Dioxiranes. 20. Preparation and Properties of Some New Dioxiranes[1]

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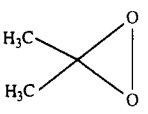
Abstract: The in situ method for producing dioxiranes has been modified to permit the isolation in ketone solution of some nonvolatile dioxiranes. The dioxiranes have been characterized spectroscopically and, in some cases, by chemical reactions.

Introduction

In 1985 we described[2] the isolation in solution of dimethyldioxirane (**1**) as well as some related dioxiranes. Dimethyldioxirane is a powerful oxygen atom donor, and the availability of this unique reagent in solution has permitted the synthesis of materials which were difficult or impossible to obtain with more classical oxygen atom transfer reagents.[3] The dioxirane isolation procedure has also led to physical organic studies of the oxygen atom transfer reaction, including rate studies,[4] linear free energy relationship determinations,[4a,b,5] and kinetic isotope measurements.[4c,6] While these uses of isolated dioxiranes can be expected to continue to be important, the isolation method does have a limitation with respect to some applications. The method involves distillation of the dioxirane from the generation vessel, which has, so far, limited the method to dioxiranes which are reasonably volatile. In addition, this method generally affords dioxirane solutions in the somewhat limiting concentration range of 0.05–0.12 M. A recent report[7] by Curci and co-workers does, however, describe the extension of the isolation method to methyl(trifluoromethyl)dioxirane (**2**), which was obtained in concentrations in the 0.65–0.82 range. A number of dioxiranes



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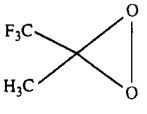

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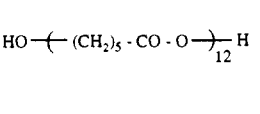

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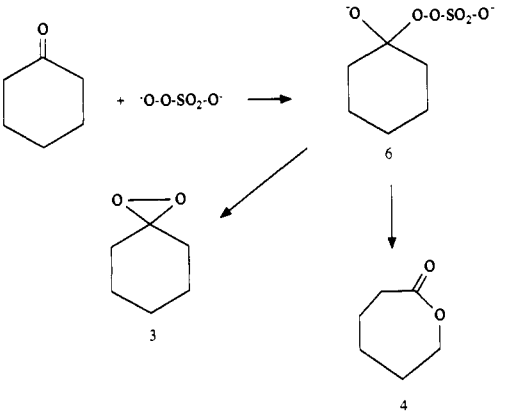
have also been produced[8] during the photolysis of diazo compounds or diazirines in inert matrices at low temperature, but these conditions seem unlikely to be useful in preparative chemistry. In some cases, scaling up the in situ method of Edwards and Curci has proven useful in extending the synthetic usefulness of dioxiranes.

Scheme 1



We have sought a procedure which would give higher concentrations of dioxiranes as well as one that would permit the synthesis of additional members of this interesting class of compounds. We describe here a modification to the prototypal Edwards–Curci[9] conditions that has permitted us to synthesize several new dioxiranes, including some spiro dioxiranes. The dioxiranes are obtained in solutions of their precursor ketones or in solutions containing the ketone and a volatile solvent. In addition, some of these dioxiranes can be obtained in concentrations which are up to 10-fold higher than those obtained in our earlier report. The key part of the modified procedure is the use of heavy salting-out so as to obtain solutions of the dioxiranes in their precursor ketones.

Results and Discussion

The procedure we have used (Scheme I) works best for ketones with low water solubilities. In a typical procedure, the ketone precursor to the dioxirane, a buffer (pH 7.4), and crushed ice are stirred well with a mechanical stirrer. All materials to be used in the preparation, including drying agents when used, are cooled in an ice–salt bath before use. A cold slurry of Oxone in water is added to the reaction vessel while the pH is maintained between 7 and 8.5 by addition of cold 15% KOH. The Oxone slurry is added over a 5–10-min period followed by additional stirring for 1–2 min. At this point, the reaction mixture is an intense yellow-to-gold color, depending on the dioxirane. The reaction mixture is then poured into a cold mixture of sodium sulfate, sodium dihydrogen phosphate, and sodium monohydrogen phosphate (4:1:1, 50–100 g). This mixture is stirred vigorously for a few seconds and then poured into a cold separatory funnel, taking care to minimize the transfer of undissolved salts to the separatory funnel. The yellow organic layer is then separated and dried with cold sodium sulfate. The solution is then decanted and,

(1) Part 19: Murray, R. W.; Singh, M. *Magn. Reson. Chem.* **1991**, *29*, 962.

(2) Murray, R. W.; Jeyaraman, R. *J. Org. Chem.* **1985**, *50*, 2847.

(3) (a) Adam, W.; Chan, Y.-Y.; Cremer, D.; Scheutzow, D.; Schindler, M. *J. Org. Chem.* **1987**, *52*, 2800. (b) Murray, R. W. *Chem. Rev.* **1989**, *89*, 1187. (c) Murray, R. W. In *Molecular Structure and Energetics. Unconventional Chemical Bonding*; Liebman, J. F., Greenberg, A., Eds.; VCH Publishers: New York, 1988; Vol. 6, pp 311–351. (d) Curci, R. In *Advances in Oxygenated Processes*; Baumstark, A. L., Ed.; JAI Press: Greenwich, CT, 1990; Vol. 2, Chapter 1. (e) Adam, W.; Curci, R.; Edwards, J. O. *Acc. Chem. Res.* **1989**, *22*, 205. (f) Adam, W.; Hadjiarapoglou, L. P.; Curci, R.; Mello, R. In *Organic Peroxides*; Ando, W., Ed.; John Wiley Interscience: New York, in press.

(4) (a) Baumstark, A. L.; McCloskey, C. J. *Tetrahedron Lett.* **1987**, *28*, 3311. (b) Murray, R. W.; Shiang, D. L. *J. Chem. Soc., Perkin Trans. 2* **1990**, 746. (c) Mello, R.; Fiorentino, M.; Fusco, C.; Curci, R. *J. Am. Chem. Soc.* **1989**, *111*, 6749. (d) Baumstark, A. L.; Vasquez, P. C. *J. Org. Chem.* **1988**, *53*, 3437.

(5) Murray, R. W.; Jeyaraman, R. J.; Pillay, M. K. *J. Org. Chem.* **1987**, *52*, 746.

(6) (a) Murray, R. W.; Jeyaraman, R. J.; Mohan, L. *J. Am. Chem. Soc.* **1986**, *108*, 2470. (b) Murray, R. W.; Shiang, D. L.; Singh, M. *J. Org. Chem.* **1991**, *56*, 3677.

