STUDIES IN THE DITHIOLE SERIES

by

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THESIS PRESENTED FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF EDINBURGH

MAY 1968

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. D. Leaver for his constant patience and encouraging supervision which made this period of research so interesting and enjoyable.

I am grateful to the University of Edinburgh for the provision of laboratory facilities and jointly to Monsanto Chemicals Limited and the Science Research Council for the granting of an Industrial Fellowship.

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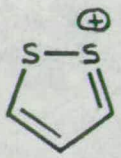
INTRODUCTION

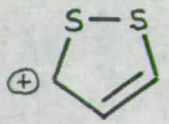
PART A : DITHIOLETHIONES AND THEIR RELATIONSHIPS TO THE DITHIOLIUM CATIONS

The aromatic five-membered dithiole ring system exists in two isomeric forms, these being the 1,2-(I) and 1,3-dithiolium (II) cations. Such cations are resonance hybrids of the following canonical structures.

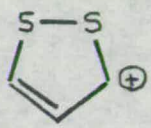


(Ia)

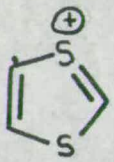
(Ib)



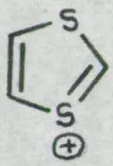
(Ic)



(Id)



(IIa)



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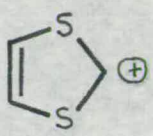
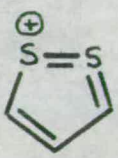
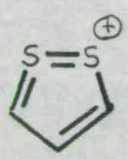


(IIc)

Since it is known[1] that by utilising the 3d orbitals in bonding, sulphur can expand its outer shell to hold more than the octet, other canonical structures should also be considered, where either or both of the hetero atoms accommodates ten electrons in its outer shell. This possibility would allow the forms shown below to be considered as possible contributors to the resonance hybrids.

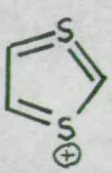


(Ie)

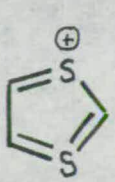


(If)

(Ig)



(IId)



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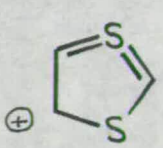
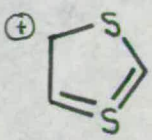
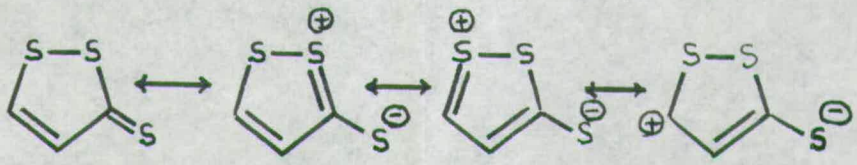


(IIf)

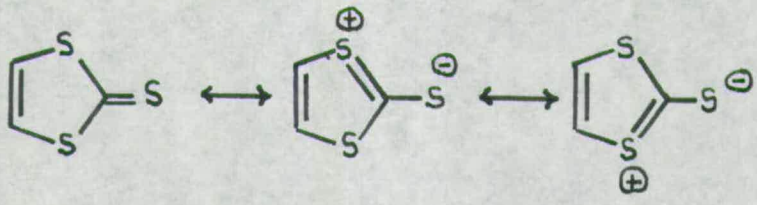


(IIg)

Thiones derived from these parent nuclei are designated 1,2-dithiole-3-thiones (III) and 1,3-dithiole-2-thiones (IV) and these may be regarded as potentially aromatic in character since they may give rise to charge separated structures through polarisation of the thiocarbonyl group.



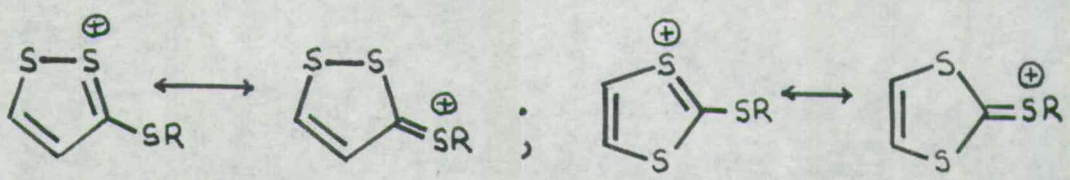
(III) (IIIa) (IIIb) (IIIc)



(IV) (IVa) (IVb)

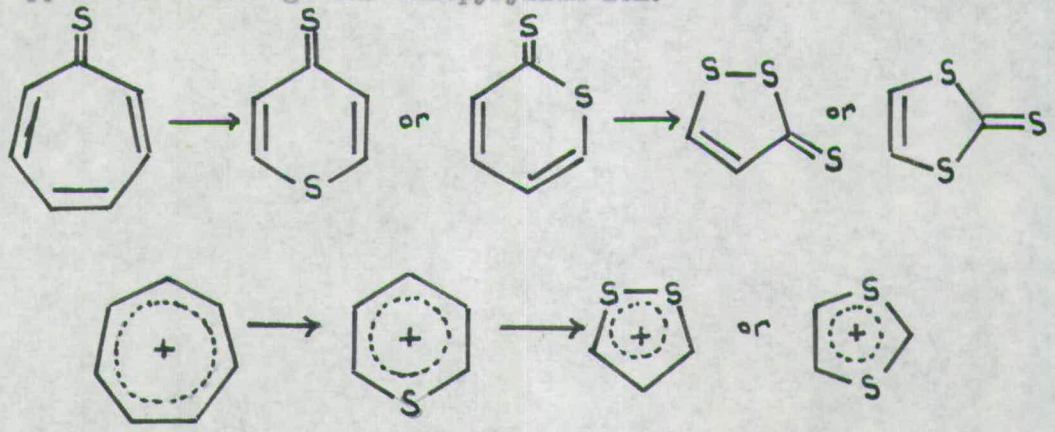
As with the dithiolium salts, by involving d-orbital resonance, further structures for these dithiolethiones may be considered and their participation is suggested by measurements of the C-S bond lengths in a dithiolethione[2]. If no resonance stabilisation occurred in these compounds, (III) would tend to react as an α, β-unsaturated thione while (IV) would show olefinic reactivity.

With alkyl esters of inorganic acids, these dithiolethiones give rise to salts which may be regarded as alkylthiodithiolium salts (V), (VI), the cations having the following contributing structures.



(Va) (Vb) (VIa) (VIb)

Considering the concept of isosterism[3], which allows replacement of -CH=CH- by -$\ddot{S}$-, these dithiole ring systems may be considered as having been derived from seven membered ring systems by two successive such replacements, the dithiolethiones arising from thiotropone and thiopyran-thiones, while the parent dithiolium cations would arise from the tropylium ion through the thiopyrylium ion.

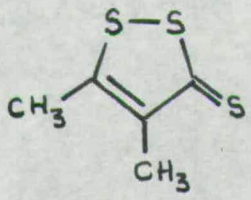


The canonical structures involving 3d orbitals in bonding are similarly isosteric if the replacements are looked upon as a substitution of =$\ddot{S}$= for =CH-CH=.

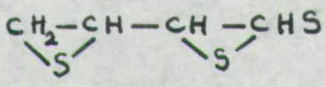
Consideration of these ideas indicates that the nuclei of such dithiole ring systems should be susceptible to nucleophilic but not to electrophilic attack. On the basis of the various canonical forms shown previously, nucleophilic attack on the dithiolium nucleus would be expected to take place in the 3-position of the 1,2-dithiolium cation and in the 2-position of the 1,3-dithiolium cation. The same conclusions result from calculations, involving the use of the simple M.O./L.C.A.O. method[4], which also show that free radical attack would be expected at the same positions. If the highly improbable electrophilic attack took place at all, it would do so at the least electropositive position of the rings, the 4-position in both types of cation.

Further electron-donating substituents on the ring would be expected to stabilise the system since, on the basis of the resonance theory, this would lead to an increase in the number of structures contributing to the resonance hybrid, whereas electron-attracting substituents would be expected to decrease the stability of the ring.

4,5-Dimethyl-1,2-dithiole-3-thione (VII) was the first member of the series to be isolated[5] but the structure remained in doubt for many years. The structure (VIII) was originally suggested for this material, although Selker and Kemp[6], who obtained it while investigating rubber vulcanisation, supposed

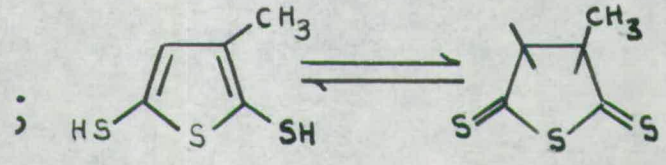


(VII)



(VIII)

it to be 3-methylthiophen-2,5-dithiol (IX). In 1951, however, the structure (VII) was established[7].

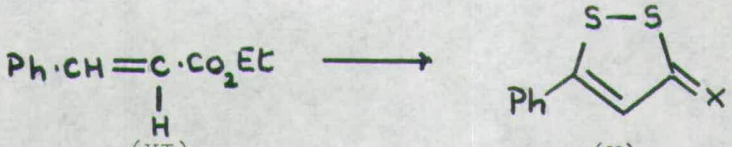


(IX)

Many methods are known for the preparation of 1,2-dithiole-3-thiones and these were reviewed in 1965[8]. Three important methods, from the point of view of this thesis, are as follows :-

i) <u>5-Phenyl-1,2-dithiole-3-thione</u>

5-Phenyl-1,2-dithiole-3-one (X; X = O) is obtained in good yield through the reaction of sulphur with boiling ethyl cinnamate[9,10], (XI). The ketone is sulphurised readily to the thione (X; X = S) by reaction with phosphorus pentasulphide[10]. The reverse transformation of thione to ketone is achieved by treating a solution of the thione

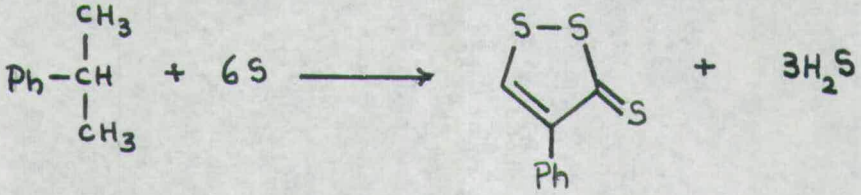


(XI) (X)

with mercuric acetate[11].

ii) 4-Phenyl-1,2-dithiole-3-thione

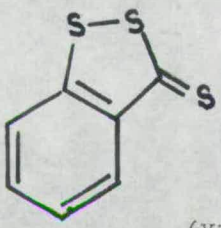
4-Phenyl-1,2-dithiole-3-thione (XII) is obtained when a mixture of cumene, sulphur and isoquinoline is heated at 160° for 174 hr.[12].



(XII)

iii) 4,5-Benzo-1,2-dithiole-3-thione

The method of Klingsberg[13] is used for the preparation of 4,5-benzo-1,2-dithiole-3-thione (XIII); 2,2'-dithiodibenzoic acid and phosphorus pentasulphide are refluxed for 45 min. in pyridine.

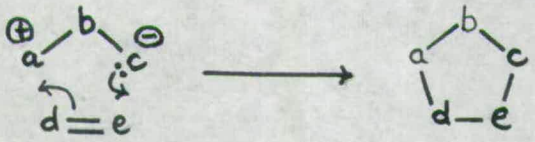


(XIII)

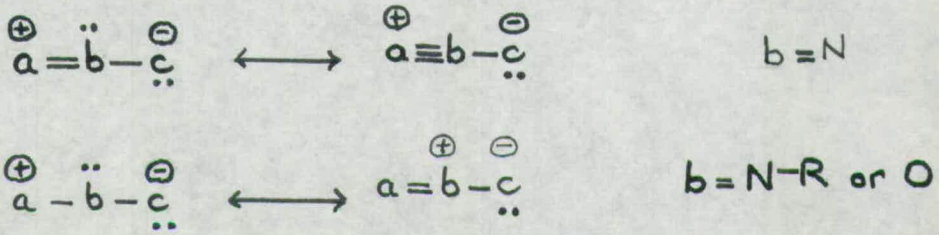
CYCLO-ADDITION REACTIONS OF DITHIOLETHIONES AND RELATED COMPOUNDS

Huisgen[14] classifies cyclo-addition reactions according to the number of new σ-bonds formed or according to the size of the ring which is formed. The most frequent case is where two reactants unite to form the cyclic compound, creating two new σ-bonds at the expense of two π-bonds.

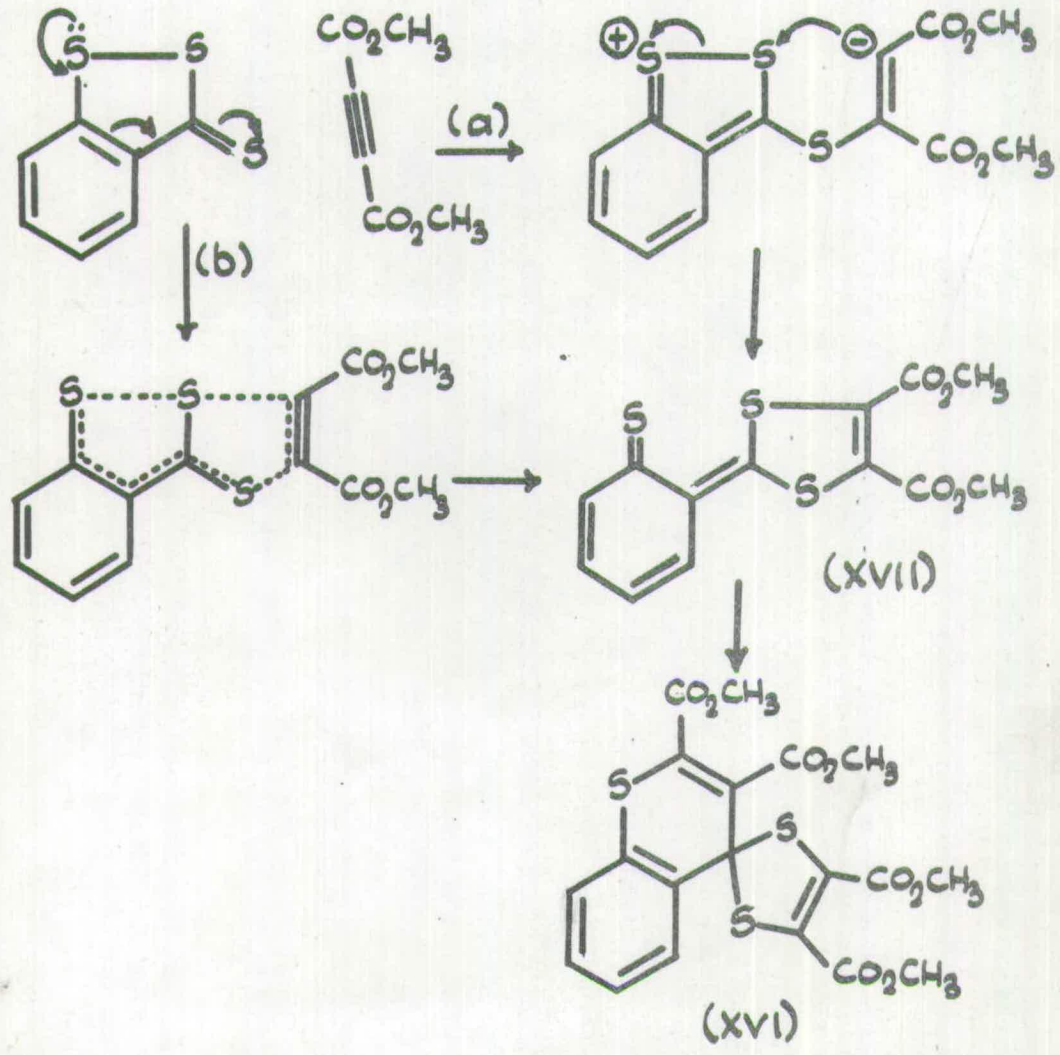
A cyclo-addition of the type 3 + 2 —> 5 leading to an uncharged 5-membered ring cannot occur with octet stabilised reactants which have no formal charges. Rather, a 1,3-dipole, a-b-c, must be defined such that atom 'a' possesses an electron sextet, i.e. an incomplete valence shell combined with a positive formal charge and that atom 'c', the negatively charged centre, has an unshared electron pair. Combinations of such a 1,3-dipole with a multiple bond system d-e, termed the dipolarophile, is referred to as a 1,3-dipolar cyclo-addition. The two components coalesce by means of a cyclic electron displacement with extinction of the formal charges to give a five-membered ring. The dipolarophile may be any double or triple bond.



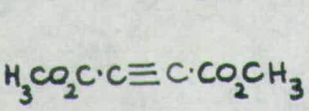
Compounds containing an electron sextet at a carbon, nitrogen or oxygen atom are not stable. The foregoing designation would therefore acquire the physical significance of a mere resonance contributor if the 1,3-dipole were capable of isolation. Stabilisation is possible if an unshared pair of electrons at atom 'b' can relieve the electron deficiency at centre 'a' by formation of an additional bond. In the new mesomeric formula in which 'b' now has the positive charge, all the centres have completely filled valence shells. Such systems are designated as 1,3-dipoles with internal octet stabilisation.



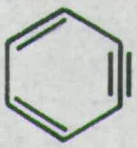
SCHEME 1



Since polarisation of the exocyclic double bond in the dithiolethiones can lead to a charged aromatic ring system, (III) (IV), Easton[15] attempted to induce them to undergo cyclisation reactions with dipolarophiles. Two dipolarophilic reagents were used in this work, (i) dimethyl acetylenedicarboxylate (XIV) and (ii) benzyne (XV).



(XIV)



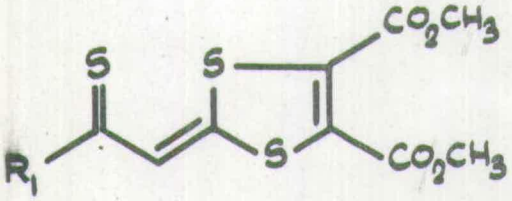
(XV)

i) Reaction with Acetylenic Compounds

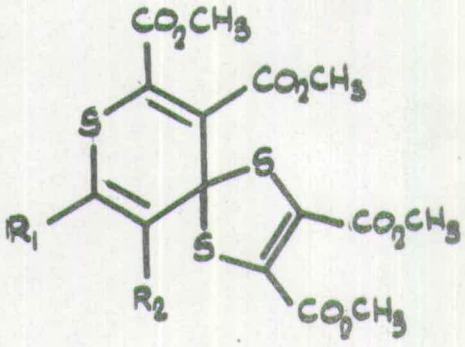
a) Dimethyl acetylenedicarboxylate

In the initial reaction, 4,5-benzo-1,2-dithiole-3-thione (XIII) was used. The thione was dissolved in benzene and an equimolecular quantity of dimethyl acetylenedicarboxylate was added. The product was identified as the di-adduct (XVI) which was thought to be formed by 1,4-addition to a highly reactive mono-adduct (XVII). Two possible mechanisms were suggested to account for the formation of the mono-adduct [Scheme 1, route (a) and (b)]. Route (a) is a two stage process in which electrophilic attack by the acetylenic ester at the electron rich exocyclic sulphur atom is followed by intramolecular nucleophilic displacement of the 2-sulphur atom. Alternatively, the two stages might be concerted, the reaction proceeding via a cyclic transition stage such as that shown in the scheme (route b).

When the reaction was repeated using methanol as solvent, the same di-adduct (XVI) was isolated. This result supports the concept of a concerted addition because methanol would be expected to interfere



(XIX)



(XVIII)

(a) R_1 = H ; R_2 = Ph

(b) R_1 = Ph ; R_2 = H

(c) R_1 = Et ; R_2 = CH_3

(d) R_1/R_2 = $-(CH_2)_3-$

(e) R_1/R_2 = $-(CH_2)_4-$

(a) R_1 = H ; R_2 = Ph

(b) R_1 = Ph ; R_2 = H

(c) R_1 = Et ; R_2 = CH_3

(d) R_1/R_2 = $-(CH_2)_3-$

(e) R_1/R_2 = $-(CH_2)_4-$

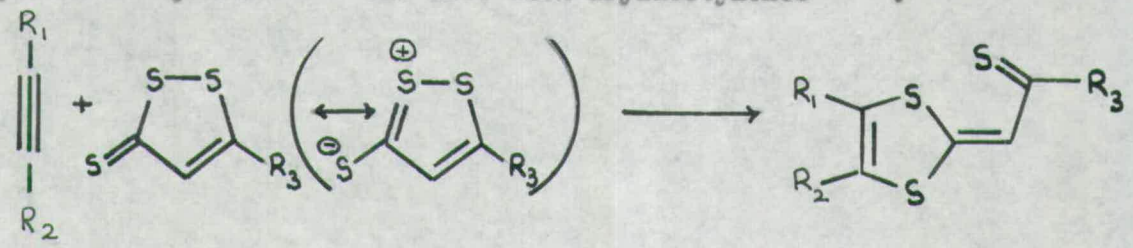
in the two-stage process by proton transfer to the anionic site of the intermediate dipolar ion.

4-Phenyl-1,2-dithiole-3-thione (XII) reacted with dimethyl acetylenedicarboxylate to give a red oil (which decomposed on standing), the ultraviolet and n.m.r. spectra of which were suggestive of a di-adduct (XVIIIa).

The isomeric 5-phenyl-1,2-dithiole-3-thione (X; X=S) gave both the mono-adduct (XIXb) and the di-adduct (XVIIIb), both of which were quite stable. Similar mono- and di-adducts were obtained from 1,2-dithiole-3-thiones bearing aliphatic substituents or fused alicyclic rings (see formulae XVIII and XIX c-e).

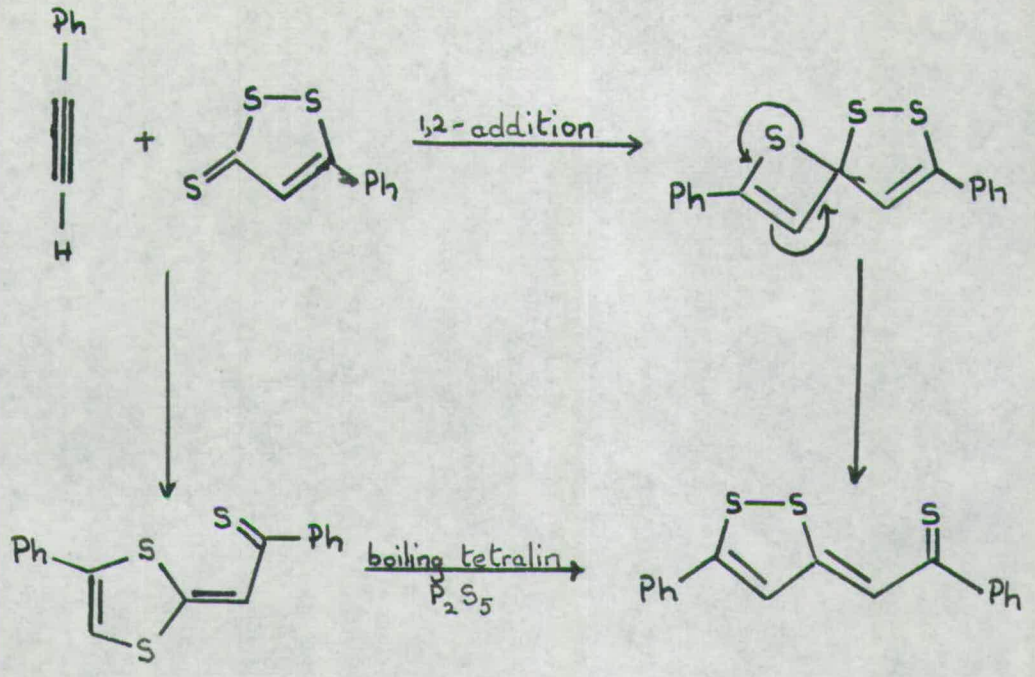
b) Phenylacetylene

2-Thioacylmethylene derivatives of 1,3-dithioles (XX) are formed in the reactions of 1,2-dithiole-3-thiones, not only with electrophilic acetylenes[16,17] but also with arylacetylenes[16,18].



(XX)

When the reaction of phenylacetylene with 5-phenyl-1,2-dithiole-3-thione is carried out in xylene in the presence of hydrogen chloride, the reaction is reported[18] to occur by 1,3-addition yielding 2-thiophenacylidene-4-phenyl-1,3-dithiole (XXI). However, when the reactants are refluxed for 15 hr. in dry xylene, the diphenylthiothiophthen (XXII) is obtained.

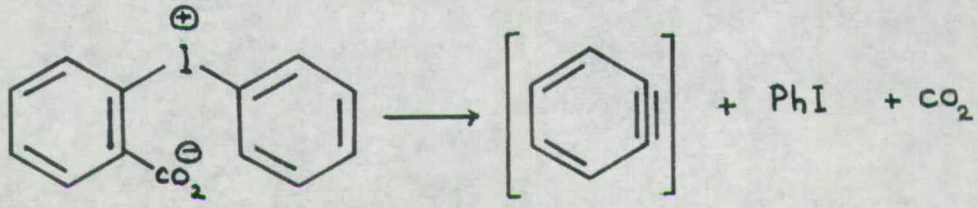


(XXI) (XXII)

Brown[19] proposed a mechanism involving 1,2-addition of phenylacetylene to the thione followed by ring opening to give the thiothiophthen (XXII), but it has since been shown by Mowat[20] that the isomerisation of (XXI) to (XXII) is purely thermal and is intramolecular (i.e. there is no dissociation to phenylacetylene and recombination by 1,2-addition).

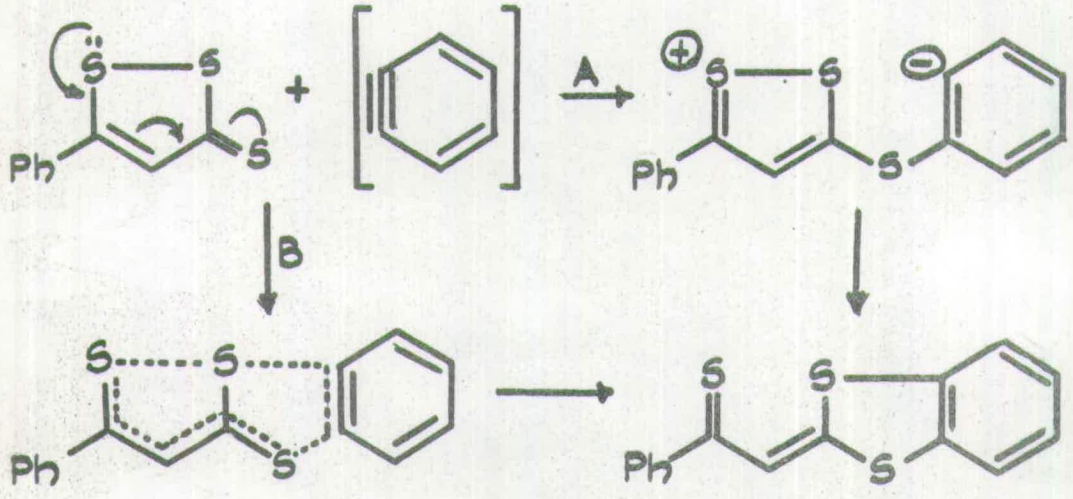
ii) Reactions with Benzyne

Previous cyclo-addition reactions between dithiolethiones and benzyne were performed by Easton[21] who used two methods to generate benzyne : (a) decomposition of phenyliodoniobenzene-2-carboxylate (XXIII) in a high boiling aprotic solvent



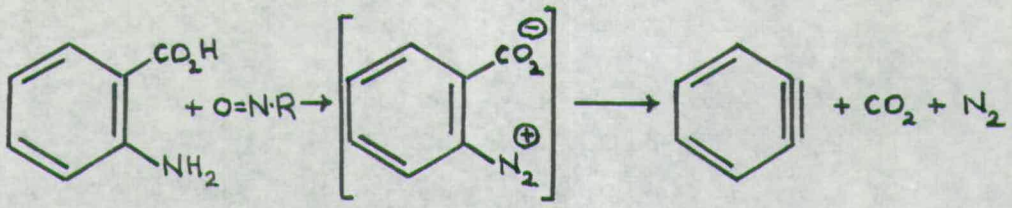
(XXIII)

SCHEME 2



(XXIV)

and (b) aprotic diazotisation of anthranilic acid[22].



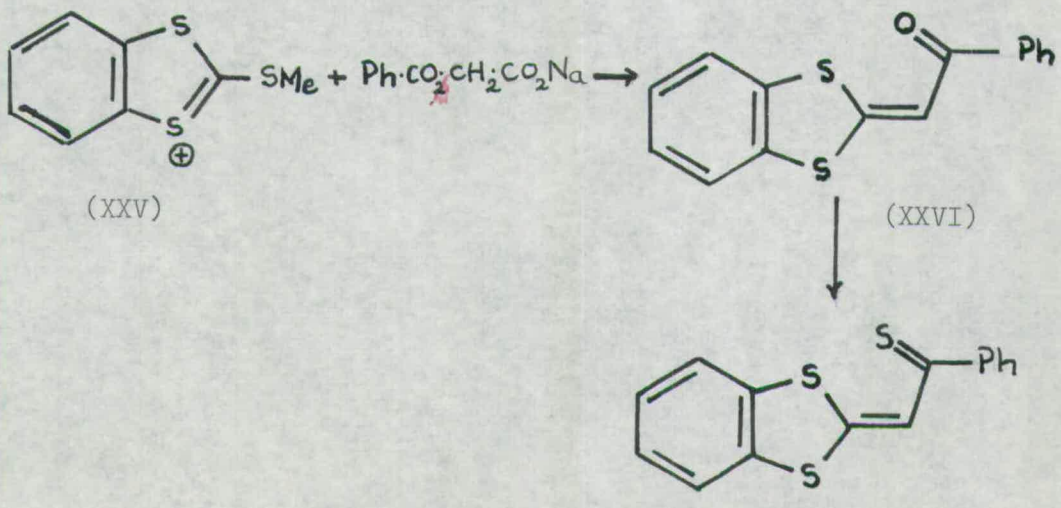
The sole characterisable product of the reaction of benzyne with 5-phenyl-1,2-dithiole-3-thione was 4,5-benzo-2-thiophenacylidene-1,3-dithiole (XXIV) and two suggested pathways for its formation are shown in Scheme 2.

Route A involves electrophilic attack by benzyne at the exocyclic sulphur atom, to give a dipolar intermediate, and route B is a concerted cyclo-addition.

The yield of the adduct was very low (7%) when the benzyne was generated by method (a), but rather better (28%) when method (b) was used.

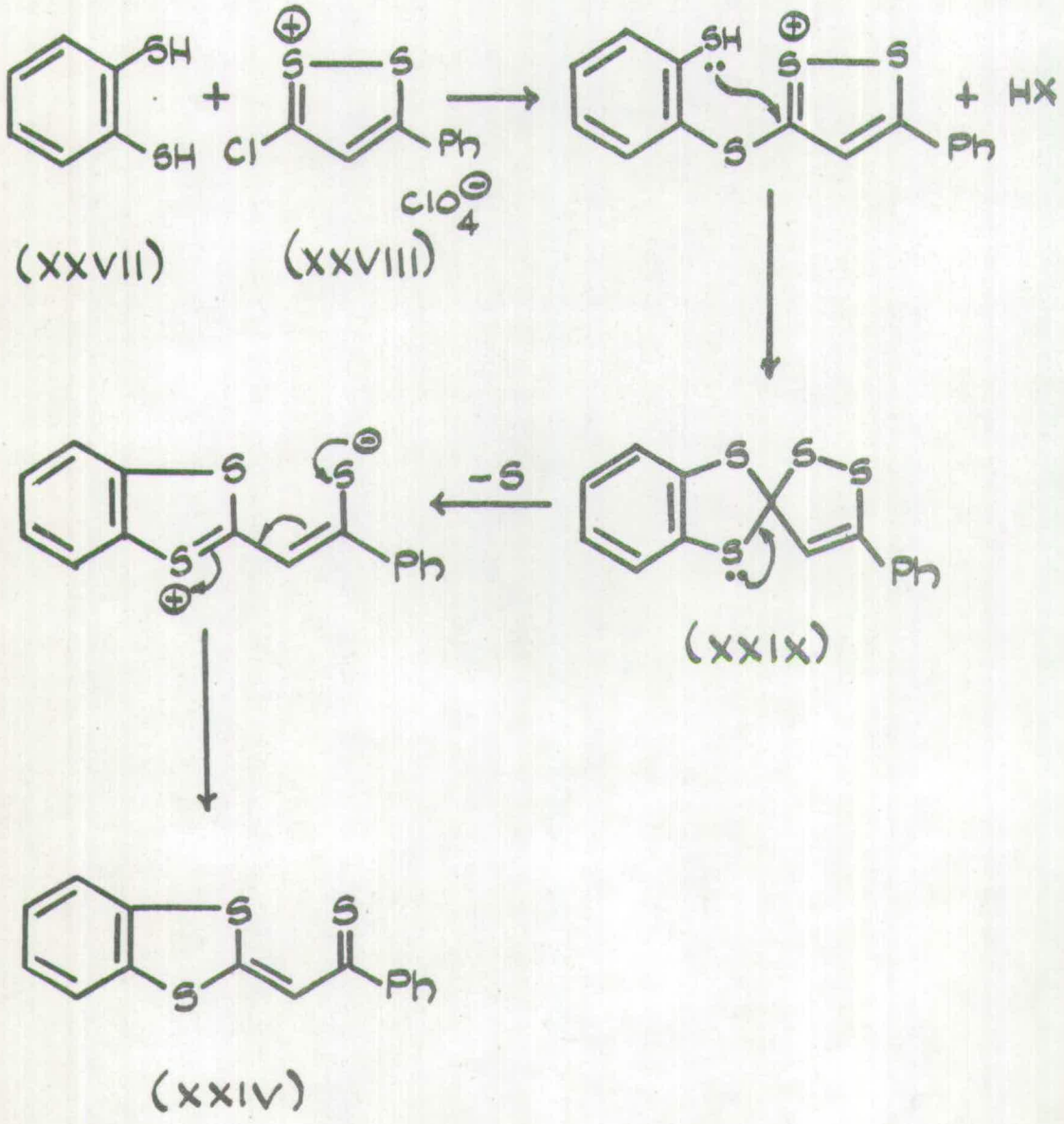
The product (XXIV) was readily identified since it had been obtained by two other routes, as detailed below.

(a) The benzodithiolium salt (XXV) reacts with sodium benzoylacetate to give a ketone (XXVI) which is converted into the thione (XXIV) by the action of phosphorus pentasulphide[17].



(XXV) (XXVI) (XXIV)

SCHEME 3


SH
SH
+
S
S
Cl
Ph
ClO4
(XXVII)
(XXVIII)
SH
S
S
Ph
+ HX
S
S
S
S
Ph
(XXIX)
-S
S
S
S
Ph
S
S
Ph
(XXIV)

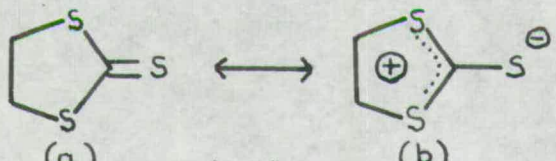
(b) Benzene-1,2-dithiol (XXVII) reacts with 3-chloro-5-phenyl-1,2-dithiolium perchlorate (XXVIII) in acetone at room temperature to give the same compound[23] (XXIV). The mechanism proposed for this reaction (scheme 3) involves displacement of chloride ion from the 3-position in the chloro compound (XXVIII) by one of the thiol groups in(XXVII); the second thiol group then attacks the three position forming an unstable spiran intermediate (XXIX). Opening of the dithiole ring with loss of sulphur then leads to the thiophenacylidene compound (XXIV).

No products were isolated from the reactions of 4-phenyl- and of 4,5-benzo-1,2-dithiole-3-thione with benzyne.

The reaction of 1,3-dithiolan-2-thione with benzyne gave a small yield of 4,5-benzo-1,3-dithiole-2-thione but only when diphenyl-iodonium-2-carboxylate was used to generate benzyne.

REACTIONS OF 1,3-DITHIOLANTHIONES WITH DIMETHYL ACETYLENEDICARBOXYLATE

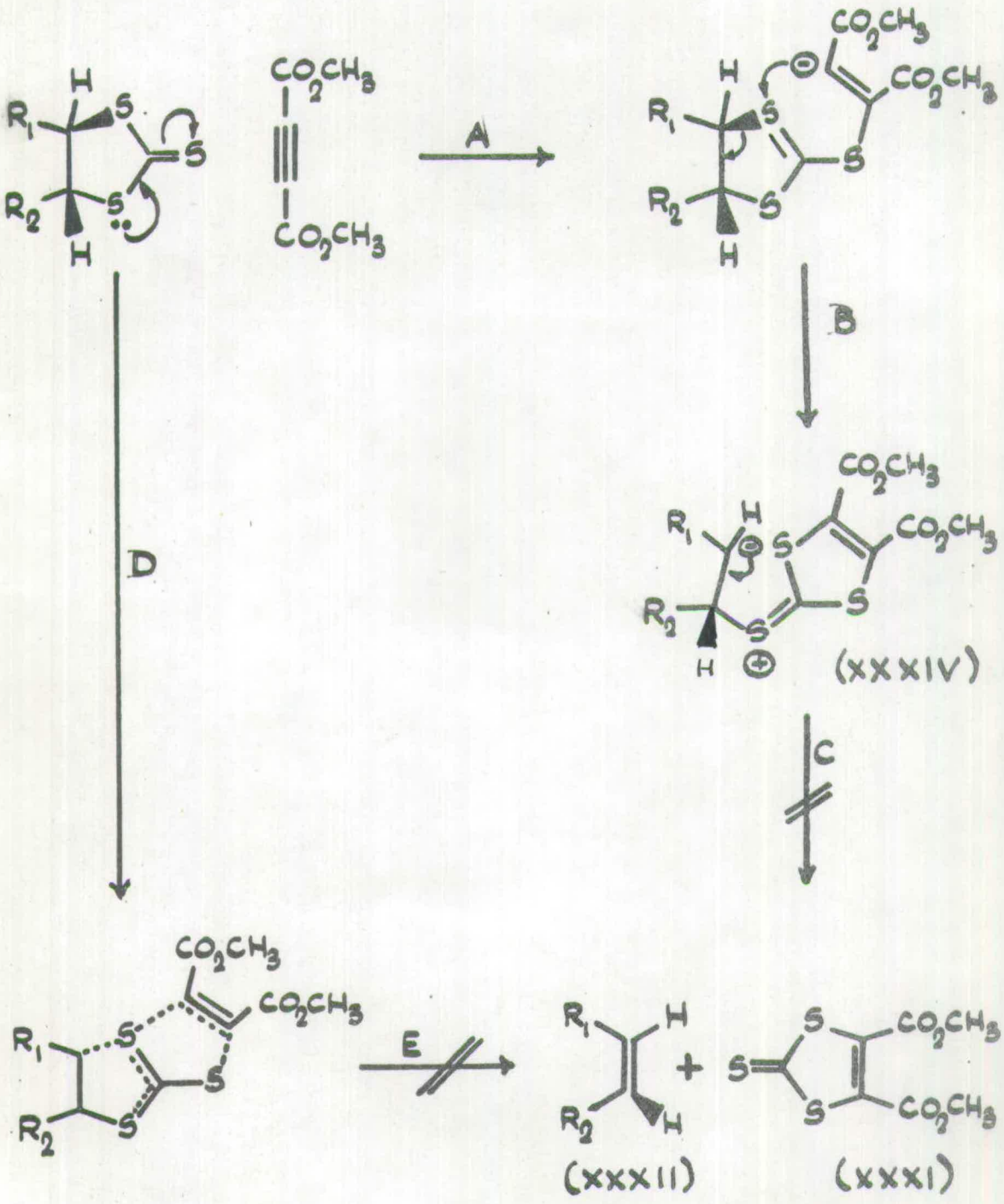
A comparison of the reactions of 1,3-dithiolan-2-thione with those of its dehydrogenated analogue, 1,3-dithiole-2-thione has been published[24]. The fact that the dithiolanthiones give rise to alkylthio salts suggests that a dipolar structure (XXX)



(a) (XXX) (b)

similar to that of the dithiolethione makes a significant contribution to the resonance hybrid.

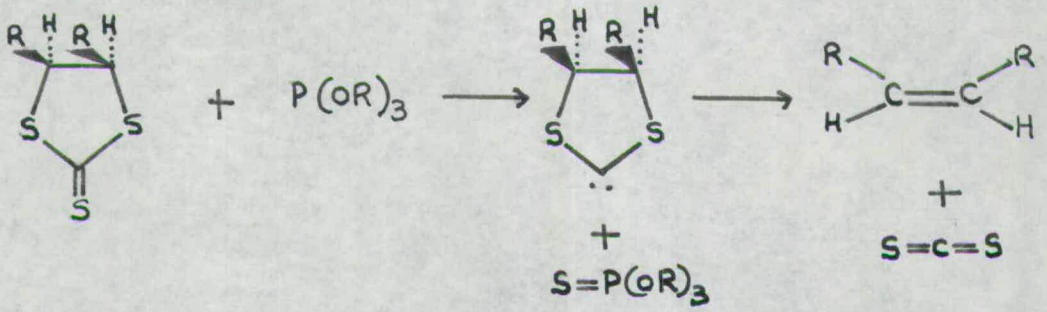
SCHEME 4



It thus seemed to Easton[25] to be feasible to react 1,3-dithiolan-2-thiones with dimethyl acetylenedicarboxylate. He first investigated the reaction of 1,3-dithiolan-2-thione with dimethyl acetylenedicarboxylate and, at 140°, obtained the expected ethylene and 4,5-dimethoxycarbonyl-1,3-dithiole-2-thione (XXXI).

Again there are two possible mechanisms (scheme 4), one proceeding in two stages, via a dipolar intermediate and another proceeding in one stage via a cyclic transition stage.

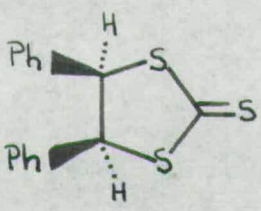
At this stage of the investigation it was noted that the final result of the reaction - namely, elimination of the trithiocarbonate group to form an olefine - was the same as that of the newly-reported[26] reactions of 1,3-dithiolan-2-thiones with trialkyl phosphites. These reactions had been shown to yield cis- and trans-stilbene and cis- and trans-but-2-enes, stereospecifically, from their corresponding trithiocarbonates (dithiolanthiones); they are, therefore, cis-elimination reactions.



Further, it was found that when trans-4,5-tetramethylene-1,3-dithiolan-2-thione was treated with trialkyl phosphites under the usual conditions, no 1,2-elimination occurred. The cis-isomer, on the other hand, yielded cis-cyclohexene normally. The explanation afforded by

the authors is that a concerted cyclo-elimination mechanism is required for the product-forming step (c.f. Scheme 4, route D). Elimination is effectively blocked in those cases in which cis-elimination would lead to an excessively strained structure, [e.g. trans-cyclohexene (XXXII); $R_1/R_2 = -(CH_2)_4-$].

This result prompted Easton to examine the stereospecificity of the acetylene reaction by allowing dimethyl acetylenedicarboxylate to react with cis-4,5-diphenyl-1,3-dithiolan-2-thione (XXXIII). In this case both cis- and trans- stilbene were obtained from the reaction mixture in roughly equal amounts thus showing quite clearly that the reaction is not stereospecific and further that the reaction does not proceed via a cyclic transition state.

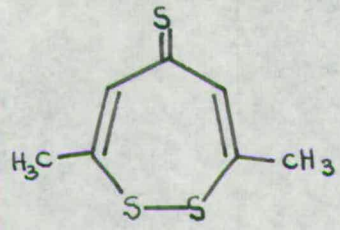


(XXXIII)

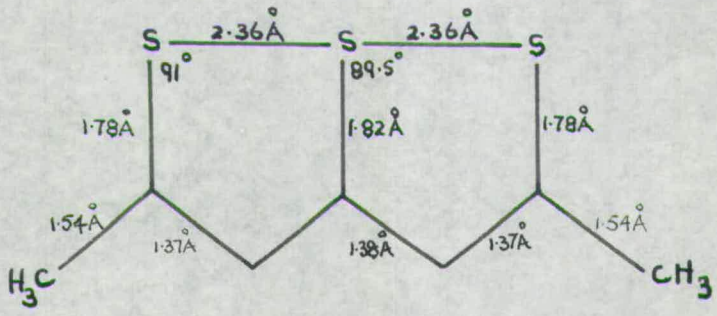
The action of the diester on pure cis-stilbene, under the conditions used in the reaction, produced no isomerisation to the trans-isomer. Easton proposed that the dithiole ring is initially cleaved only at one of the C-S bonds to give the intermediate dipolar ion (XXXIV). Before electron rearrangement is completed, with the elimination of olefin, one carbon atom will be free to rotate about the carbon-carbon single bond in (XXXIV), thus accounting for the roughly 1:1 mixture of stereoisomeric olefins obtained.

