \qquad \text{eq.49}$$

(30) (16) (23)

[R = Me, t-Bu, Ph, CH_2Ph; R' = i-Pr, t-Bu]

Of the α-siloxy thiols(16) tried in the reaction above (eq.49), only α-siloxy neopentane thiol(35) gave a satisfactory yield (84%) (in the reaction with N-benzylthiophthalimide(36)). To improve the yield (2%) in the α-siloxy s-butyl thiol(37) reaction, a more reactive sulfur transfer reagent, N-benzylthiosuccinimide(38), was prepared. Reaction between this and α-siloxy s-butyl thiol gave the corresponding α-siloxy disulfide in only 15% yield (nevertheless an improvement over the previous 2% yield).

Because some difficulty was encountered in finding a good synthetic route to α-siloxy disulfides(<u>23</u>), another approach was investigated while the reactions discussed in the preceding paragraph were being attempted. This was reaction <u>via</u> a tin sulfide (eq.50).



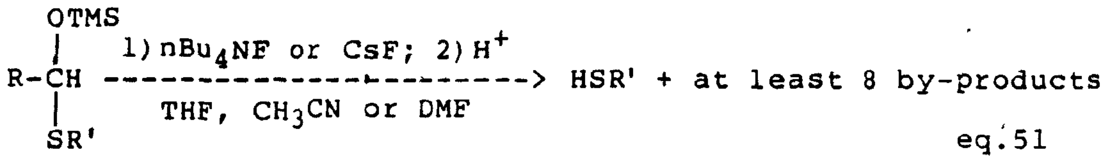
$$\overset{\mathrm{OTMS}}{\overset{|}{\mathrm{R{-}CH{-}SH}}} + \mathrm{Me_3SnCl} \dashrightarrow \overset{\mathrm{OTMS}}{\overset{|}{\mathrm{R{-}CH{-}S{-}SnMe_3}}} \xrightarrow{\mathrm{R'SCl}} \overset{\mathrm{OTMS}}{\overset{|}{\mathrm{R{-}CH{-}SS{-}R'}}}$$

(<u>16</u>) (<u>23</u>)

eq.50

The inspiration for this approach came from a literature[90] disulfide preparation using a sulfenyl chloride(<u>32</u>) and a tin sulfide. In the present work, the tin sulfide was prepared but the subsequent reaction with R'SCl was not attempted, mainly because no satisfactory desilylation procedure was eventually found for the α-siloxy disulfides(<u>23</u>).

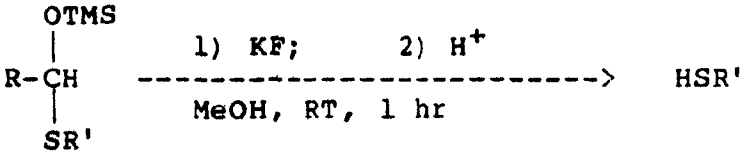
A brief review of possible desilylation methods was given in the introduction. It was necessary to try several of these before satisfactory results were obtained. First, tetra-n-butylammonium fluoride and then cesium fluoride were tried as desilylation agents. The quantity of tetra-n-butylammonium fluoride or cesium fluoride was systematically varied from 0.01-0.20 equiv. (based on siloxy compound). Aprotic solvents such as THF, acetonitrile and DMF were tried in turn. Unfortunately, very low yields of the desired compound and many by-products were obtained(eq.51).



$$\mathrm{R{-}}\underset{\mathrm{SR'}}{\overset{\mathrm{OTMS}}{\mathrm{CH}}} \xrightarrow[\text{THF, CH}_3\text{CN or DMF}]{\text{1) nBu}_4\text{NF or CsF; 2) H}^+} \text{HSR' + at least 8 by-products}$$

eq.51

Further attempts to desilylate the α-siloxy sulfides were carried out in THF using potassium fluoride. Again, low yields and by-products resulted. When potassium fluoride in methanol was used, however, desilylation of the α-siloxy sulfides took place at room temperature after 1 hour and the thiol products were obtained in good yield(eq.52).



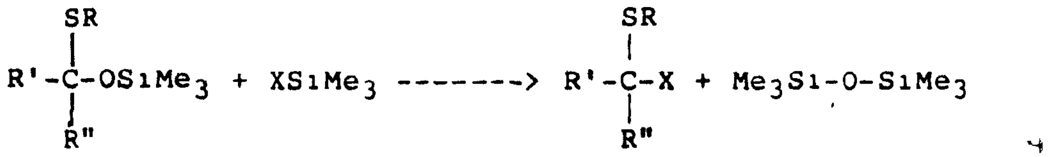
$$\mathrm{R{-}}\underset{\mathrm{SR'}}{\overset{\mathrm{OTMS}}{\mathrm{CH}}} \xrightarrow[\text{MeOH, RT, 1 hr}]{\text{1) KF; 2) H}^+} \mathrm{HSR'}$$

eq.52

After the reaction, solvent and aldehyde were removed <u>in</u> <u>vacuo</u> and the solution was diluted with aqueous acid. The product was extracted with hexane. Yields of a variety of thiols are collected in Table 2.

Desilylation of the α-siloxy disulfides(<u>23</u>) using potassium fluoride in methanol unfortunately did not give good results. Nor did any other set of conditions tried for α-siloxy sulfides. Some of the many unsuccessful attempts are described in the experimental section.

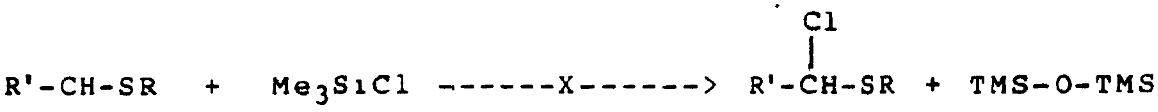
In a separate investigation, the α-siloxy sulfides(1) (the preparation of which has already been described) were used to study the formation of α-bromosulfides(39). Previous work in this lab[28] has shown that these reactions may be conveniently carried out in an NMR tube, enabling the progress of substituent exchange to be monitored by NMR. In this earlier study, the formation of α-iodosulfides(11) was investigated. Other α-halosulfides are expected to be more stable than α-iodosulfides and hence more easily isolable. The α-siloxy sulfides(1) should have considerable potential as reagents for the preparation of a variety of α-functionalized sulfides via a one step synthesis using X-SiMe3 type reagents (X= SR, CN, $SSiMe_3$, etc.)(eq.53).



$$R'-\underset{R''}{\overset{SR}{C}}-OSiMe_3 + XSiMe_3 \text{-------}\!> R'-\underset{R''}{\overset{SR}{C}}-X + Me_3Si-O-SiMe_3 \qquad \text{eq.53}$$

(1)

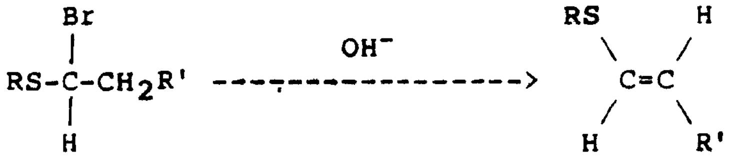
From the difference in dissociation energies between the silicon-iodide bond (77 kcal/mol)[91] and silicon-bromide bond (96 kcal/mol)[91], it is predicted that the preparation of α-bromosulfides(39) should require more vigorous reaction conditions than those for the α-iodosulfides(11). This was found to be the case; the preparation of α-bromosulfides required 3 days at room temperature while α-iodosulfides were formed after 2 minutes at 0 °C[28]. Yields and spectral data of the α-bromosulfides prepared in the present work are collected in Tables 3a and 3b. Attempts to synthesize α-chlorosulfides(40) using conditions which gave good yields of α-bromosulfides were unsuccessful. Calculation of the bond energy exchange on each side of the reaction equation (eq.54) suggests that the reaction should not proceed in the direction shown, but this is a rather simplistic treatment of the many complex factors involved.



