Decarboxylation Conditions.—To 12 g of piperidine was added 2.85 g (0.01 mole) of V and the mixture was refluxed for 6 hr. Evaporation of the piperidine afforded 2.85 g of the starting material V.

Under similar conditions compound VI was also found to be unchanged.

Decarboxylation of α-4-Nitrophenyl-*trans*-cinnamic Acid (I) in Piperidine.—To 50 ml of piperidine was added 5.4 g (0.02 mole) of α-4-nitrophenyl-*trans*-cinnamic acid (I), mp 224–225° (lit.[12] mp 224.5°), and the mixture was refluxed for 5 hr. Evaporation of the piperidine followed by the addition of ethanol to the semi-solid residue caused precipitation of 1.5 g (33.5%) of *trans*-4-nitrostilbene (II), mp 150–152° (lit.[4] mp 150–153°). Work-up of the mother liquor by evaporation of the ethanol, addition of 50% aqueous HCl, stirring for 1 hr at room temperature, extraction with chloroform, and evaporation of the chloroform gave a residue which was recrystallized from ethyl acetate to afford 2.1 g (30.4%) of the hydrochloride of 1-phenyl-1-piperidino-(1)-2-(4-nitrophenyl)ethane (X): mp 230–232°; λ_{max}^{KBr} 2.95, 3.43, 3.83, 4.1, 6.2, 6.55, 6.85, 7.4, 9.0, 11.6, 11.75, 12.1, 13.15, 13.4, 14.18, and 14.35 μ.

Anal. Calcd for $C_{19}H_{23}ClN_2O_2$: C, 65.79; H, 6.65; N, 8.07. Found: C, 65.84; H, 6.87, N, 7.84.

(12) F. K. Beilstein, "Handbuch der Organischen Chemie," Vol 9, 4th ed, 1919, p 693.

Acknowledgment.—We are indebted to Benjamin Tucker and Martha Reiter for their assistance in the experimental aspects of this work.

Studies on Cyclic Polyols. VI. Synthesis of Anhydrocyclopentanetetrols and Aminocyclopentanetriols[1]

AKIRA HASEGAWA AND HENRY Z. SABLE[2]

Department of Biochemistry, School of Medicine, Western Reserve University, Cleveland, Ohio 44106

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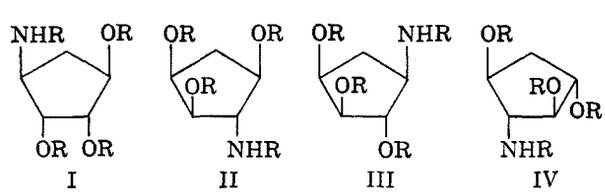
The isomeric cyclopentenediols and their diacetates are converted to the corresponding epoxides (anhydrotetrols) by treatment with *m*-chloroperoxybenzoic acid. The epoxidation obeys Henbest's rule that an allylic OH is *cis* directing in the epoxidation reaction. By nucleophilic opening with NaN_3 the epoxide group is converted to a *trans*-azido alcohol. After acetylation the azido compounds are reduced with Pd–C catalyst to aminotriol derivatives. The position of nucleophilic attack by Br^- and OH^- was previously shown to be governed by steric hindrance and electrostatic factors. In the present study one case was found in which N_3^- attacked the epoxide at the electrostatically less favorable position. A *trans*-OAc group adjacent to one end of the oxirane ring is a powerful directing influence for hydrolytic epoxide opening, and when both ends of the oxirane ring have adjacent *trans*-OAc groups the nucleophilic attack does not take place; hydrolysis of the epoxide occurs instead. Four acetamidocyclopentanetriol triacetates, DL-(1,4/2,3)-1-acetamido-2,3,4-tri-O-acetylcyclopentanetriol (Id), DL-(1,2,4/3)-3-acetamido-1,2,4-tri-O-acetylcyclopentanetriol (IId), DL-(1,2,4/3)-4-acetamido-1,2,3-tri-O-acetylcyclopentanetriol (IIId), and DL-(1,3/2,4)-2-acetamido-1,3,4-tri-O-acetylcyclopentanetriol (IVd), and the corresponding acetamido-tri-O-benzoylcyclopentanetriols (If–IVf) are described. An improved method for preparing DL-*trans*-3,4-di-O-acetylcyclopentenediol (XIIIb) has been developed.

Although aminocyclitols derived from cyclohexane are known as components of many carbohydrate antibiotics,[3,4] such as streptomycins, kanamycins, and neomycins, and the synthesis of cyclohexane aminocyclitols has been studied in several laboratories,[3,5–7] the analogous cyclopentane derivatives have been unknown. As part of our systematic study of cyclopentane cyclitols we have now synthesized several aminocyclopentanetriols which are described in the present communication (see Chart I). Some aminocyclopentanediols, aminocyclopentanetetrols, and diaminocyclopentanediols are described elsewhere.[8a]

In earlier studies the configurational uncertainties were resolved,[9,10] and some anhydrotetrols were described.[11] Epoxidation of the cyclopentenediols with

CHART I

AMINOCYCLOPENTANETRIOLS



R = H or Ac

m-chloroperoxybenzoic acid, which proceeded according to Henbest's rule,[12] produced[11] anhydrotetrols Va–VIIa, whereas VIIIa was prepared[11b,13] from the known[9a] epoxybromohydrin VIIIc by reactions of known stereospecificity. The anhydrotetrols have served as starting materials for the synthesis of many of the aminocyclitols to be reported, and the preparation of some new isomers and derivatives of anhydrotetrols (V–XI) is described below (see also Chart II).

