Ethyl and Methyl Thioxoacetates, Dienophilic Thioaldehydes Formed from Sulphenyl Chlorides by 1,2-Elimination

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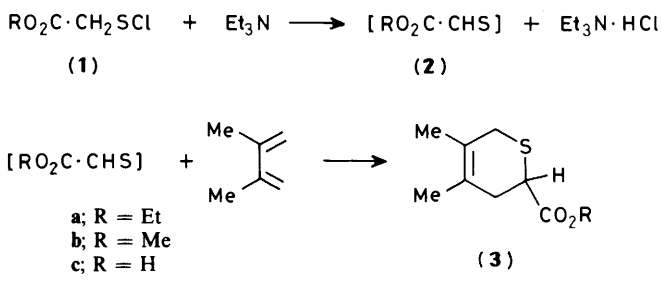
Ethoxycarbonyl- and methoxycarbonyl-methanesulphenyl chlorides react at room temperature with triethylamine to form ethyl and methyl thioxoacetates, respectively. Generation of the transient thioladehyde, ethyl thioxoacetate (**2a**), in the presence of the conjugated dienes 2,3-dimethylbuta-1,3-diene, thebaine (**7**), cyclohexa-1,3-diene, anthracene, and 9,10-dimethylanthracene gave adducts formed by cycloaddition of the thial group to the diene systems. The cycloadduct (**8**), derived from thebaine (**7**) at room temperature, isomerised at 111 °C to give the thermodynamically more stable adduct (**9**) by dissociation and recombination. The cycloadducts of anthracene and 9,10-dimethylanthracene likewise dissociated at 111 °C thereby providing a convenient, 'clean' source of ethyl thioxoacetate. When the anthracene adduct was heated with (−)-β-pinene, two 'ene' products were obtained, the major product (**17**; R = CO_2Et) arising by C–S and the minor product (**18**; R = CO_2Et) by C–C bond formation.

The Diels-Alder reaction of conjugated dienes with ethylenic or acetylenic dienophiles remains one of the most useful transformations in organic synthesis. Heterodienophiles [1] of the type, RR'C:X, have been employed less frequently but have considerable potential when only one new carbon–carbon bond is required in the product. Thioaldehydes, RCHS, would appear especially well suited as heterodienophiles in synthesis since (i) the thial π-bond is weak and should be reactive in cycloadditions, (ii) the steric demands of mono-substituted dienophiles are small, and (iii) sulphur may be removed from the cycloadducts or retained and used to facilitate further transformations, for example by enhancing the acidity of the adjacent, methine hydrogen. However, simple thioaldehydes are too reactive to allow their isolation of manipulation at ambient temperatures. For example, thiobenzaldehyde [2] polymerises in the condensed state at temperatures above 110 K. Recently, it has been shown that thioaldehydes may be stabilised sterically with, presumably, reduction in their general reactivity and synthetic utility. Thus, 2,4,6-tri-t-butylthiobenzaldehyde [3] is stable in the crystalline state at room temperature and 2,2-dimethylpropanethial [4] persists as the monomer in solution for extended periods at 20 °C. Stabilisation of thioaldehydes by strongly electron-donating groups has been known for some time [5] but, again, the reactivity of the thial group is correspondingly diminished.

We describe here in full [6] our first study of transient thioaldehydes, ZCHS, formed by base-mediated, 1,2-elimination of HX from precursors, ZCH_2SX, where Z is an electron-withdrawing group able to enhance both the rate of elimination and the dienophilic character of the thioaldehydes. In this and later studies [7] the thioaldehydes were trapped *in situ* by cycloaddition to conjugated dienes. The same procedure was adopted, in independent investigations, for transient thioaldehydes generated by either photolysis of phenacyl sulphides [4,8] or thermolysis of thiosulphinates.[9] Thus, there are now several complementary methods for the generation of thioaldehydes as reactive intermediates in organic synthesis.

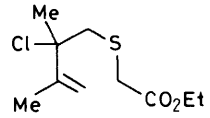
Armitage and Clark [10] reported that methanesulphenyl chloride reacted with dialkylamines to give the corresponding methanesulphenamides together with bis(dialkylamino)methanes. They suggested that the latter products might have arisen by condensation of the amines with thioformaldehyde. We reasoned that, if this were true, then elimination of hydrogen chloride from ethoxycarbonylmethanesulphenyl chloride (**1a**) might occur even more readily to form ethyl thioxoacetate (**2a**) (Scheme 1). Ethyl mercaptoacetate (5.5 mmol) was treated with



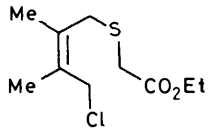
Scheme 1.

N-chlorosuccinimide (6.5 mmol) in benzene at room temperature to give a yellow solution containing the sulphenyl chloride [11] (**1a**) and succinimide. This was added at room temperature to 2,3-dimethylbuta-1,3-diene (5.0 mmol) in a mixture of benzene and methanol containing triethylamine (6.5 mmol). The reaction mixture, freed from triethylammonium chloride and succinimide, was shown by ^1H n.m.r. spectroscopy to consist largely (>90%) of the dihydrothiin (**3a**), which was obtained in good yield (65%) after distillation. Hydrolysis gave the corresponding, crystalline acid (**3c**). The formation of (**3a**) from near-stoicheiometric amounts of reactants indicated efficient formation and trapping of the transient thioaldehyde (**2a**). However, it was conceivable that the sulphenyl chloride had first added to the diene to give the derivatives (**4**) and/or (**5**) and that triethylamine had then effected cycloelimination of hydrogen chloride. This possibility was discounted with the following control experiment. 2,3-Dimethylbuta-1,3-diene was treated with the sulphenyl chloride (**1a**) as before but in the absence of triethylamine. Addition of triethylamine then gave a mixture containing (n.m.r. control) no significant amounts of the cycloadduct (**3a**). The composition of this mixture was not studied in detail, but the ^1H n.m.r. spectrum showed olefinic signals near δ 5.0 indicating the presence of 1,2-adducts [12] [*e.g.* (**4**)]. The reaction of the sulphenyl chloride (**1a**) with triethylamine, to give ethyl thioxoacetate (**2a**), was carried out in the presence of methanol. We cannot exclude the possibility

