

methyl ester, bp 106–108° (0.001 mm), n_D^{25} 1.5198. Nmr analysis of both compounds showed ca. 90% deuterium incorporation; the nmr parameters are summarized in Table I. Deuterium exchange with thiolacetic acid prior to its addition can be excluded from the nmr spectrum of the monoadduct and the fact that identical diadducts were obtained from either thiolacetic acid addition to deuteriomethyl propiolate or to β -deuterio- β -acetylthioacrylic acid methyl ester.

AIBN-Initiated Addition of Methyl Mercaptan to β -Acetylthioacrylic Acid Methyl Ester.—Methyl mercaptan (4.8 g, 0.1 mole), β -acetylthioacrylic acid methyl ester (16.8 g, 0.1 mole), and 2 mole % of AIBN were heated in a sealed tube at 60° for 16 hr. The unreacted methyl mercaptan was released at ambient temperature, and the reaction mixture was analyzed by glpc. The product distribution is tabulated in Table II. All products were identified by glpc retention time comparison with authentic samples. β , β -Diacetylthiopropionic acid methyl ester was isolated by fractional distillation. The distillation residue contained a little polymeric material, presumably due to oligomer formation during the reaction.

All other adducts were synthesized by one of the following general procedures. The reactant ratios, reaction times, yield, and some of the purified products' physical and analytical data are summarized in Table III. Nmr parameters are recorded in Table IV.

Ultraviolet Initiation.—Unsaturate and mercaptan were sealed into a magnetically stirred quartz tube. The tube was irradiated with a 70-w high-pressure mercury arc Hanau immersion lamp in a temperature-controlled water bath at $17 \pm 2^\circ$. The crude product mixture was sampled for nmr and glpc analysis. Pure products were obtained by fractional distillation *in vacuo*.

Base Catalysis.—Hydroquinone (1 mole %) as a free-radical inhibitor and 1–2 mole % of triethylene diamine were dissolved in the unsaturate and mercaptan. This reactant mixture was heated in a magnetically stirred and sealed Pyrex tube at 70°. Product analysis and purification was carried out as above.

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Alicyclic Carbohydrates. XXX.^{1a} Synthesis of the Remaining Cyclohexanetriols. Nuclear Magnetic Resonance Studies on the Nine Isomers^{1b}

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The last remaining isomers of cyclohexanetriol, which have the 1,2,4 structure, have now been prepared. Nuclear magnetic resonance (nmr) spectroscopy has been used to establish configurations of the four diastereomers with this structure, and to confirm previously assigned configurations for the three 1,2,3 diastereomers and the two 1,3,5 diastereomers. The two 1,2,4 diastereomers of 1,2-*cis* configuration were prepared from 3-cyclohexen-1-ol benzoate by the "wet Prévost" reaction, also by reaction of the free cyclohexenol with silver chlorate-osmium tetroxide. The configurations of these triols of mp 161° (tri-*p*-toluenesulfonate 110°) and 138° (tri-*p*-toluenesulfonate 140°) were shown to be DL(1,2/4) and all-*cis*, respectively. From the reaction of 3-cyclohexen-1-ol benzoate with silver chlorate-osmium tetroxide in aqueous acetone, followed by benzoylation, there was surprisingly obtained *trans*-2,5-dihydroxycyclohexanone dibenzoate, mp 186°, instead of the expected triol tribenzoate. The two 1,2,4 diastereomers of 1,2-*trans* configuration were prepared by reaction of 3-cyclohexen-1-ol with peroxyformic acid, or of its benzoate with the (dry) Prévost reagent. The configurations of these triols of mp 138° (tribenzoate 116°) and 150° (tribenzoate 154°) were shown to be DL(1,4/2) and DL(2,4/1), respectively. From the Prévost reaction there was isolated a small amount of the intermediate 2-iodo-1,4-cyclohexanediol dibenzoate, mp 176°, having the configuration DL(2,4/1). The nmr spectra of the triols in deuterium oxide were recorded. Assignments of configuration and conformation were based on first approximation methods and on a study of the shielding-desielding effects arising from anisotropy of the C–O bonds. The configurational assignments were consistent with chemical evidence.

The polyhydroxy cyclohexanes containing from one to six hydroxyl groups (*cyclitols* in the original sense³) are of unique interest as model compounds for studies in carbohydrate and stereochemistry, and because of their relationship to the biologically important³ cyclitol, myoinositol. Previous work⁴ in numerous laboratories has included extensive studies on cyclohexanol and the cyclohexanediols; isolation or synthesis of all ten diastereomeric pentols (quercitols);^{4e} and synthesis of all eight diastereomeric hexols (inositols). We now report synthesis of the remaining members of the

series of nine isomeric cyclohexanetriols.⁵ All but two of the numerous isomeric cyclohexanetetrols^{4e} are known, and syntheses of these last two isomers are in progress.⁶

In recent publications^{1a} we have emphasized the application of nmr spectroscopy to cyclitols. We have now extended this approach to cyclohexanetriols synthesized in our own and other laboratories. Excellent nmr studies on certain derivatives of the 1,2,3-triols have previously been reported,⁷ but, so far as we know, there have not been any previous nmr studies on the free 1,2,3-triols, or on any of the 1,2,4- or 1,3,5-triols or their simple derivatives.

For a triol or other trisubstituted cyclohexane, three structures are possible: 1,2,3 or vicinal (1), 1,3,5 or symmetric (2), and 1,2,4 or asymmetric (3). For the 1,2,3 structure there are predicted one DL and two *meso* diastereomers (13, 14, 15), all previously re-

(1) (a) For preceding paper, see G. E. McCasland, S. Furuta, and L. J. Durham, *J. Org. Chem.*, **31**, 1516 (1966). (b) Presented by G. E. M. at the 152nd National Meeting of the American Chemical Society, New York, N. Y., Sept 1966.

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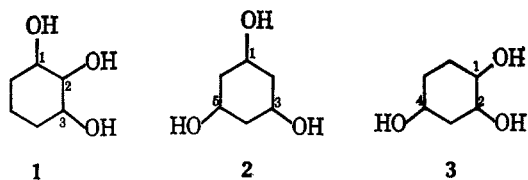
(3) G. E. McCasland, *J. Am. Chem. Soc.*, **85**, 2189 (1963).

(4) For reviews of previous work on cyclohexanetriols, see (a) T. Posternak, "Cyclitols," Eng. transl., Holden-Day, Inc., San Francisco, Calif., 1965, pp 122–127; (b) H. D. Orloff, *Chem. Rev.*, **54**, 379 (1954); (c) E. H. Rodd, "Chemistry of Carbon Compounds," Vol. II-A, Elsevier Publishing Co., New York, N. Y., 1953, pp 165, 166. For reviews on other cyclitols, see also (d) S. J. Angyal and L. Anderson, *Advan. Carbohydrate Chem.*, **14**, 135 (1959); (e) G. E. McCasland, *ibid.*, **20**, 11 (1965).

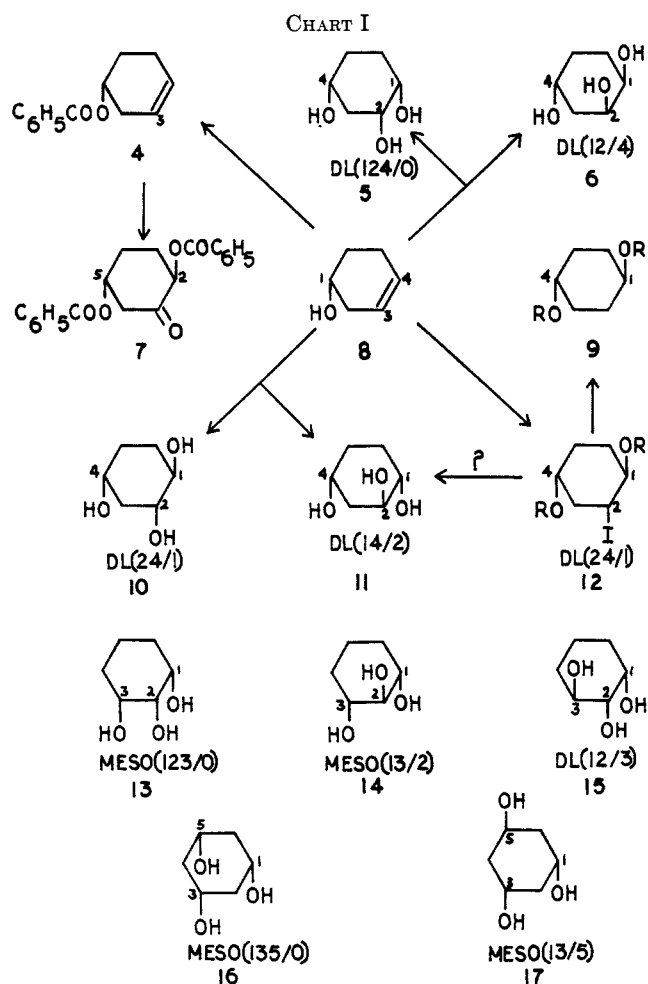
(5) There are 14 cyclohexanetriol isomers if the two enantiomers of each racemic pair are separately counted.

(6) G. E. McCasland, unpublished results.

(7) R. U. Lemieux, R. K. Kullig, and R. Y. Moir, *J. Am. Chem. Soc.*, **80**, 2237 (1958).



ported,^{4a} although the levorotatory form of **15** is known only as the tribenzoate derivative. For the 1,3,5 structure there are predicted two diastereomers (**16** and **17**), both *meso* and both previously reported^{4a} (see Chart I). For the 1,2,4 structure there are predicted



no *meso* and four racemic diastereomers (**5**, **6**, **10**, and **11**); of these, one or possibly two diastereomers previously were prepared⁸⁻¹⁰ (see below); none of the active enantiomers is yet known (see Table I).

Cyclohexanetriol stereoisomers are most conveniently designated by fractional notation,^{11,12} as in the present

(8) N. D. Zelinski and A. N. Titova, *Ber.*, **64**, 1403 (1931).

(9) (a) H. B. Henbest and B. Nicholls, *J. Chem. Soc.*, 4608 (1957). (b) Yields from the peroxyformic acid reaction reportedly can be improved by using steam hydrolysis instead of basic hydrolysis of the crude monoformate product; see J. B. Brown, H. B. Henbest, and E. R. H. Jones, *ibid.*, 3634 (1950).

(10) D. A. Prins, *Helv. Chim. Acta*, **40**, 1621 (1957).

(11) (a) For further explanation of this fractional notation for stereoisomers, see G. E. McCasland, *Advan. Carbohydrate Chem.*, **20**, 13 (1965); (b) see also G. E. McCasland, "A New General System for the Naming of Stereoisomers," Chemical Abstracts Service, Columbus, Ohio, 1953.

