α,β-Unsaturated Thiocarbonyl *S*-Sulfides (Thiosulfines). Their Generation, Intramolecular Trapping by a Non-activated C=C Dipolarophile *via* [5 + 2] Cycloaddition and *trans*-Sulfurization Ability

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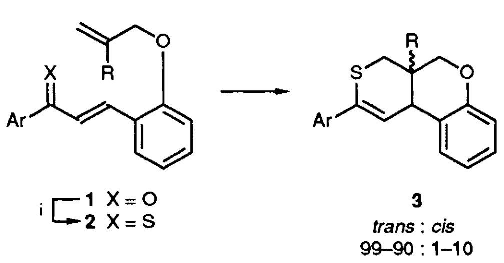
α,β-Unsaturated thiocarbonyl *S*-sulfides (thiosulfines) **10** were generated by sulfurization of the thioketones **5** and were intramolecularly trapped as 1,5-dipoles giving **8**, whereas, in the presence of Et_3N, they were transformed by *trans*-sulfurization *via* 1,5 cyclization into the thioketones **13** capable of undergoing the intramolecular hetero-Diels–Alder reaction to give cycloadducts **9**.

In a previous communication,[1] we reported the first example[2] of the intramolecular hetero-Diels–Alder (IHDA)[3] reaction of the α,β-unsaturated thioketones **2** to give **3** with high regio- and stereo-selectivities (Scheme 1); compounds **2** were formed by thionation of the corresponding ketones **1**. We envisaged that the IHDA reaction of the α,β-unsaturated thioketones **5** with a C=C-dienophile connected to the 2-position of the heterodiene system would give the usual cycloadducts **6** and/or their regioisomers **7** (Scheme 2).[4] However, the products which were isolated and identified

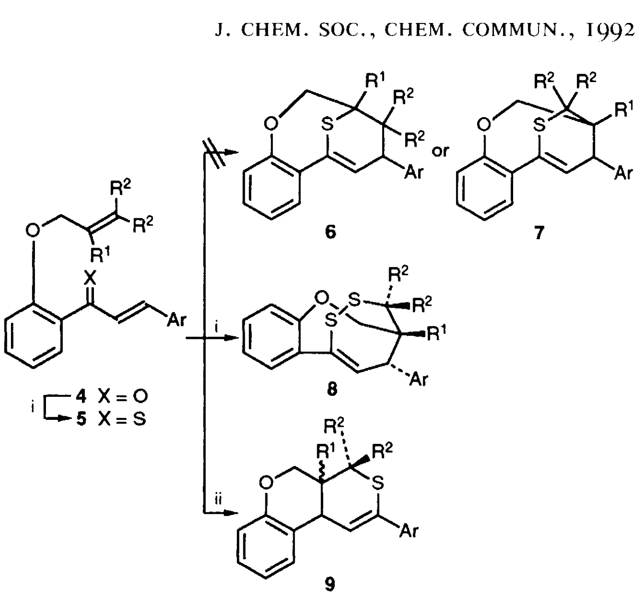


Scheme 1 *Reagent*: i, Lawesson's reagent (LR)

Table 1 Intramolecular [5 + 2] cycloaddition of α,β-unsaturated thiocarbonyl *S*-sulfides **10** to afford cycloadducts **8**[a]

Entry	Ketone	Reagent (equiv.)	Time/ min	Product	Yield[b] (%)
1	**4a**	LR (2.0)	30	**8a**	15
2	**4a**	LR (4.0)	30	**8a**	10
3	**4a**	LR (2.0) +S_8 (10)	30	**8a**	14
4	**4b**	LR (2.0)	15	**8b**	13
5[c]	**4c**	LR (2.0)	150	**8c**	16

[a] In xylene unless otherwise noted. [b] Based on an equimolar amount of the ketone **4**. [c] In toluene.



a; Ar = Ph, $R^1 = R^2 = H$
b; Ar = p-MeC_6H_4, $R^1 = R^2 = H$
c; Ar = p-$MeOC_6H_4$, $R^1 = R^2 = H$
d; Ar = Ph, R^1 = Me, R^2 = H
e; Ar = Ph, R^1 = H, R^2 = Me