that the sulphenate ester (**6**) was formed first and then underwent elimination of methanol. However, the adduct (**3a**) was still obtained, though less cleanly, when dichloromethane was used as the solvent and under these conditions, at least, direct elimination of hydrogen chloride must occur.



(**4**)

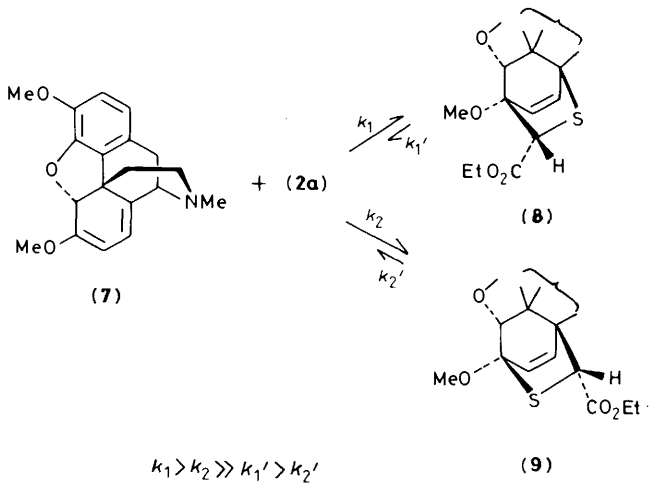


(**5**)

$EtO_2C \cdot CH_2S \cdot OMe$

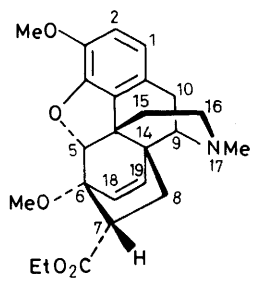
(**6**)

The reaction of ethyl thioxoacetate, generated as before in a mixture of benzene and methanol, with the unsymmetrical diene thebaine (**7**) was especially informative. The major product (**8**) (67% after purification) was accompanied by, at the most, only traces of the isomer (**9**). However, when the adduct (**8**) was heated under reflux in toluene, clean conversion into the isomer (**9**) was observed (Scheme 2). The transformation, (**8**) ⟶ (**9**), must occur by dissociation of (**8**) and recombination of the components, a point verified by heating (**8**) with 2,3-dimethylbuta-1,3-diene and observing the formation of (**3a**). Thus, addition of ethyl thioxoacetate to thebaine to give (**8**) had occurred under kinetic control. In this respect ethyl thioxoacetate behaves like ethyl acrylate, which adds to thebaine to give (**10**),[13] suggesting that the electron-withdrawing ester group effectively controls the mode[8b] of addition of the thioaldehyde. In contrast, glyoxylate esters, RO_2CCHO, add to 1-alkoxybuta-1,3-dienes in the opposite sense, to give 2-alkoxy-5,6-dihydro-2*H*-pyrans.[1,14] The structures (**8**) and (**9**) were elucidated by detailed comparison of their ^1H n.m.r. spectra (250 MHz) with that of the known acrylate adduct (**10**).[13] The spectra will be discussed with reference to the perspective drawings in the Figure. The methine protons adjacent to sulphur, 7-H in (**8**) and 8-H in (**9**), show markedly different chemical shifts. The chemical shift for 7-H in (**8**), δ 4.01, is 1.16 p.p.m. greater than that for 7-H in (**10**), which is the expected result of formal replacement of sulphur by a methylene group. However, 8-H in (**9**) resonates at δ 5.23, a value which can only be attributed to the deshielding effect of the nitrogen lone-pair. Conversely, the chemical shift, δ 2.14, of $15_{ax.}$-H in (**9**) is similar to that of the corresponding proton in (**10**), δ 1.97, whereas $15_{ax.}$-H in (**8**) resonates downfield at δ 2.74 as a consequence of deshielding by a non-bonding pair of electrons on sulphur. Confirmation of these structural assignments came from the observation of long-range, '*w*' coupling, *J* 0.7 Hz, between 7-H and 18-H in the isomer (**8**). Generally, signals for 18-H in cycloadducts of thebaine can be identified by the long-range, '*w*' coupling with 5-H. In the spectrum of (**8**), but not of (**9**), 18-H [δ 5.91 (ddd, *J* 9.1, 1.3, and 0.7 Hz)] showed additional long-range coupling, as indicated.

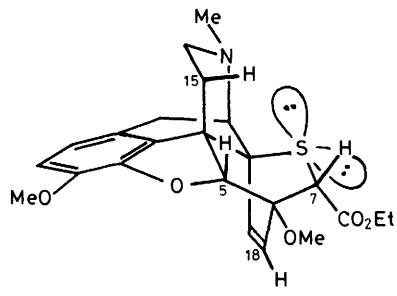


$k_1 > k_2 \gg k_1' > k_2'$

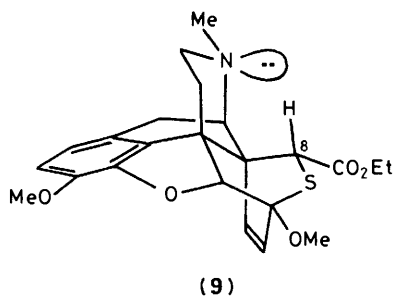
Scheme 2.



