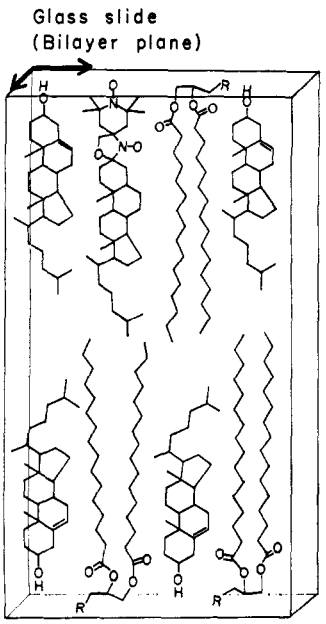
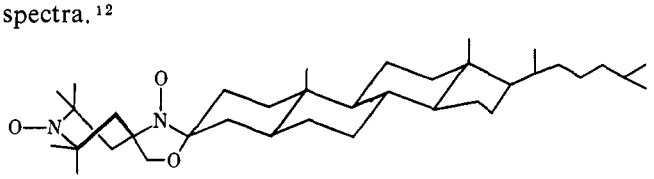


Figure 2. R = $^{-}O_3POCH_2CH_2N^{+}(CH_3)_3$. Schematic representation of a section of dipalmitoyl lecithin bilayer containing cholesterol showing the relative orientation of the dinitroxide spin label **5**.

for $\theta = 90°$, $d = \sim 250$ G.[12] While an exact calculation of E is not possible from our data, it is clear that $|E| \ll |D|$.

In the point dipole approximation $2D$ is related to the distance r between two N–O groups by the expression $2D = 55.6 \times 10^3 \times r^{-3}$.[2c,13] Measurements on molecular models of various low-energy conformations of the piperidine ring of **5** provide values for r of 3.8–5.2 Å. For twist-boat **6**, $r = 5.0$ Å, corresponding to $2D = 445$ G,[14] in reasonable agreement with $2D = 455$ G estimated from the outermost lines of the rigid glass spectrum (see above). The model of **6** also shows that line r forms an angle γ of about 20° with the long molecular axis about which **6** probably can rotate in the multilayer, undoubtedly a factor contributing to line broadening in the multilayer spectra.[12]



6

A section of the labeled dipalmitoyl lecithin–cholesterol–dinitroxide multilayer is diagrammed in Figure 2. While we undoubtedly do not have perfect orientation of label **5** in the multilayer, the difference, nevertheless, between the maximum and minimum dipolar splittings observed here is about 200 G. When this anisotropy is compared with that typically observed[2] for mononitroxide spin labels, namely about 16–20 G, it is evident that the esr spectrum of the dinitroxide label is much more sensitive to orientation within a multilayer than are conventional mononitroxides. This large anisotropy should also facilitate studies involving molecular motion within membrane and membrane model systems.

Acknowledgment. We thank the National Science Foundation (GP-27367), the National Institutes of Health (1 RO3 MH 17209), and the donors of the Petroleum Research Fund, administered by the American Chemical Society (GF 674), for generous financial support. We also thank Professor O. H. Griffith and Dr. P. Jost for stimulating discussions and the use of some of their equipment.

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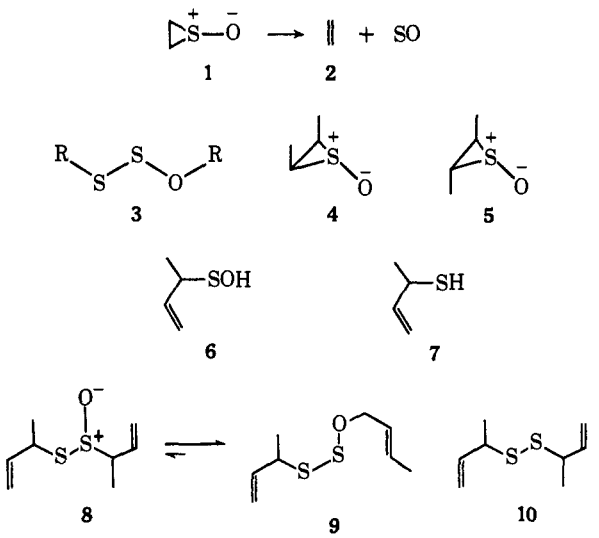
Rearrangement of Strained Dipolar Species. I. Episulfoxides. Demonstration of the Existence of Thiosulfoxylates

