

was acetylated using pyridine (20 ml.) and the above acetic-1-C¹⁴ anhydride (15 ml.) in the manner previously described,⁹ and the desired β -anomer was separated as before by fractional crystallization of the crude product from 2-propanol. The final material had m.p. 92.2–93.0°, $[\alpha]_{25}^{25}D -3.04^\circ$ (*c* 1.0, CHCl₃) and a specific radioactivity of 7.260 \pm 0.006 mc./mole.

Anomerization and C1 Acetoxy Exchange Experiments.— Since the kinetic data obtained in consecutive individual anomerization and C1 acetoxy exchange experiments were, for unknown reasons, not as reproducible as might be desired, we have wherever feasible obtained both anomerization and exchange data on the same reaction mixture, thus eliminating the uncontrollable errors attending separate experiments. Two series of experiments were conducted, one employing a 1:1 mixture of acetic anhydride and acetic acid 0.001 *M* in sulfuric acid as the anomerizing solvent, and the other employing absolute acetic acid (containing 1% acetic anhydride) 0.002 *M* in sulfuric acid. The same solvent and catalyst solution was employed in all of the experiments in each series. All solutions were thermostated at 25 \pm 0.2° prior to and during each experiment. The

procedure for a typical experiment was: The above randomly labeled tetra-*O*-(acetyl-1-C¹⁴)-2-deoxy- β -D-glucose (0.6646 g.) was dissolved in 18.0 ml. of 1:1 acetic acid-acetic anhydride, and the solution was treated at time zero with 2.0 ml. of freshly prepared catalyst solution consisting of the same solvent 0.01 *M* in sulfuric acid. Half of the resulting solution, 0.1 *M* in solute and 0.001 *M* in catalyst, was placed in a 2-dcm. jacketed polarimeter tube for polarimetric observations and the remaining half was sampled for residual radioactivity at the indicated time intervals, isolating the product from each aliquot as previously described.^{8a} The crude product in each case was dried for several days *in vacuo* over P₂O₅ and NaOH, then assayed as usual¹⁰ for its radioactivity. The C1 acetoxy exchange data pertaining to these experiments are summarized in Table III. The corresponding anomerization rate data, obtained as fully described previously,^{2,3,5} are given in Table II.

(10) W. A. Bonner, *J. Am. Chem. Soc.*, **80**, 3378 (1958); O. K. Neville, *ibid.*, **70**, 3501 (1948); V. A. Raaen and G. A. Ropp, *Anal. Chem.*, **25**, 174 (1953).

[CONTRIBUTION FROM THE STERLING-WINTHROP RESEARCH INSTITUTE, RENSSELAER, N. Y.]

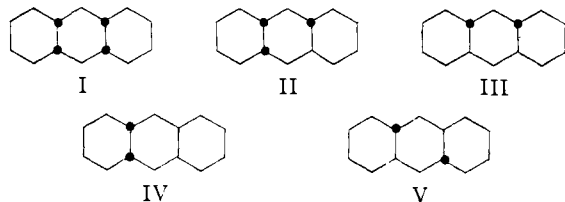
The Preparation of trans-anti-trans-Perhydroanthracene

BY ROBERT L. CLARKE

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The preparation of the fifth and last of the perhydroanthracene isomers, a *chair-boat-chair* form, is described.

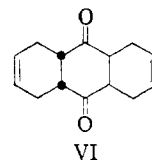
Of the five possible perhydrogenated anthracenes, the *cis-syn-cis* isomer I, m.p. 61°; the *cis-trans* isomer II, m.p. 40°; and the *trans-syn-trans* isomer III, m.p. 90°; have been known for several years.¹ Recently, Hill and Martin,² Crossley and Henbest,³ and Clarke and Johnson⁴ independently isolated the *cis-anti-cis* isomer IV, m.p. 122°. The last and possibly the most interesting of these hydrocarbons, *trans-anti-trans*-perhydroanthracene (V), m.p. 48.5–49.7°, is reported in the present paper. This compound has been isolated also by Hill and Martin.⁵ The considerable inter-



est in this isomer stems from the fact that its central ring is forced into a boat or *stretched*⁶ conformation. It constitutes one of the simplest structures containing such a system and a comparison of this isomer with the all-chair, *trans-syn-trans* isomer by combustion calorimetry should afford an estimate of the difference in energy between the boat and the

chair forms of cyclohexane. The first such determination of this energy difference by this method was recently reported by Johnson, Margrave, Bauer, Frisch, Dreger and Hubbard.⁷

