Diels–Alder and Ene Reactions of New Transient Thionitrosoarenes (Ar–N=S) and Thionitrosoheteroarenes (Het–N=S) Generated from *N*-(Arylaminosulfanyl)- and *N*-(Heteroarylaminosulfanyl)-phthalimides: Synthesis of Cyclic and Acyclic Sulfenamides

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A series of new *N*-(arylaminosulfanyl)- and *N*-(heteroarylaminosulfanyl)-phthalimide derivatives **3i–m** and **3o–r**, has been prepared by reaction of chlorosulfanylphthalimide with the trimethylsilyl derivative of the appropriate arylamine or heteroarylamine. On treatment with triethylamine at room temperature, most of these compounds **3** fragment to yield transient thionitroso species, Ar–N=S and Het–N=S, **4**, which have been intercepted, generally in good yield, with conjugated dienes (2,3-dimethylbuta-1,3-diene, isoprene, chloroprene and penta-1,3-diene) to yield cyclic 1,2-thiazine Diels–Alder adducts, and with alkenes (1-methylcyclohexene, α-pinene and β-pinene) to yield acyclic ene adducts. Competitive Diels–Alder and ene addition is observed with dimethylbutadiene and isoprene. The regiochemistry of addition of unsymmetrical dienes to thionitroso species has been elucidated. Sulfilimine **24** rearranges quantitatively to the dihydrothiophene derivative **27**, thereby excluding compounds **24** as intermediates in the formation of 1,2-thiazine adducts **5**.

Thionitrosoarenes, ArN=S, have been generated as transient species in a few laboratories, with evidence for their intermediacy being obtained from trapping reactions with conjugated dienes[1–5] and alkenes,[5] or from direct spectroscopic observation at low temperatures.[6] Alkyl-,[7] acyl-[8] and sulfonyl[8]-thionitroso derivatives have also been reported to be highly reactive intermediates which could be intercepted. The only thionitroso compounds to have been isolated are dithionitrites, R–S–N=S[9a] and *N*-(thionitroso)amines, R_2N–N=S;[9b,c] the latter compounds are stable at < *ca.* −30 °C and spectroscopic data showed a significant contribution from the dipolar structure R_2N^+=N–S^- which would explain this relative stability.[9b]

We have recently developed an expedient route to thionitrosoarenes **4**, *viz.* the base-induced fragmentation at room temperature of *N*-(arylaminosulfanyl)phthalimides **3** (Scheme 1).[5] A range of derivatives **4a–h** was captured, generally in good yield, with symmetrical dienes [*e.g.* butadiene, 2,3-dimethylbutadiene, (*E*,*E*)- and (*E*,*Z*)-hexadienes] and with alkenes (*e.g.* α-methylstyrene and isobutene).[5] The following features of these reactions are relevant to the present work.

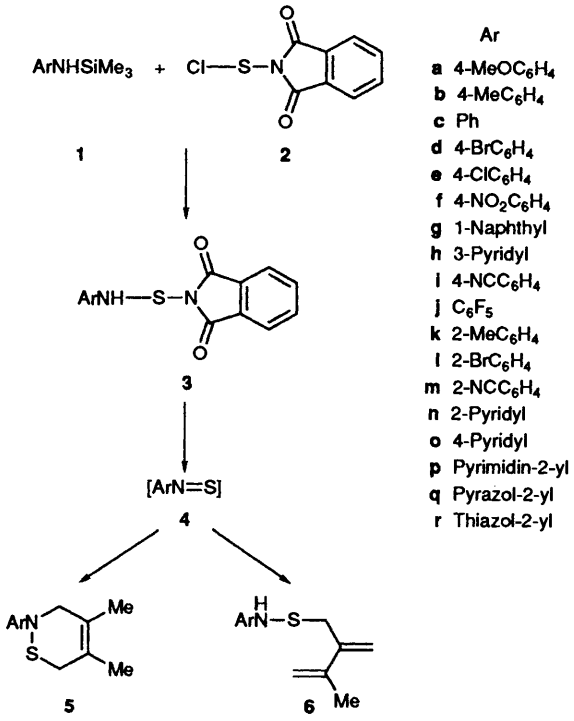
(i) Diels–Alder and ene products, **5** and **6**, respectively, were formed in competition when dimethylbutadiene was used as the trap. (ii) The ratio of Diels–Alder to ene products **5**:**6**, was very sensitive to the electronic properties of the aryl substituent attached to the thionitroso group. Electron-donating substituents on the benzene ring (*e.g.* methoxy derivative **4a**) favoured Diels–Alder reaction, while electron-withdrawing substituents (*e.g.* nitro derivative **4f**) favoured ene reaction. (iii) Ene reactions of ArN=S proceeded regiospecifically with S–C bond formation, which is the same regiospecificity that other workers had found previously for acyl- and sulfonyl-thionitroso-compounds.[8]

In this paper we continue to explore fundamental aspects of the chemistry of thionitroso compounds. In particular we will describe: (i) the generation and interception of new thionitrosoarene and -heteroarene derivatives; (ii) a study of the regiochemistry of addition of unsymmetrical dienes to ArN=S species.

The new thionitrosoarenes **4i–r** were selected as targets for the following reasons. Compounds **4i** and **4j**, which bear electron-withdrawing substituents on the aryl ring, should undergo ene reactions in preference to Diels–Alder reaction [*cf.* derivatives **4d–f**][5a,c] and so yield new sulfenamide products **6**, the chemistry of which we intend to explore. Indeed, it was hoped that the highly electron-deficient pentafluoro derivative **4j** might afford product **6j** exclusively, and so enable us, for the first time, to isolate a pure sample of the sulfenamide systems **6** uncontaminated by the isomeric Diels–Alder product **5**. Compounds **4k–m** were chosen with a view to comparing these derivatives with their *para*-isomers **4b**,[5] **4d**[5] and **4i** in trapping reactions; steric effects arising from a substituent *ortho* to the thionitroso functionality could thus be probed for the first time. 3-Thionitrosopyridine **4h** was, hitherto, the only heterocyclic thionitroso compound to have been reported.[5c] It was, therefore, of basic interest to establish whether or not the methodology outlined in Scheme 1 would provide a general route to heterocyclic thionitroso compounds. For this purpose derivatives **4n–r** were our targets, for which the starting amines were readily available.

Results and Discussion

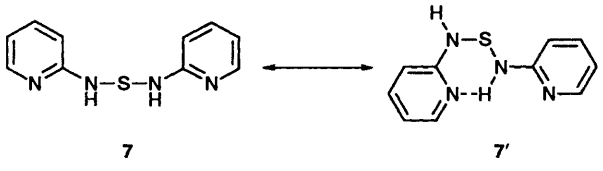
Preparation of the Sulfenamides **3i–r**.—The new sulfenamide derivatives **3i–n** and **3p–r** were obtained by reaction of equimolar quantities of chlorosulfanylphthalmide **2** with the trimethylsilyl derivative of the appropriate arylamine **1**, in dry chloroform at 0–20 °C, using the procedure described previously for derivatives **3a–h**.[5c] Isolation of compounds **3** was straightforward as they readily precipitated out of the reaction mixture, and were then allowed to react in the next step with no need for further purification. In keeping with our previous results,[5c] it was very difficult to obtain compounds **3i–r** analytically pure (indeed, the pyrimidin-2-yl derivative **3p** was the only new member of the series to give satisfactory C, H, N analytical data). Proof of structures of compounds **3** was further complicated by the absence of the parent ion in the mass spectrum (obtained in both EI and CI mode). The identity of most of the derivatives **3** rests, therefore, upon IR and NMR spectroscopic data, which were



Scheme 1

wholly consistent with the assigned structures in all cases.