PART B : THIOTHIOPHTHENS AND RELATED COMPOUNDS

An investigation by Arndt[27] in 1925 showed that the reaction of diacetylacetone with phosphorus pentasulphide gave a compound which, from its elemental analysis and molecular weight, was formulated as a cyclic disulphide (XXXV). This structure was accepted until 1958, when the compound was studied by X-ray crystallography[28]. The data so obtained did not agree with the disulphide structure but were consistent with a substituted dithiole. The bond lengths and angles were determined (XXXVI) and the carbon-carbon bond lengths were found to be similar to those found in aromatic C-C bonds. The three sulphur

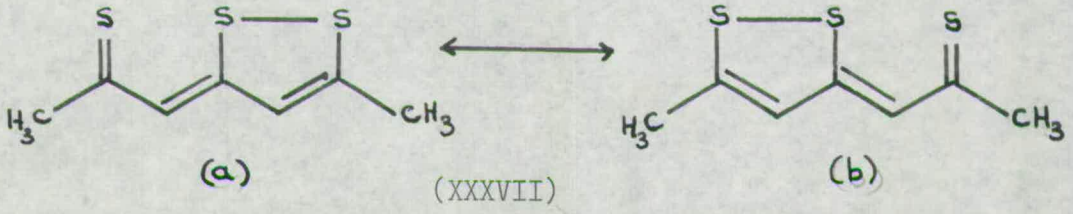


(XXXV)



(XXXVI)

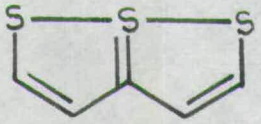
atoms were found to be almost co-linear and were equally spaced. The length of the S-S bond (2.36Å) is longer than the normal disulphide bond length (2.08Å) and suggests that the molecule is a resonance hybrid of the contributing forms shown below (XXXVIIa-b). Compounds of this type are called thiothiophthens.



(XXXVII)

It has been suggested[29] that the thiothiophthen structure would be better interpreted as involving the delocalisation of the 8 π-electrons to form an eight-centred system, with the S-S linkages being purely of π-character, since the increase in the S-S bond length is of the order of that observed in the N-N bond of N_2O_4 compared with the same bond in hydrazine. The N-N bond in N_2O_4 has been described as being a pure π-bond[30].

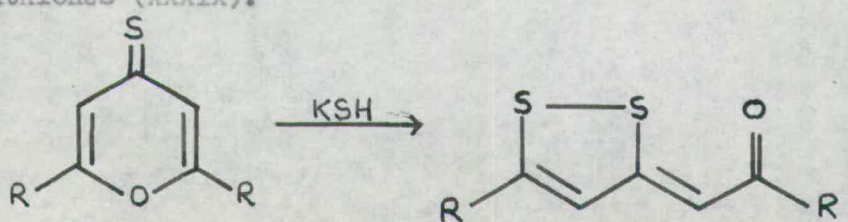
Calculations of the participation of the d-orbitals in the hybridisation of the central sulphur atom of the thiothiophthen system at first indicated that the 3-p_z- orbital was more likely to take part than the 3 d_{xy}- orbital[31], but recalculations later showed[32] that the d-orbital contributes to the hybrid to almost the same extent as the p-orbital. Utilisation of the d-orbitals would bring into consideration canonical structures of the type (XXXVIII).



(XXXVIII)

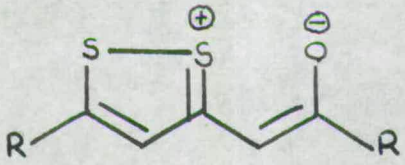
Replacement of one of the sulphur atoms occurs when thiothiophthens are treated with acid[33], mercuric acetate[34] or potassium permanganate[35]. The carbonyl compound so formed may be reconverted into the thiothiophthen with phosphorus pentasulphide.

Further evidence for the thiothiophthen structure was provided by conversion of the thione of supposed structure (XXXV), into a ketone which was examined by infrared spectroscopy[36]. The same compound and other related ketones were obtained by an alternative synthesis from γ-pyranthiones (XXXIX).



(XXXIX)

The carbonyl absorption bands of these ketones were of much lower frequency than those of either γ-pyrones or α,α'-unsaturated ketones such as dibenzylidene acetone. However, the absorptions were closely similar to those of metal-chelated β-diketones and this led the author to suggest the substituted dithiole structure in which the carbonyl group is likely to be highly polarised owing to the proximity of negative oxygen and positive sulphur :-

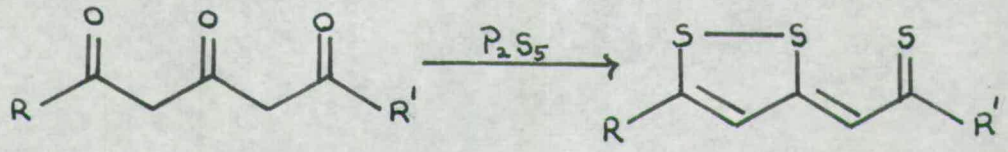


More recently, further evidence for the partial bonding of the carbonyl oxygen to the dithiole ring sulphur has been reported[37-39].

A number of alternative synthetic routes have been developed since 1958 and a wide range of substituted thiothiophthens has been prepared. The most important of these routes are listed below.

1. From 1,3,5-triketones

Dibenzoylacetone and acetylbenzoylacetone were substituted for diacetylacetone in the original synthesis, thus enabling the diphenyl (XL; R = R' = Ph) and phenyl-methyl (XL; R = Ph, R' = CH_3) thiothiophthens to be prepared[40].

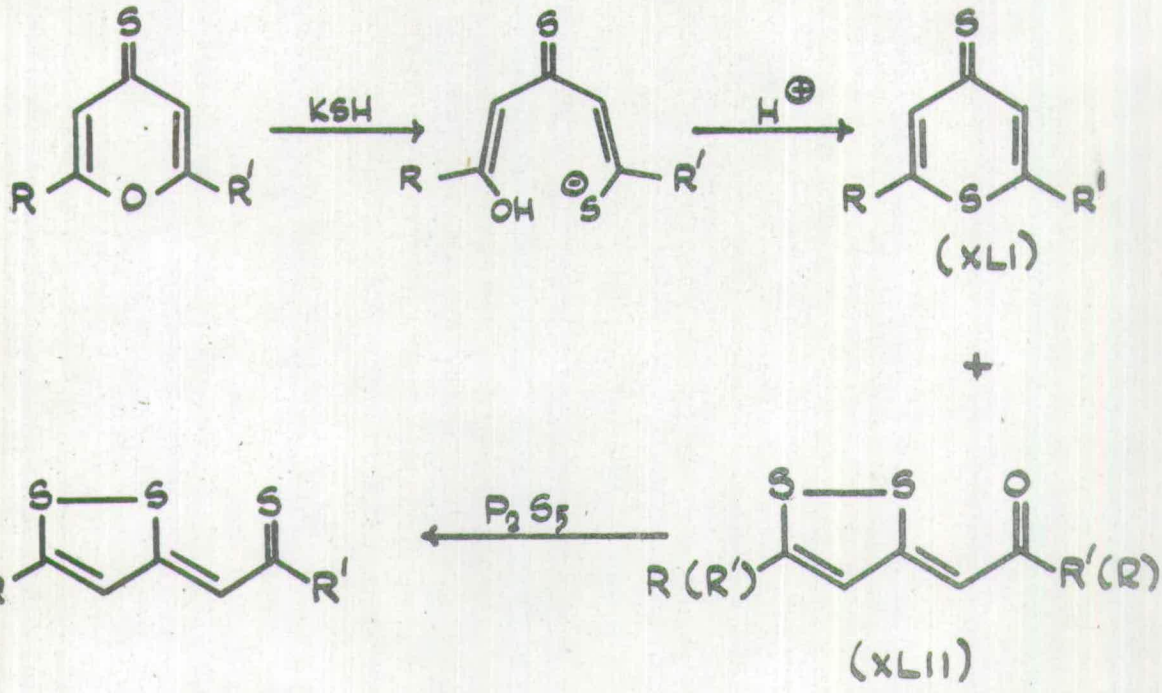


(XL)

2. From γ-pyranthiones

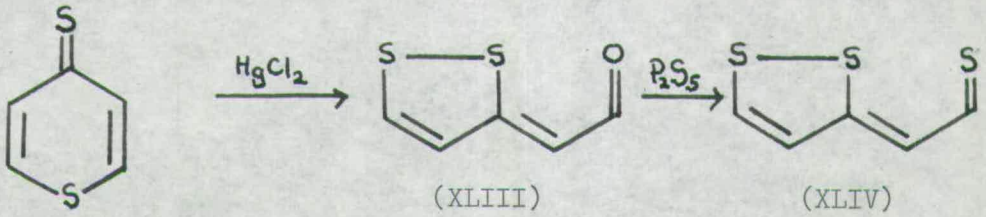
γ-Pyranthiones, when treated with potassium hydrogen sulphide yield the carbonyl analogues of thiothiophthens[36,41]. Attack by $SH^{\ominus}$

SCHEME 5



at the 2-position results in ring opening. Acidification can lead to ring closure either, with loss of water, to give the ɣ-thiopyranthione (XLI), or, oxidatively, to give the acylmethylenedithiole (XLII). Sulphurisation of the latter with phosphorus pentasulphide yields the thiothiophthen (Scheme 5). Where R is different from R', two ketones are possible as products.

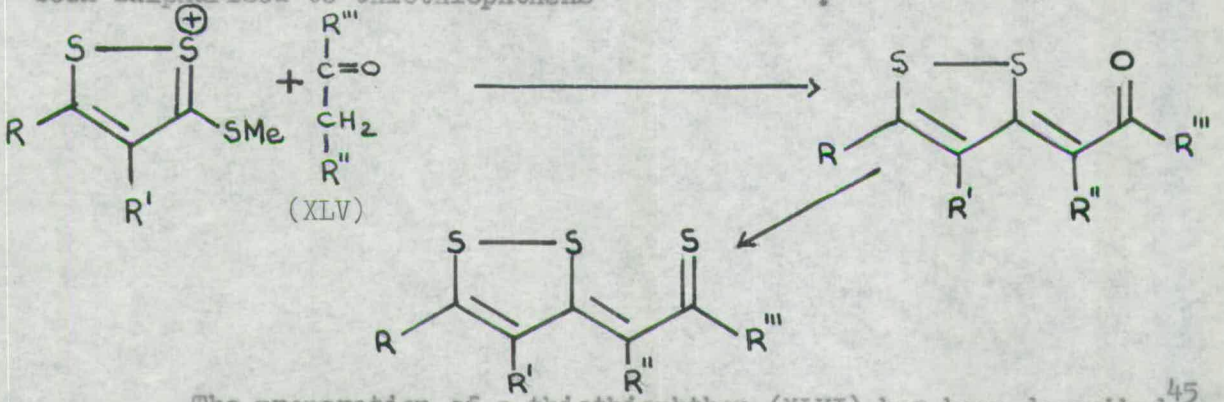
The synthesis of the parent compound was effected from the related thiopyran-4-thione[42]. Treatment with mercuric chloride formed the intermediate aldehyde (XLIII) which, on sulphurisation with phosphorus pentasulphide, yielded the unsubstituted thiothiophthen (XLIV).



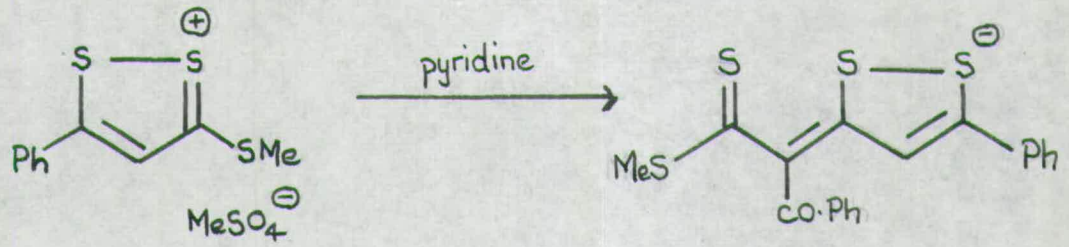
(XLIII) (XLIV)

3. From 1,2-dithiolium salts with replaceable substituents

The nucleophilic substitution of 3-methylthio-1,2-dithiolium salts by active methylene compounds (XLV) has yielded ketones which have been sulphurised to thiothiophthens[35,38,39,43,44].

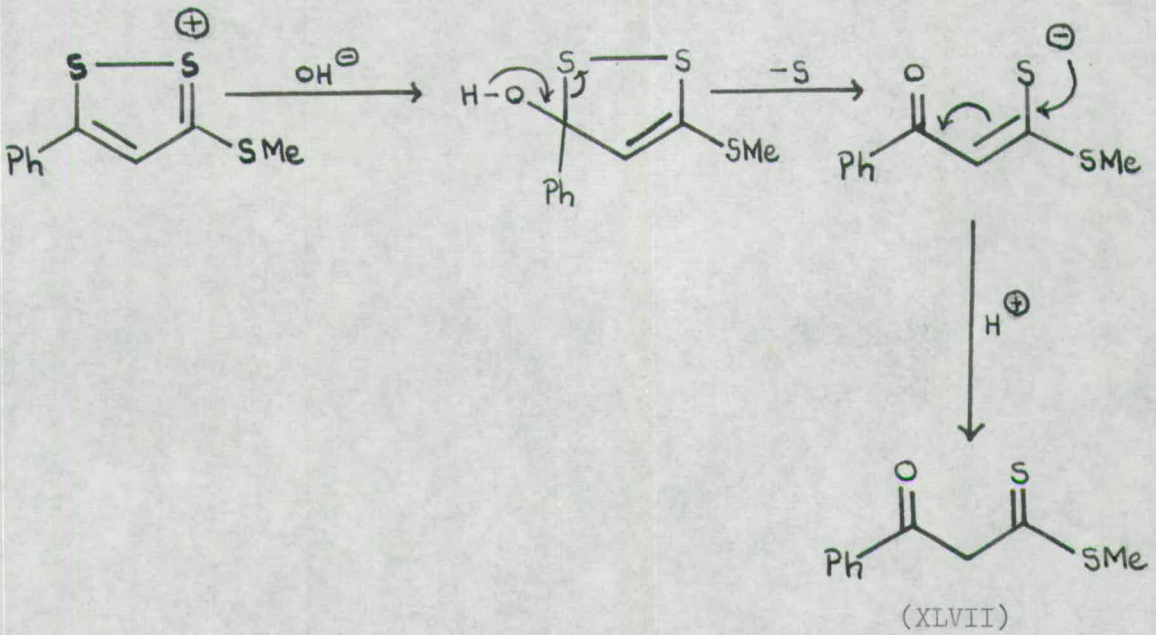


The preparation of a thiothiophthen (XLVI) has been described[45] from the basic decomposition of 3-methylthio-5-phenyl-1,2-dithiolium methyl sulphate in warm pyridine.



(XLVI)

The mechanism is not discussed but presumably the compound arises from methyl benzoyldithioacetate (XLVII) which could be formed by attack of a water molecule or hydroxide ion at the 5-position, followed by ring opening and loss of sulphur.



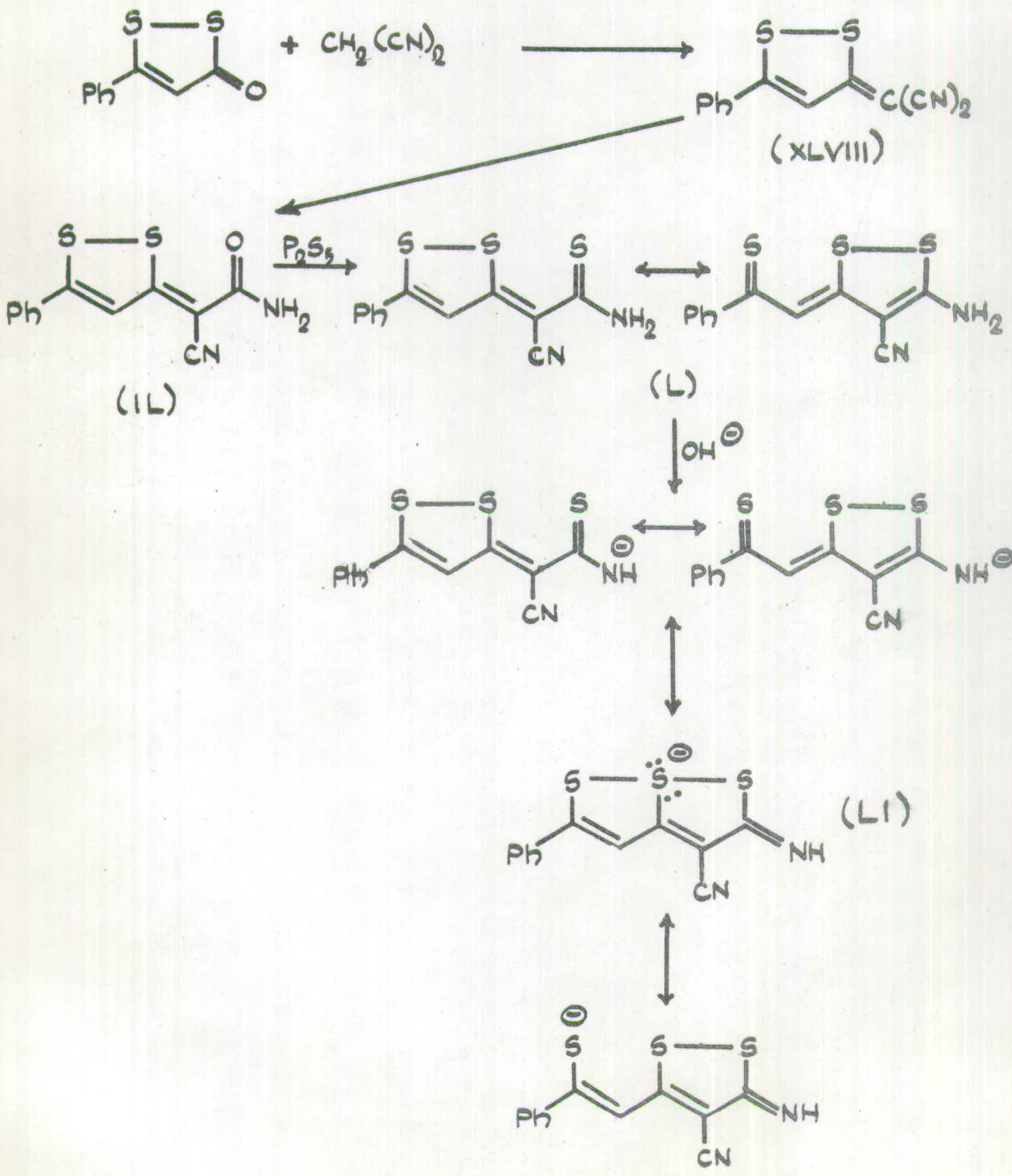
(XLVII)

This dithioester was shown to react with the 3-methylthio-1,2-dithiolium salt to yield the same product in good yield.

4. From 1,2-dithiolium salts without replaceable substituents

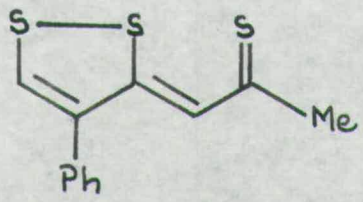
4-Phenyl- and 3-phenyl-1,2-dithiolium salts condense with methylene ketones to yield the ketone precursors of thiothiophthens[34,46].

SCHEME 6



5. From 1,2-dithiole-3-ones

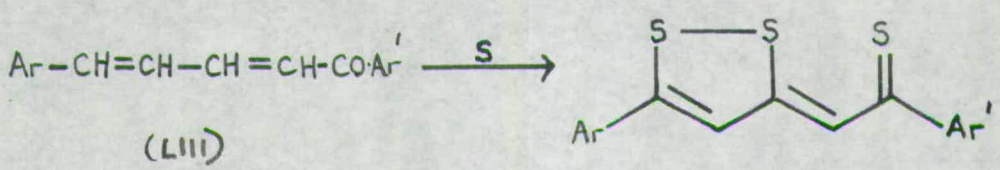
Condensation of 5-phenyl-1,2-dithiole-3-one with malono nitrile in phosphoryl chloride gave the dinitrile (XLVIII)[47]. The corresponding reaction with acetonitrile has been reported[34]. (Scheme 6) Alkaline hydrolysis of (XLVIII) gave the amide (IL) which in turn was converted to the thioamide (L). Close similarity between the visible and ultra-violet spectra of the thioamides (L) and those of the thiothiophthen (LII) prompted the author to propose that the compound (L) represents a new class of no-bond resonance compounds. The compound is stable to boiling aqueous alkali and this is explained by stating that no-bond resonance contributes, via sulphur d-orbital expansion (LI), to electron delocalisation favouring acidity and resistance to hydroxide ion attack.



(LII)

6. From αβ- γδ -unsaturated ketones

Ketone precursors of thiothiophthens may also be prepared by reaction of dienones (LIII) with sulphur at 220°[48,49].

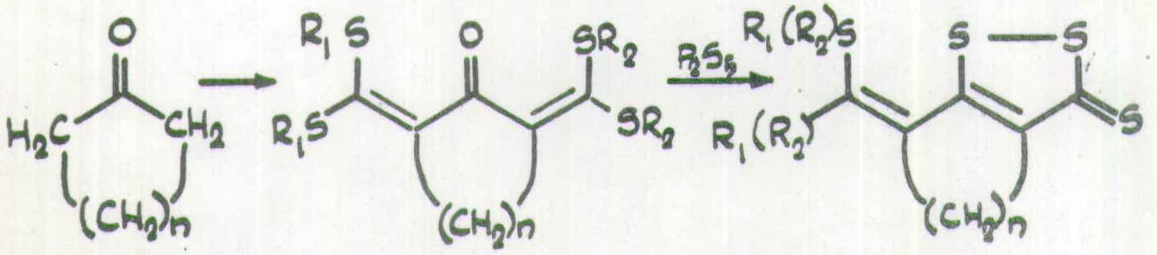


(LIII) (~~LIII~~)

7. From acylphenylacetylenes

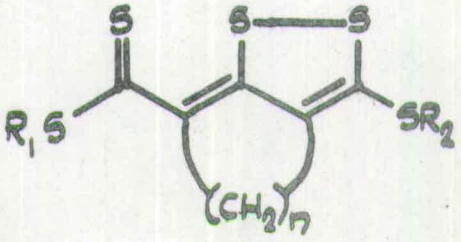
Acylphenylacetylenes (LIV) which carry an active methyl or methylene group react with thioacetic acid and sodium acetate to yield thiothiophthens directly in good yield[50].

SCHEME 7

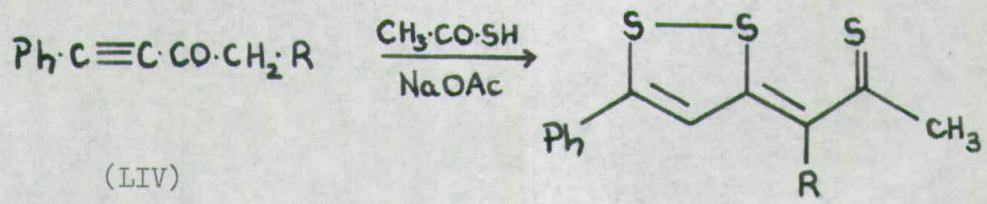


(LV) (LVI)

or



(LVII)



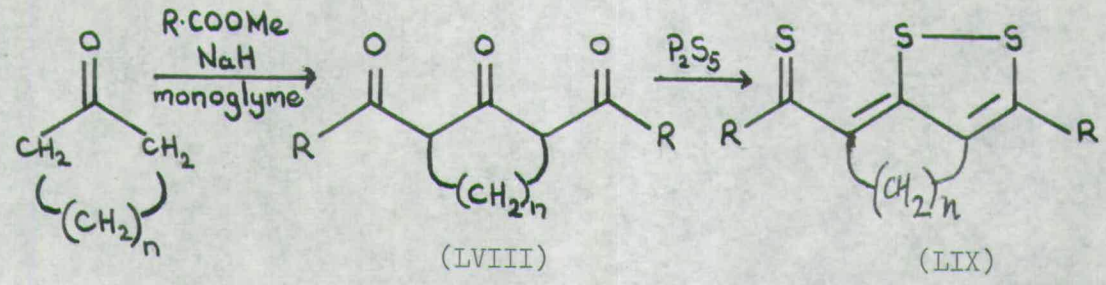
(LIV)

8. From alicyclic ketones

Reaction of carbon disulphide with active α-methylene groups under basic conditions causes addition of one equivalent of carbon disulphide. Alkylation of the resulting dithiol yields a compound which, when resubjected to this sequence, yields the substituted alicyclic ketone (LV) (Scheme 7). Sulphurisation of this ketone could, in theory, give rise to two possible products (LVI or LVII) but only one compound was obtained[51] and this was shown to be the thiothiophthen (LVII). This was demonstrated by preparing the tetramethyl (LV; $R_1 = R_2 = CH_3$), tetraethyl (LV; $R_1 = R_2 = C_2H_5$) and dimethyl-diethyl (LV; $R_1 = CH_3$, $R_2 = C_2H_5$) compounds and then converting them to the corresponding thiothiophthen (LVII) with phosphorus pentasulphide. If the 1,2-dithiole-3-thiones (LVI) had been the products, a mixture would be expected from the sulphurisation of the dimethyl-diethyl compound.

9. The preparations of thiothiophthens possessing fused carbocyclic rings have been performed by adapting a method described by Hauser[53] in which 1,3,5-triketones were formed by two fold aroylation of acetone with aromatic esters in the presence of sodium hydride. Replacement of acetone by alicyclic ketones gives the triketones (LVIII; n = 2 or 3) which on

treatment with phosphorus pentasulphide give the thiothiophthens (LIX).

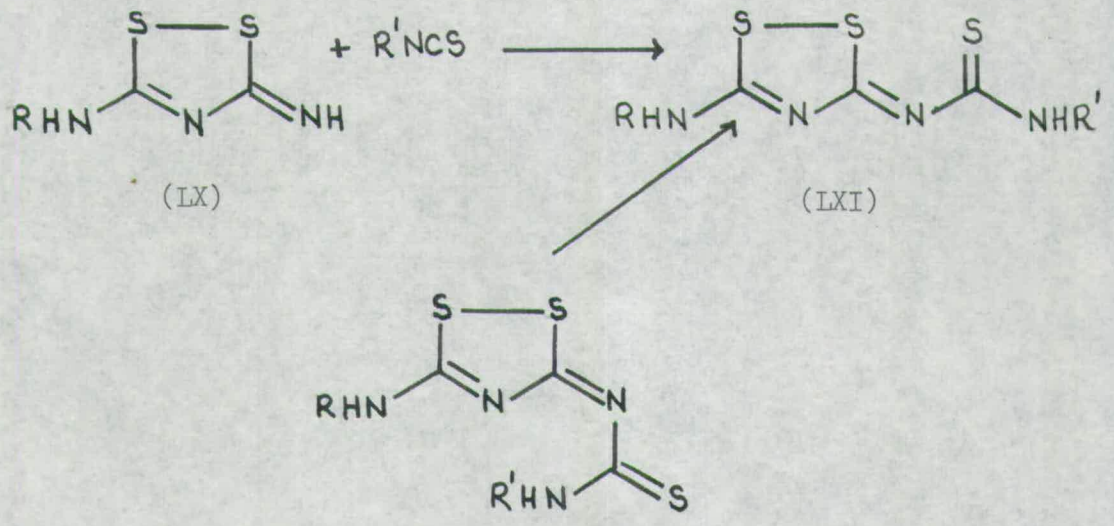


(LVIII) (LIX)

A number of these compounds have been prepared[52], the groups R being mainly phenyl or para-substituted phenyl groups.

10. Thiothiophthens containing heterocyclic nitrogen

The reaction of mono-substituted 5-amino-3-imino-1,2,4-dithiazoles (LX) with isothiocyanates produces thiothiophthens containing heterocyclic nitrogen[54] (LXI).

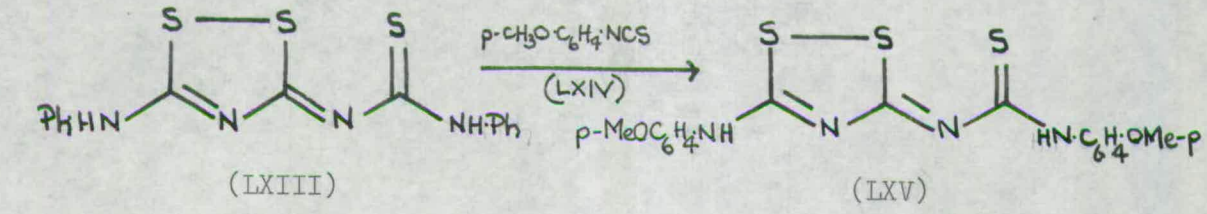


(LX) (LXI)

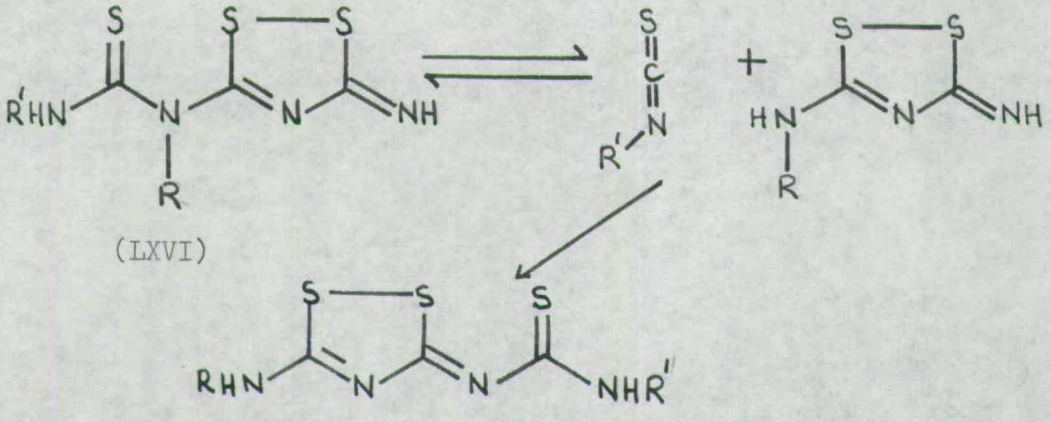
(LXII)

A colourless intermediate is obtained if the reaction is carried out at room temperature and this has been formulated as the trans-isomer (LXII). When this compound is refluxed in xylene it rearranges to give the thiothiophthen (LXI). However, since it is known that an exchange

reaction occurs between the diphenyl derivative (LXIII) and p-methoxyphenylisothiocyanate (LXIV) at 180-190°, yielding the di-p-methoxyphenyl compound (LXV), it is not impossible that the colourless intermediate is the isomer (LXVI) which thermally isomerised to the thiothiophthen (LXI) by a dissociation - recombination mechanism.



(LXIII) (LXV)



(LXVI)

(LXI)

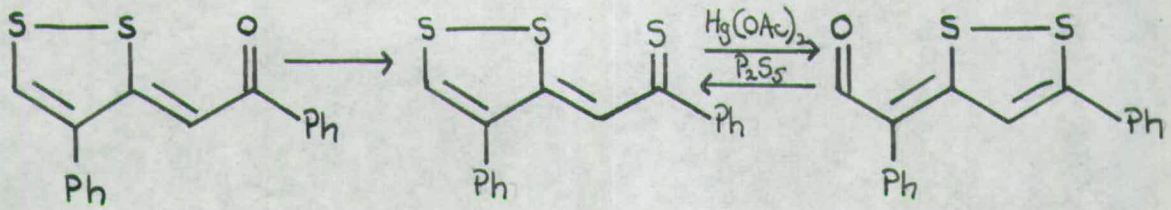
The Fine Structure of Thiothiophthens

Chemical and physical methods have been used to provide evidence for the fine structure of thiothiophthens.

Chemical Methods

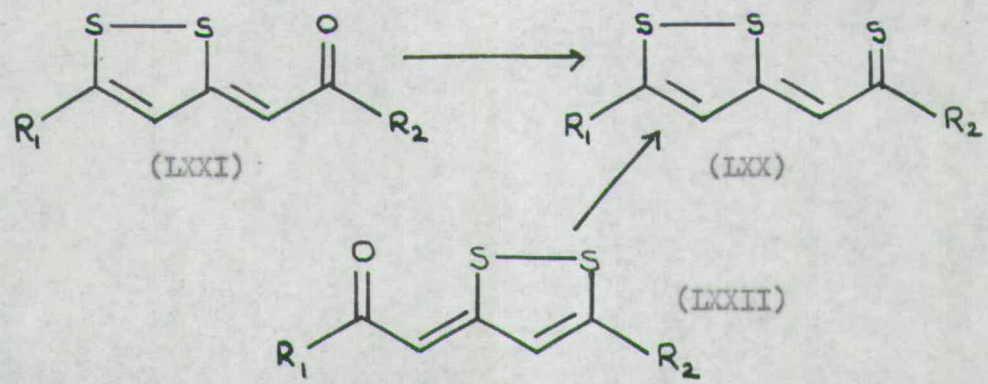
The first chemical demonstration of the symmetry of the thiothiophthens resulted from the synthesis of an unsymmetrically substituted thiothiophthen[34]. 3-Phenacylidine-4-phenyl-1,2-dithiole (LXVII) was sulphurised with phosphorus pentasulphide to the thiothiophthen (LXVIII)

which, on treatment with mercuric acetate, yielded, not the parent ketone, but an aldehydic product (LXIX). The aldehyde was reconverted into the thiothiophthen (LXVIII) by sulphurisation with phosphorus pentasulphide.



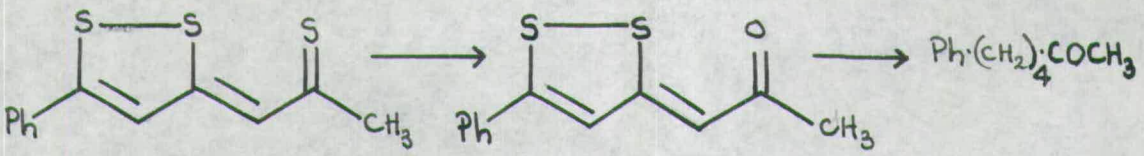
(LXVII) (LXVIII) (LXIX)

Since this work was reported, single thiothiophthens (LXX) have been obtained from several pairs of independently prepared precursors (LXXI),(LXXII)[44,48,49].



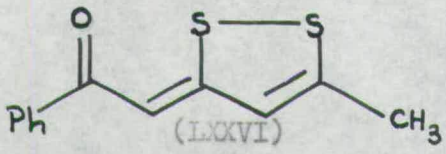
(LXXI) (LXX) (LXXII)

The conversion of unsymmetrical thiothiophthens to methylene-1,2-dithioles is of interest because there are two possible products. Thus the phenylmethylthiothiophthen (LXXIII) was converted into a ketone by treatment with acid[55] and Raney nickel desulphurisation of this product (LXXIV) gave 6-phenylhexan-2-one (LXXV) showing that its structure was (LXXIV).



(LXXIII) (LXXIV) (LXXV)

This result has, however, been questioned[41]. A ketone, prepared by reaction of potassium hydrogen sulphide with 2-methyl-6-phenylpyran-4-thione was claimed to have infrared and nuclear magnetic resonance spectra identical with those of the ketone obtained from the phenylmethylthiothiophthen (LXXIII). The n.m.r. absorption band of the methyl group was a doublet (2.51 p.p.m.; J = 1 c.p.s.) as was that of the proton (7.10 p.p.m., J = 1 c.p.s.) on the dithiole nucleus. This result is inconsistent with the structure originally proposed (LXXIV) since no coupling of the methyl protons with the ring proton would be expected. The authors therefore propose that this ketone is, in fact, 3-methyl-5-phenacylidene-1,2-dithiole (LXXVI) where 1,3- coupling is possible.

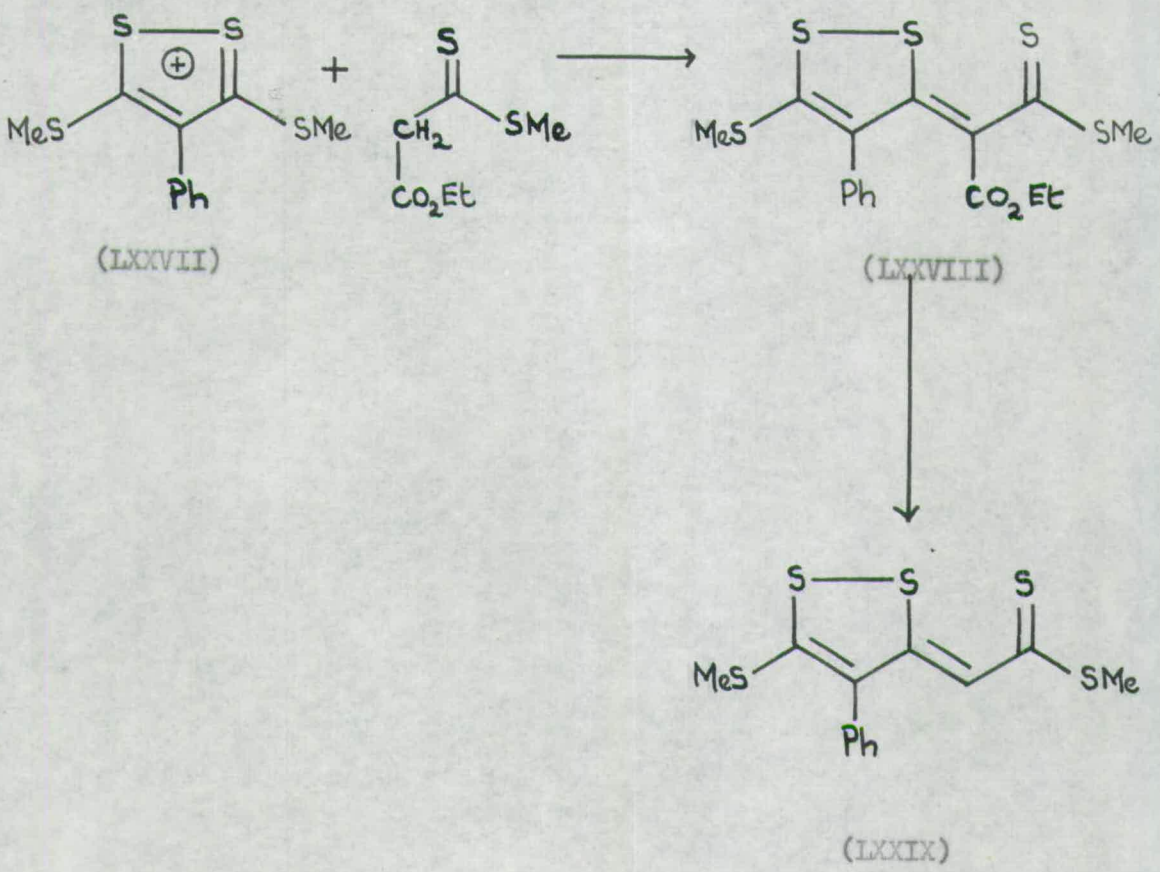


(LXXVI)

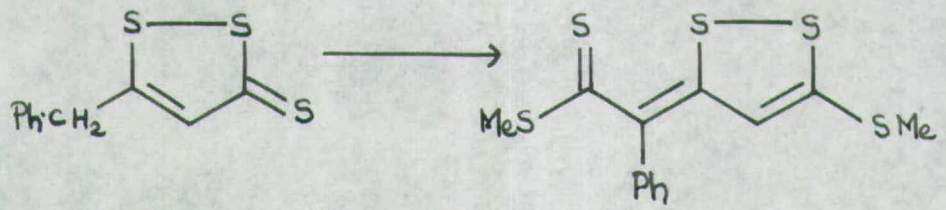
Brown[56] later synthesised the ketone (LXXIV) by an unambiguous method and showed that it was identical with the ketone obtained from the thiothiophthen by treatment with sulphuric acid. It showed no coupling of the methyl and dithiole ring protons.

Further evidence for "no-bond resonance" in the thiothiophthen system is provided by recent work involving 2-methylthio- derivatives[57].

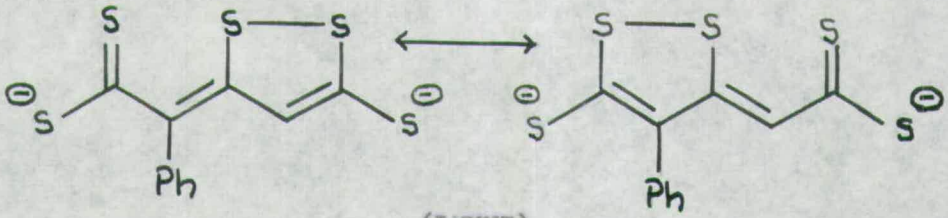
Using 3,5-bismethylthio-4-phenyl-1,2-dithiolium methiodide (LXXVII) as starting material, the 2,5-bismethylthio-6a-thiothiophthen (LXXVIII) has been prepared and converted, by the action of hydrochloric acid in acetic acid, to (LXXIX). The latter was also obtained in good yield (65%) by the condensation of carbon disulphide with 5-benzyl-1,2-dithiole-3-thione (LXXX) using sodium hydride in tetrahydrofuran, and



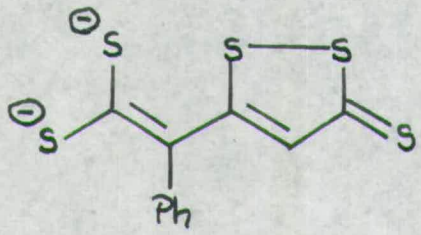
subsequent methylation of the resulting dianion [(LXXXI) rather than (LXXXII)].



(LXXX)



(LXXXI)



(LXXXII)

Physical Methods

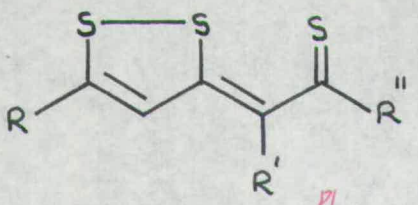
The main evidence for the fine structure of the thiothiophthens (XXXVIII) stems from (a) X-ray diffraction, (b) nuclear magnetic resonance and (c) ultraviolet absorption spectra. Although many workers have regarded the thiothiophthens as symmetrical mesomeric structures, the physical evidence upon which this conclusion is based is by no means

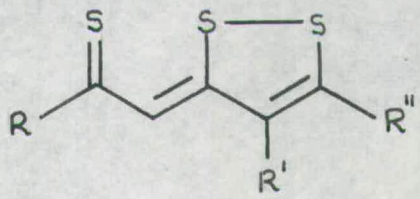
conclusive. Recent work favours the theory that the thiothiophthens should be regarded as undergoing rapid tautomerism between two equivalent unsymmetrical structures. The recent evidence is presented below together with a critical review of the earlier evidence.

a) X-ray Evidence

The bond lengths obtained by X-ray crystallography[28] for the dimethylthiothiophthen (XXXVII) clearly indicate resonance between two equivalent canonical structures, but the apparent symmetry of the molecule could be caused by degenerate valency tautomerism between two equivalent structures rather than by resonance, since both of the degenerate structures would be expected to contribute to the diffraction pattern. Brown[58] suggests that the poor reliability factors (0.3 - 0.4) obtained by these workers do not enable any definite conclusions to be drawn regarding structure, since, for a good analysis, reliability factors as low as 0.1 (for observed compared to calculated values of diffraction intensity) should be obtained. However, a later paper[59] quotes reliability factors of 0.12, 0.14 and 0.15.

Recent X-ray crystallographic work by Hordvik[60] on the unsymmetrically substituted thiothiophthens (LXXXIII) shows that the sulphur atoms are not equally spaced and that the formula (LXXXIII b)





LXXXIIIa; R = R' = R'' = H

LXXXIIIb

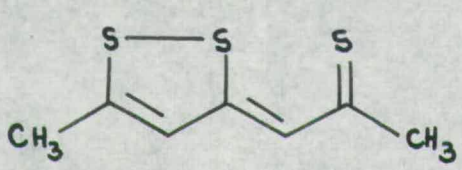
LXXXIV a; R = R'' = Me, R' = H

LXXXIVb

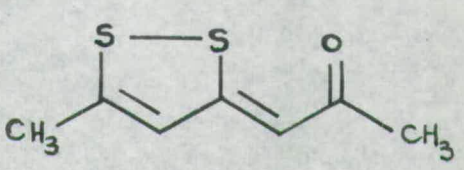
is a better representation of the molecule than (LXXXIIIa). The shorter S-S distance of 2.22Å is 0.14Å longer than the normal S-S bond length but shorter than the value (2.36Å) reported for the dimethyl compound (LXXXIV). The longer S-S distance, of 2.51Å, is, however, very much less than the van der Waals distance (3.70Å for two sulphur atoms). The explanation afforded by the authors for this result is that the symmetrical sulphur spacing, as found for compound (LXXXIV), is perturbed by unsymmetrical substitution in (LXXXIII). However, Klingsberg[61] points out that the results reported for (LXXXIV) may be partly due either to random packing of the molecules (since their shape is not altered much on flopping over) or to an ordered superstructure. This is supported by the anisotropy in the direction of the S-S bonds exhibited by the S atoms as observed in the electron density maps of (LXXXIV). If this were due to a preferred thermal vibration, the much lighter carbon atoms attached to the sulphur atoms might reasonably be expected to move together with them. Yet the electron density distribution of the carbon atoms does not indicate this to be the case, implying dissimilar S-S bonds even in (LXXXIV).