(7) Mello, R.; Fiorentino, M.; Sciacovelli, O.; Curci, R. *J. Org. Chem.* **1988**, *53*, 3891.

(8) (a) Chapman, O. L.; Hess, T. C. *J. Am. Chem. Soc.* **1984**, *106*, 1842. (b) Bell, G. A.; Dunkin, I. R. *J. Chem. Soc., Chem. Commun.* **1983**, 1213. (c) Dunkin, I. R.; Bell, G. A. *Tetrahedron* **1985**, *41*, 339. (d) Dunkin, I. R.; Shields, C. J. *J. Chem. Soc., Chem. Commun.* **1986**, 154. (e) Werstiuk, N. H.; Casal, H. C.; Scaiano, J. C. *Can. J. Chem.* **1984**, *62*, 2391. (f) Sander, W. W. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 255. (g) Sander, W. *Angew. Chem.* **1986**, *98*, 255. (h) Sander, W. *Spectrochim. Acta* **1987**, *43A*, 637. (i) Sander, W. *Angew. Chem.* **1985**, *97*, 964. (j) Sander, W. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 988. (k) Sander, W. *J. Org. Chem.* **1988**, *53*, 121. (l) Ganzer, G. A.; Sheridan, R. S.; Liu, M. T. H. *J. Am. Chem. Soc.* **1986**, *108*, 1517. (m) Sander, W. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 344.

(9) Edwards, J. O.; Pater, R. H.; Curci, R.; Di Furia, F. *Photochem. Photobiol.* **1979**, *30*, 63.

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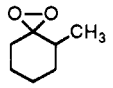
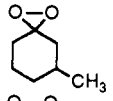
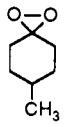
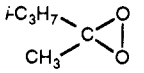
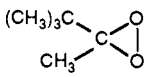
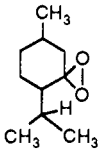
Table I. Physical Properties of New Dioxiranes

dioxirane	color	UV λ_{max} (nm)	temp,[a] (°C)	^{13}C NMR ring carbon[b]	^{13}C NMR other carbons[b]
	dark yellow	345	−17	104.51	33.36, 24.68
	dark yellow	355	−14.5	105.53	35.62, 33.49, 33.36, 13.05
	dark yellow	ca. 337[c]	−11.2	104.28	41.08, 35.23, 31.93, 23.65
	yellow	350	−18.2	104.55	32.83, 32.47, 30.86, 21.46
	dark yellow	347	−17	105.47	33.99, 16.93
	pale yellow	326[d]	−23.5	106.41	26.50
	yellow	354[e]	−10	106.45	*f*

[a] Temperature at which the NMR spectrum was obtained. [b] Absorptions which disappear upon addition of dimethyl sulfide. [c] The exact λ_{max} of 3-methylcyclohexanone dioxirane could not be determined because 3-methylcyclohexanone absorbs strongly in this region. The dioxirane also shows tailing into the visible region (430 nm). [d] A strong absorption tails into the visible to >450 nm. [e] Absorption tails into the visible to >480 nm. [f] Spectrum was too complex to assign absorptions on the basis of dimethyl sulfide reduction.

in most cases, dried with molecular sieves. This solution is then available for carrying out chemical reactions or making spectroscopic measurements. If the solution is not to be used immediately, it is stored in the freezer. The concentrations of dioxiranes obtained in this manner were in the range 0.2–0.8 M.

The spectroscopic properties of the new dioxiranes prepared using this procedure are given in Table I. In all cases, NMR absorptions assigned to the dioxiranes disappear when the solutions are treated with dimethyl sulfide. This test is useful in distinguishing the dioxiranes from the related diperoxides, which are not reduced under these conditions. The ring-carbon ^{13}C absorptions are quite characteristic and are consistent with those reported earlier[3a,7,10] for other dioxiranes.

The dioxirane from cyclohexanone, 1,2-dioxaspiro[2.5]octane (**3**), was used to carry out some typical dioxirane oxidation reactions with the results shown in Table II. This dioxirane had been prepared previously[9,11,12] using the in situ method, but no spectroscopic properties or chemistry have been reported. With few exceptions these reactions proceed in high yield. Since **3** gave early indications that it was more reactive than **1**, we attempted the epoxidation of diethyl maleate, but this material proved to be too unreactive. As seen in the cases of the stilbenes and 4-octenes (Table II), these epoxidations are stereospecific as reported[3] for other dioxiranes.

A comparison of the relative reactivity of the cyclohexanone dioxirane with that of **1** was made in several of the reaction types. These measurements were made by running the reactions under identical conditions and to conversions which permitted reproducible results. The results using *cis*-stilbene as the substrate indicate that **3** is approximately 6 times more reactive than **1** in this epoxidation. In the saturated hydrocarbon insertion reaction using adamantane as the substrate, the cyclohexanone dioxirane was found to react approximately 4 times faster than dimethyldioxirane.

We have also examined the relationship between **3** and the Baeyer–Villiger oxidation product of cyclohexanone, ϵ-caprolactone **4**. The ^{1}H NMR spectrum of a freshly prepared solution of **3** at −18 °C shows the presence of cyclohexanone, the lactone **4**, and the dioxirane **3**. When this solution is allowed to warm to room temperature, the yellow color of the dioxirane begins to disappear immediately. In 5–10 min the solution is colorless. The solution also becomes very warm as the decomposition of the dioxirane is very exothermic. The ^{1}H NMR spectrum of this solution contains absorptions for the lactone, cyclohexanone, and a new triplet at δ 3.80–3.90. Performing the same experiment in deuteriochloroform solution gives the same triplet at δ 4.06 (J = 6.6 Hz). The ^{13}C NMR spectrum also shows the appearance of new absorptions. The absorption due to the lactone did not increase in intensity. Use of a quantitative NMR method showed that at least 90% of the available dioxirane was converted to this new material under these conditions. Isolation of this material, followed by elemental analysis and molecular weight determination, indicated that it was a linear oligomer, **5**, of the lactone, containing 12 units. It has been reported[13] that polymerization of ϵ-caprolactone does not occur spontaneously. However, heating the lactone at 150 °C for 12 h gave the same oligomer found here.

A control experiment confirmed that the lactone is not converted to the oligomer when heated to 50 °C for 15 min. Thus we conclude that the oligomer is formed from the dioxirane, which under these conditions apparently decomposes in a manner that favors oligomer formation rather than lactone formation. Some evidence in support of this hypothesis was obtained by studying the controlled decomposition of the dioxirane. A solution of dioxirane **3** was stored in the freezer in cyclohexanone solution at −25 °C. It should be noted that this sample contained some

(10) (a) Murray, R. W.; Jeyaraman, R.; Pillay, M. K. *J. Org. Chem.* **1987**, *52*, 746. (b) Cassidei, L.; Fiorentino, M.; Mello, R.; Sciacovelli, O.; Curci, R. *J. Org. Chem.* **1987**, *52*, 699.