When earlier investigations in our laboratory had led to the isolation of *cis-anti-cis*-perhydroanthracene (IV),⁴ substantiation of its structure was sought through the addition of two equivalents of 1,3-butadiene to one equivalent of benzoquinone, the required *cis-anti-cis* skeleton presumably being formed; *cf.* structure VI. As an ancillary experi-



ment, the hydroanthraquinone VI was isomerized (KOH) and hydrogenated as described by Alder and Stein⁸ to give the *trans-trans*-decahydro-9,10-anthraquinone of m.p. 253–256° and this diketone was subjected to modified Wolff-Kishner conditions for reduction. The Huang-Minlon modification⁹ did not give satisfactory results but the Barton, Ives and Thomas modification¹⁰ produced a 64% yield of hydrocarbon products. Separation of this mixture of hydrocarbons was not accomplished by adsorption chromatography on silica gel or alumina with pentane as a solvent and was poorly accomplished by fractional crystallization. However, separation of the mixture into two distinct

(1) Cf. J. W. Cook, N. A. McGinnis and S. Mitchell, *J. Chem. Soc.*, 286 (1944).

(2) R. K. Hill and J. G. Martin, *Proc. Chem. Soc.*, 390 (1959).

(3) N. S. Crossley and H. B. Henbest, *J. Chem. Soc.*, 4413 (1960).

(4) R. L. Clarke and W. S. Johnson, *J. Am. Chem. Soc.*, **81**, 5706 (1959).

(5) R. K. Hill and J. G. Martin, private communication.

(6) Cf. P. Hazelbrook and L. J. Osterhoff, *Discussions Faraday Soc.*, **10**, 87 (1951). The term *twist* conformation is preferred by W. S. Johnson, J. L. Margrave, M. A. Frisch, L. H. Dreger and W. N. Hubbard, publication in press.

(7) W. S. Johnson, J. L. Margrave, V. J. Bauer, M. A. Frisch, L. H. Dreger and W. N. Hubbard, *J. Am. Chem. Soc.*, **82**, 1255 (1960).

(8) K. Alder and G. Stein, *Ann.*, **501**, 247 (1933).

(9) Huang-Minlon, *J. Am. Chem. Soc.*, **71**, 3301 (1949).

(10) D. H. R. Barton, D. A. J. Ives and B. R. Thomas, *J. Chem. Soc.*, 2056 (1955).

