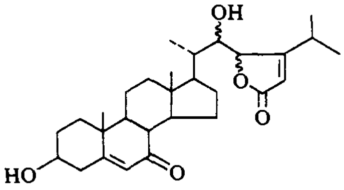
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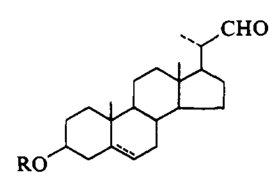
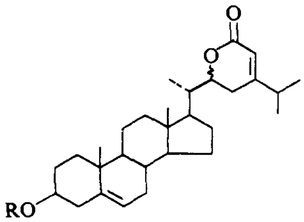
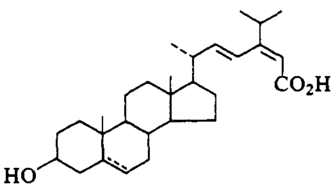
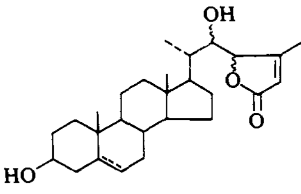
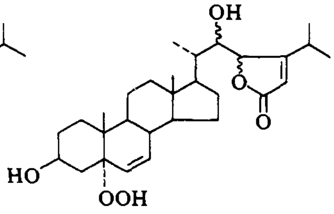

2a, R = tetrahydropyran-2′-yloxy; 5,6-double bond
b, R = H; 5α,6α-oxide


4, R = tetrahydropyran-2′-yl


5a, 5,6-double bond
b, 5α,6α-oxide


6a, 5α,6α-oxide
b, 5,6-double bond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stigmasterol 5α,6α-oxide.[10]

Exposure of dienoic acid **5a** to 2.2 molar equiv of *m*-chloroperbenzoic acid in methylene chloride (72 hr at 20°) afforded a mixture of lactones[11] which was partially resolved by chromatography on silica gel into a pure epoxy-δ-lactone [mp 217–219°; 8%][12] and an epoxy-γ-lactone fraction, A.[13] Purification of the latter mixture by repeated crystallization yielded a homogeneous γ-lactone **6a** (6%) [mp 233–235°; [α]D −68°; λ_{max} 214 mμ (log ε 4.08); $\nu_{max}^{CHCl_3}$ 1740 cm^{-1}; nmr (100 MHz) 0.65 (18-H), 1.00 (d, *J* = 7.0 Hz, 21-H), 1.06 (19-H), 1.16, 1.21 (pair of d, *J* = 7 Hz, isopropyl CH$_3$), 2.91 (d, *J* = 4 Hz, 6β-H), *ca.* 3.5 (m; addition of D$_2$O gives d at 3.55 ppm; *J* = 9 Hz, 22-H), 4.89 (d, *J* = 9 Hz, 23-H), 5.77 ppm (24′-H)].

Regeneration of the 5,6 double bond of the epoxy-γ-lactone **6a** was accomplished by treatment with zinc dust–sodium iodide–acetic acid[14] to yield the corresponding Δ^5-γ-lactone **6b** (78%) [mp 203–204; [α]D −70°; λ_{max} 216 mμ (log ε 4.18); ν_{max} 1740 cm^{-1}; nmr (100 MHz) 0.72 (18-H), 1.02 (19-H), 1.04 (d, *J* = 7 Hz, 21-H), 3.60 (d, *J* = 9 Hz, 22-H), 4.92 (d, *J* = 9 Hz, 23-H), 5.37 (6-H), 5.79 ppm (24′-H)].

Hematoporphyrin-sensitized photooxygenation[15] of the latter product in pyridine solution gave rise to the Δ^6-5α-hydroperoxide **7** which without isolation was subjected to oxidative rearrangement by cupric acetate.[16] Purification of the resulting product by preparative tlc afforded 22,23-isoantheridiol (20%) [mp 273–277°; [α]D −125°; λ_{max} 225 mμ (log ε 4.27); ν_{max} 1740, 1645, 1625 cm^{-1}; nmr (100 MHz) 0.72 (18-H), 1.05 (d, *J* = 7 Hz, 21-H), 1.21 (19-H), 3.64 (broad d, *J* = 8.5 Hz, 22-H), 4.93 (d, *J* = 8.5 Hz, 23-H), 5.70 (6-H), 5.77 ppm (24′-H); *m/e* 470 (M$^+$), 344, 326, 298, 287, 269, 251].