(1) Supported in part by U. S. Public Health Service Research Grant AM-07719 from the National Institutes of Health.

(2) To whom correspondence should be addressed.

(3) S. J. Angyal and L. Anderson, *Adv. Carbohydrate Chem.*, **14**, 136 (1959).

(4) K. L. Rinehart, Jr., "The Neomycins and Related Antibiotics," John Wiley and Sons, Inc., New York, N. Y., 1964.

(5) (a) F. W. Lichtenthaler, *Chem. Ber.*, **94**, 3071 (1961); (b) F. W. Lichtenthaler, and H. O. L. Fischer, *J. Am. Chem. Soc.*, **83**, 2005 (1961).

(6) (a) M. Nakajima, N. Kurihara, and A. Hasegawa, *Chem. Ber.*, **95**, 141 (1962); (b) M. Nakajima, A. Hasegawa, and N. Kurihara, *ibid.*, **95**, 2708 (1962); (c) *Ann. Chem.*, **689**, 235 (1965); (d) *Tetrahedron Letters*, 967 (1964); (e) M. Nakajima, A. Hasegawa, N. Kurihara, and T. Kurokawa, *Ann. Chem.*, **689**, 229 (1965); (f) M. Nakajima, N. Kuirhara, A. Hasegawa, and N. Kurokawa, *ibid.*, **689**, 243 (1965).

(7) (a) M. Nakajima, A. Hasegawa, and F. W. Lichtenthaler, *ibid.*, **669**, 75 (1963); (b) *ibid.*, **680**, 21 (1964).

(8) (a) Part VII, A. Hasegawa and H. Z. Sable, *J. Org. Chem.*, **31**, 4154 (1966); (b) part VIII, *ibid.*, **31**, 4161 (1966).

(9) (a) W. G. Young, H. K. Hall, Jr., and S. Winstein, *J. Am. Chem. Soc.*, **78**, 4338 (1956); (b) A. C. Darby, H. B. Henbest, and I. McClenaghan, *Chem. Ind.* (London), 462 (1962).

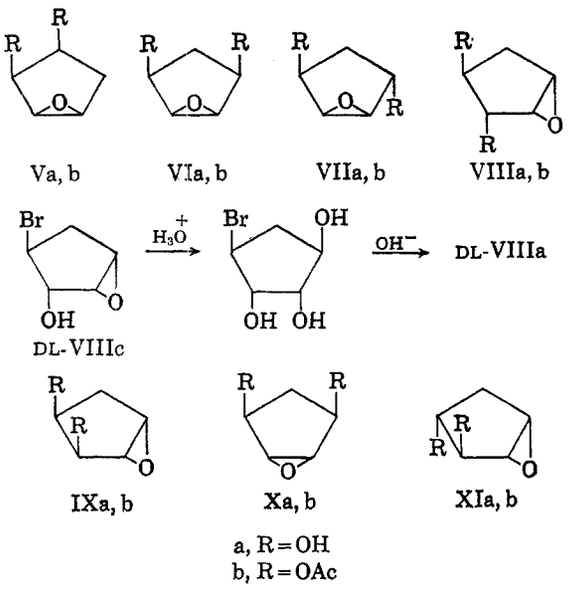
(10) (a) H. Z. Sable and T. Posternak, *Helv. Chim. Acta*, **45**, 370 (1962); (b) H. Z. Sable, W. M. Ritchey, and J. E. Nordlander, *Carbohydrate Res.*, **1**, 10 (1965).

(11) (a) H. Z. Sable, T. Adamson, B. Tolbert, and T. Posternak, *Helv. Chim. Acta*, **46**, 1157 (1963); (b) J. A. Franks, Jr., B. Tolbert, R. Steyn, and H. Z. Sable, *J. Org. Chem.*, **30**, 1440 (1965).

(12) H. B. Henbest and R. A. L. Wilson, *J. Chem. Soc.*, 1958 (1957).

(13) B. Tolbert, R. Steyn, J. A. Franks, Jr., and H. Z. Sable, manuscript in preparation.

