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STUDIES ON CYCLITOLS—XIII

SYNTHESIS AND STEREOCHEMISTRY OF CYCLOPENTANETRIOLS AND RELATED EPOXYCYCLANOLS*

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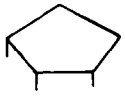
Abstract—Derivatives of the three diastereomeric 1,2,3-cyclopentanetriols, and the three diastereomeric 1,2,4-cyclopentanetriols have been synthesized via reaction sequences starting with 2-cyclopentenol, 3-cyclopentenol, and various cyclopentenediols. All four isopropylidene derivatives, three mono-O-benzoylisopropylidene acetals, and five tribenzoates have been prepared. The four 1,2-anhydrocyclopentanetriols, their acetylated derivatives, and several other substituted cyclopentane epoxides were also prepared. The kinetics of the acid-catalyzed hydrolysis of several substituted epoxides were studied, in order to assess the factors affecting such reactions. The presence or absence of intramolecular H-bonds, determined by IR spectroscopy, was useful in assigning configurations for some of the compounds. For a number of monosubstituted cyclopentane epoxides, the frequency of the IR absorption band near 840 cm^{-1}, which is characteristic of the oxirane ring, is correlated with the position and orientation of the substituent. The C—Br stretching frequencies in several bromoepoxides have been assigned and correlated with the axial or equatorial orientation of the bromo group.

IN EARLIER studies[1] the synthesis of cyclopentanoid cyclitols was reported, including tetrols, a pentol, aminotriols and aminotetrols. This work has now been extended to the cyclopentanetriols.

Three diastereomeric forms (two meso, one racemic) are possible for the 1,2,3-triols; likewise for the 1,2,4-triols. Derivatives of all six of these diastereomers have



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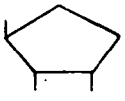

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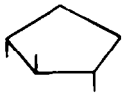

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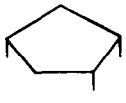

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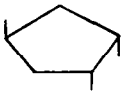

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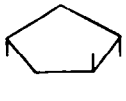

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been prepared and are described in the present work. Three routes have been followed in the syntheses: (1) epoxidation of 2-cyclopentenol and 3-cyclopentenol, and subsequent hydrolysis of the epoxyalcohols; (2) oxidation of the allylic and homoallylic

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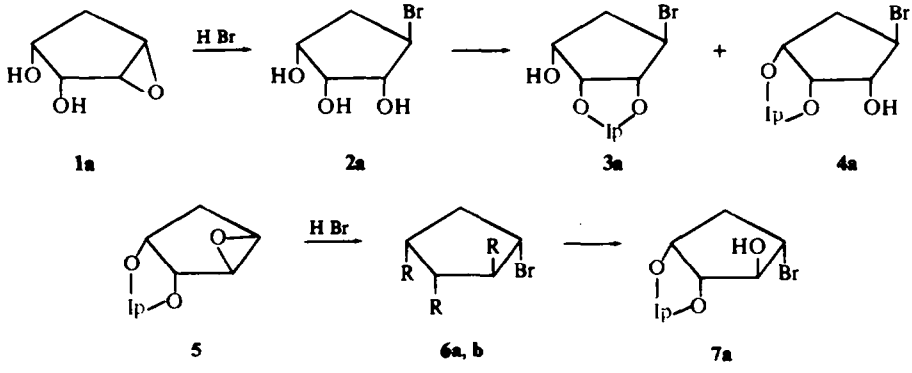
cyclopentenols by alkaline permanganate; (3) epoxidation of various cyclopentenediols, followed by epoxide-opening with HBr and subsequent reductive debromination. The stereospecificity of formation and regiospecificity[2] of opening of epoxides, and of *bis*-hydroxylation by permanganate, observed in previous studies, has been confirmed. Kinetic studies of acid-catalyzed epoxide hydrolysis have been carried out, and the mechanism of epoxide opening is discussed.