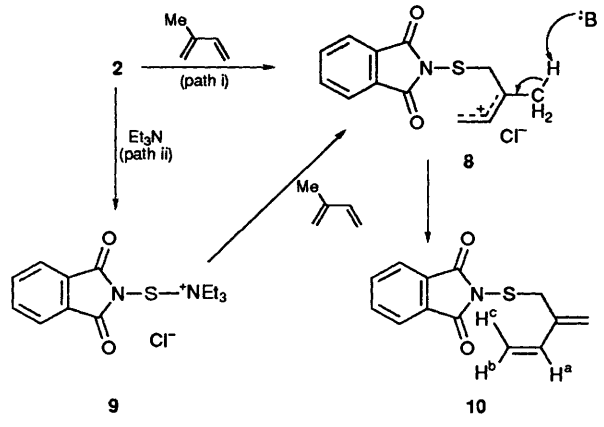
Unexpected results obtained during the synthesis of the 2-pyridyl derivative **3n** are noteworthy. This compound was obtained in only 15% yield from the silylated amine and reagent **2**; however, **3n** was obtained in *ca.* 30% yield from reagent **2** and 2-aminopyridine, *without silylation*; this is the only example from the series of compounds **3a–r** where this occurred. On one occasion, reaction of 2-aminopyridine and chlorosulfanylphthalmide cleanly yielded bis(2-aminopyridyl) sulfide **7** (28%) (NMR, IR and HRMS evidence) instead of **3n**. Compound **7**



was isolated as an air- and moisture-stable solid, which is in marked contrast to the known instability of other di(aminoaryl) sulfides.[1] The stability of **7** can be explained by hydrogen bonding between the amine hydrogen and the nitrogen atom of the pyridine ring (structure **7′**). We considered that the presence of unchanged *N,N′*-dithiobis(phthalimide) as an impurity in the sample of chlorosulfanylphthalimide might have resulted in the formation of **7**, but evidence against this proposition was obtained when no reaction was observed between pyridin-2-amine and pure *N,N′*-dithiobis(phthalimide) under identical conditions. Alternatively, compound **7** could be formed by reaction of pyridin-2-amine with **3n** under the reaction conditions. We have not explored this anomalous reaction any further, as compound **7** did not serve as a precursor of 2-thionitrosopyridine **4n** when thermolysed or treated with triethylamine in the presence of 2,3-dimethylbutadiene (no adducts were obtained) although the mass spectrum of **7** showed a fragment (*m/z* 124) corresponding to thionitroso species **4n**.

We have been unable to isolate the 4-pyridyl derivative **3o**. The reaction of 1,1,1-trimethyl-2-(4-pyridyl)silazane **1o** with the sulfenyl chloride **2** consistently failed to yield the desired product **3o**; the resulting complex product mixture could not be purified. We considered that sulfenamide derivative **3o** might be unstable to deprotonation by reaction with the basic ring nitrogen of a pyridine species present in the mixture. We therefore attempted to prepare **3o**, and to generate and trap **4o** derived therefrom, *in situ*! Accordingly, a mixture of the silylated amine **1o**, sulfenyl chloride **2**, triethylamine and isoprene was stirred at room temperature overnight. Work-up afforded the unexpected new compound **10** (15%) as the only isolated product: no pyridine-containing product was obtained. The structure of **10** followed simply and unambiguously from elemental analysis, mass, IR and NMR spectroscopic data. In subsequent experiments we (i) reproduced this yield of product **10**; (ii) established that product **10** was *not* formed in the absence of silylated amine **1o**; and (iii) failed to isolate products analogous to **10** when isoprene was replaced by dimethylbutadiene or by α-methylstyrene.

Two possible mechanisms for the formation of compound **10** are presented in Scheme 2. We think it is unlikely that the



Scheme 2

sulfenyl chloride **2** reacts directly with isoprene to form the intermediate **8** [path (i)]. There are examples of the addition of alkenesulfenyl chlorides (but these would be considerably more reactive than chlorosulfanylphthalimide) to certain dienes (not isoprene) under similar conditions.[10] We favour the alternative path (ii) in which the sulfur atom is activated to S–C bond formation by initial nucleophilic attack of triethylamine on the sulfenyl chloride **2**. Salt **9**, thus produced, could then react with C-1 of isoprene to yield the stabilised alkyl cation **8** which, on deprotonation, would afford the product **10**. Attempts to isolate the salt **9** failed, although a distinct colour change (from yellow to orange) was observed when triethylamine was added dropwise to a chloroform solution containing only chlorosulfanylphthalmide **2**. The role of reagent **1o** in the formation of product **10** is mysterious; it may simply act as a base for the final deprotonation **8**→**10**, or as a scavenger for the chloride ion produced, *via* formation of trimethylsilyl chloride.

Generation of New Thionitrosoarenes and Thionitrosoheteroarenes: Trapping Reactions with 2,3-Dimethylbutadiene.—Following procedures described previously for compounds **3a–h**,[5] precursors **3i–n** and **3p–r** were suspended in acetone at room temperature and an excess of triethylamine and diene or alkene trap were added to the suspensions. In this way, the new thionitroso compounds, **4i**, **4k–n** and **4p–r** were generated and intercepted in various yields. Adducts were formed from 2,3-dimethylbutadiene addition to pyrimidin-2-yl and pyrazol-2-yl-thionitroso derivatives **4p** and **4q**, respectively, in only very low yields (*ca.* 15%) and, although they were clearly identified in the crude product mixture (NMR and mass spectroscopic

Table 1 Properties of *N*-(arylaminosulfanyl)phthalimides **3**

Compound formula	Yield (%) [m.p. (°C)]	ν_{max}/cm^{-1} (KBr)	$\delta_H(CDCl_3; 250\ MHz)$
3i	23	3320 (NH)	7.9–7.7 (4 H, m, P)[a]
$C_{15}H_9N_3O_2S$	[177]	1780 (CO)	7.4–7.3 (4 H, m, Ar)[b]
		1730 (CO)	6.5 (1 H, s, NH)
3j	40	3310 (NH)	7.9–7.7 (4 H, m, P)
$C_{14}H_5F_5N_2O_2S$	[192–195]	1795 (CO)	5.96 (1 H, s, NH)
		1750 (CO)	
3k	74	3330 (NH)	8.12–7.97 (4 H, m, P)
$C_{15}H_{12}N_2O_2S$	[192–195]	1785 (CO)	7.52–7.09 (4 H, m, Ar)
		1730 (CO)	6.60 (1 H, s, NH)
			2.30 (3 H, s, Me)
3l	26	3290 (NH)	8.1 (1 H, m, Ar)
$C_{14}H_9BrN_2O_2S$	[150–153]	1785 (CO)	7.9–7.7 (4 H, m, P)
		1730 (CO)	7.4–7.3 (2 H, m, Ar)
			6.9–6.8 (2 H, m, Ar + NH)
3m	64	3360 (NH)	8.3 (1 H, m, Ar)
$C_{15}H_9N_3O_2S$	[221–223]	1790 (CO)	7.9–7.8 (4 H, m, P)
		1739 (CO)	7.6 (1 H, m, Ar)
			7.4 (1 H, m, Ar)
			7.0 (2 H, m, Ar + NH)
3n	15–30	3420 (NH)	8.4 (8 H, m, P + Ar)
$C_{13}H_9N_3O_2S$	[148]	1785 (CO)	7.0 (1 H, s, NH)
		1750 (CO)	
3p	85	3120 (NH)	8.65 (2 H, d, *J* 5.0, Het)[c]
$C_{12}H_8N_4O_2S$[d]	[187–188]	1780 (CO)	8.48 (1 H, s, NH)
		1735 (CO)	7.48 (4 H, m, P)
			6.93 (1 H, t, *J* 5.0, Het)
3q	50	3400 (NH)	9.25 (1 H, s, Het)
$C_{12}H_8N_4O_2S$	[174]	1785 (CO)	8.6–8.2 (2 H, m, Het)
		1730 (CO)	7.8–7.6 (4 H, m, P)
			7.4 (1 H, s, NH)
3r	89	1780 (CO)	8.50 (4 H, m, P)
$C_{11}H_7N_3O_2S_2$[e]	[>230]	1730 (CO)	7.70 (1 H, m, Het)
		(NH absent)	7.50 (1 H, m, Het)

[a] P refers to hydrogen atoms on the phthalimide ring of formula **3**. [b] Ar refers to hydrogen atoms on the substituent Ar or formula **3**. [c] Het refers to hydrogen atoms on the heterocyclic substituent Ar of formula **3**. [d] Found: C, 52.4; H, 2.8; N, 20.5. $C_{12}H_8N_4O_2S$ requires C, 52.9; H, 3.0; N, 20.6%. [e] Found: C, 46.9; H, 2.5; N, 15.2. $C_{11}H_7N_3O_2S$ requires C, 47.7; H, 2.5; N, 15.2%.

evidence), they decomposed on attempted purification by chromatography; both Diels–Alder and ene adducts were present. The pentafluorobenzene derivative **4j** has, however, remained elusive; no products derived from this intermediate were obtained from attempted trapping with dimethylbutadiene. It has become apparent, therefore, that compounds **3** which bear strongly electron-withdrawing aryl or heteroaryl groups (*viz.* **3j**, **3p** and **3q**) are unsuitable for the generation of thionitroso species. This is consistent with our previous observation that another highly electron-deficient analogue, MeC(O)N=S, was not accessible *via* this route,[5c] although it is known from other workers that acyl- and sulfonyl-N=S species, prepared by an entirely different route, can be cleanly trapped.[8]

