Ph. D.   P. Mathiaparanam   Department of Chemistry

1,3,2-Dioxaphospholene-Sulfenyl Chloride Condensation.

ABSTRACT

1,2-Diketones react with trivalent phosphorus compounds to form 1:1 adducts (or substituted 1,3,2-dioxaphospholenes). These 1,3,2-dioxaphospholenes undergo facile condensation with sulfenyl chlorides. The nature and the number of products depend on the structure of 1,3,2-dioxaphospholene. The 1:1 adduct from benzil and trimethyl phosphite, condenses with a wide variety of sulfenyl chlorides to form α-benzoyl-α-chloro benzyl sulfides and trimethyl phosphate. In addition, the 1:1 adduct from benzil and tris(dimethylamino)phosphine, reacts with p-toluene sulfenyl chloride affording α-benzoyl-α-chloro benzyl-p-tolyl sulfide and hexamethyl phosphoramide. In contrast, the adduct from biacetyl and trimethylphosphite condenses with benzene, and ethane sulfenyl chlorides to form a mixture of products identified as α-acetyl-α-chloroethyl-phenyl (or ethyl) sulfide, trimethyl phosphate, α-acetyl-α-phenyl (or ethyl) thio -ethyl-dimethyl phosphate and methyl chloride.

The condensation is rationalized in terms of a "sulfenium chloride" mechanism.

Trichlorosilane and tri-n-butylamine dechlorinate α-chloro-β-ketosulfides to the corresponding β-ketosulfides. α-Benzoyl-α-chloro benzyl sulfides react with potassium thiocyanate to give 4-thio-substituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones.

The mass spectra of a variety of α-chloro-β-ketosulfides, β-ketosulfides and 4-thio-substituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones are discussed.

1,3,2 - Dioxaphospholene -
Sulfenyl Chloride Condensation

by

Ponnampalam Mathiaparanam

A Thesis presented to
the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Department of Chemistry
McGill University
Montreal, Canada.

November 1970.

TO MY PARENTS

TABLE OF CONTENTS

Page

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

APPENDIX

List of Illustrations

Page

Page

ACKNOWLEDGEMENTS

The author wishes to acknowledge his indebtedness to those who have made this research possible, particularly the following:

Dr. David N. Harpp, for his patience, interest and encouragement;

The National Research Council of Canada, for the financial support in the form of a scholarship (1967-1970);

Mr. Victor Yu and Mr. Peter Currie for the technical assistance; and

Mr. Manuel Bernhaut, for typing the manuscript.

Chapter I

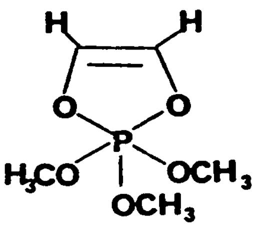
Introduction

(Throughout the text substituted 1,3,2 - dioxaphospholenes are referred to as 1:1 dicarbonyl-phosphine adducts for clarity. The nomenclature is discussed on page 9.)

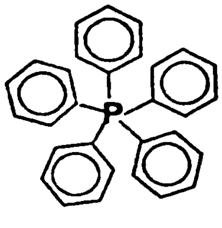
INTRODUCTION

Bonding for carbon can only be described in terms of s and p orbitals, because the 2s ⟶ 3d promotional energy for carbon is too high for effective use of d-orbitals. However, for phosphorus the 3s ⟶ 3d promotional energy is relatively low; consequently a greater contribution of 3d energy levels is anticipated in its bonding. This leads to a reduced electronegativity and greater polarizability in phosphorus and these two properties are mainly responsible for the different structures and reactions of the compounds of phosphorus and those of carbon.[1,2]

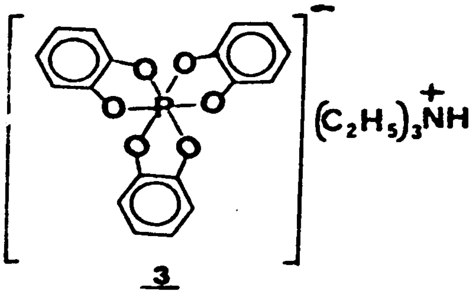
Considering the structure of phosphorus compounds, the ability of phosphorus to form 5 and 6 co-ordinated compounds (for example, 1[3], 2[4], 3[5], and 4[6]) with central shells of 10 and 12 electrons suggests strongly that at least two 3d orbitals may be used in their bonds.



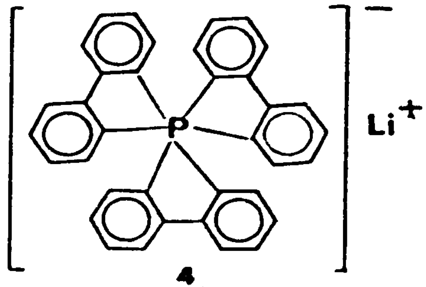
1



2



3



4

Furthermore, the reactions of most phosphorus compounds (trivalent phosphorus compounds in particular) display the "amphoteric" or "biphilic" characteristics of phosphorus. This phenomenon was first recognized in the coordination chemistry of phosphine complexes.[7] The σ-donor and π-acceptor properties of phosphines in coordination compounds led Pearson[8] to describe them as "biphilic reagents". According to him the term "biphilic reagents" refer to ligands which can donate electrons to a substrate to form a σ-bond and simultaneously accept electrons at the same centre to form a π-bond. This dual role is attributed to the relatively high polarizability of phosphorus which means that the atom can be deformed easily by both electrophiles and nucleophiles. The greater radius of phosphorus compared with that of carbon leads to a considerable reduction in repulsion energy on the approach of a nucleophile.

Some new reactions of trivalent phosphorus compounds demonstrated that the "biphilicity" of phosphorus could also be described by the σ-donor and σ-acceptor properties. This led Kirby and Warren[9] to extend the definition of biphilic reagents to include these new reactions. The term "biphilic reagents" is now modified to describe compounds which can donate electrons to a substrate to form a σ-bond and also accept them at the same centre to form a second σ or π bond. The following examples illustrate the various types of biphilic reactions of phosphorus.

σ-donor-π-acceptor systems.

(a) Donor-acceptor stages simultaneous.

Phosphine-carbene reaction.[10]

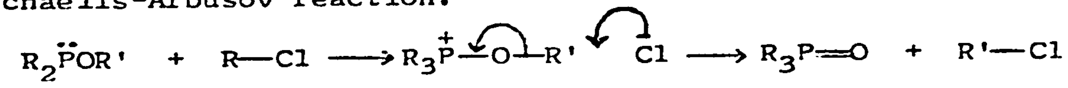
$$R_3P: \quad + \quad :CHR' \longrightarrow R_3\overset{+}{P}-\overset{-}{C}HR' \longrightarrow R_3P=CHR'$$

Phosphine-azide reaction.[11]

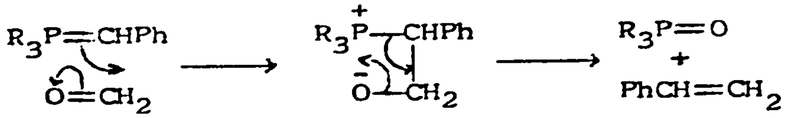
$$R_3P: \quad + \quad \overset{-}{N}=\overset{+}{N}=NAr \longrightarrow R_3\overset{+}{P}-\overset{-}{N}-N=NAr \longrightarrow R_3P=N-N=NAr$$

(b) Donor-acceptor stages separate.

Michaelis-Arbusov reaction.[12]



Wittig reaction.[13]



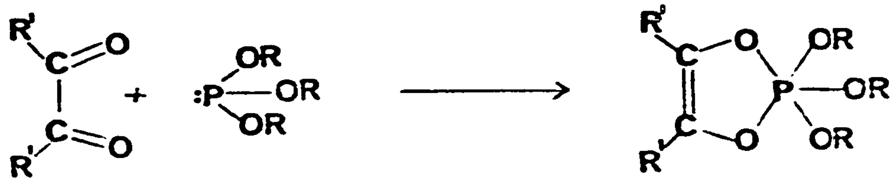
σ-donor-σ-acceptor systems.

Donor-acceptor stages separate or concerted.

Chlorine-phosphorus trichloride reaction.[14]

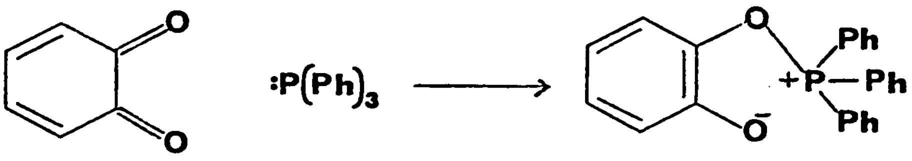
$$:PCl_3 \quad + \quad Cl_2 \longrightarrow \overset{+}{P}Cl_4 \quad \overset{-}{Cl} \longrightarrow PCl_5$$

Trialkylphosphite-1,2-diketone reaction.[15]



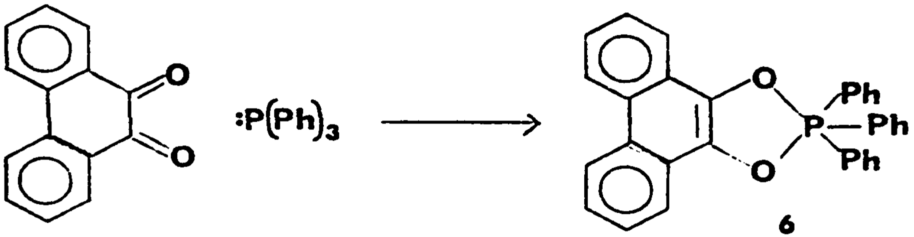
Reactions of trivalent phosphorus compounds with α-dicarbonyl compounds.

In 1955, Horner and Klupfel[16] found that triphenylphosphine readily reacted with o-benzoquinones to give 1:1 adducts for which the authors favoured a phosphonium enolate structure 5.



5

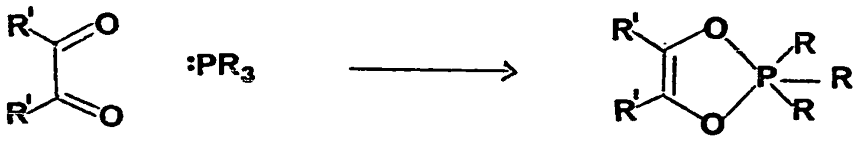
Later, Schenk et, al.[17] obtained a 1:1 adduct by both a photochemical and a thermal reaction of 9,10-phenanthrenequinone with triphenylphosphine. They assigned this adduct a cyclic structure 6 based on spectroscopic studies.



6

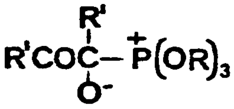
In a series of papers starting in 1958, Kukhtin et, al.[18] studied the reaction between phosphites and 1,2-dicarbonyl compounds and postulated several structures for intermediates and final products.

About the same time, Birum and Dever[19] reported a variety of 1:1 adducts from 1,2-dicarbonyl derivatives and trivalent phosphorus compounds. They assigned a cyclic structure 7 to these adducts based on ^{31}P nmr studies.



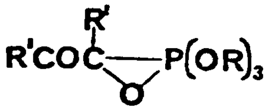
7

In 1960, Ramirez et, al.[20] started an in depth study of the reaction between trialkyl phosphites with 1,2-dicarbonyl compounds and the structures of the final products so obtained. These workers considered the following possible structures for 1:1 adducts.

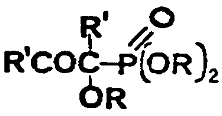


$R'CO\overset{R'}{\underset{O^-}{C}}-\overset{+}{P}(OR)_3$

8

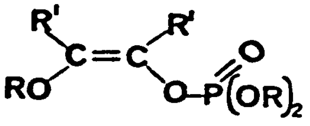


9

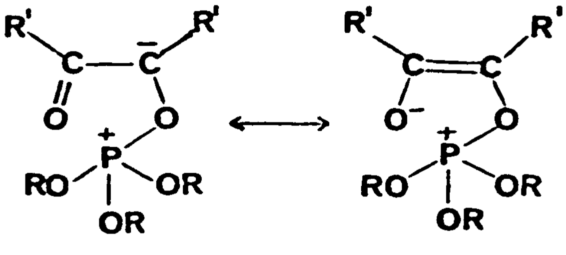


$R'CO\overset{R'}{\underset{OR}{C}}-\overset{O}{\overset{\|}{P}}(OR)_2$

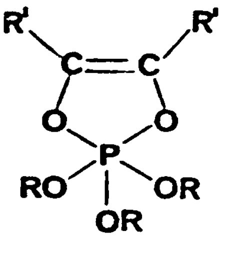
10



11



12



13

For structural studies, the adduct formed between biacetyl and trimethylphosphite (ie; R=R'=CH_3:) was considered in detail.

Infrared Spectrum:

The ir spectrum of the biacetyltrimethylphosphite adduct showed no absorption due to a carbonyl group. This excludes structures 8, 9 and 10 from further consideration. The P=O stretching vibration in phosphate esters gives rise to a strong band in the region 7.42-8.00 μ (1350-1250 cm^{-1}), but the shape and intensity of the bands of the adduct in this region are not those of a typical phosphate ester. Also, the P-O-CH_3 group of trimethylphosphate absorbs very strongly at 9.55 μ (1045 cm^{-1}). The strongest bands of the adduct are at 9.18 (1090) and 9.30 μ (1075 cm^{-1}), significantly lower than the band of the trimethylphosphate. Structure 11, which is a methylphosphate ester, is inconsistent with the infrared spectrum of the adduct.

^{31}P nmr spectrum:

The ^{31}P nuclear magnetic resonance signal due to the adduct is at a higher field (+ 53 ppm) than 85% phosphoric acid, which is used as external reference. This observation indicates that phosphorus is more shielded in the adduct than in phosphoric acid. The ^{31}P nmr signal is split into ten lines indicating that phosphorus is coupled to nine protons. In structures 12 and 13, the phosphorus nucleus is in the environment of nine methoxyl protons which could be coupled to phosphorus giving rise to ten lines. So, the chemical shift becomes the deciding factor to determine the structure of the adduct. Even though at present, one cannot relate chemical shifts to molecular structure in all valence states of phosphorus, some comparisons with related compounds can be made (see Table 1 on page 8.). From the Table 1, it is observed that there is a positive chemical shift as oxygen atoms are introduced on phosphorus. The large positive chemical shifts observed in the adducts strongly suggest an oxyphosphorane structure 13 rather than an open dipolar structure 12.

^{1}H nmr spectrum:

The ^{1}H nmr spectrum of the 1:1 adduct showed a doublet at low field 6.56 τ (J_{HP} = 13 HZ) and a singlet at 8.25 τ. The doublet at low field is assigned to the CH_3O groups, in which the proton signal is split by the phosphorus. There is one doublet only, therefore the three methoxyl groups are either equivalent or indistinguishable. The essential features of the spectrum are not altered when the adduct was dissolved in carbon tetrachloride. The methoxyl protons of trimethylphosphate show the doublet at somewhat lower field 6.30τ(J_{HP} = 13 HZ) that the doublet of the adduct. The methoxyl protons appear therefore to be more shielded in the adduct than in trimethylphosphate. Also, the position of the high field methyl singlet (8.25 τ) in the adduct is very close to that of a methyl group attached to a carbon-carbon double

Table 1

^{31}P nmr Chemical Shifts ($\delta^{31}P$) of Some Phosphorus Compounds in Different Valence States.

Compound	$\delta^{31}P^a$	Compound	$\delta^{31}P^a$	Compound	$\delta^{31}P^a$	Compound	$\delta^{31}P^a$
$(CH_3O)_3P$	-140.0^b	$(CH_3O)_3P{=}O$	-5.2^b	$(CH_3O)_4\overset{+}{P}\overset{\ominus}{BF_4}$	-1.9^c	-	-
$(C_2H_5O)_3P$	-137.0^b	$(C_2H_5O)_3P{=}O$	$+1.0^d$	$(C_2H_5O)_4\overset{+}{P}\overset{\ominus}{BF_4}$	$+24.0^c$	$(C_2H_5O)_5P$	$+70.7^e$
$(C_6H_5O)_3P$	-126.0^b	$(C_6H_5O)_3P{=}O$	$+17.0^d$	-	-	$(C_6H_5O)_5P$	$+85.6^e$

(a) The chemical shifts were reported in ppm using phosphoric acid (85%) as external standard.

(b) "Topics in Phosphorus Chemistry", Vol. 5, Interscience Publishers Inc., New York, N.Y. 1967, Chapter 5.

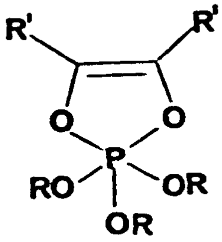
(c) Finley, J.H., Denney, D.Z. and Denney, D.B., J. Amer. Chem. Soc., 91, 5826 (1969).

(d) Denney, D.B., and Relles, H.M., ibid., 86, 3897 (1964); Denney, D.B., and Gough, S.T.D., ibid., 87, 138 (1965).

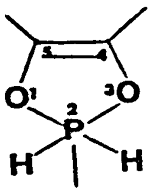
(e) Ramirez, F., Bigler, A.J. and Smith, C.P., J. Amer. Chem. Soc., 90, 3507 (1968).

bond. The ^{1}H nmr spectrum of the adducts is compatible with structure 13. The equivalency of methoxyl protons in the adduct could be explained as due to the pseudorotation of the P-O bonds, by which the methoxyl groups can be interchanged without rupture of P-O bond.[21] The possibility of a rapid equilibrium between the oxyphosphorane 13 and very small amounts of a dipolar structure 12 whereby the methoxyl groups can exchange positions, has also been suggested to account for the equivalency of the methoxyl protons.

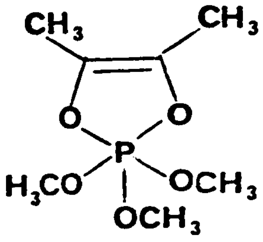
Other 1:1 adducts of α-diketones and o-quinones with tertiary phosphites displayed similar characteristics in their ir, ^{31}P nmr and ^{1}H nmr spectra.[20] These similarities strongly suggest that all the adducts have the same type of cyclic unsaturated oxyphosphorane structure 13. According to the nomenclature, structure 13 is regarded as a derivative of the 2,2-dihydro-1,3,2-dioxaphospholene 14 system. For example, the 1:1 biacetyl-trimethylphosphite adduct 15 is named as 4,5-dimethyl-2,2,2-trimethoxy-2,2-dihydro-1,3,2-dioxaphospholene.[22]



13

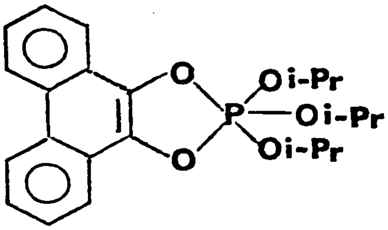


14

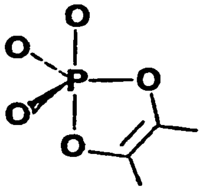


15

Further confirmation on the cyclic oxyphosphorane structure 13 of 1:1 adducts was provided by single crystal X-ray diffraction data. Studies on 9,10-phenanthrenequinone-triisopropylphosphite adduct 16 indicated that the phospholene ring is in an apical-equatorial plane of a trigonal-bipyramid 16a as shown below.[23]

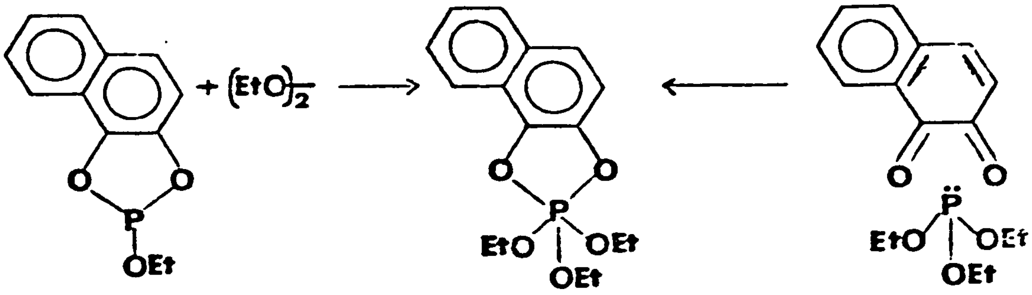


16



16a

Some of these adducts have been synthesised recently via a different route which tend to confirm the cyclic oxyphosphorane structure 13. For example, phosphite 17 reacts with diethylperoxide to give oxyphosphorane 18, which is identical to the one obtained from 1,2-napthoquinone and triethylphosphite.[24]



17

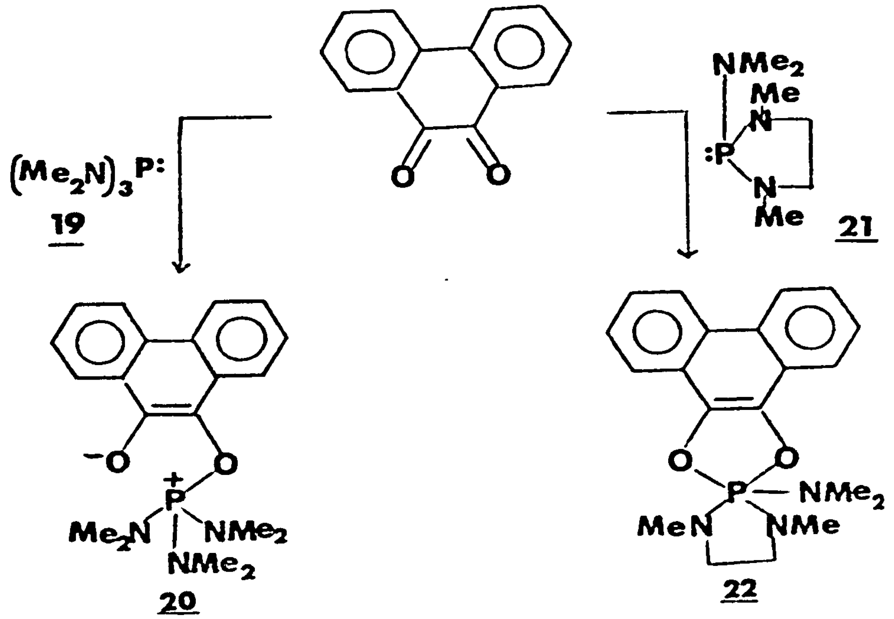
18

Extended studies by Ramirez et al,[25] on the 1:1 adducts formed from 1,2-dicarbonyl compounds with cyclic and acyclic tris(dialkylamino)phosphines indicated that

(i) the structure of the adduct depends on the steric hindrance of the groups attached to the phosphorus of the phosphines.

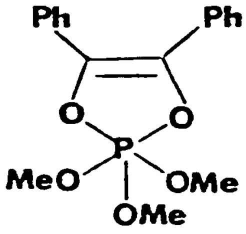
(ii) the stability of the adduct depends on both the steric hindrance of the groups and the electronegativity of the element attached to the phosphorus.

For example, the compound made from 9,10-phenanthrenequinone and tris(dimethylamino)phosphine 19 is an open dipolar ion 20 both in the crystal and in solutions,[26] whereas, the adduct made from the same quinone and the cyclic aminophosphine 21 has been assigned an oxyphosphorane structure 22.[27]



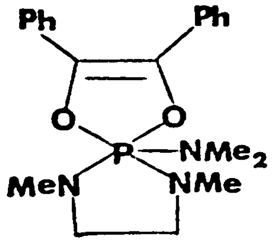
This difference in the structures of the adducts 20 and 22 is attributed to the enhanced steric hindrance of the methyl groups in the acyclic tris(dimethylamino)phosphine (19) over those in the cyclic aminophosphine 21.

The tendency of phosphites to give stable oxyphosphoranes and the reluctance of the acyclic triaminophosphines to do so, is in part due to the larger steric requirements of the dialkylamino groups. These effects can be illustrated with benzil. The adduct with trimethylphosphite is a stable oxyphosphorane 23[20] and the product with the cyclic aminophosphine 21 is a somewhat less stable oxyphosphorane 24.[28] The compound formed with tris(dimethylamino)phosphine (19).however, can be isolated in two forms.[28] The metastable one is the open dipolar ion 25a and the stable one is the oxyphosphorane 25b. In solutions both forms are in equilibrium. The nature of the solvent and dilution affect the position of the equilibrium and hence the value of the ^{31}P chemical shift.



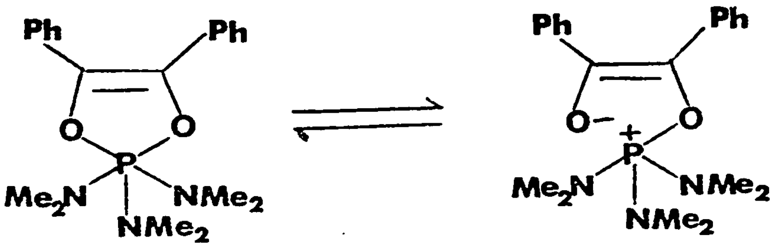
$\delta^{31}P$ = +49.5 ppm

23



$\delta^{31}P$ = +36.9 ppm

24



25a **25b**

$\delta^{31}P$ = +30.2 ppm in 1.0 M hexane.

$\delta^{31}P$ = +13.0 ppm in 1.0 M methylene chloride.

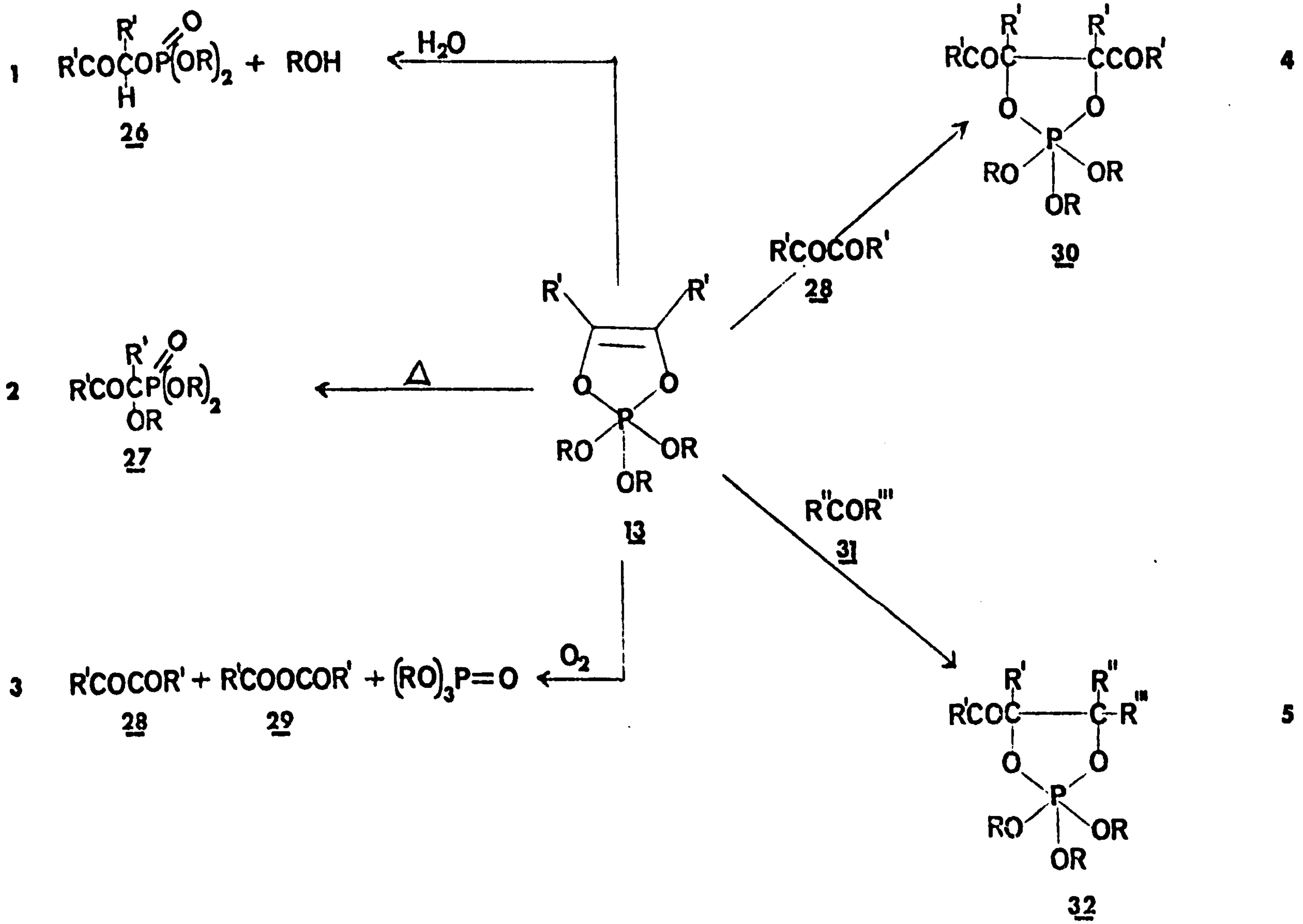
Some Properties of 1:1 Adducts.

The most characteristic property of the adducts is their tendency to undergo ring opening with a variety of reagents. Some of the reactions are summarized in Scheme I on the next page. With water, the adduct 15 forms β-ketophosphate 26 and an alcohol (cf reaction 1.).[29] On heating the adduct 15 rearranges to form α-alkoxy-β-ketophosphate 27 (cf reaction 2.).[30] With oxygen, the diketone 28, the anhydride 29 and the phosphate are formed (cf reaction 3.).[31] With diketone 28, the 1,3,2-dioxaphospholane 30 is formed (cf reaction 4.).[32]

The above reactions represent the possible side reactions in the preparation of 1:1 adducts if certain precautions are not taken. Water and oxygen are excluded by carrying out the reaction in an atmosphere of dry nitrogen. Excess heat formed in these reactions can be regulated either by external cooling or by dilution with a suitable solvent or both. The

Scheme I

Some Reactions of 1:1 Dicarbonyl-Trialkyl Phosphite Adducts.



formation of the diadduct can be avoided by adding a mole of dicarbonyl compound to slight excess of a mole of phosphite. In this way there is no free dicarbonyl compound left in the reaction mixture to react with the 1:1 adduct, thus avoiding diadduct formation. However, if the dicarbonyl compound is not very reactive, the diadduct is formed either as an impurity or as the main product.[33]

With carbonyl compounds 31, the condensation has been carried out both thermally and photochemically (cf reaction 5.).[34,35] In both cases the end product is the same 1,3,2-dioxaphospholane 32, in spite of significant differences that exist between both types of condensations.

Thermal condensation with a variety of carbonyl compounds has been reported.[34] Aliphatic acyclic ketones were found to be unreactive. Acetone for example, failed to react in 3 months at 20° and furthermore, butanone gave no product in 48 hrs at 80°. The yields from this condensation are somewhat limited, in some instances by the thermal decomposition of the product 1,3,2-dioxaphospholane 32. On the other hand, the photocondensation of 1:1 biacetyl-trimethylphosphite adduct (15) with acetone, benzophenone, and acetophenone proceeded in good yield.[35] Thus, photocondensation seems to be more generally applicable to ketones than the thermal counterpart. Also, photocondensation can be carried out at room temperature and its scope is under investigation.

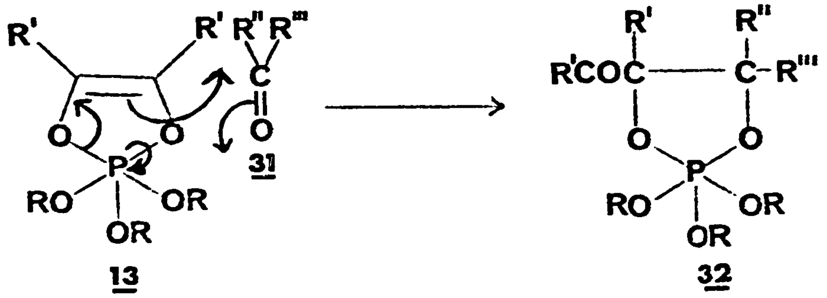
Recently, Bentrude[36] observed a significant stereochemical contrast between thermal and photochemical condensations of biacetyl ($CH_3COCOCH_3$) and 1:1 biacetyltrimethylphosphite adduct (15). The thermal reaction gave 6:1, cis:-trans mixture of the product, whereas, in the photochemical reaction, the cis:trans ratio increased from 13:1 at 15% conversion to 19:1 at 75% conversion.

These differences indicate that the photo and thermal condensations proceed via different mechanisms. The suggested mechanisms are described on page 17. The formation of oxetane intermediate 33 in photocondensation of acetone with the adduct 15 has been observed by nmr at low temperatures (-75°).[36] Studies appeared to be in progress to gain more information on the mechanism of this photocondensation.

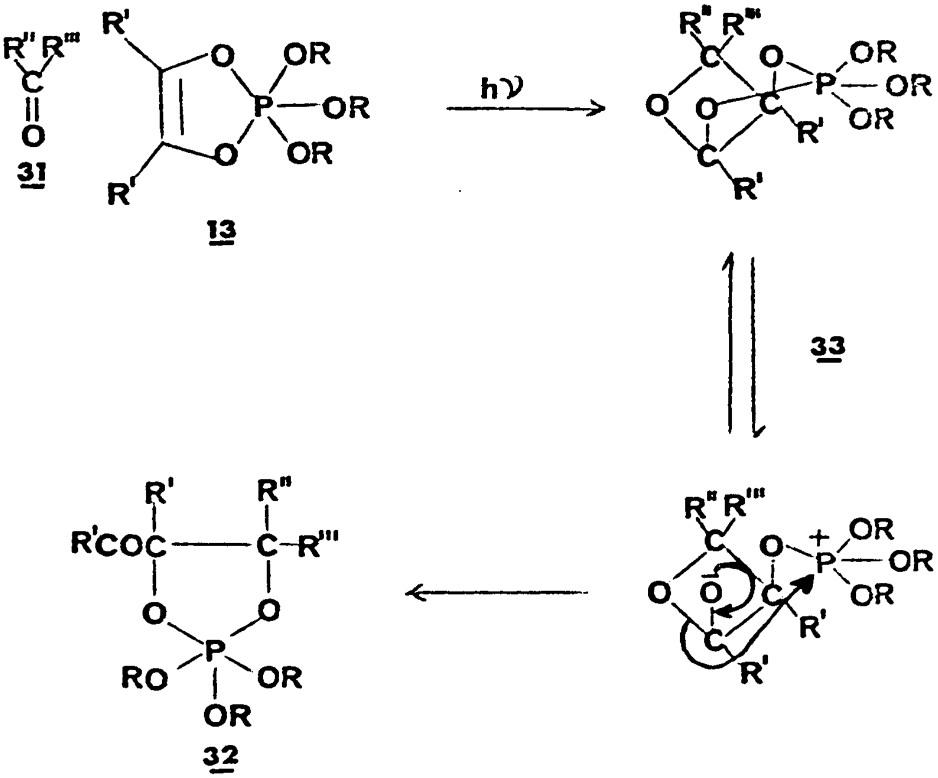
Some reactions of 1:1 biacetyl-trimethylphosphite adduct (15).

The adduct 15 was used to study other synthetically important reactions of 1:1 adducts. These are summarized in Scheme II on page 19. With systems having cumulated double bonds, the nature of the condensation seems to depend on the type of compound. With ketene, the adduct 15 reacted to give the 1,3,2-dioxaphospholane 34 (cf reaction 1.).[37] A concerted mechanism (see page 20) has been suggested for this condensation. The adduct 15 also reacted with two moles of isocyanates (R-N=C=O) to form the 5-acetylhydantoin 35 and tri-

Mechanism of thermal condensation.[34]



Mechanism of photocondensation.[35,36]



methylphosphate (cf reaction 2.).[38] The favoured mechanism is described on page 20. The condensation of <u>15</u> with carbon disulfide led to a substituted 1,2,4,5-tetrathiin <u>36</u> (cf reaction 3.).[39] The mechanistic rationalization for the formation of <u>36</u> is described on page 21. With bromine,[40] acid chlorides[41] etc., the adduct <u>15</u> condensed to form β-ketophosphates <u>37a</u> and <u>37b</u> (cf reactions 4 and 5.). Mechanistically, the reaction is interpreted as involving a phosphonium intermediate <u>38</u> which undergoes an Arbusov reaction to give the products (see page 21).

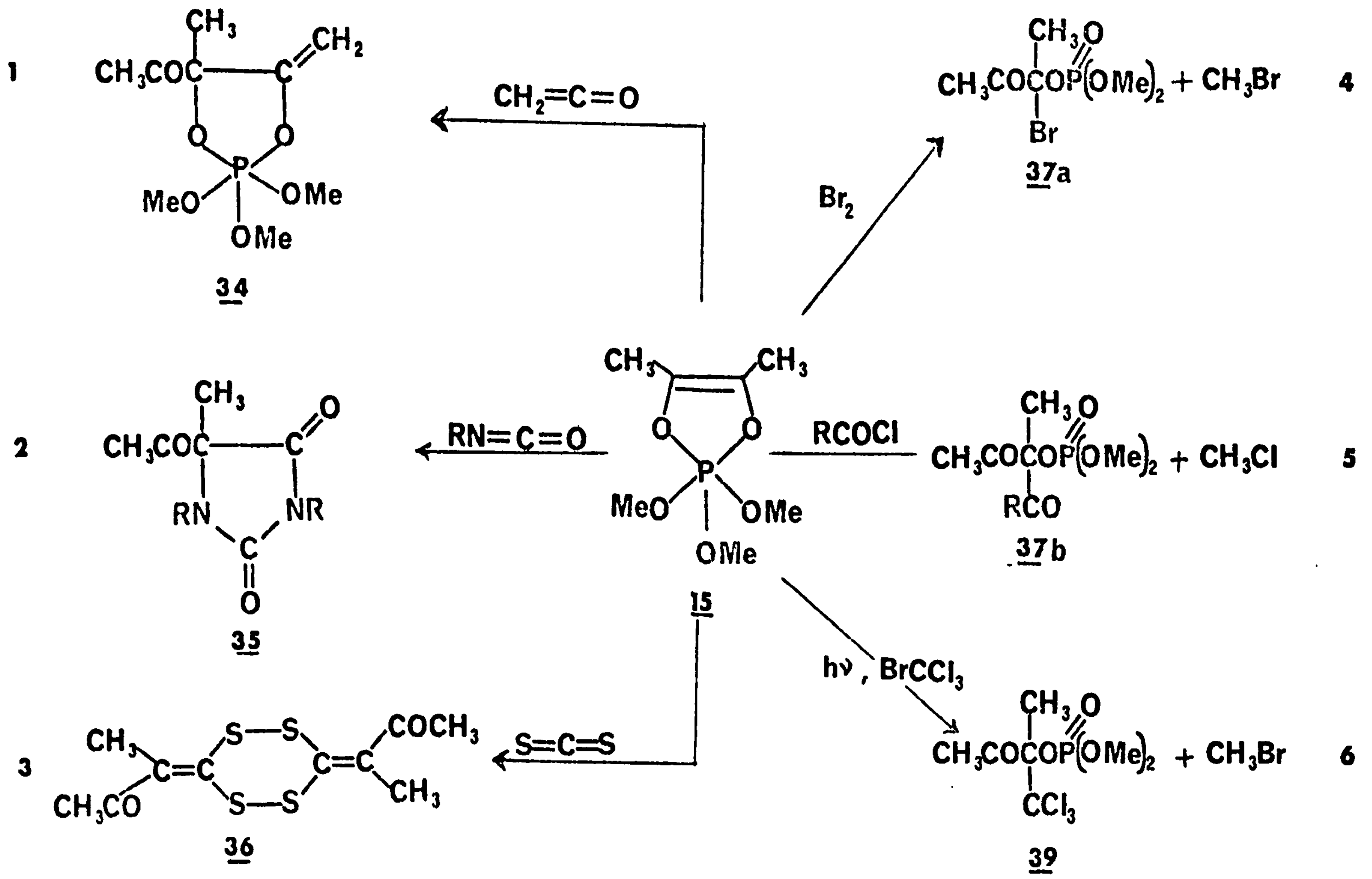
The ability of the adduct <u>15</u> to undergo free radical addition was demonstrated by the light induced reaction with bromotrichloromethane (cf reaction 6.).[42] The major identified product <u>39</u> was isolated in 83% yield. Mechanistically, this reaction is also of interest because of the reasonable explanation in terms of a novel ring opening sequence involving a phosphoranyl radical intermediate <u>41</u>. The most favoured reaction series to explain the formation of the product <u>39</u> is described on page 22.

