angles, if I^- donor ions are associated. The complex formation constant has been determined from the chemical shift of the HCI_3 carbon nucleus as a function of the iodide ion concentration by the Benesi–Hildebrand–Scott method. The value of K = 2.0 L/mol assigns the complex being relatively weak in solvents of this type.

No charge-transfer bands were observed in the absorption spectra of the complexes in solution (acetonitrile, methanol).[23] Consideration of the diffuse reflectance of solid complexes also gave unsatisfactory results because of very broad absorption bands in the near UV.

The specific electrical conductivities of the triiodomethane complexes in the solid state range at the lower end of the semiconductor region. Although it is not simple to associate the conductivities with structural properties, it is interesting that the specific conductivity in the sequence 8·2 HCI_3 < 4·2 HCI_3 < 19·HCI_3 increases with the extent of the three-dimensional $I^-\cdots HCI_3$ linkages.

Further studies of detailed structures, in connection with conductivity measurements, will show if electrical and structural properties can be correlated in this type of charge-transfer complex.

Acknowledgment. We thank Prof. Dr. W. Swodenk and Dr. J. Hocker, Bayer AG, Leverkusen, for the electrical conductivity measurements, Dipl.-Chem. W. Wald for recording the Raman spectra, and Ing. C. Schmidt for the ^{13}C NMR measurements.

Registry No. 1·2HCI_3, 88791-65-5; 2·2HCI_3, 88791-77-9; 3, 88888-16-8; 4·2HCI_3, 88791-78-0; 5·HCI_3, 88791-79-1; 6·3HCI_3, 88791-82-6; 7, 88888-17-9; 8·2HCI_3, 88888-02-2; 9, 88888-18-0; 10, 88888-19-1; 11, 88888-20-4; 12, 88888-21-5; 13·2HCI_3, 88888-04-4; 14·HCI_3, 88888-05-5; 16·2HCI_3, 88791-94-0; 17·2HCI_3, 88888-06-6; 18·4HCI_3, 88791-92-8; 19·HCI_3, 88888-07-7; 20·4HCI_3, 88888-08-8; 21·2HCI_3, 88888-10-2; 24·$^1/_2HCI_3$, 88888-12-4; 25·2HCI_3, 88888-14-6; HCI_3, 75-47-8.

Supplementary Material Available: Bond lengths and angles, atomic coordinates, and thermal parameters of the complexes 4·2 HCI_3, 8·2 HCI_3, and 19·HCI_3 (11 pages). Ordering information is given on any current masthead page.

(23) A possible increase of the n → σ* absorption intensities of HC_3,[24,25] on addition of organylammonium or potassium iodide, can be referred to the formation of triiodide I_3^- from I_2 traces. In presence of sodium thiosulfate in methanol the absorption spectrum of HCI_3 remains unchanged (above 280 nm) if iodides are added.

(24) Ito, M.; Huang, P.-K. C.; Kosower, E. M. *Trans. Faraday Soc.* **1961**, *57*, 1662–1673.

(25) Kimura, K.; Nagakura, S. *Spectrochim. Acta* **1961**, *17* 166–183.

Syntheses and Structures of Stilbene Cycles. 2. Low-Valent Titanium-Induced Ring Closures of Aromatic Bis(carbonyls)[1]

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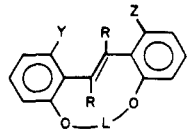
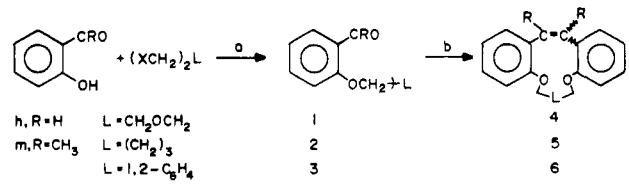
Low-valent titanium-induced reductive coupling has been used to prepare stilbene cycles. Bis(carbonyl) ethers, **1h-3h** and **1m-3m**, have been prepared from the reactions of salicylaldehyde (**h**) and 2-hydroxyacetophenone (**m**) with diethylene glycol ditosylate (**1**), 1,5-dibromopentane (**2**), and 1,2-xylylene dibromide (**3**) in HMPA/dioxane or THF, in the presence of NaOH. Bis(carbonyl) ethers, **1h**, **1m**, **2h**, and **2m**, have been cyclized with $TiCl_4$/Zn or $TiCl_3$/Zn in dioxane to give *E* and *Z* isomers of dibenzo[*a*,*e*]-7,10,13-trioxa- and -7,13-dioxacyclotrideca-1,3,5-trienes, **4h**, **4m**, **5h**, and **5m**, respectively. Compound **3h** under these conditions is not transformed into a cycle but rather forms (*E*)-1,2-bis(2-hydroxyphenyl)ethene, (*E*)-**7h**. Compound **3m** is cyclized but only (*Z*)-**6m** is isolated. Photoisomerization of (*Z*)-**6m** gives (*E*)-**6m** as the predominant isomer. Crystal structures are reported for (*Z*)-**4h**, (*Z*)-**4m**, (*E*)-**5h**, (*Z*)-**6m**, (*E*)-**6m**, and (*E*)-**7h**.

Introduction

Development of new chemical models for enzymatic catalysis is the long-range goal of research efforts in these laboratories. Designs of new models have focused on developing a moderately rigid backbone on which to anchor reacting groups in arrangements approximating those found in enzyme active sites. Stilbene cycles appear to satisfy many of the design criteria. The bridging unit, L, serves to restrict Y and Z to lie on the same side as well as control the relative conformation of the two benzenoid rings.



Scheme I



h, R = H	L = CH_2OCH_2	1	4
m, R = CH_3	L = $(CH_2)_3$	2	5
	L = 1,2-C_6H_4	3	6

a. NaOH, THF·HMPA or dioxane·HMPA b. $TiCl_4$/Zn or $TiCl_3$/Zn

A preliminary report from these laboratories[2] has outlined a convenient high yielding synthetic method (Scheme I) for the preparation of this class of compounds. The preparation of the bis(carbonyl) ethers in high yields is particularly noteworthy in the light of previously reported methods.[3] The good yields for the cyclization are expected

(1) This work is supported by a grant from NIGMS, GM29128. J. T.-R. acknowledges the CONACYT of Mexico for financial support.

(2) Tirado-Rives, J.; Gandour, R. D.; Fronczek, F. R. *Tetrahedron Lett.* **1982**, *23*, 1639–1642.

0022-3263/84/1949-1627$01.50/0

based on past and recent work from McMurry's laboratory.[4] This report details the method and shows its application in the preparation of a number of stilbene (1,2-diphenylethene) and 7,7'-dimethylstilbene (2,3-diphenyl-2-butene) cycles.

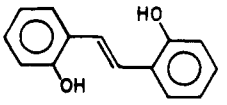
Yields continue to be quite high although geometric isomers are produced. Single-crystal X-ray analyses have been used for positive identification of six compounds. These structures have then served as benchmarks utilized for identification by NMR of geometric isomers in cases where crystal structures have not been obtained.

Results and Discussion

Syntheses. The methods described herein represent a facile two-step procedure for syntheses of 2,2' bridged stilbenes. Compounds **4h**, **4m**, **5h**, **5m**, and **6m** are prepared in overall yields of 74%, 68%, 61%, 78%, and 59%, respectively.[5] The yields have not been optimized and in some cases the reactions have been performed once.

Preparation of the bis(carbonyl) ethers, **1–3**, proceeded smoothly in yields ranging from 76% to 99% (Table I). The addition of HMPA to THF or dioxane dramatically increased the yields. This was not surprising in the light of previous work[6] on alkylation of aryloxides in pure HMPA. The advantage of using HMPA as a cosolvent was the ease of its removal by extraction with 5% aqueous KOH. HMPA did hydrolyze to some extent during the course of the reactions.

