tions[7] in cholesteryl esters, including those of lauric acid (ChL), β-naphthoic acid (ChNaph), *o*-toluic acid (ChT), 2,4-dichlorobenzoic acid (ChDCB), *p*-phenylbenzoic acid (ChPB), *trans*-cinnamic acid (ChC), and *trans*-4-carboxystilbene (ChS). No asymmetric induction was observed in control experiments in which the samples were heated slightly above the cholesteric to isotropic liquid transition temperature.

All of the cholesteryl esters used are either known[8] to form a right-handed helix in the cholesteric mesophase, or were shown to do so by the CD signs of their pitch bands.[9] Therefore, the observation that equilibration of methyl α-naphthyl sulfoxide (**1**) affords enrichment in the *R* enantiomer in ChB and ChNB, but in the *S* enantiomer in ChN, ChC, ChS, and ChPB, demonstrates that the sense of helical macrostructure alone does not control the stereochemical sense of enrichment. Note also that whereas ChNB equilibration enriches naphthyl **1** and its phenyl analogue **2** in the same sense, this sense is inverted for biphenyl sulfoxide (**3**). Enrichment senses of **1** and **3** also differ in ChPB.

While it is premature to speculate upon the details of how a chiral mesophase actually effects asymmetric transformation, we consider it probable that rather specific solute-solvent interactions play a role in "locating" the solute molecules in the chiral mesophase, the helical order of which is essential to the success of the asymmetric transformation.

On the supposition that solutes capable of structurally "mimicking" the mesophase should show still greater extents of asymmetric transformation, the diastereomeric cholesteryl methane sulfinates, **4** were prepared. Like sulfoxides, sulfinates can undergo inversion at sulfur upon heating. Although these diastereomers were not readily obtained free from one another, their absolute rotations were calculated from rotational data obtained from mixtures of different, but known ratios of the two diastereomers.[10] Equilibration of the epimers in toluene at 110 °C affords a 20% diastereomeric excess of the epimer with the *S* configuration at sulfur. When heated in ChL at a temperature slightly above the cholesteric–isotropic transition point, the sulfinates show a 1.4% enrichment in the *S* isomer. When conducted in cholesteric ChL, the sulfinate epimerization affords a 12.3% enrichment in the *R* epimer, a shift of approximately 32% from the equilibrium position in the achiral solvent and 13.7% from isotropic ChL. Use of cholesteric ChB biases the equilibrium even more strongly (16.9%) in the same direction.

Oxaziridines constitute yet another class of compounds configurationally stable at 25 °C, yet racemizable at elevated temperatures. Upon brief heating (5 min) at 148 °C in ChB, oxaziridine **5** underwent substantial decomposition. Recovery of residual **5** by molecular distillation afforded (−)-enriched **5** of 20% e.e.[11] The only prior synthesis[13] of chiral **5** (from oxidation of the imine with percamphoric acid) proceeds in low (*ca.* 3%) optical yield.[11] However, the thermal instability of **5** under the conditions needed for asymmetric induction led to highly variable results; often, no oxaziridine was recovered. In this instance, the asymmetric induction may involve selective destruction of one enantiomer rather than thermal equilibration. Recovery of **5** from mixtures of the racemate and the cholesteryl ester *without prior heating* afforded no enantiomeric enrichment.

Acknowledgment. This work has been partially supported by grants from the National Science Foundation and the National Institutes of Health.