The IR spectra of a large number of substituted cyclopentene oxides and bromocyclopentanes have been studied; the frequencies of characteristic epoxide vibrations and of C—Br stretching modes have been evaluated. The influence of other substituents on the epoxide absorption and the effect of ring-conformation on the C—Br stretching frequencies are also discussed. These observations have been applied to analysis of conformations of some of the compounds.

RESULTS AND DISCUSSION

*Syntheses.** Bromotriol **2a** obtained by treating anhydrotetrol **1a** with ethanolic HBr, was converted into a mixture of isopropylidene derivatives **3a** and **4a** as described previously.[1b] By similar treatment of the isopropylidene-anhydrotetrol **5**,[1b] the bromotriol **6a** was obtained. The conditions for opening the epoxide ring were



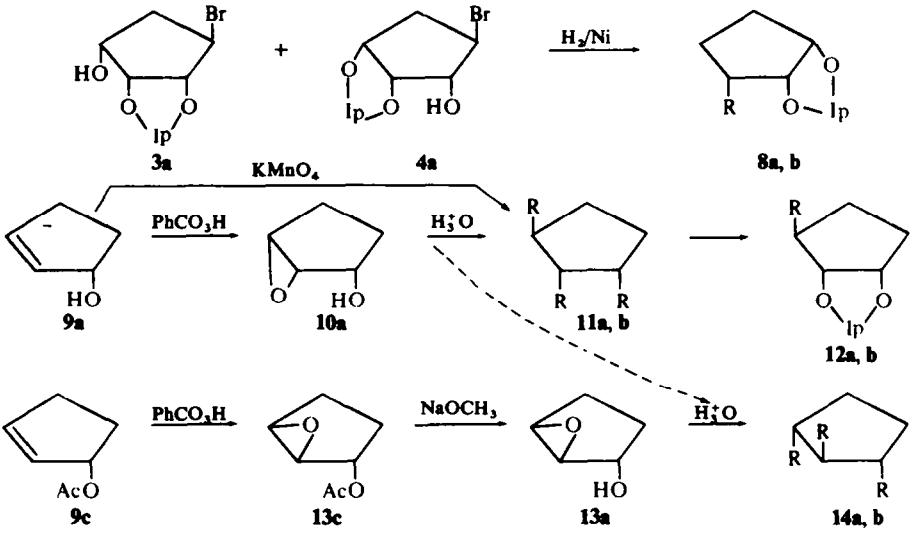
a b c d e
R = OH OBz OAc Br OMe

CHART I.

such that the dioxolane ring was also cleaved, yielding the free bromotriol rather than the acetonide. The indicated configuration of **6a** has been assigned for the following reasons. The epoxide is expected to open with inversion at the point of attack of the entering group, so two diastereoisomeric products are possible. In all the cases we have studied[1b,d] epoxide-opening by Br^- or H_2O occurs preferentially at the end of oxirane ring which has no vicinal electronegative substituent. In addition, the presence of a *trans*-substituent adjacent to the epoxide also directs the opening to the other end of the oxirane ring. In the present case both influences favor attack at the distant

* See Charts I–IV for reaction sequences. For compounds designated by a number and a letter, the letters stand for the following R substituents: (a) —OH; (b) —OBz; (c) —OAc; (d) —Br; (e) —OMe.

end of the epoxide, giving the product with configuration **6**. The two bromotriols **2a** and **6a** consumed 2·4–2·5 molar equivalents of periodate. This result substantiates the 4-bromo structures shown, since the alternative 3-bromo compounds would consume between 1 and 2 moles of periodate.* Treatment of **6a** with acetone gave the isopropylidene derivative **7a** whose IR spectrum showed a band at 3608 cm^{-1} characteristic of a free OH group.



a b c d e
R = OH OBz OAc Br OMe

CHART II

The acetonide **8a** was obtained by reductive debromination of the mixture of bromoacetonides DL-**3a** and DL-**4a**. Although these two bromoacetonides differ in constitution, it is not necessary to separate them, since both give the identical product, DL-**8a**, on reduction. The infrared spectrum of **8a** shows a doublet band at 1367 and 1376 cm^{-1} characteristic of *gem*-dimethyl groups[1b] and a sharp band at 3564 cm^{-1} which is consistent with an intramolecularly H-bonded OH group.[3,4]

