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CYCLIC SULPHURDIIMIDES

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MEHUL AMIN

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Hofmann Laboratory

Department of Chemistry

Imperial College

London SW7 2AY

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To my parents, with love.

ABSTRACT

The synthesis, chemistry and structures of dithiatetrazocines and related mono-, bi- and tri-cyclic carbon-sulphur-nitrogen heterocyclic compounds are reviewed.

Various routes to 1,5,2,4,6,8-dithiatetrazocines were investigated using sulphur transfer reagents such as sulphur monochloride, thionyl chloride, tetrasulphur tetranitride and bis(tosyl)-sulphurdiimide. The reactions of amidines with these various reagents were explored and the chemistry of diphenyl-, di(2-thienyl)-, and bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocines was investigated.

Several new methods for the synthesis of 1,2,4,6-thiatriazines were discovered during the course of the above study and mechanisms for the formation of these thiatriazines are discussed. The chemistry of S-alkoxythiatriazines, particularly their oxidation, is discussed in detail, as are mechanistic aspects of the novel formation of 2-(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine.

Reactions of dithiolates and dithiols with N,N'-dibromo-S,S-dimethyl-sulphurdiimide and of bis(sulphenyl chlorides) with N,N'-bis-(trimethylsilyl)-S,S-dimethylsulphurdiimide were investigated in an attempt to synthesise the corresponding S,S-dialkylated trithiadiazepines; however, dithiazolium salts were obtained in high yields. Reaction of benzene-1,2-bis(sulphenyl chloride) with N,N,N'-tris(trimethylsilyl)-S-iminobenzsulphenamide was also investigated and found to give benzodithiazolium chloride in high yield.

Unsuccessful attempts to synthesise two potentially 8π antiaromatic systems, 1,3,2,4-benzodithiadiazepin-5-one and 3,6-diphenyl-1,2,4,5,7-thiatetrazepine, are also described.

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ABBREVIATIONS

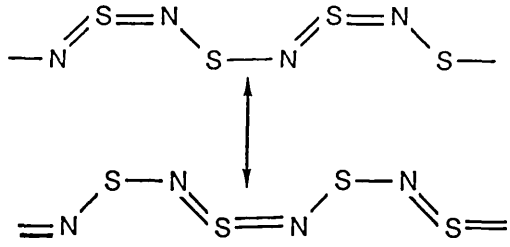
A	Å, Angstrom units
CCl_4	Tetrachloromethane
CH_2Cl_2	Dichloromethane
CH_3CN	Acetonitrile
DBU	1,8-Diazabicyclo[5.4.0]undec-7-ene
DDQ	2,3-Dichloro-5,6-dicyanobenzoquinone
DMAD	Dimethyl acetylenedicarboxylate
DMSO	Dimethyl sulphoxide
eq.	Equivalent
i.r.	Infrared
MCPBA	meta-Chloroperoxybenzoic acid
NBD	norbornadiene
n.m.r.	Nuclear magnetic resonance
TCNQ	7,7,8,8-Tetracyanoquinodimethane
TDA-1	Tris[2-(2-methoxyethoxy)ethyl]amine
THF	Tetrahydrofuran
t.l.c.	Thin layer chromatography
TMS	Tetramethylsilane or Trimethylsilyl group
u.v.	Ultraviolet
Δ	Heat under reflux

CHAPTER 1

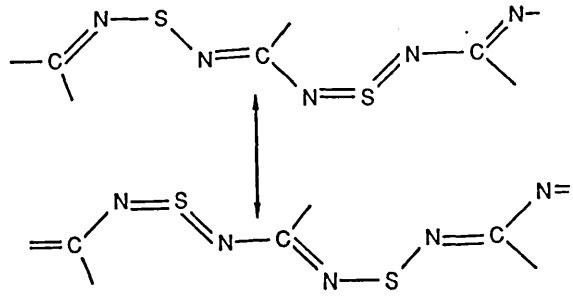
INTRODUCTION

1.1.1 1,5,2,4,6,8-Dithiatetrazocines

Poly(sulphur nitride)(1)[1] is a very important material since it was the first non-metal to show superconducting properties at 0.3 K,[2] thus extending the phenomenon of superconductivity into a new region of the Periodic Table. It is however thermally unstable and air-sensitive, which precludes any direct practical application. Since poly(sulphur-nitrogen) heterocyclic compounds have been shown to be stabilised by the introduction of carbon atoms,[3] it is possible that stabilisation of the $(\text{sulphur-nitride})_x$ polymer could be achieved in the same way.



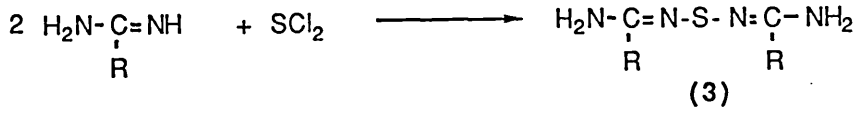
(1)



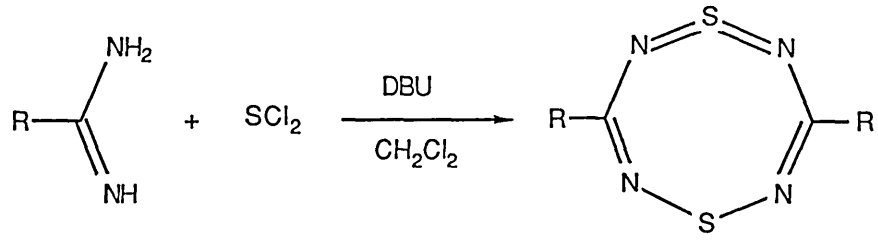
(2)

With this in mind, workers at the Woodward Institute began research directed towards the synthesis of carbon-sulphur-nitrogen polymers

(2)[4] as promising candidates for conductivity. One of the ways considered for the construction of such polymeric compounds involved the intermediate (3), the expected product from the reaction of two molecules of an amidine and one molecule of sulphur dichloride. The reaction of benzamidine with sulphur dichloride, in the presence of diazabicycloundecene, proved to be very complicated and no compound of structure (3)(R=Ph) was isolated. The product, isolated as transparent yellow plates, m.p. 225-226°C, in 5-10% yield, was found to be 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a).



(3)



(4)

a ; R = Ph
b ; R = H
c ; R = NMe_2
d ; R = p-OMe Ph
e ; R = p -CO_2Et Ph
f ; R = tert-Butyl

X-Ray crystallographic structure determination showed that the novel eight-membered heterocyclic ring was perfectly planar, with the two phenyl rings only slightly twisted out of the plane by 9.7°. All S-N

bond lengths in the dithiatetrazocine ring system (4a) were found to be equal as were those of its C-N bonds. All these findings indicated that (4a) was a delocalised 10 π system (Fig. 1.1).

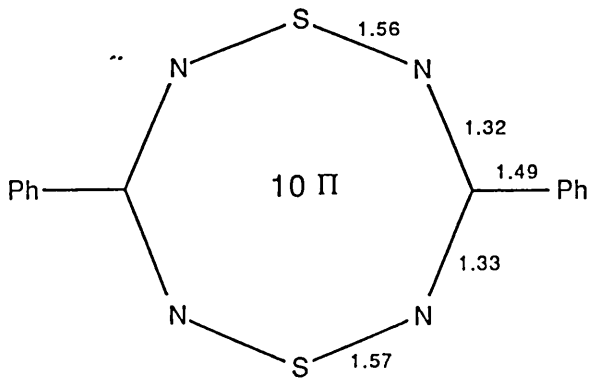


Figure 1.1 : Structure of 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine.

The observed long wavelength u.v. absorptions at 409 and 318 nm, characteristic of π to π^* transitions, were also consistent with the molecule having an aromatic nature. Compound (4a) showed slight solubility in most organic solvents and was found to possess remarkable thermal stability, decomposing only slowly to benzonitrile when heated neat at 220-240° C. It was also stable with respect to oxidation by m-chloroperoxybenzoic acid in boiling dichloromethane and unreactive towards stoichiometric amounts of various nucleophiles such as benzylamine, lithium benzothiazolyl-2-mercaptide, sodium hexamethyldisilazane and butyllithium . It was however hydrolysed to benzamidine with hydrochloric acid or potassium hydroxide in aqueous dioxane.

Attempts to prepare the parent 1,5,2,4,6,8-dithiatetrazocine (4b) by the same method proved unsuccessful, but the reaction of N,N-dimethylguanidine with sulphur dichloride gave the corresponding 3,7-bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c) as yellow crystals, m.p. 212°C, in 54% yield.

Surprisingly the ultraviolet spectrum of the bis(dimethylamino) compound (4c) was very different from that of the phenyl-substituted compound (4a), having no $\lambda_{max.}$ beyond 229 nm. X-Ray crystal structure determination provided an explanation for this, showing that the dithiatetrazocine ring of (4c) was no longer planar but folded along an axis drawn through the two sulphur atoms of the eight-membered ring. All the ring atoms were located in the two planes which intersected the above mentioned axis at an angle of 101° (Fig. 1.2).

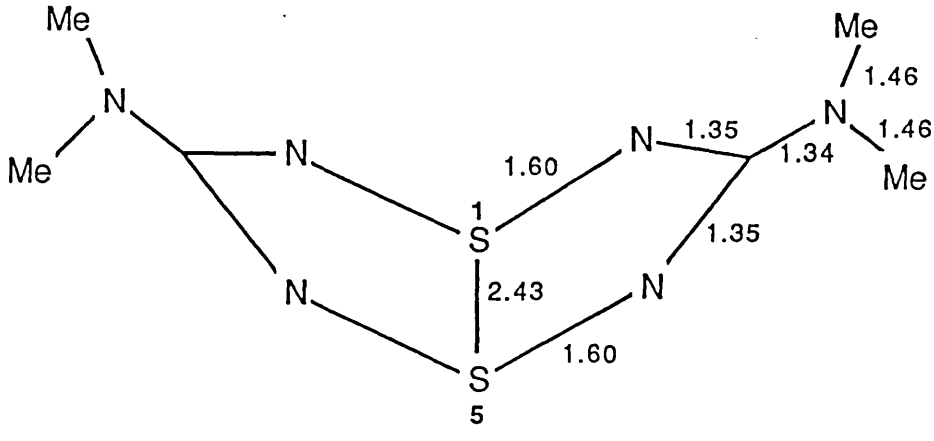
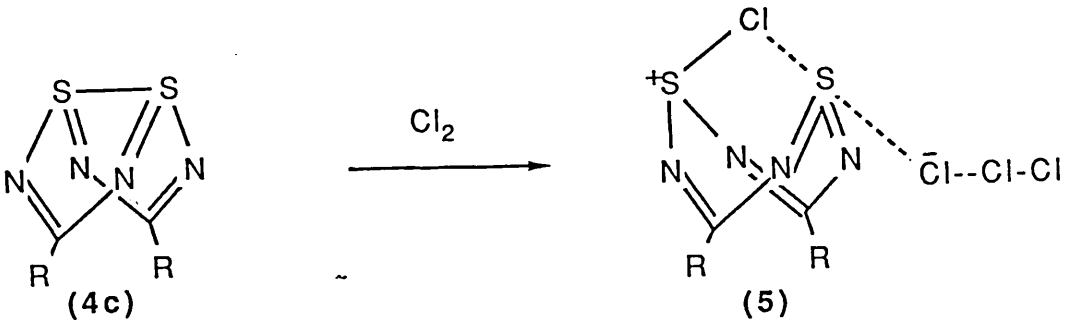


Figure 1.2 : Structure of 3,7-bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c).

The transannular S-S distance in (4c) was only 2.43 A whereas in the planar ring of (4a), this distance was 3.79 A. It was longer than a disulphide bond (2.06 A in S_8) but substantially shorter than the sum of two sulphur van der Waals radii (3.6 A), thus suggesting partial S-S bonding in (4c). To study further this remarkable effect of ring substituents on the shape and electronic spectra of 1,5,2,4,6,8-dithiatetrazocines, three more derivatives di(p-methoxyphenyl)dithiatetrazocine (4d),[4] di[p-(ethoxycarbonyl)-phenyl]dithiatetrazocine(4e)[4] and di(tert-butyl)dithiatetrazocine (4f)[5] were made; in all of these the heterocyclic ring was planar. The main aim of the present work was to improve on the synthesis of this dithiatetrazocine ring system, to study its chemistry, and to synthesise related novel cyclic sulphurdiimides.

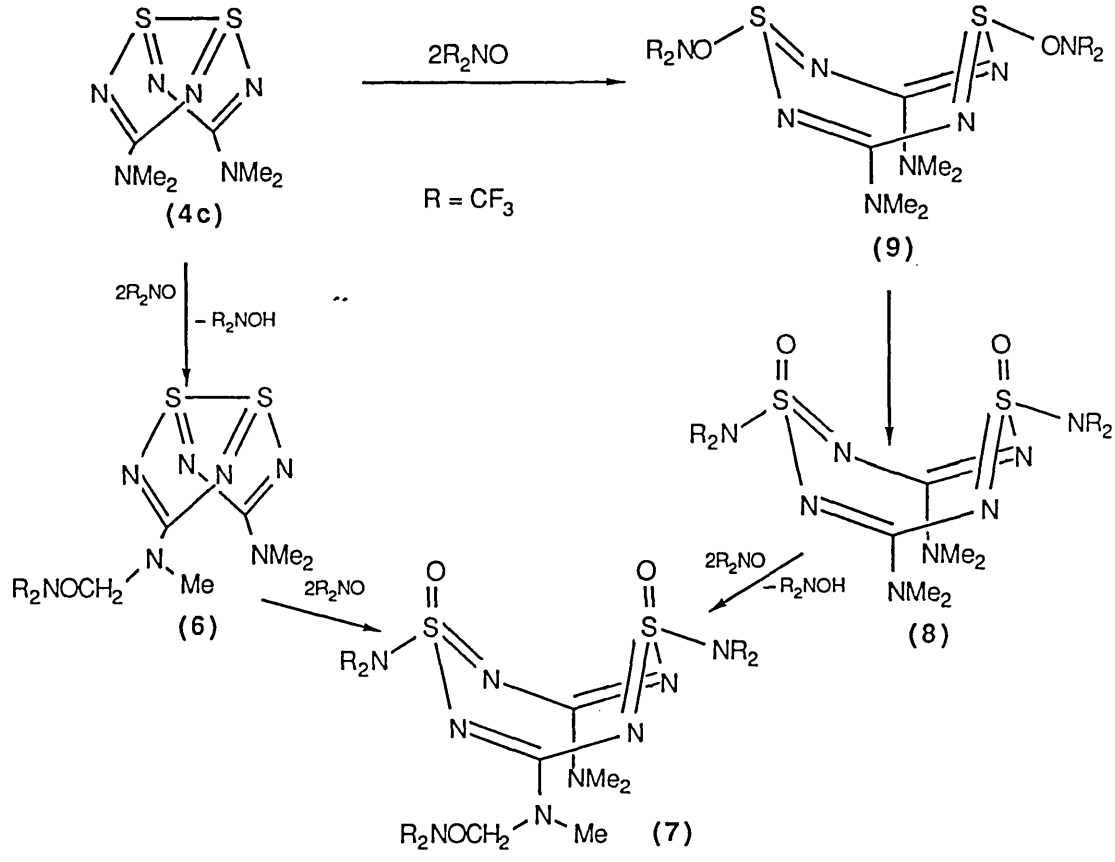
1.1.2 Oxidation of 1,5,2,4,6,8-dithiatetrazocines

Oxidation of 3,7-bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c) with chlorine in acetonitrile afforded the trichloride salt $[(Me_2N)_2C_2N_4S_2Cl]^+[Cl_3]^-$ (5). X-Ray crystallographic analysis of (5)[6] revealed a puckered heterocyclic ring ($C_2N_4S_2$) cation possessing an asymmetric S-Cl---S transannular bridge. Dithiatetrazocine (4c) was found to be inert to radical attack[7] as it failed to react with tert-butyl peroxide and benzoyl peroxide.



However it reacted with the highly nucleophilic radical bis(trifluoromethyl)nitroxide [$(CF_3)_2NO$] giving three products.[7] The two minor products (6) and (7) possessed an exocyclic $CH_2ON(CF_3)_2$ unit formed, presumably, by radical attack at a methyl group, abstraction of a hydrogen atom to produce $(CF_3)_2NOH$, and of subsequent uptake of a second molecule of $(CF_3)_2NO$ (Scheme 1.1). The major product was an air stable colourless crystalline solid with the apparent composition $(Me_2N)_2C_2N_4S_2[ON(CF_3)_2]_2$. X-Ray structural analysis revealed the rearranged structure (8). It showed a boat-shaped conformation for the heterocyclic ring with the two $N(CF_3)_2$ groups occupying equatorial sites on the same side of the ring. This geometry was considered to arise from an intramolecular rearrangement of the initially produced cis-bis(nitroxide) derivative (9).

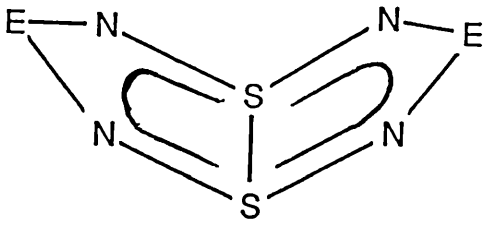
In contrast to the relative reactivity of $(Me_2N)_2C_2N_4S_2$ (4c), its phenyl substituted analogue $Ph_2C_2N_4S_2$ (4a) was completely inert; it did not undergo oxidation by any of the radical or polar oxidants mentioned above. Evidently the planar 10 π electron system of the latter seemed sufficiently robust to resist addition reactions.



Scheme 1.1 : The overall reaction sequence in the treatment of 3,7-bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c) with $(CF_3)_2NO$.

1.2 Related dithiatetrazocines

There is a family of eight-membered rings related to dithiatetrazocines in which the two carbon atoms have been replaced by other atoms such as arsenic,[8] phosphorus,[9] silicon[10] and sulphur.[11] The molecular structures of some of these derivatives exhibit a folded conformation with a close (2.50 - 2.60 A) transannular sulphur-sulphur contact (10).

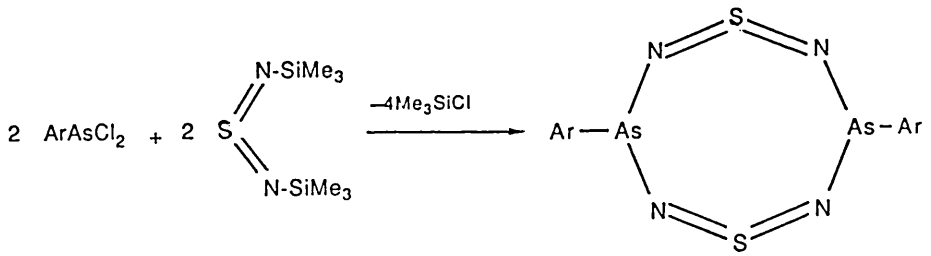


(10)

E = PMe_2
PPh_2
SCl
$SNMe_2$
$SNPPh_2$

(i) 3H,7H-1,5,2,4,6,8,3,7-Dithiatetrazadiarsocines

3,7-Diaryl-3H,7H-1,5,2,4,6,8,3,7-dithiatetrazadiarsocines (12) were made by treating arylarsenic dichlorides with N,N'-bis(trimethylsilyl)sulphurdiimide (11a) in a 1:1 mixture of hexane and dichloromethane.



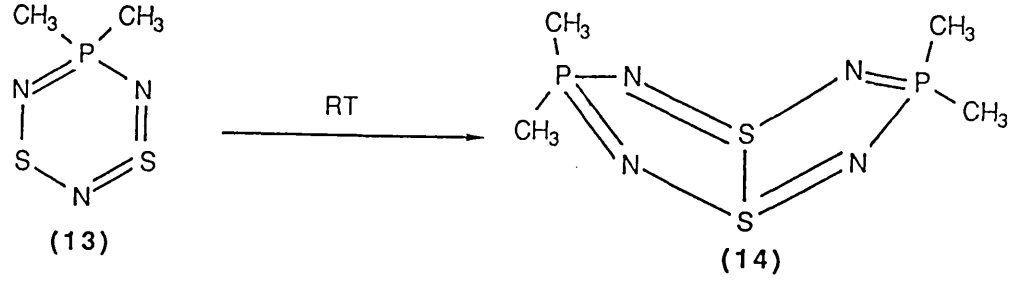
(11a) (12)

X-Ray structure determination of (12) showed that the eight-membered $As_2S_2N_4$ system existed as a boat-shaped ring with the arsenic atoms at prow and stern positions. The four nitrogen atoms were coplanar, with the two arsenic atoms on one side of the plane and the two sulphur atoms on the other side. The cross-ring sulphur-sulphur distance (4.04 A) was longer than the van der Waals contact distance (3.60-3.66 A).[12] The cross-ring As-As average distance of 3.49 A was

shorter than the sum of the van der Waals radii of arsenic (3.7 A), hence signifying weak As-As interaction. Bond angles at arsenic ranged from 94 to 101°, consistent with the formulation of the arsenic hybridization as sp^3 with an unshared pair of electrons occupying the fourth orbital. The -N=S=N- linkages in $(Ar)_2As_2S_2N_4$ (12) involve four delocalised electrons, one contributed by each nitrogen and two by the sulphur. This view was consistent with the bond lengths and the angles subtended at sulphur and nitrogen.

(ii) 1,5,2,4,6,8,3,7-Dithiatetrazadiphosphocine

Phosphodithiatriazine ((13), R=Me) decomposed at room temperature under nitrogen to give S_4N_4, $(Me_2PN)_3$, $(Me_2PN)_4$ and a yellow crystalline compound found to be dithiatetrazadiphosphocine (14). The phosphorus-31 n.m.r spectrum of (14) exhibited a singlet, indicating equivalent phosphorus atoms. The proton n.m.r spectrum consisted of two singlets, and the carbon-13 n.m.r spectrum, which showed two doublets, suggested non-equivalent pairs of methyl groups, thus ruling out a planar configuration for the eight-membered ring. Further structural information came from the Raman spectrum, which showed a strong band at 250 cm^{-1} ascribed to transannular S-S bonding; similar bonding in S_5N_6 resulted in a strong Raman band at 269 cm^{-1}.[13]



(13) (14)

X-Ray structure determination confirmed the spectroscopic assignment of an eight-membered ring with significant S-S cross-ring bonding interaction. As a result of the crystallographic mirror plane, the two sulphur and two nitrogen atoms formed two four-membered planes that intersected at an angle of 115° [cf the analogous angle of 101° in $Me_2NC(NSN)_2CNMe_2$, Section 1.1.1]. The phosphorus atoms lay out of and on opposite sides of these planes.

(iii) 3,3,7,7-Tetramethyl-1,5,2,4,6,8,3,7-dithiatetrazadisilocine

When bis(trimethylstannyl)sulphurdiimide (15) was treated with dimethyldichlorosilane in ether, 3,3,7,7-tetramethyl-1,5,2,4,6,8,3,7-dithiatetrazadisilocine (16) was obtained as a pale yellow compound (80%), m.p. 51°C.[10] It was very sensitive to hydrolysis and the X-ray analysis showed that the heterocyclic ring was not planar.

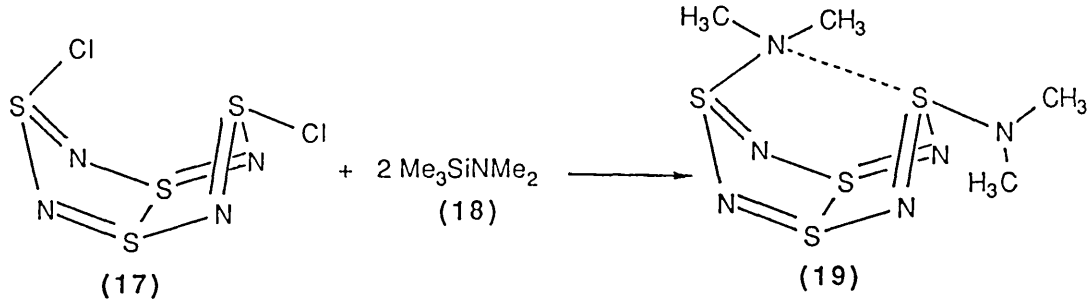


(15) (16)

(iv) 1,3,5,7,2,4,6,8-Cyclotetrathiazenes

1,5-Dichloro-1,3,5,7,2,4,6,8-cyclotetrathiazene (17)[11] was obtained from the reaction of chlorine gas with tetrasulphur tetranitride

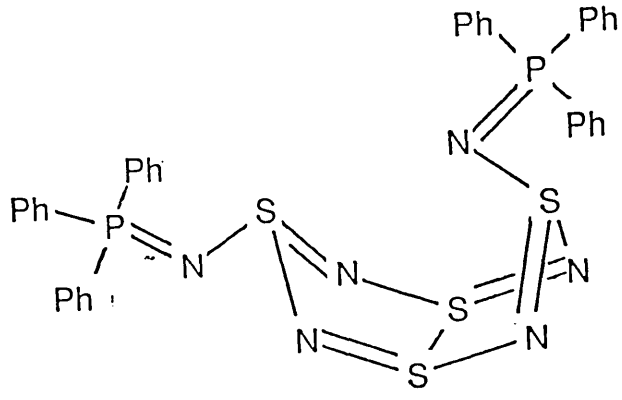
(S_4N_4) in carbon disulphide solution. X-Ray structure determination revealed the exo-endo isomer (17), with covalent S-Cl bonds. The average bond lengths were S-N 1.59 A and S-Cl 2.18 A; the angles were S-N-S 119°, N-S-N 109°, and N-S-Cl 104°. Treatment of (17) with trimethylsilyldimethylamine (18) gave 1,5-bis(dimethylamino)-1,3,5,7,2,4,6,8-cyclotetrathiazene (19).



(17) (19)

X-Ray structure analysis of (19) showed that it adopted a "saddle" conformation illustrated above. There was transannular S-S bonding and the two dimethylamino groups occupied exo and endo positions. The nitrogen atom of the exo group had a trigonal planar configuration while that of the endo was tetrahedrally co-ordinated. The lone electron pairs on nitrogen pointed exactly towards sulphur as shown.[11]

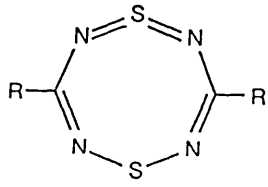
1,5-Bis(triphenylphosphinimino)cyclotetrathiazene (20)[14] was obtained as yellow crystals in 41% yield when S_4N_4 was treated with triphenylphosphine in acetonitrile at room temperature. X-Ray diffraction analysis of (20) showed that the structure consisted of a 1,5-disubstituted S_4N_4 cage where the two triphenylphosphinimino ligands were oriented in axial and equatorial directions.



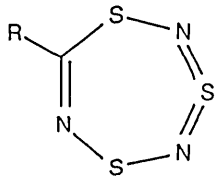
(20)

1.3 Related monocyclic 10π carbon-sulphur-nitrogen heterocycles

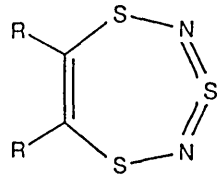
In addition to Woodward's 1,5,2,4,6,8-dithiatetrazocine (4)[4] only three other monocyclic 10π carbon-sulphur-nitrogen heterocyclic systems are known; these are the recently prepared 1,3,5,2,4,6-trithiatriazepines (21),[3, 16] 1,3,5,2,4-trithiadiazepines (22)[3, 17] and the 1,3,5,2,4,6,8-trithiatetrazocine cation (23).[15]



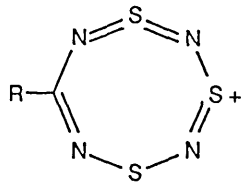
(4)



(21)



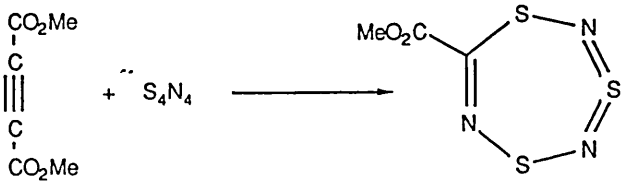
(22)



(23)

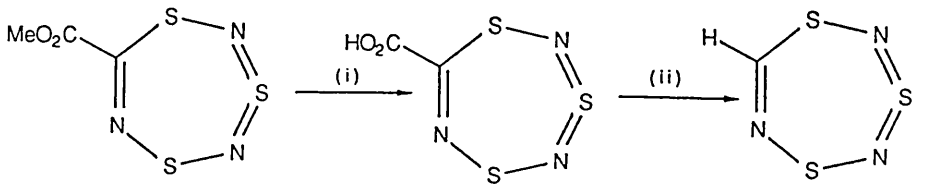
1.3.1 1,3,5,2,4,6-Trithiatriazepines

Methyl 1,3,5,2,4,6-trithiatriazepine-7-carboxylate (24) was prepared by the treatment of S_4N_4 with DMAD in boiling toluene in yields varying from 6 to 14%.[16]



(24)

Although a suitable alternative route to the trithiatriazepine system has not yet been devised, the parent compound (25) was obtained in almost quantitative yield by hydrolysis and decarboxylation of the 7-methoxycarbonyl derivative (24).[3]



(24) (25)

(i) : 5M HCl , 80°C, 2h

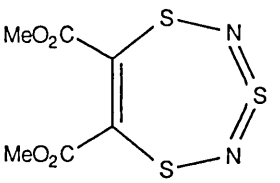
(ii) : Dioxane , reflux 2h

1,3,5,2,4,6-Trithiatriazepine (25) was formed as highly volatile, colourless plates, m.p. 43°C, with an asymmetric NSN vibration at $\nu_{max.}$ 1136 cm^{-1} and a long wavelength u.v. absorption ($\lambda_{max.}$ 327 nm), typical of an aromatic π to π^* transition. The trithiatriazepine ring proton resonated at δ 9.03 and the carbon

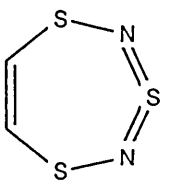
atom at δ 145.1 in the n.m.r spectra. These chemical shifts suggested a diamagnetic ring current and indicated aromatic character for trithiatriazepine. Owing to problems of disorder in the crystal lattice, the X-ray crystal structure determination for trithiatriazepine (25) could not be carried out. However the structure determination of the methyl ester (24) revealed it to be planar with intermediate bond lengths, indicating a delocalised structure.[16] The spectroscopic properties and thermal stability of trithiatriazepine (25) coupled with the planar, delocalised structure of methyl trithiatriazepine-7-carboxylate (24), indicate that it is a 10π aromatic system. The chemistry of this compound is under investigation in this Laboratory.

1.3.2 1,3,5,2,4-Trithiadiazepines

The reaction of S_4N_4 with DMAD in boiling toluene also gave the very stable dimethyl 1,3,5,2,4-trithiadiazepine-6,7-dicarboxylate (26) as a minor product.[16] This compound was the first example of the novel trithiadiazepine ring system , with 10π electrons delocalised over seven atoms. It was, therefore, of interest to synthesise the unsubstituted compound (27), to determine its stability and to see if its chemical reactivity was comparable with that of simpler heteroaromatic species.

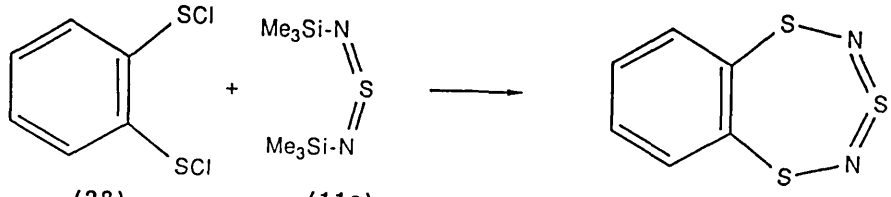


(26)



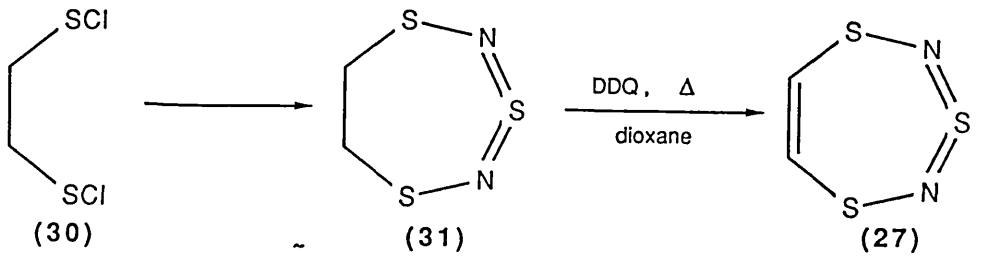
(27)

In view of the low yields and general lack of predictability of the S_4N_4 reactions, a rational synthesis was devised, initially for the benzo derivative (29).[17] This was based on the reaction of arylsulphenyl chlorides with bis(trimethylsilyl)sulphurdiimide (11a).[18] Thus, when dilute solutions in dichloromethane of benzene-1,2-bis(sulphenyl chloride) (28) and of the sulphurdiimide (11a), were added slowly and synchronously to a large volume of dichloromethane under nitrogen, 1,3,5,2,4-benzotrithiadiazepine (29) was obtained as stable, bright yellow crystals (50%). The aromatic nature of (29) was supported by its spectral properties and confirmed by X-ray diffraction which showed the molecule to be planar with delocalised ring bonds.[19]

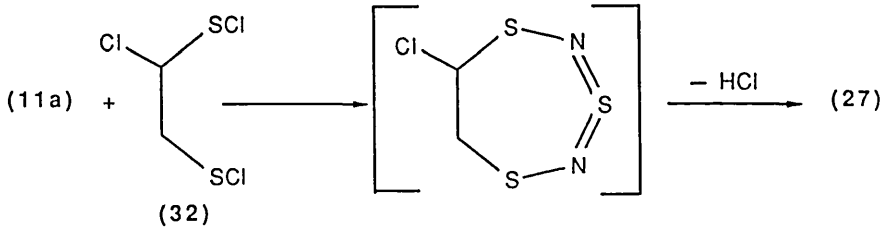


(28) (11a) (29)

This synthetic procedure could not be extended directly to the monocyclic compound because of the instability of Z-ethene-1,2-dithiol and the problems of its chlorination. However, the orange dihydro derivative (31) (20%) was obtained upon treatment of the bis(sulphenyl chloride)(30) with sulphurdiimide (11a) in dichloromethane as above.

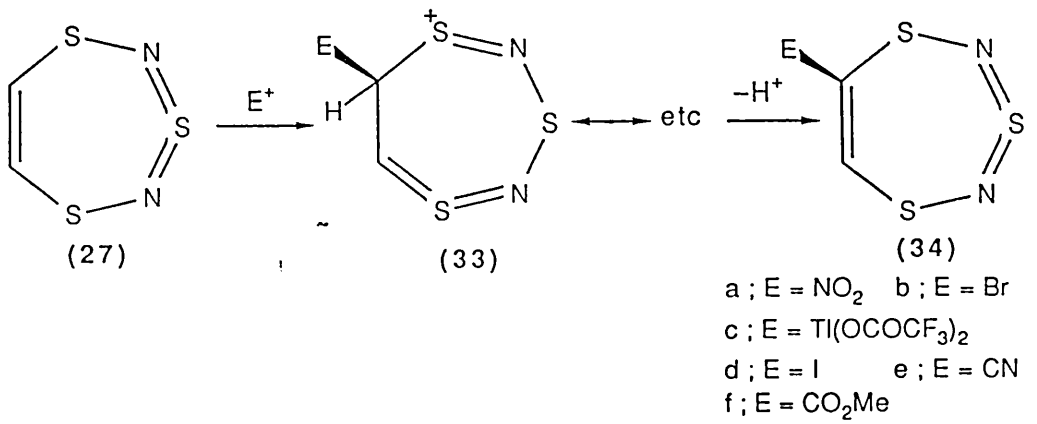


1,3,5,2,4-Trithiadiazepine (27) was obtained as stable, volatile colourless plates , m.p. 56-57°C (70%), by dehydrogenation of the dihydro derivative (31) with DDQ in boiling dioxane. An improved synthesis was observed upon the treatment of the trichloride (32) with sulphurdiimide (11a) as before, producing the parent trithiadiazepine (27), by spontaneous loss of hydrogen chloride, in 30% overall yield from ethane-1,2-dithiol. The spectroscopic properties of (27) and its X-ray diffraction analysis showed a fully delocalised structure; the molecule was planar, symmetrical, and had the intermediate bond lengths expected for an aromatic structure.



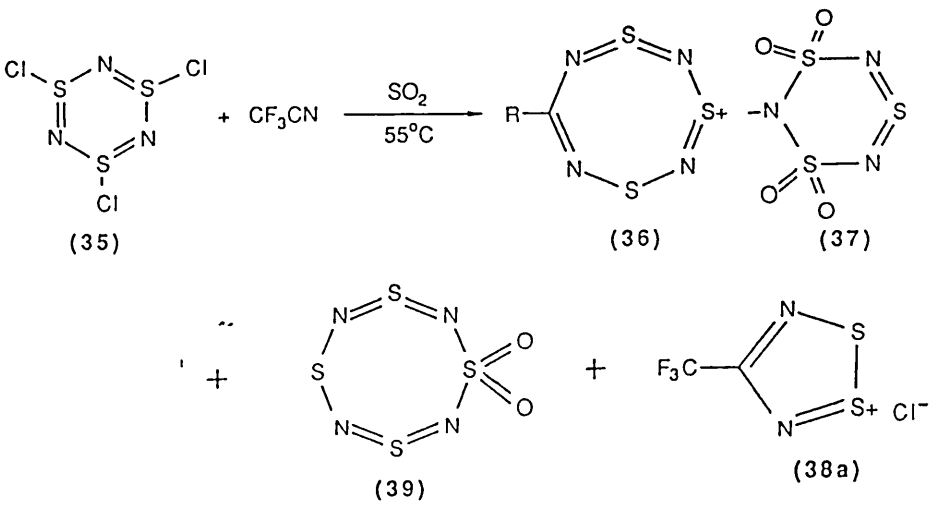
Trithiadiazepine (27) was thermally stable but it was rapidly decomposed on photolysis. It was inert towards protic and Lewis acids (acetic acid, aqueous hydrochloric acid, $AlCl_3$, and BF_3) and bases (triethylamine and benzylamine), but was rapidly destroyed by aqueous sodium hydroxide. Neither trithiadiazepine (27) nor its benzo derivative (29), despite their excess of π electrons (10π electrons over seven atoms in the trithiadiazepine ring), formed charge-transfer complexes with picric acid or tetracyanoethylene, for example. They also failed to undergo cycloaddition reactions with a range of 2π and 4π electron-rich and electron-poor components.

Trithiadiazepine (27) underwent some standard electrophilic aromatic substitution reactions, presumably via the tetrahedral intermediate (33), with the positive charge delocalised over all three sulphur atoms. Thus it has been smoothly mono- and di-nitrated and mono- and di-brominated in good yield. Electrophilic thallation of trithiadiazepine (27) with thallium tris(trifluoroacetate) in acetonitrile gave the hetarylthallium bis(trifluoroacetate) (34c) which, although it could not be isolated, was converted directly into the iodo (34d), cyano (34e), and methoxy-carbonyl (34f) derivatives of trithiadiazepine. However, trithiadiazepine (27) resisted acetylation, formylation, chlorosulphonation and nitrosation.



1.3.3 The 1,3,5,2,4,6,8-trithiatetrazocine cation

As recently as 1984, the "missing link" in the series of isoelectronic heterocycles $S_4N_4^{2+}$, $RCS_3N_4^{+}$, and $(RC)_2S_2N_4$ was synthesised by the reaction of trithiazyl trichloride (35) with trifloroacetonitrile.[15] The salt of the 7-trifluoromethyl-1,3,5,2,4,6,8-trithiatetrazocine cation (36) with the 1,1,3,3-tetraoxo-1,3,5,2,4,6-trithiatriazine anion (37) was isolated in 4% yield from the reaction mixture. Other products were the dithiadiazolium chloride (38a) and the S,S-dioxide (39). An X-ray structure analysis of the salt confirmed that the cation (36) had the planar geometry and intermediate bond lengths characteristic of a delocalised aromatic system.[15]



(35) (36) (37)

(39) (38a)

1.4 Bi- and tri-cyclic sulphurdiimides

The unique electrical property of the $(SN)_x$ polymer[20] has demonstrated the potential application of non-metallic chemistry in the development of new conducting materials. The preparation of polymers and macrocycles featuring a combination of carbon-carbon and sulphur-nitrogen linkages thus represents an appealing challenge to synthetic chemists. We now describe some further heterocyclic systems which have resulted from attempts of this kind.

1.4.1 Benzo-1,3,2,4-dithiadiazine

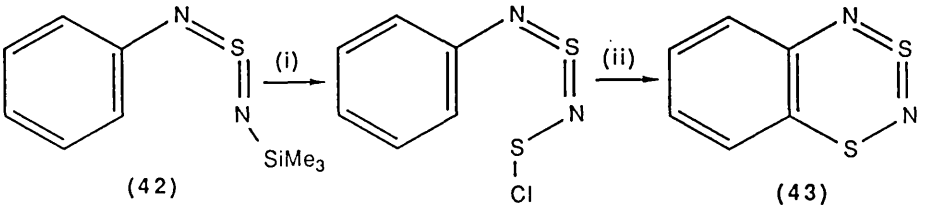
The coupling of silylated sulphurdiimides with sulphur dichloride is a widely-used method for producing conjugated sulphur-nitrogen oligomers[18, 21, 22] and polymers.[23] However, if the R group of (40) is an aromatic ring, instead of the metathetical elimination of trimethylsilyl chloride to form a N-S bond, electrophilic attack of the sulphenyl chloride group of (41) at the ortho-position of the

aromatic ring can occur.

$$\text{R-NSN-SiMe}_3 \;(40) \xrightarrow[-\text{Me}_3\text{SiCl}]{\text{SCl}_2} \text{R-NSN-SCl}\;(41)$$

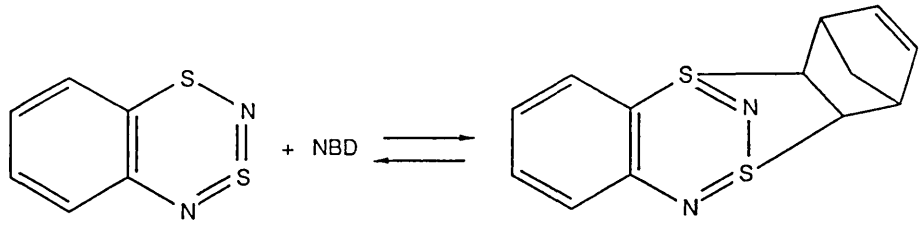
$$(40) + (41) \longrightarrow \text{R-NSN-S-NSN-R}$$

Hence when Oakley and his co-workers treated N-phenyl-N'-trimethylsilyl sulphurdiimide (42) with sulphur dichloride using the high dilution technique, they isolated deep blue fibrous needles, m.p. 48-50°C, in 33% yield. X-Ray diffraction analysis established the novel benzo-1,3,2,4-dithiadiazine structure (43).[24,25]



(i) : SCl_2 , – Me_3SiCl (ii) : –HCl

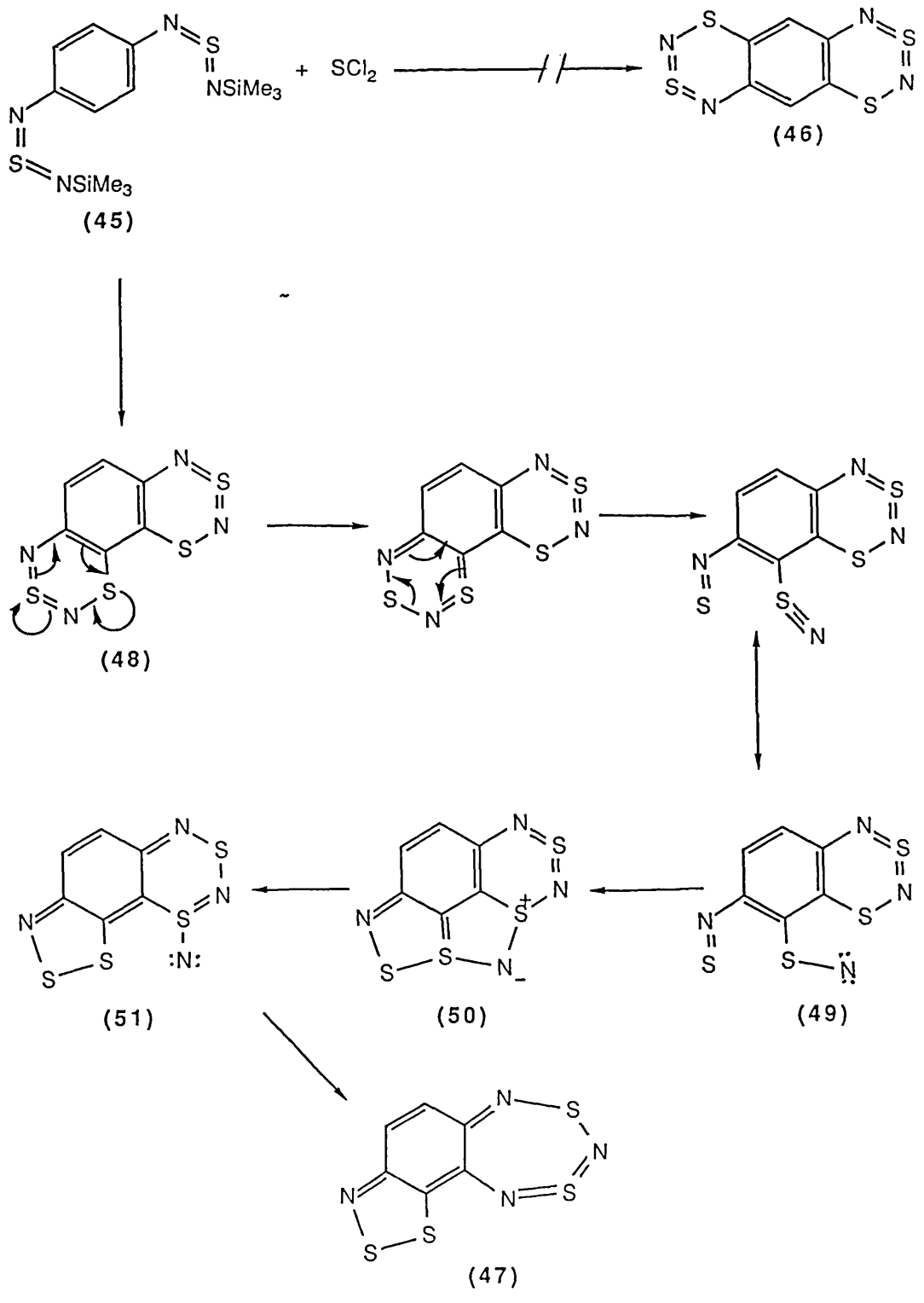
Dithiadiazine (43), formally an anti-aromatic 12π electron heterocycle, had an odour similar to that of naphthalene. It showed good solubility in organic solvents and was insoluble in water. However, it hydrolyzed slowly in moist air. It was thermally stable, recovered unchanged after being heated in refluxing toluene for 24h. When norbornadiene was added to an ethereal solution of 1,3,2,4-dithiadiazine (43), adduct (44)[25] was obtained in almost quantitative yield. When dissolved in dichloromethane or chloroform, the adduct dissociated into its separate components.



(43) (44)

1.4.2 1,2,7,9,3,6,8,10-Tetrathiatetrazacyclohept(e)indene

The above annelation reaction (Section 1.4.1) was the first example of a potentially general method for preparing electron-rich heterocycles based on the novel 1,3,2,4-dithiadiazine unit (43). To extend this work, the reaction of the bifunctional p-phenylene derivative (45), with sulphur dichloride was investigated with the intent of producing the tricyclic anthracene-like molecule (46). Apart from the principal product ie polymer $(-SNSNC_6H_4NSN-)_x$,[23] metallic golden needles, m.p. 254-257° found to be the novel 1,2,7,9,3,6,8,10-tetrathiatetrazacyclohept(e)indene (47),[26] were obtained in 1% yield (Scheme 1.2). The structure of (47) was determined by X-ray diffraction. The authors did not give an explanation for the formation of (47) rather than (46). In Scheme 1.2 we suggest a possible mechanism for the formation of (47). The treatment of (45) with two equivalents of sulphur dichloride initially forms the angular compound (48), which then rearranges to intermediate (49). This intermediate (49) could then collapse onto the adjacent dithiadiazine ring to form the tetracyclic compound (50) which then gives the observed product (47) by ring expansion of the nitrene (51).



Scheme 1.2 : Proposed mechanism for the formation of 1,2,7,9,3,6,8,10-tetrathiatetrazacyclohept(e)indene.

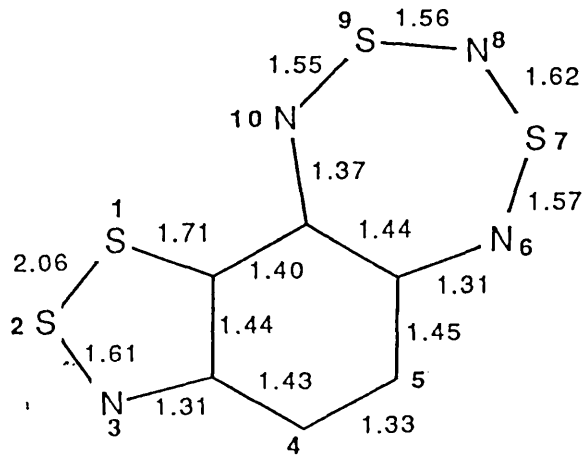
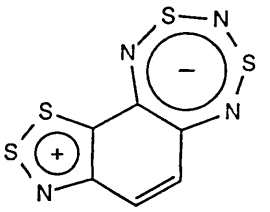


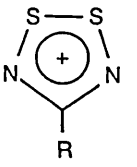
Figure 1.3 : Structure of 1,2,7,9,3,6,8,10-tetrathiatetraza-cyclohept(e)indene.