Nuclear Magnetic Resonance Spectroscopy

It would appear that the n.m.r. evidence supports symmetry for the thiothiophthen structure as is instanced by comparison of the spectrum of the dimethyl compound (LXXXV) with that of its ketone derivative[33] (LXXXVI).



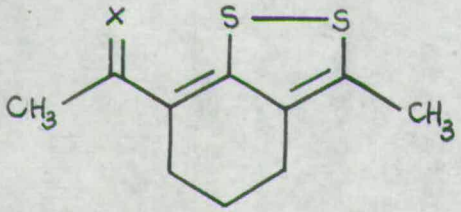
(LXXXV)



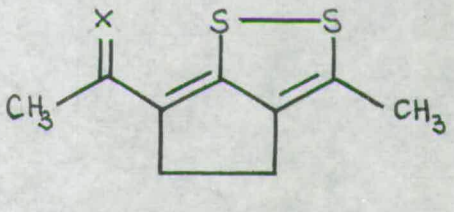
(LXXXVI)

The thione (LXXXV) shows only two lines, revealing that the two methyl groups and the two methine protons occupy identical environments. On the other hand, the ketone has a spectrum of four lines, which indicates that each methyl group and methine proton occupy structurally different positions.

Similarly, work by Brown[62] on the spectra of thiothiophthens (LXXXVII, X = S; LXXXVIII, X = S) showed, in each case, that the n.m.r.



(LXXXVII)



(LXXXVIII)

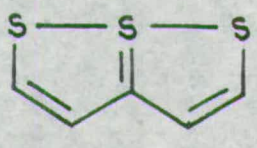
spectra were consistent with those expected of symmetrical compounds. In contrast, the corresponding ketones (LXXXVII, X = O; LXXXVIII, X = O) showed spectra which were clearly unsymmetrical.

However, evidence relating to the fine structure of the thiothiophthens obtained from n.m.r. spectra must be treated with caution since n.m.r. is known to be time dependent. If the compounds were tautomeric and the time of tautomerisation was considerably less than the time required for the protons to absorb radio frequency radiation, then a time average of the spectra of the tautomeric forms would result, thereby simulating the symmetry which has been attributed to resonance.

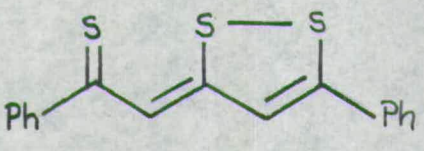
Ultraviolet Evidence

The fact that the ultraviolet spectrum of the diphenylthiothiophthen (LXXXIX) is very similar to that of 4,5-di-p-methoxyphenyl-2-thiophenacylidene-1,3-dithiole has been taken as evidence that the

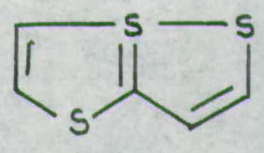
electronic systems of these two compounds are very similar[63]. The authors accept the bicyclic structure (XLII) for the thiothiophthen and conclude that the 1,3-dithiole also exists in a bicyclic form (XC).



(XLII)



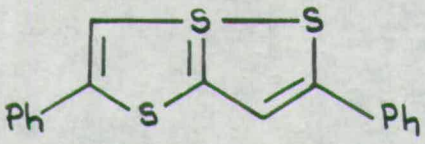
(LXXXIX)



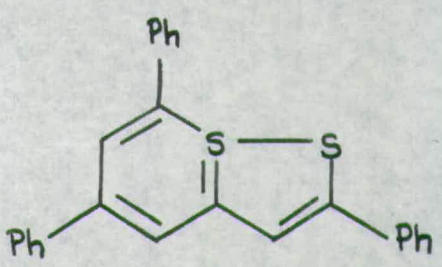
(XC)

However, similar evidence has been viewed in a different light[43]. A comparison of the visible spectrum of the diphenylthiothiophthen (LXXXIX) with those of 4-phenyl-2-thiophenacylidene-1,3-dithiole and 4,6-diphenyl-2-thiophenacylidene-2H-thiopyran showed them to be similar. Combined with this observation, a comparison of the visible spectra of these compounds with those of the corresponding ketones showed, in each case, a similar shift (60-70 mμ) to shorter wavelength in exchanging sulphur for oxygen. These facts were interpreted as evidence that the thiones existed in similar electronic forms and, since the model compounds were incapable of single bond-no bond resonance, it was reasoned that the apparent symmetry of the thiothiophthens might be due to rapid tautomerism rather than resonance.

However, it remains possible that the model compounds studied exist in bicyclic forms containing tetravalent sulphur (XCI, XCII) and this prompted McKinnon[64] and, later, Brown[62] to use reference compounds

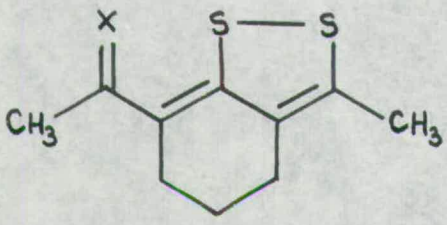


(XCI)

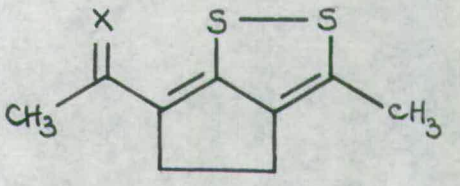


(XCII)

in which there was no such possibility. The compounds selected were 4-phenacylidene- and 4-thiophenacylidene-derivatives of 2,6-diphenyl-4H-pyran and thiopyran. The spectra of these model compounds showed that a shift of 90-100 mμ would normally be expected for a change from an acylmethylene to a thioacylmethylene compound. The shifts observed in the corresponding 1,2-dithiole, 1,3-dithiole and 2H-thiopyran derivatives are smaller (60-70 mμ), probably owing to bonding between the thione-sulphur atom and a ring-sulphur atom in the thioacylmethylene-compounds.



(XCIII)

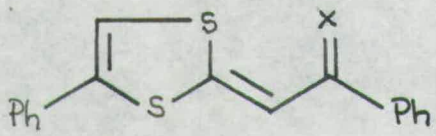


(XCIV)

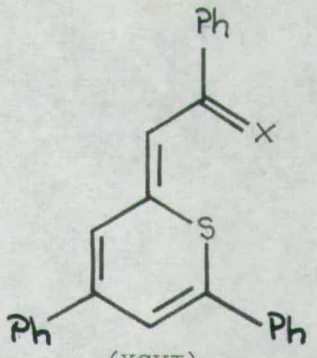
In support of this view, Brown showed that the two ketones (XCIII, X = O and XCIV, X = O) absorb at similar wavelengths in the visible region, but that conversion into the corresponding thiones causes different bathochromic shifts, of 60 mμ for (XCIII) and 89 mμ for (XCIV). Brown

concluded that whereas compound (XCIII, X = S) is a normal thiothiophthen, (XCIV, X = S) contains a substantially unmodified thioacetyl group; the thione-sulphur atom is more distant from the dithiole ring owing to distortion of the bond angles by the fused five-membered ring. If this conclusion is correct, the apparent symmetry of compound (XCIV, X = S) as revealed by its n.m.r. spectrum, must be due to tautomerism rather than resonance.

The fact that the ketone-thione bathochromic shifts in the thio-thiophthen series are similar in magnitude to those of the pairs of compounds (XCV and XCVI, X = O or S), in which d-orbital participation

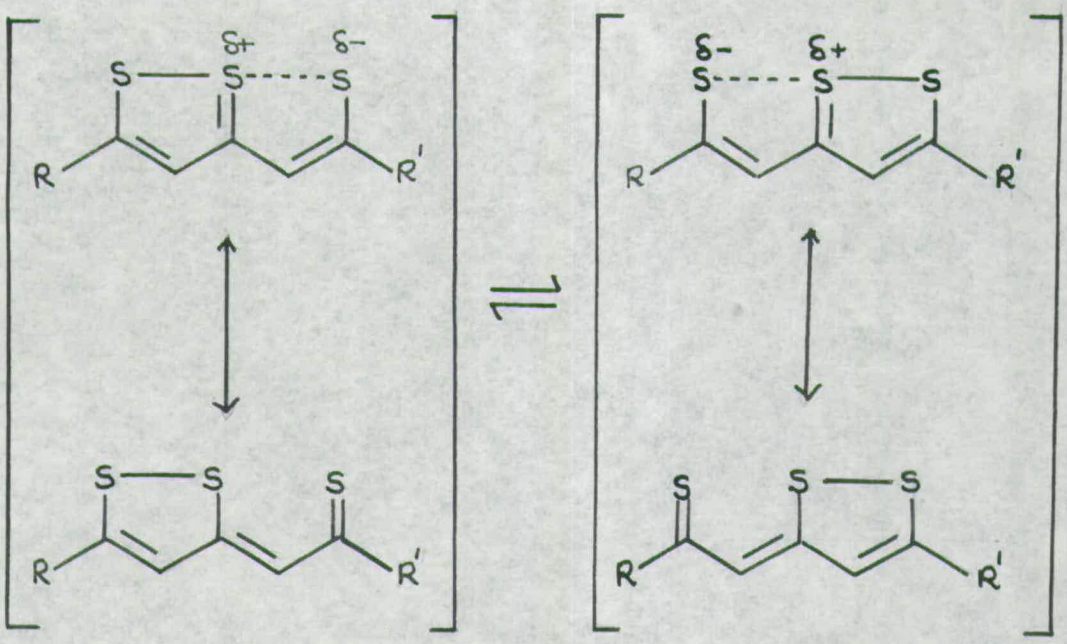


(XCV)



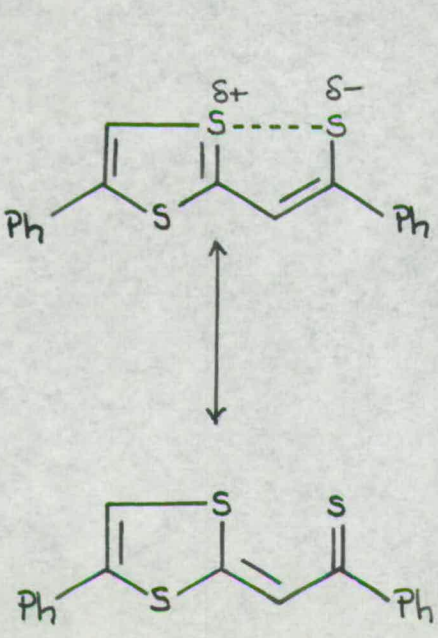
(XCVI)

is possible but cannot lead to a symmetrical structure, led Brown to propose that the extreme situation of single bond-no bond resonance is not in fact achieved and that the thiothiophthens should be regarded as undergoing rapid tautomerism between two equivalent unsymmetrical structures (XCVII, XCVIII). Both of these structures are stabilised by interaction of an electron-pair on one of the outer sulphur atoms with an empty d-orbital on the central sulphur atom.

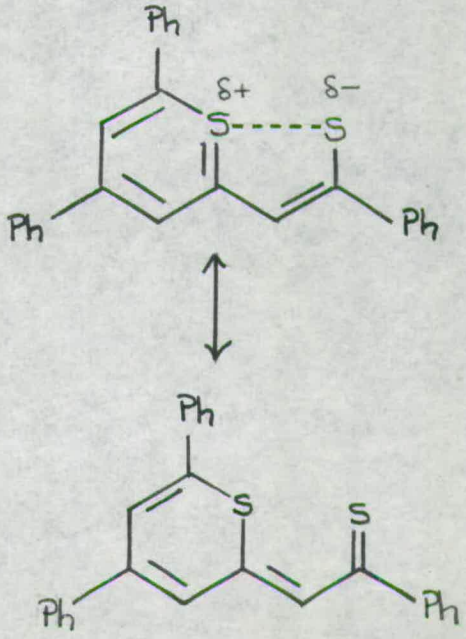


(XCVII) (XCVIII)

Each of these degenerate structures would then be exactly analogous to the probable structures of the model compounds (IC, C).



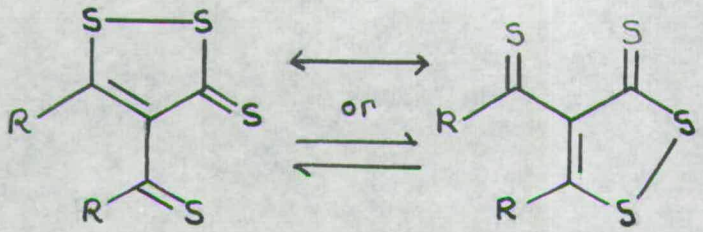
(IC)



(C)

4-THIOACYL-1,2-DITHIOLE-3-THIONES

The dithiolethiones (CI, CII) are a type that might be expected to exhibit the characteristics of "single bond-no bond resonance" postulated to occur in the thiothiophthen series.

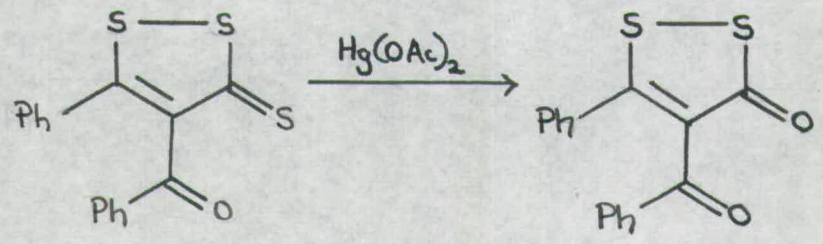


CI ; R = CH_3

CII; R = Ph

Brown[58] hoped that their synthesis and subsequent study would indicate whether this phenomenon is capable of occurring in other systems or is confined to the thiothiophthens.

An attempt to prepare 4-acetyl-5-methyl-1,2-dithiole-3-thione from ethyl diacetylacetate by reaction with phosphorus pentasulphide was unsuccessful but ethyl dibenzoylacetate reacted normally to give 4-benzoyl-5-phenyl-1,2-dithiole-3-thione[65] (CIII). Initial attempts to convert this ketone to the corresponding thione (CII) were unsuccessful but when the phosphorus pentasulphide used in the reaction was purified, the thione



(CIII) (CIV)

was obtained. Treatment of compound (CIII) with mercuric acetate gave the corresponding 4-benzoyl-dithiolone (CIV).

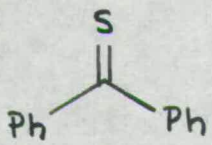
In order to provide evidence concerning the fine structure of the thioacyl compound (CII), the n.m.r. and electronic spectra of these compounds were examined. Because of certain apparent inconsistencies, however, the results were inconclusive.

Nuclear Magnetic Resonance Spectroscopy Evidence

In the n.m.r. spectra of compounds (CII) and (CIII) an absorption attributable to the o-protons of one of the phenyl groups (probably the one joined to carbonyl or thiocarbonyl) is observed and this provides evidence that, in both compounds, the phenyl groups occupy different environments. This result would not be expected for the 4-thiobenzoyl compound (CII) if it were rendered symmetrical by single bond-no bond resonance or if the two equivalent structures were undergoing rapid tautomeric interconversion.

Ultraviolet Spectra

If a classical assymmetric structure is assumed for (CII), evidence for a thiobenzoyl group might be expected from the visible spectrum since diaryl thioketones show a low intensity $\pi - \pi^*$ absorption near 600 mμ. Thiobenzophenone (CV), for example, absorbs at 599 mμ ($\log_{10} \epsilon = 2.81$)[66].

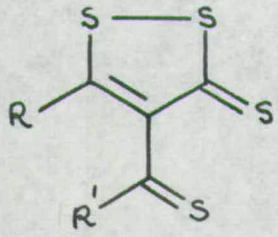


(CV)

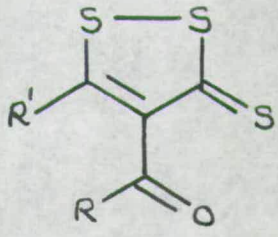
No evidence was obtained, however, for an absorption between 500 and 700 mμ in the spectrum of the thiobenzoyl compound.

Further, the diketone (CIV) has an ultraviolet spectrum which may be regarded as an approximate sum of the ultraviolet spectra of acetophenone and 5-phenyl-1,2-dithiol-3-one. If 4-benzoyl-5-phenyl-1,2-dithiole-3-thione existed in a similar form, then a spectrum similar in form to the sum of acetophenone and 5-phenyl-1,2-dithiole-3-thione would be expected. However, this is not the case. The position is further complicated by the spectrum of the thiobenzoyl compound (CII) which is closely similar to that of the benzoyl compound (CIII). The change from ketone to thione is normally accompanied by a bathochromic shift but in this case a small hypsochromic shift is observed in the long wavelength maximum.

Brown concludes that resolution of this problem must await a comparison of the products from the sulphurisation of the isomeric ketones (CVI, CVII) when, depending on whether or not they give the same product,



(CVI)



(CVII)

a decision will be possible as to the importance of non-classical structures.

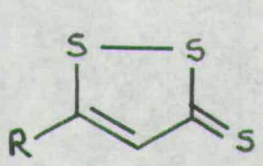
D I S C U S S I O N

SECTION I

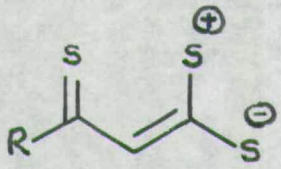
Cyclo-addition Reactions of Dithiolethiones and Dithiolanthiones

General

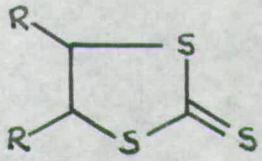
In their reactions with certain acetylenic compounds (see Introduction), 1,2-dithiole-3-thiones (III) behave formally as 1,3-dipoles (CVIII) and 1,3-dithiolan-2-thiones (CIX) undergo similar reactions (involving expulsion of a molecule of olefin) in which the 1,3-dipole (CX) is formally involved.



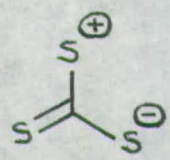
(III)



(CVIII)

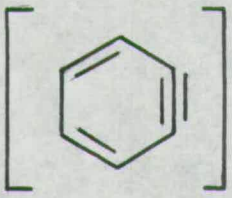


(CIX)



(CX)

The object of the present investigation was two-fold : (A) to carry out further studies of these reactions and to consolidate certain conclusions drawn by previous workers, and (B) to study the behaviour of 1,2-dithiole-3-thiones as dipolarophiles. The dipolarophiles selected for use in part (A) were benzyne (XV), dimethyl acetylenedicarboxylate (XIV) and methyl phenylpropiolate (CXI). The 1,3-dipoles ethoxycarbonylformonitrile oxide (CXII) and benzonitrile N-phenylimine (CXIII) were used in part (B).



(XV)

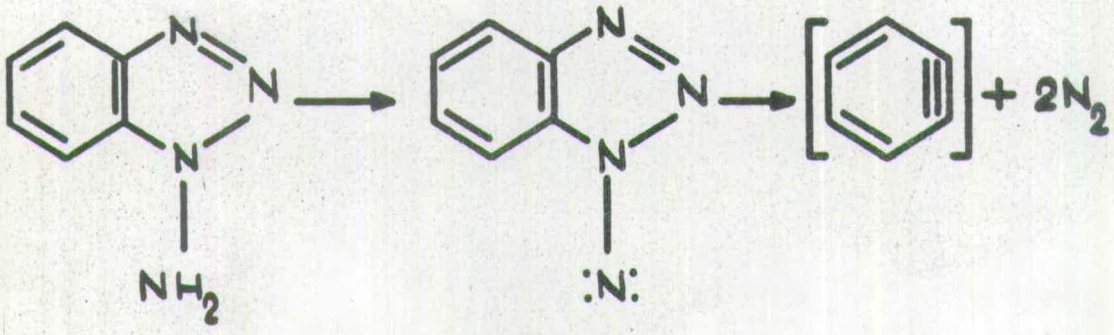
$MeO_2C \cdot C \equiv C \cdot CO_2Me$ (XIV)

$MeO_2C \cdot C \equiv C \cdot Ph$ (CXI)

$$EtO_2C \cdot \overset{\oplus}{C}{=}N{-}\overset{\ominus}{O} \longleftrightarrow EtO_2C \cdot C \equiv \overset{\oplus}{N}{-}\overset{\ominus}{O} \qquad \text{(CXII)}$$

$$Ph \cdot \overset{\oplus}{C}{=}N{-}\overset{\ominus}{N}{-}Ph \longleftrightarrow Ph \cdot C \equiv \overset{\oplus}{N}{-}\overset{\ominus}{N}{-}Ph \qquad \text{(CXIII)}$$

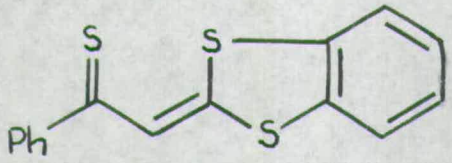
SCHEME 8



(cxv) (cxvi)

PART (A) : (i) Reactions with Benzyne

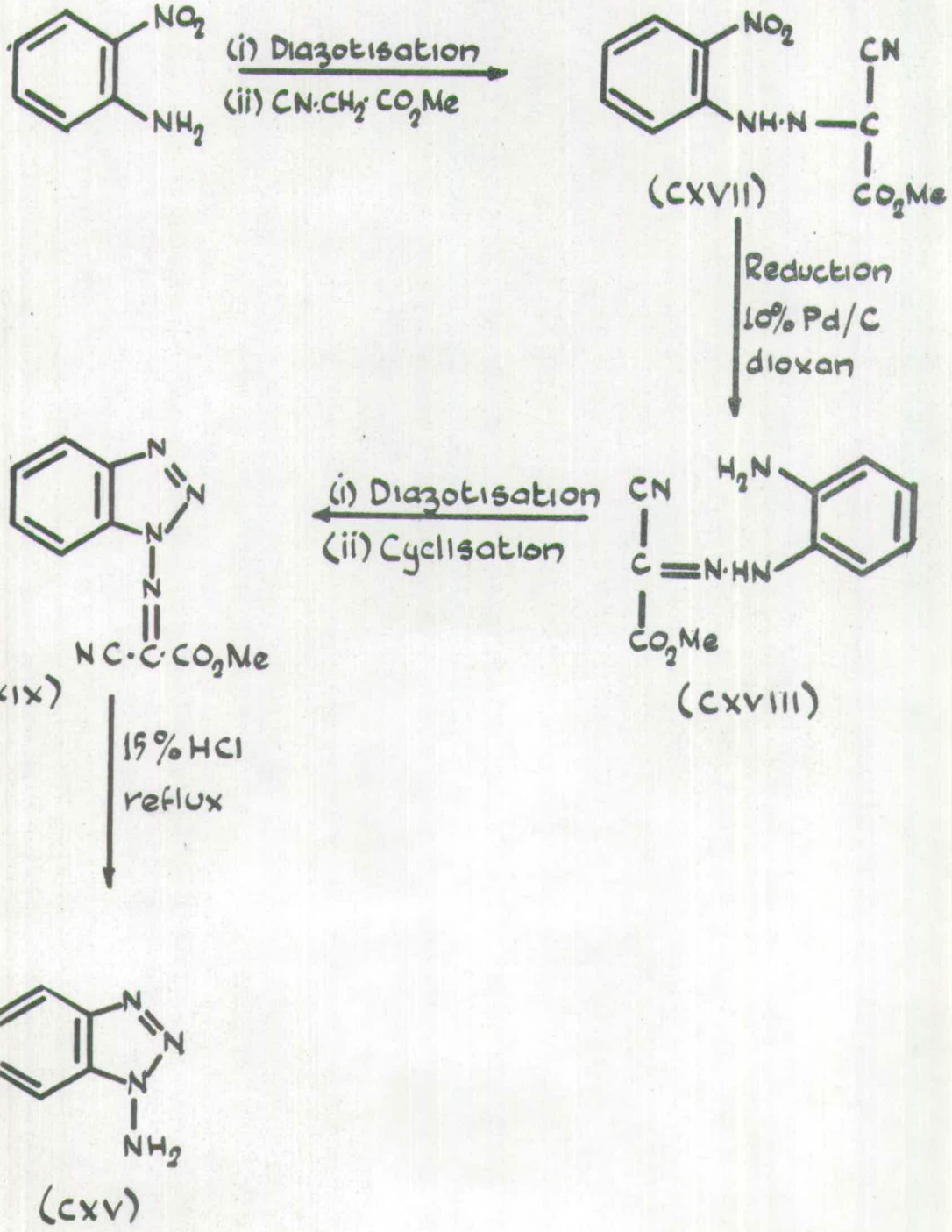
In view of the low yields of adduct (CXIV) obtained by Easton



(CXIV)

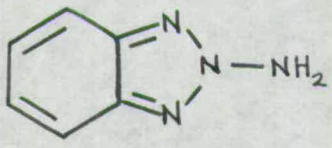
from the reaction of 5-phenyl-1,2-dithiole-3-thione with benzyne, a search was made for a more efficient method for generating benzyne. A more recent method is that described by Campbell and Rees[67] (Scheme 8) in which 1-aminobenzotriazole (CXV) is oxidised to benzyne and nitrogen, probably via the nitrene (CXVI). Unfortunately, however, a strong oxidising agent (lead tetra-acetate) was used and it was thought that reaction between oxidising agent and dithiolethione was likely. Thus the first task in the follow-up of Easton's work was to examine the effect of lead tetra-acetate and some of the milder oxidising agents known to oxidise amines and hydrazines (mercuric oxide, nickel peroxide, lead dioxide and manganese dioxide) on a typical dithiolethione (5-phenyl-1,2-dithiole-3-thione). The metal oxides were each boiled under reflux in dry benzene with 5-phenyl-1,2-dithiole-3-thione for 30 minutes and, in all cases, the thione was recovered quantitatively. Lead tetra-acetate was known to generate benzyne at room temperature from 1-amino-benzotriazole so that if this strong oxidising agent was to be used in the reaction, room temperatures could be employed. A mixture of lead

SCHEME 9


NO2
NH2
(i) Diazotisation
(ii) CN·CH2·CO2Me
NO2
CN
NH·N
C
CO2Me
(CXVII)
Reduction
10% Pd/C
dioxan
H2N
CN
C
N·HN
CO2Me
(CXVIII)
(i) Diazotisation
(ii) Cyclisation
N
N
N
N
NC·C·CO2Me
(CXIX)
15% HCl
reflux
N
N
N
NH2
(CXV)

tetra-acetate and thione in dry benzene was allowed to stand at room temperature for 30 minutes and gave a complete recovery of thione.

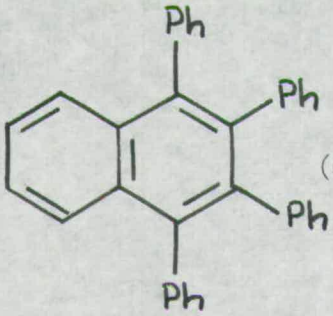
Having ascertained that the thione was resistant to attack by these oxidising agents under the selected conditions, the next step was to determine the efficiency with which the oxidising agents generated benzyne from 1-aminobenzotriazole. The 1-aminobenzotriazole used in these preliminary tests was prepared in two different ways. The first method was one described by Bianchetti and Trave[68] (Scheme 9) in which o-nitrobenzenediazonium chloride was allowed to react with methyl cyanoacetate to give methyl o-nitrophenylhydrazonocyanoacetate (CXVII). Reduction with hydrogen using a 10% palladium on charcoal catalyst in dioxan gave the corresponding amine (CXVIII) which, by reaction with sodium nitrite solution in dilute hydrochloric acid, gave methyl (benzotriazol-1-ylimino)-cyanoacetate (CXIX). Hydrolysis of this product in boiling 15% hydrochloric acid gave the required 1-aminobenzotriazole (CXV). The second method for the preparation of the latter compound was that of Campbell and Rees[69] in which benzotriazole is treated with hydroxylamine-O-sulphonic acid, in the presence of base. The resulting mixture of 1-aminobenzotriazole and 2-aminobenzotriazole (CXX)



(CXX)

is separated by chromatography on silica.

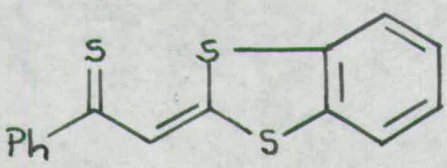
The efficiency with which the milder oxidising agents generated benzyne from 1-aminobenzotriazole was measured by dropwise addition of the amino-compound in dry benzene to a stirred mixture of the oxidising agent and tetracyclone (a benzyne acceptor) in boiling benzene. The reaction mixture was then chromatographed on alumina to give unreacted tetracyclone as a first fraction and then 1,2,3,4-tetraphenylnaphthalene (CXXI), the reaction product. Of the mild oxidising agents, the most effective was nickel peroxide, but the yield was very poor (14%). The use of lead tetra-acetate at room temperature produced a quantitative yield of the adduct (CXXI) and this method was therefore selected for use in the reactions of benzyne with dithiolethiones.



(CXXI)

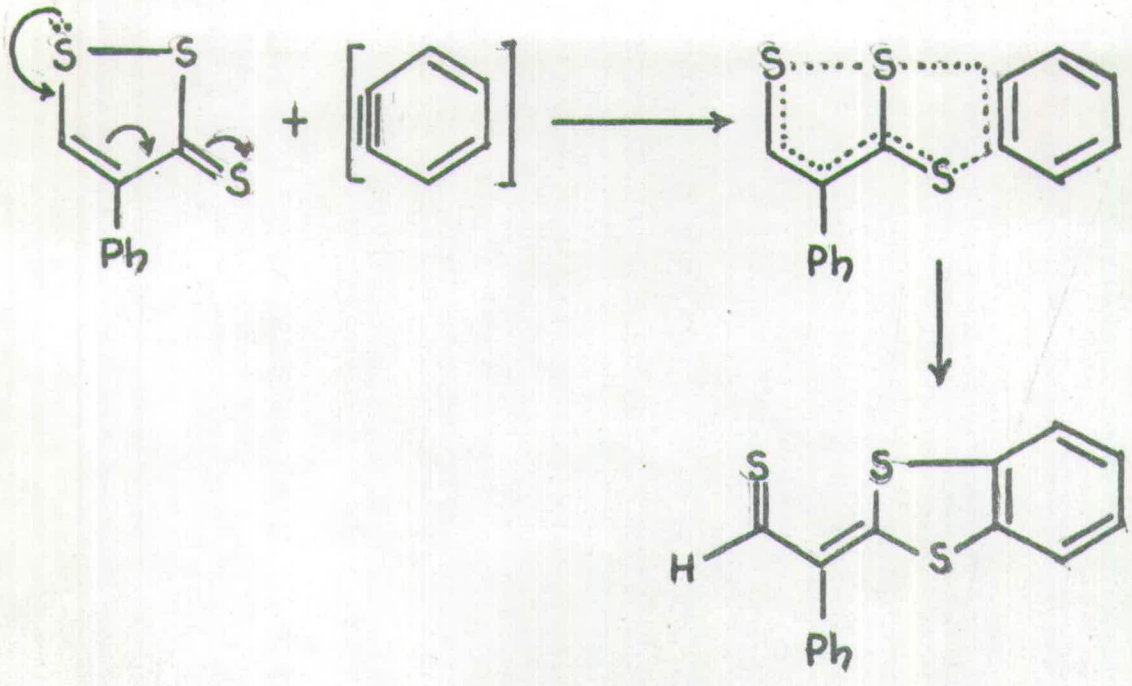
1. Reaction of 5-Phenyl-1,2-dithiole-3-thione with Benzyne

The reaction was carried out by simultaneous dropwise addition of equimolar dry benzene solutions of lead tetra-acetate and 1-amino-benzotriazole (CXV) to a stirred solution of 5-phenyl-1,2-dithiole-3-thione in dry benzene in a dry nitrogen atmosphere. The reaction mixture was then filtered and the filtrate chromatographed on alumina to give 4,5-benzo-2-thiophenacylidene-1,3-dithiole (CXIV) in 55% yield. Increasing the molar ratios of thione and lead tetra-acetate failed to improve the yield of (CXIV).



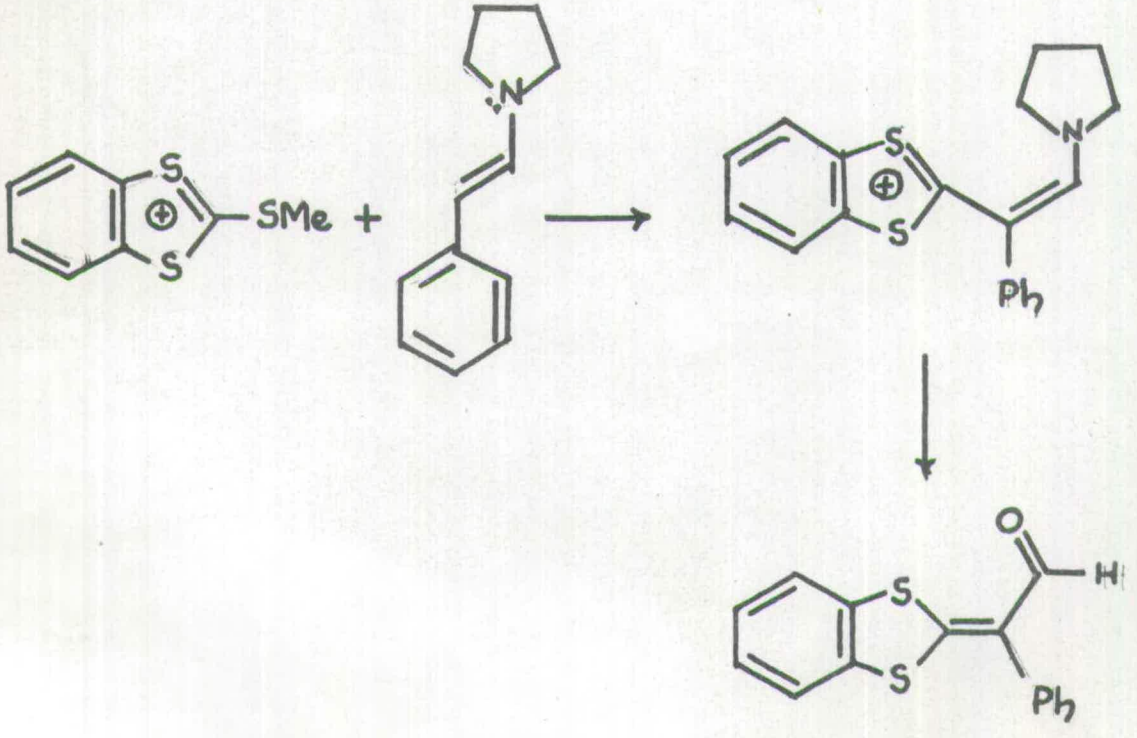
(CXIV)

SCHEME 10



(CXXIII)

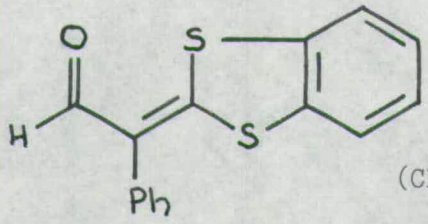
SCHEME 11



(CXXIV)

2. Reaction of 4-Phenyl-1,2-dithiole-3-thione with Benzyne

The method was similar to that described for the reaction with 5-phenyl-1,2-dithiole-3-thione and a mechanism (Scheme 10) similar to that discussed earlier (Introduction) was expected to give 2-(4,5-benzo-1,3-dithiol-2-ylidene)-2-phenylethanethial (CXXIII). The product was obtained as a brown solid (14 %) the n.m.r. spectrum of which was in general agreement with the proposed structure, showing a singlet (relative intensity 1) at 0.7τ attributable to the thioaldehyde proton and a multiplet (relative intensity 9) in the aromatic region (Table 1). However, an elemental analysis indicated a deficiency of sulphur and closely fitted that required for the corresponding aldehyde (CXXIV). An independent synthesis (Scheme 11) of this aldehyde was achieved by hydrolysis of the product formed by nucleophilic attack of N-pyrrolidino-2-phenylethylene on 2-methylthio-4,5-benzo-1,3-dithiolium perchlorate. The product obtained in this way was identical with the cyclo-addition product.



(CXXIV)

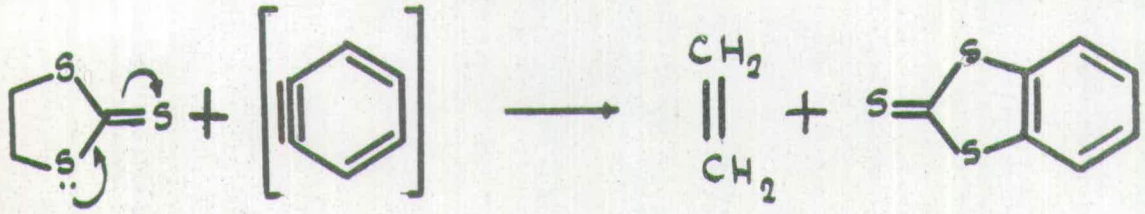
3. Reaction of 4,5-Benzo-1,2-dithiole-3-thione with Benzyne

Chromatography of the reaction mixture gave an incomplete recovery of 4,5-benzo-1,2-dithiole-3-thione but no other compound was isolated.

4. Reaction of 1,3-Dithiolan-2-thione with Benzyne

Easton obtained a poor yield (9%) of 4,5-benzo-1,3-dithiole-2-thione from this reaction (Scheme 12). Application of the improved

SCHEME 12



procedure for generation of benzyne gave a slightly improved yield (13%). No attempt was made to collect the ethylene evolved during the reaction.

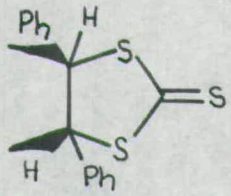
5. Reaction of 4-Phenyl-1,3-dithiole-2-thione with Benzyne

Once again the general method was used for the reaction but only trace quantities of materials could be isolated from the alumina column.

PART A : (ii) Reactions with Acetylenic Esters

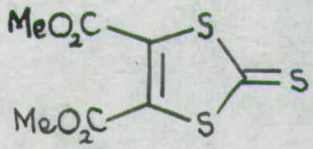
1. Reactions of 1,3-Dithiolan-2-thiones with Dimethyl acetylenedicarboxylate

In view of Easton's finding, that the reaction of cis-4,5-diphenyl-1,3-dithiolan-2-thione with dimethyl acetylenedicarboxylate is not a stereospecific elimination, it was of interest to investigate the steric course of other examples of this type of reaction. Accordingly, trans-4,5-diphenyl-1,3-dithiolan-2-thione (CXXV) was allowed to react with the ester at 110°. Gas-Liquid Chromatography of the crude reaction product showed the presence of trans-stilbene uncontaminated with the cis-isomer. Chromatography of the reaction mixture on alumina gave trans-stilbene (65%) as a first fraction and then 4,5-di-(methoxycarbonyl)-1,3-dithiole-2-thione (CXXVI), (27%), as a second fraction.



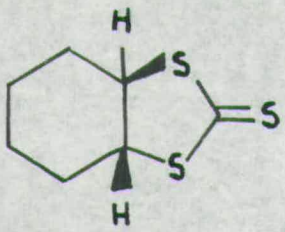
(CXXV)

The finding of stereospecificity in this reaction of the trans-diphenyl compound suggested that it might be worthwhile to repeat Easton's investigation of the cis-isomer. The results of this re-investigation fully confirmed Easton's report, namely that cis- and trans-stilbenes are formed in roughly equal amounts. The reason for the different steric courses of the two reactions is not apparent but it appears that, in the case of the cis-isomer at least, the reaction does not proceed via a bicyclic transition state of the type shown in Scheme 4 (Introduction).



(CXXVI)

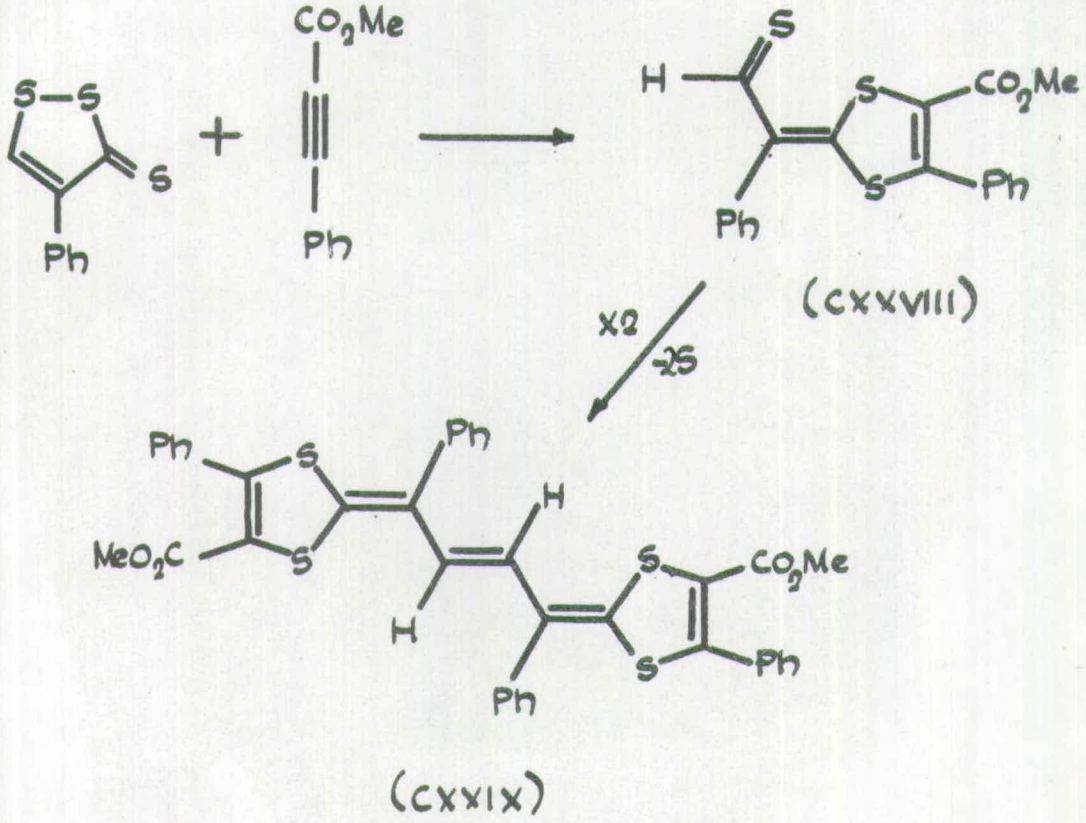
Attempts to cause reaction between trans-4,5-tetramethylene-1,3-dithiolan-2-thione (CXXVII) and dimethyl acetylenedicarboxylate at temperatures from 105° to 150° over a period of 15 minutes were unsuccessful, a quantitative recovery of (CXXVII) being obtained. Prolonged heating (1 hour) at 145-150° and subsequent chromatography on alumina in benzene gave a high recovery (68%) of (CXXVII) together with a brown glass which could not be crystallised. There was no formation of cyclohexene, a result which is similar to that obtained by Corey et al[26], who found that compound (CXXVII) gave neither cyclohexene nor carbon disulphide when treated with trialkyl phosphites, whereas the cis-isomer yields cis-cyclohexene normally (77% yield). These results were explained by suggesting that in this olefin synthesis, a concerted cyclo-elimination mechanism was required for the product forming step. Elimination is effectively blocked in those cases in which cis-elimination would lead to an excessively strained structure.



(CXXVII)

Application of this reasoning to the reaction of 1,3-dithiolan-2-thiones with dimethyl acetylenedicarboxylate, suggests that the reaction normally proceeds via a bicyclic transition state (Route D; Scheme 4). If the route involving stepwise bond-fission were followed, it should be possible to isolate 4,5-di-(methoxycarbonyl)-1,3-dithiole-2-thione and cyclohexene from the reaction of the trans-4,5-tetramethylene compound.