(**10**)



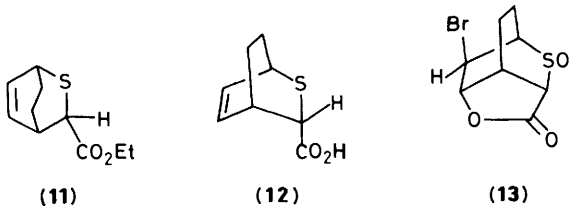
(**8**)



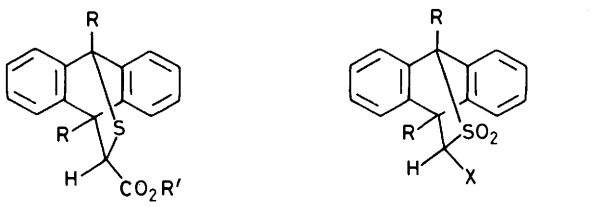
(**9**)

Figure.

Addition of ethyl thioxoacetate to cyclohexa-1,3-diene, under the foregoing conditions, gave an oily product (**11**), judged by ^1H n.m.r. spectroscopy to consist largely of a single stereoisomer. Hydrolysis of (**11**) and crystallisation of the resulting acid gave the *endo*-isomer (**12**), which was converted into the bromo lactone sulphoxide (**13**) to verify the stereochemistry. The adduct (**11**) was obtained in only 37% yield after purification. The by-products were shown, by a control experiment, to be derived by attack of the sulphenyl chloride (**1a**) on cyclohexa-1,3-diene in competition with elimination to give the thioaldehyde (**2a**). In accord with this interpretation, increasing the amount of triethylamine to 3 mol equiv. caused a two-fold increase in the yield of (**11**). Nevertheless, competitive attack of sulphenyl chlorides on dienes represents a limitation to their general use as precursors for thioaldehydes. However, less



(11) (12) (13)



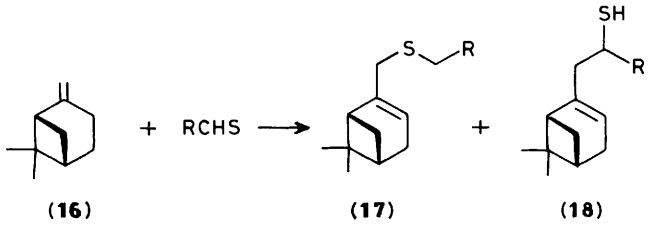
(14) (15)

a; R = H, R′ = Et
b; R = Me, R′ = Et
c; R = Me, R′ = H
d; R = R′ = Me

a; R = H, X = CO_2Et
b; R = Me, X = CO_2Me
c; R = Me, X = H

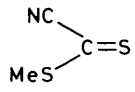
reactive sulphenyl derivatives are now available[7] which are free from this limitation.

We had earlier shown that nitrosocarbonyl compounds, a class of unstable dienophiles, can be trapped as their cycloadducts with 9,10-dimethylanthracene.[15] These adducts were stable for prolonged periods at room temperature yet dissociated readily at 60 °C, thereby allowing transfer of the labile dienophiles to a variety of conjugated dienes. We have employed the same device with ethyl (**2a**) and methyl thioxoacetate (**2b**). The sulphenyl chloride (**1a**), prepared as before from ethyl mercaptoacetate (11 mmol) and *N*-chlorosuccinimide (13 mmol), was added to a dilute solution of anthracene (11 mmol) in dichloromethane containing triethylamine (13 mmol) at room temperature. The reaction mixture was shown by ^1H n.m.r. spectroscopy to contain anthracene and the adduct (**14a**) in the ratio *ca.* 4:1. Repetition of this experiment in refluxing dichloromethane gave a corresponding ratio of 2:1 and in refluxing chloroform of 1:1. Chromatography of the mixture from the last experiment afforded the pure adduct (**14a**) (37%). No attempt was made to improve further the yield of the adduct since all the reactants were inexpensive and final, chromatographic purification seemed unavoidable. The low yield of (**14a**) must reflect the relatively low reactivity of anthracene in cycloadditions. Competitive attack of the sulphenyl chloride (**1a**) on anthracene did not occur to any significant extent, but the ^1H n.m.r. spectra of all the reaction mixtures showed broad, ethoxy signals attributable to decomposition products of ethyl thioxoacetate. Very likely, this decomposition is catalysed[4] by the triethylamine necessarily present to induce cleavage of the sulphenyl chloride. The adduct (**14a**) was characterised further as the sulphone (**15a**). Similarly, 9,10-dimethylanthracene and ethyl thioxoacetate in dichloromethane gave the oily adduct (**14b**) (46%), which was converted into the crystalline acid (**14c**). Finally, 9,10-dimethylanthracene and methyl thioxoacetate (**2b**) gave the crystalline adduct (**14d**) (49%), which was converted into the acid (**14c**) and the sulphone (**15b**). The latter was heated with sodium chloride in dimethyl sulphoxide[16] to afford, in good yield, the sulphone (**15c**), which had been prepared previously[17] from the cycloadduct of 9,10-dimethylanthracene and thiophosgene. The value of these anthracene adducts as auxilliary precursors of thioaldehydes was demonstrated as follows. The adduct (**14a**) was heated in toluene with an equimolar amount of thebaine (**7**) at 100 °C for 10 h to give the adduct (**9**) (78%) of thebaine. Similarly, the adduct (**14b**) and thebaine gave (**9**) (86%) after 5 h at 110 °C. Finally, transfer of ethyl thioxoacetate from (**14a**) to cyclohexa-1,3-diene was effected at 110 °C in 3 h to give the adduct (**11**) (79%).