(11) Camporeale, M.; Fiorani, T.; Troisi, L.; Adam, W.; Curci, R.; Edwards, J. O. *J. Org. Chem.* **1990**, *55*, 93.

(12) Pater, R. H. Ph.D. Thesis, Brown University, Providence, RI, 1977.

(13) Van Natta, F. J.; Hill, J. W.; Carothers, W. H. *J. Am. Chem. Soc.* **1934**, *56*, 455.

Table II. Chemical Reactions of Cyclohexanone Dioxirane[a]

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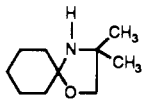
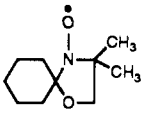
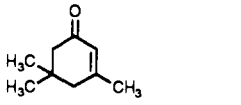
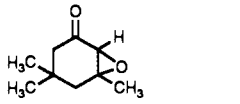
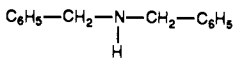
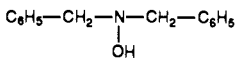
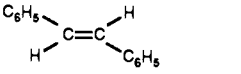
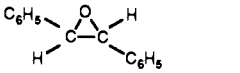
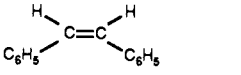
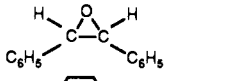
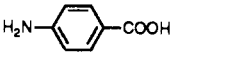
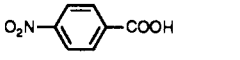
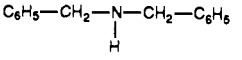
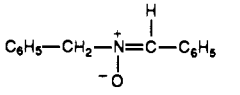
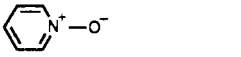
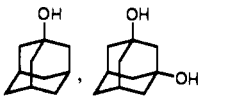
		88[b]
		83[c]
		68[d]
		100
		97
		91
		65
		100
		1-42[e] 1,3-57
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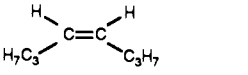
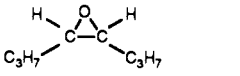
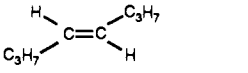
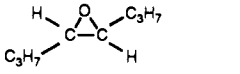
		100
		100

[a] Reaction conditions vary. See the Experimental Section. [b] Conversion after 10 min. [c] Conversion after 6 h. [d] A 24% yield of α-phenyl-*N*-benzylnitrone was also formed. [e] Traces of 1,3,5-trihydroxy- and 1,3,5,7-tetrahydroxyadamantane were also formed.

lactone from the preparation. The solution was sampled and the NMR spectrum of the contents followed with time. These analyses indicated that slow decomposition of the dioxirane was occurring to give the lactone, as evidenced by an increase in the NMR absorption. Under these conditions no oligomer is formed. These experiments indicate that caution must be exercised in experiments designed to determine whether lactone (or ester) formation proceeds through a dioxirane. Thus, the lactone present in the rapid decomposition experiments arises in the preparation, probably from the Criegee intermediate **6** (Scheme I) and not from the dioxirane as seen in the case studied here. These results may also have a bearing on some literature reports on the Baeyer–Villiger reaction of cyclohexanone. When the Baeyer–Villiger reaction of cyclohexanone was studied[11] using bis(trimethylsilyl) peroxymonosulfate and an ^{18}O tracer method, evidence was obtained for a dioxirane precursor to the lactone. On the other hand, Edwards and Pater had earlier concluded,[12] also on the basis of an ^{18}O tracer study, that the dioxirane **3** is not a precursor to the lactone. Instead, they concluded that the lactone is formed exclusively from the Criegee intermediate, **6** (Scheme I). These two studies varied in several ways in the experimental procedure used. The peroxy acids and solvents used were different. The experiments were also conducted under different temperature conditions. The more recent study using the bis(trimethylsilyl) peroxymonosulfate was carried out at −30 °C, while in the earlier study of Edwards and Pater the oxidation reaction proceeded largely at room temperature. While there could be a number of reasons for the different outcomes in these two reports, our results suggest that the temperature difference may be important. Lactone formation at the higher temperature is probably due to the Criegee intermediate pathway as concluded by Edwards and Pater. Under the lower temperature conditions of the recent report, the dioxirane apparently decomposed in a controlled manner to give the lactone.

Lactones or esters were formed in the preparation of the other dioxiranes listed in Table I. We have not carried out the same type of detailed decomposition studies on these dioxiranes as those described for the cyclohexanone dioxirane. Thus, these ester and lactone products could arise from the Criegee intermediate or the dioxirane.

Use of the described salting-out procedure should permit the preparation of many additional dioxiranes. Our goal is to synthesize a stable member of the class. We have begun experiments designed to determine which factors lend stability to the dioxiranes. We also find that the use of a solvent in addition to the parent ketone increases the stability of the dioxirane, as in the case of methylene chloride, for example. Perhaps the most important aspect of this modified procedure is that it permits confirmation of the presence of the dioxirane when the in situ method is the preferred procedure. This is likely to be the case when larger scale reactions are required. One simply has to run a small-scale in situ reaction incorporating the salting-out step. The dioxirane solution so obtained can then be used to confirm the presence of the dioxirane by spectroscopic and chemical methods.

Among the dioxiranes synthesized using this method is that from menthone. It is interesting to note that the first literature reference to a dioxirane structure was made by Baeyer and Villiger[14] in describing a reaction which now bears their names. The authors proposed a dioxirane intermediate in the conversion of menthone to its lactone using peroxymonosulfuric acid. The dioxirane mechanism for the Baeyer–Villiger reaction ultimately lost out to a competing mechanism, largely as a result of an ^{18}O study[15] by Doering and Dorfman. It is somewhat rewarding as the 100th anniversary of the Baeyer–Villiger proposal approaches to report that their proposed structure can be synthesized.