Repetition of the last three stages of the synthesis on once crystallized material obtained from fraction A followed by preparative tlc afforded a mixture of two products. These were separable by fractional crystallization into the previously obtained 22,23-iso compound (5%) and antheridiol (**1**), 2.5% [mp 250–253°; λ_{max} 222 mμ (log ε 4.22); ν_{max} 1740, 1670 cm^{-1}; nmr (CDCl$_3$–MeOD 3:1) 0.70 (18-H), 1.17 and 1.22 (pair of d, *J* = 7 Hz, isopropyl CH$_3$), 1.20 (19-H), 4.95 (d, *J* = 8 Hz, 23-H), 5.69 (6-H), 5.77 ppm (24′-H); *m/e* 470 (M$^+$), 344, 326, 298, 287, 269, 251] whose physical properties were virtually identical with those reported by McMorris, *et al.*, for the natural product.[3] The synthetic material exhibited an activity in the same range as natural antheridiol in eliciting formation of antheridial hyphae on the male plant of *Achlya bisexualis.*[17]

Consideration of the mechanism of the reactions leading to the γ-lactone **6a** from the 22,23-*trans*-dienoic acid **5a** *via* an intermediate 22,23-epoxy acid requires that antheridiol possess the 22*R*,23*S* or 22*S*,23*R* configurations at these centers.

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[10] F. Radt, Ed., "Elsevier's Encyclopedia of Organic Chemistry," Vol. 14S, Elsevier Publishing Co., New York, N. Y., 1956, p 2192S.

[11] The crude product was obtained as follows. The epoxidation mixture was first shaken thoroughly with dilute sodium carbonate solution, the combined alkaline layers were acidified with 5% hydrochloric acid, and the resulting solution was extracted with ethyl acetate. The combined organic extracts were then washed with dilute sodium bicarbonate solution (to remove *m*-chlorobenzoic acid) and water, dried, and evaporated.

[12] The properties of this compound will be discussed in the full paper.

[13] Although this fraction is a mixture of the two 22,23 *erythro* epimers it moved as a single component in several tlc solvent systems.

[14] J. W. Cornforth, R. H. Cornforth, and K. K. Mathew, *J. Chem. Soc.*, 112 (1959).

[15] A. Nickon and J. F. Bagli, *J. Amer. Chem. Soc.*, **83**, 1498 (1961).

[16] G. O. Schenk, O. A. Neumüller, and W. Eisfeld, *Angew. Chem.*, **70**, 595 (1958).

[17] We are indebted to Drs. McMorris and Barksdale of the New York Botanical Garden, Bronx, N. Y., for kindly performing this assay.

[18] Syntex Postdoctoral Fellow: (a) 1967–1968; (b) 1968–1969.

J. A. Edwards, J. S. Mills,[18a] J. Sundeen,[18b] J. H. Fried
Institute of Organic Chemistry, Syntex Research
Palo Alto, California 94304

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Photolysis of *cis,cis*-1,3-Cyclooctadiene

Sir:

Irradiation of *cis,cis*-1,3-cyclooctadiene has been reported to yield bicyclo[4.2.0]oct-7-ene.[1-3]

We wish to report the quantitative reinvestigation of this reaction, the results of which show these earlier observations to be incomplete. Our results indicate the major chemical transformation resulting from unsensitized photolysis[3] of *cis,cis*-1,3-cyclooctadiene (COD, **1**) is geometric isomerization to *cis,trans*-1,3-cyclooctadiene (**2**). Bicyclo[4.2.0]oct-7-ene (**3**) is formed,[4] as well as a small amount of *cis,cis*-1,4-cyclooctadiene (**4**).

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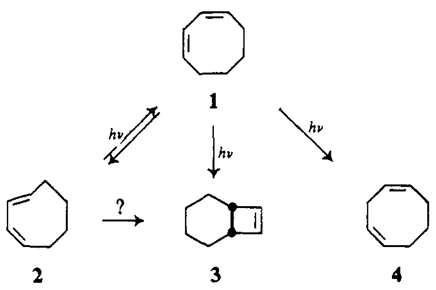
[1] R. Srinivasan, *J. Am. Chem. Soc.*, **84**, 4141 (1962).

[2] R. L. Cargill and W. G. Dauben, *J. Org. Chem.*, **27**, 1910 (1962).

[3] R. S. H. Liu, *J. Am. Chem. Soc.*, **89**, 112 (1967).

[4] Preliminary results indicate a quantum yield of 0.28 for formation of *cis,trans*-COD and 0.01 for formation of **3** after less than 10% conversion of **1**.