The 1,2/3 cyclopentanetriol DL **11a** was prepared by two methods as shown in Chart 2: (a) oxidation of 2-cyclopentenol **9a** with alkaline permanganate; (b) hydrolysis of the *cis*-anhydrotriol **10a**. The IR spectrum of the isopropylidene derivative **12a** shows a sharp band at 3617 cm^{-1} characteristic of a free OH group, and a doublet at 1367 and 1377 cm^{-1} assigned to the *gem*-dimethyl groups. As first noted by Henbest and Wilson,[5a,b] in the case of 2-cyclohexenol, an allylic OH group specifically directs attack of a peracid *cis* to the OH group. Epoxidation of **9a** in chloroform yielded predominantly the *cis*-epoxyalcohol **10a** as evidenced by the absence of free O—H absorption in the IR spectrum. Opening of the *cis*-epoxide **10a** in aqueous acid is not completely regiospecific and some of the 1,3/2 triol **14a** is formed in addition to the

*Vicinal halogenated glycols tend to consume more than the theoretical amount of periodate. For example, under the same conditions 3-chloro-1,2-propanediol consumed 1·6 molar equivalents of periodate.

major product **11a**. Separation of the two triols is accomplished by forming the acetonide **12a** and then extracting the latter into ether. Since the triol **14a** does not form an acetal, it remains in the aqueous phase and can be isolated subsequently by conversion into the tribenzoate **14b**.

The 1,3/2 isomer **14a** was also prepared, in greater yield, by the hydrolysis of the *trans*-anhydrotriol **13a**. The latter compound was formed by epoxidation of the acetoxycyclopentene **9c** followed by deacetylation with sodium methylate. The IR spectrum of **13a** shows a strong band at 3614 cm^{-1} assigned to the free OH group. A slight shoulder on the low frequency side of this band shows that a small amount of the *cis*-isomer **10a** is also present. Several authors have shown that neighbouring OAc groups can participate in the hydrolytic opening of epoxides, leading to a reversal in the usual regiospecificity observed.[1c,6] Therefore, in order to obtain a good yield of the 1,3/2 triol **14a**, deacetylation of **13c** prior to the hydrolysis was necessary.