$$R'\text{-}CH\text{-}SR + Me_3SiCl \xrightarrow{\quad X \quad} R'\text{-}\overset{\displaystyle Cl}{\overset{|}{C}}H\text{-}SR + TMS\text{-}O\text{-}TMS$$

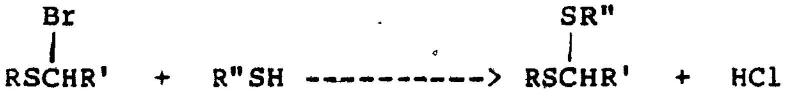
(40) eq.54

The α-bromosulfides(39) were used to prepare vinyl sulfides(14) (eq.55) and unsymmetrical thioacetals(40)(eq.56).



$$RS\text{-}\overset{\displaystyle Br}{\underset{\displaystyle H}{C}}\text{-}CH_2R' \xrightarrow{OH^-} (RS)(H)C{=}C(H)(R')$$

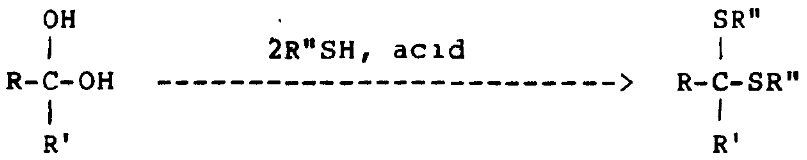
eq.55



$$RS\overset{\displaystyle Br}{\overset{|}{C}}HR' + R''SH \longrightarrow RS\overset{\displaystyle SR''}{\overset{|}{C}}HR' + HCl$$

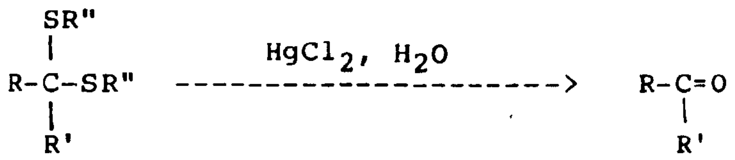
(41) eq.56

The α-siloxy sulfides(1) were also used successfully to prepare some unsymmetrical thioacetals. Thioacetals and ketals are commonly used as protecting groups for carbonyl compounds[92-95]. They are normally prepared from acetals and ketals under acid catalyzed conditions(eq.57).



$$\mathrm{R{-}\overset{\displaystyle OH}{\underset{\displaystyle R'}{C}}{-}OH} \xrightarrow{\mathrm{2R''SH,\ acid}} \mathrm{R{-}\overset{\displaystyle SR''}{\underset{\displaystyle R'}{C}}{-}SR''} \qquad \text{eq.57}$$

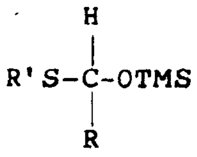
Lewis acids such as zinc chloride, and BF_3-etherate as well as hydrochloric acid and p-toluenesulfonic acid have been used. The carbonyl equivalents are readily obtained by mild hydrolysis as shown in eq.58.



$$\mathrm{R{-}\overset{\displaystyle SR''}{\underset{\displaystyle R'}{C}}{-}SR''} \xrightarrow{\mathrm{HgCl_2,\ H_2O}} \mathrm{R{-}\underset{\displaystyle R'}{C}{=}O} \qquad \text{eq.58}$$

The thioacetals and ketals prepared by traditional methods are, however, always symmetrical[96-102]. The route <u>via</u> α-siloxy sulfides gives access to unsymmetrical thioacetals(<u>40</u>) in good yield. Yields and spectral data are shown in Tables 4a and 4b.

Table 1a



$$R'S-\overset{\displaystyle H}{\underset{\displaystyle R}{C}}-OTMS$$

PREPARATION OF α-TRIMETHYLSILOXY SULFIDES

compound[a]	R	R'	yield(%)	bp(°C/mmHg)
(42)	iPr	$PhCH_2$	85	111-112/3
(43)	Et	$PhCH_2$	86	97-98/7
(44)	nPr	$PhCH_2$	77	110-112/5
(45)	iPr	Ph	74	118-120/7
(46)	nPr	$(CH_2)_5CH_3$	72	134-135/6
(47)	nPr	$(CH_2)_2SH$	47	95-96/4
(48)	nPr	$COCH_3$	67	39-46/4

a All compounds were pure by GLC analysis.

Table 1b

compound	shift	description	assignment
(<u>42</u>)	0.10	9H, s	$-OSiMe_3$
	0.93	6H, d (J = 6Hz)	$-C(CH_3)_2$
	1.20	1H, m (J = 3Hz)	-CH
	3.73	2H, s	$-CH_2-$
	4.80	1H, d	-CHS-
	7.30	5H, m	Ph
(<u>43</u>)	0.20	9H, s	$-OSiMe_3$
	0.93-1.70	5H, m	$-CH_2CH_3$
	3.90	2H, s	$-CH_2-$
	4.30	1H, m	-CH-
	7.30	5H, m	Ph
(<u>44</u>)	0.10	9H, s	$-OSiMe_3$
	0.90-2.40	5H, m	$-(CH_2)_2CH_3$
	3.70	2H, s	$-CH_2-$
	4.70	1H, br	-CH-
	7.30	5H, m	-Ph
(<u>45</u>)	0.10	9H, s	$-OSiMe_3$
	1.10	6H, d (J=6Hz)	$-C(CH_3)_2$
	2.06	1H, m	-CHS-
	4.95	1H, d	-CH-
	7.30	5H, m	-Ph

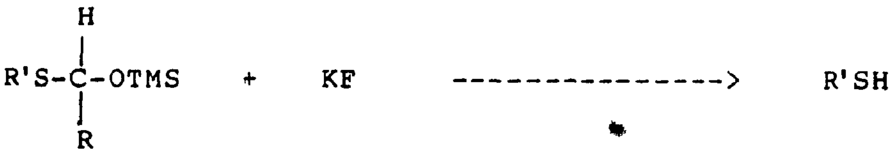
Table 1b(continued)

compound	shift	description	assignment
(<u>46</u>)	0.10	9H, s	$-OSiMe_3$
	0.93-1.40	19H, m	aliphatic
	2.30-2.60	1H, m	-CHS-
	4.40-4.90	1H, br	-CH
(<u>47</u>)*	0.03	9H,s	$-OSiMe_3$
	0.70-1.80	7H,m	$-(CH_2)_2CH_3$
	2.17	3H,s	$-COCH_3$
	5.47	1H,t(J=6Hz)	-CH-

*IR 1690 cm^{-1} (C=0)

Table 2

DESILYLATION OF α-TRIMETHYLSILOXY SULFIDES



$$R'S\text{-}\overset{H}{\underset{R}{C}}\text{-}OTMS + KF \longrightarrow R'SH$$

compound	R	R'	HSR'[c]		Yield
(48)	nPr	Ph	HSPh	(50)	84[a]
(44)	nPr	$PhCH_2$	$HSCH_2Ph$	(51)	86[a]
(43)	Et	$PhCH_2$	$HSCH_2Ph$	(51)	95[a]
(45)	iPr	Ph	HSPh	(72)	77[b]
(4)	nPr	$(CH_2)_5CH_3$	$HS(CH_2)_5CH_3$	(73)	69[b]

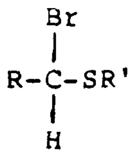
[a] The yields were determined by GLC using an internal standard.

[b] Isolated yields.

[c] All product thiols were pure by GLC analysis.

Table 3a

PREPARATION OF α-BROMO SULFIDES



$$R-\overset{\overset{\large Br}{|}}{\underset{\underset{\large H}{|}}{C}}-SR'$$

compound[a]	R	R'	Yield(%)
(53)	nPr	$PhCH_2$	71
(54)	Ph	Et	83
(55)	nPr	Ph	69
(56)	iPr	$PhCH_2$	77

a All α-bromosulfides gave one spot by TLC analysis.