Sir:

It has been generally assumed that thermal decomposition of episulfoxides (**1**) proceeds to the olefin (**2**) by elimination of sulfur monoxide (Scheme I).[1] Such a process may be concerted, with retention of configuration of the liberated olefin, when it proceeds in the manner of a nonlinear cheletropic reaction.[2] We have observed, however, that in the presence of a suitably disposed hydrogen atom, there occurs a more facile pathway, namely rearrangement to allylic sulfenic acids. These substances may be intercepted or they may dimerize to a new structural type, the thiosulfoxylate (**3**).[3]

Scheme I



1 **2** **3** **4** **5** **6** **7** **8** **9** **10**

(13) N. Hirota and S. I. Weissman, *J. Amer. Chem. Soc.*, **86**, 2538 (1964).

(14) It is evident that the calculated value of $2D$ should be extremely sensitive to the value chosen for r. Therefore, the presence of other conformations of **5** would lead to additional line broadening (see above and ref 12).

(1) (a) G. E. Hartzell and J. N. Paige, *J. Amer. Chem. Soc.*, **88**, 2616 (1966); (b) G. E. Hartzell and J. N. Paige, *J. Org. Chem.*, **32**, 459 (1967).

(2) R. B. Woodward and R. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, **8**, 781 (1969).

(3) Esters of sulfoxylic acid, $S(OH)_2$, have been described: A. Meuwsen and H. Gerbhard, *Chem. Ber.*, **69**, 937 (1936); Q. E. Thompson, *J. Org. Chem.*, **30**, 2703 (1965). We can find no mention of thiosulfoxylates.

Thus *cis*- and *trans*-2-butene episulfoxides were prepared by peracid oxidation of the episulfides,[4] and whereas the cis isomer **4**[5] was stable at 35°, the trans compound **5** decomposed smoothly in methylene chloride at this temperature ($t_{1/2}$ 3 min, monitored by nmr) with separation of water. To demonstrate the intermediacy of sulfenic acid (**6**), the trans isomer **5**, prepared at −30°, was treated with 1 equiv of triethyl phosphite[6] and allowed to warm to room temperature. The only product formed was a 1:1 mixture of 2-mercaptobut-3-ene (**7**) and triethyl phosphate, from which the thiol was recovered by distillation and shown to be identical with an authentic sample.[7] The decomposition of **5** was monitored by nmr (60 MHz) at 35°, in the absence of phosphite, and examination of the methyl region showed the initial formation (10 min) of a mixture of the four possible stereoisomers of the thiosulfinate (**8**)[8] by the growth of doublets (all J values = 7 ± 0.3 Hz at δ (CH_2Cl_2) 1.44, 1.49, 1.50, 1.52, and 1.53. Evidently several of the possible eight doublets are either coincident or else some diastereoisomer is not formed. However, after several hours at this temperature the spectrum largely simplified to that of the thiosulfoxylate (**9**) and drying, followed by distillation, gave a colorless oil (bp 30° (0.01 Torr)): 50%, mass spectral mol wt 190, calcd for $C_8H_{14}S_2O$: C, 50.48; H, 7.42; S, 33.73; found: C, 50.36; H, 7.61; and S, 34.42. The spectral data (ir (neat) 1640, 1470, 1110, 990, and 950 cm^{-1}; nmr (CCl_4) δ 1.44 (d, J = 7.0 Hz, 3 H), 1.70 (d, J = 5.0 Hz, 3 H), 3.64 (p, J = 7.0 Hz, 1 H), 4.10 (d, J = 5.0 Hz, 2 H), 5.0–6.1 (m, 5 H)) were the same as the crude reaction product and represent 80% of the total spectral intensity, 20% of the thiolsulfinate (**8**) accounting for the residual portion.

