tion of **1**, particularly by fluorenone, whereas only process 3 is observed in triplet quenching by DTBN,[11] is uncertain. Possibly energy transfer to **1** is favored by better steric accessibility. On the other hand, failure to observe process 2 was predictable. Unlike nitric oxide which is excited to a quartet by sensitization,[12] **1** lacks the singly occupied pair of degenerate orbitals present in nitric oxide and must therefore have a relatively high energy quartet state.

(11) R. E. Schwerzel and R. A. Caldwell, *J. Amer. Chem. Soc.*, in press. We thank these authors for providing a copy of their manuscript prior to publication.
(12) J. Heicklen and N. Cohen, *Advan. Photochem.*, **5**, 268 (1968).
(13) Syva Postdoctoral Fellow, 1969–1970.
(14) Syva Postdoctoral Fellow, 1970–1972.

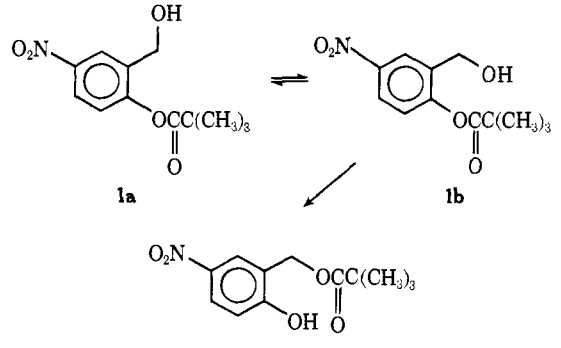
Edwin F. Ullman,* Ludwig Call,[13] S. S. Tseng[14]
Contribution No. 46, Syva Research Institute
Palo Alto, California 94304

Received November 13, 1972

Orientational Catalysis by Cyclohexaamylose

Sir:

We wish to report that inclusion of 2-hydroxymethyl-4-nitrophenyl trimethylacetate (**1**) within the cavity of cyclohexaamylose produces a sixfold acceleration in the rate of conversion of **1** to **2**. In contrast, formation of the inclusion complex of **1** with cycloheptaamylose decelerates the rate of this intramolecular transesterification by a factor of 5. We suggest that these cycloamyloses, by virtue of their ability to include organic materials within rigid binding sites,[1] perturb the equilibrium between orientational conformers **1a** and **1b**, and, thereby, force the reacting groups of **1** to assume either a mutually favorable or unfavorable orientation with respect to the activated complex. We further suggest that binding forces between cycloamylose and **1** are utilized to effect these orientational restrictions.

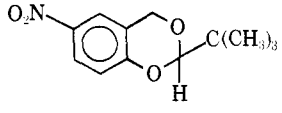


1a **1b**

2

Migration of the trimethylacetyl group[2] can be conveniently followed by measuring the increase in uv absorption at 349 nm, the isosbestic wavelength for ionization of **2**. In aqueous solutions of dilute buffers containing from 0 to 0.02 *M* cycloamylose, the acyl migration obeys a first-order rate law. The only product of the migration is **2**, as indicated by the identity of the spectra of the reaction product and analytically pure **2**.[3] Values of k_2, the maximal first-order rate constant for conversion of **1** to **2** in the presence of a saturating amount of cycloamylose, and K_d, the dissociation constant of the cycloamylose–**1** inclusion complex, have been calculated from the dependence of k_{obsd} on cycloamylose concentration.[1] At 25.2°, within the pH range 4.95–7.60, the rate of conversion of **1** to **2** displays a linear dependence on hydroxide ion activity: in the absence of added cycloamylose, $k_{obsd} = [(3.41 \pm 0.14) \times 10^5]a_{OH}$; in the presence of cyclohexaamylose, $k_2 = [(25 \pm 10) \times 10^5]a_{OH}$; and, in the presence of cycloheptaamylose, $k_2 = [(0.64 \pm 0.05) \times 10^5]a_{OH}$. Unlike the maximal rate constants, the dissociation constants of the inclusion complexes of **1** with these two cycloamyloses are pH independent: at 25.2°, $K_d = (4.78 \pm 0.25) \times 10^{-2}$ *M* for the cyclohexaamylose complex of **1** and $(9.60 \pm 0.75) \times 10^{-4}$ *M* for the cycloheptaamylose complex of **1**. At pH 6.81, in the absence of added cycloamylose, the temperature dependence of k_{obsd} implies $\Delta H^{\ddagger} = 12.9 \pm 0.2$ kcal/mol and $\Delta S^{\ddagger} = -22.6 \pm 0.3$ gibbs; in the presence of cyclohexaamylose, the temperature dependence of k_2 implies $\Delta H^{\ddagger} = 13.1 \pm 0.5$ kcal/mol and $\Delta S^{\ddagger} = -18.3 \pm 1.8$ gibbs.

