NMR and X-ray Crystallographic Studies of the Conformation of a 3,4,6-Triphenyl-δ-Lactone

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1-Oxa-3*S*,4*S*,6*R*-triphenyl-2-cyclohexanone and its enantiomer were synthesized, and the structure was determined by NMR and X-ray crystallography. The X-ray crystal structure showed that the δ-lactone adopts a boat conformation in the solid. The X-ray data showed a shortened C−O bond between the carbonyl carbon and the ether oxygen, consistent with delocalization involving the ester group. ^{1}H and ^{13}C NMR measurements in acetone-d_6 showed that the lactone is biased in favor of a boat conformation. In the less polar solvent chloroform-d_1, changes in the ^{1}H NMR coupling constants indicate a shift in the equilibrium in favor of a less rigid twist-boat conformation. The IR absorption of the lactone carbonyl at 1740 cm^{-1} would suggest a half-chair conformation inconsistent with the dominance of the boat forms shown by NMR and X-ray.

Introduction

It has been known for some time that the atoms comprising the δ-lactone grouping C−C(O)−O−C are almost coplanar.[1] For δ-lactones, this gives rise to two possible conformations: either the half-chair or the boat. Crystallographic evidence shows that both forms exist in the solid state.[2] Molecular mechanics (MM2) calculations on the unsubstituted δ-lactone showed the half-chair and boat conformations both occupying energy minima with the half-chair more stable by about 0.54 kcal/mol.[3] There is also evidence from NMR analysis to support both forms in solution.[4] Formerly, attempts were made to correlate the conformations of δ-lactones with their infrared carbonyl absorptions; where frequencies in the range 1730−1750 cm^{-1} have been attributed to the half-chair form, those in the range 1758−1765 cm^{-1} are ascribed to the boat form.[5] However, many examples are now known in which the above frequency ranges have proved to be unreliable in determining conformations.[4b,6] In addition, steric requirements of certain groups are known to force the lactone moiety out of planarity, thus making other conformations energetically viable.[7,8a]

Combined ^{13}C and ^{1}H NMR analysis provides valuable evidence about the conformation of various six-membered ring systems, in particular δ-lactones and closely related molecules.[4,8] Previous studies of a related δ-lactone, namely, 1-oxa-4,5,6-triphenyl-2-cyclohexanone, characterized three configurational isomers.[4b] The NMR evidence, in particular the ^{1}H coupling constants, supported the existence of two different lactone conformations.[4b] Two of these isomers, the all-trans and the all-cis, adopted half-chair conformations. However, in the trans-cis isomer, (axial phenyl at C-6) the boat conformation proved to be more stable.[4b] Our previous studies on the all-trans 1-oxa-3,4,5-triphenyl-2-cyclohexanone revealed a half-chair conformation.[9] This suggests that when substituents are attached to the carbons that are part of the ester moiety, their orientation directly influences the conformation that δ-lactones adopt. However, the orientation of substituents at the other two carbons of the δ-lactone is apparently less influential to the conformation adopted. We wanted to probe this concept further and now report our results.

Some studies have shown that δ-lactones can adopt conformations other than the half-chair or boat, namely, twist-boat, sofa, and other undefined forms.[7,8] Since no correlation with infrared frequency has been shown for these forms, and the proposed ones for half-chair and boat conformations have proved to be unreliable,[4b,6−8] it is important to develop a more robust method for assigning δ-lactone conformations. We decided to use a combined ^{13}C and ^{1}H NMR analysis to do a systematic study on nonfused δ-lactones to establish the conformations. While the conformation that a molecule adopts in the solid is not necessarily the same as that in solution, crystal structure information with its greater detail and precision frequently complements structures determined for molecules in more mobile states. In this study, we

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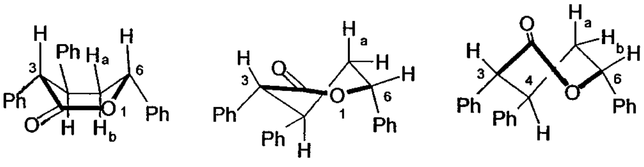
10.1021/jo0155963 CCC: $22.00



6a **6b** **6c**

Figure 1. Possible conformations: boat (**6a**), half-chair (**6b**), and twist-boat (**6c**) based on stereochemistry obtained from X-ray data and ^{1}H NMR coupling constants.

compare the conformations obtained from solution NMR with those from X-ray crystallography.