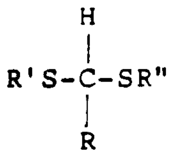
Table 3b

compound	nmr	mass (m/z,intensity)[a]
(53)	0.70-1.80(m,7H),3.65(s,2H), 5.70(t,J=6Hz,1H),7.00(s,5H)	181(1.1),179(12.9),125 (5.4),123(45.1),91(100.0)
(54)	0.80(t,J=8Hz,3H), 2.10(q, J=8Hz,2H),4.70(s,1H),6.80 -7.20(m,5H)	153(2.7),151(41.3),77 (60.7),28(100.0)
(55)	0.73-1.50(m,7H), 4.90(t, J=5Hz,1H), 6.90-7.40 (m, 5H)	165(2.0),122(63.7),77 (61.4),29(59.6),28(100.0)
(56)	0.93(d,J=6Hz,6H),1.84-2.04 (m,1H),3.60(s,2H),5.50(br, 1H), 7.50(m,5H)	181(0.6),179(12.5), 178(49.2), 91(100.0),71 (30.4),43(19.4)

a No molecular ions were observed.

Table 4a

PREPARATION OF THIOACETALS


$R'S\text{-}\overset{H}{\underset{R}{C}}\text{-}SR''$

compound[a]	R	R'	R"	Yield(%)
(57)	Ph	Et	Ph	93
(58)	nPr	Ph	Ph	72
(59)	nPr	CH_2Ph	Ph	76

a All compounds gave one spot by TLC analysis.

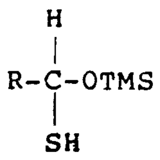
Table 4b

SPECTRAL DATA OF THIOACETALS

compound	NMR
(57)	1.06(t,J=8Hz,3H), 2.50(q,J=8Hz,2H), 4.90(s,1H), 6.96-7.40(m,10H)
(58)	0.75-1.77(m,7H), 5.00(t,J=6Hz,1H), 6.90-7.50(m,10H)
(59)	0.50-1.80(m,7H), 3.50(s,2H), 4.56(t,J=6Hz,1H), 6.60-7.20(m,10)

TABLE 5

PREPARATION OF α-TRIMETHYLSILOXYTHIOLS


$\mathrm{R{-}}\overset{\mathrm{H}}{\underset{\mathrm{SH}}{\mathrm{C}}}\mathrm{{-}OTMS}$

compound	R	yield (%)	b.p.(mmHg)	(lit.[36]b.p.(mmHg))
(60)	iPr	69	58-59/18	46/8
(61)	nPr	74	60-60.5/21	42/8
(62)	tBu	70	72-73/20	61/15

EXPERIMENTAL

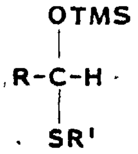
Chemical reagents were obtained from commercial sources and used without purification, unless otherwise noted. Melting points were obtained on a Gallenkamp apparatus, and are uncorrected. Acetonitrile and tetrahydrofuran were dried by distillation from P_2O_5 and sodium benzophenone ketyl respectively. Methylene chloride was washed successively with concentrated H_2SO_4, 5% $NaCO_3$ and water, dried over $CaCl_2$ and distilled from P_2O_5. Ethyl acetate was washed with 5% $NaCO_3$ and water, dried over anhydrous K_2CO_3 and distilled from P_2O_5.

Infrared spectra were recorded with a Perkin-Elmer Model 257 instrument either as neat liquid films or as KBr discs, and were calibrated using the 1601 cm^{-1} line of polystyrene. Proton nuclear magnetic resonance spectra were recorded in $CDCl_3$ solution (unless otherwise specified) on a Varian Associates T-60 or T-60A spectrometer. Chemical shifts are reported in ppm (δ) relative to tetramethylsilane (TMS) either as an internal standard or as an external standard. Abbreviations used to describe NMR absorptions are: s, singlet; d, doublet; t,triplet; q,quartet; m,multiplet; br,broad. High resolution mass spectra were obtained from a Du Pont 492B instrument using a direct insertion probe. Gas chromatographic analyses were performed on a Varian Model 3700 chromatograph with a 2m x 6mm O.D. glass column packed with 3% OV-101 on High Performance Chromosorb W (80/100 mesh). Preparative gas chromatographic separations were accomplished with a Varian Associates Autoprep 700 chromatograph equipped with a 1 ft x 0.25 in. O.D.

aluminium column packed with 10 % SE-30 on chromosorb W. Thin layer chromatography (TLC) was performed on Merck Silica Gel 60 (0.2 mm layer thickness) containing F-254 fluorescent indicator on aluminium-backed sheets. Flash chromatography refers to the technique described by Still^{111} and was carried out with Wolem 230/460 mesh silica gel.

PREPARATION OF α-TRIMETHYLSILOXY SULFIDES

Compounds 42-47 were prepared according to the general procedure given below for product 45. Yields, boilingpoints and ^{1}Hnmr shifts are displayed in Tables 1a and 1b.



$\mathrm{R{-}\underset{SR'}{\overset{OTMS}{C}}{-}H}$

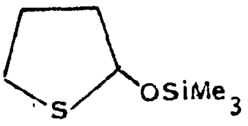
To a well stirred mixture of 5.00g (69.4 mmol) isobutyraldehyde and 10.5g (96.7 mmol) of chlorotrimethylsilane in 35mL of ether was added dropwise at room temperature a solution of 7.60g (69.0 mmol) of benzenethiol and 5.10g (70.0 mmol) of pyridine in 5mL of ether. After stirring at room temperature for 4 hr, 50mL of hexane was added to the solution which was then filtered. The filtrate was distilled under reduced pressure to give 12.9g (74 %) of the product(45), b.p. 118-120°C /7.0 mmHg. TLC (silica gel, chloroform) gave one spot.

PREPARATION OF A CYCLIC α-TRIMETHYLSILOXY SULFIDE

Method I (unsuccessful)

To a solution of 1.00g (9.6 mmol) of thiolane 1-oxide in 10mL of benzene was added at room temperature 1.47g (9.6 mmol) of chlorotrimethylsilane. The reaction mixture was refluxed overnight. Work-up procedure was identical with that used for the acyclic α-siloxy sulfides (see above). Instead of the expected product 67, the reaction gave 0.47g (55 %) of thiolane, identified by comparison (TLC, IR and ^{1}Hnmr) with an authentic sample.

Method II



To a stirred solution of 1.00g(9.6 mmol)of thiolane 1-oxide in 15mL of THF was added dropwise at -30 °C 5.8 mL of 1.65 M n-butyl lithium in hexane. After 1.5 hr at -30 °C, 1.47g (9.6 mmol) of chlorotrimethylsilane was added dropwise at -30 °C and the mixture was stirred for a further hour. It was then allowed to warm to room temperature and quenched with 20mL of water. After the addition of 15mL of ether, the mixturewas extracted (3 x 10 mL ether). The extracts were dried over magnesium sulfate and concentrated under reduced pressure. The crude product was chromatographed on silica gel (hexane/ethyl acetate) to give 0.84g (50 %) of α-trimethylsiloxythiolane(67), a colourless oil. TLC (silica gel, chloroform) gave one spot; ^{1}Hnmr:0.1(s, 9H), 0.9-1.7(m, 6H), 4.8(br. 1H).

PREPARATION OF A SYMMETRICAL DISULFIDE FROM AN α-TRIMETHYLSILOXY SULFIDE[103]

To a solution of 1.0g (3.9 mmol) of α-trimethylsiloxy-n-butyl temperature 2.47g (9.8 mmol) of iodine. The reaction mixture was stirred for 10 hr at room temperature. After washing with

10 % sodium thiosulfate solution (2 x 20mL) and water (10mL), the reaction mixture was dried over magnesium sulfate. It was concentrated under reduced pressure and chromatographed on silica gel (hexane/ ethyl acetate) to give 0.60g (72 %) of diphenyl disulfide, m.p. 57-60 °C (lit.[104] 58-60 °C); identical (TLC, IR and ^{1}Hnmr) with an authentic sample.

PREPARATION OF UNSYMMETRICAL THIOACETALS FROM α-TRIMETHYLSILOXY SULFIDES

Compounds 57-59 were prepared using the general method detailed below. Yields are given in Table 4a, spectral data in Table 4b.