<u>Preparation and Properties of Sulfenyl Chlorides.</u>

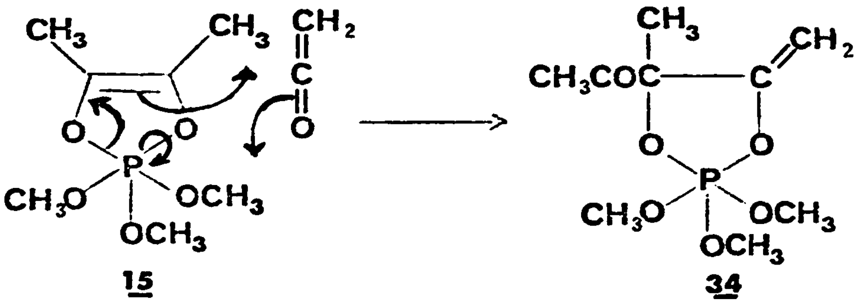
Sulfenyl chlorides are chloro derivatives of sulfenic acids (RSOH) and are represented as RSCl. The group R may be one of a large number of alkyl or aryl groups or some

Scheme II

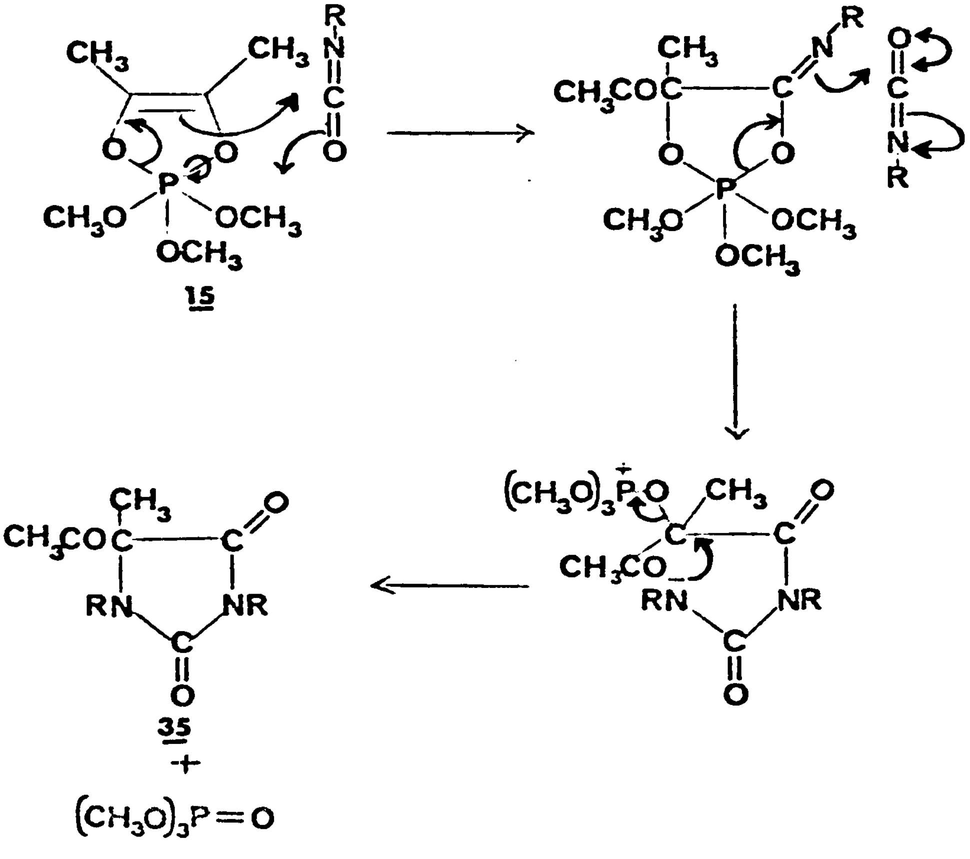
Some Reactions of 1:1 Biacetyl-Trimethyl Phosphite Adduct (15)



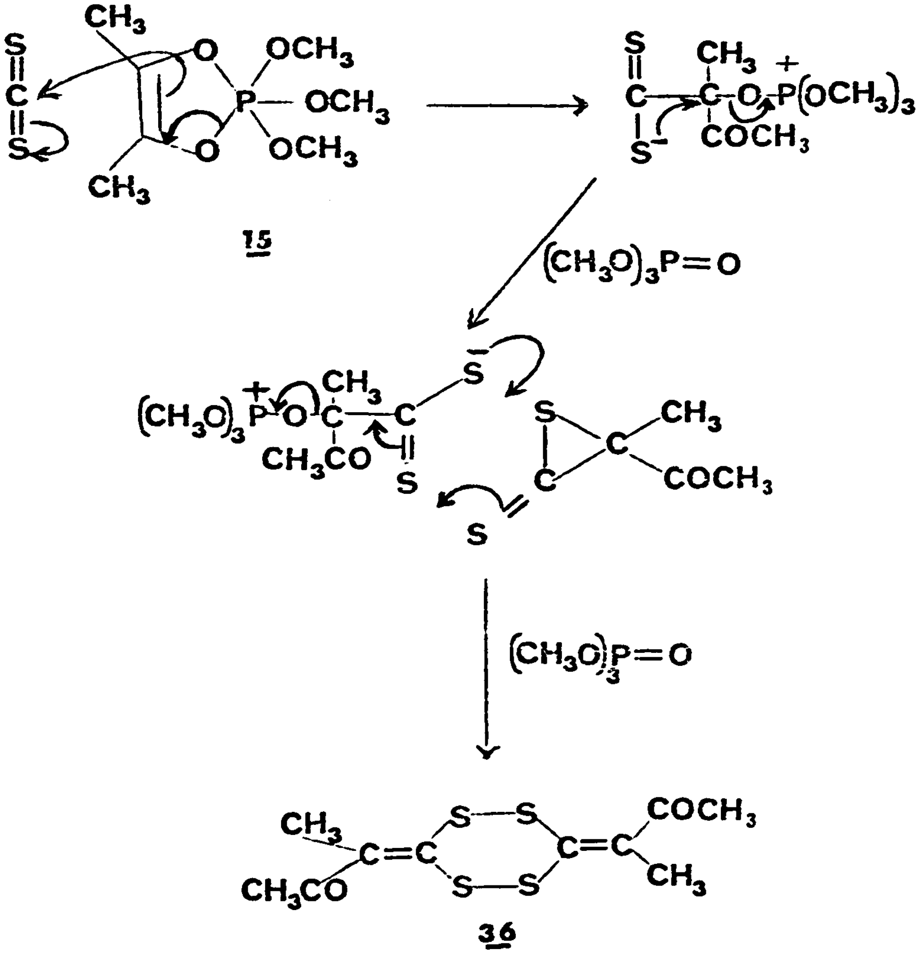
Mechanism of ketene condensation.[37]



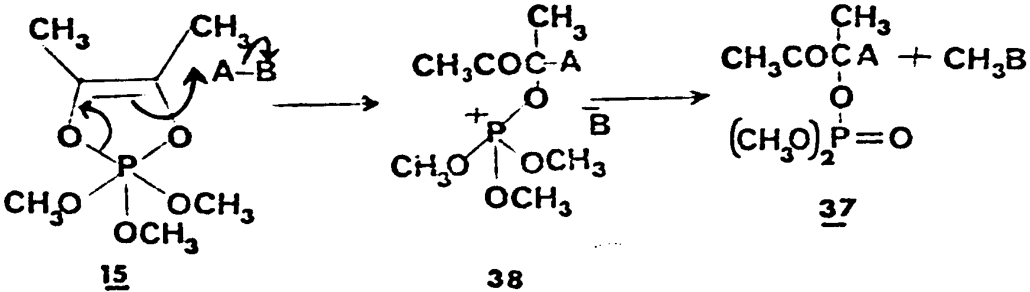
Mechanism of isocyanate condensation.[38]



Mechanism of carbon disulfide condensation.[39]



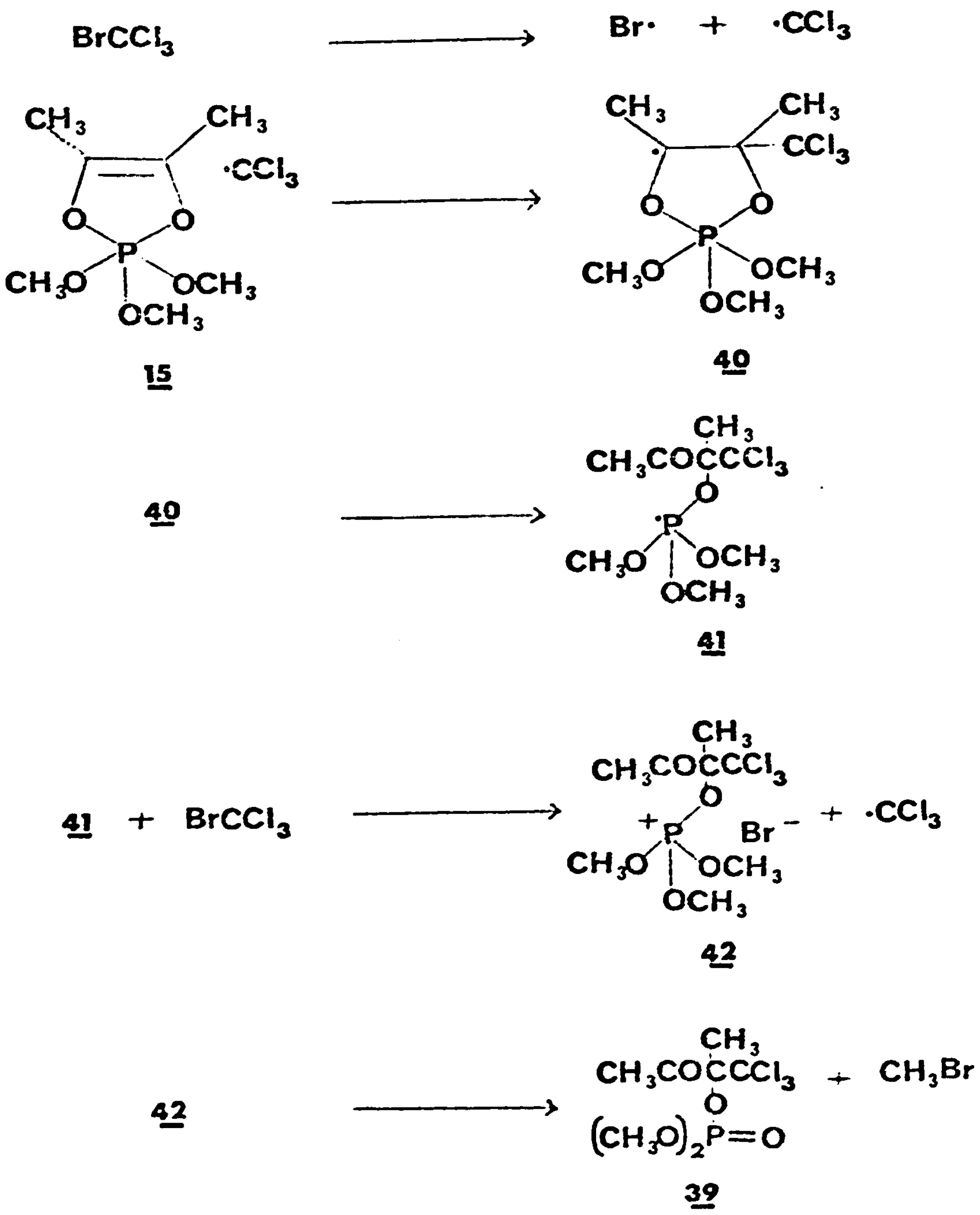
Mechanism of bromine, acid chloride condensation.[40.41]



A = Br or RCO

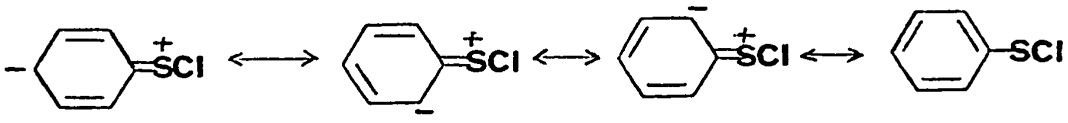
B = Br or Cl

Mechanism of bromotrichloromethane photocondensation.[46]

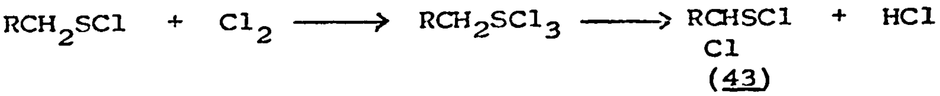


other moiety such as $(RO)_2PO$- etc. Ever since the first fully characterized sulfenyl chloride, trichloromethane sulfenyl chloride (CCl_3SCl) was reported by Rathke[43] in 1870, the number of definitely known aliphatic sulfenyl chlorides has increased steadily. Similarly, the known aromatic examples which were first reported by Zincke[44] during 1909-1918 have also increased manifold. Furthermore, since sulfenyl chlorides are key synthetic intermediates for the preparation of a number of sulfenyl derivatives, the active development of their chemistry led to the preparation of a variety of sulfenyl chlorides. Another reason for this proliferation of sulfenyl chloride chemistry is that the physical and chemical properties of different members of the same group vary widely. For example, chloromethanesulfenyl chloride ($ClCH_2SCl$) which is unstable at room temperature, adds to olefins under ionic conditions,[45] whereas, the stable trichloromethanesulfenyl chloride (CCl_3SCl) adds to olefins under free radical conditions.[46] This makes it desirable to synthesize the different structural types, since varying behaviors may be expected of them.

Different methods for the preparation of sulfenyl chlorides have been reported. Since a number of reviews[47-51] have appeared recently, only important aspects of the preparation of sulfenyl chlorides will be discussed here. Basically, sulfenyl chlorides may be prepared by the action of chlorine or other chlorinating agents on mercaptans, disulfides and certain other compounds containing divalent sulfur. The aromatic sulfenyl chlorides are much more stable than the aliphatic members.[52] The high stability of the aromatic sulfenyl chlorides have been attributed to the resonance stabilization of the aromatic ring and also to the absence of hydrogens α to the sulfur atom.



Aliphatic sulfenyl chlorides with α hydrogens will react with excess chlorine, especially at higher temperatures to give α-chlorosulfenyl chlorides (43) as indicated below.[53]



$$RCH_2SCl + Cl_2 \longrightarrow RCH_2SCl_3 \longrightarrow \underset{Cl}{RCHSCl} + HCl$$

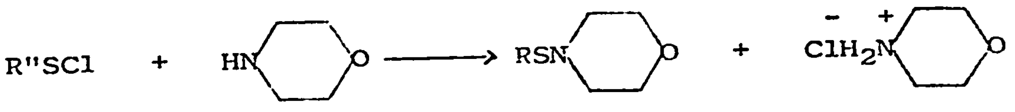
(43)

In the case of aromatic sulfenyl chlorides, excess chlorination leads to the formation of the corresponding sulfurtrichloride ($ArSCl_3$) without further decomposition to other byproducts. The aliphatic sulfenyl chlorides were found to be more stable in solvents of low polarity and at low temperatures. The major decomposition products have been shown to be the disulfide and hydrogen chloride.[52] The purity of the sulfenyl chlorides can be determined by the following methods.

Assay of Sulfenyl Chlorides.

(i). Gas-liquid phase chromatography (Glpc) method.[52]

This technique makes use of the following reaction.



44

A known amount of sulfenyl chloride is converted to the sulfenyl-morpholide 44 by adding it to a benzene solution of excess morpholine containing a known concentration of an internal standard (dibenzylether or diphenyl sulfide). The concentration of the sulfenyl chloride is obtained from the concentration of the sulfenyl-morpholide determined by Glpc analysis.

(ii). Iodometric method.[54]

This method is based on the oxidation of iodide ion by the sulfenyl chloride and a subsequent titration of the free iodine by thiosulfate.

$$2\ RSCl \quad + \quad 2\ KI \longrightarrow RSSR \quad + \quad 2\ KCl \quad + \quad I_2$$

The limitation of this method is that other oxidising agents will interfere with the results.

(iii). NMR method.

In our studies on the chlorinolysis of aliphatic disulfides, we observed a significant change (0.4-0.5τ) in the chemical shift of the protons α to the sulfur atom as the sulfenyl chloride is formed. This change in the chemical shift is used to assess the amount of sulfenyl chloride formed during chlorinolysis and the technique will be discussed in detail in the next section.

Sulfenyl chlorides from mercaptans (RSH).

When chlorine is used the mercaptan is first converted into the disulfide which is then chlorinolysed to give the sulfenyl chloride.[48] The formation of disulfide is exothermic and nearly all of the mercaptan is converted into the disulfide before the second reaction is initiated.

$$2\,RSH + Cl_2 \longrightarrow RSSR + 2\,HCl$$

$$RSSR + Cl_2 \longrightarrow 2\,RSCl$$

$$2\,RSH + 2Cl_2 \longrightarrow 2\,RSCl + 2\,HCl$$

Hydrogen chloride is formed as a byproduct and may cause side reactions. This method works well for aromatic sulfenyl chlorides. However, for aliphatic sulfenyl chlorides extreme care should be taken to prevent any side reactions, such as α-chlorination etc. In general, aliphatic sulfenyl chlorides are prepared at very low temperatures (-20° to -30°) in non polar solvents.

A process for the preparation of sulfenyl chlorides by the action of N-chlorosuccinimide and other N-chloro compounds on mercaptans has been patented and claims to be useful for preparing aromatic, benzylic,carbomethoxymethane, and substituted cysteine sulfenyl chlorides.[55]

Sulfuryl chloride has also been used to prepare sulfenyl chlorides from mercaptans. For example, trityl mercaptan reacts vigourously with sulfuryl chloride to form the sulfenyl chloride 45 in quantitative yield.[56]

$$(C_6H_5)_3CSH + SO_2Cl_2 \longrightarrow \underset{\underline{45}}{(C_6H_5)_3CSCl} + HCl + SO_2$$

Sulfenyl chlorides from disulfides (RSSR).

Several sulfenyl chlorides have been prepared by the chlorinolysis of the corresponding disulfides.[48]

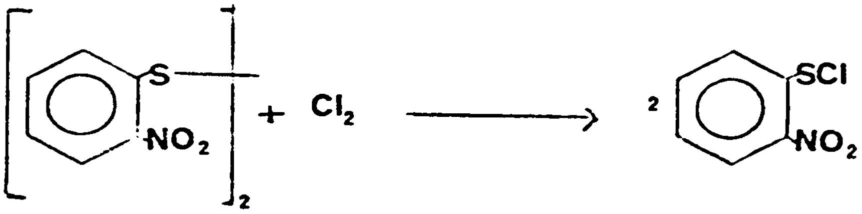
$$RSSR + Cl_2 \longrightarrow 2RSCl$$

This is essentially the second step in the preparation of sulfenyl chlorides from mercaptans and chlorine. However, hydrogen chloride which is a side product in the chlorination of mercaptans is eliminated in this case. This leads to a considerably pure sulfenyl chloride if certain precautions are taken. The reaction conditions employed in the chlorinolysis depend on the nature of the disulfide used. The chlorinolysis of certain aliphatic disulfides with α-hydrogens must be done at very low temperatures (-20° to -30°) in non polar solvents to prevent any α-chlorination. Whereas, in tertiary alkyl and benzyl disulfides chlorinolysis at low temperature leads to cleavage at S-C bond rather than at S-S bond. However, at higher temperatures S-S bond cleavage occurs giving the sulfenyl chlorides. For tertiary butyl disulfide the course of the chlorinolysis at different temperatures are as follows.[57]

$$(CH_3)_3CSSC(CH_3)_3 + Cl_2 \xrightarrow{0^\circ} (CH_3)_3CSSCl + (CH_3)_3CCl$$

$$(CH_3)_3CSSC(CH_3)_3 + Cl_2 \xrightarrow{32^\circ} 2(CH_3)_3CSCl$$

Certain aromatic disulfides, on the other hand require very drastic conditions for chlorinolysis. For example, the chlorinolysis of di-o-nitrophenyl disulfide was effected by passing chlorine into a suspension of the disulfide in carbon tetrachloride at $50-60^\circ$ in the presence of catalytic amounts of iodine.[58]



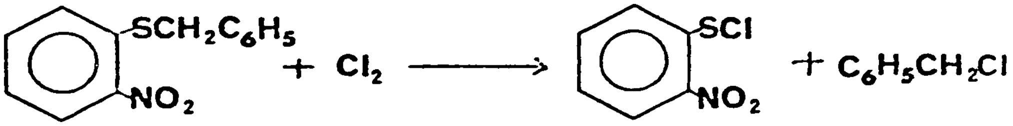
Sulfuryl chloride has been used for the preparation of sulfenyl chlorides from disulfides. This method has an advantage in that the amount of sulfuryl chloride can be weighed accurately. Benzenesulfenyl chloride is obtained in good yield by the action of sulfuryl chloride on phenyl disulfide.[59]

$$C_6H_5SSC_6H_5 + SO_2Cl_2 \longrightarrow 2C_6H_5SCl + SO_2$$

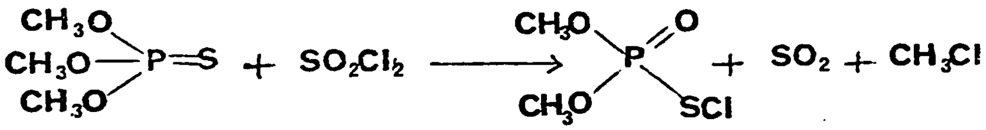
The other product of the reaction is gaseous sulfur dioxide which can be removed very easily.

Sulfenyl chlorides from other divalent sulfur compounds.

Sulfenyl chlorides can be prepared by selective cleavage of certain C-S bonds in sulfides by either chlorine or sulfuryl chloride. Benzyl,[60] tertiary butyl[61] sulfides have been cleaved by halogens to form sulfenyl halides. For example, benzyl-o-nitrophenyl sulfide undergoes benzylic cleavage on chlorinolysis to give o-nitrophenylsulfenyl chloride and benzyl chloride.[60]



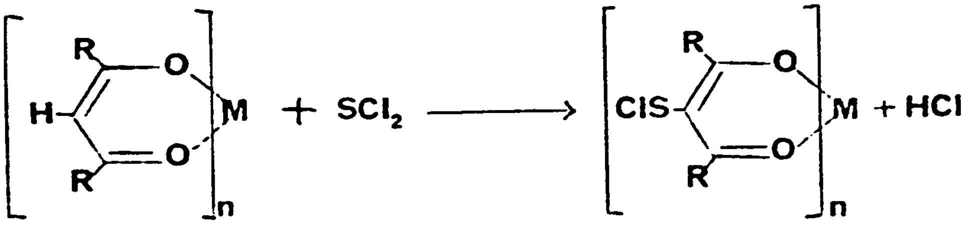
Divalent double bonded sulfur compounds have been used in the preparation of sulfenyl chlorides. O,O'-Dimethylphosphorylsulfenyl chloride (<u>46</u>) is prepared by the action of sulfuryl chloride on trimethylphosphorothionate.[62]



46

Trichloromethanesulfenyl chloride can be obtained in good yield by chlorination of thiophosgene.[63]

Sulfur dichloride (SCl_2) undergoes electrophilic substitution reactions with a variety of substrates and this property is utilised for the preparation of sulfenyl chlorides. In 1961, Kluiber[64] prepared some previously unknown chelate sulfenyl chlorides <u>47</u> by the action of sulfur dichloride on metal chelates.



47

Chapter II

Results and Discussion. Part I

Results and Discussion Part I.

Reaction of 1:1 dicarbonyl-phosphine adducts with sulfenyl chlorides.

The reactivity of 1:1 dicarbonyl-phosphine adducts towards electrophilic centres is attested by their ready condensation with bromine,[40] carbonyl compounds,[34] acid chlorides,[41] isocyanates[38] and ketene.[37] Although several electrophilic substrates have been used, up to date no reaction with a sulfur electrophile has been reported. This prompted us to explore the behaviour of 1:1 dicarbonyl-phosphine adducts towards electrophilic sulfur compounds. We selected sulfenyl chlorides in our investigation because these were known to be very reactive electrophiles under certain conditions.[50a] It was found that the 1:1 dicarbonyl-phosphine adducts condensed exothermically with a variety of sulfenyl chlorides. The nature and the number of final products depend on the type of 1:1 adduct used. These aspects are discussed in detail in the following section.

Preparation of 1:1 diketone-phosphine adducts.

In this investigation, the following two diketones were used.

(i). benzil (PhCOCOPh), a typical aromatic diketone.

(ii). biacetyl ($CH_3COCOCH_3$), a typical aliphatic diketone.

The following two trivalent phosphorus compounds with different hetero atoms adjacent to phosphorus were selected for adduct formation.

(i). trimethylphosphite $(CH_3O)_3P$: .

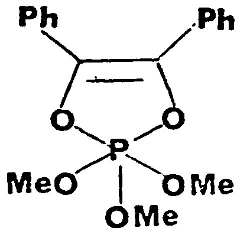
(ii). tris(dimethylamino)phosphine $(Me_2N)_3P$: (19).

Of the four possible 1:1 adducts, the following three were prepared according to reported procedures.[20a, 28]

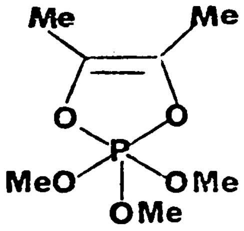
(i). 1:1 benzil-trimethylphosphite adduct (23).

(ii). 1:1 benzil-tris(dimethylamino)phosphine adduct (25).

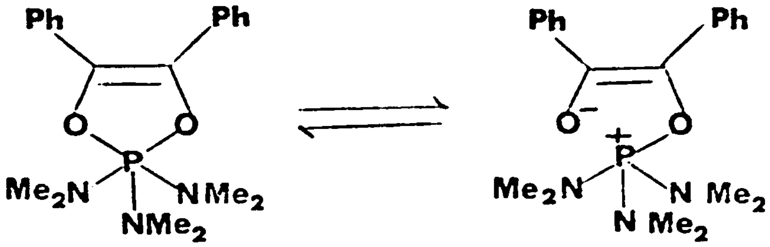
(iii). 1:1 biacetyl-trimethylphosphite adduct (15).



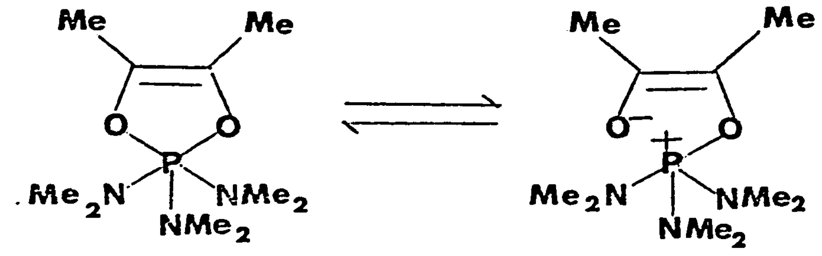
23



15



25



48

In our hands the preparation of the 1:1 biacetyl-tris(dimethylamino)phosphine adduct (48) was not successful. A black tarry product was obtained. For the preparation of the other three 1:1 adducts, the literature procedures were somewhat different for each adduct, however, in all of these reactions oxygen and water were excluded by use of a dry nitrogen atmosphere. Benzil-trimethylphosphite adduct (23) was prepared by mixing the phosphite with benzil. No cooling was necessary even though the reaction was exothermic.[20a] Whereas, for the preparation of the biacetyl-trimethylphosphite adduct (15), external cooling was employed in the initial stages of the reaction. Finally, the benzil-tris(dimethylamino)phosphine adduct (25) was prepared by adding the aminophosphine 19 to benzil dissolved in a suitable solvent (hexane or methylene chloride) with external cooling.[28] In this case, the reaction was moderated considerably by both dilution and cooling. Tris(dimethylamino)phosphine (19) is a very reactive phosphine and adduct formation is complete within a few minutes. In addition, this adduct is not very stable at elevated temperatures. Further details of the preparation of these compounds are given in the experimental section.

Preparation of sulfenyl chlorides.

A variety of sulfenyl chlorides were used in this study and some of them were prepared by modification of reported methods. New procedures were developed for others.

(i). Aromatic sulfenyl chlorides.

Benzene (49), p-chlorobenzene (50), and p-toluene (51) sulfenyl chlorides were prepared by treating the corresponding thiols with N-chlorosuccinimide in benzene.[55] Succinimide was removed by filtration and the sulfenyl chlorides were isolated after solvent removal by distillation under reduced pressure. The sulfenyl chlorides were obtained in good yield.[**]

(ii). Aliphatic sulfenyl chlorides.

The following sulfenyl chlorides were prepared by chlorinolysis of their corresponding disulfides.

(a). ethanesulfenyl chloride (CH_3CH_2SCl) (52).

(b). benzylsulfenyl chloride ($C_6H_5CH_2SCl$) (53).

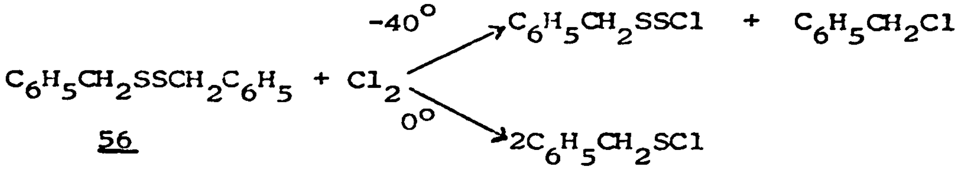
(c). carbomethoxymethanesulfenyl chloride ($CH_3O_2CCH_2SCl$) (54).

[**] See experimental section.

Ethanesulfenyl chloride (52) was best prepared by passing the theoretical amount of chlorine over neat ethyl disulfide (55) at -30°. The experimental procedure adopted was similar to that reported by Douglass[65] for methane sulfenyl chloride. The apparatus used for the chlorinolysis of disulfides is described in fig. 1. (on page 36).

$$\underset{\underline{55}}{CH_3CH_2SSCH_2CH_3} + Cl_2 \xrightarrow{-30^{\circ}} \underset{\underline{54}}{2CH_3CH_2SCl}$$

Even though benzyl disulfide (56) undergoes C-S bond cleavage at low temperature (-40°),[53] it was found that at 0° in carbon tetrachloride only S-S cleavage occurred giving benzyl sulfenyl chloride (53).



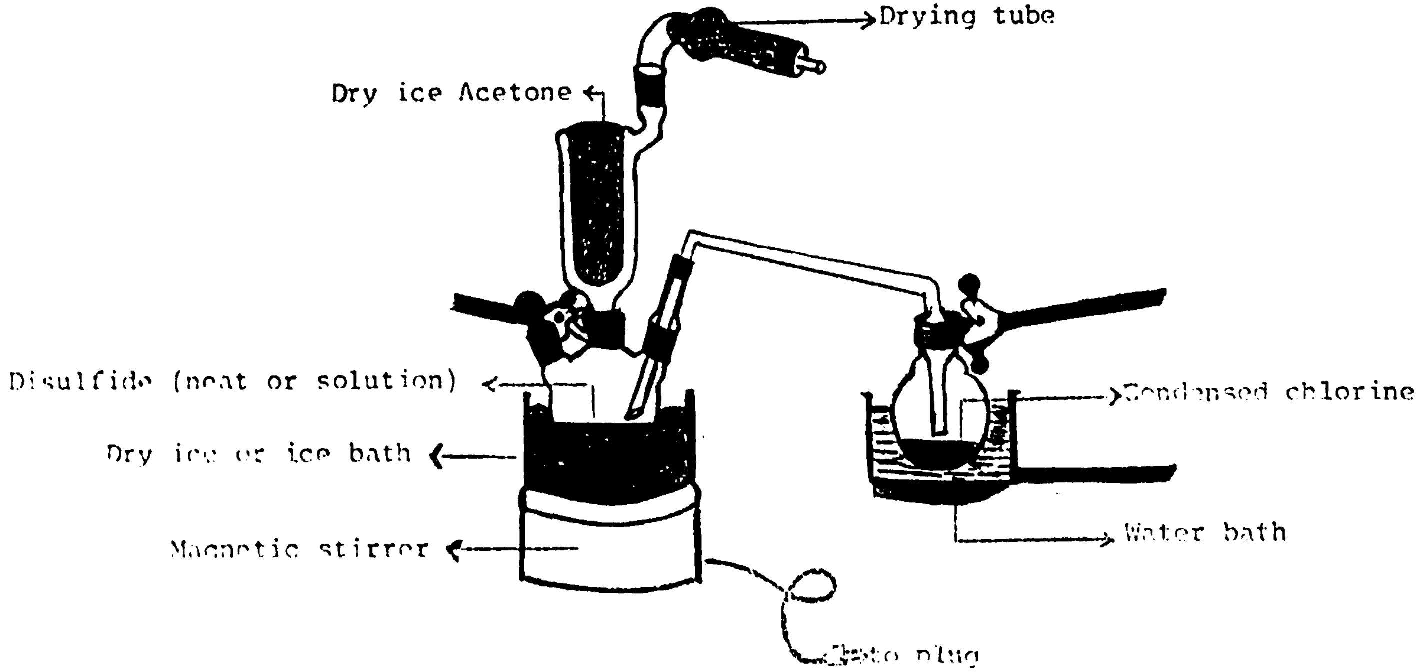
$$\underset{\underline{56}}{C_6H_5CH_2SSCH_2C_6H_5} + Cl_2 \xrightarrow{-40^{\circ}} C_6H_5CH_2SSCl + C_6H_5CH_2Cl$$

$$\underset{\underline{56}}{C_6H_5CH_2SSCH_2C_6H_5} + Cl_2 \xrightarrow{0^{\circ}} \underset{\underline{53}}{2C_6H_5CH_2SCl}$$

Similarly, carbomethoxymethyl disulfide (57) gave the sulfenyl chloride 54 on chlorinolysis in carbon tetrachloride at 0°.

$$\underset{\underline{57}}{CH_3O_2CCH_2SSCH_2CO_2CH_3} + Cl_2 \xrightarrow{0^{\circ}} \underset{\underline{54}}{2CH_3O_2CCH_2SCl}$$

Figure 1: Apparatus for Chlorinolysis of Disulfides



The chlorinolysis of the disulfides were followed by nmr at different intervals. This technique was also used to assess the purity of sulfenyl chlorides. As the sulfenyl chloride was formed a significant change (0.4 - 0.5 τ) was observed in the chemical shift of protons α to the sulfur atom. In the case of ethyl disulfide (<u>55</u>), as the methylene quartet of the disulfide at 7.30 τ disappeared, a quartet at 6.90τ due to the methylene protons of ethane sulfenyl chloride (<u>52</u>) appeared. The complete disappearance of the quartet at 7.30τ indicated the completion of chlorinolysis. Similar downfield shift (with respect to external TMS) in the chemical shifts of the α-methylene protons in benzyl (<u>56</u>) and carbomethoxymethyl (<u>57</u>) disulfides were observed. These are summarized in table 2 on page 38. The sequence of nmr runs at different stages during the chlorinolysis of carbomethoxymethyl disulfide (<u>57</u>) is illustrated in fig. 2 on page 39. This method has several advantages over the other methods (see page 25) used to assay sulfenyl chlorides.

(a). the assay of sulfenyl chlorides is rapid and convenient.

(b). the sample is not destroyed whereas in the other two chemical methods no recovery is possible.

(c). very labile sulfenyl chlorides (eg. aliphatic sulfenyl chlorides) can be analysed by use of a low temperature nmr spectrum.

Table 2

Chemical shifts of methylene protons α to suflur in some disulfides and sulfenyl chlorides.

Disulfide	Chemical shift (τ)	Sulfenyl chloride	Chemical shift (τ)
$(CH_3\underline{CH_2}S)_2$, 55	7.30	$CH_3\underline{CH_2}SCl$, 52	6.90
$(C_6H_5\underline{CH_2}S)_2$, 56	6.50	$C_6H_5\underline{CH_2}SCl$, 53	5.73
$(CH_3O_2C\underline{CH_2}S)_2$, 57	6.33	$CH_3O_2C\underline{CH_2}SCl$, 54	5.97

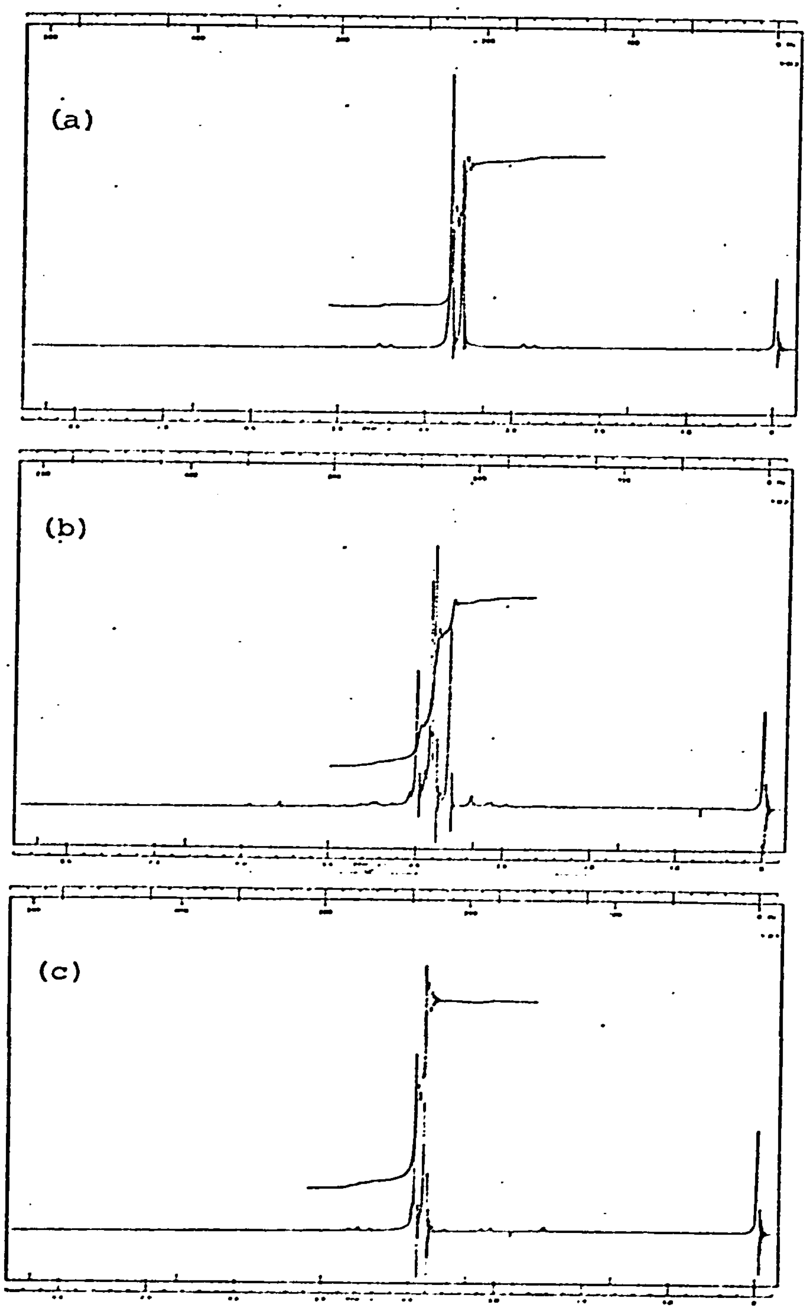
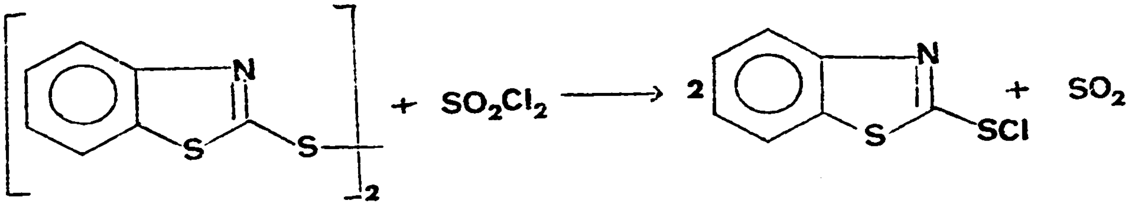


Figure 2: NMR data on the chlorinolysis of carbomethoxymethyl disulfide (57).

(a) The disulfide 57. (b) Partially chlorinolysed 57. (c) Carbomethoxymethane sulfenyl chloride (54).

(iii). 2-Benzothiazolesulfenyl chloride (58).

The sulfenyl chloride 58 was prepared by the action of sulfuryl chloride on 2,2'-dithiobis(benzothiazole) (59) in methylene chloride at room temperature.



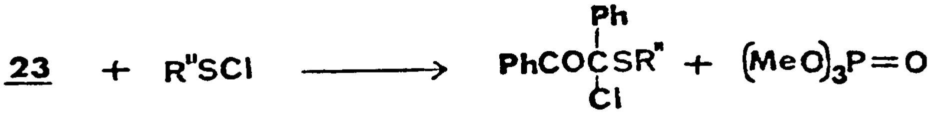
59

58

In our hands, the chlorinolysis of the above disulfide (59) failed to produce pure sulfenyl chloride 58, although this process has been claimed in patents.[66]

Benzil-trimethylphosphite adduct-sulfenyl chloride condensation.

Benzil-trimethylphosphite adduct (23) reacted with a variety of sulfenyl chlorides to give α-chloro-β-ketosulfides 60 and trimethylphosphate according to the following equation.**



$$\underline{\mathbf{23}} + R''SCl \longrightarrow PhCO\overset{Ph}{\underset{Cl}{C}}SR'' + (MeO)_3P{=}O$$

60

**A preliminary account of this work has been published: D.N. Harpp and P. Mathiaparanam, Tetrahedron Letters, 2089 (1970).

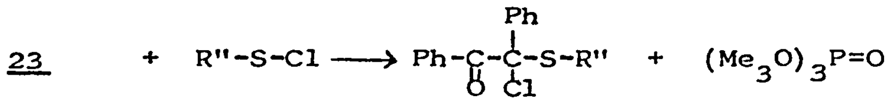
The yields, melting points and nmr data of the α-chloro-β-ketosulfides 60 are summarized in table 3 on page 42. The adduct 23 was prepared in situ and dissolved in a suitable solvent(carbon tetrachloride, benzene or methylene chloride). A stoichiometric amount of sulfenyl chloride was added slowly to the cooled solution of 23. As the addition continued, the deep red colour of the sulfenyl chloride disappeared with evolution of heat. At the end of the addition only a slight tinge of red colour remained. This colour change was used to follow all the reactions studied. The progress of the reaction can also be monitored by nmr if carbon tetrachloride is used as a solvent. In the nmr, as the addition of sulfenyl chloride progressed, the doublet at 6.35 τ (J_{HP} = 13HZ) due to the methoxyl protons of the adduct 23 diminished in intensity as the doublet at 6.30 τ (J_{HP} = 13HZ) due to the protons in trimethyl phosphate appeared with increasing intensity. Once the addition of sulfenyl chloride was over, the doublet at 6.35 τ had disappeared completely. The trimethyl phosphate was identified by gas chromatography (see experimental section) with an authentic commercial sample. The formation of products appeared to be quantitative, although the isolated yields were somewhat lower.

The infrared spectra of the α-chloro-β-ketosulfides 60 showed the carbonyl band near 1685 cm^{-1}. The mass spectra generally revealed a weak parent ion M^+, along with $(M-Cl)^+$,

$C_6H_5CO^+$ and $R''S^+$ as the major peaks. The fragmentation patterns of the chloro ketosulfides 60 will be discussed in detail on page 70. The methylene protons α to the sulfur are observed to be diastereomeric[67] even though they are separated from the asymmetric centre by a sulfur atom.

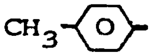
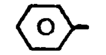
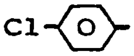
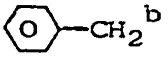
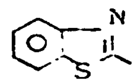
Table 3

Physical and nmr data of α-benzoyl-α-chlorobenzyl sulfides (60).



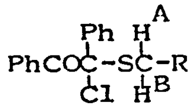
$$\underline{23} + R''\text{-}S\text{-}Cl \longrightarrow Ph\text{-}\underset{\underset{O}{\|}}{C}\text{-}\overset{\overset{Ph}{|}}{\underset{\underset{Cl}{|}}{C}}\text{-}S\text{-}R'' + (Me_3O)_3P{=}O$$

60

R'' in 60	mp of 60 (°C)	yield %	NMR DATA
 61	118-120	80	2.10-3.20(14H,m), 7.72(3H,s)
 62	113-115	82	2.10-3.00(m)
 63	122-124	83	2.10-3.00(m)
 [b] 64	109-110	80	2.0-3.0(15H,m),6.15(2H,AB, J = 12HZ)
CH_3CH_2-[b] 65	oil	60	1.80-3.10(10H,m),7.30-7.90 (2H,m),8.60-9.20(3H,m)
$CH_3O_2CCH_2$-[b] 66	65-67	75	1.90-2.65(10H,m),6.34(3H,s), 6.53(2H,AB, J = 16HZ)
 67	135-136	93	1.80-2.90(m)

[a] Satisfactory elemental analyses were obtained for these compounds.

[b] Analyses were performed on the corresponding benzyloxy-keto-sulfides.



$$\mathrm{PhCO}\overset{\overset{\displaystyle \mathrm{Ph}}{|}}{\underset{\underset{\displaystyle \mathrm{Cl}}{|}}{\mathrm{C}}}\mathrm{-S}\overset{\overset{\displaystyle \mathrm{H}^{A}}{|}}{\underset{\underset{\displaystyle \mathrm{H}^{B}}{|}}{\mathrm{C}}}\mathrm{-R}$$

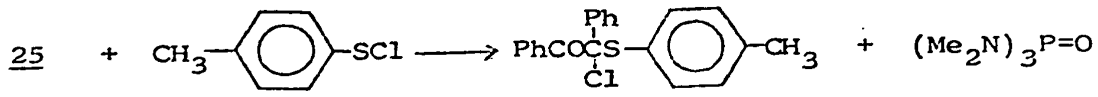
68

The methylene protons of α-chloro-β-ketosulfide 65 from the ethanesulfenyl chloride (52) condensation showed a complex multiplet instead of a quartet, thus indicating ABX_3 rather than an A_2X_3 splitting. In the case of benzyl (64) and carbomethoxymethyl (66) chloro ketosulfides, AB quartets with coupling constants 12 and 16 HZ respectively were observed. The values of the coupling constants indicated that the AB quartet was derived through vicinal coupling.[68]

The chloro-ketosulfides (61, 62, 63 and 67) from aromatic and 2-benzothiazolesulfenyl chlorides were found to be reasonably stable. They can be stored at 0° without any appreciable decomposition for several months. The benzyl (64) and carbomethoxymethyl (66) analogs showed signs of decomposition after two weeks at 0°. The chloro-ketosulfide 65 from ethanesulfenyl chloride is an oil and it can be stored in dry ice for one day without any decomposition (checked by nmr). Satisfactory analyses were obtained for the stable (aromatic and 2-benzothiazole)chloro-ketosulfides whereas the aliphatic members were characterized as their benzyloxy-ketosulfide derivatives.

Benzil-tris(dimethylamino)phosphine adduct-sulfenyl chloride condensation.

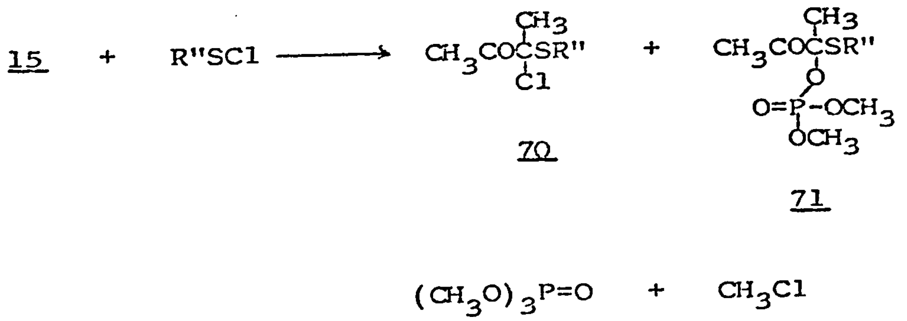
Benzil-tris(dimethylamino)phosphine adduct (25) was prepared in situ in methylene chloride[28] and a stoichiometric amount of p-toluenesulfenyl chloride (51) was added. An exothermic reaction occurred and gas chromatographic analysis of the reaction mixture indicated the presence of hexamethyl phosphoramide (69) and α-benzoyl-α-chlorobenzyl-p-tolylsulfide (61) (checked with the retention times of authentic samples). In addition, the chloro-ketosulfide 61 was isolated and was shown to be identical with an authentic sample (prepared from the adduct 23 and 51) by mixed melting point and ir. Thus, the condensation can be represented as follows.



51 61 69

Biacetyl-trimethylphosphite adduct-sulfenyl chloride condensation.

Biacetyl-trimethylphosphite adduct (15) reacted with sulfenyl chlorides to give the α-chloro- β-ketosulfides 70, trimethylphosphate, β-ketophosphates 71 and methyl chloride according to the following equation.



The reaction was carried out in carbon tetrachloride with benzene and ethanesulfenyl chlorides. The reaction mixture was analysed by nmr and the results are tabulated below.

Table 4

Yields of α-chloro-β-ketosulfide (70) and β-ketophosphate (71) in the 1:1 biacetyl-trimethylphosphite adduct-sulfenyl-chloride condensation.

Sulfenyl chloride R''	Yield (%) α-chloro-β-ketosulfide	β-keto phosphate
C_6H_5-	93 72	7 73
C_2H_5-	72 74	28 75

The changes in nmr spectra before and after the addition of benzene and ethanesulfenyl chlorides are illustred in figs. 3 & 4 respectively in the following pages. In both cases, the singlet at 7.00 τ was identified as the methyl signal of methyl chloride (reported value 6.95 τ).[68] On evaporation of the solvent at room temperature this singlet disappeared showing that it was probably due to a volatile product. The doublet at 6.30 τ (J_{PH} = 12HZ) was due to trimethyl phosphate by comparison with an authentic sample. Also, addition of few drops of trimethylphosphate to the reaction mixture increased the intensity of this doublet with respect to other peaks.