The structural parameters within the rings revealed a delocalised 18π electron system, other likely resonance contributors being dipolar forms with (52) best describing the main features of the molecular and crystal structures.[26]

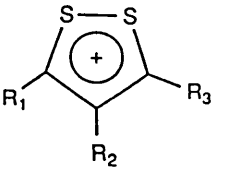
According to structure (52) the molecule consists of a cyclic five-atom 6π electron dithiazolium cation fused to a cyclic seven-atom 10π electron $C_2S_2N_3$ anion (Fig. 1.3). The strongly localised C4-C5 π-bond was reflected by its shortness (1.33 A) relative to the other C-C bonds (1.40-1.45 A) and the C-C distance in the benzene ring (1.39 A).[27] While the five-membered C_2S_2N ring was a simple analogue of dithiadiazolium (53)[28] and dithiolium (54)[29] cations, the seven-membered $C_2S_2N_3$ ring represented a novel structural unit in SN heterocyclic chemistry.



(52)



(53)



(54)

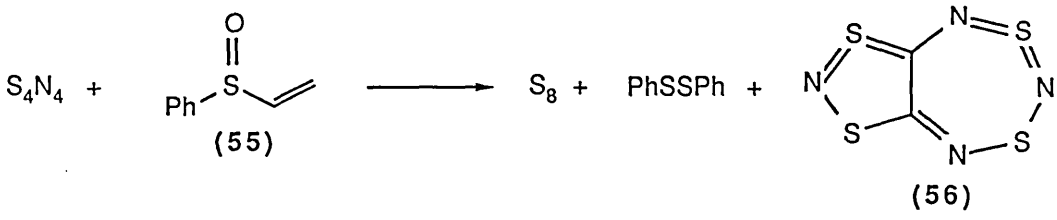
The arrangement of the molecules in the unit cell further favoured the dipolar representation (52). The molecules formed stacks, the packing being such that the five-membered ring of one molecule lay approximately over the seven-membered ring of the molecule below it. This pattern was found to repeat itself throughout the stack, producing an alternating sequence of molecules, ie the positively charged end of one molecule was sandwiched between the negative ends of its two nearest neighbours, and vice versa.

Further investigation into the synthesis of related derivatives and the chemistry of this novel 1,2,7,9,3,6,8,10-tetrathiatetraza-cyclohept[e]indene would be of interest.

1.4.3 1,3,5,7,2,4,6,8-Tetrathiatetraza-azulene

As recently as 1985, another example of the 1,3,2,4,7-dithiatriazepine ring system was reported. A green-black lustrous metallic like compound, $C_2N_4S_4$, m.p. 142-143°C, was obtained in 24% yield when S_4N_4 was heated with phenyl vinyl sulphoxide (55) in toluene. The thermal stability, deep colour, and u.v. spectrum ($\lambda_{max.}$ 492 nm) of this compound suggested a delocalised aromatic structure and indeed the X-ray diffraction showed it to be 1,3,5,7,2,4,6,8-tetrathiatetraza-azulene (56).[30] The molecule was

planar (Fig. 1.4), symmetrical about the N2-N6 axis, with all S-N bonds of approximately equal length (1.58-1.61 A), supporting a delocalised 14π system. In the crystal, the molecules pack themselves in two arrangements of nearly parallel planes with the smallest interplanar separation being only 3.26 A.



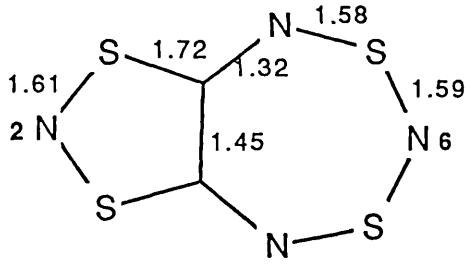
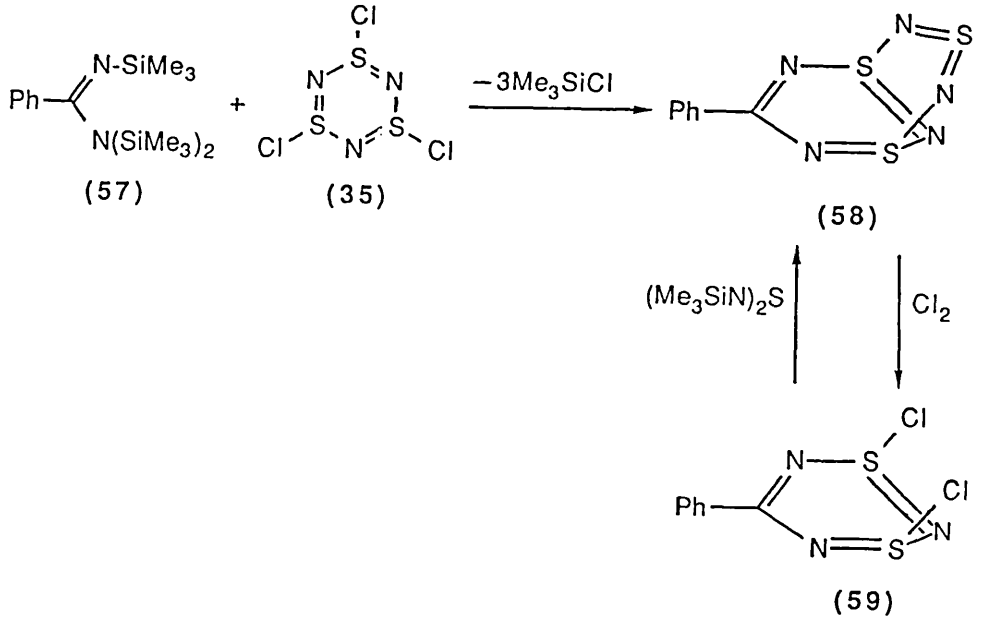


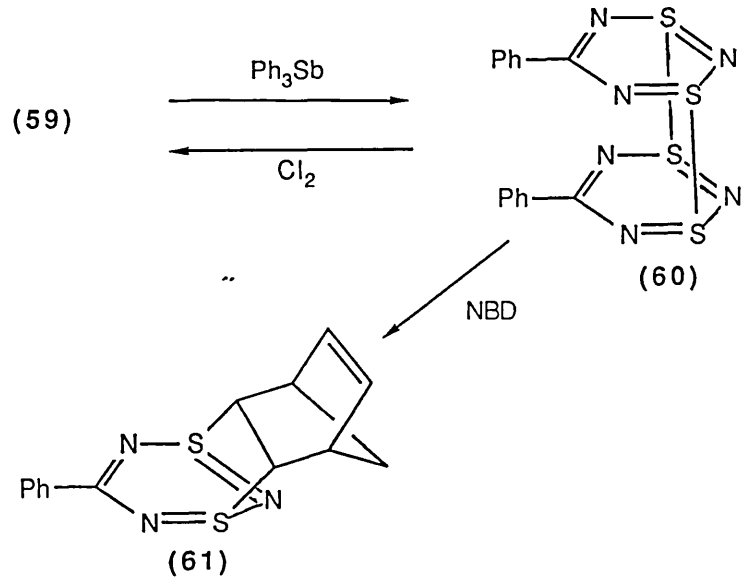
Figure 1.4 : Structure of 1,3,5,7,2,4,6,8-tetrathiatetraza-azulene.

The tetrathiatetraza-azulene (56) consisted of a 1,3,2-dithiazole ring fused with a 1,3,2,4,7-dithiatriazepine ring. Benzo-fused N-substituted 1,3,2-dithiazoles[31] and the related 1,3,2-dithiazolium cation[17,32] are known compounds. An interesting mechanism was proposed for the formation of (56); this involved the known[33] dehydrogenating properties of S_4N_4.

1.4.4 1,3,2,4,6-Dithiatriazine

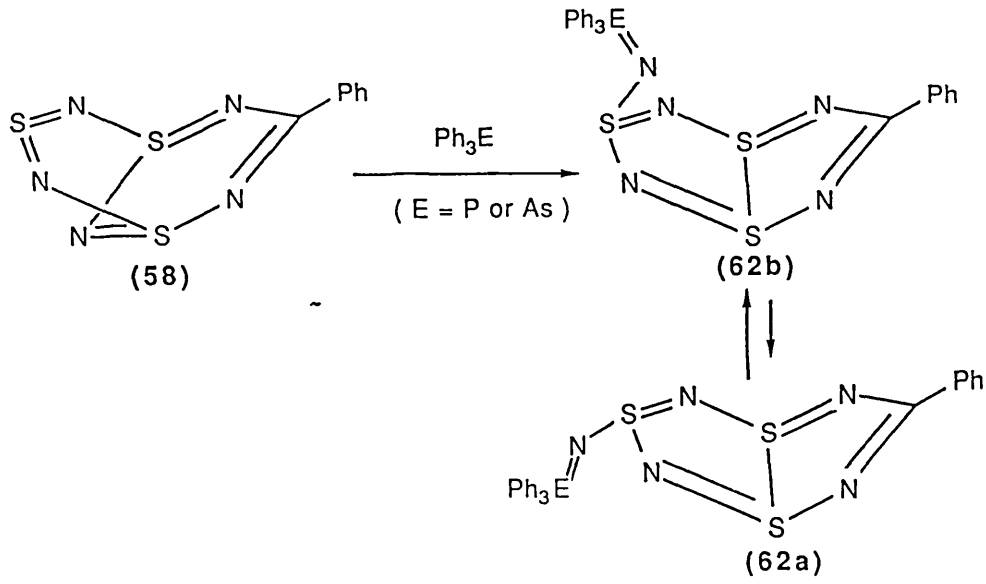
There has been considerable interest in the chemistry of organic heterocyclic thiazyl compounds. However, the methods used to form these compounds led to mixtures of products, the composition of which was difficult to anticipate. The use of N,N,N'-tris(trimethylsilyl)benzamidine (57) as a milder, more specific reagent was examined and when this was reacted with $S_3N_3Cl_3$ (35), golden air- stable plates, dec. 136°C, were obtained in 61% yield.[34] X-Ray crystallography showed this product to be the bicyclic $PhCS_3N_5$ molecule (58), where the 1,3,2,4,6-dithiatriazine skeleton was bridged by a -N=S=N- fragment across the 1,3-sulphur atoms.





Oxidation of 1,3,2,4,6-dithiatriazine (58) with chlorine yielded 1,3-dichloro-5-phenyl-1,3,2,4,6-dithiatriazine (59) (60%) as yellow moisture-sensitive plates, m.p. 119-121°C. Treatment of (59) with sulphurdiimide (11a) reformed the bicyclic structure (58). Reduction of (59) with triphenylstibine yielded a buff-coloured air-stable microcrystalline precipitate of 5-phenyl-1,3,2,4,6-thiatriazine dimer (60) (78%). The structural integrity of the six-membered CN_3S_2 ring in (60) was confirmed by its reconversion to (59) (85%) upon treatment with chlorine and through formation of the 1,3-norbornadiene adduct (61).

An efficient synthetic route to the 1,3,5,2,4,6,8-trithiatetrazocine ring system was discovered when the bicyclic compound (58) was treated with triphenylphosphine or triphenylarsine, giving isomers (62a) and (62b).[35]

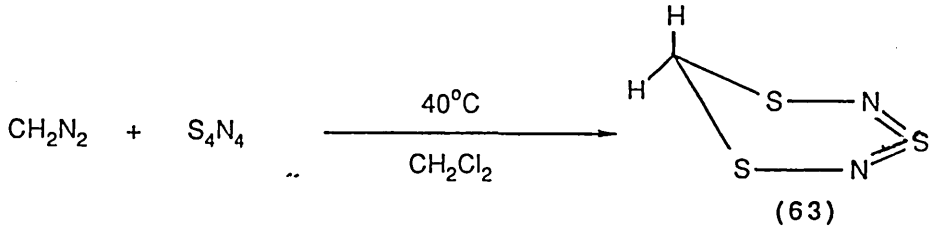


X-Ray analysis of the arsenic compound revealed the two products as exo- and endo-isomers, **(62a)** and **(62b)** respectively. It was shown that the exo-isomer **(62a)** was irreversibly converted into the endo-isomer **(62b)** at room temperature suggesting a low activation energy and establishing the latter as being the more thermodynamically stable isomer. A low energy pathway for the conversion of the exo into endo isomer could be provided by breaking of the weak transannular S-S interaction followed by ring inversion, rather than inversion at sulphur.

1.5 1,3,5,2,4-Trithiadiazine, a recent novel cyclic sulphurdiimide

The first reactions of diazo compounds with S_4N_4 produced either open chain or polymeric sulphurdiimides eg $R_2C{=}N{-}S{-}N{=}S{=}N{-}S{-}N{=}CR_2$.[36] However, when diazomethane was added to S_4N_4 in refluxing dichloromethane, a red crystalline compound, m.p. 43-45°C, found to

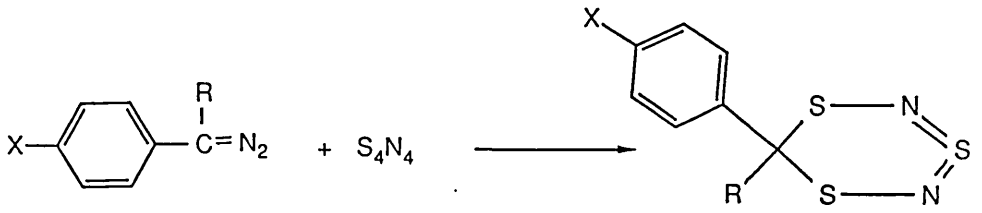
be the novel 6,6'-dihydro-1,3,5,2,4-trithiadiazine (63) and having a garlic like odour was produced in 40% yield.[37]



(63)

X-Ray crystallographic structure determination showed the six-membered ring to exist in a half chair conformation, the -S-N=S=N-S- unit being nearly planar, with a plane of symmetry through the carbon and the central sulphur atoms .[37]

Other simple aryl diazo compounds were also found to give the same trithiadiazine ring system (64).[37]

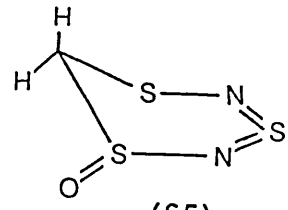


(64)

a ; X = R = H
b ; X = OMe , R = H
c ; X = NO_2 , R = H
d ; X = H , R = Ph

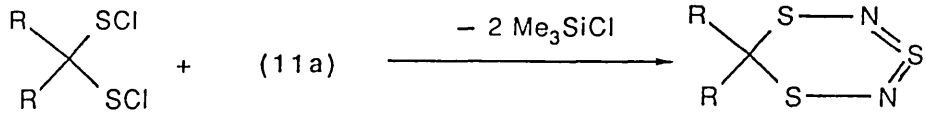
The trithiadiazines (64) were rather unstable as they slowly decomposed when stored at -10°C, and the more acidic the ring proton, the less stable the product (64). The dihydro derivative (63) was rapidly destroyed on photolysis and on treatment with triphenylphosphine. However, upon treatment with one equivalent of MCPBA, a pale yellow compound, m.p. 90-92°, shown to be the

corresponding monoxide (65), was obtained in 52% yield.[37]



(65)

Trithiadiazines (67) have since then been prepared by an independent method using the cyclisation of gem-disulphenyl chlorides (66) and bis(trimethylsilyl)sulphurdiimide (11a).[37]



(66) (67)

The chemistry of this novel trithiadiazine ring is under investigation in this Laboratory.

CHAPTER 2

1,5,2,4,6,8-DITHIATETRAZOCINES

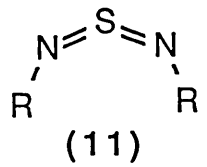
2.1 Synthesis of sulphurdiimides

To date, 1,5,2,4,6,8-dithiatetrazocines (4) (Section 1.1) have been prepared by treating the corresponding amidines with sulphur dichloride, in the presence of diazabicycloundecene.[4] However, several features considerably limit the utility and effectiveness of sulphur dichloride; it is a liquid with an unpleasant odour and is unstable due to disproportionation.

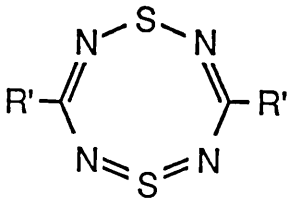
$$SCl_2 \rightleftharpoons S_2Cl_2 \rightleftharpoons S_3Cl_2 \rightleftharpoons S_nCl_2 + S_8 + Cl_2$$

Even a minimal purification procedure involves one or more distillations prior to use, and even then it tends to introduce extra chlorine atoms (Section 2.4.2). In addition to this, only very low yields of dithiatetrazocines (4) (except when $R=NMe_2$) were obtained. Hence there was a need for a better synthetic method.

Dithiatetrazocines (4) may be regarded as a cyclic counterpart of sulphurdiimides (11).



(11)



(4)

Therefore we decided to examine the methods of preparation available for sulphurdiimides (11) to see if any of these could be suitably modified for the synthesis of dithiatetrazocines.

One of the most common and useful methods for the preparation of sulphurdiimides (11) consists of the reaction of compounds with primary amino groups (RNH_2) with sulphur halogen compounds such as sulphur tetrafluoride, sulphur monochloride, sulphur dichloride, thionyl chloride or S,S-dihaloiminosulphuranes ($RN=SX_2$).[38]

Other methods used are as follows.

1. Using dialkylaminosulphanes : Aromatic amines are converted into the corresponding sulphurdiimides by treatment with dialkyaminosulphanes if a molar ratio of 1:1 is chosen.[38]

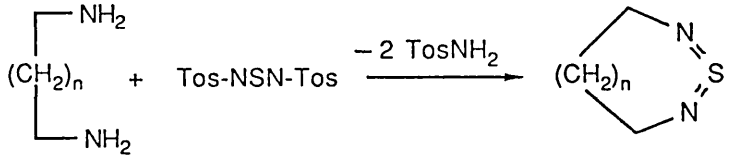
$$2\ Ar\text{-}NH_2 + 2\ Et_2N\text{-}S\text{-}NEt_2 \longrightarrow Ar\text{-}NSN\text{-}Ar + 4\ Et_2NH + 1/8\ S_8$$

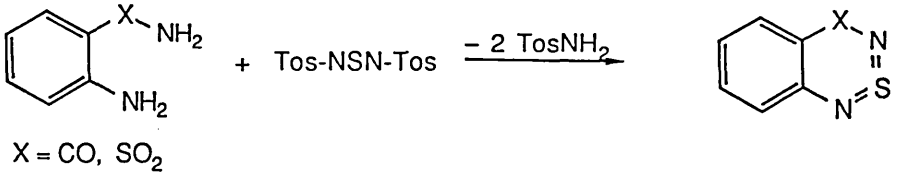
2. By transimidation : By reaction with bis(tosyl)sulphurdiimide (11b) and similar compounds, an exchange of the ligands on the N=S=N function can be achieved under mild conditions.[38]

$$R\text{-}NH_2 + \underset{(11b)}{Tos\text{-}NSN\text{-}Tos} \longrightarrow Tos\text{-}NSN\text{-}R + TosNH_2$$

$$Tos\text{-}NSN\text{-}R + RNH_2 \longrightarrow \underset{(11)}{R\text{-}NSN\text{-}R} + TosNH_2$$

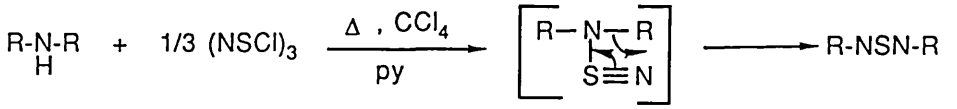
The success of this synthesis depends on there being a difference in basicity between RNH_2 and tosyl amide. Cyclic sulphurdiimides derived from aliphatic or aromatic amino compounds have been prepared by this method.[39]





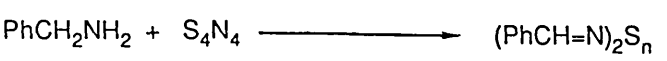
X = CO, SO_2

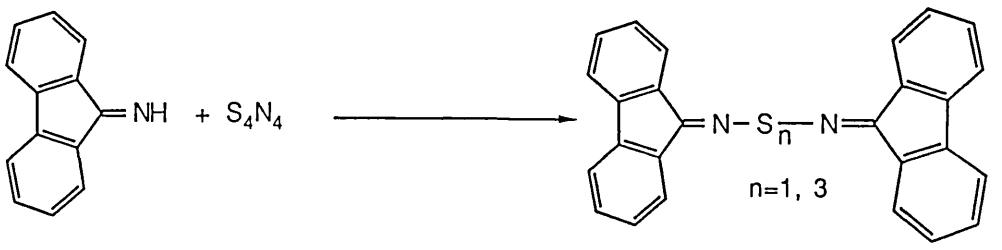
3. Using trithiazyl trichloride : Both hexamethyldisilazane and bis(pentafluorobenzenesulphenyl)amine were converted into the corresponding sulphurdiimides when treated with trithiazyl trichloride (35) in refluxing tetrachloromethane in the presence of pyridine.[40] The reaction is thought to proceed via the intermediate (68) by a novel rearrangement.



R = $SiMe_3$, C_6F_5S (68)

4. Using tetrasulphur tetranitride : S_4N_4 is frequently used as a source of the NSN moiety. When reacted with amines (R_2NH) or imines ($R_2C{=}NH$), sulphanes such as $(R_2N)_2S_n$ and $(R_2C{=}N)_2S_n$ are produced.[36]





5. Using N-Silylatedsulphurdiimides : Bis(trimethylsilyl)sulphurdiimide (11a) has been used as a reagent for the synthesis of many

other NSN compounds. Often, only one trimethylsilyl group reacts, or the displacement of the second group is much slower than that of the first one. Open chain sulphurdiimides are the reaction products of trimethylsilylsulphurdiimide (11a) with sulphenyl chlorides, sulphonyl chlorides, sulphur dichloride, or chlorine gas.

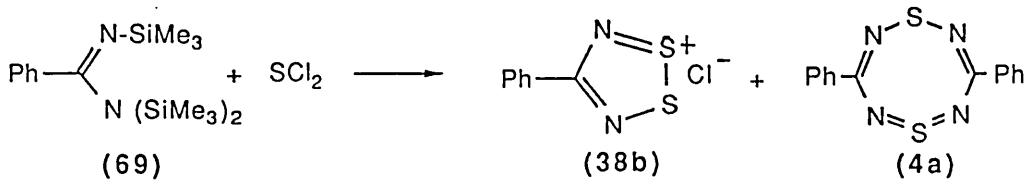
$$X\text{-}Cl + Me_3Si\text{-}NSN\text{-}SiMe_3 \xrightarrow{-\ Me_3SiCl} Me_3Si\text{-}NSN\text{-}X$$

Sulphenyl or sulphonyl chlorides which possess an additional N-sulphenyl group or a halogen atom in the molecule may be used for the preparation of cyclic sulphurdiimides (Section 5.1).

2.2 Possible approaches to the synthesis of 1,5,2,4,6,8-dithiatetrazocines

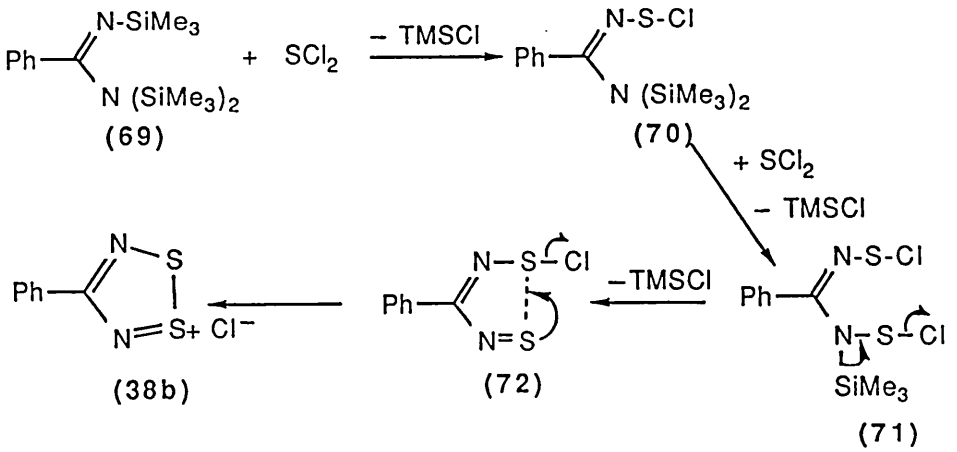
We first tried to improve the yield of dithiatetrazocine (4a) by altering the literature reaction conditions.[4] Addition of sulphur dichloride over a longer period of time (1 h) or lowering the reaction temperature (-10°C) or using a high dilution technique to minimise polymerisation did not make much difference to the yield of dithiatetrazocine (4a). However, we also isolated 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (Section 2.2.1) in low yields (10-15%).

We then speculated that if N,N,N'-tris(trimethylsilyl)benzamidine (69) was treated with sulphur dichloride, we could get a higher yield of dithiatetrazocine (4a). In fact a good yield (60%) of the dithiadiazolium chloride (38b) and only a low yield (3%) of the dithiatetrazocine (4a) was obtained.



(69) (38b) (4a)

The mechanism for the formation of dithiadiazolium chloride (38b) could be as proposed in Scheme 2.1. The initially formed sulphenyl chloride (70) reacts further with sulphur dichloride to form the bis(sulphenyl chloride) (71) followed by elimination of chlorotrimethylsilane to form the thione (72) which then cyclises to the dithiadiazolium chloride (38b).



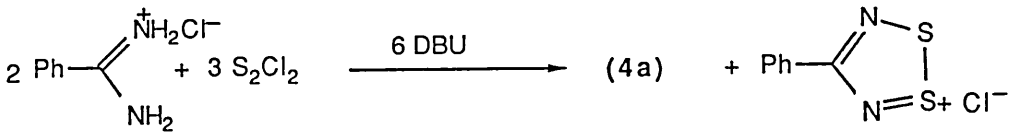
(38b) (72) (70) (71)

Scheme 2.1 : Proposed mechanism for the formation of dithiadiazolium chloride (38b) fron N,N,N'-tris(trimethylsilyl)benzamidine (69) and sulphur dichloride.

We then explored the reactions of benzamidine with other sulphur transfer reagents with the results described below.

2.2.1 Reaction of benzamidine with sulphur monochloride

When benzamidinium chloride was treated with sulphur monochloride in dichloromethane at room temperature in the presence of DBU, a low yield of dithiatetrazocine (4a) (2.6%) was obtained. A yellow air-sensitive compound, with structure (38b) (54%), was filtered off from the reaction mixture.

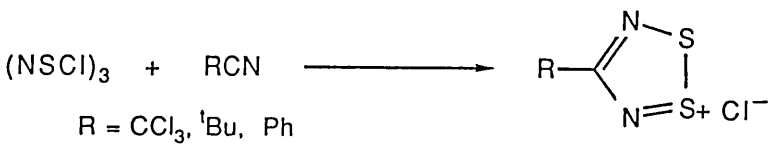


(38b)

The structure of compound (38b) was assigned on the basis of its spectral data and comparison of these data with those reported in literature.[41] The mass spectrum of dithiadiazolium chloride (38b) showed the cation molecular ion at m/z 181 with major fragment ions at M^+-46 (- NS) and M^+-78 (- NS and - S) and the u.v. spectrum (CH_2Cl_2) showed a $\lambda_{max.}$ at 395 nm. Furthermore, the i.r. spectrum was identical with the one described in literature.

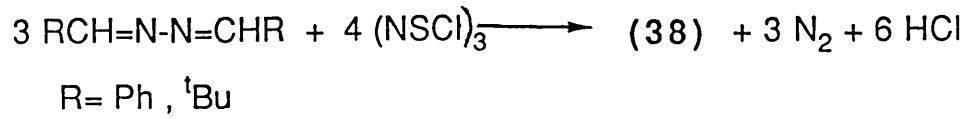
1,2,3,5-Dithiadiazolium chlorides (38) have been prepared previously by the following routes :

1. From trithiazyl trichloride and nitriles.[42]

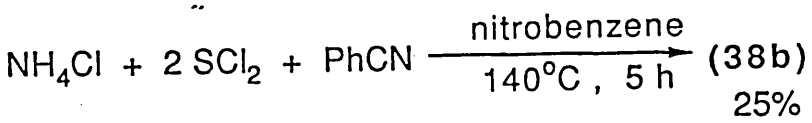


(38)

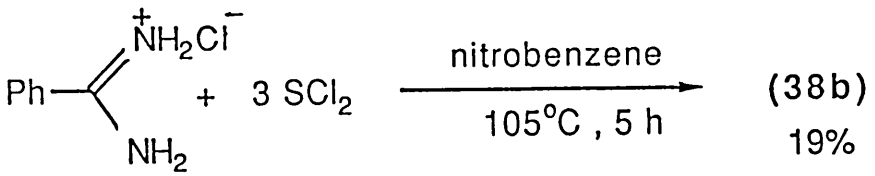
2. From trithiazyl trichloride and aldazines.[43]



3. From ammonium chloride, sulphur dichloride and benzonitrile.[41]



4. From benzamidinium chloride and sulphur dichloride.[41]



Our reaction above of benzamidinium chloride with sulphur monochloride compares favourably with these literature methods. It is milder, more convenient and the yield is as good.

2.2.2 Reaction of benzamidine with tetrasulphur tetranitride

Since S_4N_4 can be used to introduce an NSN moiety when reacted with amines and imines (Section 2.1),[36] one could expect to form the dithiatetrazocine (4) ring system when an amidine is treated with S_4N_4, as an amidine has the combined functionality of an amine and an imine.

3,7-Diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) is indeed obtained in low yields when benzamidine is reacted with S_4N_4 in refluxing aromatic hydrocarbons (Table 2.1).

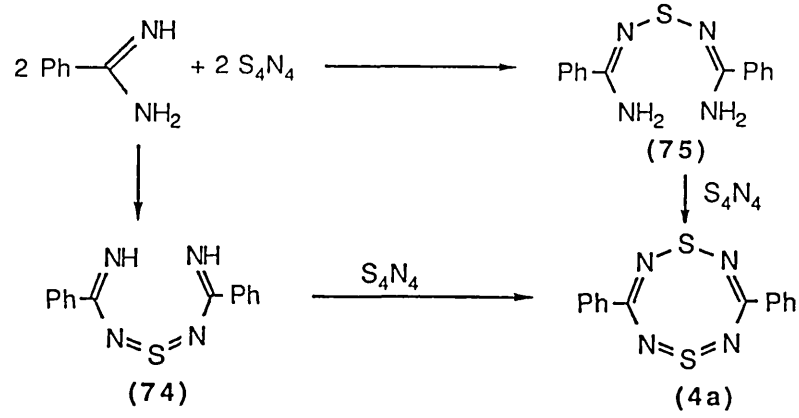
Ratio A:S_4N_4	Solvent	Temp/°C	Time/h	(4a)	(73)
1 : 1	Benzene	80	16	3	3
3 : 1	Toluene	110	3.5	7.4	-
3 : 1	Toluene	110	15	6	4
2 : 1	Xylene	140	6	6.5	9

A = benzamidine; (73) = 2,4,6-triphenyl-1,3,5-triazine

Table 2.1 : Yields (%) of the reaction products obtained from the reaction of benzamidine and S_4N_4. (See also Table 3.1, Section 3.1.1)

The yield of the dithiatetrazocine (4a) increases slightly with excess of benzamidine and when the reaction temperature is increased. However, benzamidine is also thermally decomposed to benzonitrile and 2,4,6-triphenyl-1,3,5-triazine (73)[44] and from Table 2.1, one sees the increase in the yield of triphenyltriazine (73) with the increase in reaction temperature. Benzonitrile was formed (t.l.c.) but was not isolated.

Dithiatetrazocine (4a) could be formed via the sulphurdiimide (74) or the sulphide (75).

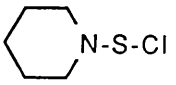


Two other products were also isolated and are discussed in Section 3.1.1 (Table 3.1).

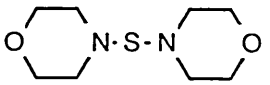
The reaction of benzamidine and S_4N_4 in dichloromethane at room or reflux temperatures in the presence of titanium tetrachloride or lead tetraacetate led mainly to baseline products, and only trace amounts of dithiatetrazocine (4a) were formed.

2.2.3 Reaction of benzamidine with sulphides and sulphurdiimides

The importance of sulphur transfer reagents in the synthesis of sulphur containing heterocyclic compounds is well known[45] and new reagents of general formulae R_2NSCl (76) or R_2NSNR_2 (77), with a nitrogen heterocycle as a leaving group[46], have been developed as alternatives to sulphur dichloride for introducing a sulphur atom between nitrogen, oxygen, or sulphur.



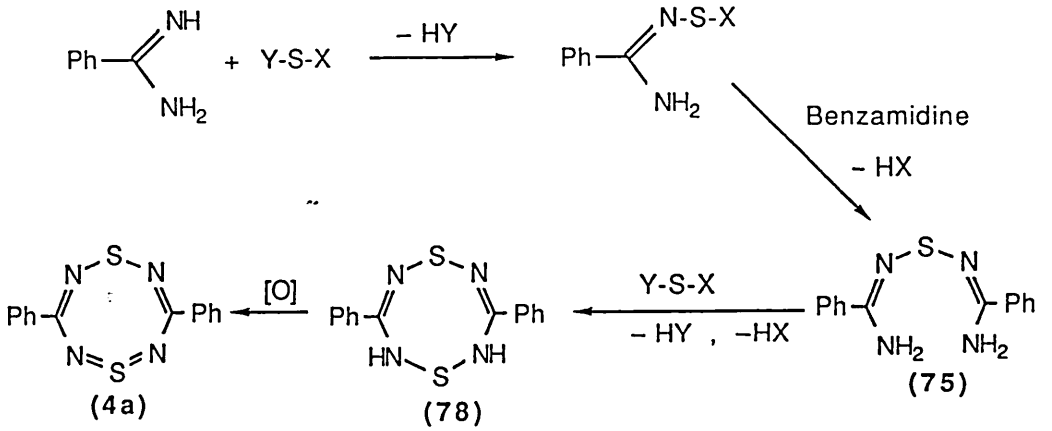
(76a)



(77a)

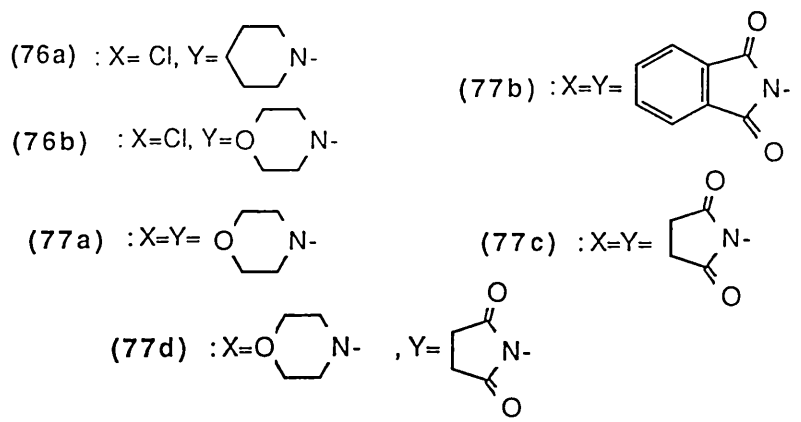
These reagents are easy to purify, do not disproportionate, and do not bring about unwanted chlorination reactions. They also act as internal bases.

Therefore one might expect benzamidine to react with either imide-N-sulphenyl chlorides (76) or N,N'-thiobisimides (77), to form the dithiatetrazocine (4a) via the intermediate (78) (Scheme 2.2).



Scheme 2.2 : Proposed scheme for the reaction of benzamidine with imide-N-sulphenyl chlorides (76) or N,N'-thiobisimides (77).

Benzamidine was treated with a range of imide-N-sulphenyl chlorides (76a,b) and N,N'-thiobisimides (77a,b,c,d) in dry dichloromethane at room temperature. Dithiatetrazocine (4a) was indeed obtained but unfortunately only in very low yields (Table 2.2).

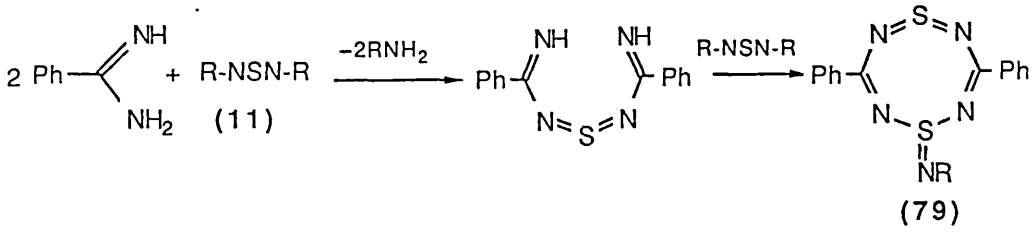


Ratio A:X-S-Y	X-S-Y	Time/h	(4a) (%)
2 : 3	(76a)	20	2.2
2 : 3	(76b)	20	0.4
2 : 2	(77a)	18	0.7
2 : 3	(77b)	72	0.5
2 : 3	(77c)	15	0.5
2 : 3	(77d)	20	0.3

A = benzamidine

Table 2.2 : The reaction of benzamidine with imide-N-sulphenyl chlorides (76) and N,N'-thiobisimides (77) at room temperature.

Benzamidine is a strong base and one might expect it to react with sulphurdiimides (11) to give the corresponding sulphilimine (79).



(79)

However when benzamidine was treated with a range of sulphurdiimides (11) (Table 2.3), low yields of dithiatetrazocine (4a) were obtained. It is possible that dithiatetrazocine (4a) could be formed from the sulphilimine (79); the latter may be unstable and, upon work-up (silica), converted into the stable dithiatetrazocine (4a), though this appears to involve a reduction reaction.

$$R\text{-}N{=}S{=}N\text{-}R'$$

(11)

a : R=R'=TMS d : R=Ph; N-R' =O

b : R=R'=Tos e : R=R'=PhC(O)-

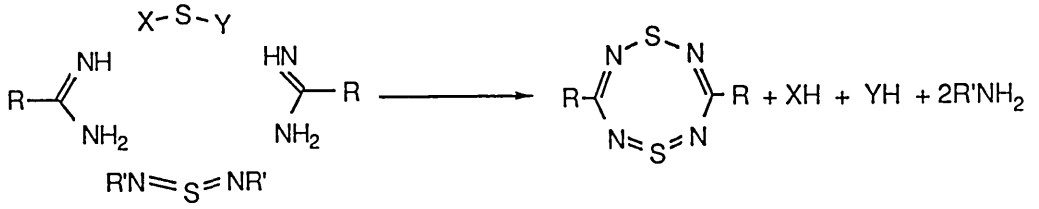
c : R=R'=^{t}Bu f : R=Tos; N-R' =O

Ratio Benzamidine:X=S=Y	X=S=Y	Solvent	Time/h	(4a) (%)
1 : 1	(11a)	CH_2Cl_2	20	0.4
1 : 1	(11b)	CH_2Cl_2	102	6.1
1 : 1	(11b)	$CHCl_3$	42	2.7
1 : 3	(11b)	CH_2Cl_2	20	5
1 : 1	(11c)	CH_2Cl_2	48	0.3
2 : 3	(11d)	CH_2Cl_2	80	0.6
1 : 1	(11e)	CH_2Cl_2	60	0.7
2 : 3	(11f)	CH_2Cl_2	92	5

Table 2.3 : The reaction of benzamidine with sulphurdiimides (11) at room temperature to give dithiatetrazocine (4a).

The best yield (6%) was obtained with bis(tosyl)sulphurdiimide (11b) in dichloromethane at room temperature. Normally, the solution of sulphurdiimide (11b) in dichloromethane was added dropwise over a period of 30 min to a stirred solution of benzamidine in dichloromethane at room temperature under nitrogen. A typical work-up procedure was simple as it involved filtration of reaction mixture (to remove tosyl amide), removal of solvent *in vacuo*, and chromatography of the residue on silica.

Examining the dithiatetrazocine structure (4) carefully, one can see that it contains formally divalent and tetravalent sulphur atoms, and a combination of divalent and tetravalent sulphur transfer reagents might give higher yields of (4). Such divalent and tetravalent sulphur transfer reagents are imide-N-sulphenyl chlorides (76) or N,N'-thiobisimides (77) and sulphurdiimides (11) respectively.



A:(11b):(76)or(77)	(76)or(77)	Method	Time/h	(4a)	(80)	(81)
1 : 1 : 1	(76a)	A	17	0.6	4	8
2 : 2 : 1	(76b)	A	48	1.7	-	-
2 : 1 : 1	(77b)	A	24	Tr	-	-
2 : 1 : 1	(77b)	B	40	9.6	15	11
2 : 1 : 1	(77b)	C	20	7.4	22	2
2 : 1 : 10	(77b)	B	20	8.4	18	5
2 : 1 : 6	(77b)	D	15	9.4	21	4
1 : 1 : 3	(77b)	D	20	8.6	15	3
2 : 1 : 1	(77c)	A	20	3	15	2
2 : 1 : 1	(77d)	A	14	1.1	20	3

A = benzamidine Tr = Trace amounts

Table 2.4 : Summary of the products obtained from the reaction of benzamidine with sulphides [(76) or (77)] and sulphurdiimide (11b) at room temperature.

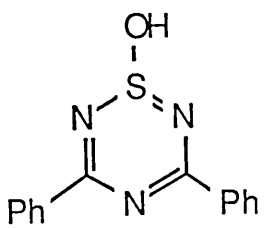
Therefore benzamidine was treated with a range of imide-N-sulphenyl chlorides (76) or N,N'-thiobisimides (77) and bis(tosyl)sulphurdiimide (11b) in combination (Table 2.4). The best combination was found to be bisphthalimidosulphide (77b) and bis(tosyl)sulphurdiimide (11b) and this combination was studied further. Adding a solution of benzamidine in dry dichloromethane slowly at room temperature under nitrogen, to a stirred mixture of sulphide (77b) and sulphurdiimide (11b) in dry dichloromethane followed by further stirring at room temperature and work-up, afforded 7.4% of dithiatetrazocine (4a). When sulphurdiimide (11b) was added to a prolonged stirred mixture of benzamidine and excess of sulphide (77b) at room temperature, a slight improvement in the yield of compound (4a) (8.4%) was observed. A slightly better yield (9.6%) was obtained when a solution of benzamidine in dry dichloromethane was added to stirred slurry of sulphide (77b) in dry dichloromethane, followed by addition of a solution of sulphurdiimide (11b) in dry dichloromethane. Refluxing the mixture of benzamidine and excess of sulphide (77b) in dichloromethane for 3 h, then cooling to room temperature followed by slow addition of a solution of sulphurdiimide (11b) in dichloromethane, afforded 9.4% of compound (4a); in refluxing chloroform, 8.6% of (4a) was obtained. The slightly lower yield in refluxing chloroform could be due to the thermal decomposition of benzamidine.[44] Using excess of sulphide (77b) does not show any improvement in the yield of dithiatetrazocine (4a).

One can conclude from the results shown in Tables 2.2, 2.3, and 2.4 that the best method available at present for the synthesis of dithiatetrazocine (4a) is the addition of a solution of benzamidine

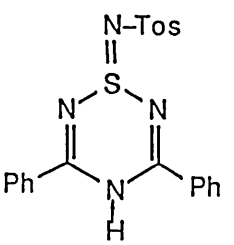
in dichloromethane to stirred slurry of sulphide (77b) in dichloromethane at room temperature, followed by slow addition of the solution of sulphurdiimide (11b) in dichloromethane. Moreover, both the sulphide (77b) and sulphurdiimide (11b) are easy to make and purify, cheap and stable. Even the work-up procedure is simple as no sulphur is formed, which makes the chromatography easy, and no base is needed.

Using these best conditions, it should now be possible to extend this methodology to other amidines. However, it was found that this method was only applicable to arylamidines (see Sections 2.4.1 and 2.4.2).

Two other compounds isolated in low yields from the reaction of benzamidine with the combination of sulphide [(76) or (77)] and sulphurdiimide (11b) were 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) and 1-(p-toluenesulphonylimino)-3,5-diphenyl-1,2,4,6-thiatriazine (81). The yields of these two compounds are shown in Table 2.4, where it is seen that their combined yields are fairly constant at about 21%. It was found that compound (81) hydrolysed on work up to give hydroxythiatriazine (80), hence the normally low yield of compound (81).



(80)

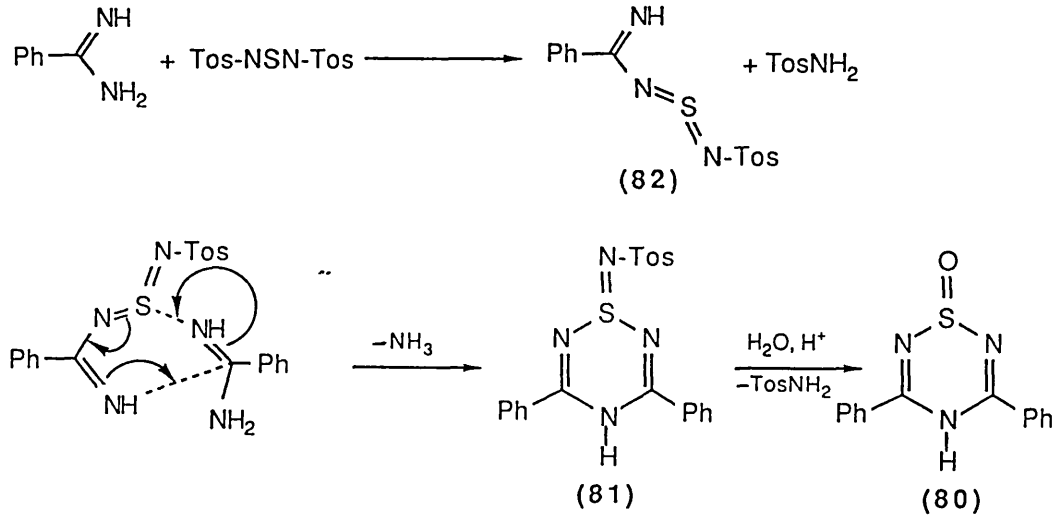


(81)

The structures of compounds (80) (Section 3.1.4) and (81) were assigned on the basis of their spectral data. 1-(p-Toluenesulphonylimino)-3,5-diphenyl-1,2,4,6-thiatriazine (81) was obtained as colourless compound, m.p. 156-158°C. Its mass spectrum did not show the molecular ion, but showed peaks at m/z 253 and 171 which are the two fragments of compound (81). The proton n.m.r spectrum showed aromatic multiplets at δ 8.25 (integral 4) and 7.40-7.55 (integral 6) while the para-substituted phenyl ring showed doublets (J 7.5 Hz) at δ 7.8 and 7.2 (integral 2) and the methyl protons were singlet (integral 3) at δ 2.35. The i.r. spectrum showed four characteristic absorption bands for arenesulphonylsulphilimines at 1260, 1130, 1080, and 985 cm^{-1}. Elemental analysis suggested the formula $C_{21}H_{18}N_4O_2S_2$.

1-(p-Toluenesulphonylimino)-thiatriazine (81) is thus the major product formed in the reaction of benzamidine and sulphurdiimide (11b), sulphide (77b) presumably not being involved. The higher yields of compound (81) compared with dithiatetrazocine (4a) could presumably result from both entropy and angle-strain factors favouring the formation of six-membered rather than the eight-membered ring.

A mechanism for the formation of compound (81) is proposed in Scheme 2.3. The initially formed sulphurdiimide (82) reacts with more benzamidine, with elimination of ammonia to form compound (81) which on work up is hydrolysed to hydroxythiatriazine (80).

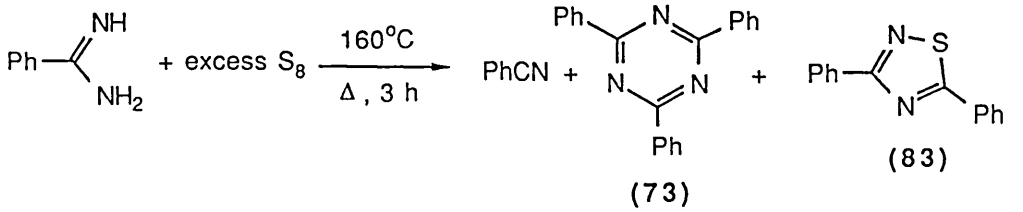


Scheme 2.3 : Proposed mechanism for the formation of sulphonyliminothiatriazine (81) and hydroxythiatriazine (80) from benzamidine and bis(tosyl)sulphurdiimide (11b).

2.2.4 Reaction of benzamidine with other sulphur transfer reagents

(i) Sulphur

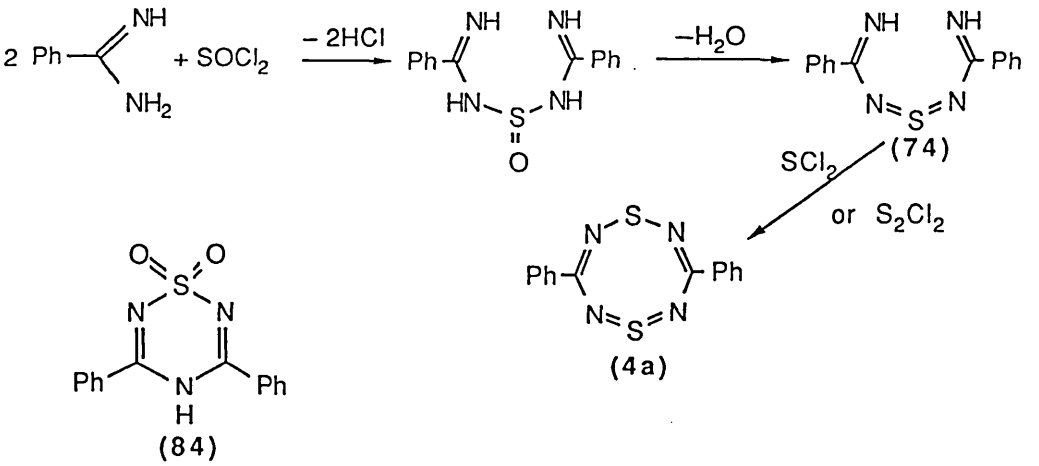
The heating together of sulphur and an amidine could provide the simplest possible heterocycle-forming reaction. We hoped that when benzamidine and sulphur are heated together, some dithiatetrazocine (4a) would be formed. However, when they were heated together at 160°C for 3 h, the products formed were benzonitrile, 2,4,6-triphenyl-1,3,5-triazine (73) (2%) and 3,5-diphenyl-1,2,4-thiadiazole (83) (24%). Both benzonitrile and triazine (73) are just thermal decomposition products of benzamidine.[44]



(73) (83)

(ii) Thionyl chloride

We speculated that benzamidine could react with thionyl chloride to form the intermediate sulphurdiimide (74), which could then be cyclised with sulphur dichloride or sulphur monochloride to form dithiatetrazocine (4a).



