which then chelates across the two iron(III) ions as found in the structure shown in Figure 1.

Acknowledgments. It is a pleasure to acknowledge the helpful discussions which were held with Drs. J. A. Bertrand, M. P. O'Hara, and S. B. Hanna during the course of this work. The financial assistance of the National Science Foundation through Grants CHE 75-20417 and CHE 77-08325 is greatly appreciated.

Supplementary Material Available: Observed and calculated structure factors (15 pages). Ordering information is given on any current masthead page.

Stereoselective Synthesis and DNMR Study of Two 1,8,15,22-Tetraphenyl[1_4]metacyclophan-3,5,10,12,17,19,24,26-octols[1,2]

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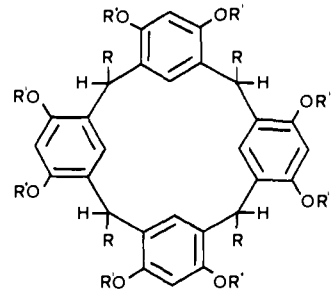
Abstract: The acid-catalyzed condensation of resorcinol with benzaldehyde initially gives a mixture of two stereoisomeric 1,8,15,22-tetraphenyl[1_4]metacyclophan-3,5,10,12,17,19,24,26-octols (**1a** and **1b**). The kinetically favored isomer **1a** is converted into the thermodynamically more stable one (**1b**), which subsequently is obtained in high yield (>80%) after longer reaction times. The configurations and conformations of the two isomers were investigated using molecular model and symmetry considerations combined with dynamic NMR measurements on the corresponding octabutyrates (**2a** and **2b**) and on the octabutyrates of the resorcinol–*p*-bromobenzaldehyde condensation products (**4a** and **4b**). The **a** isomers possess a chair-like conformation with the phenyl groups, in pairs, in axial positions on each side of the plane of the macrocyclic ring (C_{2h} symmetry). The **b** isomers possess a boat-like conformation with all four phenyl groups in the axial positions below the plane of the macrocyclic ring (C_{2v} symmetry). The **b** isomers can undergo pseudorotation [$\Delta G^{\ddagger}_{378K}$ = 79.5 ± 0.4 kJ mol^{-1} (19.0 ± 0.1 kcal mol^{-1}) (**4b**)]. The $\Delta G^{\ddagger}_{258K}$ values for the independent free rotation of *p*-bromophenyl groups in the octabutyrates **4a** and **4b** were 49.2 ± 0.4 and 54.0 ± 0.4 kJ mol^{-1} (11.8 ± 0.1 and 12.9 ± 0.1 kcal mol^{-1}), respectively. The calculations of the anisotropic effects of the aromatic rings in the macrocycles, based on the Bovey–Johnson equation, were helpful in ruling out one of the tentative stereostructures. The stereoselectivity of the reactions is attributed to a combination of three factors: the nonbonded intramolecular steric interactions in the triphenylmethane units, the reversibility of the cyclooligomerization, and the solubility differences of the two macrocyclic products.

The acid-catalyzed condensation of a phenol and an aldehyde generally results in a complex, amorphous mixture of products often possessing very high molecular weights. At the same time it has long been known that some phenols, like resorcinol, react with certain aldehydes, like benzaldehyde[3] and salicylaldehyde,[4] to give crystalline products. The structures of these phenolic compounds, which possess high melting points and fairly low solubilities in most organic solvents, were unknown for a long time.

Some 40 years ago Niederl and Vogel studied the reaction of resorcinol with a few aliphatic aldehydes.[5] In each case they obtained a single product for which they proposed the general structure I (R = alkyl; R′ = H). In view of the large number of steric and structural isomers possible, the isolation of a single macrocyclic condensation product is intriguing and tempted us to reinvestigate these condensation reactions.

In a preliminary communication we reported that the acid-catalyzed condensation of resorcinol and benzaldehyde gave a mixture of two stereoisomeric macrocycles, possessing the same



I

general [1_4]metacyclophane structure I (R = C_6H_5; R′ = H), in high yields.[6] The octabutyrate **4b** of one of the two resorcinol–*p*-bromobenzaldehyde condensation products was shown by X-ray crystallographic analysis to possess an all-axial and all-cis configuration of the phenyl groups with the macrocyclic ring in a boat-like conformation.[6-8]

In this paper we present the results of an extended study on the formation and degradation of the macrocycles in acid solution. The stereostructure of the second isomer **4a** was elucidated by correlation of the static and dynamic ^{1}H NMR data with molecular model and symmetry considerations and is in agreement

(1) (a) Cyclooligomeric Phenol–Aldehyde Condensation Products. 2. For part 1 see ref 6. (b) Taken in part from Högberg, A. G. S. Ph.D. Dissertation, Royal Institute of Technology, Stockholm, Sweden, 1977. (c) Part of this work was presented at the Euchem Conference on Ring Closure Reactions and Related Topics, Castel Gandolfo, Italy, Aug 29, 1978.

(2) Systematic names: **1a**, *r*-2,*c*-8,*t*-14,*t*-20-tetraphenylpentacyclo[19.3.1.1^{3,7}.1^{9,13}.1^{15,19}]octacosa-1(25),3,5,7(28),9,11,13(27),15,17,19(26),21,23-dodecaen-4,6,10,12,16,18,22,24-octol; **1b**, *r*-2,*c*-8,*c*-14,*c*-20-tetraphenylpentacyclo[19.3.1.1^{3,7}.1^{9,13}.1^{15,19}]octacosa-1(25),3,5,7(28),9,11,13(27),15,17,19(26),21,23-dodecaen-4,6,10,12,16,18,22,24-octol.