Considering the reaction between benzenesulfenyl chloride (49) and the 1:1 biacetyl-trimethylphosphite adduct (15) in detail (cf fig. 3), the singlets at 8.32 and 7.63 τ are due to the CH_3- and CH_3CO- protons of the α-chloro-β-ketosulfide 72 by comparison with an authentic sample (prepared from azibutanone and benzenesulfenyl chloride as indicated below).

$$\mathrm{CH_3CO\overset{CH_3}{C}N_2 + C_6H_5SCl \longrightarrow CH_3CO\underset{Cl}{\overset{CH_3}{C}}SC_6H_5 + N_2}$$

49 72

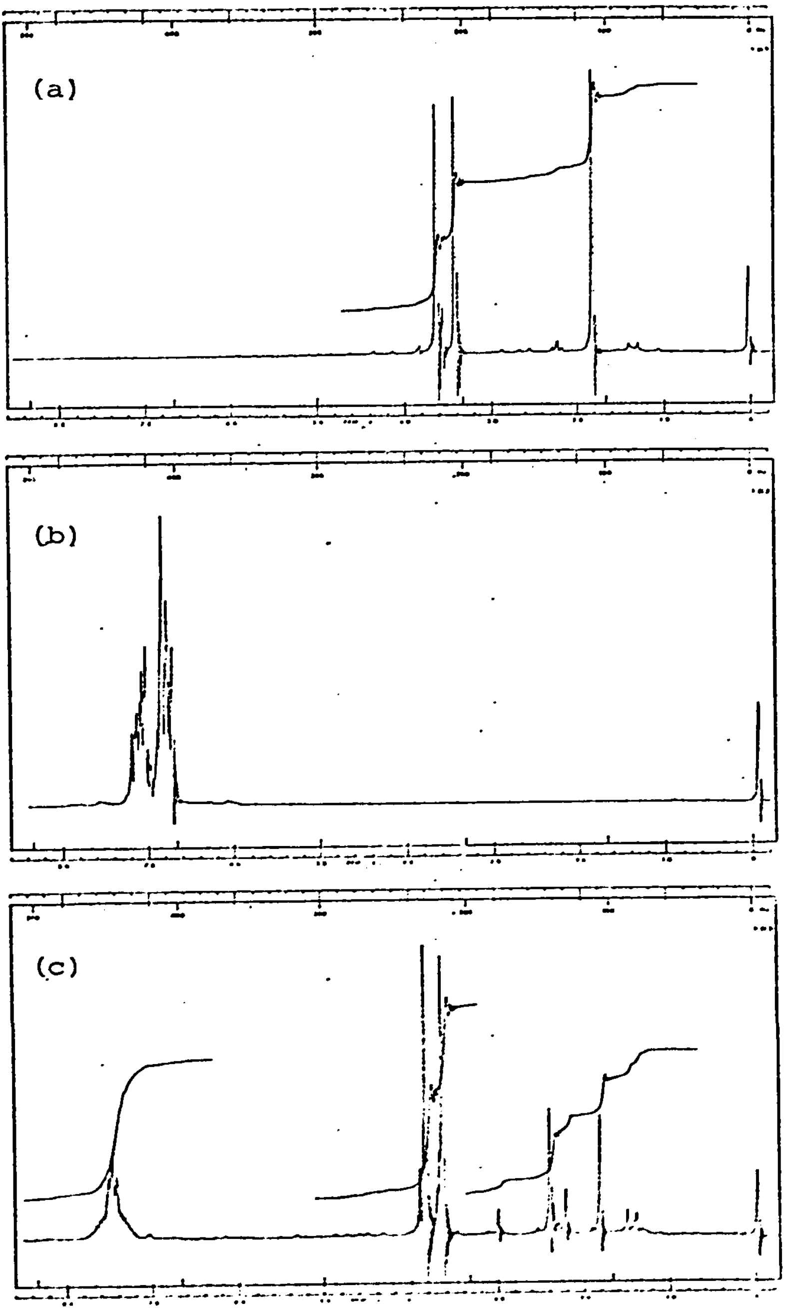


Figure 3: NMR data on the reaction of 1:1-biacetyl-trimethyl phosphite adduct (15) with benzenesulfenyl chloride (49).

(a) The adduct 15 (b) benzenesulfenyl chloride(49) (c) 15 + 49.

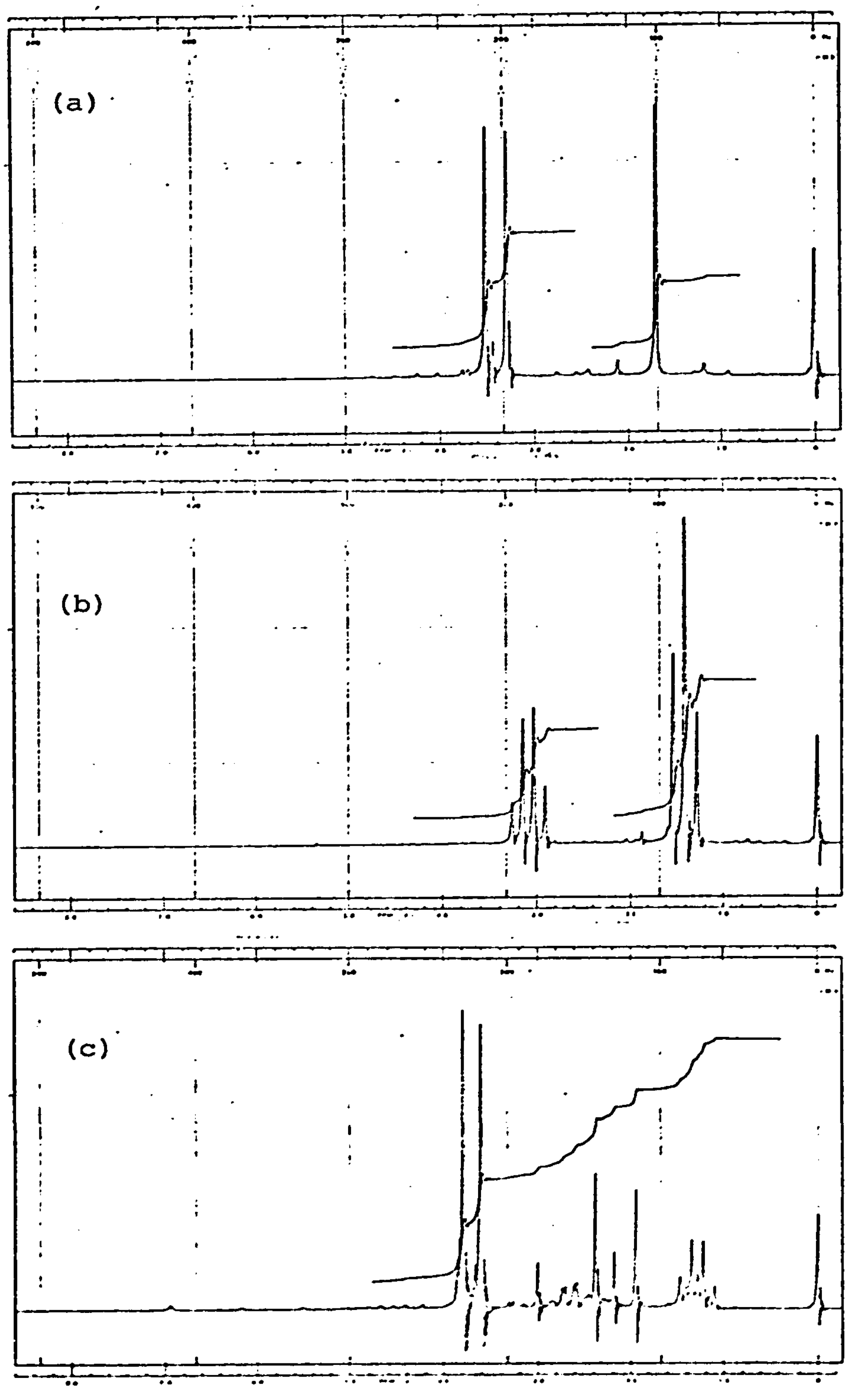


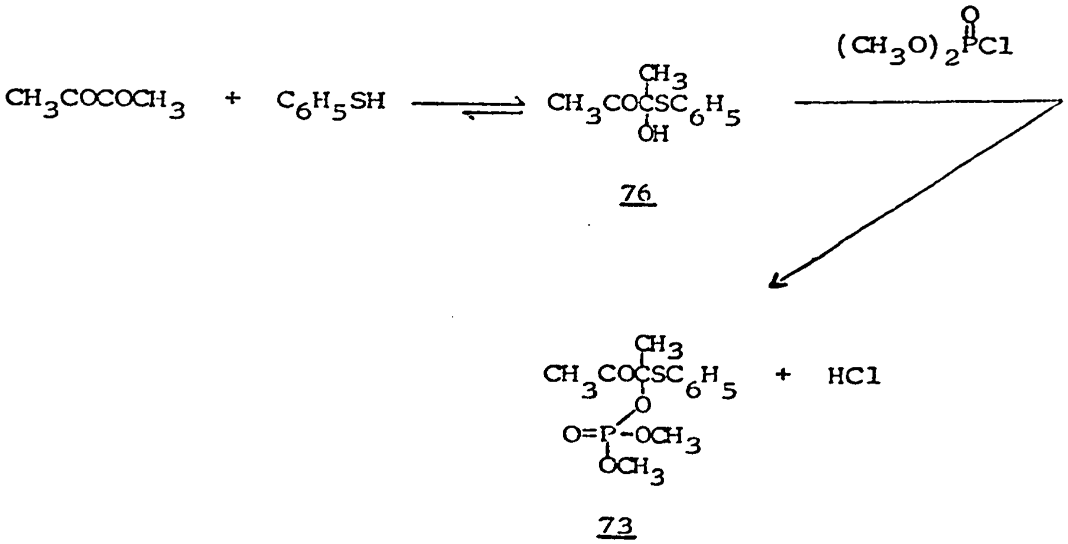
Figure 4: NMR data on the reaction of 1:1-biacetyl-trimethyl phosphite adduct (15) with ethane sulfenyl chloride (52).

(a) The adduct 15 (b) Ethanesulfenyl chloride 52
(c) 15 + 52.

The singlets at 7.80 and 7.67 τ and the doublet at 6.22 τ (J_{PH} = 12HZ) are assigned to the CH_3-, CH_3CO- and $-OCH_3$ protons of the β-ketophosphate <u>73</u>. All attempts towards the unequivocal synthesis of the β-ketophosphate <u>73</u> were unsuccessful. The following synthetic schemes were tried.

<u>Scheme III</u>

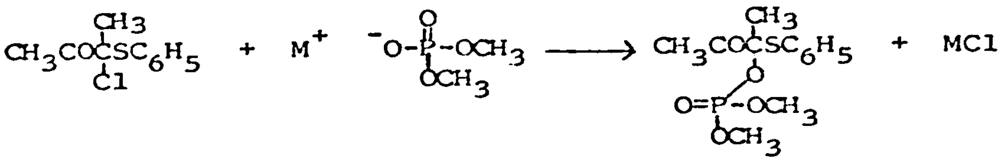
<u>Attempted synthesis of α-acetyl- α-phenylthioethyl-dimethyl-phosphate(73). Method I.</u>



This scheme is based on the reaction between thiols and carbonyl compounds. It has been shown that thiols react with carbonyl compounds to form an equilibrium mixture containing mainly α-hydroxy sulfides.[70] In this case, the reaction was extended to α-diketones. Biacetyl reacted exothermically with benzenethiol to form an equilibrium mixture containing 80% of the α-hydroxy-β-ketosulfide 76 (analysed by nmr). When dimethylphosphorochloridate was added to this mixture at room temperature, no reaction was observed after 2 days. On heating, extensive decomposition occurred. In another attempt, the above procedure was repeated in the presence of pyridine as hydrogen chloride scavenger. The analysis of the reaction mixture by nmr indicated the presence of biacetyl as the main product. Thus, pyridine seems to shift the equilibrium towards biacetyl by removing the acidic benzenethiol as a pyridinium salt.

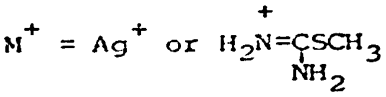
Scheme IV

Attempted synthesis of α-acetyl-α-phenylthioethyl-dimethylphosphate (73). Method II.



$$CH_3CO\underset{Cl}{\overset{CH_3}{C}}SC_6H_5 + M^+ \; {}^-O-\overset{O}{\overset{\|}{P}}(OCH_3)-OCH_3 \longrightarrow CH_3CO\overset{CH_3}{C}(O-P(=O)(OCH_3)OCH_3)SC_6H_5 + MCl$$

72 73



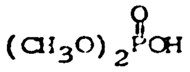
$$M^+ = Ag^+ \text{ or } H_2\overset{+}{N}=\underset{NH_2}{C}SCH_3$$

In this scheme, the nucleophilic displacement of chlorine in 72 with the dimethylphosphate anion was attempted in acetonitrile. The anticipated β-ketophosphate 73 was not obtained; instead a complex mixture of intractable decomposition products was observed.

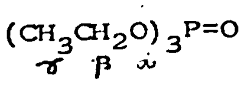
Owing to the low stability of the products of the sulfenyl chloride condensation separation of the β-ketophosphate 73 by either fractional distillation or by preparative vpc was not achieved. However, the mass spectrum of the reaction mixture revealed a weak molecular ion of 73 at m/e 304 and two other ions of medium intensity at m/e 126 and 127. While the molecular ion at m/e 304 is too weak for an exact mass measurement, ion fragments at m/e 126 and 127 were carried out. The exact masses, chemical formulae and the probable structures of ions are summarized in Table 5.

Table 5

Mass spectra data on ions at m/e 126 and 127.

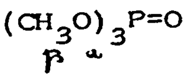
Exact Mass		Chemical formula	Possible structure
Calculated	Found		
126.0082	126.0083	$C_2H_7O_4P$	 $(CH_3O)_2\overset{O}{\overset{\|}{P}}OH$
127.0160	127.0164	$C_2H_8O_4P$	$(CH_3O)_2P(OH)_2$

These ions were not present in the mass spectra of pure samples of the α-chloro-β-ketosulfide 72 or trimethyl phosphate. Thus, they appeared to be derived from the β-ketophosphate 73. The mass spectra of several organic phosphates has been studied in some detail.[71] A distinct difference in fragmentation patterns was observed between phosphates with and without γ-hydrogens with respect to phosphorus. For example, the presence of ions at m/e 126 and 127 in triethyl phosphate (77a) and their absence in trimethyl phosphate (77b) could be attributed to the availability of γ-hydrogens in 77a.



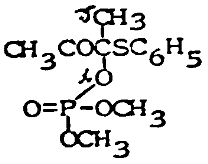
$(\underset{\gamma}{CH_3}\underset{\beta}{CH_2}\underset{\alpha}{O})_3P=O$

77a



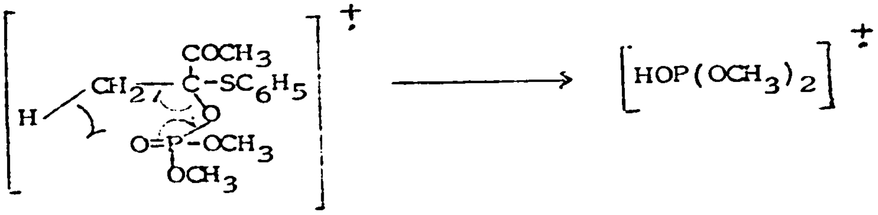
$(\underset{\beta}{CH_3}\underset{\alpha}{O})_3P=O$

77b



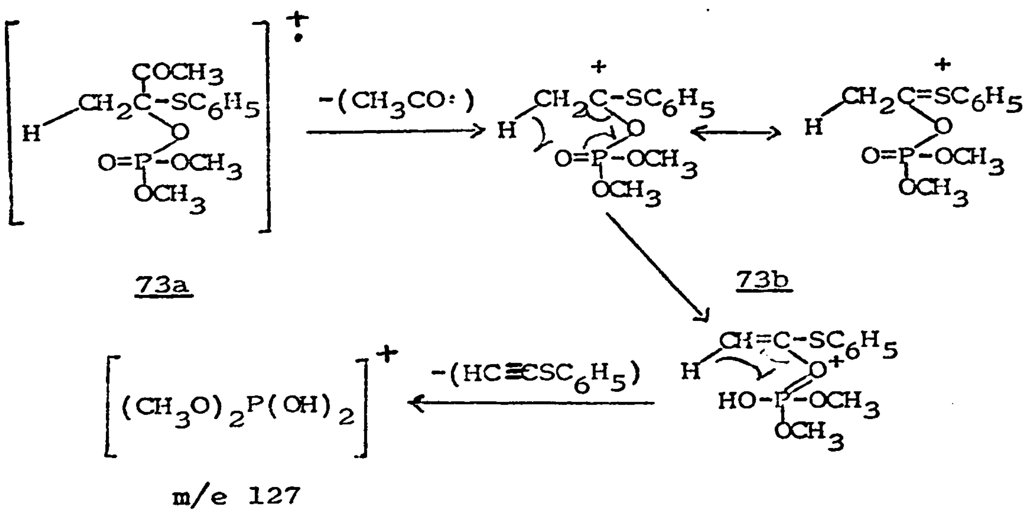
73

Here, the essential difference between trimethyl phosphate (77b) and the β-ketophosphate 73 is that the latter has three γ-hydrogens. Therefore, it is reasonable to suggest that these γ-hydrogens are involved in the formation of ions at m/e 126 and 127 in the β-ketophosphate 73. The ion (m/e 126) is probably formed by a McLafferty rearrangement of the molecular ion 73a as described below. Also, the formation of ion (m/e 127) could be rationalized as follows. The ion 73b formed by α-carbonyl cleavage,[72] probably undergoes two hydrogen shifts with elimination of phenylthioacetylene to form the ion at m/e 127. A weak molecular ion indicates that the suggested processes for the formation of ions m/e 126 and 127 are highly favourable. This has been the case with the mass spectra of certain reported phosphates.[73]



73a

m/e 126

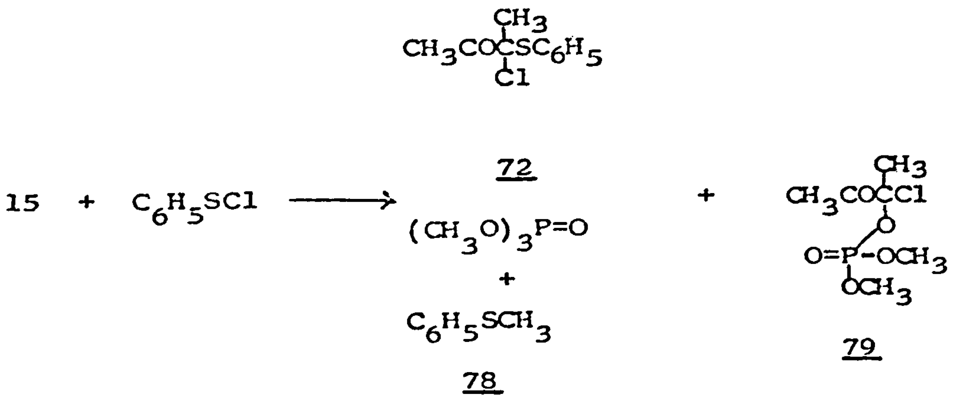


73a

73b

m/e 127

On mechanistic grounds (see next section), the following products could also be expected from the sulfenyl chloride condensation.



72

78

79

The nmr signals associated with trimethyl phosphate and the α-chloro-β-ketosulfide 72 have been identified. The absence of products 78 and 79 was conclusively demonstrated by comparing the nmr spectrum of the reaction mixture with those of the authentic samples of 78 and 79. The singlet at 7.73τ due to the methyl protons of (commercially available) methyl-phenyl sulfide 78 did not correspond with any of the peaks in the nmr spectrum of the reaction mixture. Furthermore, addition of a few drops of 78 to the reaction mixture produced a new singlet at 7.73τ, Authentic α-chloro-β-ketophosphate 79 was prepared according to a reported procedure[40] by the action of chlorine on the 1:1 biacetyl-trimethylphosphite adduct (15).

$$\underline{15} + Cl_2 \longrightarrow \underline{79} + CH_3Cl$$

Again, the singlets associated with CH_3- (7.93τ) and CH_3CO- (7.59 τ) of 79 did not correspond with those of the reaction mixture. This was further checked by addition of 79 to the reaction mixture.

Before entering upon a detailed consideration of the mechanism of these sulfenyl chloride condensations, it would be useful to summarize the findings so far. The 1:1 benzil-trimethyl phosphite adduct (23) reacts with a variety of sulfenyl chlorides to give substituted α-benzoyl-α-chlorobenzyl sulfides 60 and trimethyl phosphate. The 1:1 benzil-tris(dimethylamine)phosphine adduct (25) reacts with p-toluene sulfenyl chloride (51) to give α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) and hexamethyl phosphoramide (69). The 1:1-biacetyl-trimethylphosphite adduct (15), with ethane (52) and benzene (49) sulfenyl chlorides gives α-acetyl-α-chloroethyl-ethyl (or phenyl) sulfide 70, α-acetyl-α-thioethyl (or phenyl) ethyl-dimethylphosphate 71, methyl chloride and trimethylphosphate.

Mechanism of 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensation.

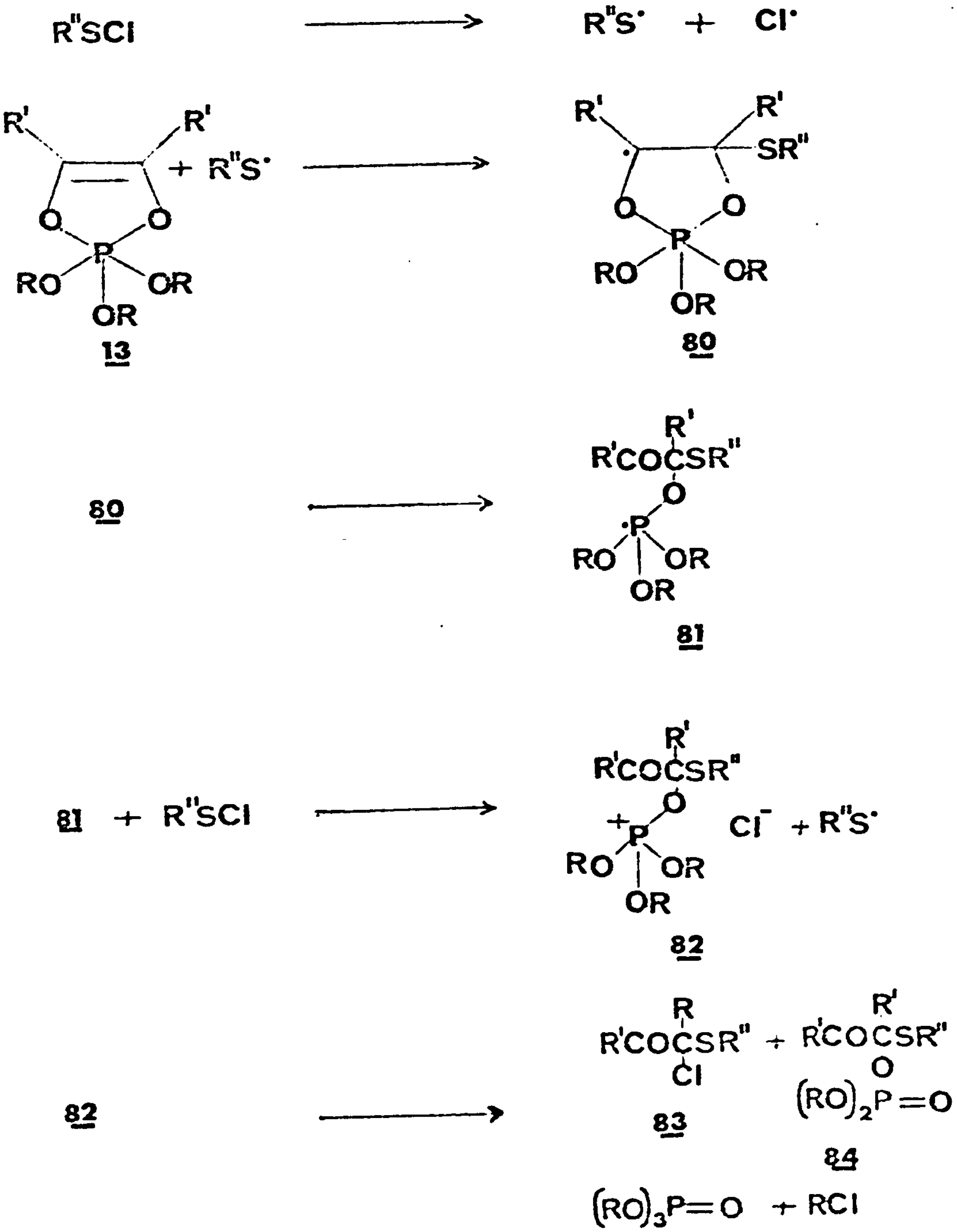
Several mechanisms can be advanced for the 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensation based on the chemistry of both 1:1 dicarbonyl-phosphine adducts and sulfenyl chlorides. These are discussed in detail below.

(a) Free radical mechanism.

A free radical mechanism has been proposed for the reaction of 1:1 biacetyl-trimethylphosphite adduct (15) with bromotrichloromethane[42] (see page 22). By analogy, one may postulate a similar mechanism (see Scheme V) for the sulfenyl chloride condensation. The 1:1 benzil-trimethylphosphite adduct-p-toluenesulfenyl chloride condensation was used to test this mechanism. The condensation proceeded in the dark

Scheme V

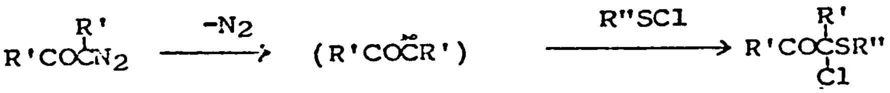
Free radical mechanism.



and in the presence of a free radical inhibitor (1,3,5-trinitrobenzene) with no appreciable change in the rate. Furthermore, gas chromatographic analysis (see experimental section on page 124) of the reaction mixture revealed the absence of p-tolyl disulfide, indicating that formation of the p-tolylthiyl ($p\text{-}CH_3C_6H_4S^{\bullet}$) radical is not important. In other free radical reactions involving thiyl radicals, disulfide is formed as a byproduct.[74] These observations make such a mechanism unlikely.

(b) Carbene mechanism.

A carbene mechanism has been suggested for the formation of α-chloro-β-ketosulfides 83 by the action of sulfenyl chlorides on α-diazoketones.[75]



$$R'CO\overset{R'}{C}N_2 \xrightarrow{-N_2} (R'CO\ddot{C}R') \xrightarrow{R''SCl} R'CO\overset{R'}{\underset{Cl}{C}}SR''$$

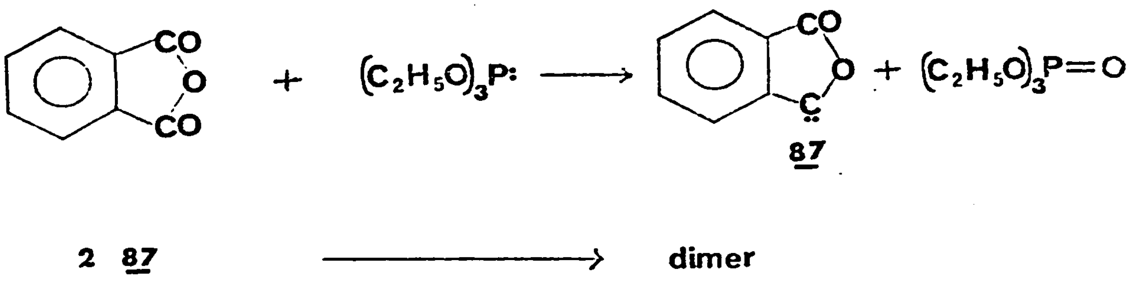
85 83

Also, the 1:1 biacetyl-trimethylphosphite adduct (15), when irradiated in cyclohexane, gave trimethylphosphate, trimethylphosphite and biacetyl as products.[76] The formation of trimethylphosphate indicates that a ketocarbene 86 might have been generated on photolysis. The mechanistic details of this reaction have not yet been published.

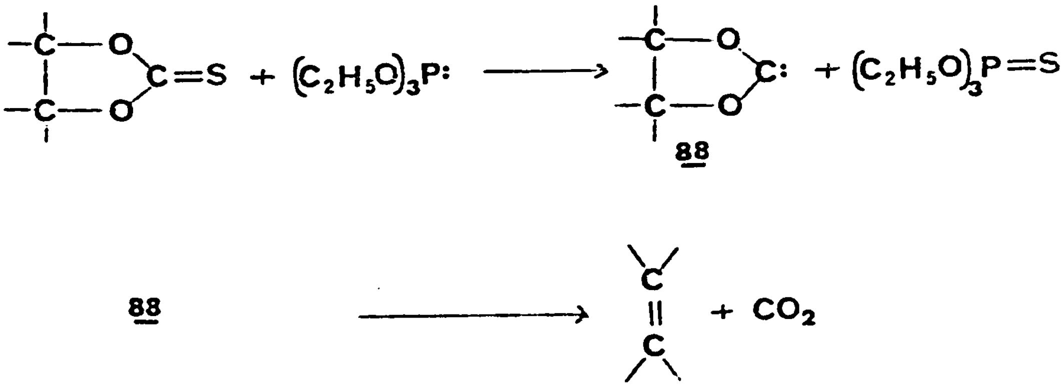
$$\underline{15} \quad + \quad \xrightarrow{h\nu} \quad (CH_3O)_3P{=}O \quad + \quad \underset{\underline{86}}{(CH_3CO\ddot{C}CH_3)}$$

Furthermore, mechanisms involving "carbene" (87,88) by elimination of a phosphate group[77] or a thiophosphate group[78] have been suggested for several reactions. Two examples are given below.

(i) Phthalic anhydride-triethylphosphite reaction.[77]



(ii). Thionocarbonate-triethylphosphite reaction.[78]



From these studies, it is therefore reasonable to propose a carbene mechanism for the sulfenyl chloride condensation. The mechanism proposed is described in Scheme VI. Several experiments (see Scheme VII on page 62) were designed to demonstrate the validity of this mechanism. Benzoylphenyl carbene (90) obtained from benzoylphenyldiazomethane (91) reacted with p-toluenesulfenyl chloride (51) to give the α-chloro-β-ketosulfide 61 in good yield (93%). Also, the ketocarbene 90 has been trapped by styrene to give the cyclobutanone 92.[79] In this case, ketocarbene 90 rearranged to diphenylketene ($Ph_2C=C=O$)[80] before addition to styrene. The assignment of the structure 92 for the cyclobutanone was confirmed by ir, nmr spectra (see experimental section on page 125). However, under identical conditions, the adduct 23 did not give 2,2,3-triphenylcyclobutanone (92) when treated with styrene. Thus, the possibility of a carbene mechanism seems remote for the 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensation.

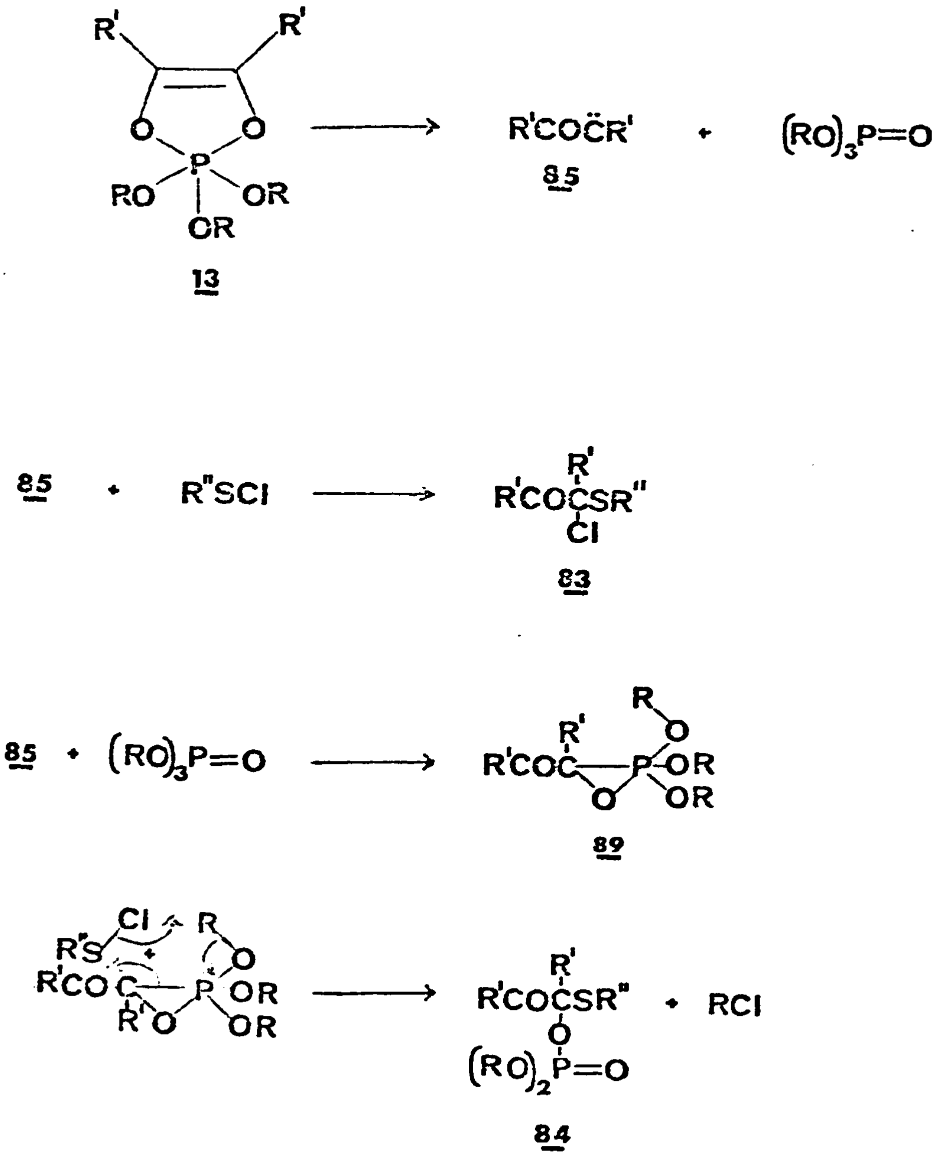
(c). Ionic mechanism.

Any ionic mechanism for the sulfenyl chloride condensation should take into account the two possible modes of polarization of sulfenyl chlorides, namely,

(i) "sulfenium chloride" mode $R''\overset{+}{S}—\overset{-}{Cl}$

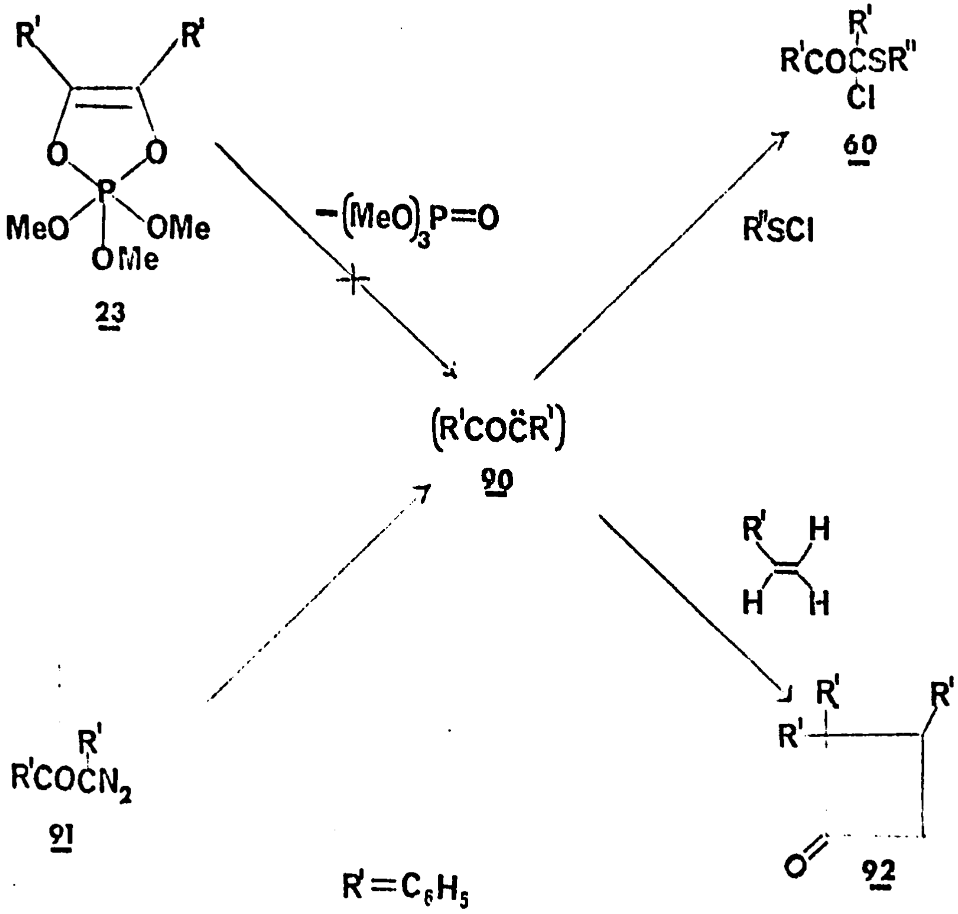
Scheme VI

Carbene mechanism.



Scheme VII

Experiments on carbene mechanism.



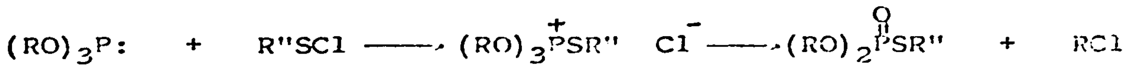
(ii) "chloronium mercaptide" mode $R'\overset{-}{S}\cdot\overset{+}{Cl}$

Even though, sulfenium chloride polarization has been favoured in most of the reactions of sulfenyl chlorides,[81] the chloronium mercaptide dissociation has been shown to occur in some reactions of strongly electrophilic sulfenyl chlorides (eg, p-nitrobenzenesulfenyl chloride). The reaction of ethane and benzenesulfenyl chlorides with trialkylphosphites[82] illustrate the sulfenium chloride polarization.

$$(RO)_3P: \quad + \quad R''SCl \longrightarrow R''S\overset{O}{\overset{\|}{P}}(OR)_2 \quad + \quad RCl$$

$R'' = C_2H_5-$ or C_6H_5-

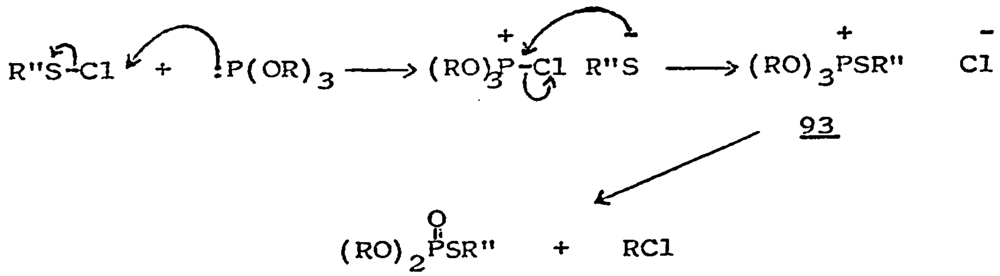
Mechanistically, this reaction is analogous to the Arbusov reaction[12] and the phosphite attacks the electrophilic sulfur to form the phosphonium intermediate 93. The chloride ion is sufficiently nucleophilic to dealkylate the phosphonium intermediate 93 by preferential attack on an alkoxy carbon to form the energetically favoured P=O bond.



$$(RO)_3P: \quad + \quad R''SCl \longrightarrow \underset{93}{(RO)_3\overset{+}{P}SR''\ \ \overset{-}{Cl}} \longrightarrow (RO)_2\overset{O}{\overset{\|}{P}}SR'' \quad + \quad RCl$$

93

An alternative mechanism would involve an initial attack of the phosphite on the halogen similar to that observed with t-butylhypochlorite.[83]



In this case, the attack on the halogen seems less likely, because the thiolate ion ($R''S^-$) would itself be strongly thiophilic and would be expected to react further with the sulfenyl chloride. This chloronium mercaptide polarization of sulfenyl chlorides, has been observed in the reaction of p-nitrobenzenesulfenyl chloride with triphenylphosphite.[84]

$$p\text{-}NO_2\text{-}C_6H_4S\text{-}Cl \quad + \quad :P(OPh)_3 \longrightarrow (PhO)_3\overset{+}{P}\text{-}Cl \quad \overset{-}{S}\text{-}C_6H_4\text{-}NO_2\text{-}p$$

$$p\text{-}NO_2\text{-}C_6H_4\overset{-}{S} \quad + \quad p\text{-}NO_2\text{-}C_6H_4S\text{-}Cl \longrightarrow (p\text{-}NO_2\text{-}C_6H_4S)_2 \quad + \quad Cl^-$$

94

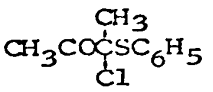
$$(PhO)_3\overset{+}{P}\text{-}Cl \quad + \quad Cl^- \longrightarrow (PhO)_3P(Cl)_2$$

95

p-Nitrophenyl disulfide (94) and the dichlorophosphorus compound 95 were isolated in good yield.

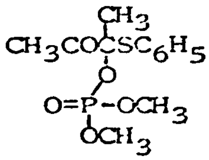
Based on these analogies, the following mechanisms can be proposed for the 1:1 dicarbonyl-phosphine adduct-benzenesulfenyl chloride condensation (see Schemes VIII and IX on pages 67&68). These two mechanisms can be distinguished by product analysis. In the 1:1 biacetyl-trimethylphosphite adduct-sulfenyl chloride condensation (R=R'=CH_3 and R"=C_6H_5), the following set of products would be expected by the two proposed mechanisms.

The expected products from "sulfenium chloride" mechanism.



$CH_3CO\overset{CH_3}{\underset{Cl}{C}}SC_6H_5$,

72

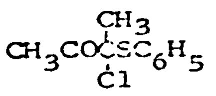


$CH_3CO\overset{CH_3}{\underset{O-P(=O)(OCH_3)_2}{C}}SC_6H_5$,

73

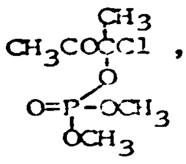
$(CH_3O)_3P=O$ and CH_3Cl

The expected products from "chloronium mercaptide" mechanism.



$CH_3CO\overset{CH_3}{\underset{Cl}{C}}SC_6H_5$,

72



$CH_3CO\overset{CH_3}{\underset{O-P(=O)(OCH_3)_2}{C}}Cl$,

79

$(CH_3O)_3P=O$ and $C_6H_5SCH_3$

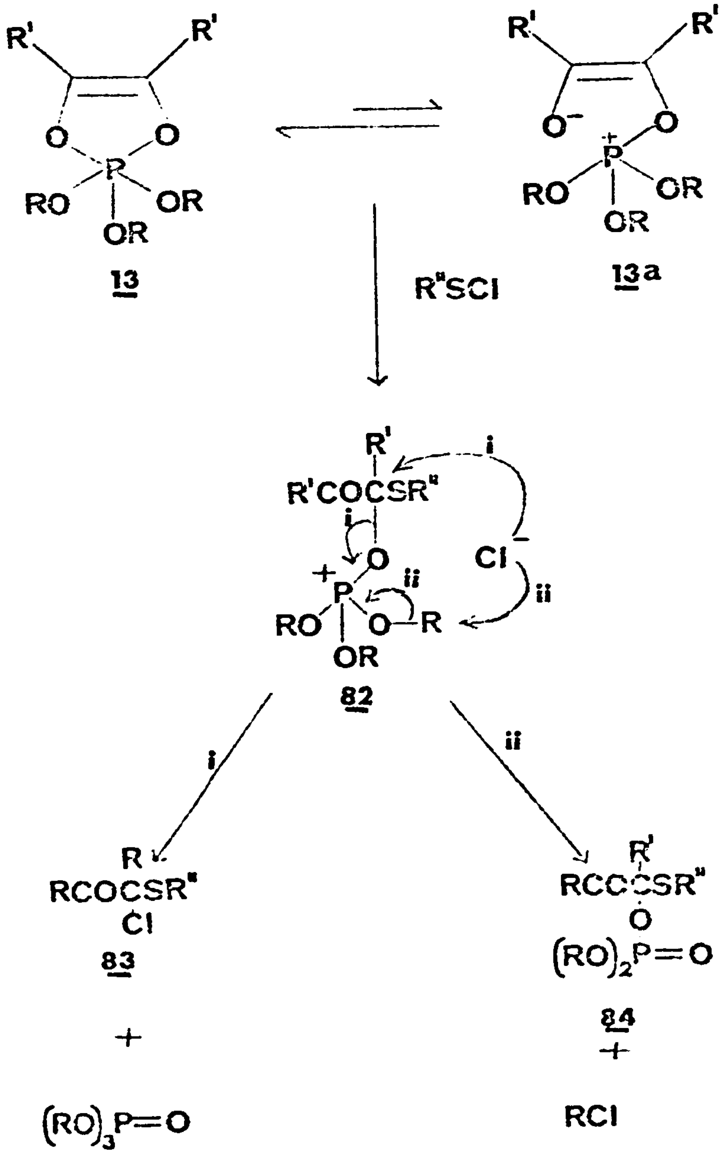
78

It has been shown earlier (see pages 44-55) that the products formed in the condensation corresponded to those predicted by the "sulfenium chloride" mechanism. Thus, it appears that the condensation in this case proceeds in this manner. The absence of phenyl disulfide in the reaction mixture (gas chromatography) makes the chloronium mercaptide mechanism unlikely, because the strong thiophilic nature of the mercaptide ion ($C_6H_5S^-$) should lead to at least some disulfide formation.