However, when benzamidine was treated with thionyl chloride in dry dichloromethane at 0°C in the presence of base, no compound of sructure (74) was isolated. We did isolate a colourless compound, m.p.>310°C, to which we assign structure (84) (Section 3.1.3).

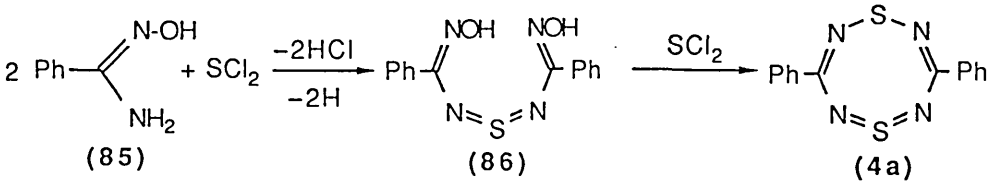
2.3 Attempted independent methods for the synthesis of dithiatetrazocines (4)

2.3.1 From benzamidoxime

Our curiosity led us to explore the reaction of benzamidoxime with sulphur transfer reagents in the hope of synthesising the dithiatetrazocine system (4a), and we now describe these reactions.

(i) With sulphur dichloride

Benzamidoxime (85) might react with sulphur dichloride to form the sulphurdiimide (86), followed by cyclisation and reduction to the dithiatetrazocine (4a).

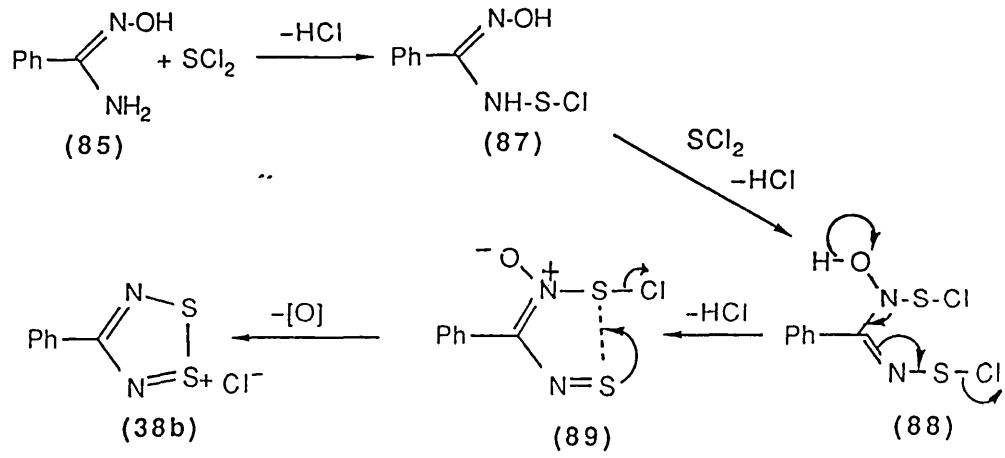


(85) (86) (4a)

This is indeed true since a low yield (5-6%) of dithiatetrazocine (4a) was obtained when benzamidoxime was treated with freshly distilled sulphur dichloride in dry dichloromethane at 0°C in the presence of DBU. However, a much better yield (32%) of 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) was also obtained.

The formation of dithiadiazolium chloride (38b) could be rationalised as proposed in Scheme 2.4. The initially formed monosulphenyl chloride (87) reacts further with sulphur dichloride to form the bis(sulphenyl chloride) (88) which then eliminates hydrogen chloride to form the N-oxide (89) followed by cyclisation

and reduction to dithiadiazolium chloride (38b).

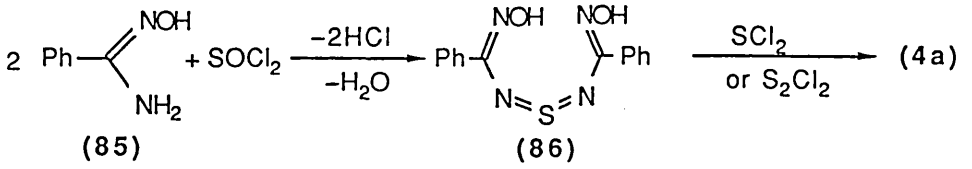


Scheme 2.4 : Proposed mechanism for the formation of dithiadiazolium chloride (38b) from benzamidoxime and sulphur dichloride.

In contrast, the reaction of benzamidoxime and sulphur monochloride proved to be very complicated and sulphur was the only isolable product. Even the attempted preparation of intermediate sulphurdiimide (86) by treating a solution of benzamidoxime with a solution of bis(tosyl)sulphurdiimide (11b) in dry chloroform failed as only benzonitrile and unreacted benzamidoxime were isolated.

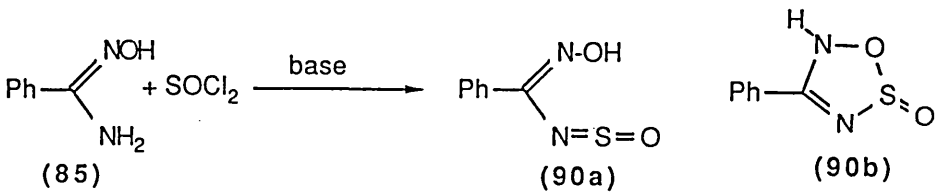
(ii) With thionyl chloride

We speculated that benzamidoxime could react with thionyl chloride to form the sulphurdiimide (86) which could then be cyclised with sulphur dichloride or sulphur monochloride to form the dithiatetrazocine (4a).



(85) (86)

However, when benzamidoxime was treated with thionyl chloride in the presence of base (Table 2.5), good yields of colourless fine needles, m.p. 88-89°C, tentatively assigned structure (90a) were obtained. No compound of structure (86) was isolated from the reaction mixture.



(85) (90a) (90b)

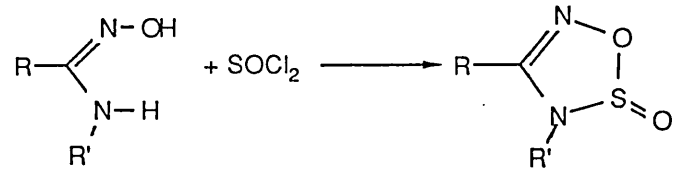
Base	(90a) (%)
pyridine	39
DBU	60
Et_3N	80

Table 2.5 : Yields (%) of N-sulphinylbenzamidoxime (90a) from benzamidoxime (85) and thionyl chloride.

The structure of compound (90a) was based on its spectral data. The mass spectrum showed a molecular ion at m/z 182 with major fragment ions at M^+-31 (- NOH), M^+-62 (- NSO) and M^+-79 (- NSO and - OH). The

proton n.m.r spectrum showed aromatic multiplets at δ 7.6-7.8 (integral 2) and δ 7.45-7.6 (integral 3) and a broad singlet at δ 8.15 (integral 1) which can be attributed to N-OH. The i.r. spectrum showed characteristic absorptions for N-OH at 3250 cm^{-1} and for N-sulphinyl compounds at 1160 cm^{-1}. Elemental analysis suggested the formula $C_7H_6N_2O_2S$.

This product was originally thought to have the oxathiadiazole oxide structure (90b) because N-alkyl and N-aryl amidoximes react with thionyl chloride in the presence of triethylamine to give good yields of 3,4-disubstituted-1,2,3,5-oxathiadiazol-2-oxides (91).[47]



(91)

Oxathiadiazol-2-oxides (91) show characteristic absorptions in the i.r. spectrum in the region 1350-1370 cm^{-1} and 1190-1210 cm^{-1} for the -OS(O)N- group which were absent in the i.r. spectrum of compound (90a) and hence the assignment of the ring-opened isomer as N-sulphinylbenzamidoxime.

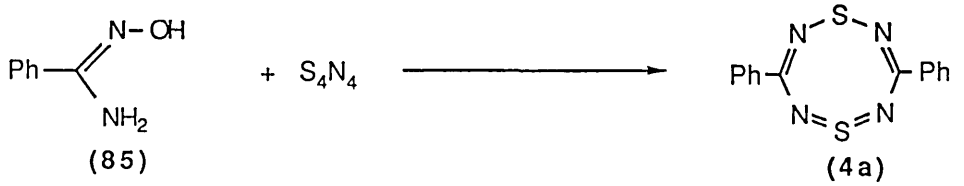
N-Sulphinylbenzamidoxime (90a) is a slightly air-sensitive crystalline compound which can be stored under nitrogen at room temperature or at -10°C for prolonged periods. It is surprisingly stable to silica but decomposes thermally to benzonitrile when heated at reflux in toluene (5 h).

Having isolated the intermediate (90a), we decided to treat it with more benzamidoxime to give the sulphurdiimide (86) which could be further cyclised with sulphur dichloride or sulphur monochloride to the dithiatetrazocine (4a). However, no reaction was observed when either benzamidoxime or benzamidine was treated with N-sulphinylbenzamidoxime (90a) in dichloromethane at either room or reflux temperatures. Even in the presence of base (pyridine or triethylamine) no reaction was observed. In refluxing benzene (10 h) there was slow decomposition of the N-sulphinylbenzamidoxime (90a) to benzonitrile.

(iii) With tetrasulphur tetranitride

S_4N_4 reacts with amines and oximes to give sulphanes. Therefore we speculated that benzamidoxime might react with S_4N_4 to give dithiatetrazocine (4a) since benzamidoxime contains the functionality of both an amine and an oxime.

Dithiatetrazocine (4a) was indeed obtained, but only in low yield (4%), when benzamidoxime and S_4N_4 were heated together in refluxing toluene for relatively long periods (Table 2.6). The reaction was slower than with benzamidine (Section 2.2.2, Table 2.1) and the yields are lower and hence it has no advantages.



(85) (4a)

Benzamidoxime:S_4N_4	Solvent	Temp/°C	Time/h	(4a)
2 : 1	toluene	110	3	-
2 : 1	toluene	110	12	4
4 : 1	xylene	140	6	0.4

Table 2.6 : Yields (%) of dithiatetrazocine (4a). (See also Table 3.3, Section 3.1.4)

Other products obtained were 2,5-diphenyl-1,3,4-triazole (92), hydroxythiatriazine (80) and thiatriazin-1,1-dioxide (84) (Table 3.3, Section 3.1.4).

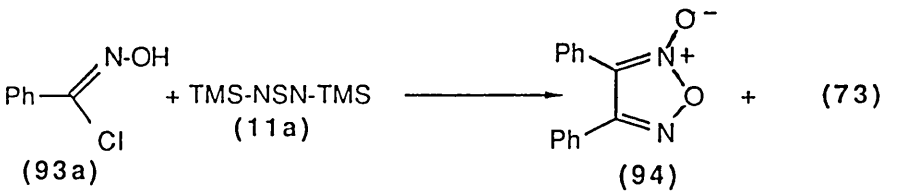
2.3.2 Miscellaneous

(i) Using α-chloro-oximes

We speculated that we could displace the chlorine atom in the α-chloro-oxime (93) by bis(trimethylsilyl)sulphurdiimide (11a) to give the sulphurdiimide intermediate (86), which could then be cyclised to the dithiatetrazocine (4a) with either sulphur dichloride or sulphur monochloride.



However, when α-chlorobenzaldoxime (93a) was treated with sulphurdiimide (11a), only triazine (73) (7%) and 3,4-diphenyl-1,2,5-oxadiazol-2-oxide (94) (5%) were isolated from the complex reaction mixture.

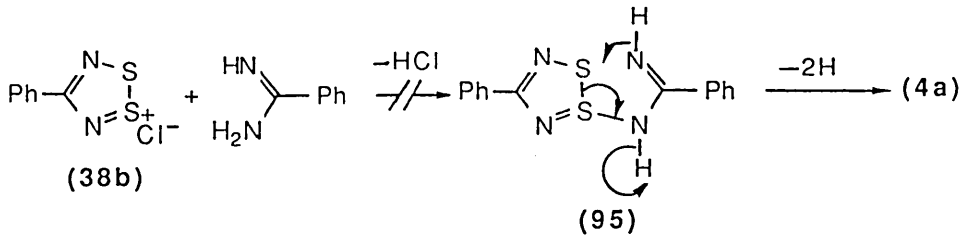


The structures of compounds (73) and (94) were assigned by direct comparison of their spectral data with authentic samples. Triazine (73) is a trimer of benzonitrile while the oxadiazol-2-oxide (94) is a dimer of benzonitrile oxide ($Ph-C\equiv\overset{+}{N}-\overset{-}{O}$).

With the α-chloro-oxime (93b) ($R=CO_2Et$), upon treatment with sulphurdiimide (11a), only S_4N_4 (15%) was obtained and the remainder was baseline products.

(ii) Using 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b)

We hoped that dithiadiazolium chloride (38b) could be cyclised via the intermediate (95) to the dithiatetrazocine (4a) when treated with benzamidine in the presence of base.

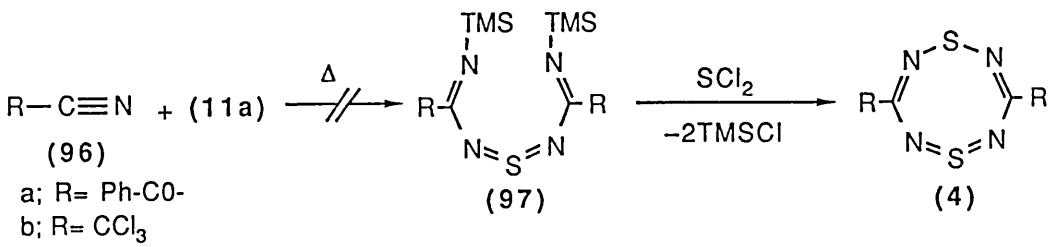


(38b) (95)

However when dithiadiazolium chloride (38b) was treated with benzamidine in dry acetonitrile at either room (15 h) or reflux (6 h) temperatures in the presence of DBU, there was no sign of the formation of dithiatetrazocine (4a) and only baseline products were obtained.

(iii) Using activated nitriles

Activated nitriles (96) were heated with bis(trimethylsilyl)-sulphurdiimide (11a) in the hope to get the sulphurdiimide intermediate (97) which could then be cyclised to dithiatetrazocine (4a) with either sulphur dichloride or monochloride.



(96)
a; R= Ph-CO-
b; R= CCl_3

(97) (4)

The nitriles (96a) and (96b) were heated neat with bis(trimethylsilyl)sulphurdiimide (11a) (Table 2.7) and then cooled to room temperature when dry dichloromethane was added. At 0°C, a solution of sulphur dichloride in dry dichloromethane was added to

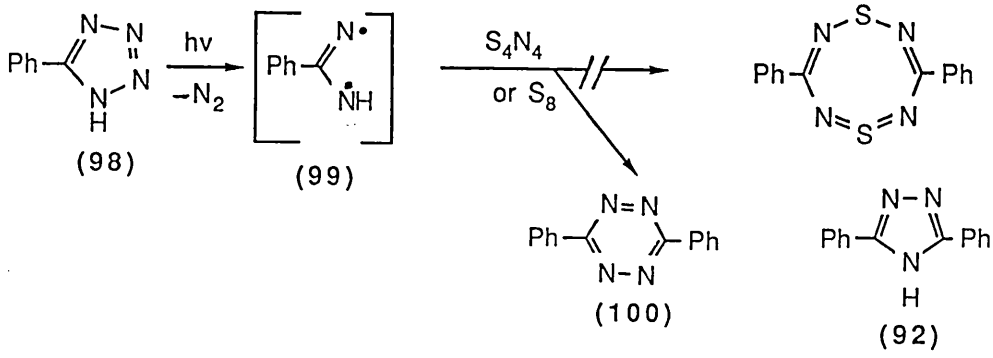
the above solution and the resulting reaction mixture was stirred further at room temperature. Upon work-up, only low yields of S_4N_4 were obtained (Table 2.7). S_4N_4 is known to be formed in the reaction of sulphurdiimide (11a) with sulphur dichloride.[22]

R-C≡N	Temp/°C	Time/h	S_4N_4
R=			
Ph-CO-	100	8	25
CCl_3	80	9	28

Table 2.7 : Yields (%) of S_4N_4 from the reaction of activated nitriles (96), sulphurdiimide (11a) and sulphur dichloride.

(iv) Using tetrazoles

Photolysis of tetrazole (98) produces the reactive intermediate (99)[48] which we speculated might react with sulphur or S_4N_4 to produce the dithiatetrazocine (4a).



(98) (99) (100) (92)

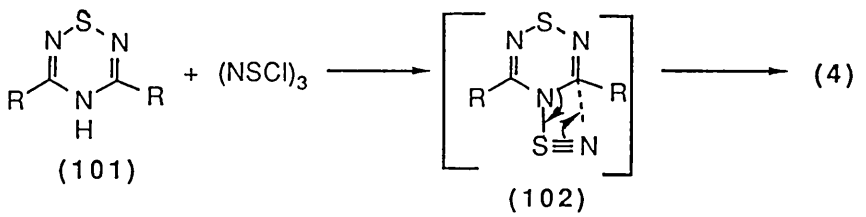
However, when 5-phenyl-1,2,3,4-tetrazole (98a) was photolysed in dry acetonitrile at room temperature in presence of sulphur or S_4N_4, low yields of 3,6-diphenyl-1,2,4,5-tetrazine (100) (16 and 33%

respectively) were obtained, together with the triazole (92) (20 and 13% respectively). The observed products are the usual photolysis products of the tetrazole (98),[49] without the intervention of the sulphur reagents.

We thought that when the tetrazole (98) was heated in the presence of S_4N_4, dithiatetrazocine (4a) might just possibly be formed via the intermediate (99). However, this reaction in refluxing xylene (15 h) was very complex with some formation of tetrazine (100) while the reaction in refluxing bromobenzene was clean, again with formation of the tetrazine (100) (15%) and unreacted tetrazole (98). Even in the presence of sulphur at 200°C (3.5 h), tetrazine (100) (15%) was formed together with triazole (92) (81%). Tetrazine (100) could be formed by the dimerisation of the intermediate (99) followed by dehydrogenation by sulphur or S_4N_4.

(v) Using trithiazyl trichloride

A possible novel route to the dithiatetrazocine (4) could be ring expansion of the thiatriazine intermediate (102).



(101) (102)

However, when diethyl 1,2,4,6-thiatriazine-3,5-dicarboxylate (101) was treated with trithiazyl trichloride (35) in dry

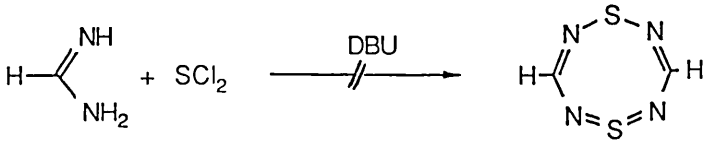
tetrachloromethane at reflux in the presence of pyridine, only baseline products and S_4N_4 (45%) were obtained. S_4N_4 could have arisen from the intermediate (102) (see also Sections 3.2.2, 5.1 and 5.2).

We were thus unsuccessful in finding an independent route to the dithiatetrazocine (4) after having tried a variety of possibilities.

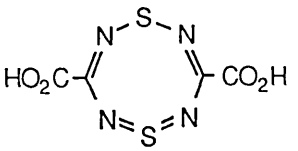
2.4 Derivatives of 1,5,2,4,6,8-dithiatetrazocines

2.4.1 Attempted synthesis of the parent dithiatetrazocine system

All attempts to prepare the parent dithiatetrazocine (4b), by a similar reaction of formamidine and sulphur dichloride in the presence of DBU were unsuccessful.



(4b)

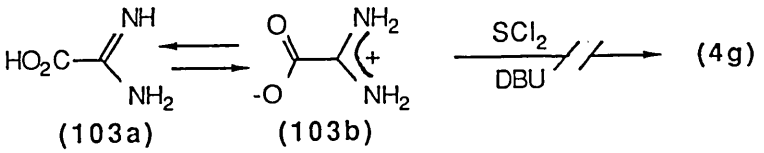


(4g)

An intractable tar was obtained when formamidine was treated with S_4N_4 in refluxing hydrocarbons [benzene (10 h), toluene (13 h), xylene (15 h)], and baseline products were obtained when formamidine was treated with bis(tosyl)sulphurdiimide (11b).

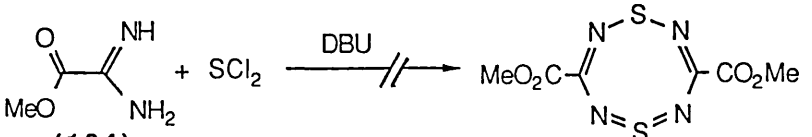
Therefore we considered an indirect route to the parent dithiatetrazocine system (4b) via the dithiatetrazocine-3,7-dicarboxylic acid (4g), followed by thermal decarboxylation.

However, the reaction of amidino carboxylic acid (103a) with sulphur dichloride in the presence of DBU, did not take place at all and amidine (103a) (80%) was recovered. This may be explained by its highly insoluble nature (only soluble in 8 M HCl) and its existence as zwitterionic form (103b).



(103a) (103b)

We then decided to start with its methyl ester (104) in the hope of obtaining the dithiatetrazocine diester (4h) which we would then hydrolyse to the corresponding acid (4g). Unfortunately, the reaction of the methyl amidino carboxylate (104) with sulphur dichloride in the presence of DBU was very complex and no compound of structure (4h) was isolated.

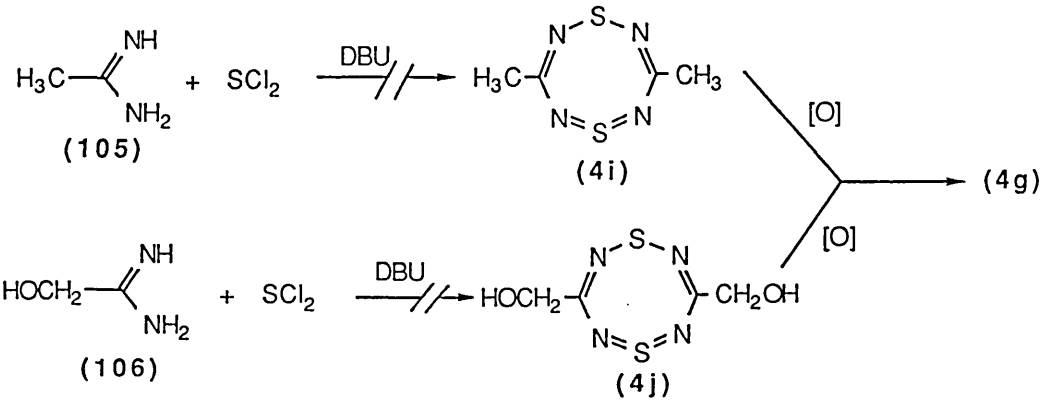


(104) (4h)

Even the treatment of amidino carboxylic acid (103) or its methyl ester (104) with S_4N_4 in xylene at reflux or with sulphurdiimide (11b) in dichloromethane at room temperature were fruitless in synthesising the corresponding dithiatetrazocines (4g) and (4h). In

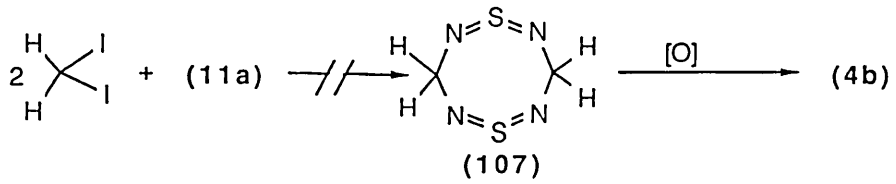
the case of the free acid (103), no reaction was observed at all but with the methyl ester (104), intractable tars were obtained.

We next turned our attention to acetamidine (105) and hydroxyacetamidine (106) and hoped to treat these with sulphur dichloride in the presence of DBU to get the respective dithiatetrazocines (4i) and (4j) and then oxidise these derivatives to the dicarboxylic acid derivative (4g).



However, acetamidine (105) and hydroxyacetamidine (106) reacted with sulphur dichloride in the presence of DBU to give very complex reaction mixtures from which no compounds of structures (4i) or (4j) could be isolated. Intractable tars were obtained when both these amidines [(105) and (106)] were heated with S_4N_4 in aromatic hydrocarbons and baseline products were obtained when they were treated with sulphurdiimide (11b).

We finally attempted to prepare the 3,7-dihydro-1,5,2,4,6,8-dithiatetrazocine (107) which we could then dehydrogenate to the parent dithiatetrazocine (4c).

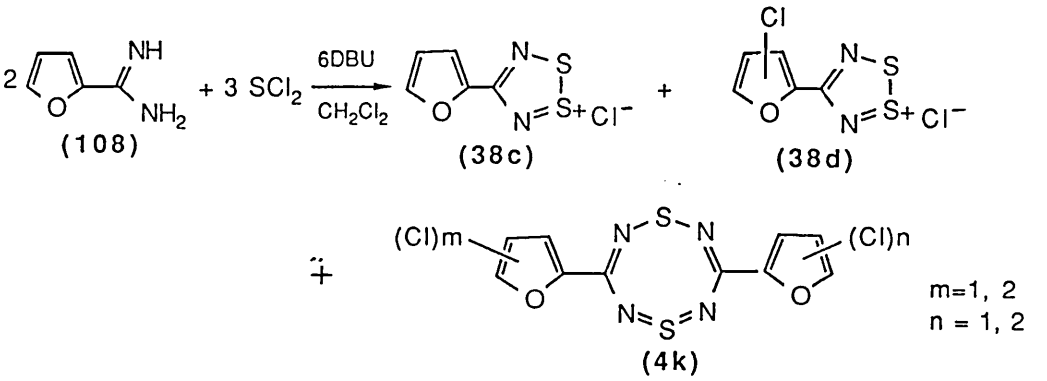


However, there was apparently no reaction between diiodomethane and sulphurdiimide (11b) at room temperature in dry dichloromethane and in refluxing toluene (10 h), even upon addition of tetra-n-butylammonium fluoride (1 eq).

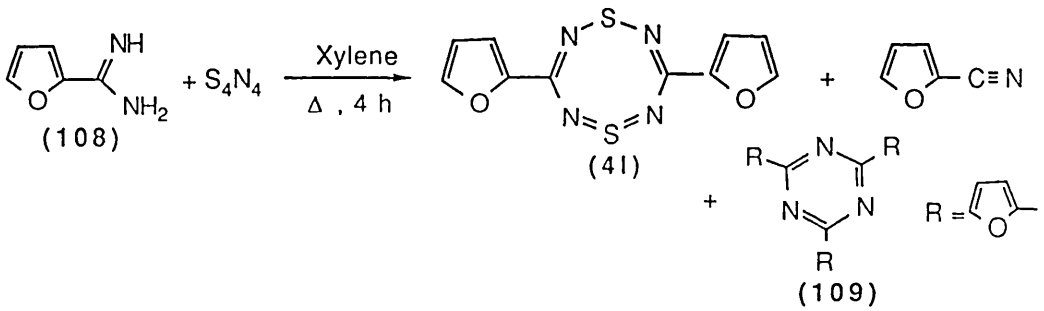
Therefore, we were unsuccessful in the synthesis of the parent dithiatetrazocine (4c) both by independent methods and the new methods we discussed in Section 2.1.

2.4.2 3,7-Di(2-furyl)- and 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocines

When 2-furylamidine (108) was treated with freshly distilled sulphur dichloride in dry dichloromethane at 0°C in the presence of DBU, the major product isolated was a burgundy coloured air-sensitive crystalline compound. Its mass spectrum revealed that it was a mixture of 4-(2-furyl)- and 4-(monochloro-2-furyl)-1,2,3,5-dithiadiazolium chlorides, (38c) and (38d) respectively. A minor product, a yellow crystalline compound, was also isolated and its mass spectrum and hplc (MeOH) suggested that it was a mixture of polychlorinated dithiatetrazocines (4k).



The problem of polychlorination was overcome by reacting the 2-furylamidine (108) with S_4N_4 in xylene at reflux (4 h). A low yield (2%) of 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) was obtained together with a colourless compound, assigned the structure 2,4,6-tris(2-furyl)-1,3,5-triazine (109) (according to its spectral data and direct comparison of these data with that reported in literature). 2-Cyanofuran was also formed (t.l.c.) but was not isolated. Triazine (109) and 2-cyanofuran are the thermal decomposition products of 2-furylamidine (108) (cf benzamidine Section 2.2.2).



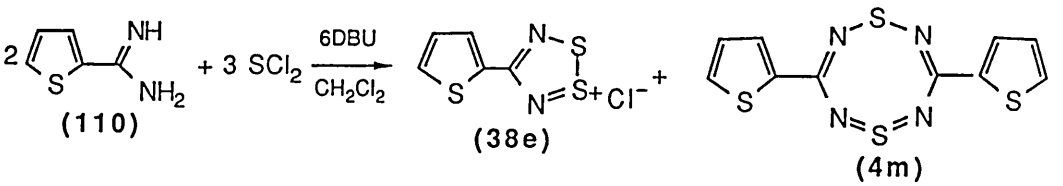
3,7-Di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) was obtained as deep yellow needles (ethyl acetate), m.p. 214-216°C and was found to be only slightly soluble in most organic solvents. The mass spectrum showed the molecular ion m/z at 278 with major fragment ions at M^+-107 (- 2-cyanofuran and - N), M^+-153 (- 2-cyanofuran, - N, and - NS) and M^+-185 (- 2-cyanofuran, - N, - NS, and - S). The proton n.m.r spectrum showed multiplets at δ 7.63, 7.24 and 6.89; all with equal integrals. The u.v. (EtOH) spectrum showed $\lambda_{max.}$ at 448, 338, 323, and 272 nm similar to the diphenyl compound (4a) (Figure 2.1), thus suggesting a planar conformation for the dithiatetrazocine ring in compound (41). Elemental analysis suggested the formula $C_{10}H_6N_4O_2S_2$. Again a low yield of dithiatetrazocine (41) (1.4%) was obtained when 2-furylamidinium chloride was treated with sulphurdiimide (11b) in dry dichloromethane at room temperature (in the presence of DBU) under nitrogen. Stirring the reaction mixture for prolonged periods led to still lower yields of compound (41).

We wondered whether chlorination of the furan ring had occurred before the dithiatetrazocine ring formation or after this ring formation. Therefore, we treated di(2-furyl)dithiatetrazocine (41) with excess of sulphur dichloride in dry dichloromethane at 0°C and at room temperature. To our surprise, no chlorination of the furan ring of the dithiatetrazocine (41) was observed and hence the chlorination had probably occurred before dithiatetrazocine ring formation.

Treatment of 2-thienylamidine (110) with feshly distilled sulphur dichloride in dry dichloromethane at 0°C in the presence of DBU, afforded 4-(2-thienyl)-1,2,3,5-dithiadiazolium chloride (38e) as the

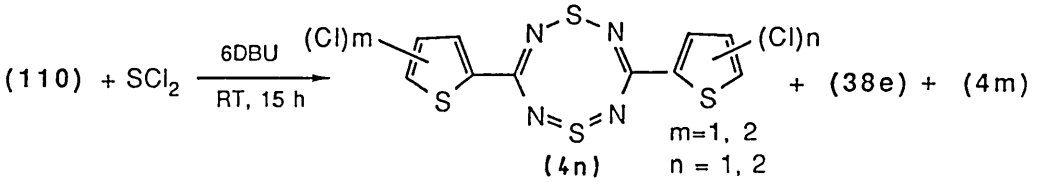
major product (69%).

4-(2-Thienyl)-1,2,3,5-dithiadiazolium chloride (38e) was obtained as red air-sensitive crystals, m.p. 162-164°C. The mass spectrum showed the molecular ion of the cation at m/z 187 with major fragment ions at M^+-46 (- NS) and M^+-78 (- NS and - S) and the elemental analysis suggested the formula $C_5H_3ClN_2S_3$.



(110) (38e) (4m)

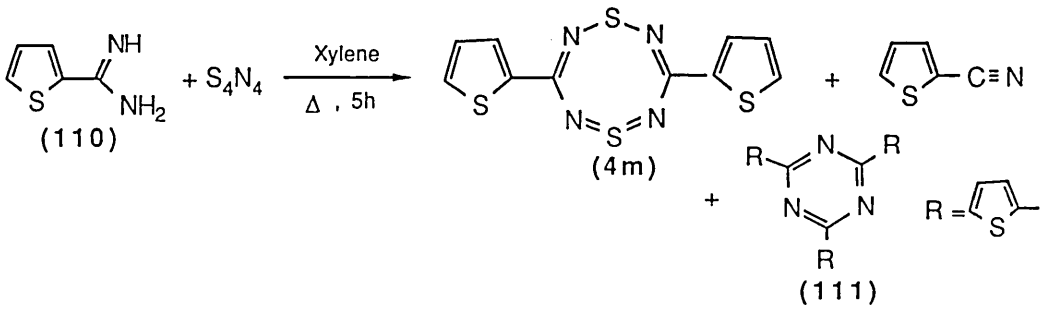
A low yield (7.3%) of 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) was also obtained, and this was not chlorinated (cf the 2-furylamidine case above). However prolonged stirring of the reaction mixture at room temperature (15 h) led to a low yield of polychlorinated di(2-thienyl)dithiatetrazocines (4n) together with unchlorinated dithiatetrazocine (4m) (3%).



(4n)

3,7-Di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) was obtained as orange-yellow needles (ethyl acetate), m.p. 271-273°C and was only slightly soluble in most organic solvents. The mass spectrum showed the molecular ion m/z at 310 with major fragment ions at M^+-109 (- 2-cyanothiophene), M^+-123 (- 2-cyanothiophene and - N), M^+-169 (- 2-cyanothiophene, - N, and - NS) and M^+-201 (- 2-cyanothiophene, - N, - NS and - S). The proton n.m.r spectrum showed double doublets at δ 8.30 (J 1 and 4 Hz), 7.64 (J 1 and 5 Hz) and 7.23 (J 4 and 5 Hz) all with equal integrals. The u.v. spectrum (EtOH) showed $\lambda_{max.}$ at 447, 351, 318, and 217 nm (Figure 2.1) suggesting a planar conformation for the dithiatetrazocine ring and the elemental analysis suggested the formula $C_{10}H_6N_4S_4$.

When 2-thienylamidine (110) was heated with S_4N_4 in dry xylene at reflux (5 h), a low yield of the same dithiatetrazocine (4m) (3.5%) was obtained together with 2-cyanothiophene and 2,4,6-tris(2-thienyl)-1,3,5-triazine (111) (11%).



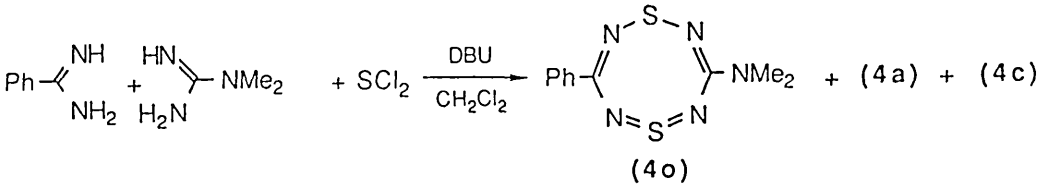
Treatment of amidine (110) with sulphurdiimide (11b) in dry dichloromethane at room temperature under nitrogen, also gave di(2-

thienyl)dithiatetrazocine (4m) but in even lower yield (1.7%).

2.4.3 Unsymmetrical dithiatetrazocines

It would be of interest to prepare mixed derivatives of the dithiatetrazocine system to investigate whether they are planar or puckered and moreover to see the effect on the yields.

When a mixture of benzamidine and N,N-dimethylguanidine was treated with freshly distilled sulphur dichloride in dry dichloromethane at 0°C in the presence of DBU, 3,7-diphenyl-, 3,7-bis(dimethylamino)- and 3-(dimethylamino)-7-phenyl-1,5,2,4,6,8-dithiatetrazocines (4a) (9.5%), (4c) (5%), and (4o) (3%) respectively were obtained. The combined yields of dithiatetrazocines in this experiment was 17.5%.



(4o)

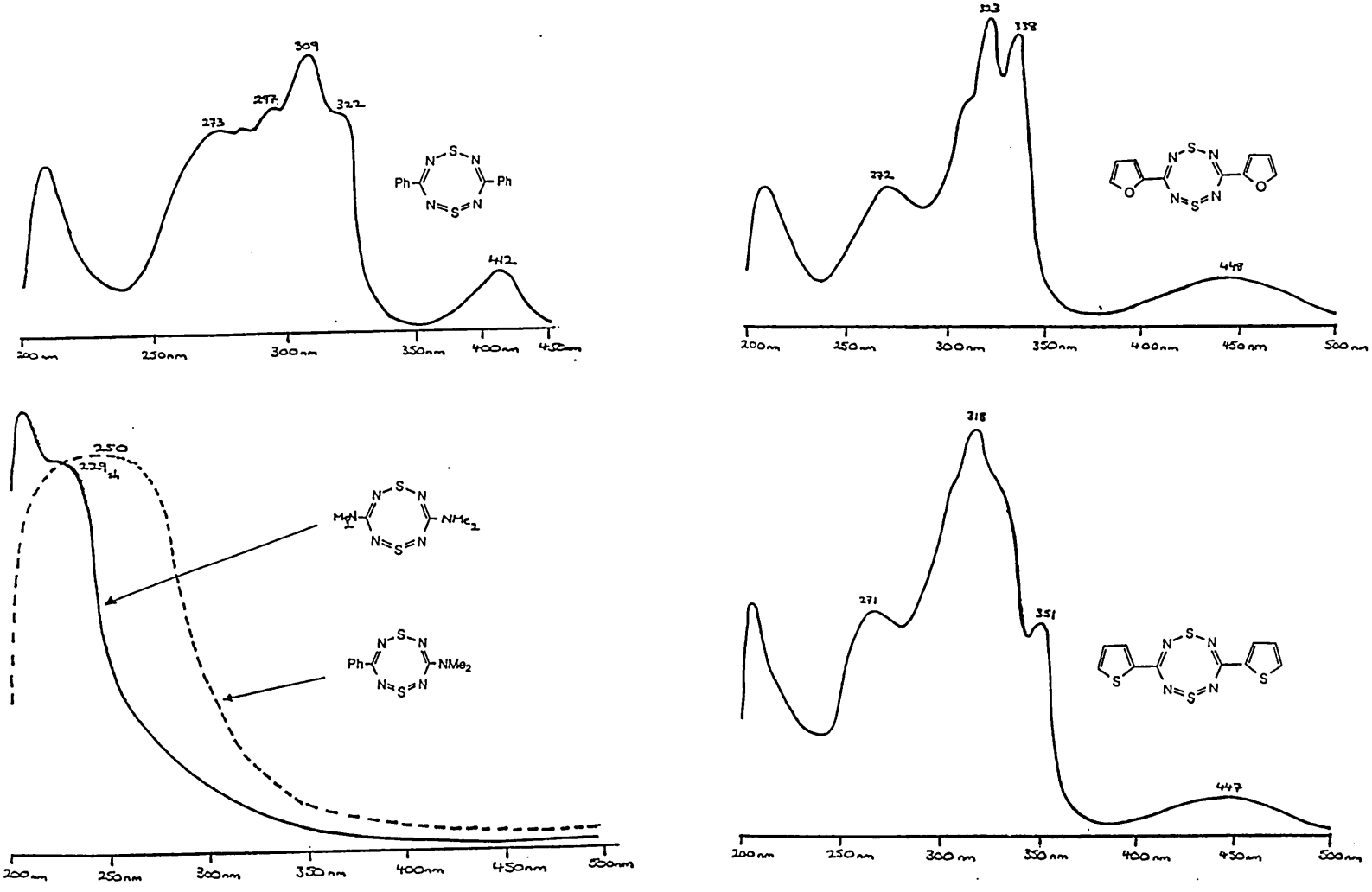
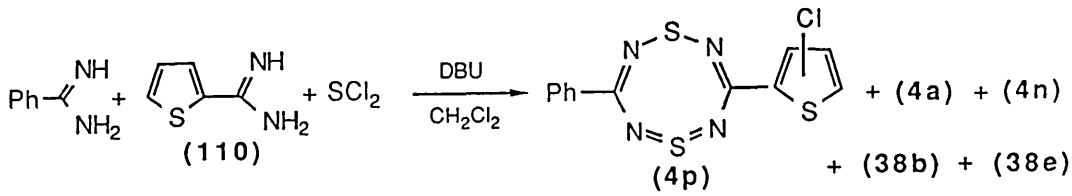


Figure 2.1 : Ultra-violet spectra of 1,5,2,4,6,8-dithiatetrazocines (4).

3-(Dimethylamino)-7-phenyl-1,5,2,4,6,8-dithiatetrazocine (4o) was obtained as pale yellow crystals, m.p. 182-183°C and was readily soluble in organic solvents. The mass spectrum showed a molecular ion at $\underline{m}/\underline{z}$ 265 with major fragment ions at $\underline{M}^+$-84 [- $C(N_2)NMe_2$], $\underline{M}^+$-130 [- $C(N_2)NMe_2$, and - NS], and $\underline{M}^+$-162 [- $C(N_2)NMe_2$, - NS, and - S]. The proton n.m.r spectrum showed aromatic multiplets at δ 8.17 (integral 2) and 7.35-7.50 (integral 3) and a singlet for the methyl protons at δ 3.21 (integral 6). The u.v. spectrum (EtOH) showed $\lambda_{max.}$ at 250 nm, similar to that of the bis(dimethylamino)-dithiatetrazocine (4c) and in striking contrast with the more complex spectra of the diaryl derivatives [(4a), (4l) and (4m)] (Figure 2.1). This suggests that the monoaminodithiatetrazocine (4o) has a similar puckered structure to the dimethylaminodithiatetrazocine (4c), in contrast to the planar diaryl structures.[4] It is interesting to note from this evidence that only one electron-releasing dimethylamino group appears to be necessary to cause the heterocyclic ring to pucker.

When a mixture of benzamidine and 2-thienylamidine (110) was treated with freshly distilled sulphur dichloride at 0°C in dry dichloromethane in the presence of DBU, a complex mixture was obtained. We were unable to separate this complex mixture but mass spectrum and hplc (MeOH) indicated that it was a mixture of 3,7-diphenyl-, polychlorinated 3,7-bis(2-thienyl)- and 3-(monochloro-2-thienyl)-7-phenyl-1,5,2,4,6,8-dithiatetrazocine (4p). In addition, a mixture of 4-phenyl-, and 4(2-thienyl)-1,2,3,5-dithiadiazolium chlorides [(38b) and (38e)] was also obtained (identified by mass spectrum).



2.5 Chemistry of dithiatetrazocines

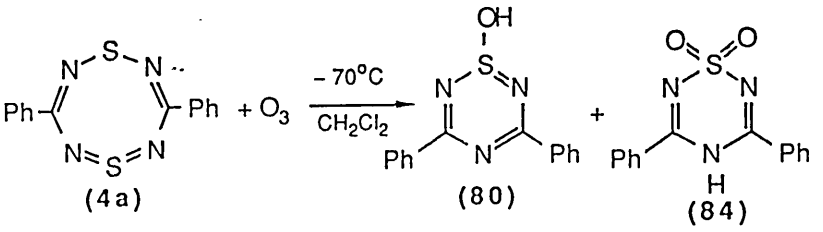
(i) 3,7-Diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a)

Compound (4a) was stable with respect to oxidation by MCPBA in refluxing dichloromethane or 1,2-dichloroethane and even to dinitrogen tetraoxide (N_2O_4) in dichloromethane at 0°C. No adduct was formed with NBD in ether at room or refluxing temperatures, and it was found to be inert towards diazomethane. It was also stable to nucleophiles as it did not react with triphenylphosphine in refluxing toluene (9 h) and xylene (8 h). Nor did it react with tosyl azide in refluxing benzene, toluene or xylene and chloramine-T in methanol at room or reflux temperatures. All of this agrees with its stability as a 10π electron aromatic system (Section 1.1). Attempted nitration with nitronium tetrafluoroborate failed.

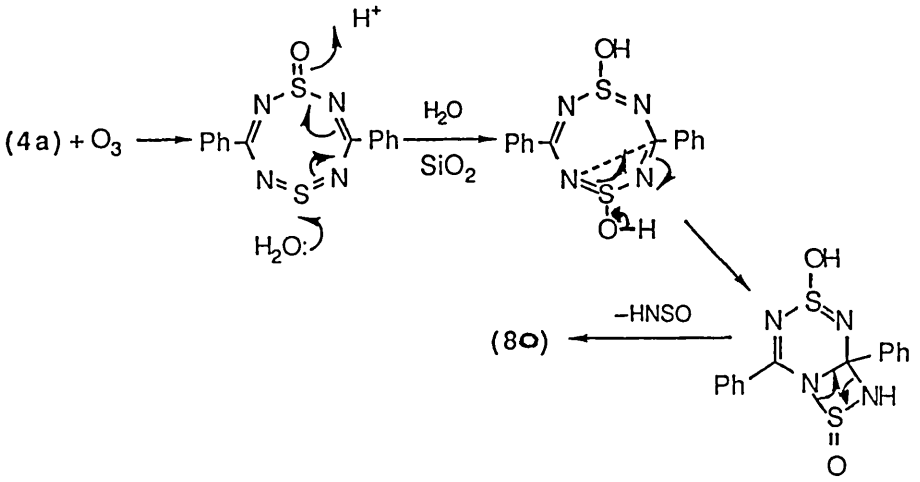
However it was reduced to benzamidine and sulphur with anhydrous hydrazine in the presence of 10% palladium on charcoal (Section 5.3).

When ozone was passed through a stirred slurry of dithiatetrazocine (4a) in dry dichloromethane at -78°C for 30 min, and the mixture warmed to room temperature and chromatographed on silica, hydroxythiatriazine (80) (32%) and thiatriazin-1,1-dioxide (84) (3%)

were obtained. When ozone was passed through for 1 h at -70°C, a slight increase in the yields of the two thiatriazines [(80) (38%) and (84) (5%)] was observed.



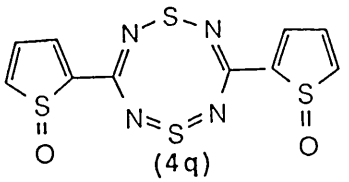
It seems that the dithiatetrazocine ring has been oxidised, then hydrolysed followed by ring contraction to give the observed product (80) (Scheme 2.5). Further oxidation with ozone of either the intermediates or the hydroxythiatriazine (80) leads to the thiatriazin-1,1-dioxide (84).



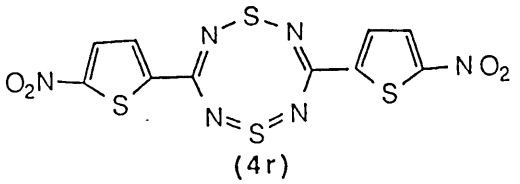
Scheme 2.5 : The formation of hydroxythiatriazine (80) by ozonolysis of the dithiatetrazocine (4a).

(ii) 3,7-Di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m)

Since we had found that the diphenyldithiatetrazocine (4a) was stable to oxidation by MCPBA or N_2O_4, we had hoped to oxidise the thiophene rings in compound (4m) to give the corresponding sulphoxide e.g. (4q) or sulphone. It was hoped that the oxidised thiophene rings could then be degraded further.



(4q)



(4r)

However oxidation of compound (4m) with either MCPBA, in dichloromethane or dichloroethane, up to reflux temperatures, or N_2O_4 failed to give any S-oxides; in all cases, compound (4m) was recovered in 80-90% yield. Similarly attempted nitration of compound (4m) with nitronium tetrafluoroborate in ether or acetonitrile up to reflux temperatures failed to give any nitro derivatives e.g. (4r), 90-95% of the starting material (4m) being isolated.

(iii) 3,7-Bis(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c)

Since the two sulphur atoms in (4c) are reasonably close to each other (even closer than in S_4N_4), we had hoped that compound (4c) would undergo cycloaddition reactions. However it failed to react with diazomethane, DMAD, NBD and phenyl vinyl sulphoxide (Table 2.8). In all cases, 90-95% of the dithiatetrazocine (4c) was recovered.

CH_2N_2	DMAD	NBD	phenyl vinyl sulphoxide
Ether	Toluene	Ether	Xylene (Δ, 6 h)
(RT, 10 h)	(Δ, 10 h)	(RT, 6 h)	PhBr (Δ, 4 h)
	Xylene	Ether	
	(Δ, 8 h)	(Δ, 5 h)	
	PhBr		
	(Δ, 4 h)		

PhBr = bromobenzene

Table 2.8 : Attempted cycloaddition reactions with 3,7-bis-(dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c).

Summary

Several novel methods for the synthesis of dithiatetrazocines (4) are reported. Low yields of diphenyldithiatetrazocine (4a) were obtained when either benzamidine or benzamidoxime was heated with S_4N_4. Low yields of compound (4a) were also obtained when benzamidine was treated with a range of either imide-N-sulphenyl chlorides (76) or N,N'-thiobisimides (77) and sulphurdiimides (11), but these reagents are stable, and easy to make and purify.

We were unable to synthesise the parent dithiatetrazocine (4b). However 3,7-di(2-furyl)- and 3,7-di(2-thienyl)-1,5,2,4,6,8,-dithiatetrazocines were synthesised by treating the corresponding amidines with either S_4N_4 or bis(tosyl)sulphurdiimide (11b). The u.v. spectra of these two dithiatetrazocines suggested planar heterocyclic rings. An unsymmetrical dithiatetrazocine, 3-(dimethylamino)-7-phenyl-1,5,2,4,6,8-dithiatetrazocine (4o) was synthesised and its heterocyclic ring appeared to adopt a puckered conformation.