(3) (a) Baeyer, A. *Ber.* **1872**, *5*, 25. (b) Michael, A. *Am. Chem. J.* **1883**, *5*, 338. (c) Michel, A.; Ryder, J. P. *Ber.* **1886**, *19*, 1388. (d) Liebermann, C.; Lindenbaum, S.; Glawe, A. *Ibid.* **1904**, *37*, 1171. (e) Fabre, R. *Ann. Chim. (Paris)* **1922**, *18*, 82. (f) Mertens, E.; Fonteyn, M. *Bull. Soc. Chim. Belg.* **1936**, *45*, 186.

(4) Liebermann, C.; Lindenbaum, S. *Ber.* **1904**, *37*, 2728.

(5) Niederl, J. B.; Vogel, H. J. *J. Am. Chem. Soc.* **1940**, *62*, 2512.

(6) Erdtman, H.; Högberg, S.; Abrahamsson, S.; Nilsson, B. *Tetrahedron Lett.* **1968**, 1679.

(7) Nilsson, B. *Acta Chem. Scand.* **1968**, *22*, 732.

(8) An attempted X-ray analysis of the second octabutyrate isomer was unsuccessful because the inherent molecular symmetry caused a systematic absence of reflections which led to ambiguities in the crystal space group determination (Bo Nilsson, personal communication, 1969). Assuming the nonstandard space group $P2_1/n$, Palmer et al.[9] have, however, been successful with the corresponding octaacetate.

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with the results of a recent X-ray crystallographic study.[9] An hypothesis for the origin of the stereoselectivity of the reaction is advanced.

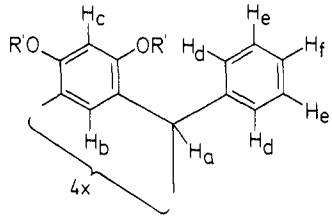
Results

Equimolar amounts of resorcinol and benzaldehyde were reacted in ethanolic hydrochloric acid. Using 1 M concentrations of the reactants, both macrocyclic products precipitated during the reaction. The yields of the two phenols **1a** and **1b** were determined as a function of the reaction time, as shown in Figure 1. While the yield of isomer **1b** and the combined yields of the two isomers increased with the reaction time, the yield of the initially predominantly formed isomer **1a** reached a maximum after 1 h and then decreased. The final product consisted of only the less soluble isomer **1b**, indicating that the formation of isomer **1a** was reversible under the reaction conditions. This was confirmed in a separate set of experiments in which a suspension of the isomer **1a** was treated under conditions similar to those used in the condensation reaction. After 5 h 80% of the material was recovered as an equal mixture of **1a** and **1b**. After 10 h all of the recovered material (80%) consisted of isomer **1b** only. After a similar treatment (heterogeneous solution) of isomer **1b** for 20 h, 87% of the unchanged starting material was recovered. Acidic treatment of isomer **1b** in homogeneous and consequently very dilute solution (ca. 2 mM) led to extensive degradation and only 18% of isomer **1b** was recovered. In neither experiment starting with isomer **1b** was any isomer **1a** detected in the final product.

Butyration of the crude resorcinol–benzaldehyde condensation product furnished a crystalline mixture consisting solely of the octabutyrates **2a** and **2b**. These could be separated by fractional recrystallization from methanol and ethanol.[10]

Similarly, the condensation of resorcinol with *p*-bromobenzaldehyde gave two stereoisomeric condensation products **3a** and **3b**, which upon butyration yielded the two octabutyrates **4a** and **4b**, respectively.

The octabutyrates possessed spectral properties in agreement with the [1$_4$]metacyclophane structure I (R = C_6H_5 or *p*-BrC_6H_4; R′ = COC_3H_7). Their ^{1}H NMR spectra provided the basis for the stereochemical assignments. The designations of the hydrogen atoms are given below. At ambient temperature the H_a resonances appear as a singlet and those of the H_b protons as a pair of singlets of equal intensity. In addition, in the two isomers **4a** and **4b** the H_c resonances appear as a separate pair of singlets of equal intensity and the H_d and H_e protons as a pair of doublets of a AA′XX′ system. While the H_a signals in all four octabutyrates remain as singlets throughout the temperature interval investigated, the other parts of the spectra show a characteristic temperature dependence. The H_b singlets in the spectra of octabutyrates **2b** and **4b** coalesce to one singlet at high temperatures (T_c = 375 and 378 K, respectively), whereas those in the spectra of octabutyrates **2a** and **4a** remain unchanged. In the NMR spectra of the two *p*-bromosubstituted isomers the same difference in the temperature dependence is observed for the H_c pair of singlets, i.e., coalescence into one singlet (**4b**) ($T_c \approx 350$ K) vs. no change (**4a**).