Scheme I



The photochemistry of *cis,cis*-1,3-cyclooctadiene can be summarized as shown in Scheme I.[5,6]

cis,cis-COD (purified by gas chromatography) was irradiated at 25° in degassed *n*-hexane with a wavelength of 2480 ± 40 Å.[7] For short reaction times, *cis,trans*-COD and **3** were the major and minor products (Table I).[8,9] No polymerization was observed for those reactions which were stopped after small amounts of isomerization, as determined by the addition of an internal standard after photolysis. Longer runs with higher conversion of *cis,cis*-COD gave only a slight amount of polymer.

Table I. Photolysis of *cis,cis*-1,3-Cyclooctadiene (8.5×10^{-4} *M*)[a] at 2480 ± 40 Å

Time, hr	Bicyclo[4.2.0]-oct-7-ene, mol %	*cis,trans*-1,3-Cyclooctadiene, mol %	*cis,cis*-1,4-Cyclooctadiene, mol %
0.50	0.9	12.1	
1.0	2.0	20.4	
3.0	7.4	31.5	2.4
4.0	12.4	31.1	3.2
9.0	26.3	24.6	5.6

[a] Solvent, *n*-hexane; temperature, 25°.

Analysis was performed on a capillary gas chromatograph with the injection port at room temperature and the column at 60°. This eliminated the possibility of thermal isomerization of *cis,trans*-COD on the column.[10]

cis,trans-COD was prepared independently by the method of Liu[3] and isolated following the procedure described by Cope.[11] The infrared spectrum was identical with that reported for *cis,trans*-COD.[11] Bicyclo-[4.2.0]oct-7-ene was prepared following the procedure of Liu[3] by irradiation of *cis,cis*-COD with acetophenone as a sensitizer, while maintaining the reaction vessel at 80°. The infrared spectrum was identical with that reported by Evans.[12]

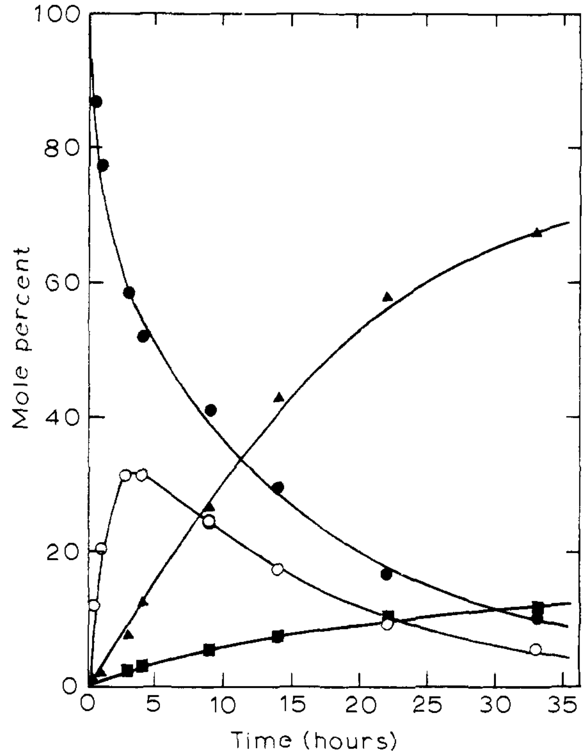


Figure 1. Mole per cent *vs.* time for the photolysis of *cis,cis*-1,3-cyclooctadiene in *n*-hexane (8.5×10^{-4} *M* at 25°): ○, *cis,trans*-1,3-cyclooctadiene; ▲, bicyclo[4.2.0]oct-7-ene; ■, *cis,cis*-1,4-cyclooctadiene; ●, *cis,cis*-1,3-cyclooctadiene.

Bicyclo[4.2.0]oct-7-ene and *cis,trans*-COD, from the photolysis, were identified by gas chromatographic comparison with the independently prepared materials on a 50 ft × 0.02 in. *m*-bis(*m*-phenoxyphenoxy)benzene with Apiezon L and CO-880 additive, and a 150 ft × 0.01 in. Ucon LB-550-X capillary column.

