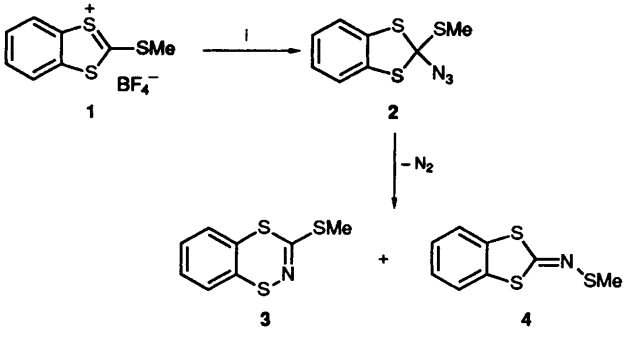
Substituted 1,4,2-Dithiazines: Synthesis by Ring Expansion of 1,3-Dithiolium Cations, Solution Redox Properties and X-Ray Crystal Structures of a Monocyclic and a Bicyclic Derivative

Martin R. Bryce,* Gordon R. Davison, Andrei S. Batsanov and Judith A. K. Howard
Department of Chemistry, University of Durham, Durham, DH1 3LE, UK

A range of derivatives of the 8 π-electron 1,4,2-dithiazine system, *viz.* compounds **11a–d** and **19–24**, have been synthesised by ring expansion of the corresponding 1,3-dithiolium salts **8a–d** and **13–18**, respectively, using a mixture of iodine and aqueous ammonia at room temperature. A mechanism is proposed for the reaction. Competing reaction of compound **14** yields the imine **26** as a minor product. Single crystal X-ray analyses of compounds **11a** and **23** reveal that the 1,4,2-dithiazine ring adopts a boat conformation with fold angles about the S • • • S axis of 50 and 48°, respectively. The 1,4,2-dithiazine heterocycle is oxidised electrochemically to yield the cation radical at E_1^{ox} *ca.* 1.0–1.2 V (*versus* Ag/AgCl); some derivatives are further oxidised to the dication at E_2^{ox} *ca.* 1.4–1.7 V.

Heterocyclothiazenes display a fascinating array of chemical, physical and structural properties as a consequence of the extensive π-electron delocalisation and multiple bonding that occurs in the heterocycle.[1] Most attention has focussed on systems which are formally heteroaromatic, possessing 6 or 10 π-electrons as the neutral species, or 6 π-electrons as either the free radical, the cation or the anion. Eight π-electron heterocyclothiazenes are generally far harder to synthesise, and, consequently, their chemistry is less well explored. Thermal and photochemical rearrangements, cycloadditions, co-ordination to transition metals and multistage redox behaviour are known for a few eight π heterocycles, *e.g.* $R_2C_2N_2S_2$, RCN_3S_2 and $R_2C_2N_3S^-$ ring systems.[1a]

From this viewpoint we were attracted to the 8 π-electron, $R_3C_3NS_2$, 1,4,2-dithiazine system, which has received scant attention, and our studies on the synthesis of derivatives of this heterocycle are the subject of this paper.[2] Ground-work by Fanghänel,[3] followed by Nakayama *et al.*[4] established that monocyclic 1,4,2-dithiazine and 1,4,2-benzodithiazine derivatives could be obtained by reaction of azide ion with 1,3-dithiolium and 1,3-benzodithiolium cations, respectively. However, yields were frequently low and the reactions are complicated by competing imine formation (which is sometimes the major pathway) from the intermediate nitrene (Scheme 1).[4b]



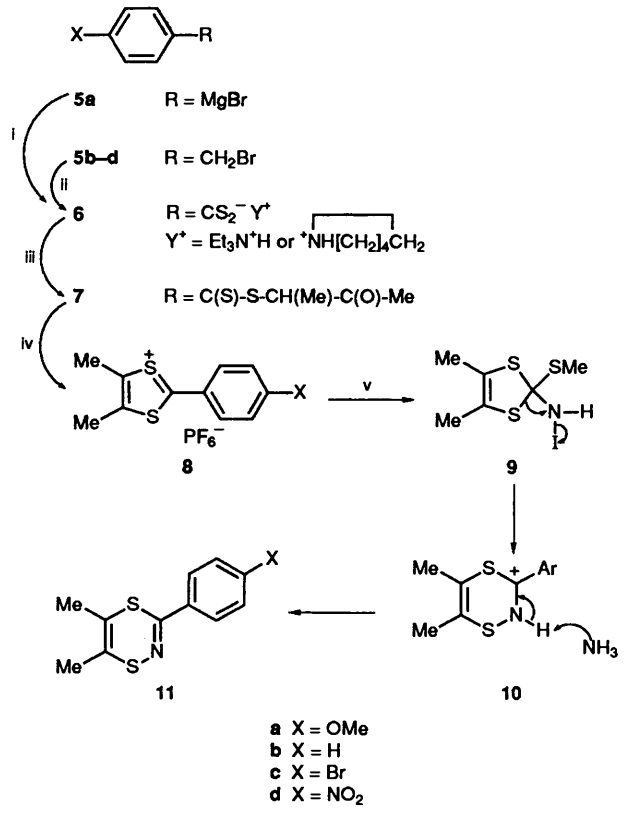
Scheme 1 *Reagent:* i, NaN_3

Desulfurisation of the product dithiazine can also occur under the reaction conditions, to yield isothiazoles.[3a,4c] It was reported that the parent, unsubstituted, 1,4,2-dithiazine could not be obtained by this route,[4b] and the majority of derivatives characterised were substituted with phenyl or benzo groups.[3,4] Yonemoto *et al.* have extended this methodology and shown that nucleophilic sulfenamides [*e.g.* $Me_2NC(S)SNH_2$][5] and, more recently, a mixture of iodine and aqueous ammonia at room temperature,[6] react with 1,3-dithiolium cations to yield 1,4,2-dithiazines. The latter conditions appeared to be the most straightforward reported so far, offering the advantages of good yields, simple experimental procedures, mild conditions and no imine formation, although the 1,4,2-dithiazines obtained by this method all carried two or three phenyl substituents.

We now describe our studies on the ring expansion of a range of 1,3-dithiolium cations, using a modification of the iodine–ammonia system, to afford new monocyclic and bicyclic 1,4,2-dithiazines, the majority of which do not contain phenyl substituents. We also report the first X-ray crystal structures of the 1,4,2-dithiazine system, and a study of the solution redox properties of this heterocycle.