(16) (17) (18)

Scheme 3.



(19)

Baldwin and Lopez[6] showed that *S*-alkyl thiosulphinates are cleaved thermally to form thioaldehydes in high yield. They also demonstrated the formation of thiobenzaldehyde and thioacetaldehyde by thermolysis of the corresponding anthracene and 9,10-dimethylanthracene adducts, respectively. Further, when *S*-benzyl phenylmethanethiosulphinate was heated in the presence of an excess of β-pinene (**16**) the 'ene' reaction products (**17**; R = Ph) (19%) and (**18**; R = Ph) (37%) were obtained (Scheme 3). We find that ethyl thioxoacetate reacts similarly with β-pinene, but gives a markedly different ratio of products. Thus, the anthracene adduct (**14a**) and β-pinene (2 mol equiv.) were heated in toluene for 4 h at 111 °C to give the adducts (**17**; R = CO_2Et) (78%) and (**18**; R = CO_2Et) (21%). In this respect, ethyl thioacetate resembles the electron-deficient dithioester (**19**), which reacts[18] with β-pinene to give the sulphide [**17**; RCH_2 = MeSCH(CN)] as the sole (83%) identified product.

Experimental

M.p.s. were determined with a Kofler hot-stage apparatus. Except where otherwise stated, i.r. spectra were recorded for solids in KBr discs and for liquids in chloroform solutions, n.m.r. spectra were recorded at 90 MHz for deuteriochloroform solutions, and light petroleum refers to the fraction b.p. 60—80 °C. Chromatography was carried out on silica. Solutions of products in organic solvents were dried with anhydrous magnesium sulphate and evaporated under reduced pressure.

Preparation[11] *of Ethoxycarbonyl-*(**1a**) *and Methoxycarbonylmethanesulphenyl Chloride* (**1b**).—Ethyl or methyl mercaptoacetate was added dropwise with stirring to a suspension of *N*-chlorosuccinimide in the appropriate solvent (see the following preparations of individual cycloadducts) at room temperature. A yellow colour, signifying the formation of the sulphenyl chloride, generally developed soon after addition of a small quantity of the thiol. The *N*-chlorosuccinimide dissolved as the reaction proceeded. After 2 h, the solution of the sulphenyl chloride was removed by pipette or decantation from any precipitate of succinimide and added directly to the appropriate solution of the diene containing triethylamine which had been purified by distillation from pellets of KOH. *N*-Chlorosuccinimide was purified by washing with water to remove succinimide, drying *in vacuo* over P_4O_{10}, and crystallisation from benzene. Purified material was stored at 5 °C (storage at room temperature led to significant decomposition, without change in appearance, within 1 week).

Ethyl 3,6-*Dihydro*-4,5-*dimethyl*-2H-*thiin*-2-*carboxylate* (**3a**) *and the Corresponding Acid* (**3c**).—Ethoxycarbonylmethanesulphenyl chloride (**1a**), prepared from ethyl mercaptoacetate (0.66 g, 5.5 mmol) and *N*-chlorosuccinimide (0.87 g, 6.5 mmol) in benzene (10 ml), was added dropwise with stirring during 10 min to 2,3-dimethylbuta-1,3-diene (0.41 g, 5 mmol) in benzene (10 ml) and methanol (10 ml) containing triethylamine (0.65 g, 6.5 mmol). After 30 min at room temperature, the mixture was stirred with aqueous sodium carbonate (30 ml) and the layers separated. The aqueous layer was extracted with dichloromethane and the combined organic solutions washed with water, dried, and evaporated to give an orange oil. Distillation (Kugelrohr, 110—120 °C, 0.02 mmHg) gave the *ethyl ester* (**3a**) (0.65 g, 65%) (Found, M^+, 200.0837. $C_{10}H_{16}O_2S$ requires *M*, 200.0871); $\nu_{max.}$ 1 725 cm^{-1}; δ 1.26 (t, *J* 7 Hz, CH_2Me), 1.68 (br s, 4- and 5-Me), 2.45 (m, 3-H_2), 3.08 (m, 6-H_2), 3.60 (t, *J* 6.5 Hz, 2-H), and 4.20 (q, *J* 7 Hz, CH_2Me). The ester (**3a**) (1.93 g) in ethanol (2 ml) was added to sodium hydroxide (0.8 g) in water (20 ml) and the mixture stirred at room temperature for 20 h and worked up in the usual way to give the *carboxylic acid* (**3c**) (1.02 g), m.p. 97—98 °C (from light petroleum) (Found: C, 56.0; H, 6.9; S, 18.6. $C_8H_{12}O_2S$ requires C, 55.8; H, 7.0; S, 18.6%); $\nu_{max.}$ 1 710 cm^{-1}; δ 1.70 (br s, 4- and 5-Me), 2.47 (m, 3-H_2), 3.09 (m, 6-H_2), 3.66 (t, *J* 6.4 Hz, 2-H), and 8.0 (br s, CO_2H, exchangeable with D_2O).