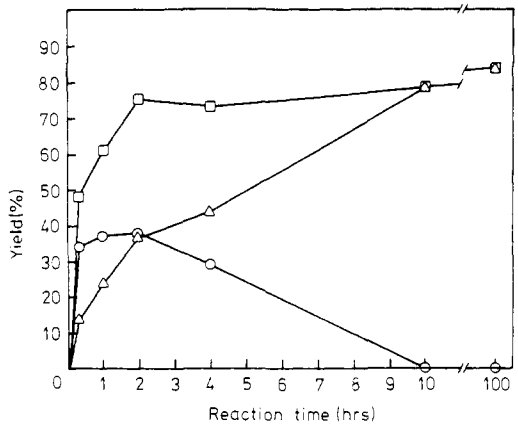


Figure 1. The reaction of resorcinol (1.0 M) and benzaldehyde (1.0 M) in a mixture of ethanol and concentrated hydrochloric acid (4:1) at 75 °C. The yields of the cyclooligomers **1a** (○) and **1b** (△) and total yield (□) vs. reaction time.

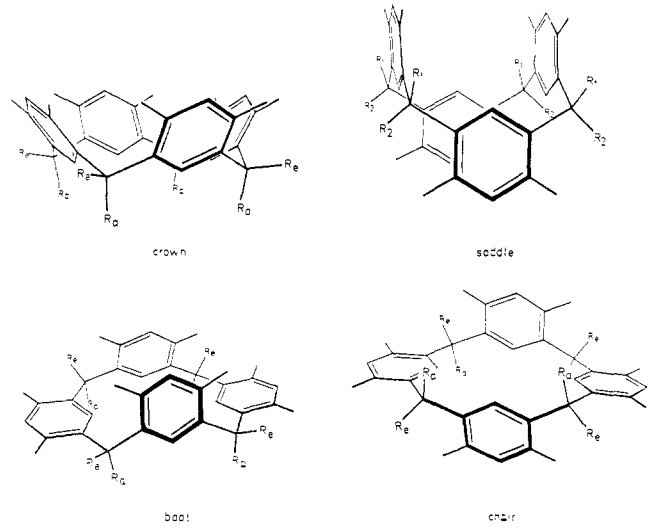


Figure 2. Principal nondissymmetrical conformations of [1$_4$]metacyclophane.

The AA′XX′ spectra of octabutyrates **4a** and **4b** changed to ABXY spectra at low temperatures ($T_c \approx 240$ and = 276 K, respectively).

The free-energy barriers, $\Delta G^{\ddagger}$, for the conformational processes were obtained from complete band-shape analyses of the NMR spectra.[11]

Discussion

Preliminary studies indicated that the stereostructure of the isomer **4a**, which at this time was unknown to us,[8] might be deduced from the known stereostructure of isomer **4b** by comparing the DNMR properties of the two compounds. Then, once the stereostructures of both isomers were at hand, DNMR measurements appeared to be a suitable technique for correlation of the resorcinol–*p*-bromobenzaldehyde isomers with the analogous condensation products (e.g., isomers **2a** and **2b**), allowing the assignment of the stereostructures of the latter in an indirect manner.[25]

Conformational Analysis of the Tetraphenyl[1$_4$]metacyclophane Ring System. The stereochemistry of the tetraphenyl[1$_4$]metacyclophanes may be defined by a combination of the following three stereochemical elements: (1) *the conformation of the macrocyclic ring* where four principal symmetrical arrangements of the metaphenylene groups are possible and where the macrocycle may possess a crown (C_{4v}), a saddle (D_{2d}), a boat-like (C_{2v}), or a chair-like (C_{2h}) conformation (Figure 2); (2) *the relative configuration of the phenyl groups* giving the all-cis, the cis-

(9) Palmer, K. J.; Wong, R. Y.; Jurd, L.; Stevens, K. *Acta Crystallogr., Sect. B* **1976**, *32*, 847. Our attention was drawn to this reference while our DNMR work was in progress.

(10) Michael obtained two compounds by repeatedly extracting the phenolic condensation product with ethanol.[3b] In our hands this method gave almost pure phenol **1b** as a crystalline residue, whereas phenol **1a**, contaminated by some phenol **1b**, was recovered from the ethanol solution.

(11) Binsch, G. *Top. Stereochem.* **1968**, *3*, 97.

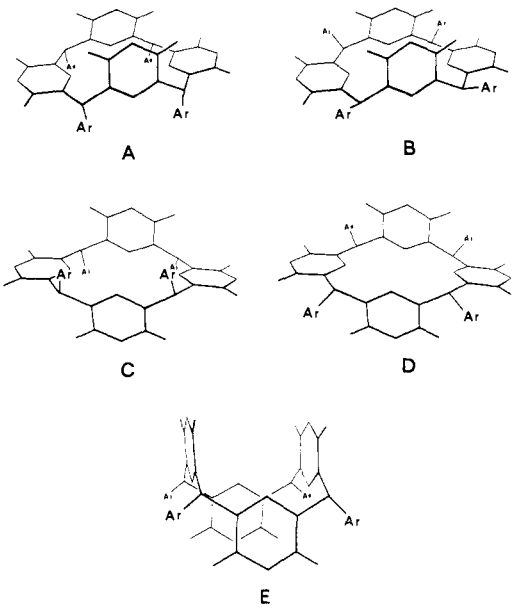


Figure 3. Hypothetical stereostructures A–E of macrocycle I (R = Ar). The OR′ groups are only indicated.

cis-trans, the cis-trans-trans, and the trans-cis-trans arrangement; (3) *the individual configuration of the phenyl groups* where in conformations of the macrocycle with *C* symmetry the phenyl groups may be either axial or equatorial.