Experimental Section

Materials. Acetone (Fisher reagent grade) was fractionally distilled over potassium carbonate. Cyclohexanone, 2-methylcyclohexanone, 3-methylcyclohexanone, 4-methylcyclohexanone, menthone, 3-methyl-2-butanone, and 3,3-dimethyl-2-butanone, all obtained from Aldrich Chemical Co., were distilled at reduced pressure before use. Adamantane, cyclohexene, *cis*-stilbene, *trans*-stilbene, dimethyl sulfide, phenyl methyl sulfide, *N,N*-dibenzylamine, ethyl *trans*-cinnamate (all obtained from Aldrich), pyridine, 4-aminobenzoic acid (Fisher), *cis*-4-octene (Chem. Samples Co.), and isophorone (Eastman) were of the highest purity and were used as received after verification of their purity by GLC. 3,3-Dimethyl-1-oxa-4-azaspiro[4.5]decane was prepared by the literature procedure.[16a] Anhydrous sodium sulfate, sodium dihydrogen phosphate, sodium monohydrogen phosphate, KOH, and phosphate buffer (pH 7.41) were obtained from Fisher Scientific. Oxone (Du Pont), $2KHSO_5 \cdot KHSO_4 \cdot K_2SO_4$, was obtained from Aldrich and used as received. The dimethyldioxirane solution in acetone was prepared according to the literature procedure[2] and was assayed for dioxirane content using phenyl methyl sulfide and the GLC method.

Instrumentation. ^1H and ^{13}C NMR spectra were obtained on a Varian XL-300 NMR spectrometer with $CDCl_3$ as the solvent unless stated otherwise. All NMR data are reported in ppm or δ values downfield from TMS. Low-temperature ^1H and ^{13}C NMR spectra of the dioxiranes were recorded in the parent ketones. The multiplicities of ^{13}C NMR signals were determined by the attached proton test (APT) or the distortionless enhancement by polarization transfer (DEPT) pulse sequence. Electron impact mass spectra were recorded, at a 70-eV ionizing voltage, on a Hewlett-Packard 5988A twin EI and CI quadrupole mass spectrometer connected to a Hewlett-Packard 5890A gas chromatograph fitted with a Hewlett-Packard 12 m × 0.2 mm × 0.33 m Ultra-1 (cross-linked methyl silicone) column. UV spectra were obtained on a Hitachi U-2000 UV–vis spectrophotometer. Infrared spectra were recorded on a Perkin-Elmer Model 1600 FT-IR spectrophotometer. ESR

(14) Baeyer, A. V.; Villiger, V. *Ber.* **1899**, *32*, 3625.
(15) Doering, W. von E.; Dorfman, E. *J. Am. Chem. Soc.* **1953**, *75*, 5595.
(16) (a) Hancock, E. M.; Cope, A. C. *J. Am. Chem. Soc.* **1944**, *66*, 1738. (b) Van Natta, F. J.; Hill, J. W.; Carothers, W. H. *J. Am. Chem. Soc.* **1934**, *56*, 455.

spectra were recorded at X-band with a Varian E-12 spectrometer equipped with a dual cavity. Melting points were determined either on a Dynamic Optics AHT 713921 hot-stage apparatus or on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Gas chromatography was performed on a Perkin-Elmer Sigma 2000 gas chromatograph using a flame ionization detector, a J and W Scientific fused silica DB-210 capillary column (30 m × 0.318 mm; film thickness 0.5 m), and He as the carrier gas. The chromatograph was interfaced with a Shimadzu Chromatopac C-R3A integrator. Preparative GC was performed on a Varian Aerograph Model 700 gas chromatograph (He carrier gas and TCD) using a 12 ft × $^3/_8$ in. aluminum column packed with 8% SF-96 methyl silicone on Chromosorb G 60/80 mesh. Analytical TLC was accomplished using Merck Kieselgel 60 PF_{254} plastic sheets precoated with a 0.20-mm thickness of silica gel. Preparative TLC was performed on Analtech silica gel GF uniplates (20 × 20 cm, 1000 μm). Flash chromatography was performed on Merck Kieselgel 60 (230–400 mesh ASTM). Chromatographic separations (radial chromatography) on the Chromatotron Model 8924 (Harrison Research) were accomplished using 2-mm Kieselgel 60 PF_{254} gypsum plates. Elemental analyses were performed by Atlantic Microlab, Inc. (Atlanta, GA). The molecular weight determination was performed by Schwarzkopf Microanalytical Laboratory (New York).

Preparation of Dioxiranes. The general procedure described in the text was used with only minor modifications to synthesize the additional dioxiranes.

a. 4-Methyl-1,2-dioxaspiro[2.5]octane (2-Methylcyclohexanone Dioxirane). A mixture of 2-methylcyclohexanone (45 mL), phosphate buffer solution (50 mL), and ice (10–15 g) was stirred at 0 °C (ice–salt bath). Cooled Oxone (90 g) was added as a slurry in 200 mL of water over 5 min. A KOH solution (10–15%), cooled to 0–5 °C, was added simultaneously to maintain the pH at 7–8.5. A yellow color is formed immediately upon combining the reagents. The mixture was stirred vigorously for 2–3 min and then poured into a beaker containing a cooled mixture of anhydrous Na_2SO_4, $NaH_2PO_4{\cdot}H_2O$, $Na_2HPO_4{\cdot}7H_2O$ (4:2:1), and the combined mixture was stirred vigorously in an ice–salt bath. The liquid phase was transferred rapidly to a cooled separatory funnel, and the aqueous phase separated out. The dark yellow organic phase was dried with cold anhydrous Na_2SO_4 and used without further purification for UV and NMR spectral determinations (Table I).

The reaction mixture also contained the Baeyer–Villiger product 7-methyl-2-oxepanone, which was identified by comparing its properties with those of an authentic sample prepared by treating the ketone with MCPBA.

b. 5-Methyl-1,2-dioxaspiro[2.5]octane (3-Methylcyclohexanone Dioxirane). The general procedure was used to give the dioxirane solution with spectral properties as given in Table I. A decomposed solution of the dioxirane indicated by NMR that a lactone was present. The reaction mixture was fractionally distilled. The fraction containing the lactone (160–165 °C, 3 mmHg) was collected and further analyzed by GLC. The GLC analysis indicated that this fraction contained an equal mixture of the two possible lactones, 6-methyl-2-oxepanone and 4-methyl-2-oxepanone. These lactones were identified by comparing their properties with those of authentic samples.

c. 6-Methyl-1,2-dioxaspiro[2.5]octane (4-Methylcyclohexanone Dioxirane). The general procedure was used to prepare the dioxirane whose properties are given in Table I. A decomposed solution of the dioxirane showed the presence of a lactone, which was separated by fractional distillation. The lactone, 5-methyl-2-oxepanone, had spectral properties identical to those of an authentic sample.

d. Isopropylmethyldioxirane. The general procedure was used to prepare the dioxirane. A decomposed sample of the dioxirane solution contained NMR absorptions due to isopropyl acetate. No evidence for the presence of methyl isobutyrate, the other possible Baeyer–Villiger product, was observed.

e. *tert*-Butylmethyldioxirane. The dioxirane was prepared by the general procedure. Its spectral properties are given in Table I. The reaction solution also contained *tert*-butyl acetate, which was identified by a comparison of its properties with those of an authentic sample. No evidence was found for trimethylacetate.

f. Menthone Dioxirane. The dioxirane was prepared by the general procedure. Its spectral properties are given in Table I. The reaction mixture also showed the presence of the lactone, 6-methyl-3-(1-methylethyl)-2-oxepanone, based on GC/MS and NMR data.