Because the photochemical transformation of *cis,cis*-COD to *cis,trans*-COD in which a sensitizer was not present had not been previously reported, the course of the photolysis of *cis,cis*-COD to essentially complete conversion was followed (Figure 1). This indicated that *cis,trans*-COD reaches a maximum of 31.5% after 41.3% conversion of *cis,cis*-COD. Further irradiation causes the relative amount of the *cis,trans* isomer to diminish until, at 89.8% conversion of *cis,cis*-COD, the system contains 67.4% bicyclo[4.2.0]oct-7-ene, 11.3% *cis,cis*-1,4-COD, and only 5.8% *cis,trans*-COD.[13]

It has been observed that *cis,trans*-COD rapidly isomerizes to bicyclo[4.2.0]oct-7-ene at 80°.[10] To ascertain whether the bicyclic was a photochemical product or a thermal product of *cis,trans*-COD, the extent of its thermal formation at 25° from **2** was determined. An 8.5×10^{-4} *M* solution of *cis,trans*-COD heated at 25° for 9 hr gave less than 1% conversion to bicyclo[4.2.0]oct-7-ene, indicating that thermal formation of bicyclo[4.2.0]oct-7-

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(5) Bicyclo[4.2.0]oct-7-ene might result from an excited ground state of *cis, trans*-COD.

(6) Although bicyclo[4.2.0]oct-7-ene is inefficienly formed, its presence indicates that singlet excitation of *cis,cis*-COD can result in ring closure, whereas triplet excitation yields only geometric isomerization to *cis,trans*-COD.

(7) An Osram HBO 500-W high-pressure mercury lamp and a Bausch and Lomb grating monochromator with a dispersion of 16 Å/mm, set at a 4-mm slit width, were used to obtain the 2480-Å radiation.

(8) The photolysis was repeated using ether as the solvent, and a reaction was also run in which the solution was degassed on a mercury-free vacuum line, to exclude the possibility of mercury sensitization. The results in both cases were unchanged from those reported in Table I.

(9) R. S. H. Liu, private communication. Professor Liu has informed us that he has reinvestigated this system and has obtained results similar to ours.

(10) K. M. Shumate, P. N. Neuman, and G. J. Fonken, *J. Am. Chem. Soc.*, **87**, 3996 (1965).

(11) A. C. Cope and C. L. Bumgardner, *ibid.*, **78**, 2812 (1956).

(12) M. V. Evans and R. C. Lord, *ibid.*, **83**, 3409 (1961).

(13) Preliminary results indicate a quantum yield of 0.80 for conversion of *cis,trans*-COD to *cis,cis*-COD, for conversion of less than 5% **1**.

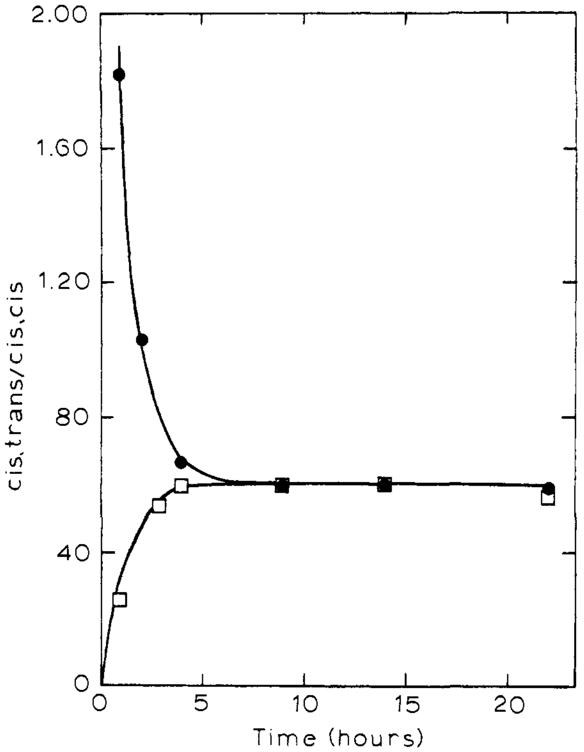

Figure 2. Photostationary-state composition of 1,3-cyclooctadiene *vs.* time: ●, *cis,trans/cis,cis* starting with *cis,trans*-COD; ☐, *cis,trans/cis,cis* starting with *cis,cis*-COD.

ene from **2** at 25° is minimal. The photolysis was also carried out in a water-cooled cell at 10°. These conditions did not reduce the yield of bicyclo[4.2.0]oct-7-ene. These data indicate that bicyclo[4.2.0]oct-7-ene is a product of photolysis, and not the result of thermal isomerization of *cis,trans*-COD.