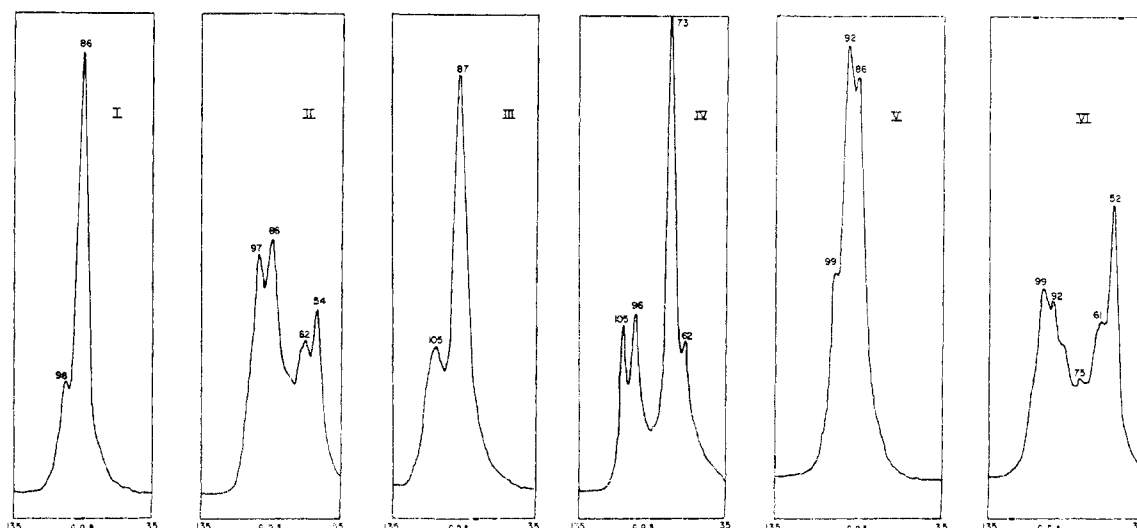


Fig. 1.—N.m.r. spectral curves of (I) *cis*-decalin, (II) *trans*-decalin, (III) *cis-anti-cis*-perhydroanthracene, (IV) *trans-anti-trans*-perhydroanthracene, (V) *cis-syn-cis*-perhydroanthracene and (VI) *trans-syn-trans*-perhydroanthracene.

fractions was achieved by vapor phase chromatography. The fraction with the longer retention time on the column proved to be almost pure *cis-anti-cis*-perhydroanthracene (IV). The fraction with the shorter retention time appeared to contain two components. Six recrystallizations of this mixture from absolute ethanol afforded an estimated 21% yield (purified and based on starting diketone) of a new perhydroanthracene which melted at 48.2–49.2°. Two further recrystallizations raised this melting point only to 48.5–49.7°. The residue from the mother liquor from the last recrystallization melted over this identical range. The crystals of this compound show the unusual property of plastic flow when subjected to slight pressure.

Careful infrared spectral examination of the residues from the purification just described gave evidence for the presence of this new isomer as the predominant component together with indications of the presence of the *cis-trans* isomer II. There was no evidence for the presence of any of the *cis-syn-cis* (I) or the *trans-syn-trans* (III) isomers.

Measurement of the areas under the two peaks recorded in the vapor phase chromatography revealed that the *cis-anti-cis* isomer IV constituted 15% of the mixture. Of the 85% of material represented by the other peak, a fair estimate, based on the infrared studies, is that the *cis-trans* isomer II constituted 15% of the mixture and the 49° isomer accounted for 70% of it. No pure *cis-trans*-perhydroanthracene was actually isolated from the reaction mixture.

A comparison of the relative retention times of the five purified perhydroanthracene isomers on a vapor phase chromatographic column showed: *trans-syn-trans*-III = *cis-trans*-II < the new isomer < *cis-syn-cis*-I < *cis-anti-cis*-IV. The shape of the chromatographic curve coupled with retention time data indicated that little or no I was present.

The hydrocarbon melting at 48.5–49.7° has been assigned the *trans-anti-trans*-perhydroanthracene structure (V), this being the only remaining theoretically possible and as yet unknown perhydroan-

thracene. The assignment of the all-*cis* and all-*trans* configurations, respectively, to the recently reported *cis-anti-cis* isomer IV and the presently reported *trans-anti-trans* isomer V are supported by n.m.r. spectral data. In Fig. 1, curve I shows the essentially single resonance peak produced by *cis*-decalin and curve II shows the two sets of resonances produced by *trans*-decalin.¹¹ A similar relationship has been reported for two *trans*-decalols and three *cis*-decalols by Musher and Richards.¹² Curves III and V were produced by *cis-anti-cis*-perhydroanthracene and *cis-syn-cis*-perhydroanthracene, respectively. Curves IV and VI were produced by *trans-anti-trans*-perhydroanthracene and *trans-syn-trans*-perhydroanthracene, respectively. The correlation noted above for the decalin series holds very well for these anthracenes also.