In the 1:1 benzil-trimethylphosphite adduct-sulfenyl chloride condensation (R'=Ph and R=CH_3), the only products formed are the α-chloro-β-ketosulfide and trimethyl phosphate. Although, these products can be accounted by both mechanisms, the sulfenium chloride pathway is preferred because there is no disulfide formation. It seems that in this case, path i is preferred exclusively to path ii. This could be rationalized as follows. In path i, the tertiary carbon undergoing nucleophilic attack is not only benzylic but also α to the carbonyl group and to sulfur. All these characteristics accelerate the substitution at the carbon.[85] Moreover, additional driving force is introduced into path i by the elimination of the very stable trimethylphosphate through energetically favoured P=O bond formation. In path ii, even though there are three primary carbons which can undergo nucleophilic attack, the only driving force available is P=O bond formation. In the biacetyl-trimethylphosphite adduct-sulfenyl

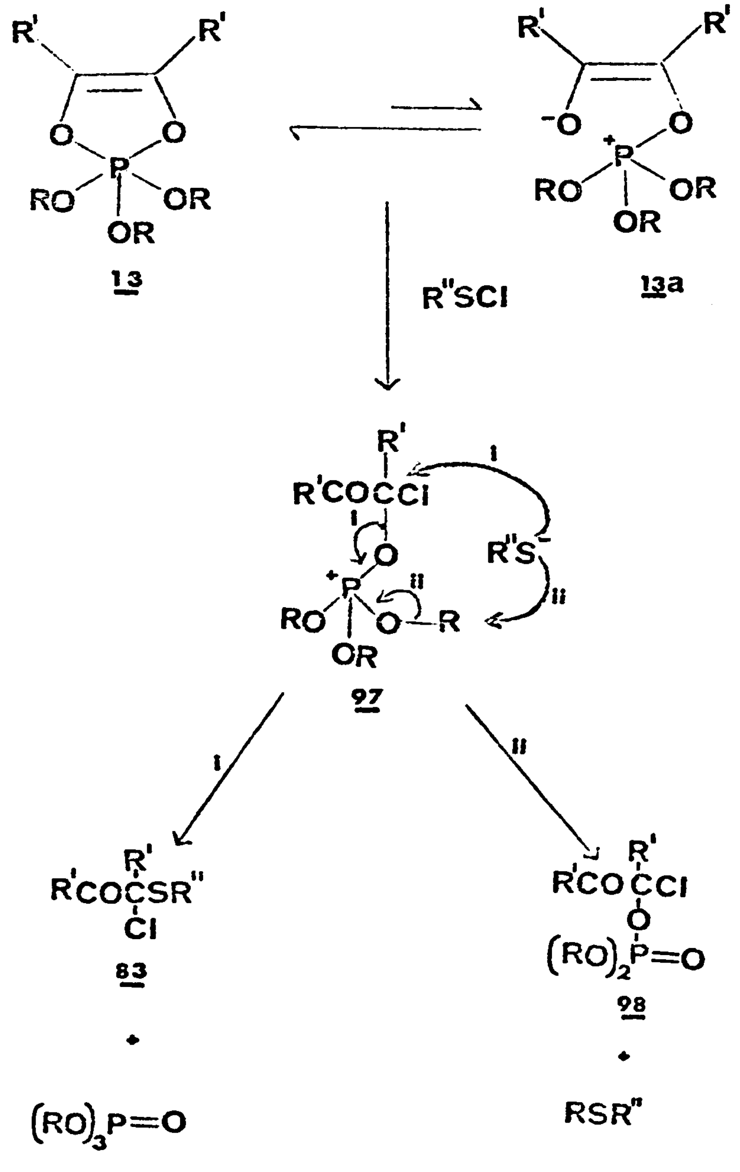
Scheme VIII

The "sulfenium chloride" mechanism.



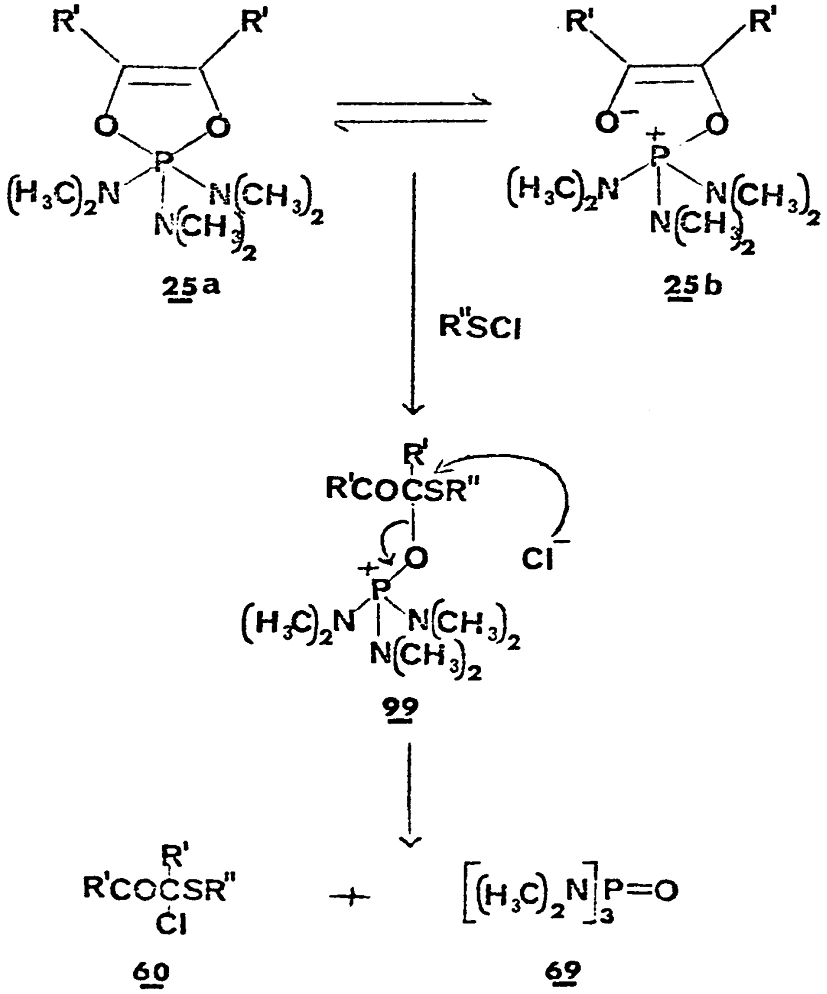
Scheme IX

The "chloronium mercaptide" mechanism.



Scheme X

Suggested mechanism for benzil-tris(dimethylamino)phosphine adduct-sulfenyl chloride condensation.



$R' = C_6H_5$

chloride condensation ($R'=R=CH_3$), which lacks the benzylic group path ii competes with path i to a significant extent (see Table 4).

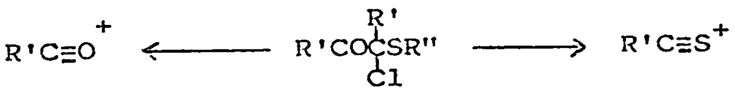
The condensation of sulfenyl chlorides with 1:1 benzil-tris(dimethylamino)phosphine adduct (25) can also be rationalized on the basis of sulfenium chloride mechanism. This condensation is similar to that of 1:1 benzil-trimethylphosphite adduct and sulfenyl chlorides, except that path ii is eliminated. The mechanism is described in Scheme X on page 69.

All attempts to trap the intermediate 82 (see Scheme VIII) as 2,4,6-trinitrobenzene sulfonate ($TNBS^-$) 100 and hexachloro antimonate ($SbCl_6^-$) 101 to obtain additional evidence for the "sulfenium chloride" mechanism, were not successful.

In summary, all the 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensations studied, appear to follow the sulfenium chloride mechanism.

Mass spectra of α-chloro-β-ketosulfides.

The α-chloro-β-ketosulfides showed certain similarities in their fragmentation patterns in spite of the structural differences in them. The following fragmentations seems to be common for all the α-chloro-β-ketosulfides studied so far.



$$R'C\equiv O^{+} \longleftarrow R'CO\underset{Cl}{\overset{R'}{C}}SR'' \longrightarrow R'C\equiv S^{+}$$

83

Like other carbonyl derivatives,[71] the chloroketosulfides 83 undergo α-carbonyl cleavage to give $R'C\equiv O^{+}$. The ion $R'C\equiv S^{+}$ has been shown to occur in the mass spectra of some sulfides.[86] When R' = C_6H_5, the ion $C_6H_5CO^{+}$ undergoes further fragmentation to $C_6H_5^{+}$ and then to $C_4H_3^{+}$. These processes are substantiated by the metastable peaks at m/e 56.5 and 33.8 respectively.

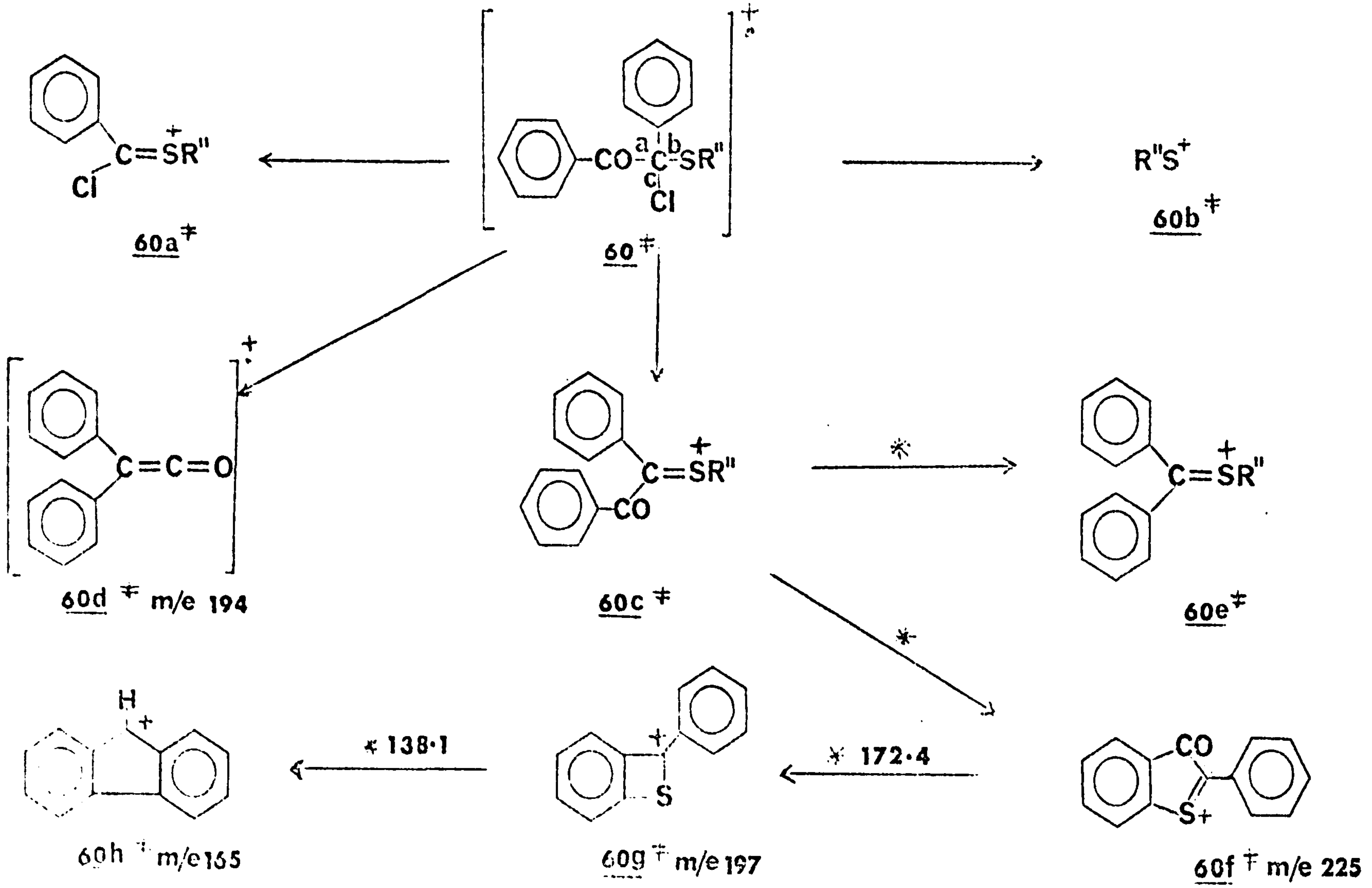
$$\begin{array}{ccccc} C_6H_5CO^{+} & \xrightarrow{*56.5} & C_6H_5^{+} & \xrightarrow{*33.8} & C_4H_3^{+} \\ m/e\ 105 & & m/e\ 77 & & m/e\ 51 \end{array}$$

(i). α-Benzoyl-α-chlorobenzyl sulfides.

Considering the α-benzoyl-α-chlorobenzyl sulfides (60), their mode of fragmentation appears to depend on the nature of R". When R" does not have hydrogens α to sulfur (R" = p-$CH_3C_6H_4$-, C_6H_5-, p-ClC_6H_4- and 2-benzothiazolyl), the formation of various ions can be rationalized according to Scheme XI on the following page.

Scheme XI

The main fragmentation pathway of α-benzoyl-α-chlorobenzyl sulfides.



The ions $60a^{\ddagger}$, $60b^{\ddagger}$ and $60c^{\ddagger}$ are formed by benzylic cleavage of a, b and c bonds respectively. The ion $60d^{\ddagger}$ at m/e 194, is assigned as diphenylketene ion and this is confirmed by exact mass measurements (see Table 6). When R" = C_6H_5, the formation of ion $60e^{\ddagger}$ from $60c^{\ddagger}$ is substantiated both by a metastable peak at m/e 249.5 and by exact mass measurements. The ions $60f^{\ddagger}$, $60g^{\ddagger}$ and $60h^{\ddagger}$ seemed to be formed from $60c^{\ddagger}$ as indicated in Scheme XI and these are substantiated by both metastable peaks and by exact mass measurements. These data are summarized in Table 6.

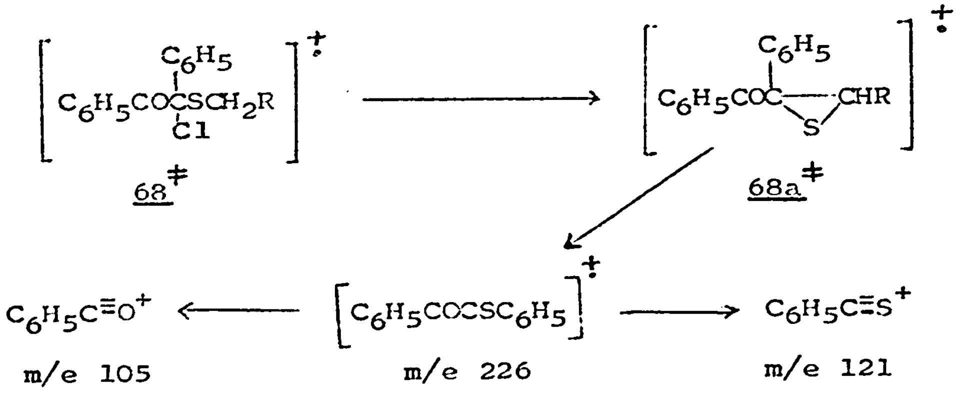
Table 6

Exact mass data on α-benzoyl-α-chlorobenzyl-phenyl sulfide (62).

ion	Chemical formula	Exact mass calculated	Exact mass found
60d	$C_{14}H_{10}O$	194.0729	194.0732
60e	$C_{19}H_{15}S$	275.0896	275.0894
60f	$C_{14}H_9OS$	225.0372	225.0374
60g	$C_{13}H_9S$	197.0420	197.0425
60h	$C_{13}H_9$	165.0706	165.0704

When R" has hydrogens α to sulfur (when R" = $C_6H_5CH_2$-

and MeO_2CCH_2-), the fragmentation patterns are somewhat different. The main difference being the elimination of HCl instead of Cl^- from the molecular ion $\underline{68}^{+\cdot}$. This process seemed to be so favourable that the molecular ion $\underline{68}^{+\cdot}$ is absent in these chloroketosulfides. The ion at m/e 226 is formed most probably from ion $\underline{68a}^{+\cdot}$ but this cannot be confirmed by metastable peaks.



When R" = p-$CH_3C_6H_4$- or $C_6H_5CH_2$-, the ion at m/e 91 due to $C_7H_7^+$ (tropylium ion) is also observed. This breaks down further to give $C_5H_5^+$ at m/e 65 (metastable at m/e 46.4).

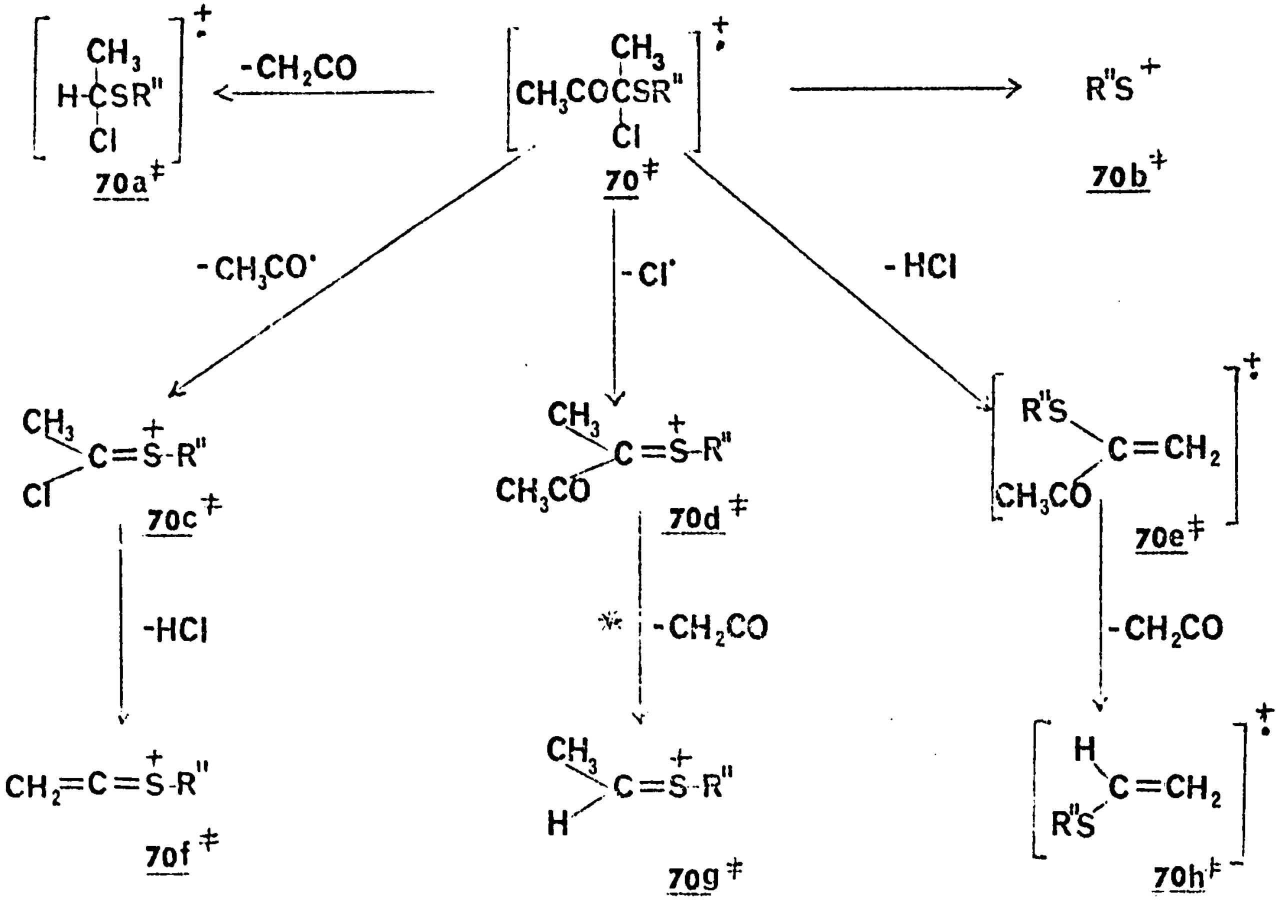
$$\underset{m/e\ 91}{C_7H_7^+} \xrightarrow{*46.4} \underset{m/e\ 65}{C_5H_5^+}$$

(ii) <u>α-Acetyl-α-chloroethyl sulfides.</u>

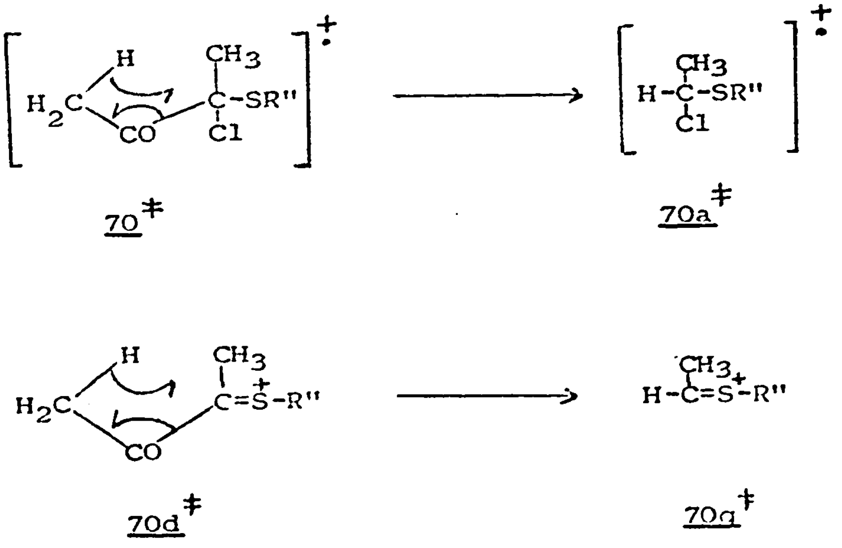
The main pathways of fragmentation of α-acetyl-α-chloroethyl sulfides ($\underline{70}$) are summarized in Scheme XII on next page.

Scheme XII

The main fragmentation pathways of α-acetyl-α-chloroethyl sulfides.



In these chloroketosulfides the molecular ion is much more intense than in the case of α-benzoyl- α-chlorobenzyl sulfides. Not only Cl^- but also HCl is eliminated from the molecular ion $\underline{70}^{+\cdot}$ to give ions 70d and 70e. The ion $R''S^+$ is formed by α-thio cleavage. The elimination of ketene (CH_2CO) which is characteristic of some acetyl (CH_3CO) groups,[71] occurs in the molecular ion as well as in other ions containing the group. The ketene elimination may proceed via a four centre mechanism as follows.

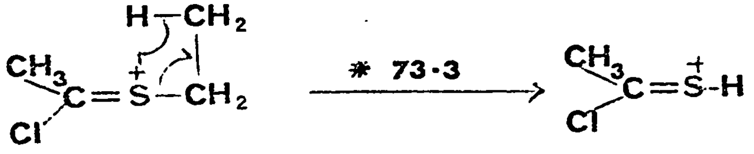


$\underline{70}^{+\cdot}$ $\underline{70a}^{+\cdot}$

$\underline{70d}^{+\cdot}$ $\underline{70a}^{+}$

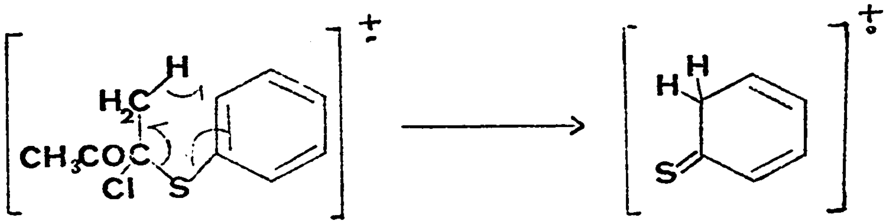
When R" = CH_3-CH_2-, ethylene elimination is observed from ions containing ethyl group.[72] For example, the ion at m/e = 123 eliminates ethylene to give fragment m/e = 95.

This is substantiated by the presence of a metastable peak at m/e = 73.3.



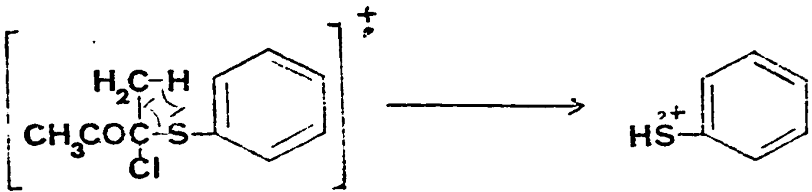
m/e 123 m/e 95

The aromatic ring participates when R" = C_6H_5, the following fragmentation leading to the ion at m/e = 110.



72 ‡ m/e 110

A four centre fragmentation can also be advanced to rationalize the formation of the fragment at m/e = 110.



72 ‡ m/e 110

The six centre fragmentation is preferred to the four centre process although definitive experimentation is lacking.[72]

Chapter III

Results and Discussion (Part II).

Results and Discussion Part II

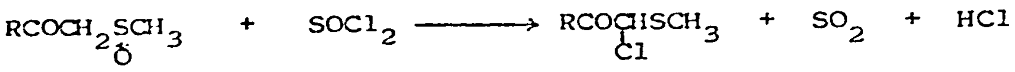
Reactions of α-chloro-β-ketosulfides.

The versatility of α-chloro-β-ketosulfides as useful intermediate is illustrated by their conversion to α-hydroxy acids, α-ketoaldehydes, α-hydroxyaldehydes, methylketones, aldoses and a variety of heterocyclic compounds.[87,88] Besides the 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensation, there are two other methods available for the preparation of α-chloro-β-ketosulfides.

The decomposition of α-diazoketones with sulfenyl chlorides.[75]

$$\mathrm{RCO\overset{R'}{C}N_2} \quad + \quad \mathrm{R''SCl} \longrightarrow \mathrm{RCO\overset{R'}{\underset{Cl}{C}}SR''} \quad + \quad \mathrm{N_2}$$

The action of thionyl chloride on β-ketosulfoxides.[88]



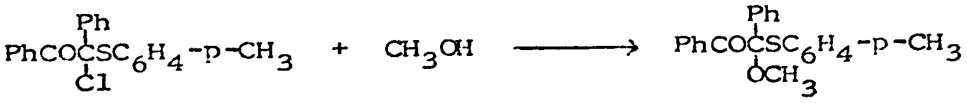
$$\mathrm{RCOCH_2\underset{O}{S}CH_3} \quad + \quad \mathrm{SOCl_2} \longrightarrow \mathrm{RCO\underset{Cl}{C}HSCH_3} \quad + \quad \mathrm{SO_2} \quad + \quad \mathrm{HCl}$$

In these methods, the reactants (α-diazoketones or β-ketosulfoxides) must be prepared separately. However, in the 1:1 dicarbonyl-phosphine adduct-sulfenyl chloride condensation, the chloro ketosulfides can be generated in one step from readily available compounds. Furthermore this condensation yields a new series of α-chloro-β-ketosulfides in which carbon bearing the chlorine is tertiary.

One would expect that the chlorine atom in the α-chloro-β-ketosulfides should be very reactive, due to the sulfur participation (as shown).

$$\mathrm{RCO}\overset{\mathrm{R}}{\underset{\mathrm{Cl}}{\mathrm{C}}}\text{---}\mathrm{SR''} \longleftrightarrow \mathrm{RCO}\overset{\mathrm{R}}{\underset{\mathrm{Cl^-}}{\mathrm{C}}}=\overset{+}{\mathrm{S}}\mathrm{R''}$$

This can be substantiated by fact that α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) was converted within few minutes to α-benzoyl-α-methoxybenzyl-p-tolyl sulfide (102) in good yield (80%) by heating with methanol and silver carbonate.



$$\mathrm{PhCO}\overset{\mathrm{Ph}}{\underset{\mathrm{Cl}}{\mathrm{C}}}\mathrm{SC_6H_4\text{-}p\text{-}CH_3} + \mathrm{CH_3OH} \longrightarrow \mathrm{PhCO}\overset{\mathrm{Ph}}{\underset{\mathrm{OCH_3}}{\mathrm{C}}}\mathrm{SC_6H_4\text{-}p\text{-}CH_3}$$

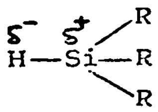
61 102

In this study, some new reactions of α-chloro-β-ketosulfides were investigated.

Reaction of α-chloro-β-ketosulfides with trichlorosilane-tri-n-butylamine.

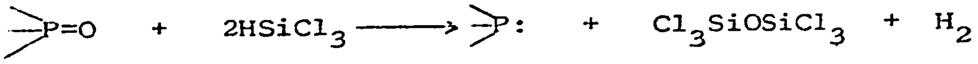
Silicon hydrides 103 reduce a number of organic functional groups, presumably because of the hydridic nature of the hydrogen attached to silicon.[89]

ie,



103

Their use as synthetic reagents is on the increase because of their ready availability and efficient mode of reaction.[90] Trichlorosilane (105) for example, has been shown to be superior to lithium-aluminum hydride in the reduction of phosphine oxides to phosphines.[91]



105

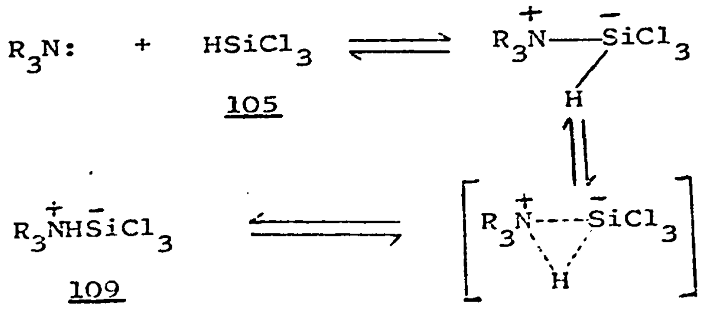
Reductions of amine oxides[92] and sulfoxides[93] using trichlorosilane have also been reported.

The effectiveness of organic bases as catalysts for the addition of trichlorosilane to acrylonitrile[94] and phenylacetylene[95] has added another dimension to the rapidly expanding field of organosilicon chemistry. Recently Benkeser et al[96] found that in the presence of tertiary amines trichlorosilane (105) effected dehalogenation with a variety of organic halides. The products so obtained, were considered to be significant from both synthetic and mechanistic standpoints.

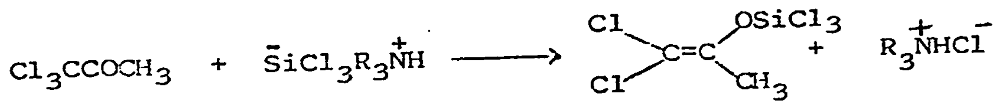
For example, 1,1,1-trichloro-2-propanone (106) gave 1,1-dichloro-2-propanone (107) in high yield (80%) when treated with trichlorosilane (105) and tri-n-butylamine (108).

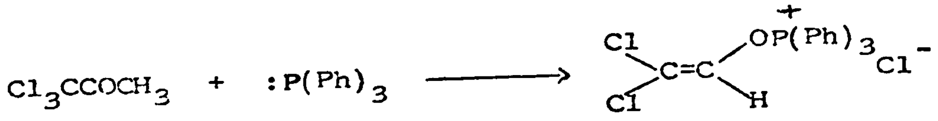
$$\underset{\underline{106}}{Cl_3CCOCH_3} + \underset{\underline{105}}{HSiCl_3} + \underset{\underline{108}}{(n\text{-}C_4H_9)_3N:} \longrightarrow \underset{\underline{107}}{HCCl_2COCH_3} + SiCl_4 + \underset{\underline{108}}{(n\text{-}C_4H_9)_3N:}$$

Physical evidence which substantiates the existence of the trichlorosilyl anion (109) in the reaction has been reported.[97] This anion has been shown to be formed by the following mechanism.

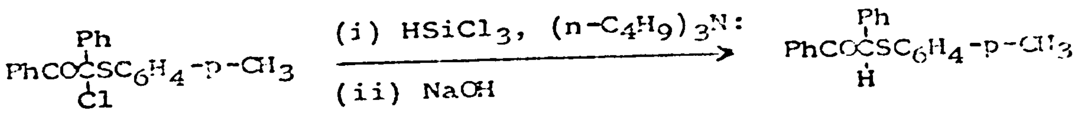


The trichlorosilyl anion (109) offers a striking parallel to phosphines in view of the isoelectronic relationship between them. The isolation of 1,1-dichloro-2-trichlorosilyloxy-propene (110) from the 1,1,1-trichloro-2-propanone (106) and trichlorosilane-tri-isopropylamine reaction and subsequent hydrolysis of 110 to the product 107 illustrates its close similarity to 111 in the triphenylphosphine-chloral reaction.[98]


106 109 110

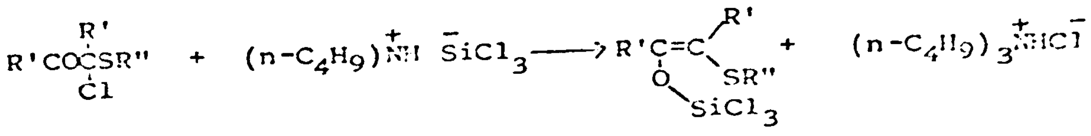

111

Prompted by the clean and selective dehalogenation work of Benkeser,[96] the trichlorosilane-tertiary amine combination was used to dehalogenate α-chloro-β-ketosulfides 83. For example, α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) was reduced to α-benzoylbenzyl-p-tolyl sulfide (112) in quantitative yield (by nmr).


61 112

In a series of experiments, the α-chloro-β-ketosulfides 60 were generated in situ by the 1:1 benzil-trimethylphosphite adduct-sulfenyl chloride condensation and dehalogenated using trichlorosilane (105) and tri-n-butylamine (108). The results are summarized in Table 7 on the following page. In the aliphatic series, the α-chloro-β-ketosulfides 70 were also generated in situ by the 1:1 biacetyl-trimethylphosphite adduct-sulfenyl chloride condensation and dehalogented by trichlorosilane (105) and tri-n-butylamine (108). The dehalogenation proceeded in good yield (61%) with α-acetyl-α-chloroethyl-phenyl sulfide (72). Owing to its low thermal stability the dehalogenation of α-acetyl-α-chloroethyl-ethyl sulfide (74) led to extensive decomposition. When a pure sample of 72 (prepared from azibutanone and benzenesulfenyl chloride, see page 120) was used, α-acetylethyl-phenyl sulfide (118) was obtained in higher yield (80%). However, α-acetylethyl-ethyl sulfide (119) cannot be obtained from pure 74 owing to the low thermal stability of 74.

All dehalogenation reactions were carried out in dry 1,2-dimethoxyethane. The workup was initially alkaline in order to eliminate any side reactions arising from the hydrolysis of the probable intermediate 120.

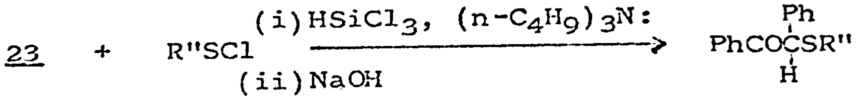


83

120

Table 7

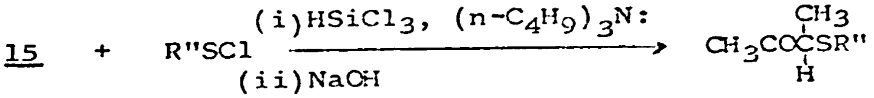
Physical and spectroscopic data of β-ketosulfides.



$$\underline{23} + R''SCl \xrightarrow[\text{(ii)NaOH}]{\text{(i)HSiCl}_3,\ (n\text{-}C_4H_9)_3N:} PhCO\overset{Ph}{\underset{H}{C}}SR''$$

115

R" in 115	M.P.(°)	Yield (%)	ir (CO) band in cm^{-1}	nmr data (τ)
p-CH_3-C_6H_4-, 112	94-6	80	1670	1.80-3.10(14H,m), 4.12(H,S)7.73 (3H,S).
C_6H_5-CH_2-, 113	70-2	60	1670	2.10-2.80(15H,m), 4.62(H,S)6.33 (2H,AB)J=14HZ.
CH_3CH_2-, 114	78-80	62	1670	1.80-2.90(10H,m), 4.37(H,S)7.50 (2H, Split AB , J=7HZ)8.83 (3H,t, J=7HZ).

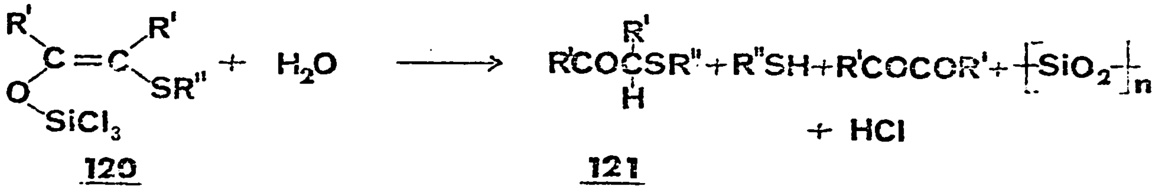


$$\underline{15} + R''SCl \xrightarrow[\text{(ii)NaOH}]{\text{(i)HSiCl}_3,\ (n\text{-}C_4H_9)_3N:} CH_3CO\overset{CH_3}{\underset{H}{C}}SR''$$

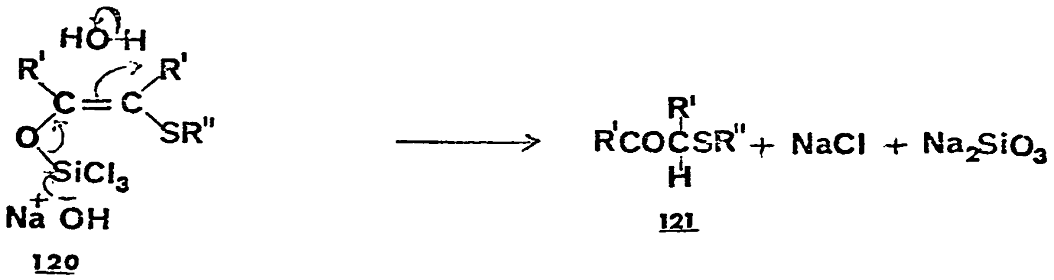
116

R" in 116	B.P °/mm	Yield (%)	ir (CO) band in cm^{-1}	nmr data (τ)
C_6H_5-, 118	78-80/0.003	61	1720	2.30-2.85(5H,m), 6.29(H,q,J=7HZ), 7.80(3H,S), 8.63 (3H,d,J=7HZ).
C_2H_5-, 119	decomposed	-	-	-

This intermediate 120 is not only an enol ether but also an enol thioether. Consequently, acidic hydrolysis would lead to the cleavage of both these groups.



Basic hydrolysis however, would only lead to enol ether cleavage giving the β-ketosulfide 121 as shown below.



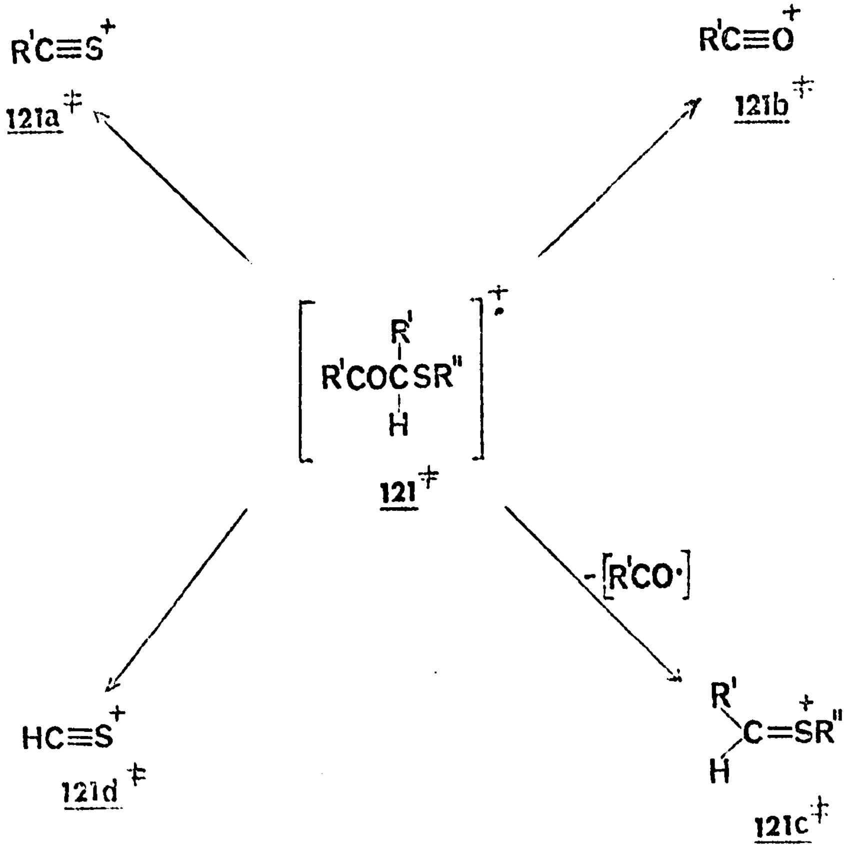
The ir and nmr data of these β-ketosulfides 121 are summarized in Table 7.

Mass spectra of β-ketosulfides.

In the mass spectra, all β-ketosulfides 121 showed the molecular ion M^{+} 121‡, $R'C\equiv O^{+}$ 121b‡, $R'C\equiv S^{+}$ 121a‡, $HC\equiv S^{+}$ 121d‡ and $[M - R'C\equiv O]^{+}$ 121c‡ (see Scheme XIII on the following page). When R' = C_6H_5, the $C_6H_5C\equiv O^{+}$, m/e 105 apparently

Scheme XIII

The main fragmentation pathways of β-ketosulfides.



undergoes further fragmentation to $C_6H_5^+$ m/e 77 and then to $C_4H_3^+$ m/e 51. These latter pathways are substantiated by the presence of metastable peaks at m/e 56.5 and 33.8 respectively.[72]

$$\begin{array}{ccccc} C_6H_5C{\equiv}O^+ & \xrightarrow{*\ 56.5} & C_6H_5^+ & \xrightarrow{*\ 33.8} & C_4H_3^+ \\ m/e\ 105 & & m/e\ 77 & & m/e\ 51 \end{array}$$

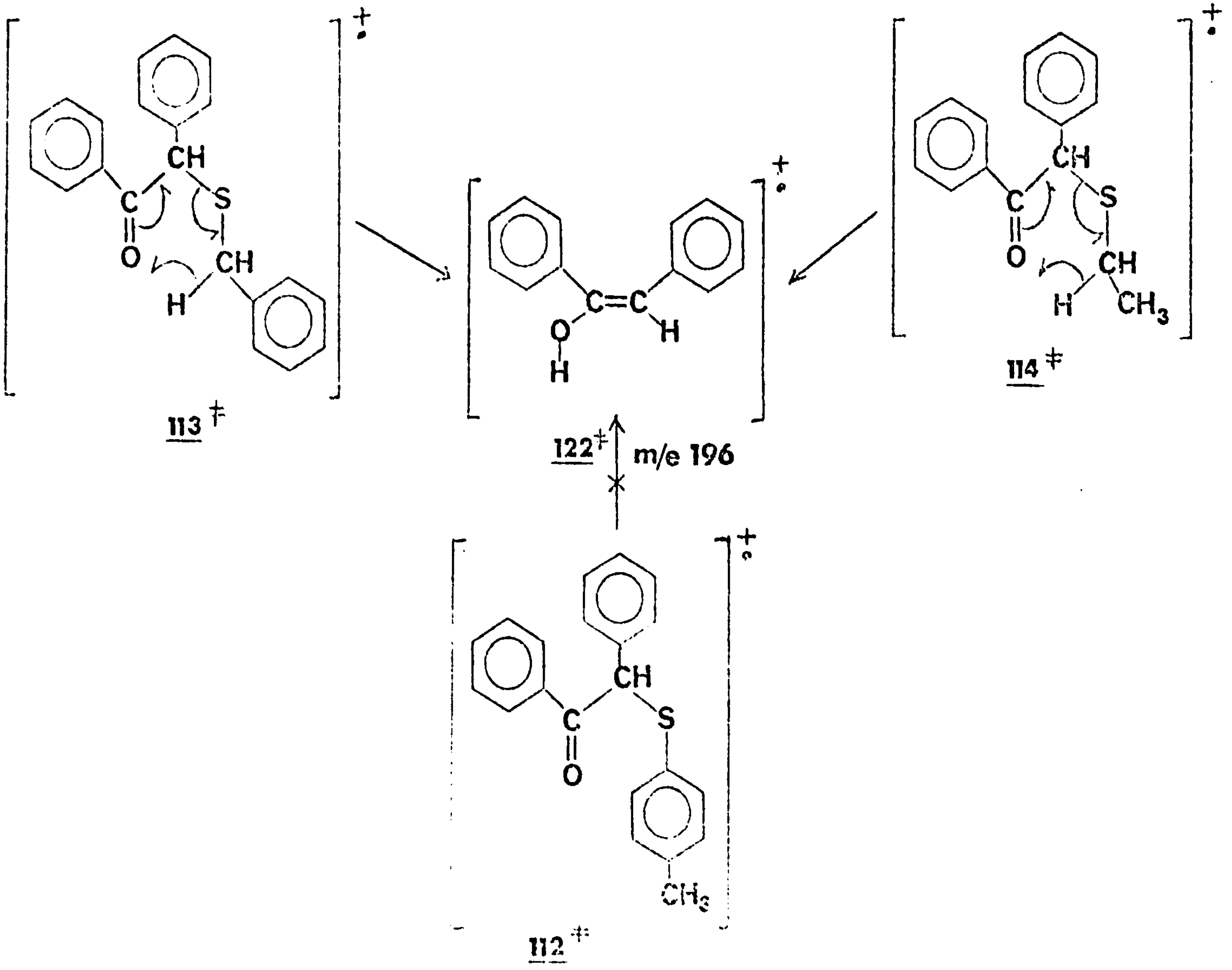
When R" = $C_6H_5CH_2$- or p-$CH_3C_6H_4$-, an intense peak at m/e 91 due to $C_7H_7^+$ (tropylium ion) was observed. This ion fragmented further to $C_5H_5^+$ m/e 65, which was confirmed by the presence of a metastable peak at m/e 46.4.

$$\begin{array}{ccc} C_7H_7^+ & \xrightarrow{*\ 46.4} & C_5H_5^+ \\ m/e\ 91 & & m/e\ 65 \end{array}$$

When R' = C_6H_5, the peak at m/e 121 was assigned to $C_6H_5C{\equiv}S^+$. Similar ions ($RC{\equiv}S^+$) have been observed in the mass spectra of other sulfur compounds.[86] Similarly, the peak at m/e 59, when R' = CH_3 was assigned to $CH_3C{\equiv}S^+$. When R = C_6H_5 and R" = $C_6H_5CH_2$- or CH_3CH_2-, the ion $\underline{122}^{\ddagger}$ at m/e 196 appears to be formed by a McLafferty rearrangement[99] as shown in Scheme XIV on next page. The fact that ion $\underline{122}^{\ddagger}$ is not formed from $\underline{112}^{\ddagger}$ suggests that one of the hydrogens of the methylene group α to sulfur participates in the rearrangement. Certain peaks which reflect their unique structural features are also

Scheme XIV

McLafferty rearrangement in some β-ketosulfides.



observed in the mass spectra of some β-ketosulfides. The molecular ion 113‡ undergoes a benzylic cleavage and a possible rearrangement to give the ion 113e‡ at m/e 227.