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(7) The term equilibration is used loosely, since total equilibration may not have been attained. Some of the cholesteryl esters showed evidence of minor decomposition, especially after long heating. Such decomposition can reduce the degree of order in the liquid crystal and long reaction times were in fact observed to reduce the magnitude of asymmetric induction, thwarting determination of the true equilibrium position.
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(9) F. D. Saeva, *Mol. Cryst. Liq. Cryst.*, **18**, 375 (1972).
(10) Fraction crystallization afforded mixtures of different ratios as judged by specific rotations. Treatment of these fractions with a several-fold excess of phenylmagnesium bromide afforded partially resolved methylphenyl sulfoxide. The enantiomeric composition of the sulfoxide was taken to represent the diastereomeric composition of sulfinate precursor. Thus, for the sulfinate having the *S* configuration at sulfur $[\alpha]^{24}_D = -85.3°$, whereas its epimer (*R* configuration at sulfur) has $[\alpha]^{24}_D = 19.2°$ (*c* 1–2, $CHCl_3$).
(11) The absolute configuration and enantiomeric composition of a number of oxaziridines can be determined by NMR methods using chiral solvating agents such as 2,2,2-trifluoro-1-(9-anthryl)ethanol.[12] This work is being described elsewhere.
(12) W. H. Pirkle, D. L. Sikkenga, and M. S. Pavlin, *J. Org. Chem.*, **42**, 384 (1977).
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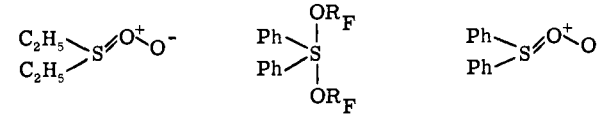
Evidence for the Formation of Sulfinyl Oxides in the Reactions of Alkoxysulfuranes with Hydrogen Peroxide. The Oxidation of Sulfides to Sulfoxides, and Olefins to Epoxides[1]

Sir:

The reactions of sulfur compounds with singlet oxygen have received much recent attention.[2] Foote[2a,c] has reported the trapping of a transient intermediate in the singlet oxygen oxidation of diethyl sulfide to which he assigns the sulfinyl oxide (or persulfoxide)[2a] structure **1**. We here report evidence for similar intermediates in reactions of di- and trialkoxysulfuranes with hydrogen peroxide.

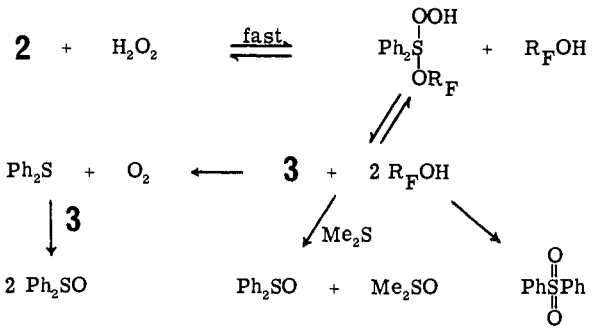


1 **2** [R_F = $PhC(CF_3)_2$] **3**

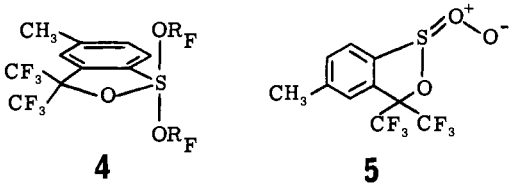
The reaction of **2**[3] with H_2O_2 to give **3**, or its functional equivalent, is evidenced by the change in products as a function of added dimethyl sulfide. Treatment, at −78 °C, of a CH_2Cl_2 solution 1.3 M in dimethyl sulfide and 1.5 M in sulfurane **2** with an amount of H_2O_2 (in ether)[4] equivalent to the sulfurane rapidly gave 52% of dimethyl sulfoxide (Me_2SO).[5] The reaction of dimethyl sulfide with H_2O_2 is slow under these conditions in the absence of **2**. In the absence of dimethyl sulfide, the reaction of **2** with H_2O_2 at −78 °C gives diphenyl sulfone (80%), diphenyl sulfoxide (15%), and a trace of diphenyl sulfide.[6]

The ligand exchange reactions of Scheme I might be expected to be fast on the basis of earlier work on sulfuranes.[3,7] The rearrangement of **3** to sulfone is shown by the above product data to be competitive with the loss of oxygen to give sulfide or, in the presence of dimethyl sulfide, with the pictured reductive scavenging reaction. Diphenyl sulfoxide could result either from hydrolysis of **2** by reaction with adventitious water, or from the reduction of **3** by added sulfide, or from the oxidation by **3** of the diphenyl sulfide generated in the reaction.[8]