Figure 2 presents the infrared spectral curves for the complete series of perhydroanthracene isomers.^{13,14}

The decahydro-9,10-anthraquinone used for the reduction under study has been shown by Alder and Stein⁸ to be the most stable form of perhydro-9,10-anthraquinone, presumably one of the *trans-trans* forms. It has been reported that in the case of certain 15-ketosteroids¹⁵ the course of a Wolff-Kishner-type reduction is not predicted upon the stability relationships of isomeric molecular species but upon kinetic factors. Thus, digitogenone diacetate (C/D *trans*, the unstable isomer) and isodigitogenone (C/D *cis*, the stable isomer) are both reduced by the Wolff-Kishner method to gitogenin (C/D *trans*) as the sole pure product. Under the reducing conditions presently reported, it is probable that all isomeric forms of the perhydro-9,10-anthraquinone were present to some extent. The

(11) The n.m.r. spectral curves for *cis*- and *trans*-decalin were kindly furnished by Dr. J. N. Shoolery.

(12) J. Musher and R. E. Richards, *Proc. Chem. Soc.*, 230 (1958).

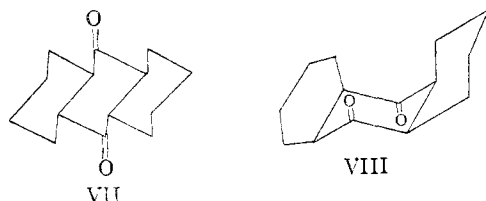
(13) A sample of *cis-trans*-perhydroanthracene was kindly furnished by Dr. J. W. Cook.

(14) I thank Miss C. M. Martini for recording the infrared spectral curves.

(15) C. Djerassi, T. T. Grossnickle and L. B. High, *J. Am. Chem. Soc.*, **78**, 3166 (1956), and references therein.

products actually found appear to be related largely to the reactivities of these isomers.

Examination of models leads to the conclusion that the *trans-syn-trans*-diketone VII would be least susceptible to reduction due to its eclipsed



carbonyl groups, and that the *cis-syn-cis*-diketone VIII, containing a 1,3-diaxial methylene interaction, would exist in least quantity under the reaction conditions. The *trans-anti-trans*-diketone, because of the boat conformation of its center ring, can twist in a manner so as to remove part of the eclipsing of its carbonyl groups and thus undergo reduction to V. Reduction of the *cis-trans*-diketone requires that the center ring adopt a boat conformation at some stage in order to uncover the second carbonyl and produce II. The formation of the *cis-anti-cis* hydrocarbon, IV affords no steric problems. Thus, the sole formation of II, IV and V can be rationalized.

Acknowledgments.—My sincere appreciation is expressed to Dr. W. S. Johnson for his many helpful discussions and for making the Megachrom apparatus available; to Dr. E. J. Eisenbraun, Mr. E. J. Warawa and Miss B. Bach for performing the large scale vapor phase separations; and to Mr. H. P. Warrington for his micro-scale vapor phase chromatographic determinations.

Experimental¹⁶

Wolff-Kishner Reduction¹⁰ of *trans-trans*-9,10-Diketoperhydroanthracene.—Anhydrous hydrazine, prepared by refluxing 120 ml. of 100% hydrazine hydrate with 120 g. of sodium hydroxide pellets for 3 hr., was distilled directly from the sodium hydroxide into a solution of 20 g. of sodium in 900 ml. of diethylene glycol. The resulting solution was found to boil with an internal temperature of 185°. This solution was cooled to 150° and 40 g. (0.18 mole) of *trans-trans*-9,10-diketoperhydroanthracene, m.p. 251–256°,¹⁷ was added. The mixture was heated to boiling; dissolution of the diketo compound was accompanied by gas evolution. It was then heated under reflux for 24 hr., the condenser was set for distillation, and the mixture was distilled until the internal temperature rose to 210°. The distillate was set aside and the reaction mixture was then refluxed for a second 24-hr. period, cooled and diluted with 1 l. of water. The distillate which had been set aside above was added to this mixture and the total material was extracted twice with pentane. The pentane extracts were dried over sodium sulfate.