Results and Discussion

Synthesis of 1,4,2-*Dithiazines.*—The general synthetic route adopted for the target 2-phenyl-1,3-dithiolium salts **8a–d** is shown in Scheme 2. This series of precursors was selected because of their accessibility from dithiobenzoate salts **6** using known procedures for other 1,3-dithiolium salts.[7] 4-Methoxybenzyl bromide is very unstable,[8] so a Grignard route starting from 4-bromoanisole, *via* **5a**, was used to prepare salt **6a**.[9] Salts **6b–d** were obtained from benzyl bromide derivatives **5b–d** by reaction with sodium methoxide and elemental sulfur.[10] In previous work using this reaction, the dithiocarboxylic acids had generally been liberated from their sodium salts by treatment with hydrochloric acid, followed by isolation as the piperidinium salt.[7] We have now found that for the present series of compounds this procedure suffers two disadvantages: the piperidinium dithiobenzoate salts **6** (Y^+ = piperidinium) were generally difficult to separate from piperidinium hydrochloride, and in the case of the 4-bromo derivative, the thioamide **12** was the only product obtained. These problems were readily overcome, and yields and purity of the products **6** improved, by acidification of the sodium salt of the dithiobenzoates with sulfuric acid, followed by isolation as the triethylammonium salts **6a–d** (27–49% yield). Alkylation of the salts **6a–d** with 3-chlorobutan-2-one gave the corresponding dithioesters **7a–d** as red oils (39–86% yield) which on treatment with sulfuric acid at −20 °C cyclised efficiently to yield 1,3-dithiolium cations which were isolated as the hexafluorophosphate salts **8a–d** (55–87% yield). The ^1H NMR spectra of salts **8** showed a singlet peak at δ_H *ca.* 2.8, which is diagnostic of methyl group protons on a 1,3-dithiolium ring.[7b–e] Other dithiolium cations used in this study are the known compounds **13–18**, which were prepared by literature methods (see Experimental section).



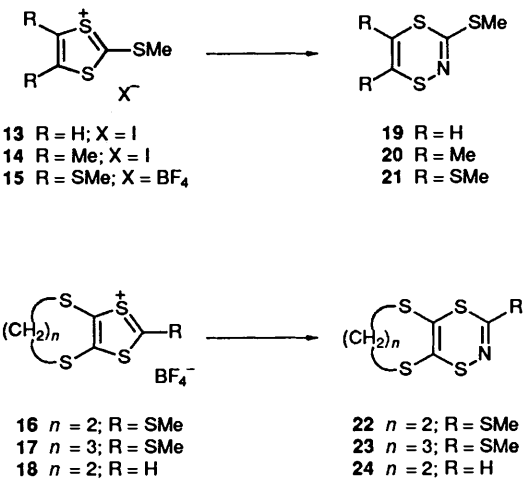
Scheme 2 *Reagents and conditions:* i, carbon disulfide, Et_2O, 20 °C, followed by sulfuric acid (aq), triethylamine; ii, elemental sulfur, sodium methoxide, MeOH, reflux, followed by sulfuric acid (aq), triethylamine or piperidine; iii, 3-chlorobutan-2-one, CH_2Cl_2, 20 °C; iv, sulfuric acid (conc.), $CHCl_3$, −20 °C, followed by water, HPF_6, 20 °C; v, iodine, ammonia (aq), MeCN, 20 °C

12

The 1,4,2-dithiazine synthesis described recently by Yonemoto and Shibuya used a large excess of aqueous ammonia and equimolar amounts of dithiolium cation and iodine in acetonitrile at room temperature.[6] We initially used these conditions and found that dithiolium cations **8a–d** yielded the novel 1,4,2-dithiazine derivatives **11a–d** in 33–52% yield. However, optimisation of the conditions by increasing the amount of iodine to 5 molar equivalents led to a significant improvement in the yields of the products **11a–d** which were raised to 56–94%.

Ring expansion of dithiolium cation derivatives **13–18**, which bear either a methylthio substituent or a hydrogen atom at C-2, has proved to be less efficient than for the 2-aryl derivatives described above. Compounds **20–23** are formed in 12–54% yield in the presence of 5 equivalents of iodine (1 equivalent of iodine gave compound **20** in only 8% yield). Surprisingly, the highest yield (14%) of compound **19**, which is unsubstituted at C-5 and C-6, was obtained with 1 equivalent of iodine; 5 equivalents of iodine reduced the yield of **19** to only 6%.

1,4,2-Dithiazines **11a–d**, **22** and **23** are air-stable for at least several months at room temperature; derivatives **19–21** and **24**, however, are substantially less stable, requiring storage at 0 °C;

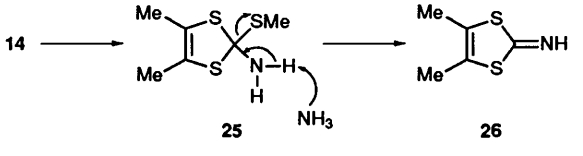


decomposition occurs at room temperature to yield numerous unidentified products (TLC evidence). The low isolated yield of **19** in the presence of an excess of iodine could be due to oxidation of the product by the halogen. It would seem, therefore, that an excess of iodine is beneficial only when the product 1,4,2-dithiazine is a stable compound. Compound **24**, is, notably, a rare example of a 1,4,2-dithiazine derivative that is unsubstituted at C-3.[3e]

We attempted to prepare the parent, unsubstituted 1,4,2-dithiazine from 1,3-dithiolium tetrafluoroborate, 0.9 equivalents of iodine and an excess of ammonia, both at 0 °C and at 20 °C. A complex product mixture, which resisted purification, resulted under both reaction conditions. Nonetheless, evidence for the formation, in very low yield, of the parent 1,4,2-dithiazine came from ^1H NMR and mass spectroscopic analysis (a correct high-resolution mass spectrum was obtained) of the product mixture resulting from reaction at 20 °C.

NMR spectra confirmed the 1,4,2-dithiazine structures **11a–d** and **19–24** and excluded the possibility that the compounds were imine isomers (*i.e.* analogues of compound **4**). In each case, ^1H NMR spectra showed that the substituents at C-5 and C-6 were inequivalent (*cf.* the imine **26** discussed below, where the two methyl groups are indistinguishable). In the proton-coupled ^{13}C NMR spectra of **11a–d**, the dithiazine ring carbon, C-3, appears as a triplet with $^3J_{CH}$ *ca.* 4 Hz, arising from coupling to two hydrogen atoms on the phenyl ring: this value is similar to that of the analogous carboxylic acid carbon of benzoic acid ($^3J_{CH}$ 4.1 Hz)[11] while the imine isomer would have no $^3J_{CH}$ coupling to the imine carbon. Furthermore, X-ray crystal analyses of both compounds **11a**,[2] and **23** unequivocally prove the 1,4,2-dithiazine structures (see below).

The only imine product we have observed is compound **26**, which was isolated in 8% yield alongside the major product **20** from reaction of the dithiolium cation **14**. The methylthio group



has been lost in the formation of compound **26** (in contrast to the imine **4**) possibly by way of the intermediate **25**. Fanghänel has reported one example of an analogous imine product in previous work on the reaction of a substituted 1,3-dithiolium cation with sodium azide, when acid work-up was used;[12] a quite different mechanism may operate under these conditions.