To 1.1g (4.1 mmol) of α-trimethylsiloxy-n-butyl benzyl sulfide in 25mL tetrahydrofuran at -5 °C was added dropwise 0.75g (4.1 mmol) of trimethylsilyl phenyl sulfide in 3mL of tetrahydrofuran. Stirring was continued for 2 hr at -5 °C . The reaction mixture was then allowed to warm to room temperature and stirred for a further 2 hr. Work up was effected by washing with 20mL of 5% aqueous sodium bicarbonate solution. After drying over magnesium sulfate, the reaction mixture was concentrated and chromatographed on silica gel to give 0.90g (76%) of a colourless oil(59), one spot by analytical TLC.

DESILYLATION OF α-TRIMETHYLSILOXY SULFIDES

Method I

Thiols 50 – 52 were prepared according to the procedure given below. Yields are given in Table 2. To a stirred solution of 0.50g (1.9 mmol) of α-trimethylsiloxy-n-propyl phenyl sulfide in 10mL of methanol was added 0.19g (2.9 mmol) of potassium fluoride at room temperature. Stirring was continued at room temperature for 2 hr. After the addition of a few drops of 6N hydrogen chloride solution to the reaction mixture, it was subjected to preparative gas chromatography to give 1.6g (86%) of benzyl thiol(51).

(In all cases odor, TLC, GLC, ^{1}Hnmr and IR spectra were identical with those of authentic samples).

Method II

Thiols 72 and 73 were prepared using Method II. Yields are given in Table 2.

To a stirred solution of 1.0g (3.8 mmol) of α-trimethylsiloxy sulfide(45) in 20mL of methanol was added 0.34g (5.7 mmol) of potassium fluoride at room temperature. Stirring was continued overnight. The reaction mixture was then evaporated under reduced pressure until all the solvent had been removed. The white crystals remaining were dissolved by the addition of 20mL of water. The solution thus obtained was acidified and extracted with pentane (3 x 20mL). The extracts were dried over magnesium sulfate. Removal of solvent gave 0.30g (77 %) of benzenethiol (72).

(In all cases odor, TLC, GLC, ^{1}Hnmr and IR spectra were identical with those of authentic samples).

PREPARATION OF α-BROMO SULFIDES

Compounds 53-56 were prepared according to the following general procedure. Yields are reported in Table 3a, spectral data in Table 3b.

To a solution of 0.65g (2.70 mmol) of α-trimethylsiloxybenzyl ethyl sulfide in 15mL of tetrahydrofuran was added dropwise 0.42g (2.70 mmol) of bromotrimethylsilane in 3mL of tetrahydrofuran at room temperature. The reaction mixture was concentrated *in vacuo*, to give 0.52g (83 %) of α-bromobenzyl ethyl sulfide(54).

PREPARATION OF A VINYL SULFIDE FROM AN α-BROMOSULFIDE

A mixture of 0.79g (3.1 mmol) of benzyl α-bromoisobutyl sulfide and 15 mL of 6N potassium hydroxide solution was refluxed for 10 minutes. The reaction mixture was extracted with methylene chloride (3 x 10mL). The combined extracts were concentrated and chromatographed on silica gel (hexane/ethyl acetate) to give 0.45g (82 %) of benzyl 2-methylpropenyl sulfide(63) as a colourless oil; one spot by analytical TLC. ^{1}Hnmr: 1.63(b, 6H), 3.70 (s, 2H), 5.53 (s, 1H), 7.16 (s, 5H).

PREPARATION OF α-TRIMETHYLSILOXY THIOLS

All α-trimethylsiloxy thiols were prepared according to ref. 36. Details of the procedure are given below for product 36. Hydrogen sulfide was bubbled into a well stirred mixture of 8.78g (0.10 mol) of pivalaldehyde, 11.10g (0.10 mol) of chlorotrimethylsilane and 8.10g (0.10 mol) of pyridine in 200mL of absolute ether at -10 °C. After stirring for 1 hr at -10°C 100mL of hexane was added to the reaction mixture. The precipitates were removed by filtration. The filtrate was concentrated and distilled under reduced pressure to give 13.52g (70 %) of α-trimethylsiloxyneopentyl thiol as a colourless oil, b.p. 72-73 °C /20mmHg (lit.[36] 61 °C /15 mmHg).

All α-trimethylsiloxy thiols were identical (^{1}Hnmr) with compounds reported in the literature[36].

ATTEMPTED TRAPPING OF A THIOALDEHYDE

To 0.60g (3.13 mmol) of α-trimethylsiloxyneopentyl thiol in 10mL of DMF was added slowly at 0 °C 0.75g (3.13 mmol) of sodium hydride. After the reaction mixture had been stirred for 30 min at 0 °C 0.20g (3.13 mmol) of cyclopentadiene was added dropwise. The reaction mixture was stirred for a further 1 hr and then allowed to warm to room temperature. Concentration *in vacuo* gave 0.32g of crude product (a mixture by analytical TLC). After chromatography, the fractions containing the suspected adduct yielded insufficient material for ^{1}Hnmr.

ATTEMPTED PREPARATION OF A SOLID α-TRIMETHYLSILOXY THIOL

To a well-stirred mixture of 0.5g (3.7 mmol) of terephthalaldehyde, 1.16g (10.7 mmol) of chlorotrimethylsilane and 0.84g (10.6 mmol) of pyridine in 100mL of ether at -10 °C was added hydrogen sulfide. Stirring was continued for 2 hr at -10 °C. The reaction mixture was allowed to warm to room temperature. After the addition of 100mL of hexane it was filtered. The filtrate was concentrated under reduced pressure and then chromatographed on silica gel (hexane/ methylene chloride). It gave 0.16 g of a mixture which possibly contained the desired compound (by ^{1}Hnmr) accompanied by many compounds without trimethylsiloxy groups.

PREPARATION OF AN UNSYMMETRICAL SULFIDE FROM AN α-TRIMETHYLSILOXY SULFIDE

The method of Chan and co-workers[14] was used. To a solution of 1.0g (3.9 mmol) of α-trimethylsiloxy-n-butyl phenyl sulfide was added dropwise at -60 °C 1.90 mL of 1.65 M n-butyl lithium in hexane. After stirring for 1 hr at -60 °C, 0.53g (3.9 mmol) of benzyl bromide was added dropwise at -60 °C. Stirring was continued for 2 hr at -60 °C. The reaction mixture was then allowed to warm to room temperature. Stirring was continued overnight, and then the reaction mixture was washed with water (2 x 30mL) and dried over magnesium sulfate. Solvent was removed under reduced pressure to give white crystals which were recrystallized from hexane/ methylene chloride to give 0.41g (66 %) of benzyl phenyl sulfide(<u>71</u>), m.p. 40-41 °C (lit.[105] 41-43.5 °C); identical (TLC, GLC and ^{1}Hnmr) with an authentic sample.

PREPARATION OF α-TRIMETHYLSILOXY SULFIDES FROM α-TRIMETHYLSILOXYISOBUTYL THIOL

α-Trimethylsiloxyisobutyl Benzyl Sulfide (42)

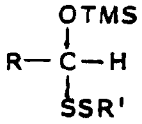
To a solution of 0.77g (4.3 mmol) of α-trimethylsiloxyisobutyl thiol in 10mL of DMF was added dropwise 2.6mL of a 1.65M solution of n-butyl lithium in hexane. The solution was stirred for 1.5 hr at -60 °C and then 0.73g (4.3 mmol) of benzyl bromide in 3mL of DMF was added dropwise. Stirring was continued for 2 hr at -60 °C; the reaction mixture was then allowed to warm to room temperature, and stirred for a further 1 hr. The reaction mixture was quenched by the addition of 10mL of 5% sodium hydroxide solution, extracted with pentane (3 x 20mL) and the extracts were dried over magnesium sulfate. After removal of solvent in vacuo, the product was chromatographed on silica gel (hexane/ ethyl acetate) to give 0.71g of a colourless oil which was identical (by TLC, GLC, ^{1}Hnmr and IR) with an authentic sample of 42.