Three more reactions were run in a manner identical with that just described. The pentane extracts from all four reactions were combined, concentrated to a 500-ml. volume and poured onto a column of 250 g. of silica gel. Elution of the column with 2.5 l. of pentane removed the hydrocarbon portion of the product. Evaporation of the pentane from

(16) All melting points are corrected. The infrared spectra were determined in potassium bromide with a Perkin-Elmer model 21 double-beam recording spectrophotometer equipped with a sodium chloride prism. The n.m.r. spectra were recorded by Varian Associates, Palo Alto, Calif., on an approximately 10% solution in carbon tetrachloride with added tetramethylsilane as an internal reference.

(17) The stable isomer reported by Alder and Stein (ref. 4) as resulting from isomerization with alkali melted at 245°. In this Laboratory most of the product melted at 253–256°. Some lesser crops melting 251–255° were included in these experiments.

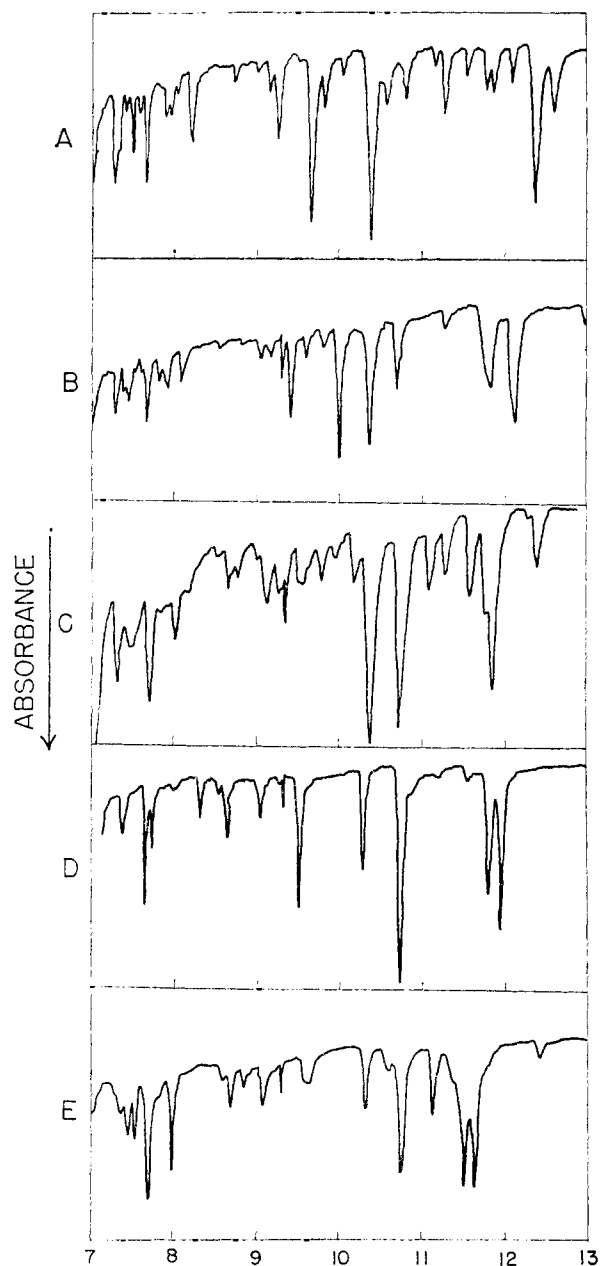


Fig. 2.—Infrared absorption curves of the perhydroanthracene isomers: (A) *cis-syn-cis*-, (B) *cis-anti-cis*-, (C) *cis-trans*-, (D) *trans-syn-trans*-, (E) *trans-anti-trans*-.

the eluate afforded 90 g. (64% yield) of an oily mixture of perhydroanthracenes. About 75% of this mixture crystallized at 25°.