Scheme 2 *Reagents and conditions*: i, LR in refluxing solvent; ii, $Et_3N + S_8$

Table 2 *trans*-Sulfurization of thiocarbonyl *S*-sulfides **10** and subsequent IHDA reaction of thioketone **13** to afford cycloadduct **9**[a]

Thioketone	Time/h	Product	Yield[b] (%)
13a	1.0	**9a**	87
13b	1.0	**9b**	64
13c	0.5	**9c**	76
13d	3.0	**9d**	74
13e[c]	0.5	**9e**	29

[a] In benzene unless otherwise noted. [b] Based on an equimolar amount of the thioketone **5**. [c] In toluene.

were neither **6** nor **7** but surprisingly the dithiepins **8** and, in the presence of $Et_3N + S_8$, compounds **9**.

We report herein the first evidence for the existence of α,β-unsaturated thiocarbonyl *S*-sulfides[5] as key intermediates leading to these products **8** and **9**.†

When the ketones **4** (3.0 mmol) were heated with Lawesson's reagent (LR; 3.0 mmol) in xylene (80 ml), the reaction mixture at first showed the characteristic blue–green colour of the thioketones **5** and/or their dimers.[7] The colour disappeared within 0.5 h. Column chromatographic (silica gel; benzene–hexane, 1:3) purification of the main product afforded compounds **8a–c**‡ ($R^1 = R^2 = H$) as viscous oils (except **8c**; m.p. 86.3–87.6 °C) (Table 1). In the **d** and **e** series (R^1 or R^2 = Me) no identifiable amount of **8d**, **e** could be isolated, the course of the reaction being unclear. The reluctance to undergo the IHDA reaction might be due to the steric effect of the substituents. The use of excess of LR or S_8 had no significant effect on the products or yields (entries 2 and 3). When the isolated, elemental sulfur-free thioketone **5** dimer[7] (1.46 mmol as monomer), which could be prepared by thionation of **4** with LR in refluxing tetrahydrofuran (THF), was heated in xylene, compound **8** was not detected. The only identified product was of the intramolecular ene reaction (Type III)[9] of **5**.§ Interestingly, on heating the dimer in the presence of Et_3N (30 ml) and S_8 (44 mmol, 30 equiv.) in refluxing benzene (30 ml) unusual results were obtained (Table 2). The product was found to be compound **9**¶ that was identical with the above IHDA adduct **3** from **2**.[1] A possible sequence leading to these products (**8** and **9**) is proposed in Scheme 3. For the formation of **10** from **5** in the presence of Et_3N and S_8,‖ the second sulfur unambiguously came, almost exclusively, from the elemental sulfur added because the yields of **9** exceeded 50% (except **9e**) based on an equimolar amount of the thioketones **5**. The thiocarbonyl *S*-sulfides **10a–c** bearing the unsubstituted allyl group ($R^1 = R^2 = H$) would readily undergo intramolecular [5 + 2] cycloaddition to give **8**. The alternative route of 1,5-cyclization was facilitated by the action of Et_3N leading to **13** *via* the dithiolenes **11** and **12**.** The subsequent inverse retro-cyclization of **12** with

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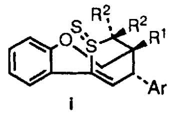
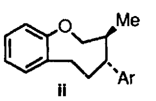
† Recently, Ishii and Nakayama *et al.* reported 1,2,4-trithiolane formation that involved intramolecular trapping of a particular thiocarbonyl *S*-sulfide with a thiocarbonyl dipolarophile.[6]

‡ Selected spectra data: **8a**: ^1H NMR (500 MHz, $CDCl_3$) δ 2.43 (dd, 1H, *J* 13.55 and 10.99 Hz, SCH_2), 2.56 (ddd, 1H, *J* 13.56, 5.12 and 0.74 Hz, SCH_2), 3.02–3.10 (m, 1H, CH), 3.83 (dd, 1H, *J* 12.09 and 10.62 Hz, OCH_2), 4.34 (dd, 1H, *J* 10.62 and 4.40 Hz, OCH_2), 4.60 (dd, 1H, *J* 5.50 and 1.46 Hz, CH-Ph), 6.48 (dd, 1H, *J* 5.50 and 1.48 Hz, CH=) and 6.87–7.53 (m, 9H, Ar-H); ^{13}C NMR δ 22.52 (SCH_2), 34.40 (CH), 41.97 (CH), 69.68 (OCH_2) and 117.32–154.31; *m/z* 312.0644, $C_{18}H_{16}OS_2$ requires 312.0647; *m/z* 312 (M^+, 8%), 280 (100, M^+ −S) and 247 (51, M^+ − S − SH).