7α-*Ethoxycarbonyl*-6,7,8,14-*tetrahydro*-8-*thia*-6α,14α-*ethenothebaine* (**8**).—Ethoxycarbonylmethanesulphenyl chloride (**1a**), prepared from ethyl mercaptoacetate (2.3 g, 19.2 mmol) and *N*-chlorosuccinimide (2.8 g, 21 mmol) in benzene (50 ml), was added dropwise with stirring during 30 min to thebaine (**7**) (5.0 g, 16.1 mmol) in benzene (50 ml) and methanol (50 ml) containing triethylamine (2.1 g, 21 mmol) at room temperature. After a further 30 min, aqueous sodium carbonate (100 ml) was added to the mixture and the layers were separated. The aqueous layer was extracted with dichloromethane and the combined organic layers were washed with water, dried, and evaporated to afford the *cycloadduct* (**8**) (4.64 g, 67%), m.p. 116—118 °C (from isopropyl alchohol) (Found: C, 64.3; H, 6.4; N, 3.1; S, 7.8. $C_{23}H_{27}NO_5S$ requires C, 64.3; H, 6.3; N, 3.3; S, 7.5%); $\nu_{max.}$($CHCl_3$) 1 740 cm^{-1}; δ (250 MHz) 1.24 (t, *J* 7.1 Hz, OCH_2Me), 1.83 (ddd, *J* 12.3, 3.5, and 1.0 Hz, $15_{eq.}$-H), 2.40 (s, NMe), 2.74 (dt, *J* 12.4 and 5.5 Hz, $15_{ax.}$-H), 3.26 (d, *J* 18.6 Hz, 10β-H), 3.45 (d, *J* 6.6 Hz, 9-H), 3.65 (s, 6-OMe), 3.83 (s, 3-OMe), 4.01 (d, *J* 0.7 Hz, 7-H), 4.15 (q, *J* 7.1 Hz, OCH_2CH_3), 4.57 (d, *J* 1.3 Hz, 5-H), 5.86 (d, *J* 9.1 Hz, 19-H), 5.91 (ddd, *J* 9.1, 1.3, and 0.7 Hz, 18-H), 6.57 (d, *J* 8.0 Hz, 2-H), and 6.65 (d, *J* 8.0 Hz, 1-H); *m*/*z* 429. The cycloadduct (**10**), prepared[13] from thebaine and ethyl acrylate, gave δ (250 MHz) 1.24 (t, *J* 7.1 Hz, OCH_2Me), 1.48 (dd, *J* 12.5 and 6.1 Hz, 8α-H), 1.84 (ddd, *J* 13.0, 2.8, and 1.7 Hz, $15_{eq.}$-H), 1.97 (dt, *J* 12.8 and 5.7 Hz, $15_{ax.}$-H), 2.37 (s, NMe), 2.85 (ddd, *J* 9.3, 6.1, and 0.7 Hz, 7-H), 3.02 (dd, *J* 12.4 and 9.5 Hz, 8β-H), 3.20 (d, *J* 6.6 Hz, 9-H), 3.21 (d, *J* 18.5 Hz, 10β-H), 3.61 (s, 6-OMe), 3.82 (s, 3-OMe), 4.13 (qABq, J_{AB} 10.6 Hz, $J_{vic.}$ 7.1 Hz, Δδ 0.045, OCH_2Me), 4.60 (d, *J* 1.5 Hz, 5-H), 5.55 (d, *J* 8.2 Hz, 19-H), 5.83 (br d, *J* 8.2 Hz, 18-H), 6.54 (d, *J* 8.8 Hz, 1-H), and 6.62 (d, *J* 8.8 Hz, 2-H).

8α-*Ethoxycarbonyl*-6,7,8,14-*tetrahydro*-7-*thia*-6α,14α-*ethenothebaine* (**9**).—The foregoing cycloadduct (**8**) (0.150 g) was heated under reflux in toluene for 8 h. Evaporation of the solution and crystallisation of the residue from diethyl ether gave the *cycloadduct* (**9**) (0.123 g, 82%), m.p. 125—128 °C (Found: C, 64.3; H, 6.3; N, 3.2; S, 7.8. $C_{23}H_{27}NO_5S$ requires C, 64.3; H, 6.3; N, 3.3; S, 7.5%); $\nu_{max.}$ 1 735 cm^{-1}; δ (250 MHz) 1.26 (t, *J* 7.1 Hz, OCH_2Me), 1.87 (ddd, *J* 13.0, 3.5, and 1.5 Hz, $15_{eq.}$-H), 2.14 (ddd, *J* 12.0, 13.0, and 5.5 Hz, $15_{ax.}$-H), 2.36 (s, NMe), 3.24 (d, *J* 18.6 Hz, 10β-H), 3.60 (s, 6-OMe), 3.64 (d, *J* 6.6 Hz, 9-H), 3.81 (s, 3-OMe), 4.13 (qABq, J_{AB} 10.6 Hz, $J_{vic.}$ 7.1 Hz, Δδ 0.022, OCH_2Me), 4.98 (d, *J* 1.6 Hz, 5-H), 5.23 (s, 8-H), 5.73 (d, *J* 9.1 Hz, 19-H), 6.21 (dd, *J* 9.1 and 1.6 Hz, 18-H), 6.57 (d, *J* 8.0 Hz, 1-H), and 6.65 (d, *J* 8.0 Hz, 2-H); (Found, M^+ 429.1604. $C_{23}H_{27}NO_5S$ requires *M*, 429.1710). Alternatively, the cycloadduct (**9**) was obtained, in similar yields, by heating equimolar amounts of thebaine (**7**) and the anthracene adduct (**14a**) or the 9,10-dimethylanthracene adduct (**14b**) in toluene. The cycloadduct (**9**) was readily separated from anthracene or 9,10-dimethylanthracene by chromatography in chloroform.