(12) Early investigators specified the three 1,2,3-cyclohexanetriols by arbitrary prefixes α , β , and γ , and the 1,3,5-triols by α and β . Now that the configurations are known, it would seem better to abandon these Greek letter prefixes. Steroid prefixes, e.g., " α , β , α " sometimes have been used for cyclohexanetriols but seem undesirable because the cyclohexane ring (unlike

a steroid ring system) has no fixed conformation or unequivocal "front" or "back." Prefixes such as "*cis*, *cis*, *trans*" seem needlessly clumsy. According to *Chemical Abstracts* rules, an asymmetrical cyclohexanetriol (III) is numbered 1,2,4 (not 1,3,4), regardless of the configuration.

(13) (a) C. J. Gogek, R. Y. Moir, and C. B. Purves, *Can. J. Chem.*, **29**, 946 (1951); (b) C. J. Gogek, R. Y. Moir, J. A. McRae, and C. B. Purves, *ibid.*, **29**, 938 (1951).

Typical cyclohexanetriols are readily soluble in water. They have lower melting points and higher solubilities in nonpolar solvents than inositols or quercitols (pentols). They are most frequently characterized by preparation of the tribenzoates. The triols all have nearly the same R_f values for paper chromatography, at least with the solvent systems so far used.

In our work now reported, the four predicted diastereomers (all racemic) of 1,2,4-cyclohexanetriol were prepared, using 3-cyclohexen-1-ol^{13a} or its benzoate^{13a} as starting material. Two diastereomers (mp 138 and 161°) necessarily having the 1,2-*cis* configurations **5** and **6** were prepared by reaction with silver chlorate-osmium tetroxide,^{14a} or, with lower yields, by the "wet Prévost" method.¹⁵ The mp 161° triol was converted to its tri-*p*-toluenesulfonate, mp 110°, and the mp 138° triol was converted to its tri-*p*-toluenesulfonate, mp 140°. Two diastereomers (mp 138 and 150°) necessarily having the 1,2-*trans* configurations **10** and **11** were prepared by the dry Prévost method¹⁶ or, with lower yields, by use of peroxyformic acid.¹⁷ The initial products of the Prévost reaction were the tribenzoates (mp 116 and 154°, respectively); hydrolysis gave the triols. An unexpected product from the silver chlorate reaction of 3-cyclohexen-1-ol benzoate (**4**) was the 5-monobenzoate of 2,5-dihydroxycyclohexanone, isolated as the dibenzoate, **7**. An intermediate isolated from the dry Prévost reaction was the iododiol dibenzoate **12**.

Nmr Spectra of the 1,2,4-Cyclohexanetriols.—For nmr assignments of conformation¹⁸ and configuration to the cyclohexanetriols, we have relied rather heavily upon an analysis of the relative shielding (or deshielding) effects of an axial or equatorial hydroxyl group upon neighboring protons (1,2 or 1,3 interactions).

(14) (a) T. Posternak and H. Friedli, *Helv. Chim. Acta*, **36**, 251 (1963); (b) T. Posternak and F. Ravenna, *ibid.*, **30**, 441 (1957); (c) T. Posternak and P. Waegell, *ibid.*, **44**, 257, 267 (1961).

(15) (a) F. V. Brucher, Jr., and G. Evans, III, *J. Org. Chem.*, **23**, 618 (1958); (b) R. B. Woodward and F. V. Brucher, Jr., *J. Am. Chem. Soc.*, **80**, 209 (1958).

(16) (a) C. Prévost, *Compt. Rend.*, **196**, 1129 (1933); **197**, 1661 (1933); (b) G. E. McCasland and E. C. Horswill, *J. Am. Chem. Soc.*, **76**, 1654 (1954); (c) G. E. McCasland, S. Furuta, L. F. Johnson, and J. N. Shoolery, *J. Org. Chem.*, **28**, 894 (1963); (d) C. V. Wilson, *Org. Reactions*, **9**, 332 (1957).

(17) A. Roebuck and H. Adkins, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p 217.

(18) It is here assumed that the favored chair conformation of any tri-substituted cyclohexane (1,2,3, 1,2,4, or 1,3,5) will be either triaxial or monoaxial-diequatorial unless some unusual structural feature is present. The populations of triaxial or diaxial-monoequatorial molecules ordinarily should be negligible. Probably boat or twist forms need not be considered for the triols or their simple derivatives.

TABLE I
 THE NINE ISOMERIC CYCLOHEXANETRIOLS

Configuration and formula	Mp, °C			Ref
	Triol	Tribenzoate	Triacetate (or other derivative)	
1,2,3 Structure				
<i>meso</i> (1,2,3/0), ^a 13 (all- <i>cis</i>)	148	142	47	<i>b</i>
<i>meso</i> (1,3/2), ^c 14	108	142	126	<i>b</i>
DL(1,2/3), ^d 15	(DL) 125	(DL) 181	...	<i>b</i>
D(1,2/3)	(+71°) 134	(+193°) 143		
L(1,2/3)	...	(-191°) 143		
1,2,4 Structure				
DL(1,2,4/0), 5 (all- <i>cis</i>)	(DL) 138	...	Tri- <i>p</i> -toluenesulfonate, 140	<i>e</i>
DL(1,2/4), 6	(DL) 161	(DL) 129	Tri- <i>p</i> -toluenesulfonate, 110	<i>e</i>
DL(1,4/2), 11	(DL) 138	(DL) 116	...	<i>e</i>
DL(2,4/1), 10	(DL) 150	(DL) 154	...	<i>e, f</i>
1,3,5 Structure				
<i>meso</i> (1,3,5/0), ^c 16 (all- <i>cis</i>)	184 (·2H ₂ O 110)	...	79 (triphenylurethane, 245)	<i>b, g-i</i>
<i>meso</i> (1,3/5), ^d 17	145	...	(Triphenylurethane, 160)	<i>b, g-i</i>

^a Formerly known as γ . ^b See ref 4a. ^c Formerly known as α . ^d Formerly known as β . ^e This article. ^f See ref 8, 9, and 10. ^g See W. Wislicenus, *Ber.*, **27**, 358 (1894). ^h See H. Stetter and K. H. Steinacker, *Chem. Ber.*, **85**, 451 (1952). ⁱ See S. Fürberg and O. Hassel, *Acta Chem. Scand.*, **4**, 597 (1950).

Such analyses have been described by Lemieux and Stevens¹⁹ and Bhacca and Williams.²⁰ The successful application of this approach in the cyclohexanetriol series gives further support to its potential value for use in a variety of cyclic molecules. The configurational assignments reached are consistent with chemical evidence.

The 100-Mcps spectra of the four diastereomeric 1,2,4-triols in deuterium oxide using DSS internal reference are shown in Figure 1. Of the four spectra shown, only the spectrum for the 1,2-*trans* triol (**11**) of mp 138° (Figure 1a) fits the diastereomer DL(1,4/2). The unperturbed quintet at 4.1 ppm is due to the equatorial O-C-H proton H-4, which has two axial and two equatorial neighboring methylene protons, with signals at higher field. The two axial O-C-H protons, H-1 and H-2 (3.47 and 3.72 ppm), show perturbation indicative of their mutual coupling. Although these two protons, H-1 and H-2, would be expected to be shielded by the equatorial hydroxyl groups at C-2 and C-1, respectively, they are magnetically quite different because of additional deshielding of H-2 by the 4-hydroxyl group (1,3-diaxial interaction). The splitting pattern of H-2 is typical of an axial proton having two axial and one equatorial neighboring protons ($J = 10, 8, \text{ and } 4.5 \text{ cps}$). The pattern for H-1 is less well defined, probably because of virtual coupling, resulting from the fact that some of the methylene protons at higher field have nearly equal chemical shifts.

By similar reasoning, the spectrum for the mp 150° triol (Figure 1b) seems to fit only the all-equatorial diastereomer DL(2,4/1) (**10**), whose O-C-H ring protons are all axial.²¹ The axial proton H-4 produces an unperturbed signal at 3.7 ppm, which is approximately a triplet of triplets resulting from two diaxial and two axial-equatorial interactions. The two-proton signal centered at about 3.4 ppm was nearly unchanged at

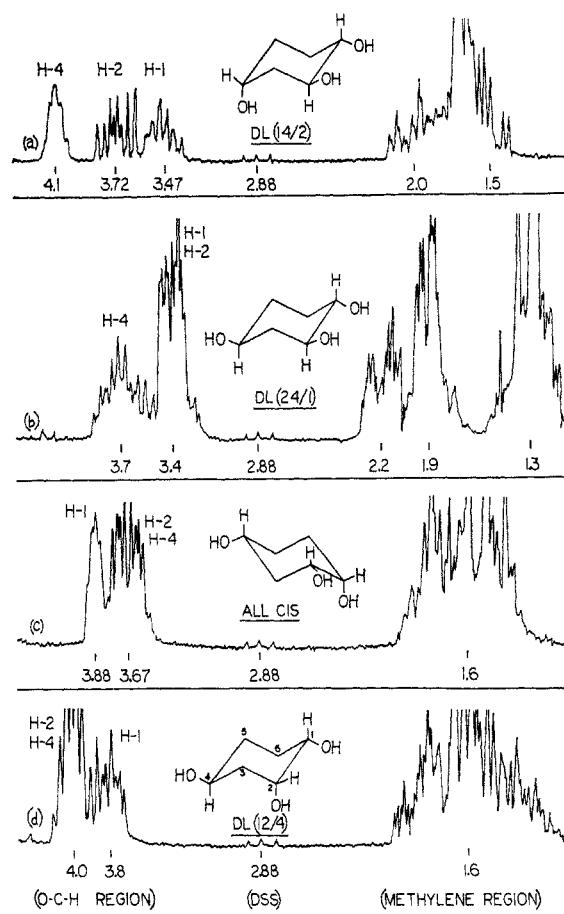


Figure 1.—Nmr spectra at 100 Mcps of the four diastereomeric 1,2,4-cyclohexanetriols in deuterium oxide using DSS internal reference: (a) DL(1,4/2), mp 138°; (b) DL(2,4/1), mp 150°; (c) DL(1,2,4/0), mp 138°; (d) DL(1,2/4), mp 161°.

60 Mcps, suggesting that these two protons, H-1 and H-2, are magnetically equivalent or nearly so. Since these protons appear at higher field than the axial proton H-4, H-1 must be shielded by the equatorial 2-hydroxyl group and H-2 by the equatorial 1-hydroxyl group, as would be expected.^{19,20} Thus the two 1,2-*trans* diastereomers **11** and **10** (mp 138 and 150°) of 1,2,4-cyclohexanetriol are clearly distinguished.

(19) R. U. Lemieux and J. D. Stevens, *Can. J. Chem.*, **43**, 2059 (1965).