Results and Discussion

Single-crystal X-ray diffraction analysis of the triphenyl-δ-lactone was obtained and clearly showed the boat conformation. A sketch of the boat conformation **6a** is shown in Figure 1. Dihedral angles $C_3-C_4-C_5-C_6$ and $C_3-C_2-O_1-C_6$ were found to be 7 and 4°, respectively. These compare very favorably with X-ray data of another similarly substituted δ-lactone with a boat conformation.[4c] Likewise, bond angles $C_2-O_1-C_6$ and $O_1-C_2-C_3$ of 117.5 and 116.1°, respectively, were found, similar to other boat conformations.[4c] The shortened C−O bond length between the carbonyl carbon and ether oxygen is consistent with delocalized pi bonding between the carbonyl group and the adjacent ring oxygen. The X-ray data exhibit an orderly intermolecular dipolar arrangement of the carbonyl groups. The lactones pack in such a way that the carbonyl oxygen of one molecule is in close proximity to the ether oxygen of its neighbor. The essentially planar ester group found in the crystal structure further supports the delocalization model for ester electrons.

Configurational and Conformational Assignment from NMR Analysis. The δ-lactone, 1-oxa-3*S*,4*S*,6*R*-triphenyl-2-cyclohexanone **6**, and its enantiomer were synthesized by the condensation of 2-phenylethanal **1** and chalcone **2** using the method of Meerwein.[10] In Scheme 1, the synthesis is outlined and the numbering system shown for compounds **3** and **6**. The resulting keto aldehyde **3** was isolated, purified, and characterized by ^{1}H and ^{13}C NMR. This keto aldehyde **3** was then subjected to an internal Cannizzaro reaction involving a hydride transfer, which finally produced lactone **6**. The same lactone **6** was also obtained by oxidation of **3** to the ketoacid **4** followed by reduction to the hydroxy acid **5**, which cyclized when heated in a vacuum.

The yield of keto aldehyde **3** was fairly high (greater than 75%) in our study. The proton NMR of **3** displayed a large coupling constant of 10.7 Hz for J_{23}, which is consistent with restricted rotation about the C2−C3 bond. Newman projections of the three most stable conformers **3a**−**c** are shown in Scheme 2. The large coupling constant J_{23} is indicative of the dominance of conformer **3a**. In this arrangement, H2 and H3 are anti, consistent with the large coupling constant. Also worthy of note is the proximity of the two carbonyl groups (gauche) in this conformer. Thus, it appears that the stereochemistry of the keto aldehyde in solution is dominated by dipolar interaction of the carbonyl groups rather than by steric hindrance.

The magnitude of the coupling constants for the diastereotopic protons at C-4 with H3 also supported restricted rotation about the C3−C4 bond. Newman projections of the three stable conformers **(3d**−**f)** due to rotation about the C3−C4 bond are shown in Scheme 3. Two of these conformers, **3e** and **3f**, are consistent with the large (9.7 Hz) and small (3.7 Hz) coupling constant observed for J_{34}. Of these only **3e**, with the carbonyls in a gauche position, has the appropriate position for the hydride transfer during the internal Cannizzaro reaction.

Thus, the stereochemistry of the lactone formed appears to be dominated by the dipolar carbonyl interaction in the keto aldehyde **3**. This preferred stereochemical arrangement of the keto aldehyde **3** gives credence to the dominance of lactone **6** as the major configurational isomer as shown in Scheme 4.