Chemical evidence for the structure of the major component **9** of the equilibrium mixture was obtained by reduction ($LiAlH_4$) to 2-mercaptobut-3-ene (**7**) and crotyl alcohol.[7] Since **9** represents an as yet unobserved functionality it was decided to synthesize it by another route. Thus, but-3-en-2-yl disulfide (**10**), obtained by oxidative coupling (iodine, pyridine) at −20° of mercaptan (**7**), was oxidized (−20°) with *m*-chloroperbenzoic acid. The initial product was thiosulfinate (**8**) which on standing at room temperature (nmr) and work-up gave the same mixture of **8** and **9** (20:80), identical in spectral properties and reductive cleavage with that above. The interconversion of **8** and **9** is an example of a [2,3]-sigmatropic rearrangement[9] which is well studied in the case of allylic sulfoxides.[10] In accord with our findings, it has been shown[10] that electron-withdrawing substituents, here the second sulfur atom, favor the sulfenic form, as **9**, in the equilibrium.[11]

The equilibrium mixture slowly decomposes on storage at room temperature and quite rapidly at 80°.

Since our results seemed to be in contradiction to those earlier described,[1] relating to fragmentation of **1** to **2**, we have investigated the high-temperature behavior of **4** and **5**. We determined the yield and proportions of olefin formed (Table I), by injection of the stereoisomeric episulfoxides into the heated inlet of a glpc system[12] and comparison with calibrated mixtures of *cis*- and *trans*-2-butene. It is evident that both isomers, at sufficiently high temperatures, do eject sulfur monoxide to yield the butenes, the yield of which is improved with increasing temperature.

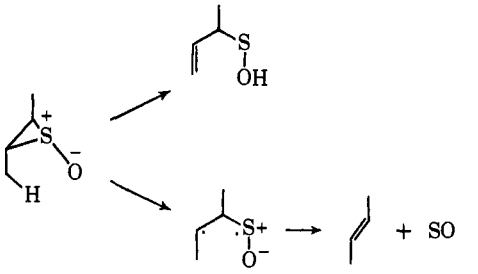
Table I. Episulfoxide Pyrolysis

Injector temp, °C	Cis: % butene[a]	Cis: cis:trans[b]	Trans: % butene[a]	Trans: cis:trans[b]
85	1.5			
150	18		1.5	
	1.5[c]		1.5[d]	
200	60	95:5	9	35:65
260	80	92:8	36	36:64
			20[d]	40:60
300	90	90:10	45	40:60
340	96	81:19	49	43:57

[a] Error estimated to be ±10%. [b] Error estimated to be ±2%. [c] Previously decomposed by heating to 100° for 2 min; there are other peaks in the glpc. [d] Previously decomposed by heating to 40° for 5 min; there are other peaks in the glpc.

The simplest rationale for all these observations is that episulfoxides may decompose by two routes, Scheme II. The first is a facile rearrangement to a sulfenic acid, when the stereochemistry is favorable, and the second is a pathway of higher activation energy, which leads through a partially stereospecific route to olefin and presumably sulfur monoxide.[13] For this

Scheme II



11

(4) K. Kondo, A. Negishi, and M. Fukuyama, *Tetrahedron Lett.*, 2461 (1969).

(5) This cis isomer, 4, has been demonstrated to possess the anti configuration; *cf.* ref 4.

(6) Phosphites have been previously shown to be good trapping agents for sulfenic acids; *cf.* R. D. G. Cooper and F. J. Jose, *J. Amer. Chem. Soc.*, **92**, 2575 (1970). The cis isomer 4 was stable to this reagent over 24 hr at room temperature.

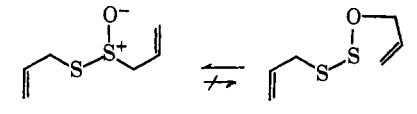
(7) Glpc analyses were performed on a 10-ft glass column of 5% SE-30 on Chromosorb W at 60° column temperature.

(8) It has already been demonstrated that alkyl sulfenic acids dehydrate to thiosulfinates; *cf.* J. R. Shelton and K. E. Davis, *J. Amer. Chem. Soc.*, **89**, 718 (1967).

(9) J. E. Baldwin, R. E. Hackler, and D. P. Kelly, *Chem. Commun.*, 538 (1968).