Yonemoto and Shibuya considered that 1,4,2-dithiazine formation, using the iodine–ammonia methodology, proceeded

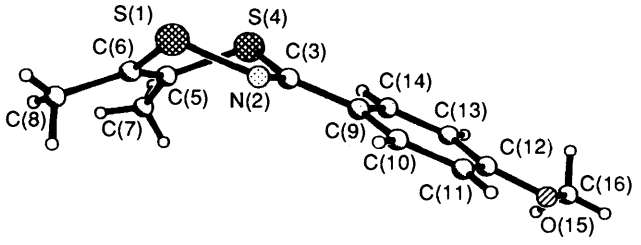


Fig. 1 X-ray molecular structure of 1,4,2-dithiazine derivative **11a**

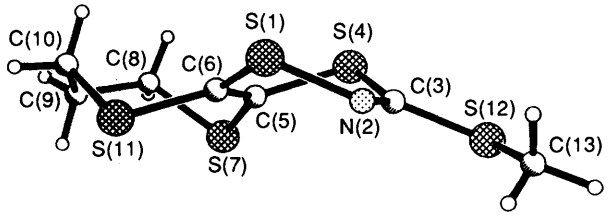


Fig. 2 X-ray molecular structure of 1,4,2-dithiazine derivative **23**

Table 1 Cyclic voltammetric data for 1,4,2-dithiazine derivatives[a]

Compound	E_1^{ox}/V	E_1^{red}/V	$E_1^{\ddagger}$/V	E_2^{ox}/V	$\Delta E/V$[b]
11a	1.12	0.97	1.05	1.70	0.66
11b	1.18	1.10	1.14	1.72	0.58
11c	1.18	1.12	1.15	1.72	0.57
11d	1.24	1.16	1.20	*c*	
20	1.03	*c*		*c*	
21	1.17	1.07	1.12	1.43	0.31
22	1.20	1.13	1.17	1.58	0.41
23	1.27	1.17	1.22	1.57	0.35
24	1.24	1.15	1.20	1.52	0.32
27	1.39	0.83	*d*	*c*	

[a] Compound (*ca.* 10^{-3} mol dm^{-3}) in anhydrous dichloromethane, electrolyte $Bu_4N^+PF_6^-$ (*ca.* 10^{-2} mol dm^{-3}), Pt electrode, *vs.* Ag/AgCl, 20 °C using a BAS 100 electrochemical analyser. [b] $\Delta E = E_2^{ox} - E_1^{\ddagger}$. [c] Not observed. [d] Not applicable due to irreversibility of E_1.

via a nitrenium ion intermediate.[6] These are contentious species[13] and an alternative route to compounds **11a–d** and **19–24** (shown for the phenyl derivatives in Scheme 2) would seem to be more likely. Nucleophilic addition to C-2 of a 1,3-dithiolium cation is a common reaction[14] and intermediate **9**, thus formed, could then lose iodide ion with concomitant S–N bond formation, to afford the cation **10**, which is then deprotonated to yield the product.

X-Ray Crystal Structures of 1,4,2-*Dithiazine Derivatives* **11a** *and* **23**.—Single crystal X-ray diffraction studies of compounds **11a** and **23** confirmed their proposed structures (Figs. 1 and 2) and provided the first data on the 1,4,2-dithiazine ring geometry. In both molecules **11a** and **23**, this ring adopts a boat conformation, which can also be described as a folding along the S(1) · · · S(4) line (by 50.0 and 47.9° in structures **11a** and **23**, respectively). Similar conformations have been observed in 1,4-dithiin[15] and tetracyano-1,4-dithiin[16] (folding by 43 and 56°, respectively). In both **11a** and **23** the substituents attached to C(3) are almost coplanar with the S(1)–N(2)–C(3)–S(4) plane (plane A) thus maximising their conjugation with the N(2)=C(3) bond. In compound **11a** plane A and the benzene ring form a dihedral angle of 2.9°, while the O(15)–C(16) bond is rotated out of the benzene plane by 1.8°. In compound **23**, the N(2)–C(3)–S(12)–C(13) torsion angle is 7.7°; the seven-membered heterocycle adopts a chair conformation folding by 53.6° along the S(7) · · · S(11) axis, and by 60.7° along the C(8) · · · C(10) axis. The S(7)–C(5)–C(6)–S(11) and S(1)–C(6)–C(5)–S(4) planes form a dihedral angle of 172.9°.

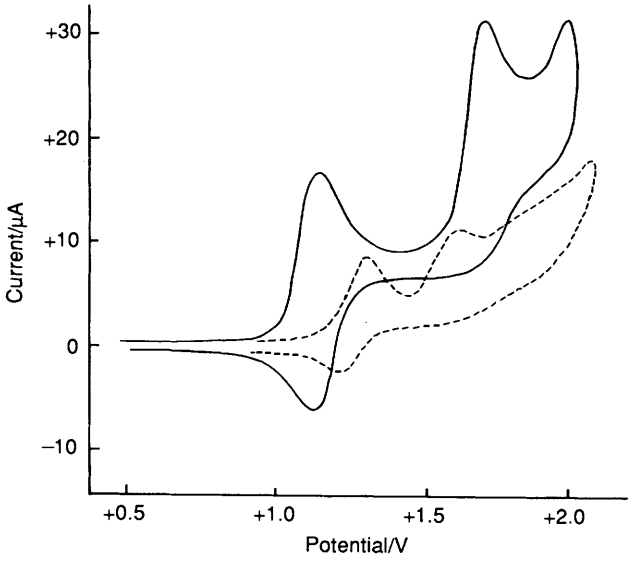


Fig. 3 Cyclic voltammograms of compounds **11c** (——) and **23** (· · ·)

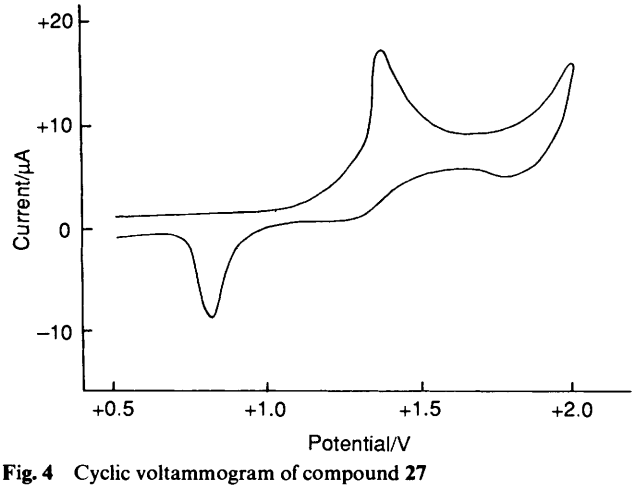
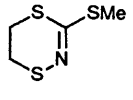


Fig. 4 Cyclic voltammogram of compound **27**

The bond distances within the dithiazine ring are essentially the same in compounds **11a** and **23**. The N(2)=C(3) and C(5)=C(6) double bonds are localised (*cf.* standard values [17] of 1.28 and 1.32 Å) while the C–S bond lengths are comparable to normal single $C(sp^2)$–S bonds in heterocycles (average 1.75 Å) or aryl-SR groups (average 1.77 Å).[17] The S(1)–N(2) bond in compounds **11a** and **23** is significantly longer than is usual for C=N–SR units (1.63–1.68 Å)[17] where π–π^* interactions increase the effective bond order, and is in the range for R_2N–SR groups (1.70–1.72 Å)[17] revealing essentially single bond character.