Cyclization of the bis(carbonyl) ethers by titanium-induced reductive coupling gave mixtures of *E* and *Z* isomers in yields (Table II) ranging from 60% to 91%. The one exception was **3h** which gave (*E*)-**7h** (in 74% yield) rather



E-7h

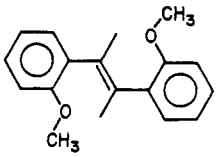
than **6h**. There was no significant difference in the yields or *Z*/*E* ratio when $TiCl_4$/Zn (Method A) or $TiCl_3$/Zn (Method B) was employed in cyclization of **1h** and **1m**.

A comment should be made on the cyclization of **3m** and the attempted cyclization of **3h**. For **3m**, only (*Z*)-**6m** is isolated and the yields vary with reaction time. For **3h**, only (*E*)-**7h** is isolated. When salicylaldehyde is allowed to react under the same conditions (Method A), (*E*)-**7h** is the major product formed[7] along with 1,2-bis(2-hydroxyphenyl)ethane. The failure to observe the diarylethane in the case of **3h** suggests that the xylyl group is lost after cyclization, presumably from (*E*)-**6h**. It is also possible in the case of **3m** that (*E*)-**6m** is formed but the xylyl group is cleaved, either totally or partially.

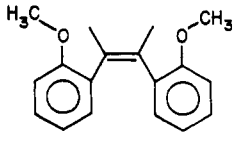
The *Z* isomer was predominant in most mixtures and was more favored in **m** than in the **h**. The isomers were easily separated by standard methods. For **4m–6m**, irradiation of the isomeric mixtures resulted in enrichment of the *E* isomer to 90% or greater.

The predominance of *Z* isomer in the **m** series is not surprising, since titanium-induced coupling of acetophenone gives (*Z*)-2,3-diphenyl-2-butene as the major product.[8] In light of the recent report[9] on the mechanism of titanium-induced reductive coupling of ketones, this predominance of *Z* suggests that it may be the thermodynamically more stable isomer. The proposed mechanism[9] involves consecutive steps for the breaking of C–O bonds in the diol intermediate to form alkene. Assuming that free rotation can occur in the radical formed from breaking one C–O bond, then product geometry will be determined by the lower energy transition state leading from this radical to product. Factors which favor one transition state over the other may be reflected in the relative stability of the products.

Compounds were identified by NMR and X-ray crystallography. For all isomeric pairs, except **5m**, a crystal structure was determined for at least one isomer. Identification of (*E*)- and (*Z*)-**5m** was made by ^1H NMR based on spectral characteristics (see below) of the stilbene portion of the spectra. These spectral characteristics were observed in the *E* and *Z* isomers of **4m**, **6m**, and 2,3-bis(2-methoxyphenyl)-2-butene[10] (**8m**). The identification



E-8m



Z-8m

was also consistent with the observation that (*Z*)-**5m** was the predominant isomer formed.

NMR Data. NMR spectra for all the compounds prepared show symmetric patterns. This is interesting in that crystal structures of (*E*)-**4h**, (*Z*)-**4h**, (*E*)-**5h**, and (*Z*)-**4m** are unsymmetric. As suggested earlier,[2] this indicates a rapid conformational equilibration in solution among the rotamers. This equilibration can arise from rotations in the bridging unit and the bonds connecting the aryl rings to the double bond.

Differences between the spectra of *E* and *Z* isomers are consistent with previous observations. To summarize for ^1H NMR, the following trends are observed: (a) Aromatic resonances are further downfield for the *E* isomer. (b) The olefinic resonance (stilbenes) is further downfield for the *E* isomer, as noted for stilbene itself.[11] (c) The allylic methyl resonance (dimethylstilbenes) is further downfield for the *Z* isomer.[12] To summarize for ^{13}C NMR, the following trends are suggested: (a) The allylic methyl resonance (dimethylstilbenes) is further downfield for the *E* isomer. (b) The olefinic carbon resonance is further downfield for the *Z* isomer in stilbenes, but in dimethylstilbenes this resonance is at nearly the same frequency in both isomers. The conclusion is that ^1H NMR is more useful in distinguishing between *E* and *Z* isomers in stilbenes and dimethylstilbenes.

Some interesting ^1H NMR spectra are produced in the **5** series. In particular the three central methylene reso-

(3) Vögtle, F.; Weber, E. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 753–776. Vögtle, F.; Heimann, U. *Chem. Ber.* **1978**, *111*, 2757–2764.
(4) McMurry, J. E.; Fleming, M. P.; Kees, K. L.; Krepski, L. R. *J. Org. Chem.* **1978**, *43*, 3255–3266. McMurry, J. E.; Miller, D. D. *J. Am. Chem. Soc.* **1983**, *103*, 1660–1661.
(5) For **4h**, the reported[2] overall yield of 60% has increased due to improvement in the isolation procedure for **1h**.
(6) Shaw, J. E.; Kunerth, D. C. *J. Org. Chem.* **1974**, *39*, 1968–1970.
(7) Jungk, S. J.; Tirado-Rives, J.; Gandour, R. D., unpublished results.
(8) Mukaiyama, T.; Sato, T.; Hanna, J. *Chem. Lett.* **1973**, 1041–1044. McMurry et al.[4] reported a 90:10 mixture of *Z* to *E* isomers, but doubted the spectral assignments (see Experimental Section, ref 4) for the isomers. We got a similar result to Mukaiyama et al. for coupling of acetophenone and 3:1 (*Z*:*E*) ratio for coupling of 2-methoxyacetophenone.
(9) Dams, R.; Malinkowski, M.; Westdrop, I.; Geise, H. Y. *J. Org. Chem.* **1982**, *47*, 248–259.
(10) Fronczek, F. R.; Oliver, M. A.; Gandour, R. D. *Acta Crystallogr. Sect. C*, in press.
(11) Jackman, L. M.; Sternhill, S. "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry", 2nd ed.; Pergammon: Oxford, 1969; p 224.
(12) Inamoto, N.; Masuda, S.; Nagai, Y.; Simaura, O. *J. Chem. Soc.* **1963**, 1433–1436.