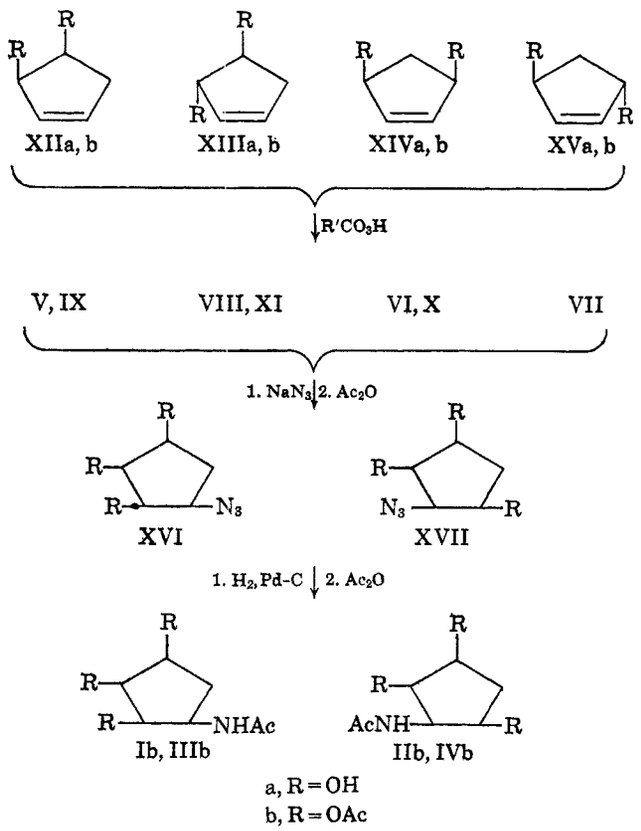
CHART II
ANHYDROCYCLOPENTANETETROLS



An improved method for synthesizing DL-*trans*-3,4-cyclopentenediol (XIII) is also described.

The general reaction sequence for synthesis of the aminocyclopentanetriols shown in Chart III involves nucleophilic opening of the oxirane ring of the anhydrotetrols by NaN_3 and catalytic reduction[14] of the azidocyclitols to produce aminotriols. Sixteen racemic pairs of isomeric monoaminocyclopentanetriols are

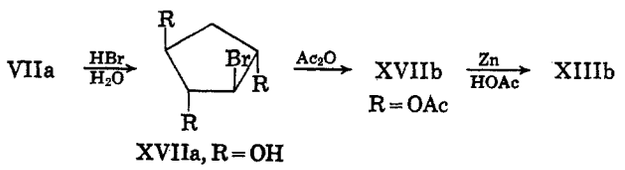
CHART III
GENERAL REACTION SEQUENCE



possible. Four of these (I–IV) are described in the present work, and two others are described in an accompanying paper.[8a] The configurations were assigned on the basis of the known structure of the starting material and the assumed nucleophilic attack of the N_3^- ion. The position of attachment of the nitrogen atom was determined from the consumption of periodate by the acetamidocyclopentanetriols: I and III consume 2 moles of periodate per mole of substance, whereas II and IV consume 1 mole of periodate.

Results

Preparation of *trans*-3,4-Cyclopentenediol XIII.—Existing methods[15] for preparing XIII are difficult and give poor yields. A more convenient synthesis starts with the more readily available[11b,13] anhydrotetrol VIIa. Treatment with HBr in absolute ethanol converted VIIa to the bromotriol XVIIa. The latter was



acetylated and the triacetate XVIIb was treated with zinc and acetic acid to produce XIIIb, identified by its infrared spectrum.

Synthesis of Anhydrotetrols and Anhydrotetrol Diacetates.—When the anhydrotetrols Va–VIIIa were treated with acetic anhydride in pyridine solution to produce the corresponding diacetates, only VIb was obtained as a solid (mp 86–87°). Of the other three isomers, only VIIb was prepared in sufficient quantity to be characterized by its boiling point and index of refraction. All the compounds have been characterized by their infrared spectra.

Treatment of XIIb with *m*-chloroperoxybenzoic acid in AcOH–$CHCl_3$ gave DL-(1,2/3,4)-3,4-di-O-acetyl-1,2-anhydrocyclopentanetetrol (IXb), mp 58°, in 70% yield. Under the same reaction conditions XIVb was converted to *meso*-(1,4/2,3)-1,4-di-O-acetyl-2,3-anhydrocyclopentanetetrol (Xb). All-*cis* isomers Vb and VIb were also prepared and, since IXb and Xb differ from these, the proposed configurations are established, unless epoxide migration occurred during the epoxidation reaction. That such migration did not occur is shown by the nature of the tetrols produced by hydrolysis of either IXb or Xb, or of the free anhydrotetrols (IXa or Xa) formed from them by deacetylation under mild conditions.[8b] Acid hydrolysis of IXa, Xa, and Xb produced the known DL-(1,2,4/3)-cyclopentanetetrol.[11b] However when IXb was hydrolyzed, the oxirane ring opened at the more hindered position, owing to participation of the adjacent *trans*-acetoxyl group,[8b] producing DL-(1,2,3/4)-cyclopentanetetrol. Undoubtedly the opening of the oxirane ring of Xb also proceeds in whole or in part by acetoxyl assistance, but the product is the same as that obtained from the free anhydrotetrol. The products obtained from XIIb and XIVb further substantiate Henbest's observation[12] that bulky allylic substituents are *trans* directing in the epoxidation reaction. The production of pure

(14) (a) F. D. Cramer in "Methods in Carbohydrate Chemistry," Vol. 1, R. L. Whistler and M. L. Wolfrom, Ed., Academic Press Inc., New York, N. Y., 1962, p 243; (b) B. R. Baker and A. H. Haines, *J. Org. Chem.*, **28**, 442 (1963).