An alternative mode of conformational analysis consists of viewing the molecule as being composed of four fused and partially overlapping triphenylmethane units. Each macrocyclic isomer is then uniquely described by the sum of the conformations of the various triphenylmethane units.

Symmetry Consideration of the NMR Spectra. Analysis of the NMR spectra recorded at ambient temperature suggest, that in each isomer all four phenyl groups are in equivalent positions while there are two different arrangements of the resorcinol moieties. These stereochemical requirements are only satisfied by the five stereostructures of macrocycle I shown in Figure 3.[12] Two of these, A (which is the stereostructure of isomer **4b** as determined by X-ray crystallographic analysis)[6,7] and B, possess an all-cis configuration and a flexible boat-like conformation (C_{2v}) with all the phenyl groups in axial positions in A and in equatorial positions in B. Within both these principal nondissymmetrical conformations, a continuum of conformers is possible differing mainly in the angle between the planes of the horizontally oriented resorcinol units. As long as a symmetry plane bisecting this angle is maintained, the C_{2v} symmetry of the conformer is retained. In either stereostructure A or B tilting the horizontally oriented resorcinol units downward until they become parallel to each other (intersecting angle 180°) gives the intermediate stereostructure E (C_{2v}) possessing an all-cis configuration and a saddle conformation. Finally stereostructures C and D possess a cis-trans-trans configuration and a rigid chair-like conformation (C_{2h}) with all the phenyl groups in axial positions in C and in equatorial positions in D.

Molecular Model Considerations. Molecular models (CPK) of stereostructures A and C appear to be relatively free of steric compression and the phenyl groups are fairly free to rotate. However, a gradually increasing intramolecular steric repulsion and interlocking of the phenyl groups are observed in models of stereostructures B, E, and D, the C_{2h} symmetry of the latter structure being virtually impossible to maintain in the model.

Calculations of the Aromatic Ring Current Effects. The anisotropic ring current effects on the intraannular H_b protons were

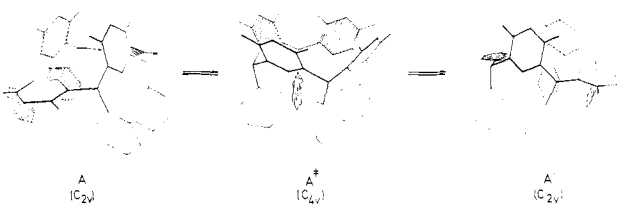


Figure 4. Pseudorotation of a molecule possessing stereostructure A. A nondissymmetrical transition state A‡ is indicated.

calculated for the hypothetical stereostructures A–E using the Bovey-Johnson equation[13] and compared with the experimentally found values (0.45 and 0.27 ppm for **2a** and **2b**, respectively). The interatomic distances were measured on Dreiding models. For the flexible stereostructures A and B the best $\Delta\delta H_b$ values (0.5 ppm for both A and B) were obtained for conformers having angles between the "horizontally" oriented rings of 0° for A and 150° for B. Acceptable calculated values (0.3 and 0.1 ppm) were also found for the stereostructures C and E, while the value calculated for stereostructure D (1.9 ppm) was too high, making this structure unlikely.

Structural Significance of the Dynamic NMR Measurements. The dynamic NMR measurements indicated that the **b** isomers can undergo two different conformational processes, with a high and a low energy barrier. For the **a** isomers only the low-energy process was observed.

A priori three different dynamic processes can be considered which listed in decreasing order of the extent of the conformational changes involved are (1) *inversion of the macrocyclic ring*,[14] which requires the flipping of the metaphenylene rings through the plane of the macrocyclic ring (axial and equatorial substituents are exchanged; the hypothetical interconversion of molecules possessing stereostructures A and B (possibly via an intermediate stereostructure E) or C and D are examples of an inversion); (2) *pseudorotation of the macrocyclic* ring,[14] which is a degenerate process and only possible in molecules possessing stereostructures A or B (C_{2v} symmetry) (it involves the interchange of vertically and horizontally oriented resorcinol units; axial and equatorial substituents are *not* exchanged); (3) *independent free rotation of the four phenyl groups*.

The High Energy Barrier. The dynamic NMR features of isomers **2b** and **4b** at elevated temperatures show that the exchange of the H_b protons takes place between equally populated states while the signals of the H_a proton are unaffected. Also, heating the isomers to a temperature above the coalescence temperature does not result in a mixture of isomers. Both these observations are inconsistent with an inversion process. Inspection of molecular models shows that inversion requires the phenyl groups to pass between the resorcinol units leading to an exceedingly crowded transition state.

However, the high temperature features are in good accordance with a pseudorotation in a molecule with the stereostructure A (as in isomer **4b**). The pseudorotation possibly takes place via a nondissymmetrical (C_{4v}) transition state A‡ (see Figure 4). A similar process is, in principle, possible in molecules possessing stereostructure B too. However, in this case, as in the inversion process, the pseudorotation suffers from a very crowded transition state B‡ since the phenyl groups have to pass between the resorcinol units. The free-energy barrier to pseudorotation is therefore likely to be much higher in molecules possessing stereostructure B than in those possessing stereostructure A.

In the alternative mode of analyzing this conformational interconversion, the pseudorotation of the macrocycle is equivalent to the simultaneous change of pitch of the propeller conformations of all four triphenylmethane units. This takes place by a two- (or three-) ring flip mechanism in the all-axial isomer and by a one- (or zero-) ring flip mechanism in the all-equatorial isomer.