The 1,2,4-derivatives were prepared as follows. The *cis*-isomer was obtained by

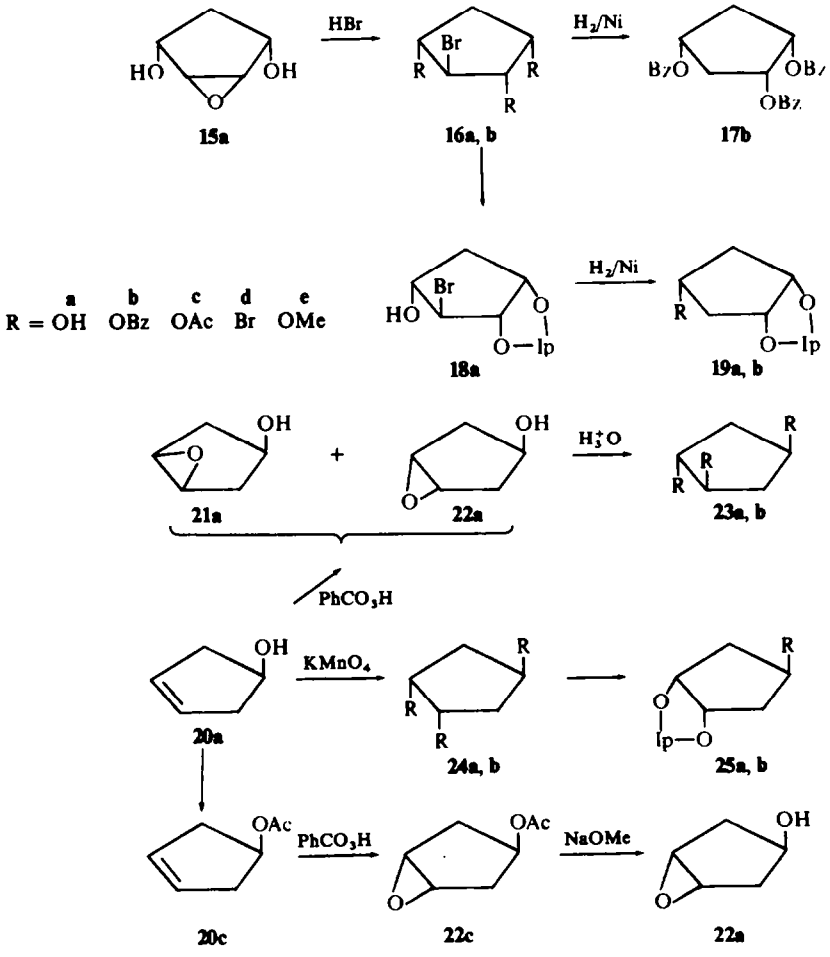


CHART III

reductive debromination of the previously reported[1b] bromotriol derivatives **16b** and **18a**. The triol is converted easily into an isopropylidenetriol **19a** whose IR spectrum has a sharp peak at 3580 cm^{-1} and a doublet at 1364 and 1372 cm^{-1}. The 1,2/4 triol **24a** was prepared by alkaline permanganate oxidation of **20a**. Subsequent treatment of the crude oxidation product with acetone or benzoyl chloride yielded the derivatives **25a** and **24b**.

The acetonide **25a** has a sharp band in the IR at 3620 cm^{-1} assigned to a free OH group, and the characteristic *gem*-dimethyl absorption bands are at 1374 and 1380 cm^{-1}. Epoxidation of **20a** in chloroform yielded a mixture of the *cis*- and *trans*-anhydrotriols **21a** and **22a** from which the lower boiling *cis*-isomer was obtained by fractional distillation.[7] The *trans*-isomer **22a** could be prepared free of the *cis*-isomer by the reaction sequence shown, involving the acetylated intermediates. Because of their symmetry, **21a** and **22a** yield on hydrolysis only the DL-1,4/2 triol **23a**.

Proof of the proposed structures depends on the route of synthesis, chemical reactivity of the products, the IR and NMR spectral data. The all-*cis* nature of **8a** and and **19a** is supported by the structures of the starting bromotriols and by the presence of intramolecular H-bonds in these compounds. In the cyclopentane series only vicinal *cis*-glycol groups can form from isopropylidene derivatives, and an OH group can form an H-bond only with an acceptor atom which is *cis* to it.[4] Thus both **8a** and **19a** must contain a substituted *cis*-glycol group and an OH group *cis* to this group. The 1,2/3 and 1,2/4 configurations assigned to **11a** and **24a** are substantiated by the synthetic route of *cis*-hydroxylation, by the formation of the isopropylidene derivatives **12a** and **25a**, and by the absence of intramolecular H-bonds in these derivatives. The NMR spectra[26] of **19b** and **25b** clearly indicate that these are symmetrical molecules with only two types of chemically distinct methylenic protons. In contrast, the methylene region of the NMR spectra of **8a** and **12a** is more complicated[26] and consists of several overlapping signals, as would be expected for these unsymmetrical compounds. The structures of the *trans*-isomers **14a** and **23a** are indicated from the structures of the starting anhydrotriols, the known *trans* nature of epoxide-opening reactions, and the inability of these compounds to form acetals.

