mass spectrum, obsd m/e (composition, calcd millimass) 332.19489 ($C_{20}H_{28}O_4$, 332.19876), 314.18755 ($C_{20}H_{26}O_3$, 314.18820), 304.20156 ($C_{19}H_{28}O_3$, 304.20385), 288.20633 ($C_{19}H_{28}O_2$, 288.20893), 286.19460 ($C_{19}H_{26}O_2$, 286.19328), 258.19644 ($C_{18}H_{26}O$, 258.19837), 229.19613 ($C_{17}H_{25}$, 229.12286), 124.12273 (C_9H_{16}, 124.12520), 109.10213 (C_8H_{13}, 109.10173).

For 4: mp 199–204 °C; $[\alpha]$ −21.7° (MeOH); IR (neat) 3108–3615 (br d), 1755 (vs), 1459, 1252, 1123, 1063, 1039, 970 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) see Table I, also complex absorption from δ 0.8–1.0, 1.10–1.80); 70 eV low-resolution EI mass spectrum, m/z (relative intensity) 332 (2.4), 288 (2.9), 286 (3.0), 260 (3.8), 258 (3.8), 231 (21.7), 230 (100), 215 (9.7), 181 (23), 124 (66.2), 123 (38.9), 109 (94.7).

X-ray Analysis of 2. Crystal data: $C_{24}H_{36}O_6$, $M_r = 420.6$, tetragonal, $P4_1$; $a = b = 10.782$ (6) Å, $c = 18.531$ (13) Å, $v = 2154.3$ Å^3 at 138 K, $Z = 4$, $D_x = 1.296$ gm cm^{-3}, $F000) = 912$, μ(Mo Kα) = 0.5 cm^{-1}. The intensities of all 2302 unique reflections with $2\theta \leq 53°$ were collected at 138 ± 2 K using graphite-monochromated Mo Kα radiation on an Enraf-Monius CAD-4 diffractometer using techniques described before;[11] 2152 reflections were considered observed on the basis, $I \geq 2\sigma(I)$. The structure was solved by direct methods using the program MULTAN[12] and refined using anisotropic temperature factors with full-matrix least-squares methods.[13] Hydrogen atoms located from a difference Fourier map were refined isotropically. Refinement converted to a final $R = 0.032$, $R_w = 0.036$, $s = [\sum w\Delta F^2/(m-n)]^{1/2} = 1.4$, Δ/σ (average) = 0.1. The final atomic parameters are listed in Table II.

Acknowledgment. This investigation was supported by Grants CA-17256 and CA-17562 awarded by the National Cancer Institute, DHEW. Low-resolution FAB and high-resolution EI mass spectra were kindly provided by Dr. C. Costello at the mass spectrometry facility at the Massachusetts Institute of Technology, supported by a grant (principal investigator, Professor K. Biemann) from the Biotechnology Research Branch, Division of Research Resources. We thank the NSF, Grant CHE-8113507, for assistance in the purchase of a high-field NMR spectrometer. We thank Dr. K. Reutzler, Smithsonian Institution, for sponge identification and Ms. L. Craft for assistance in specimen collection.

Registry No. 2, 97042-20-1; 3, 96999-35-8; 4, 96999-36-9.

Supplementary Material Available: Bond distances, bond angles, and anisotropic thermal parameters for non-hydrogen atoms and hydrogen atom parameters (4 pages). Ordering information is given on any current masthead page.

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(13) Sheldrick, G. M. "SHELX76". Program for Crystal Structure Determination, University of Cambridge, England.

Stereochemistry of the Photoinduced Addition of Nucleophiles to the Enone of Decompostin[†]

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Irradiation of decompostin (1) in methanol gave 6-*epi*-methoxydesacetyldecompostin (**2b**). Irradiation of a benzene solution of decompostin in the presence of a nucleophile [ROH; R = H, Me, or $CH(CH_3)_2$] gave the products **3a–c** in a regio- and stereospecific manner. The structure and stereochemistry of **3b** were proven by X-ray diffraction analysis of a single crystal.

The photochemical addition of alcohols to cycloalkenes has been studied extensively.[1] A highly strained "twisted" double bond has been postulated as the intermediate responsible for the products observed.[2] Spectroscopic evidence for the formation of a "twisted" double bond on laser photolysis of 1-phenylcyclohexene has been described by Salem et al.[3] The photoadditions of alcohols and other nucleophiles to cyclohexenone, cycloheptenones, and cyclooctenones have been also investigated and found to proceed in a regio- and stereospecific manner.[4] In all the examples described in the literature, the double bond is located in the same ring as the ketonic group.[2-4]

Decompostin is a natural product isolated from *Cacalia decomposita* A. Gray. Its structure[5] and absolute configuration[6] were shown to be 1. The ketone group at C-9 is cross-conjugated with the furan group and the 1,10 double bond. We decided to study the photoaddition of alcohols and other nucleophiles to the 1,10 double bond of decompostin.