Ethyl 2-*Thiabicyclo*[2.2.2]*oct*-5-*ene*-3-*carboxylate* (**11**), *the Corresponding Acid* (**12**), *and the Bromo Lactone Sulphoxide* (**13**).—Ethoxycarbonylmethanesulphenyl chloride (**1a**), prepared from ethyl mercaptoacetate (1.32 g, 11.0 mmol) and *N*-chlorosuccinimide (1.74 g, 13.0 mmol) in benzene (20 ml), was added dropwise with stirring during 10 min to cyclohexa-1,3-diene (0.88 g, 11.0 mmol) in benzene (20 ml) and methanol (20 ml) containing triethylamine (1.32 g, 13.0 mmol) at room temperature. After a further 30 min the mixture was diluted with water and the organic products isolated, as before, as a yellow oil (2.0 g). Chromatography gave the *cycloadduct* (**11**) (37%) as an oil, b.p. 120 °C (0.02 mmHg, Kugelrohr distillation) (Found: M^+, 198.0716. $C_{10}H_{14}O_2S$ requires *M*, 198.0714); $\nu_{max.}$ 1 730 cm^{-1}; δ 1.27 (t, *J* 7 Hz, Me), 1.1—2.2 (m, CH_2CH_2), 3.4 (m, 1- and 4-H), 4.07 (d, *J* 3.5 Hz, 3-H), 4.19 (q, *J* 7 Hz, OCH_2Me), 6.29 (t, *J* 8 Hz, 5- or 6-H), and 6.69 (t, *J* 8 Hz, 5- or 6-H). The yield of (**11**) increased *ca.* 2-fold when an excess (3 mol equiv.) of triethylamine was used. Alternatively, cyclohexa-1,3-diene (40 mg, 0.50 mmol) and the anthracene adduct (**14a**) (150 mg, 0.51 mmol) were heated under reflux in toluene (10 ml) for 3 h to give, after chromatography, the cycloadduct (**11**) (79%). The ester (**11**) (0.5 g) was hydrolysed for 24 h at room temperature in ethanol (2 ml) and water (10 ml) containing sodium hydroxide (0.2 g) to give 2-*thiabicyclo*[2.2.2]*oct*-5-*ene*-3-endo-*carboxylic acid* (**12**) (66%), m.p. 113—114 °C (from hexane) (Found: C, 56.45; H, 5.9; S, 19.0. $C_8H_{10}O_2S$ requires C, 56.45; H, 5.9; S, 18.8%); $\nu_{max.}$ 1 700 cm^{-1}; δ 1.1—2.3 (m, CH_2CH_2), 3.46 (m, 1- and 4-H), 4.05 (d, *J* 3.5 Hz, 3-H), 6.20 and 6.64 (2 × br t, *J* 7.5 Hz, 2 × vinyl-H), and 8.60 (br s, CO_2H, exchangeable with D_2O). The acid (**12**) (0.21 g) in 5% aqueous sodium carbonate (10 ml) was treated dropwise, with stirring at room temperature, with bromine–water until the colour of bromine persisted. The mixture was extracted with chloroform and the extracts were dried and evaporated to give a gummy solid (0.19 g). A solution of this product in acetone was diluted with diethyl ether to induce crystallisation of the *bromo lactone sulphoxide* (**13**), m.p. 215—217 °C (decomp.) (from chloroform) (Found: C, 35.8; H, 3.4; S, 12.5. $C_8H_9BrO_3S$ requires C, 36.2; H, 3.4; S, 12.1%); $\nu_{max.}$ 1 795 cm^{-1}; δ[$(CD_3)_2SO$] 1.35—2.0 (3 H, m), 2.05—2.40 (1 H, m), 3.10—3.45 (1 H, m), 3.75 (1 H, br t, *J* 4 Hz), 4.50 (1 H, d, *J* 5 Hz), 4.75 (1 H, d, *J* 4 Hz), and 5.04 (1 H, d, *J* 7 Hz); (Found M^+, 265.9443 and 263.9452. $C_8H_9{}^{81}BrO_3S$ and $C_8H_9{}^{79}BrO_3S$ require *M*, 265.9436 and 263.9456).

11-*Ethoxycarbonyl*-9,10-*dihydro*-9,10-*thiaethanoanthracene* (**14a**) *and the Corresponding Sulphone* (**15a**).—Ethoxycarbonylmethanesulphenyl chloride (**1a**), prepared from ethyl mercaptoacetate (1.32 g, 11.0 mmol) and *N*-chlorosuccinimide (1.74 g, 13.0 mmol) in chloroform (20 ml), was added dropwise with stirring to anthracene (1.96 g, 11.0 mmol) and triethylamine (1.32 g, 13.0 mmol) in chloroform (40 ml) with heating under reflux. After 30 min, the mixture was cooled, washed with dilute hydrochloric acid then water, dried, and evaporated. The residue was chromatographed to give the *cycloadduct* (**14a**) (37%), m.p. 135—137 °C (from diethyl ether) (Found: C, 72.9; H, 5.5; S, 11.1. $C_{18}H_{16}O_2S$ requires, C, 73.0; H, 5.4; S, 10.8%); $\nu_{max.}$ 1 720 cm^{-1}; δ 1.15 (t, *J* 7 Hz, Me), 4.09 (q, *J* 7 Hz, CH_2),