The suggestion that catalysis by cyclohexaamylose arises from the selection of a "reactive" ground state orientational conformer of **1** in a prior equilibrium binding process is supported by the following observations. (1) The reversal in the effects of cyclohexaamylose and cycloheptaamylose, which differ only in the sizes of their binding sites,[4] is indicative of a mechanism in which reactivity is determined by the geometry of the fit of the reactant to the binding site. (2) Orientational restriction in the ground state of **1** is equivalent to the freezing of an internal rotational degree of freedom, a process which involves an entropy change of about 4.5 gibbs.[5] The cyclohexaamylose-induced rate acceleration is entirely entropic in origin with $\Delta\Delta S^{\ddagger} = 4.3 \pm 2.0$ gibbs. (3) The inclusion complex of cyclohexaamylose with **3**[6] ($K_d = (1.22 \pm 0.15) \times 10^{-2}$ *M*) is more stable than the cyclohexaamylose–**1** inclusion complex by a factor which agrees, within experimental error, with the observed rate acceleration. Hence, to the extent that **3** accurately simulates the activated complex for the conversion of **1** to **2**,[7] the driving force for catalysis can be attributed



3

(1) D. W. Griffiths and M. L. Bender, *Advan. Catal. Relat. Subj.*, **23**, 209 (1973).
(2) A detailed investigation of this intramolecular transesterification is in progress; several similar transacylations have been previously described: M. Wakselman, *C. R. Acad. Sci., Ser. C*, **262**, 770 (1966); B. Helferich and H. Liesen, *Chem. Ber.*, **83**, 567 (1950); B. Helferich and H.-O. Muller von Blumencron, *ibid.*, **86**, 1058 (1953); W. Korytnyk and B. Paul, *J. Org. Chem.*, **32**, 3791 (1967).
(3) Mp 140–141°; nmr (acetone-d_6) δ 1.10 (s, 9), 5.21 (s, 2), 7.05–8.25 (m, 3). *Anal.* Calcd for $C_{12}H_{15}NO_5$: C, 56.91; H, 5.97; N, 5.53. Found: C, 56.73; H, 6.01; N, 5.49.
(4) Whereas the diameter of the cyclohexaamylose cavity is 4.5 Å, the diameter of the cycloheptaamylose cavity is more than 2 Å larger.[1]
(5) M. I. Page and W. P. Jencks, *Proc. Nat. Acad. Sci. U. S.*, **68**, 1678 (1971).
(6) Mp 82–83°; nmr (acetone-d_6) δ 1.05 (s, 9), 4.87 (s, 1), 5.07 (s, 2), 6.83–8.07 (m, 3). *Anal.* Calcd for $C_{12}H_{13}NO_4$: C, 60.75; H, 6.37; N, 5.90. Found: C, 60.89; H, 6.43; N, 5.94.
(7) A large difference between the values of K_d for the two enantiomers of **3** is unlikely since previous investigations of the association of the cycloamyloses with chiral materials have failed to reveal a significant dependence of K_d on the chirality of the substrate: H. P. Benschop and G. R. Van den Berg, *Chem. Commun.*, 1431 (1970); K. Flohr, R. M. Paton, and E. T. Kaiser, *ibid.*, 1621 (1971); C. van Hooidonk and C. C. Groos, *Recl. Trav. Chim. Pays-Bas*, **89**, 845 (1970).