Bromination of the allylic acetoxycyclopentene **9c** yielded a mixture (Chart 4) of the isomeric 1-acetoxy-2,3-dibromocyclopentanes, **36** and **37**, which were not separated. The mixture was treated with NaOH[8] which converts the all-*trans* isomer **36** into the *cis*-bromoepoxide **10d**. Both steric and electronic factors[5a,b] direct the epoxidation of 3-bromocyclopentene **9d** and of *cis*-3,5-dibromocyclopentene **28d** to yield predominantly the *trans*-bromoepoxides **13d** and **29d**. The IR and NMR spectra of the product **13d** differed from those of the *cis*-isomer **10d**. Treatment of 4-bromocyclopentene **20d** with AcOBr (Experimental) yielded a mixture of the isomeric 1-acetoxy-2,4-dibromocyclopentanes, **38** and **39**. Integration of the acetyl signals in the NMR spectrum indicated that this material contained at least 90% of one isomer, which is concluded to be **38** on the basis of the following observation. The methylene region of the spectrum showed two well-separated signals, corresponding to one proton each, at δ 2·14 (doublet of triplets) and at δ 3·06 (quintet) and a complex signal centered at δ 2·72 corresponding to two protons. A complex signal centered at δ 4·40, corresponding to two protons, was assigned to the protons (H_2 and H_5) α to the bromo groups, and the low-field quintet at δ 5·25 was assigned to the proton (H_1) α to the acetoxyl group. Double irradiation experiments showed that