Scheme 4 rationalizes the major configurational isomer isolated and depicts the hydride transfer occurring from the same side as the phenyl at C-3. If the hydride transfer were to occur from the bottom, as shown in Scheme 5, the configurational isomer with phenyl up at C-6 would dominate. In this situation, the OCH_3 group would be on top and would encounter nonbonded steric hindrance with the phenyl at C-3. In fact, this was not the major isomer isolated. Thus, the model for *steric approach control* is supported rather than the model for *product development control*.[11]

Other isomers are possible, but due to steric hindrance, the hydride transfer seems to occur only from the top (the same side as the phenyl at C-3). This results in lactone **6** with the configuration as shown in Scheme 4. The ^{13}C NMR spectrum of the mother liquor showed at least two other carbonyl compounds. No attempts were made to isolate other configurational isomers from the mother liquor. The yield of lactone from the keto aldehyde was small (approximately 25%) in our study. The ^{13}C NMR spectrum of this sample did show evidence for two compounds, possibly two lactones (ratio of 23:1). The minor product was not identified, but peaks appear in regions expected for another lactone isomer.

In the oxidation of **3** to the ketoacid **4**, neither attempts to purify the ketoacid nor configurational assignments were made. The ^{13}C NMR spectrum was used to determine effective completion of the reaction. The ketoacid **4** was reduced using sodium borohydride to produce the hydroxy acid **5**. The yield was low. We did not attempt to quantify the isolated products **4** and **5** or assign configuration. From the ^{1}H and ^{13}C NMR data, the lactone isolated after heating in a vacuum was identical to that obtained from the internal Cannizzaro reaction. Thus, it appears that the hydride addition from the borohydride was also guided by steric approach control, similar to the hydride transfer in the Cannizzaro reaction. The lactone isolated from this latter path (heating in a vacuum) showed no signs of other isomers, unlike that from the Cannizzaro path.

The configuration of lactone **6** was clearly established from the X-ray analysis and showed a trans relationship between H3 and H4. In acetone, the large coupling constant of 11.5 Hz (J_{34}) can be best accommodated by three conformations: boat **6a**, half-chair **6b**, and twist-

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(10) Meerwein, H. *J. Prakt. Chem.* **1918**, *97*, 225.

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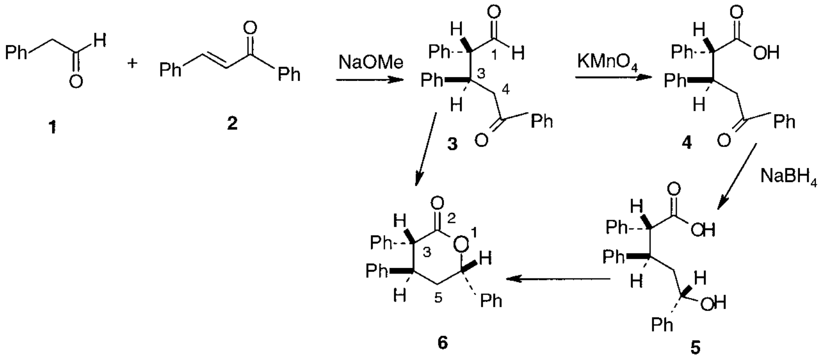
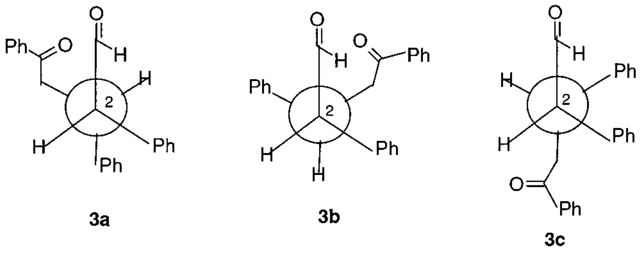
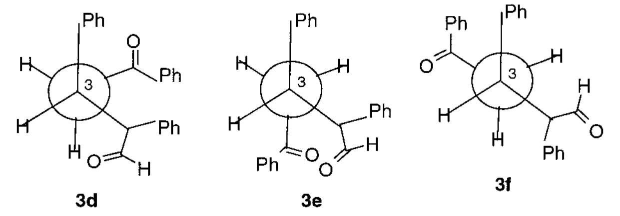
Scheme 1