The crystal packing of compounds **11a** and **23** reveals no specifically close intermolecular interactions; the only contact which is shorter than twice the Van der Waals radius of the sulfur atom (1.80 Å)[18] is S(1) · · · S(4) (3.53 Å) in compound **23**.

Solution Electrochemistry of 1,4,2-*Dithiazine Derivatives*.—The redox properties of the 8 π-electron 1,4,2-dithiazine ring have been studied by cyclic voltammetry. The data for compounds **11a–d**, **20–24**, and the saturated analogue **27**,[6] are



27

Table 2 Analytical and spectroscopic data for dithioesters **7a–d**

Compound (Formula)	Analysis Found (%) (Required) C	H	N	$M^+ + 1^a$ ($M + 1$)	ν_{max}(neat liquid)/cm^{-1}	$\delta_H(CDCl_3)$ (J/Hz)
7a ($C_{12}H_{14}O_2S_2$)	56.5 (56.7)	5.5 (5.5)		255.0500 (255.0514)	2965, 1715, 1595, 1505, 1170, 1040, 880, 830	1.56 (3 H, d, J 7), 2.32 (3 H, s), 3.86 (3 H, s), 4.92 (1 H, q, J 7), 6.89 (2 H, d, J 9), 8.10 (2 H, d, J 9)
7b ($C_{11}H_{12}OS_2$)	57.3 (58.9)	5.5 (5.4)		225.0428 (225.0408)	2940, 1720, 1450, 1360, 1235, 1045, 870, 765	1.60 (3 H, d, J 7), 2.33 (3 H, s), 4.90 (1 H, q, J 7), 7.39 (2 H, t, J 8), 7.55 (1 H, t, J 7), 8.01 (2 H, d, J 8)
7c ($C_{11}H_{11}BrOS_2$)	44.5 (43.6)	3.8 (3.7)		302.9287 (302.9513)	2935, 1720, 1580, 1480, 1230, 1045, 880, 825	1.56 (3 H, d, J 8), 2.30 (3 H, s), 4.82 (1 H, q, J 7), 7.51 (2 H, d, J 8), 7.86 (2 H, d, J 8)
7d ($C_{11}H_{11}NO_3S_2$)	49.2 (49.1)	4.1 (4.1)	4.8 (5.2)	270 (270)	3110, 2935, 1720, 1525, 1345, 1050, 845, 750	1.61 (3 H, d, J 7), 2.35 (3 H, s), 4.82 (1 H, q, J 7), 8.08 (2 H, d, J 9), 8.22 (2 H, d, J 9)

[a] CI.

Table 3 Analytical and spectroscopic data for dithiolium cations **8a–d**

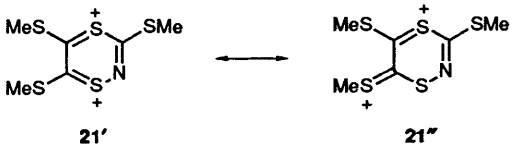
Compound (Formula)	Analysis Found (%) (Required) C	H	N	M^{+a} (M)	ν_{max}/cm^{-1}	$\delta_H(CF_3CO_2H)$, (J/Hz)
8a ($C_{12}H_{13}F_6OPS_2$)	37.8 (37.7)	3.4 (3.4)		237 (237)	1595, 1300, 1275, 1180, 960, 835, 595, 550[b]	2.8 (6 H, s), 4.1 (3 H, s), 7.3 (2 H, d, J 9), 8.0 (2 H, d, J 9
8b ($C_{11}H_{11}F_6PS_2$)	37.3 (37.5)	3.0 (3.1)		207 (207)	1455, 1410, 1340, 1320, 1300, 1035, 770, 690[c]	2.82 (6 H, s), 7.7–8.1 (5 H, m)
8c ($C_{11}H_{10}BrF_6PS_2$)	31.0 (30.6)	2.4 (2.3)		*d*	1585, 1540, 1410, 1300, 1080, 1010, 965, 835[b]	2.8 (6 H, s), 7.85 (2 H, d, J 9), 7.98 (2 H, d, J 9)
8d ($C_{11}H_{10}F_6NO_2PS_2$)	33.0 (33.3)	2.6 (2.5)	3.4 (3.5)	*d*	1615, 1535, 1370, 1355, 1325, 1300, 840, 745[b]	2.9 (6 H, s), 8.2 (2 H, d, J 9), 8.7 (2 H, d, J 9),

[a] FAB (MeOH). [b] KBr disk. [c] Hexachlorobutadiene mull. [d] Sample did not give a mass spectrum.

collated in Table 1. The cyclic voltammograms of compounds **11c**, **23** and **27** are shown in Figs. 3 and 4. Each member of the 1,4,2-dithiazine series **11a–d** and **20–24** undergoes a single-electron oxidation to form the cation radical at a half-wave potential, $E_1^{\frac{1}{2}}$, of between 1.03 and 1.22 V (*versus* Ag/AgCl). This is a reversible process for the 3-phenyl derivatives **11a–d**, but is irreversible for the 3-methylthio and 3-hydro derivatives **20–24**, for which the corresponding cathodic reduction is either seen as only a weak shoulder or is absent altogether. The 3-phenyl series **11a–d** display a clear dependence of $E_1^{\frac{1}{2}}$ peak potential upon the electronic nature of the substituent attached to the *para*-position of the phenyl ring. The heterocycle is harder to oxidise (0.11–0.16 V increase in the values of $E_1^{\frac{1}{2}}$) when the electron-withdrawing bromo or nitro substituents are present (compounds **11c** and **11d**) compared to the *para*-methoxy derivative **11a**. These data are consistent with the solid-state conformation of compound **11a**, discussed above, in which the phenyl ring is almost coplanar with the S(1)–N(2)–C(3)–S(4) plane.