The new thionitroso derivatives **4i** and **4k–n** and **4r** were, however, trapped cleanly and efficiently by dimethylbutadiene (Table 2). The relatively electron-withdrawing 4-cyano- and 2-pyridyl-substituents on **4i** and **4n**, respectively, predictably control the course of reaction to favour formation of ene products **6** over Diels–Alder products **5**, in accord with previous results with systems **4a–h**.[5c] 2-Thionitrosothiazole **4r** was trapped in 60% yield: ene adduct **6r** predominated over Diels–Alder isomer **5r** (4:1 ratio) implying that **4r** behaves as an electron-deficient thionitroso species. It is notable that 2-methylthionitrosobenzene **4k** also gave predominantly the ene product **6k** (the ratio of **5k**:**6k** was 1:2). This is in marked contrast to the product distribution observed for the 4-methyl isomer **4b** (the ratio of **5b**:**6b** was 3:2).[5c] Compounds **4l** and **4m**, which also carry a substituent *ortho* to the N=S group, also gave a significantly higher proportion of ene adduct than their *para* substituted isomers. The results obtained with **4k–m** provide clear evidence that steric effects, as well as electronic effects, can influence the ratio of Diels–Alder:ene adducts that are formed in competition when a thionitroso group is intercepted by a conjugated diene. (Previously we had tentatively suggested that steric effects were contributing to the isomer distribution obtained from 1-naphthyl derivative **4g**, which yielded **5g** and **6g** in a 9:11 ratio.[5a,c]) The predominance of ene adducts from *ortho*-substituted thionitrosobenzenes generated from precursors **3k–m** led us to repeat earlier work[4] in which only Diels–Alder adducts with dimethylbutadiene had been identified from trapping *ortho*-cyanothionitrosobenzenes, generated by fragmentation of 3-azido-2,1-benzoisothiazoles. We established that the ene adducts had previously been overlooked in this reaction and they were, in fact, formed in preference to the Diels–Alder isomers.[5d] It is now clear, therefore, that irrespective of the mode of generation of the thionitrosobenzene derivative, an *ortho* substituent on the benzene ring leads to an increased proportion of ene adduct in the product mixture.

We have investigated the trapping of thionitrosobenzene derivatives **4a**, **4b** and **4d** with dimethylbutadiene in a range of solvents, namely, dimethylformamide, acetonitrile, acetone, chloroform and toluene, and established that for each derivative the polarity of the solvent exerts an effect upon the ratio of adducts obtained (Table 3). The more polar solvents favour the formation of the ene adduct over the Diels–Alder adduct. This can be explained by postulating a more polar transition state for the ene adduct than for the Diels–Alder adduct.

Ene Reaction of Thionitrosoarenes.—We next turned our attention to new ene reactions of thionitrosoarenes with

Table 2 Properties of the Diels–Alder adducts **5** and ene adducts **6** from dimethylbutadiene addition to thionitroso compounds **4**

Thionitroso compound **4**	Combined yield of adducts **5** + **6**	Isomer ratio	$\delta(CDCl_3$; 250 MHz/ ppm, excluding aromatics)	M^+ Found (Required)
4i	65%	**5i** (20%)	3.90 (2 H, s, CH_2N) 2.93 (2 H, s, CH_2S) 1.58 (6 H, s, 2 × CH_3)	230.0848 (230.0877)
		6i (80%)	5.2–4.7 (5 H, m, 2 × $=CH_2$ + NH) 3.39 (2 H, s, CH_2S) 1.80 (3 H, s, CH_3)	
4k	50%	**5k** (45%)	3.75 (2 H, m, CH_2N) 2.85 (2 H, m, CH_2S) 2.30 (3 H, s, $ArCH_3$) 1.70 (3 H, s, CH_3) 1.60 (3 H, s, CH_3)	219.1052 (219.1082)
		6k (55%)	5.2–4.7 (5 H, m, 2 × $=CH_2$ + NH) 3.44 (2 H, s, CH_2S) 2.38 (3 H, s, $ArCH_3$) 1.90 (3 H, s, CH_3)	
4l	80%	**5l** (12%)	3.75 (2 H, m, CH_2N) 2.80 (1 H, m, CH_2S) 1.75 (3 H, s, CH_3) 1.60 (3 H, s, CH_3)	254.9777 (245.9717, for ^{79}Br)
		6l (88%)	5.40 (1 H, s, NH) 5.1–4.7 (4 H, m, 2 × $=CH_2$) 3.37 (2 H, s, CH_2S) 1.85 (3 H, s, CH_3)	
4m	58%	**5m** (9%)	3.84 (2 H, m, CH_2N) 2.95 (1 H, m, CH_2S) 1.69 (3 H, s, CH_3) 1.64 (3 H, s, CH_3)	230.0370 (230.0877)
		6m (91%)	5.50 (1 H, s, NH) 5.1–4.8 (4 H, m, 2 × $=CH_2$) 3.43 (2 H, s, CH_2S) 1.83 (3 H, s, CH_3)	
4n	65%	**5n** (60%)	4.40 (2 H, m, CH_2N) 3.05 (2 H, m, CH_2S) 1.70 (6 H, s, 2 × CH_3)	206.0877 (206.0763)
		6n (40%)	6.50 (1 H, s, NH) 5.2–4.8 (4 H, m, 2 × $=CH_2$) 3.55 (2 H, s, CH_2S) 1.87 (3 H, s, CH_3)	
4r	60%	**5r** (20%)	4.24 (2 H, m, CH_2N) 3.10 (1 H, m, CH_2S) 1.65 (3 H, s, CH_3) 1.50 (3 H, s, CH_3)	212.0362 (212.0442)
		6r (80%)	5.1–4.9 (5 H, m, 2 × $=CH_2$ + NH) 3.60 (2 H, m, CH_2S) 1.80 (3 H, s, CH_3)	

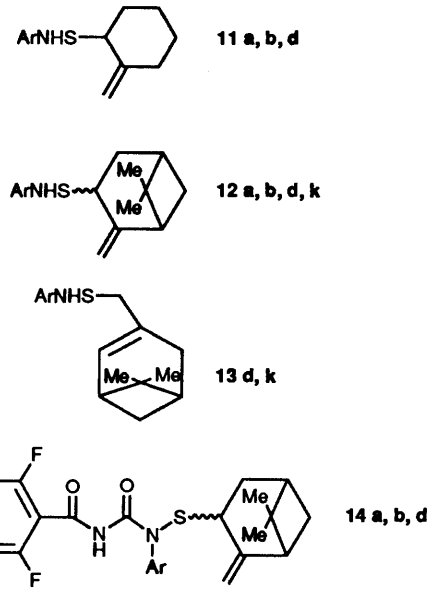
Table 3 Ratio of the adducts **5** and **6** for dimethylbutadiene addition to thionitroso compounds **4** in various solvents.

Thionitroso Compound	4-$MeOC_6H_4N$=S **4a**	4-MeC_6H_4N=S **4b**	4-BrC_6H_4N=S **4d**
Adducts	**5a**:**6a**	**5b**:**6b**	**5d**:**6d**
Solvent			
Dimethylformamide	80:20	55:45	23:77
Acetonitrile	83:17	59:41	25:75
Acetone[a]	85:15	60:40	25:75
Chloroform	85:15	70:30	35:65
Toluene	88:12	76:24	50:50

[a] Ref. 5*c*.

alkenes. Hitherto, the only alkenes known to react with ArN=S species were α-methylstyrene and isobutene.[5a,c] We now report that 1-methylcyclohexene, α-pinene and β-pinene all react with thionitrosoarenes; sulfenamides **11**–**13**, respectively, were thereby obtained, typically in 50–80% yields. Cyclohexene was unreactive under the same conditions. The successful reactions of ArN=S with β-pinene are especially noteworthy. This is the first exocyclic methylene group to participate in an ene reaction of a thionitroso species; Meth-Cohn and van Vuuren reported that β-pinene gave no defined adducts with thionitrosoformates and -sulfonates under conditions where a range of alkenes (including cyclohexene) reacted cleanly.[8] (β-Pinene is known to react in this way with the N=S bond of sulfonyl sulfinyl amines, $ArSO_2N$=S=O).[11] The regiochemistry of these new ene reactions to ArN=S, which proceed exclusively with C–S bond formation (IR and NMR evidence) is the same as all other reported ene reactions of thionitroso compounds.[5,8]

The ene adducts **11**–**13** are oils which gradually decompose

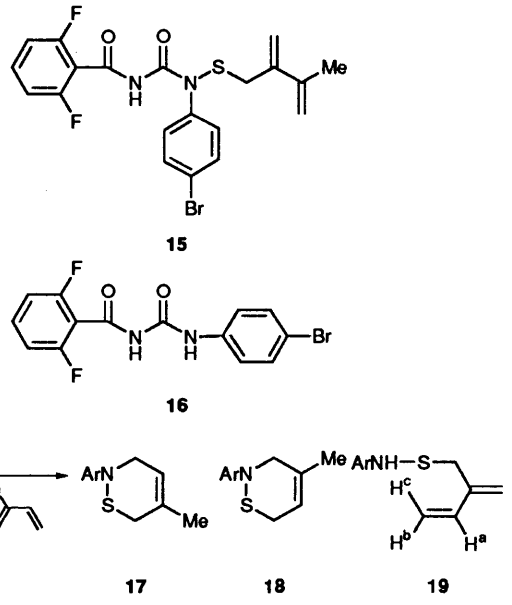


For **a**, **b**, **d**, **k** see Scheme 1

upon storage at room temperature, and with a view to assisting their isolation and purification we investigated derivatisation of the sulfenamide NH group. Attempted reactions with acetyl chloride, benzoyl chloride or phenyl isocyanate failed to yield isolable products. However, when 2,6-difluorobenzoyl isocyanate was added to a solution of the α-pinene adducts **12a**, **12b** and **12d**, the derivatised products **14a**, **14b** and **14d**, respectively, were isolated as shelf-stable solids in low yields. Similar reaction of 2,6-difluorobenzoyl isocyanate with crude mixtures of Diels–Alder and ene adducts **5a**/**6a**, **5b**/**6b** and **5d**/**6d** allowed the Diels–Alder adducts **5a**, **5b** and **5d** to be isolated pure after column chromatography. The derivatised ene adduct **15** was also isolated in the last case; ^{1}H NMR spectra showed that compound **16** was also present, resulting from N–S bond cleavage and loss of a thiol fragment.