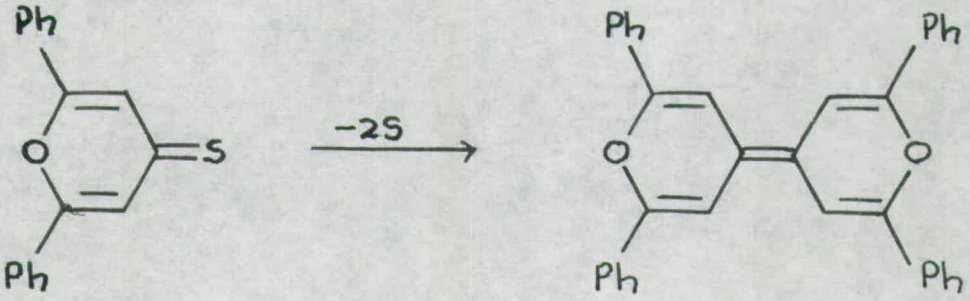
SCHEME 13


S—S
S
Ph
+
CO2Me
Ph
H
S
S
CO2Me
S
Ph
Ph
(CXXVIII)
X2
-2S
Ph
S
Ph
MeO2C
S
H
H
S
CO2Me
S
Ph
Ph
(CXXIX)

2. Reaction of 4-Phenyl-1,2-dithiole-3-thione with Methyl Phenylpropiolate

When a mixture of methyl phenylpropiolate and 4-phenyl-1,2-dithiole-3-thione dissolved in dry benzene was boiled under reflux for four days, a red crystalline solid was obtained which crystallised from pyridine as red needles m.p. 268-274°. The n.m.r. spectrum (Table 1) indicated that the ratio of aromatic : methyl : olefinic protons was 10 : 3 : 1 which is that required for the 1 : 1 cyclo-adduct (CXXVIII; Scheme 13). However, a molecular weight determination and elemental analysis indicated that the reaction had proceeded further and that two molecules of (CXXVIII) had combined with loss of sulphur atoms.

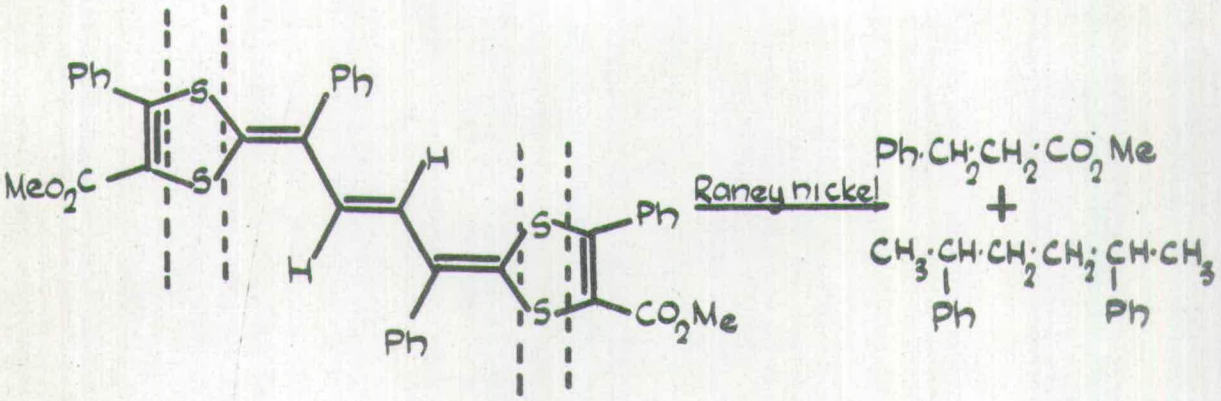
This result suggested that the product might possess the structure (CXXIX) which could have been formed by a process analogous to the formation of dipyrrylenes[70] (e.g. CXXX) by the action of heat on pyranthiones (e.g. CXXXI).



(CXXXI) (CXXX)

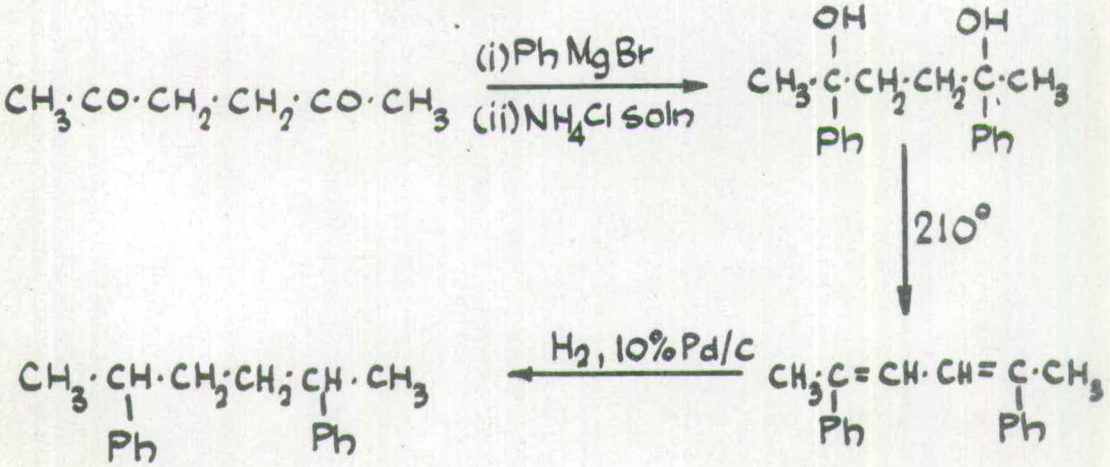
The structure (CXXIX) of the product was confirmed by desulphurisation with Raney nickel to yield a mixture of methyl β-phenylpropionate (isolated, after hydrolysis, as the acid) and 2,5-diphenyl-hexane (Scheme 14).

SCHEME 14



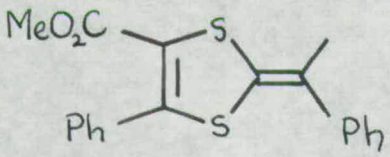
(CXXIX)

SCHEME 15

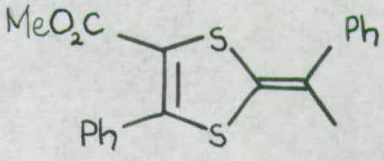


An authentic specimen of the latter compound was synthesised from hexane-2,5-dione by the route shown in Scheme 15 and showed an infrared spectrum identical with that of the desulphurisation product. Gas chromatographic comparison of the two samples showed that each contained the same two components, presumably the meso and racemic forms of 2,5-diphenylhexane.

The product (CXXIX) was evidently a mixture of geometrical isomers since the n.m.r. spectrum showed two O-CH_3 peaks in the intensity ratio 3 : 1. If we assume that this central double bond is always trans, then three geometrical isomers (CXXIX a, b and c) are possible and these will contain, collectively, two different types of alkylidene dithiole unit, (CXXXII) and (CXXXIII).



(CXXXII)

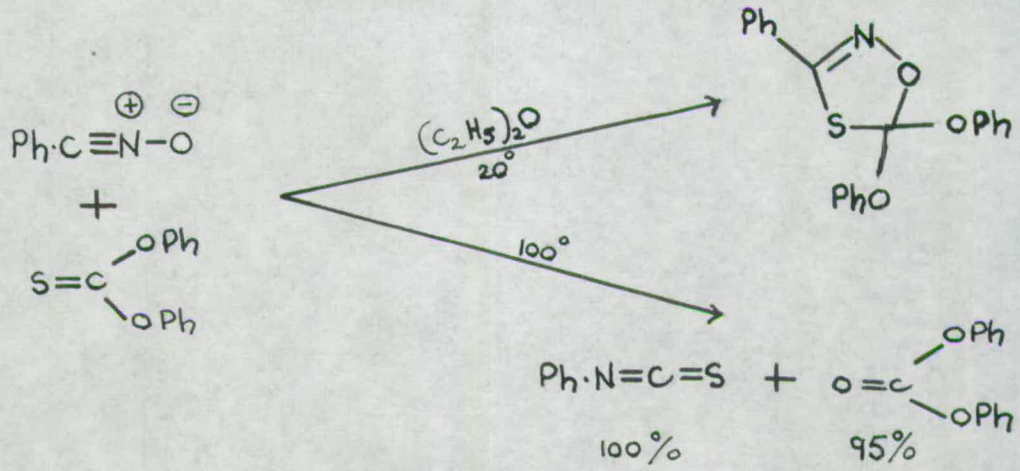


(CXXXIII)

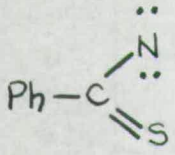
The ratio 3 : 1 will then represent the relative abundance of these two units among all three geometrical isomers; if a statistical distribution of the units is assumed, then the ratio of the three isomers (a : b : c) must be 9 : 6 : 1 or 1 : 6 : 9.

PART B : (i) Reactions with Ethoxycarbonylformonitrile oxide

Aromatic and aliphatic nitrile oxides add readily and in good yield to thioketones to produce 1,4,2-oxathiazoles[71]. With the exception of the 3,5,5-triphenyl derivative, all the 1,4,2-oxathiazoles studied by Huisgen[14] decomposed exothermally at 90-150° to form isothiocyanates and the oxygen analogues of the original thiocarbonyl compounds. Huisgen proposed that the molecular rearrangement required



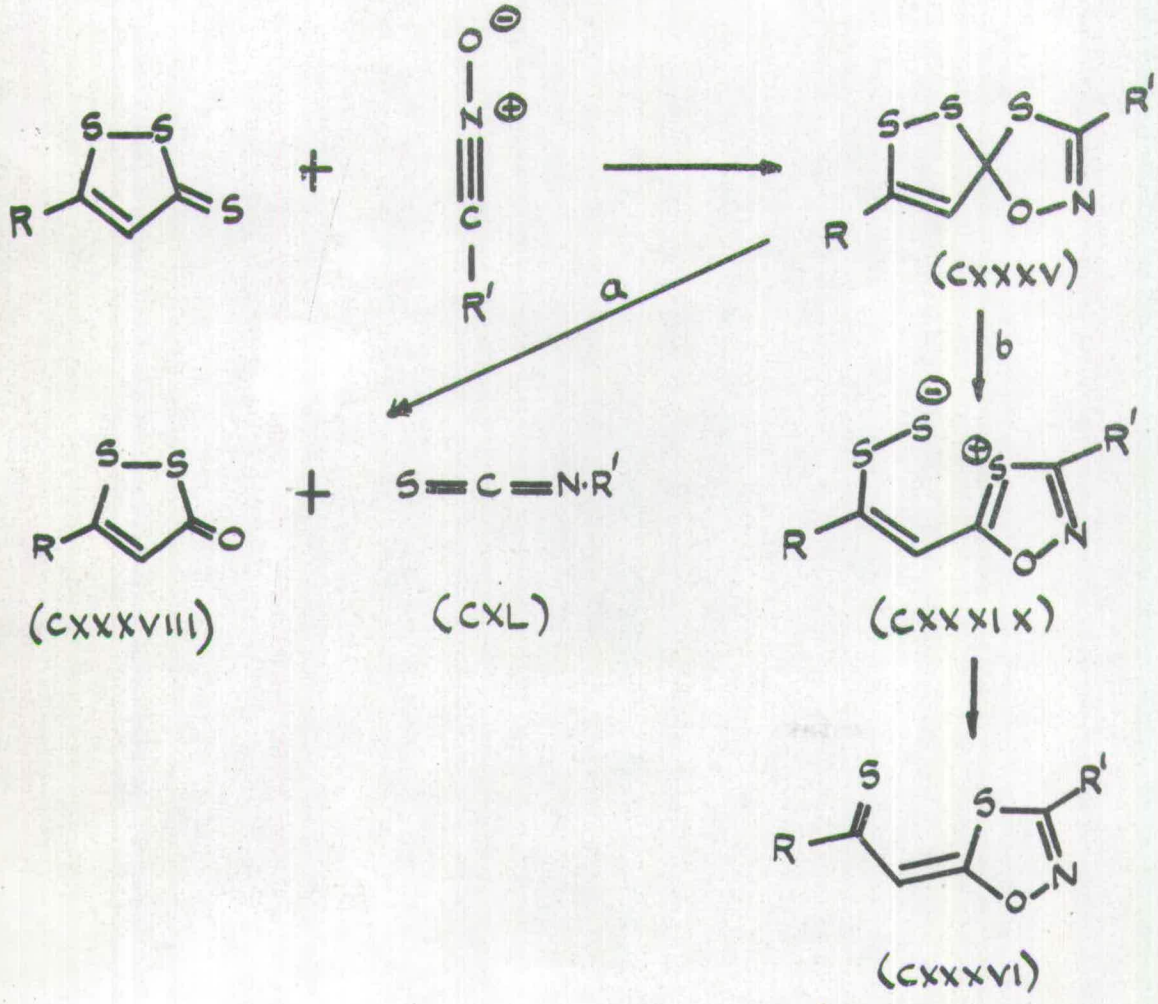
to produce the isothiocyanate proceeds concurrently with the ring opening since a thiononitrene (e.g. CXXXIV) could not be intercepted. In the reactions of thionamides and thioureas with nitrile oxides, cleavage followed 1,3-addition even at room temperatures.



(CXXXIV)

This work of Huisgen strongly suggests that 1,3-dipolar addition reactions should take place between dithiolethiones and nitrile oxides. The initial adducts would be spiro compounds (CXXXV) analogous to those postulated by Brown[72] as intermediates in the reactions of 2-chlorodithiolium

SCHEME 16



salts with bidentate nucleophiles. Two modes of decomposition (Scheme 16) can be envisaged for such a compound : (a) to give a dithiolone and an isothiocyanate, as in the reactions studied by Huisgen, or (b) to give a thioacylmethyleneoxathiazole (CXXXVI) as in the reactions studied by Brown. Ethoxycarbonylformonitrile oxide (CXXXVII) was chosen for this investigation because of the ready availability of its precursor, ethyl chlorohydroxyiminoacetate[73].

$$EtO_2C - \dot{C} \equiv \overset{\oplus}{N} - \overset{\ominus}{O}$$

(CXXXVII)

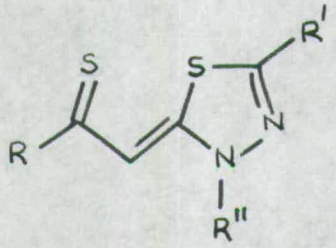
Reaction of 5-Phenyl-1,2-dithiole-3-thione with Ethoxycarbonylformonitrile oxide

The experiment was performed by addition of triethylamine to a vigorously stirred solution of 5-phenyl-1,2-dithiole-3-thione and ethyl chlorohydroxyiminoacetate in dry benzene. Chromatography of the benzene-soluble products gave a 25% recovery of thione and a 64% yield of the corresponding ketone (CXXXVIII; R = Ph). The absence of 3-ethoxycarbonyl-5-thiophenacylidene-1,4,2-oxathiazole [(CXXXVI); R = Ph; R' = CO_2Et.] in the reaction product showed that decomposition of the spiro-compound [(CXXXV); R = Ph; R' = CO_2Et] takes place entirely according to route (a). The oxathiazolium system present in the zwitterion (CXXXIX) is unknown and is very probably unstable, thus rendering route (b) an unfavourable mode of decomposition. In order to search for the presence of the isothiocyanate [(CXL); R' = CO_2Et] among

the products, the reaction was repeated and this time the benzene was evaporated and then, using a fractionating column, distilled under reduced pressure. The infra red spectrum of the distillate indicated the presence of an ethoxycarbonyl group (1735 cm^{-1}) and an isothiocyanate group (1960 cm^{-1}). The product reacted with aniline to give a white solid which was identified as N-ethoxycarbonyl-N'-phenylthiourea, thus identifying the original reaction product as ethoxycarbonyl isothiocyanate.

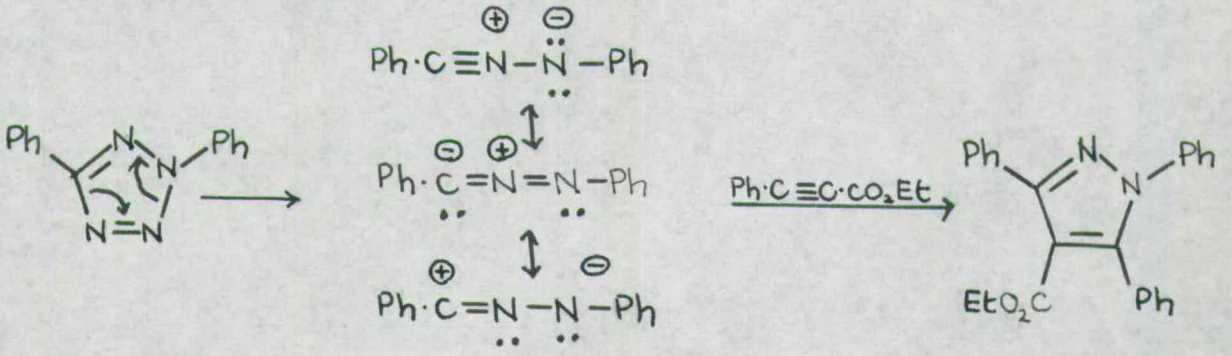
PART B : (ii) Reactions with Benzonitrile N-phenylimine

Huisgen has shown[14] that nitrile imines react with thiocarbonyl compounds in the same way as nitrile oxides. The resulting thiadiazoles, however, are much more thermally stable than the oxathiazoles and there is no report of a fragmentation reaction leading to an isothiocyanate. It seemed possible, therefore, that the adducts formed by 1,3-dipolar addition of nitrile-imines to the thiocarbonyl group of 1,2-dithiole-3-thiones might decompose to thioacylmethylene-thiadiazoles (CXLI) by a route analogous to (b) in Scheme 16.



(CXLI)

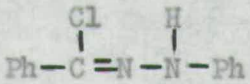
Benzonitrile N-phenylimine has been synthesised by Huisgen[14] who used two methods. The first method involved the thermolysis of 2,5-diphenyltetrazole (CXLII) by heating at 160° in the presence of a 1,2-dipolarophile (ethyl phenylpropiolate) to give an 84% yield of the monoadduct (CXLIII).



(CXLII)

(CXLIII)

Huisgen realised, however, that the high temperature required for the opening of the aromatic tetrazole nucleus was a serious disadvantage since it restricted the choice of dipolarophile. His search for a better method for the preparation of nitrileimines led him to the second method in which a carboxylic acid hydrazide chloride is treated with a suitable base to liberate a nitrileimine. This method proved to be much superior to the earlier method since it allowed the liberation of nitrileimines even at room temperature[74,75]. For example, the action of triethylamine on N-(α-chlorobenzylidene)-N'-phenylhydrazine[73] (CXLIV) results in 1,3-elimination of hydrogen chloride. In the presence of ethyl phenylpropiolate yields as high as 86% of ethyl 1,3,5-triphenylpyrazole-4-carboxylate (CXLIII) were obtained.



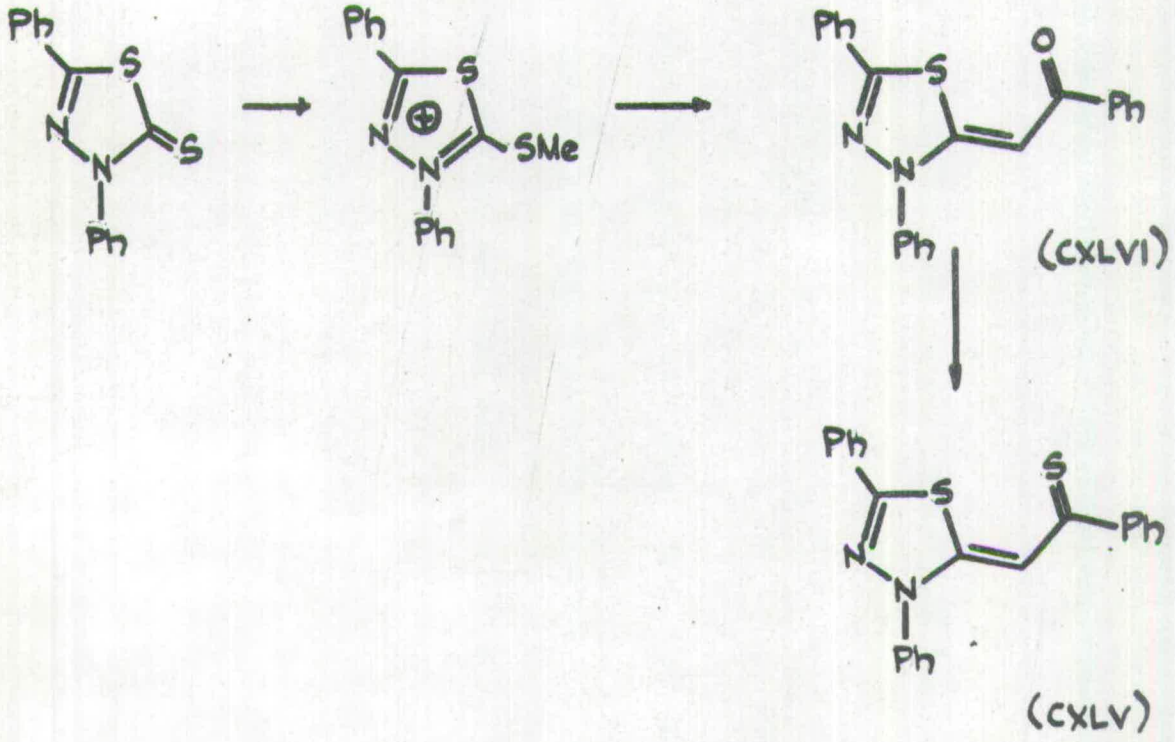
(CXLIV)

1. Reaction of 5-Phenyl-1,2-dithiole-3-thione with Benzonitrile N-phenylimine

In the initial reaction, an equimolar solution of triethylamine in dry benzene was added dropwise and with stirring to a solution of 5-phenyl-1,2-dithiole-3-thione and N-(chlorobenzylidene)-N'-phenylhydrazine (CXLIV) in dry benzene at room temperature. Working up of the reaction mixture obtained under these conditions led to partial recovery of thione and compound (CXLIV).

The reaction was repeated, this time using two moles of triethylamine to one each of thione and (CXLIV). When addition of the amine was complete, the reaction mixture was stirred at 50° for 3 hr. After being

SCHEME 17



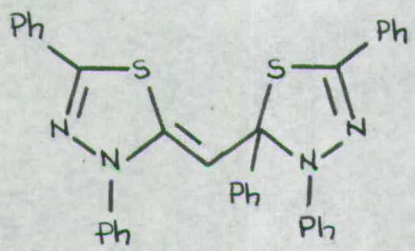
washed with water and concentrated, the benzene solution deposited red prisms (m.p. 197-198°) (44.5%). The n.m.r. spectrum of this product (Table 1) showed all the protons to be in the aromatic region and the elemental analysis gave results consistent with that expected of the thiadiazole (CXLV). The benzene mother liquor was chromatographed on alumina to give sulphur as a first fraction, and recovered thione (21%) as a third fraction. The second fraction gave a yellow solid (m.p. 179°d), the identification of which is dealt with later (this page). The fourth fraction was found to be identical (infrared spectrum and mixed melting point) with the previously isolated red solid, bringing the total yield up to 59%.

That the red solid was (CXLV) was shown by an unambiguous synthesis (Scheme 17) in which 2-methylthio-1,3,4-thiadiazolium perchlorate (obtained from 3,5-diphenyl-1,3,4-thiadiazole-2-thione[76]) was allowed to react with sodium benzoylacetate[43] to give the phenacylidene compound (CXLVI). The latter was converted to the thione (CXLV) by treatment with phosphorus pentasulphide. The infrared spectrum of this material was identical with that of the cyclo-addition product and the mixed melting point was undepressed.

The yellow solid (m.p. 179°d) isolated from the second chromatography fraction showed n.m.r. absorptions at 4.4 τ (singlet; relative intensity 1) and at 2.24-2.86 τ (multiplet; relative intensity ca.25). The elemental analysis was consistent with that of an adduct formed from one molecule of compound (CXLV) and an additional molecule of the imine. That it was indeed formed in this way was shown by allowing compound

(CXLV) to react with another mole of the nitrileimine to give the same solid (47%).

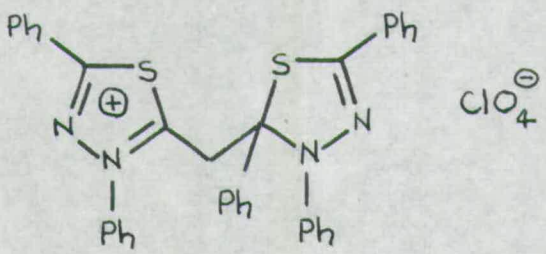
The most probable mode of reaction is by cyclo-addition of the nitrileimine to the thiocarbonyl group of compound (CXLV) to give a compound of structure (CXLVII).



(CXLVII)

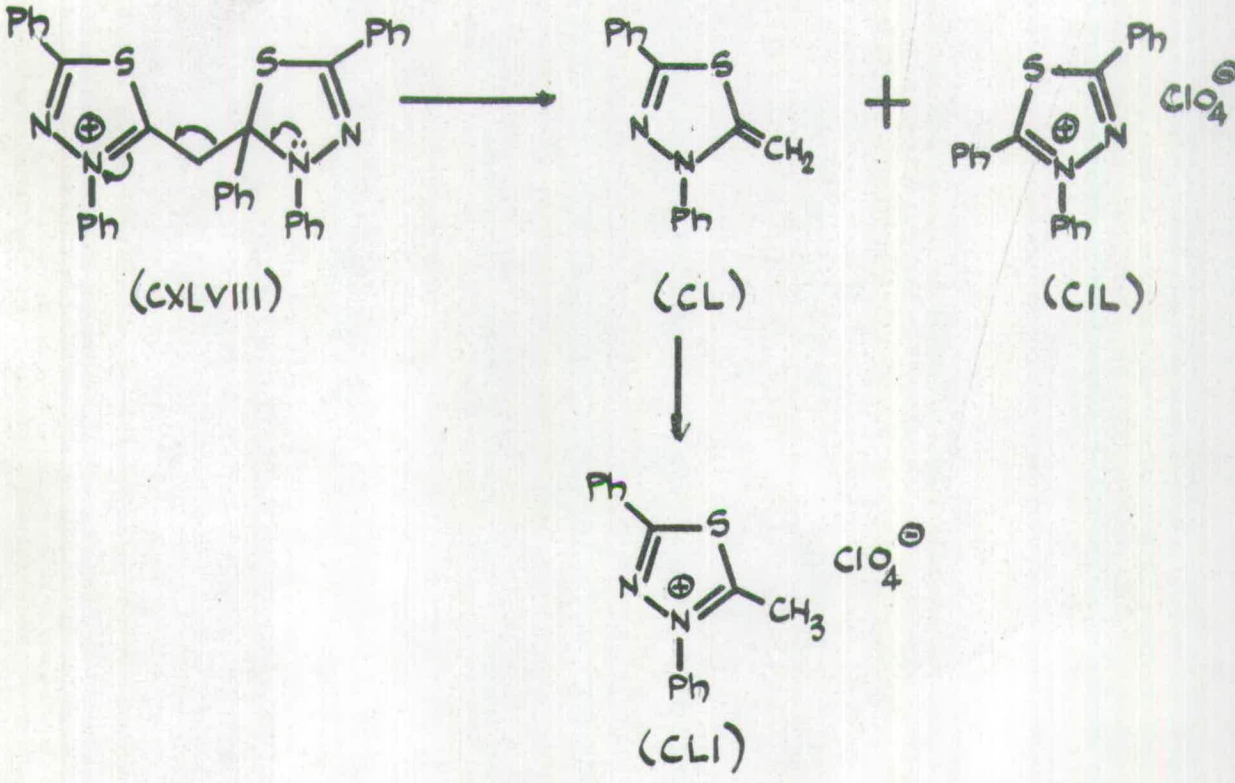
This structure is in agreement with the n.m.r. spectrum since the proton of the methine group joining the two rings would be expected to give rise to a singlet in the olefinic region. The remaining 25 protons are aromatic.

Protonation of structure (CXLVII) would be expected to occur at the methine carbon atom to give a salt (e.g. CXLVIII), the n.m.r. spectrum of which would show a two proton singlet in place of the one proton singlet and probably at a higher τ value than the latter. Accordingly, the yellow product was treated with perchloric acid but neither the n.m.r. spectrum nor the elemental analysis of the resulting perchlorate was in agreement with the structure (CXLVIII).



(CXLVIII)

SCHEME 18



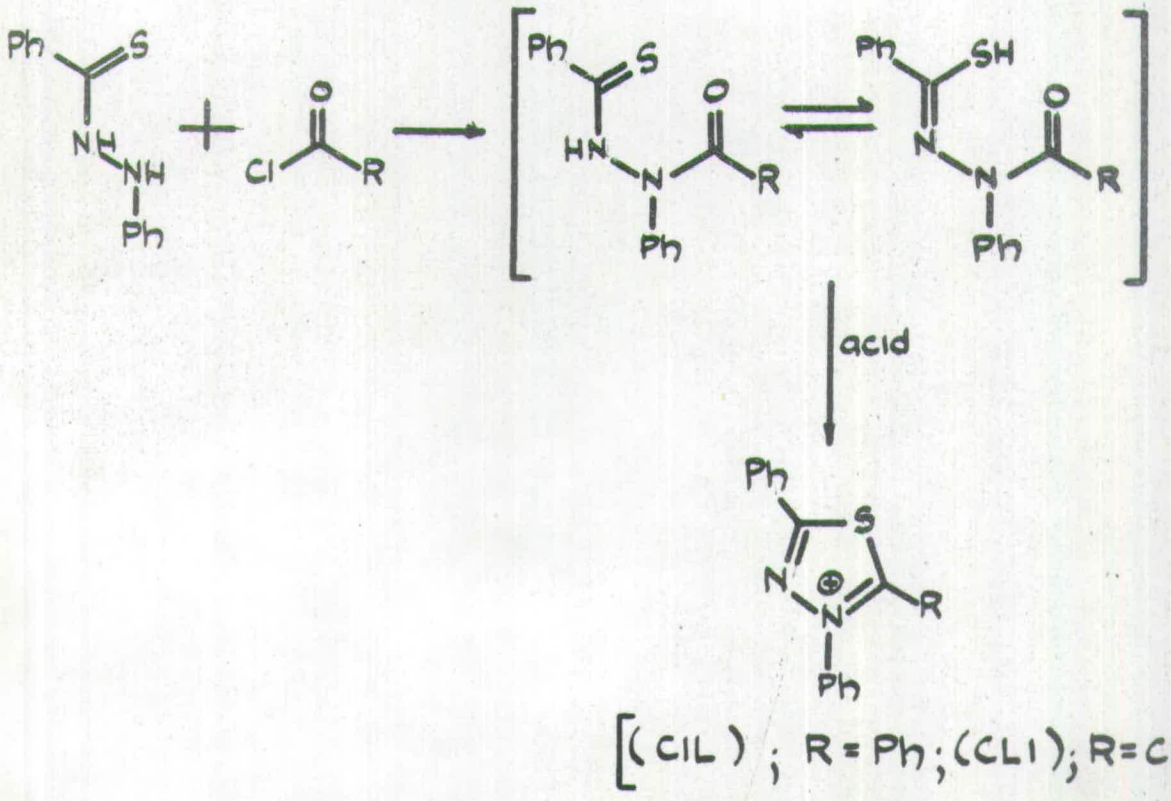
(CXLVIII) (CL) (CIL)

(CLI)

In particular the chlorine content was approximately twice that required for (CXLVIII) and the ratio of aromatic protons (multiplet, τ=1.83-2.40)to aliphatic protons (singlet, τ = 6.92) was 20 : 2 (CXLVIII requires 25 : 2). On the basis of these results, it seemed reasonable to suggest that when (CXLVII) is treated with perchloric acid, an unstable salt (CXLVIII) is formed and then decomposes according to Scheme 18. The formation of the aromatic triphenylthiadiazolium ion (CIL) is accomplished by expulsion of a neutral fragment (CL) which, being the anhydro-base of the methyldiphenylthiadiazolium ion (CLI), is rapidly protonated in the acid medium. It would thus be this mixture of thiadiazolium salts to which the elemental analysis was related and which would account for the apparently high proportion of aliphatic proton resonance in the n.m.r. spectrum. (Since the product was recrystallised before these measurements were made, the two salts would not necessarily be present in equimolecular proportions, as required by Scheme 18). To show that this explanation was correct, it was necessary to prepare the perchlorates (CLI) and (CIL) and to compare the infra red spectrum of a mixture of the two with the supposed mixture obtained by the attempted preparation of the perchlorate (CXLVIII).

As a first step in the preparation of (CIL) and (CLI), N-phenyl-N'-thiobenzoylhydrazine was prepared by the method of Jensen and Miguel[77] in which carboxymethyl dithiobenzoate, dissolved in dilute aqueous sodium hydroxide solution, was added to phenylhydrazine. The product was refluxed for a few minutes with a solution of either benzoyl chloride or acetyl chloride in benzene to give solids which, when treated with perchloric acid in methanol, gave the perchlorates (CIL) and (CLI)

SCHEME 19

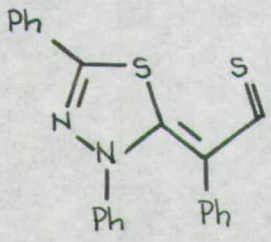


[(CIL) ; R = Ph ; (CL1); R = CH

respectively (Scheme 19). The n.m.r. absorptions of the individual salts (CIL) and (CLI) (Table 1) together accounted for all the absorptions in the spectrum of the product obtained by treatment of (CXLVII) with perchloric acid. An equimolar mixture of (CIL) and (CLI) gave an infra red spectrum which was very similar to that of the product obtained from compound (CXLVII), the only differences (in the relative intensities of certain absorptions) being attributable to different molar ratios of (CIL) and (CLI) present in the two sets of mixtures. This evidence then strongly supports the proposal that the yellow product (m.p. 179°d) possesses the structure (CXLVII).

2. Reaction of 4-Phenyl-1,2-dithiole-3-thione with Benzonitrile N-phenylimine

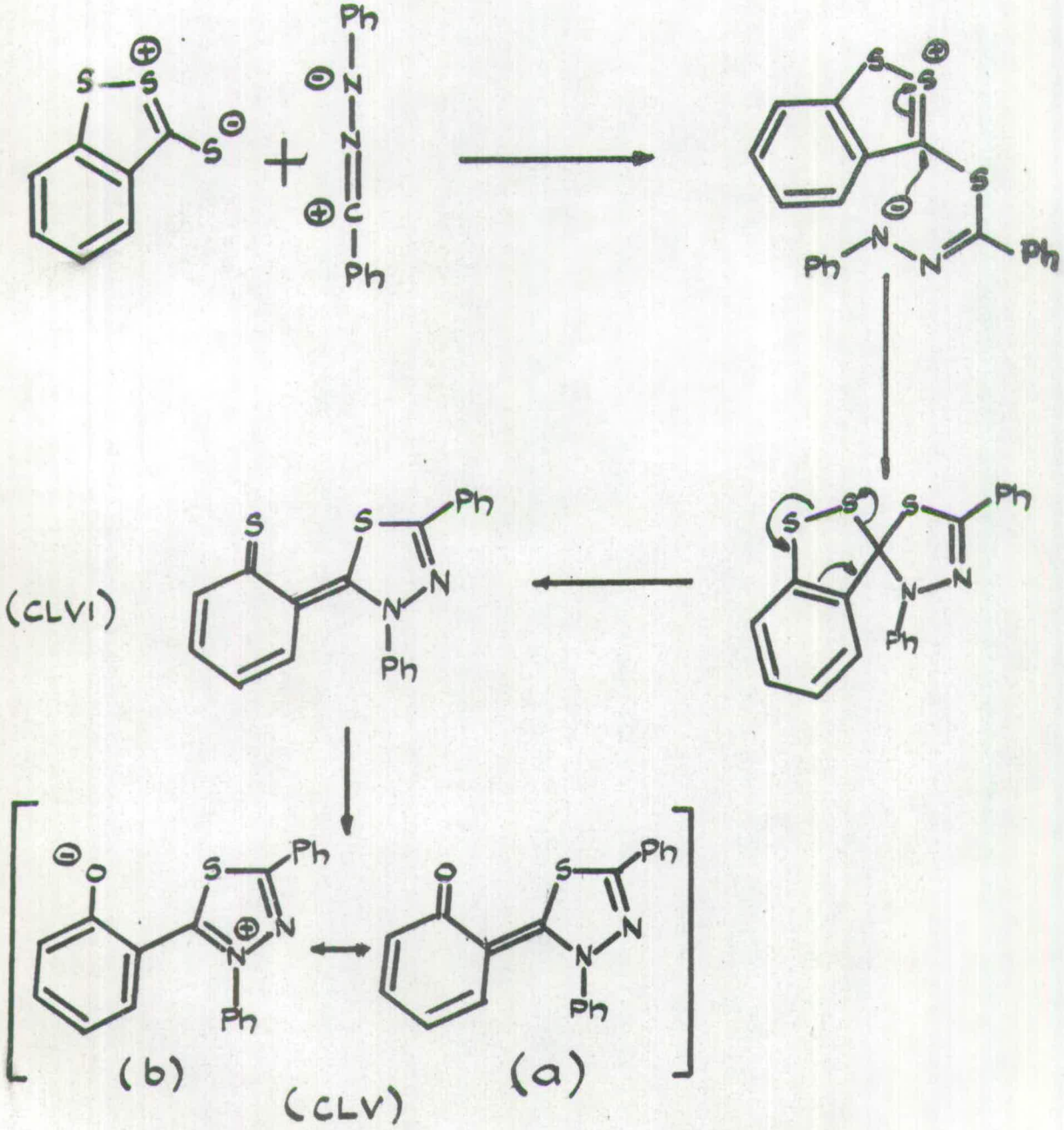
The reaction was carried out in a manner similar to that described for 5-phenyl-1,2-dithiole-3-thione. The first reaction was carried out at room temperature but when the reaction was repeated using a reaction temperature of 50°C, the yield of product was improved. Concentration of the benzene solution yielded brown plates (m.p. 208°; 22%), the elemental analysis of which was consistent with that required for 2-(3,5-diphenyl-1,3,4-thiadiazol-2-ylidene)-2-phenylethanethial (CLII).



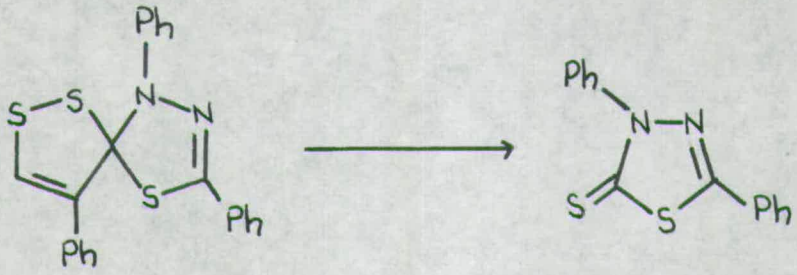
(CLII)

The n.m.r. spectrum of the compound showed a low field resonance (-0.05τ) attributable to the thioaldehyde proton and a multiplet at 1.95 - 3.02τ attributable to the aromatic protons, [relative intensities 1:15; (CLII) requires 1:15]. The mother liquor was chromatographed on alumina to give two fractions, the first of which contained

SCHEME 20



4-phenyl-1,2-dithiole-3-thione (20% recovery) and the second a yellow solid (m.p. 152-153°) which was identified as 3,5-diphenyl-1,3,4-thiadiazole-2-thione (CLIII) by infrared spectrum and mixed melting



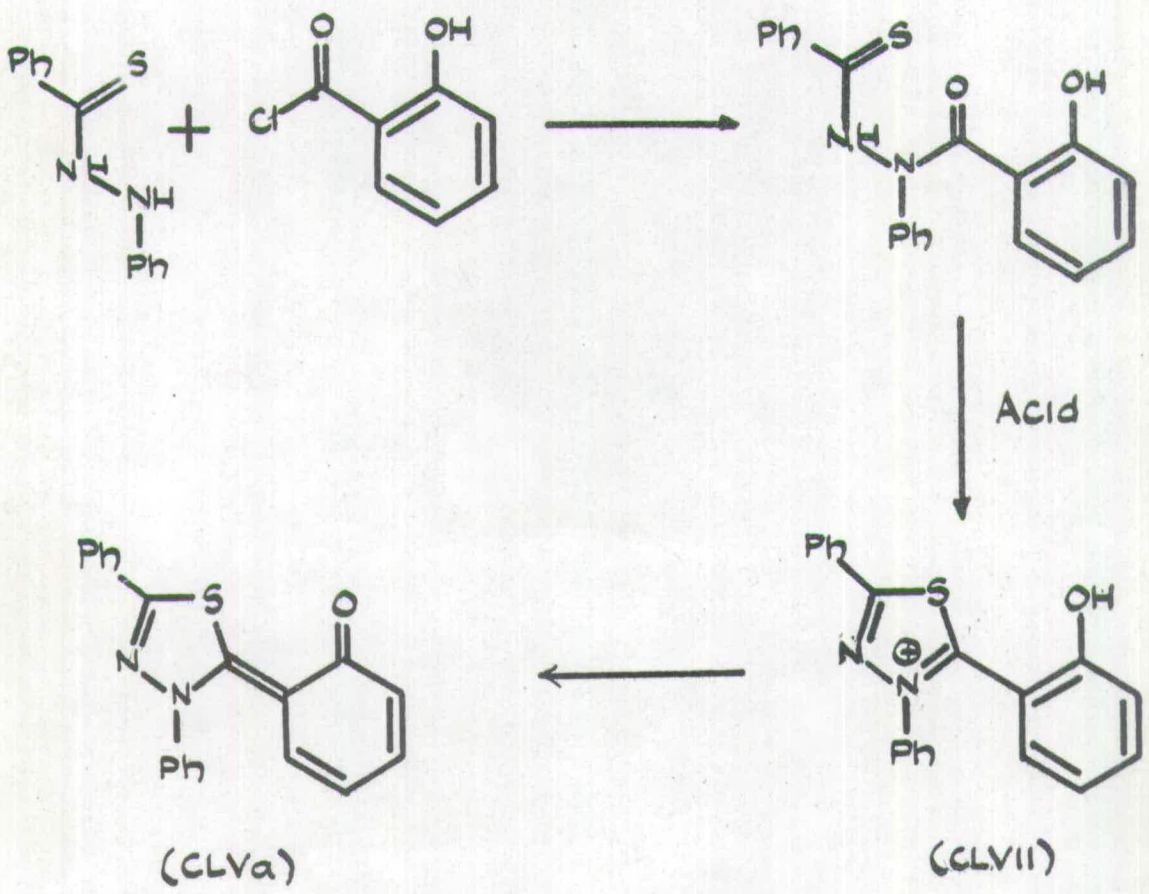
(CLIV) (CLIII)

point evidence. The presence of this thione in the product is very difficult to explain since its production from the dithiolethione, via the intermediate (CLIV) would involve the fission of a carbon - carbon bond in addition to the disulphide bond.

3. Reaction of 4,5-Benzo-1,2-dithiole-3-thione with Benzonitrile N-phenylimine

Again the method was similar to that described for the reaction of 5-phenyl-1,2-dithiole-3-thione with the nitrile imine at 50°. Chromatography of the reaction mixture gave four main fractions, the first of which were identified as sulphur and 4,5-benzo-1,2-dithiole-3-thione. The third fraction yielded a small amount of a red oil which could not be crystallised and the fourth gave a yellow crystalline solid (m.p. 164-166°). The elemental analysis of this compound compared closely with that required for the thiadiazolylidenecyclohexadienone (CLV) which could have been formed, oxidatively, from the corresponding thione (CLVI), the latter being the expected decomposition product of the

SCHEME 21



(CLVa) (CLVII)

initial cyclo-adduct (Scheme 20).

The spectroscopic properties of the compound, however, did not lend support to this structure. The infra red spectrum showed a carbonyl band at 1640 cm^{-1}. but, in view of the probable large contribution of the dipolar canonical structure (CLVb), a frequency lower than this would have been expected for a compound of structure (CLV). The n.m.r. spectrum showed absorptions only in the aromatic region (a multiplet at 1.84 - 2.82τ). This is not the type of spectrum expected of a compound possessing structure (CLV) since the partly quinonoid character of the oxygenated ring would probably raise the signals of the protons in this ring to higher magnetic field values.

In order to reach a definite conclusion on these points, synthesis of compound (CLV) was undertaken by the unambiguous method outlined in Scheme 21. A solution of N-phenyl-N'-thiobenzoylhydrazine in benzene was allowed to react with salicyl chloride and the product was treated with perchloric acid to give 3,5-diphenyl-2-(o-hydroxyphenyl)-1,3,4-thiadiazolium perchlorate (CLVII) as yellow plates. Addition of dilute sodium hydroxide to the salt (CLVII) gave an orange solid m.p. 225-226°, the elemental analysis of which was in agreement with that required for (CLV). The n.m.r. spectrum (Table 1) showed (a) a multiplet, 2.72-4.07τ (quinonoid ring protons), (b) a multiplet 1.90-2.52τ (phenyl group protons); the relative intensities were 4:10 which is the ratio required for (CLV). The infra red spectrum of this product (C=O bond at 1640cm^{-1}) was quite different from that of the yellow compound (m.p. 164-166°) which thus remains unidentified.