Results and Discussion

Irradiation of 1 in methanol gave as the main isolated product the 6-*epi*-methoxy derivative **2a**, obtained previously[6] by saponification of decompostin in methanolic solution. Formation of **2a** could be explained by the loss of the acetate in a vinylogous β-cleavage photoreaction and

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[†] Contribution No. 721 of the Instituto de Química, UNAM.

(1) Kropp, P. J. "Organic Photochemistry", Padwa, A., Ed.; Marcel Dekker Inc.: New York, 1979; Vol. 4, Chapter 1, p 1.

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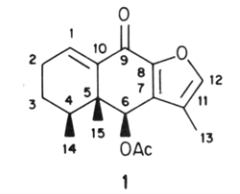
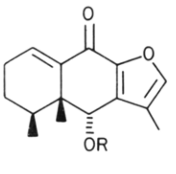
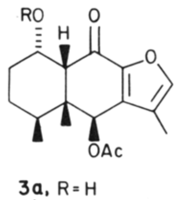


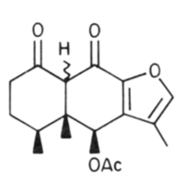
1



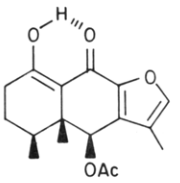
2a, R=Me
2b, R=Ac



3a, R=H
3b, R=Me
3c, R=CH(CH$_3$)$_2$
3d, R=Ac



4



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stereospecific trapping of the resulting zwitterion[7] or by a nucleophilic attack of methanol at C-6 and elimination of the acetoxy group with inversion of the configuration at this chiral center, a mechanism postulated earlier[6] for the epimerization observed for C-6 under saponification conditions.

Irradiation of a benzene solution of decompostin in the presence of methanol gave the expected methyl ether derivative **3b**. The configuration of the newly formed chiral centers C-1 and C-10 could not be deduced by the ^{1}H NMR data exhibited by **3b** (see Table I). A doublet at δ 2.49 (1 H, J = 3.34 Hz) could be assigned to H-10 by double-resonance experiments. Its coupling constant suggested an equatorial–axial interaction with H-1, which was observed as a ddd at δ 3.67 (1 H, J = 3.34, 2.67, and 2.45 Hz) due to additional equatorial–equatorial and equatorial–axial interactions with H-2 and H-2′. These interactions can only be explained if the A ring of **3b** is in a "steroid chair" conformation with the substituent at C-1 axial and trans to axial H-10. This stereochemistry and conformation are present in the molecule **3b** with cis or trans A/B rings fusion as observed in Dreiding models. The strong downfield shift found for H-6 (δ 6.94) did not help to establish the correct stereochemistry of **3b**.[6-8] This was solved by X-ray diffraction analysis of a single crystal of **3b**.

Figure 1 shows the molecular structure with the numbering scheme. The cyclohexane ring adopts a chair conformation with the C-1 methoxy and C-14 methyl groups occupying axial sites and the C-15 methyl group in an equatorial site. The cyclohexane ring is trans-fused to cyclohexenone ring which exhibits a puckered-sofa conformation. The five-membered ring and the acetoxy group are planar within the limit of experimental error. The five numbered ring atoms C-6 to C-9 with O-2, O-4, and C-13 form a planar system. The methyl at C-5 and the acetoxy groups are oriented so as to minimize gauche interactions between these two substituents. The molecules are packed in the crystal structure by normal van der Waals interactions.

The X-ray crystallographic analysis of **3b** confirmed the trans relationship of the β-axial proton at C-10 and the α-axial methoxy group at C-1. This stereochemistry can be explained by an initial isomerization to the *trans*-alkenone followed by syn addition of methanol to the highly strained 1,10 double bond.[2-4]