Reactions of Unsymmetrical Dienes with Thionitrosoarenes.—Reactions of thionitrosoarenes with unsymmetrical dienes have not been investigated previously. With the aim of examining the regioselectivity of the Diels–Alder reaction we chose initially to compare the reactivity of the (relatively) electron-rich methoxyphenyl- and methylphenyl-derivatives **4a** and **4b**, with the more electron-deficient bromophenyl- and 3-pyridyl-derivatives **4d** and **4h** in reactions with isoprene, chloroprene and penta-1,3-diene. If thionitrosoarenes were to react with isoprene in the fashion of sulfinyl amines, sulfodiimides or chalcogenoaldehydes and -ketones, then 5-substituted thiazines **17** should be the major product with electron-deficient dienophiles, whereas the 4-substituted thiazines **18** should predominate with electron-rich dienophiles.[12] Nitroso analogues are rather unpredictable in this respect.[12] Meth-Cohn and van Vuuren reported no regioselectivity in the reaction of isoprene with the highly electron-deficient phenyl thionitrosoformate $PhCO_2N$=S; a 1:1 mixture of 4- and 5-substituted thiazines was obtained (alongside the ene product).[8]

Thionitrosoarenes **4a**, **4b**, **4d** and **4h** were generated and trapped with isoprene under conditions identical with those used for reaction with dimethylbutadiene.[5] In each case ^{1}H NMR analysis of the crude reaction mixture showed the presence of the three expected products, which could not be separated by chromatography: these were the two regioisomeric Diels–Alder adducts **17** and **18**, plus the ene adducts **19**, formed in the ratios shown (Scheme 3). Two points were clearly apparent from the NMR spectra. Firstly, formation of the 5-



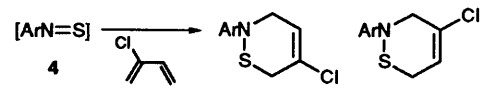
ArN=S species	Combined yield 17 + 18 + 19	Product ratio 17	18	19
4a	60	65	22	13
4b	60	50	16	34
4d	55	25	8	67
4h	60	26	9	65

Scheme 3

substituted isomer **17** is significantly favoured over the 4-substituted isomer **18** to the same extent (*ca.* 3:1 ratio) with all four thionitrosoarenes studied. Secondly, the Diels–Alder products **17** and **18** predominate over the ene product **19** for the more electron-rich derivatives **4a** and **4b**, but this situation is reversed for the more electron-deficient derivatives **4d** and **4h**: this is entirely consistent with the pattern of dimethylbutadiene addition to the same thionitrosoarenes.[5]

The structures of the two regioisomers **17** and **18** were assigned from ^{1}H NMR data by comparison with the spectra of the corresponding butadiene and 2,3-dimethylbutadiene adducts which we had analysed previously.[5] For the 5-substituted dihydrothiazines **17**, the 6-methylene group is in a similar environment to that of the dimethylbutadiene adducts[5] (*i.e.* there is a methyl group on the adjacent carbon C-5) whereas the 3-methylene group of isomer **17** is similar to that of the butadiene adducts (*i.e.* no methyl group on the adjacent carbon C-4). This situation is reversed in the 4-substituted regioisomers **18**. The methylene signals in the butadiene adducts are consistently seen downfield (by *ca.* 0.1 ppm) of those in the corresponding dimethylbutadiene adducts.[5] Hence, the resonances at higher chemical shift values in the isoprene adducts (δ_H 4.0 and 3.0) are from CH_2N and CH_2S groups, respectively, with no substituent on the adjacent carbon, while those resonances further upfield (δ_H 3.9 and 2.9) are from CH_2N and CH_2S groups, respectively, with a methyl substituent on the adjacent carbon. A COSY spectrum of the product mixture from reaction of **4d** and isoprene confirmed the presence of three separate sets of signals arising from three different products (*viz.* **17d**, **18d** and **19d**) in the mixture.

Thionitroso compounds **4a**, **4b** and **4d** each reacted with chloroprene to yield 1,2-thiazine adducts **20** and **21** in high yield. The ratios of regioisomeric adducts are shown in Scheme 4. There was no regioselectivity in the reactions of **4a** and **4b**. In contrast to this, 4-bromophenyl derivative **4d** afforded a major



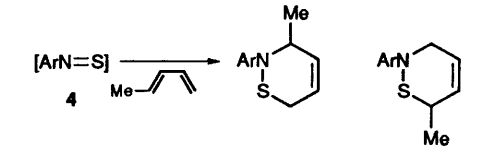
20 **21**

ArN=S species	Combined yield (%) **20** + **21**	Product ratio **20**:**21**
4a	60	1:1
4b	50	1:1
4d	30	1:2

Scheme 4

and minor isomer in a 2:1 ratio. Structural assignments were simplified as the two regioisomeric adducts formed from **4b** and **4d** could be cleanly separated by column chromatography. Two overlapping multiplets in the ^{1}H NMR spectra, at δ_H *ca.* 6.0, were assigned to the vinylic protons, whereas the peaks at δ_H 4.2 and 3.2, were assigned to the CH_2N and CH_2S protons, respectively, with no distinction in chemical shift values between the two regioisomers. ^{1}H NMR Decoupling experiments were performed on the pure isomers **20d** and **21d**. The spectrum of the major isomer showed a multiplet at δ_H 6.16: when the CH_2N protons at δ_H 4.2 were decoupled, the multiplet collapsed into a triplet, J 4.4 Hz, whereas when the CH_2S protons at δ_H 3.2 were decoupled, the coupling constant of the resulting triplet at δ_H 6.16 was J 1.6 Hz. Therefore, the multiplet at δ_H 6.16 was assigned to the vinylic proton adjacent to CH_2S, because a smaller coupling constant resulted when these protons were decoupled. Therefore, the major isomer is 4-chloro derivative **21**. Conversely, when the septet at δ_H 6.05 for the minor isomer was decoupled at δ_H 3.2, it collapsed to a triplet, J 3.5 Hz, and when decoupled at δ_H 4.2 it collapsed to a triplet, J 1.5 Hz. Therefore, the minor isomer is the 5-chloro derivative **20**.

We have also studied the reaction of penta-1,3-diene with thionitrosoarenes. Kresze and Wagner established that cycloadditions of *N*-sulfinyltoluene-*p*-sulfonamide, Ts–N=S=O, with 1-substituted 1,3-dienes (including penta-1,3-diene) are often dependent upon the reaction temperature.[13] At low temperatures, 3-substituted dihydrothiazine *S*-oxides are usually formed, while at higher temperatures, under conditions of thermodynamic control, the less sterically crowded 6-substituted isomers are produced.[13] The thionitrosoarenes **4a**, **4b** and **4d** reacted with penta-1,3-diene at 20 °C to yield mixtures of 3- and 6-substituted dihydrothiazines **22** and **23**, respectively, in the ratios shown in Scheme 5 (no ene adducts were detected).



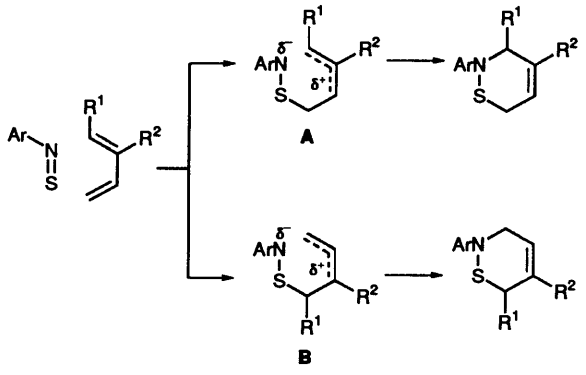
22 **23**

ArN=S species	Combined yield (%) **22** + **23**	Product ratio **22**:**23**
4a	70	3:1
4b	70	3:1
4d	70	2:1

Scheme 5

Isomer ratios were determined from the integrals of the methyl signals in the ^{1}H NMR spectra; these appeared, in all cases, as two doublets between δ_H 1.0 and 1.5. The doublet with the higher chemical shift value was assigned to the 3-methyl group (due to the greater deshielding effect of ArN compared with S).