(15) (a) R. Criegee, *Ann. Chem.*, **481**, 263 (1930); (b) Y. Gaoni, *Bull. Soc. Chim. France*, 705 (1959).

samples of XIa and XIb remains an unsolved problem. Treatment of the free diol XIIIa with the peroxy acid gave a crystalline product identical with authentic VIIIa. This result could not have been predicted, since the allylic and homoallylic hydroxyl groups are *trans* to each other, and both are *cis* directing in the epoxidation reaction.[9b] Evidently in this situation the effect of the allylic group predominates over that of the homoallylic. On the other hand treatment of the diacetate XIIIb under the usual conditions gave a mixture of VIIIb and XIb which could not be separated. Apparently the homoallylic substituent is close enough to the ethylenic functional group to offer steric hindrance to the entering oxygen atom. A related instance of steric hindrance by a nearby (but not adjacent) group is seen in the relative rates of hydrolysis of Va and VIIIa reported previously;[11b] the appreciably lower rate of hydrolysis of VIIIa was ascribed to hindrance by the *trans*-hydroxyl group across the ring from the oxirane group.

Synthesis of Aminocyclopentanetriols.—We reported previously that in the cyclopentane series epoxide opening by either a strong nucleophile (Br^-) or a weak nucleophile (H_2O) occurred with one Walden inversion at the point of attack and with no rearrangement in the rest of the molecule,[11] and that the position of nucleophilic attack was governed by steric hindrance and by electrostatic factors. In the present study epoxide opening has been achieved by treating the anhydrotetrols with NaN_3 at reflux temperature for 3–4 hr in aqueous 2-methoxyethanol solution containing NH_4Cl. The products could not be isolated from the reaction mixture. Instead, after removal of solvent, the crude mixture was subjected to acetylating conditions and the azidotriol triacetates XVIb and XVIIb were purified by chromatography on alumina. The azido compounds were easily identified by their infrared spectra, which always contain the strong band at 2120 cm^{-1} ascribed to the N≡N stretching mode.[16] The azido groups were reduced to amino groups by catalytic reduction at 60–70°, with Pd–C catalyst[14] in absolute ethanol and the products were acetylated further to produce the aminotriol tetraacetates.

Treatment of the symmetrical all-*cis* anhydrotetrol VIa by the procedure shown in Chart IV can give rise only to an azidotriol whose configuration is DL-II. The final product, DL-(1,2,4/3)-3-acetamido-1,2,4-tri-O-acetylcyclopentanetriol (IId), mp 139°, is therefore a convenient reference substance. Similar treatment of the unsymmetrical all-*cis* anhydrotetrol Va should produce a mixture of II and XIX. Epoxide opening of Va by water or Br^- was found to occur predominantly at C-1, producing substances[11b,13] with configuration XIX. In the present case, however, the only aminotriol isolated was identical with IId obtained from VIa, and was obtained in an over-all yield of 30%. An explanation for the different behavior of Va in these reactions is presented in the Discussion below. Compound IIe, prepared from IId, consumed 1 mole equiv of periodate.

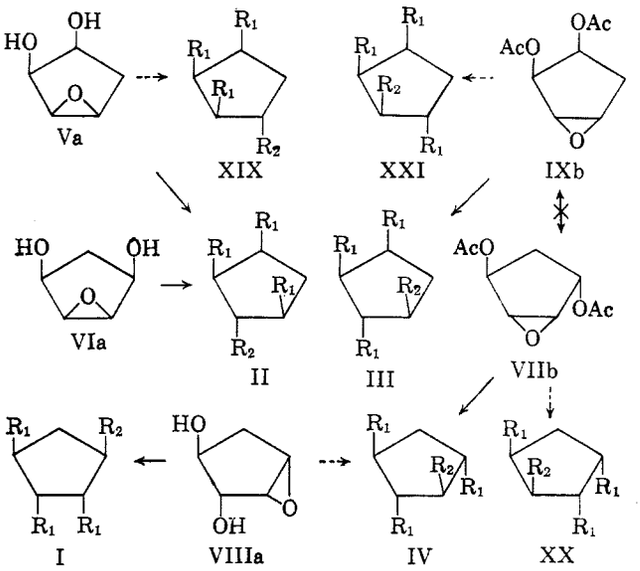
The unsymmetrical anhydrotetrol VIIb can theoretically give rise to two azidotriols, IV and XX. Acid hydrolysis of VIIa produces almost exclusively the 1,3/2,4-tetrol[11a] corresponding to IV, presumably because of steric hindrance of the adjacent hydroxyl group. In the present case (attack by azide on the diacetates) steric hindrance will be even more severe, owing to the increased size of the acetoxyl group. Consequently we believe that the product in this case must have configuration IV rather than XX. The yield of IVd (57%) which is only a little smaller than the yield of IId from VIa (71%) suggests that the nucleophilic opening by N_3^- proceeds faster than the acetoxyl-assisted hydrolysis with which it probably competes, and which would yield a tetrol having configuration XX. One additional possibility which must be considered is that during the opening reaction with N_3^- epoxide migration occurred,[17] which resulted in the formation of IXb. However, VIIb and IXb should then give the same products, and this is not the case. Under identical reaction conditions IXb is converted in 62% yield into the aminotriol tetraacetate IIId (mp 112°), which is different from IVd (mp 106°). The alternative configuration XXI which could arise from IXb is excluded because IIIe consumes 2 moles of periodate, whereas XXIe should consume only 1 mole per mole. Epoxide migration has therefore not occurred in either case. The theoretical arguments against the formation of XXI from IXb are exactly the same as those advanced in the choice between IV and XX.