A second oxidation, E_2^{ox}, to form the 6 π-electron 1,4,2-dithiazine dication is observed for compounds **11a–c** and **21–24**, but not for compounds **11d** and **20** (Table 1). This second oxidation is an irreversible redox wave. Scanning to 2.0 V (*i.e.* well beyond the potential of E_2^{ox}) has no effect on the reversibility of E_1; this implies that the dication does not decompose in a chemical reaction (*e.g.* with solvent or with oxygen). It is more likely, therefore, that the dication reacts with the corresponding neutral species in a coproportionation process, with single-electron transfer generating radical cations.

The difference, ΔE, between the first and second oxidation potentials in a multi-stage redox system is a measure of the coulombic repulsion in the dication redox stage.[19] It is notable that for the 1,4,2-dithiazine derivatives the value of ΔE is significantly reduced (*i.e.* less coulombic repulsion) for derivatives **21–24**, which carry thioalkyl substituents at C-5



21′ **21″**

Table 4 Analytical and spectroscopic data for 1,4,2-dithiazine derivatives **11a–d** and **19–24**

Compound (Formula)	Analysis Found (%) (Required) C	H	N	*m/z* (Required)	ν_{max}/cm^{-1}	δ_H($CDCl_3$), (*J* Hz)	δ_C($CDCl_3$)
11a ($C_{12}H_{13}NOS_2$)	57.1 (57.3)	5.1 (5.2)	5.2 (5.6)	252.0493 (M^+ + 1) (252.0517)	2920, 1605, 1505, 1260, 1175, 1030, 920, 830[a]	2.05 (3 H, s), 2.10 (3 H, s), 3.83 (3 H, s), 6.89 (2 H, d, *J* 9), 7.95 (2 H, d, *J* 9)	18.7, 20.7, 55.2, 113.6, 121.5, 128.4, 129.9, 130.9, 161.9, 163.1
11b ($C_{11}H_{11}NS_2$)	59.9 (59.7)	5.2 (5.0)	5.8 (6.3)	221.0295 (M^+) (221.0333)	2920, 1545, 1445, 1225, 1070, 915[b]	2.07 (3 H, s), 2.12 (3 H, s), 7.37–8.02 (5 H, m)	18.5, 20.5, 120.9, 127.9, 128.2, 130.2, 130.8, 135.5, 162.8
11c ($C_{11}H_{10}BrNS_2$)	43.7 (44.0)	3.3 (3.4)	4.3 (4.7)	302, 300 (M^+ + 1) (302, 300)	2910, 1480, 1390, 1215, 1070, 1010, 910, 830[a]	2.07 (3 H, s), 2.12 (3 H, s), 7.65 (2 H, d, *J* 9), 8.02 (2 H, d, *J* 9)	18.5, 20.6, 120.6, 125.6, 129.4, 130.3, 131.3, 134.3, 161.5
11d ($C_{11}H_{10}N_2O_2S_2$)	49.6 (49.6)	3.7 (3.8)	10.5 (10.5)	265.9995 (M^+) (266.0184)	2920, 1605, 1530, 1355, 920, 860, 850, 755[a]	2.06 (3 H, s), 2.11 (3 H, s), 8.15 (2 H, d, *J* 8), 8.24 (2 H, d, *J* 8)	18.6, 20.8, 120.5, 123.7, 129.5, 130.7, 141.2, 149.2, 160.6
19 ($C_4H_5NS_3$)	*c*			162.9562 (M^+) (162.9584)	3040, 2930, 1550, 1510, 970, 915, 800, 670[b]	2.54 (3 H, s), 6.33 (1 H, d, *J* 7), 6.91 (1 H, d, *J* 7)	17.7, 118.8, 129.8, 161.0
20 ($C_6H_9NS_3$)	37.9 (37.7)	4.6 (4.7)	7.5 (7.3)	191 (M^+) (191)	2920, 1535, 1435, 1185, 1090, 940, 765, 750[a]	2.02 (3 H, s), 2.06 (3 H, s), 2.82 (3 H, s)	13.4, 13.9, 23.5, 122.1, 122.5, 157.9
21 ($C_6H_9NS_5$)	*c*			255.9855 (M^+ + 1) (255.9417)	2920, 1525, 1425, 1310, 965, 915, 850, 735[b]	2.44 (3 H, s), 2.49 (3 H, s), 2.54 (3 H, s)	16.9, 17.9, 17.9, 122.1 137.5, 163.6
22 ($C_6H_7NS_5$)	*c*			253.9277 (M^+ + 1) (253.9260)	2930, 1525, 1410, 1285, 980, 920, 850, 730[b]	2.53 (3 H, s), 3.29 (4 H, m)	17.1, 29.9, 30.5, 113.7, 124.8, 165.4
23 ($C_7H_9NS_5$)	31.5 (31.4)	3.4 (3.4)	4.9 (5.2)	266.9531 (M^+) (266.9339)	2920, 1530, 1410, 1280, 975, 920, 865, 845[a]	2.28 (2 H, m), 2.49 (3 H, s), 2.74 (4 H, m)	16.8, 32.7, 33.2, 33.7, 122.2, 141.9, 165.1
24 ($C_5H_5NS_4$)	*c*			207.9259 (M^+ + 1) (207.9383)	2920, 1560, 1410, 1285, 970, 910, 855, 780, 745[b]	3.30 (4 H, m), 8.35 (1 H, s)	29.3, 29.8, 110.1, 119.5, 154.2

[a] KBr disk. [b] Neat liquid. [c] Analysis not obtained because sample was a viscous oil.

and C-6 (Table 1). This implies that these substituents are involved in charge delocalisation (*e.g.* canonical structures **21′** and **21″** for the dication). A comparison of the data given in Table 1 with those reported previously for 1,4-dithiin derivatives,[20] shows that incorporation of a nitrogen atom into the heterocycle considerably increases the oxidation potential of the system, and increases the value of ΔE (*e.g.* for the parent, unsubstituted 1,4-dithiin, $E_1^{\frac{1}{2}}$ and $E_2^{\frac{1}{2}}$ occur at 0.69 and 0.80 V, respectively, *versus* standard calomel electrode).[20]

The cyclic voltammetric behaviour of the related saturated compound **27** has also been studied (Fig. 4). This compound shows quite different redox properties in comparison with the 8 π-electron systems discussed above. A single oxidation peak is observed at a significantly higher potential, with the accompanying cathodic peak shifted to low potential, which is typical of an irreversible process.

Conclusions

A range of novel, substituted 1,4,2-dithiazine derivatives **11a–d** and **19–24** have been synthesised by ring expansion of 1,3-dithiolium cations, using a mixture of iodine and aqueous ammonia under very mild conditions. The redox properties of the 8 π-heterocycle have been studied by cyclic voltammetry, and the structures of the 1,4,2-dithiazine derivatives **11a** and **23** have been unequivocally confirmed by X-ray crystallography. Extension of this straightforward methodology to the synthesis of other C, N, S heterocycles is underway and will be reported in due course.