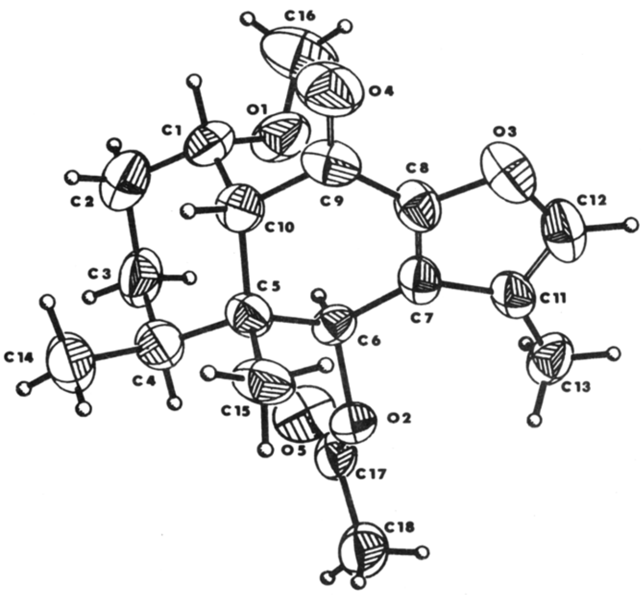

Figure 1. The molecular conformation of 1-methoxydecompostin showing atom numbering. The thermal ellipsoids are drawn at 50% probability level.

Irradiation of a benzene solution of decompostin in the presence of isopropyl alcohol gave the expected isopropyl ether **3c** as the sole product. The coupling constant found for H-1/H-10 interactions and for H-1/H-2α and H-1/H-2β (see Table I) indicate that **3c** has the same conformation and stereochemistry as **3b**, therefore a syn photoaddition to the strained trans 1,10 double bond had occurred in a regio- and stereospecific manner.

Irradiation of a benzene solution of **1** in the presence of water resulted in regio- and stereospecific addition of water to the 1,10 double bond. The product obtained, **3a**, showed H-1 as a multiplet at δ 3.9 and H-10 as a broad doublet (J = 3 Hz) at δ 3.10 (see Table I). It is interesting to note that H-6 was shifted upfield and appeared as a broad singlet (1 H) at δ 6.00.

Oxidation of **3a** gave the 1,3-diketo derivative **4**. H-10 of this product was observed at δ 3.55. Repeated chromatography on silica gel transformed the 1,3-diketo derivative **4** into a keto enol which can be represented by **5**. Its ^{1}H NMR spectrum did not show the signal ascribed to H-10; instead, an enolic proton was observed at δ 10.6 (exchangeable with D$_2$O). In the IR spectrum, **5** showed a very weak ketonic band at 1677 cm^{-1} and a strong absorption at 1604 cm^{-1} ascribed to the enolic double bond.

Attempts to form **3d** by photoaddition of acetic acid to the 1,10 double bond of decompostin were unsuccessful; the only product obtained and characterized under different experimental conditions was **3a**. Photochemical addition of acetic acid to 2,3-benzo-2,6-cycloheptadienone has been shown to proceed very slowly[9] and with poor yield. Formation of **3a** could be explained by a much faster competing addition of the water present in the reaction medium to the 1,10 double bond.

Photolysis of 6-*epi*-decompostin, **2b**, under the same conditions described for **1** did not produce any photoproduct, starting material being recovered quantitatively. A reasonable explanation for the photochemical inertness

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[7] This mechanism was suggested by one of the referees, to whom we express our gratitude; see: Turro, N. J. "Modern Molecular Photochemistry", The Benjamin/Cummings Pub. Co.: Menlo Park, CA, 1978; pp 559–60.

[8] Bohlmann, F.; Ehlers, D.; Zdero, Ch. *Phytochemistry* **1978**, *17*, 467, 1135 and references there cited.

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[11] "International Tables for X-ray Crystallography", Kynoch Press: Birmingham, 1974; Vol. IV.

Table I. ^{1}H NMR Chemical Shifts for Compounds 1, 2a, 2b, 3a, 3b, 3c, 4 and 5[a]

cmpd	H_1	H_6	H_{10}	H_{12}	H_{13}	H_{14}	H_{15}	others
1	6.95 t (4)	6.30 s		7.40 q (1)	1.95 d (1)	1.00 d (6.5)	1.10 s	C-6 OAc 2.20 s
2a	7.12 t, (4)	4.22 s		7.44 bs	2.12 bs	1.02 d (6.5)	0.88 s	C-6 OMe 3.2 s
2b	7.20 t (4)	5.95 s		7.45 q (2)	2.12 d (2)	0.98 d (6.5)	1.00 s	C-6 OAc 2.05 s
3a	3.9 m	6.00 bs	3.10 bd (3)	7.4 q (1)	2.02 d (1)	0.8 d (6)	1.05 s	C-6 OAc 2.05 s, C-1 OH 4.22 bs
3b	3.67 ddd (3.34, 2.57, 2.45)[b]	6.94 s	2.49 d, (3.34)[b]	7.46 q (1)	1.98 d (1)	0.96 d (7)	1.00 s	C-6 OAc 2.17 s, C-1 OMe 3.05 s
3c	3.83 ddd (3.25, 2.35, 2.24)[b]	6.95 s	2.46 d (3.25)[b]	7.35 q (1)	1.95 d (1)	0.94 d (6.5)	1.00 s	C-6 OAc 2.17 s, isopropyl Me 0.6 d (6.5), 0.94 d (6.5), isopropyl H 3.28 m
4		6.05 s	3.55 bs	7.45 d (1)	2.07 d (1)	0.95 d (7)	1.00 s	C-6 OAc 2.07 s
5		6.30 s		7.30 d (1)	1.90 d (1)	0.97 d (7)	1.15 s	C-6 OAc 2.2 s, enolic H 10.6 s, exchangeable with D_2O