Nucleophilic opening of the unsymmetrical anhydrotetrol VIIIa can lead to compounds with configurations I and IV. Only one tetraacetate was isolated, in 44% over-all yield, mp 134–136°, which differed from IVd. The corresponding acetamidotriol consumed 2 mole equiv of periodate, and the proposed configuration Id seems certain.

When the symmetrical anhydrotetrol diacetate Xb was subjected to similar usual conditions, the epoxide ring opened but the infrared spectrum of the product did not contain the band at 2120 cm^{-1} characteristic of the azido compounds. The only product isolated

CHART IV

FORMATION OF AZIDOTRIOLS AND ACETAMIDOTRIOLS

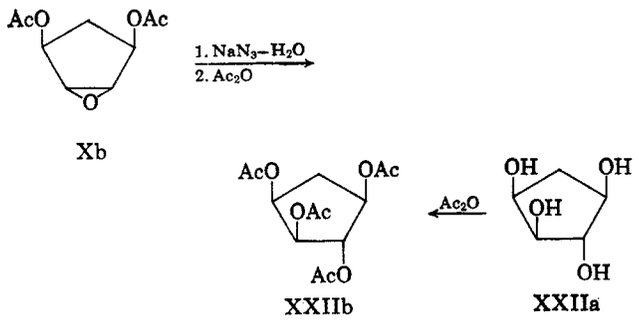


	a	b	c	d	e	f
I–IV, XIX–XXI, R_1 =	OH	OAc	OAc	OAc	OH	OBz
R_2 =	N_3	N_3	NH_2	NHAc	NHAc	NHAc

(16) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd ed, Methuen and Co. Ltd., London, 1958, Chapter 15.

(17) S. J. Angyal and P. T. Gilham, *J. Chem. Soc.*, 3691 (1957).

after chromatography was a crystalline tetraacetate, mp 81–82°, which was identical with the tetraacetate XXIIb obtained by acetylation of authentic XXIIa.



In this case there is steric hindrance to the attack by an external nucleophilic agent at either end of the oxirane ring. This hindrance appears to be large enough to allow only intramolecular attack, as judged by the isolation of only the hydrolytic product.

Discussion

Sodium azide has been used as a nucleophilic agent for displacing sulfonate groups in carbohydrates[14] and cyclitols[18a,b] and elsewhere. Most of the examples reported involve uncomplicated nucleophilic displacements, but in one case,[18a] the conversion of (1,2,3,5/4,6)-penta-O-acetyl-3-O-mesylcyclohexanehexol to (1,2,4,5/3,6)-penta-O-acetyl-1-azidocyclohexanepentol, the reaction probably proceeds through intermediate formation of an epoxide which is then opened by N_3^-. When this work was undertaken we were unaware of any studies in which direct application had been made of N_3^- for epoxide opening. Since completion of this work the opening of steroid epoxides by azide has been reported.[18c]

In our earlier studies[11] we found that opening of Va, VIIIa, and VIIIc by H_2O or Br^- in aqueous acid involved preferential attack of the nucleophile at the end of the oxirane ring farthest from the hydroxyl group. This stereoselectivity was ascribed to destabilization of the transition state carbonium ion by the adjacent electronegative substituent. In the present work, treatment of Va with azide under much less acidic conditions led to a compound with configuration II, rather than configuration XIX which was expected on the basis of the earlier studies. This result strongly suggests that the nucleophilic attack by azide is purely an SN2 reaction with no transition-state carbonium ion involved.

In the study of cyclopentane and cyclohexanetetrols,[10b,19] the methylene signals in the nmr spectra gave valuable information concerning the configurations of the isomeric compounds. All compounds obtained in a pure state in the present study contain at least one acetyl group. The acetyl methyl signals obscure the methylene signals, and so far no suitable solvent has been found for the acetamido tribenzoates. The unsymmetrical substitution of the compounds and the additional spin–spin coupling due to the nitrogen atom will complicate the spectra, but it seems desirable nevertheless to pursue this aspect of the study to obtain independent substantiation of the proposed structures.

(18) (a) T. Suami and S. Ogama, *Bull. Chem. Soc. Japan*, **37**, 1238 (1964); (b) T. Suami and K. Yabe, *ibid.*, **38**, 855 (1965); (c) F. Winternitz and C. R; Engel, *Steroids*, **6**, 805 (1965).

(19) G. E. McCasland, S. Furuta, L. F. Johnson, and J. N. Shoolery, *J. Org. Chem.*, **28**, 894 (1963).

Experimental Section

Microanalyses.—Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn.

Spectra.—Infrared spectra were measured with a Perkin-Elmer Model 237B spectrophotometer. The samples were examined as Nujol mulls or KBr disks (solids), or thin films (liquids). Nmr spectra were recorded on a Varian Associates A-60 nmr spectrometer.