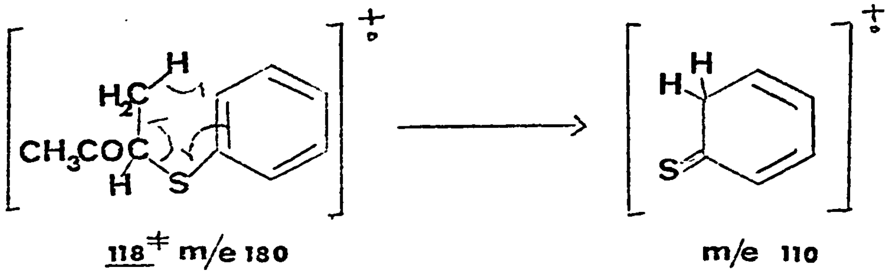
$$\mathrm{PhCO\overset{Ph}{\underset{H}{C}}S{-}CH_2Ph \longrightarrow PhCO\overset{Ph}{C}{=}\overset{+}{S}{-}H}$$

113‡, m/e 318 113e‡, m/e 227

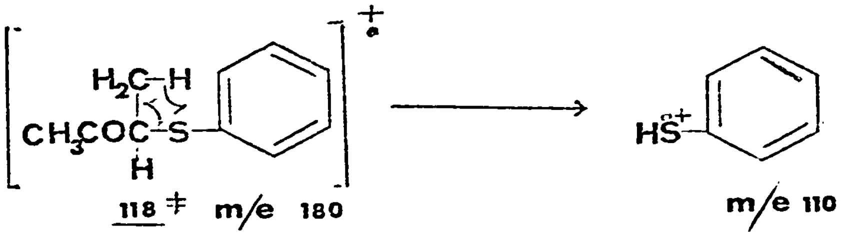
Also, the ion 114c‡ at m/e 151 undergoes further fragmentation with elimination of ethylene to give an ion 114e‡ at m/e 123. Similar olefin eliminations have been observed in the mass spectra of other alkyl sulfides with β-hydrogens.[86]

114c‡ m/e 151 **114e‡ m/e 123**

This olefin elimination was further confirmed by the presence of a metastable peak at m/e 100.1. The ion 118‡ undergoes fragmentation to the ion at m/e 110 presumably because of the proximity of the phenyl and methyl groups. Several analogies to this type of rearrangement have been reported.[72]



A four centre fragmentation mechanism can be proposed for the formation of the ion at m/e 110. The six centre fragmentation is preferred in most of the reported systems, although definitive experimentation is lacking.[72]



Reaction of α-chloro-β-ketosulfides with potassium thiocyanate.

The reactions of metal thiocyanates with a number of organic substrates have been widely used for the preparation of various heterocyclic compounds.[100] Recent research with metal thiocyanates has been concerned not only with extending their applications, but also with problems of structure of the products and reaction mechanisms.[101] In most organic reactions, sodium, potassium and ammonium thiocyanate were used because of their high solubilities in polar organic solvents.

The effective agent, thiocyanate ion, exhibits "ambident" character since the negative charge is delocalized over sulfur and nitrogen as shown below.

$$\bar{S}-C\equiv N \longleftrightarrow S=C=\bar{N}$$

<u>123</u> <u>124</u>

The thiocyanate ion is regarded as a resonance hybrid of <u>123</u> and <u>124</u>, where the disposition of charge over the ion varies with its environment in a crystal, a solvent, a stable complex or a transition state complex of a chemical reaction. For example, the infrared absorption and X ray diffraction data for solid potassium thiocyanate have been interpreted in terms of a resonance structure to which form <u>123</u> contributes about 70 percent.[102] Considering the metal complexes which contain thiocyanate ligands, metal-sulfur bonds have been found in some and metal-nitrogen bonds in others.[103] Furthermore, the important feature of the reactions of inorganic thiocyanates with an organic substrate is that the product is frequently an isothiocyanate ($R-N=C=S$), instead of, or together with a thiocyanate ($R-S-C\equiv N$).[104] The mechanistic details of these reactions are complicated by the following factors.

(a). the structure of the organic compound. e.g. whether the reaction occurs on a primary, secondary or tertiary carbon atom.

(b). the structure of the reagent.

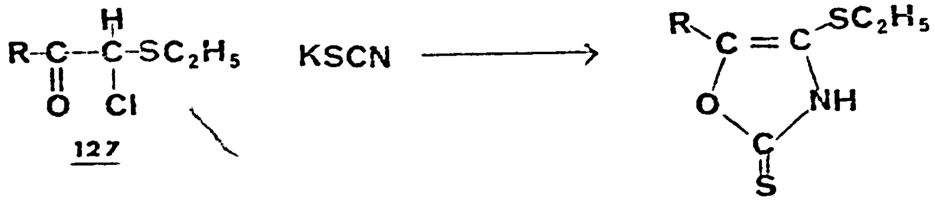
(c). the interplay of structural and environmental factors in the formation of a transition-state complex.

(d). the inherent thermal instability of some thiocyanates or the effects of catalysts on them leading to their isomerization.

In the reaction of α-haloketones 125 with potassium thiocyanate, the thiocyanoketone 126 is formed.[105]

$$\underset{\underline{125}}{RCOCH_2Cl} + KSCN \longrightarrow \underset{\underline{126}}{RCOCH_2SCN} + KCl$$

In contrast, α-chloro-β-ketosulfide 127 with potassium thiocyanate is reported to give the oxazolothione-2 128.[106]


127

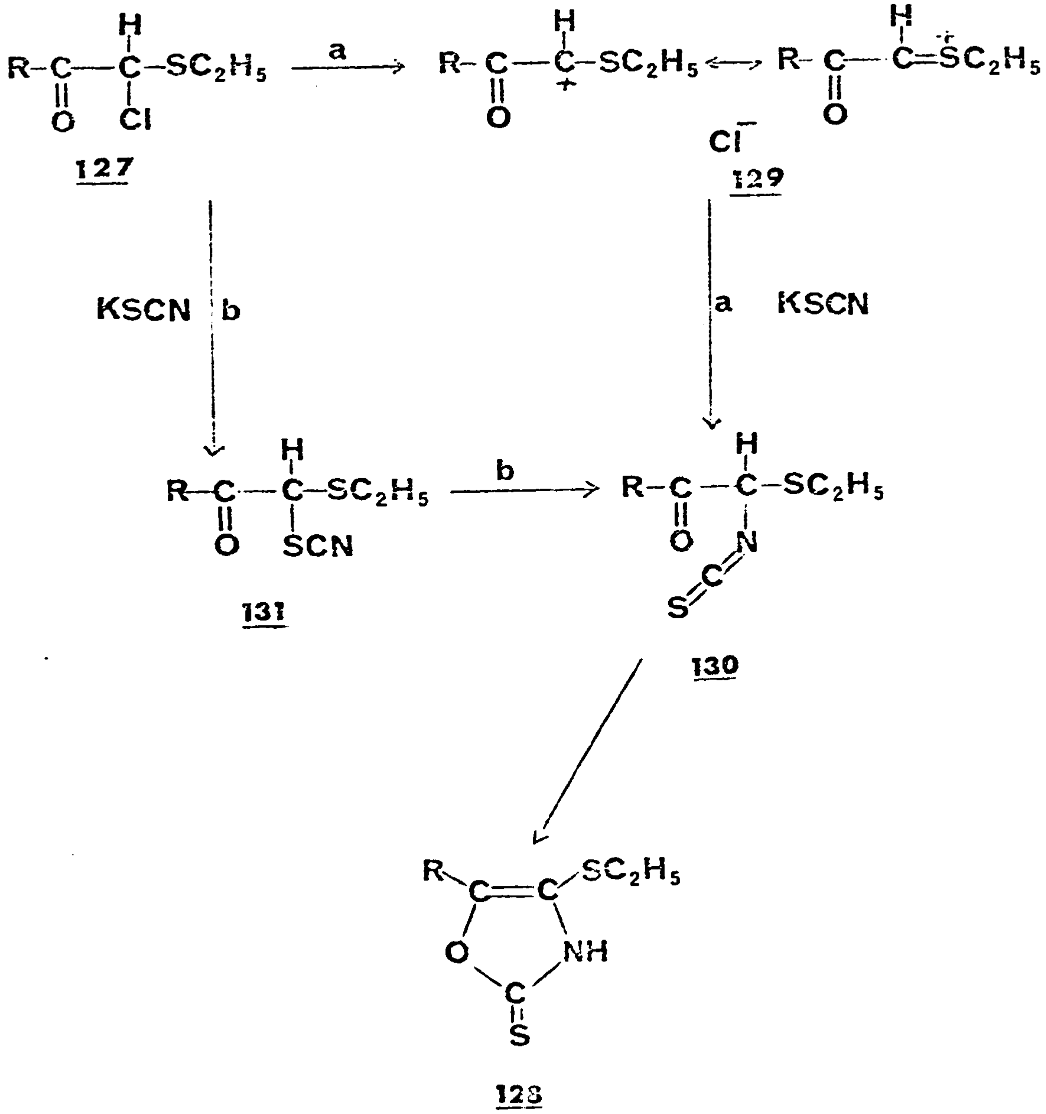
128

These contrasts in the behaviour of thiocyanate ion have been rationalized as follows.[107] In the α-chloroketonethiocyanate reaction, the carbon atom undergoing nucleophilic attack is primary and the reaction has been suggested to follow an SN_2 mechanism. However, in the α-chloro-β-ketosulfide-thiocyanate reaction the carbon is secondary. Moreover, the carbon-chlorine bond is much more loosened by the influence of α-sulfur (see page 79). These factors would be expected to favour an SN_1 mechanism. In an SN_1 reaction, the incoming nucleophile attacks the carbonium ion intermediate largely because of the gain in electrostatic stability resulting from the neutralization of charge. So in an ambident nucleophile, the approach of the atom having the highest concentration of negative charge would be favoured on energetic grounds. For the thiocyanate ion, nitrogen being more electronegative than sulfur, would have the greatest electron density. Thus, in the α-chloro-β-ketosulfide-thiocyanate reaction, the thiocyanate ion would attack the carbonium ion centre through nitrogen forming an isothiocyanate 130. This isothiocyanate 130 likely cyclized to give the oxazolothione-2 128 as described in path a on Scheme XV. These rationalizations should be considered critically, because the isothiocyanate 130 could also be formed via path b (see Scheme XV) by isomerization of thiocyanate 131. Such a possibility has not yet been ruled out.

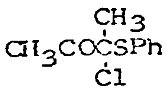
In this investigation, the reaction of thiocyanate

Scheme XV

Mechanism of α-acyl-α-chloromethyl-ethyl sulfide-thiocyanate reaction.

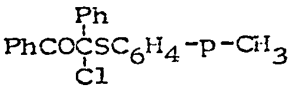


ion with a number of α-chloro-β-ketosulfides (72, 74, 61 and 64) having a tertiary carbon adjacent to sulfur was studied.



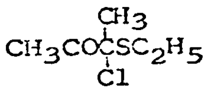
$CH_3CO\overset{CH_3}{\underset{Cl}{C}}SPh$

72



$PhCO\overset{Ph}{\underset{Cl}{C}}SC_6H_4\text{-p-}CH_3$

61



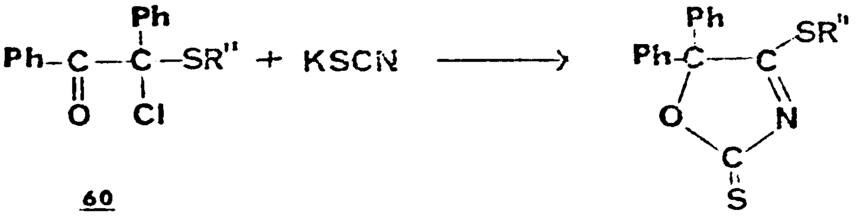
$CH_3CO\overset{CH_3}{\underset{Cl}{C}}SC_2H_5$

74

$PhCO\overset{Ph}{\underset{Cl}{C}}SCH_2Ph$

64

The chloro ketosulfides 72 and 74 reacted with potassium thiocyanate but the products from the reaction decomposed during workup in spite of several attempts (by distillation under reduced pressure, column chromatography etc.) to isolate them. However, **two other** chloro ketosulfides 61 and 64 reacted with potassium thiocyanate affording 4-substituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones 132.

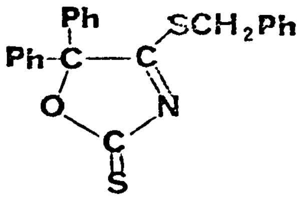


60

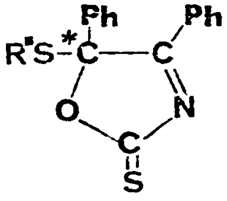
132

When potassium thiocyanate was added to the solution of the chloro ketosulfide 60 in anhydrous acetone, it dissolved completely and potassium chloride precipitated out as a white solid within a few minutes. Workup and column chromatography provided a syrup which gave satisfactory elemental analysis and was homogeneous on tlc (thin layer chromatography). The yield, uv and nmr data are summarized on Table 8 on page 97. The ir spectrum of the products 132 had no carbonyl, thiocyanate or isothiocyanate bands.

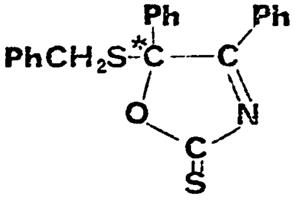
On mechanistic grounds, the structure 135 can also be assigned to the product of this reaction.



134



135



136

The structure 135 for the product was ruled out by the following reasoning. The two possible structures when R" = $C_6H_5CH_2$- , are 134 and 136. In 134, the benzylic protons are enantiomeric[67] and therefore would be expected to give a singlet (2H) in the nmr. However, in 136 the benzylic protons are diastereomeric[67] because of their proximity to the asymmetric centre. In these systems such diastereomeric benzylic protons give an

Table 8

Physical and spectroscopic data of 5,5-diphenyl-4-benzyl (and p-tolyl) thio-3-oxazoline-2(1H)-2-thiones 132.

$$\underline{60} + KSCN \longrightarrow \underline{132} + KCl$$

R" in 132	Yield (%)	UV* max m (ε)	nmr data (τ)
p-tolyl-133	82	232 (2920) 295 (1543)	2.10-2.90(14H,m) 7.60 (3H,s).
benzyl-134	90	228 (3483) 296 (1711)	2.10-2.90(15H,m) 5.77 (2H,s).

---

*ether was used as solvent.

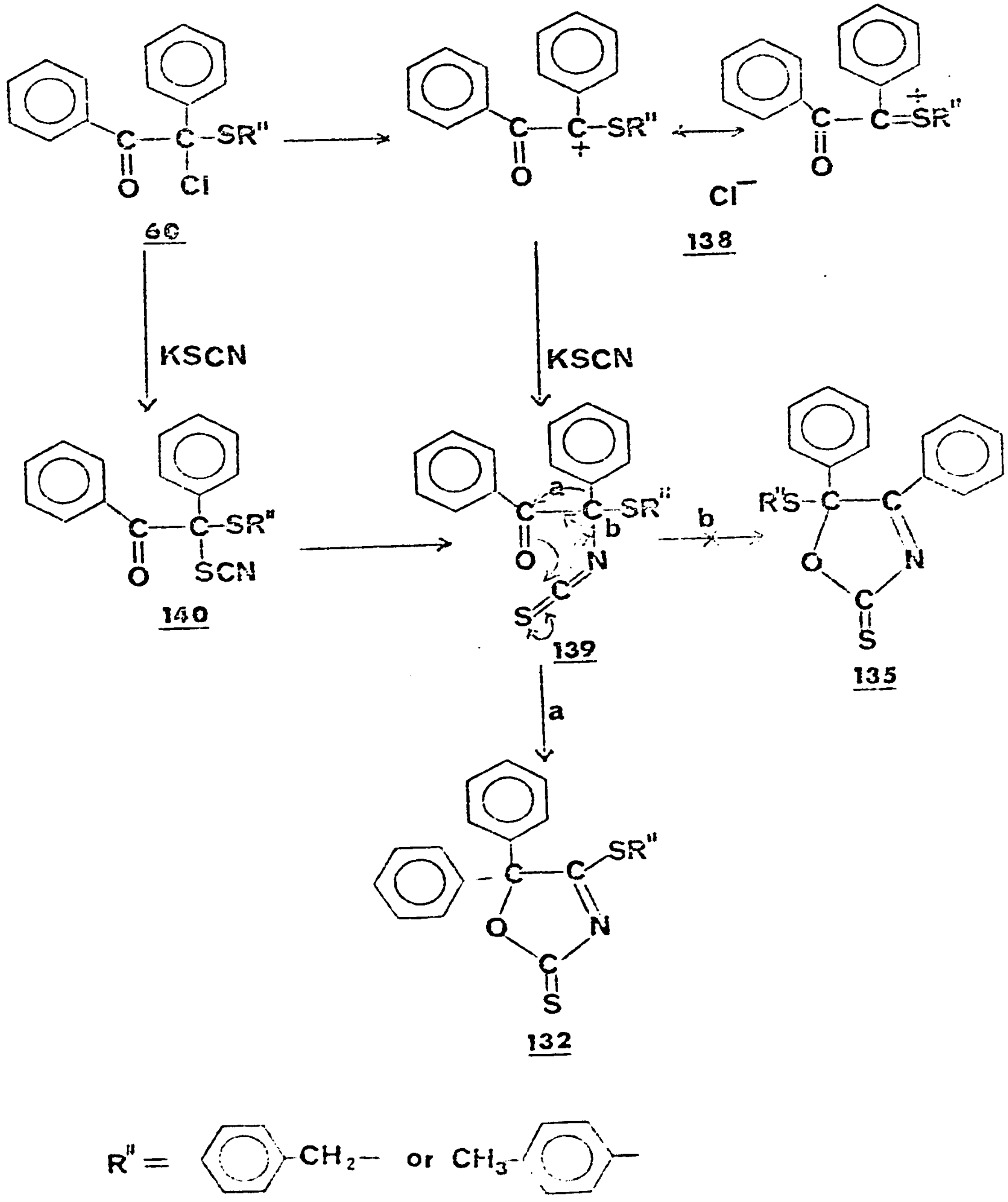
AB pattern in the nmr spectrum. (see page42 for other examples of diastereomeric protons.). The product from the thiocyanate reaction showed a singlet (2H) for the benzylic protons. Therefore, the structure 134 is favoured for the product. The UV spectra of the products from the reaction of potassium thiocyanate with 61 and 64 are similar. Since, 134 is the is the favoured structure for the product from 64, therefore a similar structure 133 is assigned to the product from 61. The mass spectra of 133 and 134 are discussed in detail in the next section.

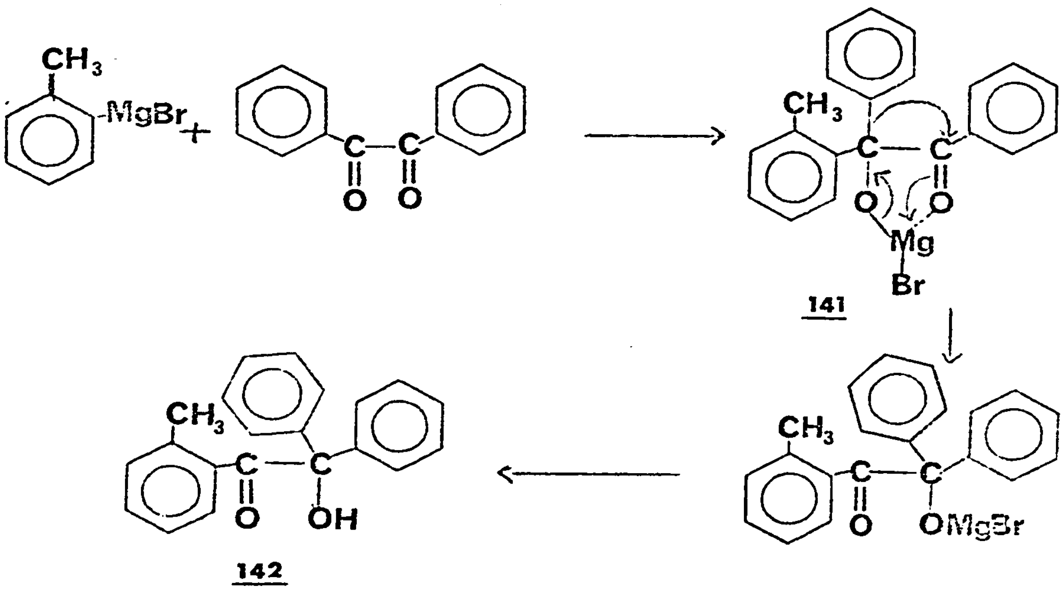
Mechanistically, the reaction can be considered to follow the pathway as shown in Scheme XVI on page 99. The isomerization of tertiary thiocyanate 140 to isothiocyanate 139 under the reaction conditions can reasonably be expected to occur. Similar isomerizations of tertiary thiocyanates have been reported.[101] The isothiocyanate 139 can cyclize to the product 132 with concomitant phenyl migration. The possibility of sulfur migration (path b) was ruled out on the basis of the structure of the product (nmr analysis). This mechanism involved a nucleophilic push, electrophilic pull involving phenyl migration to give the cyclized product 132.

A similar mechanism has been suggested for the reaction of O-tolylmagnesium bromide with benzil.[102]

Scheme XVI

Mechanism of α-benzoyl-α-chlorobenzyl-benzyl (or p-tolyl) sulfide-thiocyanate reaction.





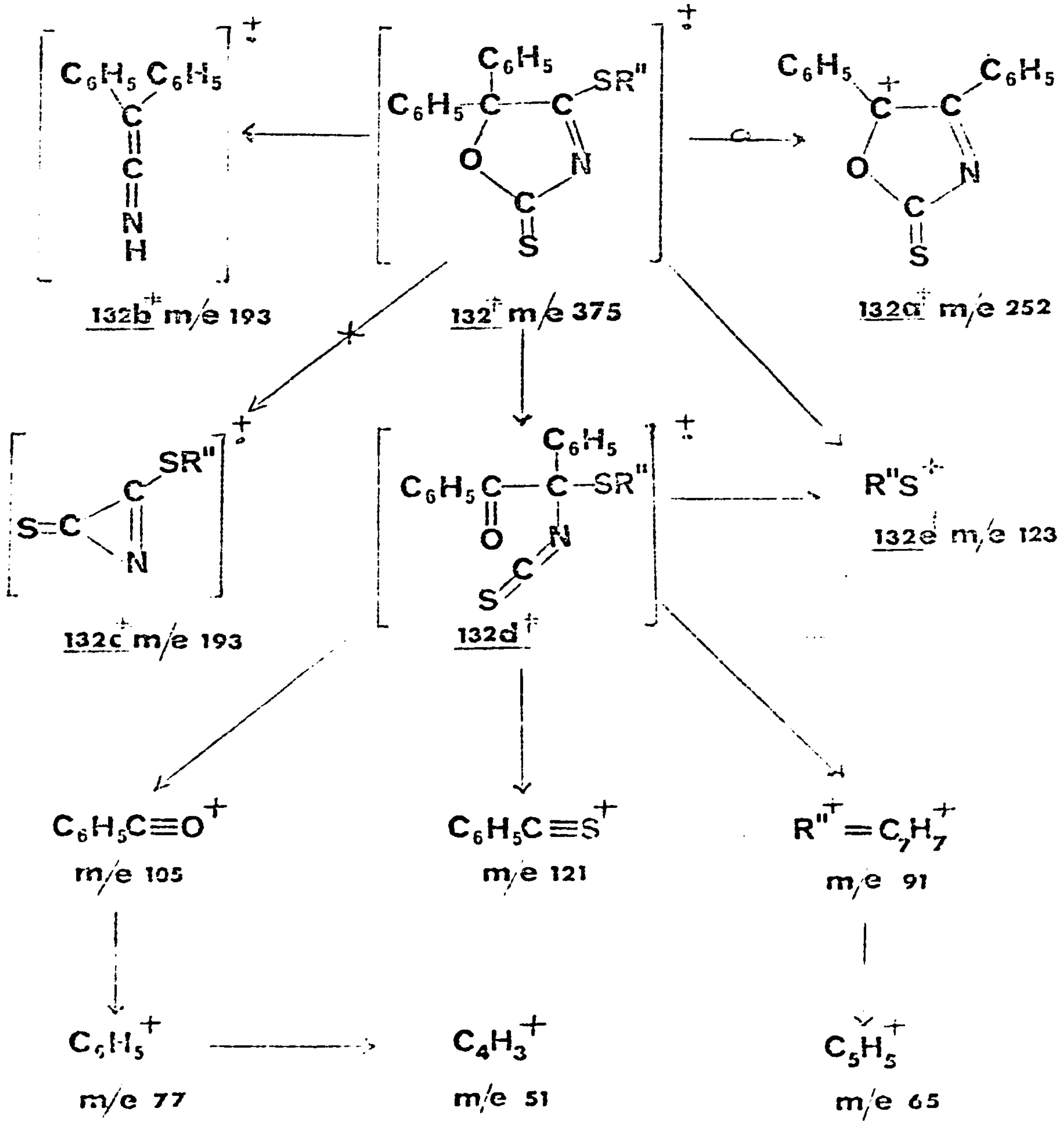
It is likely that this rearrangement is facilitated by chelation with magnesium atom as in 141, which increases the electrophilic character of the carbonyl group. The phenyl group migrates to give the rearranged α-hydroxy ketone 142.

Mass spectra of 5,5-diphenyl-4-benzyl (and p-tolyl) thio-3-oxazoline-2(1H)-2-thiones.

The main fragmentation pathways in the mass spectra of 133 and 134 are illustrated on Scheme XVII on the following page. These mass spectra are very similar. The molecular ion $132^{+\cdot}$ m/e 375 appears to undergo an α-thio cleavage and a possible phenyl shift to give ion $132a^{+\cdot}$ m/e 252. This is

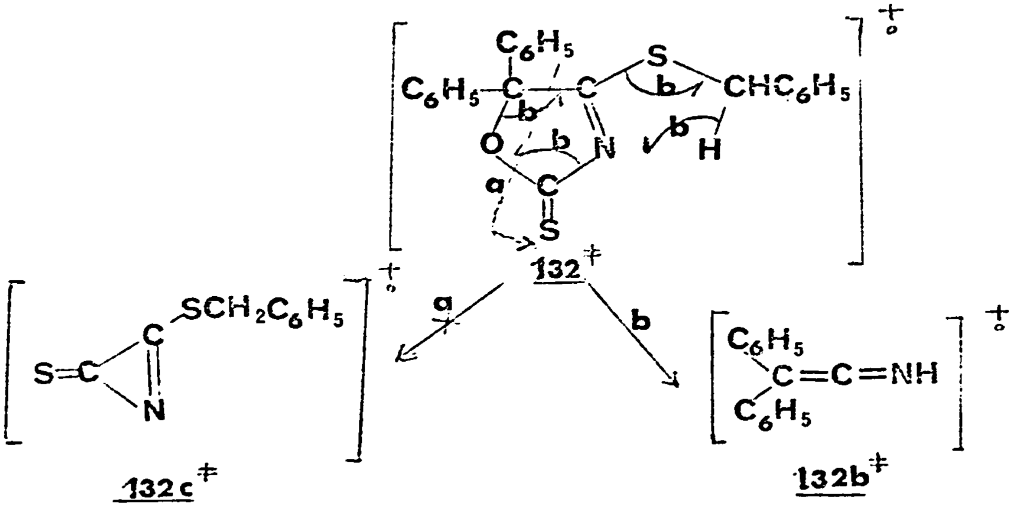
Scheme XVII

The main fragmentation pathways of 5.5-diphenyl-4-benzyl (p-tolyl) thio-3-oxazoline-2(1H)-2-thiones.



R'' = $C_6H_5CH_2$ or p $CH_3C_6H_4$

confirmed by exact mass measurements (see Table 9). The ion 132e$^{+\cdot}$, m/e 123 is also formed by the above process. The ion at m/e 193 can be obtained by two pathways. The molecular ion 132$^{+\cdot}$ may lose benzophenone to give 132c$^{+\cdot}$ or it can eliminate COS and R''S with hydrogen transfer to give the ion 132b.$^{+\cdot}$ When R'' = PhCH$_2$-, the two pathways are as shown below.



Formation of 132b$^{+\cdot}$ and not 132c$^{+\cdot}$ is established by exact mass measurements (see Table 9). In the case of 132c$^{+\cdot}$, the calculated and found exact masses are not in agreement. Molecular ion 132$^{+\cdot}$ can also give the ion 132d$^{+\cdot}$ by ring opening with a phenyl shift (this process occurs in other analogous systems eg. cyclic sulfites).[109] This ion 132d can undergo further fragmentation to ions at m/e 121, 105, 91, 77, 65 and 51 as shown in Scheme XVII. The pathways are discussed in detail

Table 9

Exact mass data on 5,5-diphenyl-4-benzyl(p-tolyl)thio-3-oxazoline-2(1H)-2-thiones.

	Exact Mass			
Ion	Calculated	Found for $\underline{133}$	Found for $\underline{134}$	Chemical formula
$\underline{132}^{\ddagger}$	375.0752	375.0726	375.0739	$C_{22}H_{17}NOS_2$
$\underline{132a}^{\ddagger}$	252.0483	252.0463	252.0504	$C_{15}H_{10}NOS$
$\underline{132b}^{\ddagger}$	193.0891	193.0874	193.0913	$C_{14}H_{11}N$
$\underline{132c}^{\ddagger}$	193.0020	193.0874	193.0913	$C_9H_7NS_2$

in the previous section on the mass spectra of α-chloro-β-ketosulfides (see pages 70-74).

Summary

Thermally stable α-chloro-β-ketosulfides 83 are converted to the corresponding β-ketosulfides 121 by trichlorosilane (105) and tri-n-butylamine (108). This reaction can be carried out in one step by generating the chloro ketosulfide in situ (from readily available compounds), and thus, provides a convenient method for the preparation of β-ketosulfides.

α-Benzoyl- α-chloro benzyl sulfides 60 react with potassium thiocyanate to give 4-thio-substituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones 132 in high yield. The ready availability of α-chloro-β-ketosulfides 83 and the clean reaction with potassium thiocyanate, provides a convenient synthetic route to this new heterocyclic system 132.

Mechanistic rationalizations of these reactions and the mass spectra of β-ketosulfides 121 and 4-thio-substituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones 132 are discussed.

Chapter IV

Experimental

Experimental

1. Melting points were obtained on a Gallenkamp melting point apparatus and are corrected.

2. Infrared spectra were recorded on a Perkin-Elmer (Model 257 or Model 337) Grating Infrared spectrophotometer. Spectra of solids were obtained using potassium bromide pellets and a film technique was used for liquid samples. Spectra were calibrated with the 1601.4 cm^{-1} band of a polystyrene film reference.

3. Ultraviolet spectra were recorded on a Unicam SP-800 ultraviolet spectrophotometer.

4. Nuclear magnetic resonance spectra were recorded on Varian Associates A-60 or T-60 spectrometers. All proton spectra are reported in tau (τ) units relative to tetramethyl silane (TMS). Abbreviations used in reporting nmr spectra are: s, singlet; d, doublet; t, triplet; q, quartet and m, multiplet. Unless otherwise stated, deuterochloroform was used as a solvent.

5. Mass spectra were recorded on an AEI-MS-902 mass spectrometer equipped with a direct insertion probe.

6. Gas chromatographic (VPC) analyses were performed on an F and M (Model 5750) Research chromatograph. Two 6' x 1/8" stainless steel columns were used: 10% silicone gum rubber UC-W98 on Diatoport-S (UC-W98 column) and 10% Apiezon-L on chromasorb W/AW-MCDS (Apiezon-L column).

7. Organic microanalyses were performed by Scandanavian Microanalytical Laboratories, Herlev, Denmark, and Organic Microanalyses (Dr. C. Daessle), Montreal, Canada.

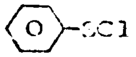
8. Trimethyl phosphite (Aldrich Chemical Co. Ltd.) was purified by prolonged treatment with molecular sieves "Linde" Type 3A(1/16") followed by fractional distillation. Tris(dimethylamino)phosphine (Eastman Kodak Chemical Co. Ltd.) was used without further purification. Carbonyl compounds (benzil, biacetyl etc.) were freshly distilled or recrystallized from aprotic solvents. The solvents were purified according to the procedures described in "Laboratory Techniques in Organic Chemistry", by K.B. Wiberg, McGraw-Hill Book Co. Inc., New York (1960), pp. 240-252.

Preparation of aromatic sulfenyl chlorides.

The procedure used was a modification on the method of H. Emde.[55] In a 500 ml. flask, fitted with a dropping funnel and a reflux condenser carrying a drying tube, was placed N-chloro succinimide (0.2 mole, 26.7 g). Benzene (120 ml) was added and the contents of the flask were stirred magnetically to form a slurry. A solution of the aromatic thiol (0.2 mole) in benzene (50 ml) was added dropwise with the flask being cooled by ice water (temperature about 10°). An orange-red colour developed after 5 min. and it deepened as the addition continued. After the addition was complete, the reaction mixture was stirred for 24 hrs. at room temperature. The white solid (succinimide) was removed by filtration and the deep red filtrate was concentrated under reduced pressure. Carbon tetrachloride (30 ml) was added to the red oil to precipitate the last traces of succinimide. After filtration the filtrate was concentrated and the residual red oil was distilled under reduced pressure. The yield and boiling points are tabulated below.

Table 10

Physical data of some aromatic sulfenyl chlorides.

Sulfenyl chloride	Yield (%)	B.P. (°/mm)	Reported B.P. (°/mm)
 51	70	44/0.3	77.5-78.5/2.5[a]
 50	86	90/0.4	94/6.0[b]
 49	73	58/0.8	73-75/9.0[a]

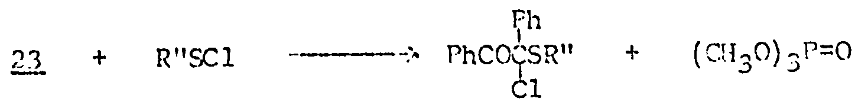
(a) Lecher, H., Holschneider, F., Koberle, K., Speer, W. and Stocklin, P., Ber., 58, 409 (1925). (b) Gebauer-Fulnegg, E., J. Amer. Chem. Soc., 49, 2270 (1927).

Reaction of Aromatic Sulfenyl chlorides with the 1:1-benzil-trimethyl phosphite adduct (23).

In a 50 ml three necked round bottom flask fitted with a dropping funnel, gas inlet tube and a condenser connected to a mercury trap, was placed benzil (2.10 g, 0.01 mole). The flask was flushed with dry nitrogen for 15 min. Trimethyl phosphite (1.24 g, 0.01 mole) was added; an exothermic reaction occurred immediately and the pale yellow viscous liquid was stirred for one hour. Benzene (10 ml) was added to dissolve the syrup. This was followed by the aromatic sulfenyl chloride (0.01 mole) in benzene (10 ml). As the addition continued, the deep red colour of the sulfenyl chloride changed to pale yellow. Once the addition was complete, the reaction mixture was stirred for one hour at room temperature. The solvent was removed on a flash evaporator and n-hexane (15 ml) was added to the residue. A white crystalline solid separated on cooling and was filtered and recrystallized from n-hexane-benzene. The melting points, yields, and analytical data of the aromatic chloro ketosulfides are summarized in Table 11. The reaction mixture showed the presence of trimethyl phosphate when compared with an authentic sample by gas chromatography using an Apiezon L column. No aromatic disulfides were detected.

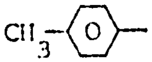
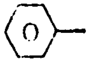
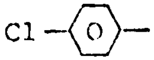
Table 11[**]

Physical and analytical data of α-benzoyl-α-chlorobenzyl sulfides 60.



$$\underline{23} + R''SCl \longrightarrow PhCO\overset{Ph}{\underset{Cl}{C}}SR'' + (CH_3O)_3P{=}O$$

60

R" in 60		M.P. °C	Yield(%)	Analytical data							
				Calculated				Found			
				C	H	S	Cl	C	H	S	Cl
	61	118-20	80	71.47	4.86	9.09	10.05	71.32	4.86	9.04	9.82
	62	113-15	82	70.88	4.46	9.46	10.46	70.94	4.52	9.35	10.02
	63	122.24	83	64.34	3.78	8.59	18.99	64.31	3.86	8.57	19.04

[**] See Table 3 on page 42 for nmr data.

Reaction of benzylsulfenyl chloride (53) with 1:1-benzil-trimethyl phosphite adduct (23).

The adduct 23 was generated from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, $\sim$0.01 mole) as described previously. Benzylsulfenyl chloride (53) was obtained by the chlorinolysis of benzyldisulfide (55) and the progress of the reaction was monitored by ^{1}H nmr. As the chlorinolysis progressed, the benzylic proton singlet at 6.50 τ (due to benzyldisulfide) (55) disappeared and a singlet (due to the benzylic protons of benzylsulfenyl chloride) (53) appeared at 5.73 τ. Benzyldisulfide (55) (1.23 g, 0.005 mole) in carbon tetrachloride (10 ml) was cooled to 0-5° and chlorine (0.36 g, $\sim$0.005 mole) was bubbled through the solution. The resulting yellowish red solution was stirred for 20 min. at 10° and added dropwise to adduct 23 in carbon tetrachloride (10 ml). The yellowish red colour was discharged as the addition progressed. After one hour at room temperature, the solvent was removed on a flash evaporator under reduced pressure; last traces were removed using a vacuum pump. The resulting white α-chloro-β-ketosulfide 64 was recrystallised from n-hexane-benzene. Yield 2.8 g (80%). m.p.:- 109-110°. ir, 1685 cm^{-1} (CO); nmr, 2.00-3.00 (15H, m); 6.15 (2H, AB, J = 12 HZ). Owing to the low stability of the α-chloro-β-ketosulfide 64, it was converted to the α-benzyloxy-β-ketosulfide for elemental analysis. To the reaction mixture obtained by adding benzylsulfenyl chloride (53) (0.01 mole) to adduct 23 (0.01 mole) in benzene (10 ml) was added benzyl alcohol (1.10 g, 0.01 mole) and silver carbonate (1.50 g). The mixture was stirred overnight at room temperature. Silver salts were removed by filtration and the filtrate was concentrated. The α-benzyloxy-β-ketosulfide so formed, was recrystallized from methanol. Yield 3.0 g (71%), m.p.:- 99-100°; ir, 1685 cm^{-1} (CO); nmr, 1.74-2.84 (20H, m), 5.34 (2H, AB, J = 11 HZ), 6.60 (2H, AB, J = 12.0 HZ).

Analytical data

Calculated for $C_{28}H_{24}O_2S$: C, 79.21; H, 5.70; S, 7.55;
Found: C, 79.19; H, 5.76; S, 7.53.

Reaction of ethane sulfenyl chloride (52) with 1:1-benzil-trimethyl phosphite adduct (23).

The adduct 23 was generated from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, 0.01 mole) as described previously. Ethane sulfenyl chloride (52) was obtained by the chlorinolysis of ethyl disulfide (55) at -20°. This reaction was monitored by nmr. As the chlorinolysis progressed the methylene quartet of ethyl disulfide (55) at 7.30 τ disappeared and instead a quartet at 6.90 τ due to the methylene protons of ethane sulfenyl chloride (52) appeared.

The disappearance of the quartet at 7.30 τ indicated the completion of the chlorinolysis. Chlorine (0.40 g) was allowed to evaporate into ethyl disulfide (55) (0.61 g, 0.005 mole) at -20°. The reaction mixture was stirred to dissolve the precipitated ethanesulfur trichloride. The resulting homogeneous red solution was added dropwise to 1:1-benzil-trimethyl phosphite adduct in methylene chloride (10 ml) with external cooling. As the addition progressed, the deep red colour of ethane sulfenyl chloride (52) disappeared. Once the addition was complete, the reaction mixture was stirred for 30 min. The solvent and trimethyl phosphate were removed under reduced pressure. The crude α-chloro-β-ketosulfide 65 was obtained as an oil. It was purified to some extent by repeated extraction with n-hexane and concentration of the n-hexane extracts. Yield 1.72 g (60%). ir, 1685 cm^{-1} (CO); nmr, 1.80-3.10 (10H, m), 7.30-7.90 (2H, m), 8.60-9.20 (3H, m). For analysis, the α-chloro-β-ketosulfide 65 was converted to the α-benzyloxy-β-ketosulfide. To the reaction mixture obtained by adding ethane sulfenyl chloride (52) to the adduct 23, was added benzyl alcohol (1.20 g) and silver carbonate (1.50 g). The reaction mixture was stirred overnight. Workup as before gave the α-benzyloxy-β-ketosulfide which on recrystallization from methanol melted at 104-6°. Yield 2.10 g (60%). ir, 1685 cm^{-1} (CO); nmr, 1.70-2.70 (15H, m), 5.23 (2H, AB, J = 11.5HZ), 7.37-8.27 (2H, m), 1.00 (3H, t, J = 8 HZ).

Analytical data

Calculated for $C_{23}H_{22}O_2S$: C, 76.21; H, 6.12; S, 8.85;
Found: C, 76.06; H, 6.12; S, 8.90.

Reaction of carbomethoxy methanesulfenyl chloride (54) with 1:1-benzil-trimethyl phosphite adduct (23).

The adduct 23 was prepared from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, ~0.01 mole) as described previously. Carbomethyoxymethanesulfenyl chloride (54) was generated by chlorinolysis of carbomethoxymethyl disulfide (57). As before, this reaction was monitored by nmr. As chlorinolysis progressed the singlet at 6.33 τ due to the methylene protons of the disulfide 57 decreased in intensity while the singlet at 5.97 τ due to the methylene protons in the sulfenyl chloride 54 increased in intensity. Carbomethoxymethyl disulfide (57) (1.05 g, 0.005 mole) was dissolved in carbon tetrachloride (10 ml) and the solution was cooled to 0-10° by an ice bath. Chlorine (0.80 g) was bubbled into the solution. As chlorinolysis proceeded, the solution turned orange and the colour deepened. The deep orange solution of the sulfenyl chloride 54 was added dropwise to the 1:1 adduct 23 in methylene chloride (10 ml) with external cooling.

The deep orange colour was discharged as the addition continued. At the end of the addition, the reaction mixture was stirred for 30 min. Then, solvent was removed under reduced pressure and n-hexane (10 ml) was added to filtrate. On cooling overnight, the α-chloro-β-ketosulfide 66 crystallized out. (Sometimes scratching was necessary to induce crystallization). Yield 2.5 g (75%), m.p.:- 65-7°. ir, 1685 cm^{-1} (CO); nmr, 1.90-2.65 (10H, m), 6.53 (2H, AB, J = 16 HZ), 6.34 (3H, s). For analysis, the α-chloro-β-ketosulfide 66 was converted to the α-benzyloxy-β-ketosulfide by treating the above reaction mixture with benzyl alcohol (1.20 g) and silver carbonate (1.50 g). Workup as before and recrystallization from methanol yielded pure α-benzyloxy-β-ketosulfide. Yield 2.5 g, (60%). m.p.:- 106-8°. ir, 1685 cm^{-1}(CO); nmr, 1.70-2.80 (15H, m), 7.03 (2H, s), 6.55 (3H, s), 5.32 (2H, AB, J = 11 HZ).

Analytical data

Calculated for $C_{24}H_{22}O_4S$: C, 70.91; H, 5.46; S, 7.88.

Found: C, 70.76; H, 5.57; S, 7.86.