4.12 (d, *J* 3.5 Hz, SC*H*CO_2Et), 5.07 (d, *J* 3.5 Hz, 10-H), 5.13 (s, 9-H), and 7.1—7.55 (m, Ar-H). The adduct (**14a**) (0.30 g, 1.0 mmol) in dichloromethane (10 ml) at 5 °C was treated dropwise during 15 min with 70% 3-chloroperbenzoic acid (0.74 g, 3.0 mmol) in dichloromethane. The mixture was kept at room temperature for 24 h, washed successively with aqueous sodium sulphite and aqueous sodium hydrogen carbonate, dried, and evaporated. Crystallisation of the residue from ethanol gave the *sulphone* (**15a**) (92%), m.p. 205.5—206.5 °C (Found: C, 65.7; H, 4.9; S, 10.0. $C_{18}H_{16}O_4$ S requires C, 65.8; H, 4.9; S, 9.8%); $\nu_{max.}$ 1 740 cm^{-1}; δ 1.18 (t, *J* 7 Hz, Me), 3.91 (d, *J* 3 Hz, SC*H*CO_2Et), 4.17 (q, *J* 7 Hz, CH_2), 4.81 (d, *J* 3 Hz, 10-H), 5.53 (s, 9-H), and 7.2—7.7 (m, Ar-H).

9,10-*Dihydro*-11-*methoxycarbonyl*-9,10-*dimethyl*-9,10-*thiaethanoanthracene* (**14d**), *the Corresponding Ethyl Ester* (**14b**) *and Acid* (**14c**), *and the Derived Sulphones* (**15b**) *and* (**15c**).—Methoxycarbonylmethanesulphenyl chloride (**1b**), prepared from methyl mercaptoacetate (0.58 g, 5.5 mmol) and *N*-chlorosuccinimide (0.87 g, 6.5 mmol) in dichloromethane (10 ml), was added dropwise with stirring to 9,10-dimethylanthracene[15] (1.13 g, 5.5 mmol) and triethylamine (0.66 g, 6.5 mmol) in dichloromethane (30 ml) with heating under reflux. After 30 min, the mixture was cooled, washed with dilute hydrochloric acid and then water, dried, and evaporated. Chromatography of the residue gave the *methyl ester* (**14d**) (0.84 g, 49%), m.p. 97—99 °C [from benzene–light petroleum (b.p. 40—60 °C)] (Found: C, 73.5; H, 5.8; S, 10.6. $C_{19}H_{18}O_2S$ requires C, 73.5; H, 5.85; S, 10.3%); $\nu_{max.}$ 1 738 cm^{-1}; δ 2.12 (s, Me), 2.25 (s, Me), 3.52, (s, OMe), 3.83 (s, SC*H*CO_2Me), and 7.1—7.5 (m, Ar-H). The foregoing procedure, with ethyl mercaptoacetate in place of methyl mercaptoacetate, gave the *ethyl ester* (**14b**), which was obtained after chromatography as an oil (42%) (Found: M^+, 324.1171. $C_{20}H_{20}O_2S$ requires *M*, 324.1184); $\nu_{max.}$ 1 735 cm^{-1}; δ 1.11 (t, *J* 7 Hz, CH_2*Me*), 2.18 (s, Me), 2.30 (s, Me), 3.84 (s, SC*H*CO_2Et), 4.05 (q, *J* 7 Hz, C*H*$_2$Me), and 7.15—7.50 (m, Ar-H). Hydrolysis of the ethyl ester (**14b**) with aqueous ethanolic sodium hydroxide at room temperature, as before, gave the corresponding acid (**14c**), m.p. 173—175 °C (from diethyl ether); $\nu_{max.}$ 1 715 cm^{-1}; δ 2.20 (s, Me), 2.31 (s, Me), 3.87 (s, SC*H*CO_2H), 7.15—7.50 (m, Ar-H), and 7.9 (br s, CO_2H, exchangeable with D_2O). Oxidation of the methyl ester (**14b**) with 3-chloroperbenzoic acid, as described before for the anthracene derivative (**14a**), gave the *sulphone* (**15b**) (81%), m.p. 194.5—195.5 °C (from methanol) (Found: C, 66.6; H, 5.3; S, 9.1. $C_{19}H_{18}O_4S$ requires C, 66.65; H, 5.3; S, 9.4%); $\nu_{max.}$ 1 750 cm^{-1}; δ 2.03 (s, Me), 2.24 (s, Me), 3.64 (s, OMe), 3.79 (s, C*H*SO_2), and 7.15—7.64 (m, Ar-H). The sulphone (**15b**) (144 mg) was heated at 160 °C for 6 h in dimethyl sulphoxide (0.6 ml) containing water (1.6%) and sodium chloride (25 mg). The dark mixture was diluted with water and the organic products were extracted into chloroform. The extracts were washed with water, dried, and evaporated. Chromatography of the residue gave the *sulphone*[17] (**15c**) (102 mg), m.p. 232—235 °C (from methanol) (Found: C, 71.9; H, 5.75; S, 11.3. $C_{17}H_{16}O_2S$ requires C, 71.8; H, 5.7; S, 11.3%); δ 1.98 (s, Me), 2.23 (s, Me), 2.97 (s, CH_2), and 7.20—7.57 (m, Ar-H).