We have established, therefore, for the first time, that electronic factors are important in determining the regiochemical outcome of Diels–Alder reactions of thionitroso compounds. The regioselectivity is broadly similar to that observed in reactions Ar–N=S=O, for which Kresze and Wagner proposed that the reaction proceeded through a dipolar transition state.[13] If this model is applied to thionitroso compounds the adduct ratios obtained in the reactions of Ar–N=S with isoprene, chloroprene and penta-1,3-diene can be explained qualitatively in terms of the substituent, R, on the diene either stabilising or destabilising the proposed transition states (Scheme 6). Reactions of thionitrosoarenes with isoprene



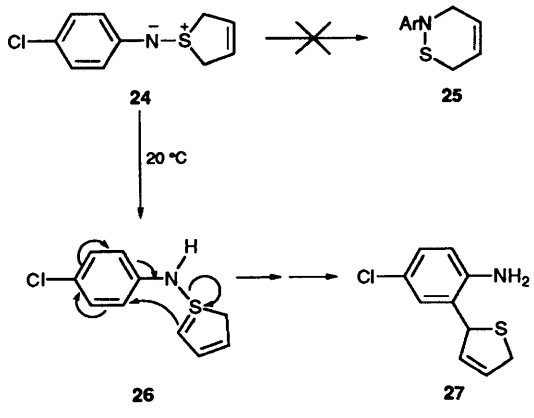
A **B**

Scheme 6

(R^2 = Me) will yield predominantly isomer **17**, because transition state **B** is stabilised relative to transition state **A**; with chloroprene (R^2 = Cl) transition state **B** is destabilised and, therefore, formation of isomer **21** is relatively more favoured; with penta-1,3-diene there is no stabilisation of transition state **B**, and the 3-substituted isomer **22** predominates.

Synthesis and Rearrangement of the Sulfilimine **24**.—We considered the possibility that thionitrosoarenes might react with dienes *via* a chelotropic pathway, initially to yield a dihydrothiophene-*S*,*N*-ylide **24** which could isomerise to the observed dihydro-1,2-thiazine heterocycle **25**. Precedents for this are provided by the reaction of butadiene and sulfur dioxide to give dihydrothiophene 1,1-dioxide (as the thermodynamic product),[14] and the similar reaction of sulfur monoxide under appropriate conditions.[15]

We, therefore, decided to synthesise the sulfilimine **24** by an unambiguous route and examine its rearrangement. The conditions described by Claus *et al.*[16] for the preparation of arylsulfilimines were modified, and reaction of 2,5-dihydrothiophene with 4-chloroaniline yielded compound **24** as an



24 **25** **26** **27**

Scheme 7

unstable yellow solid (45% yield). When kept at room temperature for a few hours compound **24** was transformed quantitatively into a white crystalline product which was shown on the basis of an elemental analysis and its spectroscopic data to be the isomeric dihydrothiophene derivative **27** (see Scheme 7). No dihydrothiazine **25** was detected. This rearrangement of **24** to yield **27** is directly analogous to that observed previously for *S,S*-dimethyl-*N*-arylsulfilimines,[17] and presumably proceeds by the way of intermediate **26**. This result provides firm evidence that sulfilimines **24** are not intermediates in the addition of dienes to ArN=S species.

Conclusions.—We have shown that compounds **3** are versatile precursors of transient thionitroso-arenes and -heteroarenes which readily undergo Diels–Alder reactions with acyclic dienes, and ene reactions with a range of alkenes. Thionitroso compounds are emerging as valuable intermediates in the synthesis of new cyclic and acyclic nitrogen- and sulfur-containing molecules.

Experimental

General Information.—Details of equipment, purification of solvents and chromatographic procedures are the same as those reported previously,[5c] with the addition that NMR spectra of compounds **14**, **15** and **16** were obtained using a GE 300 Spectrometer, and decoupling experiments were performed on a Bruker AMX 500 Spectrometer.

Preparation of N-(*Arylaminosulfanyl*)- *and* N-(*Heteroarylaminosulfanyl*) *-phthalimides* **3i–r**: *General Procedure.*—The preparation of compound **3n** is representative. To a stirred solution of 2-amino-1-trimethylsilylpyridine (2.0 g, 12 mmol) dissolved in freshly distilled chloroform (25 cm^3) under dry nitrogen was added *N*-chlorosulfanylphthalimide **2**[18] (2.5 g, 12 mmol) dissolved in freshly distilled chloroform (25 cm^3) dropwise over 5 min. A precipitate quickly formed and stirring was continued for 1 h. The precipitate was filtered off *in vacuo*, washed with chloroform and dried to give the product **3** as a white solid which was pure as judged from its ^1H NMR spectrum. New derivatives prepared using this procedure are collated in Table 1. These are: *N*-(4-cyanophenylaminosulfanyl)phthalimide **3i**, *N*-(pentafluorophenylaminosulfanyl)-phthalimide **3j**, *N*-(2-methylphenylaminosulfanyl)phthalimide **3k**, *N*-(2-bromophenylaminosulfanyl)phthalimide **3l**, *N*-(2-cyanophenylaminosulfanyl)phthalimide **3m**, *N*-(2-pyridylaminosulfanyl)phthalimide **3n**, N-(*pyrimidin-2-ylaminosulfanyl*)*phthalimide* **3p**, *N*-(pyrazol-2-ylaminosulfanyl)phthalimide **3q**, N-(*thiazol-2-ylaminosulfanyl*)*phthalimide* **3r**. Compounds **3** could not be chromatographed nor could their ^{13}C NMR be recorded because of their insolubility in standard solvents at room temperature; they could be recrystallised from chloroform–methanol, but this did not increase their purity, as judged by C, H, N analysis. Data for compounds **3i–r** are collated in Table 1. None of the compounds gave a parent ion in the mass spectrum, using EI, CI and FAB techniques.

Generation of Thionitroso Compounds **4** *from Precursors* **3** *and Trapping with Dimethylbutadiene: General Procedure.*—To a stirred suspension of compound **3** (0.5 mmol) in acetone (50 cm^3) (or an alternative solvent, Table 3) at 20 °C under dry nitrogen, was added, sequentially, dimethylbutadiene (1.0 cm^3, 9 mmol) and triethylamine (2.0 cm^3, 14 mmol). Stirring was continued at 20 °C until the suspension became a clear solution (typically 3–24 h) whereupon solvent was removed under reduced pressure and the residue was stirred vigorously with cyclohexane (100 cm^3) for 30 min. The precipitated triethylammonium phthalimide was filtered off and the filtrate was evaporated to yield an oily product mixture. ^1H NMR Analysis of the mixture was performed at this stage to assess isomer ratios (as given in Table 2). Separation of the mixtures of adducts **5** and **6** from minor by-products (*e.g.* azobenzene and sulfur diimide derivatives and phthalimide) was achieved by column chromatography (silica column 20 × 4 cm) eluted with cyclohexane–dichloromethane (1:1 v/v) which yielded an inseparable mixture of adducts **5** and **6** as oils. Yields and NMR data for the chromatographed isomer mixtures are presented in Table 2.

By this method mixtures of the following compounds were prepared: 2-(4-cyanophenyl)-4,5-dimethyl-3,6-dihydro-2*H*-1,2-thiazine **5i** and *N*-(4-cyanophenyl)-2,3-dimethylenebutane-1-sulfenamide **6i**; 2-(2-methylphenyl)-4,5-dimethyl-3,6-dihydro-2*H*-1,2-thiazine **5k** and *N*-(2-methylphenyl)-2,3-dimethylenebutane-1-sulfenamide **6k**; 2-(2-bromophenyl)-4,5-dimethyl-3,6-dihydro-2*H*-1,2-thiazine **5l** and *N*-(2-bromophenyl)-2,3-dimethylenebutane-1-sulfenamide **6l**; 2-(2-cyanophenyl)-4,5-dimethyl-3,6-dihydro-2*H*-1,2-thiazine **5m** and *N*-(2-cyanophenyl)-2,3-dimethylenebutane-1-sulfenamide **6m**; 4,5-dimethyl-2(2-pyridyl)-3,6-dihydro-2*H*-1,2-thiazine **5n** and *N*-(2-pyridyl)-2,3-dimethylenebutane-1-sulfenamide **6n**; 2-(thiazol-2-yl)-4,5-dimethyl-3,6-dihydro-2*H*-1,2-thiazine **5r** and *N*-(thiazol-2-yl)-2,3-dimethylenebutane-1-sulfenamide **6r**.

Trapping of Thionitroso Compounds **4** *with Isoprene.*—Following the procedure described above, the thionitroso compounds **4a**, **4b**, **4d** and **4h** were generated and intercepted with isoprene. Work-up procedures were the same as for the dimethylbutadiene adducts. The yields of products and ratios of adducts **17**:**18**:**19** are given in Scheme 3. The following compounds were obtained.