Table 1 N.M.R. Spectral Data

Internal Standard: Tetramethylsilane
s = singlet, d = doublet, q = quartet; m = multiplet
o = ortho m = meta p = para

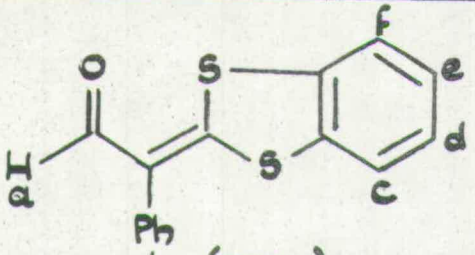
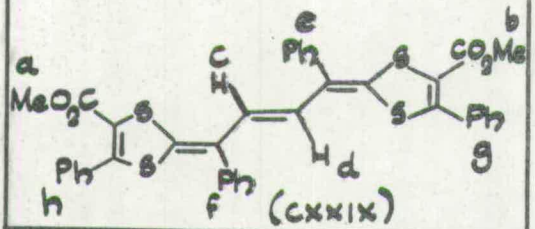
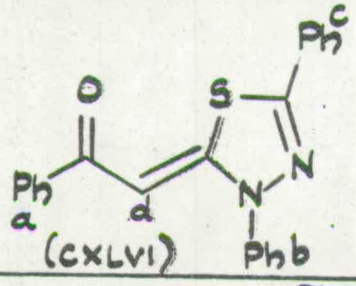
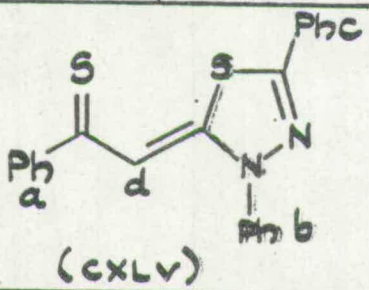
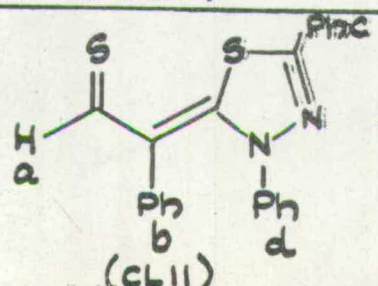
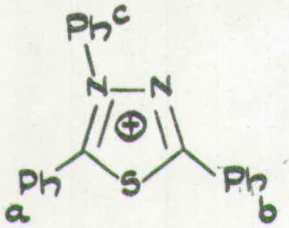
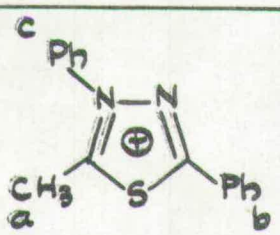
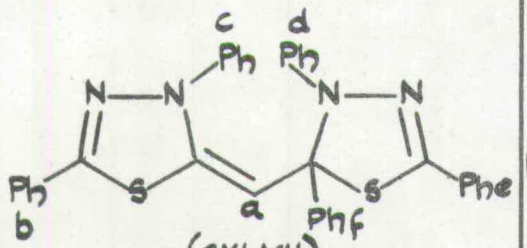
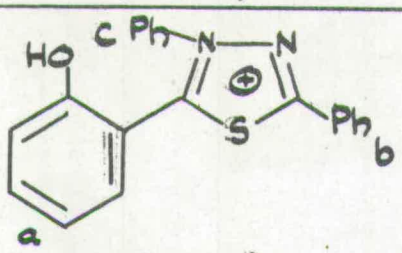
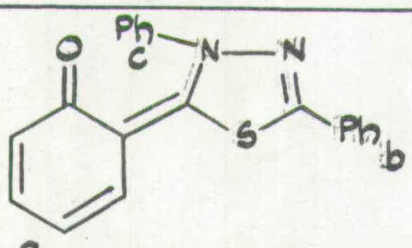
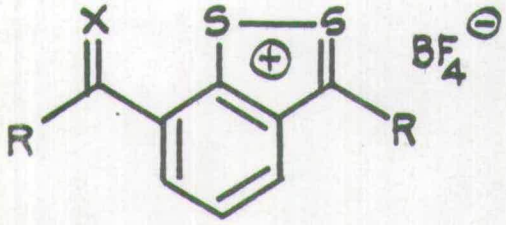
Compound	Proton	τ values	number of protons
 (CXXIV)	a	0.72s	1
	b,c,d,e,f	2.45 – 2.93m	9
 (CXXIX)	a, b	6.40s, 6.45s	6
	d, c	4.15 d	2
	e,f,g,h	2.65s, 2.72s	20
 (CXLVI)	d	3.29s	1
	a,b (-g)	2.16q	15
	c,(ab-m,p)	2.30 – 2.75m	
 (CXLV)	a,b,c,d	2.0 – 2.78m	—
 (CL11)	a	-0.05s	1
	b,c,d(-g)	1.95 – 2.76m	15
	b,c,d(m,p)	3.02 d	

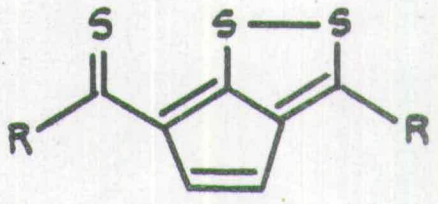
Table 1 N.M.R. Spectral Data (continued)

Compound	Proton	τ values	number of protons
 (CIL)	b (-σ)	1·85 - 2·00m	2
	a,c & b(m,p)	2·30 - 2·40m	13
 (CLI)	a	6·89s	3
	c, (-σ)	1·88 - 2·06m	10
	b & c(-m,p)	2·24 - 2·40m	
 (CXLVII)	a	4·4s	~1
	b,c,d,e,f	2·24 - 2·86m	25
 (CLVII)	a	2·54 - 3·08m	4
	b, (σ)	1·86 - 2·00m	10
	c & b(m,p)	2·28 - 2·37m	
 (CLVa)	a	2·72 - 4·07m	4
	c, (σ)	1·90 - 2·07m	10
	b & c(m,p)	2·35 - 2·53m	

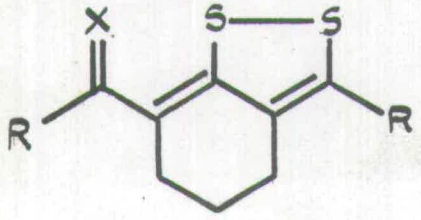


(CLVIII)

a : R = Ph ; X = S
b : R = Ph ; X = O
c : R = p-Tolyl ; X = S
d : R = p-Tolyl ; X = O
e : R = p-Anisyl ; X = S
f : R = p-Anisyl ; X = O
g : R = MeS- ; X = S

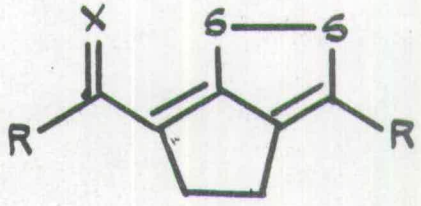


(CLIX)



(CLX)

a : R = Ph ; X = S
b : R = Ph ; X = O
c : R = p-Tolyl ; X = S
d : R = p-Tolyl ; X = O
e : R = p-Anisyl ; X = S
f : R = p-Anisyl ; X = O
g : R = MeS- ; X = S
h : R = H ; X = S



(CLXI)

a : R = Ph ; X = S
b : R = Ph ; X = O

SECTION II

Synthesis of Compounds potentially capable of exhibiting "No-Bond Resonance"

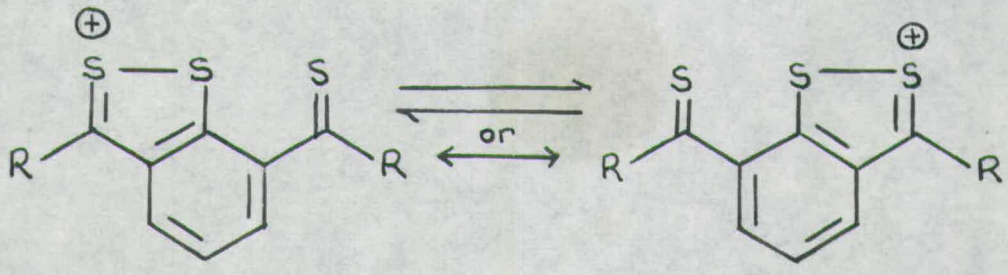
Part A : Dehydrogenation Products of Thiothiophthens

The main objectives of the work described in this part of the thesis were the syntheses (a) of members of the novel class of compounds represented by formula [(CLVIII); X=S] and (b) of compounds of type (CLIX).

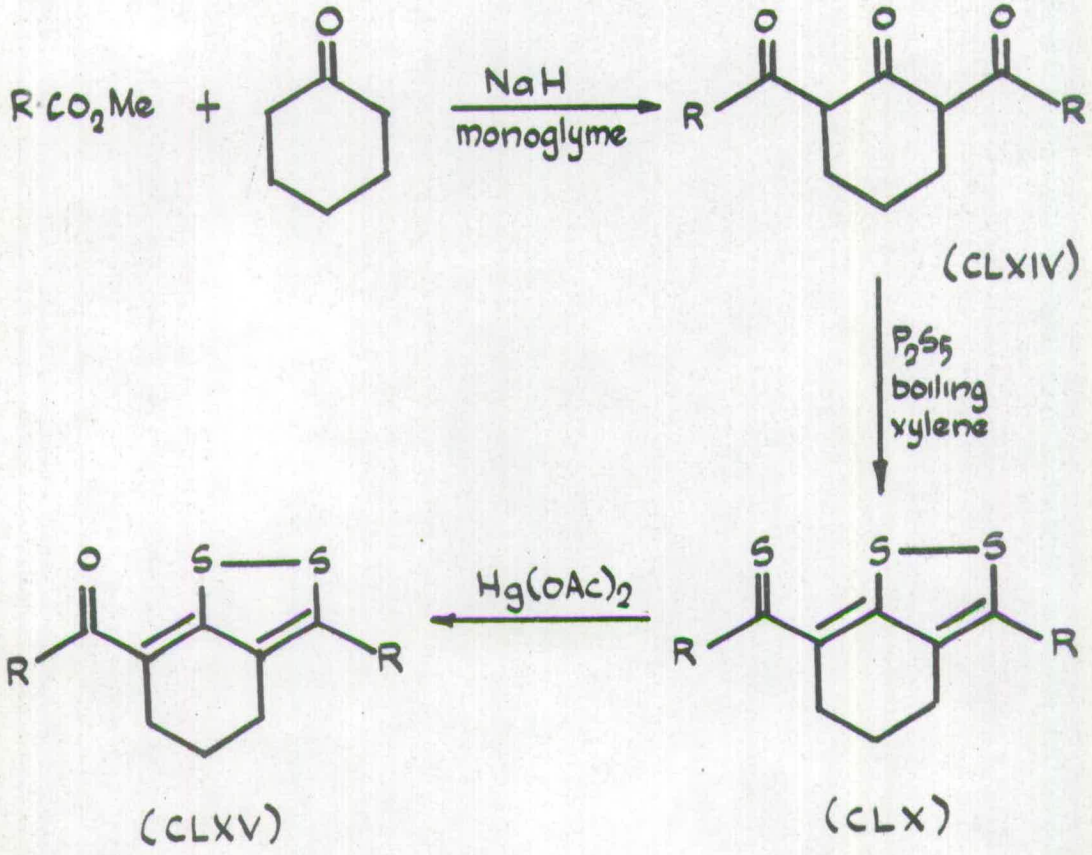
Compounds of type (CLIX) are thioacyl derivatives of cyclopenta [c] -1,2-dithiole, an unknown iso-π-electronic analogue of azulene for which considerable stability has been predicted[78].

Since these substances are dehydrogenation products of the thio-thiophthens (CLX) and (CLXI) respectively, a number of representatives of these classes of compounds were required as starting materials. Accordingly, the thiothiophthens (CLX a, c, e, g and h) and (CLXIa) were synthesised together with certain of the corresponding ketones (CLX b, d and f; CLXIb). The yield of (CLXh) was insufficient for further study.

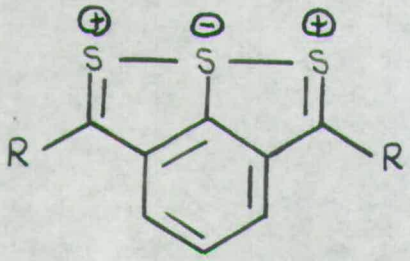
Interest in cations of the type (CLVIII; X = S) arises because of the possibility that they might exhibit tautomerism or resonance between two equivalent structures :



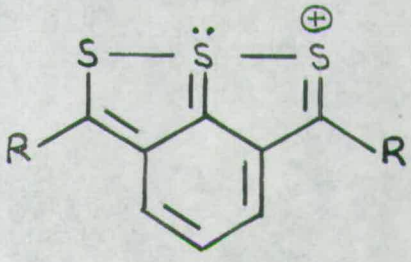
SCHEME 22


R·CO2Me +
NaH
monoglyme
R
R
(CLXIV)
P2S5
boiling
xylene
Hg(OAc)2
R
R
(CLX)
R
R
(CLXV)

In this instance participation of the d-orbitals of the central sulphur atom seems improbable because it would involve canonical structure (CLXII) with charge separation or (CLXIII) with a quinonoid benzene ring.



(CLXII)



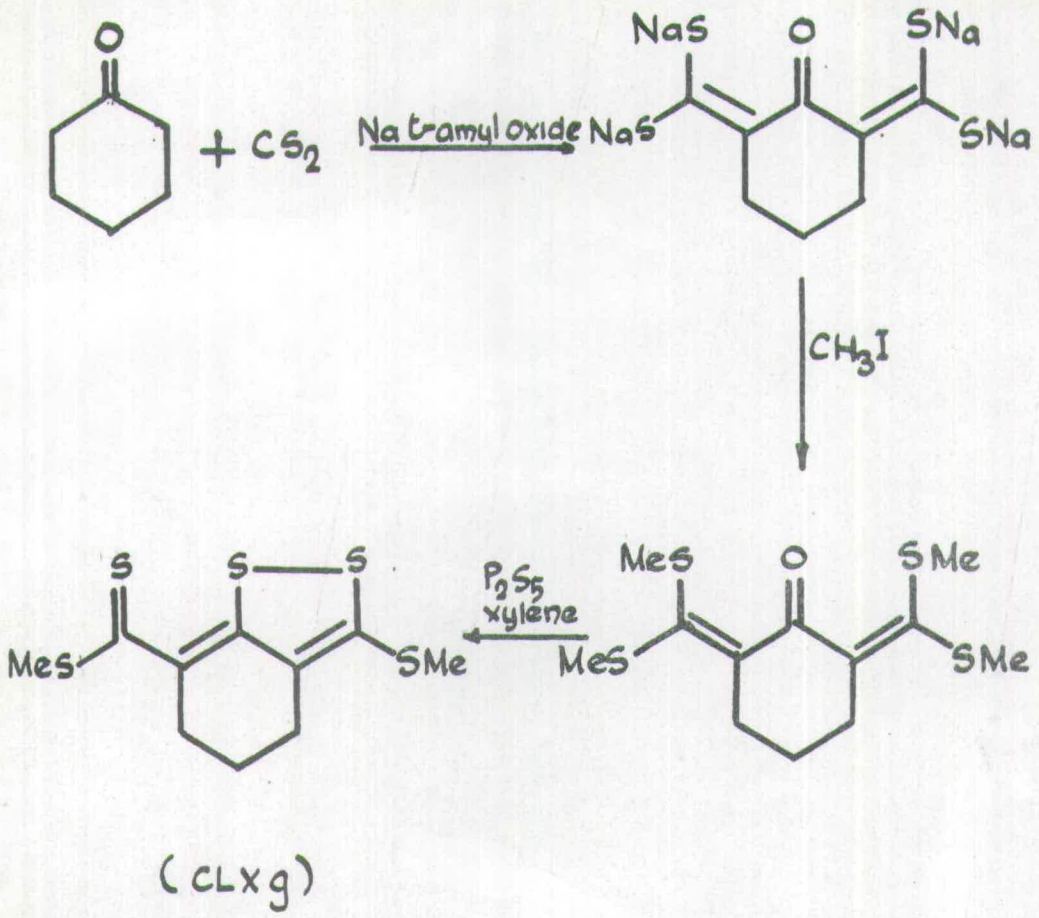
(CLXIII)

1. Preparation of Starting Materials

With the exception of the thiothiophthen (CLXg), the thiothiophthens were prepared by treating the triketones (CLXIV) with phosphorus pentasulphide. The triketones were obtained from the appropriate cyclic ketone by a general method[53] involving reaction with the methyl ester of an aromatic carboxylic acid (or a methyl ester not possessing an active α-methylene group) in the presence of sodium hydride (Scheme 22). Conversion to the corresponding ketone (CLXV) was effected by treatment with a solution of mercuric acetate in either acetone or an acetone chloroform mixture (depending on the solubility of the thiothiophthen in acetone).

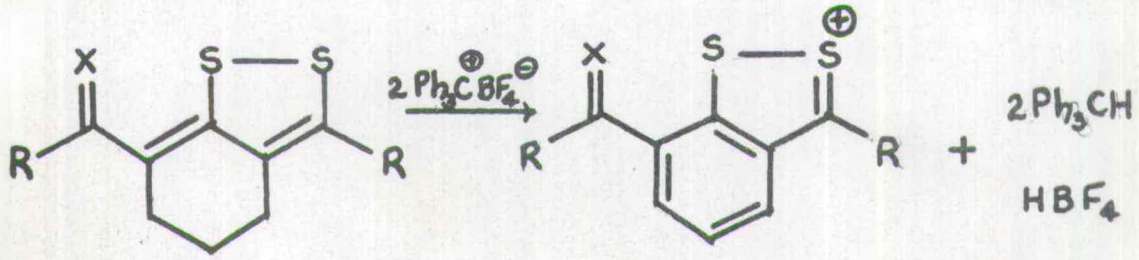
The yield of the thiothiophthen (CLXh) was insufficient to allow conversion into the ketone. The ketodialdehyde (CLXIV; R = H) was prepared by replacing the aromatic ester used in the triketone preparation by methyl formate, an aliphatic ester which does not contain an active α-methylene group and which, therefore, is not prone to attack by sodium

SCHEME 23



(CLXg)

SCHEME 24



hydride. The dialdehyde was obtained in good yield, but conversion to the thiothiophthen gave an extremely poor yield. The preparations of the compounds [CLX (a),(b),(c),(d),(e) and (f)] have since been described in the literature[52].

Compound (CLXg) was prepared by the method of Thuillier and Vialle[51] (scheme 23). Attempts to convert this thiothiophthen into the corresponding ketone by using either mercuric acetate in acetone or concentrated sulphuric acid failed, the reagent apparently causing breakdown of the molecule.

2. Dehydrogenation

Dehydrogenation of the thiothiophthens (CLX; X = S) to the 7-thioacylbenzo[c]-1,2-dithiolium fluoborates (CLVIII; X = S) was accomplished by treatment with trityl fluoborate[79] in acetic acid (Scheme 24) and the 7-acyl compounds (CLVIII; X = O) were prepared similarly for spectroscopic comparison with the thiones. Attempts to dehydrogenate the thiothiophthen (CLXIa) using the same reagent were apparently unsuccessful since none of the expected 3-phenyl-6-thiobenzoylcyclopenta [c] -1,2-dithiole (CLIX; R = Ph) could be isolated. The only well defined product from this reaction was a black crystalline solid (m.p. 300°) which showed infra red absorptions characteristic of the fluoborate ion. The yield was insufficient for detailed investigation.

3. Spectroscopic studies of the thiothiophthens and their Dehydrogenation Products

(a) N.m.r. Spectra

The n.m.r. spectra of the thiothiophthens (CLX, a,c,e,g and h) and (CLXIa) (Table 2) indicated symmetrical structures, the two groups (R)

giving only one set of signals and the protons of the fused carbocyclic ring giving either the triplet-quartet* system [for compounds (CLX; X = S)] consistent with that expected of a symmetrical α,γ-disubstituted trimethylene compound or a singlet [for compound (CLXIa)].

In contrast the ketones (CLX b,d and f) and (CLXIb) (Table 2) although giving one set of signals for the two R groups, gave a more complex pattern of absorptions due to the carbocyclic methylene groups. For example, the methylene groups of the ketone (CLXIb) showed an A_2B_2 multiplet which was replaced by a singlet in the spectrum of the corresponding thione (CLXIa). The methylene protons of the six-membered carbocyclic rings in the ketones (CLX b, d and f) were observed as two complex multiplets rather than the relatively simple triplet-quintet system of the thiothiophthens.

The n.m.r. spectra of the dehydrogenation products (CLVIII; X = S) also showed evidence of molecular symmetry (Table 2). The two groups (R) gave rise to only one set of signals and the three protons of the fused benzene ring gave an A_2B multiplet (almost A_2X) in the region 0.9-1.9τ.

Unexpectedly the n.m.r. spectra of the corresponding ketones (CLVIII; X = O) contained an A_2B multiplet which was almost identical in appearance with that in the spectra of the thiones. In other respects, however, the spectra of the ketones were unexceptional and clearly consistent with the unsymmetrical nature of the molecules. Thus the di-p-anisyl

* The expected pattern of absorption is a triplet-quintet but one line of the quintet was evidently too weak to be seen.

compound (CLVIIIf) showed two methoxyl absorptions near 5.9τ and two A_2B_2 multiplets in the aromatic proton region; the di-p-tolyl compound (CLVIIId) similarly showed separate absorptions for each of the p-tolyl groups.

The n.m.r. spectral evidence thus suggests that the dithiolium cations (CLVIII; X = S) possess symmetrical structures, a state of affairs similar to that found for the parent thiothiophthens (CLX; X = S). This apparent symmetry could be due either to resonance or to degenerate tautomerism but the evidence available was insufficient to allow a distinction to be made.

Table 2 N.M.R. Spectral Data

Internal Standard: Tetramethylsilane

s = singlet; d = doublet; t = triplet; q = quartet; quin = quintet; m = multiplet.

o = ortho m = meta p = para

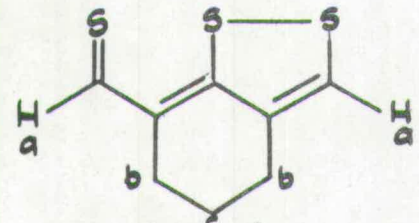
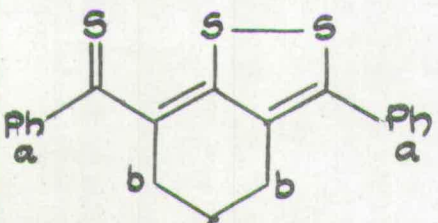
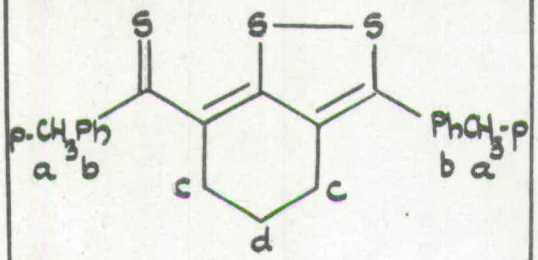
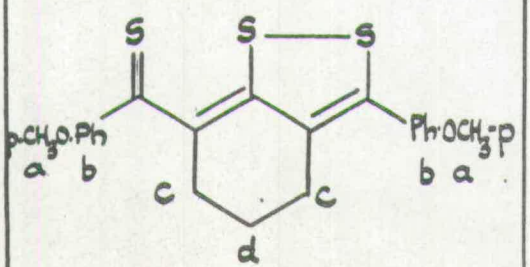
Compound	Proton	τ values	coupling constant J.c.p.s.	number of protons
 (CLXh)	a	1·18 s	-	2
	b	6·97 t	6	4
	c	7·94 q	6	2
 (CLXa)	a	2·61 s	-	10
	b	7·1 t	6	4
	c	8·12 q	~6	2
 (CLXc)	a	7·60 s	-	6
	b	2·74 s	-	8
	c	7·08 t	6	4
	d	~8·2 q	~6	2
 (CLXe)	a	6·16 s	-	6
	b	2·5 - 3·2 A_2B_2	-	8
	c	7·07 t	6	4
	d	~8·25 q	~6	2

Table 2 N.M.R. Spectral Data (continued)

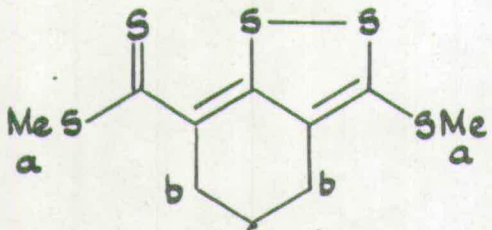
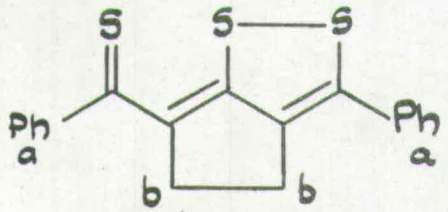
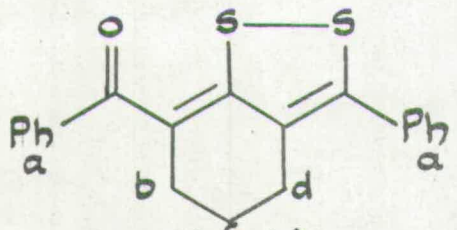
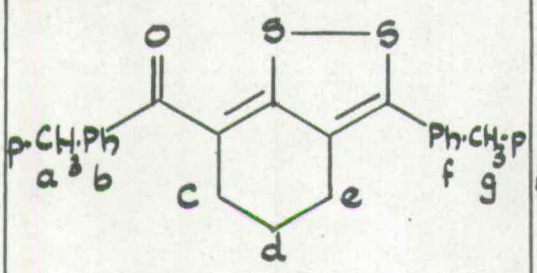
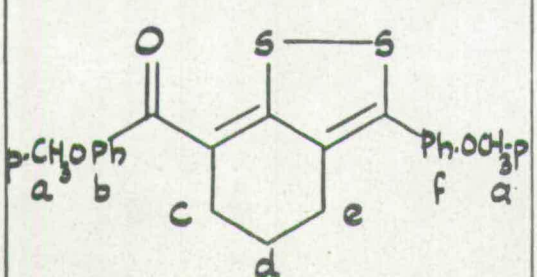
Compound	Proton	τ values	coupling constant J.c.p.s.	number of protons
 (CLXg)	a	7.38s	-	6
	b	7.19t	6	4
	c	~8.0q	6	2
 (CLX1a)	a	2.10 - 2.74m	-	10
	b	6.49s	-	4
 (CLXb)	a	2.60s	-	10
	b, d	7.05 - 7.3m	-	4
	c	8.0 - 8.35m	-	2
 (CLXd)	a, g	7.59s	-	6
	b (-a)	2.31 - 2.44d	9-10	~2
	f&b(-m,p)	2.68s	-	6
	d	7.95 - 8.5m	6	2
	c, e	7.0 - 7.4m	-	4
 (CLXf)	a	6.16s	-	6
	b, f	2.20 - 3.10m	-	8
	c, e	7.05 - 7.30m	-	4
	g	8.02 - 8.62m	-	2

Table 2 N.M.R Spectral Data (continued)

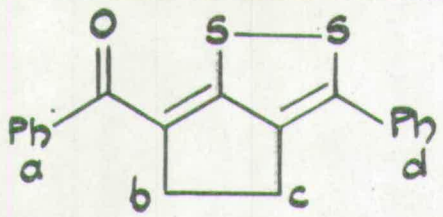
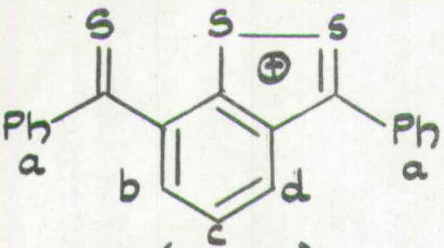
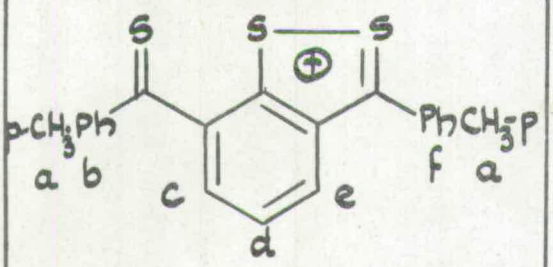
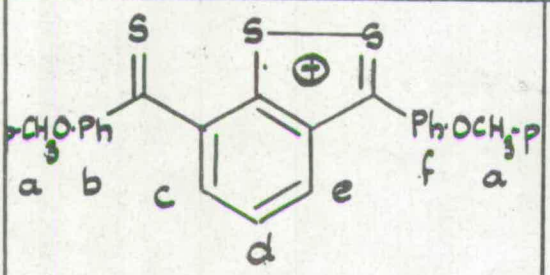
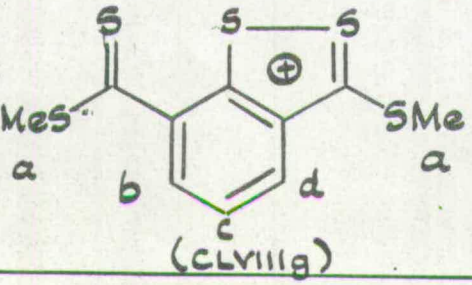
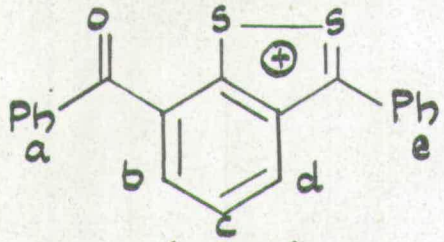
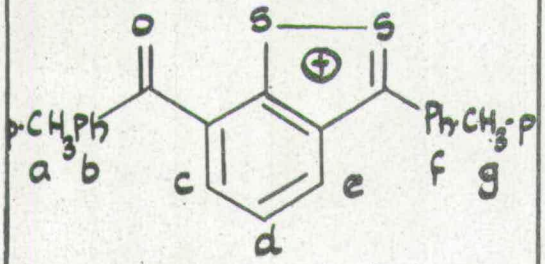
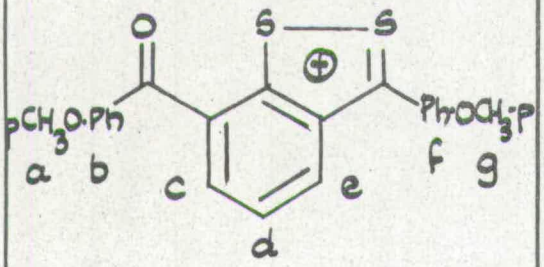
Compound	Proton	τ values	coupling constant J.c.p.s.	number of protons
 (CLX1b)	a, (o)	2·0 - 2·2m	-	2
	d, a(m,p)	2·40 - 2·76m	-	8
	b, c	6·34 - 6·96 A_2B_2	-	4
 (CLVIIIa)	a	2·20s	-	10
	b, d	1·0d	8-9	~2
	c	1·70t	8-9	~1
 (CLVIIIc)	a	7·40s	-	6
	b, f	2·15 - 2·47 A_2B_2	-	8
	c, e	0·94d	8	2
	d	1·67t	8	~1
 (CLVIIIe)	a	5·91s	-	6
	b, f	2·05 - 2·75 A_2B_2	-	8
	c, e	1·02d	8-9	2
	d	1·70t	8-9	~1
 (CLVIIIg)	a	6·87s	-	6
	b, d	0·94d	8-9	2
	c	1·84t	8-9	1

Table 2 N.M.R. Spectral Data (continued)

Compound	Proton	τ values	coupling constant J.c.p.s.	number of protons
 (CLVIIIb)	a, e	1.92 - 2.42 m	-	10
	b, d	1.00 - 1.15 m *	-	2
	c	1.60 - 1.85 m †	-	~1
 (CLVIIId)	a, g	7.38s, 7.42s	-	6
	b, f	2.00 - 2.51 m	-	8
	c, e	0.98 - 1.80 d	~8	2
	d	1.59 - 1.85 t	~8	1
 (CLVIIIF)	a, g	5.87s, 5.88s	-	6
	b, f	1.83 - 2.74 m	-	8
	c, e	0.98 d	8	2
	d	1.66 t	8	1

* Approximates to a doublet † Approximates to a triplet

(b) Ultraviolet and Visible Spectra

The electronic spectra (Fig. 1) of the 3-thioacylmethylene-1,2-dithioles (thiothiophthens) resembled those of the previously investigated compounds of this class; the ultraviolet absorption bands were more intense and the visible bands less intense than those of the corresponding acylmethylene compounds (Fig. 2). Both bands showed a bathochromic shift consequent upon the change from ketone to thione, the shift in the visible band being the greater.

The magnitudes of these shifts ($\Delta\lambda$) of the visible absorption bands are shown in Table 3 together with the corresponding values for a number of previously known compounds. A value of $\Delta\lambda$ = 90-100mμ has been regarded[62] as normal for compounds in which there is no bonding interaction between the sulphur atom in the thioacyl group and that in the heterocyclic ring. Smaller values of $\Delta\lambda$ (usually near 60mμ) are found for compounds in which such interaction is possible. It is noteworthy that all the thiothiophthens synthesised in the present investigation show values of $\Delta\lambda$ well below the "normal" range and, in the case of the compounds with a fused 6-membered ring, lower (42-46mμ) than any value previously reported. In agreement with Brown's observations[62], the value of $\Delta\lambda$ for the pair of compounds (CLXI a and b) with a fused 5-membered ring is the highest in the series but it is not sufficiently high to support his contention that the presence of a 5-membered ring distorts the bond angles of the thiothiophthen system sufficiently to prevent the bonding interaction mentioned previously. In this particular instance, and in certain of the pairs of compounds studied by Brown, there

is some uncertainty in the evaluation of $\Delta\lambda$ because the visible absorption band shows a double maximum in the spectrum of the ketone and a single maximum in that of the thione.

The ultraviolet spectra of the thioacylbenzodithiolium salts (CLVIII; X = S) were similar to those of the corresponding acyl compounds (CLVIII; X = O). The bathochromic shifts ($\Delta\lambda$) of the visible absorption bands for a change from thioaroyl to aroyl were 94 [for the compounds (CLVIII a and b)], 90 [for (CLVIII e and f)] and 100mμ [for (CLVIII c and d)] all of which values are within the range observed for the model compounds (CLXVI and CLXVII). This evidence, however, cannot be held to indicate that the cations exist as unsymmetrical structures because the compounds used as models for the thiothiophthen series are no longer suitable for comparison with the cationic compounds. Moreover, the intensities of the visible absorption bands (ϵ 1000) in this series are lower than those of the corresponding bands in the thiothiophthen series (ϵ in the range 2000-5000).

The low intensities suggest that the visible bands might be n-π^* absorptions of the carbonyl or thiocarbonyl groups and this interpretation is consistent with the hypsochromic shift observed when methoxy groups are introduced into the p-positions of the aryl groups [cf. thiobenzophenone (λ max 599mμ) with 4,4'-dimethoxythiobenzophenone (λ max 577mμ)[80]]. p-Methoxy substitution causes the near ultraviolet band, which is, presumably, a π - π^* absorptions of the benzodithiolium nucleus, to suffer a bathochromic shift which is comparable to the shift observed in changing from 2-phenyl-(λ max 388mμ) to 2-p-methoxyphenyl-benzo-1,3-dithiolium perchlorate (λ max 440mμ)[81].

This interpretation of the spectra necessitates the assumption that the apparent symmetry of the cations is due to tautomerism rather than to resonance. Had the phenomenon been due to resonance, the spectra might have been expected to show an intense band of relatively long wavelength, analogous to those found in the spectra of cyanine dyes. This band would have been shifted to longer wavelengths by p-methoxy-substitution and would have been absent from the spectra of the ketones (CLVIII; X = O).

Table 3

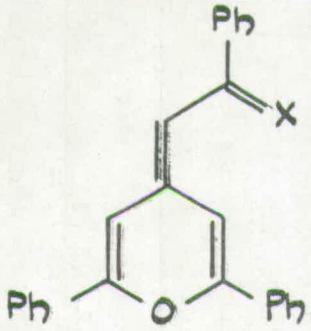
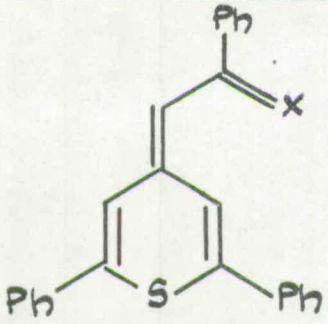
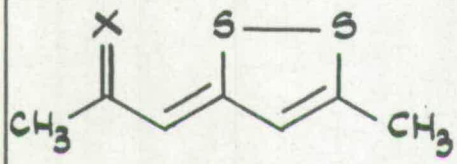
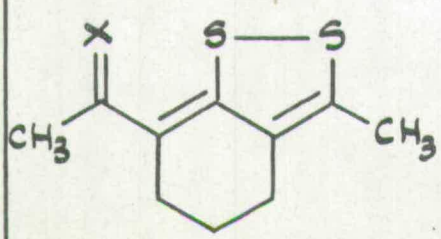
Compound		Visible λmax mμ	Difference Δλ in mμ
 (CLXVI)	X = O[64]	420	94
	X = S[64]	514	
 (CLXVII)	X = O[64]	440	101
	X = S[64]	541	
	X = O[85]	400 417	72 55 } 63
	X = S[85]	472	
	X = O[72]	418 437	69 50 } 60
	X = S[72]	487	

Table 3 (continued)

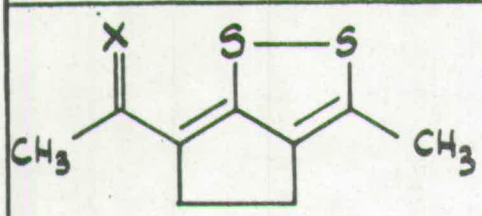
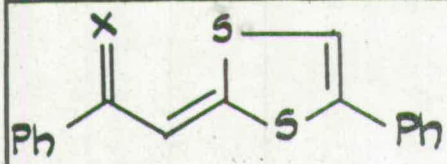
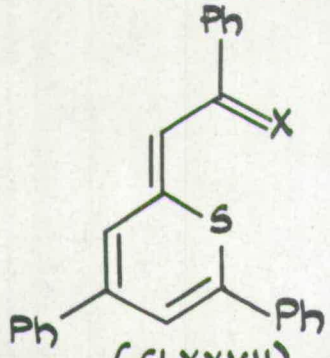
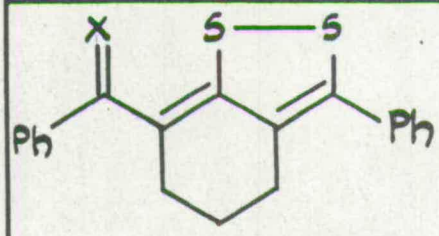
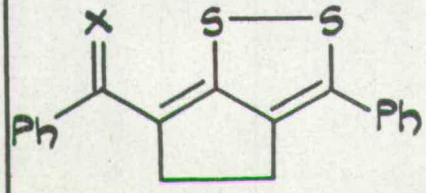
Compound		Visible λmax mμ	Difference Δλ in mμ
	x = O[62]	416 434	98 80 } 89
	x = S	514	
	x = O[64]	418	69
	x = S[64]	487	
 (CLXXVII)	x = O[64]	475	60
	x = S[64]	535	
 (CLX a or b)	x = O	458	46
	x = S	504	
 (CLXI a or b)	x = O	492 468	56 80 } 68
	x = S	548	

Table 3 (continued)

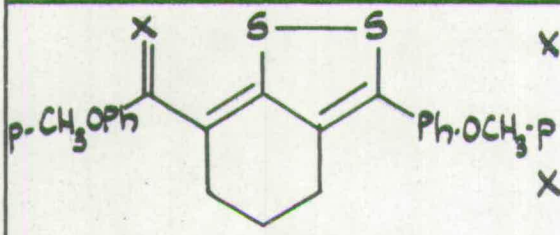
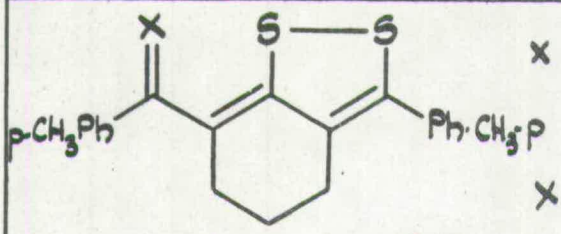
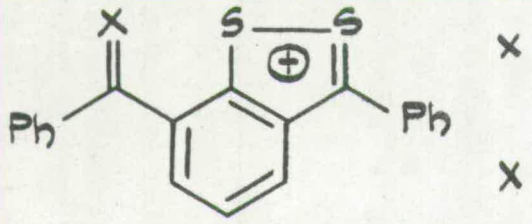
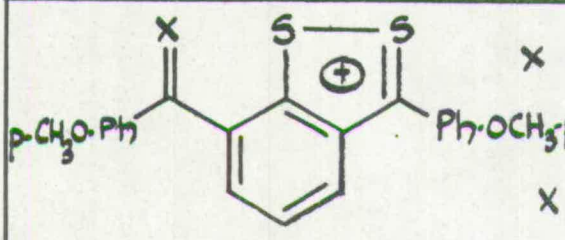
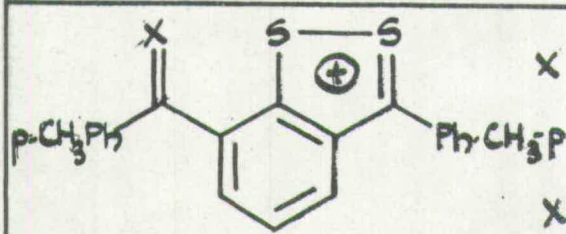
Compound	Visible λmax mμ	Difference Δλ in mμ
 (CLX e or f)	x = O: 464 x = S: 506	42
 (CLX c or d)	x = O: 460 x = S: 506	45
 (CLVIII a or b)	x = O: 400 x = S: 494	94
 (CLVIII e or f)	x = O: 390 x = S: 480	90
 (CLVIII c or d)	x = O: 394 x = S: 494	100

FIGURE 1

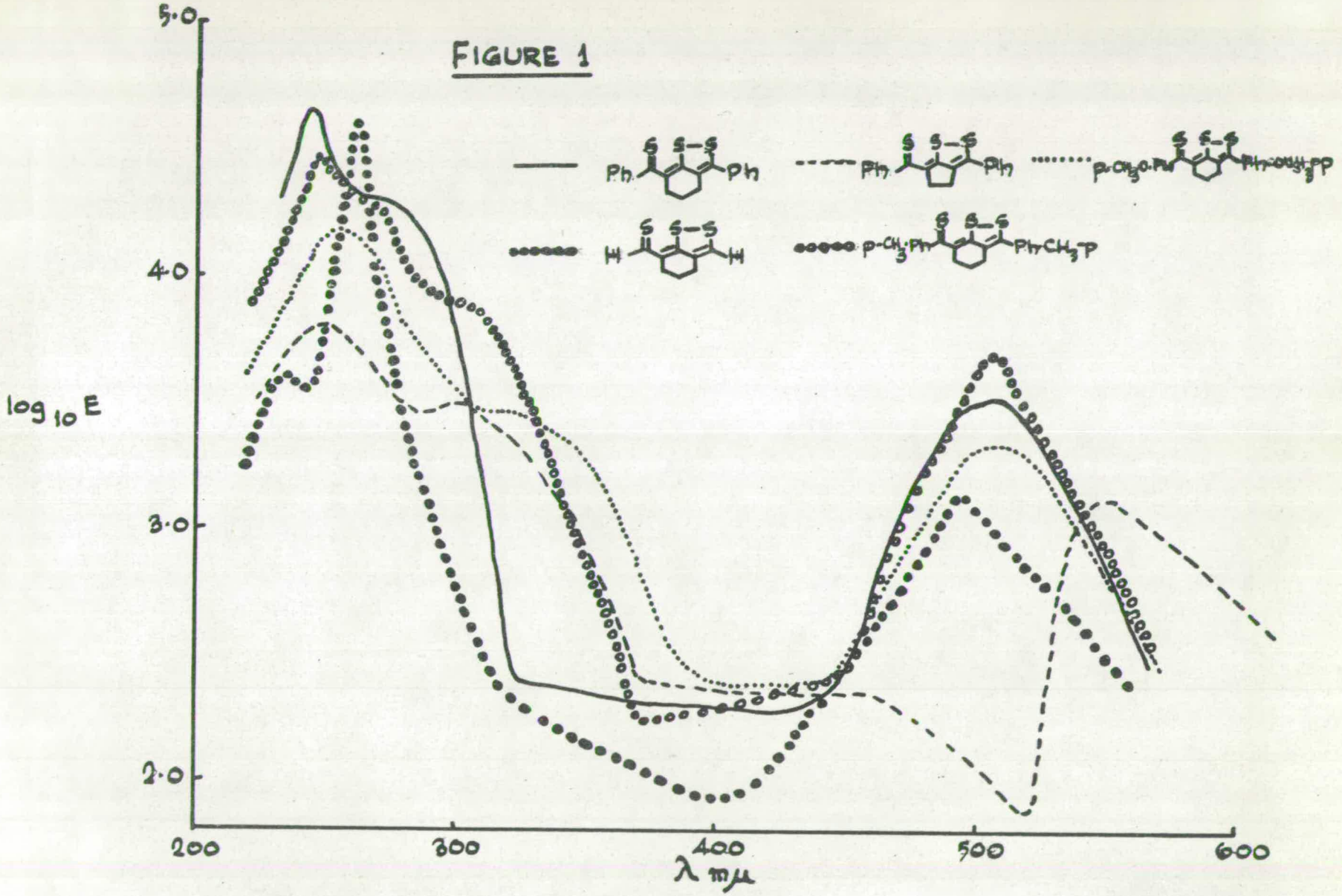

5·0
4·0
3·0
2·0
log 10 E
200
300
400
500
600
λ mμ
Ph
Ph
Ph
Ph
H
H
p-CH3·Ph
Ph·CH3·P