Scheme I



The analogous reaction of trialkoxysulfurane **4**[9] with H_2O_2 gives a related scavengeable intermediate formulated as **5** or **6**.[10] The reaction of **4** with H_2O_2 at −78 °C in CH_2Cl_2 gives sultone **7**[9] quantitatively. In the presence of excess[11] dimethyl sulfide (0.2 M) the transient intermediate is diverted quantitatively to give sultine **8** instead of sultone **7** and 90% of Me_2SO is formed.[5] Addition of the trapping agent 30 s after the H_2O_2 was added to **4** at −78 °C gave only **7**, providing evidence for the transient nature of **5** (or **6**).



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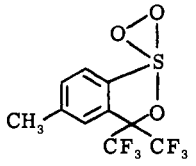
5



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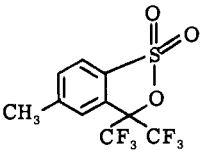

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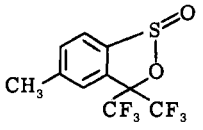

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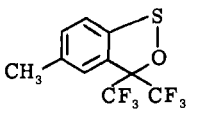
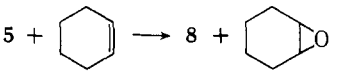


9

Foote and Peters[2a,c] have found that sulfinyl oxide **1** reacts differently at −78 °C than at room temperature in aprotic solvents. At low temperature the ratio of sulfide oxidation to singlet oxygen quenching is increased. Also, sulfone formation becomes more important at low temperatures. We have found similar results for the reaction of sulfinyl oxide **3** at −78 and 0 °C. At 0 °C sulfone formation is drastically reduced (from 80% at −78 °C to 27% at 0 °C) and sulfide formation is enhanced (from <5% at −78 °C to approximately 25% at 0 °C).[6] In view of the recognized[2a,c] ability of sulfides to quench singlet oxygen it is not surprising that the oxygen produced by the decompositions of sulfinyl oxide **3** appears to be in the triplet state. No products from singlet oxygen reactions were found when singlet oxygen traps[12] were present. In contrast, **5** (or **6**) does not give oxygen and sultene **9** even at temperatures up to 56 °C.

Competitive kinetics studies of the oxidation, with **3**, of mixtures of symmetrically disubstituted diphenyl sulfides at −78 °C showed the oxidant to be electrophilic, describing a ρ of −0.43.[13] A parallel study with **5** (or **6**) gave a ρ of −0.86.[14] The difference in selectivity, as indicated by the different magnitudes of ρ for **5** (or **6**) and **3**, may be explained by reference to the inductive electron-withdrawing effect of the additional oxygen ligand in **5** (or **6**). If this inductive effect is more important than the possible p_π–d_π electron-donating resonance interaction, it would make **5** (or **6**) more susceptible to nucleophilic attack than is **3**, providing a rationale for the observed magnitudes of ρ.

When sulfinyl oxide **3** is generated in the presence of cyclohexene no reaction with olefin is observed. However, sulfinyl oxide **5** (or **6**) is trapped by added olefin. When the intermediate is generated in the presence of excess[11] cyclohexene or norbornene then allowed to warm to room temperature, sultine **8** is produced quantitatively.[5] The product from the olefin is the epoxide. An oxenoid mechanism, which could resemble those in biological epoxidations,[15] is suggested for the epoxidation reactions.



When norbornene is treated with excess oxidizing agent[16] at −78 °C and then warmed to room temperature, *exo*-norbornene oxide[17] is obtained in 65% yield.[5] Similarly[16] cyclohexene is converted into the epoxide in 94% yield.[5]

Rebek[18] and Newman and Blum[19] have also reported methods of activating hydrogen peroxide for olefin epoxidation. However, both of these systems involve peracid-like intermediates. Michejda[20] has reported epoxidations of olefins by a reactive intermediate generated from oxygen and dimethylamino radicals; however, this system suffers from further reaction of epoxides from unhindered olefins to form amino alcohols. Thus, the combination of sulfurane **4** and H_2O_2 joins a growing group of epoxidizing agents. The mildness of the reaction conditions (−78 °C), the time required for reaction (seconds), and the ease of workup (sultine **8** and R_FOH can be removed by base extraction) could make this a very useful system for some epoxidation reactions.