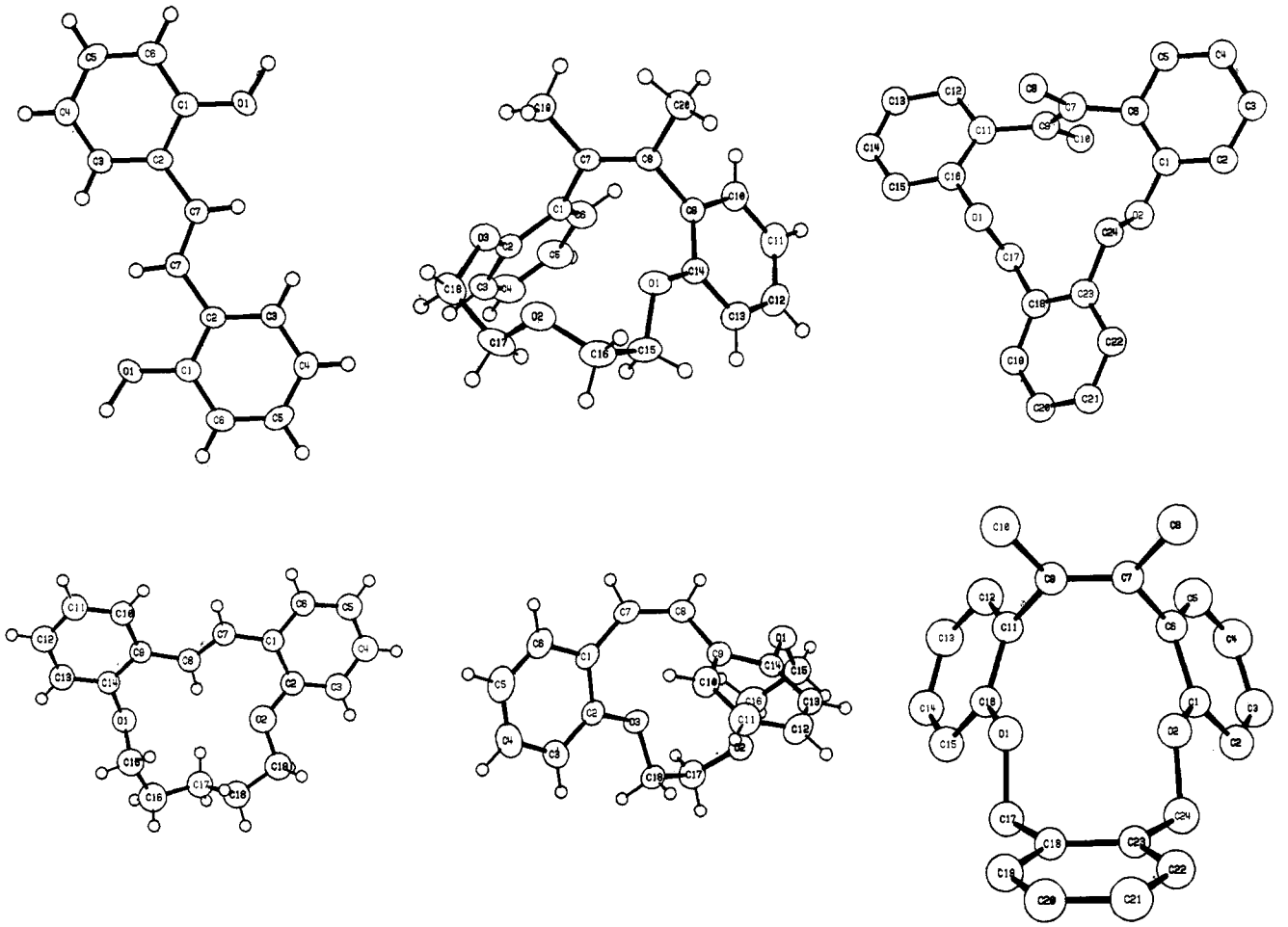


Figure 1. ORTEP drawings of (*E*)-**7h** (top left), (*Z*)-**4m** (top center), (*E*)-**6m** (top right), (*E*)-**5h** (bottom left), (*Z*)-**4h** (bottom center), and (*Z*)-**6m** (bottom right).

nances of the bridging unit show a variety of chemical shifts. Protons on carbons 11 and 9 are equivalent,

$$\underset{11}{-O-CH_2-}\underset{10}{CH_2-}\underset{9}{CH_2-}CH_2-CH_2-O-$$

but the geminal protons on these carbons are not always equivalent because they are part of a ring. For a reference point, resonances for the analogous methylenes in the bis(carbonyl) open-chain compounds, **2h** (**2m**), are 9, 11 [δ 1.90 (1.95)], and 10 [δ 1.70 (1.74)]. The central methylene, 10, is, as expected, more shielded. This is not the case in the cycles.

For (*Z*)-**5h**, 9 and 11 (δ 1.43) are shielded more than 10 (δ 1.65) whose resonance is slightly upfield from its position in the open-chain compound. However in (*Z*)-**5m**, one proton on 10 (δ 2.26) is deshielded and the other (δ 1.48) is shielded. Protons on 9 and 11 (δ 1.58, 1.78) are shielded with respect to their positions in the open-chain compounds. For (*E*)-**5h**, 9 and 11 (δ 1.85) are slightly upfield while 10 (δ 2.05) is deshielded. In (*E*)-**5m**, the chemical shifts (δ 1.75–1.86) are too close to assign, although it can be deduced that 9 and 11 are slightly deshielded while 10 is slightly shielded. The general trend in these cycles is that 9 and 11 are shielded while 10, except for (*Z*)-**5h**, is deshielded compared to open-chain compounds.

These perturbations in chemical shifts arise from restriction of the methylene groups to lie in the shielding and deshielding regions of the aromatic rings and the double bond. Based on magnitudes of some of the chemical shift changes and estimates of distances from X-ray structures, the aromatic rings have a greater effect on the methylenes than the double bond. A case in point is (*Z*)-**5m** in which 10 is deshielded by 0.5 ppm. Assuming the conformation of (*Z*)-**5m** is similar to (*Z*)-**4m** (see Figure 1) and the solid-state conformation approximates that in solution, then 10 would be positioned over the face of the double bond which is a shielding region. This methylene is positioned in the deshielding regions of both aromatic rings. Magnetic lines of force are stronger for an aromatic ring than a double bond at distances farther from the electron cloud.[13] The above assertion that the aromatic rings are dominating these perturbations appears justified.

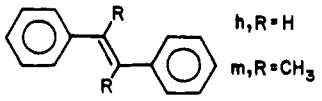
The ^{1}H NMR spectra of (*E*)- and (*Z*)-**6m** reveal differences in the rigidity of the two cycles. The benzylic protons in both spectra appear as an AB pattern. In (*E*)-**6m**, $\Delta\delta$ is 0.05 ppm and J is approximately 9.2 Hz. For (*Z*)-**6m**, $\Delta\delta$ is 0.25 ppm and J is approximately 9.8 Hz. The larger chemical shift difference for the *Z* isomer is postulated from an examination of molecular models to arise from a less flexible conformation.

X-ray Structures. Single-crystal X-ray analyses of (*Z*)-**4h**, (*Z*)-**4m**, (*E*)-**5h**, (*Z*)-**6h**, (*Z*)-**6m**, and (*E*)-**7h** were performed. The crystal structure of (*E*)-**4h** was published[2] previously.

The structures of these compounds are shown in Figure 1 and coordinates, bond lengths, bond angles, and thermal parameters are given in the tables in the supplementary material. A comparison of geometrical features of the double bond linking the aromatic rings of the structures in Figure 1 with those reported for (*E*)-1,2-diphenylethene ((*E*)-**9h**),[14] (*E*)-2,3-diphenylbutene ((*E*)-**9m**),[15] (*E*)-**4h**,[2]

(13) Bovey, F. A. "Nuclear Magnetic Resonance Spectroscopy"; Academic Press: New York, 1969; pp 64–65.

(*E*)-**8m**,[10] and (*Z*)-**8m**[10] is given in Table III.



E-9

There are a couple of noticeable differences between the ethenes (**h**) and butenes (**m**) that are independent of geometrical isomer. First, d_2 and d_3 are shorter in **h** compounds (mean 1.466 Å) than in **m** (mean 1.491 Å, excluding (*E*)-**6m** and **9m**). Second, θ_2 and θ_3 are smaller in **m** (mean 122°, excluding (*E*)-**6m** and **9m**) than in **h** (mean 127°). Both trends are a manifestation of the difference in steric bulk between a hydrogen and methyl group.

The most significant effect of replacing vinyl hydrogens with methyls is the conformation of the aromatic rings with respect to the double bond. In the (*E*)-**h** series Φ_2 and Φ_3 are close to 0° or 180°, while in the (*E*)-**m** series, these dihedral angles approach 90° and −90°. In *Z* isomers, steric interactions between the two rings force them away from coplanarity with the double bond. The addition of methyl groups reinforces this effect.

It is noteworthy that four cycles reported here have chiral conformations in the solid state. Two compounds, (*Z*)-**4h** and **4m**, crystallize in chiral space groups. The conformational chirality arises from the bridging unit, in particular its conformation at the point of attachment to the aromatic rings (compare Φ_4 and Φ_5, especially in (*E*)-**4h** and (*E*)-**5h**).

Comparison of the conformations of the bridging units in (*E*)-**4h** and (*E*)-**5h**, which crystallize isomorphously, reveal that the two are virtually identical. For (*E*)-**4h**, the conformational assignments for C6–O7–C8–C9–O10–C11–C12–O13–C1 are t–t–g^+–t–c–g^+–t–c (*c* = ±90°, clinal). For (*E*)-**5h**, the assignments for C2–O2–C19–C18–C17–C16–C15–O1–C14 are t–t–g^+–t–c–g^+–t–c. Most of the dihedral angles are within 5° of each other and the ideal values, *t* = ±180° and *g* = ±60°. The significant differences in dihedral angles occur about the central atom of the bridge, C9–O10 (−161.9) and O10–C11 (90.1) for (*E*)-**4h** and C18–C17 (−154.8) and C17–C16 (79.9) for (*E*)-**5h**.