From thionitroso compound **4a**. 2-(4-Methoxyphenyl)-5-methyl-3,6-dihydro-2*H*-1,2-thiazine **17a**, $\delta_H(CDCl_3)$ (excluding aromatics) 5.60 (1 H, m, =CH), 4.05 (2 H, m, CH_2N), 3.71 (3 H, s, OCH_3), 2.90 (2 H, m, CH_2S) and 1.75 (3 H, s, CH_3). 2-(4-Methoxyphenyl)-4-methyl-3,6-dihydro-2*H*-1,2-thiazine **18a**, $\delta_H(CDCl_3)$ 5.83 (1 H, m, =CH), 3.90 (2 H, m, CH_2N), 3.70 (3 H, s, OCH_3), 3.00 (2 H, m, CH_2S) and 1.75 (3 H, s, CH_3). *N*-(4-Methoxyphenyl)-2-methylenebut-3-ene-1-sulfenamide **19a**, $\delta_H(CDCl_3)$ 6.35 (1 H, dd, H_a, J_{ac} 16.9 and J_{ab} 10.2), 5.30 (1 H, d, H_c, J_{ac} 16.9), 5.16 (1 H, d, H_b, J_{ab} 10.2), 5.10 and 4.84 (both H, s, =CH), 4.70 (1 H, s, NH, D-exchanged), 3.73 (3 H, s, OCH_3) and 3.36 (2 H, s, CH_2S).

From thionitroso compound **4b**. 2-(4-Bromophenyl)-5-methyl-3,6-dihydro-2*H*-1,2-thiazine **17b**, 4-methyl-2-(4-methylphenyl)-3,6-dihydro-2*H*-1,2-thiazine **18b** and *N*-(4-methylphenyl)-2-methylenebut-3-ene-1-sulfenamide **19b**.

From thionitroso compound **4d**. 2-(4-Bromophenyl)-5-methyl-3,6-dihydro-2*H*-1,2-thiazine **17b**, 2-(4-bromophenyl)-4-methyl-3,6-dihydro-2*H*-1,2-thiazine **18b** and *N*-(4-bromophenyl)-2-methylenebut-3-ene-1-sulfenamide **19b**.

From thionitroso compound **4h**. 5-Methyl-2-(3-pyridyl)-3,6-dihydro-2*H*-1,2-thiazine **17h**, 4-methyl-2-(3-pyridyl)-3,6-dihydro-2*H*-1,2-thiazine **18h** and *N*-2-methylenebut-(3-pyridyl)-3-ene-1-sulfenamide **19h**.

The ^1H NMR spectra of the isoprene adducts of **4b**, **4d** and **4h** are virtually identical with those obtained from **4a**, listed above (δ_H ± 0.05 ppm for all peaks) so the data are not listed again.

Trapping of Thionitroso Compounds **4** *with Chloroprene.*—Following the procedure described above, compounds **4a**, **4b** and **4d** were generated and trapped with chloroprene (50% solution in xylene). Isomers **20b**, **21b** and isomers **20d**, **21d** were separated by column chromatography (silica, eluent cyclohexane) whereas the mixture of isomers **20a** and **21a** could not be separated. Yields of products and ratios of adducts **20**:**21** are given in Scheme 4. The following compounds were obtained.

From thionitroso compound **4a**. 5-Chloro-2-(4-methoxyphenyl)-3,6-dihydro-2*H*-1,2-thiazine **20a**, $\delta_H(CDCl_3)$ (excluding aromatics) 6.04 (1 H, m, 4-H), 4.10 (2 H, m, CH_2N), 3.78 (3 H, s, OMe) and 3.40 (1 H, m, CH_2S). 4-Chloro-2-(4-methoxyphenyl)-3,6-dihydro-2*H*-1,2-thiazine **21a**, $\delta_H(CDCl_3)$ 6.14 (1 H, m, 5-H), 4.10 (2 H, m, CH_2N), 3.78 (3 H, s, OMe) and 3.40 (1 H, m, CH_2S).

From thionitroso compound **4b**. 5-*Chloro*-2-(4-*methylphenyl*)-3,6-*dihydro*-2H-1,2-*thiazine* **20b**, a colourless oil (Found: M, 225.0353. $C_{11}H_{12}ClNS$ requires 225.0379); $\delta_H(CDCl_3)$ 6.05 (1 H, m, 4-H), 4.21 (1 H, m, CH_2N), 3.23 (1 H, m, CH_2S) and 2.29 (3 H, s, Me). 4-Chloro-2-(4-methylphenyl)-3,6-dihydro-2*H*-1,2-thiazine **21b**, a colourless oil, *m*/*z* (EI) 225 (M^+); $\delta_H(CDCl_3)$ 6.15 (1 H, m, 5-H), 4.16 (1 H, m, CH_2N), 3.19 (1 H, m, CH_2S) and 2.29 (3 H, s, Me); $\delta_C(CDCl_3)$ 147.8, 131.3, 129.3, 127.0, 122.2, 118.8, 55.6, 30.3 and 28.1.

From thionitroso compound **4d**. 2-(4-*Bromophenyl*)-5-*chloro*-3,6-*dihydro*-2H-1,2-*thiazine* **20d**, a white solid, m.p. 59–62 °C (Found: C, 41.3; H, 3.2; N, 4.7. $C_{10}H_9BrClNS$ requires C, 41.38; H, 3.10; N, 4.82%); *m*/*z* (EI) 289 (M^+); $\delta_H(CDCl_3)$ 6.05 (1 H, m, 4-H), 4.10 (1 H, m, CH_2N) and 3.40 (1 H, m, CH_2S); $\delta_C(CDCl_3)$ 149.5, 131.7, 128.3, 123.1, 120.4, 114.2, 52.2 and 32.1. 2-(4-*Bromophenyl*)-4-*chloro*-3,6-*dihydro*-2H-1,2-*thiazine* **21d**, a colourless oil (Found: M, 288.9338. $C_{10}H_9BrClNS$ requires 288.9328); δ_H 6.16 (1 H, m, 5-H), 4.20 (1 H, m, CH_2N) and 3.22 (1 H, m, CH_2S); $\delta_C(CDCl_3)$ 150.0, 132.1, 131.3, 122.6, 120.8, 114.6, 55.8 and 28.9.

Trapping of Thionitroso Compounds **4** *with Penta*-1,3-*diene*.—Following the procedure described above, compounds **4a**, **4b** and **4d** were generated and trapped with penta-1,3-diene to give inseparable mixtures of adducts **22** and **23** as oils. The yields of products and ratios of isomers are given in Scheme 5. The following compounds were obtained.

From thionitroso compound **4a**. (3-*RS*)-2-(4-Methoxyphenyl)-3-methyl-3,6-dihydro-2*H*-1,2-thiazine **22a**, *m*/*z* (EI) 221 (M^+); $\delta_H(CDCl_3)$ 6.0–5.7 (2 H, m, 2 × =CH), 3.8 (1 H, m, CHN), 3.7 (3 H, s, OMe), 3.5 and 2.3 (each 1 H, m, CH_2S), 1.4 (3 H, d, *J* 6.7, Me). (6-*RS*)-2-(4-Methoxyphenyl)-6-methyl-3,6-dihydro-2*H*-1,2-thiazine **23a**, $\delta_H(CDCl_3)$ 6.0–5.7 (2 H, m, 2 × =CH), 3.8 (2 H, m, CH_2N), 3.7 (3 H, s, OMe), 3.5 (1 H, m, CHS) and 1.0 (3 H, d, *J* 7.2, Me).

From thionitroso compound **4b**. (3-*RS*)-2-(4-Methylphenyl)-3-methyl-3,6-dihydro-2*H*-1,2-thiazine **22b** (Found: M, 205.034 78. $C_{12}H_{15}NS$ requires 205.0925); $\delta_H(CDCl_3)$ 5.9–5.7 (2 H, m, 2 × =CH), 3.9 (1 H, m, CHN), 3.4 and 2.3 (each 1 H, m, CH_2S), 2.18 (3 H, s, Me) and 1.4 (3 H, d, *J* 8.6, Me); 6(*RS*)-2-(4-methylphenyl)-6-methyl-3,6-dihydro-2*H*-1,2-thiazine **23b**, $\delta_H(CDCl_3)$ 5.9–5.7 (2 H, m, 2 × =CH), 3.9 (2 H, m, CH_2N), 3.4 (1 H, m, CHS), 2.3 (3 H, s, Me) and 1.1 (3 H, d, *J* 7.1, Me).