Decomposition of Cyclohexanone Dioxirane Solutions. In order to determine the relationship between the dioxirane and the lactone product, the decomposition of the dioxirane was studied under a variety of conditions.

A solution of the dioxirane was prepared in the usual way and dried with anhydrous Na_2SO_4 and 3-Å molecular sieves. A variable-temperature NMR study was made on this solution. The low-temperature (−10 °C) NMR spectrum shows the presence of dioxirane, cyclohexanone, and caprolactone. This same spectrum was observed at −4 °C, −2 °C, and 0 °C. At +2 °C, the spectrum contained additional absorptions, with a triplet in the ^1H spectrum at δ 3.84 (J = 6.4) being the most pronounced. The ^{13}C spectrum indicated that the dioxirane had completely decomposed. When this experiment is repeated outside of the NMR probe, the solution is observed to become very warm as soon as decomposition begins. When the decomposition is allowed to take place at room temperature, then the solution obtained has the same NMR spectrum as that obtained from the +2 °C decomposition.

Next, a series of experiments were carried out which were designed to determine, in a more quantitative way, the relationship between the dioxirane and the material formed on its decomposition. A solution of the cyclohexanone dioxirane was prepared and the dioxirane content assayed in the usual manner using phenyl methyl sulfide. This sample also contained lactone extracted from the preparation solution. An aliquot of this solution was kept at room temperature. The yellow color of the dioxirane began to fade immediately and was completely gone after 15 min. The solution also became very warm. A lock solvent for the NMR determination (benzene-d_6, 1 mL) was then added. A known amount of dioxane was also added as an internal standard for peak integration. A separate aliquot of the stock solution was treated with dimethyl sulfide and then also prepared for NMR integration by adding benzene-d_6 and dioxane. The ^1H NMR spectra of both samples were then determined. The concentration of dioxirane was determined from the dimethyl sulfide treated sample by integrating the dimethyl sulfoxide and dimethyl sulfone peaks. The amount of decomposition product formed was determined by integrating the peak (triplet at δ 4.05) due to a CH_2 group in the decomposition product, which we ultimately showed was an oligomer of the lactone. These experiments demonstrated that approximately 90% of the available dioxirane was converted to the oligomer. The peak due to the lactone did not increase in intensity.

Separate experiments were performed to determine the product of low-temperature decomposition of the dioxirane. A solution of the dioxirane was prepared and dried with Na_2SO_4 and molecular sieves. The solution was then stored in the freezer at −25 °C. Aliquots were removed from this solution over time. NMR spectra of the aliquots were measured at −5 °C. The caprolactone and cyclohexanone distributions in the aliquots were determined from the ratio of the integrated areas of the CH_2 protons (δ 3.90–4.08) of the lactone and the CH_2 protons (δ 1.85–2.30) of cyclohexanone. These experiments were continued over a period of 20 days. The ratio between lactone and cyclohexanone changed over this time in the direction of increased lactone content. When the experiments were terminated after 20 days, a 16.3% change had been measured. These experiments indicate that dioxirane is converted to lactone at low temperature. This process is extremely slow, however. The NMR spectra also indicated that no oligomer of the lactone is formed under these conditions.

Characterization of the Oligomer of Caprolactone. A solution of cyclohexanone dioxirane in cyclohexanone was kept at room temperature for 10 min. The temperature of this solution rose from 22 to 60 °C in a few seconds. The solution was pumped on the vacuum line at room temperature in order to remove cyclohexanone and lactone. After 3 days of pumping, a white waxy solid was obtained. An NMR spectrum of this material showed that it was free of cyclohexanone and lactone. This solid, with mp 45–46 °C, was recrystallized from hot ethanol to give a white solid with mp 52–53 °C. An oligomer of the lactone is reported[16b] to have a mp of 53–55 °C. These same authors report a satisfactory elemental analysis. They found molecular weights from 3660 to 4300. ^1H NMR ($CDCl_3$): δ 1.25–1.50 (m, 2 H), 1.50–1.80 (m, 4 H), 2.31 (app t, J = 7.5 Hz, 2 H), 4.06 (t, J = 6.75 Hz, 2 H). ^{13}C NMR ($CDCl_3$): δ 24.54, 25.49, 28.31, 34.08, 64.13 (CH_2O), 173.54 ($CH_2(C{=}O)O$). A sample of oligomer with mp 63 °C is reported[17] to have the following data. ^1H NMR: δ 1.30–1.90 (m, $(CH_2)_3$), 2.32 (t, $OC(=O)CH_2$), 4.07 (t, $CH_2OC{=}O$). Anal. Calcd for $(C_6H_{10}O_2)_{12}$: C, 63.13; H, 8.83. Found: C, 62.62; H, 8.76. Molecular weight found 1349, calcd for $(C_6H_{10}O_2)_{12}$ 1369.68.

Relative Rate Studies. Reactions of the cyclohexanone dioxirane and dimethyldioxirane with *cis*-stilbene and adamantane were carried out under pseudo-first-order conditions with the dioxirane in excess. To a cold (−20 °C, dry ice–CCl_4 bath), magnetically stirred solution of *cis*-stilbene (0.189 g, 1.04 mmol) in 10 mL of acetone was added a solution of 0.06 M dimethyldioxirane in acetone (55 mL, 3.3 mmol). The progress of the reaction was followed by periodic sampling and GLC analysis. The GLC conditions used were as follows: temp 1, 60 °C, time 1, 5 min; rate 20 °C/min, temp 2, 200 °C; time 2, 5 min; detector 250 °C; injector

(17) Brode, G. L.; Koleske, J. V. In *Polymerization of Heterocyclic Hydrocarbons*; Vogl, O., Furukawa, J., Eds.; Marcel Dekker, New York, 1973; p 117.