Experimental

General.—Details of instrumentation and general procedures are the same as those reported recently.[7e]

Table 5 Crystallographic data

	11a	**23**
Crystal system	monoclinic	monoclinic
Space group	$P2_1/c$	$P2_1/c$
a/Å	14.226(2)	8.509(2)
b/Å	10.896(2)	8.540(2)
c/Å	8.142(2)	15.732(3)
β/(°)	104.44(2)	93.36(2)
U/Å^3	1222.1(3)	1141.3(4)
Z	4	4
D_c/g cm^{-3}	1.37	1.56
Formula	$C_{12}H_{13}NOS_2$	$C_7H_9NS_5$
M	251.4	267.5
F(000)	528	552
μ(MoKα)/cm^{-1}	4.13	9.69
Crystal size/mm	0.20 × 0.62 × 0.85	0.3 × 0.5 × 0.5
max. 2θ(°)	50	55
Unique reflections	2133	2616
Reflections with $I > 2\sigma(I)$	1899	2062
Absorption correction:		
Transmission factors, min., max.	0.5203/0.6857	0.2989/0.3297
No. of ψ-scans (reflections) used	140(8)	360(10)
Refined parameters	197	154
R	0.047	0.039
$R_G = wR$	0.066	0.051
Goodness-of-fit	2.50	1.80
Weighting scheme, g[a]	0.0004	0.0003
Residual difference feature, max. (min.)/e Å^{-3}	0.21 (−0.26)	0.36 (−0.24)

[a] Weighting scheme $w^{-1} = \sigma^2(F) + gF^2$ was used.

Table 6 Bond distances[a] (Å) and angles (°) in compounds **11a** and **23**

	11a		**23**
S(1)–N(2)	1.709(2)	S(1)–N(2)	1.707(2)
N(2)–C(3)	1.274(3)	N(2)–C(3)	1.265(3)
C(3)–S(4)	1.785(2)	C(3)–S(4)	1.784(3)
S(4)–C(5)	1.762(2)	S(4)–C(5)	1.767(3)
C(5)–C(6)	1.336(3)	C(5)–C(6)	1.352(4)
C(6)–S(1)	1.752(2)	C(6)–S(1)	1.749(3)
C(3)–C(9)	1.477(3)	C(3)–S(12)	1.748(3)
C(5)–C(7)	1.498(4)	C(5)–S(7)	1.757(3)
C(6)–C(8)	1.504(3)	C(6)–S(11)	1.753(3)
C(12)–O(15)	1.361(3)	S(7)–C(8)	1.812(4)
O(15)–C(16)	1.419(3)	C(8)–C(9)	1.499(5)
		C(9)–C(10)	1.518(5)
		C(10)–S(11)	1.822(4)
		S(12)–C(13)	1.798(4)

	11a	**23**		**11a**		**23**
N(2)–S(1)–C(6)	105.1(1)	104.6(1)	N(2)–C(3)–C(9)	120.6(2)	N(2)–C(3)–S(12)	122.7(2)
S(1)–N(2)–C(3)	119.2(2)	119.0(2)	S(4)–C(3)–C(9)	116.5(1)	S(4)–C(3)–S(12)	110.9(1)
N(2)–C(3)–S(4)	122.9(2)	126.4(2)	S(4)–C(5)–C(7)	114.9(2)	S(4)–C(5)–S(7)	113.7(1)
C(3)–S(4)–C(5)	100.5(1)	99.5(1)	C(6)–C(5)–C(7)	125.2(2)	C(6)–C(5)–S(7)	126.3(2)
S(4)–C(5)–C(6)	119.9(2)	119.8(2)	C(5)–C(6)–C(8)	124.9(3)	C(5)–C(6)–S(11)	125.7(2)
S(1)–C(6)–C(5)	119.5(2)	121.6(2)	S(1)–C(6)–C(8)	115.3(2)	S(1)–C(6)–S(11)	112.5(1)
C(3)–C(9)–C(10)	119.8(2)	—	C(11)–C(12)–O(15)	115.6(2)	C(5)–S(7)–C(8)	103.9(1)
C(3)–C(9)–C(14)	122.3(2)	—	C(13)–C(12)–O(15)	124.6(2)	S(7)–C(8)–C(9)	116.1(2)
C(10)–C(9)–C(14)	117.9(2)	—	C(12)–C(13)–C(14)	119.3(2)	C(8)–C(9)–C(10)	114.9(3)
C(9)–C(10)–C(11)	120.8(2)	—	C(13)–C(14)–C(9)	121.8(2)	C(9)–C(10)–S(11)	117.0(3)
C(10)–C(11)–C(12)	120.3(2)	—	C(12)–O(15)–C(16)	117.6(2)	C(10)–S(11)–C(6)	104.1(2)
C(11)–C(12)–C(13)	119.8(2)	—				

[a] Benzene C–C min. 1.375(4) max. 1.399(3) average 1.384 Å.

Preparation of Dithiobenzoic Acid Salts **6a–d**.—These compounds were prepared using literature routes. Triethylammonium 4-methoxydithiobenzoate **6a**,[9] a brick-red powder (40%), m.p. 73–74 °C, was obtained from the reaction of carbon disulfide with 4-methoxybenzylmagnesium bromide. For compounds **6b–c** the reactants and optimum molar ratios were benzyl bromide derivative **5b** or **5c** (1 equiv.), sulfur (3 equiv.) and sodium (3 equiv.) in an excess of methanol, whereas the best yields of compound **6d** were obtained from compound **5d** (1 equiv.), sulfur (2 equiv.) and sodium (2 equiv.) in an excess of methanol, with work-up under nitrogen. There was obtained: piperidinium salt **6b**,[21] a brick-red powder (49%) m.p. 94–96 °C; triethylammonium salt **6c**,[21] a dark brown powder (39%) m.p. 67–69 °C; and

Table 7 Atomic co-ordinates (× 10^4) for compound **11a**

Atom	*x*	*y*	*z*
S(1)	8588(1)	5244(1)	2188(1)
N(2)	7402(1)	5262(2)	2283(3)
C(3)	6840(2)	6097(2)	1493(3)
S(4)	7233(1)	7260(1)	272(1)
C(5)	8357(2)	7659(2)	1645(3)
C(6)	8962(2)	6779(2)	2417(3)
C(7)	8523(3)	9009(3)	1918(6)
C(8)	9934(2)	7000(4)	3630(5)
C(9)	5811(1)	6142(2)	1553(3)
C(10)	5457(2)	5287(2)	2532(3)
C(11)	4508(2)	5333(2)	2640(3)
C(12)	3885(2)	6225(2)	1765(3)
C(13)	4212(2)	7049(2)	751(3)
C(14)	5173(2)	6998(2)	659(3)
O(15)	2970(1)	6211(2)	1997(2)
C(16)	2309(2)	7113(3)	1137(5)

Table 8 Atomic co-ordinates (× 10^4) for compound **23**

Atom	*x*	*y*	*z*
S(1)	1519(1)	4083(1)	3087(1)
S(4)	1227(1)	6170(1)	1433(1)
S(7)	3775(1)	8269(1)	2086(1)
S(11)	3794(1)	6186(1)	3941(1)
S(12)	1554(1)	3351(1)	420(1)
N(2)	1626(3)	3240(3)	2108(1)
C(3)	1492(3)	4097(3)	1452(2)
C(5)	2534(3)	6692(3)	2301(2)
C(6)	2581(3)	5828(3)	3023(2)
C(8)	3304(4)	9734(4)	2864(3)
C(9)	4021(4)	9497(4)	3748(3)
C(10)	3300(5)	8178(5)	4242(2)
C(13)	1549(5)	1279(4)	625(3)

triethylammonium salt **6d**,[22] a dark brown powder (27%), m.p. 78–80 °C.

