Sequential Pericyclic Reactions of Unsaturated Xanthates. One-pot Synthesis of Hydrobenzo[*c*]thiophenes

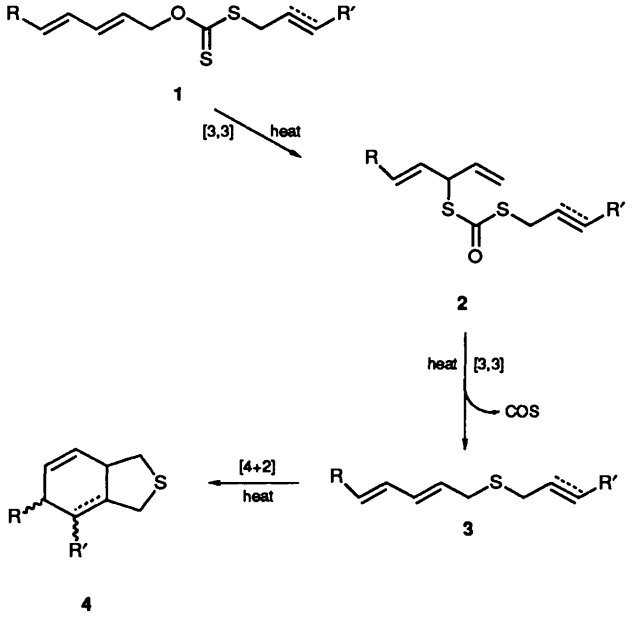
Kazunobu Harano, Masashi Eto, Kikuma Ono, Keisuke Misaka and Takuzo Hisano*
Faculty of Pharmaceutical Sciences, Kumamoto University, 5-1 Oe-honmachi, 862 Kumamoto, Japan

O-Alka-2,4-dienyl *S*-(alk-2-ynyl or alk-2-enyl) dithiocarbonates (xanthates) underwent [3,3]-sigmatropic rearrangement to give the dithiol esters which, on heating, extruded carbon oxysulfide (COS) to give the allylically rearranged sulfides which then underwent intramolecular Diels–Alder cycloaddition to give hydrobenzo[*c*]thiophenes. Lewis acids catalysed the extrusion and intramolecular cycloaddition reactions, in which the reactivity and *endo*-selectivity were remarkably enhanced. The structures of the cycloadducts were determined on the basis of the X-ray structure of a hydrobenzo[*c*]thiophene.

Based on these findings together with MO calculation data, the observed reaction behaviours are discussed in terms of frontier molecular orbital considerations.

Allylic sulfides and their oxidation products are important synthons for carbon skeleton construction,[1] because of their diverse chemical reactions.

In this connection, we have reported a new synthetic method for allylic sulfides (Scheme 1).[2] The reaction consists of



Scheme 1

sequential [3,3]-sigmatropic reactions of allylic xanthates **1** (*O*-alk-2-enyl *S*-alkyl dithiocarbonates), which undergo [3,3]-sigmatropic rearrangements to give allylically isomerized dithiol esters **2** (*S*-alk-2-enyl *S*-alkyl dithiocarbonates),[3] which decompose, on heating under more severe reaction conditions, into the allylically rearranged sulfides **3** (alk-2-enyl alkyl sulfide) with extrusion of carbon oxysulfide (COS). The pyrolytic reaction showed typical concerted reaction behaviour and was catalysed by phenols and Lewis acids.[4]

As an extension, we have recently communicated the three-step sequential pericyclic reactions of *O*-alka-2,4-dienyl *S*-(alk-2-enyl or alk-2-ynyl) xanthates leading to hydrobenzo[*c*]-thiophenes.[5]

We now discuss the reactions in detail, with newly obtained data, in order to clarify the overall character of the reactions.

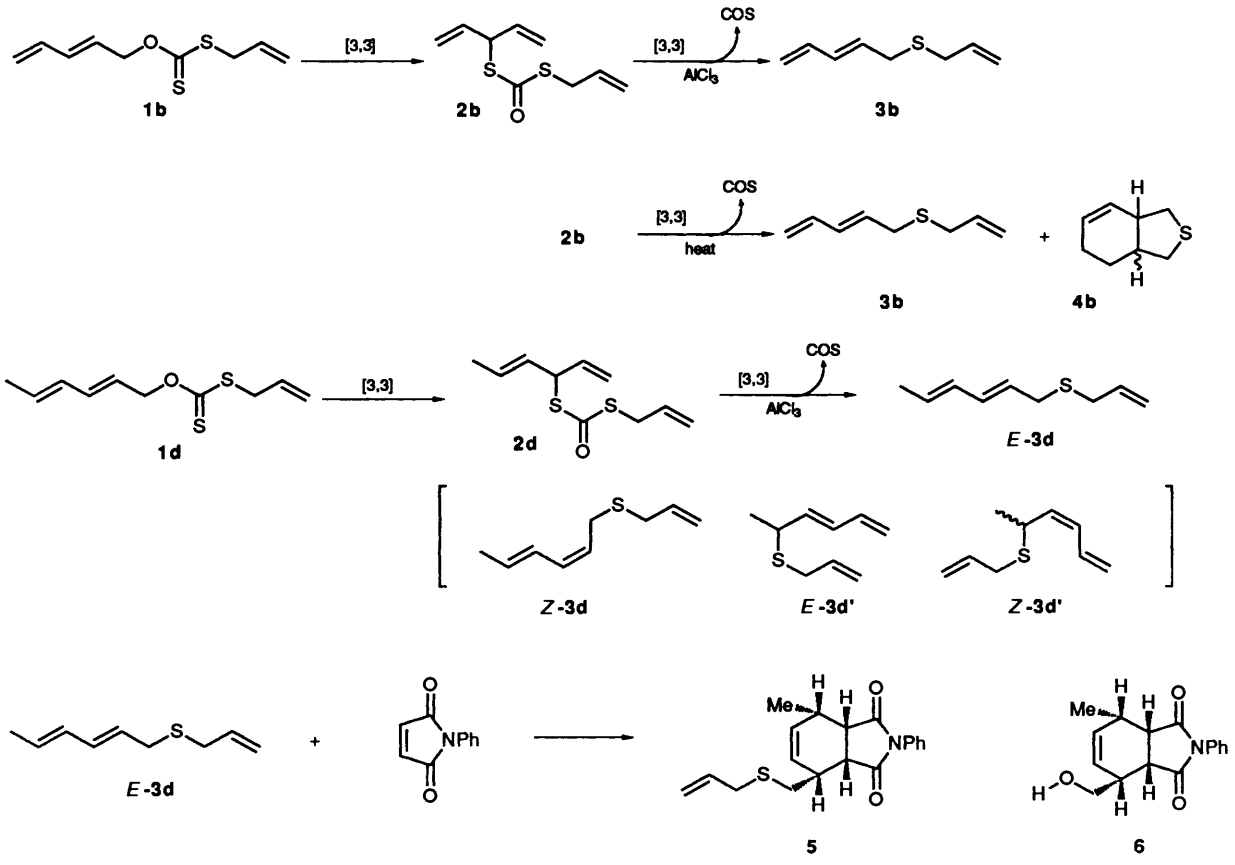
Results

Regioselectivity in the Formation of Alka-2,4-dienyl Sulfides.—*O*-Penta-2,4-dienyl *S*-allyl xanthate **1b** underwent [3,3]-sigmatropic rearrangement to give *S*-allyl *S*-(1-vinylallyl) dithiocarbonate **2b** (Scheme 2). The dithiol ester was treated with $MeAlCl_2$ at room temperature to give penta-2,4-dienyl allyl sulfide **3b** in 46% yield. When the pyrolysis of the dithiol ester **2b** was carried out in the absence of $MeAlCl_2$, severe reaction conditions were required for extrusion of COS (200 °C), producing a mixture of the sulfide **3b** and the intramolecular cycloadduct **4b**.

O-Sorbyl *S*-allyl xanthate **1d** also underwent [3,3]-sigmatropic rearrangement to give *S*-allyl *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2d**, which was treated with $AlCl_3$ in chloroform at room temperature to give allyl sorbyl sulfide **3d**. In the extrusion of COS with allylic shift, two allylic isomers each having two geometric isomers (*E*-**3d**, *Z*-**3d**, *E*-**3d**′ and *Z*-**3d**′) are possible. However, the ^1H NMR spectrum of the crude product did not show any signals assignable to the allylic isomers, *E*-**3d**′ and *Z*-**3d**′. The ^1H NMR spectrum of **3d** showed that the allylic shift occurred exclusively toward the terminal vinyl carbon of **2d**. To establish the configuration of **3d**, the Diels–Alder adduct **5** with *N*-phenylmaleimide was prepared. The two allylic proton signals corresponding to the 2- and 5-positions in **3d** resonate at 2.52–2.72 ppm. The ^1H NMR spectrum resembles that of the [4 + 2]π adduct **6** of sorbyl alcohol and *N*-phenylmaleimide, suggesting that the sulfide **3d** has *E*, *E*-configuration.