Vapor Phase Chromatography.—A micro-sample of the hydrocarbon mixture was injected into a Perkin-Elmer Vapor Fractometer, model 198B, equipped with a 2-meter column containing Apiezon L grease. The column was operated at 240° under 20 p.s.i. of helium with a flow rate of 42 ml./min. Two separate peaks were observed representing 85% and 15% of the material for the early and the late peaks, respectively.

For separation of the large sample into its components, macro gas chromatography was employed with two different column packings. Separation of about 45 g. of the product was carried out as a series of approximately 1- to 2-ml. injections of the molten perhydroanthracene mixture into a Beckman GC-100 Megachrom preparative gas chromatography apparatus with repeated collection of fractions in individual traps maintained at 0°. The eight 6' by 3/8" columns

of acid-washed C-22 firebrick (40-60 mesh) coated with Ucon Polar substrate were connected in parallel. These columns were heated at 210° under 10 p.s.i. of helium. The detector was maintained at 255° at 250 ma.

A typical chromatogram showed a large leading peak (22 min.) and a trailing minor peak (28 min.). The leading peak showed a trailing shoulder.¹⁸ The first material was collected up to the approximate time that the shoulder appeared. The combined first peak material (26.5 g.) was a mushy solid which showed no evidence of any of the trailing peak material upon rechromatography on a micro-column. It was dissolved in 26 ml. of absolute ethanol and the solution was chilled to -15° to give 23.1 g. of sticky solid. This solid was recrystallized from 23 ml. of absolute ethanol to give 20.2 g. of solid, m.p. 43-47°, and this product was recrystallized from 25 ml. of ethanol to give 18.9 g. Recrystallization a fourth and fifth time from 30 ml. and 25 ml. of alcohol, respectively, with cooling to 5° afforded 14.4 g. of *trans-anti-trans-perhydroanthracene* (V), m.p. 48.0-49.3°. The material collected from the macro vapor phase column which corresponded to the trailing peak amounted to 6.5 g. It was combined with the corresponding fraction described below.

The process of separation described above was the more satisfactory of the two macro separations and was done after the techniques of collection had been perfected on the first half of the sample. The first portion of the hydrocarbon mixture was put through the Megachrom apparatus equipped with tubes containing Apiezon J. In this run the total first peak material was combined (24.1 g.) and recrystallized from 24 ml. of absolute ethanol, again from 28 ml. of this solvent and a third time from 32 ml. of the same solvent to give 10.9 g. of needles, m.p. 46.0-48.5°. Three further recrystallizations from absolute ethanol afforded 7.4 g. of needles, m.p. 48.2-49.2°. Two final recrystallizations gave 5.2 g. of *trans-anti-trans-perhydroanthracene* (V) m.p. 48.5-49.7°, after being dried for 7 hr. at 25° (15 mm.) and 8 hr. at 25° (1.6 mm.). The solid recovered by concentration of the filtrate from the last recrystallization and the 5.2-g. sample melted over an identical range. A mixture

(18) The retention time of this shoulder was too low to correspond to isomer I; its identity was never established.

of this material and the *cis-trans* isomer II,¹³ m.p. 39-40.5°, liquefied at 25°.

Anal. Calcd. for C₁₄H₂₄: C, 87.42; H, 12.58. Found: C, 87.5; H, 12.4.

The filtrates from the first three recrystallizations of the first peak material from the Apiezon J column were combined, diluted with 300 ml. of water, and this mixture was extracted twice with pentane. The pentane extracts were washed with water, dried over sodium sulfate, and the pentane was removed by warming the solution to a final temperature of 135°. The residual oil, 10.1 g., showed an infrared spectrum in which all bands could be accounted for by the *cis-trans* and the *trans-anti-trans* hydrocarbons with the latter strongly predominating. The 10.1 g. of oil was chilled to 0°, seeded with the *trans-anti-trans* isomer, and left standing at 0° for 6 days. The oil remaining, 2.8 g., was separated by centrifugation and its infrared spectrum examined for evidence of the presence of the *trans-syn-trans* (III) or the *cis-syn-cis* (I) isomers. None was found.