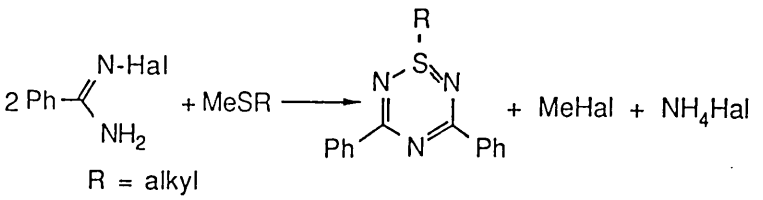
Both the diphenyl- and the di(2-thienyl)-dithiatetrazocines were stable towards oxidising agents, electrophiles, and nucleophiles, and 3,7-bis(dimethylamino)-dithiatetrazocine did not undergo cycloaddition reactions.

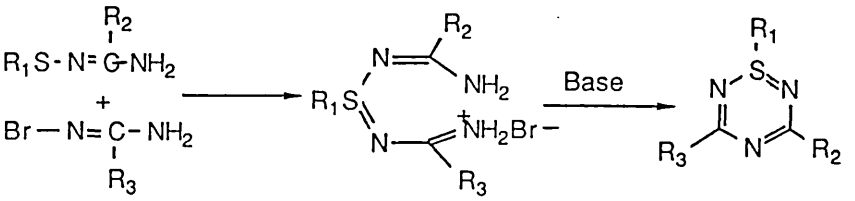
CHAPTER 3

1,2,4,6-THIATRIAZINES

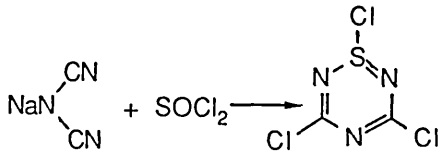
3.1 Synthesis of thiatriazines

1,2,4,6-Thiatriazines are known with a wide range of substituents on sulphur and carbon. For example, derivatives with alkyl or aryl groups in the 1, 3, and 5-positions have been prepared by the reaction of N-haloamidines with thiolates or N-sulphenylamidines as shown below.[50]

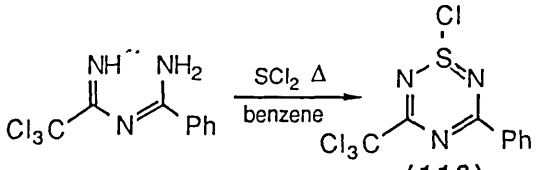




The fully chlorinated compound (112) has been prepared from sodium dicyanoamide and thionyl chloride,[51] and mixed derivatives, eg 1-chloro-3-phenyl-5-(trichloromethyl)-1,2,4,6-thiatriazine (113) are accessible via ring closure reactions between imidoylamidines and sulphur dichloride.[52]

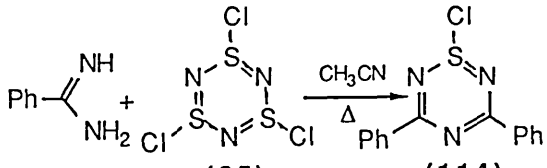


(112)



(113)

Recently, Oakley and his coworkers have shown that 1-chloro-3,5-diphenyl-1,2,4,6-thiatriazine (114) can be prepared by treating benzamidine with trithiazyl trichloride (35) in refluxing acetonitrile.[53, 54]



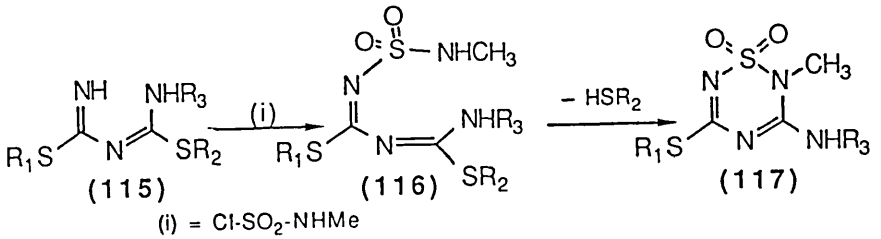
(35) (114)

In general these thiatriazines are air-sensitive, crystalline compounds with a tendency to undergo spontaneous decomposition. X-Ray structure determinations of derivatives have shown that the ring system is not completely planar.[53, 54, 55]

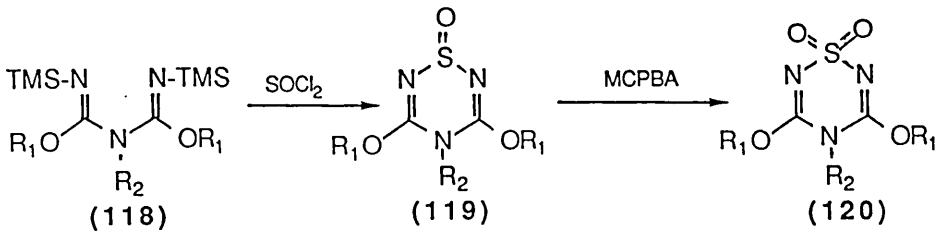
However the well known 1,2,4,6-thiatriazin-1,1-dioxides are air-stable, high melting, crystalline compounds. Interest in the biological activity of certain 1,2,4,6-thiatriazin-1,1-dioxide derivatives has led to the development of synthetic routes to the 2-

alkyl, 2,4-dialkyl, and 4 H derivatives of this ring system.

2-Alkyl-1,2,4,6-thiatriazin-1,1-dioxides (117) have been synthesised by treating the di-isothiobiurets (115) with methylaminosulphonyl chloride and then cyclising the intermediates (116) in refluxing acetonitrile.[56]

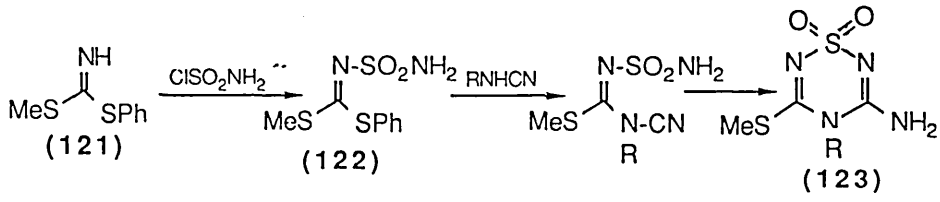


The corresponding 4-alkylthiatriazin-1,1-dioxides (120) have been prepared by cyclisation of bis(trimethylsilyl)di-isobiurets (118) with thionyl chloride to give the mono S-oxides (119) followed by oxidation with MCPBA.[57]

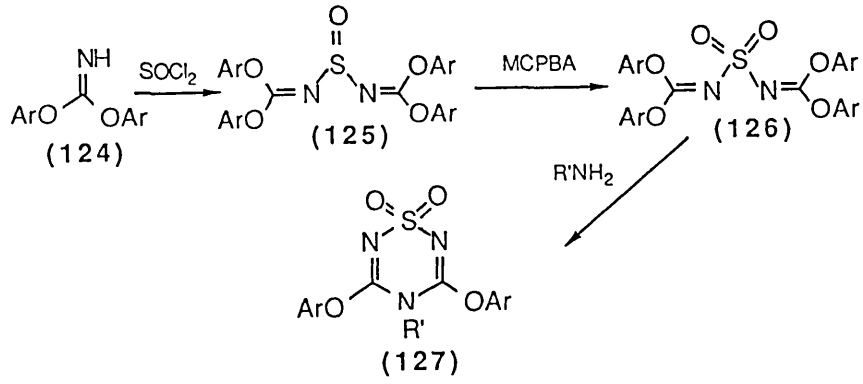


Owing to difficulty in the preparation of higher alkyl di-isobiurets, a general route to 4-alkylthiatriazin-1,1-dioxides was achieved by treating the dithio-imidocarbonate (121) with sulphamoyl

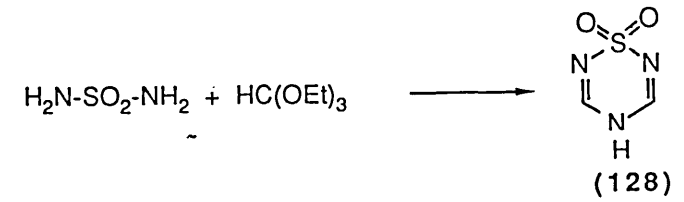
chloride to produce the sulphamide derivative (122). Treatment of (122) with one equivalent of sodium hydride followed by reaction with an alkylcyanamide gave the 4-alkylthiatriazin-1,1-dioxide (123).[57]



Recently, a simplified and efficient method for the synthesis of 4-alkylthiatriazin-1,1-dioxides was reported. This involved the sulphamide intermediate (126), which was prepared by treating diaryl carbonimidates (124) with thionyl chloride to give the derivative (125) followed by oxidation with MCPBA. Reaction of (126) with one equivalent of primary amine gave 4-alkylthiatriazin-1,1-dioxide (127) by displacement of two aryloxy groups.[58]



The parent ring system, 4H-1,2,4,6-thiatriazin-1,1-dioxide (128) was made by treating sulphamide with an excess of ethyl orthoformate in a sealed tube at 130°C for 12 h.[59]



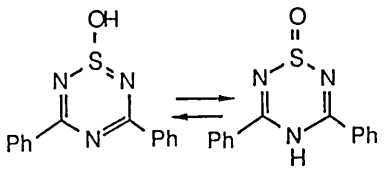
(128)

During the course of our own work, we discovered several novel methods for the synthesis of 1,2,4,6-thiatriazines and these methods are described below.

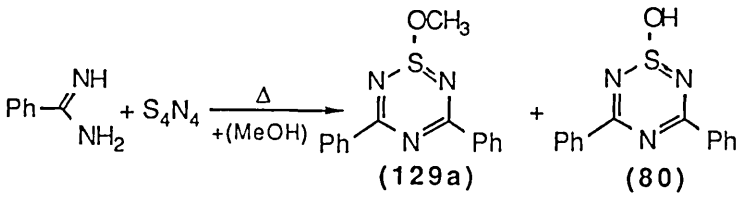
3.1.1 Reaction of benzamidine with S_4N_4

When benzamidine and S_4N_4 were heated together in refluxing aromatic hydrocarbons followed by addition of methanol to the reaction mixture, 1-methoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129a) and 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) were obtained (Table 3.1).

Hydroxythiatriazine (80a) is in equilibrium with the 1-oxo form (80b) shown, but for simplicity it is referred to as the hydroxy compound (80a) throughout this thesis.



(80a) (80b)



(129a) (80)

Ratio A:S_4N_4	Solvent	Temp/°C	Time/h	(129a)	(80)
1 : 1	Benzene	80	16	14	22
3 : 1	Toluene	110	3.5	3	9
3 : 1	Toluene	110	15	22	14
2 : 1	Xylene	140	6	17	7

A=benzamidine

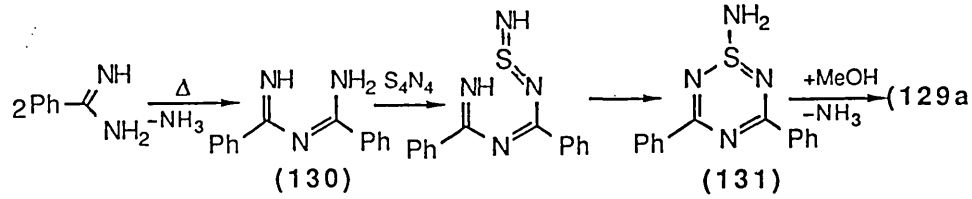
Table 3.1 : Yields (%) of methoxythiatriazine (129a) and hydroxythiatriazine (80) from benzamidine and S_4N_4. See also Table 2.1, Section 2.2.2.

1-Methoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129a) was obtained as colourless prisms, m.p. 105-106°C, readily soluble in organic solvents. Its structure was assigned on the basis of its spectral data. The mass spectrum showed the molecular ion ($\underline{M}^+$) at $\underline{m/z}$ 283 with major fragment ions at $\underline{M}^+$-31 (- OMe), $\underline{M}^+$-134 (- OMe and - PhCN) and $\underline{M}^+$-180 (- OMe, - PhCN and - SN). The proton n.m.r spectrum showed that the two phenyl rings were symmetrical and mono-substituted with multiplets at δ 8.51-8.55 (integral 4) and δ 7.54-7.68 (integral 6); the methoxy protons were seen as a singlet at δ 3.41 (integral 3). The ^{13}C n.m.r spectrum further proved that the two phenyl rings were symmetrical by showing singlets at δ 132.46, 128.69 and 128.21; the thiatriazine ring carbon atom showed a singlet at δ 168.36 and the methoxy carbon showed a singlet at δ 50.15. The i.r. spectrum showed absorptions at 1580, 1390 and 1020 cm^{-1}, characteristic of the stretching vibrations of the thiatriazine ring,[52] while that at 950 cm^{-1} is attributed to the stretching vibration of the S-OMe group. Elemental analysis

suggested the formula $C_{15}H_{13}N_3OS$.

The methoxythiatriazine (129a) hydrolysed slightly to the corresponding hydroxythiatriazine (80) upon column chromatography on silica gel and also when left standing in air, suggesting that the methoxy group on the sulphur atom is labile. One can see from Table 3.1 that substantial amounts of methoxythiatriazine (129a) were formed when the yield of hydroxythiatriazine (80) is also taken into account.

The mechanism for the formation of methoxythiatriazine (129a) can be rationalised as shown in Scheme 3.1.



Scheme 3.1 : Proposed mechanism for the formation of methoxythiatriazine (129a) from benzamidine and S_4N_4.

Since benzamidine loses ammonia on thermolysis and 2,4-diphenyl-1,3,5-triazapenta-1,3-diene (130) is formed,[60] we can speculate that intermediate (130) reacts with S_4N_4 to form aminothiatriazine (131) which then reacts with methanol to give methoxythiatriazine (129a). Without the addition of methanol, the methoxythiatriazine (129a) is not formed, but hydroxythiatriazine (80) was isolated. It could be that the aminothiatriazine (131) is formed but is unstable on silica and is hydrolysed to the hydroxy compound (80).

3.1.2 Reaction of benzamidine with bis(tosyl)sulphurdiimide (11b) in chloroform

When solutions of bis(tosyl)sulphurdiimide (11b) and benzamidine in dry chloroform are added simultaneously and synchronously to a large volume of vigorously stirred solvent at reflux temperature under nitrogen , 1-ethoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129b) is obtained in varying yields (43-56%). The ethoxy group in this unexpected product must have come from residual ethanol in the solvent even though the chloroform was dried by distillation from phosphorus pentoxide and passage through a column of basic alumina prior to use.

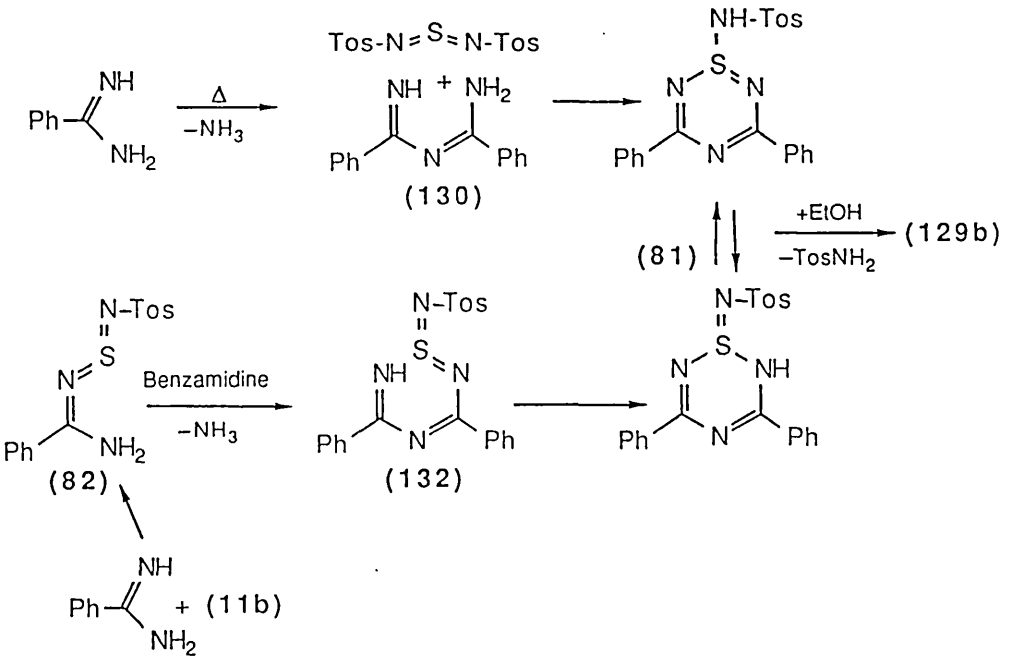
However when the reaction is performed in the presence of ethanol (1 eq), there is no trace of the formation of the ethoxythiatriazine (129b) and only baseline products are obtained. Even in the presence of either basic or neutral alumina or silica, no ethoxythiatriazine (129b) is formed. Unfortunately, this curious reaction was not very reproducible and was therefore not investigated further.

The structure of ethoxythiatriazine (129b), obtained as colourless prisms, m.p. 94-95°C, was assigned on the basis of its spectral data. The mass spectrum showed a molecular ion at m/z 297 with the major fragment ions at M^+-45 (- OEt), M^+-148 (- OEt and - PhCN) and M^+-194 (- OEt, - PhCN and - NS). The proton n.m.r spectrum showed that the phenyl rings were symmetrical and mono-substituted, with multiplets at δ 8.35-8.50 (integral 4) and δ 7.35-7.50 (integral 6). The presence of the ethoxy group was demonstrated by a quartet at δ 3.67 (integral 2) and a triplet at δ 1.18 (integral 3). The ^{13}C n.m.r spectrum further proved that the two phenyl rings were symmetrical by showing singlets at δ 132.37, 128.61, 128.17 and

136.69. The thiatriazine ring carbon showed a singlet at δ 167.95 while the ethoxy carbons appeared as a triplet at δ 60.99 and a quartet at δ 15.34. The characteristic stretching vibrations of the thiatriazine ring[52] were observed at 1560, 1400 and 1020 cm^{-1} in the i.r. spectrum. The stretching vibrations of the S-OEt group appeared at 1000 and 870 cm^{-1}. Furthermore, elemental analysis suggested the formula $C_{16}H_{15}N_3OS$.

The ethoxythiatriazine (129b), like the methoxythiatriazine (129a), also hydrolysed slowly to the corresponding hydroxythiatriazine (80) on column chromatography (silica) and when left standing in air.

The formation of the ethoxythiatriazine (129b) can be rationalised as shown in Scheme 3.2.

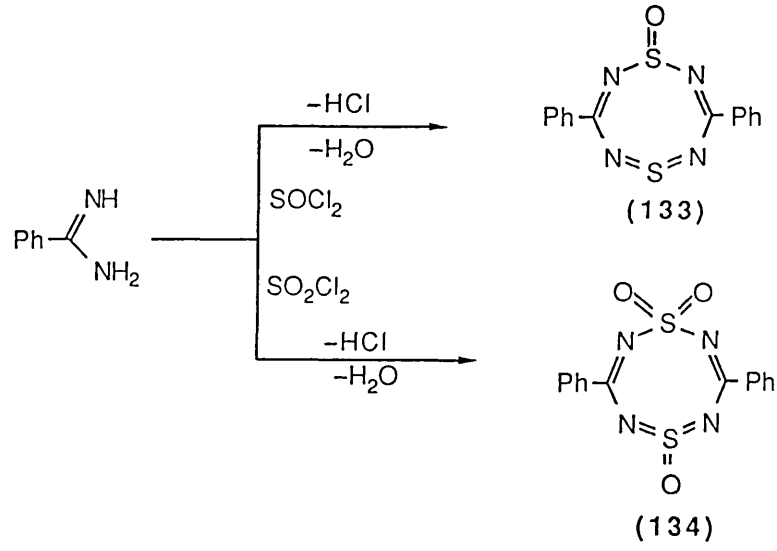


Scheme 3.2 : Proposed mechanism for the formation of ethoxythiatriazine (129b) from benzamidine and bis(tosyl)sulphurdiimide (11b).

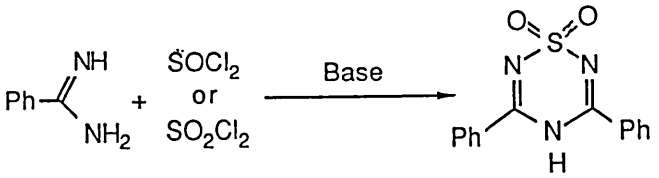
Benzamidine loses ammonia on thermolysis and triazapenta-1,3-diene (130) is formed,[60] which is then cyclised by bis(tosyl)sulphurdiimide (11b) to give 1-(p-toluenesulphilimino)thiatriazine (81). Compound (81) then reacts with the residual ethanol in the solvent to give the ethoxythiatriazine (129b). Alternatively, benzamidine reacts with bis(tosyl)sulphurdiimide (11b) to form the sulphurdiimide (82) which then reacts with more benzamidine by loss of ammonia to form intermediate (132). Cyclisation of intermediate (132) gives the sulphiliminothiatriazine (81) which then reacts with the residual ethanol to give the ethoxythiatriazine (129b).

3.1.3 Reaction of benzamidine with thionyl or sulphuryl chloride

One might expect benzamidine to react with thionyl or sulphuryl chloride, in a similar way as with sulphur dichloride (Section 2.2), to give oxides of dithiatetrazocines (133) and (134) respectively.



However when benzamidine was treated with thionyl or sulphuryl chloride in the presence of base, colourless prisms (ethanol), m.p. >310°C, tentatively assigned structure (84) were obtained in low yield (Table 3.2).



(84)

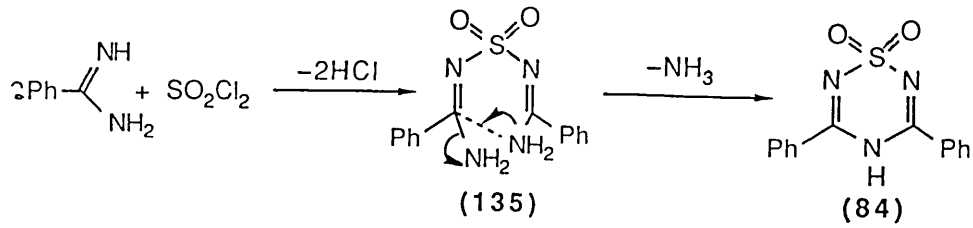
Reagent	Base	(84)
$SOCl_2$	DBU	16
$SOCl_2$	Et_3N	22
SO_2Cl_2	DBU	6

Table 3.2 : Yields (%) of thiatriazin-1,1-dioxide (84) from benzamidine and thionyl or sulphuryl chloride.

The structure (84) was assigned according to its spectroscopic and analytical data (indicating $C_{14}H_{11}N_3O_2S$). The mass spectrum showed a molecular ion at m/z 285 with major fragment ions at M^+-64 (- SO_2), M^+-167 (- SO_2 and - PhCN) and M^+-181 (- SO_2, - PhCN, and - N). The characteristic stretching vibrations of the thiatriazine ring were observed at 1570 and 1027 cm^{-1} in the i.r. spectrum. The absorption at 3280 cm^{-1} can be attributed to NH stretching and those at 1320 and 1161 cm^{-1} are characteristic of $-SO_2-$ stretching. The proton n.m.r spectrum, showed that the two phenyl rings were symmetrical

and mono-substituted with multiplets at δ 8.02-8.14 (integral 2) and δ 7.55-7.78 (integral 3); the N-H proton had exchanged with the deuteriated solvent and its signal could not be seen. The ^{13}C n.m.r spectrum further indicated that the two phenyl rings were symmetrical by showing singlets at δ 130.90, 128.69, 128.49 and 132.90. The thiatriazine ring carbon showed a singlet at δ 158.34.

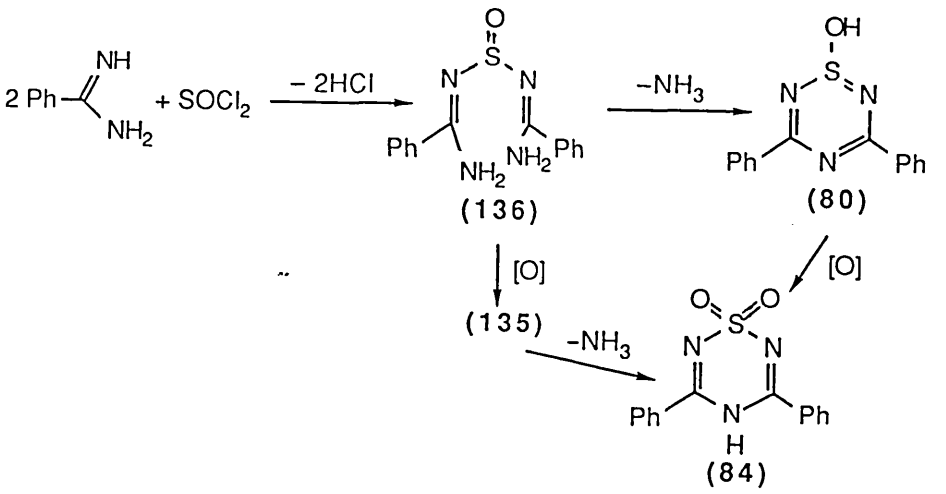
We were puzzled by the low yields obtained of the thiatriazin-1,1-dioxide (84) with sulphuryl chloride. The mechanism for the formation of thiatriazin-1,1-dioxide (84) can be rationalised as proposed in Scheme 3.3. The reaction could proceed via the sulphamide intermediate (135) and loss of ammonia from compound (135) then leads to the thiatriazin-1,1-dioxide (84).



(135) (84)

Scheme 3.3 : Proposed mechanism for the formation of thiatriazin-1,1-dioxide (84) from benzamidine and sulphuryl chloride.

However the reaction of benzamidine with thionyl chloride could proceed via the sulphoxide intermediate (136) and then loss of ammonia leads to the hydroxythiatriazine (80) which is somehow oxidised to the thiatriazin-1,1-dioxide (84) (Scheme 3.4)



Scheme 3.4 : Proposed mechanism for the formation of thiatriazin-1,1-dioxide (84) from benzamidine and thionyl chloride.

The oxidising agent could be thionyl chloride itself.[100] The thiatriazin-1,1-dioxide (84) could also be formed by oxidation of the sulphoxide (136) to sulphamide (135) followed by loss of ammonia.

This reaction would be very useful if generally applicable. We investigated a series of reactions where the Ph in the benzamidine was replaced by H, Me, NH_2, CO_2H, CO_2Me, CH_2OH, or NHAc. However none of these reactions gave the corresponding thiatriazin-1,1-dioxides.

3.1.4 Reaction of benzamidoxime with S_4N_4

The main aim of reacting benzamidoxime (85) with S_4N_4 was to synthesise the diphenyldithiatetrazocine (4a). In fact dithiatetrazocine (4a) was obtained in very low yield (see Section 2.3.1, Table 2.6) only when benzamidoxime and S_4N_4 were heated together in toluene at reflux for a long period of time (Table 3.3). Other products obtained in substantial yields, when benzamidoxime and S_4N_4 were heated together in refluxing aromatic hydrocarbons were hydroxythiatriazine (80), 2,5-diphenyl-1,3,4-triazole (92) and thiatriazin-1,1-dioxide (84) (Table 3.3).

Ratio (85):S_4N_4	Solvent	Temp/°C	Time/h	(4a)	(92)	(80)	(84)
2 : 1	Toluene	110	3	-	5	5	17
2 : 1	Toluene	110	12	4	2	10	16
4 : 1	Xylene	140	6	0.4	10	4	25

(85)=benzamidoxime

Table 3.3 : Yield (%) of products obtained when S_4N_4 is reacted with benzamidoxime.

Compounds (92) and (84) were charaterised according to their spectral and analytical data and by comparision with authentic samples.

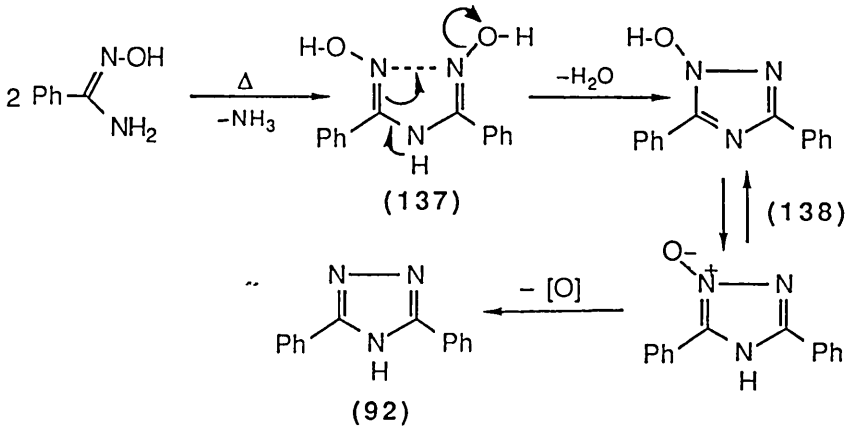
The structure of 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) was assigned according to its spectral data. Compound (80) was obtained as colourless compound, m.p. 156-158°C, and the mass

spectrum showed the molecular ion at m/z 269 with major fragment ions at M^+-16 (- O), M^+-17 (- OH), M^+-48 (- SO), M^+-120 (- OH and - PhCN) and M^+-166 (- OH, - PhCN, and - NS). The i.r. spectrum showed absorption bands at 1590 and 1030 cm^{-1}, characteristic of the stretching vibrations of the thiatriazine ring. Absorptions at 3380 cm^{-1} and 1060 cm^{-1} can be attributed to the N-H and SO groups. The proton n.m.r spectrum, showed aromatic multiplets at δ 8.20-8.35 (integral 4) and δ 7.50-7.77 (integral 6) and a broad singlet at δ 10.03 (integral 1) due to NH.

In a blank experiment, benzamidoxime was heated, without S_4N_4, in refluxing toluene and xylene. In toluene no triazole (92) was formed even after prolonged heating (15 h), while in xylene (7 h) substantial amounts of triazole (92) were formed. Therefore one can assume that triazole (92) obtained from the reaction of benzamidoxime with S_4N_4 (Table 3.3) is just the thermolysis product of benzamidoxime.

When benzamidoxime is heated, N,N'-dihydroxy-1,3,5-triazapenta-1,3-diene (137) could be formed (by loss of ammonia), and could then undergo cyclodehydration; reduction of the N-hydroxytriazole (138) thus formed would give the triazole (92).

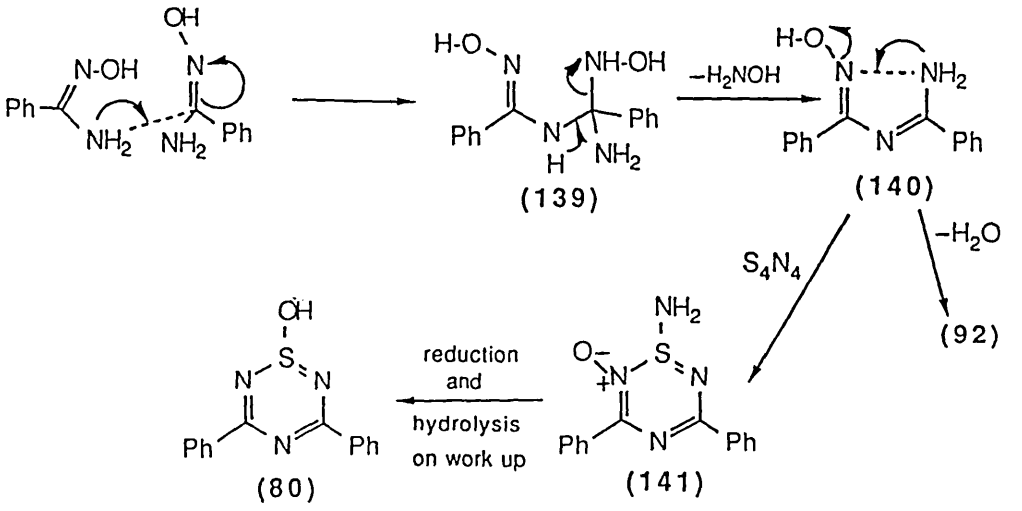
Alternatively, thermolysis of benzamidoxime could yield the intermediate (139) which subsequently eliminates hydroxylamine to form the triazapenta-1,3-diene (140) followed by dehydration to form the triazole (92) (Scheme 3.5).



The proposed mechanism for the formation of hydroxythiatriazine (80) from the reaction of benzamidoxime with S_4N_4 is illustrated in Scheme 3.5.

Thermolysis of benzamidoxime could form the adduct intermediate (139) which then eliminates hydroxylamine to form the N-hydroxytriazapenta-1,3-diene (140). Reaction of S_4N_4 with compound (140) could form the thiatriazine-N-oxide (141) which is then reduced by S_4N_4 and hydrolysed upon work up to hydroxythiatriazine (80).

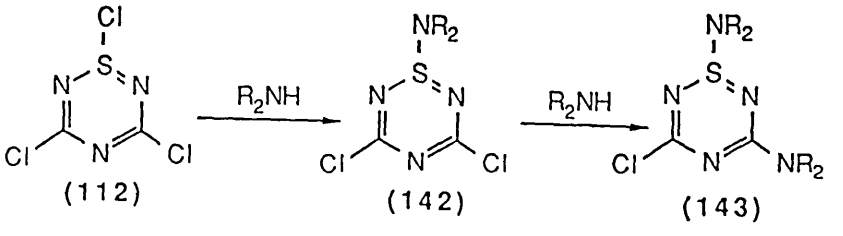
We do not have a convincing explanation for the formation of the thiatriazin-1,1-dioxide (84).



Scheme 3.5 : Proposed mechanism for the formation of hydroxythiatriazine (80) from benzamidoxime and S_4N_4.

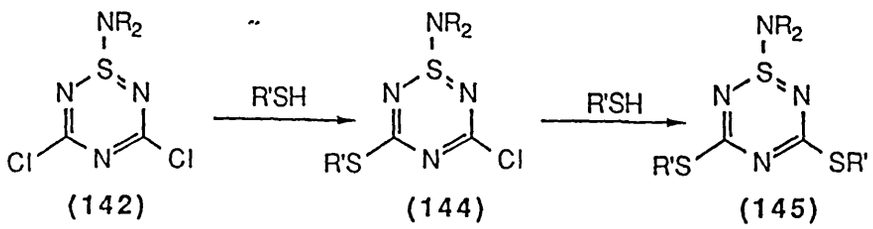
3.2 Chemistry of the thiatriazines

The early chemistry of the thiatriazines involved substitution reactions of 1,3,5-trichloro-1,2,4,6-thiatriazine (112) with secondary amines to give aminothiatriazines (142).



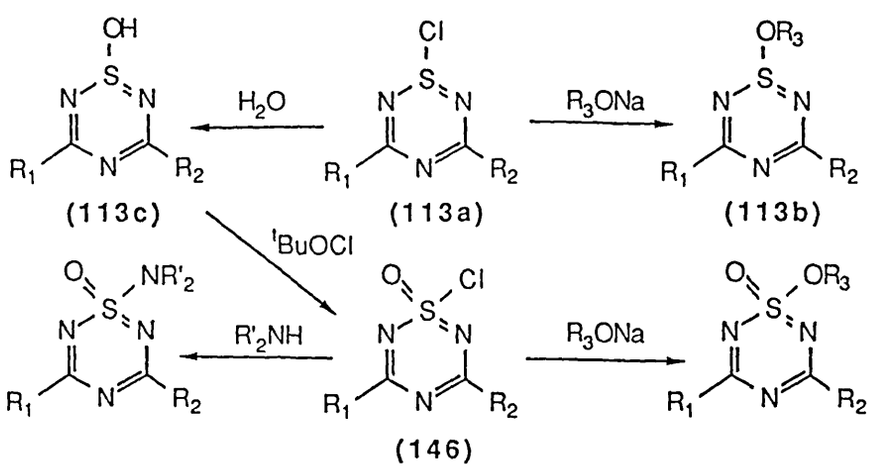
Treatment with an excess of amine was shown to produce the diamino compound (143); further reaction was not observed.[61]

In contrast, thiols reacted with 1-amino-3,5-dichlorothiatriazine (142) to give either compound (144) by displacement of one chlorine atom or compound (145) by displacement of both chlorine atoms.[62]



(142) (144) (145)

The chemistry of 1-chlorothiatriazines (113a) has been much studied.[52] The chlorine atom on the sulphur has acid chloride character and is rapidly substituted by nucleophiles such as sodium alkoxides or secondary amines. Hence the reaction of thiatriazines (113a) with sodium alkoxide leads to 1-alkoxy-1,2,4,6-thiatriazines (113b), while they are hydrolysed by water to hydroxythiatriazines (113c).

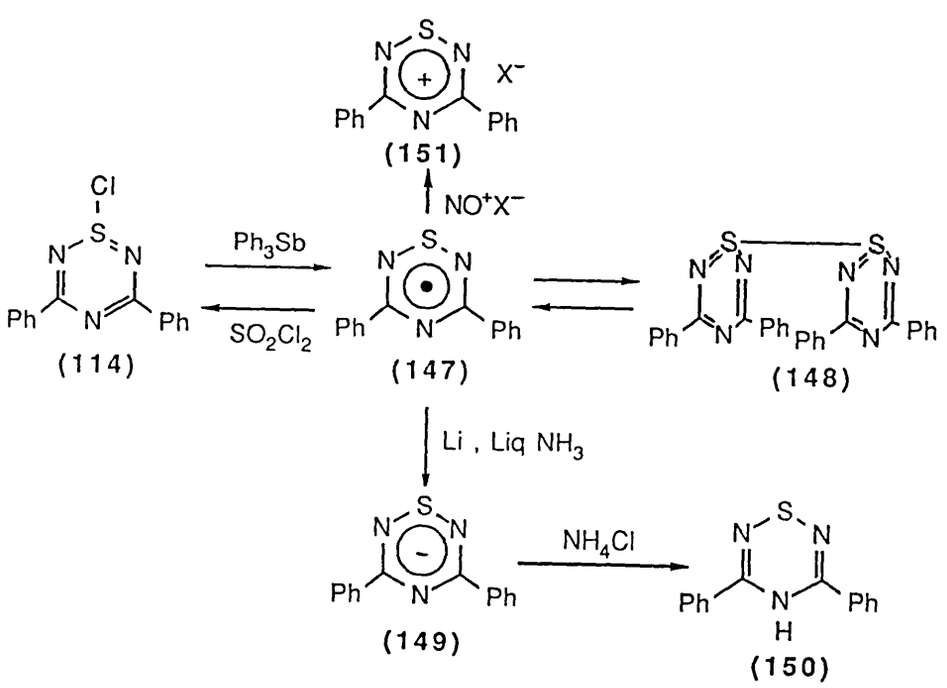


(113c) (113a) (113b)

(146)

The sulphur atom of the hydroxythiatriazines (113c) was oxidised by tert-butylhypochlorite to give 1-chloro-1-oxo-1,2,4,6-thiatriazine (146), the chlorine atom of which is readily displaced by nucleophiles such as sodium alkoxide and secondary amines.

Recently, Oakley et al reduced 1-chloro-3,5-diphenyl-1,2,4,6-thiatriazine (114) with triphenylantimony to produce the stable 3,5-diphenyl-1,2,4,6-trithiatriazinyl radical (147).[53,54] In the solid state, the radical (147) formed the sulphur-sulphur bridged dimer (148). They also found that the radical (147) could be reduced by sodium or lithium in liquid ammonia.[63] Although they were unable to isolate the anion (149) itself, they characterised the imide (150) by acidification of the reduced solution in ammonia with ammonium chloride. Both the imide (150) and the radical (147) were converted into the oxidised chlorothiatriazine (114) by teatment with sulphuryl chloride.[63] Oxidation of (148) with nitrosonium salts generated the corresponding cation (151).[63]

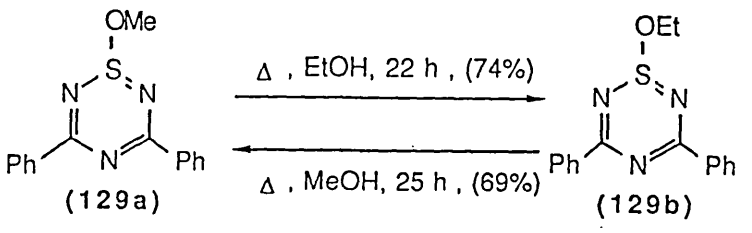


With supplies of 1-alkoxy- and 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazines (80) and (129) in hand, we decided to explore their chemistry partly because very little was known about them, and partly to confirm our structural assignments.

3.2.1 1-Alkoxy-3,5-diphenyl-1,2,4,6-thiatriazine

3.2.1.1 Miscellaneous

Both the methoxy- and ethoxy-thiatriazines (129a) and (129b) were hydrolysed slowly in air and on silica to the corresponding hydroxythiatriazine (80). This indicates that the alkoxy group on the sulphur atom is labile and this was also demonstrated by converting the methoxythiatriazine (129a) into the ethoxythiatriazine (129b) in refluxing ethanol, and vice versa. The reaction had to be followed by proton n.m.r. spectroscopy since (129a) and (129b) had very similar R_f values (0.56 and 0.54 respectively in 50% dichloromethane in petrol).

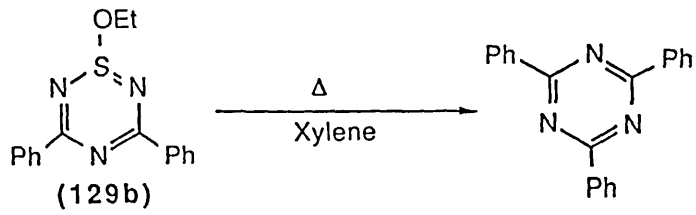


However, the conversions were not quantitative and substantial amounts of the hydroxythiatriazine (80) were isolated, 21% from the methoxy compound and 29% from the ethoxy compound. This can be explained by the solvents not being completely anhydrous, and by

further hydrolysis on silica.

A high yield of hydroxythiatriazine (80) (90%) was obtained simply by heating the ethoxythiatriazine (129b) in water for 3 h.

Thermolysis of the ethoxythiatriazine (129b) in refluxing xylene (2.5 h) gave the 2,4,6-triphenyl-1,3,5-triazine (73) (11%). This is an interesting reaction whose mechanism is yet unknown.



(129b) (73)

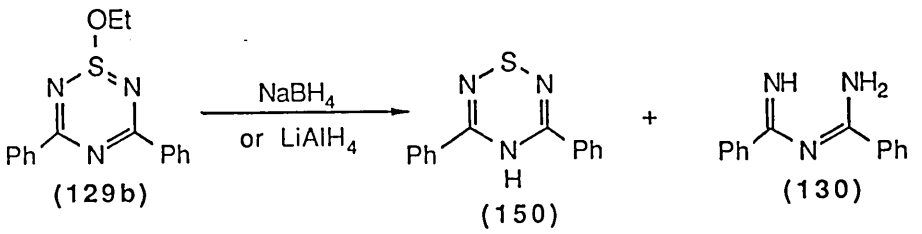
When the ethoxythiatriazine (129b) was treated with either tosylamide, tosylazide, or triphenylphospine in refluxing toluene, no reaction incorporating these reagents was observed. Unreacted thiatriazine (129b) and low yields of triazine (73) were isolated (Table 3.4). It seems that the thiatriazine (129b) was simply decomposing thermally to give the triazine (73).

Reagent	Time/h	(73) (%)	Unreacted (129b) (%)
$TosNH_2$	24	5	59
$TosN_3$	23	8	28
PPh_3	20	6	34

Table 3.4 : Attempted reaction of ethoxythiatriazine (129b) in toluene at reflux with various reagents.

The methoxythiatriazine (129a) did not react with chloramine-T in methanol either at room (14 h) or at reflux (8 h) temperatures, thiatriazine (129a) being recovered in high yield (92%).

Ethoxythiatriazine (129b) was reduced to the 4H-thiatriazine (150) in low yields either by sodium borohydride (10%) or lithium aluminium hydride (3%). The major product in both cases was base line material, which could be 2,4-diphenyl-1,3,5-triazapenta-1,3-diene (130), a very polar compound, produced by further reduction of thiatriazine (150).



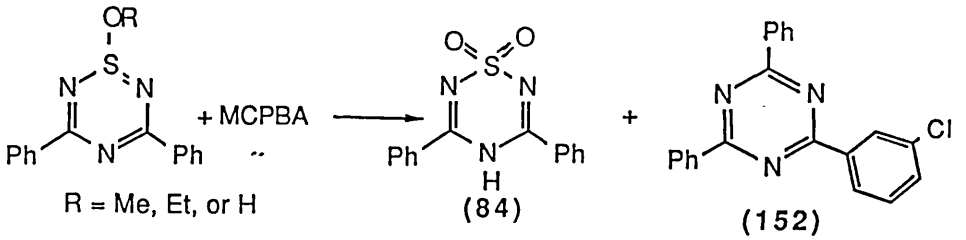
(129b) (150) (130)

3,5-Diphenyl-1,2,4,6-thiatriazine (150) was obtained as a red crystalline compound, m.p. 132-133°C, and the mass specrum showed the molecuar ion at m/z 253 with major fragment ions at M^+-1 (- H), M^+- 104 (- H and - PhCN) and M^+- 150 (- H, - PhCN and - NS). Compound (130) has been synthesised by the reduction of the thiatriazinyl radical (147) (Section 3.2), and our product has the same properties as those reported.[63]

3.2.1.2 Oxidation

1-Alkoxy-3,5-diphenyl-1,2,4,6-thiatriazines (129) (R=Me, Et) was oxidised by MCPBA in dichloromethane at room temperature, to 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84). Another product,

assigned structure (152), was also obtained in low yield (Table 3.5).



2-(m-Chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) was obtained as colourless needles, m.p. 198-199°C, and its mass spectrum indicated that it contained one chlorine atom, with the molecular ion at m/z 343 and major fragment ions at M^+-206 (- 2PhCN) and M^+-241 (- 2PhCN, and - Cl). The proton n.m.r spectrum showed multiplets at δ 8.6-8.8 (integral 6) and δ 7.55-7.65 (integral 8). Furthermore, the elemental analysis suggested the formula $C_{21}H_{14}ClN_3$.

Triazine (152) was made independently (55%) by heating a mixture of m-chlorobenzoyl chloride, benzonitrile, ammonium chloride and aluminium trichloride at 180°C overnight, following a similar procedure for 2(p-chlorophenyl)-4,6-diphenyl-1,3,5-triazine.[64] This product was identical with that from the MCPBA reaction.

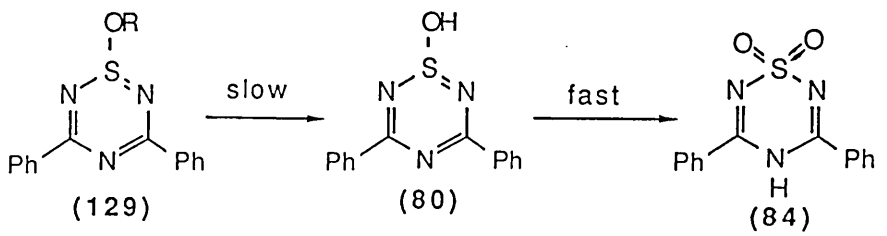
In order to gain some insight into the mechanism for the formation of triazine (152), the reaction was explored further (Table 3.5).

R	Eq of MCPBA	Solvent	Temp/°C	Time/h	(84)	(152)
Et	1.5	CH_2Cl_2	20	22	57	23
Et	2	CH_2Cl_2	20	18	64	18
Et	3	CH_2Cl_2	40	4	85	6
Et	4	CH_2Cl_2	20	7	81	9
Et	1+3*	CH_2Cl_2	20	15	47	18
Et	4	Benzene	20	29	82	15
Et	18	MeCN	20	48	86	-
H	1	CH_2Cl_2	20	2	48	20

* = m-chlorobenzoic acid

Table 3.5 : Summary of reaction conditions for the study of oxidation of alkoxy thiatriazine (129) with MCPBA.

From Table 3.5, one can see that ethoxythiatriazine (129b) is oxidised by MCPBA via hydroxythiatriazine (80) to the thiatriazin-1,1-dioxide (84). The intermediate hydroxythiatriazine (80) was detected by t.l.c. by comparision with an authentic sample.



(129) (80) (84)

The oxidation of hydroxythiatriazine (80) to thiatriazin-1,1-dioxide (84) by MCPBA is indeed fast as shown in a separate experiment (see Table 3.5, R=H).

Increasing the number of equivalents of MCPBA, should increase the yield of the thiatriazin-1,1-dioxide (84) and hopefully decrease the

yield of the triazine (152). Even a change in solvent might eliminate the formation of the triazine (152) altogether. Using an excess of MCPBA or an increase in temperature did lead to decreased yields of the triazine (152) and increased yields of the thiatriazin-1,1-dioxide (84) (Table 3.5). Changing the solvent from dichloromethane to benzene led to a slower oxidation rate but a considerable amount of triazine (152) (15%) was formed. In acetonitrile, even though the oxidation was much slower and needed a vast excess of oxidant (MCPBA), the triazine (152) was not formed and a high yield (86%) of the thiatriazin-1,1-dioxide (84) was obtained. Hence one can conclude that there are two processes going on, one is obviously the oxidation and the other is the reaction of MCPBA with either the ethoxy- (129b) or the hydroxy-thiatriazine (80) or both to form the triazine (152).

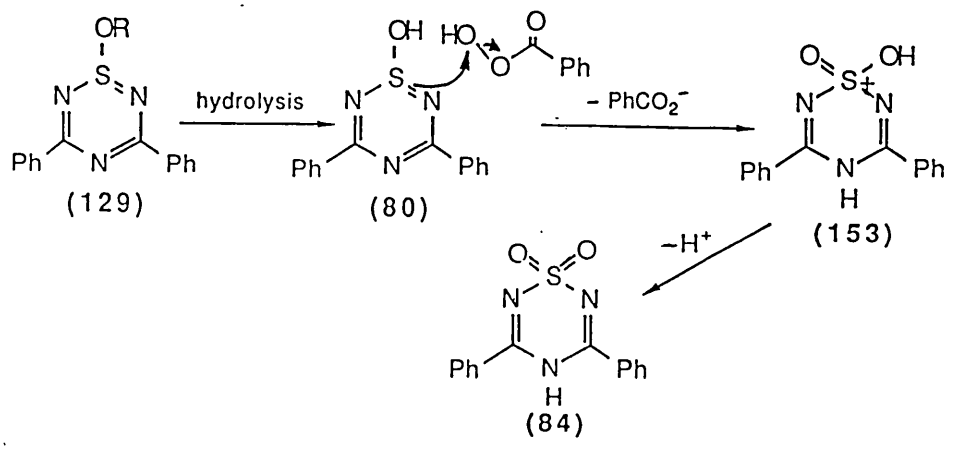
One might assume that m-chlorobenzoic acid is responsible for the formation of the triazine (152). However, much to our surprise, the addition of an excess of m-chlorobenzoic acid to the oxidation reaction in dichloromethane did not lead to increased yield of the triazine (152) (Table 3.5). Furthermore, ethoxythiatriazine (129b) did not react at all with m-chlorobenzoic acid in dichloromethane at room temperature or in 1,2-dichloroethane under reflux. This all suggests that the free acid is not involved in the reaction.