Reaction of 2-benzothiazolesulfenyl chloride (58) with 1:1-benzil-trimethylphosphite adduct (23).

2-Benzothiazolesulfenyl chloride (58) was prepared by the action of sulfuryl chloride on 2,2'-dithiobis(benzothiazole) (59). To a suspension of freshly recrystallized 2,2'-dithiobis(benzothiazole) (59) (1.65 g, 0.005 mole) in methylene chloride (20 ml) at room temperature was added sulfuryl chloride (0.68 g, 0.005 mole). As the reaction progressed, the suspended disulfide 59 dissolved and the solution turned deep red. After 1 hr at room temperature, it was added to the adduct 23 prepared as before from benzil (2.10 g, 0.01 mole) and trimethylphosphite (1.25 g, 0.01 mole) in benzene (10 ml). As the addition progressed the deep red colour of 2-benzothiazolesulfenyl chloride (58) changed to pale yellow. Once the addition was complete the reaction mixture was stirred at room temperature for 1 hr. The solvent was removed under reduced pressure and the resulting pale yellow solid was recrystallized from methylene chloride-n-hexane. The α-chloro-β-ketosulfide 67 crystallized out as white plates. Yield 3.7 g (93%). m.p.:- 135.6°. ir, 1680 cm^{-1} (CO); nmr, 1.80-2.90 (m).

Analytical data

Calculated for $C_{21}H_{14}OS_2NCl$: C, 63.70; H, 3.56; N, 3.54; S, 16.20; Cl, 8.96. Found: C, 63.36; H, 3.56; N, 3.37; S, 16.31; Cl, 9.57.

Reaction of p-toluenesulfenyl chloride (51) with 1:1-benzil-tris(dimethylamino) phosphine adduct (25).

In a 50 ml, three necked round bottom flask fitted with a dropping funnel, gas inlet tube and a condenser connected to mercury trap was placed benzil (1.05 g, 0.005 mole). Dry methylene chloride (10 ml) was added to dissolve the benzil and the solution was cooled to 5°. The reaction system was flushed with dry nitrogen for 15 min. Tris(dimethylamino) phosphine (0.8 g, ~0.005 mole) was added dropwise with stirring. The yellow colour of the solution turned deep red and stirring was continued for 30 min. at 5°, after the addition was complete. p-Toluenesulfenyl chloride (51) (0.8 g, 0.005 mole) in methylene chloride (10 ml) was added to the adduct 25. After one hour at room temperature, the solvent was removed under reduced pressure and n-hexane (10 ml) was added to the residue. On cooling, a yellowish white solid precipitated out. Yield 0.8 g (45%). Recrystallization from n-hexane gave white needles melting at 117-18°. This product was shown to be identical to the α-chloro-β-ketosulfide 61 obtained from the 1:1-benzil-trimethylphosphite adduct-p-toluenesulfenyl chloride reaction by mixed melting point and ir. Chromatographic analysis of the mother liquor, using an Apiezon L column revealed the presence of the α-chloro-β-ketosulfide 61 and hexamethylphosphoramide (62). No p-tolyldisulfide was detected.

Preparation of 1:1-biacetyl-trimethylphosphite adduct (15).

This adduct 15 was prepared according to a reported procedure.[20] Biacetyl (14.8 g) was added dropwise to trimethylphosphite (27.0 g) under dry nitrogen, with stirring and external cooling. The mixture was then kept at 60° for 15 min. and submitted to fractional distillation. The colourless 1:1-biacetyl-trimethylphosphite adduct (15) was collected at 46°/0.6 mm. Reported b.p., 45-47°/0.5 mm. Yield 33.5 g (86%).

Reaction of benzenesulfenyl chloride (49) with 1:1-biacetyl-trimethylphosphite adduct (15).

Biacetyl-trimethylphosphite adduct (15) (2.10 g, 0.01 mole) was dissolved in carbon tetrachloride (10 ml) under dry nitrogen. The solution was cooled to 5°. Benzenesulfenyl chloride (49) (1.45 g, 0.01 mole) in carbon tetrachloride (5 ml) was added dropwise. An exothermic reaction occurred with a disappearance of the red colour of sulfenyl chloride 49 . At the end of the addition, the reaction mixture was stirred for ten minutes. The nmr spectrum of the reaction mixture showed the following; 2.30-2.90 (5H,m), 6.30 (3H, d, J = 12 HZ), 6.22 (3H, d, J = 12 HZ), 7.00 (3H, s), 7.63 (3H, s), 7.67 (3H, s), 7.80 (3H, s), 8.32 (3H, s).

Reaction of ethane sulfenyl chloride (52) with 1:1-biacetyl-trimethylphosphite adduct (15).

The above procedure was repeated using ethane sulfenyl chloride (52) (0.01 mole) instead of benzene sulfenyl chloride (49). The nmr spectrum of the reaction mixture showed the following:- 6.30 (3H, d, J = 12 HZ), 6.24 (3H, d, J = 12 HZ), 7.00 (3H, s), 7.62 (3H, s), 7.67 (3H, s), 7.82 (3H, s), 8.07 (3H, s), 7.10-7.90 (2H, m), 8.40-8.93 (3H, m).

Preparation of biacetylmonohydrazone.

The reported procedure for the preparation of biacetyl monohydrazone[110] has been modified as follows. A solution of biacetyl (10 ml) in benzene (10 ml) was cooled in an ice bath and anhydrous hydrazine (3.87 g) was added dropwise with stirring. About ten minutes after the addition was complete, a white solid precipitated out which was filtered. The crude monohydrazone was dissolved in hot benzene and this layer decanted. On cooling, biacetyl monohydrazone crystallized out. Yield 7.5 g (65%). m.p.:- 64-65°, reported m.p. 67°.[110]

Preparation of azibutanone.

Two procedures were used to prepare azibutanone from biacetyl monohydrazone.

Procedure I: using silver oxide.

Biacetyl monohydrazone (6.0 g) in methylene chloride (20 ml) was added to vigorously stirred suspension of silver oxide (20 g) and anhydrous sodium sulfate (20 g) in methylene chloride (80 ml). After the initial reaction had subsided, the mixture was stirred at room temperature for 24 hrs. The inorganic salts were removed by filtration. The residue was washed with several portions of methylene chloride until the washings were devoid of yellow colour. The washings were combined and concentrated on a flash evaporator. The residual red oil was distilled under reduced pressure using a water aspirator. The product boiling at 32°/7 mm was collected. Yield 3.0 g (51%). Reported b.p. 45°/12-13 mm.[110] ir, 1650 cm^{-1} (CO), 2070 cm^{-1}(-N=N); nmr, 7.85 (3H, s), 8.22(3H, s).

Procedure II: using mercuric oxide (yellow).

Biacetyl monohydrazone (10.0 g) in methylene chloride

(50 ml) was added to a vigourously stirred suspension of yellow mercuric oxide (22 g) and anhydrous sodium sulfate (30 g) in methylene chloride (150 ml) containing two drops of alcoholic sodium hydroxide. After the initial reaction had subsided, the mixture was stirred for 24 hrs. Azibutanone was isolated by a similar workup as in Procedure I. Yield 9.0 g (90%).b.p. 32°/7mm.

Preparation of α-acetyl-α-chloroethyl-phenyl sulfide (72).

Benzenesulfenyl chloride (49) (1.45 g, 0.01 mole) in carbon tetrachloride (10 ml) was added dropwise to a solution of azibutanone (0.98 g, 0.01 mole) in carbon tetrachloride (10 ml) at -10°. As the addition continued, the deep red colour of the sulfenyl chloride 49 and the orange colour of azibutanone turned lighter with vigourous evolution of nitrogen. At the end of addition, a light yellow colour was obtained. The solvent was removed and the residual oil distilled under reduced pressure. The α-chloro-β-ketosulfide 72 distilled at 126°/0.005 mm as a pale yellow oil. Yield 1.7 g (80%). ir. 1725 cm^{-1} (CO); nmr, 2.20-2.70 (5H, m), 7.62 (3H, s), 8.21 (3H, s). Exact mass data: calculated for $C_{10}H_{11}OSCl$, 214.0219. Found; 214.0224.

Preparation of α-acetyl- -chloroethyl-ethyl sulfide (74).

Ethyl disulfide (55) (2.44 g, 0.02 mole) was reacted at -30° with chlorine (1.42 g, 0.02 mole). The deep red ethanesulfenyl chloride (52) was added dropwise to azibutanone (3.95 g, 0.04 mole) in carbon tetrachloride (30 ml) at -20°. As the addition continued, the colour of the reaction mixture became lighter and was accompanied by the evolution of nitrogen. After the addition was complete, the solvent was removed on a flash evaporator and the residue yellow oil was distilled under reduced pressure. The α-chloro-β-ketosulfide 74 distilled at 44°/0.1 mm as a pale yellow oil. Yield 5.6 g (84%). Owing to its low stability at room temperature, the product was stored in dry ice. ir, 1730 cm^{-1} (CO); nmr, 7.30 (2H, AB, J = 7 HZ), 7.59 (3H, s), 8.03 (3H, s), 8.75 (3H, split t, J = 7 HZ). Exact mass data: Calculated for $C_6H_{11}OSCl$, 166.0219. Found, 166.0204.

Preparation of Dimethylphosphorochloridate.

Trimethyl phosphite (7.4 g) in benzene (15 ml) was cooled in an ice bath. Chlorine gas was bubbled through the solution until it turned pale yellow. The solvent and other volatile products were removed on a flash evaporator and the residue was distilled under reduced pressure. Yield 7.2 g (85%), B.P.:- 66°/10 mm. Reported b.p. 75-80°/20-25 mm.[111]

Preparation of S-methyl isothiuronium dimethyl phosphate.

This compound was prepared by a modification of the reported procedure.[112] In a 150 ml flask, fitted with a reflux condenser carrying a drying tube, was placed trimethyl phosphate (14.0 g), thiourea (7.6 g) and acetonitrile (35 ml). The reaction mixture was stirred and refluxed. The thiourea dissolved on warming and after 1 1/2 hrs a white solid precipitated out from the clear solution and refluxing was continued for another 2 hrs. The reaction mixture was cooled and white crystals of S-methyl isothiouronium dimethylphosphate were filtered out. Yield 17.7 g (82%), m.p. 139-41°; reported m.p. 136°.[112]

Attempted preparation of α-acetyl-α-phenylthioethyl dimethyl phosphate (73).

Procedure I: using dimethyl phosphorochloridate.

Benzenethiol (1.10 g, 0.01 mole) was added to neat biacetyl (0.86 g, 0.01 mole) in a 15 ml flask fitted with a condenser and drying tube. Once the exothermic reaction had subsided, dimethyl phosphorochloridate (1.45 g, 0.01 mole) was added and the reaction mixture was stirred for 2 days at room temperature. Analysis of the reaction mixture by nmr indicated no reaction. On heating, extensive decomposition occurred.

Procedure II: using dimethyl phosphorochloridate and pyridine.

To the mixture of benzenethiol (1.10 g, 0.01 mole) and biacetyl (0.86 g, 0.01 mole) prepared as in Procedure I, was added dimethyl phosphorochloridate (1.45 g, 0.01 mole) and pyridine (0.80 g, 0.01 mole). The reaction mixture was stirred at room temperature for 2 days. Analysis of the reaction mixture by nmr indicated the presence of biacetyl as the major product. Extensive decomposition occurred on heating.

Procedure III: using S-methyl isothiouronium dimethyl phosphate.

α-Acetyl-α-chloro ethyl-phenyl sulfide (72) (2.15 g, 0.01 mole) was dissolved in acetonitrile (10 ml). S-Methyl isothiouronium dimethyl phosphate (2.16 g, 0.01 mole) was added and the reaction mixture was warmed to 60° for 2-3 hrs. The mixture was cooled and filtered. After removal of acetonitrile, a black tarry product was obtained. Analysis of this product by nmr indicated a complex mixture.

Procedure IV: using silver dimethyl phosphate.

Silver dimethyl phosphate was prepared according to the reported procedure.[113] Silver dimethyl phosphate (2.33 g, 0.01 mole) was used instead of S-methyl isothiouronium dimethyl phosphate in Procedure III. A complex mixture of decomposition products was obtained.

Reaction of p-toluene sulfenyl chloride (51) with 1:1-benzil-trimethyl phosphite adduct (23) in the presence of 1,3,5-trinitrobenzene as free radical inhibitor.

The adduct 23 was generated as described previously from benzil (2.10 g, 0.01 mole) and trimethylphosphite (1.25 g, 0.01 mole). It was dissolved in benzene (10 ml) and 1,3,5-trinitrobenzene (0.2 g) was added. The colour changed to deep red. p-Toluenesulfenyl chloride (51) (1.58 g, 0.01 mole) in benzene (5 ml) was added dropwise. At the end of the addition, the yellow reaction mixture was stirred for an additional 10 min. Benzene was removed on a flash evaporator and the residue recrystallized from n-hexane-methylene chloride mixture. Yield 2.8 g (80%). m.p.:- 120-122°. This product was shown to be identical with α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) by mixed melting point and ir spectra.

Gas chromatographic analysis of the mother liquor on Apiezon-L column showed the presence of trimethyl phosphate and α-chloro-β-ketosulfide 61.

Reaction of p-toluenesulfenyl chloride (51) with azibenzil (91).

In a 50 ml erlenmeyer flask equipped with a magnetic stirrer was placed dry monoglyme (10 ml). Azibenzil (91) (2.22 g, 0.01 mole) was added with stirring and the resulting orange solution was cooled in an ice bath. p-Toluene sulfenyl chloride (51) (1.59 g, 0.01 mole) was added dropwise to the azibenzil solution. As the addition progressed, the orange colour of the azibenzil solution became lighter with evolution of nitrogen. Once the addition was complete, the pale yellow solution was stirred for 10 min. at room temperature. The solvent was removed and the residue was recrystallized from n-hexane-methylene chloride. The yield of white crystalline product was 3.2 g (93%). m.p.:- 120-122°. This product was shown to be identical with α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) by mixed melting point and ir spectra.

Reaction of Azibenzil (91) with styrene.

A solution of azibenzil (91) (4.4 g, 0.02 mole) and styrene (2.1 g, 0.02 mole) containing few crystals of 1,3,5-trinitrobenzene (polymerization inhibitor) in ether (10 ml) was heated under reflux for 41 hrs. At the end of the reflux period, the solvent was removed under reduced pressure and the residual orange viscous oil was dissolved in acetic acid and cooled. The yellow crystals were separated by filtration and recrystallized from ethanol. Pale yellow crystals (3.1 g, 52%) of 2,2,3-triphenyl cyclobutanone (<u>92</u>) melting at 136-8° were obtained. This product on further recrystallization from n-hexane-methylene chloride yielded white crystals melting at 137-8°. Reported m.p. 132-6°.[79] ir, 1775 cm^{-1} (CO); nmr, 2.20-3.20 (15H, m), 5.47 (2H, split t, J = 9 HZ), 6.50 (2H, d, J = 9 HZ).

<u>Attempted reaction of 1:1-benzil-trimethylphosphite adduct (<u>23</u>) with styrene.</u>

The adduct <u>23</u> was generated as described previously from benzil (2.10 g, 0.01 mole) and trimethylphosphite (1.25 g, 0.01 mole). It was dissolved in dry ether (10 ml) and styrene (1.05 g, 0.01 mole) containing a few crystals of 1,3,5-trinitrobenzene were added. The reaction mixture was refluxed for 41 hrs and monitored by gas chromatography using Apiezon L and UCW-98 columns and by tlc on silica gel using 1:1-methylene chloride-hexane as eluent. The analysis of the reaction mixture showed the absence of 2,2,3-triphenylcyclobutanone (<u>92</u>).

Preparation of 2,4,6-trinitrobenzene sulfonic acid.

The reported procedure[114] was slightly modified for the preparation of this sulfonic acid. To picryl chloride (10 g, 0.04 mole) in absolute ethanol (100 ml) was added anhydrous sodium metabisulfite (10 g, 0.053 mole). The mixture was heated under reflux with **vigo**rous stirring for 3 hrs and then cooled to below 5° and filtered. The crude sodium salt was washed with several portions of cold absolute ethanol until the wash solution was colourless. After the solid was air dried for 15 min., it was mixed with reagent grade acetone (30 ml). Then concentrated hydrochloric acid (10 ml) was added with swirling over a 5 minute period. The precipitated sodium chloride was removed by filtration and washed with acetone (10 ml). The acetone solvent and excess water were removed at reduced pressure with gentle heating on a water bath. The light yellow product so formed was recrystallized from acetone-chloroform. The sulfonic acid was dried for 3 hrs, at 80°, under 1 mm pressure over phosphorus pentoxide. Yield 10.6 g (90%). m.p. 189-93°. Reported m.p. 193-5°.[114]

Preparation of silver 2,4,6-trinitrobenzene sulfonate.

A modification on the reported procedure[114] was adopted for the preparation of this silver salt. A solution of silver nitrate (6.8 g, 0.04 mole) in warm water ([illegible] ml) was added in one portion to 2,4,6-trinitrobenzene sulfonic acid (8.8 g, 0.03 mole) in warm water (20 ml). The mixture was cooled and the product was collected by filtration. The silver salt was washed with cold ethanol (25 ml) and ether (25 ml), then dried over phosphorus pentoxide at 80° and at 1 mm pressure overnight. Yield 9.4 g (78%).

Attempted preparation of α-benzoyl-α-p-tolylthiobenzyloxy-trimethoxy phosphonium- 2,4,6-trinitrobenzene sulfonate (100).

Silver 2,4,6-trinitrobenzene sulfonate (4.00 g, 0.01 mole) was dissolved in acetonitrile (10 ml), and the solution was cooled to 0°. p-Toluenesulfonyl chloride (51) (1.58 g, 0.01 mole) in acetonitrile (10 ml) was added dropwise. An exothermic reaction occurred at once and silver chloride was precipitated as a white solid. Once the addition was complete, the reaction mixture was stirred for 10 min. at 0° and silver chloride was filtered out. The filtrate was added dropwise to a solution of 1:1-benzil-trimethylphosphite adduct (23) prepared from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, 0.01 mole) in acetonitrile (10 ml) at 0° under nitrogen. A dark red solution was obtained. Acetonitrile was removed under reduced pressure. Nmr analysis of the residue indicated that a complex mixture of products were present.

Attempted preparation of α-benzoyl-α-p-tolylthiobenzyloxy-trimethoxy phosphonium hexachloro antimonate (101).

p-Toluene sulfenyl chloride (51) (1.58 g, 0.01 mole) in methylene chloride (10 ml) was added dropwise to a solution of antimony pentachloride (2.99 g, 0.01 mole) in methylene chloride (10 ml) at 0° under nitrogen. An exothermic reaction set in and the solution turned green. This solution was added dropwise to a solution of 1:1-benzil-trimethylphosphite adduct (23) generated from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, 0.01 mole) under nitrogen in methylene chloride (10 ml) at 0°. The colour of the reaction mixture turned from green to dark red. At the end of the addition, the reaction mixture was stirred for 10 min. at 0°. Methylene chloride was removed and the residue showed a complex mixture by nmr.

Reaction of α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) with methanol.

α-Benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) (0.5 g) and silver carbonate (0.5 g) were added to methanol (10 ml) and the reaction mixture was kept at 60° for five minutes. Silver salts were removed by filtration. The filtrate on evaporation yielded α-benzoyl-α-methoxybenzyl-p-tolyl sulfide (102). Yield 0.4 g, (80%). m.p.:- 107-9° after recrystallization from methanol. ir, 1675 cm^{-1} (CO); nmr, 1.93-3.13 (14 H, m), 6.43 (3H, s), 7.75 (3H, s).

Analytical data

Calculated for $C_{22}H_{20}O_2S$: C, 75.83; H, 5.79; S, 9.20.
Found: C, 75.86; H, 5.89; S, 9.25.

Reaction of α-benzoyl-α-chlorobenzyl-p-tolyl sulfide (61) with trichlorosilane (105) and tri-n-butylamine (108).

In a 50 ml flask, fitted with a condenser carrying a drying tube and a dropping funnel, was dissolved α-benzoyl-α-chlorobenzyl sulfide (61) (0.70 g, 0.02 mole) in dry 1,2-dimethoxyethane (10 ml). Tri-n-butylamine (108) (0.37 g, 0.02 mole) was added, followed by trichlorosilane(105) (0.36 g, 0.026 mole). The reaction mixture was refluxed for 2-3 hrs. At the end of the reflux period, it was cooled and poured into a cold solution of 2N sodium hydroxide with stirring. The sodium hydroxide solution was extracted with several portions of methylene chloride. The methylene chloride extracts were combined and washed successively with water, dilute acid and then water and dried over anhydrous sodium sulfate. The solvent was removed under reduced pressure and the residual solid recrystallized from ethanol (95%). Yield 0.62 g, (98%). m.p.:- 91-3°. See Tables 7 and 12 for spectroscopic and analytical data.

Reaction of α-benzoyl-α-chlorobenzyl sulfide 60 prepared in situ with trichlorosilane (105) and tri-n-butylamine (108).

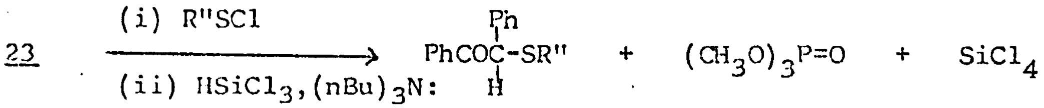
1:1-Benzil-trimethylphosphite adduct (23) was generated as described before from benzil (2.10 g, 0.01 mole) and trimethyl phosphite (1.25 g, 0.01 mole). Dry 1,2-dimethoxyethane (10 ml) was added, followed by sulfenyl chloride (0.01 mole) in the same solvent (10 ml). The pale yellow solution was stirred for 15 min. Tri-n-butylamine (108) (1.85 g, 0.01 mole) and trichlorosilane (105) (1.80 g) were added. The reaction mixture was refluxed with stirring for 2-3 hrs. The reaction mixture was worked up as in the previous experiment. The product crystallized out from ethanol (95%). The yield, m.p., analysis and spectroscopic data are summarized in Tables 7 and 12.

Reaction of α-acetyl-α-chloroethyl phenyl sulfide (72) with trichlorosilane (105) and tri-n-butylamine (108).

In 50 ml round bottom flask, fitted with a condenser carrying a drying tube and a dropping funnel, was dissolved

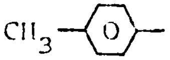
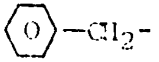
Table 12**

Physical and analytical data of β-ketosulfides.



$$23 \xrightarrow[\text{(ii) } HSiCl_3,(nBu)_3N:]{\text{(i) } R''SCl} PhCO\overset{Ph}{\underset{H}{C}}-SR'' + (CH_3O)_3P{=}O + SiCl_4$$

115

R" in 115	m.p. (°)	Yield (%)	Analysis data					
			Calculated			Found		
			C	H	S	C	H	S
 112	94-6	80	79.21	5.70	10.07	79.16	5.72	9.98
 113	70-2	60	79.21	5.70	10.07	79.02	5.75	9.97
CH_3CH_2- 114	78-80	62	74.96	6.29	12.51	74.85	6.33	12.43

** See Table 7 on page 84 for ir and nmr data.

α-acetyl- α-chloroethyl-phenyl sulfide (72) (1.20 g) in 1,2-dimethoxyethane (10 ml). Tri-n-butylamine (108) (1.10 g) and trichlorosilane (105) (1.40 g) were added and the reaction mixture was refluxed overnight with stirring. Then, the cooled reaction mixture was poured into 2N sodium hydroxide solution and extracted with methylene chloride. The extract was washed successively with water, dilute acid and water, dried over anhydrous sodium sulfate. The solvent was removed on a flash evaporator and the residual oil distilled under reduced pressure. α-Acetyl ethyl-phenyl sulfide (118) distilled over at 78-80° at 0.003 mm. Yield 0.80 g (80%). ir, 1720 cm^{-1} (CO); nmr, 2.30-2.85 (5H, m), 6.29 (H, q, J = 7 HZ), 7.80 (3H, s), 8.63 (3H, d, J = 7 HZ). Exact mass data: Calculated for $C_{10}H_{12}OS$, 180.0609; Found, 180.0608.

Analytical data

Calculated for $C_{10}H_{12}OS$: S, 17.79. Found: S, 17.85.

Attempted reaction of α-acetyl- α-chloroethyl-ethyl sulfide (74) with trichlorosilane (105) and tri-n-butylamine (108).

The procedure described in the previous experiment was repeated with α-acetyl- α-chloroethyl-ethyl sulfide (74) (1.66 g), trichlorosilane (105) (1.80 g) and tri-n-butylamine

(108) (1.85 g). A black tarry product was obtained, probably due to decomposition of the starting material.

Reaction of α-acetyl-α-chloroethyl sulfides (70) prepared in situ with trichlorosilane (105) and tri-n-butylamine (108).

Benzenesulfenyl chloride (49) (1.45 g, 0.01 mole) was added to a solution of 1:1-biacetyl-trimethylphosphite adduct (15) (2.10 g, 0.01 mole) in 1,2-dimethoxyethane (10 ml) under nitrogen. Once the exothermic reaction was over, trichlorosilane (105) (1.80 g) and tri-n-butylamine (108) (1.85 g) were added and the reaction mixture was refluxed overnight. The cooled reaction mixture was poured into cold 2N sodium hydroxide solution and extracted with methylene chloride. The extract was washed with water, dilute acid and then water, dried over anhydrous sodium sulfate. After the removal of solvent under reduced pressure, the residual oil was chromatographed on florisil using methylene chloride. Pure α-acetylethyl-phenyl sulfide (118) was obtained after concentrating the methylene chloride fractions. Yield 1.10 g (61%). Spectroscopic data were identical with the sample prepared previously.

When ethane sulfenyl chloride (52) was used instead of benzenesulfenyl chloride (49) in the above procedure, an intractable tarry product was obtained.

Reaction of α-benzoyl- α-chlorobenzyl sulfides (60) with potassium thiocyanate. Formation of 5,5-diphenyl-4-p-tolyl (or benzyl) thio — 3-oxazoline-2(1H)-2-thiones. 132.

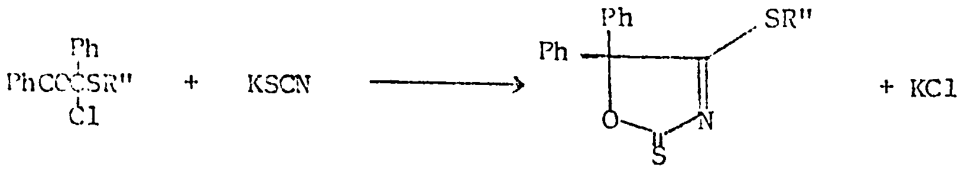
Potassium thiocyanate (0.50 g) was added to a solution of α-benzoyl- α-chlorobenzyl sulfide 60 (0.05 mole) in anhydrous acetone (10 ml) at room temperature. After few minutes the potassium thiocyanate completely dissolved and the solution turned cloudy. A white solid appeared on the walls of the flask and the reaction mixture was stirred overnight. The white solid (potassium chloride) was filtered and washed with several portions of dry acetone. The acetone washings were combined and concentrated under reduced pressure. The resulting dark red oily residue was dissolved in ether and the ether solution was filtered to remove any inorganic salts. The orange oily residue obtained after removing the ether was purified by column chromatography on florisil using 1:1-hexane-methylene chloride as eluent. The yellow oil obtained after concentrating the fractions was homogeneous on tlc (solvent: 1:1-hexane-methylene chloride). The yields and analytical data are summarized in Table 13.

Attempted reaction of α-acetyl- α-chloroethyl sulfides 70 with potassium thiocyanate.

α-Acetyl- α-chloroethyl sulfide 70 (0.05 mole) was used instead of α-benzoyl- α-chlorobenzyl sulfide 60 and the same procedure was repeated. The crude product obtained after workup decomposed on attempted purification by column chromatography and on distillation under reduced pressure.

Table 13

Physical and analytical data of 5,5-diphenyl-4-benzyl (and p-tolyl) thio-3-oxazoline-2(5H)-2-thiones.**



60

132

R" in 132	Yield (%)	Analytical data							
		Calculated				Found			
		C	H	N	S	C	H	N	S
$CH_3-C_6H_4-$ 133	82	70.37	4.56	3.73	17.08	70.24	4.61	3.63	16.94
$C_6H_5-CH_2-$ 134	90	70.37	4.56	3.73	17.08	70.34	4.70	3.70	17.02

** See Table 8 on page 96for nmr and uv data.

CONCLUSIONS AND CLAIMS TO ORIGINAL WORK.

It has been demonstrated that 1,3,2-dioxaphospholenes undergo facile condensation with sulfenyl chlorides. The nature and the number of products depend on the structure of the 1,3,2-dioxaphospholenes. The 1:1 adduct from benzil and trimethyl phosphite condenses with a wide variety of sulfenyl chlorides to form α-benzoyl-α-chlorobenzyl sulfides and trimethyl phosphate. In addition, the 1:1 adduct from benzil and tris(dimethylamino)phosphine, reacts with p-toluene sulfenyl chloride affording α-benzoyl-α-chlorobenzyl-p-tolyl sulfide and hexamethyl phosphoramide. In contrast, the 1:1 adduct from biacetyl and trimethyl phosphite condenses with benzene and ethane sulfenyl chlorides to form a mixture of products identified as α-acetyl-α-chloroethyl-phenyl (or ethyl) sulfide, trimethyl phosphate, α-acetyl-α-phenyl (or ethyl) thioethyl-dimethyl phosphate and methyl chloride. In general, this condensation reaction provides a convenient route to generate in one step, α-chloro-α-ketosulfides in high yield from readily available compounds. The condensation is rationalized in terms of a "sulfenium chloride" mechanism.

Thermally stable α-chloro-β-ketosulfides are converted to the corresponding β-ketosulfides in good yield by trichlorosilane and tri-n-butylamine. This reaction can be carried out in one step by converting the chloro ketosulfides in situ.

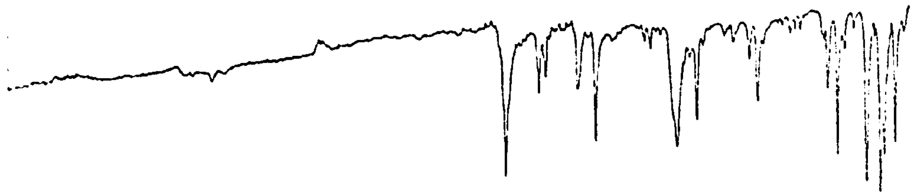
α-Benzoyl-α-chlorobenzyl sulfides were shown to react with potassium thiocyanate to give 4-thiosubstituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones in high yield. The ready availability of α-chloro-β-ketosulfides and their clean reaction with potassium thiocyanate provides a general synthetic route to the new heterocyclic system.

The mass spectra of a variety of α-chloro-β-ketosulfides, β-ketosulfides and 4-thiosubstituted-5,5-diphenyl-3-oxazoline-2(1H)-2-thiones are discussed. Several fragmentation pathways are suggested and rationalized by exact mass measurements and metastable peaks.

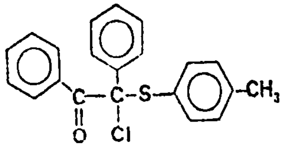
During the course of this investigation several pure sulfenyl chlorides were prepared for the first time by modified procedures. The use of nmr to assay the purity of labile sulfenyl chlorides is introduced and the advantages over the other assay methods are discussed.

Appendix

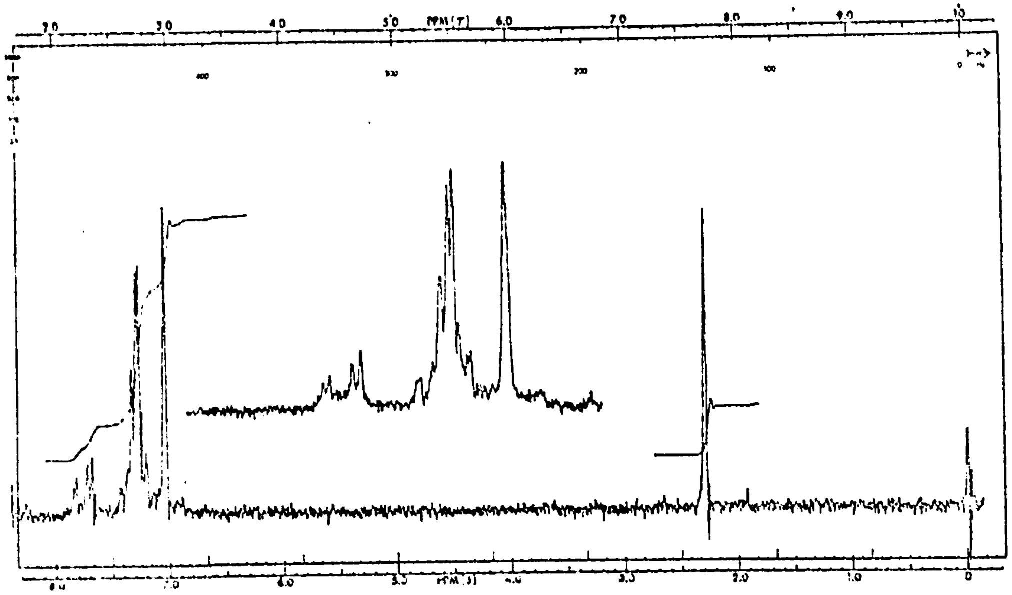
Spectra



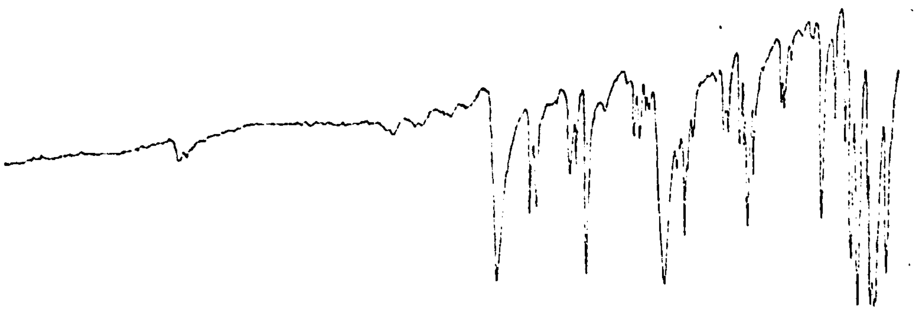
ir spectrum of α-benzoyl-α-chlorobenzyl-p-tolyl sulfide, (61).



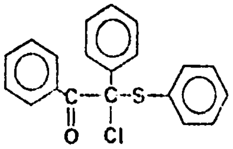
61



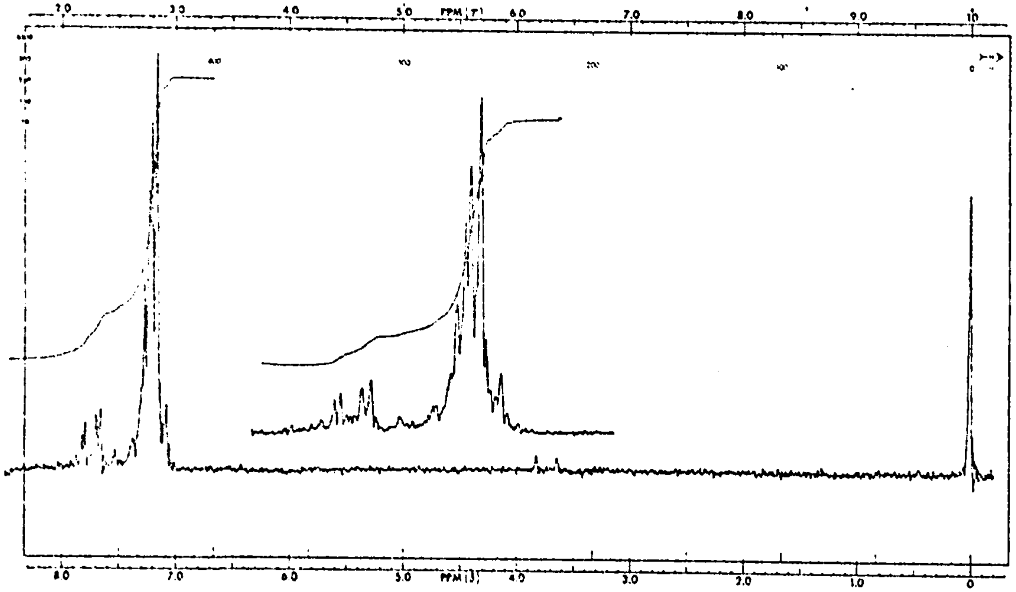
nmr spectrum of α-benzoyl-α-chlorobenzyl-p-tolyl sulfide, (61).



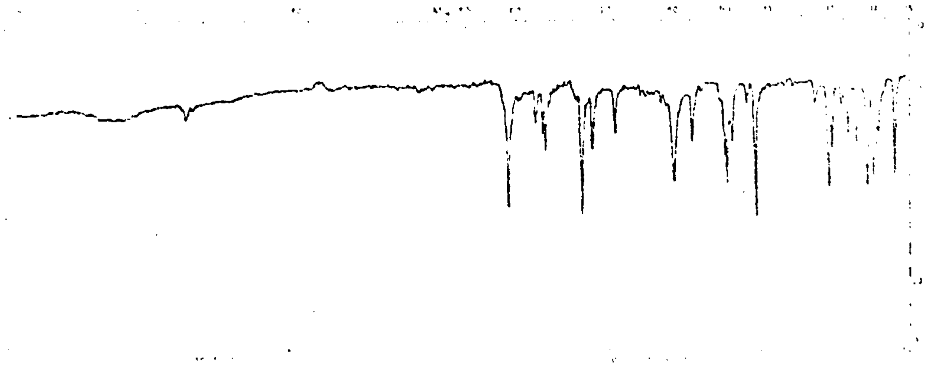
ir spectrum of α-benzoyl-α-chlorobenzyl-phenyl sulfide,(62).



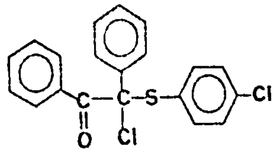
62



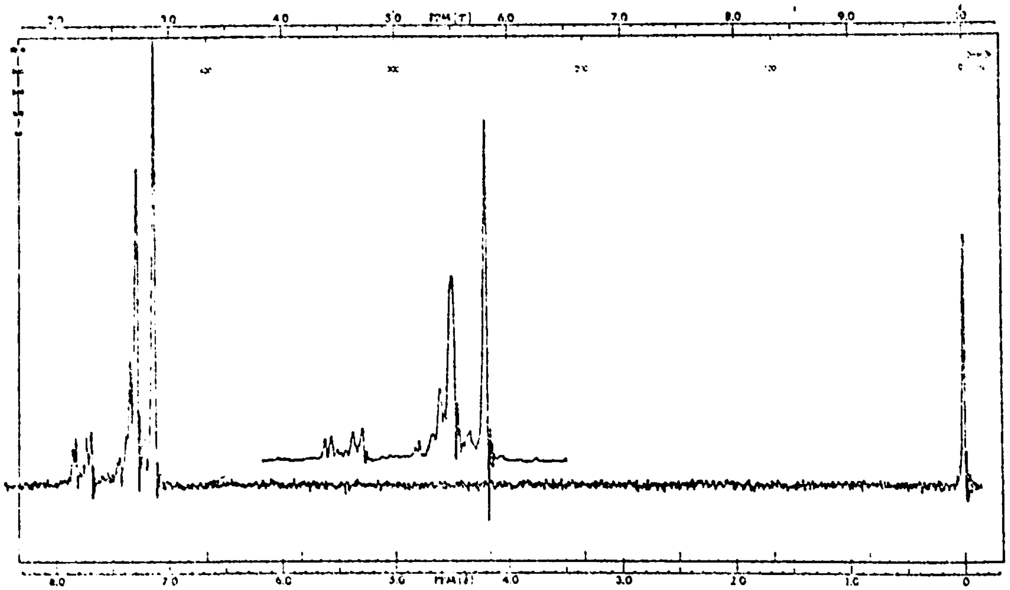
nmr spectrum of α-benzoyl-α-chlorobenzyl-phenyl sulfide,(62).



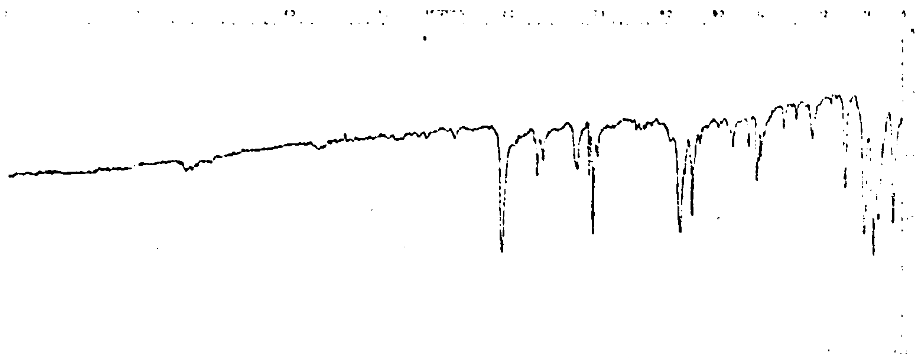
ir spectrum of α-benzoyl-α-chlorobenzyl-p-chlorophenyl sulfide,(63).



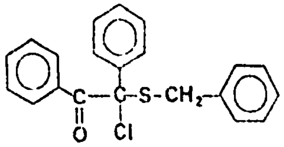
63



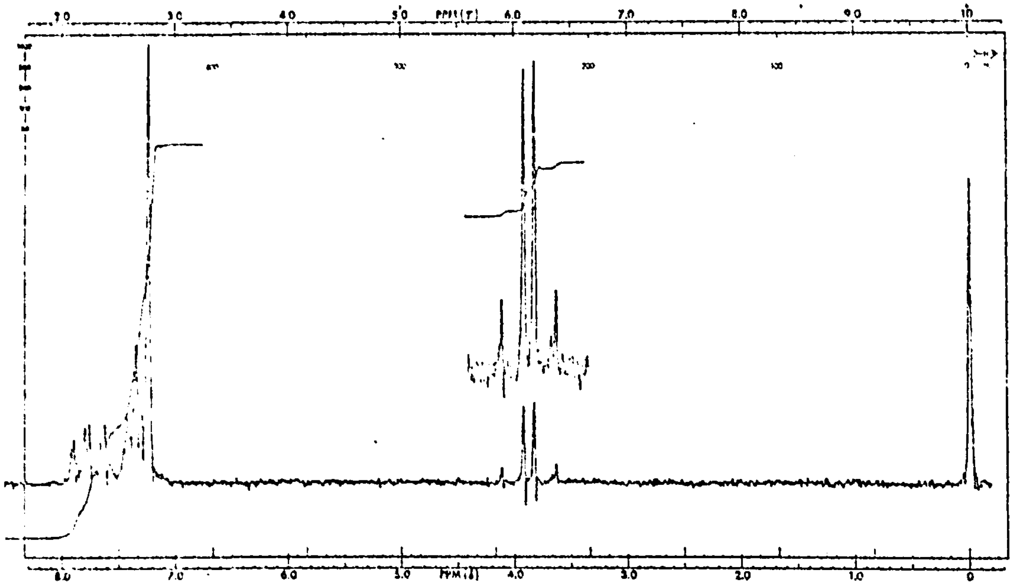
nmr spectrum of α-benzoyl-α-chlorobenzyl-p-chlorophenyl sulfide,(63).



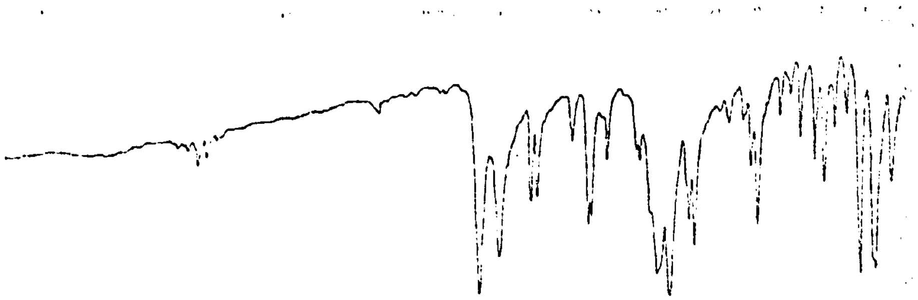
ir spectrum of α-benzoyl-α-chlorobenzyl-benzyl sulfide,(64).