From thionitroso compound **4d**. 3(*RS*)-2-(4-Bromophenyl)-3-methyl-3,6-dihydro-2*H*-1,2-thiazine **22d**, $\delta_H(CDCl_3)$ 6.0–5.8 (2 H, m, 2 × =CH), 4.0 (1 H, m, CHN), 3.4 and 2.5 (each 1 H, m, CH_2S) and 1.5 (3 H, d, *J* 6.6, Me); $\delta_C(CDCl_3)$ 151.0, 131.5, 125.4, 124.2, 120.5, 112.6, 52.5, 26.9 and 20.4; 6(*RS*)-2-(4-bromophenyl)-6-methyl-3,6-dihydro-2*H*-1,2-thiazine **23d**, $\delta_H(CDCl_3)$ 6.0–5.8 (2 H, m, 2 × =CH), 4.0 (2 H, m, CH_2N), 3.4 (1 H, m, CHS) and 1.2 (3 H, d, *J* 7.2, Me); $\delta_C(CDCl_3)$ 156.2, 131.5, 127.2, 126.5, 119.6, 112.4, 49.0, 26.2 and 18.5.

Trapping of Thionitrosoarenes and Heteroarenes with Alkenes: General Procedure.—The procedure, and the scale of the reactions, were the same as described above for reactions of dimethylbutadiene. The crude product mixture was placed under high vacuum to remove excess of alkene and then analysed by 250 MHz ^1H NMR spectroscopy; silica gel column chromatography, eluent dichloromethane, gave the ene adduct as a yellow oil. The following compounds were thereby obtained.

From reactions of 1-methylcyclohexene. N-(4-*Methoxyphenyl*)-2-*methylenecyclohexane*-1-*sulfenamide* **11a** (80%) (Found: M, 249.1222. $C_{14}H_{19}NOS$ requires 249.1232); $\delta_H(CDCl_3)$ 7.20–6.75 (4 H, m, Ar), 4.75 (1 H, s, $=CH_2$), 4.60 (1 H, s, NH), 4.52 (1 H, s, $=CH_2$), 3.71 (3 H, s, OMe), 2.24 (1 H, m, SCH) and 2.0–1.5 (8 H, m, cyclohexane). N-(4-*Methylphenyl*)-2-*methylenecyclohexane*-1-*sulfenamide* **11b** (95%) (Found: M, 233.1238. $C_{14}H_{19}NS$ requires 233.1286); $\delta_H(CDCl_3)$ 7.10–6.90 (4 H, m, Ar), 5.00–4.50 (3 H, m, $=CH_2$ + NH), 2.34 (3 H, s, Me) and 2.0–1.0 (9 H, m, cyclohexane). N-(4-*Bromophenyl*)-2-*methylenecyclohexane*-1-*sulfenamide* **11d** (85%) [Found: M, 297.6110. $C_{13}H_{16}BrNS$ requires 297.6141 (for ^{79}Br]; $\delta_H(CDCl_3)$ 7.31–6.90 (4 H, m, Ar) 5.20–4.95 (3 H, m, $=CH_2$ + NH) and 2.30–1.50 (9 H, m, cyclohexane).

From reactions of α-*pinene*. N-(4-Methoxyphenyl)-6,6-dimethyl-2-methylenebicyclo[3.1.1]heptane-3-sulfenamide **12a** (25%), *m*/*z* (EI) 257 (M^+); $\delta_H(CDCl_3)$ 7.05–6.75 (4 H, m, Ar), 5.25 (1 H, s, NH), 4.75 (1 H, s, $=CH_2$), 4.45 (1 H, s, $=CH_2$), 3.70 (1 H, d, SCH, *J* 9.0), 3.65 (3 H, s, OMe), 2.60–1.50 (6 H, m, ring CH), 1.25 (3 H, s, gem Me) and 0.70 (3 H, s, gem Me). 6,6-*Dimethyl*-2-*methylene*-N-(4-*methylphenyl*)*bicyclo*[3.1.1]*heptane*-3-*sulfenamide* **12b** (60%) (Found: M, 273.1552. $C_{17}H_{23}NS$ requires 273.1523); $\delta_H(CDCl_3)$ 7.1–6.9 (4 H, m, Ar), 5.30 (1 H, s, NH), 4.75 (1 H, s, $=CH_2$), 4.45 (1 H, s, $=CH_2$), 3.80 (1 H, d, SCH_2, *J* 8.8), 2.40–1.40 (6 H, m, ring CH), 2.35 (3 H, s, Me), 1.25 (3 H, s, gem Me) and 0.70 (3 H, s, gem Me); $\delta_C(CDCl_3)$ 129.8, 115.2, 117.0, 110.6, 51.4, 40.3, 40.0, 29.0, 27.5, 26.8, 25.9 and 21.5. N-(4-Bromophenyl)-6,6-dimethyl-2-methylenebicyclo[3.1.1] heptane-3-sulfenamide **12d** (45%), *m*/*z* (EI) 339 and 337 (M^+); $\delta_H(CDCl_3)$ 7.40–7.05 (4 H, m, ArH), 5.40 (1 H, s, NH), 4.75 (1 H, s, $=CH_2$), 4.45 (1 H, s, $=CH_2$), 3.82 (1 H, d, SCH, *J* 9.0), 2.45–1.45 (6 H, m, ring CH), 1.25 (3 H, s, gem Me) and 0.70 (3 H, s, gem Me).

6,6-*Dimethyl*-2-*methylene*-N-(2-*methylphenyl*)*bicyclo*[3.1.1]-*heptane*-3-*sulfenamide* **12k** (68%) (Found: M, 273.1551. $C_{17}H_{23}NS$ requires 273.1523); $\delta_H(CDCl_3)$ 7.60–6.80 (4 H, m, ArH), 5.44 (1 H, s, NH), 4.80 (1 H, s, $=CH_2$), 4.35 (1 H, s, $=CH_2$), 3.90 (1 H, d, *J* 9.2, SCH), 2.60–1.10 (6 H, m, ring CH), 2.37 (3 H, s, Me), 1.35 (3 H, s, gem Me) and 0.90 (3 H, s, gem Me).

From reactions with β-*pinene*. N-(4-Bromophenyl)-6,6-dimethylbicyclo[3.1.1]hept-2-en-3-ylmethanesulfenamide **13d** (60%) [Found: M, 337.0527. $C_{16}H_{20}BrNS$ requires 337.0397 (for ^{79}Br)]; $\delta_H(CDCl_3)$ 7.30–6.80 (4 H, m, ArH), 5.25 (1 H, s, NH), 4.75 (1 H, s, =CH), 3.14 (2 H, s, CH_2S), 2.50–1.55 (6 H, m, ring CH), 1.32 (3 H, s, gem Me) and 0.90 (3 H, s, gem Me).

6,6-Dimethyl-*N*-(2-methylphenyl)bicyclo[3.1.1]hept-2-en-3-ylmethanesulfenamide **13k** (50%), *m*/*z* 273 (M^+); δ_H 7.35–6.70 (4 H, m, ArH), 5.00 (1 H, s, NH), 4.57 (1 H, s, =CH), 3.01 (2 H, m, CH_2S), 2.28–1.48 (6 H, m, ring CH), 2.04 (3 H, s, Me), 1.20 (3 H, s, gem Me) and 0.78 (3 H, s, gem Me).

Reaction of Ene Adducts **12a**, **12b** *and* **12d** *with* 2,6-*Difluorobenzoyl Isocyanate: General Procedure*.—To a stirred solution of the purified ene adduct (0.36 mmol) in toluene (20 cm^3) was added 2,6-difluorobenzoyl isocyanate (80 mg, 0.44 mmol). The resulting mixture was stirred at 20 °C under dry nitrogen for 2 h after which it was evaporated under reduced pressure and the residue chromatographed on a silica column, with dichloromethane as eluent. The following compounds were obtained.

2,6-N-[N-(6,6-*dimethyl*-2-*methylenebicyclo*[3.1.1]*heptan*-3-*ylsulfanyl*)-N-(4-*methoxyphenyl*)*carbamoyl*]*benzamide* **14a**, a white solid (10 mg, 6%), m.p. 96–98 °C, *m*/*z* (CI) 473 (M^+ + 1); $\delta_H(CDCl_3)$ 9.40 [1 H, s, NHC(O)] 7.50–6.95 (7 H, m, ArH), 5.40 (2 H, s, $=CH_2$), 4.05 (1 H, d, *J* 9.4, SCH), 3.84 (3 H, s, OMe),

2.45–1.50 (6 H, m, ring CH), 1.35 (3 H, s, gem Me) and 0.71 (3 H, s, gem Me).

2,6-*Difluoro*-N-[N-(6,6-*dimethyl*-2-*methylenebicyclo*[3.1.1]-*heptan*-3-*ylsulfanyl*)-N-(4-*methylphenyl*)*carbamoyl*]*benzamide* **14b**, a white solid (25 mg, 15%), m.p. 96–98 °C (Found: C, 65.6; H, 4.8; N, 5.6. $C_{25}H_{26}F_2N_2O_2S$ requires C, 65.8; H, 5.7; N, 6.1%); *m/z* (CI) 457 ($M^+ + 1$); $\delta_H(CDCl_3)$ 9.40 [1 H, s, NHC(O)], 7.50–6.80 (7 H, m, ArH), 5.40 (2 H, s, $=CH_2$), 4.05 (1 H, d, *J* 9.0, SCH), 2.35–1.50 (9 H, m, CH_3Ar + ring CH), 1.30 (3 H, s, gem Me) and 0.68 (3 H, s, gem Me).