The 1,4 isomer from the photolysis solution, presumably resulting from a sigmatropic 1,3-hydrogen shift of the suprafacial type,[14] was identified by gas chromatographic comparison with the authentic material. This was prepared by the reaction of lithium aluminum hydride with 1-bromo-2,4-cyclooctadiene.[15]

The nmr spectrum consisted of a multiplet from δ 6.1 to 5.0 (4 H) for the vinylic hydrogens, a multiplet between δ 2.9 and 2.5 (2 H) for the allylic hydrogens at the 3 position, a multiplet from δ 2.5 to 1.9 (4 H) for the allylic hydrogens at the 6 and 8 positions, and a multiplet from δ 1.7 to 1.1 (2 H) for the methylene hydrogens at the 7 position.

Three other components were also present in the mixture in a total yield of 7.3%. One of these, produced in 5.3% yield, showed a retention time near that of *cis*-bicyclo[4.2.0]oct-7-ene, and could be bicyclo[3.3.0]oct-2-ene.[16] The other products were each present in approximately 1% yield.

Prolonged irradiation of *cis,cis*-COD results in a photostationary state between *cis,trans*-COD and *cis,cis*-COD with a *cis,trans/cis,cis* ratio of 0.60. This was verified by irradiating *cis,trans*-COD and observing the formation of the photostationary state between **2** and **1** from the opposite direction. Figure 2 shows the formation of the photostationary state starting from *cis,cis*-COD and also from *cis,trans*-COD.

These data clearly point to a photostationary state between *cis,trans*-COD and *cis,cis*-COD.

Photochemical conversion of *cis,trans*-COD to bicyclo[4.2.0]oct-7-ene is excluded, as this would produce *trans*-bicyclo[4.2.0]oct-7-ene by a disrotatory[17] process, and only *cis*-bicyclo[4.2.0]oct-7-ene was observed.

There is no evidence to indicate that bicyclo[4.2.0.]oct-7-ene is formed by thermal isomerization of *cis,trans*-COD under the experimental conditions employed in this work. This, however, does not exclude the possibility that **3** could form from **2** if the *cis,trans* isomer were formed in the excited ground state from *cis,cis*-COD and isomerization to **3** occurred before vibrational relaxation were complete. Since the reaction was run in the liquid phase, this would be somewhat unique. This possibility of bicyclo[4.2.0]-oct-7-ene being formed from the excited ground state, through a thermal conrotatory process and not directly from *cis,cis*-COD, is presently being investigated by studying the gas-phase photolysis of this system at various wavelengths.

Acknowledgment. The authors are grateful to the Robert A. Welch Foundation for support of this work through a grant to Professor W. Albert Noyes, Jr., for study of "Intersystem Crossover and Internal Conversion: Isomer Formation." We also wish to thank Professor W. Albert Noyes, Jr., for his help and advice during this work.

William J. Nebe, Gerhard J. Fonken
Department of Chemistry
The University of Texas at Austin, Austin, Texas 78712

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[14] R. B. Woodward and R. Hoffmann, *J. Am. Chem. Soc.*, **87**, 2511 (1965).

[15] D. S. Glass, R. S. Boikess, and S. Winstein, *Tetrahedron Lett.*, 999 (1966).

[16] K. M. Shumate and G. J. Fonken, *J. Am. Chem. Soc.*, **88**, 1073 (1966).

[17] R. B. Woodward and R. Hoffmann, *ibid.*, **87**, 395 (1965).

Fluorine Chemical Shifts of Substituted Aliphatic Monofluorides. Effect of Solvent

Sir:

We have found long-range ^{19}F chemical shifts in fluoroalkanes substituted by electronegative groups in a position remote from the fluorine. Shielding effects as large as 3 ppm over six carbon atoms are observed when trifluoroacetic acid is used as solvent (see Table I). These long-range shifts should be compared with the enhanced long-range inductive effects found in solvolyses of fluoro-substituted tosylates[1] and are not observed in the nonpolar solvent trichlorofluoromethane.

Fluorine-19 chemical shift measurements in aryl fluorides are valuable as a technique for studying a wide variety of substituent effects and intra- and intermolecular processes.[2,3] However, the relative importance of the

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[1] P. E. Peterson, R. J. Bopp, D. M. Chevli, E. L. Curran, D. E. Dillard, and R. J. Kamat, *J. Am. Chem. Soc.*, **89**, 5902 (1967).

[2] For a recent review see J. W. Emsley, J. Feeney, and L. H. Sutcliffe, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Pergamon Press, New York, N. Y., 1966, Chapter 11.

[3] (a) R. W. Taft, E. Price, I. R. Fox, I. C. Lewis, K. K. Anderson, and G. T. Davis, *J. Am. Chem. Soc.*, **85**, 709, 3146 (1963); (b) W. A. Sheppard and R. M. Henderson, *id.*, **89**, 4446 (1967), and references contained therein.