When attempts were made to obtain compound **6c** as the piperidinium salt, 1-[4-bromophenyl(thiocarbonyl)]piperidine **12** was isolated instead (48% yield), m.p. 114–117 °C (from ethanol) (lit.,[23] 105–108 °C) (Found: M, 282.98991. $C_{12}H_{14}BrNS$ requires *M* 283.00301); $\delta_H(CDCl_3)$ 1.57 (2 H, d, *J* 4.8), 1.79 (4 H, t, *J* 6.2), 3.51 (2 H, t, *J* 5.3), 4.33 (2 H, t, *J* 4.6), 7.16 (2 H, d, *J* 8.4) and 7.48 (2 H, d, *J* 7.9); $\nu_{max}(C_4Cl_6$, mull)/cm^{-1} 2945, 1495, 1480, 1445, 1435, 1395, 1290, 1240, 1135 and 900.

Preparation of the Dithioesters **7a–d**: *General Procedure.*—A solution of 3-chlorobutan-2-one (11.7 g, 0.11 mmol) in dry dichloromethane (50 cm^3) was added dropwise over 0.8 h to a stirred solution of the salt **6** (53 mmol) in dry dichloromethane (250 cm^3) at 20 °C. After 22 h at 20 °C, solvent was removed under reduced pressure and the residue chromatographed on a silica column eluted with dichloromethane to yield the product as a viscous red oil, which was used in the next step without further purification. There was thus obtained: 3-oxobutan-2-yl 4-methoxydithiobenzoate **7a** (39%); 3-oxobutan-2-yl dithiobenzoate **7b** (86%); 3-oxobutan-2-yl 4-bromodithiobenzoate **7c** (74%); and 3-oxobutan-2-yl 4-nitrodithiobenzoate **7d** (42%). Analytical and spectroscopic data for **7a–d** are collated in Table 2.

Preparation of 1,3-*Dithiolium Cation Salts* **8a–d**: *General Procedure.*—A solution of the dithioester **7** (16.5 mmol) in dry chloroform (10 cm^3) was added dropwise with stirring over 0.3 h to conc. sulfuric acid (20 cm^3) at −20 °C. The solution was then stirred at between −15 and −5 °C for a further 2.5 h after which it was warmed to 20 °C and added dropwise to water (400 cm^3). Hexafluorophosphoric acid (60%; 15 cm^3) was then added with stirring. The resultant precipitate was extracted into dichloromethane (6 × 80 cm^3) and the combined organic layers were washed with water, dried ($MgSO_4$) and then partially evaporated under reduced pressure to a volume of *ca.* 100 cm^3. This solution was then added to ether (500 cm^3), with stirring, to produce a precipitate of salt **8**, which was filtered off and washed thoroughly with ether. No further purification was necessary. There was thus obtained: 2-(4-*methoxyphenyl*)-4,5-*dimethyl*-1,3-*dithiolium hexafluorophosphate* **8a** a yellow solid (79%), m.p. 214–217 °C; 4,5-*dimethyl*-2-*phenyl*-1,3-*dithiolium hexafluorophosphate* **8b** a cream solid (55%), m.p. 225–227 °C (decomp.); 2-(4-*bromophenyl*)-4,5-*dimethyl*-1,3-*dithiolium hexafluorophosphate* **8c** a bright yellow solid (87%), m.p. 208–209 °C (decomp.); 4,5-*dimethyl*-2-(4-*nitrophenyl*)-1,3-*dithiolium hexafluorophosphate* **8d** a pale orange solid (78%), m.p. 229–230 °C (decomp.). Analytical and spectroscopic data for salts **8a–d** are collated in Table 3. Literature procedures gave the dithiolium salts **13**,[24] **14**,[7e] **15**,[25] **16**,[26] **17**[27] and **18**,[26] starting from the corresponding thiones.

Preparation of the 1,4,2-*Dithiazines* **11a–d** *and* **19–24**. *General Procedure.*—To a stirred solution of the 1,3-dithiolium cation salt **8a–d**, or **13–18** (1.3 mmol) and iodine (0.84 g, 6.6 mmol) [0.17 g, (1.3 mmol) for compounds **13** and **18**] in acetonitrile (40 cm^3) was added dropwise ammonia solution (33%; 0.8 cm^3, 13 mmol) at 20 °C. After being stirred for 1.5 h, the solution was added to water (300 cm^3) and the resultant aqueous solution was extracted with dichloromethane (3 × 50 cm^3). The organic layers were combined, dried ($MgSO_4$) and evaporated under reduced pressure to give the crude product which was chromatographed on a silica column eluted with dichloromethane–hexane (1:1 v/v). There was thus obtained: 3-(4-*methoxyphenyl*)-5,6-*dimethyl*-1,4,2-*dithiazine* **11a** a yellow solid (56%), m.p. 56–58 °C; 5,6-*dimethyl*-3-*phenyl*-1,4,2-*dithiazine* **11b**, an orange oil (87%); 3-(4-*bromophenyl*)-5,6-*dimethyl*-1,4,2-*dithiazine* **11c**, a yellow solid (94%), m.p. 58–59 °C; 5,6-*dimethyl*-3-(4-*nitrophenyl*)-1,4,2-*dithiazine* **11d**, an orange–red solid (61%), m.p. 128–129 °C; 3-*methylthio*-1,4,2-*dithiazine* **19**, an orange oil (14%); 3-*methylthio*-5,6-*dimethyl*-1,4,2-*dithiazine* **20**, an orange solid (38%) m.p. 42–44 °C; 3,5,6-*tris*(*methylthio*)-1,4,2-*dithiazine* **21**, an orange oil (38%); 3-*methylthio*-6,7-*dihydro*[1,4]*dithiino*[2,3-e][1,4,2]*dithiazine* **22**, a yellow oil (54%); 3-*methylthio*-6,7,8-*trihydro*[1,4]*dithiepino*[2,3-e][1,4,2]*dithiazine* **23**, yellow crystals, m.p. 125–127 °C (from hexane–dichloromethane) (12%); and 6,7-*dihydro*[1,4]*dithiino*[2,3-e]-[1,4,2]*dithiazine* **24**, a yellow oil (25%). Analytical and spectroscopic data for **11a–d** and **19–24** are collated in Table 4.