Comparisons of conformations about the bridging units in (*Z*)-**4h** and **4m** reveal considerable differences. Conformational assignments for C2–O3–C18–C17–O2–C16–C15–O1–C14 are t–t–g^+–ac^-–t–g^-–g^+–ac^- (*ac* = ±120°, anticlinal) in (*Z*)-**4h** and for C14–O1–C15–C16–O2–C17–C18–O3–C2 are t–t–g^+–g^+–t–g^+–g^+–t in (*Z*)-**4m**. In both cases the t and g dihedral angles deviate as much as 25° from the ideal values. In structural terms, the three oxygens of the bridge are pointing in the same direction in (*Z*)-**4m**, but in (*Z*)-**4h** O2 is pointing in the opposite direction from O1 and O3.

Summary and Conclusions

A high-yielding procedure for the preparation of stilbene cycles has been described. Geometrical isomers are produced but can be readily separated if necessary. Photoisomerization can enrich the mixture in the amount of *E* isomer for diphenylbutene cycles.

X-ray structures have positively identified five of the cycles. With these structures and others, enough data have been provided to confirm previous criteria used to identify by NMR *E* and *Z* isomers of diphenylethenes and butenes.

Work is in progress in this laboratory on functionalized derivatives of **4h**. These derivatives are designed to provide intramolecular interactions mimicking those found in enzyme active sites. The long-range goal of this work is to synthesize a framework, much like a peptide backbone in an enzyme, on which to anchor functional groups.

Experimental Section

General Procedures. Melting points were determined on a Electrothermal apparatus and are uncorrected. ^{1}H NMR spectra were recorded on a Bruker WP-200 at 200 MHz. ^{13}C NMR spectra were obtained on a Bruker WP-200 operating at 50.32 MHz. Unless otherwise noted all NMR samples were run in $CDCl_3$ and chemical shifts are expressed as ppm relative to internal Me_4Si. IR spectra were obtained on a Perkin Elmer Model 621 grating infrared spectrometer and UV spectra on a Varian Associates Cary 118. Mass spectra were obtained by Don Patterson in these laboratories on a Hewlett-Packard Model 5985 GC-mass spectrometer. Dioxane was dried by distillation from sodium. THF was distilled from sodium benzophenone ketyl. Purification of the $TiCl_4$ was accomplished by refluxing over copper scouring pads (Chore Boy) followed by distillation. Zinc dust was activated by washing with 5% HCl, water, ethanol, and ether and dried in vacuo. Titanium(III) chloride (Alfa) was used as received. Photoisomerizations were conducted in THF using an Ace photochemical reaction vessel with a 550-W Canrad-Hanovia lamp.

Syntheses of Bis(carbonyl) Ethers. A solution of the required electrophile (0.5 mmol per mmol of phenol) in THF[16] (0.25 to 1 mL per mmol of phenol) was added slowly[17] to a previously prepared refluxing solution of the appropriate phenol and NaOH (1.1 mmol/mmol phenol) in HMPA/THF (0.5 to 2 mL/mmol phenol, 25% v/v[18]). The resulting mixture was refluxed 3–6 h, cooled to room temperature, and diluted with water. Exhaustive extraction with ethyl ether, washing of the etheral layer with 5% aqueous KOH[18] and brine, and drying over Na_2SO_4 or $MgSO_4$ followed by removal of the solvent in vacuo afforded the products in high yields (Table I).

Analytical data for all compounds follow.

1,5-Bis(2-formylphenoxy)pentane (2h): white powder; mp 50.5–53 °C; ^{1}H NMR (*J* in Hz) δ 10.472 (2 H, s), 7.786 (2 H, dd, J_1 = 7.763, J_2 = 1.761), 7.492 (2 H, td, J_1 = 7.922, J_2 = 1.761), 6.966 (4 H, m) 4.085 (4 H, m), 1.904 (4 H, m), 1.704 (2 H, m); ^{13}C NMR δ 189.455 (d), 152.377 (s), 135.764 (d), 128.411 (d), 125.177 (s), 120.699 (d), 112.610 (d), 68.362 (t), 28.865 (t), 22.793 (t); IR (KBr) 3080, 3052, 2945, 2913, 2860, 1675, 1598, 1463, 1390, 1290, 1237, 1192, 1160, 1049, 1036, 1018, 842, 755 cm^{-1}; MS, *m/e* (relative intensity) 272 (6.9), 270 (7.1), 149 (17.7), 131 (12.5), 122 (85.9), 121 (100.0), 104 (11.0), 94 (7.9), 93 (8.5), 85 (9.6), 77 (13.0), 69 (34.2), 65 (11.3), 41 (9.1); UV (MeOH) λ (ε) 319 (6268), 253 (14 625), 214 (32 732) nm.

1,2-Bis(2-formylphenoxymethyl)benzene (3h): white needles; mp 113.5–115 °C; ^{1}H NMR (*J* in Hz) δ 10.421 (2 H, s), 7.778 (2 H, dd, J_1 = 7.780, J_2 = 1.838), 7.465 (6 H, m), 7.005 (4 H, m), 5.298 (4 H, s); ^{13}C NMR δ 188.74 (d), 160.240 (s), 135.617 (d), 134.000 (s), 128.708 (d), 128.460 (d), 124.794 (d), 120.806 (d), 112.611 (d), 68.162 (t); IR (KBr) 3075, 3055, 2864, 1680, 1603, 1489, 1462, 1449, 1400, 1388, 1292, 1240, 1192, 1167, 1105, 1048, 1002, 760 cm^{-1}; MS, *m/e* (relative intensity) 225 (22.9), 224 (41.6), 206 (13.6), 197 (41.1) 179 (21.2), 169 (11.2), 141 (12.2), 129 (16.9), 105 (100.0), 104 (47.9), 103 (32.7), 91 (27.0), 78 (25.8), 77 (16.2), 65 (16.4); UV (MeOH) λ (ε) 317 (7208), 253 (15 768), 215 (45 953) nm.

1,5-Bis(2-acetylphenoxy)-3-oxapentane (1m): slightly yellowish powder; mp 69.5–70.0 °C; ^{1}H NMR (*J* in Hz) δ 7.706 (2 H, dd, J_1 = 7.813, J_2 = 1.465), 7.410 (2 H, td, J_1 = 7.813, J_2 = 1.953), 6.957 (4 H, m), 4.072 (8 H, AA′BB′ system), 2.603 (6

(14) Berenstein, J. *Acta Crystallogr. Sect. B* **1975**, *B31*, 1268–1271.
(15) Valle, G.; Busetti, V.; Galiazzo, G. *Cryst. Struct. Commun.* **1981**, *10*, 867–870.

(16) Dioxane was utilized in place of THF for **2h**.
(17) For compounds **1m–3m**, slow addition was not required. All reagents can be mixed and heated at once.
(18) When salicylaldehyde was used (**1h–3h**) it was necessary to utilize a 50% (v/v) mixture of HMPA/THF to minimize byproducts. This made additional alkaline washings necessary.