Pericyclic Reaction of O-(*Alka*-2,4-*dienyl*) S-(*Alk*-2-*ynyl or Alk*-2-*enyl*) *Xanthates.*—Heating of *O*-penta-2,4-dienyl *S*-prop-2-ynyl dithiocarbonate **1a** at 180–190 °C in the presence of *p*-nitrophenol (PNP) gave a colourless oil with extrusion of COS gas. The ^1H NMR spectrum of the product showed the absence of olefinic protons assignable to the diene moiety, indicating that the cycloaddition reaction had taken place to give the tetrahydrobenzo[*c*]thiophene **4a** in 47% yield. The ^1H NMR spectrum of **4a** exhibited three olefinic proton signals at 5.61–5.78 ppm and six methylene proton signals at 3.02–3.55 ppm. The methylene protons on C-1 appeared as an AB quartet (*J* 12.5 Hz). The methine proton on C-3a resonated at 2.49 ppm as a multiplet.

Thermolysis of the rearranged product **2b** of *O*-penta-2,4-dienyl *S*-allyl dithiocarbonate **1b** at 190 °C in the presence of PNP gave the cycloadduct **4b** in only 15% yield, whereas, heating allyl penta-2,4-dienyl sulfide **3b** in refluxing toluene for



Scheme 2

35 h gave the hexahydrobenzo[*c*]thiophene derivative **4b** in 55% yield. The ^{1}H and ^{13}C NMR spectra supported formation of the cycloadduct. The ^{13}C NMR spectrum showed a duplicated signal pattern (six sp^3 and two sp^2 carbons) suggesting that the product is a mixture of *cis*- and *trans*-fused cycloadducts (*cis*-**4b** and *trans*-**4b**). This together with the ^{1}H–^{1}H COSY data rules out the possibility of formation of the bridged cycloadducts (**4b**′ and **4b**″) (see Scheme 6 for bridged analogues). Inspection of the S-CH_2-proton signals indicates that the *cis*:*trans* product ratio is 4:6. The major product was assigned to be the *trans*-fused adduct based on the MM2 calculations* and the X-ray crystal structure of an analogous compound is described below.

Similarly, heating of the dithiol ester **2c** derived from *O*-sorbyl *S*-prop-2-ynl xanthate **1c** at 180–190 °C in the presence of PNP gave the tetrahydrobenzo[*c*]thiophene **4c** in 62% yield. The ^{1}H NMR spectrum resembles that observed for **4a**. The spectral pattern can be interpreted as that of a single product. Since, **3c** has the *E*,*E*-configuration, the configuration of the C-4 methyl group was taken to be *anti* with respect to the C-2a proton.

Thermolysis of *S*-allyl *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2d** derived from *O*-sorbyl *S*-allyl xanthate **1d** at 200 °C gave a colourless oil with extrusion of COS gas. The ^{1}H NMR spectrum of the product showed formation of hydrobenzo[*c*]-thiophene derivative **4d**. The product ratio, *cis*:*trans* is 28:72, determined by inspection of the C^5-methyl signals. The presence of PNP did not bring about any remarkable improvement of yield and *cis*:*trans* ratio (see Exp. 7 and 8, Table 1).

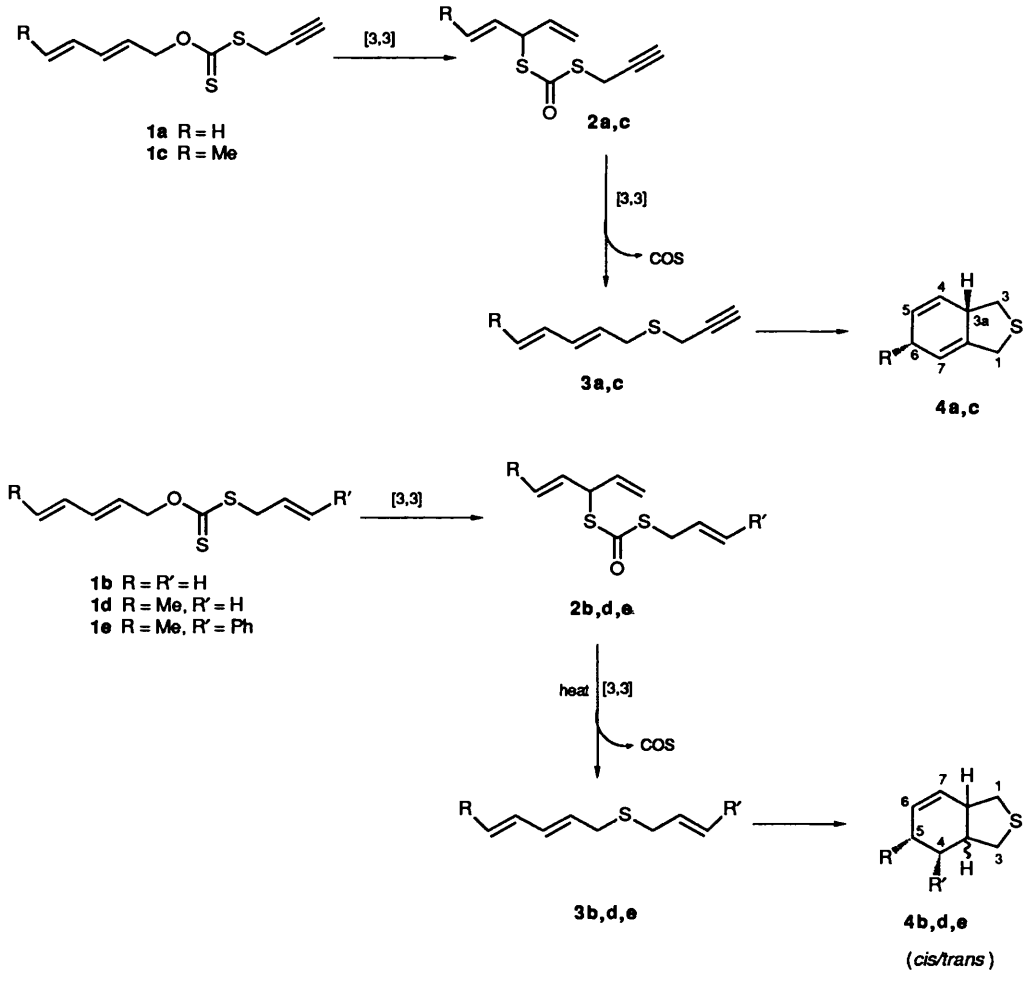
Similarly, heating of the *S*-cinnamyl analogue **2e** in refluxing toluene gave a mixture of *cis*- and *trans*-fused cycloadducts **4e**. The 5-Me groups of *cis*-**4e** and *trans*-**4e** resonate at 0.83 and 0.69 ppm, respectively, indicating that the 5-methyl protons are shielded by the ring current of the *cis*-oriented 4-phenyl group. The presence of a bulky group at the γ-position of the *S*-allyl group in **3** did not interfere with the formation of the cycloadduct.

Pericyclic Reaction of O-(*Alka*-2,4-*dienyl*) S-(3-*Ethoxycarbonylallyl*) *Xanthates*.—Next, we studied the pericyclic reaction of *O*-penta-2,4-dienyl *S*-(3-ethoxycarbonylallyl) xanthate **1f** (Scheme 4). The alkylation of potassium *O*-penta-2,4-dienyl dithiocarbonate with 3-ethoxycarbonylallyl bromide gave the allylically rearranged dithiol ester **2f** in high yield (Table 2). The dithiol ester was treated with $MeAlCl_2$ in $CHCl_3$ at room temperature to give a mixture of the sulfide **3f** and the cycloadducts **4f** in 84% total yield. Heating of the mixture in refluxing toluene for 10 h gave a mixture of the hydrobenzo[*c*]-thiophenes **4f** in the ratio of *cis*:*trans*, 1:9.

Similarly, allylic rearrangement of *O*-sorbyl *S*-(3-ethoxycarbonylallyl) xanthate **1g** gave the dithiol ester **2g**. The dithiol ester **2g** was treated with an equimolar amount of $AlCl_3$ at room temperature to give a mixture of hydrobenzo[*c*]thiophene derivatives **4g** in the ratio of *cis*:*trans*, 2:98.