(12) Combination of the three stereochemical elements, described in the beginning of the discussion section, indicates that there are 31 diastereomeric isomers of the macrocyclic ring system I (R = C_6H_5; R′ = H) including six enantiomeric pairs.

(13) (a) Johnson, C. E.; Bovey, F. A. *J. Chem. Phys.* **1958**, *29*, 1012. (b) Farnum, D. G.; Wilcox, C. F. *J. Am. Chem. Soc.* **1967**, *89*, 5379.

(14) For definitions of ring inversion and ring pseudorotation see: Anet, F. A. L. *Fortschr. Chem. Forsch.* **1974**, *45*, 169, and references cited therein.

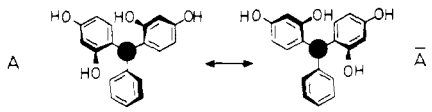


Figure 5. The two low-energy conformations A and Ā of 2,2′,4,4′-tetrahydroxytriphenylmethane. The closed circles indicate the methine hydrogens located above the plane of the paper.

As demonstrated by Mislow and co-workers, the former process proceeds via a less crowded transition state and is therefore energetically more favorable.[15] In the present system an additional steric factor might be considered. In addition to the nonbonded interactions between the three aromatic rings within each triphenylmethane unit, the conversion of the macrocycle A in the boat-like conformation to the crown conformation causes the four axial phenyl groups to move closer together, and thus the nonbonded interactions among them probably contribute to the free energy of the barrier to pseudorotation.

Similar values for the free energy of the barrier to pseudorotation, as determined by the coalescence method,[11] were found for both octabutyrates **2b** and **4b** ($\Delta G^{\ddagger}_{375K}$ = 79.4 and $\Delta G^{\ddagger}_{378K}$ = 79.5 kJ mol^{-1}). The $\Delta G^{\ddagger}_{378K}$ obtained for **4b** by the complete band-shape analysis was 79.5 ± 0.4 kJ mol^{-1}. This indicates that octabutyrate **2b** possesses the same general stereostructure A as octabutyrate **4b**.

The Low Energy Barrier. In the ^{1}H NMR spectra of the isomer **4a** and **4b** at elevated temperatures (in Me_2SO-d_6), the signals of the H_d and H_e protons appear as two doublets. At low temperatures (in $CDCl_3$) these doublets are each split into a pair of doublets of equal intensity indicating the presence of a rotational barrier for the *p*-phenylene groups. From an inspection of molecular models, it appears that the transition state of this relatively unfavorable one-ring flip process is considerably more crowded when the phenyl groups are in equatorial positions than when they are in axial positions. The magnitudes of the $\Delta G^{\ddagger}$ values of these barriers in isomers **4a** and **4b** may therefore be used to determine the relative positions of the phenyl groups in the two isomers relative to each other. Since isomer **4a** possesses a lower $\Delta G^{\ddagger}_{258K}$ value than isomer **4b** (49.2 ± 0.4 and 54.0 ± 0.4 kJ mol^{-1}, respectively), and the phenyl groups are known to occupy axial positions in isomer **4b**, it follows that the phenyl groups occupy axial positions in isomer **4a** as well. This isomer (and by analogy **2a**) was therefore assigned the stereostructure C. The lower $\Delta G^{\ddagger}$ value observed for isomer **4a** is also consistent with the fact that less nonbonded interaction occurs between the four phenyl groups when they are distributed two on each side of the molecule instead of all on the same side.

The preference for axial substituents has been demonstrated in structurally related compounds like 9-phenyl- and 9,10-diphenyl-9,10-dihydroanthracenes[16] and 9-phenylxanthenes.[17]

Origin of the Stereoselectivity of the Reaction. The resorcinol–benzaldehyde cyclooligomerization probably proceeds by a step-growth mechanism as postulated for the condensation of phenols with aldehydes under acidic conditions.[18] A likely intermediate in the reaction sequence is 2,2′,4,4′-tetrahydroxytriphenylmethane.[19] Hypothetically this molecule can adopt any one of eight propeller-shaped conformations (four *dl* pairs). Molecular-model considerations indicate that the A and Ā conformations (Figure 5) are sterically the least crowded. The two isomers **1a** and **1b** may be considered to be composed of four partially overlapping triphenylmethane subunits A,A,Ā,Ā and A,Ā,A,Ā, respectively. These are the only two permutations of the low-energy conformations A and Ā that give a cyclic assemblage (the permutation A,A,A,A, e.g., gives an S-shaped assemblage).

Statistically, the cis-trans-trans isomer **1a** is twice as likely to be formed as the all-cis isomer **1b**. In addition, molecular-model considerations confirmed by the dynamic NMR measurements (vide supra) indicate that additional nonbonded interactions exist between the phenyl groups in the all-cis isomer compared with the cis-trans-trans isomer. Similar difference in nonbonded interactions may appear in the earlier stages of the reaction sequence and in the final ring-closure step, which may explain why the isomer ratio **1a**:**1b** initially obtained (ca. 3–4 to 1) is larger than that statistically expected.