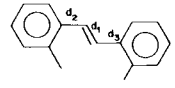
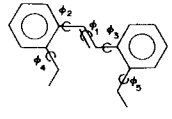
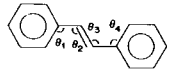
Table I. Summary of Experimental Conditions and Yields in the Preparation of Bis(carbonyl) Ethers

phenol	electrophile	rxn time, h	product	yield, %
salicylaldehyde	$(TsOCH_2CH_2)_2O$	3	**1h**	89.4
	$(BrCH_2CH_2)_2CH_2$	3	**2h**	96.5
	$(BrCH_2)_2(1,2\text{-}C_6H_4)$	3	**3h**	76.0
2-hydroxyacetophenone	$(MsOCH_2CH_2)_2O$	3	**1m**	89.0
	$(BrCH_2CH_2)_2CH_2$	4	**2m**	86.5
	$(BrCH_2)_2(1,2\text{-}C_6H_4)$	6	**3m**	100.0

Table II. Summary of Reaction Conditions and Yields of Stilbenes Prepared with $TiCl_4$/Zn (Method A) or $TiCl_3$/Zn (Method B)

bis(carbonyl) ether	reflux time, h	product	yield, %	*Z*/*E*	method
1h	6.3	(*Z*)- and (*E*)-**4h**	82.5	40/60	A
2h	20	(*Z*)- and (*E*)-**5h**	63.5	62/38	A
3h	3.5	(*E*)-**7h**	73.8	0/100	A
1m	16	(*Z*)- and (*E*)-**4m**	81.9	59/41	A
2m	30	(*Z*)- and (*E*)-**5m**	91.0	76/24	B
3m	3	(*Z*)-**6m**	60.0	100/0	B

Table III. Comparison of Geometrical Features of Stilbenes

	(*E*)-**7h**	(*E*)-**4h**[a]	(*E*)-**5h**	(*E*)-**6m**	(*E*)-**8m**[b]	(*E*)-**9m**[c]	(*E*)-**9h**[d]	(*Z*)-**4h**	(*Z*)-**4m**	(*Z*)-**6m**	(*Z*)-**8m**[a]
											
d_1 (Å)	1.328 (4)	1.326 (2)	1.310 (6)	[1.315 (16)][e]	1.321 (6)	[1.337]	1.318 (3)	1.326 (4)	1.332 (3)	1.331 (8)	1.310 (10)
d_2 (Å)	1.476 (4)	1.461 (2)	1.450 (7)	[1.457 (13)]	1.494 (5)	[1.575]	1.469 (4)	1.465 (4)	1.508 (3)	1.476 (8)	1.494 (11)
d_3 (Å)	1.476 (4)	1.471 (2)	1.462 (7)	[1.513 (13)]	1.494 (5)	[1.575]	1.469 (4)	1.468 (3)	1.494 (3)	1.485 (8)	1.489 (10)
											
ϕ_1 (deg)	180	−176.4	−176.2	[172.1]	180	180	180	−5.0	−5.7	−2.2	−9.8
ϕ_2 (deg)	17.6	171.8	174.3	[118.5], [−83.5]	115.8	[119.2], [−80.1]	5.0	−52.0	−73.7	−87.8	113.4
ϕ_3 (deg)	−17.6	−17.0	−16.3	[106.5], [−84.8]	−115.8	[114.0], [−88.0]	−5.0	145.3	125.0	90.4	118.2
ϕ_4 (deg)	−149.2	89.7	93.7	−85.4	180.0			165.7	165.2	166.3	176.8
ϕ_5 (deg)	149.2	177.0	−175.4	−83.2	180.0			−125.9	−155.1	−160.5	171.5
											
θ_1 (deg)	122.1 (3)	119.4 (1)	124.4 (5)	[120.4]	122.1 (4)	[119.5]	123.3 (2)	123.3 (2)	121.1 (2)	123.4 (6)	122.3 (8)
θ_2 (deg)	125.2 (3)	127.3 (1)	129.5 (5)	[111.1]	121.9 (4)	[118.8]	126.7 (2)	128.6 (2)	121.6 (2)	122.0 (6)	121.9 (7)
θ_3 (deg)	125.2 (3)	128.2 (1)	129.0 (5)	[109.0]	121.9 (4)	[118.8]	126.7 (2)	127.6 (3)	123.3 (2)	122.0 (6)	121.8 (7)
θ_4 (deg)	122.1 (3)	124.2 (1)	120.4 (5)	[119.3]	122.1 (4)	[119.5]	123.3 (2)	120.5 (2)	123.2 (2)	122.8 (6)	121.7 (8)

[a] Reference 2. [b] Reference 10. [c] Reference 15. [d] Reference 14. [e] Quantities in brackets denote those values affected by disorder.

Table IV. Summary of Crystal Data

	(E)-7h	(E)-5h	(E)-6m	(Z)-4h	(Z)-4m	(Z)-6m
compd						
formula	$C_{14}H_{12}O_2$	$C_{19}H_{20}O_2$	$C_{24}H_{22}O_2$	$C_{18}H_{18}O_3$	$C_{20}H_{22}O_3$	$C_{24}H_{18}O_2$
formula weight	212.3	280.4	342.2	282.3	310.4	338.4
crystal system	orthorhombic	orthorhombic	orthorhombic	monoclinic	orthorhombic	monoclinic
space group	*Pbca*	*Pbca*	*Pbca*	$P2_1$	$P2_12_12_1$	$P2_1/n$
a, Å	18.591 (4)	22.369 (4)	9.812 (4)	7.609 (3)	11.510 (3)	9.435 (4)
b, Å	11.392 (7)	19.107 (3)	22.150 (6)	7.956 (4)	18.511 (5)	17.329 (4)
c, Å	5.098 (1)	7.211 (1)	17.437 (5)	12.614 (4)	7.877 (4)	11.519 (3)
β, deg				99.98 (3)		95.41 (3)
Z	4	8	8	2	4	4
density, g cm^{-3}	1.306	1.208	1.200	1.247	1.228	1.199
μ, cm^{-1}	0.81	0.72	0.70	0.78	0.76	0.81
θ limits, deg	$1 \leq \theta \leq 25$	$1 \leq \theta \leq 20$	$1 \leq \theta \leq 20$	$1 \leq \theta \leq 27$	$1 \leq \theta \leq 28$	$1 \leq \theta \leq 20$
unique data	944	1441	1765	2140	2316	1738
obsd data	514	751	1036	1344	1334	896
variables	97	85	113	189	209	105
R	0.044	0.069	0.101	0.050	0.042	0.062
R_w	0.048	0.066	0.105	0.061	0.055	0.068
residual, eÅ^{-3}	0.15	0.29	0.52	0.21	0.18	0.26
refinement type	anisotropic, isotropic H	isotropic	isotropic	anisotropic	anisotropic	isotropic

H, s); ^{13}C NMR δ 198.277 (s), 157.674 (s), 133.274 (d), 129.780 (d), 127.985 (s), 120.369 (d), 112.316 (d), 69.141 (t), 67.443 (t), 31.400 (q); IR (KBr) 3072, 2942, 2910, 1665, 1596, 1580, 1480, 1447, 1417, 1358, 1295, 1240, 1164, 1120, 1082, 1065, 1047, 950, 940, 756 cm^{-1}; MS, *m/e* (relative intensity) 342 (M$^+$, 0.6), 207 (18.6), 164 (10.8), 163 (100.0), 162 (30.4), 150 (18.0), 149 (40.7), 147 (24.4), 136 (73.0), 135 (25.5), 121 (73.8), 120 (15.8), 119 (40.3), 115 (14.1), 107 (84.1), 105 (11.6), 95 (13.2), 92 (21.7), 91 (85.9), 87 (15.5), 77 (30.0), 65 (17.9), 43 (14.4); UV (MeOH) λ (ϵ) 305 (6784), 246 (14 405), 212 (37 732) nm.

1,5-Bis(2-acetylphenoxy)pentane (2m): white needles; mp 105.0–106.0 °C; ^{1}H NMR (*J* in Hz) δ 7.720 (2 H, m), 7.422 (2 H, m), 6.956 (4 H, m), 4.082 (4 H, m), 2.611 (6 H, s), 1.947 (4 H, m), 1.740 (2 H, m); ^{13}C NMR δ 199.2 (s), 158.0 (s), 133.3 (d), 130.0 (d), 128.2 (s), 120.3 (d), 112.2 (d), 68.1 (t), 31.6 (q), 28.7 (t), 22.8 (t); IR (KBr) 3112, 3073, 2964, 2931, 2888, 1665, 1596, 1488, 1470, 1455, 1416, 1400, 1361, 1300, 1250, 1172, 1130, 1048, 1023, 969, 836, 778, 766 cm^{-1}; MS, *m/e* (relative intensity) 340 (M$^+$, 0.2), 325 (2.6), 219 (2.2), 205 (8.5), 189 (7.1), 158 (17.7), 149 (14.5), 137 (66.6), 136 (18.9), 121 (100.0), 119 (12.7), 93 (12.0), 92 (11.1), 91 (38.9), 77 (14.1), 69 (86.4), 65 (18.4), 43 (15.8), 41 (25.5); UV (MeOH) λ (ϵ) 305 (7742), 246 (15 484), 212 (43 226) nm. Anal. ($C_{21}H_{24}O_4$) C, H.