In order to get definitive evidence for the stereochemistry of the cycloadduct **4g**, a single crystal X-ray analysis was undertaken. The oily product was converted into the crystalline derivatives by oxidation to the sulfone **7** and by $LiAlH_4$ reduction to the alcohol **8** followed by formation of the *p*-chlorobenzoate **9** and phenylurethane derivatives **10** (Scheme 5). A single crystal suitable for X-ray analysis was obtained from the sulfone **7**. The ORTEP drawing of **7** is depicted in Fig. 1 and the fractional coordinates are given in Table 3. The X-ray analysis demonstrated that the main product is the *trans*-fused

* The MM2 calculations on *trans*-fused **2b** and *cis*-fused **2b** indicate that *trans*-fused **2b** is 1.22 kcal mol^{-1} more stable than *cis*-fused **2b**.[6]



Scheme 3

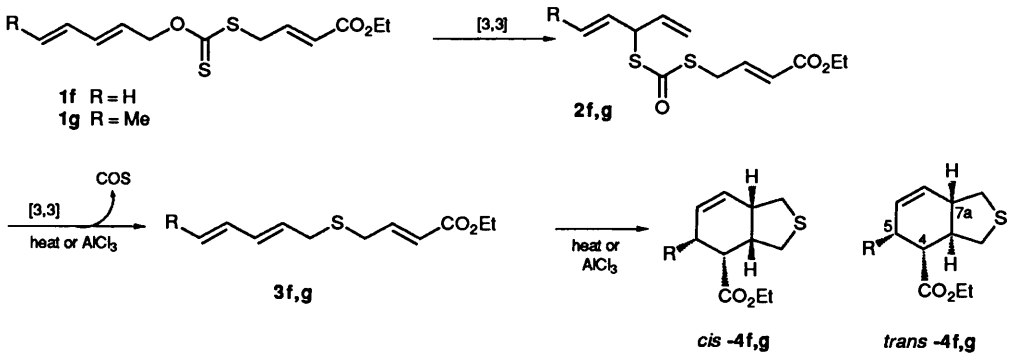
Table 1 Products from sequential pericyclic reactions of the *O*-(alka-2,4-dienyl) *S*-(alky-2-ynyl and alk-2-enyl) xanthates [R–CH=CH–CH=CH–CH_2–O(C=S)S–CH_2CH=CHR' or R–CH=CH–CH=CH–CH_2–O(C=S)S–$CH_2C{\equiv}CR'$] **1** with/without catalyst

Exp. No.	Xanthate **1** CH_2CH=CHR' or $CH_2C{\equiv}CR'$	T/°C	Cat. (mol)	t/h	Product[b] (yield %)	*cis*:*trans* ratio
	R=H					
1	$CH{\equiv}CCH_2$– **1a**	190	PNP (0.4)	0.25	**4a** (47)	—
2	CH_2=$CHCH_2$– **1b**	190	PNP (0.8)	0.25	**4b** (15) **3b** (24)	
3	CH_2=$CHCH_2$– **1b**	room temp.[c]	$MeAlCl_2$ (1.0)	1	**3b** (46)[d]	
4	sulfide **3b**	110[e]		35	**4b** (55)[f]	40:60
	R=Me					
5	$CH{\equiv}CCH_2$– **1c**	180	PNP (0.5)	0.25	**4c** (62)	—
6	CH_2=$CHCH_2$– **1d**	room temp.[c]	$AlCl_3$ (0.3)	2	**3d** (17)[d]	
7	CH_2=$CHCH_2$– **1d**	190	PNP (1.0)	0.25	**4d** (12)[f]	38:62
8	CH_2=$CHCH_2$– **1d**	200		—[g]	**4d** (59)[f]	28:72
9	$PhCH$=$CHCH_2$–**1e**	110[e]		52	**4e** (36)	

[a] PNP: *p*-Nitrophenol, ref. 2*b*. [b] Isolated yields. [c] In $CHCl_3$. [d] Yield of the sulfide. [e] Reflux in toluene. [f] A mixture of *cis*- and *trans*-fused cycloadducts. [g] Pyrolysed under reduced pressure.

cycloadduct and it is clear that the C^5-methyl and C^4-CO_2Et groups are of *anti*-configuration with respect to the 7a-proton. The ^1H and ^{13}C NMR spectral assignments based on the crystal structure are described in the Experimental section.

The effects of catalysts and reaction conditions on the yield and product ratio (*cis*:*trans*) were studied under several reaction conditions. As can be seen in Table 2, severe reaction conditions gave considerable amounts of the *cis*-isomer; thermolysis of **2g** at its distillation temperature (200 °C) gave a mixture of *cis*- and *trans*-fused adducts **4g** in the ratio of *cis*:*trans*, 43:57 in 60% yield. With *p*-nitrophenol at 80–100 °C, the amount of *trans*-isomer slightly increased with lowering of the reaction temperature. With Lewis acids at 0–20 °C, high stereoselectivity was observed (*cis*:*trans*, 5:95–2:98).

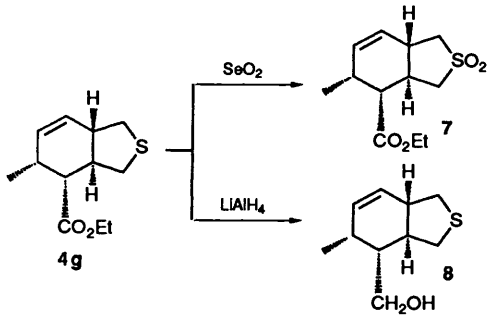


Scheme 4

Table 2 Products from sequential pericyclic reactions of *O*-(alka-2,4-dienyl) *S*-(3-ethoxycarbonylallyl) xanthates [R–CH=CH–CH=CH–CH_2–O(C=S)S–CH_2CH=CHR'] **1** with/without catalyst

Exp No.	Xanthate **1** (R' = CO_2Et) R	*T*/°C	Cat.[a] (mol)	*t*/h	Product[b] (yield %)	*cis*:*trans* ratio
10	H **1f**	room temp.[c]	$MeAlCl_2$ (1.0)	1	**3f** (84)[d]	
11	Sulfide **3f**	110[e]		10	**4f** (36)[f]	10:90
12	Me **1g**	200		—	**4g** (60)[f]	43:57
13	Me **1g**	100	PNP (1.0)	4	**4g** (64)[f]	36:64
14	Me **1g**	80	PNP (2.0)	7	**4g** (46)[f]	26:74
15	Me **1g**	room temp.[c]	$AlCl_3$ (1.1)	4	**4g** (27)[f]	2:98
16	Me **1g**	61[h]	$AlCl_3$ (2.0)	2	**4g** (41)[f]	5:95
17	Me **1g**	0–room temp.	$MeAlCl_2$ (1.0)	4	**4g** (46)[f]	2:98
18	Me **1g**	room temp.	$MeAlCl_2$ (1.1)	24	**4g** (38)[f]	2:98

[a] PNP: *p*-Nitrophenol, ref. 2b. [b] Isolated yields. [c] In $CHCl_3$. [d] A mixture of sulfide and cycloadduct. [e] Refluxed in toluene. [f] A mixture of *cis*- and *trans*-fused cycloadducts. [g] Distilled under reduced pressure. [h] Refluxed in $CHCl_3$.



9 *p*-chlorobenzoate derivative, m.p. 71–73 °C
10 *N*-phenylurethane derivative, m.p. 124–126 °C