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(4) Anhydrous H_2O_2 in Et_2O was obtained by the method of A. Reiche and C. Bischoff, *Chem. Ber.*, **94**, 2722 (1961).
(5) Yields determined by NMR.
(6) Yields determined by GLC.
(7) (a) R. J. Arhart and J. C. Martin, *J. Am. Chem. Soc.*, **94**, 5033 (1972); (b) L. J. Kaplan and J. C. Martin, *ibid.*, **95**, 793 (1973).
(8) Later results discussed in this paper indicate that sulfinyl oxide **3** does oxidize diphenyl sulfide to the sulfoxide. The extent of hydrolysis has not been determined; however, further studies are being made in this area.
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(10) In this instance the polarity rules[9] allow the alternative formulation of a cyclic peroxysulfurane since the apical positions are both occupied by oxygen ligands. This is not the case for sulfinyl oxide **3** since formation of

a cyclic peroxysulfurane would force a phenyl ring into an apical position.
(11) Sulfurane 0.125 M and trapping agent 0.2 M.
(12) Anthracene and tetraphenylcyclopentadienone were used as singlet oxygen traps. C. S. Foote, S. Wexler, W. Ando, and R. Higgens, *J. Am. Chem. Soc.*, **90**, 975 (1968).
(13) k_{rel}: *p*-Cl, 1; *p*-Me, 2.2; *p*-MeO, 2.6. $R = 0.9996$. k_{rel} was calculated using the integrated rate equation: $k_{rel} = (\log [(A - X)/A])/(\log [(B - Y)/B])$, where A and B are the amounts of sulfides at the beginning of the reaction and X and Y are the amounts of sulfoxides at the end of the reaction. Product ratios were determined by GLC.
(14) k_{rel}: *p*-Cl, 0.45; H, 1; *p*-Me, 2.1; *p*-MeO, 3.2. R = 0.9985. The same procedure was followed as outlined in footnote 13.
(15) G. A. Hamilton in "Molecular Mechanisms of Oxygen Activation", O. Hayaishi, Ed., Academic Press, New York, N.Y., 1974, pp 405–451.
(16) The solution was 0.1 M in olefin and contained 140% excess (as a slurry) of sulfurane **4** and 1 equiv of H_2O_2/equiv of **4**.
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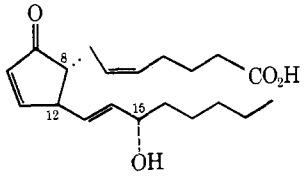
Cyclopentanone Ring Formation with Control of Side Chain Stereochemistry. A Simple Stereoselective Route to the Prostaglandins[1,2,28]

Sir:

While much is known about the control of the relative stereochemistry of substituents directly attached to a carbocyclic ring, there are few methods[3] for directly controlling the relative stereochemistry of asymmetric centers remote from a ring. Recently, we developed a method[4] for the synthesis of cyclopentanone derivatives with control of acyclic asymmetric center directly attached to the ring. We have now extended this method to the control of a more distant center.