'Ene' Reaction of Ethyl Thioxoacetate (**2a**) *and* (−)-β-*Pinene* (**16**).—(−)-β-Pinene (101 mg, 0.74 mmol) and the cycloadduct (**14a**) (110 mg, 0.37 mmol) were heated under reflux in toluene (5 ml) for 4 h. The solution was evaporated and the residue chromatographed to give *ethyl* (2-*pinen*-10-*ylthio*)*acetate* (**17**; R = CO_2Et) (73 mg, 78%) as an oil (Found: M^+, 254.1359. $C_{14}H_{22}O_2S$ requires *M*, 254.1341); $\nu_{max.}$ 1 725 cm^{-1}; δ 0.81 (s, Me), 1.10 (1 H, d, *J* 9 Hz), 1.26 (s, Me), 1.26 (t, *J* 7 Hz, OCH_2*Me*), 3.10 (s, SCH_2CO_2Et), 3.08 and 3.22 (ABq with fine coupling to 3-H, *J* 10 Hz, 10-H_2), 4.17 (q, *J* 7 Hz, OCH_2Me), and 5.43 (m, 3-H); and *ethyl mercapto*(2-*pinen*-10-*yl*)*acetate* (**18**; R = CO_2Et) (20 mg, 21%) as an oily mixture of diastereoisomers (Found: M^+, 254.1348. $C_{14}H_{22}O_2S$ requires *M*, 254.1341); $\nu_{max.}$ 1 725 cm^{-1}; δ 0.76 (*ca.* 1.3 H, s, Me), 0.80 (*ca.* 1.7 H, s, Me), 1.23 (s, Me), 1.23 (t, *J* 7 Hz, OCH_2*Me*), 3.35 (m, C*H*SH), 4.16 (q, *J* 7 Hz, OCH_2), and 5.30 (m, 3-H).

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References

1 S. M. Weinreb and R. R. Staib, *Tetrahedron*, 1982, **38**, 3087.
2 H. G. Giles, R. A. Marty, and P. de Mayo, *J. Chem. Soc., Chem. Commun.*, 1974, 409; *Can. J. Chem.*, 1976, **54**, 537.
3 R. Okazaki, A. Ishii, N. Fukuda, H. Oyama, and N. Inamoto, *J. Chem. Soc., Chem. Commun.*, 1982, 1187; *Tetrahedron Lett.*, 1984, 849; G. Hofstra, J. Kamphuis, and H. J. T. Bos, *Tetrahedron Lett.*, 1984, 873.
4 E. Vedejs and D. A. Perry, *J. Am. Chem. Soc.*, 1983, **105**, 1683.
5 R. B. Woodward, W. A. Ayer, J. M. Beaton, F. Bickelhaupt, R. Bonnett, P. Buchschacher, G. L. Closs, D. Dutler, J. Hannah, F. P. Hauck, S. Itô, A. Langemann, E. Le Goff, W. Leimgruber, W. Lwowski, J. Sauer, Z. Valenta, and H. Volz, *J. Am. Chem. Soc.*, 1960, **82**, 3800; S. McKenzie and D. H. Reid, *J. Chem. Soc., Chem. Commun.*, 1966, 401; R. K. Mackie, S. McKenzie, D. H. Reid, and R. G. Webster, *J. Chem. Soc., Perkin Trans. 1*, 1973, 657; see also citations in ref. 9.
6 Preliminary communication: C. M. Bladon, I. E. G. Ferguson, G. W. Kirby, A. W. Lochead, and D. C. McDougall, *J. Chem. Soc., Chem. Commun.*, 1983, 423; see also D. C. McDougall, Ph.D. Thesis, University of Glasgow, 1981.
7 G. W. Kirby and A. W. Lochead, *J. Chem. Soc., Chem. Commun.*, 1983, 1325; G. W. Kirby, A. W. Lochead, and G. N. Sheldrake, *ibid.*, 1984, 922; 1984, 1469.
8 (*a*) E. Vedejs, T. H. Eberkin, and D. L. Varie, *J. Am. Chem. Soc.*, 1982, **104**, 1445: (*b*) E. Vedejs, D. A. Perry, K. N. Houk, and N. G. Rondan, *ibid.*, 1983, **105**, 6999.
9 J. E. Baldwin and R. C. G. Lopez, *J. Chem. Soc., Chem. Commun.*, 1982, 1029; *Tetrahedron*, 1983, **39**, 1487.
10 D. A. Armitage and M. J. Clark, *J. Chem. Soc., Chem. Commun.*, 1970, 104.
11 H. Emde, *Ger. Offen.* 804,572/1951 (*Chem. Abstr.*, 1952, **46**, 529).
12 *Cf.* G. H. Schmid and D. G. Garratt, 'The Chemistry of Double-bonded Functional Groups,' ed. S. Patai, John Wiley and Sons, London, 1977, Part 2, ch. 9.
13 K. W. Bentley and D. G. Hardy, *J. Am. Chem. Soc.*, 1967, **89**, 3267; W. Fulmor, J. E. Lancaster, G. O. Morton, J. J. Brown, C. F. Howell, C. T. Nora, and R. A. Hardy, Jr., *ibid.*, 1967, **89**, 3322.
14 See also J. Jurczak, T. Bauer, S. Filipek, M. Tkacz, and K. Zygo, *J. Chem. Soc., Chem. Commun.*, 1983, 540.
15 G. W. Kirby, *Chem. Soc. Rev.*, 1977, **6**, 1; G. W. Kirby and J. G. Sweeny, *J. Chem. Soc., Perkin Trans. 1*, 1981, 3250.
16 *Cf.* A. P. Krapcho, *Synthesis*, 1982, 893.
17 N. J. Hales, D. J. H. Smith, and M. E. Swindles, *J. Chem. Soc., Chem. Commun.*, 1976, 981; H. Allgeier and T. Winkler, *Tetrahedron Lett.*, 1976, 215.
18 B. B. Snider, N. J. Hrib, and L. Fuzesi, *J. Am. Chem. Soc.*, 1976, **98**, 7115.

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