Scheme 5

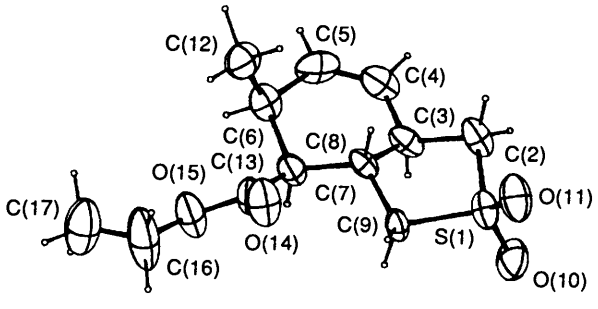


Fig. 1 ORTEP drawing of the sulfone derivative **7** of **4g**

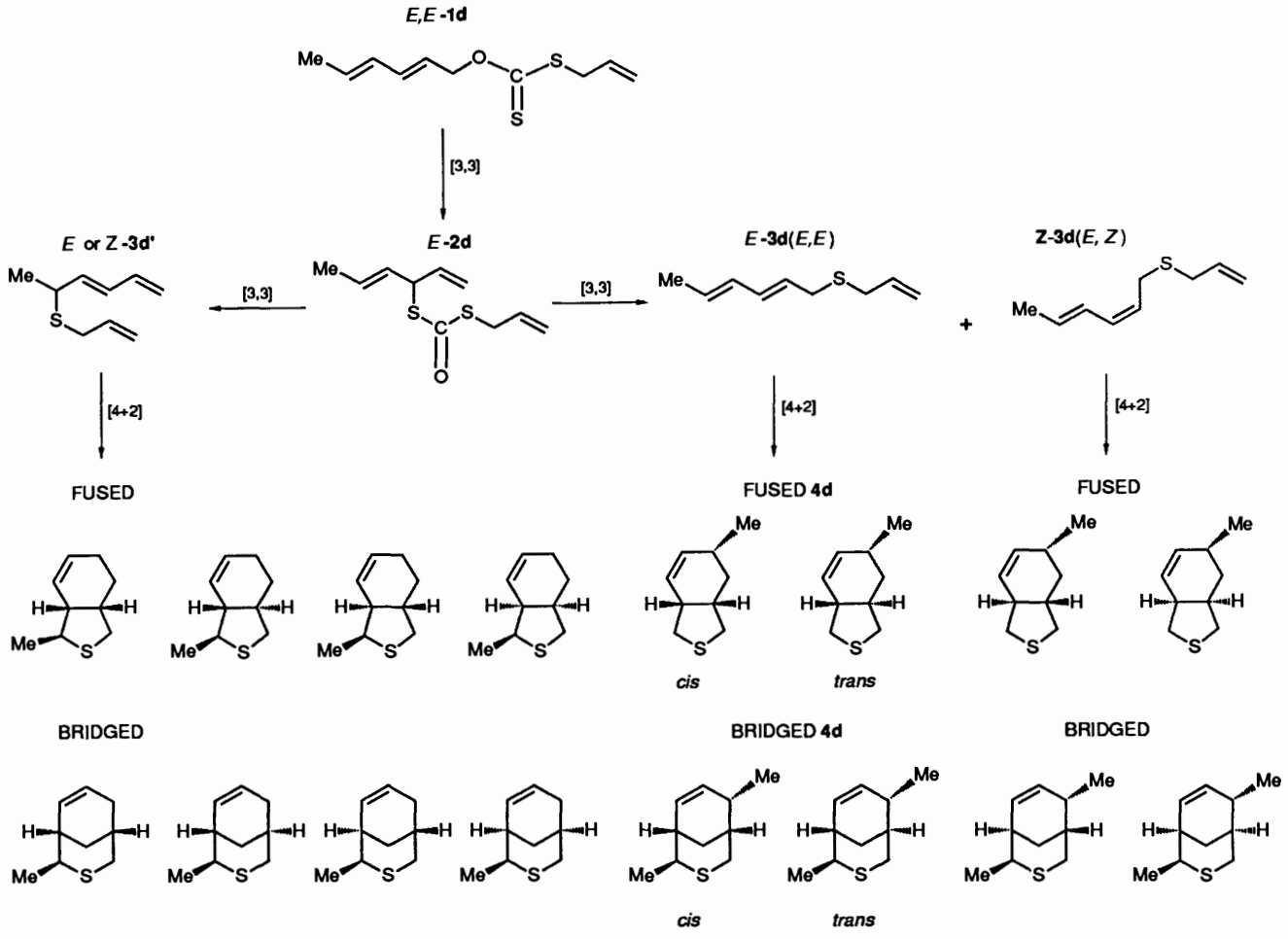
Table 3 Atomic coordinates[a] of **7** with estimated standard deviations in parentheses

Atom	*x*/*a*	*y*/*b*	*z*/*c*
S(1)	8605(1)	3194(4)	2445(2)
C(2)	8371(6)	5186(13)	2095(7)
C(3)	8786(5)	5376(12)	1470(6)
C(4)	8608(6)	6836(13)	967(7)
C(5)	8580(6)	6759(13)	224(7)
C(6)	8683(6)	5266(12)	−226(6)
C(7)	9009(5)	3866(11)	344(6)
C(8)	8624(4)	3805(10)	991(5)
C(9)	8852(5)	2451(11)	1594(5)
O(10)	9264(4)	3241(11)	3115(4)
O(11)	7963(4)	2375(10)	2523(4)
C(12)	7965(6)	4848(16)	−852(7)
C(13)	8905(6)	2291(13)	−99(5)
O(14)	8497(5)	1217(9)	−68(4)
O(15)	9393(5)	2230(9)	−583(5)
C(16)	9325(12)	810(17)	−1036(9)
C(17)	9488(10)	1054(18)	−1691(8)

Positional parameters are multiplied by 10^4

Discussion

An unsolved problem in the sequential pericyclic reaction of allylic xanthates has been that the COS extrusion required very severe reaction conditions. In this connection, Auburn *et al.*[7] reported a palladium-catalysed analogue of our sulfide formation reaction. Their catalysed reaction consists of treatment of allylic xanthates with a palladium catalyst and was proposed to proceed through an ionic intermediate under very mild reaction conditions. However, in the reaction of 1- or 3-alkylalk-2-enyl substrates, allylic shift is not regioselective, and gives mixtures of allylically isomeric sulfides because the reaction mechanism alternates from the non-ionic concerted pathway to the ionic one (*i.e.*, involving a solvent-separated ion pair or carbonium ion intermediate). In the present pericyclic reactions, both the [3,3]-sigmatropic rearrangement of allylic xanthates and the Lewis acid-catalysed extrusion reaction of the rearranged products are regioselective. In the presence of a



Scheme 6

Table 4 Change in the LUMO energy level and coefficients of the dienophile moiety[a] of **3f** due to coordination of $AlCl_3$[b]

Calc. values	Methyl crotonate	Methyl crotonate + $AlCl_3$
[HOMO (eV)	−10.54	−11.54]
LUMO (eV)	−0.11	−2.01
Coefficients (C-4=C-3=C-2=O-1)		
O-1	−0.340	−0.324
C-2	0.406	0.635
C-3	0.493	0.230
C-4	−0.649	−0.544

[a] The calculation was carried out assuming the dienophile moiety as methyl crotonate. [b] Calculated by PM3 method.

carbonyl-conjugated allyl group, formation of the cycloadducts can be carried out in a single operation without isolation of the intermediates.

In the Lewis acid-catalysed extrusion reaction, the nature of the concerted reaction is considered not to be altered by the use of Lewis acids. In the Lewis acid-catalysed extrusion reaction of *S*-(1-phenylallyl) *S*-methyl dithiocarbonate, a sizeable negative entropy of activation was observed.* This may be consistent with the non-ionic cyclic mechanism involving the catalyst whose freedom of motion might be frozen out.

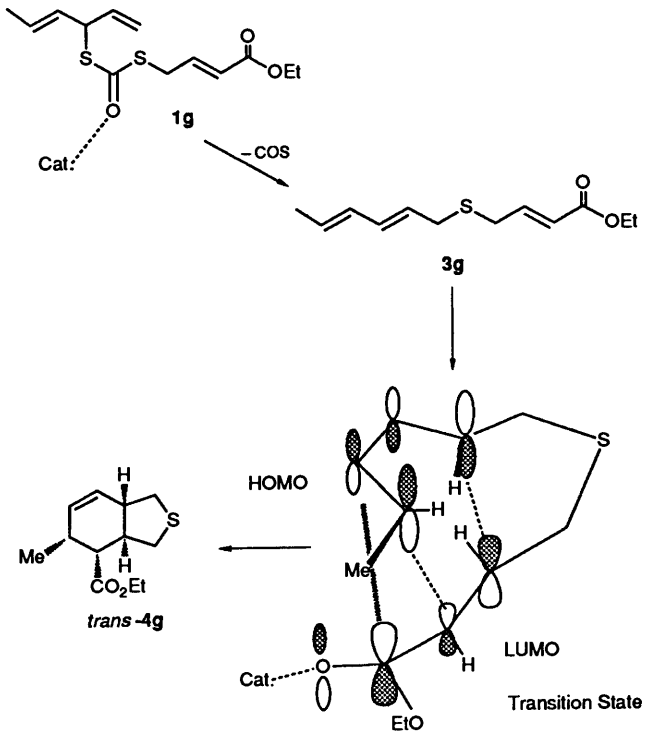
* The activation entropy is calculated to be −28 e.u. for the reaction of *S*-(1-phenylallyl) *S*-methyl dithiocarbonate in the presence of $MeAlCl_2$ (0.1 equiv.); unpublished data.

In the reaction of *O*-(hexa-2,4-dienyl) *S*-allyl xanthate **1d**, sixteen racemic stereoisomeric cycloadducts (due to three allylically and/or geometrically isomeric sulfides giving fused and bridged cycloadducts) are possible (Scheme 6). However, the present sequential pericyclic reactions are quite stereoselective. This may be due to the concerted nature of each of the reactions.

The experimental data showed that the *trans*-fused cycloadduct was formed predominantly when a carbonyl group was present in the dienophile moiety. The *trans*-cycloadduct is derived from the *endo*-transition state stabilized by the secondary orbital interaction which is boosted by coordination of Lewis acids to the carbonyl group.[8] The PM3 calculations[9] on **3f** before and after coordination of $AlCl_3$ support this assumption; the LUMO energy level is lowered from −0.11 to −2.01 eV and the coefficient of the carbonyl carbon is increased from 0.406 to 0.635 (Table 4). Thus, the *endo*-selectivity in the cycloaddition reaction can be increased by introduction of a carbonyl group into the dienophilic moiety and coordination of Lewis acids to the carbonyl group (Scheme 7).

In summary, the pericyclic reaction of allylic xanthates is particularly valuable for regioselective conversion of sensitive allylic alcohols into the corresponding sulfides without rearrangement of the carbon skeleton, and the reaction is effectively accelerated by Lewis acids. In the Lewis acid-catalysed reactions of *O*-(alka-2,4-dienyl) *S*-(alk-2-enyl) xanthates, hydrobenzo[*c*]thiophenes were produced stereoselectively.

Synthetic applications of present reactions are currently being investigated in our laboratory.