The condensation reaction is reversible, as indicated by the transient existence of **1a**, the isomerization of **1a** to **1b**, and the disappearance of **1b** from an acidic homogeneous solution. The isomerization presumably occurs by a protodealkylation process with scission of the methine–aryl C–C bonds, facilitated by the hydroxy groups in the ortho and para positions, and subsequent recombination.[20,21] The differences in the stereochemical structures of **1a** and **1b** require that at least two C–C bonds are cleaved before recombination gives the other isomer.

Thus the high stereoselectivity of the condensation reaction is apparently the result of a combination of three factors: conformational control via the nonbonded interactions within and between the triphenylmethane units of the intermediates, the reversibility of the carbon–carbon bond formations, and finally the difference in the solubilities of the two macrocyclic products. Further studies of these and related macrocycles are in progress.

Experimental Section

The NMR spectra were obtained using a Bruker WP 200 FT instrument equipped with a variable-temperature controller B-VT-1000. The recorded spectra were Fourier transforms of 40 or 80 accumulated free induction decays obtained using a 30° pulse angle, 8K data points, a spectrum width of 2000 Hz, and an exponential broadening function corresponding to a broadening of 0.24 Hz. The samples used were 0.15 M solutions in Me_2SO-d_6 or 0.04 M solutions in a mixture of $CDCl_3$ and CCl_4 (51:49 v/v).

Temperature Measurements. The temperatures were measured before and after each run using chemical-shift thermometers (CSTs). The values obtained varied between ±0.1 and ±0.7 °C from the average. The low-temperature CST was prepared by combining nine parts of a mixture of 0.03 vol % concentrated hydrochloric acid in CH_3OH with one part of CD_3OD (v/v). The high-temperature CST consisted of nine parts of a mixture of 0.03 vol % concentrated hydrochloric acid in ethylene glycol and one part of Me_2SO-d_6 (v/v). Each mixture was sealed in a NMR tube. The CSTs were calibrated using a precalibrated copper–constantan thermocouple placed in a dummy probe filled with 0.5 mL of CH_3OH or ethylene glycol.

Complete Band-Shape Analysis. The High Energy Barrier. The H_b and H_c parts of the NMR spectra of **4b**, recorded at 12 temperatures between 317 and 382 K, were visually compared with spectra simulated for a simple uncoupled two-site exchange,[22] using the CLATUX program.[11]

(15) Gust, D.; Mislow, K. *J. Am. Chem. Soc.* **1973**, *95*, 1535. Mislow, K.; Gust, D.; Finocchiaro, P.; Boettcher, R. J. *Fortschr. Chem. Forsch.* **1974**, *47*, 1.

(16) (a) Beckett, A. H.; Mulley, B. A. *J. Chem. Soc.* **1955**, 4159. (b) Brinkman, A. W.; Gordon, M.; Harvey, R. G.; Rabideau, P. G.; Stothers, J. B.; Ternary A. L., Jr., *J. Am. Chem. Soc.* **1970**, *92*, 5912. (c) Rabideau, P. W.; Paschal, J. W. *Ibid.* **1972**, *94*, 5801.

(17) McKinley, S. V.; Grieco, P. A.; Young, A. E.; Freedman, H. H. *J. Am. Chem. Soc.* **1970**, *92*, 5900.

(18) Cf. Lenz, R. W. "Organic Chemistry of Synthetic High Polymers"; Interscience: New York, 1967; p 138.

(19) This triphenylmethane is probably very reactive in acidic solution and has not been isolated yet. However, it has been shown to form under mild alkaline conditions.[6]

(20) For a treatment of reversibility and isomerization in the related Friedel–Crafts alkylation see: Norman, R. O. C.; Taylor, R. "Electrophilic Substitution in Benzenoid Compounds"; Elsevier: Amsterdam, 1965; pp 57–58 and Chapter 6, section 1.

(21) For examples of protodealkylation of di- and triarylmethanes see: (a) Kharasch, M. S.; Porsche, J. *J. Org. Chem.* **1936**, *1*, 265. (b) Burawoy, A.; Chamberlain, J. T. *J. Chem. Soc.* **1949**, 626.

(22) (a) In this treatment the T_2 value was used essentially as a line-width parameter, including the effect of unresolved long-range coupling (^4J and ^5J) between the H_a, H_b, and H_c protons, in addition to the normal transverse relaxation effects.[22b] While this approach is considered to give acceptable $\Delta G^{\ddagger}$ values (close to the coalescence point), systematic errors may be introduced into the corresponding $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ values.[22c,d] Work is now in progress to circumvent this possible source of error by studying the analogous macrocycles, in which part or all of the long-range coupling effects are eliminated by substituting deuterium for one or more of the protons coupled to the H_b protons.[22f] (b) Sutherland, I. O. *Annu. Rep. NMR Spectrosc.* **1971**, *4*, 71. (c) Drakenberg, T.; Carter, R. E. *Org. Magn. Reson.* **1975**, *7*, 307. (d) Carter, R. E.; Dahlqvist, K.-I.; Berntsson, P. *Ibid.* **1977**, *9*, 44. (e) The T_1 values of the H_{bw} and H_{bh} protons of isomer **4b** differed by less than 10%.[22f] (f) Högberg, A. G. S.; Weber, M., to be published.