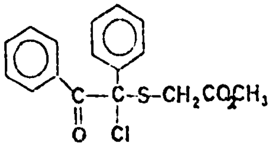
64



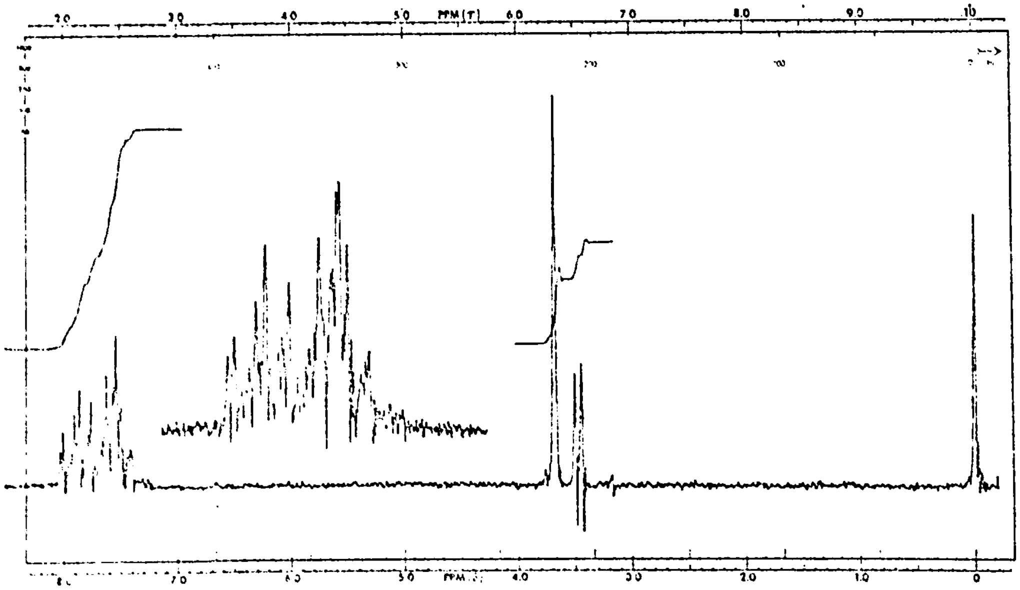
nmr spectrum of α-benzoyl-α-chlorobenzyl-benzyl sulfide,(64).



ir spectrum of α-benzoyl-α-chlorobenzyl-carbomethoxymethyl sulfide,(66).

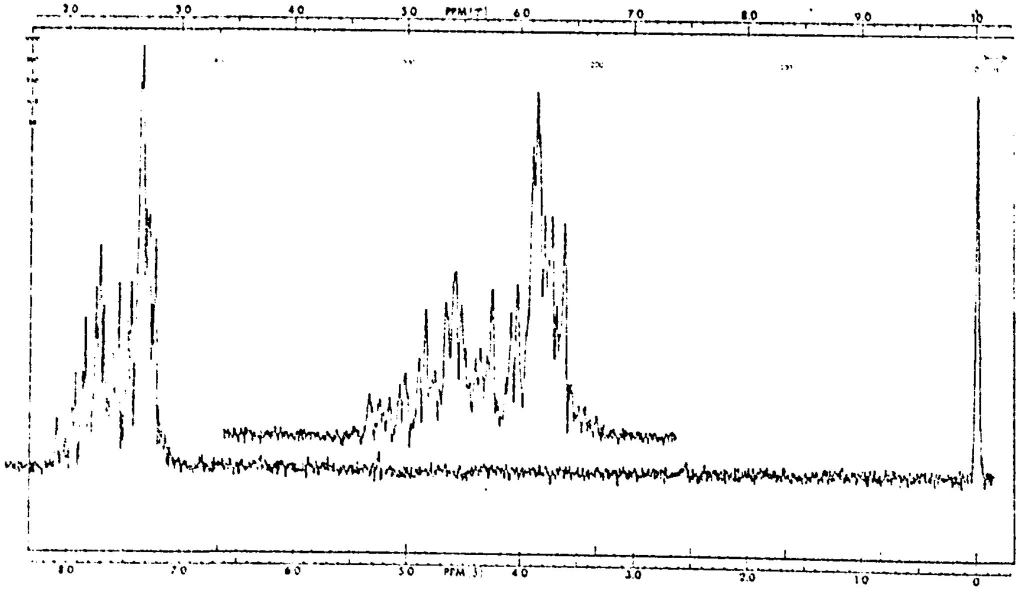


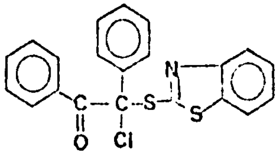
66



nmr spectrum of α-benzoyl-α-chlorobenzyl-carbomethoxymethyl sulfide,(66).

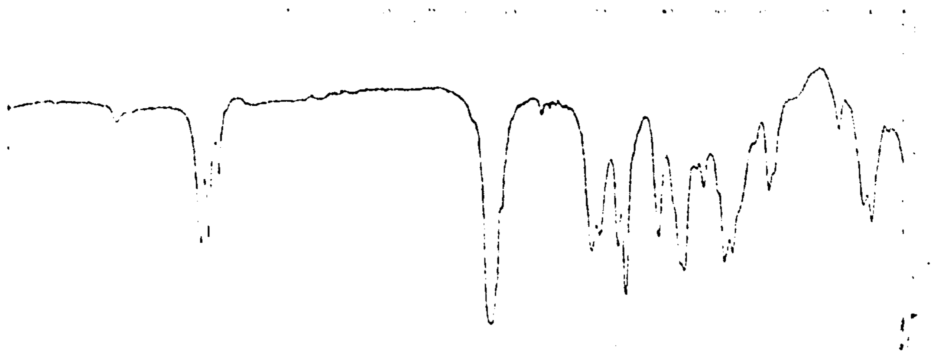
ir spectrum of α-benzoyl-α-chlorobenzyl-2-benzothiazoyl sulfide, (67).



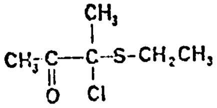


67

nmr spectrum of α-benzoyl-α-chlorobenzyl-2-benzothiazoyl sulfide, (67).

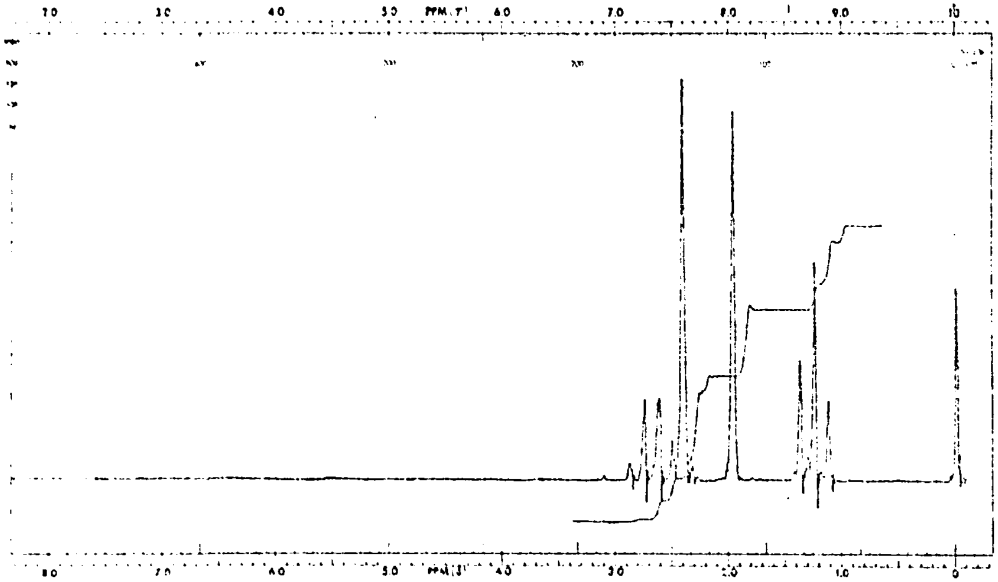


ir spectrum of α-acetyl-α-chloroethyl-ethyl sulfide, (74).

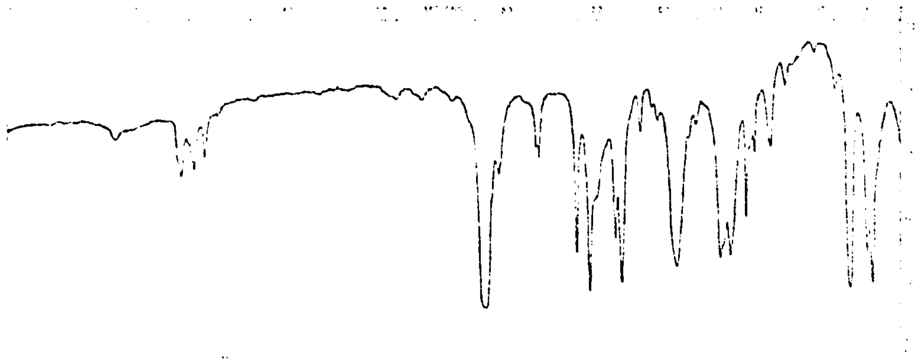


$$CH_3C(=O)C(CH_3)(Cl)SCH_2CH_3$$

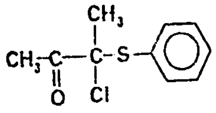
74



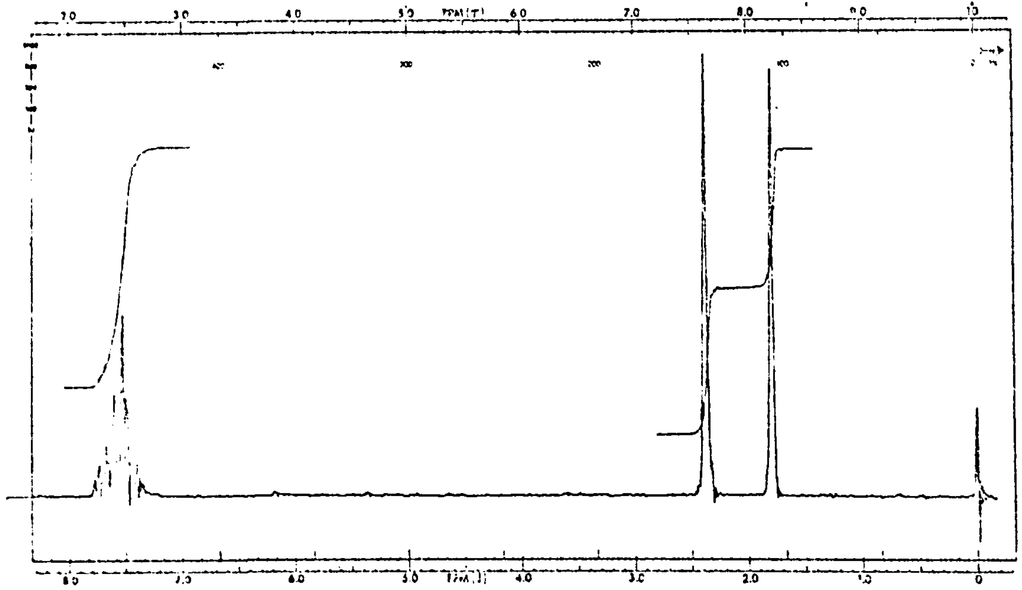
nmr spectrum of α-acetyl-α-chloroethyl-ethyl sulfide, (74).



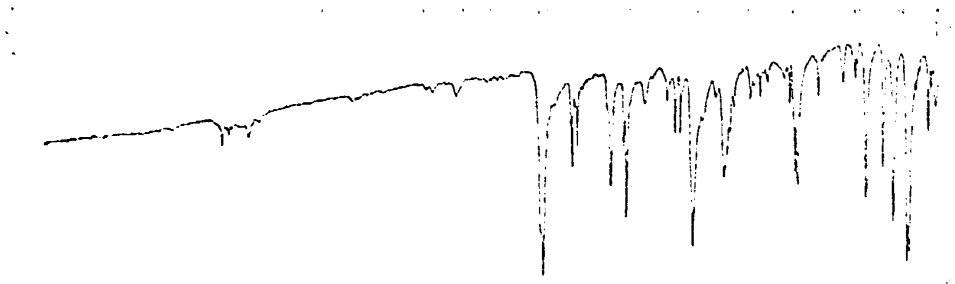
ir spectrum of α-acetyl-α-chloroethyl-phenyl sulfide, (72).



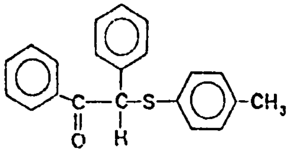
72



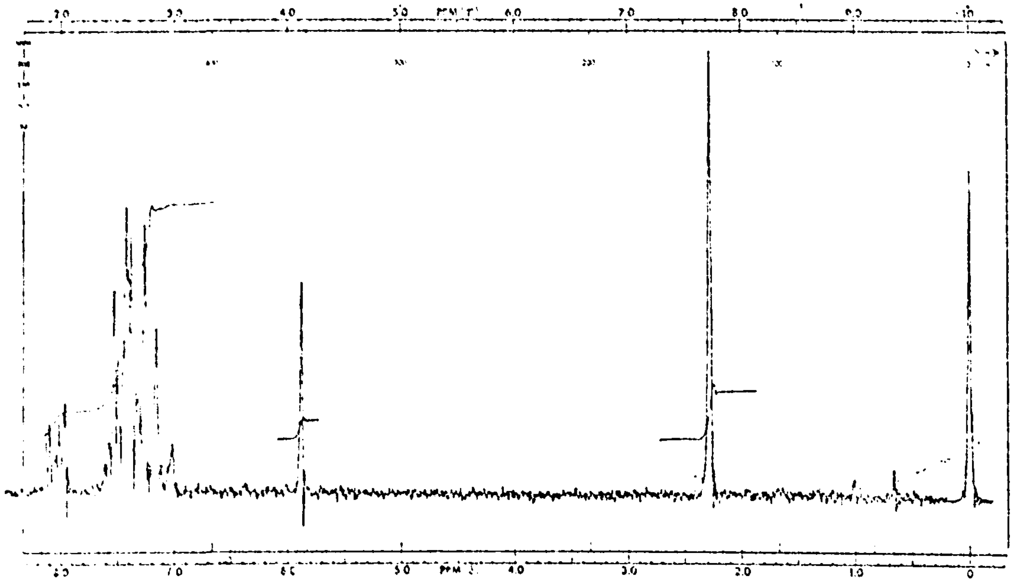
nmr spectrum of α-acetyl-α-chloroethyl-phenyl sulfide, (72).



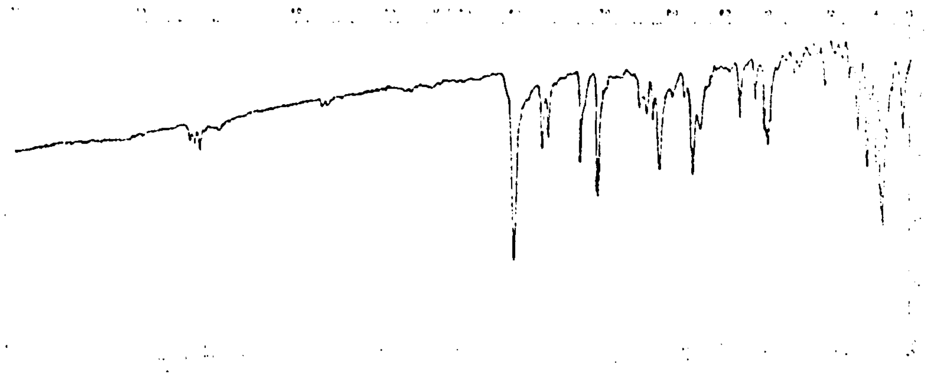
ir spectrum of α-benzoylbenzyl-p-tolyl sulfide, (112).



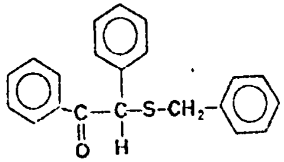
112



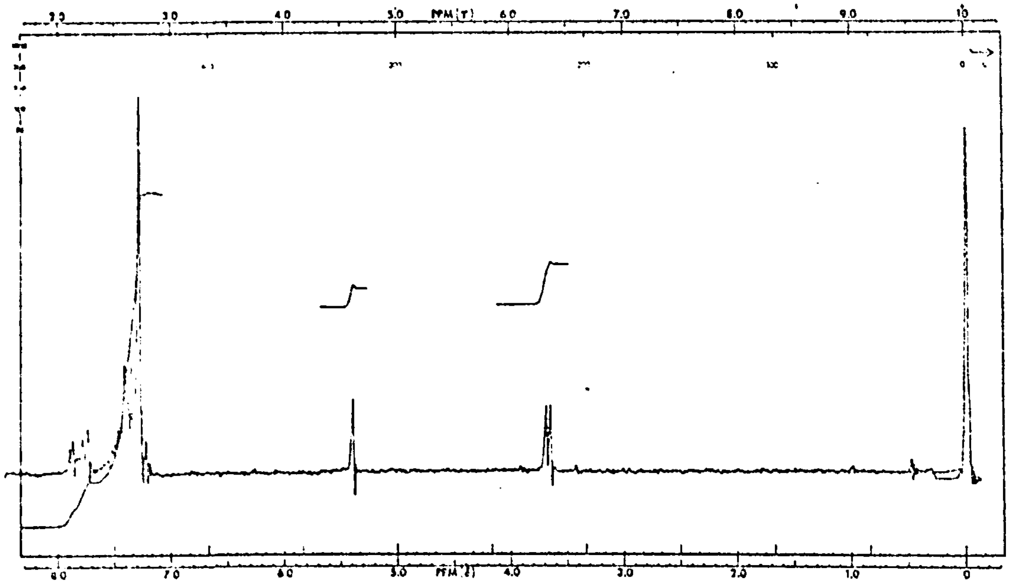
nmr spectrum of α-benzoylbenzyl-p-tolyl sulfide, (112).



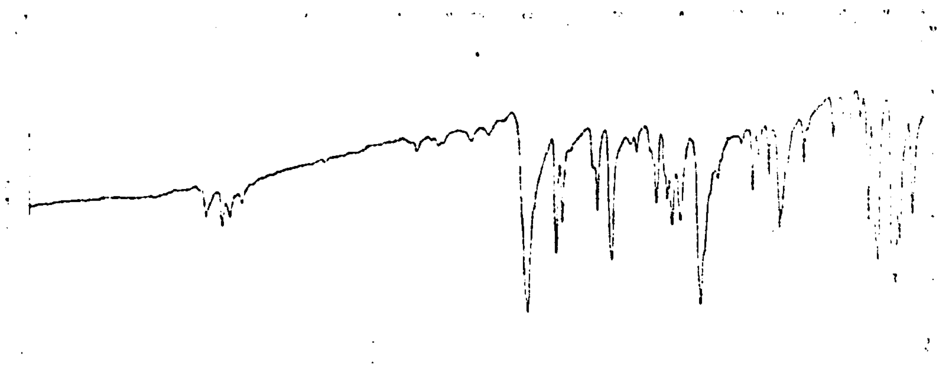
ir spectrum of α-benzoylbenzyl-benzyl sulfide, (113).



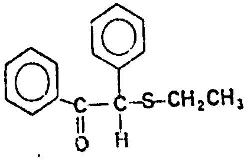
113



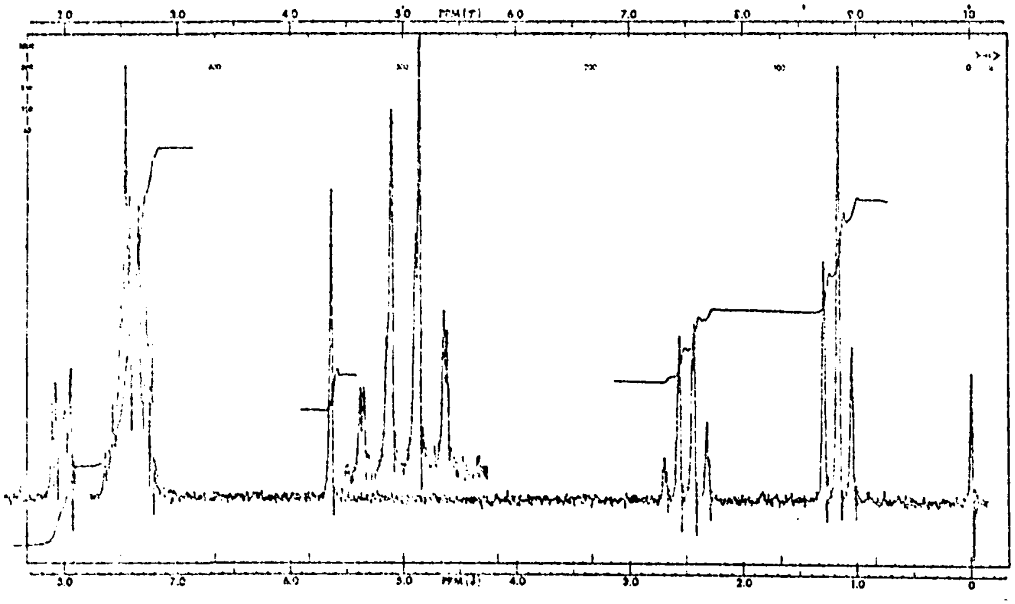
nmr spectrum of α-benzoylbenzyl-benzyl sulfide, (113).



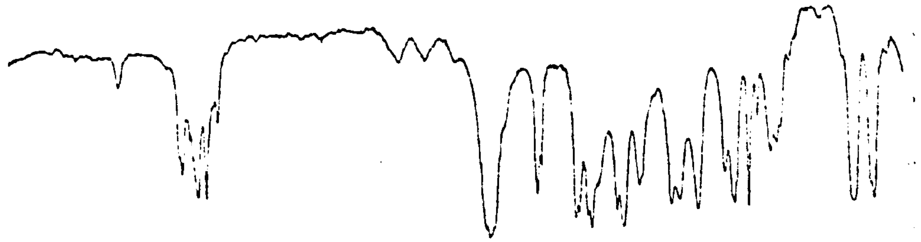
ir spectrum of α-benzoylbenzyl-ethyl sulfide, (114).



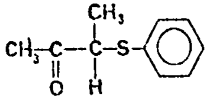
114



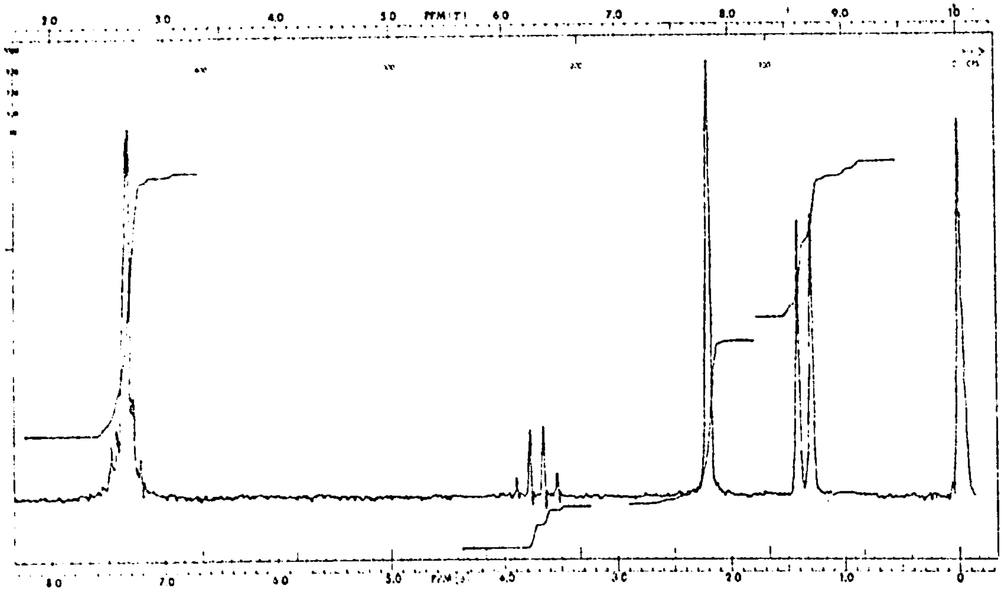
nmr spectrum of α-benzoylbenzyl-ethyl sulfide, (114).



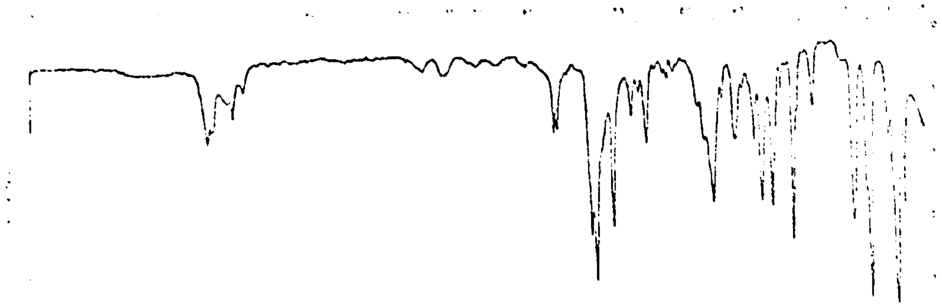
ir spectrum of α-acetylethyl-phenyl sulfide, (118).



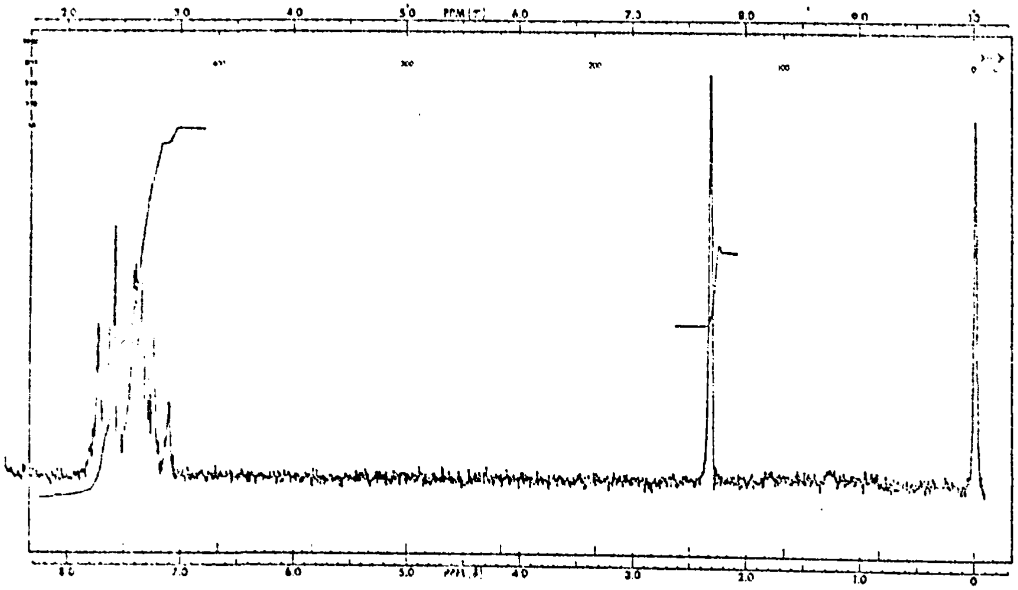
118

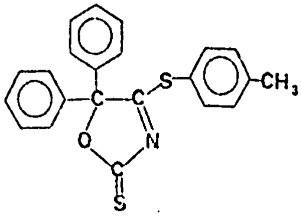


nmr spectrum of α-acetylethyl-phenyl sulfide, (118).



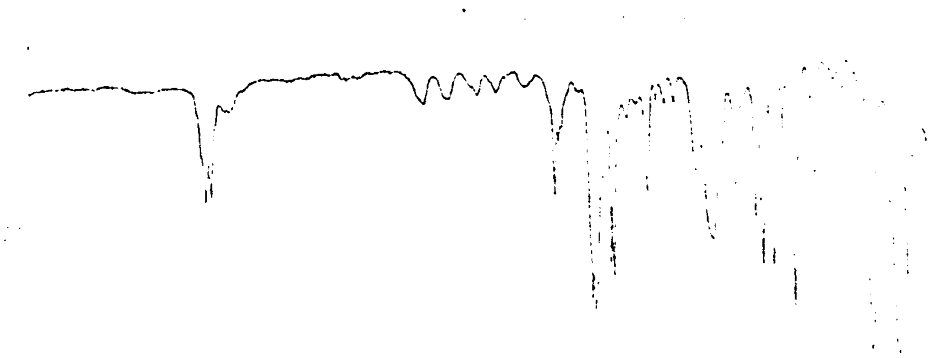
ir spectrum of 5,5-diphenyl-4-p-tolylthio-3-oxazoline-2(1H)-2-thione (133).



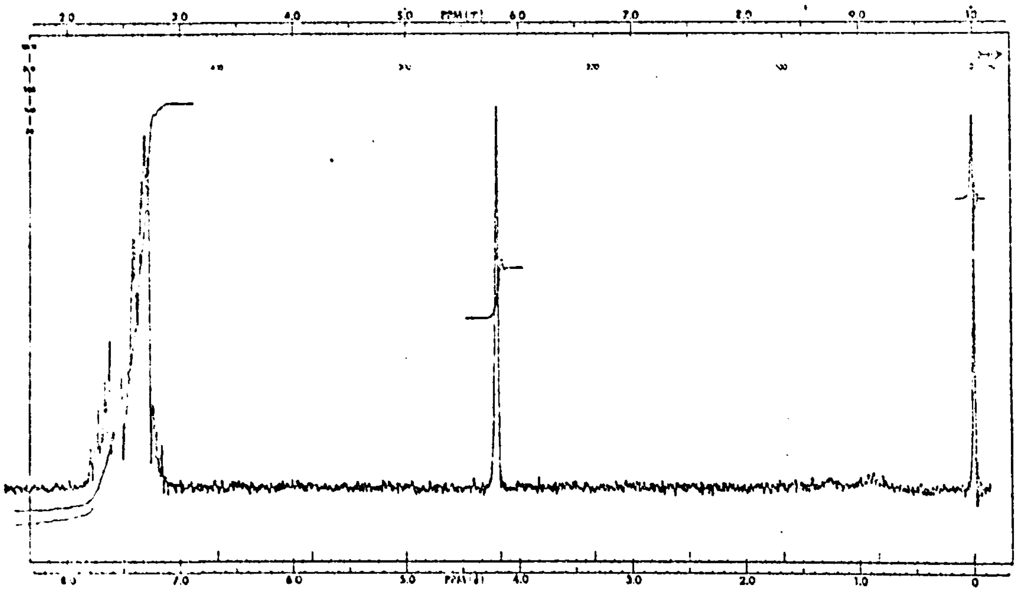


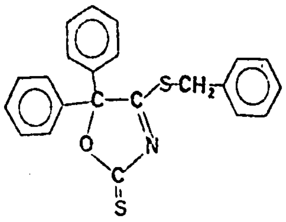
133

nmr spectrum of 5,5-diphenyl-4-p-tolylthio-3-oxazoline-2(1H)-2-thione (133).



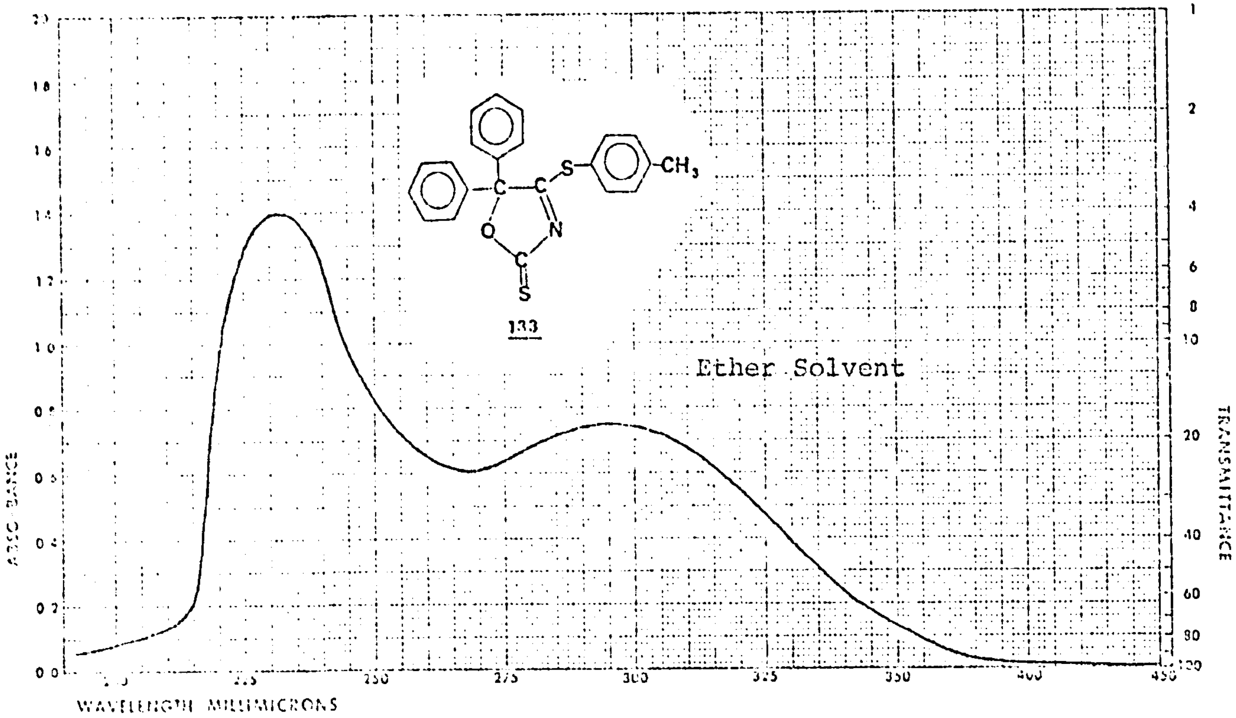
ir spectrum of 5,5-diphenyl-4-benzylthio-3-oxazoline-2(1H)-2-thione (134).



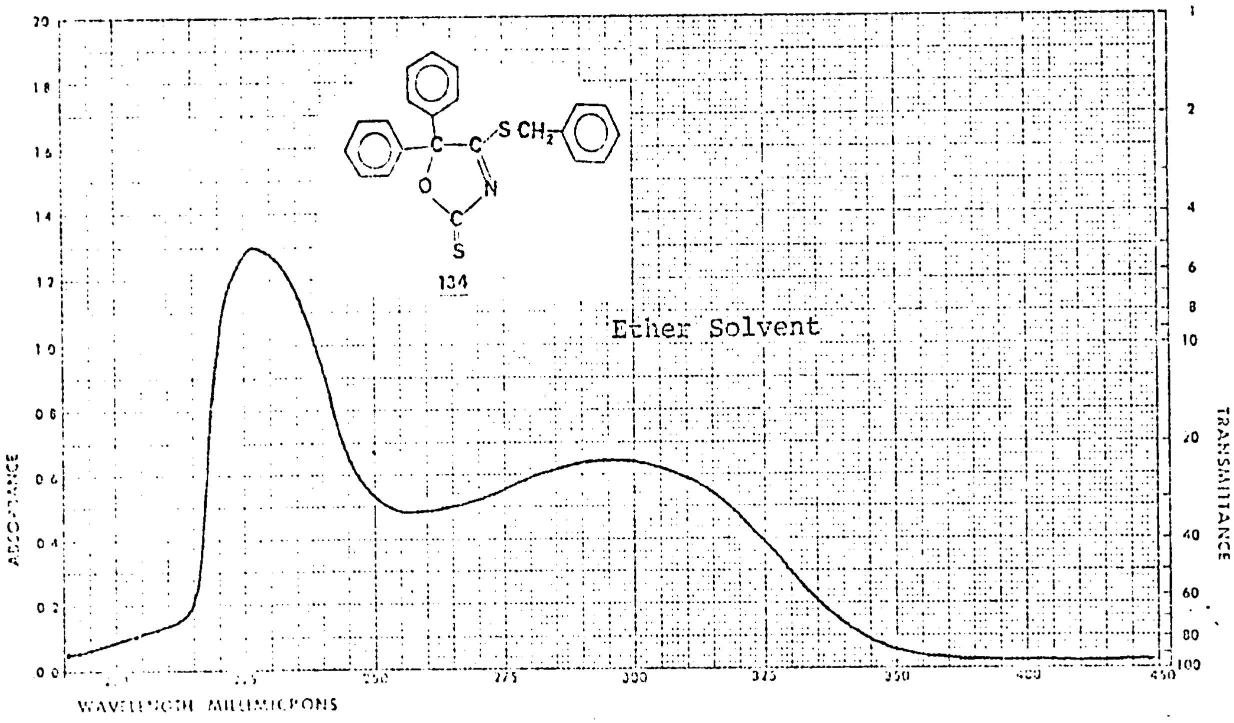


134

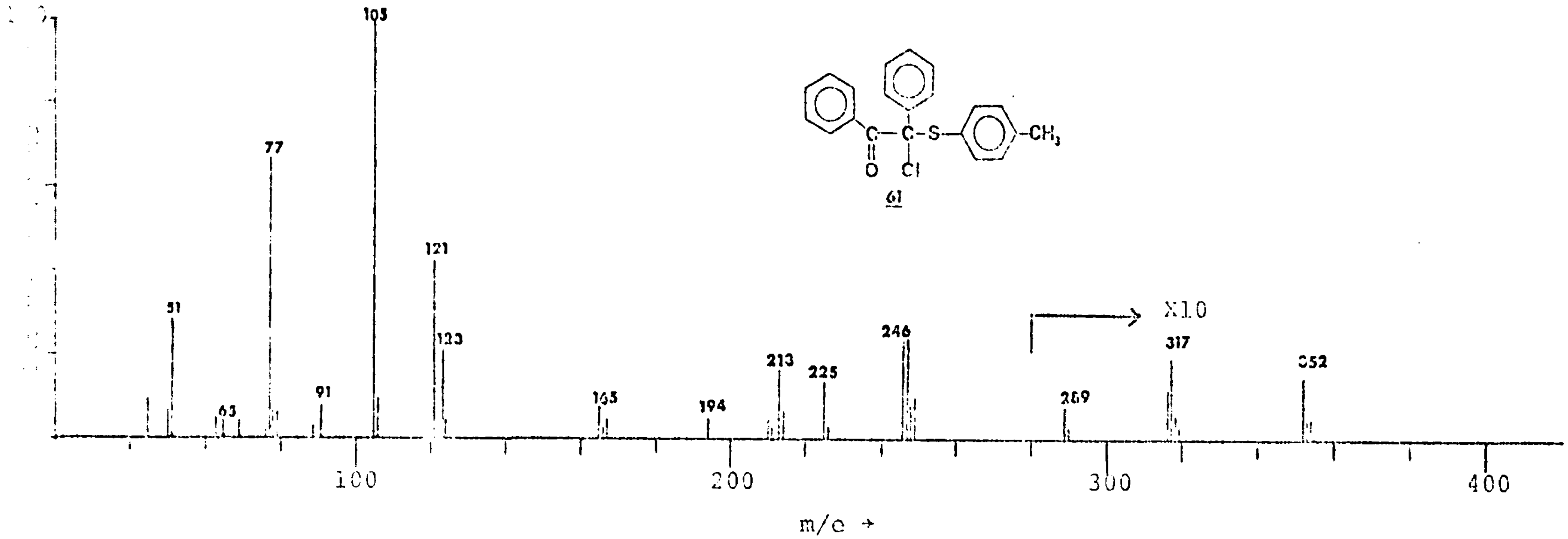
nmr spectrum of 5,5-diphenyl-4-benzylthio-3-oxazoline-2(1H)-2-thione (134).



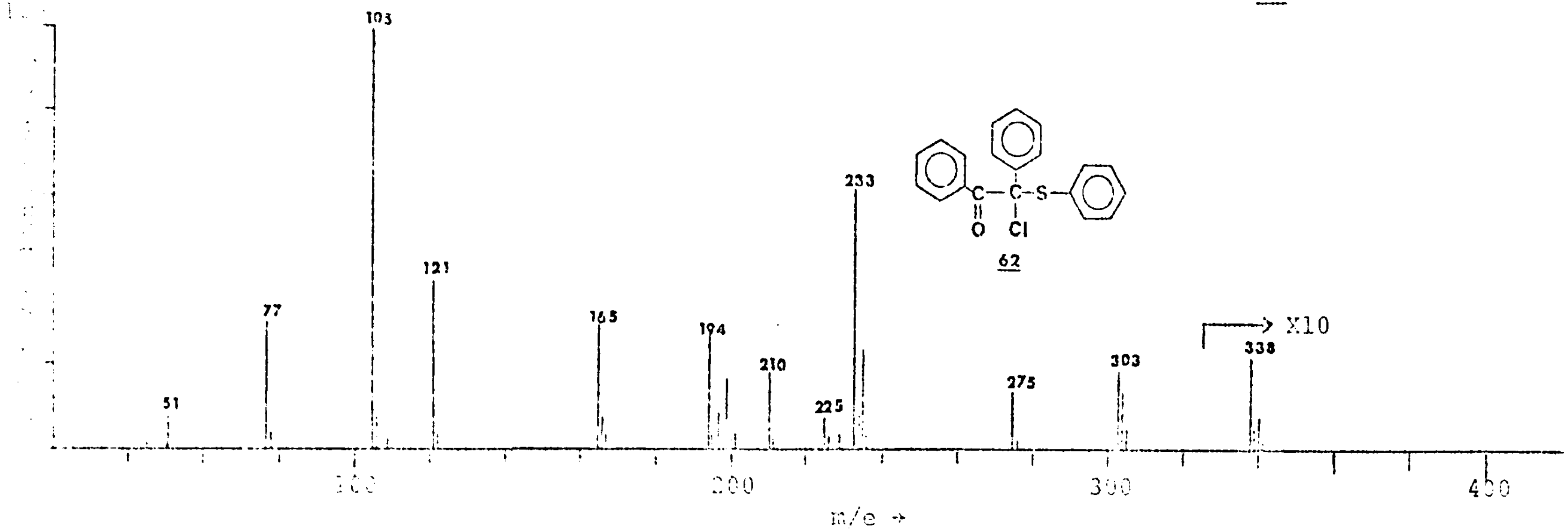
UV spectrum of 5,5-diphenyl-4-p-tolylthio-3-oxazoline-2(1H)-2-thione (133).



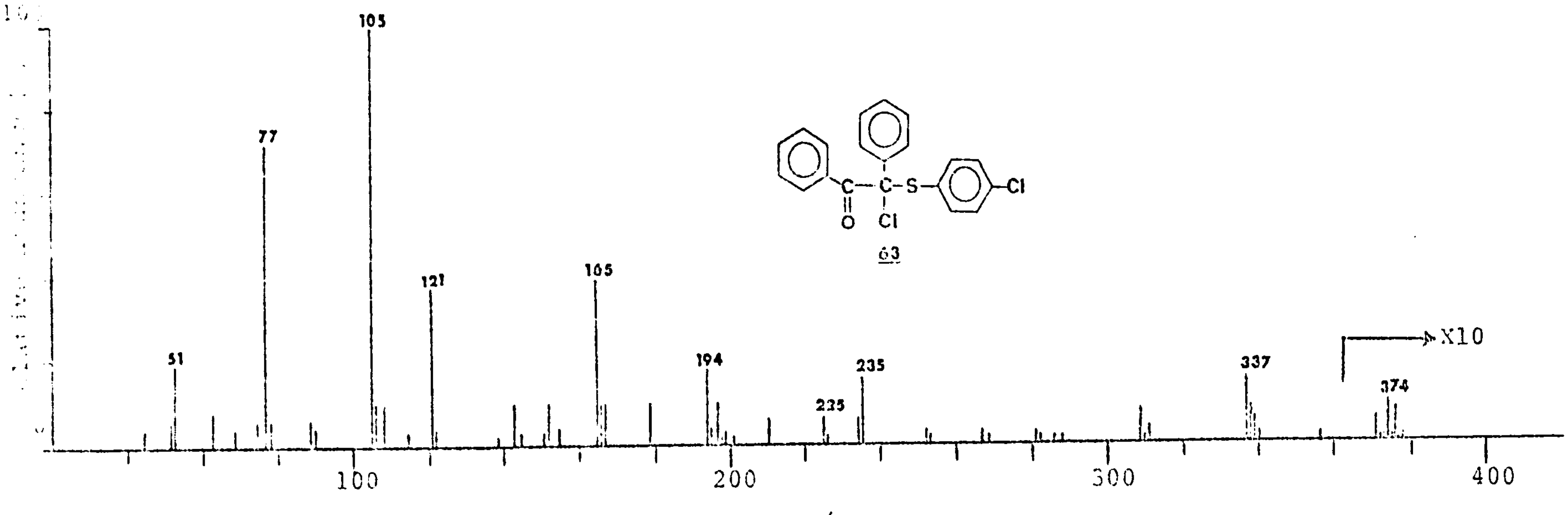
UV spectrum of 5,5-diphenyl-4-benzylthio-3-oxazoline-2(1H)-2-thione (134).



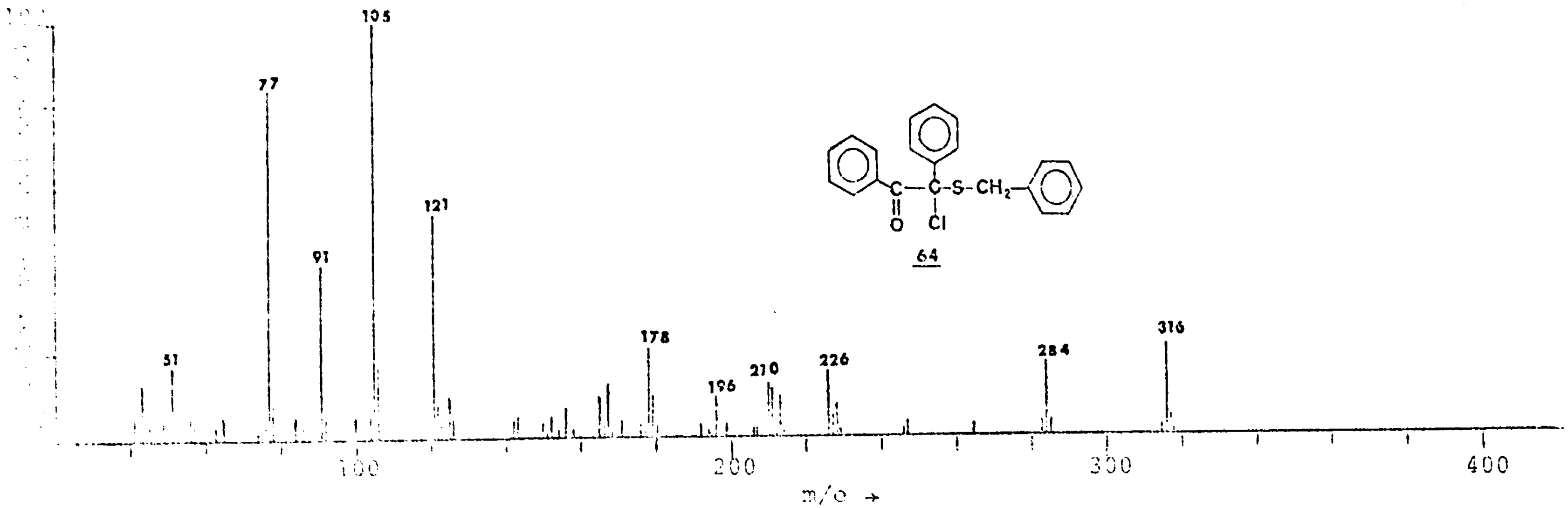
mass spectrum of α-benzoyl-α-chlorobenzyl-ptolyl sulfide, (61).