Scheme 7

Experimental

The IR spectra were obtained with a Hitachi 270–30 spectrophotometer. The ^{1}H NMR spectra were obtained with Hitachi R-600 (60 MHz) and JEOL GX-400 (400 MHz) spectrometers using tetramethylsilane as an internal standard, chemical shifts are expressed in δ values and coupling constants (J) are expressed in Hz. High resolution mass spectra (HRMS) were taken with a JEOL JMS-DX303HF spectrometer. GLC analyses were performed with a Yanagimoto G-80 gas chromatograph with a thermal conductivity detector using 10% SE-30 on Chamelite CK (60–80 mesh 3 mm × 3 m) column.

Molecular mechanics and molecular orbital calculations were performed on a FACOM M-780 computer in the Computer Center of Kumamoto University and on a Fujitsu S4/2 engineering workstation. Graphic analyses of MO and MM calculation data were performed on a Fujitsu FM-16 β HDII or a FMR-60HX personal computer.

Preparation of Potassium O-Alka-2,4-dienyl Dithiocarbonates (Typical Example).—A suspension of alka-2,4-dienol (0.04 mol), CS_2 (0.04 mol) and KOH (0.04 mol) in acetone (20 cm^3) was stirred at room temperature until the KOH pellets had disappeared. The precipitates were filtered off and washed with Et_2O. The product was pure enough to be used in the subsequent reaction.

1,3,3a,6-*Tetrahydrobenzo*[c]*thiophene* **4a**.—A suspension of (2*E*)-penta-2,4-dienol (1.2 g, 14 mmol), CS_2 (1.1 g, 14 mmol) and KOH pellets (0.80 g, 14 mmol) in dimethyl sulfoxide (DMSO) (10 cm^3) was stirred at room temperature until KOH had disappeared. Prop-2-ynyl bromide (1.7 g, 14 mmol) was added to the mixture and the mixture was stirred at room temperature for 12 h. Water was added to the mixture and the oil which separated was extracted with $CHCl_3$. The extract was dried ($MgSO_4$). Removal of the solvent and purification by chromatography on silica gel using hexane–benzene as eluent afforded the [3,3]-sigmatropic rearranged product, *S*-prop-2-ynyl *S*-(1-vinylallyl) dithiocarbonate **2a**, as a colourless oil (0.91 g, 46%); ν_{max}/cm^{-1} 1646 (C=O); δ_H 2.24 (1 H, t, J 3, ≡CH), 3.74 (2 H, d, J 3, CH_2-C≡), 4.87 (1 H, t, J 7, >CH-S), 5.20 (2 H, d, J 10, -CH=CH_2), 5.30 (2 H, d, J 17, -CH=CH_2) and 5.89 (2 H, ddd, J 7, 10 and 17, -CH=CH$_2$). The product was sufficiently pure for further synthetic purposes.

The rearranged product **2a** (0.98 g, 4.9 mmol) was heated at 180–190 °C in the presence of PNP (0.28 g, 2.0 mmol) until evolution of COS ceased. The pyrolysed product was chromatographed on silica gel to give the cycloadduct **4a** as a colourless oil (0.29 g, 47%) (Found: M$^+$, 138.0477. $C_8H_{10}S$ requires M, 138.0503); ν_{max}/cm^{-1} 2920, 1434 and 694; δ_H 2.49 (1 H, m, 3α-H), 2.71 (2 H, m, 6-H), 3.02 (2 H, m, 3β-H, 3a-H), 3.40 (1 H, d, J 13, 1α-H), 3.55 (1 H, d, J 13, 1β-H), 5.61 (1 H, br s, 7-H) and 5.78 (2 H, m, 4-H, 5-H).

1,3,3a,4,5,7a-*Hexahydrobenzo*[c]*thiophene* **4b**.—Allyl bromide (0.60 g, 5 mmol) was added to the solution of potassium *O*-[(2*E*)-penta-2,4-dienyl] dithiocarbonate (1.0 g, 5 mmol) in acetone (10 cm^3). The mixture was stirred at room temperature for 3 h. The mixture was diluted with water and extracted with Et_2O. The organic layer was dried ($MgSO_4$), filtered, and the solvent was removed under reduced pressure. The yellow oily residue was heated at 80 °C for 2 h. Chromatography on silica gel using hexane as eluent afforded *S*-allyl *S*-(1-vinylallyl) dithiocarbonate **2b** as a colourless oil (0.52 g, 52%); ν_{max}/cm^{-1}; 1644 (C=O); δ_H 3.64 (2 H, d, J 7, SCH_2–CH=CH$_2$), 4.84 (1 H, t, J 7, >CH-S), 5.13 (1 H, m, CH_2CH=CH_2), 5.19 [2 H, d, J 10, -SCH(CH=CH_2)$_2$], 5.25 (1 H, m, -CH_2CH=CH_2), 5.28 [2 H, d, J 17, SCH(CH=CH_2)$_2$], 5.82 (1 H, m, SCH_2CH=CH$_2$) and 5.84 [2 H, ddd, J 7, 10 and 17, SCH(CH=CH$_2$)$_2$].

A mixture of the dithiol ester **2b** (1.0 g, 5 mmol) and $MeAlCl_2$ (1 mol dm^{-3} solution in hexane; 5.0 cm^3, 5 mmol) in $CHCl_3$ (20 cm^3) was heated at reflux for 1 h. The mixture was poured onto ice–water. The $CHCl_3$ layer was separated and dried ($MgSO_4$). Evaporation of $CHCl_3$ gave the crude adduct, which was purified by chromatography on silica gel to give allyl penta-2,4-dienyl sulfide **3b** as a colourless oil (0.32 g, 46%); δ_H 3.09 (2 H, d, J 7, SCH_2CH=CH$_2$), 3.13 (2 H, d, J 7, H_2C^1S), 5.06 (1 H, m, J 10, 5-H), 5.10 (2 H, m, SCH_2CH=CH_2), 5.17 (1 H, d, J 17, 4-H), 5.65 (1 H, td, J 7 and 15, 2-H), 5.77 (1 H, ddt, J 7, 10 and 17, CH_2CH=CH$_2$), 6.09 (1 H, dd, J 10 and 15, 3-H) and 6.33 (1 H, dt, J 10, 10 and 17, 4-H).

The sulfide **3b** (0.2 g, 1.4 mmol) was heated in refluxing toluene (2 cm^3) for 35 h to give the cycloadduct **4b** (0.11 g, 55%) (*trans*:*cis* = 6:4) (Found: M$^+$, 140.0671. $C_8H_{12}S$ requires M, 140.0660) ν_{max}/cm^{-1} 2928, 1454 and 692; δ_H (for *trans*-fused cycloadduct) 1.65 (2 H, m, 4-H), 2.10 (2 H, m, 5-H), 2.45 (1 H, m, 3aβ-H), 2.58 (1 H, dd, J 8 and 10, 1α-H), 2.68 (1 H, dd, J 4 and 11, 3β-H), 2.73 (1 H, m, 7a-H), 3.05 (2 H, m, J 10 and 11, 1β-H, 3α-H), 5.66 (1 H, m, 7-H) and 5.72 (1 H, m, 6-H).

6-*Methyl*-1,3,3a,6-*tetrahydrobenzo*[c]*thiophene* **4c**.—A suspension of (2*E*,4*E*)-hexa-2,4-dienol (1.4 g, 14 mmol), CS_2 (1.1 g, 14 mmol) and KOH (0.78 g, 14 mmol) in DMSO (10 cm^3) was stirred at room temperature until KOH had disappeared.

Prop-2-ynyl bromide (1.7 g, 14 mmol) was added to the mixture and the mixture was stirred at room temperature for 12 h. Water was added to the mixture. The oil which separated was extracted with hexane. The extract was dried ($MgSO_4$). Removal of solvent and chromatography on silica gel using hexane–benzene as eluent afforded *S*-prop-2-ynyl *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2c** as a colourless oil (0.98 g, 33%); ν_{max}/cm^{-1}; 1646 (C=O); δ_H 1.70 (3 H, d, J 6, *Me*CH=), 2.23 (1 H, t, J 3, ≡C–H), 3.73 (2 H, d, J 3, CH_2C≡), 4.84 (1 H, t, J 7 and 8, >CHS–), 5.16 (1 H, d, J 10, SCHCH=CH_2), 5.27 (1 H, d, J 17, SCHCH=CH_2), 5.51 (1 H, m, MeCH=CH–), 5.72 (1 H, m, MeCH=) and 5.88 (1 H, ddd, J 7, 10, 17, CH=CH$_2$).

The rearranged product **2c** (0.84 g, 4.0 mmol) was heated at 180–190 °C in the presence of PNP (*p*-nitrophenol) (0.28 g, 2.0

mmol) until evolution of COS was ceased. The pyrolysed product was chromatographed on silica gel to give the cycloadduct **4c** as a colourless oil (0.15 g, 62%) (Found: M^+, 152.0646. $C_9H_{12}S$ requires *M*, 152.0660); ν_{max}/cm^{-1} 2928, 1454 and 704; δ_H 1.10 (3 H, d, *J* 7, 6-Me), 2.45 (1 H, m, 3α-H), 2.83 (1 H, m, 6α-H), 3.00 (1 H, m, 3a-H), 3.02 (1 H, m, 3β-H), 3.37 (1 H, d, *J* 13, 1α-H), 3.56 (1 H, d, *J* 13, 1β-H), 5.45 (1 H, br s, 7-H), 5.64 (1 H, m, 5-H) and 5.74 (1 H, m, 4-H).