2,6-*Difluoro*-N-[N-(6,6-*dimethyl*-2-*methylenebicyclo*[3.1.1]-*heptan*-3-*ylsulfanyl*)-N-(4-*bromophenyl*)*carbamoyl*]*benzamide* **14d**, a white solid (10 mg, 5%), m.p. 109–111 °C (Found: C, 54.4; H, 4.6; N, 5.4. $C_{24}H_{23}BrF_2N_2OS$ requires C, 54.4; H, 4.4; N, 5.4%); *m/z* (CI) 521 ($M^+ + 1$); $\delta_H(CDCl_3)$ 9.50 [1 H, s, NHC(O)], 7.50–6.85 (7 H, m, ArH), 4.95 (1 H, s, $=CH_2$), 4.92 (1 H, s, $=CH_2$), 4.0 (1 H, d, *J* 8.8, SCH), 2.35–1.55 (6 H, m, ring CH), 1.30 (3 H, s, gem Me) and 0.70 (3 H, s, gem Me).

Reaction of a Mixture of Diels–Alder and Ene Adducts **5** *and* **6** *with* 2,6-*Difluorobenzoyl Isocyanate: General Procedure.*—To a stirred solution of the crude product mixture of adducts **5a**/**6a**, **5b**/**6b** and **5d**/**6d** (180 mg) in toluene (20 cm^3) was added 2,6-difluorobenzoyl isocyanate (100 mg, 0.55 mmol). Stirring was continued at 20 °C under nitrogen for 16 h, after which the mixture was evaporated under reduced pressure and the residue was chromatographed on a silica column with dichloromethane as eluent. From the mixture **5a**/**6a**, there was obtained a pure sample of **5a** (38 mg, 41% yield, based on reagent **3a**) for which spectroscopic data were identical with those reported previously;[5c] similarly, the mixture of **5b**/**6b**, afforded a pure sample of **5b**[5c] (35 mg, 38%). The mixture of **5d**/**6d** yielded a pure sample of **5d**[5c] (20 mg, 15%) and a second oily fraction comprising 2,6-difluoro-*N*-[*N*-(3-methyl-2-methylenebut-3-enylsulfanyl)-*N*-(4-bromophenyl)carbamoyl]benzamide **15** (10 mg, 5%); *m/z* 496 (CI) ($M^+ + 1$); $\delta_H(CDCl_3)$ 9.55 (1 H, s, NH), 7.40–6.85 (7 H, m, ArH), 5.50–5.15 (4 H, m, 2 × $=CH_2$), 3.65 (2 H, s, CH_2S) and 1.96 (3 H, s, Me), and N-[N-(4-bromophenyl)carbamoyl]-2,6-difluorobenzamide **16** a small quantity of which was isolated pure, m.p. 135–136 °C and identified by comparison with authentic sample prepared as follows.

2,6-Difluorobenzoyl isocyanate (600 mg, 3.3 mmol) was added to a stirred solution of 4-bromoaniline (550 mg, 2.9 mmol) in toluene (20 cm^3). After being stirred at 20 °C under nitrogen for 10 min, the reaction mixture was cooled and the precipitate was filtered off and recrystallized from chloroform to give **16** as a *white solid* (700 mg, 68%), m.p. 135.7–135.9 °C (Found: C, 47.2; H, 2.7; N, 7.9. $C_{14}H_9BrF_2N_2O_2$ requires C, 47.2; H, 2.5; N, 7.9%); *m/z* (CI) 355 ($M^+ + 1$); $\delta_H(CDCl_3)$ 10.40 (1 H, s, NHO), 8.64 (1 H, s, NH) and 7.48–6.90 (7 H, m, ArH).

N,N'-*Thiobis*(*pyridin*-2-*amine*) **7**.—To a stirred solution of pyridine-2-amine (0.44 g, 4.7 mmol) in freshly distilled dichloromethane (10 cm^3) under dry nitrogen was added dropwise *N*-chlorosulfanylphthalimide **2** (1.0 g, 4.7 mmol) dissolved in freshly distilled dichloromethane (10 cm^3). After the mixture had been stirred for 16 h at 20 °C the precipitate was filtered off and dried to yield **7**, as a white powder (140 mg, 28%), m.p. 131–133 °C (Found: C, 55.6; H, 4.1; N, 23.6. $C_{10}H_{10}N_4S$ requires C, 55.6; H, 4.6; N, 23.6%); *m/z* (EI) 218 (M^+), 124 (Het–N=S); ν_{max}(KBr)/cm^{-1} 3130 (NH); $\delta_H(CDCl_3)$ 7.60–7.51 and 7.40–7.12 (8 H, m, ArH) and 6.85 (2 H, s, 2 × NH).

N-(2-*Methylenebut*-3-*enylsulfanyl*)*phthalimide* **10**.—To a stirred solution of *N*-trimethylsilylpyridine-4-amine (0.60 g, 3.6 mmol) isoprene (5.0 cm^3, 50 mmol) and triethylamine (2.0 cm^3, 14 mmol) dissolved in freshly distilled chloroform (10 cm^3) under nitrogen was added, dropwise, *N*-chlorosulfanylphthalimide (0.80 g, 3.7 mmol) dissolved in chloroform (20 cm^3). The mixture was stirred at 20 °C for 16 h, after which it was evaporated under reduced pressure and the residue chromatographed (silica column, eluent dichloromethane), to afford compound **10** as a white solid (150 mg, 15%), m.p. 124–126 °C (from chloroform–methanol) (Found: C, 63.3; H, 4.7; N, 5.3%; M, 245.0476. $C_{13}H_{11}NO_{12}S$ requires C, 63.6; H, 4.5; N, 5.7%, *M*, 245.0511); ν_{max}(KBr)/cm^{-1} 1785, 1740, 1715; $\delta_H(CDCl_3)$ 7.83 (4 H, m, Ar), 6.33 (1 H, dd, *J* 17.6 and 10.9, H^a), 5.47 (1 H, d, *J* 17.6, H^c), 5.24 (1 H, d, *J* 10.9, H^b), 5.04 (1 H, s, =CH), 4.98 (1 H, s, =CH) and 3.70 (2 H, s, CH_2S); $\delta_C(CDCl_3)$ 167.0, 138.6, 134.8, 133.5, 131.0, 122.8, 119.1, 114.6 and 38.3.

2-(2-*Amino*-5-*chlorophenyl*)-2,5-*dihydrothiophene* **27**.—A stirred solution of 2,5-dihydrothiophene (100 mg, 1.2 mmol) (prepared in 11% yield, following the procedure of Gardner *et al.*)[19] and 4-chloroaniline (150 mg, 1.2 mmol) dissolved in freshly distilled dichloromethane (5 cm^3) was cooled to −20 °C under nitrogen. *N*-Chlorosuccinimide (155 mg, 1.2 mmol) dissolved in dichloromethane (5 cm^3) was added dropwise over 20 min to the mixture and stirring was continued for 1 h while the solution was allowed to warm to 20 °C. During this time a white precipitate formed. On addition of DBU (360 mm^3,* 2 equiv.) to the suspension it immediately cleared to give a pale yellow solution. This, after evaporation under reduced pressure, gave a residue which was chromatographed (silica column, eluent dichloromethane). The first fractions eluted contained small amounts of unchanged 4-chloroaniline; these were followed by fractions containing two new compounds (^1H NMR evidence) one of which was presumed to be sulfilimine **24**. Evaporation of these fractions under reduced pressure yielded a yellow solid which upon storage at 20 °C for 24 h became a white solid, recrystallisation of which from light petroleum–diethyl ether (3:1, v/v) afforded *compound* **27** (115 mg, 45%) white crystals, m.p. 100–102 °C (Found: C, 56.0; H, 4.7; N, 6.1%; M, 211.0031. $C_{10}H_{10}ClNS$ requires C, 56.7; H, 4.8; N, 6.6%; M, 211.0222); ν_{max}(KBr)/cm^{-1} 3400 and 3300 (NH_2); $\delta_H(CDCl_3)$ 7.03 (2 H, m, ArH), 6.60 (1 H, d, *J* 8.2, ArH), 5.98 (2 H, m, 2 × =CH), 5.38 (1 H, m, CH), 3.93 (2 H, m, CH_2) and 3.90 (2 H, br s, NH_2); $\delta_C(CDCl_3)$, 143.1, 131.2, 130.1, 128.2 (2 coincident peaks) 127.5, 123.3, 117.7, 55.0 and 39.6.

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* 1 mm^3 = 1 μl.

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