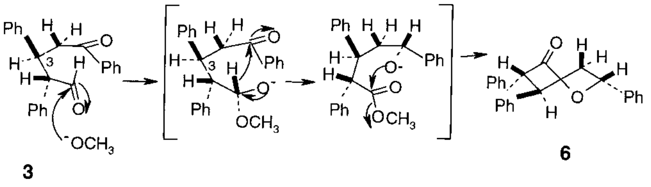
Scheme 2



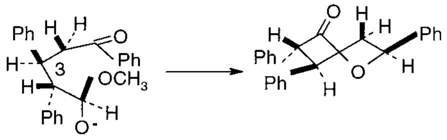
Scheme 3



Scheme 4



Scheme 5



boat **6c** (Figure 1). Bucourt[12a] and others have used the term planar to indicate the presence in a ring of a dihedral angle of zero. Thus, δ-lactones in the boat form are normally defined as diplanar; however, a perfect boat is rarely observed. The diplanar angles normally deviate from zero by ±10° and occasionally by greater amounts. The half-chair is normally defined as monoplanar, while the twist conformation, often referred to as twist-boat or skew-boat, is best described as nonplanar.

The use of modified Karplus equations[13] continues to be an important tool for assigning dihedral angles on the basis of the magnitude of vicinal proton coupling constants. However, the adjustments due to the electronegativities of attached atoms are still imprecise. In our study, the coupling constant of 8.7 Hz observed for J_{5b6} is much less than the 11.5 Hz observed for J_{34}. This difference in itself is not a measure of the extent to which the dihedral angles (H3−C3−C4−H4 and H5b−C5−C6−H6) differ; the presence of the electronegative oxygen on C-6 is an important factor in that difference. Although it is known that the presence of electronegative atoms will lower the coupling constant, the 8.7 Hz observed for J_{5b6} is much smaller than expected for a dihedral angle close to 180°, even after accounting for electronegativity. In the boat conformation (**6a**), the vicinal protons H5b and H6 would have a dihedral angle close to 180°; the twist-boat **(6c)** and half-chair **(6b)** conformations would have much lower values for the corresponding dihedral angles. In fact, in **6b**, the protons at C-5 are bisected by H6 with angles close to 60° and thus would be expected to show much smaller coupling constants for J_{5a6} and J_{5b6}. The observed value of 8.7 Hz for J_{5b6} supports an equilibrium mixture of the three conformations **6a**−**c** with a strong bias toward **6a**.

The coupling constants of 6.6 and 7.8 Hz observed for J_{45a} and J_{45b}, respectively, also support an equilibrium biased toward **6a**. Conformer **6a** would have dihedral angles H4−C4−C5−H5a and H4−C4−C5−H5b close to 120 and 0°, respectively, while **6b** and **6c** would have respective dihedral angles close to 180 and 60°. Thus, one of these coupling constants would be expected to be much greater than the 7.8 Hz observed. Coupling constants close to 8.0 Hz are associated with dihedral angles close to zero, as exhibited by boat conformations.[4b,14] This further supports an equilibrium heavily biased toward the boat conformation, **6a**. NOE experiments on lactone **6** indicate a bias toward the boat conformation in acetone. Irradiation of H3 yielded NOE at H6 (4% difference); similarly, irradiation of H6 yielded NOE at H3 (5% difference). The indicated close proximity of H3 to H6 again supports a boat conformation. Finally, irradiation of H5b yielded NOE at H4 (7% difference), indicating the close proximity of these protons, consistent with a boat conformation.

When the solvent was changed from acetone-d_6 to chloroform-d_1, there were small but definite changes in the ^{1}H NMR chemical shifts and coupling constants. In

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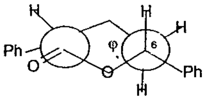
Scheme 6