5-Methyl-1,3,3a,4,5,7a-hexahydrobenzo[c]*thiophene* **4d**.—Allyl bromide (1.2 g, 0.01 mol) was added to the solution of potassium *O*-[(2*E*,4*E*)-hexa-2,4-dienyl] dithiocarbonate (2.1 g, 0.01 mol) in acetone (20 cm^3). The mixture was stirred at room temperature for 2 h. The mixture was diluted with water and extracted with Et_2O. The organic layer was dried ($MgSO_4$), filtered, and the solvent was removed under reduced pressure. The yellow oily residue was heated at 80 °C for 2 h.

Chromatography on silica gel using hexane as eluent afforded *S*-allyl *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2d** as a colourless oil (1.4 g, 64%); ν_{max}/cm^{-1} 1646 (C=O); δ_H 1.67 (3 H, d, *J* 6, *Me*CH=), 3.60 (2 H, d, *J* 7, S–C*H*$_2$–CH=CH$_2$), 4.77 (1 H, m, >CHS–), 5.07 (2 H, m, –CH$_2$CH=C*H*$_2$), 5.18 (2 H, m, SCHCH=C*H*$_2$), 5.34 (1 H, m, MeC*H*=) and 5.80 (3 H, m, 3 × C–CH=C).

The rearranged product **2d** (1.1 g, 5 mmol) was heated at 200 °C until evolution of COS had ceased. The pyrolysed product was chromatographed on silica gel to give the cycloadduct **4d** as a colourless oil (0.46 g, 59%) (*trans*:*cis*, 1.6:1) (Found: M^+, 154.0792. $C_9H_{14}S$ requires *M*, 154.0816); ν_{max}/cm^{-1} 2928, 1456 and 726; δ_H (for *trans* form) 1.00 (3 H, d, *J* 7, 5-Me), 1.23 (1 H, td, *J* 11, 13, 4α-H), 1.56 (1 H, dt, *J* 5 and 13, 4β-H), 2.23 (1 H, m, *J* 5, 5α-H), 2.48 (1 H, m, *J* 11, 3aα-H), 2.54 (1 H, m, 3α-H), 2.61 (1 H, m, *J* 11, 1α-H), 2.64 (1 H, m, 7a-H), 3.00 (1 H, dd, *J* 7 and 10, 3β-H), 3.17 (1 H, dd, *J* 7 and 11, 1β-H), 5.54 (1 H, split d, *J* 10, 6-H) and 5.71 (1 H, split d, *J* 10, 7-H); δ_H for *cis* form; 1.04 (3 H, d, *J* 7, 5-Me), 1.65 (2 H, m, 4-H), 1.74 (1 H, m, 3aβ-H), 2.13 (1 H, m, 7a-H), 2.47 (1 H, m, 5α-H), 2.48 (1 H, m, 1α-H), 2.51 (1 H, m, 3β-H), 2.86 (1 H, dd, *J* 6 and 10, 3α-H), 2.96 (1 H, dd, *J* 7 and 10, 1β-H), 5.60 (1 H, d, *J* 10, 6-H) and 5.71 (1 H, m, 7-H).

5-Methyl-4-phenyl-1,3,3a,4,5,7a-hexahydrobenzo[c]*thiophene* **4e**.—A suspension of (2*E*,4*E*)-hexa-2,4-dienol (1.4 g, 14 mmol), CS_2 (1.1 g, 14 mmol) and KOH (0.78 g, 14 mmol) in DMSO (10 cm^3) was stirred at room temperature until KOH had disappeared. Cinnamyl bromide (2.8 g, 14 mmol) was added to the mixture and the mixture was stirred at room temperature for 12 h. Water was added to the mixture. The oil was extracted with $CHCl_3$. The extract was dried ($MgSO_4$). Removal of solvent and chromatography on silica gel using hexane as eluent afforded *S*-cinnamyl *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2e** as a colourless oil (2.4 g, 59%); ν_{max}/cm^{-1} 1640 (C=O); δ_H 1.60 (3 H, d, *J* 6, *Me*CH=), 3.69 (2 H, d, *J* 7, *C*H_2CH=CHPh), 4.73 (1 H, t, *J* 7, >CHS–), 5.05 (1 H, d, *J* 10, –CH=C*H*$_2$), 5.19 (1 H, d, *J* 17, –CH=C*H*$_2$), 5.41 (1 H, m, MeCH=C*H*), 5.64 (1 H, m, MeC*H*=), 5.79 (1 H, ddd, *J* 7, 10 and 17, C*H*=CH$_2$), 6.10 (1 H, td, *J* 7 and 16, C*H*=CHPh), 6.47 (1 H, d, *J* 16, =C*H*Ph) and 7.25 (5 H, m, Ph).

The rearranged product **2e** (2.0 g, 6.9 mmol) was heated at 200 °C in refluxing toluene until the completion of the reaction was recognized by TLC. The pyrolysed product was chromatographed on silica gel to give the cycloadduct **4e** as a colourless oil (0.57 g, 36%) (*cis* and *trans* mixture) (Found: C, 78.0; H, 8.05. $C_{15}H_{18}S$ requires C, 78.21; H, 7.88%); ν_{max}/cm^{-1} 1454 and 702; δ_H (for *trans*-form) 0.69 (3 H, d, *J* 7, 5β-Me), 2.27 (1 H, m, 4β-H), 2.34 (1 H, m, 1α-H), 2.43 (1 H, m, 3aα-H), 2.51 (1 H, m, 5α-H), 2.62 (1 H, m, 3α-H), 2.82 (1 H, m, 1β-H), 3.03 (1 H, m, 3β-H), 3.09 (1 H, m, 7a-H), 5.73–5.85 (2 H, m, 4-H, 6-H) and 7.20 (5 H, m, 4α-Ph); δ_H (for *cis*-form) 0.83 (3 H, d, *J* 7, 5β-Me), 2.27 (1 H, m, 7a-H), 2.37 (1 H, m, 5α-H), 2.43 (1 H, m, 1α-H), 2.63 (1 H, m, 3aβ-H), 2.68 (1 H, m, 3β-H), 2.78 (1 H, m, 4α-H), 2.93 (1 H, m, 1β-H), 3.10 (1 H, m, 3α-H), 5.64–5.75 (2 H, m, 4-H, 6-H) and 7.20 (5 H, m, 4β-Ph).

Ethyl 1,3,3a,4,5,7a-Hexahydrobenzo[c]*thiophene-4-carboxylate* **4f**.—3-Ethoxycarbonylallyl bromide (1.9 g, 0.01 mol) was added to the solution of potassium *O*-[(2*E*-(penta-2,4-dienyl] dithiocarbonate (2.0 g, 0.01 mol) in acetone (20 cm^3). The mixture was stirred at room temperature for 1 h. The solution was diluted with water and extracted with Et_2O. The organic layer was dried ($MgSO_4$), filtered, and the solvent was removed under reduced pressure. The yellow oily residue was heated at 80 °C for 2 h. Chromatography on silica gel using hexane as eluent afforded *S*-(3-ethoxycarbonylallyl) *S*-(1-vinylallyl) dithiocarbonate **2f** in 92% (1.9 g) yield.

A mixture of **2f** (490 mg, 1.8 mmol) and $MeAlCl_2$ (1 mol dm^{-3} solution in hexane; 2.0 cm^3, 2.0 mmol) in $CHCl_3$ (5 cm^3) was stirred at room temperature for 1 h. Water was added to the mixture and $CHCl_3$ layer was separated. Evaporation of $CHCl_3$ gave a mixture of sulfide **3f** and the hydrobenzo[*c*]thiophene **4f** in 84% (320 mg) yield. The mixture was heated in refluxing toluene to give a mixture of *cis*- and *trans*-fused cycloadducts. The product was purified by chromatography on silica gel using hexane–AcOEt as eluent to give a colourless oil (138 mg, 36%) (*cis*:*trans*, 1:9) (Found: M^+, 212.0867. $C_{11}H_{16}O_2S$ requires *M*, 212.0871); ν_{max}/cm^{-1}; 2980 (CH), 1725 (C=O) and 724 (C=C); δ_C (for *cis*-fused adduct) 14.27, 28.0, 35.1, 36.3, 39.7, 42.6, 43.0, 60.6, 124.2, 125.4 and 175.0; δ_C (for *trans*-fused adduct) 14.3, 29.9, 33.7, 34.4, 45.2, 46.5, 47.5, 60.6, 126.6, 127.3 and 174.4; δ_H (for *trans*-fused adduct) 1.27 (3 H, t, *J* 7, Me), 1.94 (1 H, ddd, *J* 7, 11 and 13, 3a-H), 2.30–2.37 (1 H, m, 7a-H), 2.39–2.45 (1 H, m, 4-H), 2.50–2.65 (4 H, m, 3-H, 5-H, 1-H), 2.97 (1 H, split d, *J* 7, 3-H), 2.99 (1 H, dd, *J* 3 and 10, 1-H), 4.12–4.20 (2 H, m, –CH$_2$–Me), 5.68–5.72 (1 H, m, 6-H) and 5.75 (1 H, br d, *J* 10, 7-H).