(20) N. Bhacca and D. H. Williams, "Applications of NMR Spectroscopy in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1964: (a) Chapter 8 (the work here described is principally that of K. Tori and co-workers); (b) p 109. (c) Y. Kawazoe, Y. Sato, M. Natsume, H. Hasegawa, T. Okamoto, and K. Tsuda, *Chem. Pharm. Bull.* (Tokyo), **10**, 338 (1962).

(21) The reader should keep in mind that each axial substituent corresponds to an equatorial ring proton and vice versa.

The spectra of the two 1,2-*cis* diastereomers **5** and **6** (mp 138 and 161°) show only rather subtle differences, since the O-C-H proton H-4 in both isomers is axial, and in both isomers one of the two protons, H-1 and H-2, is axial, the other equatorial. Although the appearance in the mp 138° diastereomer spectrum (Figure 1c) of a perturbed equatorial proton signal at 3.88 ppm confirms the 1,2-*cis* configuration, it does not distinguish between the two 1,2-*cis* isomers.

However, configurational interpretation can be achieved by an analysis of the shielding-desielding effects of certain hydroxyl groups on certain O-C-H ring protons in the two diastereomers. It will be noted that the O-C-H spectrum of the mp 138° triol consists of a one-proton downfield and a two-proton upfield signal, while the corresponding spectrum of the mp 161° triol (Figure 1d) consists of a two-proton downfield and one-proton upfield signal. The one-proton upfield signal of the mp 161° triol shows a normal axial chemical shift (about 3.8 ppm). [For example, compare the shift, 3.7 ppm, of the axial proton H-4 in the DL(2,4/1) diastereomer **10** in Figure 1b; the latter proton is relatively unaffected by shielding-desielding influences.] The remaining axial proton (Figure 1d) then must have been shifted downfield, to approximately the location of the equatorial proton signal, by some strong deshielding effect. This is exactly what one would expect for the axial proton H-4 in the DL(1,2/4) configuration (**6**), owing to 1,3-diaxial interaction with the position-2 hydroxyl group. Therefore the configuration DL(1,2/4) (**6**) may be assigned to the diastereomer of mp 161°, and the all-*cis* configuration (**5**) to the diastereomer mp 138° (Figure 1c). Thus the two 1,2-*cis* triols of mp 138 and 161° were clearly distinguished.

In the all-*cis* diastereomer (**5**) the two axial protons had nearly the same chemical shift; however, it was not possible to establish definite magnetic equivalence or nonequivalence of these protons (H-2 and H-4) by comparisons of 60- and 100-Mcps spectra, because at 60 Mcps the equatorial and axial patterns overlapped.

Chemical Studies on the 1,2,4-Cyclohexanetriols.—The preparation of 1,2,4-cyclohexanetriols by hydrogenation or reduction of 1,2,4-benzenetriol has apparently never been reported. In any event, this method might produce a mixture of several isomers which would be difficult to separate. It appeared more convenient to use a *cis* or *trans* hydroxylation of 3-cyclohexen-1-ol, or one of its esters or ethers.

Synthesis of the 1,2-*cis* Diastereomers.—These diastereomers are best obtained by the reaction of 3-cyclohexen-1-ol with silver chlorate in water containing a catalytic amount of osmium tetroxide.^{14a} The crude mixed triol product, a syrup, was benzoylated in the usual manner; the mixed tribenzoates were crystallized from ethanol, giving the pure, crystalline DL(1,2/4) tribenzoate, mp 129°, in about 15% yield. This tribenzoate on hydrolysis, preferably under acidic conditions, gave the corresponding free triol, mp 161°, in about 80% yield. Since the DL(1,2,4/0) tribenzoate could not be obtained in crystalline form by evaporation of the ethanolic mother liquor from the DL(1,2/4) tribenzoate, the crude evaporation residue was hydrolyzed, giving the crystalline DL(1,2,4/0) or all-*cis* triol, mp 138°, in about 3% yield (based on cyclohexenol). On benzoylation of this pure triol, it was

still not possible to obtain the all-*cis* tribenzoate in crystalline form.

An alternative preparation of the 1,2-*cis* diastereomers (yields about the same) is to treat 3-cyclohexen-1-ol benzoate with silver acetate and iodine in acetic acid containing a little water (so-called "wet Prévost" reaction).¹⁵ The crude, mixed, partially esterified product was hydrolyzed, and the crude mixed triols so obtained were crystallized from ethanol-ethyl acetate, giving the DL(1,2/4) triol, mp 161°, in about 13% yield. From the mother liquor on partial evaporation there was obtained the DL(1,2,4/0) or all-*cis* triol, mp 138°, in about 8% yield. The later isolation of this isomer apparently was due *both* to a smaller proportion formed in the wet Prévost reaction and to a higher solubility in ethanol-ethyl acetate. If the crude mixed triols from the wet Prévost reaction are benzoylated, the DL(1,2/4) tribenzoate is obtained in about 20% yield, based on cyclohexenol benzoate; once again, the mother liquors on evaporation failed to yield the all-*cis* tribenzoate in crystalline form.

For hydrolysis of the purified tribenzoates, or of the crude mixed monobenzoate monoacetates from the "wet Prévost" reaction, we find that aqueous, ethanolic hydrochloric acid (see the Experimental Section) is considerably more satisfactory than the usual basic hydrolysis, since nonvolatile inorganic impurities are avoided. We believe that acidic hydrolysis of cyclitol esters in general deserves to be more widely used.

Synthesis of the 1,2-*trans* Isomers.—These diastereomers are best obtained by reaction of 3-cyclohexen-1-ol benzoate with silver benzoate and iodine in dry benzene (original or dry Prévost reaction¹⁶). When the crude mixed product was crystallized from ethanol, the DL(2,4/1) diastereomer (**10**), mp 154°, was first obtained, in about 20% yield. Hydrolysis of this tribenzoate, preferably under acidic conditions, gave the DL(2,4/1) triol (**10**), mp 151°, in about 80% yield. On evaporation of the ethanolic mother liquor, there was first obtained a small amount of an iododiol dibenzoate intermediate (see below), and on further evaporation, the DL(1,4/2) tribenzoate, mp 116°, in about 10% yield. The mp 154° isomer is less soluble and may also be the predominant product of the dry Prévost reaction. Hydrolysis of the mp 116° tribenzoate under acidic conditions gave the DL(1,4/2) triol (**11**), mp 138°, in about 65% yield. (Note that the melting point of this triol is nearly the same as that of the all-*cis* diastereomer.)

An alternative preparation of the 1,2-*trans* diastereomers (yields somewhat lower) is to treat 3-cyclohexen-1-ol (not the benzoate) with an aqueous solution of hydrogen peroxide and formic acid.¹⁷ The crude mixture of partially esterified triols was hydrolyzed (basic conditions),^{9b} and the resultant mixture so obtained was benzoylated in the usual manner. The mixed tribenzoates were fractionally crystallized from ethanol, giving first the DL(2,4/1) tribenzoate, mp 154°, in about 10% yield. The ethanolic mother liquor on partial evaporation gave the DL(1,4/2) tribenzoate, mp 116°, also in about 10% yield. The free triols were prepared from the tribenzoates as before.

Anomalous Oxidation to a Ketodiol.—In early experiments we attempted to prepare the 1,2-*cis*-triols by reaction of 3-cyclohexen-1-ol benzoate with silver

chlorate-osmium tetroxide in aqueous acetone. The crude product was treated with benzoyl chloride in pyridine, to facilitate isolation, and a pure, crystalline compound, mp 186°, was obtained. To our surprise, this product was not the expected triol tribenzoate, but was actually 2,5-dihydroxycyclohexanone dibenzoate (7) as shown by microanalysis and infrared and nmr spectra. The yield was about 10%. The two hydroxyl groups have a *trans* configuration, as deduced from the nmr spectrum (see the Experimental Section). Since osmium tetroxide was used only in catalytic amount, the oxidizing agent responsible for formation of the carbonyl group presumably was atmospheric oxygen, but conceivably might be chlorate ion, silver ion, or acetone. The anomalous result may be due in part to the fact that silver chlorate, although soluble in water, is nearly insoluble in 70% acetone. Thus oxidation to carbonyl might take place at the solid-liquid interface. The exact mechanism remains to be determined.

Isolation of an Iododiol Dibenzoate Intermediate.—

The mother liquor from the DL(2,4/1) tribenzoate (mp 154°) on concentration gave a small yield (0.8%) of a compound with mp 175–176°. At first this compound was thought to be another triol tribenzoate, but analysis indicated it was an iodocyclohexanediol dibenzoate. The yield can be raised to about 20% by changing the ratio of silver benzoate to iodine used in the preparation (see the Experimental Section). The structure and configuration with respect to the hydroxyl groups were established by catalytic dehalogenation²² to the previously known²³ *meso,trans* diastereomer of 1,4-cyclohexanediol dibenzoate, mp 149°, which was identical with an authentic sample. For mechanistic reasons, the iodine atom undoubtedly is *trans* to the neighboring hydroxyl group. The structure and configuration were confirmed by nmr and spin decoupling (see the Experimental Section). The mother liquor from the iododiol dibenzoate on long standing gave the remaining 1,2-*trans* isomer of the triol tribenzoate, mp 116°, as mentioned above.

The expected intermediates from the first (addition) step of the Prévost reaction with 3-cyclohexen-1-ol benzoate would be all or any of the four isomeric iododiol dibenzoates, 12, 18, 19, and 20. The latter

isomers have not been isolated, but may be present in the mother liquors. According to neighboring group theory, any of these four intermediates might react with silver benzoate to give the tribenzoate of either of the triols, 10 or 11.

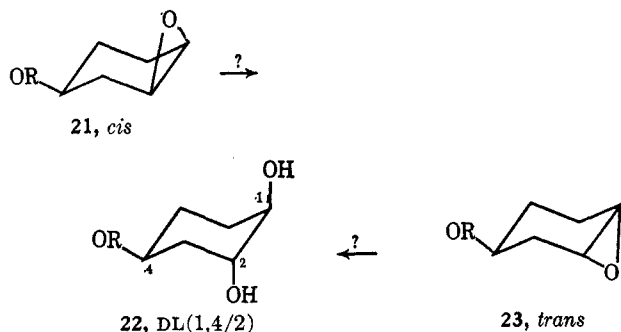
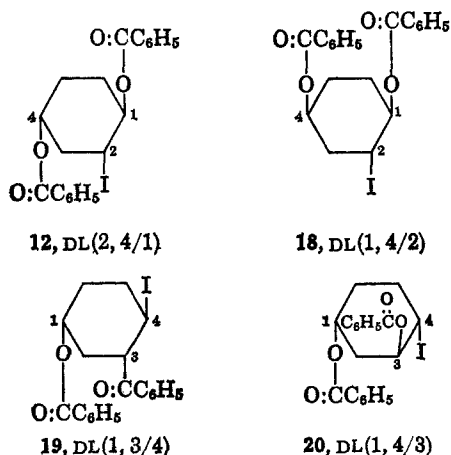
Experimentally, when the pure iododiol benzoate (12) was heated for a long time with silver benzoate in benzene, we were unable to isolate any triol tribenzoate product; starting material was recovered. For this reason, we do not believe that the iododiol dibenzoate 12 is a precursor of the triol tribenzoate 10, but conceivably it may be a precursor of the triol tribenzoate 11, since the yield of the latter from our original Prévost reaction was very small.