entirely to the optimum affinity of cyclohexaamylose for the activated complex. This is equivalent to saying that, in the ground state, a portion of the free energy gained from association of cyclohexaamylose with **1** is used to impose the orientational restriction, thereby decreasing the stability of the inclusion complex by an amount equal to the rate acceleration.

In conclusion, orientational catalysis by cyclohexaamylose supports the suggestion that binding forces between an enzyme and its substrate can be used to overcome part of the free-energy barrier to activation.[8] The cyclohexaamylose-induced rate acceleration, however, is much smaller than rate accelerations which can be achieved by converting intermolecular to intramolecular reactions.[9] Consequently, when the reacting groups in an intramolecular reaction can assume a mutually favorable orientation without introducing strain elsewhere in the system, the imposition of rigid orientational restrictions apparently leads to only a small additional rate acceleration.

Acknowledgment. Financial support from the National Science Foundation is gratefully acknowledged.

(8) W. P. Jencks, "Catalysis in Chemistry and Enzymology," McGraw-Hill, New York, N. Y., 1969, Chapter 5 and references therein.
(9) M. L. Bender, "Mechanisms of Homogeneous Catalysis from Protons to Proteins," Wiley, New York, N. Y., 1971, pp 312–317.

David W. Griffiths, Myron L. Bender*
Department of Chemistry, Northwestern University
Evanston, Illinois 60201

Received November 27, 1972

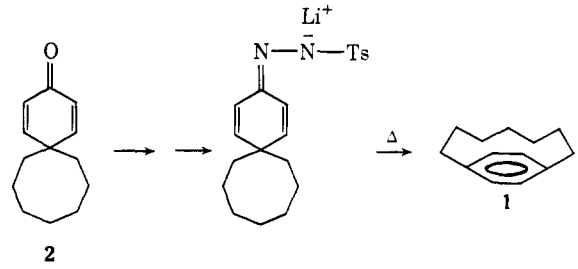
[7]Paracyclophane[1]

Sir:

The smallest known [*m*]paracyclophane[2] is the $m = 8$ isomer, first described over 11 years ago.[3] The synthesis of [8]paracyclophane was an indirect one and not obviously extended to the lower homologs.[4] A more conventional ring contraction route succeeded in providing [8]paracyclophanecarboxylic acid,[5,6] but [7]paracyclophane (**1**) has evaded synthesis for over a decade.[4]

We report here a simple, one-step synthesis of **1** and a few of the properties of this smallest of the known [*m*]paracyclophanes.

Our route was suggested by the observation that 4,4-dimethylcyclohexadienylidene[7] rearranged to *p*-xylene on generation in the gas phase.[8] Accordingly, we synthesized[9] spiro[5.7]trideca-1,4-dien-3-one (**2**) and converted it to the lithium salt of the corresponding tosylhydrazone. Flash pyrolysis of this material at 360–380° (0.1 Torr) gave a material which was resolved by gas chromatography into two peaks in the ratio 1.4/1. The yield was approximately 20%.[11] The first product was a mixture of 1-phenylheptane and 7-phenylheptene-1 (nmr analysis), and the second was the anticipated **1**.