Ethyl 5-Methyl-1,3,3a,4,5,7a-hexahydrobenzo[c]*thiophene-4-carboxylate* **4g**.—3-Ethoxycarbonylallyl bromide (1.0 g, 5.2 mmol) was added to the solution of potassium *O*-[(2*E*,4*E*)-hexa-2,4-dienyl] dithiocarbonate (1.1 g, 5.2 mmol) in acetone (10 cm^3). The mixture was stirred at room temperature for 4 h. The solution was diluted with water and extracted with Et_2O. The organic layer was dried ($MgSO_4$), filtered, and the solvent was removed under reduced pressure. The yellow oily residue was heated at 80 °C for 4 h. Chromatography on silica gel using hexane as eluent afforded *S*-(3-ethoxycarbonylallyl) *S*-(3-methyl-1-vinylallyl) dithiocarbonate **2g** in 87% (1.3 g) yield.

A solution of **2g** (0.49 g, 1.7 mmol) $AlCl_3$ (0.19 g, 1.7 mmol) in $CHCl_3$ (5 cm^3) was stirred at 0 °C for 4 h and allowed to stand at room temperature for 1 h. Water was added to the mixture and the $CHCl_3$ layer was separated. Evaporation of $CHCl_3$ and chromatography on silica gel with hexane–AcOEt gave a colourless oil (0.18 mg, 46%) (*cis*:*trans* = 2:98) (Found: M^+, 226.1007. $C_{12}H_{18}O_2S$ requires *M* 226.1028); ν_{max}/cm^{-1} 2928 (CH), 1730 (C=O) and 724 (C=C); δ_C 14.30 (CH$_2$*Me*), 17.18 (5-Me), 34.00 (C-3), 34.21 (C-1), 33.52 (C-5), 42.11 (C-3a), 47.24 (C-7a), 49.15 (C-4), 60.26 (CH$_2$O), 126.23 (C-7), 133.09 (C-6) and 173.10 (C=O); δ_H 0.93 (3 H, d, *J* 7, 4-Me), 1.28 (3 H, t, *J* 7, Me), 2.00 (1 H, oct, *J* 6, 11, 11, 11, 3a-H), 2.23–2.29 (1 H, m, 7a-H), 2.47 (1 H, br d, *J* 11, 3-Hβ), 2.53 (1 H, br d, *J* 13, 1-Hα), 2.73 (1 H, dd, *J* 6 and 11, 4-H), 2.77–2.83 (1 H, m, 5-H), 2.96 (1 H, dd, *J* 6, 10, 1-Hβ), 3.29 (1 H, dd, *J* 6, 10, 3-Hα), 4.11–4.23 (2 H, m, –CH$_2$–Me), 5.63 (1 H, ddd, *J* 3, 4 and 10, 6-H) and 5.72 (1 H, br d, *J* 10, 7-H).

Heating of **2g** at 200 °C for 4 h gave a mixture of *cis*-**4g** and *trans*-**4g** in 60% yield. The results in various reaction conditions are listed in Table 2.

Allyl Penta-2,4-dienyl Sulfide **3b**.—A solution of **2b** (1.0 g, 5 mmol) and $EtAlCl_2$ (1 mol dm^{-3} solution in hexane; 5.0 cm^3, 5 mmol) in $CHCl_3$ (20 cm^3) was allowed to react at room temperature for 1 h. The reaction mixture was poured into ice-water. The $CHCl_3$ layer was separated and dried ($MgSO_4$). Evaporation of $CHCl_3$ and chromatography on silica gel gave **3b** as a colourless oil (0.32 g, 46%); δ_H 3.09 (2 H, d, *J* 7.3, $SCH_2CH{=}CH_2$), 3.13 (2 H, d, *J* 7.3, H_2C^1S), 5.06 (1 H, m, *J* 9.9, 5-H), 5.10 (2 H, m, $SCH_2CH{=}CH_2$), 5.17 (1 H, d, *J* 16.9, 4-H), 5.65 (1 H, td, *J* 7.3, 15.0, 2-H), 5.77 (1 H, ddt, *J* 7.3, 10.3, 16.9, $CH_2CH{=}CH_2$), 6.09 (1 H, dd, *J* 10.3, 15.0, 3-H) and 6.33 (1 H, dt, *J* 9.9, 10.3, 16.9, 4-H). The sulfide **3b** was identified by transformation to the cycloadduct **4b**.

[4 + 2]π-*Cycloadduct* **5** *of Allyl Hexa-2,4-dienyl Sulfide* **3d** *and* N-*Phenylmaleimide*.—A solution of **2d** (1.0 g, 4.7 mmol) and $AlCl_3$ (0.18 g, 1.4 mmol) in $CHCl_3$ (3 cm^3) was allowed to stand at room temperature for 2 h. The reaction mixture was poured into ice–water. The $CHCl_3$ layer was separated and dried ($MgSO_4$). Evaporation of $CHCl_3$ and chromatography on silica gel gave **3d** as a colourless oil (0.12 g, 17%); δ_H 1.74 (3 H, d, *J* 6, Me), 3.08 (2 H, d, *J* 7, CH_2–$CH{=}CH_2$), 3.11 [2 H, d, *J* 7, $Me(CH{=}CH)_2CH_2$], 5.08 (2 H, m, $=CH_2$), 5.49 (1 H, m, *J* 7, $MeCH{=}CHCH{=}CH$–), 5.67 (1 H, m, *J* 6, $MeCH{=}$), 5.78 (1 H, m, *J* 7, $CH{=}CH_2$) and 6.00–6.08 (2 H, m, $MeCH{=}CHCH{=}$).

A mixture of **3d** (750 mg, 0.48 mmol) and *N*-phenylmaleimide (120 mg, 0.69 mmol) in toluene (10 cm^3) was heated at reflux for 2 h. Evaporation of toluene gave a colourless solid. Recrystallization from hexane gave colourless needles (53 mg, 34%), m.p. 71–72 °C (Found: M^+, 327.1297. $C_{19}H_{21}NO_2S$ requires *M* 327.1293); δ_H 1.48 (3 H, d, *J* 7, 4-Me), 2.51–2.53 (2 H, m, 4-H and 7-H), 3.00 (1 H, m, one of $-CH_2$–S–CH_2–) 3.18–3.27 (4 H, m, 3a-H, CH_2–S–CH_2), 3.47 (1 H, m, 7a-H), 5.12 (2 H, m, $=CH_2$), 5.79–5.91 (3 H, m, 5-H, 6-H, $-CH{=}CH_2$) and 7.16–7.45 (5 H, m, Ph).

Oxidation of **4g** *with* SeO_2 (*Formation of the Sulfone* **7**).—The hydrobenzo[*c*]thiophene **4g** (181 mg, 0.8 mmol) was added to a suspension of SeO_2 (89 mg, 0.8 mmol) in MeOH (10 cm^3). Under cooling, 30% H_2O_2 (0.8 cm^3) was added to the mixture. After stirring for 2 h, the mixture was diluted with water and extracted with $CHCl_3$. The $CHCl_3$ layer was separated and dried ($MgSO_4$). Evaporation of $CHCl_3$ gave a solid. Recrystallization from EtOH gave **7** as colourless needles (147 mg, 71%), m.p. 103–104 °C (Found: C, 55.85; 7.15. $C_{12}H_{18}O_4S$ requires C, 55.79; H, 7.02%); ν_{max}/cm^{-1} 2980 (CH), 1348, 1122 (SO_2) and 724 (CH=CH); δ_H 0.96 (3 H, d, *J* 7, 5-Me), 1.29 (3 H, t, *J* 7, CH_2Me), 2.33–2.43 (1 H, m, 2a-H), 2.73–2.85 (5 H, m, 2-H, 5-H, 6-H, 6a-H, 7-H), 3.35 (1 H, dd, *J* 6 and 11, 2-H), 3.75 (1 H, dd, *J* 7 and 13, 7-H), 4.12–4.22 (2 H, m, OCH_2–), 5.62 (1 H, d, *J* 10, 3-H) and 5.76 (1 H, ddd, *J* 3, 4 and 10, 4-H).

$LiAlH_4$ *Reduction of* **4g** (*Formation of* 3-*Hydroxymethyl Derivative* **8**).—The cycloadduct **4g** (181 mg, 0.8 mmol) was added to a suspension of $LiAlH_4$ (30 mg, 0.8 mmol) in abs. ether (20 cm^3). The mixture was stirred for 2 h under ice cooling. The reaction mixture was treated with water. The ether layer was separated and dried ($MgSO_4$). Evaporation of ether gave the crude 4-hydroxymethyl-5-methyl-1,3,3a,4,5,7a-hexahydrobenzo[*c*]thiophene **8**, which was converted into crystalline derivatives and characterized.