To summarise the above information, ethoxythiatriazine (129b) is hydrolysed somehow to the hydroxythiatriazine (80) and this hydroxythiatriazine so formed is oxidised fast to the thiatriazin-1,1-dioxide (84) and also slowly converted into the triazine (152). Hydroxythiatriazine (80) seems to be responsible for the formation

of the triazine (152). It may be that the ethoxythiatriazine (129b) is converted into the triazine (152) by the MCPBA; however we do not have enough evidence to be sure.

A mechanism for the formation of the thiatriazin-1,1-dioxide (84) can be as shown in Scheme 3.6.

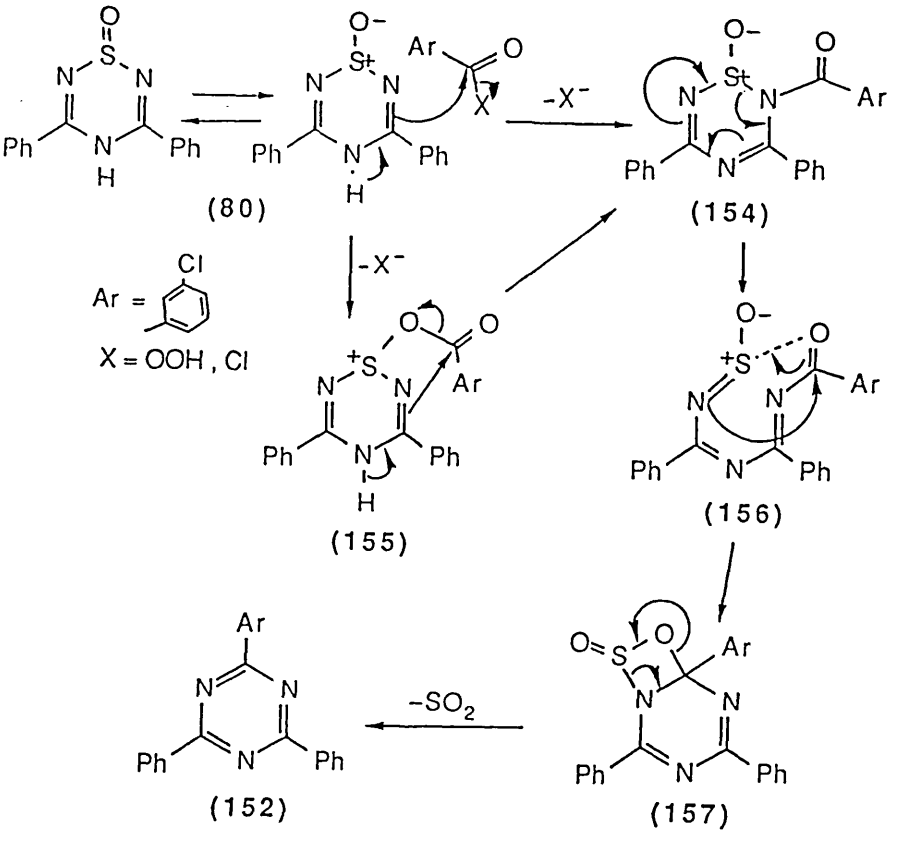
The ethoxythiatriazine (129b) is hydrolysed to the hydroxythiatriazine (80), which is further oxidised by the MCPBA to the intermediate (153) and a proton loss from (153) gives the thiatriazin-1,1-dioxide (84).



Scheme 3.6 : Proposed mechanism for the oxidation of alkoxythiatriazine (129) to thiatriazin-1,1-dioxide (84).

A very tentative mechanism is now proposed for the formation of the triazine (152) in which the MCPBA acts as an acylating agent (Scheme 3.7). N-Acylated or O-acylated thiatriazines [(154) and (155) respectively], could be formed by acylation of the hydroxythiatriazine (80) with MCPBA. Ring opening of the N-acylated

thiatriazine (154) would lead to the N-sulphinylamine intermediate (156). Nucleophilic attack by the lone pairs on the nitrogen onto the carbonyl carbon, followed by elimination of sulphur dioxide via the strained intermediate (157), could give the triazine (152) isolated. Alternatively, the O-acylated thiatriazine (155) can rearrange to the N-acylated thiatriazine (154) and then form the triazine (152) by the path described above.

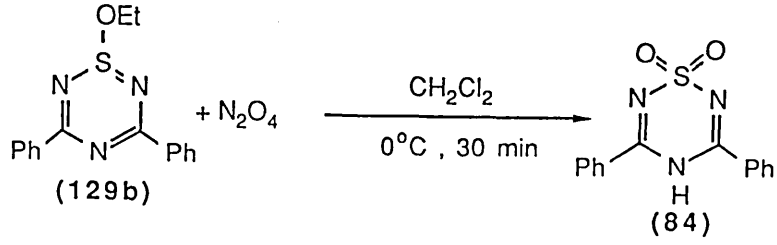


Scheme 3.7 : Proposed mechanism for the formation of 2(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) from hydroxy-thiatriazine (80) and MCPBA.

This mechanism is further supported by the fact that when the hydroxythiatriazine (80) was treated with m-chlorobenzoyl chloride in dry dichloromethane at room temperature, the triazine (152) was formed in low yield (6%) (Section 3.2.2). Furthermore, when peracetic acid is used as an oxidant, the hydroxythiatriazine gives a low yield of 2-methyl-4,6-diphenyl-1,3,5-triazine (9%), together with thiatriazin-1,1-dioxide (84) (47%).

This reaction of thiatriazines [(80) and (129)] with MCPBA provides a novel method for the synthesis of unsymmetrically substituted 1,3,5-triazines.

Finally it was found that the ethoxythiatriazine (129b) could be oxidised under mild conditions by dinitrogen tetroxide (N_2O_4) in excellent yield (93%) to the corresponding thiatriazin-1,1-dioxide (84). The reaction was fast, clean and did not need chromatographic work up as the by-products were gaseous, and there was no trace of the above triazine (152) by-product.

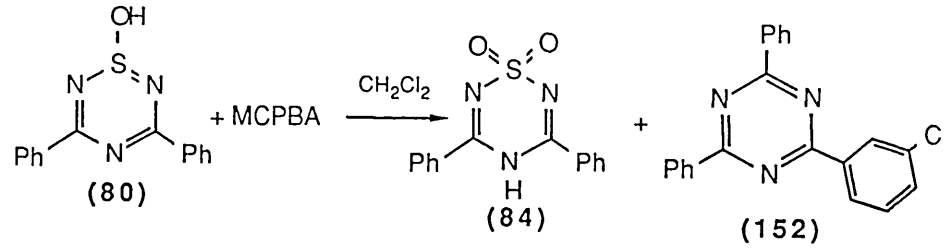


(129b) (84)

3.2.2 1-Hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine

(i) Oxidation

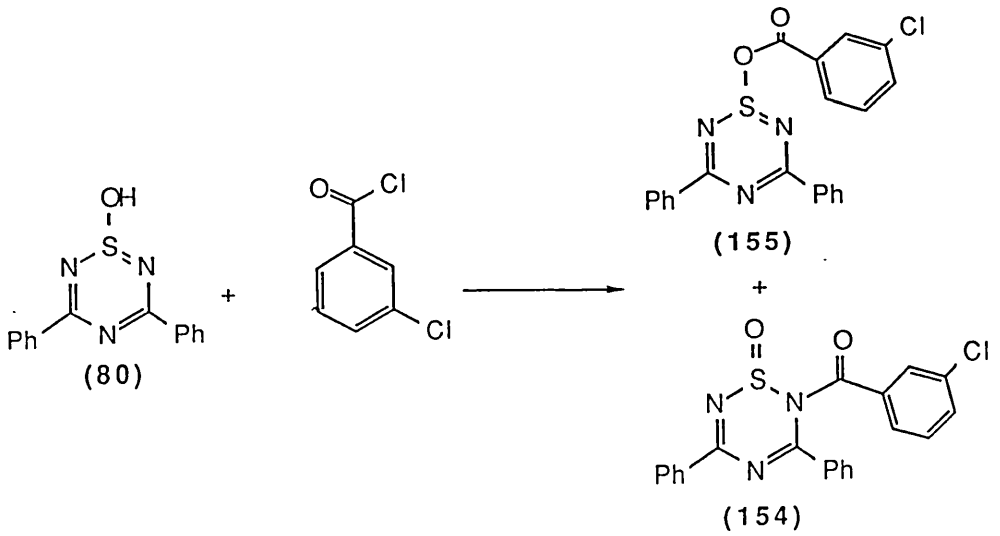
Oxidation of the hydroxythiatriazine (80) with MCPBA (1 eq) in dichloromethane at room temperature gave the expected thiatriazin-1,1-dioxide (84) (48%) and surprisingly 2(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) (20%) (Table 3.5). The mechanism of the formation of these two products is discussed in Section 3.2.1.2.



However, the hydroxythiatriazine (80) was oxidised under mild conditions by dinitrogen tetroxide (N_2O_4) in excellent yield (97%) to the corresponding thiatriazin-1,1-dioxide (84). Again the reaction was fast and clean and chromatography was not needed.

(ii) Attempted acylation

In order to support the oxidation mechanism (Section 3.2.1.2), the hydroxythiatriazine (80) was treated with m-chlorobenzoyl chloride to see if the triazine (152) is formed via the O-acylated intermediate (155) or the N-acylated intermediate (154).



It was hoped that we could isolate one of these acylated compounds and then heat it to form the triazine (152) as proposed in our mechanism (Scheme 3.7).

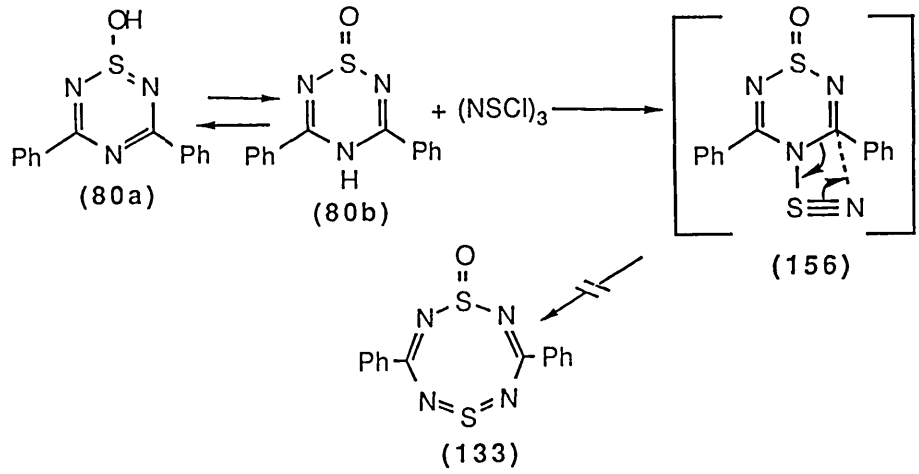
However when compound (80) was treated with m-chlorobenzoyl chloride in dry dichloromethane at room temperature and in presence of triethylamine, the triazine (152) was formed directly, though only in low yield (6%), the remainder being baseline product. The acylated intermediates (154) and (155) were not detected, though they could well be formed and transformed rapidly into the triazine (152). Whilst we do not understand why such a low yield of the triazine (152) was obtained, this reaction does lend some support to the proposition of the mechanism in Scheme 3.7 (Section 3.2.1.2), and a similar mechanism can be proposed for the formation of the triazine (152) from the compound (80) and m-chlorobenzoyl chloride.

(iii) Esterification

Treatment of the hydroxythiatriazine (80) with diazomethane in ether at room temperature afforded methoxythiatriazine (129a) in high yield (91%). Compound (129a) was identified by direct comparision with an authentic sample.

(iv) Attempted ring expansion

It was hoped that on treatment with trithiazyl trichloride (35), the thiatriazine (80) would undergo a novel ring expansion, of the type discussed in more detail in Sections 5.1 and 5.2, to give dithiatetrazocine oxide (133).



A solution of the hydroxythiatriazine (80) in dry THF was treated with a solution of trithiazyl trichloride (35) in dry THF at room temperature under nitrogen; upon chromatographic work up, S_4N_4 (9%) and unreacted thiatriazine (80) (80%) was obtained. These products could well be formed from the desired intermediate (156), exactly as described for the intermediates (102), (221), and (231) (Sections

2.3.2, 5.1 and 5.2 respectively).

Summary

Several novel methods for the synthesis of 1,2,4,6-thiatriazines are reported. 1-Methoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129a) was obtained when benzamidine and S_4N_4 were heated and methanol added during the work-up procedure. 1-Hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) and 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84) were obtained from benzamidoxime and S_4N_4, and the latter was also obtained when benzamidine was treated with either thionyl or sulphuryl chloride.

The methoxythiatriazine (129a) was converted into the ethoxythiatriazine (129b) in refluxing ethanol, and vice versa. The ethoxy compound (129b) hydrolysed to hydroxythiatriazine (80) in water at reflux and decomposed to 2,4,6-triphenyl-1,3,5-triazine (73) in xylene at reflux; it was reduced to the 4H-thiatriazine (150) by sodium borohydride. The hydroxy compound (80) was esterified by diazomethane to the methoxythiatriazine (129a).

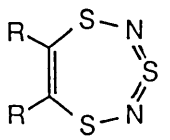
Both the methoxy- and hydroxy-thiatriazines were oxidised by MCPBA to the thiatriazin-1,1-dioxide (84) in good yield. An unsymmetrical triazine, 2-(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) was also obtained in low yields and its formation appears to involve MCPBA acting as an acylating agent.

CHAPTER 4

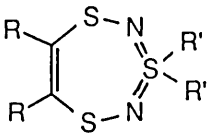
CYCLISATIONS WITH S,S-DIALKYLSULPHURDIIMIDES

4 CYCLISATIONS WITH S,S-DIALKYLSULPHURDIIMIDES

Trithiadiazepines (22) are planar and delocalised systems (Section 1.3.2); therefore it would be interesting to introduce alkyl substituents onto the central sulphur atom to give us 3,3-dialkyltrithiadiazepines (158).



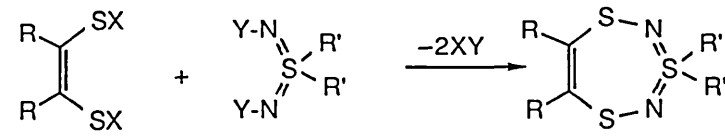
(22)



(158)

Would the trithiadiazepine ring in (158) still be planar with the two alkyl groups on the central sulphur atom being tetrahedrally arranged? Will the two alkyl groups on the central sulphur atom in (158) affect the aromaticity of the trithiadiazepine ring? If R' are benzyl groups, could they then be removed by hydrogenation to give trithiadiazepines (22)? This could thus lead to trithiadiazepines (22) which would otherwise be inaccessible via the original method or even provide us with a high yielding route.

In order to answer the above questions, a synthesis of (158) has to be devised and one can envisage it being made by cyclisation of 1,2-bis(sulphenyl chlorides) (159a) with N,N'-bis(trimethylsilyl)-S,S-dialkylsulphurdiimides (160a).



(159)
a ; X = Cl
b ; X = Na
c ; X = H

(160)
a ; Y = $SiMe_3$
b ; Y = Br

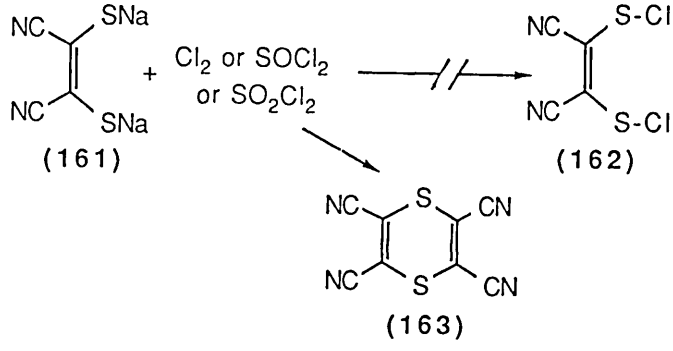
(158)

Hence the reactions of 1,2-bis(sulphenyl chlorides) (159a) with N,N'-bis(trimethylsilyl)-S,S-dialkylsulphurdiimides (160a) and of 1,2-dithiolates (159b) and 1,2-dithiols (159c) with N,N'-dibromo-S,S-dialkylsulphurdiimides (160b) were investigated with the aim to synthesise the corresponding S,S-dialkylated trithiadiazepines (158).

4.1 Reactions of N,N'-dibromo-S,S-dimethylsulphurdiimide

4.1.1 With disodium dimercaptomaleonitrile

Chlorination of disodium dimercaptomaleonitrile (161) with chlorine gas, thionyl chloride or sulphuryl chloride does not give the corresponding bis(sulphenyl chloride) (162), but gives 2,3,5,6-tetracyano-1,4-dithiin (163) instead.[65]

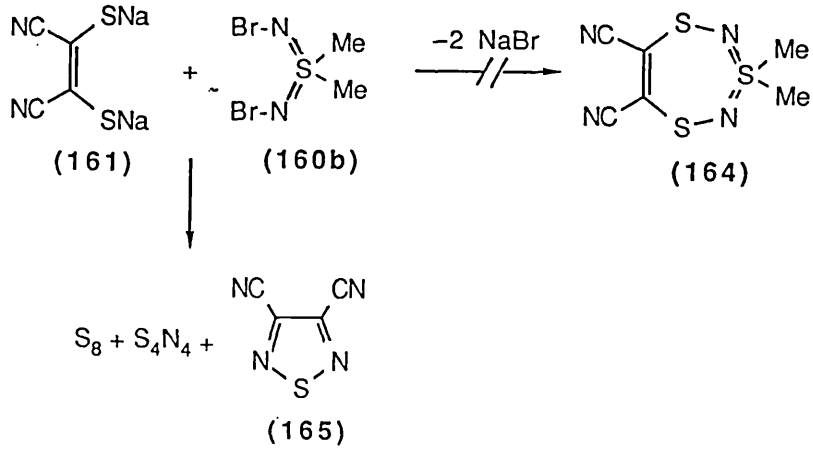


(161)

(162)

(163)

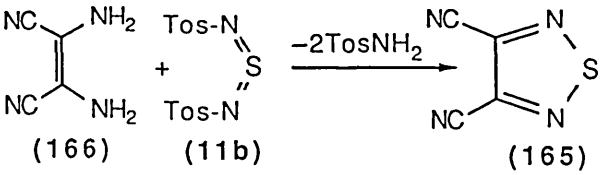
It was hoped that the disodium dimercaptomaleonitrile (161) would cyclise with N,N'-dibromo-S,S-dimethylsulphurdiimide (160b) to give 3,3-dimethyl-6,7-dicyano-1,3,5,2,4-trithiadiazepine (164).



However a complicated reaction mixture was obtained when a solution of dimethylsulphurdiimide (160b) in dry acetonitrile was slowly added to a suspension of the dithiolate (161) in acetonitrile at room temperature under nitrogen. The products isolated after column chromatography work-up were sulphur, S_4N_4 (5%) and 3,4-dicyano-1,2,5-thiadiazole (165) (26%). No apparent reaction occurred when the reaction was performed at 0°C in acetonitrile, but when this reaction mixture was warmed to room temperature, sulphur, S_4N_4 (5%) and the dicyanothiadiazole (165) (24%) were obtained. In the presence of TDA-1 (a phase transfer catalyst), the only products isolated from the complex reaction mixture were sulphur and dicyanothiadiazole (165) (27%); S_4N_4 was not formed in this case. Satisfactory yields of the dicyanothiadiazole (165) (46%) and S_4N_4 (35%) were obtained when the reaction was carried out in the presence of potassium iodide (one equivalent). When solutions of

both reactants, (161) and (160b), in dry methanol were slowly mixed simultaneously at room temperature, the products were again sulphur and dicyanothiadiazole (165) (11%). No useful reaction occurred when dichloromethane was used as a solvent; only baseline products were formed.

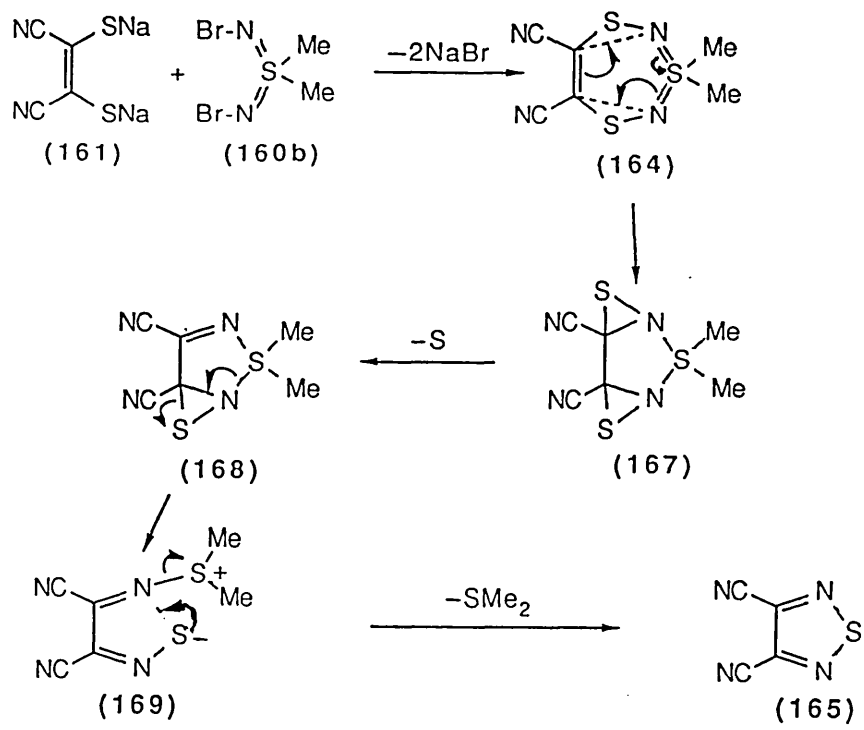
Dicyanothiadiazole (165) was identified from its spectral data and by comparison with an authentic sample made from the corresponding diamine (166) and bis(tosyl)sulphurdiimide (11b) in dry chloroform (86% yield).



(166) (11b) (165)

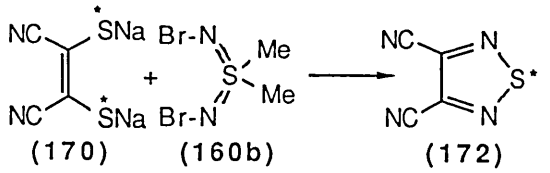
The mechanism of the formation of S_4N_4 is not clear but the formation of the dicyanothiadiazole (165) and sulphur can be rationalised as shown in Scheme 4.1.

The initially cyclised product (164), formed by nucleophilic displacement of bromide ion, undergoes ring contraction to the intermediate (167) and subsequent loss of sulphur and ring opening of the intermediate (168) leads to compound (169). Extrusion of dimethylsulphide (Scheme 4.1) leads to the observed product of dicyanothiadiazole (165). The reaction mixture did indeed have an odour of dimethyl sulphide.

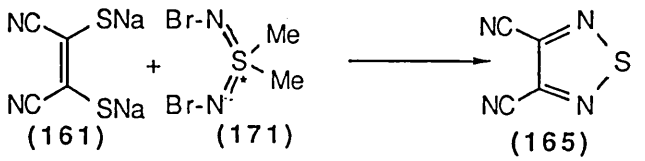


Scheme 4.1 : Mechanism for the formation of dicyanothiadiazole (165) and sulphur from disodium dimercaptomaleonitrile (161) and dibromosulphurdiimide (160b).

Further insight into the mechanism could have been sought by using the radio isotopically labelled reagents, (170) and (171). Starting with labelled disodium dimercaptomaleonitrile (170) and treating it with unlabelled sulphurdiimide (160b) would give labelled thiadiazole (172), but treating the unlabelled disodium dimercaptomaleonitrile (161) with labelled sulphurdiimide (171) would give the unlabelled thiadiazole (165).



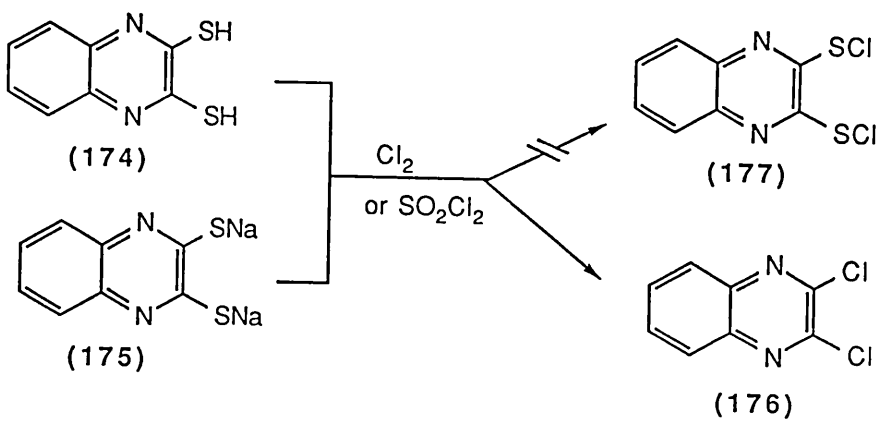
(170) (160b) (172)



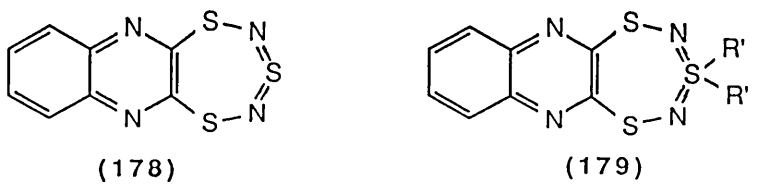
(161) (171) (165)

4.1.2 With disodium 2,3-dimercaptoquinoxaline

Treatment of quinoxaline-2,3-dithiol (174) and disodium dimercaptoquinoxaline (175) with chlorine gas or sulphuryl chloride led to the formation of 2,3-dichloroquinoxaline (176),[3b] instead of quinoxaline-2,3-bis(sulphenyl chloride) (177).

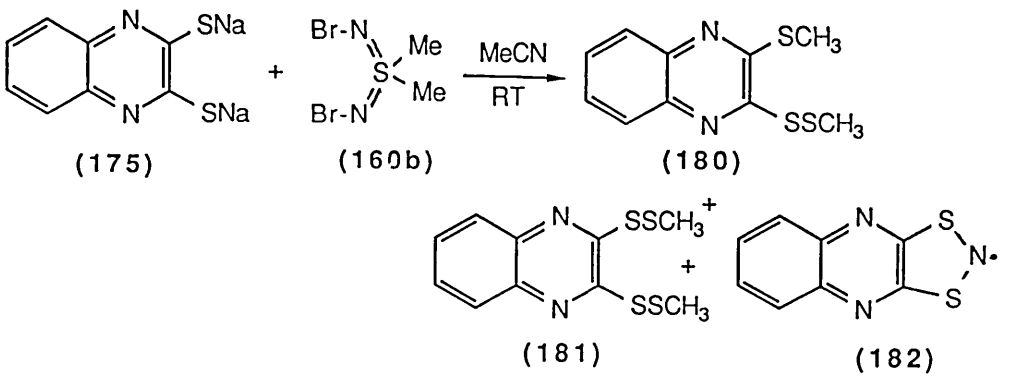


(174) (175) (177) (176)



(178) (179)

Due to lack of the availability of the bis(sulphenyl chloride) (177), the normal route to the corresponding trithiadiazepine (178) was eliminated and the one via (179) was considered by us. However, when the dithiolate (175) was treated with dibromosulphurdiimide (160b) in dry acetonitrile at room temperature, 2-methylthio-3-methyldithioquinoxaline (180) (1%), 2,3-bis(methyldithio)quinoxaline (181) (0.5%) and quinoxalino-1,3,2-dithiazol-2-yl (182) (2.2%) were isolated in very low yields from the complex reaction mixture instead of the trithiadiazepine (179) (R'= Me).



(175) (160b) (180) (181) (182)

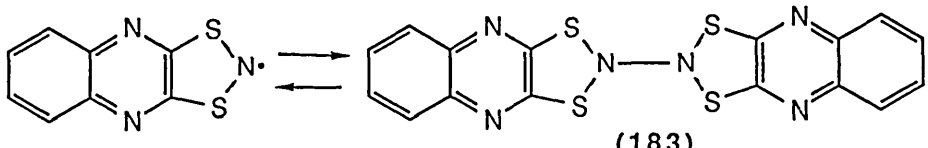
In refluxing acetonitrile, a very complicated reaction mixture was obtained from which the compound (180) (0.2%) and the dithiazolyl (182) (0.7%) were isolated. In dichloromethane, in the presence of TDA-1, the compound (180) (0.7%) and the dithiazolyl (182) (8.3%) were isolated, whereas in acetonitrile in the presence of TDA-1, only the dithiazolyl (182) (4.7%) was isolated. A very complex reaction mixture, with no trace of compounds (180), (181), (182), or the trithiadiazepine (179), was obtained when the reaction was performed in acetonitrile in the presence of potassium iodide (one equivalent).

2-Methylthio-3-methyldithioquinoxaline (180) was obtained as a pale yellow crystalline compound with m.p. 191-192°C. The mass spectrum showed a molecular ion at m/z 254 with major fragment ions at M^+-47 (- SMe) and M^+-79 (- SSMe). The proton n.m.r spectrum showed multiplets at δ 8.00-8.08 (integral 1), δ 7.90-7.97 (integral 1) and δ 7.55-7.68 (integral 2) suggesting an ortho unsymmetrically substituted aromatic ring. The two methyl groups showed singlets at δ 2.73 (integral 3) and δ 2.62 (integral 3). Furthermore, elemental analysis suggested a formula $C_{10}H_{10}N_2S_3$.

2,3-Bis(methyldithio)quinoxaline (181) was obtained as yellow needles, m.p. 115-116°C. The mass spectrum showed a molecular ion at m/z 286 with major fragment ions at M^+-47 (- SMe), M^+-94 (- 2SMe) and M^+-126 (- SSMe and - SMe). The proton n.m.r spectrum showed an AA'BB' pattern. There was a singlet at δ 2.6 (integral 6) showing that the two methyl groups were equivalent and the elemental analysis suggested a formula $C_{10}H_{10}N_2S_4$.

Quinoxalino-1,3,2-dithiazol-2-yl (182) was obtained as a dark green lustrous crystalline compound, m.p. 139-141°C. The mass spectrum showed a molecular ion at m/z 206 with major fragment ions at M^+-46 (- NS), M^+-72 (- CN_2S) and M^+-104 (- CN_2S_2) and the elemental analysis suggested a formula $C_8H_4N_3S_2$. It readily dissolves in organic solvents to form dark green solutions and in agreement with its radical nature it was impossible to obtain a proton n.m.r spectrum. Indeed, the E.S.R. spectrum of (182) (kindly measured by Dr. Peter. Beardwood at Imperial College) consisted of a 1:1:1 triplet with no hyperfine splitting due to spin coupling with aromatic protons. Thus most of the spin density seems to be localised on the heterocyclic five-membered ring. Single crystals

for an X-ray structure determination have so far not been obtained, and so we are unable to confirm its structure in the crystalline state. However, it is likely that it exists as a dimer, e.g. (183), in the crystalline state and as a radical (182) in solution.

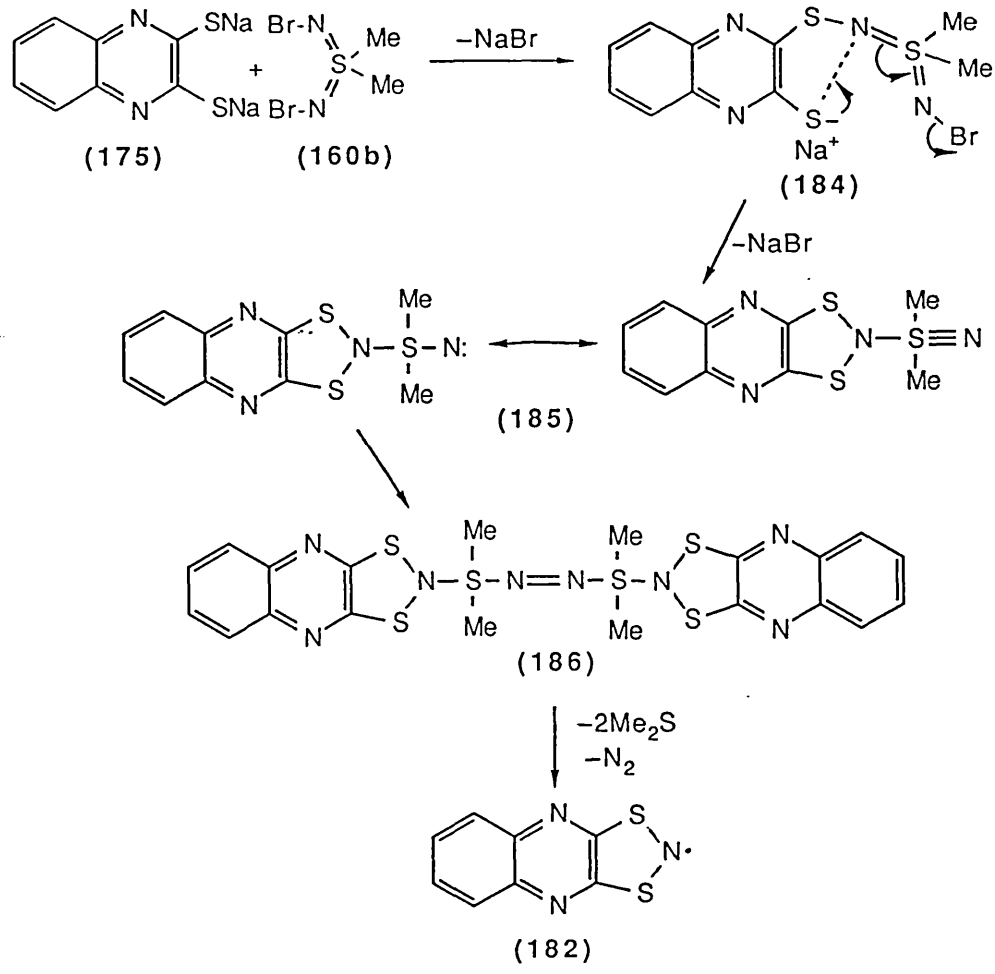


(182) (183)

The mechanism for the formation of compounds (180) and (181) is not clear but that of the dithiazolyl (182) can be rationalised as shown in Scheme 4.2.

The first product, the monothiolate (184) cyclises by nuleophilic attack onto the nitrogen atom of the sulphurdiimide (160b) by the thiolate anion to give the dithiazole intermediate (185). The intermediate (185) then dimerises to compound (186) which then loses dimethylsulphide and nitrogen to give the dithiazolyl (182). The reaction mixture had an odour of dimethylsulphide indicating its presence.

Compound (182) did not form a charge-transfer complex with TCNQ.

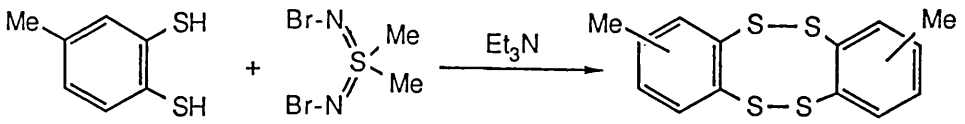


Scheme 4.2 : Proposed mechanism for the formation of quinoxalino-1,3,2-dithiazol-2-yl (182) from disodium 2,3-dimercaptoquinoxaline (175) and dibromosulphurdiimide (160b).

When quinoxaline-2,3-dithiol (174) was used as the starting material and treated with dibromosulphurdiimide (160b) in dichloromethane or acetonitrile, in the presence of triethylamine at room temperature, the dithiazolyl (182) was again formed, in 15-29% yield. However, the reaction mixtures were much cleaner than with the corresponding dithiolate (175).

4.1.3 With 3,4-dimercaptotoluene

3,4-Dimercaptotoluene (187) reacted with the dibromosulphurdiimide (160b), in the presence of triethylamine in dichloromethane to give a quantitative yield of the dimethyldibenzo-1,2,5,6-tetrathiaocin (188) as a pale yellow crystalline compound, m.p. 180-182°C.

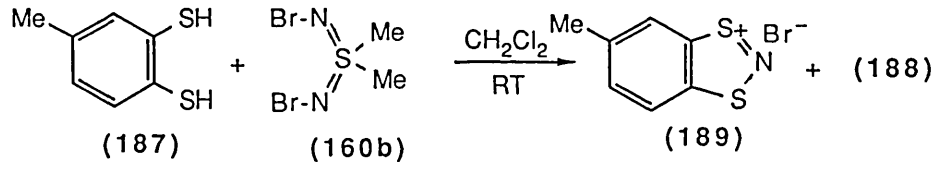


(187) (160b) (188)

The N-bromo compound (160b) has presumably oxidised the dithiol (187) to dimethyldibenzo-1,2,5,6-tetrathiaocin (188).

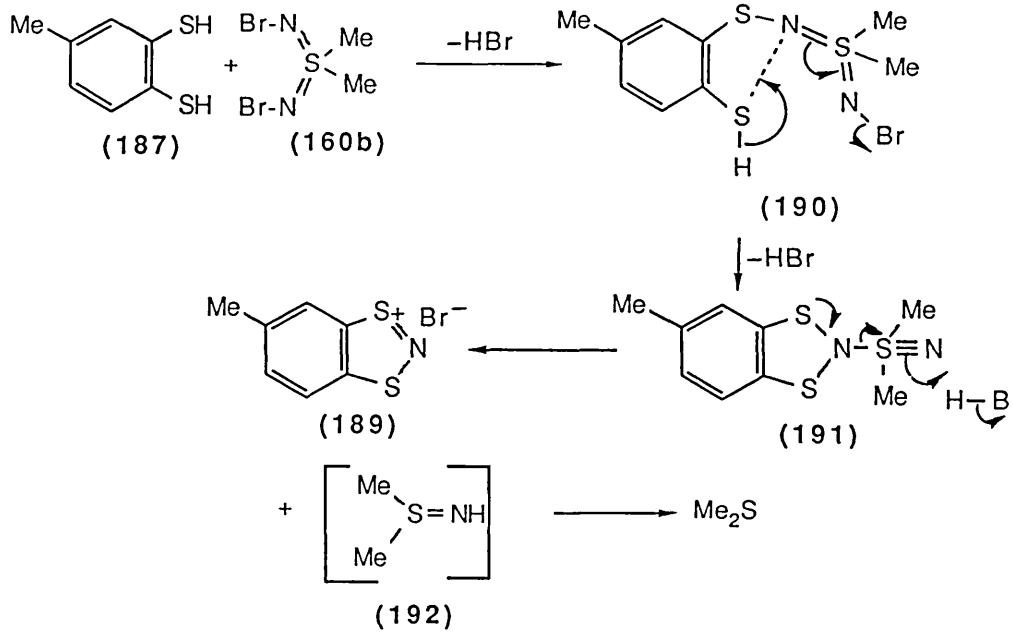
Dimethyldibenzo-1,2,5,6-tetrathiaocin (188) was identified on the basis of its spectral data. The mass spectrum showed a molecular ion at 308 with major fragment ions at $\underline{M}^+$-64 (- S) and $\underline{M}^+$-154 (- $C_7H_6S_2$). Elemental analysis suggested a formula $C_{14}H_{12}S_4$. The i.r. spectrum indicated absence of SH while the proton n.m.r spectrum had two signals for CH_3 suggesting, in spite of its sharp melting point, a mixture of the two possible isomers.

Without triethylamine, a much lower yield (21%) of the dimethyldibenzo-1,2,5,6-tetrathiaocin (188) was obtained, together with 5-methylbenzo-1,3,2-dithiazolium bromide (189) (70%) as a red cystalline compound, m.p. 134-136°C. All the spectral data of the dithiazolium bromide (189) were identical with an authentic sample.[3b]



(187) (160b) (189)

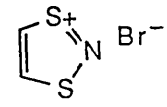
The formation of 5-methylbenzodithiazolium bromide (189) can be rationalised as shown in Scheme 4.3.



Scheme 4.3 : Proposed mechanism for the formation of 5-methylbenzo-1,3,2-dithiazolium bromide (189) from dimercaptotoluene (187) and dibromosulphurdiimide (160b).

The first product, the monothiol (190) cyclises by nucleophilic attack onto the nitrogen atom of the sulphurdiimide by the thiol , to give the five-membered dithiazole intermediate (191). Dithiazole (191) then reacts with hydrogen bromide to give the dithiazolium salt (189) and the dimethylsulphilimine (192), which is unstable, and known to decompose to dimethylsulphide.[89b] The reaction mixture did indeed have an qdour of dimethylsulphide.

The reaction of ethane-1,2-dithiol with dibromosulphurdiimide (160b), in the presence or absence of triethylamine, gave baseline products only and the corresponding dithiazolium salt (193) could not be isolated.

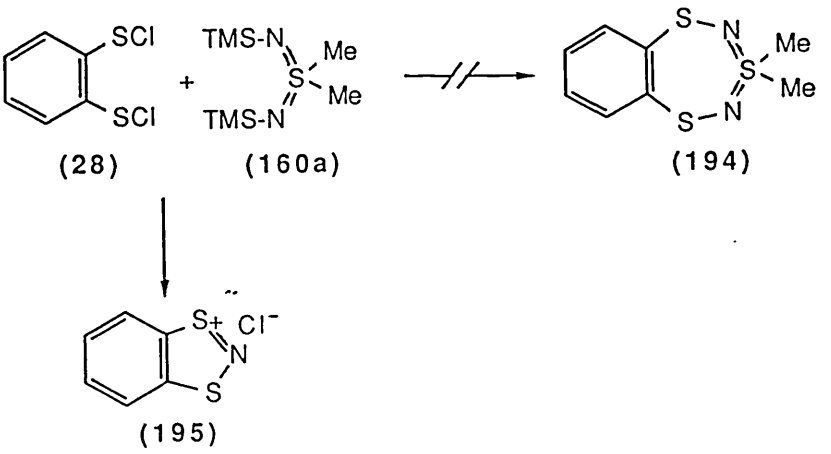


(193)

4.2 Reactions of benzene-1,2-bis(sulphenyl chloride)

4.2.1 With N,N'-bis(trimethylsilyl)-S,S-dimethylsulphurdiimide

When solutions of benzene-1,2-bis(sulphenyl chloride) (28) and bis(trimethylsilyl)dimethylsulphurdiimide (160a) in dry dichloromethane were added synchronously to a large volume of vigorously stirred solvent at room temperature under nitrogen, a yellow flocculent precipitate was obtained. It was identified as benzo-1,3,2-dithiazolium chloride (195) (86%), being identical with an authentic sample.[17] The desired trithiadiazepine (194) was not formed.

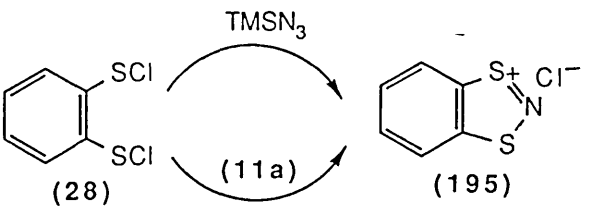


(28) (160a) (194)

(195)

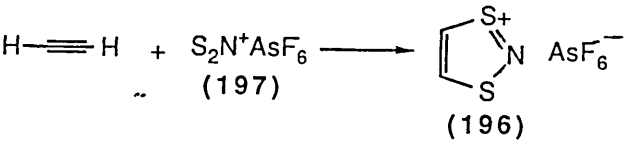
The formation of benzodithiazolium chloride (195) can be rationalised in a similar manner to that shown in Scheme 4.3 (Section 4.1.3), with the hydrogens in (187) replaced by chlorine atoms and the bromines in (160b) replaced by trimethylsilyl groups. However, ethane-1,2-bis(sulphenyl chloride) reacted with sulphurdiimide (160a) to give only baseline products and no corresponding dithiazolium salts (193) were isolated.

1,3,2-Benzodithiazolium chloride (195) has been synthesised by the treatment of benzene-1,2-bis(sulphenyl chloride) (28) with trimethylsilylazide at 0°C in dichloromethane[66] and also by the treatment of (28) with bis(trimethylsilyl)sulphurdiimide (11a).[17]



(28) (195)

The monocyclic salt, 1,3,2-dithiazolium hexafluoroarsenate (196), has also been prepared recently by the reaction of acetylene with dithionitronium hexafluoroarsenate (197) in liquid sulphur dioxide.[67]

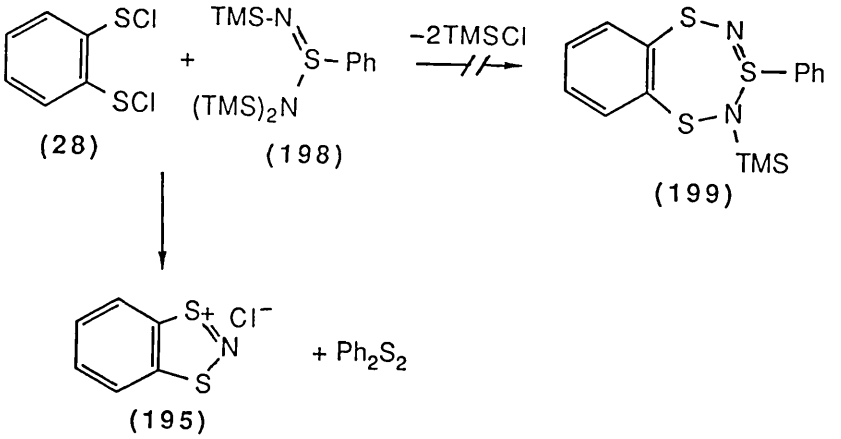


(196)

1,3,2-Dithiazolium salts are of interest because they may be reduced chemically or electrolytically to give long lived free radicals, which in turn form highly conducting charge-transfer complexes with, for example, TCNQ.[66, 67]

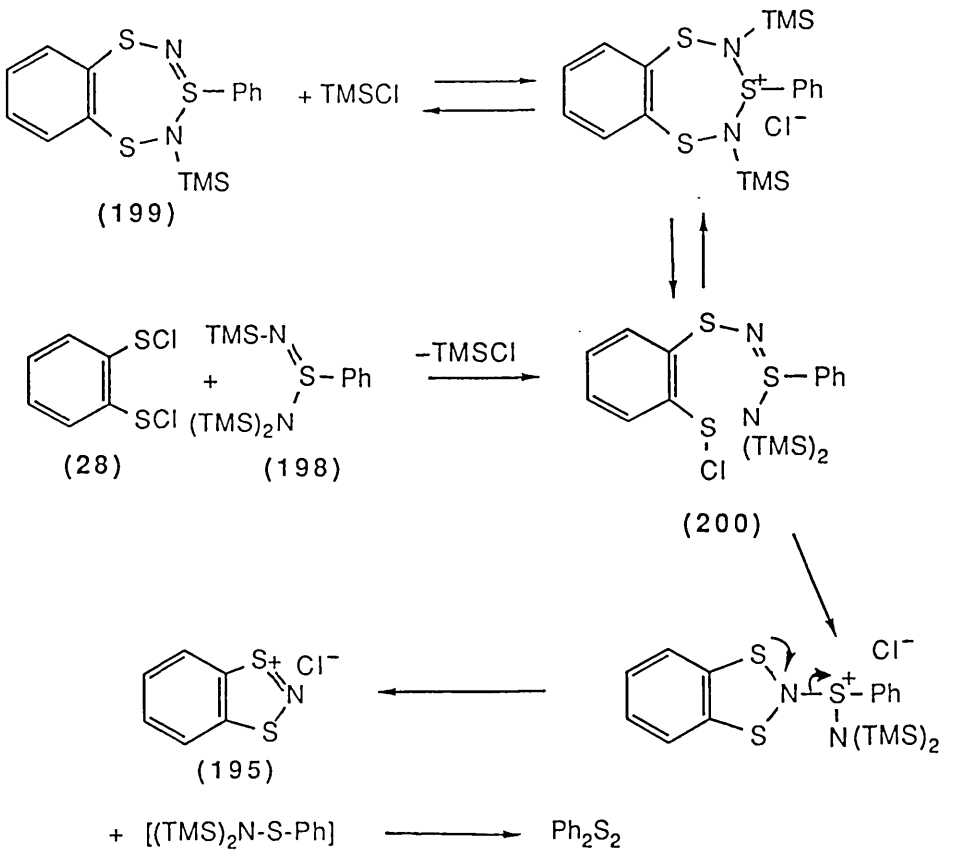
4.2.2 With N,N,N'-tris(trimethylsilyl)-S-iminobenzsulphenamide (198)

It was hoped that compound (198) would cyclise with the bis(sulphenyl chloride) (28) to give N-silylated trithiadiazepine (199), which could then lead to other N-substituted derivatives of this novel trithiadiazepine.



(28) (198) (199) (195)

In fact, when this reaction was carried out by the synchronous addition of the solutions of the reagents, (28) and (198) in dichloromethane, to a vigorously stirred solvent under nitrogen at room temperature, a high yield (91%) of 1,3,2-benzodithiazolium chloride (195) was obtained together with diphenyldisulphide (17%). The mechanism for the formation of the dithiazolium salt (195) could be as shown in Scheme 4.4.



