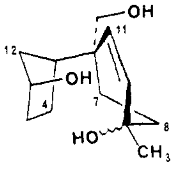

17

hexene conformation under consideration.[12] These interactions, which are absent in the cyclization **14** → **3**, are presumably responsible for the failure of the reaction **17** → **15**. Since Masuoka and Kamikawa have previously employed a biomimetic cyclization analogous to **14** → **3** in a total synthesis of (±)-vominotoxin,[4f,5] the stereochemical assignments for **3** are therefore well-founded.

This sequence is also useful for the synthesis of C15-deoxy derivatives. Thus, tosylation of **3** (*p*-TsCl, pyridine) followed by reduction with lithium triethylborohydride[13] gave **4**[14] in 41% overall yield.

This study demonstrates that the trichothecene ring system can be prepared with exceptional stereochemical control by a route involving annelation of the A ring onto a preformed bicyclic precursor. Application of this strategy to a total synthesis of verrucarol is in progress.

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(12) The cyclization of **17** to the trans-fused isomer of **15** is precluded on steric grounds, since the hydroxyl group of **17** cannot easily interact with the p lobe cis to the adjacent hydroxymethyl group.

(13) Krishnamurthy, S. *J. Organomet. Chem.* **1978**, *156*, 171.

(14) Spectral data for **4**: ^1H NMR (250 MHz, $CDCl_3$) δ 5.33 (br d, $J = 4.8$ Hz, H_{10}), 4.27 (br s, H_2), 3.51 (d, $J = 4.8$ Hz, H_{11}), 1.67 (3 H, s, allylic CH_3), 0.74 (s, 3 H, CH_3); IR (neat) 1675 cm^{-1}; high-resolution mass spectrum, calcd for $C_{13}H_2O$ 192.15141, found 192.15029.

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Stereochemistry of Photochemical Cycloaddition: 4-*tert*-Butylcyclohex-2-enone and Ethylene[1]

Summary: The photochemical cycloaddition of ethylene and 4-*tert*-butylcyclohex-2-enone is inconsistent with a model that implies overlap of orbitals at the α and β carbons of the enones.

Sir: The effective application of the photochemical cycloaddition reaction to the syntheses of complex molecules is limited by lack of knowledge of the reaction mechanism. Although some aspects of the mechanism are generally agreed upon, e.g., the intermediacy of an exiplex[2] and a reversibly formed biradical,[3] other features remain in dispute. Are trans-fused adducts (e.g., from cyclohexenone and olefins) formed via the same path as cis-fused adducts? Does cyclobutane formation always start with bonding of the olefin to the β carbon of the enone? To which face of an enone does cycloaddition occur if there is a preference? Wiesner has proposed two models by which this last question may be answered.[4] In the first (A), similar to that proposed by Stork for metal-amine reductions of enones,[5] the excited cyclohexenone adopts a half-chair conformation with a pyramidal β carbon capable of assuming the more stable configuration. Orbital overlap in the reactive excited enone is an important feature of model A; however, the required axial orientation of the orbital at C-β may be the result of a conformational preference of substituents at C-β.[6] The second model (B) assumes a planar excited state[8] in which "the β-carbon is pyramidalized in the process of reacting with the olefin".[5] Now the more stable biradical (new bond at C-β) leads to product. We report here the photoaddition of ethylene and 4-*tert*-butylcyclohex-2-enone (**1**)[9] and its bearing on the validity of Wiesner's models.