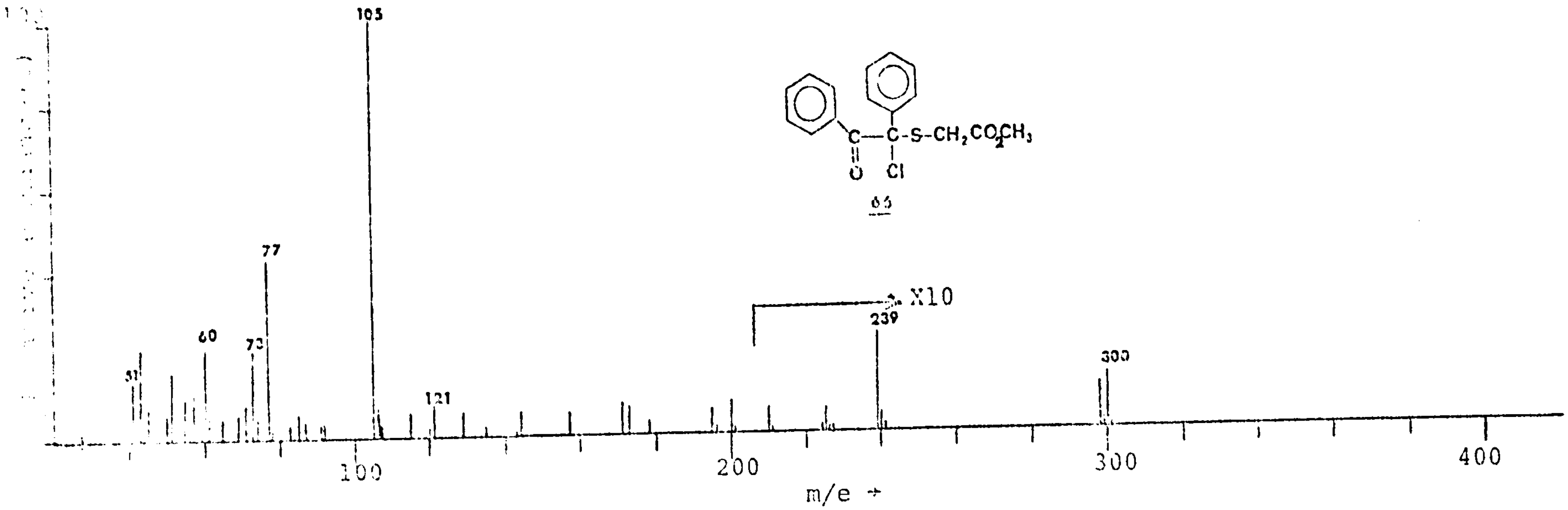
mass spectrum of α-benzoyl-α-chlorobenzyl-phenyl sulfide, (62).



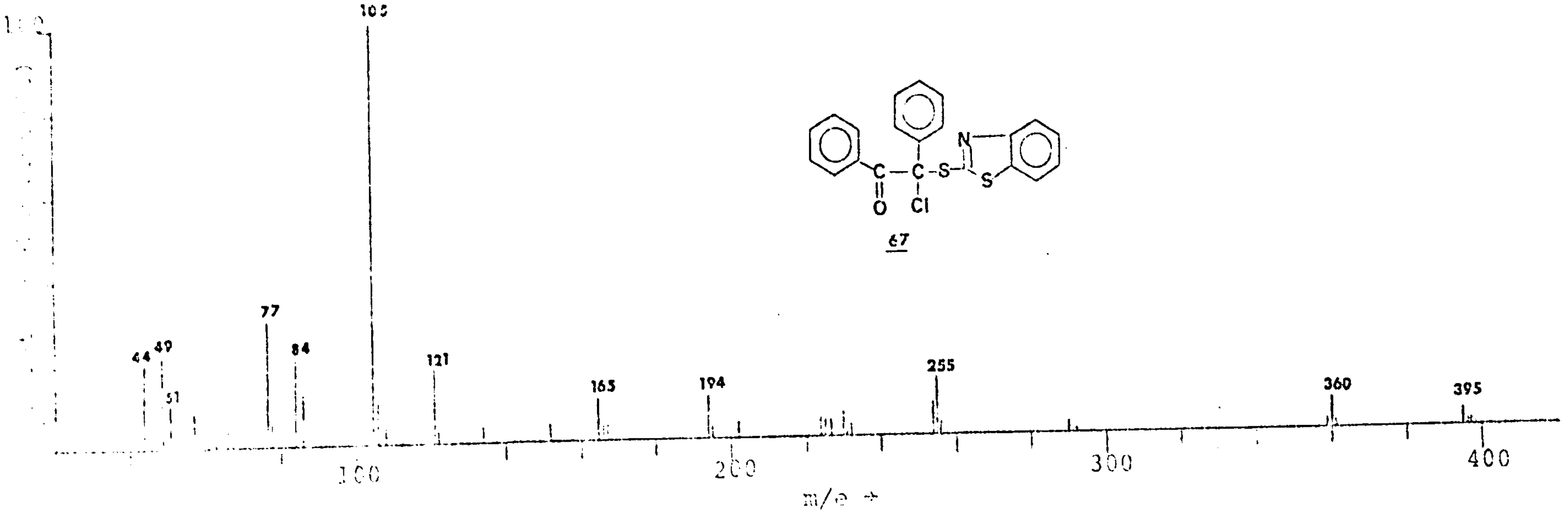
mass spectrum of α-benzoyl-α-chlorobenzyl-p-chlorophenyl sulfide,(63).



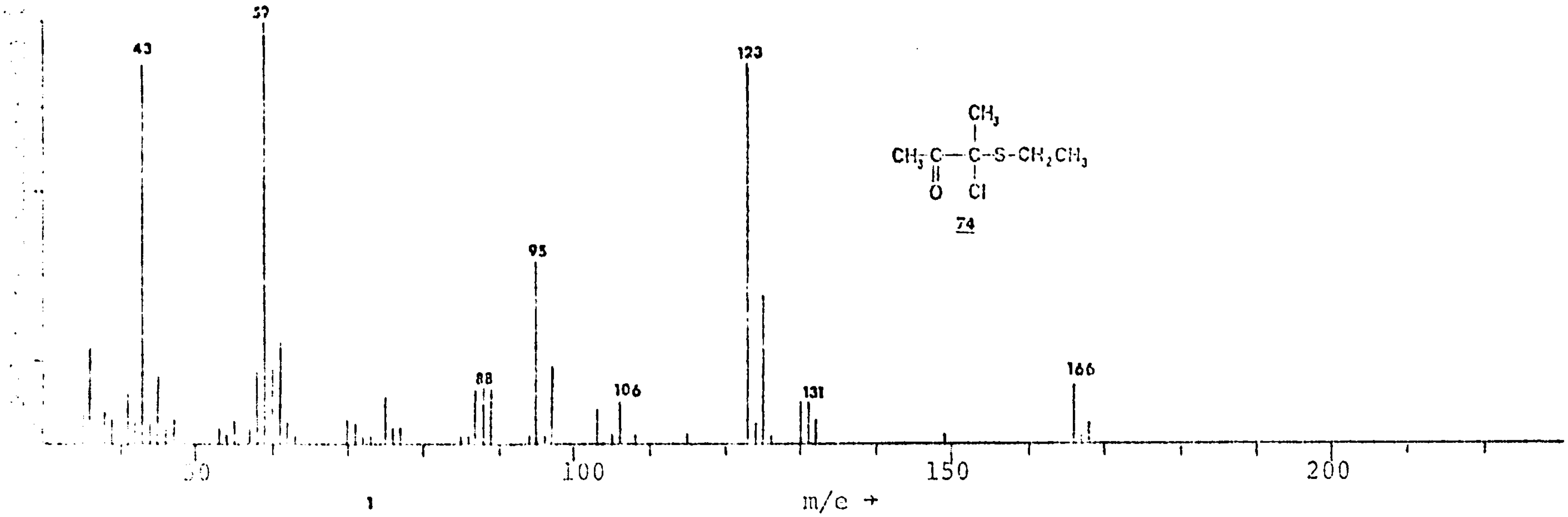
mass spectrum of α-benzoyl-α-chlorobenzyl-benzyl sulfide,(64).



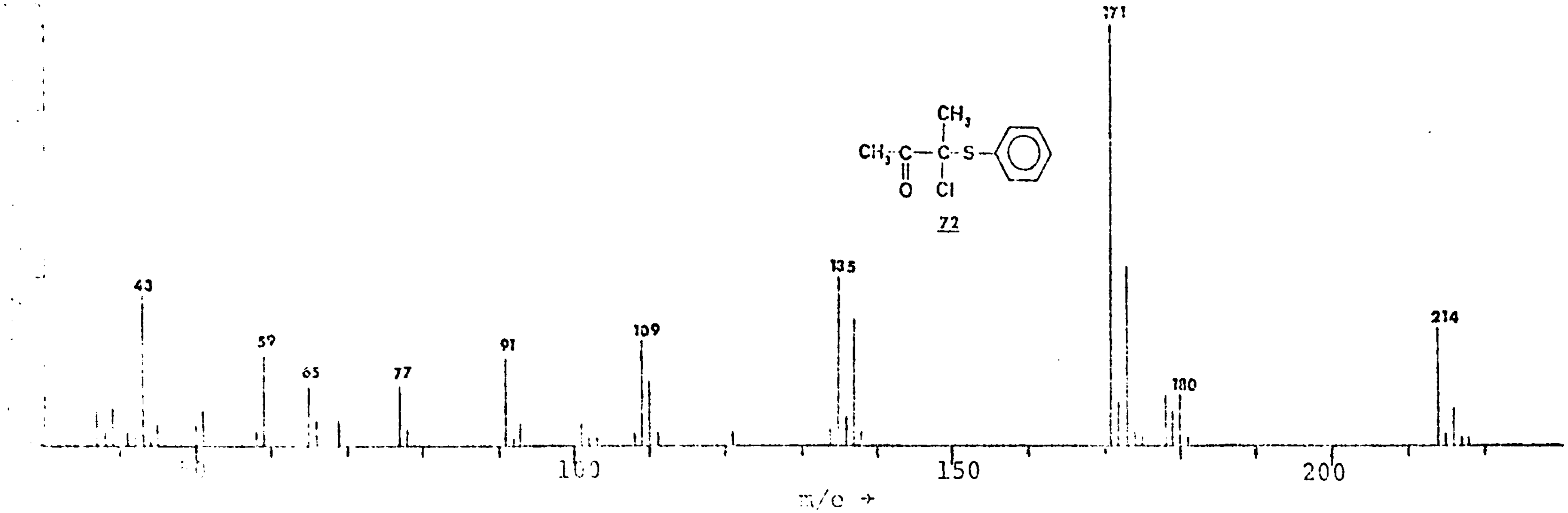
mass spectrum of α-benzoyl-α-chlorobenzyl-carbomethoxymethyl sulfide,(66).



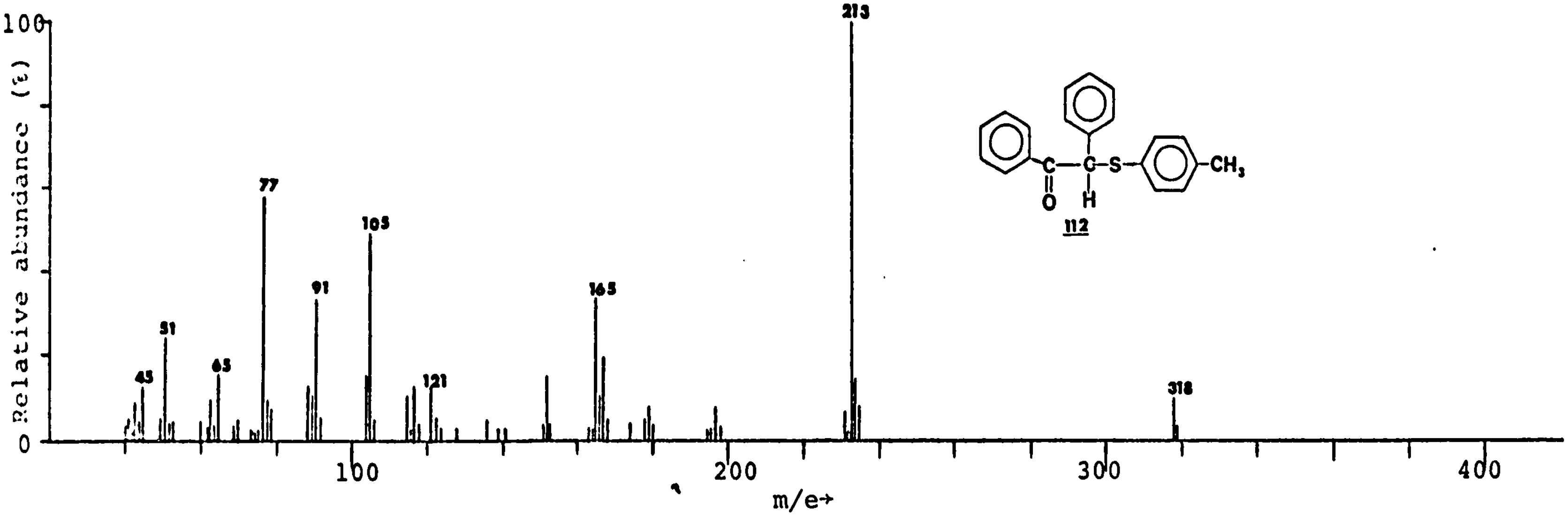
mass spectrum of α-benzoyl-α-chlorobenzyl-2-benzothiazolyl sulfide,(67).



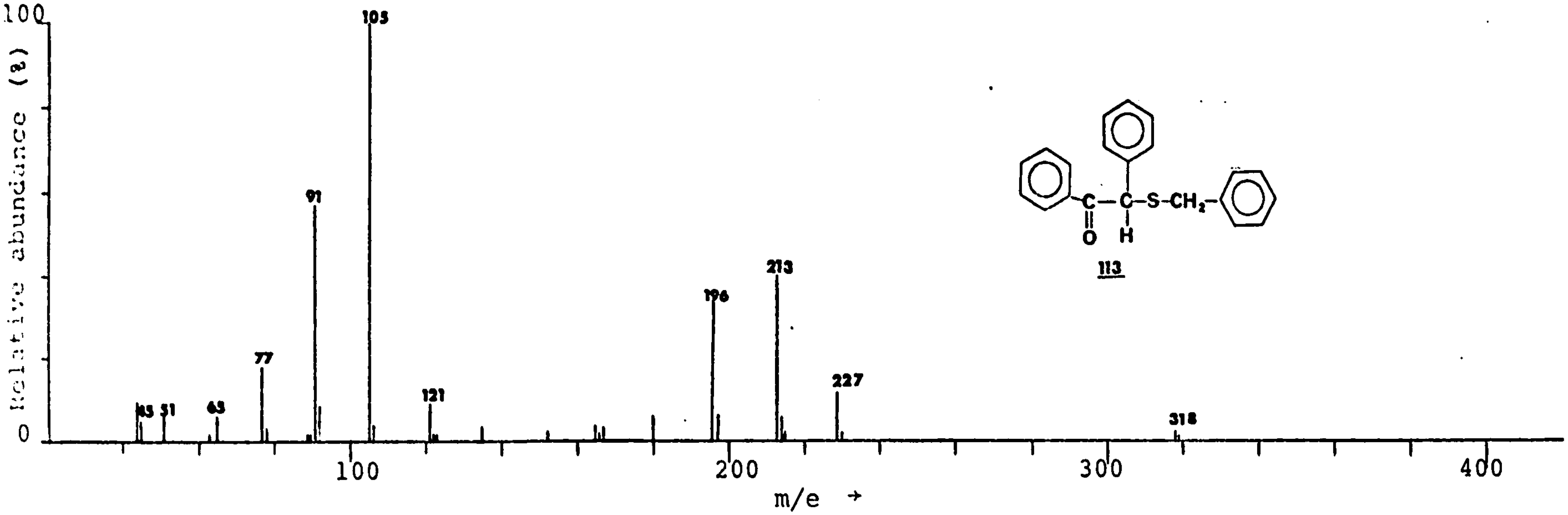
mass spectrum of α-acetyl-α-chloroethyl-ethyl sulfide,(74).



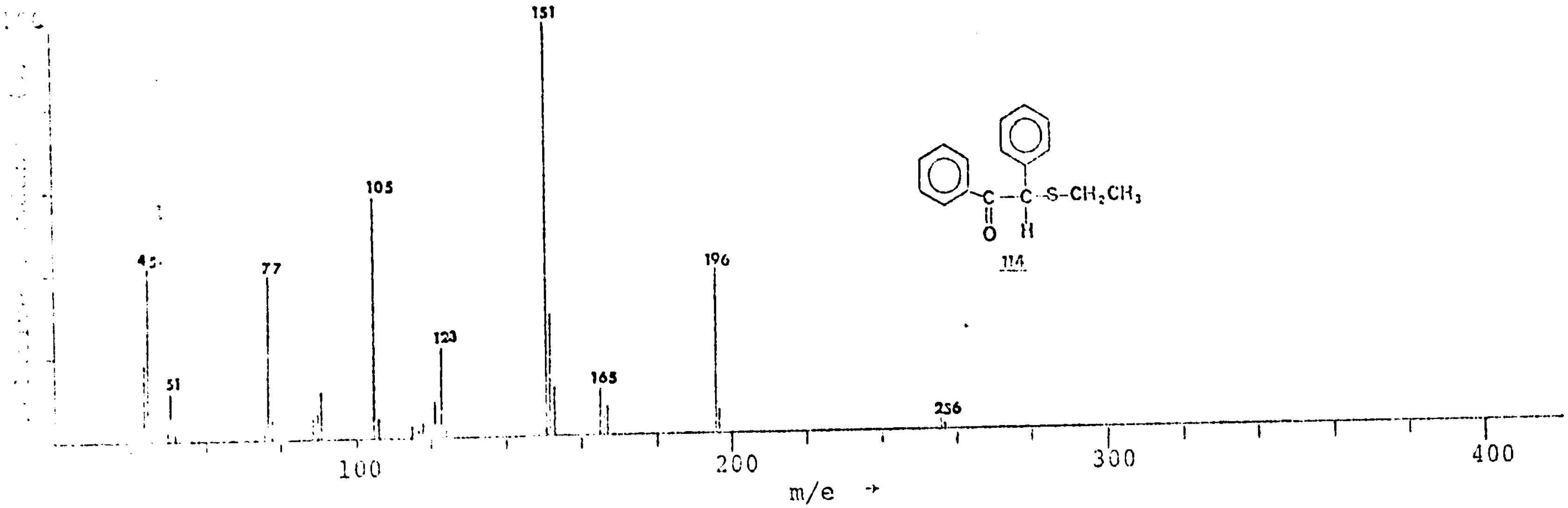
mass spectrum of α-acetyl-α-chloroethyl-phenyl sulfide,(72).



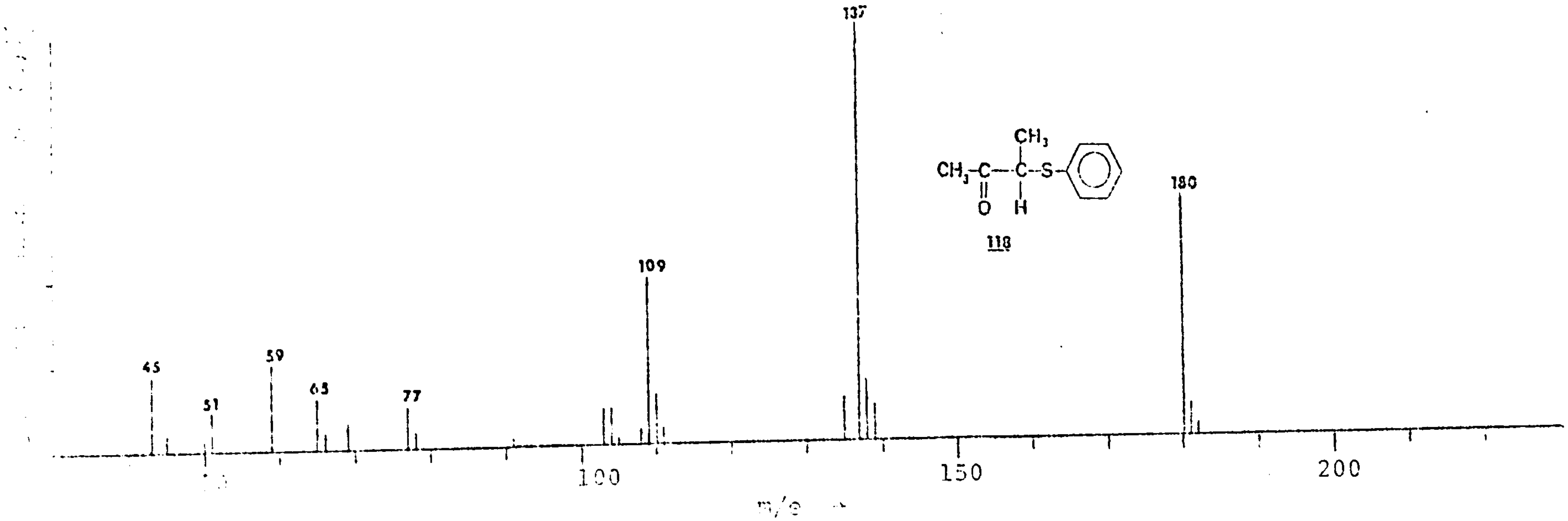
mass spectrum of α-benzoylbenzyl-p-tolyl sulfide, (112).



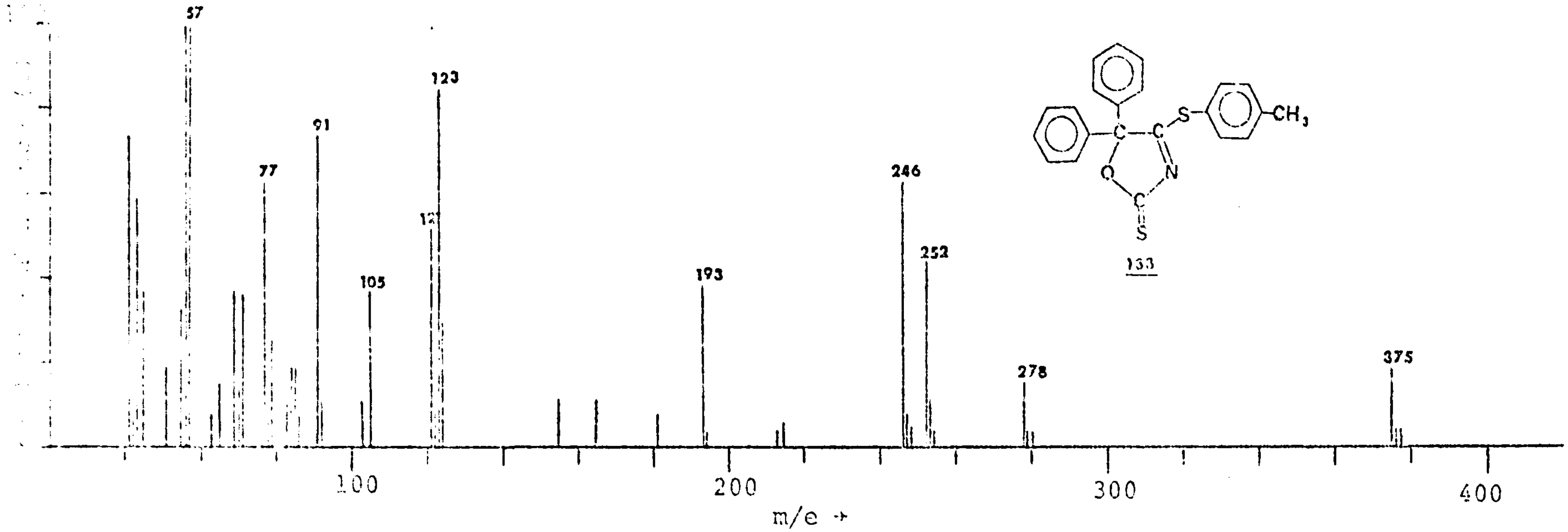
mass spectrum of α-benzoylbenzyl-benzyl sulfide, (113).



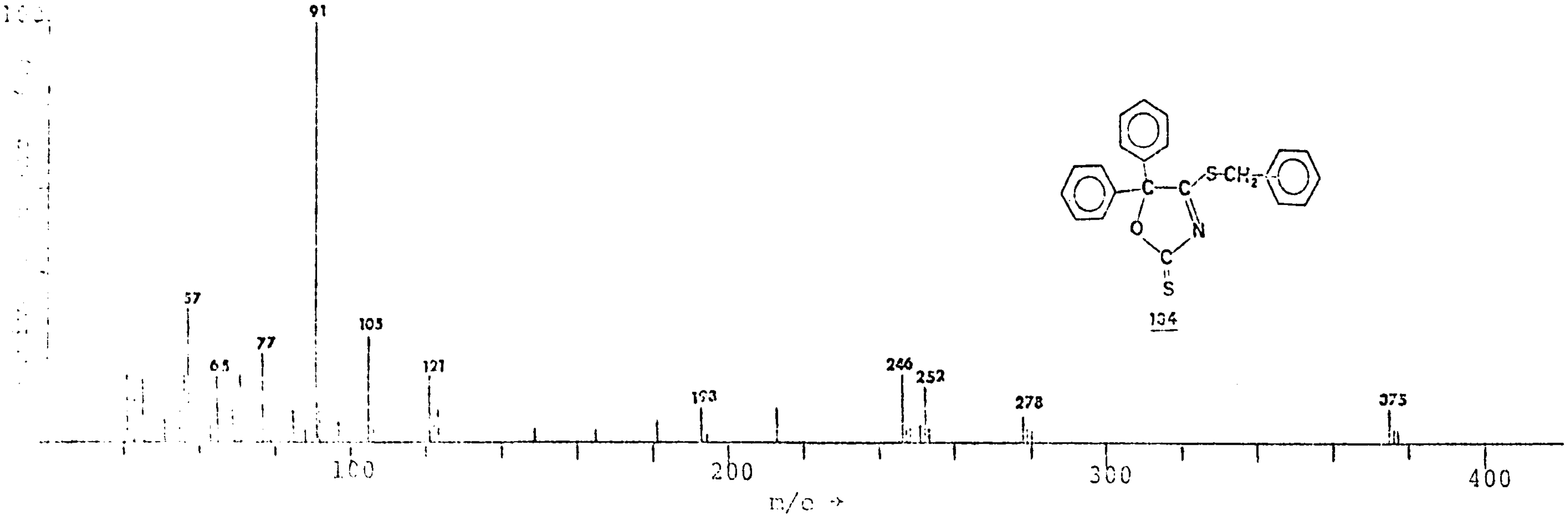
mass spectrum of α-benzoylbenzyl-ethyl sulfide, (114).



mass spectrum of α-acetylethyl-phenyl sulfide, (118).



mass spectrum of 5,5-diphenyl-4-p-tolylthio- 3-oxazoline-2(1H)-2-thione, (133).



mass spectrum of 5,5-diphenyl-4-benzylthio- 3-oxazoline-2(1H)-2-thione, (134).

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Hudson, R.F., "Structure and Mechanism in Organo-Phosphorus Chemistry", Academic Press, New York, (1965).

2. Kirby, A.J., and Warren, S.G., "The Organic Chemistry of Phosphorus", Elsevier Publishing Co., New York, (1967).

3. Ramirez, F., Glaser, S.L., Bigler, A.J. and Pilot, J.F., J. Amer. Chem. Soc., 91, 496 (1969).

4. (a). Wittig, G. and Rieber, M., Ann. Chem., 562, 187 (1949).
   (b). Wheatley, P.J., J. Chem. Soc., 2206 (1964).

5. Allcock, H.R., J. Amer. Chem. Soc., 86, 2591 (1964).

6. Hellwinkel, D., Chem. Ber., 98, 576 (1965).

7. Ref. 2, Chapter 2, pp. 18-20.

8. (a). Pearson, R.G., Gray, H.B., and Basolo, F., J. Amer. Chem. Soc., 82, 787 (1960).
   (b). Edwards, J.O. and Pearson, R.G., J. Amer. Chem. Soc., 84, 16 (1962).

9. Ref. 2., Chapter 2, p. 20.

10. (a). Speziale, A. J., Marco, G.J. and Ratts, K.W., J. Amer. Chem. Soc., 82, 1260 (1960).
    (b). Wittig, G. and Schlosser, M., Angew. Chem., 72, 324 (1960).

11. Staudinger, H. and Hauser, E., Helv. Chim. Acta., 2, 619 (1919).

12. (a). Michaelis, A. and Kaehne, R., Chem. Ber., 31, 1048 (1898).
    (b). Arbusov, A.E., J. Russ. Phys. Chem. Soc., 38, 687 (1906).

13. Wittig, G. and Schollkopf, U., Chem. Ber., 87, 1318 (1954).

14. (a). Rydon, H.N., Chem. Soc. Spec. Publ., 8, 61 (1957).
    (b). Horner, L. and Oediger, H., Chem. Ber., 91 437 (1958).

(c). Horner, L., Oediger, H. and Hoffmann, H., Ann. Chem., 626, 26 (1959).

15. Ogata, Y. and Yamashita, M., J. Amer. Chem. Soc., 92, 4670 (1970) and references cited therein.

16. Horner, L. and Klupfel, K., Ann. Chem., 591, 69 (1955).

17. Pfundt, G. and Schenk, G. O., in "1,4 Cycloaddition reactions" Ed. by J. Hamer, Academic Press, New York, N.Y. (1967), pp. 379-388.

18. (a). Kukhtin, V.A., Dokl. Akad. Nauk SSSR, 121, 466 (1958); Chem. Abstr., 53, 1105a (1959).
    (b). Kukhtin, V.A. and Cerakhova, K.M., Zh. Obshch. Khim., 30, 1208 (1960); Chem. Abstr., 55, 358h (1961).
    (c). Kukhtin, V.A., Voskoboeva, T.N. and Kirillova, K.M., ibid., 32, 2333 (1962); Chem Abstr., 58, 9127g (1963).
    (d). Kirillova, K.M. and Kukhtin, V.A., ibid., 32, 2338 (1962); Chem. Abstr., 58, 9128c (1963).

19. Birum, G.H. and Dever, J.L., Abstracts, 134th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1958, p. 101-6.

20. (a). Ramirez, F. and Desai, N.B., J. Amer. Chem. Soc., 85, 3252 (1963) and references cited therein.
    (b). Ramirez, F., Pure and Applied Chem., 9, 337 (1964).

21. (a). Berry, S.R., J. Chem. Phys., 32, 933 (1960).
    (b). Westheimer, F.H., Acc. of Chem. Research, 1, 70 (1968).
    (c). Mislow, K., ibid., 3, 321 (1970).

22. Ramirez, F., Bhatia, S.B., Bigler, A.J. and Smith, C.P., J. Org. Chem., 33, 1192 (1968).

23. (a). Hamilton, W.C., Laplaca, S.J., Ramirez, F. and Smith, C.P., J. Amer. Chem. Soc., 89, 2268 (1967).
    (b). Spratley, R.D., Hamilton, W.C. and Ladell, J., ibid., 89, 2272 (1967).

24. Denney, D.B. and Jones, D.H., J. Amer. Chem. Soc., 91, 5821 (1969).

25. Ramirez, F., Acc. of Chem. Research, 1, 168 (1968).

26. Ramirez, F., Patwardhan, A.V. and Smith, C.P., J. Amer. Chem. Soc., 87, 4973 (1965).

27. Ramirez, F., Patwardhan, A.V., Kugler, H.J. and Smith, C.P., J. Amer. Chem. Soc., 89, 6283, 6276 (1967).

28. (a). Ramirez, F., Patwardhan, A.V., Kugler, H.J. and Smith, C.P., Tetrahedron Letters, 3053 (1966).
    (b). Also, Tetrahedron, 24, 2275 (1968).

29. Kukhtin, V.A. and Orekhova, K.M., Zh. Obshch. Khim., 30, 1208 (1960); Chem. Abstr. 55, 3582 (1961).

30. (a). Kukhtin, V.A., Kirillova, K. M. and Shagidullin, R.R., Zh. Obshch. Khim., 32, 649 (1962); Chem. Abstr., 58, 546h (1963).
    (b). Kukhtin, V.A. and Kirillova, K.M., Dokl. Akad. Nauk. SSSR., 140, 835 (1961); Chem. Abstr., 56, 4607g (1962).

31. Ramirez, F., Mitra, R.B. and Desai, N.B., J. Amer. Chem. Soc., 82, 2651, 5763 (1960).

32. (a). Ramirez, F., Desai, N.B. and Ramanathan, N., J. Amer. Chem. Soc., 85, 3465 (1965) and references cited therein.
    (b). Ramirez, F., Bull. Soc. Chim. France, 8, 2443 (1966).

33. Ramirez, F. and Ramanathan, N., J. Org. Chem., 26, 3041 (1961).

34. Ramirez, F., Patwardhan, A.V. and Smith, C.P., J. Org. Chem., 31, 3159 (1966).

35. Bentrude, W.G. and Darnall, K.R., Tetrahedron Letters, 26, 2511 (1967).

36. Bentrude, W.G. and Darnall, K.R., Chem. Comm., 862 (1969).

37. Ramirez, F., Bhatia, S.B. and Smith, C.P., J. Amer. Chem. Soc., 89, 3026 (1967).

38. Ramirez, F., Bhatia, S.B. and Smith, C.P., J. Amer. Chem. Soc., 89, 3030 (1967).

39. (a). Kirby, A.J., Tetrahedron, 22, 3001 (1966).
    (b). Alcock, N.W. and Kirby, A.J., ibid., 22, 3007 (1966).

40. Ramirez, F. and Desai, N.B., J. Amer. Chem. Soc., 82, 2652 (1960).

41. Ramirez, F., Bhatia, S.B., Bigler, A.J. and Smith, C.P., J. Org. Chem., 33, 1192 (1968).

42. Bentrude, W.G., J. Amer. Chem. Soc., 87, 4026 (1965).

43. (a). Rathke, B., Ber., 3, 860 (1870).
    (b). Rathke, B., Ann., 167, 195, 200 (1873).

44. (a). Zincke, T. and Baeumer, J., Ann., 416, 86 (1918) and references cited therein.
    (b). Zincke, T. and Eismayer, K., Ber. 51, 751 (1918) and references cited therein.

45. Douglass, I.B., Martin, F.T. and Addor, R., J. Org. Chem., 16, 1297 (1951).

46. (a). Prey, V. and Gutschik, E., Monatsh., 90, 551 (1959).
    (b). Prey, V., Gutschik, E. and Berbalk, E., Monatsh., 91, 794 (1960).

47. O'Connor, R., in "Organic Chemistry, An Advanced Treatise", Vol. I, 2nd Edn., pp. 920-923, Ed. by Gilman, H., John Wiley and Sons, New York, (1943).

48. Kharasch, N., Potempa, S.J. and Wehrmeister, H.L., Chem. Rev., 39, 269-331 (1946).

49. Schoberle, A. and Wagner, A., in Houben-Weyl, "Methoden der Organischen Chemie", 4th Edn., Vol. 9, Ch. 11, pp. 263-283, Georg Thieme Verlag, Stuttgart, (1955).

50. (a). Kharasch, N., "Organo Sulfur Compounds", Vol. 1, pp. 375-391, Pergamon Press, New York, (1961).
    (b). Douglass, I.B., ibid., pp. 250-260.
    (c). Drahowzal, F.A., ibid., pp. 361-374.

51. (a). Kharasch, N., Ariyan, Z.S. and Havlik, A.J., Quart. Reports on Sulfur. Chem., Vol. I, No. 2, pp. 93-136 (1966).
    (b). Kharasch, N., Editor, ibid., Vol. 2, No. 4, pp. 289-370 (1967).

52. Behforouz, M. and Kerwood, J.E., J. Org. Chem., 34, 51 (1969).

53. (a). Brower, K.R. and Douglass, I.B., J. Amer. Chem. Soc., 73, 5787 (1951).
    (b). Douglass, I.B., Brower, K.R. and Martin, F.T., J. Amer. Chem. Soc., 74, 5770 (1952).

54. Kharasch, N. and Wald, M.M., Anal. Chem., 27, 996 (1955).

55. Emde, H., German Patent., 804, 572, (1951); Chem. Abstr., 46, 529 (1952).

56. Vorlander, D. and Mittag, E., Ber., 52, 413 (1919).

57. Schulze, W.A., Short, G.H. and Crouch, W.W., Industr. Engng. Chem., 42, 916 (1950).

58. Hubacher, M.H., in "Organic Syntheses", Coll. Vol. II, John Wiley and Sons, Inc., New York, N.Y., (1943), pp. 455-7.

59. Mueller, W.H. and Butler, P.E., J. Amer. Chem. Soc., 90, 2075 (1968).

60. Kharasch, N. and Langford, R.B., J. Org. Chem. 28, 1903 (1963).

61. Bell, R.H. and Horton, D., Carbohyd. Res., 9, 187 (1969).

62. Mueller, W.H., Rubin, R.M. and Butler, P.E., J. Org. Chem., 31, 3537 (1966).

63. Klason, P., Ber. 20, 2376 (1887).

64. Kluiber, R.W., J. Amer. Chem. Soc., 83, 3030 (1961).

65. Douglass, I.B., J. Org. Chem., 24, 2004 (1959).

66. (a). Ebelke, W.H., U.S. Patent., 2,304,557., (1942); Chem. Abstr., 37, 2746 (1943).
    (b). Messer, W.E., U.S. Patent., 2,257,974., (1942); Chem. Abstr., 36, 930 (1942).

67. Mislow, K., in "Introduction to Stereochemistry", W.A. Benjamin, Inc., New York., (1966), pp. 93-95.

68. Silverstein, R.M. and Bassler, G.C., "Spectrometric Identification of Organic Compounds", 2nd Edn., John Wiley and Sons, Inc., New York (1967), p. 144.

69. Ref. 68., p. 137.

70. Campaigne, E., in "Organo Sulfur Compounds", Vol. I., Ch. 14, Ed. by N. Kharasch, Pergamon Press, New York, (1961).

71. Budzikiewicz, H., Djerassi, C. and Williams, D.H., "Mass Spectrometry of Organic Compounds", Holden-Day, Inc., San Francisco, (1967), pp. 647-653.

72. (a). Ref. 71., Ch. 3.
    (b). Ref. 71., Ch. 6, p. 241.

73. (a). Occolowitz, J.L. and Swan, J.M., Austral. J. Chem., 19, 1187 (1966).
    (b). Nishikawa, T., Tetrahedron, 22, 1383 (1966).

74. Kharasch, N. and Ariyan, Z.S., Chem. and Ind., 929 (1964).

75. Weygand, F. and Bestmann, H.J., Z. Naturforsch., 10b, 296 (1955).

76. Bentrude, W.G., Chem. Comm., 174 (1967).

77. Ramirez, F., Yamanaka, H. and Basedow, O.H., J. Amer. Chem. Soc., 83, 173 (1961).

78. Corey, E.J. and Winter, R.A.E., J. Amer. Chem. Soc., 85, 2677 (1963).

79. Marvel, C.S. and Kohan, M.I., J. Org. Chem., 16, 741 (1951).

80. Kirmse, W., in "Carbene Chemistry", Academic Press, New York (1964), pp. 118-119.

81. Mueller, W.H., Angew. Chem. internat. Edit., 8, 482 (1969) and references cited therein.

82. Morrison, D.C., J. Amer. Chem. Soc., 77, 181 (1955).

83. Denney, D.B. and DiLeone, R.R., J. Amer. Chem. Soc., 77, 181 (1955).

84. Petrov, K.A., Sokolskii, G.A. and Poleeva, B.M., Zh. Obshch. Khim., 26, 3381 (1956); Chem. Abstr., 51, 9473 (1957).

85. Gould, E.S., "Mechanism and Structure in Organic Chemistry", Holt, Rinehart and Winston, New York (1959), pp. 269-284.

86. Ref. 71., Ch. 7., p. 285.

87. (a). Weygand, F. and Bestmann, H.J., Angew. Chem., 72, 525 (1960); Acta. Chim. Hung. Tomus., 18, 59 (1959).
    (b). Weygand, F., Bestmann, H.J., Zeimann, H. and Klieger, E., Ber., 91, 1043 (1958) and references cited therein.

88. Russell, G.A. and Ochrymowycz, L.A., J. Org. Chem., 34, 3618 (1969).

89. Bazant, V., Chvalovsky, V. and Rathonsky, J., in "Organo Silicon Compounds", Academic Press, Inc., New York, (1965), Ch. 7.

90. Calas, R., Pure Appl. Chem., 11, 61 (1966).

91. Fritsche, H., Hasserodt, U. and Korte, F., Ber., 97, 1988 (1964); 98, 176 (1965).

92. Naumann, K., Zon, G. and Mislow, K., J. Amer. Chem. Soc., 91, 2788, 7012 (1969).

93. (a). Chan, T.H., Melnyk, A. and Harpp, D.N., Tetrahedron Letters, 201 (1969).
    (b). Chan, T.H. and Melnyk, A., J. Amer. Chem. Soc., 92, 3718 (1970).

94. Nozakura, S. and Konotsune, S., Bull. Chem. Soc. Japan., 29, 322 (1956).

95. (a). Pike, R.A., J. Org. Chem., 27, 2186 (1962).
    (b). Benkeser, R.A., Dunny, S. and Jones, P.R., J. Organometal Chem. (Amsterdam), 4, 338 (1965).

96. Benkeser, R.A. and Smith, W.E., J. Amer. Chem. Soc., 90, 5307 (1968).

97. (a). Benkeser, R.A., Foley, K.M., Grutzner, J.B. and Smith, W.E., J. Amer. Chem. Soc., 92, 697 (1970).
    (b). Bernstein, S.C., J. Amer. Chem. Soc., 92, 699 (1970).

98. Hoffmann, H. and Diehr, H.J., Tetrahedron letters, 583 (1962).

99. Ref. 71., p. 18.

100. (a). Thorpe, J.F. and Whiteley, M.A., "Thorpe's Dictionary of Applied Chemistry", London, Vol. 3., p. 507, (1939).
    (b). Kirk, R.E. and Othmer, D.F., "Encyclopedia of Chemical Technology", New York, Vol. 4, p. 736 (1949); Vol. 14, p. 68 (1955).
    (c). Williams, H.E., "Cyanogen Compounds", Arnold, London (1948).

101. Bacon, R.G.R., "Organic Sulfur Compounds", Ed. by N. Kharasch, Pergamon Press, New York (1961), Ch. 27.

102. Jones, L.H., J. Chem. Phys., 25, 1069 (1956).

103. (a). Seel, F., Hanser, A. and Wesemann, D., Z. Anorg. Allg. Chem., 283, 351 (1956).
    (b). Lindquist, I. and Strandberg, B., Acta. Cryst., 10, 173 (1957).
    (c). Wagner, W.C., Mattern, J.A. and Cartledge, G.H., J. Amer. Chem. Soc., 81, 2958 (1959).

104. (a). Assony, S.J., "Organic Sulfur Compounds", Ed. by N. Kharasch, Pergamon Press, New York (1961), Ch. 28.
    (b). Kjaer, A., ibid., Ch. 34.

105. (a). Hantzsch, A. and Weber, J., Ber., 20, 3118 (1887).
    (b). Hantzsch, A. and Aripides, L., Ann., 249, 18 (1888).
    (c). Hantzsch, A., Ber., 60, 2537 (1927); 61, 1776 (1928).

106. Weygand, F., Bestmann, H.J. and Steden, F., Ber., 91, 2537 (1958).

107. (a). Bestmann, H.J., Private Communication.
    (b). Gould, E.S., "Mechanism and Structure in Organic Chemistry", Holt, Rinehart and Winston, Inc., New York (1959), p. 298.

108. (a). Roger, R. and McGregor, A., J. Chem. Soc., 442 (1934).
    (b). Ref. 107b., p. 636.

109. Pritchard, J.G. and Funke, P.T., J. Heterocyclic Chem., 3, 209 (1966).

110. Diels, O. and Pflaumer, K., Ber., 48. 223 (1915).

111. Kosalapoff, G.M., "Organo Phosphorus Compounds", John Wiley and Sons, Inc., New York (1950), p. 242.

112. Parker, J.B. and Smith, T.D., J. Chem. Soc., 442 (1961).

113. Ref. 111., Ch. 9.

114. (a). Golumbic, C. and Bergman, M., J. Org. Chem., <u>11</u>, 519 (1946).
     (b). Pettitt, D.J. and Helmkamp, G.K., J. Org. Chem., <u>29</u>, 2702 (1964).