Previous Syntheses of the 1,2,4-Cyclohexanetriols.—

In 1931, Zelinski and Titova⁸ reported the first preparation of a 1,2,4-cyclohexanetriol. By reaction of 3-cyclohexen-1-ol with peroxybenzoic acid they obtained a triol which reportedly was a sweet-tasting, very hygroscopic substance (crystals from alcohol-ether), softening at 104° and melting at 122°. This product, necessarily of the 1,2-*trans* configuration, quite possibly was a mixture of the DL(1,4/2) and DL(2,4/1) diastereomers, now known to have melting points of 138 and 150°, respectively. Nontriol impurities may also have been present, since our pure triols are not hygroscopic.

In 1957, Henbest and Nicholls⁹ by reaction of 3-cyclohexen-1-ol (or its benzyl ether) with peroxybenzoic or peroxyformic acid reportedly obtained a triol, mp 122–125°, and its tribenzoate, mp 155.5–157°. This tribenzoate no doubt is identical with our DL(2,4/1) tribenzoate, mp 153–154°, but the purity of their triol itself again is doubtful. The 4- α -naphthylurethan of the triol was also prepared, mp 201°. The 4-O-benzyl derivative was a gum.

According to Henbest and Nicholls,⁹ 4-benzyloxy-cyclohexene reacts to give a mixture of the *cis* and *trans* epoxide intermediates (21 and 23). They further suggest that the favored orientation of the benzyloxy group would be equatorial in both 21 and 23. Thus, if diaxial ring opening is assumed, both epoxides should give the same triol derivative, which would have the configuration DL(1,4/2) (formula 22). Since we now find by nmr that the product obtained actually has the configuration DL(2,4/1), it appears that the mechanism of epoxide ring opening in this reaction requires further study.



Also in the year 1957, Prins¹⁰ by reaction of 3-cyclohexen-1-ol benzoate with peroxyphthalic acid prepared a 1,2,4-triol 4-monobenzoate, mp 101–103°, which appears to be a single, pure isomer. This isomer necessarily would have the 1,2-*trans* configuration

(22) G. E. McCasland and E. C. Horswill, *J. Am. Chem. Soc.*, **75**, 4020 (1953).

(23) (a) N. A. B. Wilson and J. Read, *J. Chem. Soc.*, 1269 (1935); (b) H. Lindemann and H. Baumann, *Ann.*, **477**, 78 (1929); (c) L. Paltray and B. Rothstein, *Bull. Soc. Chim.*, **45**, 855 (1929).

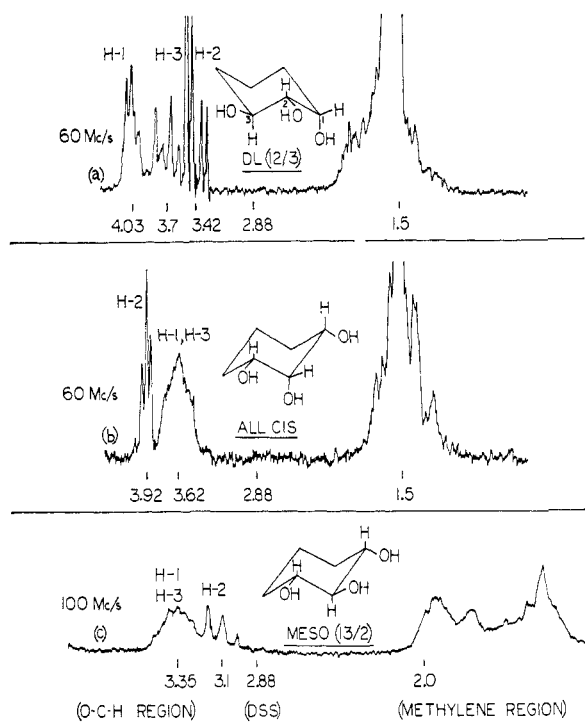


Figure 2.—Nmr spectra of the three diastereomeric 1,2,3-cyclohexanetriols in deuterium oxide using DSS internal reference: (a) DL(1,2/3), mp 125° at 60 Mcps; (b) *meso*(1,2,3/0), mp 148° at 60 Mcps; (c) *meso*(1,3/2) mp 108°, at 100 Mcps.

10 or 11 but, since it was not converted to the tribenzoate or triol, the exact identity remains undecided.

Nmr Studies on the 1,2,3-Cyclohexanetriols.—Previously reported evidence for the configurations of the 1,2,3-cyclohexanetriols has included (1) the known mechanisms of the hydroxylations or oxirane ring closings and openings used in synthesis;^{4a} (2) the relative reaction rates with glycol splitting reagents;^{14b} (3) *Acetobacter suboxydans* studies;^{14b} and (4) nmr studies on the dimethyl ether monoacetates.⁷ Since these previous studies²⁴ have fully established the configurations of the three diastereomers of 1,2,3-cyclohexanetriol, and of the two enantiomers of the DL(1,2/3) diastereomer, our purpose now was to compare the actual nmr spectra of the free triols and their tribenzoates with those which would be anticipated and to obtain evidence for the conformations in solution.

The spectra (Figure 2) of the three diastereomers of 1,2,3-cyclohexanetriol (mp 108, 125, and 148°) were examined at 60 and 100 Mcps, using deuterium oxide, with DSS as internal reference. The spectra of the tribenzoate derivatives of the mp 108 and 148° triols were also examined, using chloroform-*d*.

The 60-Mcps spectrum (Figure 2a) of the mp 125° triol (15) contained a sharp, four-line O-C-H pattern (3.42 ppm) with spacings indicative of one diaxial (8.5 cps) and one axial-equatorial (3 cps) coupling. This pattern must be produced by the axial proton H-2. The other two O-C-H proton signals were more complex because of additional coupling with adjacent methylene protons. Nevertheless, patterns appropriate for an equatorial proton (H-1, 4.03 ppm) and an axial proton (H-3, 3.7 ppm) could be recognized. The degree

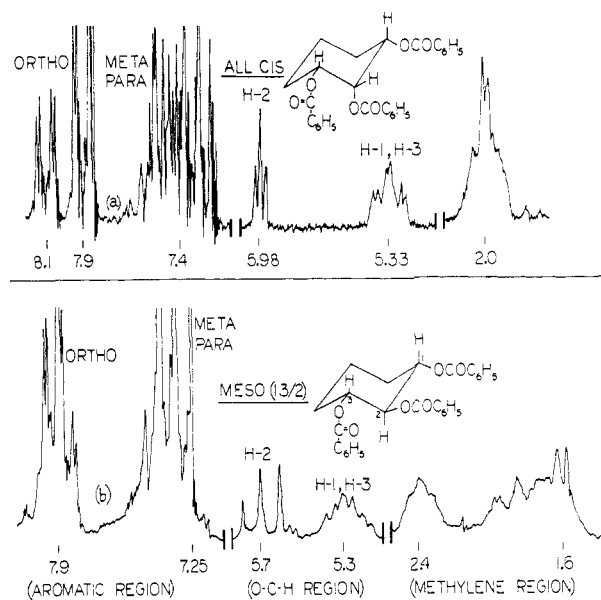


Figure 3.—Nmr spectra at 100 Mcps of two diastereomeric 1,2,3-cyclohexanetriol tribenzoates in chloroform-*d* using TMS reference: (a) *meso*(1,2,3/0), mp 142°; (b) *meso*(1,3/2), mp 142°.

of perturbation of the signals for the two axial protons indicated mutual coupling. The spectrum confirms the DL(1,2/3) configuration (15) previously assigned. The tribenzoate derivative was not available.

The spectrum (Figure 2b) of the mp 148° triol (13) at 60 Mcps contained a sharp triplet at 3.92 ppm ($J = 2-3$ cps), undoubtedly corresponding to the equatorial proton H-2 in the all-*cis* configuration. However, the signal due to the two equivalent axial protons, H-1 and H-3, appeared at 3.6 ppm and was poorly defined, because of broadening from interactions with adjacent methylene protons.

The all-*cis* or *meso*(1,2,3/0) configuration of the mp 148° triol (13) was more readily established by examining the spectrum (Figure 3a) of the corresponding tribenzoate (mp 142°). The tribenzoate spectrum at 60 Mcps contained a triplet very similar to that in the triol spectrum; however, the downfield shift of the H-2 triplet caused by benzylation was about 2.06 ppm, while the shift of the axial proton (H-1, H-3) signal was only about 1.70 ppm. At 100 Mcps this axial proton signal sharpened to a triplet of doublets, with no change in over-all signal width. The sharpening presumably is caused by decreased virtual coupling, due to a spreading out of the chemical shifts of the high-field (methylene) protons. The small spacing in the triplet of doublets had the same magnitude as the spacing in the H-2 triplet.

The unexpected triplet-like appearance of the H-1, H-3 signal in the triol and tribenzoate spectra (Figures 2b and 3a) probably is due to a combination of (a) strong coupling, and (b) similarity of axial and equatorial chemical shifts for the methylene protons at positions 4 and 6. In the triol, this similarity no doubt is brought about by the deshielding effect^{19,20} of the position-2 hydroxyl group (1,3 interactions). Although in other molecules acetylation of a hydroxyl group usually causes some loss of its deshielding effect on ring protons, the effect of benzylation is less well defined since anisotropy of the phenyl group may partially counteract the usual effect of esterification. The

(24) See also S. J. Angyal and D. J. McHugh, *J. Chem. Soc.*, 1423 (1957); 3682 (1957).

all-*cis* or *meso*(1,2,3/0) configuration (13) previously assigned^{14b} to the mp 148° diastereomer of 1,2,3-cyclohexanetriol is thus confirmed.

The spectrum of the mp 108° triol (14) (Figure 2c) was not useful for configurational interpretation, since all three O-C-H proton signals were superimposed, even at 100 Mcps. However, in the 100-Mcps spectrum (Figure 3b) of its tribenzoate, mp 142°, the signal of the axial proton H-2 was shifted far enough downfield that it could be observed as a perturbed triplet with characteristic diaxial coupling ($J = 9.5$ cps). The axial nature of H-1 and H-3 is indicated also by the width of the H-1, H-3 signal, which has roughly the appearance of a doubled triplet, 24 cps wide. This signal results from an axial-equatorial and two diaxial couplings. The latter couplings probably are unequal, owing to the greater effect of the electronegative substituent on the magnitude of one of the coupling constants. The *meso*(1,3/2) configuration (14) previously assigned^{14b} to the mp 108° diastereomer of 1,2,3-cyclohexanetriol is thus confirmed.