FIGURE 2

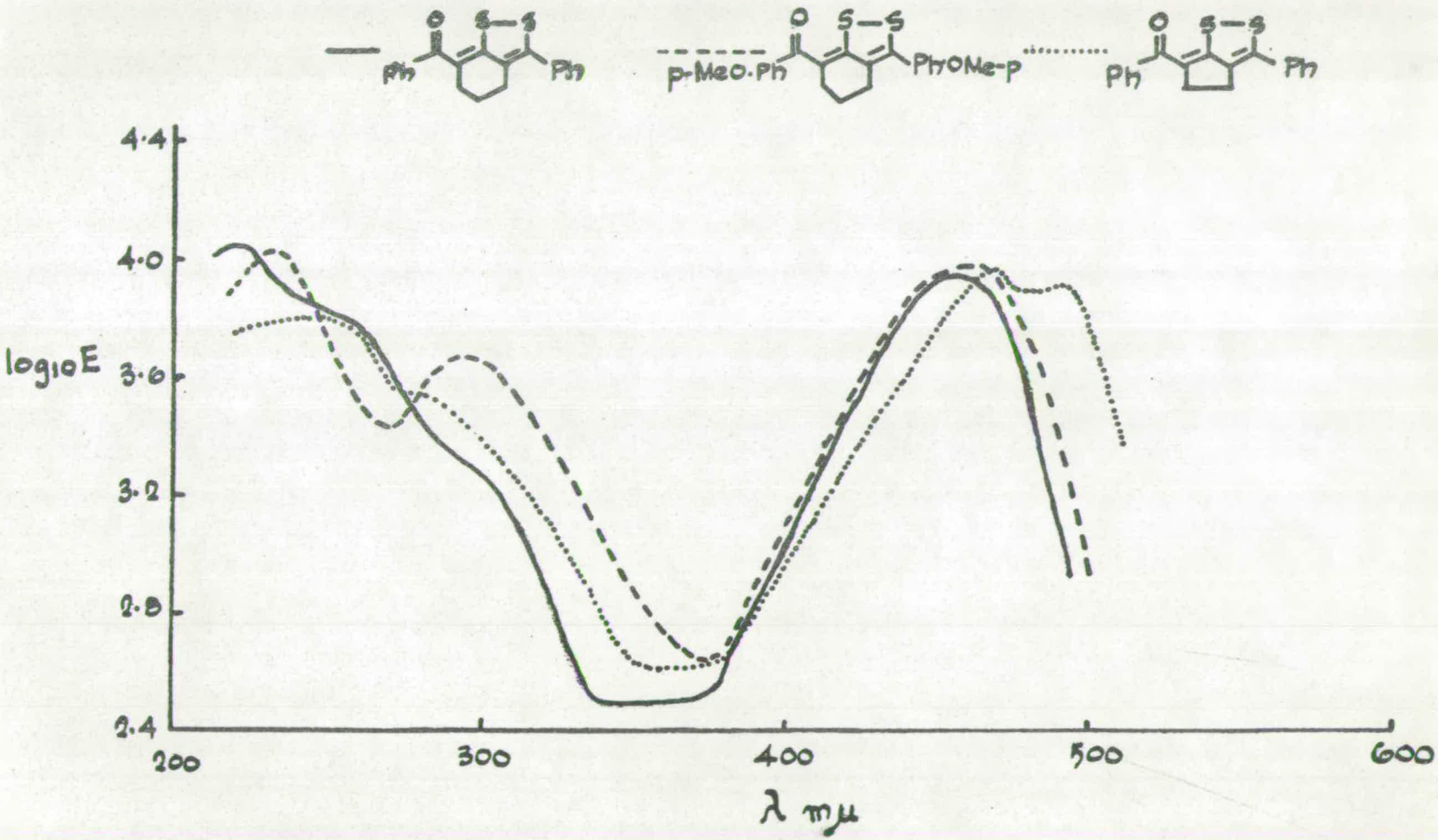

p-MeO·Ph
PhOMe-p
Ph
Ph
4·4
4·0
3·6
3·2
2·8
2·4
log10E
200
300
400
500
600
λ mμ

FIGURE 3

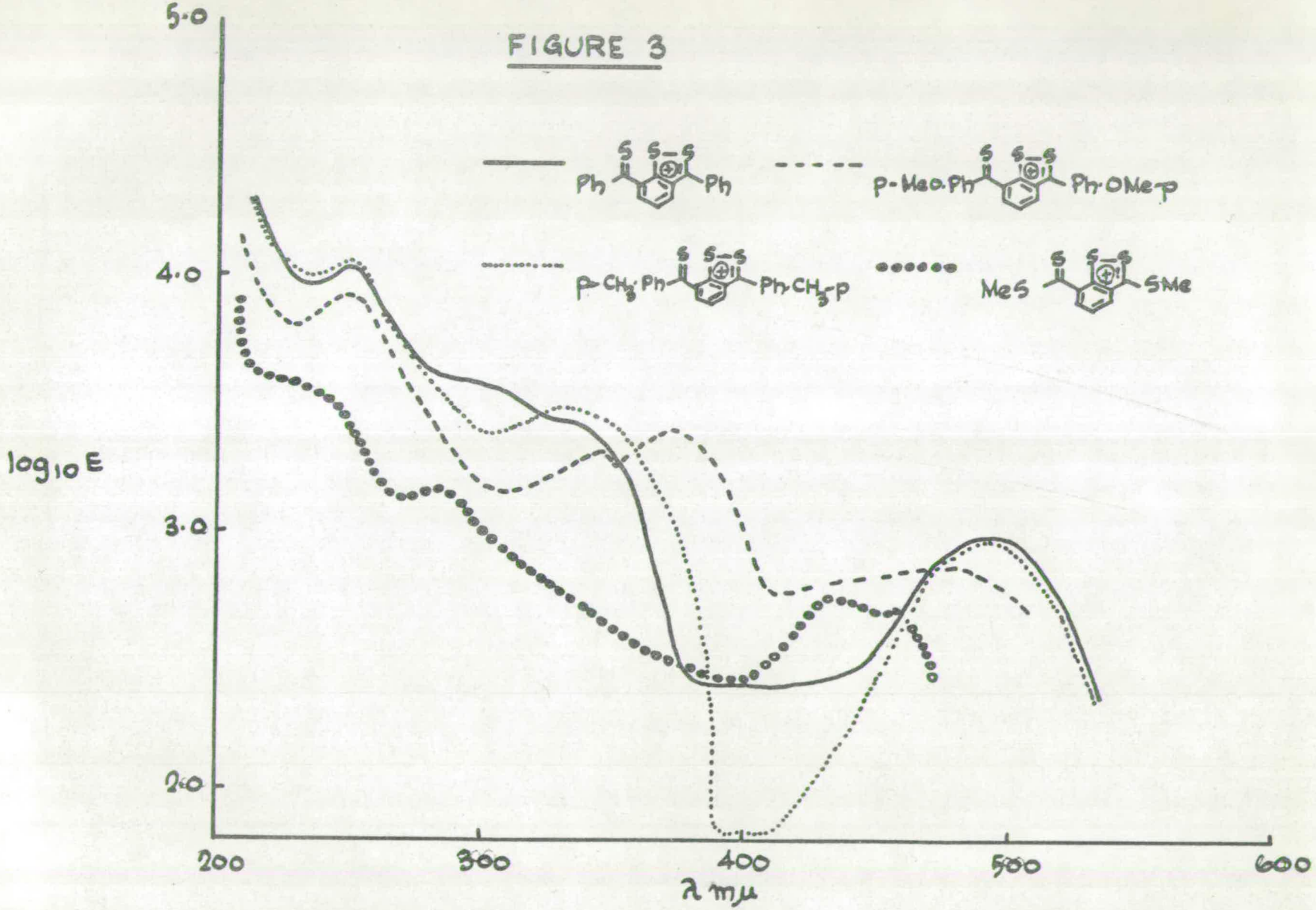
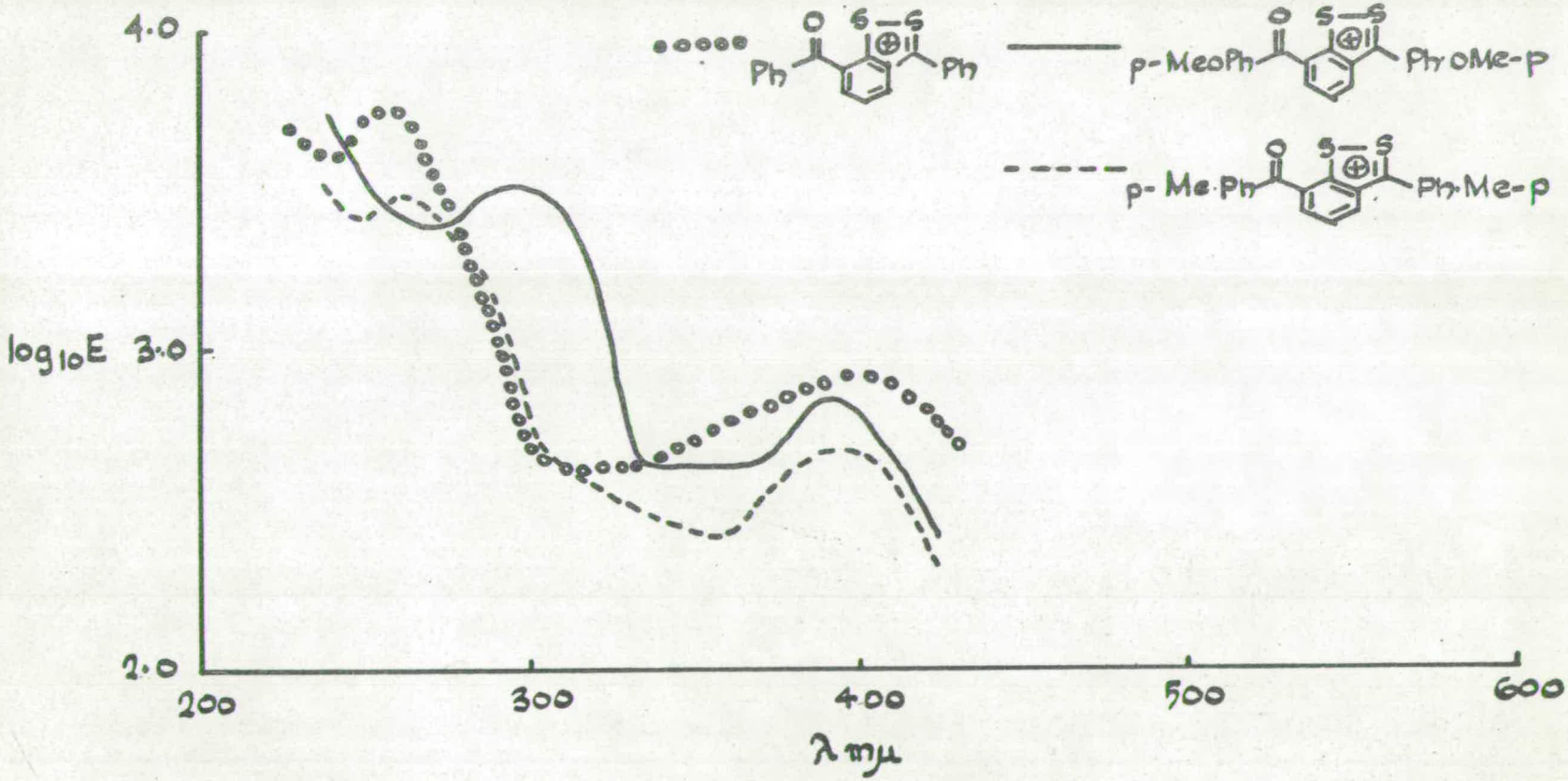
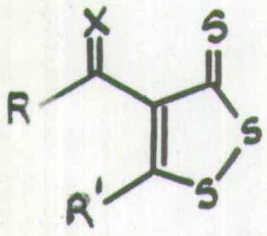

5·0
4·0
3·0
2·0
log10 E
200
300
400
500
600
λ mμ
Ph
Ph
p-MeO.Ph
Ph.OMe-p
p-CH3.Ph
Ph.CH3-p
MeS
SMe

FIGURE 4


4.0
3.0
2.0
log10E
200
300
400
500
600
λ mμ
Ph
Ph
p-MeoPh
Ph oMe-p
p-Me·Ph
Ph·Me-p



(CLXVIII)

a: R = Ph ; R' = p-Tolyl; x = O

b: R = p-Tolyl ; R' = Ph; x = O

c: R = Ph ; R' = p-Anisyl; x = O

d: R = p-Anisyl; R' = Ph; x = O

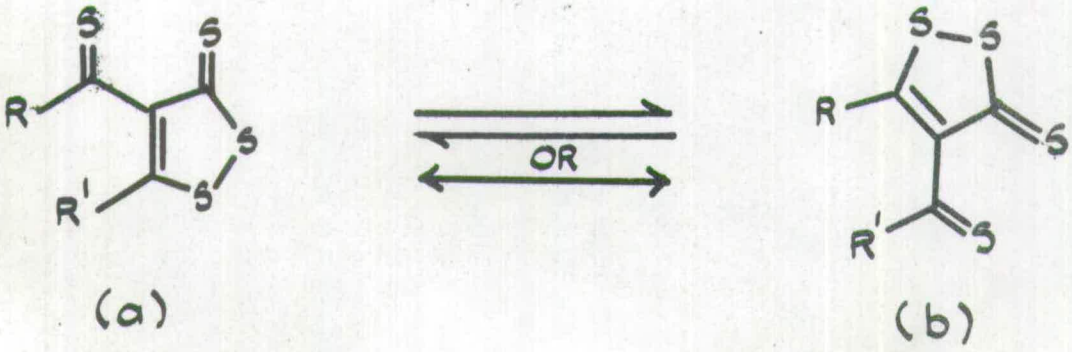
e: R = R' = p-Tolyl; x = O

f: R = R' = p-Tolyl ; x = S

g: Mixture { (i) R = Ph; R' = p-Tolyl; x =
(ii) R = p-Tolyl; R' = Ph; x =

h: Mixture { (i) R = Ph; R' = p-Anisyl; x =
(ii) R = p-Anisyl; R' = Ph; x =

SCHEME 25

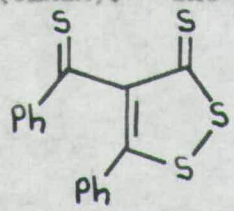


(a) (b)

PART B : 4-Thioacyl-1,2-dithiole-3-thiones

In addition to the thiothiophthens, the structure of which formed part of the discussion in Part A of this Section, there are other types of compounds which could, in principle, exhibit either single bond-no bond resonance or single bond-no bond tautomerism. The 4-thioacyl-1,2-dithiole-3-thiones (CLXVIII; X = S) constitute one such class of compounds (Scheme 25).

A preliminary investigation by Brown[58] involved the preparation of compound (CLXIX). The n.m.r. spectrum of which showed a 2-proton resonance, attributable to the ortho-protons of the thiobenzoyl group, on the low-field side of the 8 proton multiplet due to the remaining aromatic protons. This result would not be expected if the compound was rendered symmetrical by single bond-no bond resonance or if the two equivalent structures were undergoing rapid tautomeric interconversion.



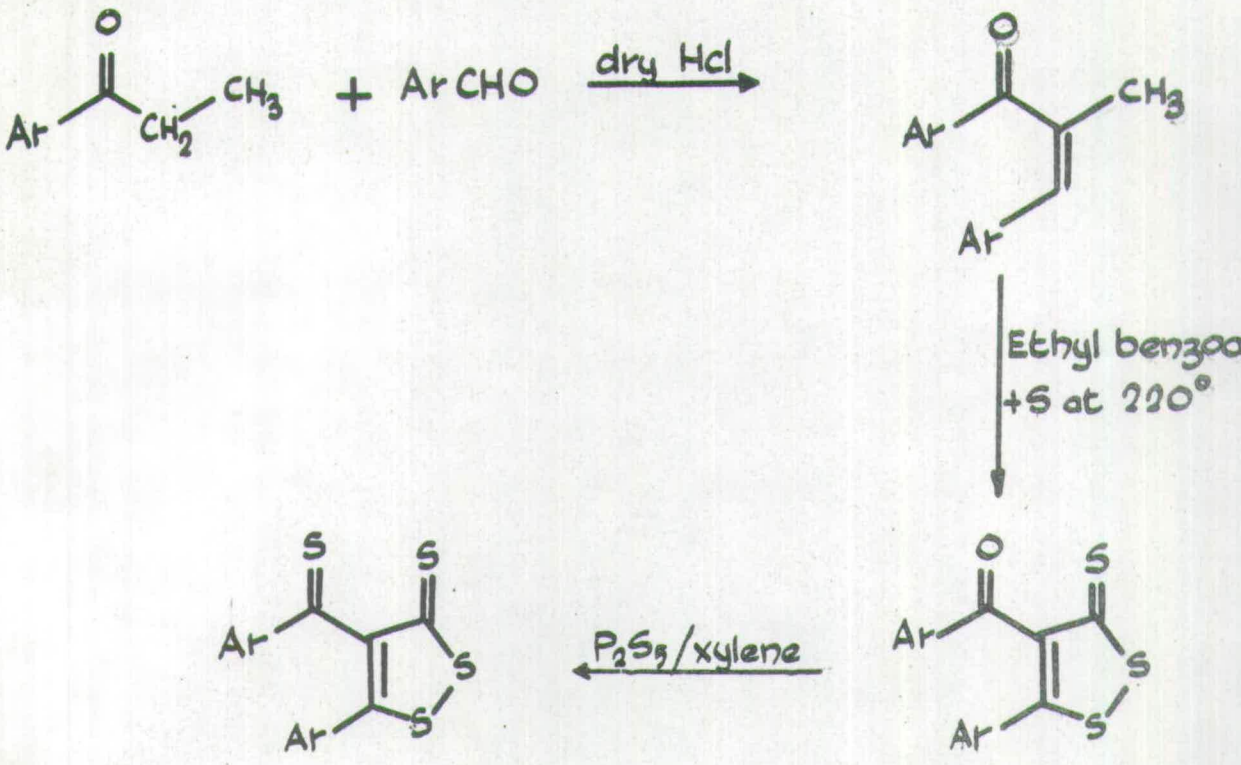
(CLXIX)

The objects of the present investigation were (i) to synthesise other compounds of type (CLXVIII; X = S), the n.m.r. spectra of which would be less open to errors of interpretation, and (ii) to attempt the synthesis of the separate tautomers [(a) and (b)] of Scheme 25.

1. The Synthetic Procedure

The compounds were prepared by a general method[82] (Scheme 26), the first stage of which involved the condensation of suitably substituted propiophenones with aromatic aldehydes according to the procedure of

SCHEME 26


Ar
CH2
CH3
+ ArCHO
dry Hcl
Ar
CH3
Ar
Ethyl benzoa
+S at 220°
Ar
S
S
S
Ar
S
P2S5/xylene
Ar
O
S
S
Ar
S

Noller and Adams[83]. The resulting benzylidene-compounds were boiled with sulphur in ethyl benzoate to give the 4-acyl-1,2-dithiole-3-thiones (CLXVIII a-e) which were converted into the thioacyl compounds by treatment with phosphorus pentasulphide in boiling xylene. As shown by Brown[84], it was necessary to purify commercial phosphorus pentasulphide by means of two successive Soxhlet extractions with carbon disulphide.

The thioacyl- compounds were isolated from the reaction mixtures by chromatography on alumina and were observed as green bands on the column whereas the initial ketones were observed as red bands. The thiones obtained from the ketones (CLXVIII a and c) gave infrared spectra identical, respectively, with those of the thiones obtained from (CLXVIII b and d) but the n.m.r. spectra, discussed below, showed that, in each case, the products were mixtures of the two possible isomeric 4-thioacyl-dithiolethiones.

2. N.m.r. Spectra (Table 4)

The n.m.r. spectra of the ketones (CLXVIII a,b,c and d) (Table 4) each showed one 3-proton singlet due to the methyl protons of a p-tolyl or p-anisyl group. The di-p-tolyl compound (CLXVIIIe) showed two methyl singlets of equal intensity.

The sulphurisation products of the isomeric phenyl-p-tolyl compounds (CLXVIIIa) and (CLXVIIIb) gave identical n.m.r. spectra which showed two methyl singlets, of similar but not quite equal intensity, together accounting for three protons. This result shows quite clearly that the products were mixtures of the two isomeric thiones which, although

capable of separate existence at ordinary temperatures, were evidently interconvertible under the conditions of their formation. The presence of two components in almost equal amounts accounts for the non-crystalline nature of these products. The sulphurisation products of the phenyl-p-anisyl compounds (CLXVIIIc) and (CLXVIIId) also gave identical n.m.r. spectra but, in this case, one of the methyl singlets was of much greater intensity than the other. Thus one of the isomers was preponderant and, as a consequence, the products were readily obtained in crystalline form. The presence of two methyl singlets in the n.m.r. spectrum of the di-p-tolyl compound (CLXVIIIf) confirms the non-equivalence of the aryl groups in these 4-thioacyl-1,2-dithiole-3-thiones.

Table 4 N.M.R. Spectral Data

Internal Standard: Tetramethylsilane

s = singlet d = doublet t = triplet m = multiplet

o = ortho m = meta p = para

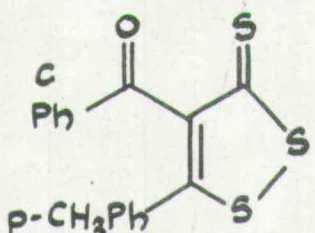
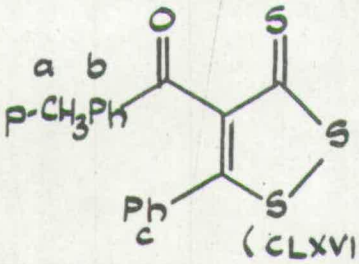
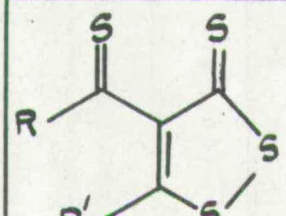
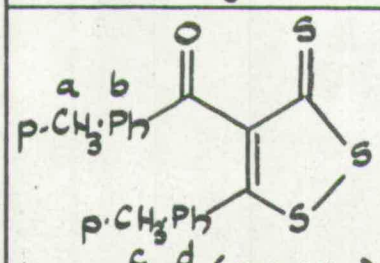
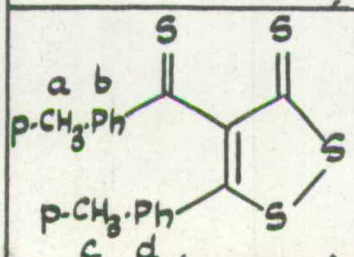
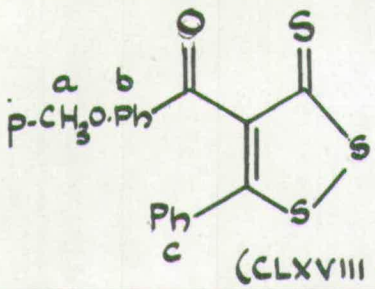
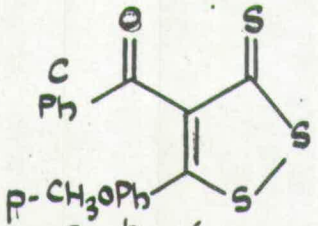
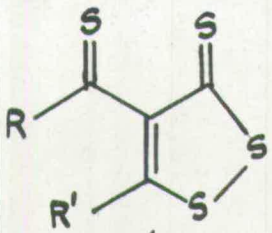
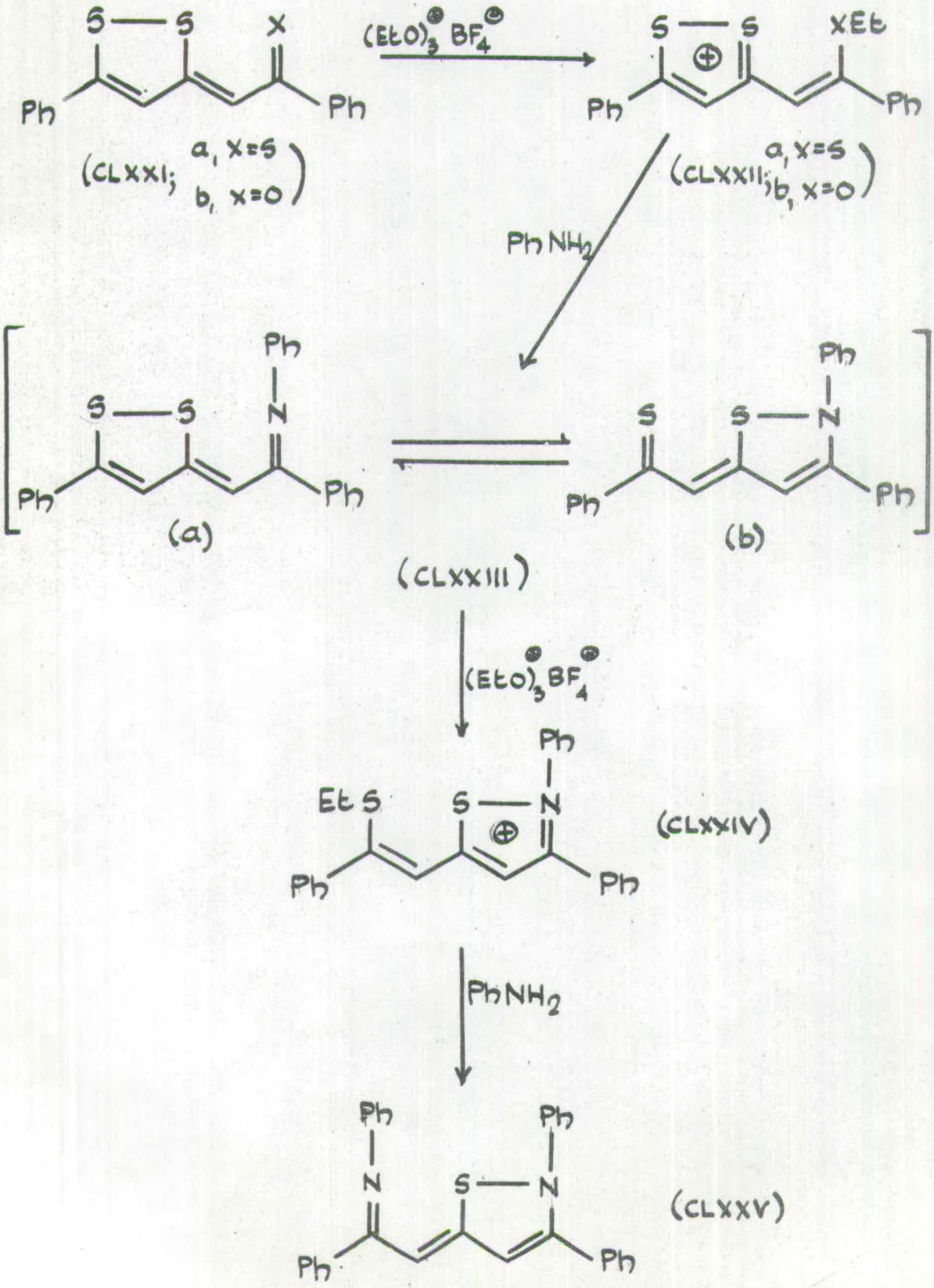
Compound	Proton	τ values	number of protons
 (CLXVIIIa)	a	7·72 s	3
	c, (o)	2·18 m	2
	b, c (m, p)	2·54 – 2·97 m	7
 (CLXVIIIb)	a	7·68 s	3
	b, c	2·13 – 2·85 m	9
 (CLXVIIIg) (i) R = Ph, R′ = p-Tolyl (ii) R = p-Tolyl, R′ = Ph	Methyl groups' protons	7·71 s, 7·73 s	3
	Aromatic protons	1·97 – 2·93 m	9
 (CLXVIIIe)	b, d	2·16 – 2·93 m	8
	a, c	7·63 s, 7·70 s	6
	a, c	7·66 s, 7·70 s	6
	b (o)	2·13 d	2
	d, b (m, p)	2·57 – 2·94 m	6

Table 4 N.M.R. Spectral Data (continued)

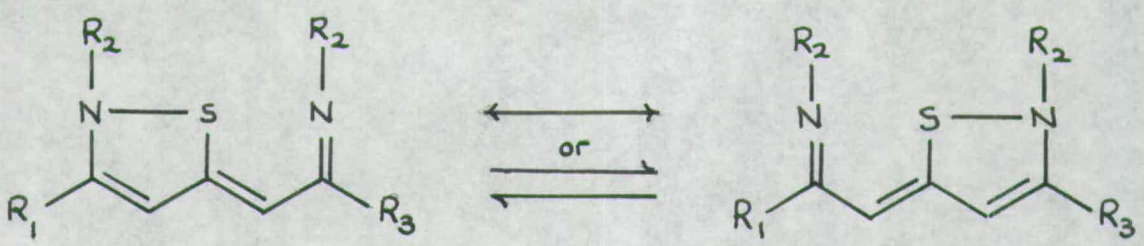
Compound	Proton	τ Values	Number of protons
 (CLXVIII d)	a	6·27 s	3
	b, c	2·11 - 3·25 m	9
 (CLXVIII c)	a	6·29 s	3
	b, c	2·09 - 3·09 m	9
 (CLXVIII h) (i) R = Ph, R′ = p-Anisyl	Methyl groups' protons	6·20 s, 6·29 s	3
(i) R = p-Anisyl, R′ = Ph	Aromatic protons	2·01 - 3·27 m	9

SCHEME 27


(EtO)3 BF4
Ph
Ph
(CLXXI; a, X=S b, X=O)
(CLXXII; a, X=S b, X=O)
PhNH2
(a)
(b)
(CLXXIII)
(CLXXIV)
(CLXXV)

PART C : (i) Compounds Derived from 3-Phenacylidene- and 3-Thiophenacylidene-5-phenyl-1,2-dithiole

Another class of compounds which might be expected to exhibit the characteristics of "single bond-no bond resonance" is that in which the two outer sulphur atoms in a thiothiophthen are replaced by nitrogen (CLXX).

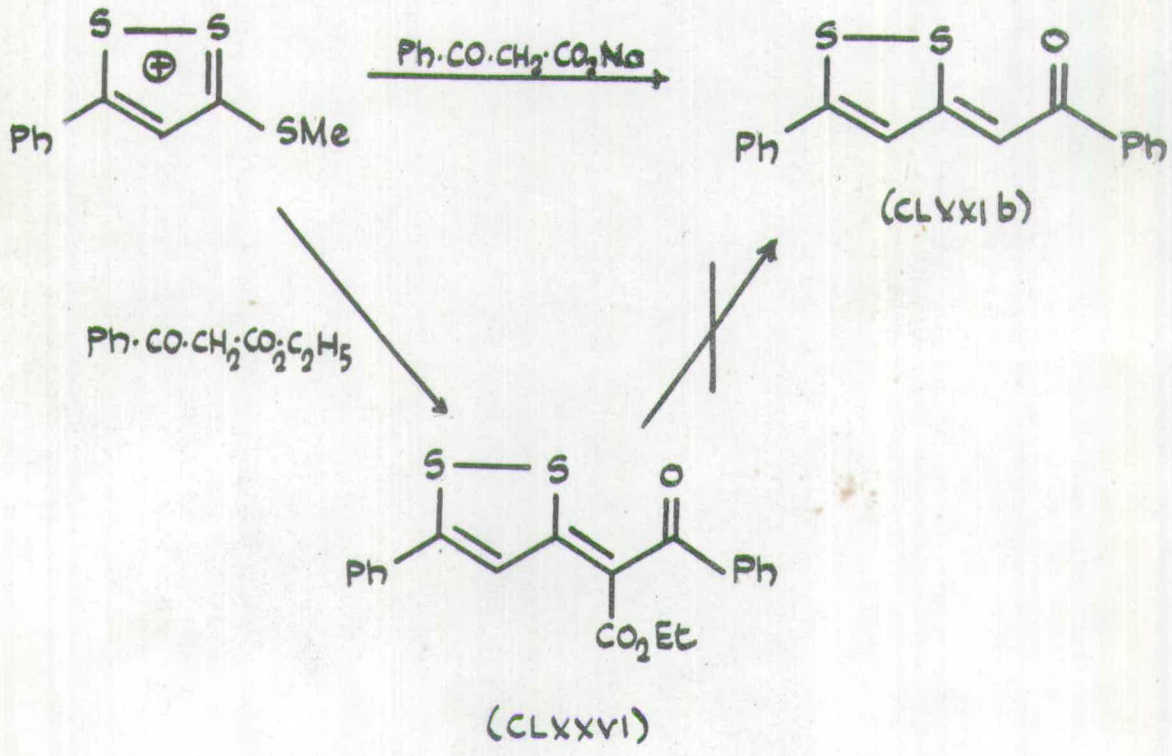


(CLXX)

As a first approach to the preparation of this type of compound the 3-thiophenacylidene- (CLXXIa) or 3-phenacylidene-5-phenyl-1,2-dithiole (CLXXIb) were chosen as starting materials. It was proposed to allow these compounds to react with triethyloxonium fluoborate to give the corresponding 1,2-dithiolium cations (CLXXIIa and b). These cations would be expected to react with aniline to give 3-(β-phenylimine-β-phenylethylidene)-5-phenyl-1,2-dithiole (CLXXIII). It is conceivable that this compound might exist as a "single bond-no bond resonance" structure or as a tautomeric mixture (CLXXIII a and b) and that it might react further with triethyloxonium fluoborate to give the 1,2-thiazolium salt (CLXXIV) which, by reaction with aniline, would give the potentially symmetrical compound (CLXXV). (Scheme 27).

The preparation of compound (CLXXIb) by reaction of 3-methylthio-5-phenyl-1,2-dithiolium iodide with sodium benzoylacetate (Scheme 28) is

SCHEME 28

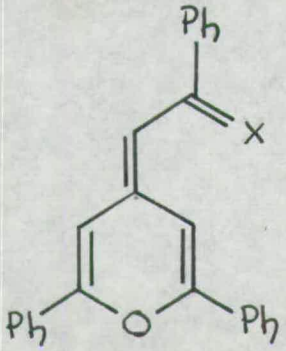

S
S
⊕
Ph
SMe
Ph·CO·CH₂·CO₂Na
S
S
O
Ph
Ph
(CLXXIb)
Ph·CO·CH₂·CO₂C₂H₅
S
S
O
Ph
Ph
CO₂Et
(CLXXVI)

described by McKinnon[86]. However, the yields obtained using this method are poor (9%) so that an attempt was made to prepare (CLXXIb) using the following closely related method. The 1,2-dithiolium cation was allowed to react with ethyl benzoylacetate to give the ester (CLXXVI) in 31% yield. It was hoped that subsequent hydrolysis and decarboxylation of this ester would give (CLXXIb) but although several methods were used in an attempt to hydrolyse (CLXXVI), none was successful. The compound (CLXXIb) was thus prepared using McKinnon's method. The preparation of 3-thiophenacylidene-5-phenyl-1,2-dithiole (CLXXIa) has been described in an earlier section of this thesis (page 9).

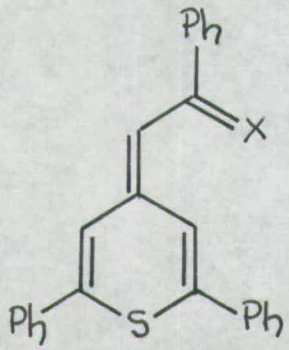
When attempts were made to react 3-thiophenacylidene- (CLXXIa) and 3-phenacylidene-5-phenyl-1,2-dithiole (CLXXIb) with triethyloxonium fluoborate, it was found that only in the case of the 3-thiophenacylidene- compound was the required dithiolium salt (CLXXIIa) obtained. This salt reacted with aniline to give 3-(β-phenylimine-β-phenylethylidene)-5-phenyl-1,2-dithiole (CLXXIIIa). Unfortunately, there was not enough time available to proceed further so that the conversion to (CLXXV) via (CLXXIV) was never tried.

PART C : (ii) Attempted Preparation of 2-Thiophenacylidene-4,6-diphenylpyran

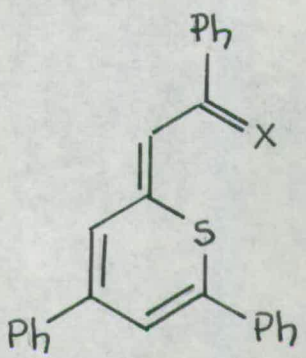
McKinnon[64] used several pyran and thiopyran derivatives (CLXVI; X = O or S) (CLXVII; X = O or S) and (CLXXVII; X = O or S) as reference



(CLXVI)

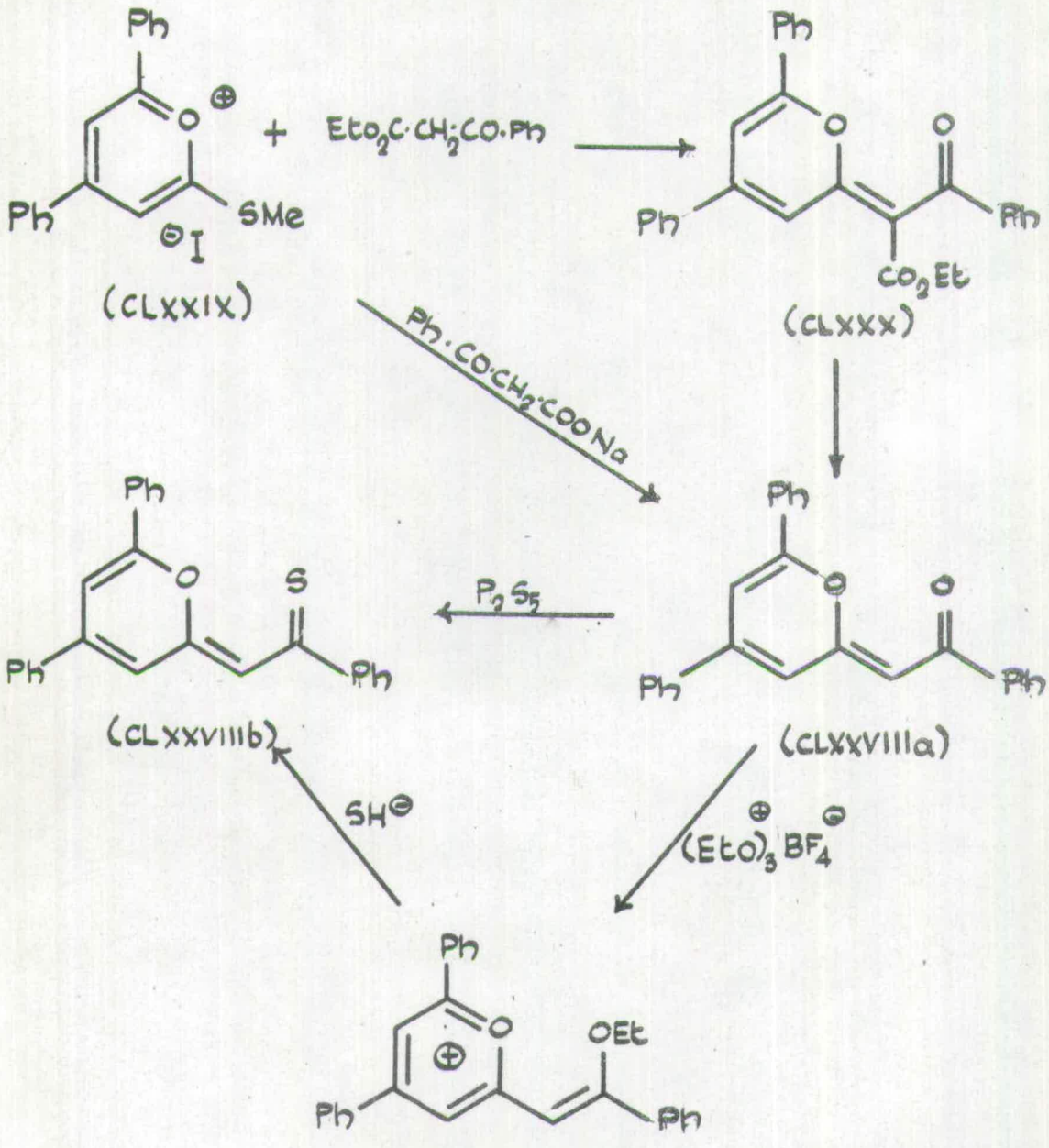


(CLXVII)

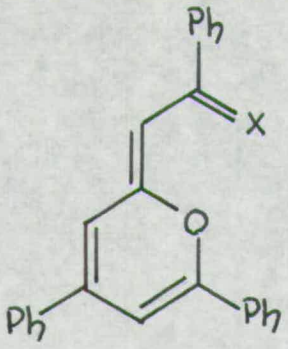


(CLXXVII)

SCHEME 29


Ph
SMe
⊖I
(CLXXIX)
+ EtO2C·CH2CO·Ph
Ph
Ph
CO2Et
(CLXXX)
Ph·CO·CH2·COONa
P2S5
S
(CLXXVIIIb)
(CLXXVIIIa)
SH⊖
(EtO)3 BF4
OEt

compounds in the interpretation of the visible and ultraviolet spectra of phenacylidene- and thiophenacylidenedithioles. To complete this series of reference compounds, McKinnon attempted to prepare 2-phenacylidene- (CLXXVIIIa) and 2-thiophenacylidene-4,6-diphenylpyran (CLXXVIIIb) and although he succeeded in making the 2-phenacylidene- compound, he



CLXXVIII; a, X = O
b, X = S

was unable to convert it to the corresponding thiophenacylidene compound.

It was proposed that the problem be approached in two ways, outlined in Scheme 29. In an attempt to improve the yield of the 2-phenacylidene- compound (CLXXVIIIa), 2-methylthio-4,6-diphenylpyrylium iodide (CLXXIX) was allowed to react with ethyl benzoylacetate to give the ester (CLXXX). Attempted hydrolysis of this ester was, however, unsuccessful. The reaction involving (CLXXIX) and sodium benzoylacetate gave a mixture of phenacylidene compound (CLXXVIIIa) and some other compound which was not identified. The proposed routes to the thiophenacylidene compound (CLXXVIIIb) were never attempted.

EXPERIMENTAL

Unless otherwise stated :

Melting point determinations were carried out in a capillary tube in an n-butyl phthalate bath and are uncorrected.

Solutions were dried over anhydrous sodium sulphate.

Ultraviolet spectra were determined, in ethanol, on a Perkin-Elmer 137 U.V. spectrophotometer.

Infrared spectra were determined as solutions in chloroform on a Unicam S.P. 200 spectrophotometer.

Nuclear Magnetic Resonance spectra were determined, in deuterochloroform, on a Perkin Elmer R. 10 (60 Mc/s) spectrometer.

SECTION I

Cyclo-addition Reactions of Dithiolethiones and Dithiolanthiones

PART (A) : (i) Reactions Involving Benzyne

GENERAL MATERIALS

5-Phenyl-1,2-dithiole-3-one

Prepared by the action of sulphur on boiling ethyl cinnamate[10]

Yield = 88.3 g. from 262 g. of ethyl cinnamate = 39%.

m.p. = 114-117° (lit.m.p.=114-117°)

5-Phenyl-1,2-dithiole-3-thione

Prepared by the action of the corresponding ketone with phosphorus pentasulphide[10]

Yield = 17.7 g. from 20 g. of dithiolone = 82%.

m.p. = 126-127° (lit.m.p.=125-127°)

4-Phenyl-1,2-dithiole-3-thione

The method of Fields[12] was used but modified such that quinoline was used as basic catalyst in place of di-o-tolyl-guanidine.

Yield = 41.3 g. from 200 g. cumene = 11%.

m.p. = 121-122° (Lit.m.p.=122°)

4,5-Benzo-1,2-dithiole-3-thione

Prepared by the action of phosphorus pentasulphide on 2,2'-dithiodibenzoic acid[13].

Yield = 9.2 g. from 20 g. of dithiodibenzoic acid = 40%.

m.p. = 94-96° (lit.m.p.=94-96°)

1,3-Dithiolan-2-thione

Prepared by the action of 1,2-dibromoethane on a solution of aqueous sodium sulphide and carbon disulphide in dimethylformamide[87].