[a] Run in $CDCl_3$ solution using Me_4Si as internal standard. Values are in ppm, figures in parentheses are coupling constants in hertz. [b] Values obtained with the aid of a Sperry-Univac V77-200/400 computer.

of **2b** could be the steric and electronic repulsion produced by the C-6 α-axial acetate group to the nucleophilic attack at C-1 from the α side, or by the β methyl groups at C-4 and C-5, from the β side of the molecule.

Experimental Section[12]

Photolysis of Decompostin (1) in Methanol. A solution of decompostin (1) (200 mg) in methanol (300 mL) in a quartz vessel was perfused with Ar for 30 min and irradiated at 300 nm and 15–20 °C. The irradiation was followed by TLC until no starting material was present, 5 h. The solvent was removed under vacuum. The gummy material obtained was purified by TLC to yield **2b** (100 mg): mp 146–148 °C; UV λ_{max} 310 nm (13 390); IR 1670, 1620, 1600, 1530, 895 cm^{-1}; MS, m/z (relative intensity) 260 (M^+ 100), 245 (27), 230 (37), 213 (55.7), 200 (42), 185 (32), 177 (20), 161 (39), 137 (63.4), 115 (38), 109 (20), 91 (42), 77 (43); $C_{16}H_{20}O_3$ requires M^+ at 260; ^{1}H NMR $CDCl_3$ see Table I.

Photolysis of Decompostin (1) in Benzene and ROH. General Procedure. Decompostin (1) (200 mg) in benzene (freshly distilled from LAH) (200 mL) and ROH (0.4 mL) was perfused with Ar for 30 min and irradiated at 300 nm room temperature until disappearance of the starting material, 1 h. The solvent was removed under vacuum and the crystalline product obtained was recrystallized from acetone–isopropyl ether.

(a) R = Me, 1-methoxy decompostin (**3b**) (95% yield): mp 192–194 °C; UV λ_{max} 285 nm (13 920); IR 1730, 1660, 1520 cm^{-1}; MS, m/z (relative intensity) 320 (M^+, 27), 288 (4), 278 (96.7), 246 (37), 228 (89.7), 213 (100), 185, 178, 137, 115, 109, 99, 91; $C_{18}H_{24}O_5$ requires M^+ at 320; ^{1}H NMR $CDCl_3$ see Table I.

(b) R = i-C_3H_7, 1-isopropyl decompostin (**3c**) (92% yield): mp 145–146 °C; UV λ_{max} 285 (18 000); IR 1740, 1670, 1525 cm^{-1}; MS, m/z (relative intensity) 348 (M^+, 35.3), 306 (70.7), 288 (1), 263 (20), 245 (50), 229 (17), 179 (100), 138 (22), 109 (38), 91 (30), 43 (90); $C_{20}H_{28}O_5$ requires M^+ at 348; ^{1}H NMR $CDCl_3$ see Table I.

Photoaddition of Water to Decompostin (1). A solution of decompostin (1) (200 mg) in benzene (200 mL) and water (5 mL) was perfused with Ar for 30 min and irradiated at 300 nm. The reaction was followed by TLC. After 9 h, the solvent was removed under vacuum and the gummy product obtained was purified by preparative TLC (benzene–AcOEt, 3:1). The noncrystalline product **3a** was obtained: UV λ_{max} 286 (7500); IR 3450, 1740, 1660, 1530 cm^{-1}; MS, m/z (relative intensity) 306 (M^+ 5), 264 (6.2), 246 (3.6), 221 (9.3), 179 (20), 137 (5), 91 (10), 43 (100); $C_{17}H_{22}O_5$ requires M^+ at 306; ^{1}H NMR $CDCl_3$ see Table I. The hydroxy deriv. **3a** was also obtained when decompostin was irradiated in acetone–water and tetrahydrofuran–water solutions.