The material corresponding to the second peak from the Apiezon J column amounted to only 0.9 g. due to technical difficulties. This 0.9 g. was combined with the 6.5 g. of corresponding second peak material from the Ucon Polar column described above and this 7.4 g. of solid was recrystallized twice from absolute ethanol to give 5.2 g. of white needles, m.p. 122-123.5°, of *cis-anti-cis-perhydroanthracene* (IV). The infrared spectrum of this material was identical with that of IV prepared earlier in this Laboratory by another method.⁴ A mixture melting point of these two samples showed no depression.

The best estimates, of yields should be based on the results from use of the Ucon Polar column for separation. Since the amount of material put on this column is known to be only approximately half of the original 90 g. of hydrocarbon, the calculated 21% yield of pure *trans-anti-trans* isomer V and 7% yield of pure *cis-anti-cis* isomer IV are not exact values.

Relative retention times for the five perhydroanthracenes were determined using the Perkin-Elmer Vapor Fractometer under the conditions described earlier. Isomers II, III and V, having relatively short retention times, were each mixed with IV for comparison. Isomer I was then mixed with V. These comparisons showed the relative retention times to be II ≅ III < V < I < IV.

[CONTRIBUTION NUMBER 1629 FROM THE STERLING CHEMISTRY LABORATORY OF YALE UNIVERSITY, NEW HAVEN, CONN.]

The Cleavage Reaction of 1,3-Diols. IV¹

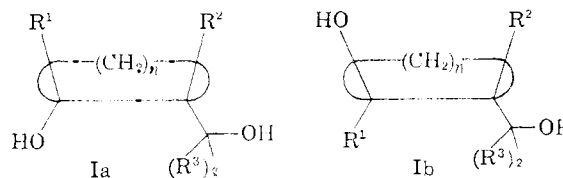
BY THOMAS E. MAGGIO² AND JAMES ENGLISH, JR.

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The syntheses of *cis*- and *trans*-1-phenyl-2-methyl-2-(α -hydroxyisopropyl)-cyclopentanol and *cis*- and *trans*-1-phenyl-2-methyl-2-(α -hydroxyisopropyl)-cyclohexanol have been accomplished. The influence of the geometry of the 1,3-diol system on the cleavage reactions of these diols has been studied and a mechanism proposed to account for the results.

In a continuation of our studies on the cleavage reactions of 1,3-diols³ the preparation of di-tertiary-1,3-diols in which the hydroxyl groups are *cis* or *trans* to one another respect to a ring system was undertaken. Although diols of the type desired had previously been prepared,⁴⁻⁶ in only one case⁷—the isopulegol hydrates—were both *cis* and *trans* isomers known. The isopulegol hy-

drates, however, do not undergo cleavage as the major reaction on treatment with acid. Because of the known³ effect of configuration on the nature of the cleavage reaction, it seemed worthwhile to study a pair such as Ia and Ib in which R¹ is aro-



matic. Aromatic groups are known⁸ to increase the amount of the cleavage reaction compared to other acid-catalyzed processes.

Acting on the hypothesis that earlier efforts³ to obtain both of the isomeric 1,3-diols from the reac-

(8) F. V. Brucher and J. English, Jr., *ibid.*, **74**, 4279 (1952).

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(2) Du Pont Teaching Fellow 1958-1959; Eastman Kodak Research Fellow 1959-1960.

(3) H. E. Zimmerman and J. English, Jr., *J. Am. Chem. Soc.*, **76**, 2294 (1954).

(4) T. Geissman and V. Tulagin, *ibid.*, **66**, 719 (1944).

(5) F. V. Brucher and H. I. Cenci, *J. Org. Chem.*, **21**, 1543 (1956).

(6) H. E. Zimmerman and J. English, Jr., *J. Am. Chem. Soc.*, **76**, 2285 (1954).

(7) H. E. Zimmerman and J. English, Jr., *ibid.*, **75**, 2367 (1953).