X-*Ray Crystal Structure Analysis of Compounds* **11a** *and* **23**.—All X-ray measurements for compounds **11a** and **23** (see Table 5) were performed on a Siemens R3m/V four-circle diffractometer with graphite-monochromated Mo-Kα radiation (λ = 0.710 69 Å) at room temperature. Reflection intensities were measured by Wyckoff (limited ω) scan technique and corrected for absorption by semi-empirical method (based on ψ-scan method). The structures were solved by direct methods and refined by full-matrix least squares using SHELXTL PLUS set of programs.[28] All non-hydrogen atoms were refined anisotropically; all H-atoms were located from difference Fourier map and refined in isotropic approximation. Bond lengths and angles are listed in Table 6; atomic co-ordinates are listed in Tables 7 and 8. Additional material available from the Cambridge Crystallographic Data Centre comprises thermal parameters, H-atom co-ordinates and all bond lengths and angles.

Acknowledgements

We thank SERC for the award of a studentship (to G. R. D.) and the Royal Society for financial support (to A. S. B.).

References

1 Reviews: (*a*) R. T. Oakley, *Progr. Inorg. Chem.*, 1988, **36**, 299; (*b*) C. J. Moody, in *Comprehensive Heterocyclic Chemistry*, ed. A. R. Katritzky and C. W. Rees, Pergamon, Oxford, 1984, Vol. 3, p. 1039; (*c*) J. L. Morris and C. W. Rees, *Chem. Soc. Rev.*, 1986, **15**, 1.
2 Preliminary communication: M. R. Bryce, G. R. Davison, J. A. K. Howard and A. Batsanov, *J. Chem. Soc., Chem. Commun.*, 1992, 478.
3 (*a*) E. Fanghänel, *Z. Chem.*, 1965, **5**, 386; (*b*) E. Fanghänel, R. Ebisch and B. Alder, *Z. Chem.*, 1973, **13**, 431; (*c*) E. Fanghänel, *J. Prakt. Chem.*, 1976, **318**, 127; (*d*) E. Fanghänel, K.-H. Kuhnemund and A. M. Richter, *Synthesis*, 1983, 50; (*e*) for a review of 1,4,2-dithiazine chemistry, see E. Fanghänel and K.-D. Remmler, *Wiss. Z., Tech. Hochsch. Leuna-Merseberg*, 1987, **29**, 705 (*Chem. Abstr.*, 1988, **109**, 54680j).
4 (*a*) J. Nakayama, K. Fujiwara and M. Hoshino, *J. Org. Chem.*, 1980, **45**, 2024; (*b*) J. Nakayama, M. Ochiai, K. Kawada and M. Hoshino, *J. Chem. Soc., Perkin Trans. 1*, 1981, 618; (*c*) J. Nakayama, A. Sasaki, A. Tokiyama and M. Hoshino, *Tetrahedron Lett.*, 1983, **24**, 3729.
5 K. Yomemoto, I. Shibuya and K. Honda, *Bull. Chem. Soc. Jpn.*, 1988, **61**, 2232.
6 K. Yonemoto and I. Shibuya, *Chem. Lett.*, 1989, 89.
7 (*a*) D. Leaver, W. A. H. Robertson and D. M. McKinnon, *J. Chem. Soc.*, 1962, 5104; (*b*) J.-M. Fabre, E. Torreilles and L. Giral, *Tetrahedron Lett.*, 1978, **39**, 3703; (*c*) M. R. Bryce, *J. Chem. Soc., Perkin Trans. 1*, 1985, 1675; (*d*) M. R. Bryce and A. J. Moore, *Tetrahedron Lett.*, 1988, **29**, 1075; (*e*) A. J. Moore and M. R. Bryce, *J. Chem. Soc., Perkin Trans. 1*, 1991, 157.
8 R. C. Cookson and S. R. Wallis, *J. Chem. Soc. B*, 1966, 1253.
9 R. W. Bost and O. L. Shealy, *J. Am. Chem. Soc.*, 1951, **73**, 25.
10 F. Becke and H. Hagan, *G.P.*, 1274121 1968, (*Chem. Abstr.*, 1969, **70**, 3573v).
11 R. J. Abraham, J. Fisher and P. Loftus, *Introduction to NMR Spectroscopy*, Wiley, Chichester, 1988, p. 55.
12 E. Fanghänel and H. Poleschner, *J. Prakt. Chem.*, 1981, **323**, 1.
13 P. G. Gassman, *Acc. Chem. Res.*, 1970, **3**, 26.
14 K. Hirai, H. Sugimoto and T. Ishiba, *Sulfur Rep.*, 1983, **3**, 1.
15 P. A. Howell, R. M. Curtis and W. N. Lipscomb, *Acta Crystallogr.*, 1954, **7**, 498.
16 W. Dollase, *J. Am. Chem. Soc.*, 1965, **87**, 979.
17 F. H. Allen, O. Kennard, D. G. Watson, L. Brammer, A. G. Orpen and R. Taylor, *J. Chem. Soc., Perkin Trans. 2*, 1987, S1.
18 A. Bondi, *J. Phys. Chem.*, 1964, **68**, 441.
19 S. Hünig and H. Berneth, *Top. Curr. Chem.*, 1980, **92**, 1.
20 K. Kobayashi and C. L. Gajural, *Sulfur Rep.*, 1986, **7**, 123, and references therein.
21 S. Kato, T. Mitani and M. Mizuta, *Int. J. Sulfur Chem.*, 1973, **8**, 359.
22 R. Mayer, H. Viola, J. Reichert and W. Krause, *J. Prakt. Chem.*, 1978, **320**, 313.
23 L. M. Werbel, *J. Heterocycl. Chem.*, 1979, **16**, 881.
24 F. Challenger, E. A. Mason, E. C. Holdsworth and R. Emmott, *J. Chem. Soc.*, 1953, 292.
25 G. C. Papavassiliou, J. S. Zambounis and S. Y. Yiannopoulos, *Chem. Scr.*, 1987, **27**, 261.
26 A. J. Moore and M. R. Bryce, *Synthesis*, 1991, 26.
27 A. J. Moore and M. R. Bryce, *Tetrahedron Lett.*, 1992, **33**, 1373.
28 G. M. Sheldrick, SHELXTL PLUS, Göttingen and Seimens PLC, 1990.

Paper 2/02726G
Received 26th *May* 1992
Accepted 3rd *June* 1992