1,2-Bis(2-acetylphenoxymethyl)benzene (3m): off-white powder; mp 73–73.3 °C; ^{1}H NMR (*J* in Hz) δ 7.612 (2 H, dd, J_1 = 1.471, J_2 = 9.089), 7.445 (2 H, dd, J_1 = 5.147, J_2 = 3.667), 7.309 (4 H, m), 6.970 (4 H, m), 5.181 (4 H, s), 2.425 (6 H, s); ^{13}C NMR δ 199.0 (s), 157.3 (s), 134.1 (s), 133.2 (d), 129.9 (d), 128.9 (d), 128.5 (s), 128.4 (d) 120.7 (d), 112.7 (d), 68.1 (t), 31.3 (q); IR (KBr) 2930, 1673, 1598, 1295, 1240, 1231, 766, 760 cm^{-1}; MS, *m/e* (relative intensity) 238 (16.4), 198 (12.9), 197 (100.0), 104 (21.2), 78 (12.6), 43 (33.9); UV (MeOH) λ (ϵ) 307 (7000), 248 (11 800), 212 (36 200) nm. Anal. ($C_{24}H_{22}O_4$) C, H.

Low-Valent Titanium-Induced Cyclizations. Method A. All glassware utilized was oven-dried overnight at 120 °C, assembled hot, and cooled under a rapid stream of argon. Still under Ar, neat $TiCl_4$ (3 mmol/mmol bis(carbonyl)) was added via syringe to a suspension of Zn dust (6 mmol/mmol bis(carbonyl)) in dioxane (ca. 2 mL/mmol of bis(carbonyl)). The resulting greenish mixture was refluxed 1 h, and a solution of the desired bis(carbonyl) compound in dioxane (2–3 mL/mmol) was added dropwise. Reflux was continued for 6–20 h,[19] and the mixture was allowed to cool to room temperature. The black suspension was diluted with 10% aqueous K_2CO_3 (ca. 15 mL/mmol of bis(carbonyl)) and stirred open to the atmosphere until oxidation of the titanium was complete (off-white suspension). Filtration, exhaustive extraction of both the filtrate and residue with ethyl ether or methylene chloride, washing of the organic layer with brine, drying over Na_2SO_4, and removal of the solvent in vacuo afforded the products in high yields (Table II).

Separation and purification details as well as analytical data for each compound follow.

(Z)- and (E)-1:2,5:6-Dibenzo-7,10,13-trioxacyclotrideca-1,3,5-triene (4h). The *E* isomer was separated by recrystallization from cyclohexane while the *Z* isomer was purified by preparative thick-layer chromatography (PTLC) (silica gel, acetone–hexane 5% v/v). Physical data for both isomers were published[2] previously, except for the melting point of (*Z*)-**4h** which could not be crystallized previously. It was recrystallized from chloroform/cyclohexane to yield colorless needles, mp 102–103 °C.

(Z)- and (E)-1:2,5:6-Dibenzo-7,13-dioxacyclotrideca-1,3,5-triene (5h). The *E* isomer was separated by recrystallization from ethyl ether. The mother liquor was highly enriched (ca. 90%) in the *Z* isomer, which was purified by PTLC (silica gel) using Et_2O:petroleum ether (1:2) as eluent.

(*E*)-**5h**: colorless needles; mp 140–141 °C; ^{1}H NMR (*J* in Hz) δ 7.690 (2 H, s), 7.468 (2 H, dd, J_1 = 7.568, J_2 = 1.953), 7.162 (2 H, ddd, J_1 = 7.324, J_2 = 7.812, J_3 = 1.953), 6.994 (2 H, ddd, J_1 = 7.324, J_2 = 7.568, J_3 = 1.465), 6.951 (2 H, dd, J_1 = 7.812, J_2 = 1.465), 4.011 (4 H, t, *J* = 5.849), 2.053 (2 H, m), 1.847 (4 H, dd, J_1 = 5.849, J_2 = 5.371); ^{13}C NMR δ 157.631 (s), 128.892 (s), 127.973 (d), 127.807 (d), 126.485 (d), 122.129 (d), 116.920 (d), 70.128 (t), 28.967 (t), 20.919 (t); IR (KBr) 3064, 3030, 2940, 2915, 2870, 1596, 1576, 1481, 1472, 1457, 1432, 1382, 1335, 1260, 1229, 1122, 1091, 1043, 1012, 987, 943, 884, 758 cm^{-1}; MS, *m/e* (relative intensity) 280 (M$^+$, 100.0), 281 (M + 1, 19.7), 282 (M + 2, 3.1), 223 (16.4), 212 (18.7), 211 (16.4), 210 (20.3), 195 (12.9), 183 (15.3), 181 (32.8), 173 (14.4), 165 (44.8), 153 (14.8), 152 (25.0), 145 (17.9), 133 (17.7), 131 (51.6), 119 (28.1), 107 (39.8), 91 (16.0), 77 (13.2), 69 (15.0), 41 (14.7); UV (MeOH) λ (ϵ) 335 (15 944), 321 (21 778), 299 (16 917), 288 (16 917), 233 (14 778), 209 (22 256) nm.

(*Z*)-**5h**: yellowish oil; ^{1}H NMR (*J* in Hz) δ 6.952 (2 H, m), 6.655 (2 H, s), 6.642 (4 H, m), 3.308 (4 H, br t), 1.648 (2 H, br), 1.426 (4 H, br q); ^{13}C NMR δ 155.756 (s), 130.728 (d), 128.260 (d), 127.760 (d), 126.623 (s), 120.468 (d), 114.636 (d), 67.771 (t), 27.060 (t), 21.015 (t); IR (KBr) 3063, 3020, 2930, 2880, 1598, 1579, 1483, 1450, 1390, 1248, 1210, 1158, 1106, 1043, 943, 748 cm^{-1}; MS, *m/e* (relative intensity) 280 (M$^+$, 100.0), 281 (M + 1, 20.3), 282 (M + 2, 3.1), 223 (17.5), 212 (20.1), 211 (16.4), 210 (22.7), 195 (15.7), 183 (17.3), 181 (37.7), 173 (16.2), 166 (10.8), 165 (56.3), 164 (12.2), 153 (17.8), 152 (30.7), 145 (21.2), 144 (10.7), 133 (21.0), 131 (60.8), 120 (10.8), 119 (28.5), 118 (22.7), 115 (14.9), 107 (48.4), 91 (20.6), 77 (16.4), 69 (14.1), 41 (16.6); UV (MeOH) λ (ϵ) 282 (br) (4817), 210 (sh) (20 037) nm.

(E)-1,2-Bis(2-hydroxyphenyl)ethene ((E)-7h). When compound **3h** was treated with $TiCl_4$/Zn (method A) (*E*)-**7h** was easily isolated in a 74% yield as a single isomer. Although several minor components were detected by TLC, their isolation and identification was not effected. Crude (*E*)-**7h** was purified by trituration with chloroform obtaining small colorless crystals: mp

(19) For (*E*)-**7h**, the mixture was refluxed for only 3.5 h; longer run times caused decomposition.

194.5–195.5 °C (lit.[20] mp 197 °C); ^{1}H NMR ($(CD_3)_2CO$, J in Hz δ 8.406 (2 H, br s), 7.587 (2 H, d, J = 7.907), 7.538 (2 H, s), 7.060 (2 H, m), 6.858 (4 H, m); ^{13}C NMR ($(CD_3)_2CO$) δ 155.619 (s), 129.035 (d), 127.232 (d), 126.279 (s), 124.362 (d), 120.774 (d), 116.753 (d); IR (KBr) 3342, 3230, 3045, 1605, 1585, 1500, 1450, 1369, 1333, 1200, 1155, 1090, 1042, 982, 972, 855, 751, 739, 595, 586 cm^{-1}; MS, m/e (relative intensity) 272 (M$^+$, 100), 273 (M + 1, 15.2), 274 (M + 2, 1.7), 211 (23.4), 197 (11.8), 195 (27.2), 183 (13.3), 181 (9.6), 165 (27.0), 152 (9.8), 188 (9.6), 91 (7.6), 82 (11.3), 77 (11.3); UV (MeOH) λ (ϵ) 331 (19832), 280 (13677), 234 (13164), 211 (23594) nm.

