Ene Reactions of Allylically Stannylated Cholestenes: Singlet Oxygenation of 7α-Triphenylstannylcholest-5-en-3β-ol, and of 7α-Triphenylstannyl- and 7α-Tributylstannyl-cholest-5-ene-3-one, and the Rearrangement of 5α-Tributylstannylperoxy-3β-benzoyloxycholest-6-ene and of 7α-Tributylstannylperoxy-3β-benzoyloxycholest-5-ene

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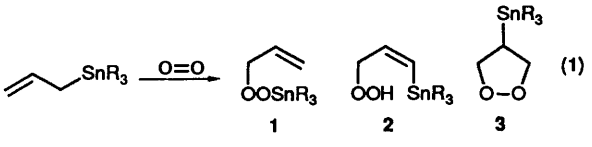
The reaction of some allylically stannylated steroids with singlet oxygen has been investigated. 7α-Triphenylstannylcholest-5-ene-3β-ol reacts on the β-face with shift of the 4β-hydrogen to give 6β-hydroperoxy-7α-triphenylstannylcholest-4-ene-3β-ol, whereas cholest-5-ene-3β-ol itself reacts on the α-face to give 5α-hydroperoxycholest-6-ene-3β-ol.

7α-Triphenylstannyl- and 7α-tributylstannylcholest-5-ene-3-one give the corresponding 6β-hydroperoxy-7α-stannylcholest-4-ene-3-one (50–55%), together with the 4,6-dien-3-one which is formed by elimination. In contrast, the parent cholest-5-en-3-one under the same conditions gives some of the 6β-hydroperoxy-4-ene-3-one, but the principal product is the hemiperketal from the 5α-hydroperoxycholest-6-ene-3-one.

In neither system was there any evidence for a metalloene reaction, nor for cycloaddition accompanied by a nucleophilic 1,2-shift of the tin.

3β-Benzoyloxy-5α-tributylstannylperoxycholest-6-ene undergoes the Schenck and Smith types of rearrangement by a radical chain mechanism to give successively the corresponding 7α- and 7β-stannylperoxy-5-enes.

An organometallic substituent often behaves in organic reactions in the same way as a hydrogen atom,[1] and we have been exploring this analogy in the context of the ene reaction. We have shown that allylic tin compounds react with singlet oxygen to give the products of both M-ene (**1**) and H-ene (**2**) reaction, and also those of cycloaddition (**3**) as shown in eqn. (1).



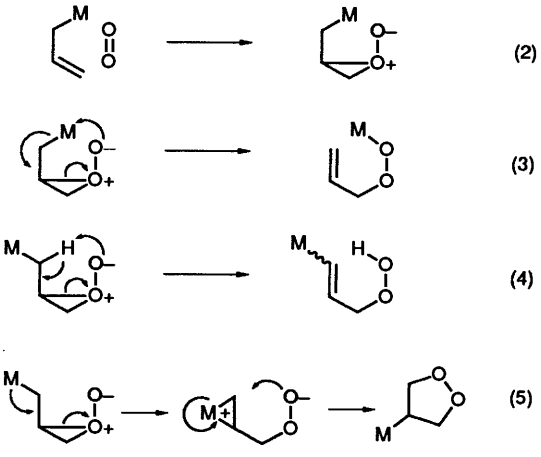
(1)

1 **2** **3**

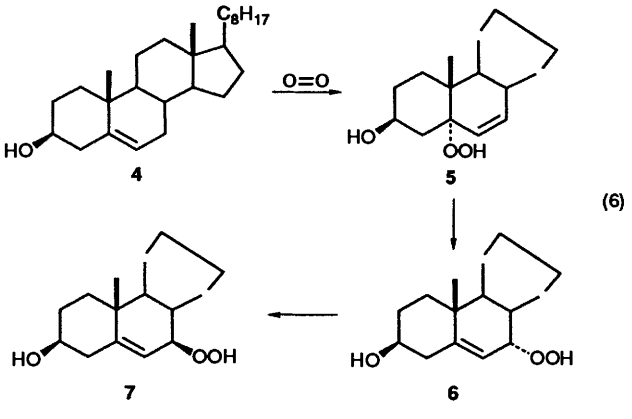
The relative yields of the three types of product depend on the structural and environmental conditions.[2,3,4] The proportion of the M-ene product **1** increases as the tin centre becomes more electropositive, and when the ^{13}C NMR chemical shift of the α-methylene group is above *ca.* 23.7, the reaction of singlet oxygen gives only the allylperoxytin compound. The cycloaddition product **3**, on the other hand, is favoured by less electronegative ligands on the tin, by a non-polar solvent, and by low temperature.

It seems likely that the mechanisms of these reactions are related to that which is commonly accepted for the H-ene reaction of allylic hydrocarbons,[2,3,4] and a reasonable model is shown in eqns. (2)–(5). A perepoxide intermediate is first formed [eqn. (2)], and this may undergo pericyclic transfer of the metal [eqn. (3)] or of hydrogen [eqn. (4)], or nucleophilic shift of the organometallic group with accompanying ring closure [eqn. (5)].

The ene reaction of singlet oxygen which has been studied most thoroughly is that involving cholesterol (**4**), and we were interested in examining the analogy between the behaviour of hydrogen and of a metal in this system. Cholesterol first gives the 5α-hydroperoxy-6-ene (**5**), and this, in a non-polar solvent rearranges first to the 7α-hydroperoxy-5-ene (**6**),[5] and then to

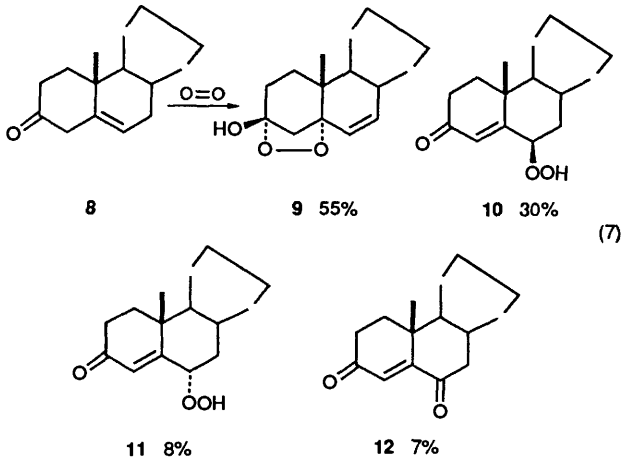


the 7β-hydroperoxy-5-ene (**7**) [eqn. (6)].[6] Both rearrangements are well established to take place through chain reactions involving the corresponding allylperoxyl radicals, the former apparently by a pericyclic process, and the latter *via* a dissociative mechanism.[7]