Yield = 8 g. from 6.3 g. of carbon disulphide = 73%.

m.p. = 35-36° (lit.m.p.[88] = 35-36°)

4-Phenyl-1,3-dithiole-2-thione

(i) Methyl mercaptan was prepared by the slow addition of dimethyl sulphate to a solution of sodium hydrogen sulphide[89].

(ii) Phenacylmethyl trithiocarbonate was prepared by adding a mixture of methyl mercaptan, carbon disulphide and ethanolic sodium ethoxide to phenacyl bromide[90].

Yield = 41.8 g. from 45 g. of phenacyl bromide = 77%

m.p. = 40-41° (lit.m.p. = 41°)

(iii) 2-Methylthio-4-phenyl-1,2-dithiolium hydrogen sulphate was prepared by warming a mixture of phenacylmethyl trithiocarbonate and concentrated sulphuric acid[91].

Yield = 6.2g. from 8g. of phenacylmethyl trithiocarbonate = 62%.

(iv) 4-Phenyl-1,3-dithiole-2-thione was obtained by shaking 2-methylthio-4-phenyl-1,2-dithiolium hydrogen sulphate with saturated sodium sulphide solution[92].

Yield = 1.47g. from 6.2g. of hydrogen sulphate = 37%

m.p. = 116-117° (lit.m.p.=116-117°)

1-Aminobenzotriazole

Method A

(i) Hydroxylamine-O-sulphonic acid was prepared by the action of 30% fuming sulphuric acid on bis-(hydroxylammonium) sulphate[93].

(ii) 1-Aminobenzotriazole: Hydroxylamine-O-sulphonic acid (30.0 g., 0.266 mole) dissolved in water (45 ml.) was added to a solution of benzotriazole (26.4 g., 0.222 mole) in aqueous sodium hydroxide solution (26.6 g. sodium hydroxide dissolved in 110 ml. water). The temperature

during addition varied from 58-62° and was then maintained within this range for a further 2 hr. Ether extraction gave a brown oil (13 g., 44%) which solidified on standing to give a brown solid m.p. 40°. Chromatography in a 30 : 70 ether - light petroleum (60-80°) mixture on silica gave

(a) 2-Aminobenzotriazole, (1.7 g., 6%), m.p. 120-122° (lit.m.p.[94] =122°)

The solvent mixture was changed to 70 : 30 ether - light petroleum (60-80°) to give

(b) 1-Aminobenzotriazole, (3.5 g., 11%), m.p. 81-83 (lit.m.p.[94] =84°)

Method B

(i) Methyl o-nitrophenylhydrazylidenecyanoacetate was prepared using a method similar to that described in Organic Reactions[95] for ethyl cyanoglyoxylate-m-chlorophenylhydrazone.

Yield = 43 g. from 41.5 g. of o-nitroaniline = 58%.

m.p. = 184-186°.

(ii) Methyl o-aminophenylhydrazylidenecyanoacetate was prepared by the reduction of the corresponding nitro-compound using 10% palladium on charcoal catalyst in dioxan.

Yield = 18 g. from 35.7 g. of o-nitro compound = 50%.

m.p. = 177-178° (lit.m.p.=181°)

(iii) Methyl(benzotriazol-1-ylimino-)cyanoacetate was prepared by a modification of the method described by Bianchetti and Trave[68]. To methyl o-aminophenylhydrazylidenecyanoacetate (2.5 g., 0.011 mole) was added methanol (15 ml.) and concentrated hydrochloric acid (3 ml.) and the mixture warmed. Traces of insoluble materials were filtered and

the filtrate diazotised at 0-5° with a solution of sodium nitrite (0.75 g., 0.011 mole) in water (5 ml.) and methanol (5 ml.). Water (100 ml.) was then added and the cream coloured precipitate was filtered. Recrystallisation from methanol gave a cream amorphous solid, (1.0 g., 40%), m.p. 180-181°d.

(iv) 1-Aminobenzotriazole was prepared by the acid hydrolysis of methyl (benzotriazol-1-ylimino)-cyanoacetate in the manner described by Bianchetti and Trave[68].

Yield = 2.3 g. from 9 g. of methyl(benzotriazol-1-ylimino)-cyanoacetate = 44%.

m.p. = 81-83° (lit.m.p.[94] = 84°)

4,5-Benzo-1,3-dithiol-2-ylidene-phenylacetaldehyde

(i) 4,5-Benzo-2-methylthio-1,3-dithiolium perchlorate

4,5-Benzo-1,2-dithiole-3-thione (1 g.) was heated with an excess of dimethyl sulphate at 150° for 2 min. The brown solution was poured into acetic acid (20 ml.) and a few drops of perchloric acid were added. After a minute or so, the perchlorate separated. Recrystallisation from acetic acid containing a drop of perchloric acid gave a white crystalline powder, (1.6 g., 100%), m.p. 198-199°.

(ii) 1-(N-Pyrrolidino)-2-phenylethylene

Freshly distilled phenylacetaldehyde (9.43 g., 0.0785 mole) and pyrrolidine (11.15 g., 0.157 mole) in benzene (40 ml.) were heated in a Dean and Stark apparatus until no further separation of water was observed. The solvent and excess amine were removed by distillation in vacuo to give a residual brown oil. Distillation in vacuo gave a

yellow oil, (9.5 g., 70%), b.p. 111°/0.2 mm.

(iii) 2-(β-N-Pyrrolidino-α-phenylvinyl)-4,5-benzo-1,3-dithiolium perchlorate

1-(N-Pyrrolidino)-2-phenylethylene (1.49 g., 0.005 mole) dissolved in dry acetone (10 ml.) was added to a solution of 4,5-benzo-2-methylthio-1,3-dithiolium perchlorate (1.49 g., 0.005 mole) dissolved in a mixture of dry acetone (20 ml.) and dry acetonitrile (20 ml.). The mixture was allowed to stand at room temperature for 20 min. and then concentrated at 40° *in vacuo* to give a yellow oil, (2.6 g.), which could not be crystallised.

(iv) 4,5-Benzo-1,3-dithiol-2-ylidene-phenylacetaldehyde

The crude oil from experiment (iii) above (2.6 g., 0.008 mole) dissolved in a mixture of dilute hydrochloric acid (30 ml.) and methyl cyanide (30 ml.) were boiled gently under reflux for 30 min. The methyl cyanide was removed by distillation and the aqueous residue cooled and extracted several times with benzene. The benzene extract was washed with water and dried (Na_2SO_4) and then the benzene distilled to give a residual oily solid. Chromatography on alumina in benzene gave a brown oil (0.075 g.) which crystallised from ethanol as yellow needles m.p. 102-103°. The infrared spectrum was identical with that of the material m.p. 102-103° obtained by the reaction of 4-phenyl-1,2-dithiole-3-thione with benzyne and the mixed melting point was undepressed.

CYCLO-ADDITION REACTIONS

Preliminary Investigations

1. Stability of the Dithiolethione system to selected Oxidising Agents

5-Phenyl-1,2-dithiole-3-thione (1g., 4.76 m.mole) and the oxidising agent (9.52 m.mole) in dry benzene (10 ml.) were boiled under reflux for 30 min. The mixture was cooled, filtered and the benzene distilled from the filtrate in vacuo. The residue was weighed and then a mixed melting point with 5-phenyl-1,2-dithiole-3-thione determined.

The oxidising agents used in these experiments were mercuric oxide (HgO), nickel peroxide (Ni_2O_3, xH_2O), lead dioxide (PbO_2) and active manganese dioxide[96] (MnO_2). In each case, the 5-phenyl-1,2-dithiole-3-thione was recovered unchanged.

A further reaction involved the use of lead tetra-acetate $Pb(OAc)_4$ as oxidising agent, but this time the mixture with the dithiolethione in dry benzene was not boiled under reflux but allowed to stand at room temperature for 30 min. Again the dithiolethione was recovered unchanged.

2. Selection of Oxidising Agent for the Generation of Benzyne from 1-Aminobenzotriazole

1-Aminobenzotriazole (0.335 g., 2.5 m.mole) dissolved in dry benzene (30 ml.) was added dropwise and with stirring over a period of 30 min. to a stirred mixture of oxidising agent (5 m.mole) and tetracyclone (1.92 g., 5 m.mole) in boiling benzene* (20 ml.) in a dry nitrogen atmosphere. The reaction mixture was boiled under reflux for a further 30 min., cooled and then filtered to remove oxidising agent. The solvent was removed by distillation in vacuo to give a residual black solid. Chromatography on alumina in a benzene - light petroleum (60-80°) 1 : 3 mixture gave 1,2,3,4-tetraphenylnaphthalene as a first fraction and then unreacted tetracyclone. The results are given in Table 5.

Table 5 : Generation of Benzyne from 1-Aminobenzotriazole

Oxidising Agent	Yield of 1,2,3,4-tetraphenyl -naphthalene (%)	Recovered tetracyclone
MnO_2	8	90
HgO	0	100
Ni_2O_3, xH_2O	14	70
*$Pb(OAc)_4$	99	50

* The reaction involving lead tetra-acetate was carried out at room temperature.

Main Investigation

1. Reaction of 5-Phenyl-1,2-dithiole-3-thione with Benzyne

(a) A solution of lead tetra-acetate (1.11 g., 2.5 m.mole) in dry benzene (30 ml.) and a solution of 1-aminobenzotriazole (0.335 g., 2.5 m.mole) in dry benzene (30 ml.) were added simultaneously, dropwise and with stirring, over a period of 10 min., to a solution of 5-phenyl-1,2-dithiole-3-thione (0.525 g., 2.5 m.mole) in dry benzene (20 ml.) and in a dry nitrogen atmosphere. The reaction mixture was then filtered and the filtrate concentrated by distillation in vacuo. The residue was chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 2 mixture to give :

(i) A maroon oil, (0.14 g.), which could not be crystallised.

(ii) A greenish-brown solid, (0.57 g.), m.p. 154-160°. Trituration with

acetone gave greenish-brown prisms, (0.35 g., 55%), m.p. 187-188°, unchanged when the compound was mixed with 4,5-benzo-2-thiophenacylidene-1,3-dithiole*. Infrared spectra confirmed the identity of the two samples.

* Authentic 4,5-benzo-2-thiophenacylidene-1,3-dithiole was provided by D.B.J. Easton.

(b) Using the same reaction conditions but 1 : 2 : 2 molar ratios of 1-aminobenzotriazole : 5-phenyl-1,2-dithiole-3-thione : lead tetra-acetate respectively, the yield of 4,5-benzo-2-thiophenacylidene-1,3-dithiole was 47%.

(c) Using 1 : 2 : 1 molar ratios of 1-aminobenzotriazole : 5-phenyl-1,2-dithiole-3-thione : lead tetra-acetate respectively, the yield of 4,5-benzo-2-thiophenacylidene-1,3-dithiole was 46%.

2. Reaction of 4-Phenyl-1,2-dithiole-3-thione with Benzyne

(a) A solution of lead tetra-acetate (1.11 g., 2.5 m.mole) in dry benzene (30 ml.) and a solution of 1-aminobenzotriazole (0.335 g., 2.5 m.mole) in dry benzene (30 ml.) were added simultaneously, dropwise and with stirring, over a period of 10 min. to a soltion of 4-phenyl-1,2-dithiole-3-thione (0.525 g., 2.5 m.mole) in dry benzene (20 ml.). The reaction mixture was filtered, the filtrate concentrated and the residue chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 2 mixture to give :

(i) A brown solid, (0.21 g.), m.p. 114-116° which recrystallised from a light petroleum - benzene mixture to give brown prisms, (0.13 g.), m.p. 119-121°. (Mixed with 4-phenyl-1,2-dithiole-3-thione m.p. 119-121°).

(ii) A brown solid, (0.22 g.), m.p. 92-95° which recrystallised from ethanol as brown prisms, (0.09 g.), m.p. 102-103°. The microanalysis of this compound was not consistent with its being the expected 4,5-benzo-1,3-dithiol-2-ylidene-phenylthioacetaldehyde but it was consistent with that of the corresponding aldehyde.

ν max 1630 cm^{-1} (CHO)

Found : C,66.58; H,4.34; S,23.8 %

$C_{15}H_{10}OS_2$ requires : C,66.63; H,3.73; S,23.7 %

The n.m.r. spectrum showed a singlet (relative intensity 1) at 0.7τ, attributable to the aldehyde proton, and a multiplet (relative intensity 9) in the aromatic proton region.

The I.R. spectrum and mixed melting point were identical with those of an authentic sample of 4,5-benzo-1,3-dithiol-2-ylidene-phenyl-acetaldehyde.

3. Reaction of 1,3-Dithiolan-2-thione with Benzyne

The reaction was carried out in a manner similar to that described for 5-phenyl-1,2-dithiole-3-thione (1a).

Quantities :

1,3-Dithiolan-2-thione	0.34 g., 2.5 m.mole
1-Aminobenzotriazole	0.335g., 2.5 m.mole
Lead tetra-acetate	1.11 g., 2.5 m.mole

The reaction mixture was filtered and the filtrate chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 2 mixture to give :

(i) Pale yellow needles,(0.06 g., 13%),m.p. 165-166°. (Mixed with authentic 4,5-benzo-1,3-dithiole-2-thione m.p. 165-166°.) The infra-red spectra of the two samples were identical.

(ii) Yellow oil,(0.16 g.),which solidified on standing, m.p. 37-39°. (Mixed with 1,3-dithiolan-2-thione, m.p. 37-39°.)

4. Reaction of 4,5-Benzo-1,2-dithiole-3-thione with Benzyne

Method :

As described in 1a above.

Quantities :

4,5-Benzo-1,2-dithiole-3-thione	0.46g., 2.5 m.mole
1-Aminobenzotriazole	0.335g.,2.5 m.mole
Lead tetra-acetate	1.11 g.,2.5 m.mole

The reaction mixture was filtered and the filtrate chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 2 mixture to give unreacted 4,5-benzo-1,2-dithiole-3-thione,(0.24 g., 54%), m.p. 93-95°.

5. Reaction of 4-Phenyl-1,3-dithiole-2-thione with Benzyne

Method :

Similar to that described in 1a above.

Quantities :

4-Phenyl-1,3-dithiole-2-thione	0.525 g., 2.5 m.mole
1-Aminobenzotriazole	0.335 g., 2.5 m.mole
Lead tetra-acetate	1.11 g., 2.5 m.mole

Chromatography on alumina in a light petroleum (60-80°) - benzene 1 : 2 mixture gave only trace quantities of materials.

PART (A) : (ii) Reactions Involving Dimethyl acetylenedicarboxylate

Phenylacetylene and Methyl phenylpropiolate

GENERAL MATERIALS

1. α-Phenylcinnamic acid

Prepared by the action of benzaldehyde on phenylacetic acid in the presence of triethylamine[97].

Yield = 43.4 g. from 42.4 g. of benzaldehyde = 49%.

m.p. = 170-172° (lit.m.p. = 172-173°)

2. Perbenzoic Acid

Prepared by the action of sodium methoxide on benzoyl peroxide[98].

Yield = 24.2 g. from 50 g. of benzoyl peroxide = 84%.

3. cis-Stilbene

α-Phenylcinnamic acid was decarboxylated using quinoline and a copper chromite catalyst at 210-220°[99].

Yield = 29.0 g. from 43.4 g. of α-phenylcinnamic acid = 85.5%.

b.p. = 171-174°/60 mm.

4. cis-Stilbene oxide

cis-Stilbene was oxidised with perbenzoic acid according to the method of Lynch and Pausacker[100].

Yield = 11.1 g. from 28.2 g. of cis-stilbene = 35%.

m.p. = 40-42° (lit.m.p. = 43°)

5. trans-4,5-Diphenyl-1,3-dithiolan-2-thione

The thione was prepared by the action of potassium methyl xanthate on cis-stilbene oxide as described by Overberger and Drucker[101].

Yield = 1.3 g. from 10.46 g. of cis-stilbene oxide = 8.5%.

m.p. = 154-156° (lit.m.p. = 155-157°)

6. trans-4,5-Tetramethylene-1,3-dithiolan-2-thione

A solution of potassium methyl xanthate was prepared by dissolving potassium hydroxide (2.88 g., 0.05 mole) and carbon disulphide (4.67 g., 0.0615 mole) in methanol (13.5 ml.). To this solution was added cyclohexene oxide (2 g., 0.0204 mole) and the homogeneous mixture was stirred for 2 hr. 10 min. The yellow crystalline solid (which started to form after 10 min.) was filtered off and recrystallised from a light petroleum (60-80°) - benzene 1 : 1 mixture.

Yield, 2.23 g. (57.5%) m.p. 168-169°.

7. Dimethyl acetylenedicarboxylate

The ester was prepared by the esterification of the monopotassium salt of acetylene dicarboxylic acid[102].

Yield = 76 g. from 100 g. of the salt = 81%.

b.p. = 101-103°/23 mm. (lit.b.p. = 95-98°/19mm.)

8. 2,5-Diphenylhexane

(i) 2,5-Diphenylhexadiene

A solution of bromobenzene (30 g., 0.19 mole) in dry ether (70 ml.) was added to magnesium turnings (27 g., 1.1 mole) contained in a three-necked 2 litre flask fitted with separating funnel, stirrer, reflux condenser and drying tube. The flask was warmed gently with a free flame until the reaction became rapid and then a solution of bromobenzene (151 g., 0.96 mole) in dry ether (380 ml.) was added at such a rate as to cause vigorous refluxing. When addition was complete, the reaction mixture was stirred for 10 min.

The reaction flask was placed in a cooling bath and then 2,5-hexanedione (28.5 g., 0.25 mole) in ether (50 ml.) was added over a period of 10 min. The cooling bath was removed and the reaction mixture boiled under reflux for a further 30 min. The reaction flask was again cooled and a solution of ammonium chloride (50 g.) in water (150 ml.) was added, slowly at first, over a period of 10 min. to give a pasty white solid. The ether layer was decanted into a separating funnel and to this was added a 50 ml. extract of the pasty residue, and the combined ether solutions were dried by shaking with dry calcium chloride. The ether was distilled *in vacuo* and the residual white solid dehydrated by heating at 210-220° in an oil bath for 1½ hr. Remaining traces of water were removed by applying a water pump vacuum to the system. A solution of the residual brown solid, in hot ethanol, was filtered and allowed to cool to give pale yellow flakes, (8.3 g., 14%), m.p. 134-136° (lit.m.p.[103] = 136-138°).

(ii) 2,5-Diphenylhexane

A suspension of 2,5-diphenylhexa-2,4-diene (4 g., 0.017 mole) and 10% palladium on charcoal (0.75 g.) in ethyl acetate (100 ml.) was agitated in a hydrogen atmosphere until hydrogen absorption had ceased (approximately 700 ml. absorbed). The catalyst was removed by filtration and the solvent removed from the filtrate *in vacuo* to give a residual colourless oil, (4.0 g., 100%). Chromatography on silica in light petroleum (60-80°) gave a colourless oil, (3.2 g., 80%).

CYCLO-ADDITION REACTIONS

1. Reaction of Dimethyl acetylenedicarboxylate with trans-4,5-Diphenyl-1,3-dithiolan-2-thione

trans-4,5-Diphenyl-1,3-dithiolan-2-thione (0.72 g., 2.5 m.mole) and dimethyl acetylenedicarboxylate (0.36 g., 2.5 m.mole) were heated at 110° for 5 min. Examination of the reaction mixture by Gas-Liquid Chromatography on a 25% poly(ethylene glycol adipate)/Celite column, 1 metre long, at 220° indicated that trans-stilbene was present in the mixture but that there was no cis-stilbene present.

Chromatography on alumina in light petroleum (40-60°) gave :

(i) A white solid, (0.28 g., 62%), m.p. 122-124° unchanged when the compound was mixed with trans-stilbene. The infrared spectrum was identical with that of trans-stilbene.

(ii) Yellow solid, (0.3 g.), m.p. 77-82° which recrystallised from light petroleum (40-60°) as yellow needles, (0.17 g., 27%), m.p. 85-87° unchanged when the compound was mixed with 4,5-dimethyldicarboxy-1,3-dithiole-2-thione*. The infrared spectra of the two samples were identical.

* Sample provided by D.B.J. Easton.

2. Reaction of Dimethyl acetylenedicarboxylate with cis-4,5-Diphenyl-1,3-dithiolan-2-thione

cis-4,5-Diphenyl-1,3-dithiolan-2-thione (0.1 g., 0.348 m.mole) and dimethyl acetylenedicarboxylate (0.05 g., 0.348 m.mole) were heated at 120° for 5 min. The reaction product was examined by Gas-Liquid Chromatography on a 25% poly(ethylene glycol adipate)/Celite column,

1 metre in length, at 220°. The presence of both cis- and trans-stilbene was indicated in the ratio of 54 : 46 respectively.

3. Reaction of Dimethyl acetylenedicarboxylate with trans-4,5-tetramethylene-1,3-dithiolan-2-thione

(i) A mixture of freshly distilled dimethyl acetylenedicarboxylate (0.746 g., 5.26 m.mole) and trans-4,5-tetramethylene-1,3-dithiolan-2-thione (1 g., 5.26 m.mole) was heated from 105° to 150° over a period of 15 min. Chromatography on alumina in benzene gave unreacted trans-tetramethylene-1,3-dithiolan-2-thione, (0.91 g., 91%), m.p. 168-169°.

(ii) A mixture of dimethyl acetylenedicarboxylate (0.494 g., 3.48 m.mole) and trans-4,5-tetramethylene-1,3-dithiolan-2-thione (0.66 g., 3.48 m.mole) was heated at 145-150° for 1 hr. Chromatography on alumina in benzene gave :

(i) Yellow solid, (0.45 g., 68%), m.p. 166-168°, unchanged when the compound was mixed with trans-4,5-tetramethylene-1,3-dithiolan-2-thione.

(ii)Brown oil, (0.09 g.), which could not be crystallised.

(iii)Brown oil, (0.19 g.), which solidified to a glass on standing and could not be crystallised.

4. Reaction of Methyl phenylpropiolate with 4-Phenyl-1,2-dithiole-3-thione

Methyl phenylpropiolate (7.32 g., 42 m.mole) and 4-phenyl-1,2-dithiole-3-thione (8.4 g., 40 m.mole) dissolved in dry benzene (120 ml.) were heated under reflux for 4 days. The benzene was distilled in vacuo

to give a residual red solid which crystallised from pyridine as small red needles,(5.4 g., 40%),m.p. 268-274°. The n.m.r. spectrum indicated that the ratio of aromatic : methyl : olefinic protons was 10 : 3 : 1 which is the required ratio for 4-phenyl-5-methoxycarbonyl-1,3-dithiol-2-ylidenephenyl(thioacetaldehyde) (i.e. the 1 : 1 cyclo-adduct). However, a molecular weight determination and elemental analysis indicated that two molecules of the thioacetaldehyde had combined, with loss of sulphur, to give (CXXIX, Scheme 13, page 46).

Found : C,67.55; H,4.48; S,18.5 % M.W. 710

$C_{38}H_{28}O_4S_4$ requires : C,67.42; H,4.17; S,18.9 % M.W. 676

The structure of the reaction product was proved as follows :

The material m.p. 268-274° (0.5 g.) suspended in ethanol (10 ml.) was boiled under reflux for 16 hr. with approximately 2 g. of Raney-nickel. The reaction mixture was hot filtered through Celite to remove the nickel and the filtrate was concentrated in vacuo to give a residual brown oil,(0.3 g.). This oil should consist of a mixture of methyl β-phenylpropionate and 2,5-diphenylhexane. Separation was effected as follows :

(i) The brown oil (0.3 g.) was heated with 10% aqueous sodium hydroxide solution (10 ml.) for 4 hr. and cooled. The aqueous layer was then acidified with dilute hydrochloric acid to give a yellow oil. The oil was extracted into ether and the extract was washed with water, dried and then concentrated to give a yellow oil,(0.07 g.),which solidified on standing (m.p. 47-48°). The infrared spectrum and a mixed melting point determination showed that the compound was identical with an authentic sample of β-phenylpropionic acid (ex B.D.H.).

(ii) The portion of the brown oil from (i) which was insoluble in dilute alkali was collected and purified by thin-layer chromatography on silica gel G (Merck). A colourless oil was obtained, the infrared spectrum of which was identical with that of authentic 2,5-diphenylhexane. Gas-Liquid Chromatography using a 6 ft. 2% poly(ethylene glycol adipate)/Celite column at 135° indicated that the synthetic 2,5-diphenylhexane and the 2,5-diphenylhexane obtained from the desulphurisation reaction each contained the same two incompletely separable components, presumed to be stereoisomers (meso and racemic).

5. Reaction of 4-Phenyl-1,2-dithiole-3-thione with Phenylacetylene

4-Phenyl-1,2-dithiole-3-thione (4.2 g., 20 m.mole) and phenylacetylene (2.04 g., 20 m.mole) in dry benzene (60 ml.) were boiled under reflux for 8 days. The reaction mixture was allowed to stand at room temperature for several weeks by which time a maroon solid possessing a green reflex, (0.18 g., m.p. 268°d), had precipitated.

Found : C,54.94; H,3.74; S,28.2%.

The filtrate was chromatographed on alumina in a light petroleum (60-80°) - benzene 4 : 1 mixture to give :

(i) A maroon oil, (0.3 g.), which could not be crystallised.

(ii) A brown solid, (0.9 g.), m.p. 107-110° which recrystallised from benzene as brown prisms, (0.5 g.), m.p. 120-122° (mixed with 4-phenyl-1,2-dithiole-3-thione m.p. 120-122°).

There were several other bands remaining on the column, but none could be isolated in sufficient quantity for examination.

PART B : Reactions Involving Ethoxycarbonylformonitrile oxide and Benzonitrile N-phenylimine

GENERAL MATERIALS

1. Ethyl chloro-oximinoacetate

Prepared by the method of Skinner[73] in which aqueous sodium nitrite is added to a cold solution of glycine ester hydrochloride in hydrochloric acid.

Yield = 10.5 g. from 34.85 g. of glycine ester hydrochloride = 28%.

m.p. = 79-80° (lit.m.p. = 80°).

2. α-Phenyl-β-benzoylhydrazine

The method of Fischer[104] was used in which a solution of phenylhydrazine in ether was treated with benzoyl chloride.

Yield = 26.3 g. from 54.07 g. of phenylhydrazine = 50%

m.p. = 168-169° (lit.m.p. = 168°)

3. α-Phenyl-β-(α'-chlorobenzylidene)phenylhydrazine

The compound was prepared by the action of phosphorus pentachloride on α-phenyl-β-benzoylhydrazine as described by Huisgen[74].

Yield = 12 g. from 20 g. of α-phenyl-β-benzoylhydrazine = 55%.

4. 3,5-Diphenyl-2-thiophenacylidene-1,3,4-thiadiazole

(i) 3,5-Diphenyl-1,3,4-thiadiazole-2-thione

The method of Fusco and Musante[76] was used in which α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine was caused to react with potassium ethyl xanthate in ethanol.

Yield = 1.87 g. from 2.3 g. of α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine = 69%.

m.p. = 151-152° (lit.m.p. = 151-152°)

(ii) 3,5-Diphenyl-2-methylthio-1,3,4-thiadiazolium perchlorate

3,5-Diphenyl-1,3,4-thiadiazole-2-thione (0.5 g., 1.94 m.mole) was heated with an excess of dimethyl sulphate at 150° for 2 min. The brown solution was poured into acetic acid (5 ml.) and a few drops of perchloric acid were added. The mixture was allowed to stand at room temperature and after a few minutes, a white solid separated, (0.615 g., 98%), m.p. 198-199°.

Found : C,46.97; H,3.80; Cl,9.60; N,7.46; S,16.1%

$C_{15}H_{13}ClN_2O_4S_2$ requires : C,46.81; H,3.40; Cl,9.20; N,7.28; S,16.6%

(iii) Benzoylacetic acid

The acid was prepared by the method of Meyer and Tögel[105] in which ethyl benzoylacetate was hydrolysed with aqueous potassium hydroxide solution.

Yield = 4.4 g. from 10 g. of ethyl benzoylacetate = 51%

m.p. = 105°d (lit.m.p. = 105°d)

(iv) 3,5-Diphenyl-2-phenacylidene-1,3,4-thiadiazole

Sodium (0.161 g., 0.00695 g.atom) was dissolved in absolute ethanol (65 ml.) and then benzoylacetic acid (1.12 g., 0.00695 mole) was added. To the resulting suspension was added 3,5-diphenyl-2-methylthio-1,3,4-thiadiazolium perchlorate (1.27 g., 0.00342 mole) and the solution warmed gently until a clear solution was obtained. The solution was then cooled, allowed to stand at room temperature for 2 days and then

the ethanol was distilled in vacuo. The residual brown solid was chromatographed on alumina in benzene to give :

(i) A brown oil (trace)

(ii) A brown oil, (0.1 g.), which crystallised from ethanol (0.01 g.) m.p. 165-166°. ν_{max} 1600 cm^{-1} (C = O)

Found : C,72.63; H,4.45; N,7.75; S,8.9%

$C_{22}H_{16}N_2OS$ requires : C,74.01; H,4.45; N,7.89; S,9.0%

(v) 3,5-Diphenyl-2-thiophenacylidene-1,3,4-thiadiazole

The ketone from (iv) above (0.02 g.) was dissolved in dry xylene (2 ml.) and boiled under reflux for 2 hr. with purified phosphorus pentasulphide. The reaction mixture was cooled and filtered and the filtrate chromatographed on alumina in benzene to give a red solid, (0.005 g.), which was shown to be a mixture containing three components (silica plate). Separation was effected by thin layer chromatography on silica gel G (Merck). The infrared spectrum of the middle fraction dissolved in chloroform was identical with that of the cyclisation product m.p. 197-198° (page 53) and the mixed melting point was undepressed.

5. 2-(3,5-Diphenyl-1,3,4-thiadiazolylidene)-cyclohexa-3,5-dienone

(i) Salicyloyl chloride

Salicylic acid, suspended in light petroleum containing pyridine, was treated with thionyl chloride[106]. A quantitative yield of salicyloyl chloride was obtained.

(ii) 2,4-Diphenyl-5-(o-hydroxyphenyl)-1,3,4-thiadiazolium perchlorate

Salicyloyl chloride (0.78 g., 5 m.mole) was added to a solution of α-phenyl-β-thiobenzoyl hydrazine (1.14 g., 5 m.mole) in benzene (5 ml.).

An exothermic reaction ensued and a brown oil was precipitated. The benzene was decanted and the residual oil was dissolved in methanol and treated with perchloric acid to give another brown oil. The methanol was distilled in vacuo and the residual oil solidified on standing. Recrystallisation from ethanol gave pale yellow prisms, (0.81 g., 35%), m.p. 212-214°. ν_{max} 1090 cm^{-1} (ClO_4^-)

Found : C,56.76; H,3.66; Cl,8.72; N,6.47; S,7.3%

$C_{20}H_{15}ClN_2O_5S$ requires : C,55.75; H,3.51; Cl,8.23; N,6.50; S,7.4%

(iii) 2-(3,5-Diphenyl-1,3,4-thiadiazolylidene)-cyclohexa-3,5-dienone

Addition of dilute aqueous sodium hydroxide to the perchlorate obtained from (ii) gave an orange solid which crystallised from ethanol as orange flakes, (0.05 g., 10%), m.p. 225-226°. ν_{max} 1610 cm^{-1} (C = O)

Found : C,72.16; H,4.60; N,8.67; S,9.3%

$C_{20}H_{14}N_2OS$ requires : C,72.70; H,4.27; N,8.48; S,9.7%

6. α-Phenyl-β-thiobenzoylhydrazine

Prepared by the action of carboxymethyl dithiobenzoate in aqueous sodium hydroxide solution on phenylhydrazine as described by Jensen and Miguel[77].

Yield = 2.5 g. from 4.24 g. of carboxymethyl dithiobenzoate = 48%.

m.p. = 86-87° (lit.m.p. = 87°)

7. Carboxymethyl dithiobenzoate

The method is described in Organic Syntheses[107].

Yield = 18.5 g. from 49 g. of benzotrichloride = 35%.

m.p. = 126-127° (lit.m.p. = 127-128°)

8. 2,3,5-Triphenyl-1,3,4-thiadiazolium perchlorate

To a solution of α-phenyl-β-thiobenzoylhydrazine (1.14 g., 5 m.mole) in dry benzene (5 ml.) was added benzoyl chloride (0.7 g., 5 m.mole) and the mixture was boiled under reflux for 5 min. The reaction mixture was allowed to cool and the precipitated solid filtered, dissolved in methanol and then treated with a few drops of perchloric acid. The mixture was set aside for 5 min. after which addition of ether precipitated a white solid, (0.81 g., 39%), m.p. 220-222°.

Found : C,57.89;H,3.60;Cl,9.13;N,7.78;S,8.1%

$C_{20}H_{14}ClN_2O_4S$ requires : C,57.90;H,3.64;Cl,8.55;N,6.75;S,7.7%

9. 2-Methyl-3,5-diphenyl-1,3,4-thiadiazolium perchlorate

To a solution of α-phenyl-β-thiobenzoylhydrazine (1.14 g., 5 m.mole) in dry benzene (5 ml.) was added acetyl chloride (0.39 g., 5 m.mole) and the mixture was boiled under reflux for 5 min. The reaction mixture was allowed to cool and the precipitated solid filtered, dissolved in methanol and then treated with a few drops of perchloric acid. The mixture was set aside for 5 min. and then ether was added to precipitate a white solid, (0.62 g.), m.p. 168-170°. Recrystallisation from ethanol gave white flakes, (0.50 g., 28%), m.p. 170-171°.

Found : C,51.51;H,3.99;Cl,10.4;N,8.46;S,9.3%

$C_{15}H_{13}ClN_2O_4S$ requires : C,51.07;H,3.71;Cl,10.05;N,7.94;S,9.1%

CYCLO-ADDITION REACTIONS

1. Reaction of 5-Phenyl-1,2-dithiole-3-thione with Ethoxycarbonylformonitrile oxide

To a solution of ethyl chloro-oximino acetate (1.51 g., 0.01 mole) in dry benzene (70 ml.) was added 5-phenyl-1,2-dithiole-3-thione (2.1 g., 0.01 mole). The solution was vigorously stirred while a solution of triethylamine (1.01 g., 0.01 mole) in dry benzene (20 ml.) was added dropwise over a period of 4 hr. at room temperature. The benzene was removed by distillation through a Vigreux column and the residue transferred to a sublimation apparatus incorporating a glass reservoir below the cold finger. The mixture was heated at 130° and 20 mm. pressure for several minutes and the colourless liquid in the glass reservoir collected. The infrared spectrum indicated

ν_{max} 1735 cm^{-1} (COOEt) and ν_{max} 1960 cm^{-1} (C = N = S)

To 0.15 g. of the suspected isothiocyanate in benzene, (5 ml.), was added aniline, (0.107 g.), in benzene (5 ml.). The resulting precipitate was filtered and recrystallised from ethanol to give white flakes m.p. 129-130° (lit.m.p.[108] for N-ethoxycarbonyl-N'-phenylthiourea is 130°).

The sublimation residue was chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 1 mixture to give :

(i) A brown solid, (0.51 g., 24%), m.p. 115-120° (mixed with 5-phenyl-1,2-dithiole-3-thione m.p. 115-120°).

(ii) A yellow solid, (1.34 g., 64%), m.p. 116-117° (mixed with 5-phenyl-1,2-dithiole-3-one m.p. 116-117°).

1. General Procedures for the Generation of Benzonitrile N-phenylimine for Cyclo-addition to 1,2-Dithiole-3-thiones

Method A

To a solution of the dithiolethione (5 m.mole) in dry benzene (30 ml.) was added α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine (5 m.mole). The solution was vigorously stirred while a solution of triethylamine (5 m.mole) in dry benzene (20 ml.) was added dropwise over a period of 3½ hr. The reaction mixture was filtered and the filtrate was chromatographed on alumina using a light petroleum (40-60°) - benzene mixture.

Method B

To a solution of the dithiolethione (5 m.mole) in dry benzene (30 ml.) was added α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine (5 m.mole). The solution was vigorously stirred while a solution of triethylamine (5 m.mole) in dry benzene (20 ml.) was added over a period of 3½ hr. A further quantity of triethylamine (5 m.mole) was added and the reaction mixture warmed at 50° for 3 hr. and then allowed to stand at room temperature overnight. The reaction mixture was then washed well with water and dried.

2. Reaction of Diphenylnitrile-imine with 5-Phenyl-1,2-dithiole-3-thione

Method A

Quantities :

5-Phenyl-1,2-dithiole-3-thione	1.05g.,5m.mole
α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine	1.53g.,5m.mole
Triethylamine	0.505g.,5m.mole

The reaction mixture was filtered and chromatographed on alumina in benzene to give :

(i) A red solid, (0.15 g.), which was shown by thin-layer chromatography to be a mixture of unreacted thione, sulphur and α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine.

(ii) A red solid, (0.54 g.), m.p. 116-118° which recrystallised from ethanol as brown prisms, m.p. 125-127° (mixed with 5-phenyl-1,2-dithiole-3-thione m.p. 125-127°).

(iii) A red solid, (0.5 g.), m.p. 190-194° which recrystallised from a 1 : 1 light petroleum (40-60°) - benzene mixture to give red prisms, (0.25 g., 14%), m.p. 196-198° (mixed with authentic 3,5-diphenyl-2-thiophenacylidene-1,3,4-thiadiazole, m.p. 196-198°).

Found : C,71.20; H,4.42; N,7.85; S,16.6%

$C_{22}H_{16}N_2S_2$ requires : C,70.94; H,4.33; N,7.52; S,17.2%

Method B

Quantities :

Same as were used in Method A except that twice as much triethylamine was used.

The reaction mixture was filtered and the filtrate concentrated to give a residual red solid. Recrystallisation from benzene gave the thione, (0.82 g., 45%), red needles, m.p. 197-198°.

The filtrate was chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give :

(i) A yellow solid, (0.17 g.), which crystallised from an ethanol-benzene mixture as yellow prisms, (0.05 g.), m.p. 117-118° unchanged when the

substance was mixed with sulphur.

(ii) A brown glass,(0.27 g.),m.p. 94-97° which recrystallised from an ethanol-benzene mixture to give yellow prisms,(0.15 g.),m.p. 179°d. The infrared and n.m.r. spectra were not inconsistent with it being the di-adduct (CXLVII) (page 54).

Found : C,74.40; H,4.52; N,9.88; S,11.3%

$C_{35}H_{26}N_4S_2$ requires : C,74.17; H,4.62; N,9.88; S,11.3%

(iii) A brown solid (0.22 g.),m.p. 120-122° (mixed with 5-phenyl-1,2 dithiole-3-thione m.p. 122-125°).

(iv) A red solid,(0.26 g.),m.p. 198-202° identical (infrared spectrum and mixed melting point) with authentic 3,5-diphenyl-2-thiophenacylidene -1,3,4-thiadiazole.

Total yield of 3,5-diphenyl-2-thiophenacylidene-1,3,4-thiadiazole = 1.08 g. (59%).

3. Reaction of Benzonitrile N-phenylimine with 4-Phenyl-1,2-dithiole-3-thione

Method A

Quantities :

4-Phenyl-1,2-dithiole-3-thione	1.05g.,5m.mole
α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine	1.153g.,5m.mole
Triethylamine	0.505g.,5m.mole

The reaction mixture was filtered and the filtrate chromatographed on alumina in a light petroleum (60-80°) - benzene 1 : 1 mixture to give :

(i) A red oil (0.87 g.), shown by thin-layer chromatography to be a mixture of sulphur, α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine and

4-phenyl-1,2-dithiole-3-thione.

(ii) A red solid, (0.55 g.), m.p. 117-119° (mixed with 4-phenyl-1,2-dithiole-3-thione, m.p. 118-120°)

(iii) A red solid, (0.27 g.), m.p. 193-196° which recrystallised from a light petroleum (40-60°) - benzene 1 : 2 mixture as brown prisms, (0.06 g., 3%), m.p. 209°d. The n.m.r. spectrum showed a low field singlet at -0.05 τ attributable to the proton of a thioaldehyde group. The ratio of the integrated intensity of this peak to that of the aromatic multiplet was 1 : 16 which is the ratio required for 3,5-diphenyl-1,3,4-thiadiazol-2-ylidene phenylthioacetaldehyde.

Found : C,70.90; H,4.24; N,7.48; S,16.6%

$C_{22}H_{16}N_2S_2$ requires : C,70.94; H,4.33; N,7.52; S,17.2%

Method B

Quantities :

The same as were used in Method A except that twice as much triethylamine was used.

The reaction mixture was filtered and the filtrate concentrated in vacuo to give a residual brown solid which recrystallised from benzene as brown prisms, (0.41 g., 22%), m.p. 208°. The infrared spectrum was identical with that of the product obtained by Method A and the mixed melting point showed no depression.

The filtrate was chromatographed on alumina in a light petroleum (40-60°) - benzene 2 : 1 mixture to give :

(i) A brown solid, (0.38 g.), m.p. 90-93 which recrystallised from ethanol as brown prisms, (0.21 g.), m.p. 118-120° (mixed with 4-phenyl-1,2-dithiole-3-thione m.p. 118-120°).

(ii) A brown solid,(0.51 g.), m.p. 114-118° which recrystallised from ethanol as pale brown needles,(0.21 g., 15%),m.p. 152-153°. The infra-red spectrum was identical with that of 3,5-diphenyl-1,3,4-thiadiazo-2-thione and the mixed melting point showed no depression.

4. Reaction of Benzonitrile N-phenylimine with 4,5-Benzo-1,2-dithiole-3-thione

Method B

Quantities :

4,5-Benzo-1,2-dithiole-3-thione	(0.92g.,5m.mole)
α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine	(1.153g.,5m.mole)
Triethylamine	(1.01g.,10m.mole)

The reaction mixture was washed well with water, dried and then the benzene distilled in vacuo to give a residual brown solid. Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A yellow solid,(0.045 g.), identified as sulphur.

(ii) A red solid,(0.2 g.), m.p. 93-95°. (Mixed with 4,5-benzo-1,2-dithiole-3-thione, m.p. 93-95°).

(iii) A red oil, (0.14 g.), which could not be crystallised.

(iv) A yellow oil,(0.72 g.),which crystallised from ethanol as yellow prisms (0.37 g.) m.p. 164-166°. ν_{max} 1640 cm^{-1} (C = O). The n.m.r. spectrum showed only aromatic protons.

Found : C,72.76; H,4.04; N,8.48; S,10.4%

$C_{20}H_{14}N_2OS$ requires : C,72.70; H,4.27; N,8.48; S,9.70%

The compound was at first thought to be the quinonoid compound (CLV, page 57) but subsequent synthesis and comparison of the infrared spectra disproved this.

5. Reaction of Benzonitrile N-phenylimine with 3,5-Diphenyl-2-thiophenacylidene-1,3,4-thiadiazole

Method B

Quantities :

3,5-Diphenyl-2-thiophenacylidene-1,3,4-thiadiazole (0.5g., 1.89m.mole)

α-phenyl-β-(α'-chlorobenzylidene)phenylhydrazine (0.436g., 1.89m.mole)

Triethylamine (0.38g., 3.78m.mole)

The reaction mixture was washed with water, dried and chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give :

(i) A yellow solid, (0.61 g.), which crystallised from an ethanol - benzene mixture as yellow hexagons, (0.41 g., 47%), m.p. 179°d. The infrared spectrum was identical with that of the compound possessing a melting point of 179°d which was obtained in chromatography fraction (ii) from method B in the reaction of 5-phenyl-1,2-dithiole-3-thione with diphenylnitrile imine and the mixed melting point showed no depression.

The compound, m.p. 179°d, (0.2 g.), was dissolved in glacial acetic acid and then a few drops of perchloric acid were added. A colourless oil, which precipitated, solidified on standing. Recrystallisation from ethanol gave a white solid, (0.1 g.), m.p. 150-152°. ν_{max} 1100 cm^{-1} ($ClO_4^{\ominus}$). The n.m.r. spectrum indicated a ratio of 30 aromatic protons to 3 aliphatic protons whereas the required ratio for

a compound formed by protonation of structure (CXLVII, page 54) is 25 : 2.

Found : C,54.74; H,4.43; Cl,9.22; N,7.74; S,8.15%

$C_{35}H_{27}ClN_4O_2S_2$ requires : C,63.00; H,4.08; Cl,5.31; N,8.40; S,9.61%

SECTION II

Thiothiophthens and Related Compounds

Part (A) : Thiothiophthens

GENERAL MATERIALS

General Method for the Preparation of 1,3,5-Triketones

The method was similar to that described by Miles et al[53], for the aroylation of β-diketones in which, under a dry nitrogen atmosphere, a solution of cycloalkanone (50 m.mole) and the appropriate methyl ester of a carboxylic acid (150 m.mole) in monoglyme (100 ml.) was added dropwise to a stirred suspension of sodium hydride (250 m.mole) in monoglyme (100 ml.) at reflux. The reaction mixture was refluxed for 6 hr. and then most of the solvent removed by distillation in vacuo. The solid residue was cooled to 0° in an ice-water bath, ether (150 ml.) added and, after stirring for a few minutes, cold water (100 ml.) was added, initially dropwise, until the excess sodium hydride was destroyed. The two layers were separated and the ethereal layer extracted with 2 x 100 ml. portions of cold water and then with 100 ml. of cold 1% aqueous sodium hydroxide solution. The extracts were combined with the initial aqueous layer and then poured into a mixture of 40-50 ml. of concentrated hydrochloric acid and 200 g. of crushed ice. The resulting viscous oil was extracted into ether, washed with water and then dried. The ether was distilled to give a residual brown oil which solidified on standing.