Irradiation of **1** in methylene chloride saturated with ethylene at −78 °C through Pyrex with a 1000-W mercury lamp[10] gave three isomeric cycloadducts, I, II, and III, in a ratio of 61:15:24, respectively. The product composition was monitored throughout the irradiation and after workup, including short-path distillation, by capillary GC and by ^{13}C NMR spectroscopy and was constant throughout; thus the observed ratios represent the relative rates at which the cycloadducts were formed. Treatment of the crude mixture of cycloadducts, in the presence of eicosane as a standard for quantitative GC, with potassium hydroxide or triethylamine gave a new mixture containing only I and II (82:18, respectively) without loss of material. Thus, III undergoes isomerization to I and must be a trans-fused C-2 epimer of the cis-fused I; II is the other cis-fused cycloadduct. Reirradiation of the equilibrated mixture (with internal standard) produced no change. Reduction of the equilibrated mixture of adducts with lithium trisiamylborohydride[11] gave two alcohols (82:18) in 83% yield. The major alcohol was isolated by preparative gas chromatography and converted into its *p*-bromobenzoate. Single crystal X-ray diffraction analysis established structure **5** for the ester and thereby the anti stereochemistry **2** for the major cycloadduct I. Structures **3** and **4** follow for cycloadducts II and III.

In a related study, Wiesner has found that cycloaddition of allene and 4-isopropylcyclohexenone gave equal amounts of the syn and anti (cis-fused) cycloadducts.[12] Our results coupled with those of Wiesner clearly rule out model A, which would require **3** to be the major (or sole) cycloadduct; on the other hand, they are consistent with, but do not prove, model B (the less well-known of Wiesner's proposals). On the other hand, since cleavage of the bi-

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(1) Grateful acknowledgement is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for the support of this research.

(2) R. A. Caldwell, D. Creed, *Acc. Chem. Res.*, **13**, 45 (1980).

(3) R. O. Loutfy and P. deMayo, *J. Am. Chem. Soc.*, **99**, 3559 (1977). See also P. B. Dervan and T. Uyehara, *ibid.*, **98**, 1262, 2003 (1976).

(4) K. Wiesner, *Tetrahedron*, **31**, 1655 (1975).

(5) G. Stork and S. D. Darling, *J. Am. Chem. Soc.*, **82**, 1512 (1960). See also D. F. Caine, *Org. React.*, **23**, 1 (1976).

(6) In all cases cited in support for this model, there is a bulky substituent at C-β.[5-7]

(7) (a) F. E. Ziegler, G. R. Ried, W. L. Stodt, and P. A. Wender, *J. Org. Chem.*, **42**, 1991 (1977); (b) R. L. Cargill, T. A. Bryson, L. M. Krueger, J. V. Kempf, T. C. McKinzie, and J. Bordner, *ibid.*, **41**, 4096 (1976).

(8) C. R. Jones and D. R. Kearns, *J. Am. Chem. Soc.*, **99**, 344 (1977).

(9) K. B. Sharpless, R. F. Lauer, and A. Y. Teranishi, *J. Am. Chem. Soc.*, **95**, 6137 (1973).

(10) The apparatus, which is useful for large-scale irradiations is described in a procedure submitted to *Organic Syntheses*.

(11) S. Krishnamurthy and H. C. Brown, *J. Am. Chem. Soc.*, **99**, 344 (1977).

(12) We thank Professor Wiesner for many useful discussions, for informing us of his recent unpublished work, and for permission to quote these results here.