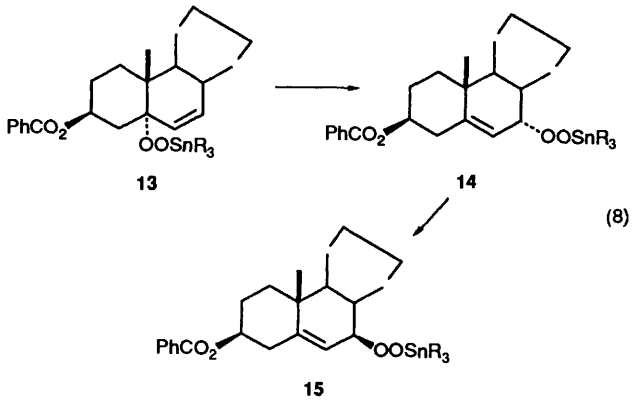
4 **5** **7** **6**

The oxygenation of cholest-5-en-3-one (**8**) is more complicated and gives principally the 5α-hydroperoxy-6-ene which cyclises to the peroxyhemiketal **9**, together with the 6β-hydroperoxy-4-ene **10** and the 6α-hydroperoxy-4-ene **11**; a small amount of the enone **12** is also formed, presumably through a carbonyl-forming elimination of **10** or **11**.[8] The hemiperketal **9** does not rearrange in solution, but the hydroperoxide **10** epimerises to **11** by a radical chain mechanism.



(7)

The rearrangements **5** ⟶ **6** and **6** ⟶ **7** provide an obvious further context in which the analogy between the behaviour of hydrogen and a metal could apply, and indeed Haynes and Vonwiller[9] have recently reported that the stannyl peroxide **13** rearranges in solution to give the allylic isomers **14** and **15** in a ratio of 3.3:1. However, they thought that, in contrast to the rearrangements **5** ⟶ **6** ⟶ **7**, these reactions were unlikely to involve allylperoxyl radicals.

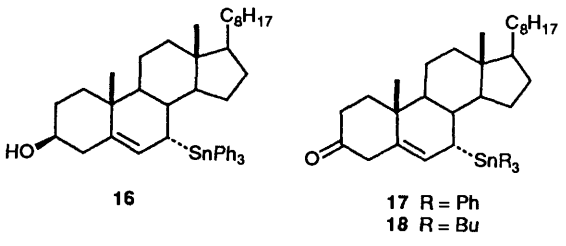


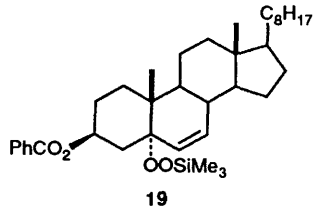
(8)

We report here a study of the singlet oxygenation of 7α-triphenylstannylcholest-5-en-3β-ol (**16**), 7α-triphenylstannylcholest-5-en-3-one (**17**), and 7α-tributylstannylcholest-5-en-3-one (**18**). The related rearrangement of the stannyl peroxide **13** has also been examined, and compared with the behaviour of the corresponding hydroperoxide and of the trimethylsilyl derivative **19**.

Results and Discussion

The Reaction of **16**, **17** *and* **18** *with* $^1O_2$.—The synthesis of the allylically stannylated cholestenes **16**, **17** and **18** has been described elsewhere.[10] Singlet oxygenation was carried out in dichloromethane as solvent using tetraphenylporphine (TPP) as sensitizer. The primary products from the photooxygenation decompose during chromatography on silica gel, or during recrystallisation, **16** giving the dienol **20**, and **17** and **18** giving the dienone **21**.





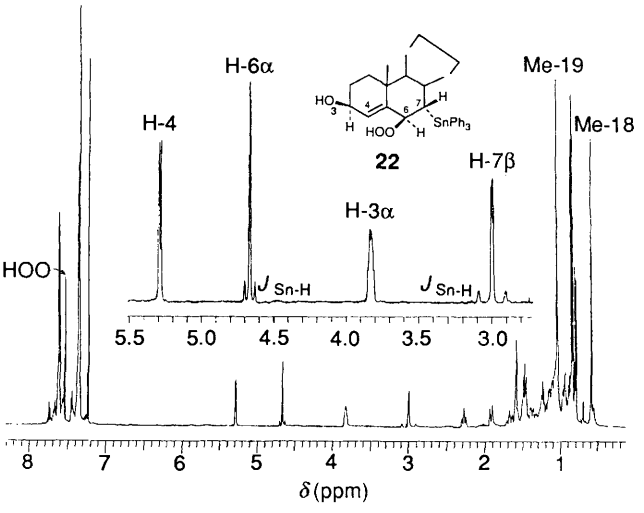
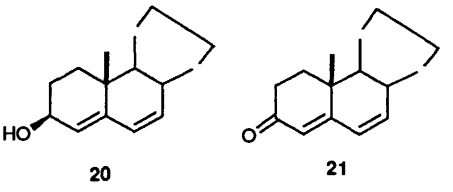


Fig. 1 ^{1}H NMR spectrum of **22**



The singlet oxygenations were therefore carried out in $CDCl_3$–TPP in an NMR tube, and the products were identified directly by high resolution NMR spectroscopy on the basis of the data obtained in the study of the protic parent compounds **4** and **8**.[7,8]

The ^{1}H NMR spectrum of the product of the reaction of the 7α-triphenylstannyl-5-ene-3β-ol **16** with singlet oxygen is shown in Fig. 1. It shows one set of signals for the groups Me-18, Me-21, Me-26, Me-27 and Me-19, and one set for the phenyl groups, indicating that a single product is formed. The singlet at δ 7.54 disappeared when D_2O was added, showing that it relates to an OH group. Irradiation of the H-3α multiplet at δ 3.82 reduced the doublet at δ 5.29 to a singlet, and irradiation of the signal at δ 2.99 reduced the doublet at δ 4.66 to a singlet, and the doublet of triplets at δ 2.28 to a triplet.