The T_2 input values were derived[23] from the width of the H_b (H_c) singlets at 297 K using the width of the H_a singlet as reference values. The $\delta\nu^\circ_{AB}$ input values were varied until a best fit was obtained. Regression analysis by a linear least-squares plot of ΔG^* vs. T gave $\Delta G^*_{378} = 79.5 \pm 0.4$ kJ mol^{-1} (19.0 ± 0.1 kcal mol^{-1}). The errors in this and the other ΔG^* values given here are the maximum residuals around the regression line.

The Low Energy Barrier. The low-temperature spectra show only AX(A'X') coupling; i.e., they change from two doublets (at ν_A and ν_X) in the fast exchange region to four doublets in the slow exchange region. Because of signal overlap only the high-field part of the spectra, i.e., the X(X') → XY part, was simulated. The spectra were simulated by the superposition of two simple two-site exchange systems (calculated by a modified CLATUX program[11]), which were displaced by J_{AX} and J_{BY}, and the differences in intensity caused by the coupling were accounted for by suitable weighting factors. This is admittedly an approximation, but was considered permissible in view of the large shift differences between the A and X sites.

Calculations of the Aromatic Ring Current Effects.[13] For each stereostructure the results are given as α° vs. calculated $\Delta\delta H_b$ (ppm), that is, the intersecting angle between the horizontally oriented resorcinol rings vs. the calculated shift difference between the vertically and horizontally oriented H_b protons. When $\alpha = 0°$, the two rings are in the same plane. Positive α values indicate that the two rings are tilted downward. When $\alpha = 180°$, A and B ≡ E. A: −20, 0.8; 0, 0.5; 20, 2.0. B: 0, 2.1; 20, 2.6; 135, 0.9; 150, 0.5. C: 0, 0.3. D: 0, 1.9. E: 180, 0.1.

Standard Procedure for the Resorcinol–Benzaldehyde Condensation. Concentrated hydrochloric acid (10 mL) was rapidly added to a homogeneous solution of 5.51 g (50 mmol) of resorcinol and 5.31 g (50 mmol) of benzaldehyde in 40 mL of 96% ethanol. The reaction mixture was stirred at 75 °C (thermostatically regulated oil bath) under nitrogen for periods varying from 20 min to 100 h (see Figure 1) and then rapidly cooled in an ice bath. The precipitate that formed during the reaction was collected by filtration and washed with a small amount of methanol and then with water until the filtrate was neutral. Addition of water to the filtrate usually gave a second precipitate which was also collected. The combined air-dried precipitates were acylated by gentle heating with a two- to threefold excess of butyric anhydride and ca. 1 mL of pyridine. The excess was then removed by distillation in vacuo. The crude butyrate mixture was triturated with ca. 15 mL of methanol. The crystals were collected by filtration and washed with a small amount of cold methanol. Care was taken not to wash away the more soluble isomer. After the mixture had been dried to constant weight, the ratio between **2a** and **2b** was determined by comparing the areas under the methine signals at δ 5.52 and 5.40 ppm in the NMR spectra. Neither the NMR spectrum nor the TLC analysis of the crystalline mixture showed the presence of any other isomers.

Control Run. The reproducibility of the acylation and workup procedure was checked by hydrolyzing an equal mixture (2 g) of the octabutyrates **2a** and **2b** in ethanolic potassium hydroxide and then rebutyrating the product as described above (86% recovery). No significant change in the isomer ratio **2a**:**2b** was observed (50.2:49.8 ± 0.6 vs 49.8:50.2 ± 1.8%).

Separation of the Octabutyrates 2a and 2b from the Crude Butyrate Mixture. To obtain the pure octabutyrates the crude butyrate of the resorcinol–benzaldehyde condensation product was extracted three to four times with hot methanol. The colorless crystals which separated from the first two extracts were recrystallized three times from methanol, yielding octabutyrate **2a**: mp 214–215 °C; UV max (95% C_2H_5OH) 270 nm (ϵ 5260), 278 (4780); IR (KBr) 1755 (ester C=O) cm^{-1}; NMR ($CDCl_3$) δ 7.13 (s, 2, H_c), 7.00–6.97 (m, 12, H_e and H_f), 6.91 (s, 2, H_c), 6.67–6.63 (br m, 8, H_d), 6.28 (s, 2, H_{bv}), 5.82 (s, 2, H_{bh}), 5.52 (s, 4, H_a), 2.36–2.10 (m, 16, CH_2CO), 1.60–1.42 (m, 16, CH_2), 0.88 (t, 12, J = 7.3 Hz, CH_3), and 0.85 (t, 12, J = 7.3 Hz, CH_3); mass spectrum m/z 1353 ($M + 1$).[24] Anal. ($C_{84}H_{88}O_{16}$) C, H. The residue after extraction was recrystallized three times from ethanol to give octabutyrate **2b**: mp 251–252 °C; UV max (95% C_2H_5OH) 271 nm (ϵ 3350), 277 (3170); IR (KBr) 1755 (ester C=O) cm^{-1}; NMR ($CDCl_3$) δ 7.04–6.99 (m, 14, H_c, H_e, and H_f), 6.91 (s, 2, H_c), 6.66 (br s, 8, H_d), 6.15 (s, 2, H_{bv}), 5.89 (s, 2, H_{bh}), 5.40 (s, 4, H_a), 2.76–1.98 (m, 16, CH_2CO), 1.67–1.34 (m, 16, CH_2), 0.95 (t, 12, J = 7.3 Hz, CH_3), and 0.81 (t, 12, J = 7.3 Hz, CH_3); mass spectrum m/z 1353 ($m + 1$).[24] Anal. ($C_{84}H_{88}O_{16}$) C, H.