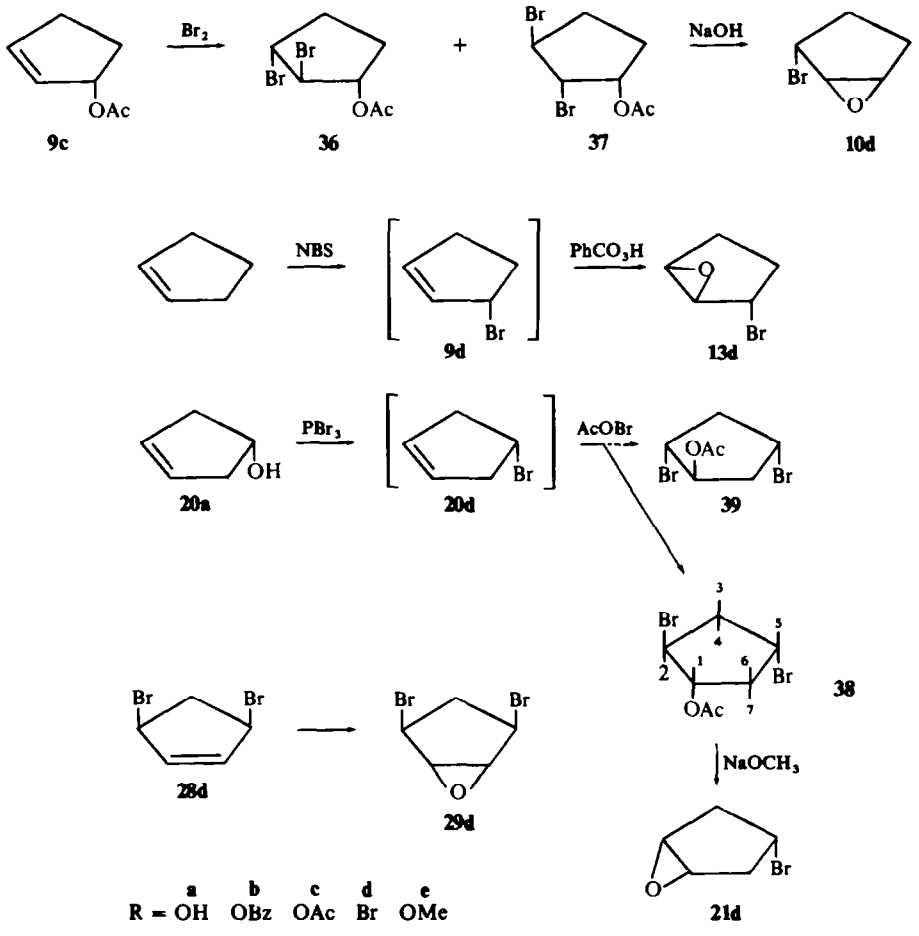


CHART IV

H_1 was coupled to the protons giving rise to the methylenic signals at δ 2·14 (J = 3·3 Hz) and δ 3·06 (J = 6·7 Hz) and that H_2–H_5 were coupled to the protons giving rise to the methylenic signal at δ 2·72. Structure **38** is most compatible with the NMR spectrum if, as several workers have reported,[9, 10] electronegative substituents have a greater deshielding effect on vicinal *trans* protons than on *cis* protons in rigid systems. On the basis of the assumption, the signal at δ 3·06 is assigned to H_6, *trans* to the vicinal OAc and Br groups; the signal at δ 2·72 is assigned to H_3 and H_4, each of which are *cis* to one and *trans* to another vicinal Br group; and the signal at δ 2·14 is assigned to H_7, *cis* to the vicinal OAc and Br groups. Treatment of **38** with $NaOCH_3$ produced the bromoepoxide **21d**.

IR spectra

(a) O-H *Stretching frequencies.* The O-H stretching frequencies for the epoxy-alcohols and isopropylidenetriols, as well as several epoxides and acetonides synthesized in earlier work, are summarized in Table 1. Kuhn[11] showed that when an OH

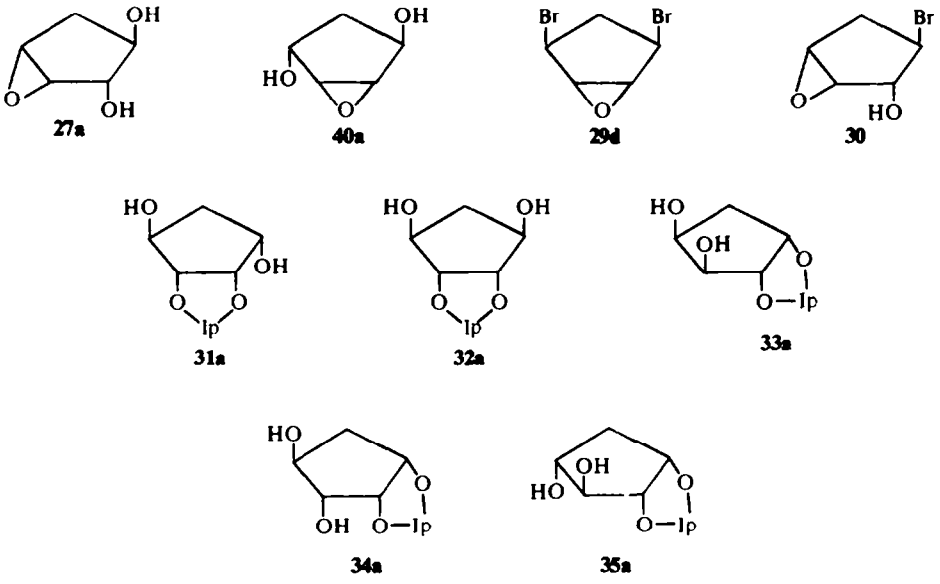


CHART V

group is H-bonded, the O-H stretching frequency is decreased relative to that in the non-bonded case. He proposed an empirical equation, subsequently revised by Brutcher and Bauer,[12] relating the observed frequency shift to the length of the H-bond. In our series of compounds, for spectra measured on dilute solutions in CS_2, the O-H stretching frequency of a free OH group is invariably greater than 3600 cm^{-1}, whereas the stretching frequency of an intramolecularly H-bonded OH group is between 3500 and 3600 cm^{-1}. In the present work the $\Delta\nu$ for triol compounds has been estimated as the difference in the absorption frequency of the *trans*-compound (unbonded OH) and the *cis*-compound (intramolecularly H-bonded OH). For the tetrol acetonides, the absorption frequency of an unbonded OH group was taken as 3609 cm^{-1}, the average value observed in those compounds in which the OH group is neither an acceptor nor a donor in an intramolecular H-bond. An estimate of the length of the H-bond has been made, using the equation of Brutcher and Bauer.*