Nmr Studies on the 1,3,5-Cyclohexanetriols.— Since the configurations of the 1,3,5-triols^{25,26} had been rigorously established by the X-ray crystallographic studies of Hassel²⁷ and co-workers at Oslo, our purpose now was to compare the actual nmr spectra with those which would be anticipated, and to obtain evidence for the conformations in solution.

The spectra (Figure 4) of the two diastereomeric 1,3,5-cyclohexanetriols were recorded at 60 and 100 Mcps, using deuterium oxide with DSS as internal reference. The high degree of symmetry of the all-*cis* diastereomer (16), mp 184°, was reflected in the unusual simplicity of the spectrum (Figure 4a). The nine ring protons produced only three signals: an axial methylene signal at 1.22, an equatorial methylene signal at 2.20, and an equatorial O-C-H signal at 3.68 ppm. At 100 Mcps the three signals were chemically shifted but not otherwise changed, indicating that the three protons of each signal are magnetically as well as geometrically equivalent.

The three-proton axial methylene signal appears as a quartet owing to near equality of the one geminal and two diaxial coupling constants (about 11–11.5 cps). The three-proton equatorial methylene signal at lower field is approximately a pair of triplets due to coupling with the geminal proton, and with two neighboring axial protons ($J = 4$ to 4.5 cps). This signal contains additional fine structure. The three-proton O-C-H signal appears as a triplet of triplets, produced by coupling with the two neighboring axial protons ($J = 11.5$ cps), and the two neighboring equatorial protons ($J = 4.5$ cps). The previously assigned²⁷ all-*cis*, all-equatorial, or *meso*(1,3,5/0) configuration (16) of this mp 184° diastereomer is thus confirmed.

The spectrum (Figures 4b and 4c) of the *meso*(1,3/5) triol (17), mp 145°, was considerably more complex than that of the all-*cis* triol. Interpretation was aided, however, by comparisons of the spectra at 100 and 60 Mcps, and by similarities in the spectra for the two diastereomers.

The two equivalent axial protons, H-1 and H-3, in the mp 145° triol (17) produced a triplet of triplets

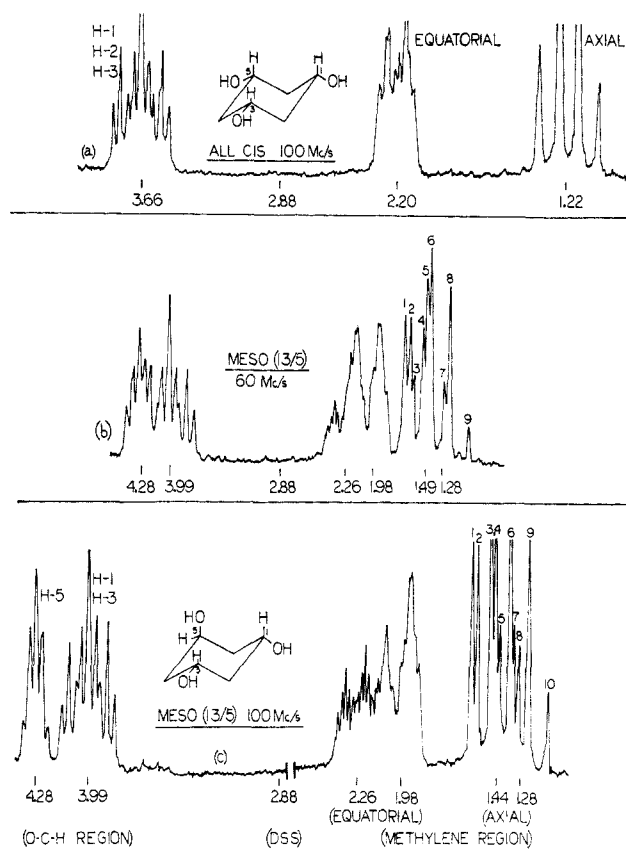


Figure 4.—Nmr spectra of the two diastereomeric 1,3,5-cyclohexanetriols in deuterium oxide using DSS internal reference: (a) *meso*(1,3,5/0), mp 184°, at 100 Mcps; (b) *meso*(1,3/5), mp 145°, at 60 Mcps; (c) same at 100 Mcps.

at 3.99 ppm (Figure 4c) which was strikingly similar in shape to the pattern of the three axial protons, H-1, H-3, and H-5, in the mp 184° triol. The downfield shift from 3.68 to 3.99 ppm may be attributed to deshielding^{19,20} by the axial hydroxyl group at position 5. The signal of the equatorial proton H-5 was well separated and appeared as a quintet at 4.28 ppm. The 3–4-cps spacing probably does not represent a true coupling constant in this complex spin system involving two neighboring axial and two neighboring equatorial methylene protons.

The axial methylene proton H-2 produced a quartet at 1.28 ppm (Figure 4c) very similar to the quartet at 1.22 ppm produced by three axial protons in the spectrum of the all-*cis* triol. The quartet now observed, however, was superimposed on an eight-line pattern at 1.44 ppm, due to the two remaining axial protons H-4 and H-6, and could be detected only by close comparison of the 60- and 100-Mcps spectra. (The eight-line pattern of the equivalent protons H-4 and H-6 is attributed to splitting by the geminal proton and by a neighboring axial and equatorial proton, at each of the positions.)

In the 60-Mcps spectrum (Figure 4b), only nine of the expected 12 lines are actually visible, due to overlapping. Lines 3, 6, 8, and 9 belong to the H-2 quartet. Lines 6 and 8 belong also to the eight-line pattern, as well as lines 1, 2, 4, 5, and 7. In the 100-Mcps spectrum (Figure 4c), ten of the 12 lines are visible. Lines 3, 6, 9, and 10 now belong to the quartet. Line 3 belongs also to the eight-line pattern, as well as lines 1, 2, 4,

(25) See Table I, footnote *g*.

(26) See Table I, footnote *h*.

(27) See Table I, footnote *i*.

5, 7, and 8. Two lines of the eight-line pattern coincide at line 5 (Figure 4b) and at line 4 (Figure 4c).

The equatorial methylene proton H-2 gave a low-field signal at 2.26 ppm with the appearance of a pair of quintets, perhaps due to long-range coupling. The remaining equatorial protons H-4 and H-6, presumably equivalent, produced a pair of multiplets at higher field (1.98 ppm), the large splitting being due to geminal coupling. The previously assigned configuration²⁷ *meso*(1,3/5) (17) for the 1,3,5-cyclohexanetriol of mp 145° is thus confirmed.

Experimental Section

All melting and boiling points have been corrected. Melting points, unless otherwise noted, were measured on a Nalge-Axelrod micro hot stage. Microanalyses were performed by the Micro-Tech Laboratories, Skokie, Ill. Darco G-60 brand^{28a} decolorizing charcoal was used. Petroleum ether (bp 30–60°) was used.

Proton magnetic resonance spectra were recorded on a Varian A-60 or HR-100 spectrometer. Field-swept double-resonance experiments were conducted on the HR-100 after the method of Johnson,²⁹ using the fixed frequency of a V-3521 nmr integrator and a variable frequency from a Hewlett-Packard hp-200-J audio oscillator monitored by a hp-521-CR frequency counter. Chemical shifts are reported as parts per million (ppm) on the δ scale. Internal tetramethylsilane (TMS) was used as zero reference in chloroform-*d* and pyridine solutions, and internal sodium 2,2-dimethyl-2-silapentane-5-sulfonate (DSS) in deuterium oxide solutions. A trace of water was present in each pyridine solution.

The 1,2-*cis* Isomers of 1,2,4-Cyclohexanetriol. DL(1,2/4) Diastereomer of 1,2,4-Cyclohexanetriol (6). A. "Wet Prévost" Method, Basic Hydrolysis.—To a mixture of 1.78 g of 3-cyclohexen-1-ol benzoate,^{13a} 3.34 g of silver acetate, and 40 ml of acetic acid was added 2.54 g of powdered iodine, in portions with stirring, during a 30-min period. Water (0.18 ml) was added, and the mixture was heated to 90–95° for 3 hr, with vigorous stirring (using a reflux condenser). The mixture was filtered and the inorganic residue was washed with hot benzene (25 ml) and with ethyl acetate (25 ml).

The combined filtrates were evaporated and the yellow, viscous residue was taken up in 10 ml of methanol (filter). To the methanol filtrate was added 1.2 g of sodium hydroxide in 15 ml of methanol, and the mixture was boiled under reflux for 2 hr. The cooled mixture was diluted with 10 ml of water and neutralized with 1 *M* sulfuric acid. The solution was evaporated and the residue was extracted repeatedly with warm absolute ethanol (filter). The ethanol filtrate was evaporated, the residual syrup was dissolved in water, and the solution was passed down a 20-ml column of Amberlite MB-1 mixed bed resin.^{28b} The column was eluted with 100 ml of water, and the eluate was evaporated, giving 0.9 g of a syrup.

The syrup was crystallized from ethanol-ethyl acetate (1:4), giving 150 mg (13%) of the triol, mp 157–159°, identical with that from procedure C (see below). The mother liquors were reserved for preparation of the all-*cis* triol, mp 138°.

In another run, the syrupy, aqueous eluate was converted directly to the mp 129° tribenzoate (see below).

B. "Wet Prévost" Method, Acidic Hydrolysis.—In another run, on 1.78 g of starting material, the crude partially esterified triol from the wet Prévost reaction was hydrolyzed with hydrochloric acid. The hydrolytic procedure was similar to that used with the "trans" triol tribenzoate, mp 154° (see below). There was obtained 0.04 g of the triol, mp 145–155°; after two recrystallizations, the melting point rose to 159–161°. The ethanol-ethyl acetate mother liquor of the mp 145–155° sample was reserved for preparation of the all-*cis* triol (see below).

C. From the Tribenzoate.—A 300-mg portion of the tribenzoate, mp 127–129°, was hydrolyzed with base by the same pro-

cedure used for the mp 116° tribenzoate (see below), giving a 60-mg (67%) yield of the recrystallized triol, mp 157–160°. A sample recrystallized again for analysis melted at 159–161°.

Anal. Calcd for C₆H₁₂O₃: C, 54.53; H, 9.15. Found: C, 54.32; H, 9.10.

A 200-mg sample of the tribenzoate hydrolyzed with hydrochloric acid, as described for the mp 116° tribenzoate (see below), gave a 50-mg (84%) yield of the triol, mp 159–161°.