Physical Constants.—Melting points were determined on a Kofler micro hot stage (Arthur H. Thomas and Co.) and are corrected. Boiling points are uncorrected. Refractive index was measured with an Abbe refractometer.

DL-(1,2/3,4)-3,4-Di-O-acetyl-1,2-anhydrocyclopentanetetrol (IXb).—*cis*-3,4-Cyclopentenediol (XIIa, 5.2 g, 0.052 mole) was dissolved in 20 ml of pyridine and 20 ml of acetic anhydride. After the mixture stood overnight at room temperature the reagents were evaporated under reduced pressure. The residual substance was dissolved in ether, washed with 2 *N* HCl, 2 *N* NaOH, and water, and dried over Na_2SO_4. Evaporation of the ether gave a colorless syrup (6.5 g) which was distilled under reduced pressure: 5.6 g (59%) of colorless oil (XIIb), bp 65–68° (0.4–0.5 torr), $n^{23}D$ 1.4545.

To a solution of 650 mg (3.53 mmoles) of XIIb in 40 ml of chloroform and 5 ml of acetic acid, 2.0 g (11.5 mmoles) of *m*-chloroperoxybenzoic acid was added and the mixture was stored in a dark place for 7 days at room temperature. The solution was then washed with 2 *N* NaOH (three 50-ml portions) and water, and dried over anhydrous Na_2SO_4. Evaporation of chloroform gave a crystalline substance which was recrystallized from ethanol as 510 mg (71%) of colorless crystals (prisms), mp 58–60°.

Anal. Calcd for $C_9H_{12}O_5$ (200.19): C, 54.00; H, 6.04. Found: C, 53.96; H, 6.09.

(1,4/2,3)-1,4-Di-O-acetyl-2,3-anhydrocyclopentanetetrol (Xb).—Compound XIVb (2.6 g, 14 mmoles), in 120 ml of chloroform and 20 ml of acetic acid, and 5.7 g (33 mmoles) of *m*-chloroperoxybenzoic acid were kept in the dark for 7 days at room temperature. The usual procedures then gave 2.5 g of colorless syrup which was distilled yielding Xb (1.3 g, 46%), bp 120–123° (0.9–1.0 torr), $n^{23}D$ 1.4598.

DL-(1,2,3/4)-1,4-Di-O-acetyl-2,3-anhydrocyclopentanetetrol (VIIb). A. From DL-(1,2,3/4)-2,3-anhydrocyclopentanetetrol (VIIa).—Compound VIIa (1.5 g, 12.9 mmoles) was dissolved in pyridine (15 ml), and acetic anhydride (10 ml) was added. The mixture was left overnight at 5° and worked up as usual. The colorless oil (2.1 g) was distilled, giving VIIb (1.8 g, 69%), bp 96–100° (0.9–1.0 torr), $n^{23}D$ 1.4596.

B. From DL-*trans*-3,5-Di-O-acetylcyclopentenediol (XVb).—Compound XVa (1.5 g, 15.0 mmoles) was acetylated (20 ml of pyridine and 10 ml of acetic anhydride) according to the usual procedure, producing XVb (2.6 g, 94%) which was dissolved in 120 ml of chloroform and 20 ml of acetic acid. *m*-Chloroperoxybenzoic acid (5.7 g, 33 mmoles) was added, and the mixture was kept in a dark place for 10 days at room temperature. The colorless oil obtained (2.63 g) was distilled giving VIIb (2.3 g, 77%), bp 97–101° (1.0 torr), $n^{22}D$ 1.4594.

DL-*trans*-3,4-Di-O-acetylcyclopentenediol (XIIIb).—Hydrogen bromide gas was vigorously bubbled for 2 min through a solution of (1,2,3/4)-DL-2,3-anhydrocyclopentanetetrol[11] (VIIa, 10 g, 8.62 mmoles) dissolved in 120 ml of ethanol. The solution was then concentrated under reduced pressure to a brown syrup (XVIIa). Half of this syrup was treated with 50 ml of pyridine and 30 ml of acetic anhydride, and the usual procedures then yielded 14 g of a slightly yellow syrup of XVIIb, which was used for the next reaction without purification. Compound XVIIb (14 g) was dissolved in 100 ml of acetic acid, zinc powder (30 g) was added, and the reaction mixture was heated to 80–90° with strong stirring. The precipitate was filtered and washed with 50 ml of acetic acid, and the combined filtrate was evaporated under reduced pressure to a red syrup. Water (50 ml) was added to the syrup and the mixture was extracted with ether. The ethereal solution was washed with 2 *N* NaOH and water, and dried over anhydrous Na_2SO_4. Evaporation of the ether

gave 5.5 g of colorless liquid, which was distilled, giving XIIIb (4.1 g, 51%), bp 71–74° (0.3 torr), $n^{25}D$ 1.4593.

DL-(1,2,3,4/)-3,4-Di-O-acetyl-1,2-anhydrocyclopentanetetrol (Vb).—Compound Va[11] (1.16 g, 1.0 mmoles) was acetylated by adding 5.0 ml of pyridine and 5.0 ml of acetic anhydride and allowing the solution to stand for 2 days at 0° The usual procedures then yielded 950 mg (48%) of colorless syrup.