250 °C. After 30 min, 14.23% of the stilbene had reacted. Similar conditions were used for the reaction of the cyclohexanone dioxirane with the stilbene except that 0.1805 g (1 mmol) of the stilbene in 10 mL of cyclohexanone was reacted with 8 mL of the dioxirane in cyclohexanone (3.2 mmol, 0.4 M). After 30 min, 86.53% of the *cis*-stilbene had reacted. A similar procedure was used for the reactions with adamantane. To a cold (−20 °C, dry ice–CCl_4 bath), magnetically stirred solution of adamantane (0.138 g, 1.01 mmol) in acetone was added a solution of 0.073 M dimethyldioxirane in acetone (41.5 mL, 3.03 mmol). For the cyclohexanone dioxirane reaction, a similar procedure was followed except that 0.139 g (1.018 mmol) of adamantane and 15 mL of the dioxirane in acetone (0.21 M, 3.15 mmol) were used. The reactions were followed by GLC analysis as before. After 180 min, 2.88% of the adamantane had reacted in the dimethyldioxirane case, whereas at the same reaction time 11.7% of the adamantane had reacted with the cyclohexanone dioxirane.

Oxidation Reactions Using Cyclohexanone Dioxirane. a. 3,3-Dimethyl-1-oxa-4-azaspiro[4.5]decyl-4-oxyl. To a cold (−20 °C, CO_2/CCl_4), magnetically stirred solution of 3,3-dimethyl-1-oxa-4-azaspiro-[4.5]decane (0.146 g, 0.865 mmol) in 1 mL of acetone was added a solution of 0.32 M cyclohexanone dioxirane in cyclohexanone (5.5 mL, 1.73 mmol). The color of the reaction mixture changed from yellow to orange in 5 min. The reaction mixture was stirred for another 5 min and then analyzed by GLC. GLC analysis indicated that 88% of the oxazolidine had been converted to nitroxide. GLC conditions used: column, DB-210; temp 1, 60 °C; time 1, 5 min; rate, 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector temp, 250 °C; detector temp, 200 °C; inlet pressure, 24 psi. Retention times: oxazolidine 8.7 min, nitroxide 11.4 min. Mass spectrum (EI, 70 eV): m/z 185 (M + 1, 0.5), 184 (M^+, 3), 141 (5), 128 (22), 99 (100), 98 (16), 97 (3), 81 (47), 69 (13), 56 (41), 55 (43), 41 (27). Exact mass calcd for $C_{10}H_{18}NO_2$ 184.24. The ESR spectrum of the nitroxide shows three lines (a_N = 14.3 G, g = 2.00577). The mass spectral and ESR data of the product are identical to those reported previously.[18,19]

b. 4,4,6-Trimethyl-7-oxabicyclo[4.1.0]heptan-2-one. To a cold (−10 °C), magnetically stirred solution of isophorone (0.139 g, 1.0 mmol) in 1 mL of CH_2Cl_2 was added a solution of 0.063 M cyclohexanone dioxirane in cyclohexanone–CH_2Cl_2 (1:4) (50 mL, 3.15 mmol). The progress of the reaction was followed by GLC. This analysis indicated an 83% conversion of the isophorone to isophorone oxide in 6 h. The product was isolated as a colorless liquid by preparative GLC. GLC conditions: column, DB-210; temp 1, 60 °C; time 1, 5 min; rate 1, 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector temp, 250 °C; detector temp, 250 °C; inlet pressure, 24 psi. Retention times: isophorone 10.8 min, isophorone oxide 10.5 min. IR (neat, KBr): 2958, 2931, 2871, 1720 (C=O), 1467, 1449, 1398, 1370, 1345, 1309, 1279, 1253, 1068, 1053, 914, 809, 790, 730 cm^{-1}. ^1H NMR ($CDCl_3$): δ 0.91 (s, 3 H, CH_3), 1.02 (s, 3 H, CH_3), 1.42 (s, 3 H, CH_3), 1.65–1.75 (m, 1 H), 1.77–1.86 (m, 1 H), 2.04–2.13 (m, 1 H), 2.58–2.67 (m, 1 H), 3.05 (s, 1 H). ^{13}C NMR ($CDCl_3$): δ 24.04 (4-CH_3), 27.83 (4-CH_3), 30.82 (6-CH_3), 36.16 (C-4), 42.74 (C-5, CH_2), 47.93 (C-3, CH_2), 61.44 (C-1, CH), 64.3 (C-6), 208.02 (C-2, C=O). The mass spectrum was identical to that published[20] for isophorone oxide.

c. *N*,*N*-Dibenzylhydroxylamine. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of dibenzylamine (0.354 g, 1.79 mmol) in 2 mL of cyclohexanone was added a solution of 0.37 M cyclohexanone dioxirane in cyclohexanone (4.9 mL, 1.79 mmol). The yellow color of the dioxirane disappeared immediately. After the reaction mixture was stirred for 5 min, cyclohexanone was removed at reduced pressure and room temperature to afford a pale yellow liquid containing a colorless, crystalline solid (0.846 g). Thin-layer chromatography (acetone–hexane 1:4) of the residue showed the presence of the hydroxylamine as the major product, nitrone as a byproduct, and caprolactone. Purification of the residue on a Chromatotron (2-mm silica gel plate) using acetone (1–5%) in hexane gave the hydroxylamine as colorless needles (0.259 g, 68% yield), mp 123–125 °C (lit.[21] mp 122–123 °C). ^1H NMR ($CDCl_3$): δ 3.78 (s, 4 H, 2 × CH_2), 5.78 (br s, 1 H, NOH, exchangeable with D_2O), 7.2–7.40 (m, 10 H, 2 × C_6H_5). ^{13}C NMR ($CDCl_3$): δ 63.74 (CH_2), 127.4 (C-4), 128.25 (C-3), 129.71 (C-2), 137.17 (C-1).

Further elution with acetone in hexane (10–20%) afforded α-phenyl-*N*-benzylnitrone as a white crystalline solid (0.09 g, 24% yield), mp 82–83 °C (lit.[21] mp 82–83 °C). The ^1H and ^{13}C NMR spectra of this material were identical to those of an authentic sample of the nitrone.

d. *trans*-Stilbene Oxide. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of *trans*-stilbene (0.0957 g, 0.531 mmol) in 2 mL of acetone was added a solution of 0.32 M cyclohexanone dioxirane in cyclohexanone (10 mL, 3.3 mmol). The progress of the reaction was followed by GLC. This analysis indicated complete conversion (>99%) of the stilbene to *trans*-stilbene oxide in 1.5 h. GLC conditions: column, DB-210; temp 1, 100 °C; time 1, 5 min; rate 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector temp, 250 °C; detector temp, 250 °C; inlet pressure, 24 psi. Retention times: *trans*-stilbene, 11.3 min; *trans*-stilbene oxide, 11.8 min. The mass spectral data for the product are identical to those for an authentic sample of *trans*-stilbene oxide.