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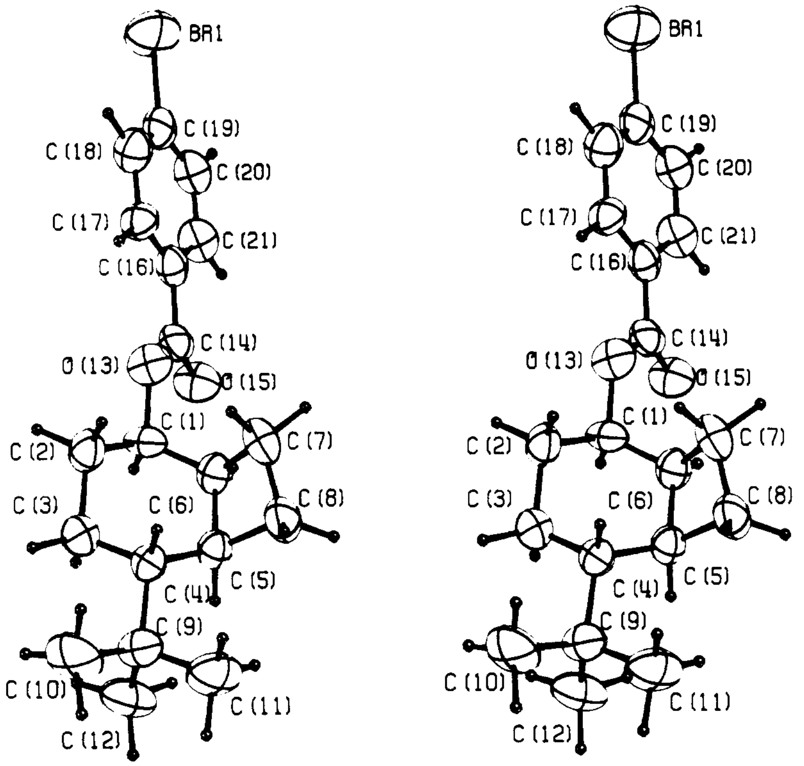
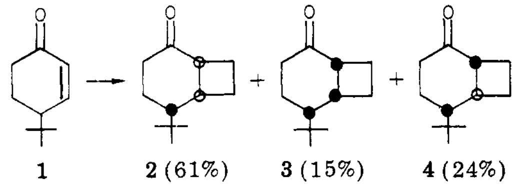
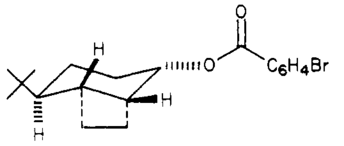


Figure 1. Stereoview of 5.



1 2 (61%) 3 (15%) 4 (24%)



5

radical intermediate(s) seems to be as much as 15 times more rapid than closure,[3] the validity of any model that ignores the complex set of rate constants involved in photochemical cycloadditions is suspect.

X-ray Analysis. The structure of compound **5** was unambiguously established by a routine single-crystal X-ray analysis. Crystals of this compound belonged to the monoclinic space group $P2_1/c$ with a = 13.590 (3), b = 20.706 (3), c = 6.670 (1) Å, β = 106.50 (1)°. The density was measured by flotation in aqueous KI as 1.36 g/cm^3. On the basis of four molecules per unit cell, the calculated density was 1.348 g/cm^3. A 1-Å data set (maximum sin θ/λ = 0.5) was collected on a Syntex P$\bar{1}$ diffractometer using copper radiation (λ = 1.5418 Å). The diffractometer was equipped with an incident-beam graphite monochromator. All diffraction data were collected at room temperature.

All crystallographic calculations were facilitated by the CRYM crystallographic computer system.[13] A trial structure was obtained by using conventional Patterson and Fourier techniques. This trial structure routinely refined to a final R index ($R = \sum||F_o| - |F_c||/\sum|F_o|$) of 0.078. The final cycles of full-matrix least-squares refinement contained the nonhydrogen coordinates in one matrix and the nonhydrogen anisotropic temperature factors, scale factor, and secondary extinction coefficient in a second matrix. The shifts calculated in the final cycle of refinement were in every case less than one-tenth the corresponding standard deviation. Hydrogen positions were calculated where possible. Methyl hydrogens were located by difference Fourier techniques. While the hydrogen parameters were added to the structure factor calculations during the later stages of refinement, they were not refined. A final difference Fourier revealed no missing or misplaced electron density. A stereoview of the molecule is given in Figure 1. Other pertinent crystallographic data are included as supplementary material.

Supplementary Material Available: Crystallographic data including coordinates and anisotropic temperature factors for nonhydrogen atoms, hydrogen coordinates, distances, and angles (2 pages). Ordering information is given on any current masthead page.

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Reaction Modes of Fluorination of Cyclic Ethers by Potassium Fluoride-18-Crown-6

Summary: The reaction scheme of the chlorine substitution of epichlorohydrin or 3,3-bis(chloromethyl)oxetane by

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[13] D. J. Duchamp, American Crystallographic Association Meeting, Bozeman, MT, 1964, paper B-14, p 29.

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