DL-(1 2 3,4/)-1,4-Di-O-acetyl-2,3-anhydrocyclopentanetetrol (VIb).—Compound VIa (1.16 g, 1.0 mmoles) was acetylated with 5.0 ml of pyridine and 5.0 ml of acetic anhydride as described above. The product (1.2 g, 60%) was recrystallized from ethanol as colorless prisms, mp 86–87°.

Anal. Calcd for $C_9H_{12}O_5$ (200.19): C, 53.99; H, 6.04. Found: C, 54.10; H, 6.21.

DL-(1,2,4/3)-3-Acetamido-1,2,4-tri-O-acetylcyclopentanetriol (IId). A. From DL-(1,2,3,4/)-1,2-Anhydrocyclopentanetetrol (Va).—To a solution of Va (1.1 g, 9.49 mmoles) in 30 ml of 2-methoxyethanol and 8 ml of water, were added 2.0 g of sodium azide and 1.0 g of ammonium chloride. The solution was refluxed for 3 hr and then concentrated under reduced pressure. The residue was acetylated with 10 ml of pyridine and 10 ml of acetic anhydride. Water (50 ml) was added to the acetylation mixture, and the mixture was extracted with ether. The ethereal solution was worked up as usual, and evaporation of the solvent gave a syrup (IIb, 2.3 g, 85%). This azido compound (1.0 g, 3.51 mmoles) was dissolved in 50 ml of ethanol; 500 mg of 10% Pd–C catalyst was added and hydrogen was bubbled through the mixture with stirring on magnetic stirrer at 60–65°. After 1 hr, 2 *N* HCl was added until the reaction mixture was slightly acidic and hydrogen was passed in for another 2 hr. The catalyst was removed by filtration, and the filtrate was evaporated under reduced pressure. The residual syrup was acetylated with 5 ml of pyridine and 5 ml of acetic anhydride under the usual conditions. The syrupy product was chromatographed on a column of Al_2O_3 (1 cm in diameter, 50 g), with chloroform as the developing solvent. The crystalline product (IId, 325 mg, 31%) was recrystallized from ether, mp 139°.

Anal. Calcd for $C_{13}H_{19}NO_7$ (301.29): C, 51.82; H, 6.36; N, 4.65. Found: C, 51.59; H, 6.23; N, 4.80.

B. From (1,2,3,4/)-2,3-Anhydrocyclopentanetetrol (VIa).—To a solution of VIa (500 mg, 4.31 mmoles) in 15 ml of 2-methoxyethanol and 4 ml of water, 1.0 g of sodium azide and 0.4 g of ammonium chloride were added, and the mixture was refluxed for 3 hr, and concentrated under reduced pressure. Acetylation was carried out with 10 ml of acetic anhydride and 10 ml of pyridine, the azido compound (IIb, 1.1 g, 3.89 mmoles) was dissolved in 50 ml of absolute ethanol, 500 mg of 10% Pd–C catalyst was added, and reduction was carried out as before. The residual syrup was acetylated with 7 ml of pyridine and 7 ml of acetic anhydride and the crude tetraacetate IId was chromatographed over Al_2O_3 (30 g, 1.0 cm in diameter) with chloroform as solvent. The product (730 mg, 56%) was recrystallized from ether as needles, mp 139°. Mixture melting point with the substance obtained from Va did not show any depression and the infrared spectra of both products were identical.

DL-(1,2,4/3)-3-Acetamido-1,2,4-tri-O-benzoylcyclopentanetriol (IIf).—Compound IId (301 mg, 1.0 mmoles) was dissolved in 20 ml of methanol saturated with dry NH_3; the mixture was left overnight at room temperature. The reagents and acetamide were evaporated under reduced pressure leaving a crystalline residue IIe, which was benzoylated by adding 6 ml of pyridine and 650 mg (5.61 mmoles) of benzoyl chloride at 5° and allowing the mixture to stand overnight at 5°. The reaction mixture was poured into 50 ml of ice water and the solution was left for 5 hr at room temperature. A crystalline precipitate which separated was recrystallized from 70% ethanol as needles (IIf), mp 171°.

Anal. Calcd for $C_{28}H_{25}NO_7$ (487.49): C, 68.98; H, 5.17; N, 2.87. Found: C, 69.17; H, 4.99; N, 3.00.

DL-(1,4/2,3)-1-Acetamido-2,3,4-tri-O-acetylcyclopentanetriol (Id).—Compound VIIIa (800 mg, 6.90 mmoles) in 30 ml of 2-methoxyethanol, and 8 ml of water was treated with NaN_3 for 4 hr and the product was worked up in the usual way. The crude azidotriol triacetate (Ib, 1.67 g) was dissolved in 50 ml of absolute ethanol, 600 mg of 10% Pd–C catalyst was added, and reduction was carried out as usual. After acetylation the product was chromatographed over Al_2O_3 (1 cm in diameter, 20 g of Al_2O_3). Elution with chloroform gave Id (903 mg, 44%). Recrystallization from ether gave platelets, mp 134–136°.