α-Trimethylsiloxyisobutyl Hexyl Sulfide

Using the method detailed above, α-trimethylsiloxyisobutyl thiol (0.77g, 4.32 mmol) and 1-bromohexane (0.77g, 4.32 mmol) gave 1.06g (67%) of α-trimethylsiloxyisobutyl hexyl sulfide, a colourless oil, identical (TLC, GLC, ^{1}Hnmr and IR) with an authentic sample.

PREPARATION OF UNSYMMETRICAL α-TRIMETHYLSILOXY DISULFIDES

Compounds 64-67 were prepared according to the general procedure given below for product 64.



$$R-\overset{\displaystyle OTMS}{\underset{\displaystyle SSR'}{C}}-H$$

α-Trimethylsiloxyneopentyl Benzyl Disulfide (64)

To a solution of 0.61g (3.4 mmol) of α-trimethylsiloxyneopentyl thiol in 15mL of benzene was added 0.55g (3.3 mmol) of benzyl thiophthalimide. The reaction mixture was refluxed overnight. When it had cooled to room temperature, 10mL of pentane was added and the mixture was filtered and concentrated in vacuo. The crude product was then chromatographed on silica gel to give 0.54g (84 %) of α-trimethylsiloxyneopentyl benzyl disulfide(64), a colourless oil, one spot by TLC, ^{1}Hnmr: 0.13(s, 9H), 0.9(s, 9H), 3.8(s, 2H), 4.4(s, 1H), 7.2(s, 5H); mass spectrum*: m/e 301(0.1), 299(0.7), 196(22.5), 125(3.4), 159(55.7), 91(100.0), 81(24.1), 73(93.9).

* No molecular ion detected.

-Trimethylsiloxyneopentyl Phenyl Disulfide (65)

Reaction of 0.34g (1.4 mmol) of N-phenyl thiophthalimide with 0.25g (1.4 mmol) of α-trimethylsiloxyneopentyl thiol gave 0.16g (40 %) of the product (65), a colourless oil, one spot by TLC, ^{1}Hnmr: 0.1(s, 9H), 0.9(s, 9H), 4.5(s, 1H), 7.0-7.4(m, 5H).

-Trimethylsiloxyisobutyl Benzyl Disulfide (66)

Reaction of 0.33g (1.85 mmol) of α-trimethylsiloxyisobutyl thiol and 0.41g (1.85 mmol) of N-benzyl thiosuccinimide gave 0.08g (15 %) of the product (66), a colourless oil, one spot by TLC, ^{1}Hnmr: 0.1(s,9H), 0.9(d, 6H), 1.2(d, 1H), 3.8(s, 2H), 4.1-4.4(m ,1H), 7.2 (s, 5H).

-Trimethylsiloxyneopentyl Methyl Disulfide (67)

Reaction of 0.79g (5.0 mmol) of methyl thiopthalimide with 0.81g (5.0 mmol) of α-trimethylsiloxyneopentyl thiol gave 0.69g (57 %) of the product (67), a colourless oil, one spot by TLC, ^{1}Hnmr: 0.19(s, 9H), 0.93(s, 9H), 2.33(s, 3H), 4.57(s, 1H).

ATTEMPTED PREPARATION OF A HYDRODISULFIDE FROM AN α-TRIMETHYLSILOXY DISULFIDE

All attempts at desilylation (which was tried under a variety of conditions) gave unsatisfactory results. The detailed procedure for one trial is given below. To a solution of 0.17g (0.54 mmol) of α-trimethylsiloxyisobutyl benzyl disulfide in 15mL of methanol was added 0.10g (3.0 mmol) of potassium fluoride at room temperature. Stirring was continued at room temperature for 20 hr. Solvent was removed under reduced pressure to give white crystals. They were dissolved in 5mL of water and the resulting solution was acidified. It was extracted with pentane (4 x 15mL). The extracts were concentrated under reduced pressure to give an orange-coloured oil (8 spots by TLC). ^{1}Hnmr analysis of the product showed no peaks corresponding to the hydrodisulfide (29) (by comparison with the spectrum of an authentic sample).

PREPARATION OF BENZYL HYDRODISULFIDE(29)

To a solution of 0.42g (2.1 mmol) of acetyl benzyl disulfide in 15mL of ether was added dropwise 5mL of an ethanolic solution of 5N HCl. The reaction mixture was stirred overnight at room temperature. Volatiles were evaporated under vacuum. Further purification of the product was not necessary (see Böme and co-workers[55]). The reaction yielded 0.27g (82 %) of compound 29, a colourless oil, one spot by analytical TLC, ^{1}Hnmr: 2.80 (s, 1H), 3.66 (s, 2H), 7.33(s, 5H), [lit.[106] ^{1}Hnmr: 2.75 (s, 1H), 3.80 (s, 2H), 7.50 (s, 5H)].

PREPARATION OF ACETYL BENZYL DISULFIDE (68)

This compound was prepared according to ref. 57.
To a solution of 2.0g (9.0 mmol) of N-benzyl thiosuccinimide 0.76g (10.0 mmol) of thioacetic acid. After stirring for 2 days at room temperature, the reaction mixture was concentrated to give a yellow oil. It solidified on addition of hexane. The solid was recrystallized from hexane/methylene chloride to give

13.4g (92 %) of the product(68), m.p. 54-56 °C (lit.[60] 54-55 °C), IR: 1690 cm^{-1} (C=O), ^{1}Hnmr: 2.3(s, 3H), 3.9(s, 2H), 7.3(s, 5H).

PREPARATION OF SULFENYL CHLORIDES

The sulfenyl chlorides were prepared according to the procedures given below. For benzylsulfenyl chloride, all three methods were used. For phenylsulfenyl chloride, method II only was used.

Method I

Chlorine was bubbled into a solution of 4.0g (16.3 mmol)of dibenzyl disulfide in 50mL of carbon tetrachloride at 0 °C. The reaction mixture was stirred for 30 minutes. Analysis by ^{1}Hnmr indicated that the reaction had taken place to give orange benzylsulfenyl chloride (86 %, estimated by ^{1}Hnmr), ^{1}Hnmr (CCl_4): 4.25(s, 2H), 7.23(s, 5H).

Method II

The same procedure as above was used, but dibenzyl disulfide was replaced by benzyl mercaptan. From 0.42g (3.4 mmol) of benzyl thiol, 2.6 mmol of benzyl sulfenyl chloride was obtained (76 %, estimated by ^{1}Hnmr).

Method III

The procedure of ref.89, which uses SO_2Cl_2, was followed. From 8.0g (32.5 mmol) of dibenzyl disulfide, 53.1 mmol of benzyl sulfenyl chloride was obtained (95 %, estimated by ^{1}Hnmr).

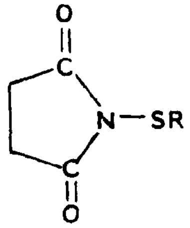
PREPARATION OF SULFUR TRANSFER REAGENTS

N-TRIMETHYLSILYL SUCCINIMIDE

A modified method based on the procedures in references 82 and 109 was used. To a solution of 6.6g (6.7 mmol) succinimide and 0.1g (1.5 mmol) of benzimidazole in 100mL of THF at room temperature was added dropwise 8.0g (5.0 mmol) of hexamethyldisilazane in 50mL of THF . After the reaction mixture had been stirred for 1 hr at room temperature it was refluxed for 1.5 days. It was then distilled to give 7.4g (65 %) of product, b.p. 105-107 °C/ 7 mmHg (lit.[109] 120 °C/ 8 mmHg); ^{1}Hnmr: 0.33 (s, 9H), 2.55 (s, 4H).