The ^{13}C NMR spectrum (see Experimental section) shows a C–Sn group at δ 39.41 (J^{119}Sn 392, J^{117}Sn 373.6 Hz), a C–OH group at δ 62.85, a C–OOH group at δ 90.5 (*J* Sn 140.3), and two olefinic carbons at δ 130.87 and 142.84.

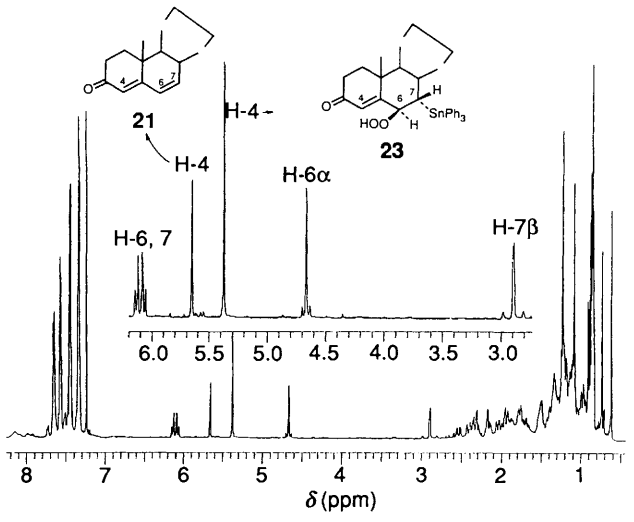
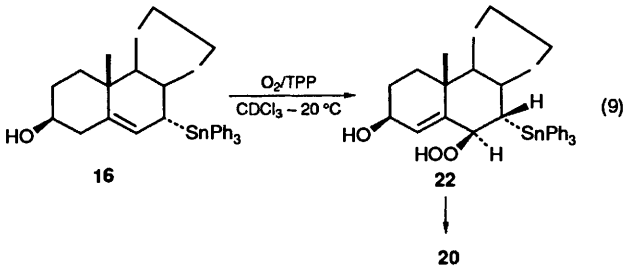


Fig. 2 ^{1}H NMR spectrum of the products of the reaction of **17** with $^1O_2$

These data identify the product as **22** [eqn. (9)]. The stereochemistry at C-6 was determined by NOE-difference and proton–proton spin decoupling difference techniques.[11] When Me-19 was irradiated, H-8 (δ 2.28) and H-2α (δ 1.40) gave a positive NOE effect of 11% and 8% respectively, whilst H-3α, H-4, H-6α and H-7β showed no significant effect.

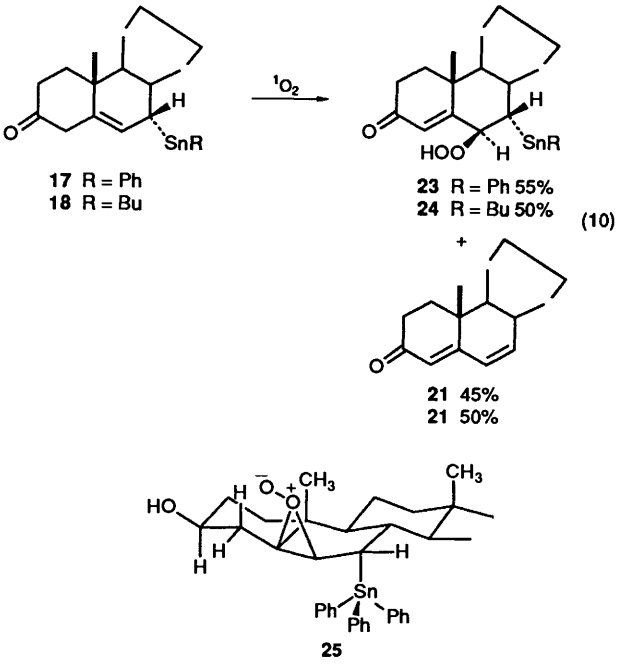
The hydroperoxide **22** is stable in non-polar solvents, and showed no decomposition or epimerisation (*cf.* **10** ⟶ **11**) during a week at room temperature. This stabilisation may result from hydrogen bonding between the OH and OOH groups which are closely oriented on the β-face. This hydrogen bonding would be expected to inhibit homolytic abstraction of the OOH hydrogen atom, which is one step in the chain mechanism. However, **22** is sensitive to moisture, and it decomposed to **20** when attempts were made to isolate it by chromatography or recrystallisation.



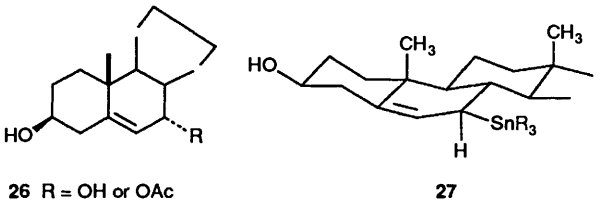
Under the same conditions, the 7α-triorganostannyl-5-en-3-ones **17** and **18** reacted with singlet oxygen to give the hydroperoxides **23** and **24** respectively, along with some of the dienone **21** which is formed by elimination. The structures of the products were identified from the NMR spectra: that of **21** is known and those of **23** and **24** were identified by comparison with that of **22** which is discussed above (see Figs. 1 and 2).

The hydroperoxides **23** and **24** underwent elimination to give **21** even in a non-polar solvent, and there was no evidence for an epimerisation equivalent to that of **10** ⟶ **11**. This elimination probably reflects the stability of the conjugated dienone system.

In contrast to their protic parents the stannylated cholestenes **16**–**18** therefore react stereospecifically on the β-face to give only the respective 6β-hydroperoxycholest-5-enes. In terms of the mechanistic model of eqns. (2)–(5) it seems that steric hindrance by the 7α-triorganostannyl group directs the attack of singlet oxygen to the β-face of the double bond to give the β-perepoxide as shown in **25**, and only the 4β hydrogen is then appropriately oriented to take part in the second step of the ene reaction.