The nmr spectrum (Figure 1d) was recorded at 60 and 100 Mcps using deuterium oxide as solvent. Even at 100 Mcps, no individual proton signals could be identified. The three O-C-H protons appeared in the region 3.5–4.2 ppm. At 100 Mcps, these signals consisted of a downfield two-proton component and an upfield one-proton component (not completely separated). The upfield component, a complex multiplet, because of its width (about 20 cps) must be axial. The downfield component apparently results from superposition of an axial proton signal on the equatorial proton H-2 signal. The six methylene protons produced a very complex pattern in the region 1.1–2.3 ppm, which has not been interpreted.

The spectrum at 60 Mcps was also recorded in pyridine. Signals for the six methylene protons appeared in the region 1.5 to 2.8 ppm. Signals for two of the O-C-H protons appeared in the region 4.3–4.7 ppm. The signal for the third O-C-H proton (4.1 ppm) was badly broadened by long-range or possibly virtual couplings.³⁰ From the width, this signal appears to be produced by H-1 rather than H-4, which would be still broader.

DL(1,2/4) Diastereomer of 1,2,4-Cyclohexanetriol Tribenzoate (6). A. "Wet Prévost" Method, Basic Hydrolysis.—The crude, syrupy triol (aqueous eluate, 0.9 g) obtained after basic hydrolysis of the crude "wet Prévost" reaction product (see above) was benzoylated in the usual manner, giving 675 mg of the tribenzoate, mp 124–126°. A sample was recrystallized, raising the melting point to 127–129°. The compound was identical with that from procedure B.

B. Silver Chlorate Method.—A mixture of 2.0 g of 3-cyclohexen-1-ol,^{13a} 6.0 g of silver chlorate, 5 mg of osmium tetroxide, and 50 ml of water was stirred at 25° for 3 days in the dark. The solution was adjusted with 12 *M* hydrochloric acid to pH 1.0, stirred 30 min, and filtered. The filtrate was adjusted with powdered sodium bicarbonate to pH 8.0 and extracted with ethyl acetate for 24 hr, using a continuous extractor. The separated and dried organic phase was evaporated, giving a syrup.

To the syrup was added 10 ml of dry pyridine and 7.5 ml of benzoyl chloride, at 0°, with stirring. After 24 hr at 25°, chloroform was added and the mixture was processed in the usual manner. The crude product was recrystallized from 95% ethanol, giving 1.4 g (15%) of product, mp 125–126°. This product on recrystallization gave 1.1 g of colorless crystals, mp 125–127°.

Anal. Calcd for C₂₇H₂₄O₆: C, 72.96; H, 5.44. Found: C, 72.70; H, 5.56.

The ethanolic mother liquors were reserved for preparation of the all-*cis* triol, mp 138° (see below).

The nmr spectrum was recorded at 60 and 100 Mcps, using chloroform-*d*. Signals for the 15 aromatic protons were observed at 7.9–8.2 (*ortho*) and 7.2–7.7 ppm (*meta* and *para*). Signals for the six methylene protons appeared at 1.7–2.8 and for the three O-C-H ring protons at 5.4–5.9 ppm. The signals were not sufficiently resolved even at 100 Mcps to permit any detailed configurational interpretation.

DL(1,2/4) Diastereomer of 1,2,4-Cyclohexanetriol Tri-*p*-toluenesulfonate (6).—To a solution of 80 mg of the triol, mp 161°, in 5.0 ml of pyridine was added 95 mg of *p*-toluenesulfonyl chloride. The solution was kept at 25° for 3 days, then poured into 20 ml of ice-cold water. After 2 hr, the precipitate was collected and washed with 50 ml of 1 *M* hydrochloric acid, and with water (100 ml). The product was recrystallized from 95% ethanol, giving 30 mg (77%) of colorless crystals, mp 104–108°. After one more crystallization, a sample melted at 107–110°.

Anal. Calcd for C₂₇H₃₀O₉S₃: C, 54.54; H, 5.05; S, 16.16. Found: C, 54.34; H, 5.27; S, 16.07.

The nmr spectrum at 60 and 100 Mcps was recorded, using chloroform-*d*. Signals for the 12 aromatic protons were observed at 7.2–7.85 and for the tosyl methyl protons at 2.44 ppm (sharp

(28) (a) A product of the Darco Division, Atlas Powder Co., Wilmington, Del.; (b) Resinous Products Division, Rohm and Haas Co., Philadelphia, Pa.; (c) Aldrich Chemical Co., Milwaukee, Wis.

(29) L. F. Johnson, "Varian Associates Technical Information Bulletin," Vol. 3, No. 3, Varian Associates, Palo Alto, Calif., 1963, pp 5–7, 11–13.

(30) E. Becker, *J. Chem. Educ.*, **42**, 591 (1965).

singlet). Methylene proton signals were observed at 1.5–2.4 and O–C–H signals were observed at 4.4–4.9 ppm.

DL(1,2,4/0) or All-*cis* Diastereomer of 1,2,4-Cyclohexanetriol (5). A. "Wet Prévost" Method, Basic Hydrolysis.—The ethanol-ethyl acetate mother liquors from the DL(1,2/4) triol, mp 157–159°, on partial evaporation gave colorless crystals mp 132–135°. This product was recrystallized, giving 30 mg (8%) of colorless crystals, mp 136–138°.

Anal. Calcd for $C_6H_{12}O_3$: C, 54.53; H, 9.15. Found: C, 54.13; H, 9.02.

B. "Wet Prévost" Method, Acidic Hydrolysis.—From the mother liquor of the mp 145–155° triol fraction there was obtained 0.25 g (21%) of the all-*cis* triol, mp 120–130°; after two recrystallizations, the melting point rose to 136–138°.

C. Silver Chlorate Method.—The ethanolic mother liquors from the DL(1,2/4) tribenzoate, mp 126°, were evaporated. To the residual syrup (0.9 g) was added 20 ml of ethanol and 20 ml of 6 *M* hydrochloric acid and the mixture was boiled for 48 hr under reflux. Most of the ethanol was removed by evaporation and the aqueous solution was repeatedly extracted with benzene. The acidic aqueous phase on evaporation gave a syrup which was crystallized from ethanol-ethyl acetate (1:4), giving 90 mg (34%, based on tribenzoate) of colorless product, mp 128–131°. A sample was recrystallized, raising the melting point to 135–137°. The triol product was identical with that from procedure A. On attempted benzylation of this triol, no crystalline product could be obtained.

The nmr spectrum (Figure 1c) was recorded at 60 and 100 Mcps using deuterium oxide. Signals for the three O–C–H ring protons appeared in the region 3.4–4.1 ppm. The equatorial proton H-1 appeared as a perturbed quartet, not too well resolved, at about 3.88 ppm. The axial proton H-2 appeared as an eight-line pattern with spacings of 11, 5, and 3 cps consistent with the presence of one axial-axial and two axial-equatorial couplings. The other axial proton, H-4, is assumed to produce a broad pattern which is covered up by the H-1 and H-2 signals.

By use of nuclear magnetic double resonance at 100 Mcps, the nature of the eight-line H-2 pattern was confirmed and a 3-cps coupling between H-1 and H-2 was demonstrated.

The complicated pattern of the six methylene protons (15 or more peaks) could not be readily interpreted, even at 100 Mcps. By use of double resonance, however, it was shown that H-1 is coupled to methylene protons whose signals appear at 1.6 and 1.9 and H-2 to protons with signals at about 1.7 and 1.8 ppm.

DL(1,2,4/0) Diastereomer of 1,2,4-Cyclohexanetriol Tri-*p*-toluenesulfonate (5).—An 80-mg portion of the all-*cis* triol, mp 138°, was treated by the same procedure used for the mp 161° diastereomer, giving a 320-mg (82%) yield of the once-recrystallized product as colorless crystals, mp 139–140°.

Anal. Calcd for $C_{27}H_{30}O_9S_3$: C, 54.54; H, 5.05; S, 16.16. Found: C, 54.45; H, 5.11; S, 15.95.

The nmr spectrum was recorded at 60 and 100 Mcps, using chloroform-*d*. Signals for the 12 aromatic protons were observed at 7.2–7.85, and for the tosyl methyl group at 2.46 ppm (sharp singlet). Ring methylene protons were observed in the region 1.5–2.4, and O–C–H protons in the region 4.1–4.8 ppm. At 100 Mcps the signal for one of the O–C–H protons moved downfield to 4.7 ppm. This proton is presumed to be equatorial, because of the signal's width at half-height of about 9 cps. Other signals were not sufficiently separated for identification.

DL(2/5) or *trans* Diastereomer of 2,5-Dihydroxycyclohexanone Dibenzoate (7).—A mixture of 2.5 g of 3-cyclohexen-1-ol benzoate,^{13a} 3.0 g of silver chlorate, 5 mg of osmium tetroxide, and 30 ml of acetone-water (7:3) was stirred for 3 days at 25° in the dark. Water (5.0 ml) was added, and stirring was continued for 3 days more. The solution was adjusted with 6 *M* hydrochloric acid to pH 1.0 and stirred for 30 min. Silver chloride was removed by filtration and the filtrate was neutralized with powdered sodium carbonate and evaporated.

To the residue was added 15 ml of pyridine and 8.0 g of benzoyl chloride at 0° with stirring. After 24 hr at 25°, the product was isolated with the aid of chloroform in the usual manner, giving a syrup which was dissolved in 10 ml of dry benzene and passed over a 15 × 1 cm column of benzene-wet aluminum oxide. The column was eluted with 100 ml of benzene. The eluate on evaporation gave a syrup which was crystallized from chloroform-absolute ethanol (3:5). After 5 days, the crystals were collected (0.5 g, 10%, mp 184–186°), and recrystallized, giving 0.40 g of colorless product, mp 185–186°, used for the analysis. The

analysis showed the product to be a ketodiol dibenzoate, not the expected triol tribenzoate.

Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.96; H, 5.44. Calcd for $C_{20}H_{18}O_6$: C, 70.99; H, 5.36. Found: C, 70.81; H, 5.44.

The infrared spectrum contained a C=O stretching absorption maximum at 1740 (alicyclic carbonyl with neighboring electro-negative substituent) in addition to the benzoate ester carbonyl absorption at 1700 cm^{-1} .

The nmr spectrum was recorded at 60 and 100 Mcps using chloroform-*d*. Signals for the ten aromatic protons were observed in the regions 7.9–8.2 (*ortho*) and 7.4–7.6 ppm (*meta* and *para*). The O–C–H proton signals at 5.1–5.6 ppm were poorly separated, even at 100 Mcps.

However, the signals of the two α -carbonyl methylene protons, H-6_a and H-6_b, could be distinguished at 100 Mcps. The H-6_a signal at 2.8 ppm was a four-line pattern with spacings of 14 and 10 cps. These spacings are attributed to geminal and diaxial interactions. A small additional splitting of about 1 cps is perhaps due to long-range coupling through the carbonyl group to the axial proton H-2. The H-6_b signal at 3.1 ppm consisted of an eight-line pattern with spacings of 14, 5, and 1.5 cps. These spacings are attributed to geminal (14 cps) and axial-equatorial (5 cps) couplings. The 1.5-cps coupling once again is perhaps due to long-range coupling with H-2.