Formation of the p-*chlorobenzoate* **9**. *p*-Chlorobenzoyl chloride (88 mg, 0.5 mmol) was added to a solution of **8** (92 mg, 0.5 mmol) and pyridine (40 mg, 0.5 mmol) in benzene (20 cm^3). The reaction mixture was stirred at room temperature for 5 h. Water was added to the reaction mixture, which was then extracted with benzene. The extract was dried ($MgSO_4$) and concentrated to give the residue, which was purified by chromatography on silica gel to give **9** (104 mg, 60%), m.p. 62–64 °C (from EtOH) [Found: M^+, 322.0799 and 324.0745 (100.00:42.83). $C_{17}H_{19}ClO_2S$ requires *M*, 322.0794 and 324.0769 (100.00:39.400)]; ν_{max}/cm^{-1} 2932 (C–H), 1714 (C=O) and 731 (*cis* CH=CH); δ_H 1.00 (3 H, d, *J* 7, 5-Me), 1.78 (1 H, oct, *J* 6, 11, 11 and 11, 3a-H), 2.25–2.31 (1 H, m, 4-H), 2.32–2.38 (1 H, m, 7a-H), 2.51 (1 H, dd, *J* 9 and 12, 1-Hα), 2.65–2.66 (1 H, m, 5-H), 2.71 (1 H, dd, *J* 10 and 11, 3-Hβ), 2.92–2.95 (1 H, m, 3-Hα), 2.98 (1 H, dd, *J* 7 and 9, 1-Hβ), 4.32 (1 H, dd, *J* 8 and 11, $-CH_2$–O), 4.40 (1 H, dd, *J* 7 and 11, $-CH_2$–O), 5.68 (2 H, ddd, *J* 2 and 4, 10.3, 5-H), 5.73 (1 H, d, *J* 10, 7-H), 7.42 (2 H, d, *J* 9, aromatic H) and 7.85 (2 H, d, *J* 9, aromatic H).

Formation of the isocyanate **10**. Phenyl isocyanate (60 mg, 0.5 mmol) was added to a solution of **8** (92 mg, 0.5 mmol) in benzene (20 cm^3). The reaction mixture was stirred at room temperature for 3.5 h. Water was added to the reaction mixture, which was then extracted with benzene. The extract was dried ($MgSO_4$) and concentrated to give the residue, which was recrystallized from ethanol to give **10** (104 mg, 63%), m.p. 113–115 °C (Found: M^+, 303.1293. $C_{17}H_{21}NO_2S$ requires *M* 303.1293); ν_{max}/cm^{-1} 3364 (N-H), 2920 (C-H), 1704 and 1536 (–CONH) and 732 (*cis* CH=CH); δ_H 0.96 (3 H, d, *J* 7, 5-Me), 1.71 (1 H, oct, *J* 6, 11, 11 and 11, 3a-H), 2.14–2.22 (1 H, m, 4-H), 2.27–2.34 (1 H, m, 7a-H), 2.48 (1 H, dd, *J* 10 and 13, 1-Hα), 2.58–2.60 (1 H, m, 5-H), 2.67 (1 H, dd, *J* 10 and 11, 3-Hβ), 2.91 (1 H, dd, *J* 6 and 10, 3-Hα), 2.96 (1 H, dd, *J* 7 and 10, 1-Hβ), 4.15 (1 H, dd, *J* 9 and 11, $-CH_2$–O–), 4.28 (1 H, dd, *J* 6 and 11, $-CH_2$–O–), 5.66 (2 H, ddd, *J* 3, 4 and 10, 6-H), 5.71 (1 H, d, *J* 10, 7-H), 6.64 (1 H, br s, N-H) and 7.05–7.39 (5 H, m, aromatic H).

Crystal Data.—$C_{12}H_{18}O_4S$ **7**, *M* = 258.26: monoclinic, *a* = 18.623(9) Å, *b* = 8.228(4) Å, *c* = 17.716(8) Å, β = 107.38(4)°, *V* = 2591(2) $Å^3$, D_m = 1.320 g cm^{-3} (aq. KI), D_c = 1.325 g cm^{-3}, *Z* = 8, Mo-Kα radiation (40 kV–20 mA), λ = 0.7107 Å.

The cell constants were determined from a least-square procedure using the value of the Bragg angles of 20 reflections measured on a RIGAKU AFC-6 four-circle autodiffractometer equipped with a graphite monochromated Mo-Kα source, which is interfaced to a PANAFACOM U-1200 minicomputer.

The space group *C*2/*c* (No. 15) was selected from systematic absences and number of molecules per unit cell (*Z* = 8) and was later confirmed in the course of the structure refinement. Intensity data were collected in the range $2\theta < 55°$ using the $\omega - 2\theta$ scan technique. The variable scan rate was adopted. Two reflections were monitored after every measurement of 100 reflections. Of the 1904 independent reflections, 925 were treated as observed ($F_o > 3.5\sigma F$). The intensities were corrected for Lorentz and polarization effects, but no correction was applied for absorption.

Structure solution and refinement. An overall temperature factor (2.45 $Å^2$) obtained from a Wilson plot gave the correct solution. The structure was solved by the direct method using the MULTAN78 series of programs.[10a] An *E* map calculated with 198 signed *E*'s (*E* > 1.2), which gave a figure of merit of 1.4001, revealed the positions of all the expected non-hydrogen atoms. Refinements were carried out by the block-diagonal least-square method. Six cycles of isotropic refinement and six cycles of anisotropic refinement led to a *R* index of 0.126. All the hydrogens were located at calculated positions. After adding the hydrogens, but keeping their positional and thermal parameters fixed [*B*(H) = *B*(C) + 1.0] and refining, we obtained a final *R* of 0.081. In final refinements, both positional and thermal parameters of the five hydrogens attached to the ester groups were fixed and the following weights were used for the observed reflections: *w* = 1.0 for $F_o < 80.0$, $w = 6400/F_o^2$ for $F_o > 80.0$.

All structure-solving programs and drawing program (ORTEP)[10b] were from the Computer Centre of Kumamoto

University with the Universal Crystallographic Computation Program System (UNICS III).[10c]

Atomic positional parameters, anisotropic temperature factors, and bond lengths and angles have been deposited with the Cambridge Crystallographic Data Centre.*

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* For full details of the CCDC deposition scheme see, 'Instructions for Authors', *J. Chem. Soc., Perkin Trans 1*, 1993, Issue 1.

References

1 (*a*) J. F. Biellman and J. B. Ducep, *Organic Reactions*, ed. by W. G. Dauben, Wiley, New York, 1982, Vol. 27, ch 1.
2 (*a*) K. Harano, N. Ohizumi and T. Hisano, *Tetrahedron Lett.*, 1985, **26**, 4203; (*b*) K. Harano, N. Ohizumi, K. Misaka, S. Yamashiro and T. Hisano, *Chem. Pharm. Bull.*, 1990, **38**, 619.
3 (*a*) T. Taguchi, K. Kawazoe, K. Yoshihira, M. Mori, K. Tabata and K. Harano, *Tetrahedron Lett.*, 1965, 2717; (*b*) K. Harano and T. Taguchi, *Chem. Pharm. Bull.*, 1972, **20**, 2348, 2357; (*c*) K. Harano and T. Taguchi, *Chem. Pharm. Bull.*, 1975, **23**, 467.
4 K. Harano, S. Yamashiro, K. Misaka and T. Hisano, *Chem. Pharm. Bull.*, 1990, **38**, 2956.
5 K. Harano, K. Ono, M. Nishimoto, M. Eto and T. Hisano, *Tetrahedron Lett.*, 1991, **32**, 2387.
6 N. L. Allinger, *J. Am. Chem. Soc.*, 1977, **99**, 8127; N. L. Allinger and Y. H. Yuh, *QCPE*, 1980, **12**, 395.
7 P. R. Auburn, J. Whelan and B. Bosnich, *J. Chem. Soc., Chem. Commun.*, 1986, 146.
8 I. Fleming, *Frontier Orbitals and Organic Chemical Reactions*, Wiley, London, 1976, p. 161.
9 J. J. P. Stewart, *J. Comp. Chem.*, 1989, **10**, 221.
10 (*a*) P. Main, S. E. Hull, L. Lessinger, G. Germain, J. P. Declercq and M. M. Woolfson, *MULTAN78*, a System of Computer Programs for Automatic Solution of Crystal Structures from X-ray Diffraction Data, University of York, York, England, 1978; (*b*) C. K. Johnson, *ORTEP*, Report ORNL-3794, Oak Ridge National Laboratory, Oak Ridge, TN, 1965. The program was locally modified for use of *X–Y* plotters devised for personal computers; (*c*) T. Sakurai and K. Kobayashi, *Rikagaku Kenkyusho Hookoku*, 1979, **55**, 69: S. Kawano, *Koho, Comput. Center Kyushu Univ.*, 1983, **16**, 113.

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