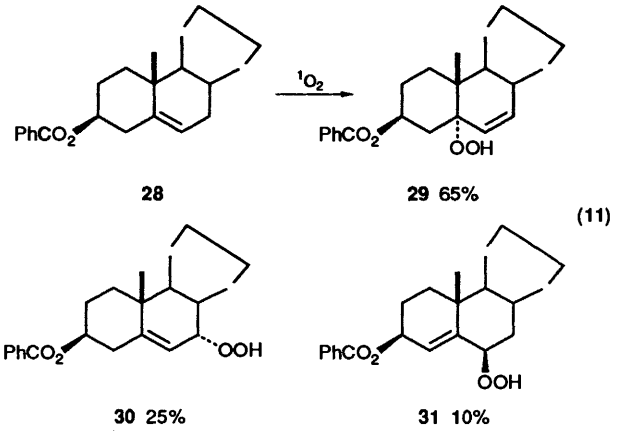
In order to compare the reactivity of cholest-5-en-3-one **8** with its 7α-triphenylstannyl derivative **17**, the singlet oxygenation of the two compounds was monitored by NMR spectroscopy under identical conditions. The reaction of **8** required 2.5 h for completion, whereas that of **17** was complete in 1 h. Further, it has been reported that the 7α-hydroxy- and 7α-benzoyloxy-cholestenes **26** are unreactive to singlet oxygen.[12,13] It therefore appears that a 7α-stannyl substituent has a significant activating effect. This may reflect the stabilising effect that an axially orientated stannyl group may have on the partial positive charge which is generated in the intermediate **25** at C-6, but, in the reaction of neither **16**, **17** or **18**, was there any evidence for this leading to complete migration and cycloaddition according to eqn. (5). Perhaps this is precluded by the ring strain which would be involved in the formation of the polycyclic dioxolanes.



In the light of these results, it would be very interesting to investigate the reaction of 7β-stannylcholest-5-en-3β-ols **27** with singlet oxygen, but unfortunately our attempts to prepare these compounds have as yet been unsuccessful.

The Rearrangement of 5α- and 7α-Hydroperoxy- and of 5α- and 7α-Stannylperoxy-3β-benzoyloxycholest-5-ene.—As oxygenation of 7α-stannylcholest-5-en-3β-ol **16** had failed to give the 5α-stannylperoxy-6-en-3β-ol **13**, the 5α-hydroperoxide was prepared as shown in eqn. (11). Singlet oxygenation of 3β-benzoyloxycholest-5-ene (**28**)[5] was carried out in pyridine with Rose Bengal as the sensitizer, to give the three hydroperoxides **29**, **30** and **31**. A partial ^{1}H NMR spectrum of the mixture is shown in Fig. 3.

The spectra of the hydroperoxides **29** and **30** were assigned by reference to the spectra of the corresponding hydroperoxides **5** and **6** from cholesterol,[7] and that of **31** was identified by



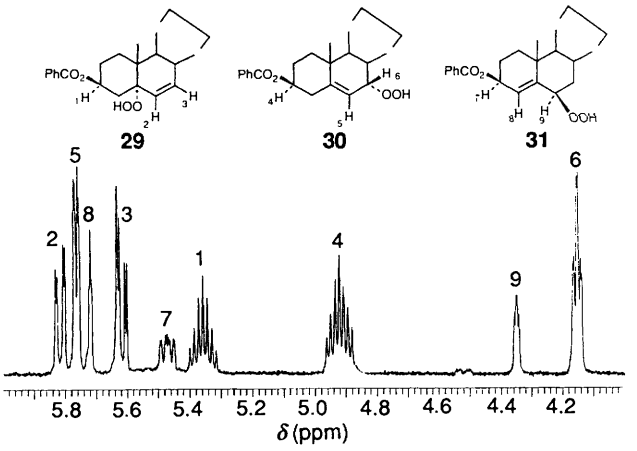


Fig. 3 Partial ^1H NMR spectrum of the products of the reaction of **28** with $^1O_2$. The numbering of the hydrogen atoms to correspond with the various peaks in the spectrum is arbitrary.

decoupling experiments and by comparison with the spectrum of the corresponding hydroperoxide **10** from cholest-5-en-3-one.[8] In a non-polar solvent, the 5α-hydroperoxide **29** rearranged in 72 h to the 7α-hydroperoxide **30**, while the 6β-hydroperoxide **31** remained unchanged (Fig. 4). Then, more slowly, **30** epimerised to give a 9:1 mixture of the 7α and 7β isomers **30** and **32**, eqn. (12); this is similar to the behaviour of the hydroperoxide from cholest-5-en-3β-ol itself.[7]

The 5α-hydroperoxide **29** was then separated and treated with tributyltin methoxide to give, in quantitative yield, the 5α-tributylstannyl peroxide **13**, which is moisture-sensitive. In $CDCl_3$ at room temperature, with no special precautions to avoid hydrolysis, **13** rearranged to give in 3 days a 1:3 mixture of **13** and the 7α-stannylperoxide **14**. Under these conditions it is possible that the reaction may proceed through a small equilibrium concentration of the hydroperoxide. If the reaction was carried out in the presence of an excess of tributyltin methoxide in a sealed NMR tube, to avoid possible hydrolysis, the rearrangement was much slower than that of the corresponding hydroperoxide **29** as shown in Table 1 and Fig. 5, and gave after 12 days 50% of **13**, 40% of **14** and 10% of the β-epimer **15**.