From the nature of the coupling shown by the two protons H-6_a and H-6_b, it appears that both of the O–C–H protons, H-2 and H-5, are axial. This means that the compound has the 2,5-*trans* or diequatorial configuration. If H-2 were equatorial, one might expect it to show a relatively sharp three- or four-line pattern, not superposed on the axial H-5 signal.

The 1,2-*trans* Isomers of 1,2,4-Cyclohexanetriol. DL(2,4/1) Diastereomer of 1,2,4-Cyclohexanetriol Tribenzoate (10). A.

Prévost Reaction.—To a slurry of 5.7 g of dry silver benzoate in 20 ml of dry benzene was added a solution of 3.2 g of iodine in 30 ml of the same solvent. After stirring for 30 min, 1.26 g of 3-cyclohexen-1-ol benzoate^{13a} was added, and the resulting mixture was boiled under reflux for 1 hr (anhydrous conditions). After standing at 25° for 12 hr, the mixture was filtered and the filtrate was washed successively with water, saturated sodium bicarbonate, 3% sodium thiosulfate, and again with water. The dried benzene solution was evaporated and the residue was crystallized from absolute ethanol, giving 0.70 g (25%) of product, mp 148–150°. A second crop of 100 mg, mp 148–150°, was obtained. The first crop was recrystallized from chloroform-absolute ethanol, giving a 0.55-g (20%) yield of colorless product, mp 152–153°. This product was again recrystallized for analysis, giving 0.50 g, mp 153–154°.

Anal. Calcd for $C_{27}H_{24}O_6$: C, 72.97; H, 5.41. Found: C, 72.87; H, 5.37.

The second crop mother liquor was reserved for use in preparations of the iododiol dibenzoate and the DL(1,4/2) triol tribenzoate (see below).

B. Peroxyformic Acid Reaction, Basic Hydrolysis.—To a mixture of 4.0 ml of 30% hydrogen peroxide and 15 ml of 90% formic acid was added slowly with stirring 2.0 g of 3-cyclohexen-1-ol^{13a} (temperature kept at 40–45°). After 24 hr at room temperature, the solution was evaporated. To the viscous residue was added an ice-cold solution of 2.0 g of sodium hydroxide in 4.0 ml of water, with stirring. After 1 hr, an additional 20 ml of water was added and the resulting solution was extracted with ethyl acetate for 24 hr using a continuous extractor.

The separated dried organic phase upon evaporation gave a gum. To this gum, at 0° with stirring, was added 10 ml of pyridine and 7.5 ml of benzoyl chloride. After 24 hr, chloroform was added and the mixture, processed in the usual manner, gave a gum which was crystallized from 95% ethanol (10 ml). A 0.90-g (10%) yield of colorless crystals, mp 150–152°, was obtained. The mother liquors were reserved for preparation of the mp 116° tribenzoate (see below).

The product was recrystallized, giving 0.70 g of colorless crystals, mp 152–153°. A sample again recrystallized had a constant melting point of 153–154°. The product was identical with that from procedure A.

The nmr spectrum was recorded at 60 and 100 Mcps using chloroform-*d*. Signals for the 15 aromatic protons appeared at 7.85 (*ortho*) and 7.1–7.6 ppm (*meta* plus *para*). Signals for the three O–C–H ring protons appeared in the region 5.0–5.7 ppm. Signals for the six methylene protons were found in the region 1.6–2.9 ppm. Configurational interpretation was not attempted.

DL(2,4/1) Diastereomer of 2-Iodo-1,4-cyclohexanediol Dibenzoate (12). A. From Tribenzoate Mother Liquors.—By evaporation of the ethanolic mother liquors from the DL(2,4/1) tribenzoate second crop prepared by the dry Prévost reaction (see above), there was obtained a syrup. This was taken up in 7.0 ml of absolute ethanol. After 7 days, a 25-mg (0.9%) yield of colorless crystals, mp 170° dec (capillary), was obtained. This product was recrystallized, giving 15 mg of product, mp 174° dec, identical with that from procedure B. The mother liquor from the 25-mg crop was reserved for preparation of the mp 116° triol tribenzoate (see below).

This iododiol dibenzoate failed to yield any triol tribenzoate even after prolonged boiling (30 hr) with silver benzoate and benzene (with or without a little added water); only starting material was recovered.

B. Prévost Reaction with Equimolar Quantities.—To a solution of 1.78 g of 3-cyclohexen-1-ol benzoate^{18a} in 20 ml of dry benzene was added 2.29 g (1 mole) of dry silver benzoate and a solution of 2.54 g (1 g-atom) of iodine in 20 ml of benzene. The mixture was stirred at 25° (not heated) for 2 days (anhydrous conditions). The filtered solution was washed successively with *M* hydrochloric acid, saturated sodium bicarbonate, 5% sodium thiosulfate, and water, and then dried. On evaporation there was obtained a syrup which was crystallized from absolute ethanol, giving 0.8 g (20%) of colorless needles, mp 175–176°. A sample was recrystallized for analysis.

Anal. Calcd for C₂₇H₂₄O₆: C, 72.97; H, 5.41. Calcd for C₂₀H₁₉O₄I: C, 53.33; H, 4.22. Found: C, 53.39; H, 4.50.

A sample on dehalogenation gave the known *trans*-1,4-diol dibenzoate (see below).

The nmr spectrum at 100 Mcps and integral were recorded, using chloroform-*d*. The ten aromatic protons were observed at 7.2–8.2, the two O–C–H protons at 4.7–5.2, the I–C–H proton at 4.2 ppm, and one of the methylene protons was observed at 3.0 ppm. (Signals of the five remaining methylene protons were in the region 1.4–2.8 ppm.)

By double resonance, it was shown that the methylene proton (H-3_e) with the isolated signal at 3.0 ppm (pair of multiplets) is coupled both to the I–C–H proton (H-2) and to one of the O–C–H protons (H-4). The compound therefore has the 2-iodo 1,4-diacyloxy structure (not 1-iodo-2,4-diacyloxy).

The O–C–H two-proton pattern was a broad, unresolved multiplet; the absence of any high, narrow signal near or atop the multiplet suggests that both H-1 and H-4 are axial. The axial I–C–H proton (H-2) produced a sharp, eight-line pattern, with spacings indicative of two diaxial couplings and one axial-equatorial coupling (*J* = 15, 12, and 5 cps). The equatorial methylene proton (H-3_e) signal was a pair of multiplets, with spacings compatible with one geminal and two axial-equatorial couplings. The compound was thus shown to have an all-equatorial conformation, indicating that the configuration is DL(2,4/1) (formula 12).

Dehalogenation²² of the Iododiol Dibenzoate to *meso,trans*-1,4-Cyclohexanediol Dibenzoate (9).—To a 500-mg sample of the above iododiol dibenzoate, mp 176°, dissolved in 250 ml of 95% ethanol, was added about 5 g of Raney nickel catalyst and about 3 g of Amberlite IR-45 anion-exchange resin.^{28b} The mixture was hydrogenated at 3 atm and 30° for 30 hr. The filtered solution was evaporated; the crystalline residue was twice recrystallized from 95% ethanol, giving 0.3 g (83%) of *meso,trans*-1,4-cyclohexanediol dibenzoate, as colorless needles, mp 142–144°. A sample was recrystallized, mp 147–149° (lit.²³ mp 151°).

The product was shown by infrared spectra and mixture melting point to be identical with an authentic sample prepared from the commercial^{28c} diol *cis-trans* mixture. (The *cis*-1,4-diol dibenzoate reportedly²³ melts at 117°, and the *cis*- and *trans*-1,3-diol dibenzoates melt at 63 and 124°, respectively.²³)

DL(1,4/2) Diastereomer of 1,2,4-Cyclohexanetriol Tribenzoate (11). A. Prévost Reaction.—The ethanolic mother liquors from the iododiol dibenzoate (procedure A) upon standing for several weeks at 0°, yielded 300 mg (11%) of colorless crystals, mp 110–113°. This material was recrystallized, giving 200 mg of the triol tribenzoate, mp 113–115°, identical with that from procedure B below.

B. Peroxyformic Acid Reaction.—The 95% ethanolic mother liquors from the triol tribenzoate of mp 154° (see above) on partial evaporation yielded 0.80 g (9%) of colorless, crystalline product, mp 114–116°. A sample recrystallized for analysis melted at 115–116°.

Anal. Calcd for C₂₇H₂₄O₆: C, 72.96; H, 5.44. Found: C, 72.92; H, 5.39.

The nmr spectrum was recorded at 60 Mcps using chloroform-*d*. The 15 aromatic protons produced signals at 7.2–7.7 (*meta* plus *para*) and 7.9–8.25 ppm (*ortho*). The spectrum of the three O–C–H ring protons in the region 5.2–5.9 ppm consisted of complex overlapping signals in which part of an eight-line pattern at about 5.7 ppm could be discerned. This pattern may be assigned to H-2 because of its similarity to the H-2 pattern of the corresponding free triol (see below). Signals for the six methylene protons were observed in the region 1.2–2.8 ppm.

DL(2,4/1) Diastereomer of 1,2,4-Cyclohexanetriol (10). A. Basic Hydrolysis.—A 300-mg portion of the tribenzoate, mp 154°, was hydrolyzed with base by the same procedure (see below) used for the mp 116° tribenzoate, giving a 60-mg (67%) yield of the recrystallized triol, mp 145–147°. A sample was recrystallized again for analysis, mp 148–150°.

Anal. Calcd for C₆H₁₂O₃: C, 54.53; H, 9.15. Found: C, 54.59; H, 8.92.

B. Acidic Hydrolysis.—A 200-mg portion of the tribenzoate, mp 154°, was hydrolyzed with acid by the same procedure (see below) used for the mp 116° tribenzoate, giving a 50-mg (84%) yield of the recrystallized triol, mp 148–150°. A sample was again recrystallized, mp 150–151°. The product was identical with that from procedure A.

The nmr spectrum (Figure 1b) was recorded at 60 and at 100 Mcps, using deuterium oxide. The 60-Mcps signals were not sufficiently separated for identification. At 100 Mcps, the O–C–H ring proton signals were observed in the region 3.2–3.9 ppm. The axial proton H-4 was apparently neither shielded nor deshielded by the hydroxyl groups at positions 1 and 2. The signals for H-1 and H-2 (both also axial) were observed at about 3.4 ppm. The methylene spectrum was observed in the regions 1.1–1.6 (three protons), 1.7–2.1 (two protons), and 2.1–2.35 ppm (one proton).

DL(1,4/2) Diastereomer of 1,2,4-Cyclohexanetriol (11).