Scheme 4.4 : Proposed mechanism for the formation of diphenyldisulphide and benzo-1,3,2-dithiazolium chloride (195) from benzene-1,2-bis(sulphenyl chloride) (28) and N,N,N'-tris(trimethylsilyl)-S-iminobenzsulphenamide (198).

The first product, the monosulphenyl chloride (200), can cyclise by nucleophilic attack of the sulphenyl chloride on either nitrogen atom of the sulphurdiimide group to give five- and seven-membered ring intermediates; the former could lead to 1,3,2-benzodithiazolium chloride (195) and diphenyldisulphide. The intermediate (200) could also be produced by a reversible reaction of the desired product (199) with the trimethylsilyl chloride formed as the reaction proceeds.

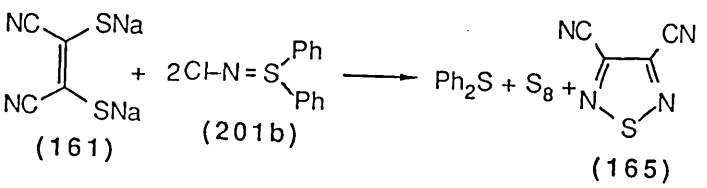
4.3 Reactions of N-halodiphenylsulphilimines

4.3.1 With disodium dimercaptomaleonitrile

In view of the complex and unexpected reactions observed with dithiolates (161) and (175) and dibromosulphurdiimide (160b) described above, we decided to investigate the reaction between these dithiolates and the simpler N-halosulphilimines (201).

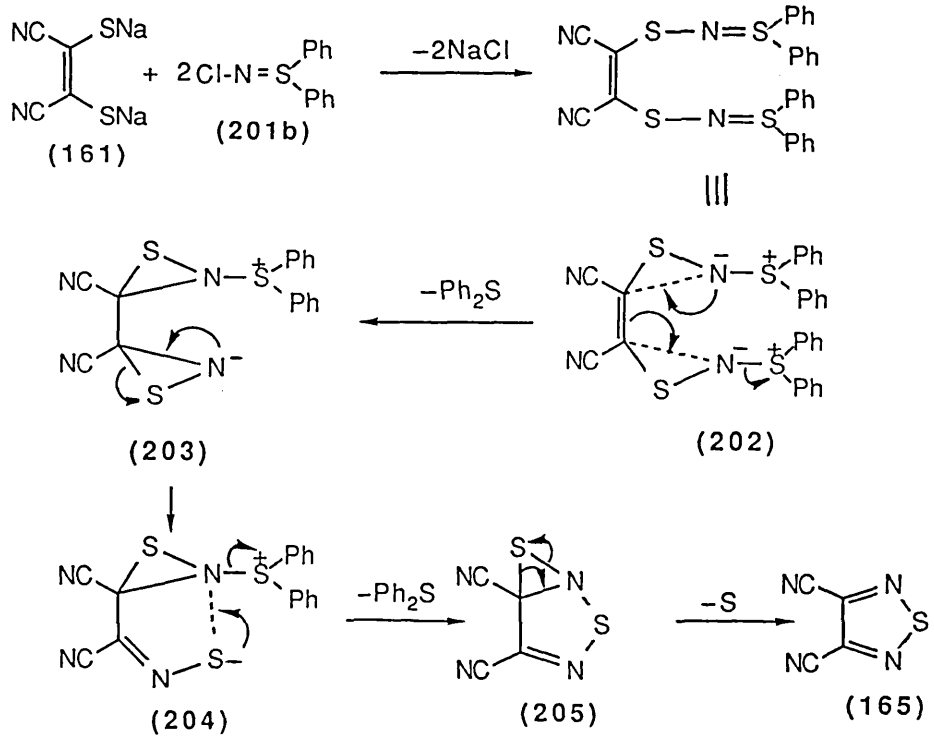
At room temperature and in acetonitrile, the dithiolate (161) reacted with N-bromodiphenylsulphilimine (201a) to give diphenylsulphide (72%) and baseline products.

However with N-chlorodiphenylsulphilimine (201b), in addition to diphenylsulphide (76%), sulphur and the dicyanothiadiazole (165) (17%) were also isolated.



(161) (201b) (165)

A mechanism for the formation of these three products could be rationalised as shown in Scheme 4.5.

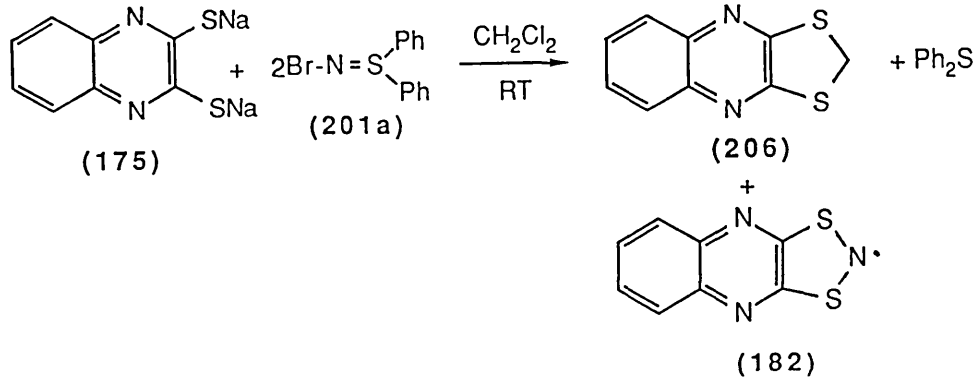


Scheme 4.5 : Proposed mechanism for the formation of dicyanothiadiazole (165) and diphenylsulphide from disodium dimercaptomaleonitrile (161) and N-chlorosulphilimine (201b).

Nucleophilic displacement of the chloride ion leads to the adduct (202) which subsequently eliminates diphenylsulphide via intermediates (203) and (204) to give thiadiazole intermediate (205). Extrusion of sulphur from (205) produces the dicyanothiadiazole (165).

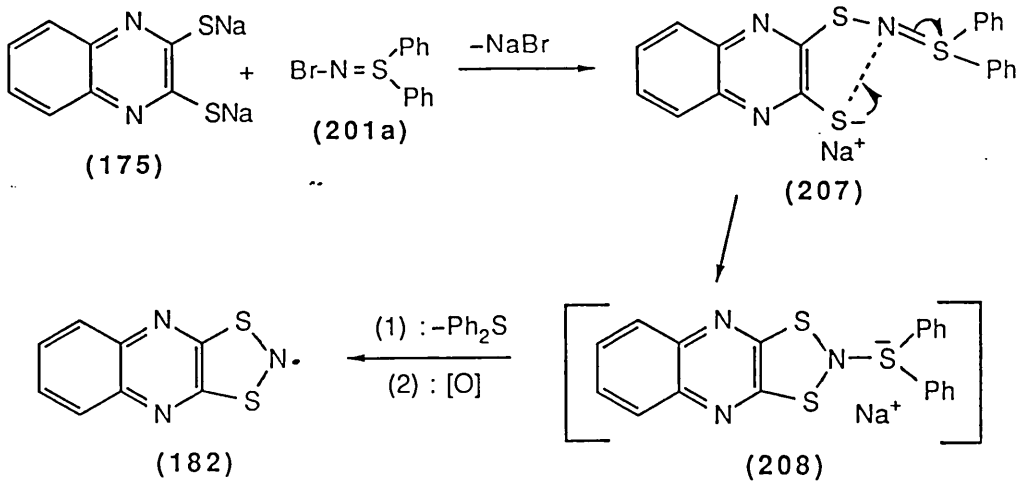
4.3.2 With disodium 2,3-dimercaptoquinoxaline

Disodium 2,3-dimercaptoquinoxaline (175) reacted with N-bromo-diphenylsulphilimine (201a) at room temperature in dichloromethane in the presence of TDA-1 to give quinoxalino-1,3,2-dithiazol-2-yl (182) (5%) together with diphenylsulphide (49%) and quinoxalino-1,3-dithiole (206) (56%).



It is obvious that the solvent, dichloromethane, has reacted with the dithiolate (175) to give the dithiole (206). An authentic sample of (206) was synthesised by treating the dithiolate (175) with diiodomethane in acetonitrile.

A mechanism for the formation of (182) and diphenylsulphide could be as shown in Scheme 4.6.



Scheme 4.6 : Proposed mechanism for the formation of dithiazolyl (182) and diphenylsulphide from disodium 2,3-dimercaptoquinoxaline (175) and N-bromodiphenylsulphilimine (201a).

The first product (207), cyclises via nucleophilic attack onto the nitrogen atom of the sulphilimine by the thiolate to give dithiazole intermediate (208). Subsequent loss of diphenylsulphide followed by oxidation leads to the dithiazolyl (182). N-Bromodiphenylsulphilimine could be the oxidant here.
However, the reaction of (175) with the N-chloro-diphenylsulphilimine (201b) gave diphenylsulphide (62%) only.

Summary

Both N,N'-dibromo-S,S-dimethylsulphurdiimide (160b) and N-halo-diphenylsulphilimines (201) reacted similarly with either disodium dimercaptomaleonitrile (161) or disodium 2,3-dimercaptoquinoxaline (175). Disodium 2,3-dimercaptoquinoxaline (175) gave an interesting stable free radical, quinoxalino-1,3,2-dithiazol-2-yl (182) in reasonable yields, whereas disodium dimercaptomaleonitrile (161) gave 3,4-dicyano-1,2,5-thiadiazole (165), involving an unusual rearrangement.

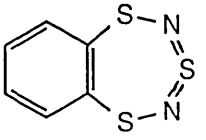
Cyclisations of benzofused-1,2-dithiols or -1,2-dithiolates with N,N'-dibromo-S,S-dimethylsulphurdiimide (160b) and of 1,2-bis(sulphenyl chlorides) with N,N'-bis(trimethylsilyl)-S,S-dimethylsulphurdiimides (160a), led to five-membered benzo-1,3,2-dithiazolium salts (189) and (195) in high yields. The seven-membered trithiadiazepine derivatives (158) were not observed, possibly because they were unstable and ring contracted to benzodithiazolium salts, or because entropy factors favoured exclusively the formation of five-membered rings.

CHAPTER 5

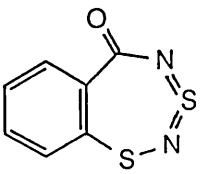
OTHER SULPHUR-NITROGEN HETEROCYCLIC RINGS

5.1 Attempted synthesis of 1,3,2,4-benzodithiadiazepin-5-one

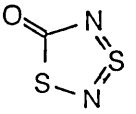
Replacing one of the divalent sulphur atoms in benzotrithiadiazepine (29) by a carbonyl group would lead to benzodithiadiazepin-5-one (209), giving an interesting new compound structurally related to 1,3,2,4-dithiadiazol-5-one (210),[68] pyrrolo[2,3,e]-2,1,3-thiadiazin-4-one (211),[69] and 2,1,3-benzothiadiazin-4-one (212).[39b]



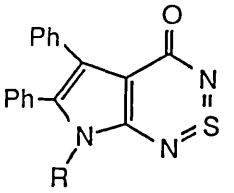
(29)



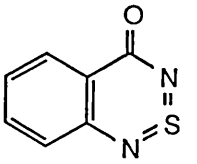
(209)



(210)

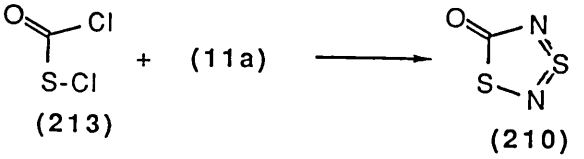


(211)



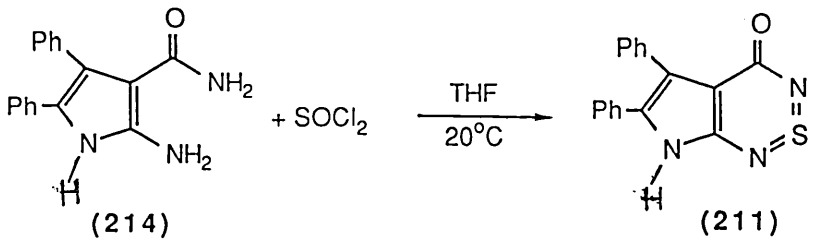
(212)

Dithiadiazol-5-one (210) has been synthesised by treating 1-(chlorothio)formyl chloride (213) with bis(trimethylsilyl)-sulphurdiimide (11a) in tetrachloromethane at room temperature.[68] Compound (210) is a stable, yellow crystalline compound with m.p. 41°C.



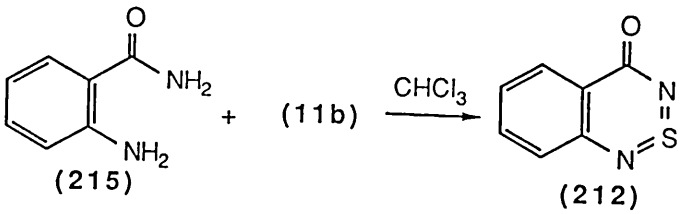
(213) (210)

Treatment of 2-aminopyrrole-3-carboxamide (214) with thionyl chloride in THF at room temperature afforded pyrrolothiadiazin-4-one (211), as a stable red crystalline compound, m.p. 265°C.[69]



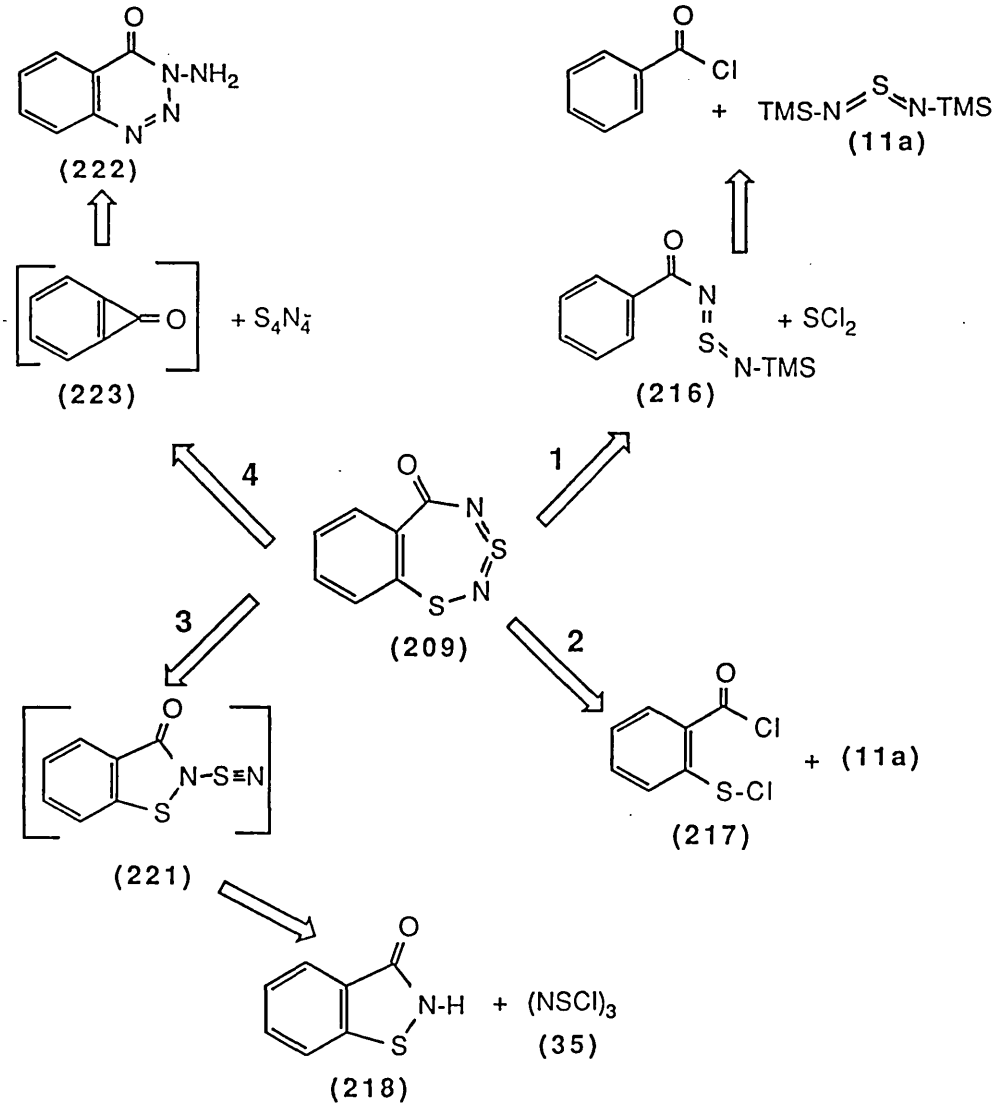
(214) (211)

When a suspension of 2-aminobenzamide (215) in dry chloroform was treated with a solution of bis(tosyl)sulphurdiimide (11b) in dry chloroform at room temperature, benzothiadiazin-4-one (212) was obtained as a stable yellow crystalline compound, m.p. 119-121°C.[39b]



(215) (212)

1,3,2,4-Benzodithiadiazepin-5-one (209) is potentially an 8π antiaromatic system and we attempted, unsuccessfully, to synthesise it to see if it would be stable. Possible disconnections to it are illustrated in Scheme 5.1.

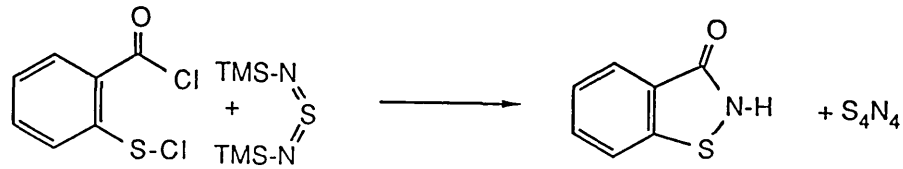


Scheme 5.1 : Possible disconnections for the synthesis of 1,3,2,4-benzodithiadiazepin-5-one (209).

Route 1 : When benzoyl chloride was treated with sulphurdiimide (11a) in tetrachloromethane or dichloromethane at room temperature or under reflux, no compound corresponding to N-(benzoyl)-N'-

(trimethylsilyl)sulphurdiimide (216) could be isolated from the complex reaction mixture. It was hoped that the addition of sulphur dichloride to the resulting reaction mixture of benzoyl chloride and sulphurdiimide (11a) would give compound (209) without isolating the intermediate (216). However a very complex reaction mixture was obtained from which only small amounts of S_4N_4, resulting from the reaction of sulphur dichloride with sulphurdiimide (11a), could be isolated. No product of structure (209) was isolated.

Route 2 : 2-(Chlorosulphenyl)benzoyl chloride (217) [prepared from 2,2'-dithiosalicylic acid by treatment of thionyl chloride followed by chlorine gas[70]] was treated with sulphurdiimide (11a) under nitrogen in dichloromethane at room and refluxing temperatures. Each of these reagents was dissolved in dry dichloromethane and the resulting solutions were added slowly and synchronously to a large volume of vigorously stirred solvent, thus maintaining conditions of high dilution to minimise polymerisation reactions. The solvent was removed in vacuo and the residue chromatographed to give, somewhat surprisingly, 1,2-benzisothiazolin-3-one (218); a small quantity of S_4N_4 was also isolated from the reaction mixture (Table 5.1).



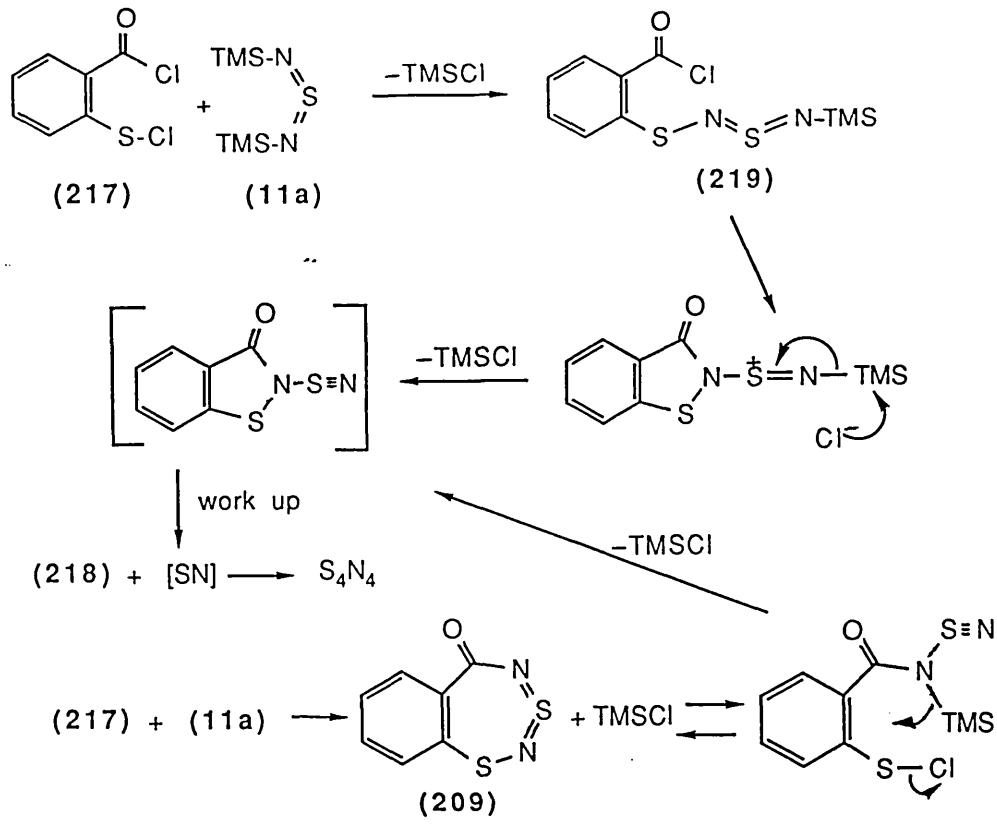
(217) (11a) (218)

Temp/°C	(218)	S_4N_4
-10	80	8
0	65	15
20	67	26
40	68	21

Table 5.1 : Yields(%) of 1,2-benzisothiazolin-3-one (218) and S_4N_4 from the reaction of (217) and (11a) in dichloromethane.

The structure of (218) was assigned on the basis of spectral data. The mass spectrum showed a molecular ion ($\underline{M}^+$) at m/z 151 with major fragment ions at $\underline{M}^+$-28 (- CO) and $\underline{M}^+$-43 (- CONH). An absorption at 1640 cm^{-1} in the i.r. spectrum was assigned as appropriate for a tertiary amide. The proton n.m.r. spectrum showed a multiplet at δ 7.10-7.90 which suggested an unsymmetrically ortho substituted aromatic ring. At this point, 1,2-benzisothiazolin-3-one (218) was prepared independently by treating 2-(chlorosulphenyl)benzoyl chloride (217) with aqueous concentrated ammonia solution, giving (218) (89%) as a colourless compound, m.p. 155-156°C, identical with the above product.

The formation of 1,2-benzisothiazolin-3-one and S_4N_4 can be rationalised as shown in Scheme 5.2.

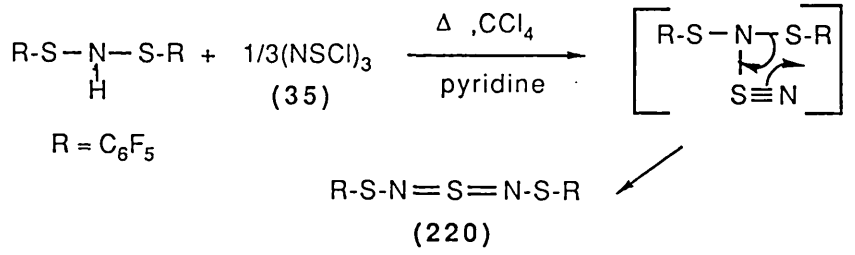


Scheme 5.2 : Proposed mechanism for the formation of 1,2-benzisothiazolin-3-one (218).

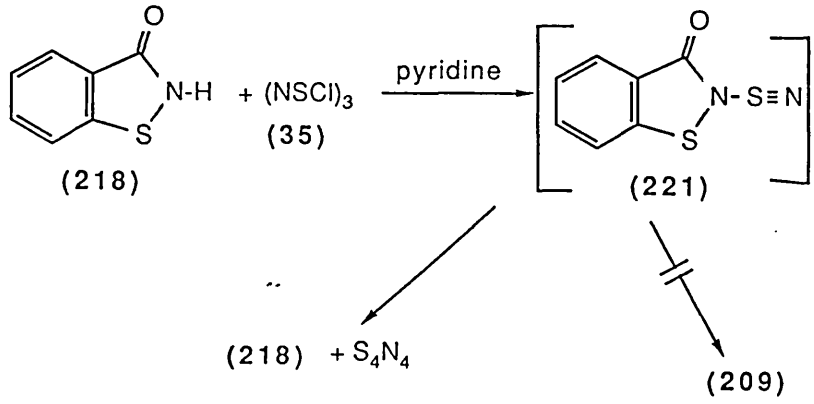
The first product, the benzoyl chloride sulphurdiimide (219), can cyclise by nucleophilic attack on the carbonyl carbon by either nitrogen atom of the sulphurdiimide group, to give five- and seven-membered ring intermediates; these can lead, as shown, to the 1,2-benzisothiazolin-3-one (218). The intermediate (219) could also be produced by a reversible reaction of the desired product (209) with the chlorotrimethylsilane formed as the reaction proceeds. Liberation of the reactive intermediate S≡N could be responsible for the observed formation of S_4N_4.

A comparable ring contraction in a cyclisation reaction with sulphurdiimide (11a) has been proposed in the preparation of benzotrithiadiazepine (29) from benzene-1,2-bis(sulphenyl chloride) and sulphurdiimide (11a); 1,3,2-benzodithiazolium chloride (195) and S_4N_4 were also isolated in this reaction as by products (Section 1.3.2).[17] Their formation was accounted for in exactly the same way as that proposed above.

Route 3 : N,N'-Bis(pentafluorobenzenesulphenyl)amine has been shown to react with trithiazyl trichloride (35) in refluxing tetrachloromethane, in the presence of pyridine, to give sulphurdiimide (220), possibly by the route shown.[40]



This raises the possibility that similar treatment of benzisothiazolin-3-one (218) with trithiazyl trichloride (35) could give the desired product (209) by a novel ring expansion reaction of the intermediate (221). However, when compound (218) was treated with trithiazyl trichloride (35) in refluxing tetrachloromethane or in THF at room temperature, in the presence of pyridine, a dark green reaction mixture was formed, which slowly turned yellow and upon work-up (removal of solvent *in vacuo* and chromatography of the residue), gave benzisothiazolin-3-one (218) and S_4N_4 (see Table 5.2).



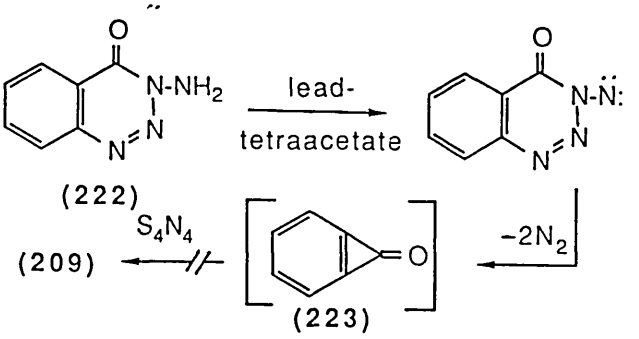
Solvent	Temp/°C	Time/h	S_4N_4	(218)
CCl_4	77	2	26	95
THF	20	3	15	90
THF	67	3	30	97

Table 5.2 : Yields(%) of benzisothiazolin-3-one (218) and S_4N_4 obtained when (218) was treated with trithiazyl trichloride (35).

Both recovered benzisothiazolin-3-one (218) and S_4N_4 could be formed from decomposition of the adduct (221) as described before (Sections 2.3.2, and 3.2.2).

Route 4 : Oxidation of 3-aminobenzotriazinone (222) with lead tetraacetate leads to the highly reactive benzocyclopropenone (223) by the loss of nitrogen.[71] We speculated that the generation of (223) in the presence of S_4N_4 could lead to the benzo compound (209). However in the presence of lead tetraacetate in dry dichloromethane at room temperature (18 h), S_4N_4 failed to react with any oxidation products of aminobenzotriazinone (222).

Since S_4N_4 has been shown to possess dehydrogenating properties,[33] it is possible that it could dehydrogenate the aminobenzotriazinone (222) to form the benzocyclopropenone (223) intermediate, which might react with excess of S_4N_4 to form benzodithiadiazepin-5-one (209).

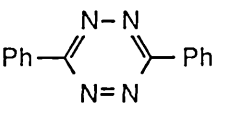


However, aminobenzotriazinone (222) did not react with S_4N_4 in refluxing toluene (18 h) and a very complex reaction mixture was obtained in refluxing xylene (5 h).

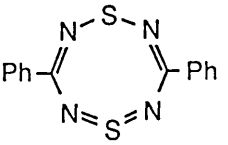
Thus a reasonable selection of different possible routes to benzodithiadiazepin-5-one (209) has been attempted but none of these were successful.

5.2 Attempted synthesis of 3,6-diphenyl-1,2,4,5,7-thiatetrazepine

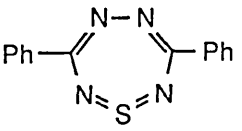
Formal introduction of a sulphur atom into 3,6-diphenyl-1,2,4,5-tetrazine (100) or removal of one from the dithiatetrazocine ring (4a) could lead to 3,6-diphenyl-1,2,4,5,7-thiatetrazepine (224), potentially an 8π antiaromatic system. In view of our general interest in seven-membered sulphur-nitrogen heterocycles, this was considered to be a worthwhile target.



(100)

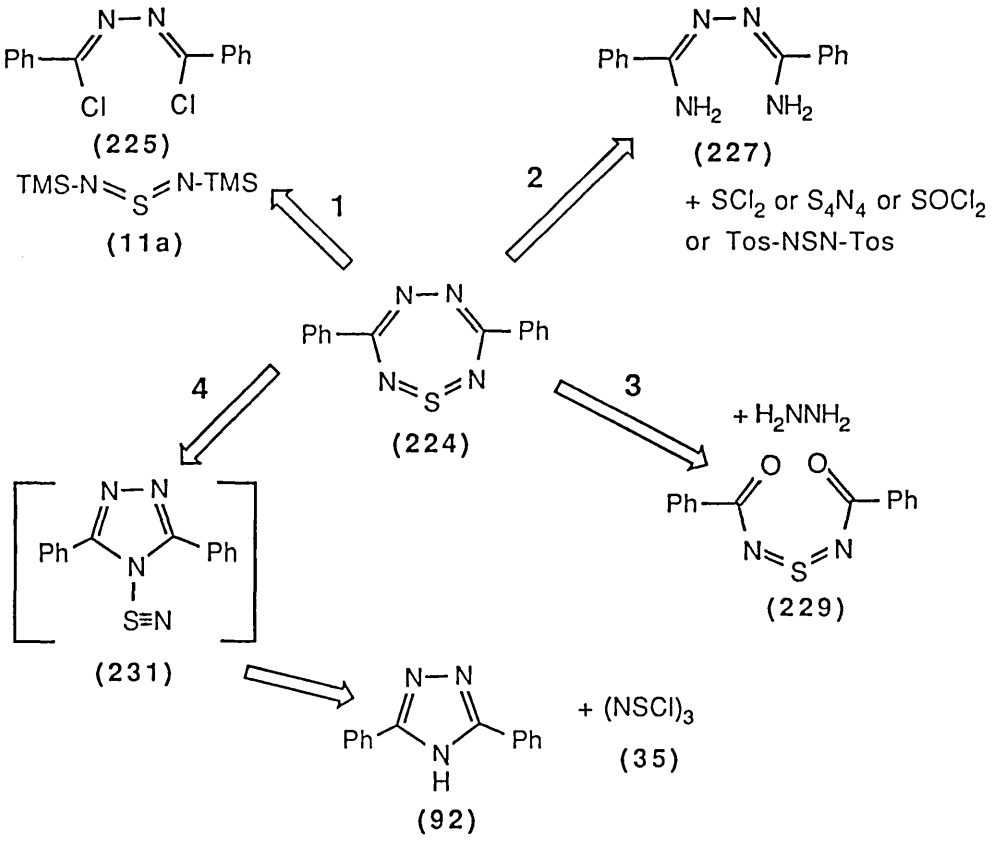


(4a)



(224)

Possible disconnections to thiatetrazepine (224) are illustrated in Scheme 5.3.



Scheme 5.3 : Possible disconnections to 3,6-diphenyl-1,2,4,5,7-thiatetrazepine (224).

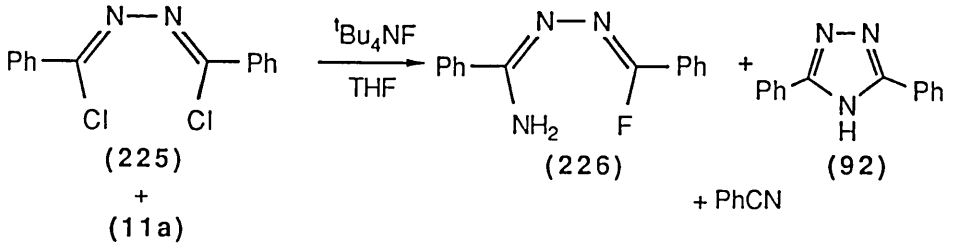
Route 1 : One might expect 1,4-dichloro-1,4-diphenyl-2,3-diazabut-1,3-diene (225) to react with bis(trimethylsilyl)sulphurdiimide (11a) via nucleophilic displacement of the chlorine atoms by nitrogen atoms of the sulphurdiimide (11a), to give either the thiatetrazepine (224) or the five-membered ring compound, 2,5-diphenyl-1,3,4-triazole (92). In the event dichlorodiazabutadiene (225) did not react with the sulphurdiimide (11a) at room temperature or under reflux in dichloromethane, acetonitrile, or THF (Table 5.3). No cyclisation reaction was observed even in the presence of either sodium iodide or potassium fluoride, or when the reactants were heated together at 160°C for 8h. In all cases, 90-95% of the dichlorodiazabutadiene (225) was recovered.

Solvent	Temp/°C	Time/h
CH_2Cl_2	20	240
CH_2Cl_2	40	48
CH_3CN	20	48
CH_3CN	80	24
CH_3CN^*	20	24
CH_3CN^*	80	10
THF	20	72
THF	67	24
THF**	20	48
THF**	67	48
Neat	160	9

* = 10% NaI ** = 2 KF

Table 5.3 : Summary of conditions for the attempted reaction between dichlorodiazabutadiene (225) and sulphurdiimide (11a).

When the above reaction was carried out in the presence of tetra-tert-butylammonium fluoride in THF, we obtained benzonitrile, 2,5-diphenyl-1,3,4-triazole (92) (36%), and a compound tentatively assigned structure (226) (10%). Compound (226) was presumably formed by displacement of one chlorine atom by an amine group, as before, and of one chlorine atom by a fluoride ion from the reagent.

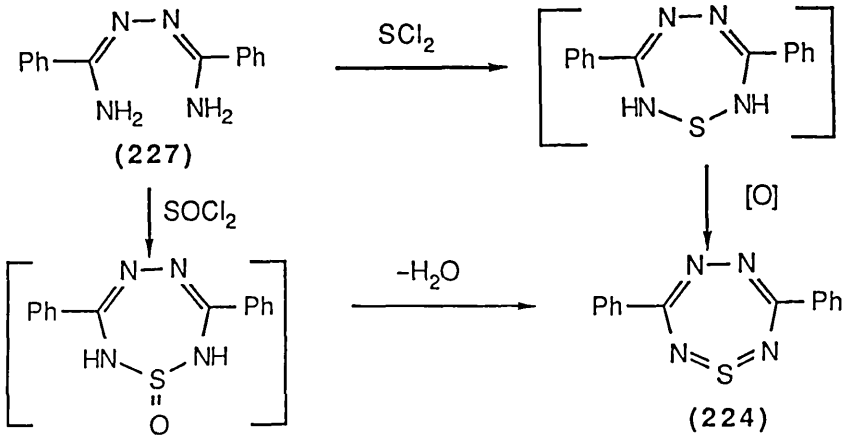


The mass spectrum of compound (226) shows a molecular ion at m/z 241, with peaks at M^+-19 (- F), M^+-123 (- HF and - PhCN) and M^+-137 (-HF, - PhCN and - N), and its proton n.m.r spectrum contained the expected complex aromatic signals [multiplets at δ 7.72-7.95 (integral 4) and δ 7.35-7.50 (integral 6)] in addition to a broad singlet at δ 5.65 (integral 2) attributed to the NH_2 group. The i.r. spectrum of this compound showed a characteristic NH_2 stretch at 3517 cm^{-1}, an imine stretch at 1652 cm^{-1} and a C-F stretch at 1295 cm^{-1}. Furthermore, the elemental analysis suggested a formula of $C_{14}H_{12}N_3F$, and hence the assignment as 1-amino-4-fluoro-1,4-diphenyl-2,3-diazabuta-1,3-diene.

Compound (226) is an air stable, pale yellow crystalline compound, m.p. 96-97°C. It is stable on prolonged storage at room temperature and, somewhat surprisingly, decomposes only very slowly to the

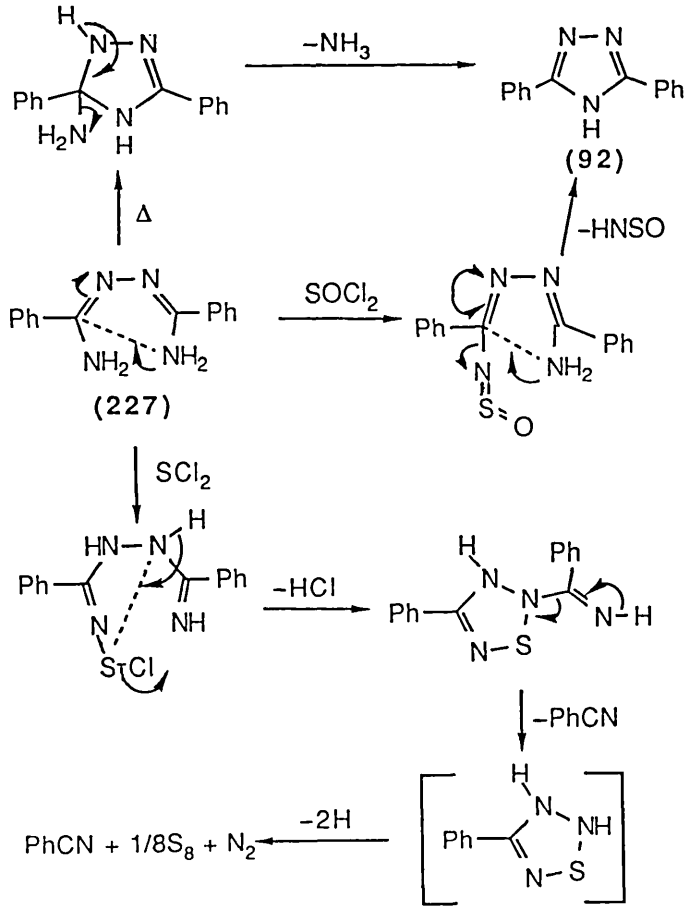
triazole (92) on heating in refluxing xylene (7 h).

Route 2 : Another possibility for the synthesis of compound (224) is the ring closure of 1,4-diamino-1,4-diphenyl-2,3-diazabut-1,3-diene (227) with sulphur dichloride, thionyl chloride, S_4N_4, or bis(tosyl)sulphurdiimide (11b).



However the products resulting from the reaction of diamino-diazabutadiene (227) with SCl_2 or $SOCl_2$ (room temperature or refluxing THF) were sulphur, benzonitrile and triazole (92). It was found that diaminodiazabutadiene (227) was transformed to triazole (92) on heating, but at a much higher temperature (refluxing xylene, see page 156). Benzonitrile was detected by t.l.c.

The proposed formation of these products is illustrated in Scheme 5.4.



Scheme 5.4 : Proposed mechanism for the formation of 2,5-diphenyl-1,3,4-triazole (92), benzonitrile and sulphur.

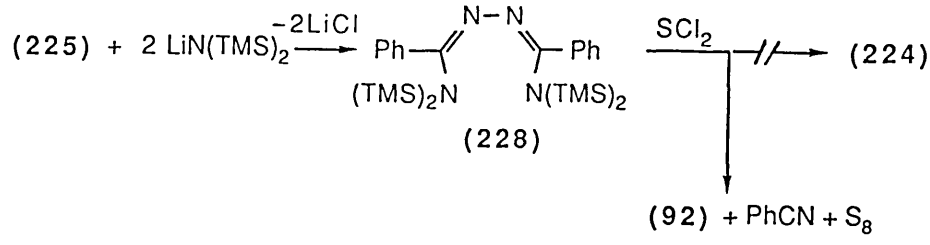
The structure of compound (92) was assigned on the basis of its spectral data. The mass spectrum showed the molecular ion ($\underline{M}^+$) at $\underline{m}/\underline{z}$ 221 with the major fragment ion at $\underline{M}^+$-103 corresponding to loss of PhCN. The proton n.m.r spectrum showed two multiplets at δ 8.10-8.20 (integral 2) and δ 7.40-7.55 (integral 3) which suggested that the two phenyl rings in triazole (92) were symmetrical. Furthermore, elemental analysis suggested a molecular formula $C_{14}H_{11}N_3$ and the melting point was identical to the one reported in the literature.[72]

Triazole (92) was obtained in varying low yields when the reaction conditions were varied from room temperature to refluxing THF (Table 5.4).

Temp/°C	SCl_2	$SOCl_2$
20	23	13
67	4	6

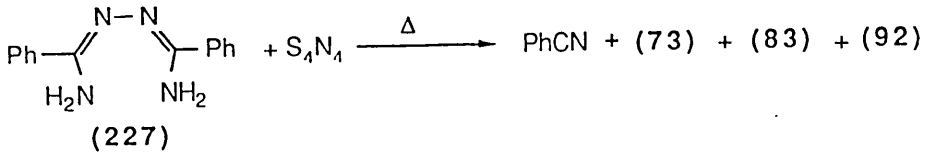
Table 5.4 : Yields(%) of 2,5-diphenyl-1,3,4-triazole (92) obtained when 1,4-diamino-1,4-diphenyl-2,3-diazabuta-1,3-diene (227) was treated with SCl_2 or $SOCl_2$ in THF.

It was hoped that when dichlorodiazabutadiene (225) was treated with lithium bis(trimethylsilyl)amine, a reactive intermediate (228) would be formed and when treated with SCl_2 would lead to the desired product (224). Again, the only products were sulphur, benzonitrile and triazole (92) (29%).



Diaminodiazabutadiene (227) did not react with S_4N_4 in refluxing benzene (24 h). However in refluxing toluene (21 h), it reacted to give benzonitrile, 2,4,6-triphenyl-1,3,5-triazine (73) (5%), 3,5-diphenyl-1,2,4-thiadiazole (83) (8%) and triazole (92) (39%). In refluxing xylene (12 h), the products were again benzonitrile,

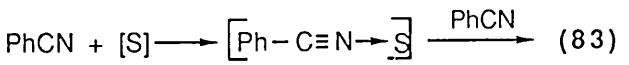
triphenyltriazine (73) (5%), diphenylthiadiazole (83) (7%) and triazole (92) (70%).



(227)

In a blank experiment, diaminodiazabutadiene (227) was heated, without S_4N_4, in refluxing xylene and the transformation to the triazole (92) was found to be much slower than in the presence of S_4N_4.

Thiadiazole (83) could be formed by the reaction of benzonitrile and sulphur as shown below.

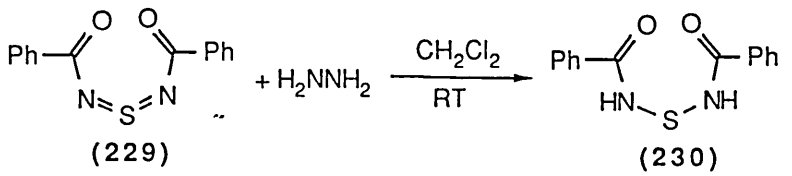


Triazole (92) could be formed by evolution of ammonia upon heating compound (227) (Scheme 5.5).

Diaminodiazabutadiene (227) did not give the desired thiatetrazepine (224) when treated with bis(tosyl)sulphurdiimide (11b). Instead, sulphur, benzonitrile and tosylamide were the only products formed. It is of course possible that thiatetrazepine (224) was formed but was unstable and decomposed to benzonitrile and sulphur.

Route 3 : Bis(benzoyl)sulphurdiimide (229) did not condense with anhydrous hydrazine to give thiatetrazepine (224). In fact the sulphurdiimide (229) was reduced by hydrazine in dichloromethane at room temperature to bis(benzamido)sulphide (230) in good yield

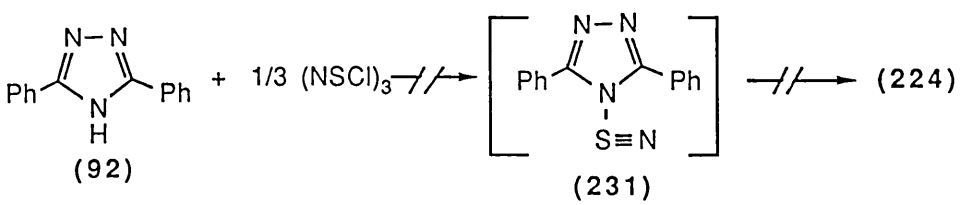
(65%).



(229) (230)

An even better yield of (230) (80%) was obtained when the reaction temperature was lowered to 0°C. Attempts to oxidise the bis-(benzamido)sulphide (230) back to bis(benzoyl)sulphurdiimide (229) with manganese dioxide and lead tetraacetate were unsuccessful.

Route 4 : Attempted ring expansion of triazole (92) with trithiazyl trichloride (35) to give thiatetrazepine (224) failed in THF at room temperature; only S_4N_4 (12%) and triazole (92)(95%) were obtained. The two products isolated here could again be formed via the intermediate (231), as proposed earlier for intermediate (221) (Section 5.1).

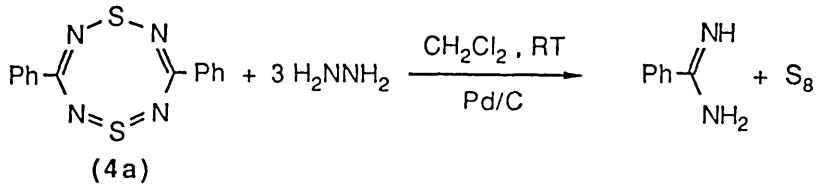


(92) (231)

5.3 Reduction of cyclic sulphurdiimides with hydrazine.

The somewhat unexpected reduction of bis(benzoyl)sulphurdiimide (229) by hydrazine (Section 5.2) lead us to explore the extension of this reaction to other cyclic sulphurdiimides, in particular to dithiatetrazocine and trithiadiazepine systems.

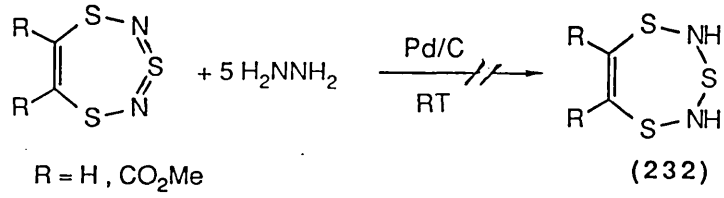
3,7-Diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) was not reduced by anhydrous hydrazine in dichloromethane at room temperature, but in the presence of catalytic amounts of 10% palladium on charcoal, it was extensively reduced at room temperature to benzamidine (75%) and sulphur.



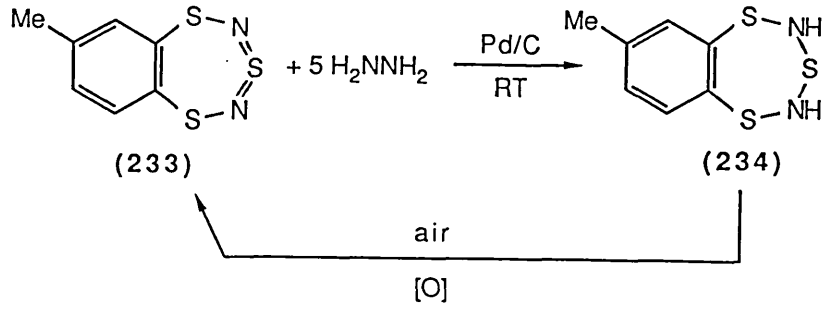
(4a)

This reaction provides a new degradation of the dithiatetrazocine ring, under mild conditions.

1,3,5,2,4-Trithiadiazepine and dimethyl 1,3,5,2,4-trithiadiazepin-6,7-dicarboxylate were treated with hydrazine in dichloromethane at room temperature in the presence of palladium on charcoal, but gave baseline products only. The initial reduced products (232) could be unstable or they could be further reduced to baseline products.



However, the corresponding benzofused trithiadiazepine (233) was reduced by hydrazine in the presence of palladium on charcoal in dichloromethane at room temperature to give the 7-methyl-1,3,5,2,4-benzotrithiadiazepane (234) (48%) as colourless needles, m.p. 161-162°C (decomp.).



The structure of compound (234) was assigned on the basis of spectral data. The mass spectrum showed a molecular ion ($\underline{M}^+$) at $\underline{m/z}$ 216 with the major fragment ions at $\underline{M}^+$-48 (- SNH_2) and $\underline{M}^+$-62 (- NHSNH). There was a NH stretch at 3330 cm^{-1} in the i.r. spectrum. The proton n.m.r spectrum showed a broad singlet at δ 6.76 (integral 2) again suggesting a NH proton. Furthermore, elemental analysis suggested a formula $C_7H_8N_2S_3$.

In air at room temperature, the benzotrithiadiazepane (234) slowly oxidised back to the trithiadiazepine (233).

This reduction/oxidation sequence has yet to be applied in the chemistry of bicyclic trithiadiazepines.

Summary

We unsuccessfully attempted to synthesise 1,3,2,4-benzodithiadiazepin-5-one (209) by the cyclisation of benzoyl chloride and 2-(chlorosulphenyl)benzoyl chloride (217) with bis(trimethylsilyl)-sulphurdiimide (11a). The latter reaction gave 1,2-benzisothiazolin-3-one (218) and S_4N_4. Other methods attempted were the ring expansion of benzisothiazolin-3-one (218) with trithiazyl trichloride (35) and the reaction of benzocyclopropenone (223) with S_4N_4.