Isomerization of Phenol 1a to Phenol 1b. A solution of 2.71 g (2.0 mmol) of the octabutyrate **2a** in 25 mL of a mixture (4:1 v/v) of ethanol (96%) and concentrated hydrochloric acid was stirred at 75 °C for periods of 1, 5, 10, or 20 h. The phenolic precipitate was acylated as described above and the resulting mixture of octabutyrates was analyzed by NMR. Recovered yields [given as reaction time (h), yield of **2a** (%), yield of **2b** (%)]: 1, 75, 9; 5, 38, 40; 10, 0, 80; 20, 0, 84.

Attempted Isomerization of Phenol 1b. A. In Heterogeneous Solution. In an experiment similar to the above the octabutyrate **2b** was heated with acid for 20 h. The resulting phenol was butyrated and 87% of butyrate **2b** was recovered. No butyrate **2a** could be detected. (**B**). **In Homogeneous Solution.** A homogeneous solution of 1.36 g (1.0 mmol) of the octabutyrate **2b** in a mixture of 400 mL of butanol and 100 mL of concentrated hydrochloric acid was stirred at 75 °C for 10 h. The solution was concentrated to about 50 mL in vacuo, washed with water until it was neutral, and evaporated to dryness in vacuo. The phenolic residue was acylated with butyric anhydride (20 mL) and pyridine in the usual way. The butyrated mixture was stirred with cold methanol (ca. 20 mL) and filtered. The crystalline residue consisted of 0.24 g (18%) of octabutyrate **2b**. Evaporation of the filtrate gave 1.07 g of an amorphous material (a glass). No octabutyrates **2a** or **2b** could be detected in this material either by TLC or by NMR.

Octabutyrates 4a and 4b. The resorcinol–*p*-bromobenzaldehyde condensation product gave two octabutyrates. **4a**: mp 314–316 °C; IR (KBr) 1755 (ester C=O) cm^{-1}; NMR (T = 30 °C) ($CDCl_3$) δ 7.23 (d, 8, J_{de} = 8.6 Hz, H_e), 7.02 (s, 2, H_c), 6.92 (s, 2, H_c), 6.55 (d, 8, J_{de} = 8.3 Hz, H_d), 6.22 (s, 2, H_{bv}), 5.84 (s, 2, H_{bh}), 5.49 (s, 4, H_a), 2.40–2.13 (m, 16, CH_2CO), 1.63–1.42 (m, 16, CH_2), 0.883 (t, 12, J = 7.3 Hz, CH_3), and 0.876 (t, 12, J = 7.3 Hz, CH_3); ($T \approx -70$ °C) ($CDCl_3$–CCl_4, 51:49 v/v) (downfield part) δ 7.27 (br d, 4, J_{de} = 8.8 Hz, H_e), 7.17 (br d, 4, J_{de} = 8.4 Hz, H_e), 6.93 (s, 2, H_c), 6.82 (s, 2, H_c), 6.75 (br d, 4, J_{de} = 8.6 Hz, H_d), 6.29 (br d, 4, J_{de} = 8.2 Hz, H_d), 6.12 (s, 2, H_{bv}), 5.73 (s, 2, H_{bh}), and 5.36 (s, 4, H_a). Anal. ($C_{84}H_{84}Br_4O_{16}$) C, H; Br: calcd, 19.15; found, 19.69. **4b**: mp 241–242 °C; IR (KBr) 1755 (ester C=O) cm^{-1}; NMR (T = 30 °C) ($CDCl_3$) δ 7.25 (d, 8, J_{de} = 7.1 Hz, H_e), 6.99 (s, 2, H_c), 6.93 (s, 2, H_c), 6.53 (v br s, 8, H_d), 6.07 (s, 2, H_{bv}), 5.76 (s, 2, H_{bh}), 5.35 (s, 4, H_a), 2.33–2.02 (m, 16, CH_2CO), 1.68–1.37 (m, 16, CH_2), 0.94 (t, 12, J = 7.3 Hz, CH_3), and 0.84 (t, 12, J = 7.3 Hz, CH_3); (T = −49 °C) ($CDCl_3$–CCl_4, 51:49 v/v) (downfield part) δ 7.30–7.15 (m, 8, H_e), 6.90 (s, 2, H_c), 6.82 (s, 2, H_c), 6.74 (br d, 4, J_{de} = 8.3 Hz, H_d), 6.20 (br d, 4, J_{de} = 7.6 Hz, H_d), 5.94 (s, 2, H_{bv}), 5.61 (s, 2, H_{bh}), and 5.23 (s, 4, H_a). Anal. ($C_{84}H_{84}Br_4O_{16}$) C, H, Br.

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(23) Lidén, A.; Sandström, J. *Tetrahedron* **1971**, *27*, 2893.

(24) The signals appeared as a cluster of poorly resolved peaks with the ($M + 1$) peak as the most intense one. Mass calibration was performed using an internal perfluorokerosene reference sample.

(25) An examination of several other analogous condensation products had already revealed that other physical and spectroscopic properties, including melting points, solubilities, ^1H and ^{13}C NMR chemical shift parameters (recorded at ambient temperature), IR, UV, or mass spectrometric data, could not be used for unambiguously assigning the **a** and **b** isomers.