(10) R. Tang and K. Mislow, *J. Amer. Chem. Soc.*, **92**, 2100 (1970), and references cited therein.

(11) We have reinvestigated allicin, the antibacterial principle of *Allium sativum* (garlic), and shown by nmr studies and reductive cleavage that it exists entirely as the thiosulfinate form i; *cf.* C. J. Cavallito, J. S. Buck, and C. M. Suter, *ibid.*, **66**, 1952 (1944).



i ii

(12) All glpc analyses of olefins were performed on a 10-ft column of 5% $AgNO_3$ saturated TEG on Chromosorb P at 0° column temperature. No interconversion took place under these conditions.

(13) A recent report (*cf.* D. C. Dittmer, G. E. Kuhlmann, and G. C. Levy, *J. Org. Chem.*, **35**, 3676 (1970)) describes the results of pyrolysis of dibenzoylstilbene episulfoxide. We believe the difference between these results and our own to lie in the presence of aryl substituents in the stilbene cases, which allow interconversion to the postulated 1,2-oxathietane.

latter pathway we propose a diradical intermediate, **11**, which explains the lack of complete stereospecificity in the olefin product due to bond rotation in this intermediate.[14]

Acknowledgment. We wish to thank the U. S. Public Health Service, the National Science Foundation, the Petroleum Research Fund, administered by the American Chemical Society, Eli Lilly and Company, and Hoffmann La Roche for support of this research.

(14) Such intermediates are readily formed in high-temperature reactions of dipolar or ylide species; *cf.* J. E. Baldwin, W. F. Erickson, R. E. Hackler, and R. M. Scott, *Chem. Commun.*, 576 (1970).

(15) A. P. Sloan Fellow, 1969–1971.

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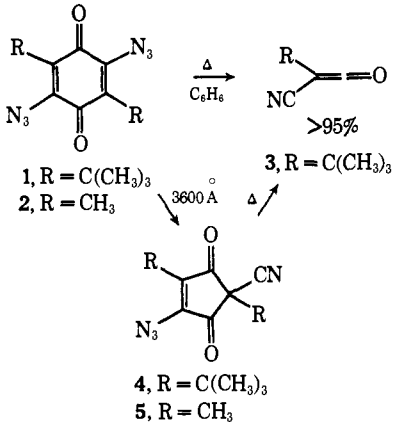
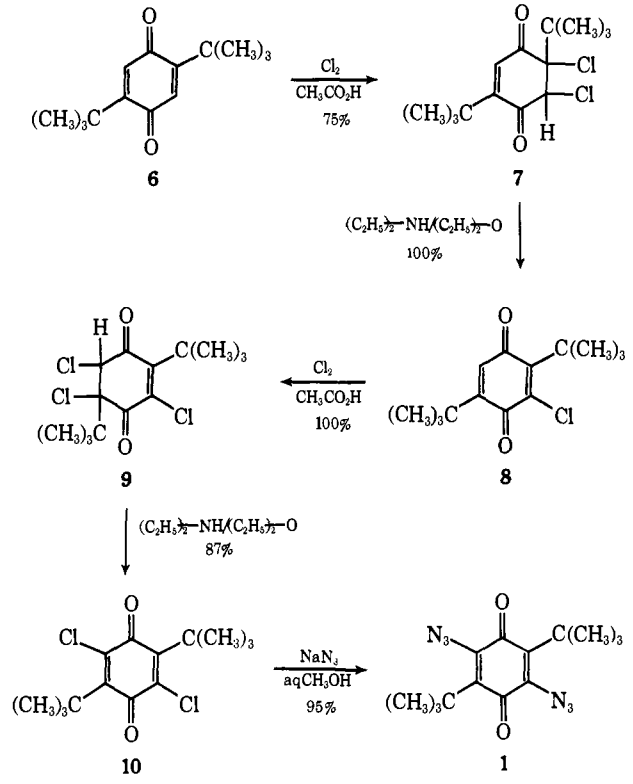
Rearrangements of Azidoquinones. VIII. Photolytic Rearrangement of 2,5-Diazido-1,4-benzoquinones to 2-Cyano-4-azido-1,3-cyclopentenediones, Precursors to Cyanoketenes

Sir:

In an earlier communication,[1] the pyrolytic cleavage of 2,5-diazido-3,6-di-*tert*-butyl-1,4-benzoquinone (**1**) to 2 mol of *tert*-butylcyanoketene (**3**) was reported. Described here is the photolysis of the diazidoquinones **1** and **2**[2] in anhydrous benzene with 3600-Å light. This reaction results in ring contraction to the 2-cyano-4-azido-1,3-cyclopentenediones, **4** and **5**, respectively. No ketene products are observed. However, subsequent thermal decomposition of 2-cyano-4-azido-2,5-di-*tert*-butyl-1,3-cyclopentenedione (**4**) in refluxing benzene results in a nearly quantitative yield of *tert*-butylcyanoketene (**3**).



2,5-Diazido-3,6-di-*tert*-butyl-1,4-benzoquinone (**1**) is conveniently prepared from 2,5-di-*tert*-butyl-1,4-benzoquinone (**6**) as outlined below. This method represents a pedestrian high-yield route to the diazide **1** from readily available starting materials.[3] The quinone **6** (44 g) was suspended in 400 ml of glacial acetic acid and chlorine gas was rapidly passed through the stirred reaction mixture for 30 min. The dichloride **7** was isolated (75%) by pouring the reaction solution into ice–water and recrystallizing the resulting white solid from diethyl ether. Dehydrohalogenation of **7** by slowly adding a stoichiometric amount of diethylamine, 10.8 g in 50 ml of ether, to a solution of **7**, 43.2 g in 500 ml of diethyl ether, gave 3-chloro-2,5-di-*tert*-butyl-1,4- benzoquinone (**8**) in quantitative yield. Chlorination of 38 g of chloroquinone **8** in 200 ml of glacial acetic acid at room temperature for 6 hr gave **9** as a light yellow oil.[4] Diethylamine (10.2 g) dehydrohalogenation of **9**, 45 g in 250 ml of diethyl ether, gave 2,5-di-*tert*-butyl-3,6-dichloro-1,4-benzoquinone (**10**) as a beautiful yellow crystalline solid in 87% yield. Reaction of a methanolic solution of **10**, 10 g in 750 ml of CH_3OH, with aqueous sodium azide,[2] 5 g in 15 ml of H_2O, gave 2,5-diazido-3,6-di-*tert*-butyl-1,4-benzoquinone (**1**) in 95% isolated yield.[5] Spectral data for compounds **1** and **7**–**10** are presented in Table I.



Solutions (1%) of the azidoquinones **1** and **2** in anhydrous benzene were irradiated with 3600 Å light for 7 hr at ambient temperature. At the end of this time tlc and spectral (ir, nmr) analysis of the reaction solution showed only one major product, the cyclopentenediones. These compounds were isolated by column chromatography on 30 g of 40–60 mesh silica gel using 1:1 petroleum ether–chloroform as the eluent. Critical structural data for the cyclopentenediones follow:[6]

(1) H. W. Moore and W. Weyler, Jr., *J. Amer. Chem. Soc.*, **92**, 4132 (1970).

(2) The azidoquinones are readily obtained in high yield *via* the reaction of sodium azide with 2,5-dichloro-3,6-dialkyl(or aryl)-1,4-benzoquinones in ethanol and/or tetrahydrofuran. For synthetic procedures to azidoquinones see H. W. Moore, H. R. Shelden, D. W. Deters, and R. J. Wikholm, *ibid.*, **92**, 1675 (1970).

(3) This is the only synthetic procedure we have been able to develop for the diazide **1**. All other methods failed primarily due to dealkylation reactions induced by hydrogen halides. For example, reaction of 2,5-di-*tert*-butyl-3-chloro(or bromo)-1,4-benzoquinone with HCl or HBr results in the loss of the 2-*tert*-butyl group giving the corresponding 2,3-dihalo-5-*tert*-butylquinol in high yields.

(4) The nmr spectrum of **9** showed it to be a mixture of isomers in the ratio of 1:3.4 as evidenced by the methine proton absorptions at δ 4.87 and 4.68.

(5) The diazide **1** can be recrystallized from C_2H_5OH–$CHCl_3$ (4:1) below 50°.