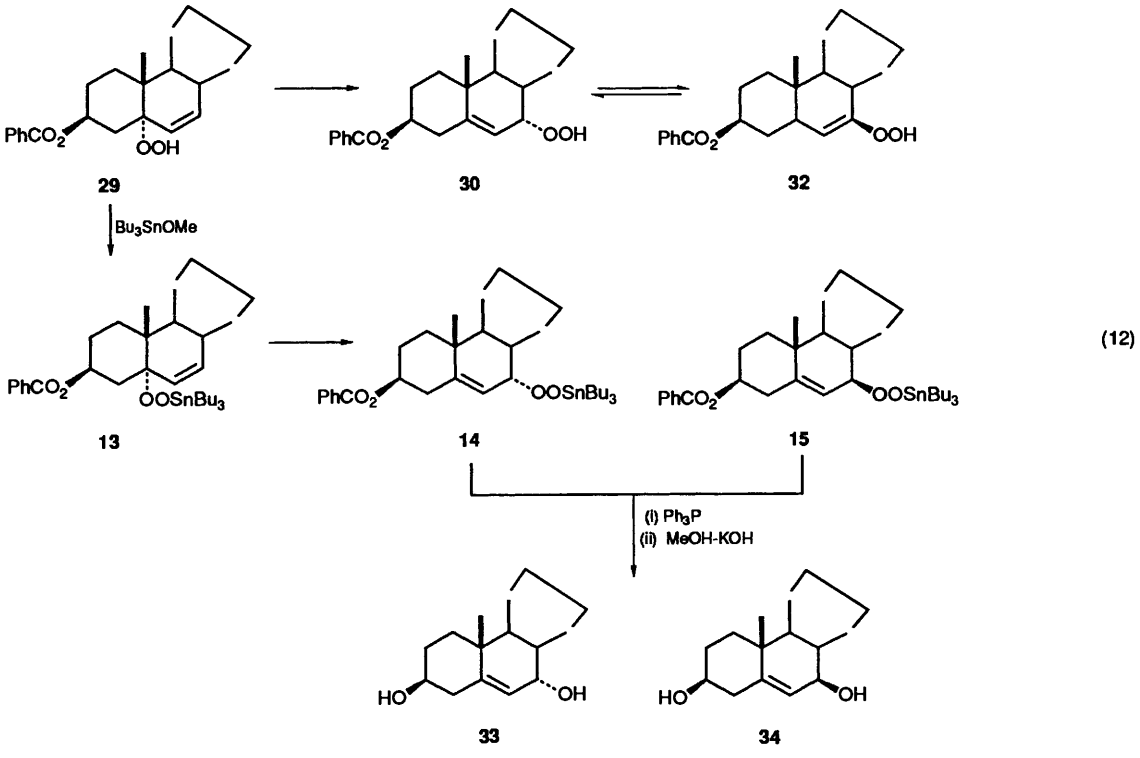
When 5 mol% of 2,6-di-*tert*-butyl-4-methylphenol was added as a radical inhibitor, no rearrangement of **13** to **14** could be detected during 12 days. This establishes that **13** is formed in a radical chain reaction and the epimerisation of **14** is probably also homolytic. The mechanism of the rearrangement of the stannyl peroxide **13** is thus apparently similar to that of the corresponding 5α-hydroperoxides (*e.g.* **5** ⟶ **6**) as shown in eqns. (13) and (14). This emphasises once more the analogy

$$5\alpha\text{-OO}\cdot \longrightarrow 7\alpha\text{-OO}\cdot \qquad (13)$$

$$7\alpha\text{-OO}\cdot + 5\alpha\text{-OOSnR}_3 \longrightarrow 7\alpha\text{-OOSnR}_3 + 5\alpha\text{-OO}\cdot \qquad (14)$$
$$\mathbf{13} \qquad\qquad \mathbf{14}$$

between the behaviour of hydrogen and of an organometallic group.[1]

The S_H2 reaction of a stannylperoxyl radical at tin to displace a different stannylperoxyl radical appears to have no exact precedent in the literature, although many other homolytic substitutions at tin are known[14] and we have postulated the intramolecular displacement at tin of RO· by R′O· in the rearrangement of radicals derived from stannylmethyloxiranes.[15]



(12)

Table 1 Rearrangement of **13** to **14** and **15** in $CDCl_3$ at room temperature

Time (h)	Composition of mixture (%)		
	13	**14**	**15**
48	94	6	0
90	84	16	0
138	74	26	0
173	65	35	5
240	61	39	7
284	50	40	10
407	30	55	15
583	15	67	18

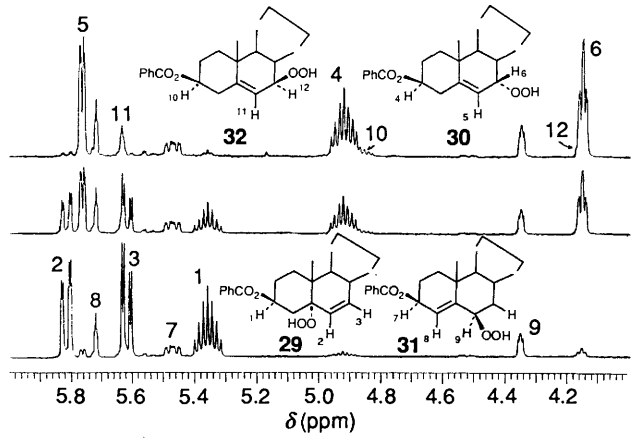


Fig. 4 Partial ^1H NMR spectrum of the hydroperoxides **29**, **30**, **31** and **32**

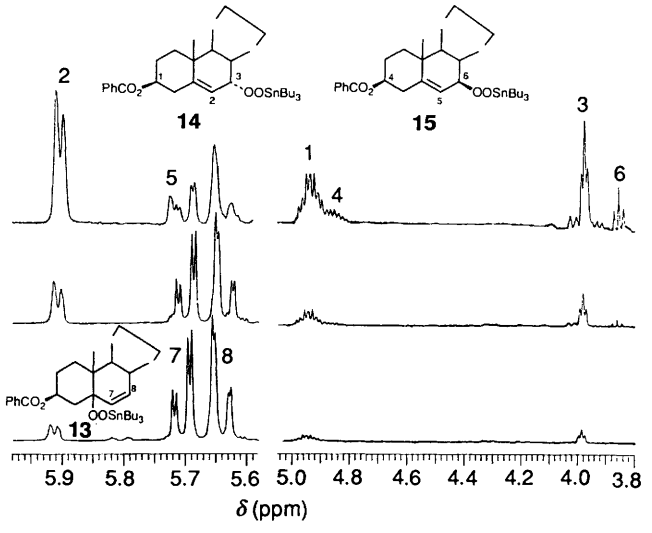


Fig. 5 Partial ^1H NMR spectrum of the stannyl peroxide **13** at different times. The numbering of the hydrogen atoms to correspond with the various peaks in the spectrum is arbitrary.

The slow rearrangement of **13** may suggest that the substitution at tin may be slower than that at hydrogen, but the unknown rate of initiation would also be kinetically important.

The rearrangement of **13** in $CDCl_3$ was then carried out on a larger scale. After 25 days, the mixture was reduced with triphenylphosphine and hydrolysed to give the known diols **33** and **34**[7] as shown in eqn. (12).