1. 2,6-Dibenzoylcyclohexanone

Quantities :

Cyclohexanone (4.9g., 50m.mole)

Methyl benzoate (20.4g., 150m.mole)

Sodium hydride (6g., 250 m.mole)

Monoglyme (200 ml.)

The residual brown solid obtained from the reaction mixture was hot filtered in 95% ethanol and on standing colourless flakes separated, (5.6 g., 37%), m.p. 126-128°.

Found : C,78.0; H,6.06%

$C_{20}H_{18}O_3$ requires : C,78.41; H,5.92%

2. 2,5-Dibenzoylcyclopentanone

Quantities :

Cyclopentanone (4.2g., 50m.mole)

Methyl benzoate (20.4g., 150m.mole)

Sodium hydride (6g., 250m.mole)

Monoglyme (200 ml.)

The reaction product crystallised from ethanol as yellow flakes, (9.2 g., 63%), m.p. 120-121°.

Found : C,78.02; H,5.34%

$C_{19}H_{16}O_3$ requires : C,78.06; H,5.52%

3. 2,6-Di-p-toluoylcyclohexanone

Quantities :

Cyclohexanone (4.9g., 50m.mole)

Methyl p-toluate (22.5g., 150m.mole)

Sodium hydride (6g., 250m.mole)

Monoglyme (200 ml.)

The triketone was obtained as a yellow solid which recrystallised from an ethanol - ethyl acetate 1 : 1 mixture to give yellow prisms, (1.48 g., 9%), m.p. 160-162°. ν_{max} 1620 cm^{-1} (C = O) was a broad band, indicating that this is an enol form.

Found : C,79.36; H,6.69%

$C_{22}H_{20}O_3$ requires : C,79.50; H,6.06%

From the filtrate there separated a pale yellow solid,(2.1 g., 12%), m.p. 175-178°. ν_{max} 1590 cm^{-1} and 1610 cm^{-1} (C = O) were sharp, thus supporting the triketone structure.

4. 2,6-Di-p-Anisoylcyclohexanone

Quantities :

Cyclohexanone (3.26g., 33.4m.mole)

Methyl anisate (16.6g., 100m.mole)

Sodium hydride (4g., 160m.mole)

Monoglyme (166 ml.)

Recrystallisation of the reaction product from ethanol gave yellow feathery crystals,(1.68g., 17.5%), m.p. 152-154°. ν_{max} 1600 cm^{-1} and 1670 cm^{-1} (C = O).

Found : C,71.96; H,5.50%

$C_{22}H_{22}O_5$ requires : C,72.11; H,5.95%

5. Cyclohexan-2,6-dial-1-one

Quantities :

Cyclohexanone (3.26g., 33.4m.mole)

Ethyl formate (7.4g., 100m.mole)

Monoglyme (150 ml.)

Sodium hydride (4.0g., 166m.mole)

The triketone was obtained as a brown oil (3.9 g.) which could not be crystallised. This crude oil was used in the sulphurisation experiment.

6. Ethyl cyclohexanone-2,5-dioxalate

The method was similar to that employed for the preparation of acetone dioxalic ester[109]. The triketone was obtained as a brown oil which could not be crystallised. An attempt to purify the oil by chromatography on alumina in benzene was unsuccessful.

7. 1,5-Bis-ethoxycarbonyl-2,4-trimethylenepentan-1,3,5-trione

A method similar to that described for the preparation of acetonedioxalic ester[110] was used.

Quantities :

Sodium ethoxide (11.5g. sodium in 150ml. ethanol)

Cyclohexanone (24.5g., 0.25 mole)

Ethyl oxalate (77.5g., 0.532 mole)

The triketone was obtained as a brown oil, (17.8 g., 24%). Attempts to purify this oil were unsuccessful, so the crude product was used in the sulphurisation reaction.

8. Triphenylmethyl fluoborate

The salt was prepared by the method of Dauben et al[79].

Yield = 25.5g. from 22.5g. of triphenylcarbinol = 90%

m.p. = 215°d (lit.m.p. = 215°d[111], 200°d[79], 195-196°[112])

9. 2,6-Bis-(dimethylthiomethylene)-cyclohexanone

The method of Thuillier and Vialle[113] was used.

Yield = 9.88g. of ketone from 4.9g. of cyclohexanone = 64.5%.

Thiothiophthens and Derived Compounds

General Method for the Sulphurisation of Triketones

The method was similar to that described by Brown[114]. A solution of the triketone in dry xylene was boiled under reflux for 1 hr. with phosphorus pentasulphide. Unreacted phosphorus pentasulphide was destroyed by heating the xylene solution with an equal volume of dilute hydrochloric acid (10%) on a boiling water-bath for 15 min. The organic layer was separated, washed with water, dried and the xylene removed by distillation in vacuo. The residue was purified to give the thiothiophthen. The n.m.r. spectra of the thiothiophthens indicated symmetrical molecular structures and are given in detail in Table 2.

1. Meribicyclo-1,5-diphenyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

2,6-Dibenzoylcyclohexanone	(1g., 3.27m.mole)
Phosphorus pentasulphide	(2 g.)
Xylene	(20 ml.)

The distillation residue was recrystallised from ethyl acetate to give the thione,(0.67g., 58%),purple prisms, m.p. 153-154° (lit.m.p.[52] = 163°).

Found : C,68.36; H,4.88; S,27.20%

$C_{20}H_{16}S_3$ requires : C,68.14; H,4.58; S,27.20%

2. Meribicyclo-1,5-diphenyl-2,4-dimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

2,5-Dibenzoylcyclopentanone (5g., 17.2m.mole)

Xylene (100 ml.)

Phosphorus pentasulphide (10 g.)

When the excess phosphorus pentasulphide had been destroyed by boiling with dilute hydrochloric acid, the reaction mixture was cooled and filtered to give purple prisms. Recrystallisation from 1,1,2-trichloroethane gave the thione, (3.8 g., 66%), purple needles, m.p. 227-228°, (lit.m.p.[52] = 233°).

Found : C,66.99; H,4.08; S,28.5%

$C_{19}H_{14}S_3$ requires : C,67.41; H,4.17; S,28.4%

3. Meribicyclo-1,5-di-p-tolyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

2,6-Di-p-toluoylcyclohexanone (1.3g., 3.45m.mole)

Phosphorus pentasulphide (2.6 g.)

Xylene (20 ml.)

When the excess phosphorus pentasulphide had been destroyed by boiling with dilute hydrochloric acid, the reaction mixture was cooled and the precipitated solid filtered. Recrystallisation from ethyl acetate gave the thione, (1.14 g., 87%), maroon prisms, m.p. 221-223°, (lit.m.p.[52] = 225°).

Found : C,69.21; H,5.47; S,24.9%

$C_{22}H_{20}S_3$ requires : C,69.43; H,5.30; S,25.3%

4. Meribicyclo-1,5-di-p-anisyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

2,6-Di-p-anisoylcyclohexanone (1.68g., 5.05m.mole)

Phosphorus pentasulphide (4 g.)

Xylene (20 ml.)

The reaction product was chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give a purple solid m.p. 206-210°. Recrystallisation from 1,1,2-trichloroethane gave the thione, (1.0 g., 52%), purple needles possessing a green reflex, m.p. 214-215°, (lit.m.p.[52] = 219°).

Found : C,63.58; H,4.81; S,23.2%

$C_{22}H_{22}O_2S_3$ requires : C,63.91; H,5.28; S,23.2%

5. Meribicyclo-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thial

Quantities :

Cyclohexan-2,6-dial-1-one (3.9g., 25.3m.mole)

Phosphorus pentasulphide (6 g.)

Xylene (80 ml.)

The reaction product was chromatographed on alumina in light petroleum (40-60°) to give a maroon oil which solidified on standing. Recrystallisation from ethanol gave the thione, (0.01 g., 0.2%), maroon plates possessing a gold reflex, m.p. 80-81°.

Found : C,48.15; H,4.00; S,47.8%

$C_8H_8S_3$ requires : C,48.03; H,3.97; S,48.0%

6. Meribicyclo-1,5-bis-methylthio-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

The method of Thuillier and Vialle[51] was used.

Quantities :

Ketone	(6.76g., 23.2m.mole)
Phosphorus pentasulphide	(14 g.)
Xylene	(140 ml.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave the thione, (3.0 g., 44%) red needles possessing a yellow reflex, m.p. 147-148°, (lit.m.p. = 148°).

7. Meribicyclo-1,5-bisethoxycarbonyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

1,5-bis-ethoxycarbonyl-2,4-trimethylenepentan-1,3,5-trione	(6.8g., 32.8m.mole)
Phosphorus pentasulphide	(13.6 g.)
Toluene	(160 ml.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A maroon oil (0.05 g.) which could not be crystallised.

(ii) A purple oil which crystallised from ethyl acetate to give the thione, maroon needles, (0.02 g.), m.p. 77-78°.

Found : C,49.63; H,4.92%

$C_{14}H_{16}O_4S_3$ requires : C,48.81; H,4.68%

8. 1,5-Bis-ethoxycarbonyl-3,5-epidithiopenta-2,4-diene-1-thione

Acetonedioxalic ester (5 g., 19.35m.mole) in dry benzene (120 ml.) was boiled under reflux for 2 hr. with phosphorus pentasulphide (10 g.). The reaction mixture was allowed to cool to room temperature and filtered. The residual solid was washed well with benzene and then the combined filtrates washed with several portions of water and then dried. The benzene was removed in vacuo to give a residual brown oil. Chromatography on alumina in benzene gave :

(i) A purple solid (0.25 g.). Recrystallisation from ethyl acetate gave the thione, (0.1 g., 2%), maroon plates, m.p. 140-141°. ν_{max}=1700cm^{-1} (COOEt).

Found : C,43.49; H,4.43; S,31.3%

$C_{11}H_{12}S_3O_4$ requires : C,43.40; H,3.98; S,31.6%

(ii) Trace quantity of a maroon solid.

(iii) The solvent was changed to chloroform and a maroon solid (0.05g.) was eluted. Recrystallisation from ethyl acetate gave blue-green needles, (0.02 g.), m.p. 216-218°. ν_{max}=1720cm^{-1} (COOEt).

Found : C,55.81; H,5.60; S,8.1%

$C_{22}H_{24}O_9S$ requires : C,56.89; H,5.21; S,6.9%

General Method for the Dehydrogenation of the Thiothiophthens

The thiothiophthen and triphenylmethyl fluoroborate were boiled under reflux for 5 min. in glacial acetic acid in a manner similar to that described by Bouttrone[115] for the dehydrogenation of 9,10-dihydroanthracene and 4,5,9,10-tetrahydropyrene using trityl perchlorate.

The n.m.r. spectral data for the dehydrogenation products of the thio-thiophthens are given in Table 2.

9. Dehydrogenation of Meribicyclo-1,5-diphenyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.352g., 1m.mole)
Triphenylmethyl fluoborate	(0.66g., 2m.mole)
Glacial acetic acid	(10 ml.)

The reaction mixture was allowed to cool and on standing 3-phenyl-7-thiobenzoylbenzo(c)-1,2-dithiolium fluoborate, (0.22 g.,51%), brown needles, m.p. 212-214°d, was obtained.

Found : C,55.34; H,3.58; S,22.3%

$C_{20}H_{13}BF_4S_3$ requires : C,55.05; H,3.00; S,22.1%

10. Dehydrogenation of Meribicyclo-1,5-diphenyl-2,4-dimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.2 g., 0.57 mole)
Triphenylmethyl fluoborate	(0.2 g., 0.57 mole)
Glacial acetic acid	(10 ml.)

The reaction mixture was cooled and extracted into carbon disulphide, the insoluble material being filtered. The filtrate was chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give :

(i) A brown solid (0.14 g.). Recrystallisation from ethanol gave colourless flakes, (0.08 g.), m.p. 92-93°. (Mixed with triphenylmethane m.p. 92-93°).

(ii) A purple solid, (0.03 g.), m.p. 225-226° (mixed with the thione m.p. 225-226°).

(iii) A maroon solid (0.05 g.). Trituration in benzene gave maroon prisms, (0.025 g.), m.p. 241-242° which was not identified.

The carbon disulphide insoluble material was recrystallised from 1,1,2-trichloroethane to give a fluoborate (0.04 g.), black needles, m.p. 290°. ν_{max}=1080 cm^{-1} ($BF_4^{\ominus}$). The material was not identified.

11. Dehydrogenation of Meribicyclo-1,5-di-p-tolyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.38 g., 1m.mole)
Triphenylmethyl fluoborate	(0.66g., 2m.mole)
Glacial acetic acid	(10 ml.)

The reaction mixture was allowed to cool and a black solid separated. Recrystallisation from glacial acetic acid (10 ml.) gave 3-p-tolyl-7-p-thiotoluoylbenzo(c)-1,2-dithiolium fluoborate, (0.2g., 43%), yellow-green needles, m.p. 192-194°.

Found	:	C,57.24;	H,4.18; S,20.6%
$C_{22}H_{17}BF_4S_3$ requires	:	C,56.90;	H,3.69; S,20.7%

12. Dehydrogenation of Meribicyclo-1,5-di-p-anisyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.207 g., 0.5m.mole)
Triphenylmethyl fluoborate	(0.33 g., 1m.mole)
Glacial acetic acid	(4 ml.)

The reaction mixture was allowed to cool and a black solid separated. Recrystallisation from acetic acid gave 3-p-anisyl-7-p-thioanisoylbenzo(c)-1,2-dithiolium fluoborate,(0.17 g., 68.5%), black needles possessing a green reflex,(m.p. 166-168°).

Found : C, 53.10; H, 3.35; S,19.3%

$C_{22}H_{17}BF_4O_2S_3$ requires : C,53.11; H,3.42; S,19.4%

13.Dehydrogenation of Meribicyclo-1,5-bis-methylthio-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.292 g., 1m.mole)
Triphenylmethyl fluoborate	(0.66 g., 2m.mole)
Glacial acetic acid	(8 ml.)

The reaction mixture was allowed to cool and brown needles separated. Trituration in 1,1,2-trichloroethane gave 3-methylthio-7-methyl-dithiocarboxylate-benzo(c)-1,2-dithiolium fluoborate, (0.25 g., 41%), red needles, m.p. 240-242°.

Found : C,32.22; H,2.18; S,42.1%

$C_{10}H_9BF_4S_5$ requires : C,31.91; H,2.41; S,42.6%

General Method for the Desulphurisation of Thiothiophthens

The thiothiophthen dissolved in acetone or an acetone-chloroform mixture was treated with a solution of mercuric acetate in acetone. The

mixture was gently refluxed on a steam-bath for 30 min. and then set aside for a further 1 hr. The solvent was removed by distillation in vacuo and the residual solid chromatographed on alumina in benzene. The n.m.r. spectral data is given in Table 2.

14. Desulphurisation of Meribicyclo-1,5-diphenyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.5 g., 1.42m.mole)
Mercuric acetate	(1.28 g., 4m.mole)
Acetone	(200 ml.)

The crude product was chromatographed on alumina in benzene to give :

(i) A maroon solid, (0.04 g.), m.p. 153-154° (mixed with thione m.p. 153-154°).

(ii) A brown solid (0.32 g.). Recrystallisation from an ethanol-ethyl acetate mixture gave the ketone, (0.21 g., 40%), orange prisms, m.p. 174-175°, (lit.m.p.[52] = 175°) ν_{max} 1560cm^{-1} (C = O).

Found : C,71.01; H,4.70; S,19.6%

$C_{20}H_{16}OS_2$ requires : C,71.39; H,4.79; S,19.1%

15. Desulphurisation of Meribicyclo-1,5-diphenyl-2,4-dimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.4 g., 1.13m.mole)
Mercuric acetate	(0.96 g., 3.0m.mole)
Acetone	(200 ml.)

Chromatography on alumina in benzene gave a brown solid. Recrystallisation from an ethanol - ethyl acetate mixture gave the ketone, (0.035 g.), brown prisms, m.p. 156-158°, (lit.m.p.[52] = 163°). ν_{max} = 1550 cm^{-1} (C = O).

Found : C,70.03; H,4.54; S,19.3%

$C_{19}H_{14}OS_2$ requires : C,70.71; H, 4.42; S,19.9%

16. Desulphurisation of Meribicyclo-1,5-di-p-tolyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.67 g., 1.87m.mole)
Mercuric acetate	(1.5 g., 4.7m.mole)
Chloroform	(200 ml.)
Acetone	(200 ml.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave an orange solid. Recrystallisation from a benzene - ethyl acetate mixture gave the ketone, (0.15 g., 22%), orange needles, m.p. 226-227° (lit.m.p.[52] = 228°). ν_{max} 1620 cm^{-1} (C = O).

Found : C,72.38; H,5.70; S,17.9%

$C_{22}H_{20}OS_2$ requires : C,72.49; H,5.53; S,17.6%

17. Desulphurisation of Meribicyclo-1,5-di-p-anisyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-thione

Quantities :

Thione	(0.5 g., 1.82m.mole)
Mercuric acetate	(1.0 g., 3.1m.mole)

Chloroform (100 ml.)

Acetone (250 ml.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave a yellow solid. Recrystallisation from an ethyl acetate - benzene 10 : 1 mixture gave the ketone, (0.10 g., 20%), orange needles, m.p. 230-231°, (lit.m.p.[52] = 233°). ν_{max} 1605 cm^{-1} (C = O).

Found : C,66.23; H,5.39; S,16.7%

$C_{22}H_{22}O_3S_2$ requires : C,66.39; H,5.48; S,16.1%

General Method for the Dehydrogenation of Ketones

The method was similar to that described for the dehydrogenation of thiothiophthens (page 111) in which triphenylmethyl fluoborate in glacial acetic acid was used. The n.m.r. spectral data is given in Table 2.

18. Dehydrogenation of Meribicyclo-1,5-diphenyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-one

Quantities :

Ketone (0.21 g., 0.624m.mole)

Triphenylmethyl fluoborate (0.41 g., 1.24m.mole)

Glacial acetic acid (10 ml.)

The reaction mixture was allowed to cool and a brown solid crystallised. Recrystallisation from acetic acid gave 3-phenyl-7-benzoylbenzo(c)-1,2-dithiolium fluoborate, (0.19 g., 74%), yellow needles,

m.p. 225-226°. ν_{max} 1620 cm^{-1} (C =O).

Found : C,57.45; H,3.26; S,15.70%

$C_{20}H_{13}BF_4OS_2$ requires : C,57.16; H,3.12; S,15.3%

19. Dehydrogenation of Meribicyclo-1,5-di-p-tolyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-one

Quantities :

Ketone (0.09 g., 0.2m.mole)

Triphenylmethyl fluoborate (0.14g., 0.4m.mole)

Glacial acetic acid (3 ml.)

Recrystallisation of the precipitated solid from glacial acetic acid gave 3-p-tolyl-7-p-toluoylbenzo(c)-1,2-dithiolium fluoborate, (0.06 g., 38%), yellow needles, m.p. 200-201°. ν_{max} 1610 cm^{-1} (C = O).

Found : C,58.19; H,3.75; S,13.8%

$C_{22}H_{17}BF_4OS_2$ requires : C,58.94; H,3.82; S,14.3%

20. Dehydrogenation of Meribicyclo-1,5-di-p-anisyl-2,4-trimethylene-3,5-epidithiopenta-2,4-diene-1-one

Quantities :

Ketone (0.17 g., 0.41m.mole)

Triphenylmethyl fluoborate (0.271 g., 0.82m.mole)

Glacial acetic acid (4 ml.)

When the reaction mixture was allowed to cool, a brown solid separated. Recrystallisation from acetic acid gave 3-p-anisyl-7-p-anisoylbenzo(c)-1,2-dithiolium fluoborate, (0.11 g., 36%), brown plates, m.p. 205-206°. ν_{max} 1600 cm^{-1}, (C = O).

Found : C, 55.19; H, 3.52; S, 13.5%

$C_{22}H_{17}BF_4O_3S_2$ requires : C, 55.01; H, 3.57; S, 13.4%

Part (B) : 4-Thioacyl-1,2-dithiole-3-thiones

GENERAL MATERIALS

1. p-Methylpropiophenone

The method of Noller and Adams[83] was used in which propionic anhydride was added with stirring to a suspension of anhydrous aluminium chloride in toluene.

Yield = 15.1 g. from 13 g. of propionic anhydride = 51%

b.p. = 120°/12 mm.

2. p-Methoxypropiophenone

The method of Noller and Adams[83] was used in which propionic anhydride was added to a cold stirred mixture of anhydrous aluminium chloride and anisole in carbon disulphide.

Yield = 68.9 g. from 65 g. of propionic anhydride = 93%

m.p. = 26-27° (lit.m.p. = 24-26°)

General Method for the Preparation of Benzylidenepropiophenones

The propiophenone and arylaldehyde were treated with dry hydrogen chloride until an equimolecular quantity had been taken up. The resulting dark oil was stored for 12 hr. in a closed vessel and then heated gently on a sand-bath in a current of air until there was no further apparent hydrogen chloride evolution. The reaction mixture was then boiled with 50% aqueous potassium hydroxide solution, cooled and the oil extracted into ether. The extract was washed with water and then dried.

3. Benzylidene-p-methylpropiophenone

Quantities :

p-Methylpropiophenone (18 g., 0.1215 mole)

Benzaldehyde (12.85 g., 0.1215 mole)

Dry hydrogen chloride (4.44 g., 0.1215 mole)

The crude reaction product was distilled in vacuo to give the ketone, (21.1 g., 73.5%), yellow oil, b.p. 170°/1.5 mm. ν_{max} 1600 cm^{-1} (C = O).

Found : C, 86.31; H, 6.53%

$C_{17}H_{16}O$ requires : C, 86.40; H, 6.83%

4. p-Methylbenzylidenepropiophenone

Quantities :

Propiophenone (15.2 g., 0.114 mole)

p-Tolualdehyde (14.8 g., 0.114 mole)

Dry hydrogen chloride (4.16 g., 0.114 mole)

Distillation in vacuo gave the ketone, (17.9 g., 67%), yellow oil, b.p. 135-138°/0.05 mm. Crystallisation, from light petroleum (40-60°) gave white prisms m.p. 66-67°. ν_{max} 1620 cm^{-1} (C = O).

Found : C, 86.24; H, 6.83%

$C_{17}H_{16}O$ requires : C, 86.40; H, 6.83%

5. p-Methylbenzylidene-p-methylpropiophenone

Quantities :

p-Methylpropiophenone (12.21 g., 0.0825 mole)

p-Tolualdehyde (10 g., 0.0825 mole)

Dry hydrogen chloride (3.05 g., 0.0825 mole)

Distillation in vacuo gave the ketone, (14.63 g., 71%), yellow oil, b.p. 168-171°/0.5 mm. ν_{max} 1620 cm^{-1} (C = O).

6. p-Methoxybenzylidene propiophenone

Quantities :

Propiophenone	(32.6 g., 0.243 mole)
Anisaldehyde	(33.1 g., 0.243 mole)
Dry hydrogen chloride	(8.88 g., 0.243 mole)

Distillation in vacuo gave the ketone, (27.3 g., 45%), yellow oil, b.p. 200-203°/2.5 mm. ν_{max} 1580 cm^{-1} (C = O).

Found : C,81.15; H,6.16%

$C_{17}H_{16}O$ requires : C,80.93; H,6.39%

7. Benzylidene-p-methoxypropiophenone

Quantities :

p-Methoxypropiophenone	(68.9 g., 0.42 mole)
Benzaldehyde	(44.5 g., 0.42 mole)
Dry hydrogen chloride	(15.4 g., 0.42 mole)

Distillation in vacuo gave the ketone, (78.65 g., 79%), yellow oil, b.p. 194-196°/2.5 mm. ν_{max} 1620 cm^{-1} (C = O).

Found : C,80.21; H,6.17%

$C_{17}H_{16}O_2$ requires : C,80.93; H,6.39%

General Method for the Preparation of 4-Aroyl-5-aryl-1,2-dithiole-3-thiones

The appropriate benzylidene propiophenone dissolved in ethyl benzoate was heated to reflux (220°) with sulphur for 5 min. and then

at 210-215° for 3 hr. Xylene was added to the hot solution which was then allowed to cool overnight. The precipitated sulphur was filtered off and washed with xylene and then the filtrates were combined and the xylene and ethyl benzoate removed by distillation at 150° in vacuo to give a residual oil. The n.m.r. spectra of the pure products are given in Table 4.

8. 4-Benzoyl-5-p-tolyl-1,2-dithiole-3-thione

Quantities

p-Methylbenzylidene propiophenone	(44.14 g., 0.1875 mole)
Ethyl benzoate	(100 g.)
Sulphur	(59 g., 1.83 g.atom)

An ethyl acetate - ethanol mixture was added to the distillation residue and the undissolved sulphur was filtered off. A brown solid (9.46 g.) m.p. 125-129° separated from the filtrate and was powdered and extracted three times with boiling light petroleum (60-80°). The residue crystallised from an ethanol - ethyl acetate 1 : 2 mixture to give the thione (3.29 g., 5%), red plates, m.p. 148-149°. ν_{max} 1670cm^{-1} (C = O).

Found	:	C,62.18;	H,4.16; S,28.9%
$C_{17}H_{12}OS_3$ requires	:	C,62.16;	H,3.68; S,29.3%

9. 5-Phenyl-4-p-toluoyl-1,2-dithiole-3-thione

Quantities :

Benzylidene-p-methylpropiophenone	(37.38g., 0.1585 mole)
Ethyl benzoate	(84 g.)
Sulphur	(49.5 g., 1.55 g.atom)

An ethyl acetate - ethanol 1 : 1 mixture was added to the distillation residue and the undissolved sulphur was filtered off. No crystals separated from the filtrate so the solvent was removed by distillation in vacuo and the residual oil chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give a red glass (4.95 g.). Crystallisation from an ethyl acetate - ethanol 1 : 1 mixture gave red prisms,(2.8 g.),m.p. 50-51°. Recrystallisation from an ethanol - tetrahydrofuran 4 : 1 mixture gave the thione,(1.8 g., 4%), red plates, m.p. 86-88°. ν_{max} 1600 cm^{-1} (C = O).

Found : C,61.94; H,3.90; S,29.0%

$C_{17}H_{12}OS_3$ requires : C,62.16; H,3.68; S,29.3%

10.4-p-Toluoyl-5-p-tolyl-1,2-dithiole-3-thione

Quantities

p-Methylbenzylidene-p-methyl-propiophenone	(14.26 g., 0.057 mole)
Ethyl benzoate	(30 g.)
Sulphur	(17.75 g., 0.555 g.atom)

The distillation residue was chromatographed on alumina in a benzene - light petroleum (40-60°) 2 : 1 mixture to give a viscous red oil (5.09 g.) which set to a glass on standing. Crystallisation from an ethanol - ethyl acetate 1 : 1 mixture gave the thione,(3.31 g., 10%), red prisms, m.p. 157-158°. ν_{max} 1610 cm^{-1} (C = O).

Found : C,63.04; H,4.25; S,28.0%

$C_{18}H_{14}OS_3$ requires : C,63.12; H,4.12; S,28.1%

11. 4-Benzoyl-5-p-methoxyphenyl-1,2-dithiole-3-thione

Quantities :

p-Methoxybenzylidene propiophenone (26 g., 0.111 mole)

Ethyl benzoate (59 g.)

Sulphur (34.5 g., 1.08 g.atom)

The residual oil was chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 2 mixture to give a viscous red oil (27.1 g.) which, after two successive crystallisations from an ethyl acetate - ethanol 1 : 1 mixture gave the thione, (7.2 g., 19%), orange prisms, m.p. 90-91°. ν_{max} 1610 cm^{-1} (C = O).

Found : C,59.51; H,3.34; S,28.0%

$C_{17}H_{12}O_2S_3$ requires : C,59.27; H,3.51; S,27.9%

12. 4-p-Methoxybenzoyl-5-phenyl-1,2-dithiole-3-thione

Quantities :

Benzylidene-p-methoxypropiophenone (75 g., 0.32 mole)

Ethyl benzoate (170 g.)

Sulphur (99.2 g., 3.1 g.atom)

Addition of an ethyl acetate - ethanol 1 : 1 mixture to the distillation residue precipitated a further quantity of sulphur which was filtered. From the filtrate there separated an orange solid. Recrystallisation from an ethyl acetate - ethanol 1 : 1 mixture gave the thione, (18.1 g., 17%), m.p. 151-152°. ν_{max} 1620 cm^{-1} (C = O).

Found : C,59.36; H,4.01; S,27.5%

$C_{17}H_{12}O_2S_3$ requires : C,59.27; H,3.51; S,27.9%

ENVIRONMENTAL CHEMISTRY SEMINAR

DEPARTMENT OF CHEMISTRY

UNIVERSITY OF EDINBURGH

"Sensitive Surfaces Waters-A Scottish Perspective"

by

Dr D. E. Wells

DAFS Freshwater Fisheries Laboratory, Pitlochry

T100 at 11.10am

Wednesday 8th January 1986

Dr Wells will be dealing with some aspects of the "Acid Rain" problem.

Purification of Phosphorus Pentasulphide

The "crude" phosphorus pentasulphide (10 g.) was placed in a Soxhlet apparatus and continuously extracted with carbon disulphide (150 ml.) for 4 hr. Pale yellow crystals of phosphorus pentasulphide (5.2 g.) separated. These were filtered and again subjected to the same procedure to give white prisms (3.8 g.).

4-Thioaroyl-5-Aryl-1,2-dithiole-3-thiones

General Procedure for Sulphurisation of 4-Aroyl-5-Aryl-1,2-dithiole-3-thiones

The 4-aroyl-5-aryl-1,2-dithiole-3-thione dissolved in dry xylene was boiled under reflux with purified phosphorus pentasulphide for 2 hr. and then set aside for 2 hr. at room temperature. The reaction mixture was filtered and the residual solid washed twice with cold xylene. The combined filtrates were chromatographed on alumina. The n.m.r. spectral data of the products is given in Table 4.

1. Product from 4-Benzoyl-5-p-tolyl-1,2-dithiole-3-thione

Quantities :

4-Benzoyl-5-p-tolyl-1,2-dithiole-3-thione	(1.0g.,2.9m.mole)
Xylene	(4.2 ml.)
Phosphorus pentasulphide	(1.0 g.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A green band which gave a brown oil (0.1 g.). Crystallisation from an ethanol - ethyl acetate 1 : 1 mixture (2 ml.) gave brown prisms,

(0.06 g., 6%), m.p. 120°. The infrared spectrum indicated the absence of starting material.

Found : C,59.28; H,3.87; S,37.2%

$C_{17}H_{12}S_4$ requires : C,59.26; H,3.51; S,37.2%

(ii) A red band which gave a red solid (0.11 g.). Recrystallisation from an ethyl acetate - ethanol 1 : 1 mixture gave red prisms, (0.06 g.), m.p. 146-148°, unchanged when the compound was mixed with starting material. The infrared spectrum confirmed the identity of the compound.

2. Product from 4-p-Toluoyl-5-phenyl-1,2-dithiole-3-thione

Quantities :

4-p-Toluoyl-5-phenyl-1,2-dithiole-3-thione	(1 g., 2.9m.mole)
Xylene	(4.2 ml.)
Phosphorus pentasulphide	(1 g.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A green band which gave a brown oil (0.1 g.). Crystallisation from an ethanol - ethyl acetate 1 : 1 mixture (2 ml.) gave brown prisms, (0.07 g., 7%), m.p. 125-127°. The n.m.r. and infrared spectra were identical with those obtained from fraction (i), experiment 1.

3. 4-p-Thiotoluoyl-5-p-tolyl-1,2-dithiole-3-thione

Quantities :

4-p-Toluoyl-5-p-tolyl-1,2-dithiole-3-thione	(1 g., 2.9m.mole)
Xylene	(4 ml.)
Phosphorus pentasulphide	(1 g.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A green band which gave a brown oil (0.09 g.). Crystallisation from an ethyl acetate - ethanol 1 : 1 mixture (2 ml.) gave the thione, (0.06 g., 6%), brown prisms, m.p. 151-152°.

Found : C,60.44; H,4.37; S,34.7%

$C_{18}H_{14}S_4$ requires : C,60.29; H,3.94; S,35.8%

(ii) A red band which gave a red solid,(0.06 g.),m.p. 148-149° undepressed when mixed with starting material.

4. Product from 4-Benzoyl-5-p-methoxyphenyl-1,2-dithiole-3-thione

Quantities :

4-Benzoyl-5-p-methoxyphenyl-1,2-dithiole-3-thione	(2 g., 5.8m.mole)
Xylene	(8 ml.)
Phosphorus pentasulphide	(2 g.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A green band which gave a brown oil (0.1 g.). Crystallisation from an ethyl acetate - ethanol 1 : 1 mixture (2 ml.) gave brown prisms possessing a green reflex,(0.065 g., 3%),m.p. 133-136°.

Found : C,56.84; H,3.62; S,35.1%

$C_{17}H_{12}OS_4$ requires : C,56.63; H,3.36; S,35.6%

(ii) A red band which gave a red oil (0.05 g.) which solidified on standing. The infrared spectrum was identical with that of the starting material and the mixed melting point showed no depression.

5. Product from 4-p-Methoxybenzoyl-5-phenyl-1,2-dithiole-3-thione

Quantities :

4-p-Methoxybenzoyl-5-phenyl-1,2-dithiole-3-thione	(1.3 g., 3.77m.mole)
Xylene	(5.2 ml.)
Phosphorus pentasulphide	(1.3 g.)

Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave :

(i) A green band which gave a brown oil (0.03 g.). Crystallisation from an ethanol - ethyl acetate 1 : 1 mixture (1 ml.) gave brown prisms possessing a green reflex, (0.02 g., 1.5%), m.p. 133-136°. The infrared and n.m.r. spectra were identical with those obtained from fraction (i) in experiment 4.

(ii) A red band which gave a red solid (0.04 g.), the infrared spectrum of which was identical with that of the starting material.

Part (C) : Compounds Derived from 4,6-Diphenylpyran and 3-Phenacylidene- and 3-Thiophenacylidene-5-phenyl-1,2-dithiole

(i) Compounds Derived from 3-Phenacylidene- and 3-Thiophenacylidene-5-phenyl-1,2-dithiole

1. Triethyloxonium fluoborate

The method is described in "Organic Syntheses"[116].

Yield = 60 g. from 35 g. of epichlorohydrin = 83%

m.p. = 91-92° (lit.m.p. = 91-92°)

2. 3-Phenacylidene-5-phenyl-1,2-dithiole

METHOD A

(i) 3-Methylthio-5-phenyl-1,2-dithiolium iodide

5-Phenyl-1,2-dithiole-3-thione (5 g., 23.8 m.mole) was boiled under reflux with iodomethane (30 ml.) for 3 hr. The methiodide gradually separated from solution as red plates (7.75 g., 80%).

(ii) 3-Phenacylidene-5-phenyl-1,2-dithiole

Sodium (0.27 g., 0.011 g.atom) was dissolved in ethanol (190 ml.) and then benzoyl acetic acid (1.93 g., 0.011 mole) was added. To the mixture was added 5-phenyl-3-methylthio-1,2-dithiolium iodide (3.87 g., 0.011 mole) with shaking and the mixture gently heated until it was homogeneous. The reaction mixture was then poured into water and the resulting brown oil extracted into chloroform, washed with water and then dried. The chloroform was distilled and the residue chromatographed on alumina in a light petroleum (40-60°) - benzene 2 : 1 mixture to give as a third fraction an orange band which, on concentration, gave a brown solid (0.45 g.). Recrystallisation from ethanol gave the ketone,

(0.3 g., 9%), brown flakes, m.p. 131-132°.

METHOD B

(i) Ethyl 2'-(5-phenyl-1,2-dithiole-3-ylidene)benzoylacetate

To a solution of sodium (0.23 g., 0.01 g.atom) in ethanol (20 ml.) was added ethyl benzoylacetate (1.92g., 0.01 mole). To the resulting solution was added 3-methylthio-5-phenyl-1,2-dithiolium iodide (3.52 g., 0.01 mole) and the mixture boiled under reflux for 1 hr. The ethanol was removed by distillation and the residue chromatographed on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture to give :

(i) A brown band which gave a brown solid (0.5 g.) which was not identified.

(ii) A brown band which gave a brown solid (0.57 g.). Recrystallisation from an ethanol - benzene mixture gave brown prisms (0.41 g.), m.p. 125-127°. The infrared spectrum was identical with that of 5-phenyl-1,2-dithiole-3-thione and the mixed melting point was undepressed.

(iii) A green band which gave a brown solid (1.65 g.). Recrystallisation from ethanol gave the ester, (1.0 g., 27%), brown flakes, m.p. 129-130°. ν_{max} 1690 cm^{-1} (COOEt). N.m.r. spectrum (a) singlet, 1.28τ (dithiole ring proton); (b) multiplet, 2.14τ -2.74τ (phenyl protons); (c) quartet 5.78τ-6.15τ, triplet 9.02τ -9.25τ (ethyl protons); relative intensities 1 : 10 : 5, the ester requires 1 : 10 : 5.

Found : C, 64.84; H, 4.52; S, 17.8%

$C_{20}H_{16}O_3S_2$ requires : C, 65.19; H, 4.38; S, 17.40%

Attempted Hydrolysis of the Ester

(a) The ester (0.5 g., 0.00136 mole) and 15% HCl (40 ml.) were boiled under reflux for 6 hr. No hydrolysis occurred.

(b) The ester (0.5 g., 0.00136 mole) in 80% acetic acid (40 ml.) was boiled under reflux for 3 hr. to give unchanged ester.

(c) The ester (1.45 g., 0.00408 mole) was dissolved in boiling glacial acetic acid and then 48% HBr (4 ml.) was added. The mixture was boiled for 24 hr. and then a further 4 ml. of HBr was added and boiling was continued for another 24 hr. No 5-phenyl-3-phenacylidene-1,2-dithiole was obtained.

3. 3-Thiophenacylidene-5-phenyl-1,2-dithiole

(i) 2-Thiophenacylidene-5-phenyl-1,3-dithiole

5-Phenyl-1,2-dithiole-3-thione (6.3 g., 0.03 mole) and phenylacetylene (9.18 g., 0.09 mole) dissolved in dry benzene (100 ml.) were boiled under reflux for several days by which time 4.1 g. (27%) of thione, m.p. 194-196° had separated.

(ii) 3-Thiophenacylidene-5-phenyl-1,2-dithiole

2-Thiophenacylidene-5-phenyl-1,3-dithiole (4.1 g., 0.0131mole) was heated in an open tube at 200° for 3 hr. The mixture was then allowed to cool and recrystallised from 1,2,2-trichloroethane to give the thione (2.1 g., 50%), purple prisms possessing a green reflex, m.p. 163-164° (lit.m.p. 163-164°).

Reaction of 3-Phenacylidene-5-phenyl-1,2-dithiole with Triethyloxonium fluoborate

3-Phenacylidene-5-phenyl-1,2-dithiole (0.3 g., 0.001 mole) and

triethyloxonium fluoborate (0.2 g., 0.001 mole) dissolved in dry chloroform (5 ml.) were boiled under reflux for 5 min. and then allowed to stand at room temperature for several days. A brown solid, (0.4 g.), m.p. 128-154° separated which was not purified.

Reaction of 3-Thiophenacylidene-5-phenyl-1,2-dithiole with Triethyloxonium fluoborate

3-Thiophenacylidene-5-phenyl-1,2-dithiole (0.31 g., 0.001 mole) and triethyloxonium fluoborate (0.2 g., 0.001 mole) dissolved in dry chloroform (5 ml.) was boiled under reflux for 5 min. and then allowed to stand overnight at room temperature. The addition of ether gave a brown oil which solidified on standing to give the dithiolium salt, (0.32 g., 64%), brown prisms, m.p. 143-144°. N.m.r. spectrum : (a) singlet, 1.38τ (dithiole ring proton); (b) multiplet, 1.90 -2.37τ, (olefinic proton and phenyl protons); (c) quartet 6.68 -7.05τ; triplet 8.56 -8.80τ, (ethyl protons); relative intensities 1 : 11 : 5, the dithiolium salt requires 1 : 11 : 5

Found : C,52.73; H,3.65; S,22.5%

$C_{19}H_{17}BF_4S_3$ requires : C,53.27; H,4.00; S,22.5%

Reaction of 3-(α-Ethylthiobenzylidene)-5-phenyl-1,2-dithiolium fluoborate with Aniline

A solution of aniline (0.4 g., 0.004 mole) in ethanol (5 ml.) was added to a solution of triethyloxonium fluoborate (0.85 g., 0.002 mole) in ethanol (5 ml.) and the mixture allowed to stand at room temperature for 2 hr. The ethanol was distilled and the residue chromatographed

on alumina in benzene to give a red band. Distillation gave a residual brown solid which recrystallised from an ethanol - benzene mixture to give the 1,2-dithiole, (0.5 g., 33%), reddish-brown prisms, m.p. 160°d. N.m.r. spectrum : (a) multiplet, 2.08 -2.22 τ, dithiole ring proton and olefinic proton); (b) multiplet, 2.56 -3.01 τ, (phenyl protons), relative intensities 2 : 15, the 1,2-dithiole requires 2 : 15.

Found : C,74.14; H,4.58; N,3.5; S,17.4%

$C_{23}H_{17}NS_2$ requires : C,74.36; H,4.61; N,3.8; S,17.3%

Part (C) : (ii) 4,6-Diphenylpyran Derivatives

GENERAL MATERIALS

1. 2-Methylthio-4,6-diphenylpyrylium iodide

4,6-Diphenylpyran (1.25 g., 0.0054 mole) was boiled under reflux for 3 hr. with iodomethane (20 ml.). The iodide gradually separated from the reaction mixture as red plates, (1.8 g., 86%), m.p. 182-184°.

2. Ethyl 2-(4,6-diphenylpyran-2-ylidene)benzoylacetate

Sodium (0.04 g., 0.0017 g.atom) was dissolved in ethanol (5 ml.) and then ethyl benzoylacetate (0.32 g., 0.00166 mole) was added. To the resulting solution was added 2-methylthio-4,6-diphenylpyrylium iodide (0.6 g., 0.0015mole) and the mixture boiled under reflux for 1 hr. The ethanol was then distilled and the residue chromatographed on alumina in benzene to give :

(i) A yellow oil (trace).

(ii) A brown oil (0.04 g.) which remains unidentified.

(iii) A red band which gave a red solid. Recrystallisation from ethanol gave the ester, (0.13 g., 20 %), red needles, m.p. 171-172°. ν_{max} 1660 cm^{-1} (COOEt), $_{max}$1620cm^{-1} (C = O). N.m.r. spectrum : (a) multiplets at 1.69τ and 3.17τ (pyran ring protons); (b) multiplet, 1.88 -2.75 τ, (phenyl protons); (c) quartet, 5.70 - 6.04 τ ; triplet 8.86 -9.08 τ (ethyl protons); relative intensities 2 : 15 : 5, the ester requires 2 : 15 : 5.

Found : C,79.22; H,5.23%

$C_{28}H_{23}O_4$ requires : C,79.41; H,5.47%

2-Phenacylidene-4,6-diphenylpyran

METHOD A

Sodium (0.071 g., 0.00288 g.atom) was dissolved in ethanol (50 ml.) and then benzoylacetic acid (0.51 g., 2.88 m.mole) was added. To the resulting suspension was added 2-methylthio-4,6-diphenylpyrylium iodide (1.18 g., 2.88m.mole) and the mixture was warmed to give a clear solution. The reaction mixture was then poured into water and the resulting red oil was extracted into chloroform, washed with water and then dried. The chloroform was distilled and the residue chromatographed on alumina in benzene to give :

(i) A yellow band which gave a brown oil (0.37 g.) possessing a strong odour of acetophenone.

(ii) A red band which gave a red solid (0.2 g.) which was shown by comparison of infrared spectra to be a mixture of the required pyran and some other unidentified compound.

METHOD B

Ethyl 2-(4,6-diphenylpyran-2-ylidene)-benzoylacetate (0.08 g., 0.2 m.mole) dissolved in acetic acid was boiled under reflux and then 48% hydrogen bromide (0.2 ml.) was added. The mixture was refluxed for 48 hr., the addition of hydrogen bromide being repeated after 24 hr. The reaction mixture was cooled, poured into water and the mixture basified with dilute sodium hydroxide solution. The product was extracted into chloroform, washed with water and then dried. Chromatography on alumina in a light petroleum (40-60°) - benzene 1 : 1 mixture gave a purple band which gave a maroon oil (trace) which was not identified.

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