(*E*)- and (*Z*)-1:2,5:6-Dibenzo-3,4-dimethyl-7,10,13-trioxacyclotrideca-1,3,5-triene (4m). *E* and *Z* isomers were prepared from **1m** (Method A) and separated by PTLC (silica gel, 7.5% acetone in hexane, v/v).

(*E*)-**4m**: mp 71–72.5 °C; ^{1}H NMR δ 7.273–7.171 (4 H, m), 7.057–6.948 (4 H, m), 4.164–4.080 (4 H, m), 3.955–3.808 (4 H, m), 1.747 (6 H, s); ^{13}C NMR δ 156.340 (s), 135.363 (s), 130.472 (s), 129.674 (d), 127.658 (d), 121.873 (d), 115.841 (d), 70.788 (t), 70.605 (t), 21.540 (q); IR (KBr) 2918, 2868, 1598, 1582, 1487, 1445, 1263, 1143, 1085, 1061, 1032, 943, 913, 841, 753 cm^{-1}; MS, m/e (relative intensity) 310 (M$^+$, 100), 311 (M + 1, 21.3), 312 (M + 2, 3.3), 251 (12.4), 237 (14.3), 223 (24.2), 178 (14.3), 165 (13.2), 147 (16.2), 146 (15.7), 145 (36.1), 133 (10.9), 132 (11.4), 131 (18.4), 121 (13.2), 119 (13.4), 115 (11.9), 107 (10.8), 91 (22.7), 7.7 (12.5); UV (MeOH) λ (ϵ) 278 (3400), 274 (3600), 208 (26487) nm.

(*Z*)-**4m**: colorless needles: mp 93–94 °C; ^{1}H NMR δ 6.946 (2 H, m), 6.666 (6 H, m), 3.906 (8 H, m), 2.103 (6 H, s); ^{13}C NMR δ 155.499 (s), 134.515 (s), 130.995 (d), 130.582 (s), 126.760 (d), 120.090 (d), 113.585 (d), 69.870 (t), 68.437 (t), 20.284 (q); IR (KBr) 3062, 3027, 2968, 2950, 2930, 2903, 1598, 1582, 1485, 1461, 1442, 1401, 1380, 1244, 1213, 1139, 1128, 1100, 1062, 1044, 910, 835, 749 cm^{-1}; MS, m/e (relative intensity) 310 (M$^+$, 100.0), 311 (M + 1, 224.), 312 (M + 2, 4.5), 295 (10.1), 152 (20.0), 146 (27.2), 133 (20.2), 131 (40.2), 119 (34.9); UV (MeOH) λ (ϵ) 288 (br, 5028), 210 (sh, 24581) nm. Anal. ($C_{20}H_{22}O_3$) C, H.

Method B. In a dry box with an argon atmosphere titanium(III) chloride and zinc dust were weighed and the reaction apparatus assembled. After removal to a hood, dry dioxane was added by syringe and the reaction heated to reflux. A solution of the diketone in dioxane was added over 20 min. Refluxing was continued for an additional period which is indicated below. After cooling, the reaction mixture was added to 10% K_2CO_3 (100 mL) and stirred until the suspension turned white. After filtration through a fritted (fine) funnel the filter cake was washed three times with 50 mL of CH_2Cl_2. The combined washes were dried over $MgSO_4$ and the solvent was removed to give the crude product (Table II).

Separation and purification techniques as well as analytical data for each compound prepared by this method follow.

(*Z*)- and (*E*)-1:2,5:6-Dibenzo-3,4-dimethyl-7,13-dioxacyclotrideca-1,3,5-triene (5m). These were prepared from **2m** with a reflux time of 30 h to give a 91% yield of a mixture of isomers. The ratio of *Z* to *E* in the crude reaction mixture was 76/24 as determined by HPLC (Waters Model 6000A) (μ-Bondapak C18; MeOH/water 90/10). Isomers were separated by column chromatography (neutral alumina, hexane–methylene chloride).

(*Z*)-**5m**: mp 78.0–79.2 °C; ^{1}H NMR δ 7.00–6.90 (4 H, m), 6.70–6.63 (4 H, m), 4.04–3.94 (2 H, m), 3.83–3.72 (2 H, m), 2.36–2.15 (1 H, m), 2.09 (6 H, s), 1.89–1.67 (2 H, m), 1.64–1.35 (3 H, m); ^{13}C NMR δ 155.5 (s), 134.8 (s), 131.5 (d), 131.0 (s), 126.9 (d), 119.8 (d), 113.2 (d), 66.9 (t) 27.3 (t), 20.4 (t), 20.2 (q); IR (KBr) 3078, 2960, 2920, 2880, 1597, 1580, 1493, 1482, 1472, 1448, 1254, 1205, 1130, 1120, 1057, 1047, 953, 940, 762, 755, 749 cm^{-1}; MS, m/e (relative intensity) 308 (M$^+$, 80.6), 309 (M + 1, 19.9), 310 (M + 2, 3.0), 224 (11.9), 223 (17.7), 189 (10.1), 188 (27.5), 187 (38.5), 178 (15.5), 173 (11.9), 165 (15.3), 158 (12.5), 152 (10.5), 147 (27.5), 146 (23.7), 145 (100.0), 131 (23.4), 121 (27.5), 119 (11.9), 115 (11.6), 107 (23.7), 91 (22.4), 77 (12.1), 69 (12.4), 41 (17.8); UV (MeOH) λ (ϵ) 281 (3800), 274 (4000), 208 (28900) nm.

(*E*)-**5m**: mp 63.0–64.5 °C; ^{1}H NMR δ 7.27–7.16 (4 H, m), 7.05–6.94 (4 H, m), 4.08–3.90 (4 H, m), [1.88–1.75 (m) + 1.75 (s)] (12 H); ^{13}C NMR δ 156.4 (s), 135.1 (s), 130.7 (s), 129.7 (d), 127.6 (d), 121.6 (d), 115.9 (d), 70.6 (t), 28.3 (t), 22.9 (t), 21.7 (q); IR (KBr) 2920, 2863, 1600, 1581, 1488, 1245, 1198, 1127, 1091, 1032, 998, 750 cm^{-1}; MS, m/e (relative intensity) 308 (M$^+$, 76.2), 309 (M + 1, 18.4), 310 (M + 2, 3.1), 224 (11.1), 223 (17.6), 189 (10.7), 188 (26.4), 187 (32.8), 178 (13.4), 173 (13.2), 165 (14.8), 158 (12.8), 152 (10.2), 147 (27.2), 146 (23.2), 145 (100.0), 131 (22.9), 121 (30.7), 119 (12.5), 115 (12.7), 107 (23.9), 91 (27.2), 89 (10.5), 77 (13.4), 69 (15.2), 41 (16.1); UV (MeOH) λ (ϵ) 281 (3700), 276 (3600), 208 (25700) nm.

(*Z*)- and (*E*)-1:2,5:6,9:10-Tribenzo-3,4-dimethyl-7,12-dioxacyclododeca-1,3,5,9-tetraene (6m). The *Z* isomer was prepared from **3m** with a reflux period of 3 h. The crude oily solid was triturated with methanol to leave a white solid.

Irradiation of (*Z*)-**6m** with UV light gave (*E*)-**6m** in a 88/12 ratio, *E*/*Z*. The *E* isomer was purified by TLC(silica gel; hexane/ethyl acetate) and recrystallized (cyclohexane).