We also unsuccessfully attempted to synthesise 3,6-diphenyl-1,2,4,5,7-thiatetrazepine (224) by cyclising either dichlorodiazabut-1,3-diene (225) with bis(trimethylsilyl)sulphurdiimide (11a) or diaminodiazabut-1,3-diene (227) with sulphur dichloride, S_4N_4, thionyl chloride or bis(tosyl)sulphurdiimide (11b). Instead of cyclisation of bis(benzoyl)sulphurdiimide (229) with hydrazine, reduction of the sulphurdiimide (229) was observed.

Diphenyldithiatetrazocine (4a) was degraded under mild conditions to benzamidine and sulphur, while the 7-methyl-1,3,5,2,4-benzotrithiadiazepine (233) was reduced to 7-methyl-1,3,5,2,4-benzotrithiadiazepane (234) by anhydrous hydrazine in dichloromethane at room temperature in the presence of palladium on charcoal.

EXPERIMENTAL SECTION

6 EXPERIMENTAL

Solvents and reagents

Petrol refers to the fraction boiling in the range 40-60°C. If higher boiling fractions were used the boiling range is specified. Ether refers to diethyl ether. All petroleum fractions were redistilled through a 36 cm Vigreux column prior to use. Ether and THF were dried by distillation from potassium-benzophenone ketyl. Benzene, toluene, and xylene were pre-dried over sodium wire and then distilled from calcium hydride. Dichloromethane, dichloroethane, chloroform and tetrachloromethane were dried by distillation from phosphorus pentoxide and then stored over 3A molecular sieves. Chloroform was passed through a column of Brockmann Grade 1 basic alumina immediately prior to use. Acetonitrile was dried by distillation from calcium hydride under nitrogen. Ethanol and methanol were dried by distillation from the corresponding magnesium alkoxide. All purified and dried solvents were stored under dry nitrogen.

Sulphur dichloride was distilled from phosphorus pentachloride at atmospheric pressure under nitrogen directly prior to use. Sulphur monochloride was distilled from sulphur and charcoal, the fraction distilling at 135-137°C was stored in a dark container in the refrigerator. Thionyl and sulphuryl chlorides were distilled under nitrogen directly prior to use. Other reagents which were prepared by literature methods are indicated by references in the text as appropriate.

Chromatography

Chromatography refers to medium pressure (hand bellows) column chromatography on silica (Merck Kieselgel 60 H), which was carried out as follows, unless otherwise indicated.

The mixture to be separated was pre-adsorbed onto the minimum amount of silica by evaporation of a slurry in a suitable solvent (usually dichloromethane), and applied to the top of a column prepared from a suspension of the silica (approximately 15 g per gram of the mixture to be separated, but with a minimum amount of 1 g of silica) in petrol. Columns were eluted first with petrol then with petrol-dichloromethane mixtures (5% dichloromethane in petrol, then 10%, 15% etc) unless otherwise stated.

Thin layer chromatography (t.l.c.) was used throughout to monitor reactions, analyse column eluates and determine the purity of compounds. Aluminium backed silica plates (Merck Kieselgel 60 GF_{254}) were used for this purpose. After elution the plates were observed under ultra-violet light at 254 and 300 nm.

Spectra

Ultra-violet spectra were recorded in the range 500-200 nm using a Perkin-Elmer 551 instrument and were externally calibrated using holmium oxide (360.8 nm). Molar absorptivity (ε) was calculated in units of $dm^3\ mol^{-1}\ cm^{-1}$.

Infra-red spectra (i.r.) were recorded in the range 4000-600 cm^{-1} using either a Perkin-Elmer 298 grating spectrophotometer externally calibrated against polystyrene (1602 cm^{-1}) or Perkin-Elmer 1710 infra-red spectrometer. Spectra were recorded as thin films or nujol mulls between sodium chloride plates, as solutions in the solvent

specified, or as KBr discs.

Proton nuclear magnetic resonance spectra (n.m.r.) were recorded at 60 MHz on a Varian EM360 spectrometer, at 90 MHz on a Perkin-Elmer R32 spectrometer, or at 250 MHz on a Bruker WM250 spectrometer. Chemical shifts (δ_H) are given in parts per million relative to tetramethylsilane as an internal reference.

Carbon-13 n.m.r. spectra were recorded at 62.9 MHz on a Bruker WM250 spectrometer and were fully proton decoupled. Chemical shifts (δ_C) are given in parts per million relative to tetramethylsilane as an internal reference.

Low resolution mass spectra (m.s.) and accurate mass measurements were recorded on an AE1 MS12 mass spectrometer or a VG Micromass 7070B mass spectrometer, using Electron Impact ionisation (EI) unless otherwise stated. In some cases Fast Atom Bombardment (FAB) was used.

Other data

Melting points were determined using a Kofler hot stage apparatus and are uncorrected. Elemental micro-analysis were carried out in the Imperial College Chemistry Department Micro-analytical Laboratory under the supervision of Mr. K. I. Jones.

Reactions of benzamidine

Benzamidine was liberated from its hydrochloride salt (Aldrich) with aqueous sodium hydroxide (5 M) and extracted into dichloromethane, the solution was dried with magnesium sulphate, filtered and the solvent evaporated to give benzamidine, m.p. 67-69°C.

(i) With sulphur dichloride : A solution of sulphur dichloride (1.35 ml, 2.19 g, 21.25 mmol) in dry dichloromethane (20 ml) was added dropwise over 1 h to a stirred solution of benzamidine (1.70 g, 14.17 mmol) and DBU (6.35 ml, 42.5 mmol) in dry dichloromethane at 0°C under nitrogen. When the addition was complete the reaction mixture was stirred for a further 2 h at 0°C and then at room temperature for 1 h. A flocculent air-sensitive yellow precipitate (later identified as 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (10%) as described on page 172) was removed by filtration under nitrogen, and then the solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur and with 10% dichloromethane in petrol, 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) (127 mg, 6%) was obtained as yellow plates, m.p. 224-225°C (lit.,[4] 225-226°C); $\lambda_{max.}$ (EtOH) 274 (ε, 26400), 283 (26100), 297.5 (29700), 310 (37500), 323 (28900), and 414 nm (7200); $\nu_{max.}$ (Nujol mull) 1595, 1485, 1450, 1365, 1320, 1298, 1233, 1160, 1030, 1000, 970, 940, 925, 780, and 690 cm^{-1}; δ_H (400 MHz, CD_2Cl_2) 7.46-7.51 (m), 7.545-7.60 (m), and 8.53-8.57 (dd); m/z (190°C) 298 (M^+, 24%), 195 (M^+-PhCN, 6), 181 (M^+-$PhCN_2$, 5), 167 (2), 149 ($PhCN_2S^+$, 9), 135 ($PhCNS^+$, 100), 103 (PhCN, 41), 77 (Ph^+, 14), 64 (S_2, 22) and 46 (NS, 62).

The above reaction was repeated at -10°C; 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (15%) and dithiatetrazocine (4a) (5.5%) were obtained by a similar work-up procedure.

Benzamidine (0.72 g, 6mmol) was dissolved in dry dichloromethane (50 ml) and sulphur dichloride (0.93 g, 0.60 ml, 9 mmol) was dissolved in dry dichloromethane (50 ml). The two dichloromethane solutions thus prepared were added synchronously and dropwise over 10 h to a large flask containing dry dichloromethane (1.5 l) and DBU (2.74 g, 2.7 ml, 18 mmol) which was vigorously stirred under nitrogen at room temperature. When the addition was complete the mixture, a cloudy orange-brown solution, was stirred for further 15 h, the solvent was evaporated and the residue chromatographed on silica as described above to give sulphur and dithiatetrazocine (4a) (61 mg, 6.8%).

(ii) With sulphur monochloride : To a stirred suspension of benzamidinium chloride (2.4 g, 15.33 mmol) and DBU (7 g, 6.9 ml, 46 mmol) in dry dichloromethane (45 ml), a solution of sulphur monochloride (1.84 ml, 23 mmol) in dry dichloromethane (20 ml) was added dropwise over 30 min at 0°C under nitrogen. The resulting dark red-brown reaction mixture was stirred for a further 2 h at 0°C and then for 3 h at room temperature. The yellow precipitate of dithiadiazolium chloride (38b) (1.78 g, 54%) was removed by filtration under nitrogen, and then the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (59 mg, 2.6%).

(iii) With imide-N-sulphenyl chlorides (76) and N,N'-thiobisimides (77)

Method A : To a stirred solution of benzamidine in dry dichloromethane at room temperature under nitrogen, a solution of either imide-N-sulphenyl chloride (76)[73] or N,N'-thiobisimide (77)[74] in dry dichloromethane was added dropwise over a period of 30 min. The reaction mixture was further stirred at room temperature (see Table 2.2), then the solvent was evaporated and the residue chromatographed on silica. Elution with 10% dichloromethane in petrol gave dithiatetrazocine (4a). For the results, see Table 2.2, Section 2.2.3.

Method B : To a stirred slurry of bis-N-thalimidosulphide (77b)[74b] (1.36 g, 4.2 mmol) in dry dichloromethane (20 ml) at room temperature under nitrogen, was added dropwise over 10 min a solution of benzamidine (1 g, 8.4 mmol) in dry dichloromethane (20 ml). The yellow reaction mixture was further stirred at room temperature for 72 h, filtered, the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (6 mg, 0.5%).

(iv) With sulphurdiimides[18, 75]

Typical procedure : To a stirred solution of benzamidine (0.76 g, 6.3 mmol) in dry dichloromethane (40 ml) was added dropwise over 30 min a solution of bis(tosyl)sulphurdiimide (11b)[75a] (2.3 g, 6.3 mmol) in dry dichloromethane (40 ml), while the reaction mixture was stirred under nitrogen at room temperature. The red-brown cloudy,

reaction mixture was further stirred at room temperature for 102 h, filtered, the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (57 mg, 6.1%).

(v) With bis(tosyl)sulphurdiimide (11b) and imide-N-sulphenyl chloride (76) or N,N'-thiobisimide (77)

Method A :

Typical procedure : To a stirred solution of benzamidine (240 mg, 2mmol) in dry dichloromethane (30 ml) at room temperature under nitrogen, was added a solution of N(thiomorpholino)succinimide (77d)[74c] (216 mg, 1 mmol) in dry dichloromethane (30 ml), dropwise over 10 min. After 1 h, a solution of bis(tosyl)sulphurdiimide (11b) (370 mg, 1 mmol) in dry dichloromethane (20 ml) was added over 10 min at room temperature under nitrogen. The resulting reaction mixture was further stirred at room temperature for 14 h, the solvent was evaporated and the residue chromatographed on silica. Elution with 10% dichloromethane in petrol gave dithiatetrazocine (4a) (3.3 mg, 1.1%). Elution with ether gave a colourless compound which was assigned the structure of 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) (54 mg, 20%), m.p. 156-158°C (Found: C, 62.2; H, 4.1: N, 15.6, and M^+, 269.0618. $C_{14}H_{11}N_3OS$ requires C, 62.4; H, 4.1; N, 15.6%, and M, 269.0623); $\nu_{max.}$ (Nujol mull) 3380, 1622, 1618, 1600, 1590, 1565, 1455, 1275, 1070, 1030, 990, 930, 735, 720, 712, 690, 670, amd 620 cm^{-1}; δ_H (90 MHz, d_6 DMSO) 7.50-7.70 (6 H, m), 8.20-8.35 (4 H, m), and 10.03 (1 H, s, br); m/z (160°C) 269 (M^+, 5%), 253 (M^+-O, 37), 252 (M^+-OH, 25), 221 (M^+-SO, 19), 149 ($PhCN_2S^+$,

15), 135 ($PhCNS^+$, 4), 118 ($PhCHN_2^+$, 12), 104 ($PhCHN^+$, 100), 103 (PhCN, 52), 91 (3), 77 (Ph^+, 26), and 46 (NS, 37), and with ethyl acetate a colourless compound was obtained which was tentatively assigned the structure of 1-(p-toluenesulphonylimino)-3,5-diphenyl-1,2,4,6-thiatriazine (81) (13 mg, 3%), m.p. 156-158°C (Found: C, 59.0; H, 4.2; N, 12.9. $C_{21}H_{18}N_4O_2S_2$ requires C, 59.7; H, 4.3; N, 13.3%); $\nu_{max.}$ (Nujol mull) 1610, 1600, 1590, 1565, 1280, 1260, 1130, 1080, 1015, 985 and 715 cm^{-1}; δ_H (250 MHz; d_6 acetone) 2.35 (3 H, s), 7.20 (2 H, d, J 7.5 Hz), 7.475 (6 H, m), 7.80 (2 H, d, J 7.5 Hz) and 8.25 (4 H, m); m/z (200°C) 253 (M^+-TosN, 17%), 171 ($TosNH_2$, 44), 155 (Tos^+, 40), 149 ($PhCN_2S^+$, 7), 135 ($PhCNS^+$, 4), 104 ($PhCNH^+$, 43), 91 (100), 77 (Ph^+, 17), and 46 (NS, 10). For further results see Table 2.4, Section 2.2.3.

Method B :

Typical procedure : To a stirred suspension of bisphthalimidosulphide (77b) (1.8 g, 5.5 mmol) in dry dichloromethane (40 ml) was added at room temperature under nitrogen, a solution of benzamidine (1.32 g, 11 mmol) in dry dichloromethane (20 ml), dropwise over 10 min. After 30 min a solution of bis(tosyl)sulphurdiimide (11b) (2.6 g, 7 mmol) in dry dichloromethane (40 ml) was added dropwise over 20 min to the reaction mixture at room temperature under nitrogen. The resulting mixture was further stirred at room temperature for 40 h, filtered, the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (158 mg, 9.6%), hydroxythiatriazine (80) (223 mg, 15%) and 1-(p-

toluenesulphonylimino)-diphenylthiatriazine (81) (247 mg, 11%).

Method C : To a stirred slurry of a mixture of bis(tosyl)sulphurdiimide (11b) (720 mg, 1.95 mmol) and bisphthalimidosulphide (77b) (630 mg, 1.95 mmol) in dry 1,2-dichloroethane (20 ml), at room temperature under nitrogen, was added dropwise over 1 h a solution of benzamidine (468 mg, 3.9 mmol) in dry 1,2-dichloroethane (50 ml). The resulting mixture was stirred at room temperature for a further 20 h, filtered, the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (43 mg, 7.4%), hydroxythiatriazine (80) (115 mg, 22%) and 1-(p-toluenesulphonylimino)-diphenylthiatriazine (81) (18 mg, 2%).

Method D :

Typical procedure : To a stirred slurry of bisphthalimidosulphide (77b) (1.94 g, 6 mmol) in dry dichloromethane (50 ml) was added benzamidine (0.24 g, 2 mmol) and then the mixture was refluxed for 3 h under nitrogen, cooled to room temperature, when a solution of bis(tosyl)sulphurdiimide (11b) (0.37 g, 1 mmol) in dry dichloromethane (30 ml) was added dropwise over 1 h. The resulting mixture was then further stirred at room temperature for 15 h, filtered, the solvent was evaporated and the residue chromatographed on silica as described above to give dithiatetrazocine (4a) (28 mg, 9.4%), hydroxythiatriazine (80) (56 mg, 21%) and 1-(p-toluenesulphonylimino)-diphenylthiatriazine (81) (17 mg, 4%).

(vi) With sulphur A mixture of benzamidine (343 mg, 2.86 mmol) and sulphur (960 mg, 30 mmol) was heated at 160°C for 3 h and then

cooled to room temperature, when dichloromethane (50 ml) was added. After filtration, the solvent was evaporated and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave 2,4,6-triphenyl-1,3,5-triazine (73) (5.3 mg, 2%) as colourless needles (toluene), m.p. 225-230°C (lit.,[72] m.p. 231°C); $\nu_{max.}$ (Nujol mull) 1590, 1520, 1460, 1370, 840, 740, 685, and 645 cm^{-1}; δ_H (90 MHz, $CDCl_3$) 7.6-7.7 (3 H, m), and 7.7-7.9 (2 H, m); m/z (180°C) 309 (M^+, 37%), 103 (M^+-2PhCN, 100), 76 (10), and 51 (2), followed by benzonitrile and with 50% dichloromethane in petrol, 3,5-diphenyl-1,2,4-thiadiazole (83) (81 mg, 24%) was obtained as colourless needles (hexane), m.p. 86-88°C (lit.,[72] m.p. 86-88°C); $\nu_{max.}$ ($CHCl_3$) 1465, 1434, 1410, 1323, 1270, 1110, 980, and 895 cm^{-1}; m/z (100°C) 238 (M^+, 34%), 135 (M^+-PhCN, 100), 119 (5), 108 (PhS^+, 3), 103 (PhCN, 60), 77 (Ph^+, 18), and 51 (7).

(vii) With thionyl chloride

Typical procedure : To a slurry of benzamidinium chloride (1.64 g, 10.5 mmol) and DBU (6.3 ml, 42 mmol) in dry dichloromethane (45 ml), a solution of thionyl chloride (1.2 ml, 16 mmol) in dry dichloromethane (20 ml) was added dropwise over 10 min while the reaction mixture was stirred under nitrogen in an ice-water bath. After 2 h, the cooling bath was removed and stirring was continued overnight at room temperature. The resulting orange-yellow reaction mixture was diluted with more dichloromethane (50 ml) and washed with water (2 x 100 ml) and then with saturated brine (50 ml). The orange-yellow organic phase was dried over anhydrous magnesium sulphate, filtered, the solvent was evaporated and the residue chromatographed on silica. Elution with ethyl acetate gave a

colourless compound assigned as 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84) (233 mg, 16%), m.p. > 310°C (Found: C, 58.5; H, 3.8; N, 14.55; S, 11.6; M^+, 285.0567. $C_{14}H_{11}N_3O_2S$ requires C, 58.9; H, 3.9; N, 14.7; S, 11.2%; M, 285.0572.); ν_{max} (Nujol mull) 3280, 1640, 1602, 1570, 1320, 1272, 1176, 1161, 1027, 985, 841, 811, and 690 cm^{-1}; δ_H (250 MHz, d_6 DMSO) 7.55-7.78 (3 H, m) and 8.02-8.14 (2 H, m); δ_C (62.9 MHz, d_6 DMSO) 128.49, 128.69, 130.90, 132.90, and 158.34; m/z (260°C) 285 (M^+, 57%), 221 (M^+-SO_2, 22), 118 ($PhCN_2H^+$, 42), 104 ($PhCNH^+$, 100), 91 (14), 77 (Ph^+, 42), and 51 (25).

(viii) With sulphuryl chloride The same procedure as described above for thionyl chloride was used.

4-Phenyl-1,2,3,5-dithiadiazolium chloride (38b)

The title compound was obtained as a flocculent yellow precipitate from the reaction of benzamidine with sulphur dichloride (see page 165). The precipitate was collected by filtration under nitrogen and washed with dry dichloromethane to give pure 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (306 mg, 10%) as a fine yellow powder, m.p. 70-73°C; $\lambda_{max.}$ (CH_2Cl_2) 395 nm (ε 680); $\nu_{max.}$ (nujol mull) 1600, 1390, 1340, 1150, 1070, 1025, 1000, 920, 890, 840, 780, 706, and 695 cm^{-1}; m/z (100°C) 181 (M^+, 100%), 135 (M^+-NS, 39), 117 ($PhCN_2^+$, 5), 103 (PhCN, 25), 89 (25), 78 (NS_2, 94), 77 (Ph^+, 21) and 46 (NS, 9). The sample was identical with the one reported in literature.[41]

Reaction of N,N,N'-tris(trimethylsilyl)benzamidine (69) with sulphur dichloride

To a stirred solution of N,N,N'-tris(trimethylsilyl)benzamidine (69)[76] (4.84 g, 14.36 mmol) in dry dichloromethane (100 ml) at 0°C under nitrogen, was added dropwise over 2 h a solution of sulphur dichloride (1.4 ml, 21.54 mmol) in dry dichloromethane (100 ml). After 1 h, the cooling bath was removed and the reaction mixture was stirred at room temperature for 2 h. The yellow flocculent precipitate of 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (1.87 g, 60%) was filtered under nitrogen and washed with dry dichloromethane. The solvent was removed in vacuo and the residue chromatographed on silica. Elution with petrol gave sulphur and with 20% dichloromethane in petrol, dithiatetrazocine (4a) (128 mg, 3%) was obtained.

Reactions of tetrasulphur tetranitride

(i) With benzamidine

Typical procedure : S_4N_4 [77] (423 mg, 2.3 mmol) and benzamidine (821 mg, 6.84 mmol) were heated at reflux in dry toluene (50 ml) under nitrogen for 15 h. Methanol (5 ml) was added to homogenise the mixture and then the solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur and with 20% chloroform in petrol, 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) (63 mg, 6%) followed by 2,4,6-triphenyl-1,3,5-triazine (73) (28 mg, 4%), m.p. 225-230°C (identical spectral data with the earlier sample) and benzonitrile were obtained. Elution with chloroform gave

colourless prisms (hexane), assigned the structure of 1-methoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129a) (210 mg, 22%), m.p. 105-106°C (Found: C, 63.6; H, 4.4; N, 14.75. $C_{15}H_{13}N_3OS$ requires C, 63.6; H, 4.6; N, 14.8%); $\nu_{max.}$ ($CHCl_3$) 1580, 1480, 1380, 1350, 1280, 1140, 970, 950, 635, and 610 cm^{-1}; δ_H (250 MHz, d_6 acetone) 3.41 (3 H, s), 7.54-7.68 (6 H, m), and 8.51-8.55 (4 H, m); δ_C (62.9 MHz, $CDCl_3$) 50.15, 128.21, 128.69, 132.46, 136.61, and 168.36; m/z (160°C) 283 (M^+, 2.5%), 252 (M^+-OCH_3, 100), 149 ($PhCN_2S^+$, 28), 103 (PhCN, 31), 76 (12), and 46 (NS, 66). Elution with ether gave 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80) (130 mg, 14%), m.p. 156-158°C (indentical spectral data with the earlier sample).

The above reaction was repeated at reflux in dry benzene (16 h), toluene (3.5 h), and xylene (6 h). The results are summarised in Tables 2.1 and 3.1 (Sections 2.2.2, and 3.1.1).

In the presence of lead tetraacetate : To a stirred solution of S_4N_4 (334 mg, 1.82 mmol) and benzamidine (377 mg, 3.1 mmol) in dry dichloromethane (40 ml) at room temperature under nitrogen, was added in portions over 20 min, lead tetraacetate (1.37 g, 3.1 mmol). The reaction mixture was stirred for a further 3 h at room temperature and then at reflux temperature for 5 h, filtered, the solvent was evaporated and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave compound (4a) (1 mg, 0.2%).

In the presence of titanium tetrachloride : To a stirred solution of S_4N_4 (479 mg, 2.6 mmol) in dry dichloromethane (50 ml) at room

temperature under nitrogen, was added a catalytic amount of titanium tetrachloride (0.05 ml). To the resulting red-orange slurry, was added a solution of benzamidine (617 mg, 5.1 mmol) in dry dichloromethane (20 ml) over 15 min. The resulting brown-black reaction mixture was stirred at room temperature for 1 h and then at reflux temperature for 6 h, filtered, the solvent was removed *in vacuo* and the residue chromatographed on silica as described above to give compound (4a) (7 mg, 0.9%) followed by S_4N_4 (232 mg, 48%).

(ii) With benzamidoxime

Typical procedure : S_4N_4 (319 mg, 1.7 mmol) and benzamidoxime (85)[78] (472 mg, 3.4 mmol) were heated at reflux in dry toluene (20 ml) under nitrogen for 12 h. The solvent was evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave dithiatetrazocine (4a) (20 mg, 4%). Elution with 50% ether in petrol gave 2,5-diphenyl-1,3,4-triazole (92) (6 mg, 2%) as colourless crystals, m.p. 194-195°C (lit.,[72] 192-193°) (Found: C, 75.6; H, 5.0; N, 18.8. Calc. for $C_{14}H_{11}N_3$ C, 76.0; H, 5.0; N, 19.0%); $\nu_{max.}$ (Nujol mull) 1610, 1560, 1440, 1180, 1140, 1000, 790, 730, 710, 700, and 690 cm^{-1}; δ_H (90 MHz, d_6 acetone) 7.4-7.55 (3 H, m) and 8.1-8.2 (2 H, m); m/z (160°C) 221 (M^+, 100%), 118 (M^+-PhCN, 61), 105 (11), 91 (17), and 77 (Ph^+, 19) and in ether, hydroxythiatriazine (80) (48 mg, 10%) (identical spectral data with the earlier sample) was obtained. Elution with ethyl acetate gave thiatriazin-1,1-dioxide (84) (80 mg, 16%) (identical spectral data with the earlier sample).

The above reaction was repeated at reflux in toluene (3 h), and xylene (6 h) and the results are summarised in Table 3.3 (Section 3.1.4).

(iii) With 1,4-diamino-1,4-diphenyl-2,3-diazabuta-1,3-diene (227)

S_4N_4 (365 mg, 2 mmol) and 1,4-diamino-1,4-diphenyl-2,3-diazabuta-1,3-diene (227)[79] (952 mg, 4 mmol) were heated at reflux in dry toluene (50 ml) under nitrogen for 21 h. The solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur and with 20% dichloromethane in petrol, 2,4,6-triphenyl-1,3,5-triazine (73) (40 mg, 5%), m.p. 225-230°C (identical spectral data with the earlier sample) was obtained, followed by benzonitrile. Elution with 50% dichloromethane in petrol gave 3,5-diphenyl-1,2,4-thiadiazole (83) (75 mg, 8%) as colourless needles, m.p. 86-88°C (identical spectral data with the earlier sample). Elution with 50% ethyl acetate in dichloromethane gave 2,5-diphenyl-1,3,4-triazole (92) (342 mg, 39%), m.p. 194-195°C (lit.,[72] m.p. 192°C) (identical spectral data with the earlier sample).

Reactions of benzamidoxime

(i) With sulphur dichloride To a solution of benzamidoxime (85) (2.14 g, 15.7 mmol) and DBU (7 ml, 47 mmol) in dry dichloromethane (45 ml), a solution of sulphur dichloride (1.5 ml, 23.5 mmol) in dry dichloromethane (20 ml) was added dropwise over 10 min while the reaction mixture was stirred under nitrogen in an ice-water bath. After 2 h, the cooling bath was removed and the resulting dark reaction mixture was stirred at room temperature for 2 h. The yellow

precipitate of 4-phenyl-1,2,3,5-dithiadiazolium chloride (38b) (1.09 g, 32%) was removed by filtration under nitrogen, the solvent evaporated and the residue chromatographed on silica. Elution with 10% dichloromethane in petrol gave dithiatetrazocine (4a) (129 mg, 5.6%).

(ii) With thionyl chloride

Typical procedure : To a stirred solution of benzamidoxime (3.8 g, 28 mmol) and dry pyridine (6.8 ml, 84 mmol) in dry dichloromethane (100 ml), a solution of thionyl chloride (2 ml, 28 mmol) in dry dichloromethane (50 ml) was added dropwise over 45 min at 0°C under nitrogen. After 2 h the cooling bath was removed and the pale yellow reaction mixture was stirred for further 2 h at room temperature, the solvent was evaporated and the residue chromatographed on silica. Elution with 50% ethyl acetate in dichloromethane gave, as colourless fine needles (petrol 80-100°C), a compound which was tentatively assigned the structure of N-sulphinylbenzamidoxime (90a) (1.97 g, 39%), m.p. 88-89°C (Found: C, 46.45; H, 3.3; N, 15.3; S, 16.9. $C_7H_6N_2O_2S$ requires C, 46.1; H, 3.3; N, 15.4; S, 17.6%); $\nu_{max.}$ (Nujol mull) 3250, 1606, 1568, 1505, 1455, 1400, 1300, 1180, 1160, 1030, 930, 850, 800, 773, 710, 700, 678, 630, and 620 cm^{-1}; δ_H (90 MHz, $CDCl_3$) 7.45-7.6 (3 H, m) 7.6-7.8 (2 H, m) and 8.15 (1 H, s, br); m/z (140°C) 182 (M^+, 14%), 152 (M^+-NO, 16), 120 (M^+-NSO, 28), 118 ($PhCN_2H^+$, 4), 104 ($PhCNH^+$, 73), 103 (PhCN, 100), 77 (Ph^+, 28), 64 (25), and 48 (SO, 12). For related experiments see Table 2.5, Section 2.3.1.

Attempted reaction of activated nitriles with bis(trimethylsilyl)sulphurdiimide (11a)

General procedure : A mixture of the nitrile (96a or b) (1 eq) and bis(trimethylsilyl)sulphurdiimide (11a)[18] (0.6 eq) was heated under nitrogen (see Table 2.7). The reaction mixture was then cooled to room temperature, when dry dichloromethane (25 ml) was added and the mixture further cooled to 0°C. A solution of sulphur dichloride (0.5 eq) in dry dichloromethane (20 ml) was added dropwise over 30 min. After approximately 1 h, the cooling bath was removed and the reaction mixture was stirred at room temperature for 5-6 h, the solvent was evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave S_4N_4; the rest was baseline product (see Table 2.7, Section 2.3.2).

Reactions of 5-phenyl-1,2,3,4-tetrazole

(i) With sulphur : A solution of 5-phenyl-1,2,3,4-tetrazole (98)[80] (73 mg, 0.5 mmol) and sulphur (32 mg, 1 mmol) in dry acetonitrile (60 ml) was irradiated at 254 nm in a Rayonet Photochemical Reactor for 5 h. A continuous stream of nitrogen was passed through the solution during irradiation. The solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur; with 50% ether in petrol 3,6-diphenyl-1,2,4,5-tetrazine (100) (9.4 mg, 16%) was obtained as carmine red crystalline compound, m.p. 193-194°C (Lit.,[72] m.p. 195°C). Elution with ether gave 2,5-diphenyl-1,3,4-triazole (92) (11 mg, 20%) as a colourless compound, m.p. 192°C (identical spectral data with the earlier sample).

A mixture of tetrazole (98) (292 mg, 2mmol) and sulphur (192 mg, 6 mmol) was heated on an oil bath at 200°C for 3.5 h, cooled to room temperature and then dichloromethane (50 ml) was added, the mixture filtered, the solvent evaporated and the residue chromatographed on silica as described above to give sulphur, tetrazine (100) (28 mg, 15%) and triazole (92) (146 mg, 81%); further elution with ether gave unreacted tetrazole (98) (55 mg, 19%).

(ii) With tetrasulphur tetranitride : A solution of tetrazole (98) (146 mg, 1mmol) and S_4N_4 (91 mg, 0.5 mmol) in dry acetonitrile (100 ml) was irradiated at 254 nm in a Rayonet Photochemical Reactor for 5 h. A continuous stream of nitrogen was passed through the solution during irradiation. The solvent was evaporated and the residue chromatographed on silica. Elution with 50% ether in petrol gave tetrazine (100) (39 mg, 33%) followed by unreacted S_4N_4 (47 mg, 52%) and with ether, triazole (92) (14 mg, 13%) was obtained.

S_4N_4 (184 mg, 1 mmol) and tetrazole (98) (146 mg, 1 mmol) were heated at reflux in dry toluene (20 ml) under nitrogen for 15 h. T.l.c. of the reaction mixture showed it to be a complex mixture from which sulphur, benzonitrile and tetrazine (100) were the only identifiable products. The solvent was evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave tetrazine (100) (5 mg, 4%).

The above reaction was repeated in refluxing bromobenzene (2h) and a much cleaner reaction mixture was obtained; upon work-up tetrazine (100) (15%) together with unreacted tetrazole (98) (20%) were obtained.

3,7-Di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41)

2-Furylamidine (108) was liberated from its hydrochloride[81] salt with aqueous sodium hydroxide (5 M) and extracted into dichloromethane, the solution was dried with magnesium sulphate, filtered and the solvent evaporated to give 2-furylamidine, m.p. 55-57°C.

(i) From the reaction of 2-furylamidine (108) and S_4N_4 : S_4N_4 (368 mg, 2 mmol) and 2-furylamidine (108) (440 mg, 4 mmol) were heated at reflux in dry xylene (20 ml) under nitrogen for 4 h. The solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur and with 5% dichloromethane in petrol, 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) (11 mg, 2%) was obtained as yellow plates (ethyl acetate), m.p. 214-216°C (Found: C, 43.1; H, 2.25; N, 19.8, and M^+, 277.9923. $C_{10}H_6N_4O_2S_2$ requires C, 43.15; H, 2.2; N, 20.1% and M 277.9932); $\lambda_{max.}$ (EtOH) 210 (ε, 15700), 272 (16100), 322.5 (36000), 338 (34100), and 448 nm (5000); $\nu_{max.}$ (CCl_4) 3735, 2926, 2855, 1735, 1577, 1508, 1490, 1459, 1428, 1398, 1368, 1265, 1158, and 1017 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 6.89 (1 H, m), 7.24 (1 H, m), and 7.63 (1 H, m); m/z (180°C) 278 (M^+, 26%), 200 (M^+-NS_2, 9), 172 (M^+-$C_5H_3N_2O$, 44), 139 ($C_5H_3N_2OS$, 9), 125 (C_5H_3NOS, 13), 94 ($C_5H_4NO^+$, 22), 78 (NS_2, 6), and 46 (NS, 100). Elution with 50% dichloromethane in petrol gave 2-cyanofuran, followed by 2,4,6-tris(2-furyl)-1,3,5-triazine (109) (76 mg, 20%) as colourless plates, m.p. 244-245·C (lit.,[82] 238-240·C) (Found: M^+, 279.0641. $C_{15}H_9N_3O_3$ requires 279.0644); $\nu_{max.}$ (CCl_4) 2926, 2855, 1585, 1520, 1480, 1420, 1356, 1265, 1197, and 1012 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 6.61 (1 H, dd, J 1.5 and 4 Hz), 7.62 (1 H, dd, J 1 and 4 Hz), and

7.715 (1 H, dd, J 1 and 1.5 Hz); m/z (180°C) 279 (M^+, 62%), and 93 (C_5H_3NO, 100).

(ii) From the reaction of 2-furylamidine (10a) and bis(tosyl)sulphurdiimide (11b) : To a stirred slurry of 2-furylamidinium chloride (1.46 g, 10 mmol) and DBU (1.52 g, 1.5 ml, 10 mmol) in dry dichloromethane (20 ml) at room temperature under nitrogen, was added dropwise over 30 min a solution of bis(tosyl)sulphurdiimide (11b) (3.7 g, 10 mmol) in dry dichloromethane (20 ml). The dark reaction mixture was stirred for further 3 h at room temperature, filtered, the solvent was evaporated, and the residue chromatographed on silica. Elution with 10% dichloromethane in petrol gave 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) (20 mg, 1.4%).

When the above reaction was repeated but with stirring at room temperature for 15 h, a lower yield (0.2%) of 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) was obtained.

Treatment of 2-furylamidinium chloride with sulphur dichloride in the presence of DBU

To a stirred slurry of 2-furylamidinium chloride (2.55 g, 17.5 mmol) and DBU (8 g, 7.8 ml, 52.5 mmol) in dry dichloromethane (50 ml) at 0°C under nitrogen, was added dropwise over 30 min a solution of freshly distilled sulphur dichloride (2.7 g, 1.7 ml, 26.25 mmol) in dry dichloromethane (20 ml). After 3 h the cooling bath was removed and the reaction mixture was stirred at room temperature for 4 h. A burgundy coloured precipitate (330 mg), a mixture of 4(2-furyl)-1,2,3,5-dithiadiazolium chloride (38d) [m/z (80-180°C) 171 (M^+,

78%), 125 (35) and 93 (20)], and 4(monochloro 2-furyl)-1,2,3,5-dithiadiazolium chloride (38c) [m/z (80-180°C) 205 (M^+, 39%), 159 (16) and 127 (8)], was removed by filtration under nitrogen, and then the solvent was evaporated and the residue chromatographed on silica. Elution with 5% dichloromethane in petrol gave yellow crystals found to be a mixture of di-, tri-, and tetra-chlorinated 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (4k) (11 mg); $\nu_{max.}$ (CCl_4) 2928, 2289, 1550, 1496, 1382, 1347, 1250, 1206, 1154, 1106, 1066, 1016 and 904 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 6.4 (m) and 7.26 (m); m/z (190°C) 416 (M^+ tetrachloro, 1%), 382 (M^+ trichloro, 21), 346 (M^+ dichloro, 35), 205 (6), 159 (100), 127 (33) and 46 (97).

Reaction of 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) with sulphur dichloride

To a stirred solution of 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) (5 mg, 0.02 mmol) in dry dichloromethane (10 ml) at room temperature under nitrogen, was added a solution of sulphur dichloride (6 mg, 4µl, 0.06 mmol) in dry dichloromethane (1 ml). The mixture was stirred at room temperature for 15 h, the solvent evaporated, and the residue chromatographed on silica. Elution with 10% dichloromethane in petrol gave 3,7-di(2-furyl)-1,5,2,4,6,8-dithiatetrazocine (41) (3 mg, 60%).

3,7-Di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m)

(i) From the reaction of 2-thienylamidine (110) and sulphur dichloride

To a stirred slurry of 2-thienylamidinium chloride [83] (1.63 g, 10 mmol) and DBU (4.6 g, 4.5 ml, 30 mmol) in dry dichloromethane (40

ml) at 0°C under nitrogen, was added dropwise over 30 min a solution of sulphur dichloride (1.5 g, 0.95 ml, 15 mmol) in dry dichloromethane (20 ml). After 2 h, the cooling bath was removed and the reaction mixture was stirred at room temperature for 5 h. A flocculent red precipitate (later indentified as 4-(2-thienyl)-1,2,3,5-dithiadiazolium -chloride (38e) and described on page 185) was removed by filtration under nitrogen, and then the solvent was evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) (113 mg, 7.3%) as orange-yellow plates (ethyl acetate), m.p. 271-273°C (Found: M^+, 309.9475. $C_{10}H_6N_4S_4$ requires 309.9475); $\lambda_{max.}$ (EtOH) 204 (ε, 7400), 271 (7200), 318 (12900), 351 (6600), and 447 nm (1100); $\nu_{max.}$ (CCl_4) 2927, 2854, 1532, 1509, 1427, 1377, and 1036 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 7.23 (1 H, dd, J 4 and 5 Hz), 7.64 (1 H, dd, J 1 and 5 Hz), and 8.3 (1 H, dd, J 1 and 4 Hz); m/z (200°C) 310 (M^+, 57%), 201 (M^+-C_5H_3NS, 6), 187 ($C_5H_3N_2S_3^+$, 3), 141 ($C_5H_3NS_2^+$, 100), 109 (C_5H_3NS, 36), 78 (NS_2, 7), and 46 (NS, 86).

When the above reaction was repeated with stirring of the reaction mixture at room temperature for 15 h, 4-(2-thienyl)-1,2,3,5-dithiadiazolium chloride (38e) (30%), a mixture of mono-, di-, and tri-chlorinated 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocines (4n) [m/z (200°C) 414 (M^+ trichloro, 3%), 378 (M^+ dichloro, 29), 344 (M^+ monochloro, 100), 175 (60), 141 (89), 109 (50) and 46 (91)] and 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) (2.9%) were obtained.

(ii) From the reaction of 2-thienylamidine (110) and S_4N_4

S_4N_4 (368 mg, 2 mmol) and 2-thienylamidine (110) (504 mg, 4 mmol) (m.p. 61-63°C, generated from the hydrochloride as described for furylamidine) were heated at reflux in dry xylene (40 ml) under nitrogen for 5 h. The solvent was evaporated and the residue chromatographed on silica. Elution with petrol gave sulphur and with 50% dichloromethane in petrol 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) (22 mg, 3.5%) was obtained, followed by 2,4,6-tris(2-thienyl)-1,3,5-triazine (111) (48 mg, 11%) as a colourless compound, m.p. 196-198°C (lit. ,[82] 192-194°C) (Found: M^+, 326.9941. $C_{15}H_9N_3S_3$ requires 326.9959); $\nu_{max.}$ (CCl_4) 2927, 1532, 1509, 1427, 1378, 1334, 1222, and 1036 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 7.2 (1 H, dd, J 5.25 and 3.5 Hz), 7.6 (1 H, dd, J 5.25 and 1 Hz), and 8.26 (1 H, dd, J 3.5 and 1 Hz); m/z (160°C) 327 (M^+, 97%) and 109 (C_5H_3NS, 100).

(iii) From the reaction of 2-thienylamidine (110) and bis(tosyl)sulphurdiimide (11b)

To a stirred slurry of 2-thienylamidinium chloride (1.8 g, 11 mmol) and DBU (1.7 g, 1.6 ml, 11 mmol) in dry dichloromethane (30 ml) at room temperature under nitrogen, was added dropwise over 30 min a solution of bis(tosyl)sulphurdiimide (11b) (5.55 g, 15 mmol) in dry dichloromethane (20 ml). The orange-red reaction mixture was stirred at room temperature for 5 h, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave 3,7-di(2-thienyl)-1,5,2,4,6,8-dithiatetrazocine (4m) (20 mg, 1.7%).

4-(2-Thienyl)-1,2,3,5-dithiadiazolium chloride (38e)

The title compound was obtained as a flocculent red precipitate from the reaction of 2-thienylamidinium chloride (38e) and sulphur dichloride (see page 183). The precipitate was collected by filtration under nitrogen and washed with dry dichloromethane to give pure 4-(2-thienyl)-1,2,3,5-dithiadiazolium chloride (38e) (1.53 g, 69%) as a fine red powder, m.p. 162-164°C (Found: M^+, 186.9461. $C_5H_3{}^{35}ClN_2S_3$ requires 186.9458); m/z (150°C) 187 (M^+, 100%), 141 (M^+-NS, 55), 109 (C_5H_3NS, 41), 78 (NS_2, 98), and 46 (NS, 12).

3-(Dimethylamino)-7-phenyl-1,5,2,4,6,8-dithiatetrazocine (4o)

To a stirred mixture of benzamidine (1.2 g, 10 mmol), N,N-dimethylguanidine sulphate (1.36 g, 5 mmol) and DBU (7.6 g, 7.5 ml, 50 mmol) in dry dichloromethane (30 ml) at 0°C under nitrogen, was added a solution of sulphur dichloride (3.1 g, 1.9 ml, 30 mmol) in dry dichloromethane (20 ml) dropwise over 10 min. After 1 h the cooling bath was removed and the dark reaction mixture was stirred at room temperature for 3 h, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with petrol gave sulphur and with 10% dichloromethane in petrol, 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) (141 mg, 9.5%) was obtained. Elution with dichloromethane gave 3-(dimethylamino)-7-phenyl-1,5,2,4,6,8-dithiatetrazocine (4o) (80 mg, 3%) as a pale yellow crystalline compound, m.p. 182-183°C (Found: C, 45.4; H, 4.4; N, 26.3, and M^+, 265.0452. $C_{10}H_{11}N_5S_2$ requires C, 45.3; H, 4.2; N, 26.4% and M 265.0456); $\lambda_{max.}$ (EtOH) 250 nm (ε, 9400); $\nu_{max.}$ (CCl_4) 2927, 1561, 1456, 1411, 1372, 1357, 1243, 1175, 1146, 1086, and 1027

cm^{-1}; δ_H (250 MHz, $CDCl_3$) 3.21 (6 H, s), 7.35-7.5 (3 H, m), and 8.17 (2 H, dd, J 1.5 and 8.5 Hz); m/z (160°C) 265 (M^+, 100%), 181 (M^+-$C_3H_6N_3$, 20), 162 (M^+-PhCN, 28), 135 ($PhCNS^+$, 11), 116 (M^+-PhCN-NS, 25), 103 (PhCN, 14), 102 (22), 78 (NS_2, 21), 69 (23), and 46 (NS, 80). Elution with 5% ether in dichloromethane gave 3,7-bis(N,N-dimethylamino)-1,5,2,4,6,8-dithiatetrazocine (4c) (59 mg, 5%).

Treatment of 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a)

(i) With hydrazine

To a solution of 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) (42 mg, 0.14 mmol) in dry dichloromethane (15 ml) was added a solution of anhydrous hydrazine[84] (14 mg, 0.42 mmol) in dry dichloromethane (2 ml) while the reaction mixture was stirred under nitrogen at room temperature. After 1 h, 5% palladium on charcoal (49 mg) was added and the reaction mixture was stirred at room temperature for 3 h, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with petrol gave sulphur (6 mg, 65%) and with methanol, benzamidine (25 mg, 75%) was obtained.

(ii) With ozone

Ozone was passed through a stirred slurry of 3,7-diphenyl-1,5,2,4,6,8-dithiatetrazocine (4a) (55 mg, 0.2 mmol) in dry dichloromethane (15 ml) at -78°C for 30 min. On warming to room temperature, the orange-yellow reaction mixture turned pale yellow and was further stirred at room temperature for 15 h, the solvent evaporated and the residue chromatographed on silica. Elution with ether gave 1-hydroxy3,5-diphenyl-1,2,4,6-thiatriazine (80) (16 mg,

32%) (spectral data identical with the earlier sample) and with ethyl acetate, 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84) (1.6 mg, 3%) (spectral data identical with the earlier sample) was obtained.

The above reaction was repeated with the ozone being passed through for 1 h at -70°C; hydroxythiatriazine (80) (38%) and thiatriazin-1,1-dioxide (84) (5%) were obtained.

1-Ethoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129b)

Solutions of benzamidine (966 mg, 8 mmol) and bis(tosyl)sulphurdiimide (11b) (3 g, 8 mmol) in dry chloroform (50 ml) were added synchronously over 30 min to vigorously stirred dry chloroform (50 ml) at reflux under nitrogen. After the addition was complete the reaction mixture was stirred at reflux temperature for further 4 h and then at room temperature for 15 h. The solvent was removed *in vacuo* and the residue was chromatographed on silica. Elution with 50% dichloromethane in petrol gave colourless prisms (hexane), which were assigned the structure of 1-ethoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129b) (671 mg, 56%), m.p. 94-95°C (Found: C, 64.9; H, 5.0; N, 14.15; S, 10.9. $C_{16}H_{15}N_3OS$ requires C, 64.6; H, 5.0; N, 14.1; S, 10.8%); $\nu_{max.}$ (Nujol mull) 1580, 1560, 1498, 1450, 1400, 1350, 1290, 1080, 1020, 1000, 975, 935, 870, 818, 802, 735, 695, 685, and 620 cm^{-1}; δ_H (90 MHz, $CDCl_3$) 1.18 (3 H, t, *J* 7 Hz), 3.67 (2 H, q, *J* 7 Hz), 7.35-7.50 (6 H, m), and 8.35-8.50 (4 H, m); δ_C (62.9 MHz, $CDCl_3$) 15.34 (q), 60.99 (t), 128.17 (d), 128.61 (d), 132.37 (d), 136.69 (s), and 167.95 (s); *m/z* (120°C) 297 (M^+, 3%), 252 (M^+-OCH_2CH_3, 73), 149 ($PhCN_2S^+$, 28), 103 (PhCN, 32), 76

(15), and 46 (NS, 100).

2-(m-Chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152)

A mixture of m-chlorobenzoyl chloride (2.54 g, 14.5 mmol), benzonitrile (3.7 g, 36.2 mmol), ammonium chloride (3.21 g, 59.5 mmol) and aluminium trichloride (2.8 g, 20.9 mmol) was heated at 150°C for 16 h, cooled and then treated with ice and concentrated hydrochloric acid. The colourless precipitate was filtered, washed well with methanol, and the solution of this precipitate in tetrachloromethane was passed through a short column of alumina (neutral) to remove polar contaminants. Evaporation of the solvent gave crude triazine (152) and crystallisation from toluene gave colourless needles of 2-(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) (2.75 g, 55%), m.p. 198-199°C (Found: C, 73.8; H, 4.1; Cl, 9.75; N, 12.2. $C_{21}H_{14}ClN_3$ requires C, 73.4; H, 4.1; Cl, 10.3; N, 12.2%); $\nu_{max.}$ ($CHCl_3$) 1590, 1515, 1450, and 1370 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 7.55-7.65 (8 H, m), and 8.60-8.80 (6 H, m); δ_C (62.9 MHz, $CDCl_3$) 127.02, 128.55, 128.94, 129.02, 129.72, 132.22, 132.49, 134.87, 136.08, 138.28, 170.45, and 171.78; m/z (220°C) 343 (M^+, 65%), 137 (M^+-2PhCN, 50), 103 (PhCN, 100), and 76 (18).

Reactions of 1-ethoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129b)

(i) With methanol

Ethoxythiatriazine (129b) (64.5 mg, 0.22 mmol) was heated in methanol (25 ml) under nitrogen at reflux for 25 h. The reaction was followed by proton n.m.r spectroscopy. The solvent was removed in

vacuo and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave methoxythiatriazine (129a) (41 mg, 67%) and with ether, hydroxythiatriazine (80) (17 mg, 29%) was obtained.

Similar treatment of methoxythiatriazine (129a) (32 mg, 0.11 mmol) in dry ethanol (15 ml) at reflux for 22 h gave ethoxythiatriazine (129b) (25 mg, 74%) and hydroxythiatriazine (80) (6 mg, 21%).

(ii) With tosyl azide

A mixture of ethoxy compound (129b) (18 mg, 0.06 mmol) and tosyl azide (24 mg, 0.12 mmol) was heated in refluxing dry toluene (20 ml) for 23 h, the solvent evaporated, and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave 2,4,6-triphenyl-1,3,5-triazine (73) (2.3 mg, 8%) and unreacted ethoxythiatriazine (129b) (5 mg, 28%).

(iii) With tosyl amide

A mixture of ethoxy compound (129b) (17 mg, 0.057 mmol) and tosyl amide (19.5 mg, 0.11 mmol) was heated in refluxing toluene (20 ml) for 24 h. The solvent was removed in vacuo and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave 2,4,6-triphenyl-1,3,5-triazine (73) (1.3 mg, 5%) followed by unreacted ethoxythiatriazine (129b) (10 mg, 59%).