Jones Oxidation of 3a. Product **3a** (50 mg), in acetone, was treated with Jones reagent at 5 °C. Water was added and the reaction mixture extracted with AcOEt, washed with water, saturated sodium bicarbonate solution, and water and dried, and the solvent was removed under vacuum. The product obtained showed two spots by TLC (**4a** and **4b**). Repeated chromatography on silica gel yielded **5**: mp 144–146 °C; UV λ_{max} 205 (7 500), 245 (5 000), 285 (10 000), 341 (15 500); IR ν_{max} 1743 (s), 1677 (w), 1604 (s), 1527 (m) cm^{-1}. MS, m/z (relative intensity) 304 (M^+ 48), 262 (60.8), 245 (12), 228 (10), 213 (5), 189 (37), 151 (100), 137 (15), 124 (62), 109 (15), 91 (14); $C_{17}H_{20}O_5$ requires M^+ at 304.

Photolysis of Decompostin in Benzene and Acetic Acid. A solution of decompostin (1) (100 mg) in dry benzene (100 mL) and AcOH (freshly distilled from P_2O_5; 0.1 mL) was perfused in a quartz vessel with Ar for 30 min and irradiated at 300 nm and 15–20 °C. The reaction was followed by TLC. After 7.5 h, 0.5 mL of saturated aqueous sodium bicarbonate solution was added to neutralize the AcOH. Solvent was removed under vacuum. The residue was then extracted with AcOEt, washed with water, dried, and the solvent was removed under vacuum. The crude product obtained was chromatographed over silica gel. Product **3a** was obtained in 25% yield.

X-ray Analysis of 3b. Colorless crystals of 1-methoxydecompostin were grown by slow evaporation from an acetone–hexane solution. These crystals are orthorhombic. Data were collected by using a single crystal (0.36 × 0.32 × 0.40 mm) mounted on top of a glass fiber. Systematic absences established the space group $P2_12_12_1$. Intensities were collected on a Nicolet R3m automated diffractometer using graphite-monochromatized Mo K_α radiation (λ = 0.7107 Å). Lattice constants were determined from the setting angles of 25 machine-centered reflections with $5.4 < 2\theta < 15.2°$, a = 8.408 (3) Å, b = 12.108 (3) Å, c = 16.447 (7) Å, V = 1674.5 Å^3, $F(000)$ = 688, T = 293 K, D_{calcd} = 1.27 g cm^{-3}, Z = 4 and μ(Mo K_α) = 0.86 cm^{-1}. Data collection (ω scan mode, variable scan speed, scan width 1.0°(θ), two standard reflections monitored every 50 measurements) yielded 1295 reflections of which 1077 were greater than $2.5\sigma(I)$. The intensities were corrected for the Lorentz polarization factor but an absorption was not applied. The crystal structure was solved by direct methods using the program package SHELXTL.[10] The program SOLV was employed using 150 phases with $|E| > 1.5$ and 9 reflections in the starting set. The trial structure was refined by a blocked cascade least-squares procedure with anisotropic temperature factors for the non-H atoms and with a fixed isotropic temperature, U = 0.06 Å^2, for the H atoms. The function minimized was $\sum\omega|\Delta F|^2$ with a weighting scheme $\omega^{-1} = |\sigma^2(F_o) + G(F_o)^2|$ with a final G = 0.002. Atomic scattering factors from "International Tables from X-Ray Crystallography"[11] were used. Refinement converged to R = 0.052, R_ω = 0.059, and S = 1.19. The final difference map had a maximum density of 0.4 e Å^{-3}. All computations were performed in a Nova 4 computer and plots were drawn on a Tektronix plotter.

Acknowledgment. We thank Messrs. René Villena, Luis Velasco, and Humberto Bojórquez for their technical assistance.

Registry No. 1, 24405-79-6; **2a**, 96791-32-1; **2b**, 24405-81-0; **3a**, 96791-33-2; **3b**, 96791-34-3; **3c**, 96791-35-4; 4 (isomer 1), 96791-36-5; 4 (isomer 2), 96791-37-6; **5**, 96791-38-7.

Supplementary Material Available: Tables of atomic positions, thermal parameters, bond distances, bond angles, and torsion angles (11 pages). Ordering information is given on any current masthead page.

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[12] Melting points were determined in a Fischer-Jones apparatus and are uncorrected. ^{1}H NMR spectra were recorded in $CDCl_3$ using Me_4Si as internal standard at 80 or 100 MHz. Coupling constants were calculated using a Sperry-Univac 477-200/400 computer. Chemical Shifts are given in δ. X-ray work was carried out on a Nicolet R-3M diffractometer.