Silylation of the 7α-hydroperoxide **29** with bis(trimethylsilyl)-acetamide gave the 7α-silylperoxide **19** [eqn. (15)].

No rearrangement of **19** in $CDCl_3$ could be detected in 11 days. This is not unexpected, as homolytic substitution at silicon—the equivalent of eqn. (14)—usually occurs much less readily at silicon than at tin.

Conclusions

This work has shown up a further effect of allyl stannylation in that in the cholest-5-enes, 7α-stannyl substituents are themselves chemically inert towards singlet oxygen, but they enhance the reactivity and direct attack away from the α-face to give regio- and stereospecifically the 6β-hydroperoxy-4-enes.

No other reaction is known which has a similar mechanism to that of the Schenck rearrangement of allylic hydroperoxides, and the demonstration that the stannyl peroxides also rearrange by a radical chain mechanism provides a useful new context in which this unique process can be investigated.

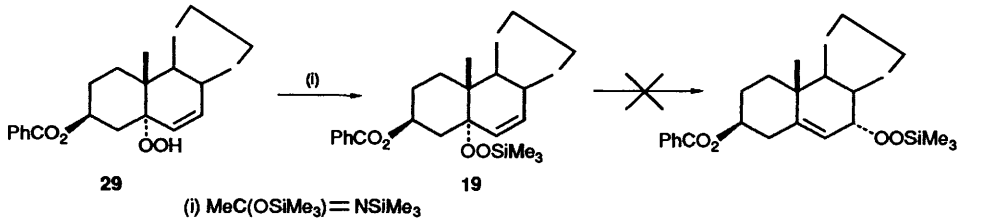
Experimental

^1H and ^{13}C NMR spectra were recorded on a Varian VXR-400 spectrometer, using $CDCl_3$ as solvent. Chemical shifts were measured relative to the solvent, taking δ_H 7.24 and δ_C 77.00. Coupling constants J are in Hz. Mass spectra were recorded on a VG 7070H spectrometer, and IR spectra on a Perkin-Elmer PE983 instrument. Column chromatography was carried out on Merck silica gel (70–230 mesh).

Photooxygenations were performed using a sodium lamp and tetraphenylporphine in CH_2Cl_2 (Method 1), or Rose Bengal in pyridine (Method 2) as reported previously.[7,8] Reactions were also carried out in an NMR tube with a stream of oxygen bubbling through the solution (Method 3).

Cholesta-4,6-dien-3β-ol (**20**).—7α-Triphenylstannylcholest-5-en-3β-ol[10] (**16**; 0.2 g) was subjected to photooxidation by Method 1. When the reaction was complete the solvent was removed by evaporation and the residue was chromatographed on silica gel with pentane–diethyl ether (9:1 v/v) as eluent, to give **20** which was recrystallised from acetone; m.p. 117–118 °C (lit.,[16] 119–120 °C). δ_H (3 H, s, Me-18), 0.868 (3 H, d, J 6.61, Me-26 or 27), 0.872 (3 H, d, J 6.58, Me-27 or 26), 0.91 (3 H, d, J 6.52, Me-21), 1.00 (3 H, s, Me-19), 4.28 (1 H, m, H-3α), 5.36 (1 H, brs, H-4), 5.65 (1 H, dd, J 9.82 and 1.12, H-7) and 5.91 (1 H, dd, J 9.82 and 2.59, H-6); δ_C 11.99, (C-18), 16.25 (C-19), 18.65, 20.73, 22.56, 22.82, 23.81, 23.88, 28.00, 28.34, 29.14, 33.57, 35.13, 35.79, 36.15, 37.41, 39.49, 39.83, 43.42, 51.40, 54.05, 56.09, 68.11 (C-3), 125.95 (C-4), 127.91 (C-7), 131.76 (C-6) and 145.03 (C-5).

7α-Triphenylstannyl-6β-hydroperoxycholest-4-en-3β-ol (**22**).—The stannylcholestenol **16** (15 mg) reacted with $^1O_2$ in an



(15)

NMR tube by Method 3 to give a quantitative yield of **22** as shown in Fig. 1. δ_H 0.60 (3 H, s, Me-18), 0.815 (3 H, d, *J* 6.46, Me-21), 0.86 (3 H, d, *J* 6.61, Me-26 or 27), 0.87 (3 H, d, *J* 6.52, Me-26 or 27), 1.06 (3 H, s, Me-19), 1.92 (1 H, dt, *J* 12.63 and 3.30, H-1β), 2.28 (1 H, td, *J* 10.77 and 3.71, H-8), 2.99 (1 H, dd, *J* 3.72 and 1.47, *J* Sn 75.15, H-7β), 3.82 (1 H, m, H-3α), 4.66 (1 H, d, *J* 1.47, *J* Sn 28.14, H-6β), 5.29 (1 H, d, *J* 4.21, H-4) and 7.54 (1 H, s, OOH); δ_C 12.08 (C-18), 18.64 (C-19), 19.89, 20.98, 22.56, 22.84, 23.15, 24.29, 27.17, 27.45, 28.06 (*J* Sn 21.8), 31.60, 33.76, 35.28, 35.89 (*J* Sn 35.1), 37.01, 39.41 (*J* ^{119}Sn 392.0, *J* ^{117}Sn 373.6, C-7), 39.55, 39.59, 42.36, 52.52, 55.41, 62.85 (C-3), 90.50 (*J* Sn 140.3, C-6), 130.87 (C-4), 142.84 (C-5) and 128.58, 128.96, 132.71 and 140.29 (4 Ar carbons). The structure was assigned by spin decoupling and NOE experiments as described in the text.