particular, J_{34} changed from 11.5 to 9.5 Hz; to a lesser degree, J_{56} couplings changed from 8.7 and 4.4 Hz to 7.2 and 5.1 Hz, respectively. These changes suggest either a shift in the conformational equilibrium or a widening of dihedral angles.[12] In a study of substituted 4-oxo-1,3-dioxans, Äyräs[8a] determined that significant changes in the sum of $J_{\mathrm{trans}} + J_{\mathrm{cis}}$ for the fragment $-CH_2-CHR-$ can be used as a measure of shift in the conformational equilibrium. In our study of δ-lactones, slight changes in the sum $J_{5a6} + J_{5b6}$ in acetone and $CDCl_3$ of 13.1 and 12.3 Hz, respectively, were measured. A shift in the equilibrium in favor of more flexible forms, twist-boat and/or half-chair conformations, would be consistent with the observed change in coupling constants. ^1H NMR experiments were carried out between 297 and 247 K in acetone-d_6 and in chloroform-d_1. No conformational changes as a function of temperature were observed. While conformational mobility cannot be ruled out, particularly in chloroform-d_1, the major forms present in the two solvents are somewhat different.

Lambert's *R*-value method for six-membered ring compounds has been used as another indicator of conformational effects.[15] Lambert showed that the value of the ratio R ($R = J_{\mathrm{trans}}/J_{\mathrm{cis}}$) for the fragment $-CH_2-CHR-$ can be used as a measure of conformational bias. He showed that for perfect chairs and boats, the ring dihedral angle, φ, as shown in Scheme 6 is observed to be $56 \pm 2°$ while the angle for twist-boats and half-chairs will be outside that range. The values of the proton dihedral angles $H_5-C-C-H_6$ are directly influenced by this change in ring dihedral angle.

Lambert found that for conformations biased toward the boat or chair, an *R*-value of 2.0 ± 0.2 is normally expected. An *R*-value of 1.2 ± 0.2, on the other hand, is normally associated with twist-boat or half-chair conformations.[15] Note that a perfect chair is not a viable conformation for δ-lactones; thus, only the boat form will be considered for *R*-values close to 2.0. In our study of δ-lactone **6**, we applied Lambert's *R*-value method to the fragment $-CH_2-CH-O-$. For J_{5a6}/J_{5b6} in acetone, we calculated an *R*-value of 1.98, indicating a bias toward the boat, while in $CDCl_3$, the *R*-value was 1.41, supporting a twist-boat or an equilibrium of all three conformations dominated by the twist-boat. The *R*-value of 1.4 is at the upper limit of the flexible forms, as predicted for the twist-boat. In $CDCl_3$, the equilibrium is most likely biased toward the twist-boat because the steric hindrance that the phenyl at C-6 would experience in the half-chair form is alleviated. Äyräs[8a] also found a shift away from the half-chair in favor of the twist-boat to relieve steric interactions between axial groups at C-6 and nonbonded interactions with groups at C-4. Kellie and Riddell[12b] noted that one of the energy advantages of the twist-boat is relief of strains due to 1,3-diaxial interactions that would exist in the half-chair forms.

^{13}C NMR chemical shifts are very sensitive to molecular geometry and have been useful for stereochemical and conformational elucidation.[4,8,16,17] We observed only a minor chemical shift change when the solvent was changed from acetone-d_6 to chloroform-d_1. Most noticeable was the upfield shift of 3 ppm for C-5. This could be due to increased steric interaction between C-2 and C-5 as the conformation shifts from a boat to a twist-boat. Molecular models show that, as this conformational shift occurs, C-5 is brought into closer proximity with the carbonyl carbon.

Conclusions

The X-ray data showed the boat conformation with 3,4-trans and 4,6-trans configurations, which was supported by both the ^1H and ^{13}C NMR data in acetone. The magnitude of the coupling constants and the positive NOE observed between H3:H6 and H4:H5 are indicative of their close proximity. In chloroform, the equilibrium shifts in favor of the more flexible conformations, twist-boat or half-chair. The structure of the δ-lactone deduced from the NMR data in acetone, the more polar solvent, is consistent with that found in the solid, indicating a more ordered arrangement. In the solid, the X-ray data showed the lactone molecules arranged in an orderly pattern consistent with intermolecular dipolar attraction of the carbonyl groups. It is possible that, in acetone, the solvent molecules are able to replace lactone molecules and still maintain a boat conformation. In chloroform, the solvent molecules are unable to maintain the dipolar interaction and thus shift to less rigid conformations dominated by the twist-boat. On the basis of the previous literature, the IR absorption at 1740 cm^{-1} would be more consistent with the half-chair form.[5] Morimoto[6b] has also found IR conformation correlations that are inconsistent with literature expectations.[5] We suggest that the normal IR range for δ-lactones should be revised to be 1730–1750 cm^{-1} irrespective of conformation. Other factors such as internal or external steric interactions may be responsible for those δ-lactones with IR absorptions outside that range.