N-SUBSTITUTED THIOSUCCINIMIDES

N-Phenyl-Thiosuccinimide(69)



To a solution of 1.17g (8.76mmol) of N-chlorosuccinimide in 40mL of benzene was added 1.60g (8.76 mmol) of trimethylsilyl phenyl sulfide in 5mL of benzene at room temperature. The reaction mixture was stirred for 1 hr at room temperature and then it was refluxed for 1 hr. After the addition of water (20 mL) the reaction mixture was extracted with methylene chloride. The extracts were dried over magnesium sulfate and concentrated *in vacuo* to give orange crystals. Recrystallization from hexane/ methylene chloride gave 1.2g (69 %) of white crystals, m.p. 114-116 °C (lit.[107] 115-116 °C); IR: 1700 cm^{-1} (C=O); ^{1}Hnmr: 2.76 (s, 4H), 7.40 (m, 5H).

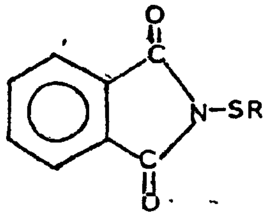
N-Benzyl-Thiosuccinimide(70)

This compound was prepared according to the method of Harpp[112].

To a solution of 8.3g (48.7 mmol) of N-trimethylsilyl succinimide in 150mL of carbon tetrachloride was added dropwise at room temperature benzyl sulfenyl chloride (48.7 mmol, estimated by ^{1}Hnmr). The reaction mixture was stirred for 2hr at room temperature. Solvent was removed under reduced pressure to give white crystals. Recrystallization from hexane/ methylene chloride gave 7.0g (65 %) of product, m.p. 162-163 °C (lit.[108] 161-163 °C); ^{1}Hnmr: 2.63 (s, 4H), 4.10 (s, 2H), 7.30 (br s, 5H).

N-SUBSTITUTED THIOPHTHALIMIDES

Method I

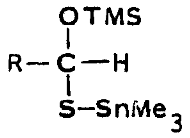


To a solution of 12g (75.7 mmol) of potassium phthalimide in 100mL of DMF was slowly added (1.5 hr) benzyl sulfenyl chloride (75.7 mmol, estimated by ^{1}Hnmr) in carbon tetrachloride at -10 °C. After stirring for 1 hr at -10 °C the temperature of the reaction mixture was warmed gradually to 40 °C. Stirring was continued overnight. Water (200 mL) was added to the reaction mixture; filtration afforded white crystals which were recrystallized from chloroform/hexane to give 10.62g (52 %) of N-thiobenzyl phthalimide, m.p. 167-168 °C (lit.[74] 161-163 °C); ^{1}Hnmr: 4.1(s, 2H), 7.1(m, 5H), 7.6(m, 4H).

Method II

To a solution of 4.0g (27.2 mmol) phthalimide and 3.3g (32.6 mmol) triethylamine in 400mL of carbon tetrachloride was added dropwise at -5 °C benzyl sulfenyl chloride (28.0 mmol, estimated by ^{1}Hnmr). The reaction mixture was stirred for 30 min at 0 °C, allowed to warm to room temperature, stirred for 30 min at room temperature, heated to 60 °C, and stirred for 20 min at 60 °C. Water (150 mL)was added and the mixture was filtered to give white crystals. These were recrystallized from hexane/chloroform to give 5.5g (75 %) of N-benzyl thiophthalimide, m.p. 167-168.5 °C (lit.[74] 161-163 °C).

SYNTHESIS OF α-TRIMETHYLSILOXYISOBUTYL TRIMETHYL TIN SULFIDE



$$\mathrm{R}-\overset{\displaystyle \mathrm{OTMS}}{\underset{\displaystyle \mathrm{S}-\mathrm{SnMe}_3}{\mathrm{C}}}-\mathrm{H}$$

The procedure is based on that of ref.90. To a solution of 0.35g (2.0 mmol) of α-trimethylsiloxyneopentyl thiol and 0.20g (2.0 mmol) of triethylamine in 50mL of benzene was added 0.40g (2.0 mmol) of trimethyltin chloride in 20mL of benzene. After stirring for 2 hr at room temperature the reaction mixture was filtered and chromatographed on silica gel (hexane/ ethyl acetate). It gave 0.37g (54 %) of α-trimethylsiloxyneopentyl trimethyltin sulfide, ^{1}Hnmr: 0.10(s, 9H), 0.19(s, 9H), 0.95(s, 9H), 4.81(s, 1H).

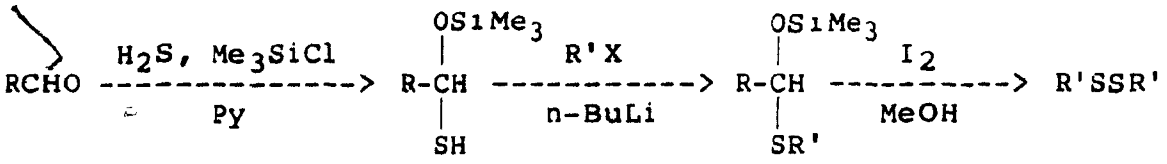
SUMMARY AND CONCLUSIONS

In this thesis, the synthesis of α-trimethylsiloxy sulfides and disulfides, potentially useful reagents for the preparation of α-functionalized monosulfides and polysulfides under mild conditions, has been achieved. One aspect of the synthetic utility of these compounds has been illustrated by preparing a new class of compounds, the α-bromosulfides, from the α-trimethylsiloxy sulfides. Further studies based on this approach may yield good synthetic routes to a number of α-functionalized sulfides and polysulfides which are difficult to synthesize at present.

The preparation of thiols and hydrodisulfides from the title compounds is a second area of synthetic application which has been investigated in this work. A satisfactory experimental procedure in which α-trimethylsiloxy sulfides are desilylated to give the corresponding thiols in good yield has been discovered.

The α-trimethylsiloxy sulfides may also be used as reagents for the synthesis of unsymmetrical sulfides. In this thesis one example of such a compound, benzyl phenyl sulfide, was prepared from α-trimethylsiloxy-n-butyl phenyl sulfide. This type of reaction could, with further study, provide a route to other unsymmetrical sulfides and polysulfides.

The same compound, α-trimethylsiloxy-n-butyl phenyl sulfide, yielded an unexpected product, diphenyl disulfide, upon treatment with iodine in methanol. This procedure has been used by Olah and co-workers[103] to convert α-keto acetoxy sulfides to the corresponding monoacetals. If the reaction observed with α-trimethylsiloxy-n-butyl sulfide is general for all such compounds, it could be useful as a source of symmetrical disulfides (eq.59).



$$\mathrm{RCHO} \xrightarrow[\text{Py}]{\mathrm{H_2S,\ Me_3SiCl}} \overset{\displaystyle \mathrm{OSiMe_3}}{\underset{\displaystyle \mathrm{SH}}{\mathrm{R{-}CH}}} \xrightarrow[\text{n-BuLi}]{\mathrm{R'X}} \overset{\displaystyle \mathrm{OSiMe_3}}{\underset{\displaystyle \mathrm{SR'}}{\mathrm{R{-}CH}}} \xrightarrow[\text{MeOH}]{\mathrm{I_2}} \mathrm{R'SSR'}$$

eq.59

Some representative members of the α-trimethylsiloxy thiols, a class of compounds closely related to the α-trimethylsiloxy sulfides and disulfides, have been synthesized. The generation and trapping of the α-trimethylsiloxy thiolates derived from these thiols are reported in this thesis.