Cholesta-4,6-dien-3-one (**21**).—7α-Triphenylstannyl- or 7α-tributylstannyl-cholest-5-ene-3-one[10] (**17** or **18**; 0.25 g) reacted with $^1O_2$ by Method 1 as described above to give, after chromatography, **21**, which was recrystallised from methanol; m.p. 81 °C (lit.,[17] 81–82 °C); δ_H 0.73 (3 H, s, Me-18), 0.839 (3 H, d, *J* 6.67, Me-26 or 27), 0.841 (3 H, d, *J* 6.52, Me-27 or 26), 0.90 (3 H, d, *J* 6.45, Me-21), 1.09 (3 H, s, Me-19), 5.64 (1 H, brs, H-4), 6.07 (1 H, dd, *J* 9.82 and 2.52, H-7) and 6.11 (1 H, dd, *J* 9.82 and 1.13, H-6); δ_C 11.87 (C-18), 18.63 (C-19), 20.65, 22.54, 22.80, 23.71, 23.82, 27.99, 28.15, 33.89, 33.95, 35.76, 36.05, 36.09, 37.73, 39.45, 39.53, 43.38, 50.66, 53.40, 55.99, 123.46 (C-4), 127.72 (C-7), 141.60 (C-6), 164.00 (C-5) and 199.61 (C-3).

When the reactions of **17** and **18** were carried out by Method 3, 45–50% of elimination product **21**, and 50–55% of photo-oxygenated products **23** and **24** were obtained with the following characteristics. **23** (see also Fig. 2): δ_H 0.64 (3 H, s, Me-18), 1.23 (3 H, s, Me-19), 2.89 (1 H, dd, *J* 3.65 and 1.75, *J* Sn 71.04, H-7β), 4.67 (1 H, d, *J* 1.69, *J* Sn 26.14, H-6α), 5.38 (1 H, s, H-4), 7.35 (9 H, m, Ph) and 7.55 (6 H, m, Ph). This compound underwent elimination to give **21** even in a non-polar solvent.

24: δ_H 0.65–2.00 (complex, Bu and ring protons), 4.41 (1 H, d, *J* 1.68, *J* Sn 23.6, H-7β), 5.85 (1 H, s, H-4). In $CDCl_3$ this compound underwent elimination in 24 h at room temperature to give **22**.

5α-Hydroperoxy-3β-benzoyloxycholest-6-ene (**29**).—Cholesteryl benzoate (**28**) (0.85 g) was caused to react with singlet oxygen by Method 2, and the progress of the reaction was followed by TLC. After 6 h, the solvent was removed under reduced pressure, and the residue was repeatedly chromatographed (eluent; pentane–diethyl ether, 10:1 v/v) to give the hydroperoxide **29** (0.45 g, 50%), m.p. 82–85 °C; δ_H 0.68 (3 H, s, Me-18), 0.84 (3 H, d, *J* 6.62, Me-26 or 27), 0.85 (3 H, d, *J* 6.62, Me-27 or 26), 0.89 (3 H, d, *J* 6.62, Me-21), 1.00 (3 H, s, Me-19), 5.36 (1 H, septet, *J* 5.46, H-3α), 5.62 (1 H, dd, *J* 10.04 and 2.64, H-7), 5.81 (1 H, dd, *J* 10.04 and 2.81, H-6), 7.34 (1 H, brs, OOH), 7.42 (2 H, m) and 7.54 (1 H, m) and 8.03 (2 H, m, Ph); δ_C: 23 signals between 10–59 ppm and also 71.03 (C-3), 84.00 (C-5), 128.87 (C-7), 136.03 (C-6), 128.30, 129.57, 130.81 and 132.77 (4 aromatic carbons) and 166.20 (C=O): *m/z* (70 eV) 489 (M^+ − OOH, 5%); ν_{max}(Nujol)/cm^{-1} 3515 (OO–H str.), 2925 and 1705 (C=O) (Found: C, 78.4; H, 9.5. $C_{34}H_{50}O_4$ requires C, 78.12; H, 9.64%).

7α-Hydroperoxy-3β-benzoyloxycholest-5-ene (**30**).—The mixture from the photooxidation of **28** was chromatographed to remove the solvent and remaining reactant, then the product was dissolved in $CHCl_3$ (10 cm^3). After 72 h the solvent was removed by evaporation and the product was isolated by chromatography. Recrystallisation from methanol gave pure **30**, m.p. 92–94 °C; δ_H 0.65 (3 H, s, Me-18), 0.847 (3 H, d, *J* 6.52, Me-26 or 27), 0.852 (3 H, d, *J* 6.73, Me-27 or 26), 0.90 (3 H, d, *J* 6.39, Me-21), 1.04 (3 H, s, Me-19), 4.15 (1 H, m, H-7β), 4.92 (1 H, septet, *J* 5.33, H-3α), 5.77 (1 H, dd, *J* 4.84 and 1.47, H-6) and 7.42–8.02 (5 H, 3 m, Ph); δ_C: 23 signals between 10–58 ppm and also 73.99 (C-3), 78.22 (C-7), 120.95 (C-6), 147.87 (C-5), 128.29, 129.56, 130.61 and 132.83 (4 aromatic carbons) and 165.91 (C=O) (Found: C, 78.0; H, 9.75. $C_{34}H_{50}O_4$ requires C, 78.12; H, 9.64%).

One chromatographic fraction from the oxygenation of **28** gave a mixture of **29** and **30** along with 6β-hydroperoxy-3β-benzoyloxycholest-4-ene (**31**) (Fig. 3). It could not be separated chromatographically from **29** and **30**, but it was characterised by NMR spectroscopy; δ_H 4.35 (1 H, dd, *J* 3.93 and 1.62, H-6α), 5.47 (1 H, ddd, *J* 10.39, 6.31 and 2.03, H-3α) and 5.72 (1 H, t, *J* 1.69, H-4); δ_C 71.04 (C-3) and 86.50 (C-6).

The rearrangement **29** ⟶ **30** ⟶ **32** was monitored by these NMR characteristics (Fig. 4).

5α-Tributylstannylperoxy-3β-benzoyloxycholest-6-ene (**13**).—Tributyltin methoxide (0.26 g, 0.76 mmol)[18] in CH_2Cl_2 (3 cm^3) was added to **29** (0.4 g, 0.76 mmol) in CH_2Cl_2 (5 cm^3) at 0 °C. The solvent was removed under reduced pressure to give **13** as a moisture-sensitive viscous oil; δ_H 0.68 (3 H, s, Me-18) 0.70–2.30 (Bu and ring protons), 5.64 (1 H, dd, *J* 10.05 and 1.74, H-7), 5.70 (1 H, dd, *J* 10.05 and 2.59, H-6) and 7.39–8.02 (5 H, 3 m, Ph); δ_C: 27 peaks between 10–58 ppm, and also 71.82 (C-3), 81.97 (C-5), 128.13, 129.49, 131.34 and 132.37 (4 aromatic carbons), 131.72 (C-7), 132.50 (C-6) and 165.93 (C=O).