Experimental Section

General Comments. Chalcone **1** and phenylacetaldehyde **2** were obtained from Aldrich Chemical Co. and were used without further purification. All melting points were taken in capillary tubes and are uncorrected. IR spectra were recorded on a Perkin-Elmer 1310 instrument as thin films on NaCl plates. Samples for IR were typically made by dissolving the compound in acetone and then placing a small amount on a NaCl plate and allowing the solvent to evaporate, thus forming a thin film. All NMR spectra were recorded on a Bruker NR/200 FT (200 MHz) spectrometer in $CDCl_3$ solution (except where noted) with TMS as the internal standard. In a typical ^{13}C NMR spectrum, the transformed peaks were referenced to $CDCl_3$ taken as 77 ppm. The coupling constants for **6** were determined from a spectrum run in acetone-d_6, as the $CDCl_3$ spectrum had unresolved peaks, particularly of the methylene protons. Coupling constants were also obtained by proton decoupling experiments. Assignments of the ^{13}C signals were aided by DEPT and $^{13}C\{^1H\}$ NOE experiments. Samples for NOE experiments were deoxygenated by passing nitrogen through the NMR sample until half the original volume of acetone-d_6 was evaporated.

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5-Oxo-2,3,5-triphenylpentanal 3. Compound **3** was prepared by the method of Meerwein:[10] mp 148−149 °C (lit.[10] not isolated); IR (cm^{-1}) 3060, 3030, 2900, 2700, 1725, 1685, 1600, 1580, 1500, 1450, 1230, 760, 700; ^1H NMR δ 3.1 and 3.3 (m, CH_2, $J = -13.6$ Hz, 9.7 Hz, 3.7 Hz, 2H), 3.9 (dd, H2, $J = 10.7$ Hz, 3.0, 1H), 4.3 (m, H3, $J = 10.7$ Hz, 9.7 Hz, 3.7 Hz, 1H), 6.8−7.8 (aromatic, 15H), 9.6 (d, H1, $J = 3.0$, 1H); ^{13}C NMR δ 42 (C-3), 43 (C-4), 64 (C-2), 128−142 (aromatic), 198 (C-5), 200 (C-1).

5-Oxo-2,3,5-triphenylpentanoic Acid 4. Compound **4** was prepared by oxidation of **3** with a known procedure[4b,10] and by using $KMnO_4$ as described. The keto aldehyde **3** (0.5 g) was added to 8 mL of water and the mixture heated to approximately 73 °C. $KMnO_4$ (0.5 g) in 10 mL of water was added over a 10 min period with stirring. The solution was heated for an additional 20 min until the color changed from purple to blackish brown. The hot solution was gravity filtered and HCl added to the cooled filtrate. A white solid precipitated from the acidified solution: ^{13}C NMR (DMSO-d_6) δ 42 (C-3), 44 (C-4), 58 (C-2), (124−142) aromatic, 174 (C-1), 198 (C-5).

5-Hydroxy-2,3,5-triphenylpentanoic Acid 5. Compound **5** was prepared by reduction of **4** with $NaBH_4$ according to a modified method:[4b] mp 144−145 °C (lit.[10] 143−143.5 °C); IR (cm^{-1}) 3500, 3030, 1710, 1600, 1500, 1460, 1370, 1310, 1230, 1180, 1070, 1020, 980, 910, 750, 725, 700; ^1H NMR (acetone-d_6) δ 2.4 (CH_2, 2H), 3.1 (H3, 1H), 3.8 (H2, 1H), 4.0 (OH, 1H), 4.3 (H5, 1H), 11.0 (COOH, 1H); ^{13}C NMR (acetone-d_6) δ 44.2 (C-4), 46.6 (C-3), 59.2 (C-2), 73.4 (C-5), 126−146 (aromatic), 174.0 (C-1).