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Fig. I

The mass spectrum of α-Trimethylsiloxyneopentyl benzyl disulfide

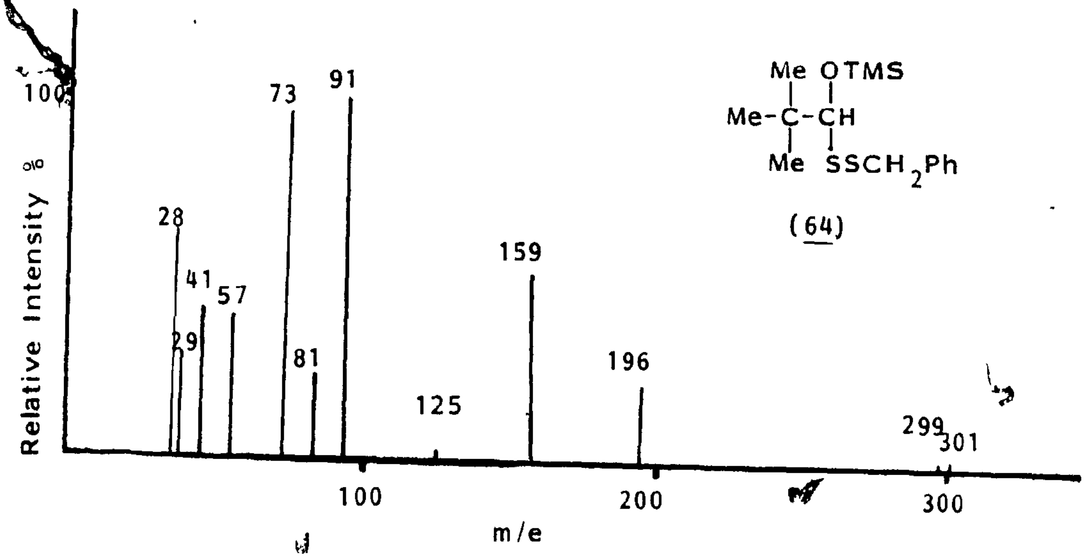
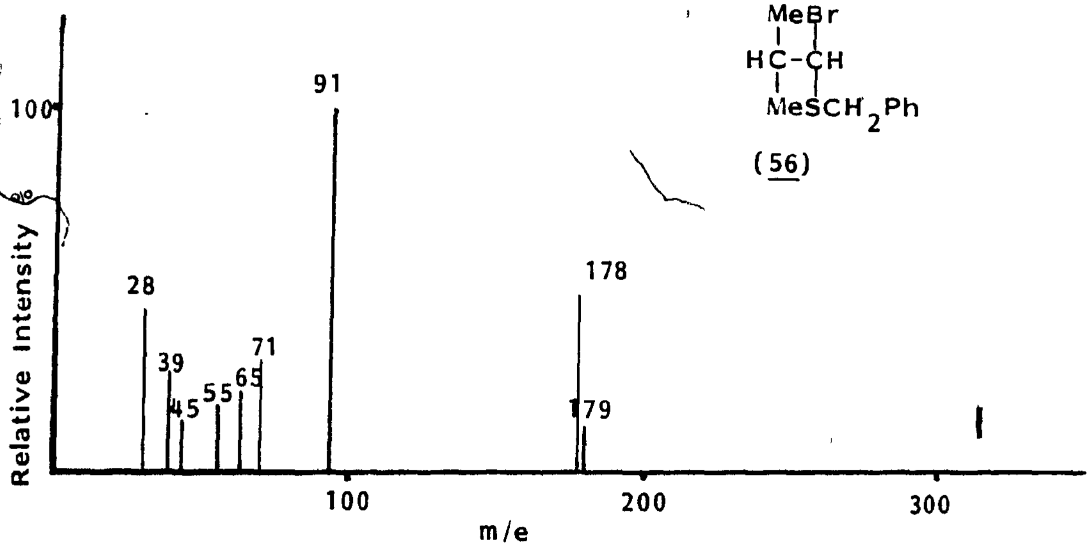


Fig. II

The mass spectrum of α-bromoisobutyl benzyl sulfide



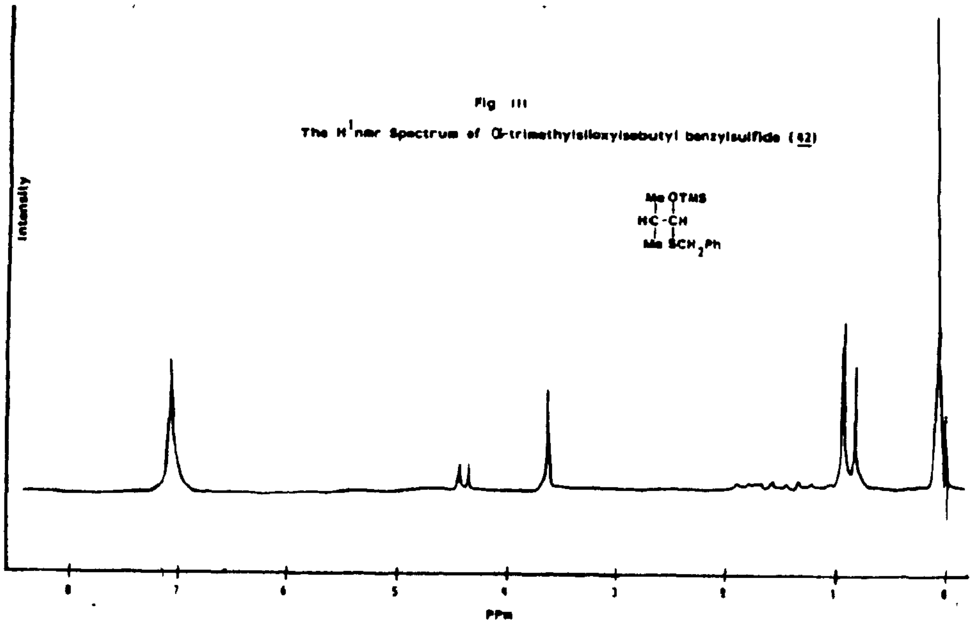


Fig III

The ^{1}H nmr Spectrum of α-trimethylsiloxyisobutyl benzylsulfide (62)

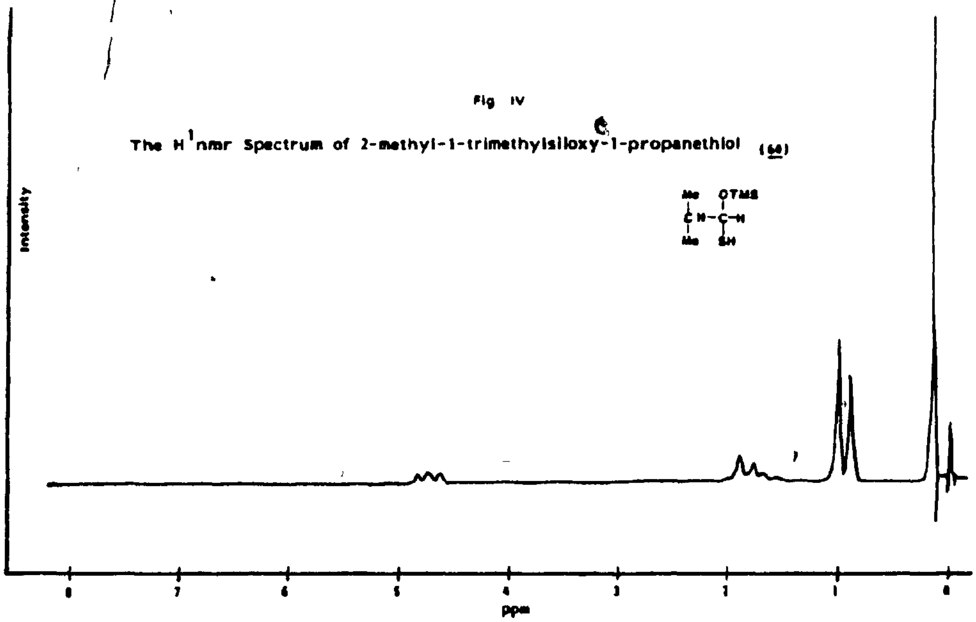


Fig IV

The ^{1}H nmr Spectrum of 2-methyl-1-trimethylsiloxy-1-propanethiol (64)