(*E*)-**6m**: mp 133–134.5 °C; ^{1}H NMR δ 7.53–7.14 (12 H, m), 5.06 (4 H, AB, $\Delta\delta$ = 9.8 Hz, J = 9.28), 1.83 (6 H, s); ^{13}C NMR δ 156.2 (s), 137.6 (s), 136.5 (s), 131.8 (d), 130.8 (s), 129.6 (d), 129.0 (d), 128.1 (d), 124.2 (d), 121.8 (d), 74.7 (t), 22.6 (q); IR (KBr) 2920, 2895, 1601, 1483, 1450, 1390, 1245, 1216, 1084, 1044, 993, 894, 855, 773 cm^{-1}; MS, m/e (relative intensity) 342 (M$^+$, 5.6), 343 (M + 1, 1.6), 344 (M + 2, 0.2), 223 (38.9), 222 (10.8), 221 (13.0), 195 (11.9), 165 (11.9), 152 (11.2), 145 (15.3), 121 (22.7), 115 (13.4), 105 (25.3), 104 (100.0), 103 (28.0), 91 (16.8), 78 (24.2), 77 (18.1); UV (MeOH) λ (ϵ) 271 (1700), 266 (1600), 208 (33600) nm.

(*Z*)-**6m**: mp 202–203 °C; ^{1}H NMR δ 7.48–7.35 (4 H, m), 7.03–6.64 (8 H, m), 4.80 (4 H, AB $\Delta\delta$ = 49.0 Hz, J = 9.77) 1.92 (6 H, s); ^{13}C NMR δ 156.4 (s), 137.2 (s), 134.9 (s), 131.3 (d), 130.4 (d), 128.9 (d), 127.0 (d), 120.2 (d), 112.1 (d), 69.9 (t), 20.2 (q); IR (KBr) 2915, 1598, 1483, 1302, 1215, 1020, 760 cm^{-1}; MS, m/e (relative intensity) 342 (M$^+$, 47.3), 343 (M + 1, 9.1), 344 (M + 2, 2.0), 327 (11.7), 238 (26.7), 237 (29.4), 224 (20.8), 223 (77.1), 222 (30.0), 221 (40.3), 197 (19.1), 195 (25.3), 165 (16.0), 152 (10.5), 146 (12.1), 145 (15.9), 121 (19.3), 105 (16.7), 104 (100.0), 103 (13.2), 78 (14.8); UV (MeOH) λ (ϵ) 281 (3100), 275 (3000), 208 (35400) nm.

X-ray Analyses. Intensity data for all six compounds were collected on an Enraf-Nonius CAD4 diffractometer equipped with Mo Kα radiation (λ 0.71073 Å) and a graphite monochromator. Variable scan rates were employed in the $\omega - 2\theta$ scans in order to achieve approximately equal precision for all observable data. For monoclinic crystals, one quadrant of data was collected; for orthorhombic crystals, one octant was obtained. Crystal data and angular limits for each structure are given in Table IV. Data reduction included corrections for background, Lorentz, and polarization effects; no absorption corrections were necessary. Equivalent data, if any, were averaged, and "observed" reflections, having $F^2 > 3\sigma(F^2)$, were used in the refinements.

All structures were solved by using direct methods program MULTAN78,[21] completed by Fourier techniques and refined by full-matrix least-squares based upon F with weights $w = \sigma^{-2}(F_o)$. Crystal quality and scattering power varied considerably, thus refinement type varied accordingly. Three of the structures were refined with isotropic thermal parameters and fixed H atoms, two with anisotropic thermal parameters and fixed H atoms, and one with anisotropic thermal parameters and isotropically refined H atoms. These types are specified in Table IV. H atoms were located from differences maps in all structures.

All refinements have proceeded smoothly except for that of compound (*E*)-**6m**, which exhibits disorder. The olefinic unit of that compound can exist in either a zigzag pattern, or a "zagzig" pattern, related to it by a rotation of 180° about the C6–C11 vector without markedly affecting the orientation or position of the stilbene phenyl rings or the methyl carbon atoms. Both conformations are present in equal amounts in the crystal, leading to two half-populated positions for C7 and two for C9. These four positions approximate a square 0.94 Å on a side; thus the disorder is well enough resolved to permit individual refinement.

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Hydrogen atoms of the methyl groups have not been located nor computed. R factors as well as residuals in final difference maps are given in Table IV. The only notable residuals are in the region of disorder of compound (*E*)-**6m**.

Supplementary Material Available: Tables of bond lengths and bond angles, coordinates, and anisotropic thermal parameters (20 pages). Ordering information is given on any current masthead page.

Synthesis of (*E*)- and (*Z*)-Cyclopropyl-3-chloroalanine

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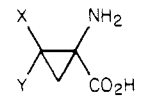
Both stereoisomers of cyclopropyl-3-chloroalanine (1) were synthesized by diazomethane cyclopropanation of the appropriate oxazolones (2). X-ray crystallographic analysis elucidated the configurations of 1 and gave some insight into its possible conformational preferences.

In pursuing our interest in cyclopropyl amino acids, we prepared the β-halo compound **1**. Since the addition of

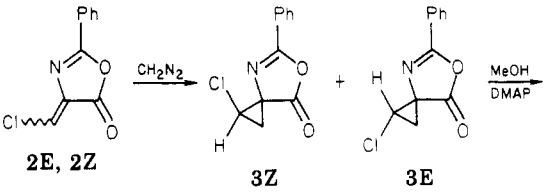


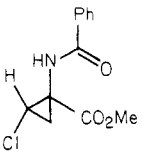
1E, X = H; Y = Cl
1Z, X = Cl; Y = H

diazomethane to unsaturated oxazolones is well-known[1] and since the requisite chloro compound **2** had been reported,[2] we prepared and studied its reaction with diazomethane. The configuration of **2** as reported in 1946 was unknown, and when the synthetic sequence (Scheme I) was carried out, only one isomer of **2** appeared to be produced, as determined by ^{1}H NMR and TLC analyses. However, when **2** was treated with CH_2N_2, a 1:11 mixture of isomeric cyclopropanes (**3**) was isolated in 75% yield. The predominant isomer of **3** was converted to the corresponding benzoyl methyl ester **4**, and X-ray crystallographic analyses showed it to be the *E* isomer. Assuming no isomerization during cyclopropanation or oxazolone ring opening, this indicated that the *E* isomer of the unsaturated oxazolone **2** also predominated. When the crude oxazolone **2E** was irradiated (3100 Å), the formation of a new product was observed by both TLC and NMR analyses. After 3 days, an apparent 1:1 mixture of **2E**/**2Z** was produced, and treatment of this mixture with CH_2N_2 followed by flash chromatography of the crude product gave a 57% yield of a **3E**/**3Z** mixture (3:2). Acid hydrolysis of **3E** and **3Z** separately afforded the hydrochlorides of **1E** and **1Z** each in 79% yield.

The conformational information obtained from the X-ray analysis is of considerable interest (Figure 1). The C(5)–C(4)(=O(1))–NH–C(1) group is analogous to a peptide unit with dimensions close to those given by Pauling[3] et al. and the C(1)–C(11)(=O(2))–O(3)–C(12) group also resembles a planar peptide unit. Hence **4** structurally approximates a dipeptide containing a cyclopropyl amino acid. The ϕ'[(C(4)–N(1)–C(1)–C(11)] and ψ'[N(1)–C(1)–C(11)–O(3)] angles are −62.5° and −33°, respectively, and these observed values are very close to the ϕ, ψ values[4] (−49°, −26°) of a right-handed 3_{10} helix or a right-handed α-helix (−58°, −47°). Thus, amino acid modifications of this type may promote the formation of a 3_{10} or an α-helix. The ϕ_2, ψ_2, ϕ_3, ψ_3 angles for the nonhelical β-bends[5] are approximately −60°, −30°, −90°, 0° (type I) and −60°, 120°, 80°, 0° (type II), and, clearly, the ϕ' and ψ' values observed about the cyclopropyl amino acid residue also approach these values. The effect of both dehydro- and cyclopropyl amino acids on peptide conformations appear to be similar, since both of the conformational states discussed above, i.e., the 3_{10} helix and the type I β-bend, also fall within the permissible regions[6] of the (ϕ, ψ) map of dehydroalanine.

Scheme I





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