1-Oxa-3*S*,4*S*,6*R*-triphenyl-2-cyclohexanone (and Enantiomer) 6. Compound **6** was prepared by two different pathways. Lactone **6** was prepared from **3** by a modification of Meerwein's reaction[10] as follows. The aldehyde **3** (8.02 g) was added to freshly prepared NaOMe (2.00 g Na in 100 mL of ice-cold MeOH) and refluxed for 2 h. After reflux, approximately one-half of the solvent was evaporated. The cooled solution was acidified with 6 M HCl while being stirred. The mixture was covered and allowed to stand at room temperature for 48 h. The crude crystals were filtered and rinsed with cold MeOH. The solid was recrystallized from EtOH: mp 135−137 °C. Lactone **6** was also prepared by heating the hydroxy acid **5** in a vacuum:[10] mp 137−138 °C (lit.[10] 138−139 °C); IR (cm^{-1}) 3040, 1740, 1600, 1500, 1460, 1370, 1310, 1230, 1180, 1070, 1020, 980, 910, 750, 725, 700; ^1H NMR (acetone-d_6) δ 2.5−2.7 (m, CH_2, $J = -14.6$ Hz, 8.7 Hz, 7.8 Hz, 6.6 Hz, 4.4 Hz, 2H), 3.5 (m, H4, $J = 11.5$ Hz, 7.8 Hz, 6.6 Hz, 1H), 4.4 (d, H3, $J = 11.5$ Hz, 1H), 6.0 (q, H6, $J = 8.7$ Hz, 4.4 Hz, 1H), 7.0−7.6 (aromatic, 15H); ^{13}C NMR (acetone-d_6) δ 39.4 (CH_2), 43.8 (C-4), 53.8 (C-3), 79.0 (C-6), 126−144 (aromatic), 172.0 (C-2).

X-ray Crystallographic Determination. Crystals of the δ-lactone **6** were grown from 95% ethanol that was slowly cooled from 40 °C to room temperature at about 2.5 °C per day. Density measured by the neutral buoyancy method in CCl_4/toluene was 1.22 g/cm^3. Density calculated from X-ray-determined lattice constants was 1.230(1) g/cm^3. The crystals belong to the space group $P2_1/c$ with $Z = 4$. Lattice constants were a 12.835(3) Å, b 5.977(1) Å, c 23.210(3) Å, and β 95.20(1)°. The crystal selected for intensity measurements was prismatic with dimensions 0.61 x 0.35 x 0.29 mm. Using Mo Kα radiation ($\lambda = 0.71073$ Å) with a graphite monochromator on a Syntex $P2_1$ diffractometer, 3136 unique reflections were measured of which 2285 had $F^2 > 3\sigma(F^2)$, and these were used in determining and refining the structure. Lorentz and polarization corrections as well as an empirical absorption correction based on psi scans were made on all data. The structure was solved using the MULTAN78 program.[18] The XTAL version 3.2[19] software was used for the remaining crystallographic programs. Hydrogen atom positions were calculated (C−H = 0.96 Å) after each refinement cycle, given an assumed isotropic displacement parameter $U = 0.038$, and were not refined. All non-hydrogen atoms were refined anisotropically by full-matrix least squares on the basis of F^2; 227 parameters were refined, including secondary extinction. The final agreement factors based on F were $R = 0.043$ and $wR = 0.040$ where $1/w = \sigma F^2 + (0.015\ F)^2$. The average and maximum shift/error ratios in the final refinement cycle were 0.005 and 0.022. Discrepancies in the final Fourier difference map ranged from −0.26 to +0.25 electrons/Å^3. The refined bond lengths and angles can be found in the CIF file. Most deviate only slightly from typical reference values.[20] The X-ray numbering system differs from that used in this article.

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Supporting Information Available: X-ray CIF file for lactone **6** has been deposited with the Cambridge Crystallographic Data Center, ref # CCD171882; ^{13}C NMR data for compounds **3**−**6**, ^1H NMR data for **3** and **6**, and ORTEP plots of lactone **6**. This material is available free of charge via the Internet at http://pubs.acs.org.

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