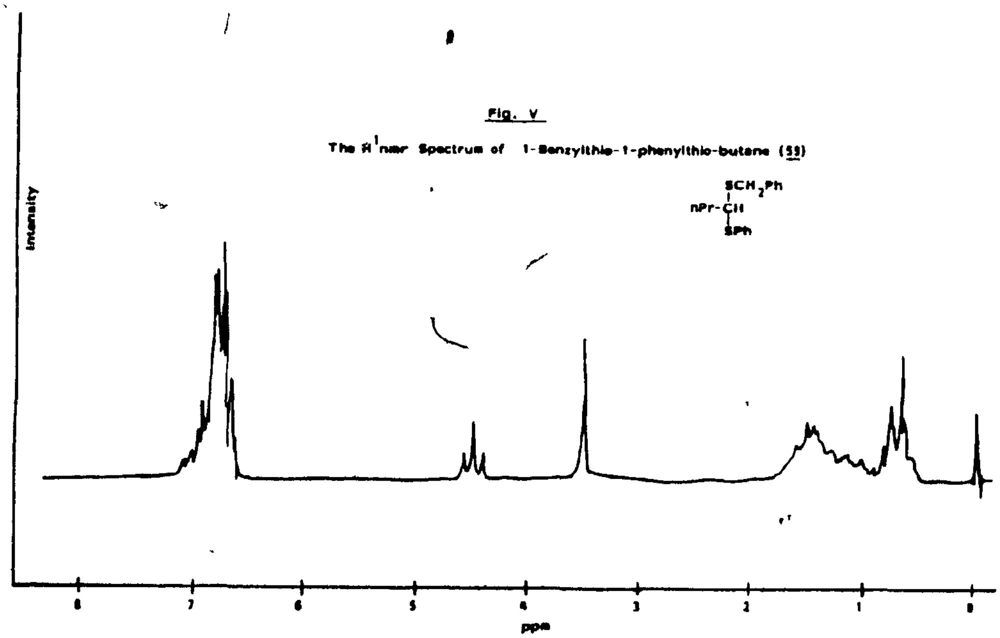


Fig. V

The H^1nmr Spectrum of 1-Benzylthio-1-phenylthio-butane (53)

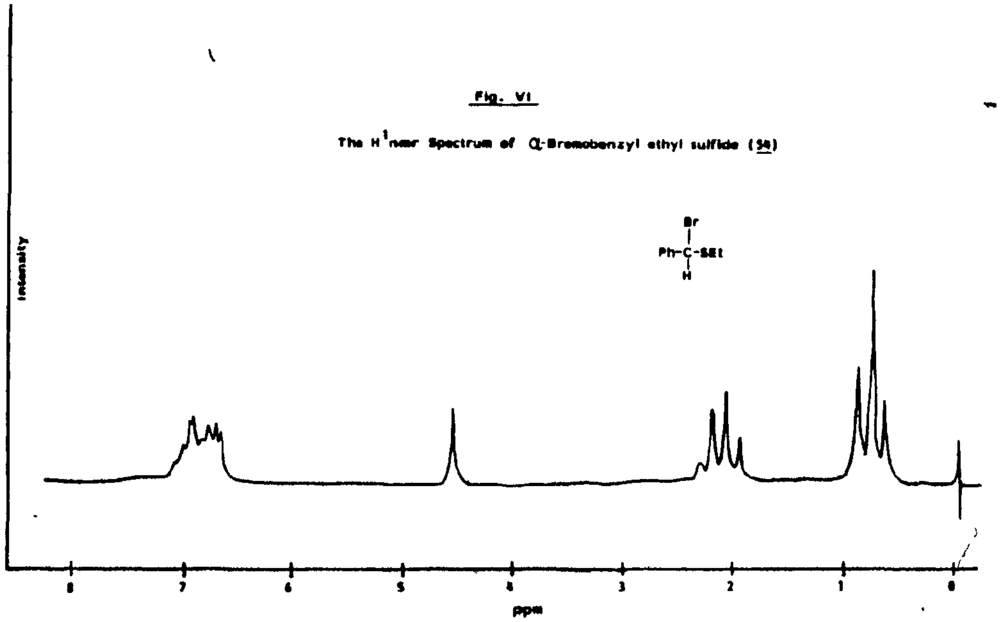


Fig. VI

The H^1nmr Spectrum of α-Bromobenzyl ethyl sulfide (54)

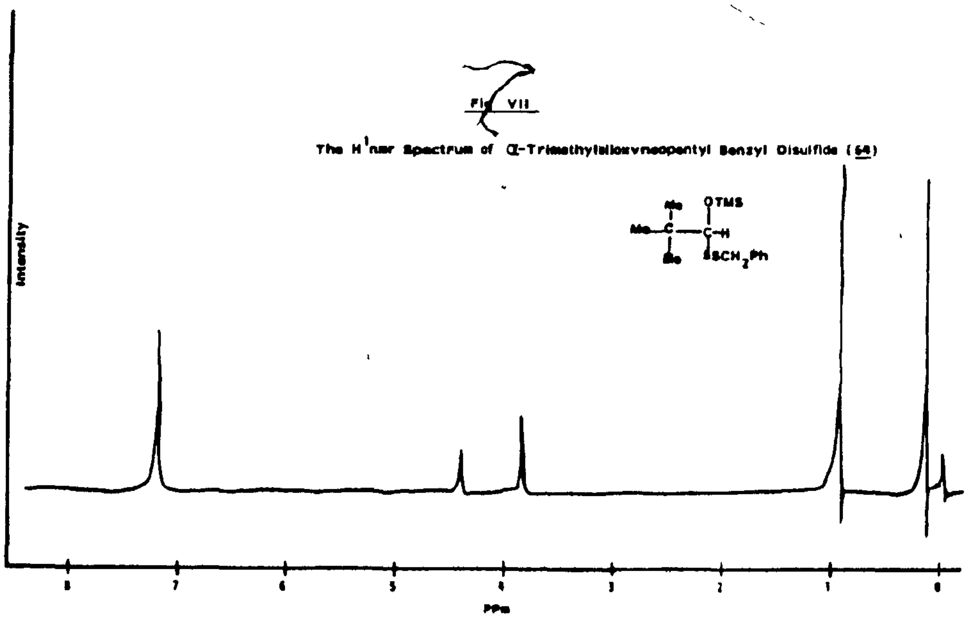


Fig. VII

The H^{1}nmr Spectrum of α-Trimethylsiloxyneopentyl Benzyl Disulfide (64)

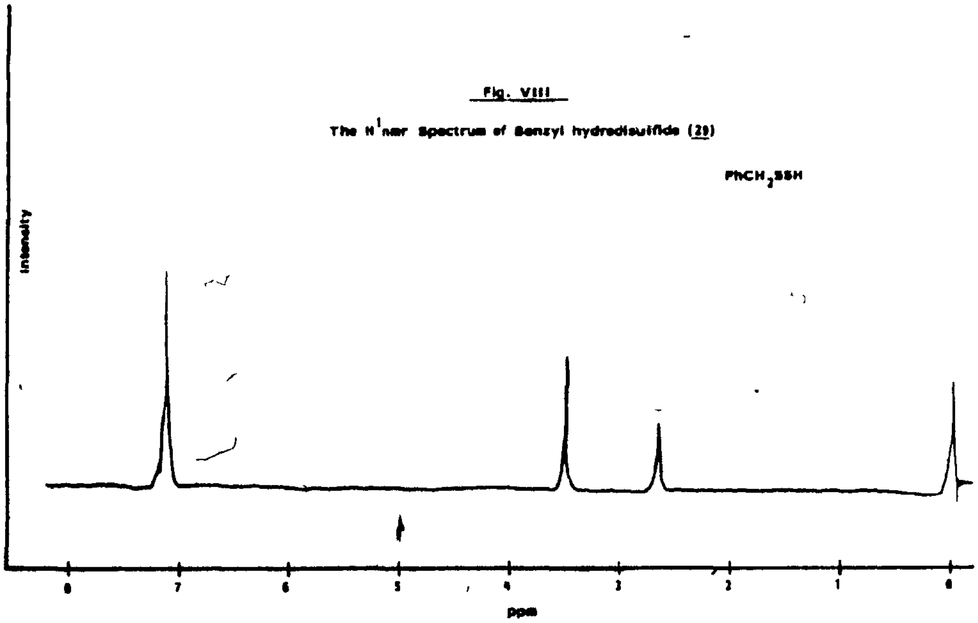


Fig. VIII

The H^{1}nmr Spectrum of Benzyl hydrodisulfide (29)