A. Basic Hydrolysis.—A mixture of 300 mg of the tribenzoate, mp 116°, with 1.0 g of sodium hydroxide, 5.0 ml of water, and 20 ml of ethanol was boiled under reflux for 2 hr. The solution was adjusted to pH 8–9 with 5 *N* sulfuric acid and evaporated to dryness. The residue was extracted repeatedly with warm absolute ethanol. Evaporation of the ethanol extract gave a syrup which was dissolved in 10 ml of water. The solution was passed through a column of 10 ml of Amberlite MB-1 mixed bed resin,^{28b} and the column was eluted with 50 ml of water. The eluate was evaporated and the residue was recrystallized from ethanol–ethyl acetate (1:4), giving a 50-mg (56%) yield of the triol, mp 135–136°. A sample recrystallized again for analysis melted at 137–138°.

Anal. Calcd for C₆H₁₂O₃: C, 54.53; H, 9.15. Found: C, 54.55; H, 8.96.

B. Acidic Hydrolysis.—A mixture of 200 mg of the tribenzoate, mp 116°, with 10 ml of 6 *M* hydrochloric acid and 10 ml of absolute ethanol was boiled under reflux for 48 hr. (In later experiments, 3 *M* hydrochloric acid was refluxed for 12 hr.) Most of the ethanol was removed by distillation and the remaining aqueous solution was extracted repeatedly with benzene. The aqueous phase was evaporated to dryness. The residue was recrystallized from ethanol–ethyl acetate (1:4), giving a 40-mg (67%) yield of the triol, mp 137–138°. The product was identical with that from procedure A.

The nmr spectrum (Figure 1a) was recorded at 60 and 100 Mcps, using deuterium oxide. The 60-Mcps signals were not well enough separated for identification. At 100 Mcps the O–C–H ring proton signals were completely separated. The axial proton H-1 appeared as a triplet of doublets at 3.47 ppm, with spacings of 8 and 4.0–4.5 cps, respectively. The axial proton H-2 appeared as an eight-line pattern at 3.72 ppm, with spacings of 10, 8, and 4.5 cps (one axial-equatorial and two axial-axial interactions). The equatorial proton H-4 appeared as an unperturbed quintet at 4.10 ppm, with a spacing of about 3 cps.

Nuclear magnetic double resonance (100 Mcps) was used to confirm the assignments just mentioned. The proton H-2 (3.72 ppm) was shown to be spin coupled to the methylene protons (H-3_e, H-3_a) having signals at about 2.0 and 1.5 ppm. The proton H-4 (4.10 ppm) was shown to be coupled to these same methylene protons.

The signals for the six methylene protons appeared in the region 1.2–2.3 ppm and with the aid of double resonance at 100

Mc some of these signals were separated well enough to be identified.

Paper Chromatography³¹ of the Cyclohexanetriols.—Chromatography was carried out using Whatman No. 4 paper in the solvent system 2-butanol-water-acetic acid (14:5:1) at room temperature. The spray used was silver nitrate in aqueous acetone followed by 0.5 *N* sodium hydroxide in aqueous methanol (brown coloration). The silver oxide background was reduced by washing with 4% sodium thiosulfate solution. Under these conditions all four diastereomeric 1,2,4-cyclohexanetriols gave substantially the same R_f value (0.57) compared with 0.21, 0.20 for *D*-glucose, 0.19 for (–)-quebrachitol, 0.09 for (–)-inositol, and 0.19 for (+)-protoquercitol.

Under similar conditions, Posternak^{31c} found that the three diastereomeric 1,2,3-cyclohexanetriols gave substantially the same R_f value (0.57) compared with 0.185 for (–)-quebrachitol, 0.10 for (–)-inositol, and 0.20 for (+)-protoquercitol.

As yet, we have found no good paper chromatographic system for separating the isomeric cyclohexanetriols from each other.

Nmr Spectra of the 1,2,3-Cyclohexanetriols.—Samples of the *meso*(1,2,3/0) and *DL*(1,2/3) cyclohexanetriols were prepared by Posternak and co-workers. Samples of the *meso*(1,2,3/0) and *meso*(1,3/2) cyclohexanetriol tribenzoates were prepared by Moir and co-workers. A sample of the *meso*(1,3/2) cyclohexanetriol was prepared by us by acidic hydrolysis of a portion of the tribenzoate. The nmr spectrum of the *DL*(1,2/3) tribenzoate has not yet been recorded.

Nmr Spectrum of *meso*(1,2,3/0) or All-*cis* Diastereomer (Mp 148°) of 1,2,3-Cyclohexanetriol (13).—The spectrum (Figure 2b) was recorded at 60 Mcps using deuterium oxide. Signals for the three O–C–H protons were observed in the region 3.4–4.0 ppm. The equatorial proton H-2 appeared as a triplet ($J = 2.5$ cps) at 3.92 ppm. The two equivalent axial protons H-1 and H-3 produced a complex multiplet at 3.62 ppm (width at half-height 15 cps). The six methylene protons produced a complex pattern in the region 0.9–1.9 ppm, which has not been interpreted.

Nmr Spectrum of *meso*(1,2,3/0) or All-*cis* Diastereomer (Mp 142°) of 1,2,3-Cyclohexanetriol Tribenzoate (13).—The spectrum (Figure 3a) was recorded at 60 and 100 Mcps using chloroform-*d*.

The 15 aromatic protons appeared in the region 7.1–8.2 ppm, with the nine *meta* and *para* protons at 7.1–7.7 ppm. The four *ortho* protons of the two equatorial benzoate groups were observed at 7.92 ppm; the two *ortho* protons of the axial benzoate group were observed at 8.12 ppm.

The three O–C–H ring protons produced signals in the region 5.0–6.1 ppm; benzylation caused the expected downfield shift. The signal for the equatorial proton H-2 was a triplet (compare the all-*cis* triol) at 6.0 ppm. The two equivalent axial protons (H-1 and H-3) now appeared as an overlapping pair of doublets at 5.33 ppm with an additional small splitting (2.5–3 cps); this pattern was more sharply defined than the corresponding pattern in the triol spectrum.

The six methylene protons produced a complex multiplet in the region 1.6–2.3 ppm, which again was not interpreted.

Nmr Spectrum of *meso*(13/2) Diastereomer (Mp 108°) of 1,2,3-Cyclohexanetriol (14).—The spectrum (Figure 2c) was recorded at 60 and at 100 Mcps using deuterium oxide. Signals for the three O–C–H protons were observed in the region 3.0–3.6 ppm. The axial proton H-2 appeared as a perturbed triplet at about 3.10 ppm, owing to coupling with the two equivalent neighboring axial protons, H-1 and H-3. The latter two protons produced a broad complex multiplet at about 3.3 ppm. The six methylene protons produced a broad, poorly resolved signal in the region 1.0–2.1 ppm.

Nmr Spectrum of the *meso*(13/2) Diastereomer (Mp 142°) of 1,2,3-Cyclohexanetriol Tribenzoate (14).—The spectrum (Figure 3b) was recorded at 60 Mcps (with integration) and at 100 Mcps, using chloroform-*d*. The nine *meta* and *para* aromatic protons appeared in the region 7.1–7.7 ppm and the six *ortho* protons appeared at 7.7–8.1 ppm (apparently not all equivalent, even though the three benzoate groups all were equatorial). The O–C–H axial proton H-2 appeared as a well-defined but perturbed triplet

at about 5.7 ppm, with spacing of about 11 cps, owing to coupling with the two equivalent neighboring axial protons. The latter two protons appeared as a broad multiplet (width at half-height about 24 cps) at about 5.3 ppm; this multiplet was better resolved than the corresponding multiplet in the triol spectrum. It appears that H-2 is deshielded by the two neighboring benzoate groups. The six methylene protons produced a pattern in the region 1.3–2.6 ppm which has not been interpreted.

Nmr Spectrum of the *DL*(1,2/3) Diastereomer (Mp 125°) of 1,2,3-Cyclohexanetriol (15).—The spectrum (Figure 2a) was recorded at 60 Mcps using deuterium oxide. Signals for the three O–C–H protons appeared in the region 3.2–4.2 ppm. The equatorial proton H-1 appeared as a narrow multiplet at 4.03 ppm, with width at half-height (about 9 cps) consistent with its couplings to neighboring axial and equatorial protons although individual coupling constants were not apparent. The axial proton H-2 was observed as a sharp pair of doublets at 3.42 ppm. The H-2 signal was perturbed by the nearby H-3 signal. The axial proton H-3 appeared as a broad complex multiplet at about 3.7 ppm, partially overlapping the H-1 multiplet; the downfield location of the H-3 multiplet is attributed to deshielding,^{19,20} by the 1-OH group. Signals for the six methylene protons were observed as a complex pattern in the region 0.9–2.1 ppm, which has not been interpreted.

Nmr Spectra of the 1,3,5-Cyclohexanetriols. *meso*(1,3,5/0) or All-*cis* Diastereomer of 1,3,5-Cyclohexanetriol (16).—The nmr spectrum (Figure 4a) of the all-*cis* triol (mp 184°) was recorded at 60 and at 100 Mcps using deuterium oxide. Integration revealed the presence of three patterns (1.22, 2.20, and 3.68 ppm), each due to a set of three protons. The signal for the three equivalent O–C–H protons (3.68 ppm) was a triplet of triplets. The three equivalent axial methylene protons appeared as a quartet at 1.22 ppm ($J = 11$ –11.5 cps). The quartet was slightly perturbed by the nearby equatorial methylene signal. The pattern produced at 2.20 ppm by the three equivalent equatorial methylene protons was essentially a pair of triplets.

***meso*(1,3/5) Diastereomer of 1,3,5-Cyclohexanetriol (17).**—The nmr spectrum was recorded at 60 Mcps (with integration) and at 100 Mcps using deuterium oxide (Figures 4b and 4c). Signals for the three O–C–H ring protons were observed in the region 3.7–4.5 ppm. The pattern due to the protons H-1 and H-3 at 3.99 ppm had the appearance of a triplet of triplets with spacings of 11–11.5 cps and 4–4.5 cps. The axial methylene proton H-2_a produced a quartet at 1.28 ppm, with spacing of 11–11.5 cps.

The two axial protons, H-4_a and H-6_a, produced an eight-line pattern at 1.44 ppm, with spacings of 13–14, 11–11.5, and 3–4 cps.

The equatorial proton H-2 appeared as a pair of quintets with spacings of 11–11.5 and about 2 cps. The two equatorial protons, H-4_e and H-6_e, appeared as a pair of rather complex multiplets with coupling constant of 13–14 cps.

Infrared Spectra.—The infrared spectrum was recorded for each new or previously known compound prepared, on a Perkin-Elmer Model 137 Infracord, or Model 421, spectrometer, using a Nujol mull, unless otherwise noted. Each spectrum was consistent with the assigned molecular structure. Any features of special interest are noted in the text.

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