The rearrangement **13** ⟶ **14** ⟶ **15** was monitored by NMR spectroscopy as shown in Fig. 5. **14**: δ_H 3.95 (1 H, t, *J* 4.27, H-7β), 4.93 (1 H, m, *J* 4.68, H-3α) and 5.91 (1 H, br, *J* 3.77, H-6). **15**: δ_H 3.84 (1 H, t, *J* 6.71, H-7α), 4.84 (1 H, m, H-3α) and 5.74 (1 H, br, H-6).

Cholest-6-en-3β,7α- and -3β, 7β-diol (**33** *and* **34**).—The stannyl peroxide **13** (0.45 g) was dissolved in $CHCl_3$ at room temperature. After 24 days, the mixture was reduced with an excess of Ph_3P at 0 °C, then a solution of KOH (0.5 g) in methanol (15 cm^3) was added. The precipitate which was formed was separated and washed with methanol. Next day, the methanol was removed by evaporation and the residue was dissolved in diethyl ether (30 cm^3), then washed with water, and dried (Na_2SO_4). The solvent was evaporated and the residue was chromatographed (eluent; pentane–diethyl ether, 3:1 v/v) to give the diol **33**, m.p. 182–185 °C (lit.,[19] 184–186 °C); δ_H: see ref. 7; δ_C 71.54 (C-3), 72.10 (C-7), 123.45 (C-6) and 147.10 (C-5), and the diol **34**, m.p. 174–178 °C (lit.,[19] 176–178 °C); δ_H: see ref. 7; δ_C 71.44 (C-3), 73.35 (C-7), 125.44 (C-6) and 143.46 (C-5).

5α-Trimethylsilyl-3β-benzoyloxycholest-6-ene (**19**).—The hydroperoxide **29** (0.5 g, 0.96 mmol) was dissolved in CH_2Cl_2 (4 cm^3) and bis(trimethylsilyl)acetamide (0.2 g, 0.96 mmol) in CH_2Cl_2 (3 cm^3) was added. The mixture was allowed to stand for 2 h at 30 °C. The solvent was evaporated to give a viscous oil which was chromatographed (solvent: pentane–diethyl ether, 10:1 v/v) to give **19**, m.p. 85 °C; δ_H 0.16 (9 H, s, $SiMe_3$), 0.69 (3 H, s, Me-18), 0.85 (3 H, d, *J* 6.59, Me-26 or 27), 0.86 (3 H, d, *J* 6.55, Me-27 or 26), 0.91 (3 H, d, *J* 6.46, Me-21), 0.99 (3 H, s, Me-19), 5.38 (1 H, septet, *J* 5.62, H-3α), 5.61 (1 H, dd, *J* 10.10 and 2.71, H-7), 5.67 (1 H, dd, *J* 10.05 and 1.74, H-6) and 7.40–8.03 (5 H, 3 m, Ph); δ_C −0.66 (SiC), 23 peaks between 10–58 ppm, and also 71.36 (C-3), 83.20 (C-5), 130.50 (C-7), 133.57 (C-6), 128.22, 129.55, 131.14 and 132.56 (4 aromatic carbons) and 166.05 (C=O); *m/z* (70 eV) 594 (M^+ 2%), 489 (M^+ − $OOSiMe_3$) (Found: C, 74.5; H, 10.0. $C_{37}H_{58}O_4Si$ requires C, 74.70; H, 9.83%).

Acknowledgements

We thank Mr. C. J. Cooksey for carrying out the NOE experiments, and the SERC for financial support.

References

1 A. G. Davies, *J. Organomet. Chem.*, 1982, **239**, 87.
2 H.-S. Dang and A. G. Davies, *J. Organomet. Chem.*, 1992, in the press.
3 H.-S. Dang and A. G. Davies, *J. Chem. Soc., Perkin Trans. 2*, 1991, 2011.
4 H.-S. Dang and A. G. Davies, *Tetrahedron Lett.*, 1991, **32**, 1745.
5 G. O. Schenck, O. A. Neumüller and W. Eisfeld, *Annalen*, 1958, **618**, 202.
6 J. I. Teng, M. J. Kulig, L. L. Smith, G. Kan and J. E. V. Lier, *J. Org. Chem.*, 1973, **38**, 119.
7 A. L. J. Beckwith, A. G. Davies, I. G. E. Davison, A. Maccoll and M. H. Mruzek, *J. Chem. Soc., Perkin Trans. 2*, 1989, 815.
8 H.-S. Dang, A. G. Davies and C. H. Schiesser, *J. Chem. Soc., Perkin Trans. 1*, 1990, 789.
9 R. K. Haynes and S. C. Vonwiller, *J. Chem. Soc., Chem. Commun.*, 1990, 448.
10 H.-S. Dang and A. G. Davies, *Synthesis*, 1992, in the press.
11 L. D. Hall and J. K. M. Sanders, *J. Chem. Soc., Chem. Commun.*, 1980, 368.
12 R. W. Denney and A. Nickon, *Org. React. (NY)*, 1973, **20**, 133.
13 A. Nickon and W. L. Mendelson, *J. Am. Chem. Soc.*, 1963, **85**, 1894.
14 K. U. Ingold and B. P. Roberts, *Free Radical Substitution Reactions*, Wiley-Interscience, New York, 1971.
15 A. G. Davies and M.-W. Tse, *J. Organomet. Chem.*, 1978, **155**, 25.
16 F. Sondheimer, C. Amendolla and C. Rosenkranz, *J. Am. Chem. Soc.*, 1953, **75**, 5932.
17 Y. Tachibana, *Bull. Chem. Soc. Jpn.*, 1986, **59**, 3702.
18 A. G. Davies, D. C. Kleinschmidt, P. R. Palan and S. C. Vasishta, *J. Chem. Soc. (C)*, 1971, 3972.
19 V. Kumar, A. Amann, G. Ourisson and B. Luu, *Synth. Commun.*, 1987, **17**, 1279.

Paper 2/00652I
Received 6th *January* 1992
Accepted 6th *March* 1992