Despite the possibility that compound **i** is the product, we consider it unlikely.[8] In addition to spectroscopic analysis, the regio- and stereo-chemistry of compound **8** was further confirmed by $NaBH_4$–$NiCl_2$ reduction of **8c** giving compound **ii**.



i



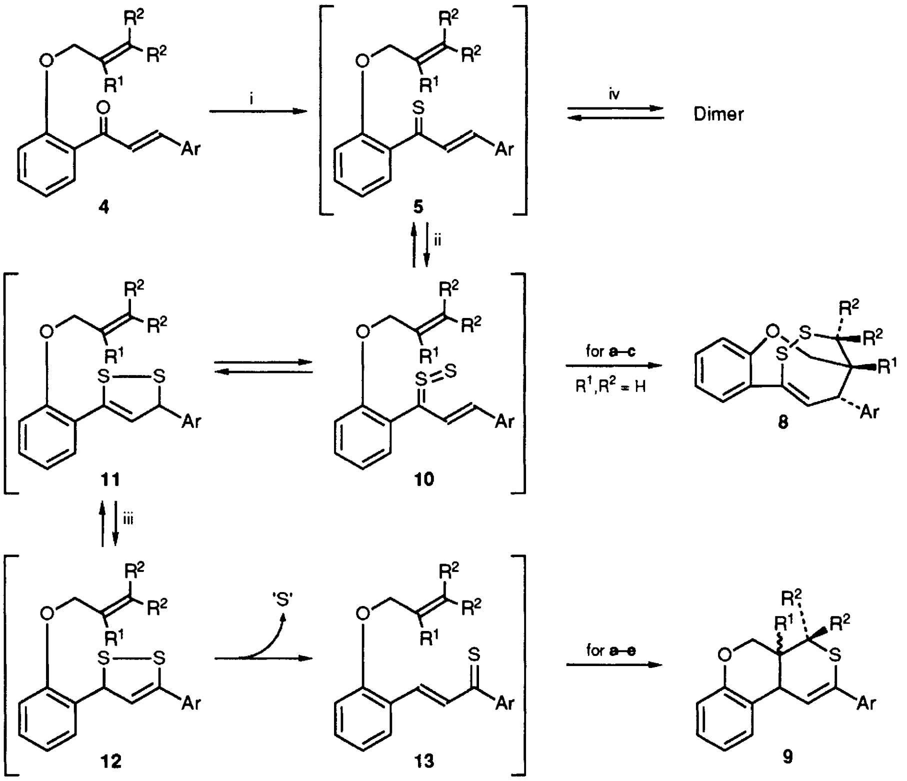
ii

§ Details will be published elsewhere.

¶ Spectroscopic data of compounds **9** and their stereoisomer ratios (determined by 500 MHz ^1H NMR and HPLC) fully coincided with those of **3** reported previously.[1]

‖ For the formation of thiocarbonyl *S*-sulfides **10**, we assumed that the second sulfur atom originated from the elemental sulfur present in the reaction mixture discounting the remaining possibility for the sulfur to arise from the thioketone itself *via*, *e.g.*, [2 + 2] dimerization.

** A similar cyclization (*trans*-oxygenation) of α,β-unsaturated thiocarbonyl *S*-oxides (sulfines) involving formation of 1,2-oxathiolenes has been reported by us.[10]



Scheme 3 *Reagents and conditions*: i, LR in refluxing solvent; ii, 'S' (S_8); iii, Et_3N; iv, heat

sulfur extrusion completed the *trans*-sulfurization. The structurally suitable thioketone **13** thus formed readily underwent the IHDA reaction to product finally the cycloadduct **9** in contrast to **5** which was reluctant to undergo the IHDA reaction.

Received, 29th November 1991; Com. 1/06057K

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