e. *cis*-Stilbene Oxide. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of *cis*-stilbene (0.183 g, 1.014 mmol) in cyclohexanone (2 mL) was added a solution of 0.13 M cyclohexanone dioxirane in cyclohexanone–CH_2Cl_2 (1:2) (7.6 mL, 1.014 mmol). The progress of the reaction was followed by GLC. This analysis indicated complete conversion of the *cis*-stilbene to *cis*-stilbene oxide in 4.5 h. GLC conditions: column, DB-210; temp 1, 60 °C; time 1, 5 min; rate 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector temp, 250 °C; detector temp, 250 °C; inlet pressure, 24 psi. Retention times: *cis*-stilbene, 11.2 min, *cis*-stilbene oxide, 12.4 min. The reaction mixture was stirred for another 30 min, and cyclohexanone and CH_2Cl_2 were removed under reduced pressure at 40–45 °C (water bath) to give a very pale yellow liquid. Purification of this material, which contains caprolactone and *cis*-stilbene oxide, by flash chromatography on Kieselgel with 2–5% ethyl acetate–hexane afforded *cis*-stilbene oxide as colorless needles (0.193 g, 97% yield), mp 38–40 °C (lit.[22] mp 42 °C). ^1H NMR ($CDCl_3$): δ 4.36 (s, 2 H, oxirane H), 7.17 (s, 10 H, Ar H). ^{13}C NMR ($CDCl_3$): δ 59.67 (oxirane C), 126.79 (C-4), 127.43 (C-3,5), 127.7 (C-2,6), 134.31 (C-1). Mass spectrum (EI, 70 eV): m/z 197 (M + 1, 5.2), 196 (M^+, 37.8), 195 (46), 179 (13.6), 178 (23.7), 168 (21), 167 (100), 152 (22), 105 (37), 90 (75.3), 89 (84.8), 77 (24.8), 63 (18.7). Exact mass calcd for $C_{14}H_{12}O$ 196.24.

f. 4-Nitrobenzoic Acid. To a cold (−10 °C), magnetically stirred solution of 4-aminobenzoic acid (0.1154 g, 0.841 mmol) in 2 mL of acetone was added a solution of 0.088 M cyclohexanone dioxirane in cyclohexanone–methylene chloride (48 mL, 4.21 mmol). The reaction mixture underwent a color change from greenish yellow to yellow over a period of 15 min. The progress of the reaction was followed by TLC. After 20 min, no starting material was evident. The CH_2Cl_2 was removed on the rotary evaporator, and the cyclohexanone was removed under reduced pressure at room temperature. The pale yellow liquid so obtained contained a pale yellow crystalline solid. Purification of this residue, which contained caprolactone and 4-nitrobenzoic acid, by flash chromatography on Kieselgel using 5–30% methanol in CH_2Cl_2 afforded 4-nitrobenzoic acid as a pale yellow solid. Recrystallization from benzene gave a pale yellow crystalline solid (0.128 g, 91% yield), mp 239–242 °C (lit.[23] mp 242 °C). The ^1H NMR and mass spectral data of this product were identical to those of an authentic sample of 4-nitrobenzoic acid. Mass spectrum (EI, 70 eV): m/z 168 (M + 1, 8), 167 (M^+, 100), 150 (4), 137 (19), 121 (56), 109 (19), 81 (11), 75 (26), 65 (97), 50 (26). Exact mass calcd for $C_7H_5NO_4$ 167.12.

g. *N*-(Phenylmethylene)benzenemethanamine *N*-Oxide (α-Phenyl-*N*-benzylnitrone). To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of dibenzylamine (0.198 g, 1.003 mmol) in 2 mL of cyclohexanone was added a solution of 0.37 M cyclohexanone dioxirane in cyclohexanone (5.5 mL, 2 mmol). The yellow color of the dioxirane disappeared quickly. After the reaction mixture was stirred for 5 min, cyclohexanone was removed at reduced pressure and room temperature to give a pale yellow liquid. Purification of the residue by preparative TLC using 30% acetone in hexane gave a white solid. Recrystallization from ethyl acetate–hexane gave 0.138 g (65% yield) of α-phenyl-*N*-benzylnitrone as colorless needles, mp 82–84 °C (lit.[21] mp 82–83 °C). ^1H NMR ($CDCl_3$): δ 5.06 (s, 2 H, $CH_2C_6H_5$), 7.35–7.55 (m, 9 H, aromatic and vinyl H), 8.15–8.3 (m, 2 H, aromatic H). ^{13}C NMR ($CDCl_3$): δ 71.22 (CH_2), 128.41, 128.56, 128.93, 129.18, 130.41, 133.2, 134.17 (C=N). Mass spectrum (EI, 70 eV): m/z 212 (M + 1, 1), 211 (M^+, 4), 195 (7), 194 (9), 92 (14), 91 (100), 65 (11). Exact mass calcd for $C_{14}H_{13}NO$ 211.26.

h. Pyridine *N*-Oxide. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of pyridine (0.187 g, 2.36 mmol) in 2 mL of cyclohexanone was added a solution of 0.37 M cyclohexanone dioxirane in cyclohexanone (6.5 mL, 2.36 mmol). The yellow color of the dioxirane was discharged immediately. The reaction mixture was stirred for 5 min

(18) Chou, S.; Nelson, J. A.; Spencer, T. A. *J. Org. Chem.* **1974**, *39*, 2356.
(19) (a) Keana, J. F. W.; Keana, S. B.; Beetham, D. *J. Am. Chem. Soc.* **1967**, *89*, 3055. (b) Murray, R. W.; Singh, M. *Tetrahedron Lett.* **1988**, *29*, 4677.
(20) *EPA/NIH Mass Spectral Data Base*; Heller, S. R., Milne, G. W. A., Eds.; U. S. Government Printing Office: Washington, DC, 1978; 1, p 513.
(21) De La Mare, H. E.; Coppinger, G. M. *J. Org. Chem.* **1963**, *28*, 1068.
(22) Pollock, J. R. A.; Stevens, R. *Dictionary of Organic Compounds*; Oxford University Press: New York, 1965; Vol. 3, p 1288.
(23) Weast, R. C.; Lide, D. R. *CRC Handbook of Chemistry and Physics*; CRC Press: Boca Raton: FL, 1989; p C-134.