2 **1**

A precise mass measurement established the formula as $C_{13}H_{18}$ (calcd, 174.14084; found, 174.14078). The nmr spectrum, which closely resembled that of [9]paracyclophane[12] (CCl_4, singlet, τ 2.93, 4 H; triplet, τ 7.36, 4 H, $J = 6.5$ Hz; sym mult, τ 8.5–9.5, 8 H; sym mult, τ 10.3–10.9, 2 H), is consistent only with **1**. Benzocyclononene is eliminated by a comparison of nmr spectra,[13] and one would not expect a singlet for the aromatic protons of [7]metacyclophane.[14] Further, the ultraviolet spectrum reported for [8]metacyclophane (266 nm, log ϵ 2.4)[15] does not compare well with that of **1**.

The ultraviolet spectrum of **1** (EtOH, nm (log ϵ), 216 (4), 245 (4), 283 (3)), does match well with that predicted by Allinger and coworkers,[4,5] 210 (4), 247 (3), 288 (2), and thus the aromatic ring is probably substantially deformed. A precise determination of the amount of bending must await the determination of the structure of **1** or a derivative, however.

Speculation on the mechanism of formation of **1** is premature, but leading possibilities include direct ring migration or carbon–carbon insertion to give a bridged Dewar benzene that subsequently opens to **1**.

(1) Support for this work by the National Science Foundation through Grant GP-30797X and by the donors of the Petroleum Research Fund, administered by the American Chemical Society, is gratefully acknowledged (5528 ACl,4).
(2) For reviews see: D. J. Cram and J. M. Cram, *Accounts Chem. Res.*, **4**, 204 (1971); and B. H. Smith, "Bridged Aromatic Compounds," Academic Press, New York, N. Y., 1964.
(3) D. J. Cram and G. R. Knox, *J. Amer. Chem. Soc.*, **83**, 2204 (1961); D. J. Cram, C. S. Montgomery, and G. R. Knox, *ibid.*, **88**, 515 (1966).
(4) After the submission of this work we became aware of the pending publication of the synthesis of [7]paracyclophane-3-carboxylic acid. We thank Professor N. L. Allinger for communication of his results prior to publication and for pointing out that [7]- and [8]paracyclophanes contain protons which resonate at extremely high fields in the nmr. N. L. Allinger and T. J. Walter, *J. Amer. Chem. Soc.*, **94**, 9267 (1972).
(5) N. L. Allinger, L. A. Freiberg, R. B. Hermann, and M. A. Miller, *ibid.*, **85**, 1171 (1963).
(6) A. T. Blomquist and L. F. Chow, cited in A. T. Blomquist and F. W. Schlaefer, *ibid.*, **83**, 4547 (1961).
(7) M. Jones, Jr., A. M. Harrison, and K. R. Rettig, *ibid.*, **91**, 7462 (1969).
(8) R. H. Levin and T. E. Berdick, unpublished observation.
(9) An improved variation of the usual[10] procedure was used: V. V. Kane, unpublished results, to be submitted shortly. Details available on request.
(10) F. G. Bordwell and K. M. Wellman, *J. Org. Chem.*, **28**, 1347, 2544 (1963).
(11) We have very probably not yet optimized conditions.
(12) D. J. Cram and M. Goldstein, *J. Amer. Chem. Soc.*, **85**, 1063 (1963).
(13) A. C. Cope and M. W. Fordice, *ibid.*, **89**, 6187 (1967).
(14) *m*-Xylene, for instance, shows a multiplet between 2.7 and 3.2.
(15) A. J. Hubert and J. Dale, *J. Chem. Soc.*, 86 (1963).

Anthony D. Wolf, Vinayak V. Kane, Ronald H. Levin Maitland Jones, Jr.*
Department of Chemistry, Princeton University
Princeton, New Jersey 08540

Received November 28, 1972

Electron Nuclear Double Resonance of Bacteriochlorophyll Free Radical *in Vitro* and *in Vivo*[1]

Sir:

This is a preliminary account of the first electron nuclear double resonance (endor)[2] studies of bacterio-

(1) Work performed under the auspices of the U. S. Atomic Energy Commission.
(2) G. Feher, *Phys. Rev.*, **103**, 834 (1956).