Anal. Calcd for $C_{13}H_{19}NO_7$ (301.29): C, 51.82; H, 6.36; N, 4.65. Found: C, 52.07; H, 6.15; N, 4.73.

DL-(1,4/2,3)-1-Acetamido-2,3,4-tri-O-benzoylcyclopentanetriol (If).—Compound Id (200 mg, 0.66 mmole) was dissolved in 10 ml of methanol saturated with dry NH_3 and the mixture was left overnight at room temperature. The reagents and acetamide were evaporated under reduced pressure leaving syrupy Ie which was benzoylated with 4 ml of pyridine and 500 mg (3.55 mmoles) of benzoyl chloride as described above. There was obtained 315 mg (97%) of white crystals (If). Recrystallization from 60% ethanol gave colorless prisms, mp 206–208°.

Anal. Calcd for $C_{28}H_{25}NO_7$ (487.49): C, 68.98; H, 5.17; N, 2.89. Found: C, 68.91; H, 5.11; N, 2.98.

DL-(1,3/2,4)-2-Acetamido-1,3,4-tri-O-acetylcyclopentanetriol (IVd).—The anhydrotetrol diacetate VIIb (1.5 g, 7.50 mmoles) in 40 ml of 2-methoxy ethanol and 10 ml of water was treated with 1.5 g of sodium azide and 0.8 g of ammonium chloride as usual. The azidotriol triacetate IVb (1.46 g, 68%) was reduced as usual and the amino compound obtained was acetylated. The acetylated product was chromatographed over a column of alumina (10 cm in diameter, 50 g of Al_2O_3) with chloroform to give 606 mg (57%) of white crystals (IVd). Recrystallization from ether gave colorless needles, mp 106°.

Anal. Calcd for $C_{13}H_{19}NO_7$ (301.29): C, 51.82; H, 6.36; N, 4.65. Found: C, 52.06; H, 6.46; N, 4.62.

DL-(1,3/2,4)-2-Acetamido-1,3,4-tri-O-benzoylcyclopentanetriol (IVf).—Compound IVd (301 mg, 1.0 mmole) was dissolved in 20 ml of methanol saturated with dry NH_3, and the mixture was left overnight at room temperature. The usual procedures gave a colorless syrup of the acetamidotriol IVe, which was benzoylated in pyridine (6 ml) with benzoyl chloride (630 mg, 4.47 mmoles) as described. The product (IVf, 460 mg, 95%) was recrystallized from 95% ethanol as colorless crystals, mp 214°.

Anal. Calcd for $C_{28}H_{25}NO_7$ (487.49): C, 68.98; H, 5.17; N, 2.87. Found: C, 69.22; H, 5.21; N, 2.96.

DL-(1,2,4/3)-4-Acetamido-1,2,3-tri-O-acetylcyclopentanetriol (IIId).—To a solution of 500 mg (2.50 mmoles) of IXb in 20 ml of 2-methoxyethanol and 5 ml of water, 1.0 g of sodium azide and 530 mg of ammonium chloride were added, and the mixture was refluxed for 4 hr, concentrated under reduced pressure, and worked up and acetylated as usual. The azidotriol triacetate IIIb (520 mg, 73%) was hydrogenated and the resulting amino compound was acetylated. After chromatography on alumina (10 g, 0.5 cm in diameter) with chloroform, there was obtained 343 mg (62%) of colorless crystals of IIId. Recrystallization from ether gave colorless plates, mp 112°.

Anal. Calcd for $C_{13}H_{19}NO_7$ (301.29): C, 51.82; H, 6.36; N, 4.65. Found: C, 51.70; H, 6.50; N, 4.87.

DL-(1,2,4/3)-4-Acetamido-1,2,3-tri-O-benzoylcyclopentanetriol (IIIf).—Compound IIId (60 mg, 0.20 mmole) was converted by the usual procedures into IIIf (90 mg, 92%). Recrystallization from 60% ethanol gave colorless needles, mp 132–133°.

Anal. Calcd for $C_{28}H_{25}NO_7$ (487.49): C, 68.98; H, 5.17; N, 2.87. Found: C, 68.99; H, 5.35; N, 2.99.

DL-(1,2,4/3)-1,2,3,4-Tetra-O-acetylcyclopentanetetrol (XXIIb).—Compound Xb (1.0 g, 5.0 mmoles) in 30 ml of 2-methoxyethanol and 8 ml of water was treated with 1.5 g of sodium azide and 800 mg of ammonium chloride as usual. The resulting syrup was acetylated giving 670 mg of syrupy substance. The infrared spectrum showed none of the characteristic absorption at 2120 cm^{-1} due to the azido group. Some of this syrup (400 mg) was chromatographed over Al_2O_3 (15 g, 0.8 cm in diameter) with chloroform, to give 338 mg (37%) of crystalline XXIIb. Recrystallization from ethanol gave needles, mp 81–82°. The mixture melting point with an authentic sample (mp 81–82°) prepared from DL-(1,2,4/3)-cyclopentanetetrol,[11] showed no depression, and the infrared spectra of both substances were identical.