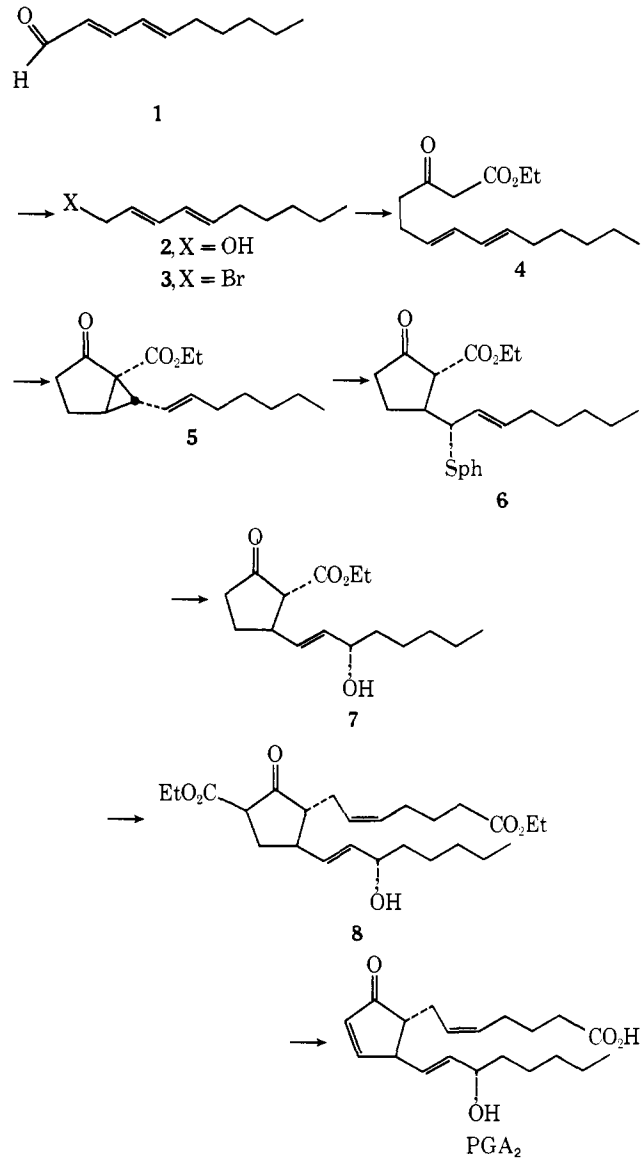
The problem of controlling the relative stereochemistry of a distal center is exemplified by prostaglandin A_2. Thus, it is easy to control the stereochemistry of C-12 relative to C-8, as the two side chains are more stable trans. Much more difficult is the control of the stereochemistry of C-15 relative to C-12. A great deal of effort has been directed toward the solution of this particular example of the general problem. Abrief review of the published solutions may help delineate the strengths and weaknesses of current methods for controlling such a distal center. We limit our consideration to those methods which allow direct construction of the specific stereochemical relationship desired. Methods which depend on the combination of optically pure component fragments[5] or specialized selective reduction[6] do not fall within the scope of that consideration.



PGA_2

S_N2' cyclization[7] has been used to control relative stereochemistry. As recent work[8] has cast doubt on "1a relation syn des substitutions S_N2''",[7] this method must be explored more fully before its generality can be assessed. The conjugate addition of a chelated cuprate to an achiral enone[9] has also been used to effect such control. The generality of this method has similarly not been explored. Finally, a method based on the 1,2 to 1,4 transfer of relative stereochemistry by allylic rearrangement was recently published.[10] This method allows the rational control of absolute and therefore relative stereochemistry.

Scheme I



Modification of our cyclopentanone synthesis[4] to allow direct control of a distal side chain asymmetric center was accomplished by incorporation of such an allylic transfer of relative stereochemistry. The sulfoxide rearrangement developed by Evans[11] was particularly suited to this purpose (Scheme I).

As this approach starts with an allylic alcohol such as **2**, its flexibility extends to the many and varied methods for the synthesis of geometrically defined olefins. For this particular application, we were gratified to learn of the availability of aldehyde **1**, an autoxidation product of vegetable oil[12] which is separated in great quantity as a by-product of commercial margarine production.

The key cyclopropane **5** was readily prepared from **1**. Thus, reduction of the aldehyde[13] ($LiAlH_4$, NaOMe, ether, 0 °C, 30 min, 84%) gave the known[14] alcohol **2**, which was smoothly converted[15] to the unstable allylic bromide **3** (PBr_3, CaH_2, ether, 0 °C to room temperature, overnight, 81%). Alkylation of the dianion of ethyl acetoacetate[16] with crude bromide **3** led to the ketoester **4**[17] (0 °C to room temperature, 20 min, 55%). Diazo transfer[18] (1.1 equiv *p*-toluenesulfonyl azide, triethyl-