and then analyzed by GLC. This analysis indicated complete conversion of the pyridine to pyridine *N*-oxide. GLC conditions: column, DB-210, temp 1, 60 °C; time 1, 5 min; rate 1, 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector and detector temp, 250 °C; inlet pressure, 24 psi. Retention times: pyridine 2.7 min, pyridine *N*-oxide 12.6 min. Cyclohexanone was removed at room temperature and reduced pressure to give a very pale yellow liquid. Purification of the residue by flash chromatography on Kieselgel using 5–20% methanol in CH_2Cl_2 afforded pyridine *N*-oxide as a white crystalline solid (0.217 g, 97% yield), mp 60–65 °C (sealed tube) (lit.[24] mp 65–66 °C). ^1H NMR ($CDCl_3$): δ 7.27–7.38 (m, 3 H), 8.21–8.29 (m, 2 H). ^{13}C NMR ($CDCl_3$): δ 125.59 (C-4), 126.79 (C-3,5), 138.86 (C-2,6). Mass spectrum (EI, 70 eV): 96 (M + 1, 5), 95 (M^+, 100), 79 (52), 78 (12), 68 (9), 52 (29), 51 (18). Exact mass calcd for C_5H_5NO: 95.09.

i. 1-Adamantanol and Adamantane-1,3-diol. To a cold (−10 °C), magnetically stirred solution of adamantane in 5 mL of cyclohexanone was added a solution of 0.25 M cyclohexanone dioxirane in cyclohexanone (50 mL, 12.5 mmol) and CH_2Cl_2 (25 mL). The progress of the reaction was followed by GLC. This analysis indicated conversion of adamantane to 1-adamantanol (42%) and adamantane-1,3-diol (57%) in 6 h. Traces of 1,3,5-trihydroxyadamantane and 1,3,5,7-tetrahydroxyadamantane were also observed. GLC conditions: column, DB-210; temp 1, 60 °C; time 1, 5 min; rate 1, 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector and detector temp, 250 °C; inlet pressure, 24 psi. Retention times: adamantane, 5.9 min, 1-adamantanol, 10 min, adamantane-1,3-diol, 12.4 min. 1-Adamantanol: The mass spectrum was identical to that of an authentic sample.[25] Adamantane-1,3-diol: The mass spectrum was identical to that of an authentic sample.[25]

j. 7-Oxabicyclo[4.1.0]heptane. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of cyclohexene in 1 mL of cyclohexanone was added a solution of 0.25 M cyclohexanone dioxirane in cyclohexanone (6 mL, 1.5 mmol). The progress of the reaction was followed by GLC. This analysis indicated complete conversion (>99%) of the cyclohexene to cyclohexene oxide in 10 min. GLC conditions: column, DB-210; temp 1, 100 °C; time 1, 5 min; rate 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector and detector temp, 250 °C; inlet pressure, 24 psi. Retention times: cyclohexene, 1.1 min, cyclohexene oxide, 4.9 min. The mass spectral data of the product were identical to those of an authentic sample of cyclohexene oxide.

k. *cis*-4,5-Epoxyoctane. To a cold (−20 °C, CO_2/CCl_4 bath), magnetically stirred solution of *cis*-4-octene (0.842 g, 0.75 mmol) in 1 mL of cyclohexanone was added a solution of 0.25 M cyclohexanone dioxirane in cyclohexanone (6 mL, 1.5 mmol). The progress of the reaction was followed by GLC. This analysis indicated that the *cis*-4-octene had been completely converted to the oxide in 10 min. GLC conditions: column, DB-210; temp 1, 100 °C; time 1, 5 min; rate 1, 20 °C/min; temp 2, 200 °C; time 2, 5 min; injector and detector temp, 250 °C; inlet pressure, 24 psi. Retention times: *cis*-4-octene, 1.4 min, *cis*-4-octene oxide, 6.7 min. The mass spectral data were identical to those of an authentic sample of the oxide.

l. *trans*-4,5-Epoxyoctane. The procedure used for the cis compound was followed. The time required for complete conversion of the *trans*-4-octene to the trans oxide was 1 h. Using the same GLC conditions the retention times were as follows: *trans*-4-octene, 1.3 min, *trans*-4-octene oxide, 6.3 min. Mass spectrum (EI, 70 eV): *m/z* 128 (M^+, 0.1), 113 (2), 110 (1), 99 (14), 85 (6), 81 (9), 72 (62), 57 (100), 56 (22), 55 (63), 43 (38), 41 (35). Exact mass calcd for $C_8H_{16}O$ 128.22.

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(24) *Organic Syntheses*; Rabjohn, N., Ed.; Wiley: New York, 1963; Collect. Vol. IV, p 828.
(25) Mello, R.; Fiorentino, M.; Fusco, C.; Curci, R. *J. Am. Chem. Soc.* **1989**, *111*, 6749.

Complexation of Chiral Glycols, Steroidal Polyols, and Sugars with a Multibenzenoid, Achiral Host As Studied by Induced Circular Dichroism Spectroscopy: Exciton Chirality Induction in Resorcinol–Aldehyde Cyclotetramer and Its Use as a Supramolecular Probe for the Assignments of Stereochemistry of Chiral Guests[1]

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Abstract: Resorcinol–dodecanal cyclotetramer **1** as an achiral host in chloroform forms hydrogen-bonded complexes with a variety of chiral di(poly)ols (**2**–**24**) including steroids and sugars. The complexation processes can be followed very conveniently by the induced circular dichroism (CD) spectroscopy. The binding constants as determined by CD titration increase in the order **15** (steroidal monool, $K = 8.7\ M^{-1}$) < **3**, **6**, and **8** (acyclic glycols, $(4.9–7.1 \times 10) < 9\alpha$, 10α, **12**, and **13** (cyclic glycols and steroidal diols, $(0.94–2.7) \times 10^2$) < **11** (steroidal triol, 6.9×10^2). This order reflects the extents of multiple host–guest hydrogen-bonding interactions. All of the resulting complexes exhibit CD with split Cotton effects as a result of exciton chirality induction in otherwise symmetric **1** upon binding of a chiral guest. The signs of split Cotton effects for complexes derived from glycols are correlated with the chiralities or absolute configurations of the guests, while those for sugar complexes are governed by the ring conformations (*C*1 or 1*C*) of sugar pyranoses. These results suggest that host **1** can be used as a novel, supramolecular probe for the assignments of stereochemistry of chiral guests.

Circular dichroism (CD) is specific to chiral molecules that absorb light. When a chiral molecule has two or more light-absorbing units (chromophores), exciton coupling therein results in split Cotton effects, the signs of which can be correlated with the absolute structure of the molecule. The stereochemistry of

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(1) Molecular Recognition. 18. Part 17: Motomura, T.; Inoue, K.; Kobayashi, K.; Aoyama, Y. *Tetrahedron Lett.* **1991**, *32*, 4757–4760.

0002-7863/92/1514-1351$03.00/0