(iv) On thermolysis

Compound (129b) (5 mg, 0.02 mmol) was heated in refluxing xylene (10 ml) for 2.5 h. T.l.c. analysis showed that all of the starting material had decomposed. The solvent was removed in vacuo and the residue chromatographed on silica. Elution with 20% dichloromethane

in petrol gave 2,4,6-triphenyl-1,3,5-triazine (73) (1 mg, 11%).

(v) With sodium borohydride

To a stirred slurry of compound (129b) (48 mg, 0.162 mmol) in methanol (20 ml) was added in portions, sodium borohydride (62 mg, 1.6 mmol) at room temperature. After the addition was complete, the pale red reaction mixture was stirred at room temperature for a further 5 h, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave unreacted ethoxythiatriazine (129b) (8 mg, 17%) followed by 3,5-diphenyl-1,2,4,6-thiatriazine (150) (3.3 mg, 10%) as a red crystalline compound, m.p. 132-133°C (lit.,[63] 134-135°C); m/z (170°C) 253 (M^+, 51%), 252 (M^+-H, 84), 221 (M^+-S, 56), 149 ($PhCN_2S^+$, 72), 118 ($PhCN_2H^+$, 37), 104 ($PhCNH^+$, 100), 91 (41), 77 (Ph^+, 61), and 46 (NS, 62).

(vi) With MCPBA

Typical procedure : To a stirred solution of compound (129b) (74 mg, 0.25 mmol) in dry dichloromethane (5 ml) at room temperature under nitrogen, was added a solution of MCPBA (washed with phosphate buffer pH 7.5) (90 mg, 0.5 mmol) in dry dichloromethane (2 ml) over 5 min. The reaction mixture was stirred at room temperature for 24 h, the solvent removed in vacuo, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave 2-(m-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) (11.5 mg, 9%) and with ethyl acetate, 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84) (53 mg, 74%) was obtained (For further results, see Table 3.5, Section 3.2.1.2).

(vii) With dinitrogen tetraoxide

To a stirred solution of compound (129b) (59 mg, 0.2 mmol) in dry dichloromethane (15 ml) at 0°C under nitrogen, was added over 5 min a solution of N_2O_4 (37 mg, 0.4 mmol) in dry tetrachloromethane (1 ml). After 30 min a colourless precipitate was formed and the reaction mixture was warmed to room temperature and stirred for 1 h. The solvent was removed in vacuo and the residue recrystallised from ethanol to give pure 3,5-diphenyl-1,2,4,6-thiatriazin-1,1-dioxide (84) (53 mg, 93%).

(viii) With m-chlorobenzoic acid

A mixture of compound (129b) (10 mg, 0.034 mmol) and m-chloro benzoic acid (12 mg, 0.068 mmol) in dry dichloromethane (10 ml) was stirred at room temperature under nitrogen for 24 h. T.l.c. analysis showed that no reaction had occurred. The solvent was evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave recovered ethoxythiatriazine (129b) (9 mg, 90%).

Similar treatment of hydroxythiatriazine (80) with m-chlorobenzoic acid resulted again in no reaction and recovery of compound (80) (85%).

Treatment of 1-methoxy-3,5-diphenyl-1,2,4,6-thiatriazine (129a) with chloramine-T

A mixture of methoxy compound (129a) (71 mg, 0.25 mmol) and chloramine-T (73 mg, 0.26 mmol) was stirred in methanol (25 ml) at room temperature under nitrogen for 14 h. There was no sign of

reaction and so the mixture was refluxed for 8 h. The solvent was removed *in vacuo* and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave unreacted methoxythiatriazine (129a) (67 mg, 92%).

Reactions of 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine (80)

(i) With MCPBA

To a stirred slurry of compound (80) (30 mg, 0.13 mmol) in dry dichloromethane (10 ml) at room temperature under nitrogen, was added a solution of MCPBA (22 mg, 0.13 mmol) in dry dichloromethane (2 ml) over 5 min. The reaction mixture was further stirred at room temperature for 2 h, the solvent removed *in vacuo*, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave 2(*m*-chlorophenyl)-4,6-diphenyl-1,3,5-triazine (152) (9 mg, 13%) and with ethyl acetate, thiatriazin-1,1-dioxide (84) (18 mg, 48%) was obtained.

(ii) With dinitrogen tetraoxide

To a stirred solution of compound (80) (54 mg, 0.2 mmol) in dry dichloromethane (15 ml) at 0°C under nitrogen, was added a solution of N_2O_4 (18 mg, 0.2 mmol) in dry tetrachloromethane (0.5 ml). After 30 min the reaction mixture was warmed to room temperature and stirred for 1h, the solvent evaporated, and the residue crystallised from ethanol to give pure thiatriazin-1,1-dioxide (84) (55 mg, 97%).

(iii) With diazomethane

To a stirred slurry of compound (80) (50.5 mg, 0.19 mmol) in dry ether (20 ml) at room temperature under nitrogen, was added a solution of diazomethane (17 mg, 0.4 mmol) in ether (3 ml). The reaction mixture became clear and was further stirred at room temperature for 2 h, the solvent evaporated, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave methoxythiatriazine (129a) (48 mg, 91%).

(iv) With m-chlorobenzoyl chloride

To a stirred solution of compound (80) (140 mg, 0.5 mmol) and triethylamine (52 mg, 0.5 mmol) in dry dichloromethane (20 ml) at room temperature under nitrogen, was added over 5 min a solution of m-chlorobenzoyl chloride (91 mg, 0.5 mmol) in dry dichloromethane (10 ml). The reaction mixture was stirred at room temperature for further 10 h, the solvent removed in vacuo, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave triazine (152) (9 mg, 6%) and with ether, unreacted compound (80) (27 mg, 19%) was obtained.

(v) With peracetic acid

To a stirred slurry of compound (80) (60 mg, 0.22 mmol) in dry dichloromethane (20 ml) at room temperature under nitrogen was added a 40% solution of peracetic acid in acetic acid (0.7 g, 4.4 mmol). The reaction mixture was further stirred at room temperature for 18 h, the solvent removed in vacuo, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave 2-methyl-4,6-diphenyl-1,3,5-triazine as a colourless compound, m.p. 107-108°C

(lit.,[85] 110°C), (Found : C, 77.4; H, 5.2; N, 17.0; $\underline{M}^+$, 247.1115. Calc. for $C_{16}H_{13}N_3$ C, 77.7; H, 5.3; N, 17.0%; $\underline{M}$, 247.1109); $\nu_{max.}$ (CCl_4) 3070, 1603, 1588, 1530, 1449, 1383, 1367, 1307, 1232, 1179, 1070, 1028, and 990 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 2.78 (3 H, s), 7.49-7.61 (6 H, m), and 8.61-8.65 (4 H, dd, $\underline{J}$ 2 and 8 Hz); $\underline{m/z}$ (140°C) 247 ($\underline{M}^+$, 15%), 244 ($\underline{M}^+$-3H, 6), 206 ($\underline{M}^+$-CH_3CN, 5), 103 (PhCN, 39), and 41 (CH_3CN12). Elution with ethyl acetate gave thiatriazin-1,1-dioxide (84) (29 mg, 47%).

Reactions of disodium dimercaptomaleonitrile

(i) With N,N'-dibromo-S,S-dimethyl-sulphurdiimide (160b)

(i) To a stirred suspension of disodium dimercaptomaleonitrile (161)[86] (925 mg, 5 mmol) in dry acetonitrile (60 ml) at room temperature under nitrogen, was added dropwise over 1 h a solution of N,N'-dibromo-S,S-dimethyl-sulphurdiimide (160b)[87] (1.25 g, 5 mmol) in dry acetonitrile (60 ml). After the addition was complete the dark brown reaction mixture was further stirred at room temperature for 18 h, filtered, the solvent removed in vacuo, and the residue chromatographed on silica. Elution with petrol gave sulphur and with 20% dichloromethane in petrol, S_4N_4 (12 mg, 5%) was obtained. Elution with 50% dichloromethane in petrol gave 3,4-dicyano-1,2,5-thiadiazole (165) (175 mg, 26%), m.p. 47-48°C (lit.,[88] 49.5-50.5°C) (identified by direct comparison, mixed m.p. 49-50°C); $\nu_{max.}$ (CCl_4) 2240, 1390, 1280, 1130, and 840 cm^{-1}; $\underline{m/z}$ (170°C) 136 ($\underline{M}^+$, 100%), 90 ($\underline{M}^+$-NS, 28), 84 ($\underline{M}^+$-2CN, 59), 76 ($\underline{M}^+$-N_2S, 4), 64 (10), 46 (27), 32 (23), and 28 (16).

(ii) The above reaction was repeated in presence of potassium iodide (1 eq) and after a similar work-up procedure, sulphur, S_4N_4 (35%), and thiadiazole (165) (46%) were obtained. In the presence of TDA-1 (4 drops), only sulphur and thiadiazole (165) (27%) were obtained.

(iii) Solutions of disodium dimercaptomaleonitrile (161) (186 mg, 1 mmol) and dibromosulphurdiimide (160b) (250 mg, 1 mmol) in dry methanol (50 ml) were added synchronously over 30 min to a flask containing dry methanol (50 ml), while the reaction mixture was stirred under nitrogen at room temperature. The dark red-brown mixture was stirred for a further 24 h at room temperature, the solvent removed in vacuo, and the residue chromatographed as described above to give sulphur and thiadiazole (165) (15 mg, 11%).

(ii) With N-chlorodiphenylsulphilimine (201b)

To a stirred suspension of disodium dimercaptomaleonitrile (161) (205 mg, 1.1 mmol) in dry acetonitrile (20 ml) in the presence of TDA-1 (3 drops) at room temperature under nitrogen, was added dropwise over 10 min a solution of N-chlorodiphenylsulphilimine (201b)[89] (500 mg, 2.1 mmol) in dry acetonitrile (20 ml). The very dark reaction mixture was stirred at room temperature for 10 h, filtered, the solvent was removed in vacuo, and the residue chromatographed on silica. Elution with petrol gave sulphur and diphenyl sulphide (299 mg, 76%) and with 50% dichloromethane in petrol, thiadiazole (165) (26 mg, 17%) was obtained.

3,4-Dicyano-1,2,5-thiadiazole (165)

To a stirred slurry of 1,2-diaminomaleonitrile (600 mg, 5.6 mmol) in dry chloroform (20 ml) at room temperature under nitrogen, was added dropwise over 20 min a solution of bis(tosyl)sulphurdiimide (11b) (2.1 g, 5.6 mmol) in dry chloroform (20 ml). The reaction mixture was stirred for a further 6 h at room temperature, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave the title compound (660 mg, 86%), m.p. 47-48°C (identical with the earlier sample).

Quinoxalino-1,3,2-dithiazol-2-yl (182)

To a stirred slurry of quinoxaline-2,3-dithiol (174)[90] (270 mg, 1.4 mmol) and dry triethylamine (283 mg, 0.4 ml, 2.8 mmol) in dry dichloromethane (50 ml) at room temperature under nitrogen, was added dropwise over 30 min a solution of dibromosulphurdiimide (160b) (345 mg, 1.4 mmol) in dry dichloromethane (50 ml). The resulting dark blue-green reaction mixture was stirred at room temperature for 20 h, the solvent removed *in vacuo*, and the residue chromatographed on alumina (neutral). Elution with 50% dichloromethane in petrol gave a dark green lustrous crystalline compound tentatively assigned the structure of quinoxalino-1,3,2-dithiazol-2-yl (182) (84 mg, 29%), m.p. 139-141°C (Found: C, 46.7; H, 1.9; N, 20.2, and M^+, 205.9847. $C_8H_4N_3S_2$ requires C, 46.6; H, 1.95; N, 20.4%, and M, 205.9847.); $\nu_{max.}$ ($CHCl_3$) 1550, 1160, 1105, and 950 cm^{-1}; ESR (hexane), 3368.15, 3378.82, and 3389.35 Gauss, g = 2.0067; m/z (100°C) 206 (M^+, 100%), 160 (M^+-NS, 46), 134 (M^+-NS-CN, 5), 102 ($C_7H_4N^+$, 21), 78 (NS_2, 6), 64 (S_2, 4), 46 (NS, 9), and 28 (5).

The above reaction was repeated in dry acetonitrile instead of dichloromethane, and quinoxalino-1,3,2-dithiazol-2-yl (182) (15%) was obtained upon similar work-up.

Reactions of disodium 2,3-dimercaptoquinoxaline (175)

(i) With N,N'-dibromo-S,S-dimethylsulphurdiimide (160b)

To a stirred suspension of disodium 2,3-dimercaptoquinoxaline (175)[91] (530 mg, 2.2 mmol) in dry acetonitrile (40 ml) at room temperature under nitrogen, was added dropwise over 30 min a solution of dibromosulphurdiimide (160b) (558 mg, 2.2 mmol) in dry acetonitrile (40 ml). The dark blue-green reaction mixture was stirred at room temperature for 30 h, filtered, the solvent evaporated, and the residue chromatographed on silica. Elution with 25% dichloromethane in petrol gave a yellow crystalline compound which was assigned the structure of 2-methylthio-3-methyldithioquinoxaline (180) (6 mg, 1%), m.p. 191-192°C (Found: $\underline{M}^+$, 254.0001. $C_{10}H_{10}N_2S_3$ requires 254.0006.); $\nu_{max.}$ ($CHCl_3$) 2920, 1550, 1160, 1100, 1000, and 950 cm^{-1}; δ_H (250 MHz, $CDCl_3$) 2.62 (3 H, s), 2.73 (3 H, s), 7.55-7.68 (2 H, m), 7.90-7.97 (1 H, m), and 8.00-8.08 (1 H, m); m/z (100°C) 254 ($\underline{M}^+$, 41%), 208 ($\underline{M}^+$-SCH_2^+, 100), 207 ($\underline{M}^+$-SCH_3, 30), 192 ($C_8H_4N_2S_2$, 32), 175 ($\underline{M}^+$-$SSCH_3$, 21), 160 ($C_8H_4N_2S$, 24), 144 (16), 134 (10), 129 (12), 102 ($C_7H_4N^+$, 15), 79 ($SSCH_3^+$, 10), 64 (S_2, 11), and 47 (SCH_3^+, 6). Elution with 50% dichloromethane in petrol gave yellow needles which were assigned the structure of 2,3-bis(methyldithio)quinoxaline (181) (3 mg, 0.5%), m.p. 115-116°C (Found: $\underline{M}^+$, 285.9724. $C_{10}H_{10}N_2S_4$ requires 285.9727.); $\nu_{max.}$ ($CHCl_3$) 2920, 1160, 1120, 1100, 1000, and 950 cm^{-1}

; δ_H (250 MHz, $CDCl_3$) 2.6 (6 H, s), 7.6-7.7 (2 H, m, BB' protons), and 8.0-8.1 (2 H, m, AA' protons); m/z (100°C) 286 (M^+, 54%), 254 (M^+-S, 4), 240 (M^+-SCH_2^+, 74), 239 (M^+-SCH_3, 42), 207 (M^+-$SSCH_3$, 15), 192 ($C_8H_4N_2S_2$, 94), 160 ($C_8H_4N_2S$, 28), 134 (C_7H_4NS, 16), 102 ($C_7H_4N^+$, 25), 79 ($SSCH_3^+$, 36), 64 (S_2, 32), and 47 (SCH_3^+, 14) followed by quinoxalino-1,3,2-dithiazol-2-yl (182) (10 mg, 2.2%) as a dark green lustrous crystalline compound (identical spectral data with the earlier sample).

(ii) With N-bromodiphenylsulphilimine (201a)

A solution of N-bromodiphenylsulphilimine (201a)[89] (540 mg, 1.9 mmol) in dry dichloromethane (50 ml) was added dropwise over 1 h, to a stirred suspension of disodium 2,3-dimercaptoquinoxaline (175) (460 mg, 1.9 mmol) and TDA-1 (3 drops) in dry dichloromethane (50 ml) at room temperature under nitrogen. The resulting dark green reaction mixture was further stirred at room temperature for 24 h, the solvent removed in vacuo, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave diphenylsulphide (175 mg, 49%) and quinoxalino-1,3,2-dithiazol-2-yl (182) (20 mg, 5%). Elution with dichloromethane gave a pale yellow crystalline compound which was assigned the structure of quinoxalino-1,3-dithiole (206) (224 mg, 56%), m.p. 160-161°C (Lit.,[92] m.p. 163°C) (Found: C, 52.5; H, 2.8; N, 13.6; S, 31.7. Calc. for $C_9H_6N_2S_2$ C, 52.4; H, 2.9; N, 13.6; S, 31.1%); $\nu_{max.}$ (Nujol mull) 1560, 1260, 1180, 1110, 1010, 760, and 660 cm^{-1}; δ_H (90 MHz, $CDCl_3$) 4.6 (2 H, s), and 7.4-7.75 (4 H, m); m/z (160°C) 206 (M^+, 100%), 160 (M^+-SCH_2^+, 53), 134 (C_7H_4NS, 5), 102 ($C_7H_4N^+$, 33),

90 (4), and 75 (15).

Reaction of 3,4-dimercaptotoluene (187) with N,N'-dibromo-S,S-dimethylsulphurdiimide (160b)

A solution of dibromosulphurdiimide (160b) (250 mg, 1 mmol) in dry dichloromethane (50 ml) was added dropwise over 20 min, to a stirred solution of 3,4-dimercaptotoluene (187) (156 mg, 1 mmol) in dry dichloromethane at room temperature under nitrogen. The red reaction mixture was stirred for a further 14 h at room temperature and then the red precipitate was filtered off, washed with dry dichloromethane, the combined dichloromethane solutions were evaporated, and the residue chromatographed on silica. Elution with 20% dichloromethane in petrol gave dimethyldibenzo-1,2,5,6-tetrathiaocin (188) (33 mg, 21%) as pale yellow crystalline compound, m.p. 180-182°C (Lit.,[93] m.p. 192-193°C); $\nu_{max.}$ (Nujol mull) 1580, 1250, 1030, 890, 810, and 660 cm^{-1}; δ_H (90 MHz, d_6 acetone) 2.4-2.5 (3 H, m), and 7.0-7.8 (3 H, m); m/z (180°C) 308 (M^+, 75%), 244 (M^+-S_2, 30), 154 ($C_7H_6S_2$, 100), and 121 (C_7H_5S, 13). The red precipitate was assigned the structure of 5-methylbenzo-1,3,2-dithiazolium bromide (189) (175 mg, 70%), m.p. 134-136°C with decomposition (identical spectral data with an authentic sample[3b]); $\lambda_{max.}$ (KBr) 1650, 1640, 1550, 1534, 1528, 1450, 820, 750, 542, and 442 cm^{-1}; δ_H (250 MHz, D_2O) 2.9 (3 H, s), 8.25 (1 H, d), 9.05 (1 H, s), and 9.16 (1 H, d); m/z 168 (M^+, 100%), 121 (M^+-HNS, 2), 95 (25), and 80 (28).

Reactions of benzene-1,2-bis(sulphenyl chloride) (28)

(i) With N,N'-bis(trimethylsilyl)-S,S-dimethylsulphurdiimide (160a)

Benzene-1,2-bis(sulphenyl chloride) (28) was prepared by the literature[94] method as follows. Benzene-1,2-dithiol (245 mg, 1.725 mmol) was dissolved in dry tetrachloromethane (20 ml) and dry chlorine gas was bubbled through the solution at 0°C for about 10 min until the initial white precipitate had redissolved and an orange homogeneous solution was obtained. The passage of chlorine gas was stopped, the cooling bath removed and nitrogen was bubbled through the solution as it warmed to room temperature. The solvent was removed *in vacuo* and the crude product was dissolved in dry dichloromethane (50 ml).

N,N'-Bis(trimethylsilyl)-S,S-dimethylsulphurdiimide (160a)[95] (407 mg, 1.725 mmol) was dissolved in dry dichloromethane (50 ml). The two dichloromethane solutions thus prepared were added synchronously over 2 h via dropping funnels to a flask containing dry dichloromethane (100 ml), with vigorous stirring under nitrogen at room temperature. When the addition was complete the reaction mixture was stirred at room temperature for a further 2 days to ensure complete reaction. The yellow flocculent precipitate was removed by filtration and washed with dry dichloromethane to give pure 1,3,2-benzodithiazolium chloride (195) (280 mg, 86%), m.p. 215-217°C (identical spectral data with an authentic sample[17]); $\lambda_{max.}$ (EtOH) 217 (log ε 3.47), 248 (3.79), 332 (3.23) and 396 nm (3.02); $\nu_{max.}$ (KBr) 1520, 1400 br, 1322, 756 s, 744, 729 s, 489, 448 s, 396, and 315 cm^{-1}; δ_H (90 MHz, D_2O) 8.18 (2 H, m, BB' protons), and 9.11

(2 H, m, AA' protons); m/z (FAB) 154 (M^+).

(ii) With N,N,N'-tris(trimethylsilyl)-S-iminobenzsulphenamide (198)

Solutions of benzene-1,2-bis(sulphenyl chloride) (28) (760 mg, 3.6 mmol) and N,N,N'-tris(trimethylsilyl)-S-iminobenzsulphenamide (198)[96] (1.09 g, 3.85 mmol) in dry dichloromethane (30 ml) were added synchronously over 1 h under nitrogen at room temperature, to stirred dry dichloromethane (250 ml). The resulting mixture was stirred at room temperature for a further 15 h, the yellow flocculent precipitate of 1,3,2-benzodithiazolium chloride (195) (515 mg, 91%) was filtered off and washed with dry dichloromethane. The combined dichloromethane solutions were evaporated in vacuo and the residue chromatographed on silica. Elution with petrol gave diphenyldisulphide (156 mg, 17%).

Reaction of 2-(chlorosulphenyl)benzoyl chloride (217) with N,N'-bis(trimethylsilyl)sulphurdiimide (11a)

2-(Chlorosulphenyl)benzoyl chloride (217) was prepared by the literature method[70] as follows. To 2,2'-dithiosalicylic acid (7 g, 22.8 mmol) in dry 1,2-dichloroethane (55 ml) containing DMF (4 drops) at reflux, was added thionyl chloride (7 ml, 11.4 g, 96 mmol) in dry 1,2-dichloroethane (15 ml) dropwise over a period of 1 h under nitrogen. The reaction mixture was then cooled to -10°C and dry chlorine gas was bubbled in for 20 min. The excess of chlorine gas was flushed out with nitrogen and then the solvent evaporated to give 2-(chlorosulphenyl)benzoyl chloride (217) (9.4 g, 100%) as a pale yellow crystalline compound, m.p. 65-66°C (lit. ,[70] m.p. 66-

68°C).

(a) At room temperature : 2-(Chlorosulphenyl)benzoyl chloride (217) (2 g, 10 mmol) was dissolved in dry dichloromethane (100 ml) and similarly bis(trimethylsilyl)sulphurdiimide (11a) (2 g, 2.4 ml, 10 mmol) was dissolved in dry dichloromethane (100 ml). The two dichloromethane solutions thus prepared were transferred to dropping funnels under nitrogen and then added synchronously over 4 h to a flask containing dry dichloromethane (200 ml), which was vigorously stirred under nitrogen at room temperature. When the addition was complete the dark red reaction mixture was stirred further for 48 h to ensure complete reaction. The solvent was then evaporated and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave S_4N_4 (120 mg, 26%) as an orange crystalline compound (spectral data identical with an authentic sample), and with 50% ethyl acetate in dichloromethane, a colourless compound was obtained which was assigned the structure of 1,2-benzisothiazolin-3(2H)-one (218) (1.012 g, 67%), m.p. 154-156°C (lit. ,[97] 157-158°C) (Found: C, 55.4; and H, 3.3. Calc. for C_7H_5NOS C, 55.6; H, 3.3%); $\nu_{max.}$ (Nujol mull) 2690, 1640, 1590, 1465, 1325, 1315, 1150, 745, and 610 cm^{-1}; δ_H (90 MHz, d_6 DMSO) 7.1-7.9 (m); m/z (160°C) 151 (M^+, 100%), 123 (M^+-CO, 6.5), 122 (5), 108 (M^+-CONH, 5), 96 (30), 91 (2), and 77 (Ph^+, 5).

(b) At 0°C : The solutions of 2-(chlorosulphenyl)benzoyl chloride (217) (1.26 g, 6.1 mmol) and bis(trimethylsilyl)sulphurdiimide (11a) (1.26 g, 6.1 mmol) in dry dichloromethane (50 ml) were prepared, transferred to dropping funnels under nitrogen and then added

synchronously over 3 h to a flask containing dry dichloromethane (100 ml) which was vigorously stirred at 0°C under nitrogen. When the addition was complete the reaction mixture was stirred for further 1 h at 0°C and for 2 h at room temperature. The solvent was evaporated and the residue chromatographed on silica as described above to give S_4N_4 (43 mg, 15%) and benzisothiazolin-3-one (218) (590 mg, 65%).

(c) At -10°C : A solution of bis(trimethylsilyl)sulphurdiimide (11a) (730 mg, 3.5 mmol) in dry dichloromethane (30 ml) was added dropwise over 30 min to a stirred solution of 2-(chlorosulphenyl)benzoyl chloride (217) (730 mg, 3.5 mmol) in dry dichloromethane (30 ml) under nitrogen at -10°C. The resulting dark reaction mixture was stirred at -10°C for 2 h and then at room temperature for 1 h. The solvent was evaporated and the residue chromatographed on silica as described above to give S_4N_4 (13 mg, 8%) and benzisothiazolin-3-one (218) (430 mg, 80%).

(d) At 40°C : A solution of bis(trimethylsilyl)sulphurdiimide (11a) (630 mg, 3.1 mmol) in dry dichloromethane (30 ml) was added dropwise over 30 min to a solution of 2-(chlorosulphenyl) benzoyl chloride (217) (640 mg, 3.1 mmol) in dry dichloromethane (30 ml) at reflux whilst the reaction mixture was stirred under nitrogen. After 3 h, the reaction mixture was cooled to room temperature, the solvent evaporated, and the residue chromatographed on silica as described above to give S_4N_4 (30 mg, 21%) and benzisothiazolin-3-one (218) (318 mg, 68%).

1,2-Benzisothiazolin-3(2H)-one (218)

A solution of 2-(chlorosulphenyl)benzoyl chloride (217) (2 g, 10 mmol) in dichloromethane (20 ml) was added dropwise over 10 min to stirred aqueous ammonia (15 ml, 0.88). During the addition, the aqueous ammonia was cooled in an ice-water bath. After the addition was complete, the reaction mixture was stirred at room temperature for 2 h, filtered and then the precipitate was crystallised from methanol to give colourless prisms of benzisothiazolin-3-one (218) (1.34 g, 89%), m.p. 155-156°C (identical spectral data with the samples described above).

Reaction of 1,4-dichloro-1,4-diphenyl-2,3-diazabut-1,3-diene (225) with bis(trimethylsilyl)sulphurdiimide (11a).

To a stirred solution of 1,4-dichloro-1,4-diphenyl-2,3-diazabut-1,3-diene (225)[98] (1.1 g, 4 mmol) and sulphurdiimide (11a) (0.912 g, 4.4 mmol) in dry THF (30 ml) was added dropwise over 10 min a solution of tetra-^{t}butylammonium fluoride in dry THF (1 M solution, 9 ml, 9 mmol) at room temperature under nitrogen. The dark reaction mixture (which later becomes yellow) was stirred for further 12 h at room temperature, the solvent evaporated, and the residue chromatographed on silica. Elution with 50% ether in petrol gave a colourless compound which was tentatively assigned the structure of 1-amino-4-fluoro-1,4-diphenyl-2,3-diazabut-1,3-diene (226) (96 mg, 10%), m.p. 96-97·C (Found: M^+, 241.1012. $C_{14}H_{12}FN_3$ requires 241.1015); $\nu_{max.}$ (CCl_4) 3517, 3397, 3064, 2349, 1652, 1614, 1602, 1578, 1539, 1495, 1447, 1392, 1295, 1064, 1027, 979, 923, and 803 cm^{-1}; δ_H (90 MHz, $CDCl_3$) 5.65 (2 H, s, br), 7.35-7.5 (6 H, m), and 7.72-7.95 (4 H, m);

$CDCl_3$) 5.65 (2 H, s, br), 7.35-7.5 (6 H, m), and 7.72-7.95 (4 H, m); m/z (120°C) 241 (M^+, 100%), 222 (M^+-F, 61), 138 (M^+-PhCN, 12), 118 ($PhCN_2H^+$, 33), 104 ($PhCNH^+$, 54), and 77 (Ph^+, 53). Elution with ether gave 2,5-diphenyl-1,3,4-triazole (92) (265 mg, 35%) (identical spectral data with an authentic sample).

Reaction of 1,4-diamino-1,4-diphenyl-2,3-diazabut-1,3-diene (227) with sulphur dichloride or thionyl chloride

Typical procedure: To a stirred solution of 1,4-diamino-1,4-diphenyl-2,3-diazabut-1,3-diene (227)[79] (5.6 g, 23 mmol) and DBU (7.14 g, 7 ml, 47 mmol) in dry THF (150 ml) at 0°C under nitrogen, was added dropwise over 30 min a solution of sulphur dichloride (3.6 g, 2.24 ml, 35 mmol) in dry THF (30 ml). After 3 h the cooling bath was removed and the stirring was continued for 2 h at room temperature, the solvent evaporated, and the residue chromatographed on silica. Elution with petrol gave sulphur and with 50% dichloromethane in petrol, benzonitrile was obtained. Elution with 20% ethyl acetate in dichloromethane gave colourless crystals of 2,5-diphenyl-1,3,4-triazole (92) (1.06 g, 23%), m.p. 194-195°C (identical spectral data with the earlier sample).

The above reaction was repeated at reflux temperature. It was also repeated with thionyl chloride instead of sulphur dichloride both at room and reflux temperatures and the results are summarised in Table 5.4 (Section 5.2).

Reaction of 1,4-dichloro-1,4-diphenyl-2,3-diazabut-1,3-diene (225) with lithium bis(trimethylsilyl)amine

Lithium bis(trimethylsilyl)amine was prepared by the literature method[99] as follows. A solution of n-butyl lithium (1.5 M, 7 ml) in pentane was added slowly to a stirred solution of hexamethyldisilazane (1.8 g, 2.4 ml, 11 mol) in dry ether (20 ml). The reaction mixture was then heated at reflux for 30 min, the solvent removed in vacuo under nitrogen and the residue dissolved in dry THF (30 ml).

The above solution was added dropwise over 20 min to a stirred solution of 1,4-dichloro-1,4-diphenyl-2,3-diazabut-1,3-diene (225) (1.33 g, 4.8 mmol) in dry THF (30 ml) at 0°C under nitrogen. After 1 h the cooling bath was removed and the dark reaction mixture was stirred at room temperature for 2 h and filtered under nitrogen.

To the resulting filtrate was added dropwise over 10 min, a solution of sulphur dichloride (0.64 ml, 10 mmol) in dry THF (10 ml) whilst the reaction mixture was stirred under nitrogen at 0°C. After 1 h, the cooling bath was removed and the dark red-brown reaction mixture was stirred at room temperature for 2 h. The solvent was removed in vacuo and the residue chromatographed on silica as described above to give sulphur, benzonitrile and 2,5-diphenyl-1,3,4-triazole (92) (310 mg, 29%).

Reaction of bis(benzoyl)sulphurdiimide (229) with anhydrous hydrazine

To a stirred solution of bis(benzoyl)sulphurdiimide (229)[75d] (1.09 g, 4 mmol) in dry dichloromethane (20 ml) at 0°C under nitrogen, was

added dropwise over 15 min a solution of anhydrous hydrazine[84] (0.256 g, 8 mmol) in dry dichloromethane (15 ml). The reaction mixture was stirred for further 1 h at 0°C and then at room temperature for 1 h. The solvent was removed *in vacuo* and the residue crystallised from ethyl acetate to give a colourless crystalline compound, assigned the structure of di(benzamido)-sulphide (230) (0.94 g, 86%), m.p. 189-190 °C (lit.,[101] 191°C); $\nu_{max.}$ (Nujol mull) 3260, 1650, 1240, 1090, 860, 820, 725, and 690 cm^{-1}; δ_H (90 MHz, d_6 DMSO) 7.4-7.6 (6 H, m), 8.0 (4 H, m), and 10.81 (2 H, s, br); *m/z* (200°C) 272 (M^+, 1%), 226 (M^+-NS, 2), 167 (M^+-PhCO, 1), 121 ($PhCONH_2$, 55), 105 ($PhCO^+$, 100), and 77 (Ph^+, 77).

The above reaction was performed at room temperature instead of at 0°C and after a similar work-up procedure, di(benzamido) sulphide (230) (65%) was obtained.

7-Methyl-1,3,5,2,4-benzotrithiadiazepane (234)

To a stirred solution of 7-methyl-1,3,5,2,4-benzotrithiadiazepine (233)[17] (68 mg, 0.32 mmol) in dry dichloromethane (20 ml) at room temperature under nitrogen, was added a solution of anhydrous hydrazine (41 mg, 1.28 mmol) in dry dichloromethane (4 ml) over 2 min. After 1 h, 5% palladium on charcoal (41 mg) was added and the reaction mixture was further stirred at room temperature for 4 h, filtered, the solvent removed *in vacuo*, and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave a colourless compound, tentatively assigned the structure of *7-methyl-1,3,5,2,4-trithiadiazepane* (234) (33 mg, 48%),

m.p. 161-162°C with decomposition (Found: C, 38.75; H, 3.6; N, 12.8, and $\underline{M}^+$, 215.9852. $C_7H_8N_2S_3$ requires C, 38.9; H, 3.7; N, 12.95%, and $\underline{M}$, 215.9850); $\nu_{max.}$ ($CHCl_3$) 3330, 1580, and 1130 cm^{-1}; δ_H (250 MHz, d_6 acetone) 2.33 (3 H, s), 6.76 (2 H, s, br), 7.13 (1 H, m), and 7.52 (2 H, m); $\underline{m/z}$ (150°C) 216 ($\underline{M}^+$, 49%), 168 ($\underline{M}^+$-H_2NS, 100), 154 ($C_7H_6S_2$, 90), and 77 (Ph^+, 10).

Reactions of trithiazyl trichloride (35)

Method A : To a stirred solution of substrate (Table 6.1, see below) (1 eq) and dry pyridine (1 eq) in dry tetrachloromethane (20 ml) at reflux under nitrogen, was added a solution of trithiazyl trichloride (35)[36] (0.33 eq) in dry tetrachloromethane (10 ml) over 10 min. After the addition was complete, the reaction mixture was heated at reflux in tetrachloromethane for 2 h, cooled to room temperature and then the solvent was removed *in vacuo* and the residue chromatographed on silica. Elution with 50% dichloromethane in petrol gave S_4N_4 and with ether or ethyl acetate, the substrate was recovered.

Method B : To a stirred solution of substrate (1 eq) and dry pyridine (1 eq) in dry THF (20 ml) at room temperature under nitrogen, was added a solution of trithiazyl trichloride (35) (0.33 eq) in dry THF (10 ml) over 10 min. After the addition was complete, the reaction mixture was stirred at room temperature for further 5 h, the solvent removed *in vacuo*, and the residue chromatographed on silica as described above to give S_4N_4 and recovered substrate.

Substrate	Method	Yield (%) of S_4N_4	Yield (%) of substrate
(101)	A	45	0
(80)	B	9	80
(218)	A	26	95
	B	15	90
(92)	B	12	95

(101) = diethyl 1,2,4,6-thiatriazine-3,5-dicarboxylate

(80) = 1-hydroxy-3,5-diphenyl-1,2,4,6-thiatriazine

(92) = 2,5-diphenyl-1,3,4-triazole

(218) = 1,2-benzisothiazolin-3(2H)-one

Table 6.1

REFERENCES

1 C. Hsu and M.M.Lakes, J. Chem. Phys., 61, 4640, (1974); M.J. Cohen, A.F.Gainto, A.J.Heeger, A.G.MacDiarmid, C.M.Mikulski, M.S.Saran and J.Kleppinger, J. Am. Chem. Soc., 98,3844, (1976).

2 V.V.Walatka, M.M.Labes and J.H.Perlstein, Phys. Rev. Lett., 31, 1139, (1973); R.L.Greene, G.B.Street and L.J.Suter, ibid., 34, 577, (1975).

3 (a) S.T.A.K.Daley, Ph.D. Thesis, University of London, (1982); (b) J.L.Morris, Ph.D. Thesis, University of London, (1985).

4 I.Ernest, W.Holick, G.Rihs, D.Schomburg, G.Shoham, D.Wenkert and R.B.Woodward, J. Am. Chem. Soc., 103, 1540, (1981).

5 R.Gleiter, R.Bartetzko and D.Cremer, J. Am. Chem. Soc., 106, 3437, (1984).

6 R.T.Boere', A.W.Cordes, R.T.Oakley and R.W.Reed, J. Chem. Soc., Chem. Commun., 655, (1985).

7 R.T.Boere', A.W.Cordes, S.L.Craig, R.T.Oakley and R.W.Reed, J. Am. Chem. Soc., 109, 868, (1987).

8 O.J.Scherer and R.Wies, Angew. Chem., Int. Ed. Engl., 10, 812, (1971); N.W.Alcock, E.M.Holt, J.Kuyper, J.J.Mayerle and G.B. Street, Inorg. Chem., 18, 2235, (1979).

9 N.Burford, T.Chivers, P.W.Codding and R.T.Oakley, Inorg. Chem., 21, 982, (1982); N.Burford, T.Chivers and J.F. Richardson, Inorg. Chem., 22, 1482, (1983).

10 G.Ertl and J.Weiss, Z. Naturforsch., 29B, 803, (1974); H.W.Roesky and H.Wiezer, Chem. Ztg., 97, 661, (1973).

11 H.W.Roesky and C.Pelz, Z. Naturforsch., 36B, 1437, (1981); Z.Zak, Acta. Crystallogr., 37B, 23, (1981).

12 J.Trotter and S.H.Whitlow, J. Chem. Soc. A, 455, (1970).

13 T.Chivers and J.Proctor, Can. J. Chem., 57, 1286, (1979).

14 J.Bojes, T.Chivers, A.W.Cordes, G.Maclean and R.T.Oakley, Inorg. Chem., 20, 16, (1981).

15 H.U.Hofs, G.Hartmann, R.Mews and G.M.Sheldrick, Angew. Chem., Int. Ed. Engl., 23, 988, (1984).

16 S.T.A.K.Daley and C.W.Rees, J. Chem. Soc., Perkin Trans. 1, 203, (1987).

17 J.L.Morris and C.W.Rees, J. Chem. Soc., Perkin Trans. 1, 211, (1987).

18 J.Kuyper and G.B.Street, J. Am. Chem. Soc., 99, 7848, (1977).

19 R.Jones, J.L.Morris, A.W.Potts, C.W.Rees, D.J.Rigg, H.S.Rzepa and D.J.Williams, J. Chem. Soc., Chem. Commun., 398, (1985).

20 M.M.Labes, P.Love and L.F.Nichols, Chem. Rev., 79, 1, (1979).

21 I.Ruppert, V.Bastain and R.Appel, Chem. Ber., 108, 2329, (1975).

22 W.Lidy, W.Sundermeyer and W.Verbeek, Z. Anorg. Allg. Chem., 406, 228, (1974).

23 O.J.Scherer, G.Wolmershauser and R.Jotter, Z. Naturforsch., 37B, 432, (1982).

24 H.Koenig and R.T.Oakley, J. Chem. Soc., Chem. Commun., 73,(1983).

25 A.W.Cordes, M.Hojo, H.Koenig, M.C.Noble, R.T.Oakley and W.T. Pennington, Inorg. Chem., 25, 1137, (1986).

26 P.W.Codding, H.Koenig and R.T.Oakley, Can. J. Chem., 61, 1562, (1983).

27 E.G.Cox, D.W.Cruickshank and J.A.S.Smith, Proc. R. Soc.

London., Ser. A., 247, 1, (1958).

28 O.Andreasen, A.C.Hazell and R.G.Hazell, Acta Crystallogr., Sect. B, 33, 1109, (1977).

29 C.T.Pedersen, Sulphur Rep., 1, 1, (1980).

30 R.Jones, J.L.Morris, C.W.Rees and D.J.Williams, J. Chem. Soc., Chem. Commun., 1654, (1985).

31 C.H.Chen and B.A.Donatelli, J. Heterocycl. Chem., 16, 183,(1979).

32 J.L.Morris and C.W.Rees, J. Chem. Soc., Perkin Trans. 1, 217, (1987).

33 V.Bertini and A.DeMunno, Gazz. Chim. Ital., 97, 1614, (1967); V.Bertini, A.DeMunno and A.Marraccini, J. Org. Chem., 37, 2587, (1972).

34 R.T.Boere', A.W.Cordes and R.T.Oakley, J. Chem. Soc., Chem. Commun., 929, (1985); R.T.Boere', C.L.French, R.T. Oakley, A.W.Cordes, J.A.J.Privett, S.L.Craig and J.B. Graham, J. Am. Chem. Soc., 107, 7710, (1985).

35 R.T.Boere', A.W.Cordes, S.L.Craig, J.B.Graham, R.T.Oakley and J.A.J.Privett, J. Chem. Soc., Chem. Commun., 807, (1986).

36 Gmelin Handbook of Inorganic Chemistry, Sulphur-Nitrogen Compounds, Part 2, 8th Edition, (1985).

37 R.M.Bannister, Chemistry Department, Imperial College, unpublished results.

38 R.Bussas, G.Kresze, H.Miinsterer and A.Schwobel, Sulphur Rep., 2, 215, (1983).

39 (a) G.Kresze and H.Grill, Tetrahedron Lett., 4117, (1969); (b) H.Grill and G.Kresze, Liebigs Ann. Chem., 749, 171, (1971); (c) W.Kosbahn and H.Schafer, Angew. Chem., Int. Ed.,

Engl., 16, 780, (1977).

40 A.Golloch and M.Kuss, Z. Naturforsch, 29B, 320, (1974).

41 G.G.Alange, A.J.Bannister, B.Bell and P.W.Millen, J. Chem. Soc., Perkin Trans. 1, 1192, (1979).

42 G.G.Alange, A.J.Bannister, B.Bell and P.W.Millen, Inorg. Nucl. Chem. Lett., 13, 143, (1977).

43 H.W.Roesky and T.Muller, Chem. Ber., 111, 2960, (1978).

44 R.L.Shriner and F.W.Neumann, Chem. Rev., 35, 351, (1944).

45 M.Davis, Adv. Heterocycl. Chem., 30, 47, (1982).

46 D.N.Harpp, K.Steliou and T.H.Chan, J. Am. Chem. Soc., 100, 1222, (1978); M.R.Bryce, J. Chem. Soc., Perkin Trans. 1, 2591, (1984).

47 A.Dondoni, G.Barbaro and A.Battaglia, J. Org. Chem., 42, 3372, (1977); D.F.Pipe, Ph.D.Thesis, University of London, (1980).

48 R.N.Butter, Comp. Heterocycl. Chem., Vol. 5, 791, (1984).

49 P.Scheiner and J.F.Dinda, Tetrahedron, 26, 2619, (1970).

50 J.Goerdeler and D.Loevenich, Chem. Ber., 87, 1079, (1954); J. Goerdeler and B.Wedekind, Chem. Ber., 95, 147, (1962); J. Goerdeler and K.Doerk, Chem. Ber., 95, 154, (1962).

51 W.Schramn, G.Voss, G.Rembarz and E.Fischer, Z. Chem., 14, 471, (1974).

52 P.P.Kornuta, L.I.Derii and L.N.Markovskii, J. Org. Chem., USSR, 16, 1130, (1980).

53 A.W.Cordes, P.J.Hayes, P.D.Josephy, H.Koenig, R.T.Oakley and W.T.Pennington, J. Chem. Soc., Chem. Commun., 1021, (1984).

54 P.J.Hayes, R.T.Oakley, A.W.Cordes and W.T.Pennington, J. Am. Chem. Soc., 107, 1346, (1985).

55 A.Kalman, G.Argay, E.Fischer, G.Rembarz and G.Voss, J. Chem. Soc., Perkin Trans. 2, 1322, (1977); A.Kalman, G.Argay, E. Fischer and G.Rembarz, Acta. Crystallogr., 35B, 860, (1979).

56 J.D.Michael, P.M.Rees and B.C.Ross, Tetrahedron Lett., 26, 1101, (1985).

57 S.J.Cousins, B.C.Ross, G.N.Maw and J.D.Michael, Tetrahedron Lett., 26, 1105, (1985).

58 J.D.Michael, Synth. Commun., 170, (1987).

59 P.Goya, C.Ochoa, J.A.Pa'ez, I.Rozas and M.Stud, Heterocycles, 22, 471, (1984).

60 D.A.Peak, J. Chem. Soc., 215, (1952).

61 W.Schramn, G.Voss, M.Michalik, G.Rembarz and E.Fischer, Z. Chem., 15, 19, (1975).

62 W.Schramn, G.Voss, G.Rembarz and E.Fischer, Z. Chem., 15, 57, (1975).

63 R.T.Boere', A.W.Cordes, P.J.Hayes, R.T.Oakley, R.W.Reed and W.T.Pennington, Inorg. Chem., 25, 2445, (1986).

64 R.D.Spencer and B.H.Beggs, Anal. Chem., 35, 1633, (1963).

65 H.E.Simmons, R.D.Vest, D.C.Blomstrom, J.R.Roland and T.L.Cairns, J. Am. Chem. Soc., 84, 4746, (1962).

66 G.Wolmershauser, M.Schnauber and T.Wilhelm, J. Chem. Soc., Chem. Commun., 573, (1984).

67 G.K.MacLean, J.Passmore, M.J.Schriver, P.S.White, D.Bethell, R.S.Pilkington and L.H.Sutcliffe, J. Chem. Soc., Chem. Commun., 807, (1983); G.K.MacLean, J.Passmore, M.N.S.Rao, M. J.Schriver, P.S.White, D.Bethell, R.S.Pilkington and L.H. Sutcliffe, J. Chem. Soc., Dalton Trans., 1405, (1985).

68 R.Neidlein, P.Leinberger, A.Gieren and B.Dederer, Chem. Ber., 111, 698, (1978).

69 M.Kim-Su, K.Eger and H.J.Roth, Arch. Pharm., 309, 721,(1976).

70 J.F.Honek, M.L.Maxini and B.Belleau, Synthetic. Commun., 13, 977, (1983).

71 J.Adamson, D.L.Forster, T.L.Gilchrist and C.W.Rees, J. Chem. Soc., C, 981, (1971).

72 Dictionary of Organic Compounds, Chapman and Hall, 5th Edition.

73 G.Weiss and G.Schulze, CA, 57, 13771e, (1962).

74 (a) J.A.Lambrech, W.H.Hensley, R.E.Kent and J.E.Lynch, CA, 54, P5716h, (1960); (b) M.V.Kalnins, Can. J. Chem., 44, 2111, (1966); (c) G.S.Borovikova, E.S.Levchenko and E.I.Kaminskaya, J. Org. Chem., USSR, 86, (1986).

75 (a) G.Kresze and W.Wucherpfenning, Angew. Chem., Int. Ed., Engl., 6, 149, (1967); (b) D.H.Clemens, A.J.Bell and J.L. O'Brien, Tetrahedron Lett., 1487, (1965); (c) G.Kresze, A. Maschke, R.Albrecht and K.Bederke, Angew. Chem., Int. Ed., Engl., 89, (1962); (d) E.S.Levchenko and E.M.Dorokhova, J. Org. Chem., USSR, 5, 1481, (1969).

76 A.R.Sanger, Inorg. Nucl. Chem. Lett., 9, 351, (1973).

77 M.Villena-Bianco and W.L.Jolly, Inorg. Synth., 9, 98, (1967); A.J.Banister, Inorg. Synth., 17, 197, (1977).

78 Methoden de Organischen Chemie, Houben-Weyl, 8, 694, (1952).

79 W.Ried and P.Schomann, Liebigs Ann. Chem., 714, 122, (1968).

80 R.M.Herbst and K.R.Wilson, J. Org. Chem., 22, 1142, (1957).

81 A.Pinner, Ber., 25, 1414, (1892).

82 W.Jarre, D.Bieniek and F.Korte, Tetrahedron, 31, 619, (1975).

83 S.Gronowitz and S.Liljefors, Acta. Chem. Scand., 31B, 771, (1977).

84 L.F.Fieser and M.Fieser, Reagents for Organic Synthesis.

85 F.Krafft and A.V.Hansen, Ber., 22, 803, (1889).

86 G.Bahr and G.Schleitzer, Chem. Ber., 90, 438, (1957).

87 R.Appel and D.Hanssgen, Angew. Chem. Int. Ed., Engl., 91, (1967).

88 J.D.Warren, V.J.Lee and R.B.Angier, J. Heterocycl. Chem., 16, 1617, (1979).

89 (a) T.Yoshimura, N.Furukawa, T.Akasaka and S.Oae, Tetrahedron, 33, 1061, (1977); (b) R.Appel and W.Buchner, Chem. Ber., 95, 855, (1962).

90 D.C.Morrison and A.Furst, J. Org. Chem., 21, 470, (1956).

91 Made by treating the corresponding dithiol (170) with sodium ethoxide.

92 K.Sasse, R.Wegler, G.Unterstenhofer, Angew. Chem., 72, 973, (1960).

93 G.Crank and M.I.H.Makin, Tetrahedron Lett., 2169, (1979).

94 F.Feher, F.Malcharek and K.Glinka, Z. Naturforsch, 26B, 67, (1971).

95 A.Appel, L.Siekmann and H.O.Hoppen, Chem. Ber., 101, 2861, (1968).

96 D.Hanssgen and R.Steffens, Z. Naturforsch, 40B, 919, (1985).

97 V.N.Klyuev and V.F.Borodkin, CA, 55, 13358i, (1961).

98 R.Stolle', J. Prakt. Chem., 85, 386, (1911).

99 E.H.Amonoo-Neizer, R.A.Shaw, D.O.Skovlin and B.C.Smith, Inorg. Synth., 8, 19.

100 M.Cushman and L.Cheng, J. Org. Chem., 43, 3781, (1978) and references therein.

101 O.Tsuge and S.Mataka, Bull. Chem. Soc. Jpn., 44, 2836, (1971).