The large $\Delta\nu$ value for the *cis*-transannular epoxyalcohol **21a** indicates that this molecule is in the V_4 conformation,† since in the alternative V^4 conformation the OH group would be too far from the epoxide oxygen to form an intramolecular H-bond. The $\Delta\nu$ values for the *cis*-vicinal epoxyalcohols, **10a**, **27a** and **30**, are much smaller than that for **21a**, and thus the length of the H-bond should be longer in these compounds. In the V_4 conformation of **10a**, **27a** and **30**, the C-3 OH group is *quasi*-equatorial and the OH···O distance is about 0·4–0·5 Å longer than it is in

*In the present work all spectra were measured on solutions in CS_2, whereas in most studies in the literature solutions in CCl_4 were used, so the exact values of the OH stretching frequencies and possibly also of the $\Delta\nu$ values that we report may not be strictly comparable with other studies.

†The terminology is that of L. D. Hall.[15] Envelope conformations are designated by a V, and twist conformations by a T, with sub and/or superscripts to designate the carbon atoms displaced below or above the principal plane of the cyclopentane ring.

TABLE 1. IR HYDROXYL ABSORPTION FREQUENCIES

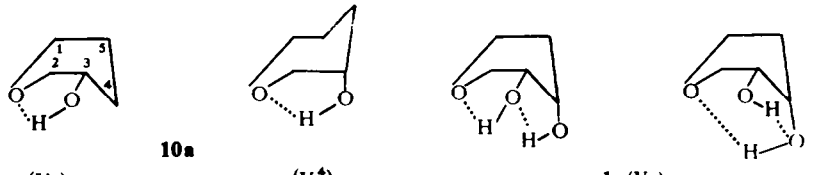
Compound[a]	O—H stretching frequency		Δν	Bond length[b]
	Free	Bonded		OH···O, Å
Epoxy alcohols:				
13a	3615			
10a		3587	28	2·75
22a	3618			
21a		3552	66	2·01
27a	3612	3587	25	2·9
30		3582	30	2·7
1a		3537, 3523	75, 89	1·95, 1·86
O-Isopropylidene derivatives:				
12a	3617			
8a		3564	53	2·15
25a	3620			
19a		3580	40	2·38
31a	3605	3547	62	2·05
34a	3609	3562	47	2·24
35a	3612	3565	44	2·30
7a	3608			
18a		3560	49	2·21
32a	3605	3548	61	2·06
33a	3618	3566	43	2·31

All values for solutions in CS_2.

[a] The synthesis of compounds not described in this work are described in Refs 1*a–d*.

[b] Calculated using the equation given by Brutcher and Bauer, Ref. 12.

21a (measured from Dreiding models). However, in the V^4 conformation of these *cis*-vicinal epoxides, the C-3 OH group is *quasi*-axial and the OH···O distance is about the same as it is in **21a**. Fales and Wildman[14] have also reported that Δν for a *cis*-vicinal epoxyalcohol is considerably smaller when the OH group is *quasi*-equatorial (25–30 cm^{-1}) than when it is *quasi*-axial (53 cm^{-1}). The Δν values observed, therefore, indicate that all these epoxides exist predominantly in the V_4 conformation. Franks *et al.*[1b] suggested that the *cis*-anhydrotetrol **1a**, which has two strong H-bonds, could be represented by Form A. The Δν values reported for this



compound are only approximate, since both OH groups are chelated, and one of the O atoms is both a donor and an acceptor. Because of this multiple H-bonding this

compound cannot be compared directly with the other compounds reported. However, since $\Delta\nu$ for **21a** is significantly larger than $\Delta\nu$ for **10a**, or for any of the 1,2-glycols, we have assumed that the apparently stronger bond in **1a** ($\Delta\nu = 89\ cm^{-1}$) is due to bonding of the transannular OH group to the oxirane oxygen, and the other ($\Delta\nu = 75\ cm^{-1}$) represents the equatorial OH group bonded to the vicinal axial OH (V_4 conformation, form B). The transannular bond (1·86 Å) seems considerably shorter than the corresponding bond in **21a**, but because of the uncertainty expressed we prefer not to draw any quantitative conclusions about the amount of puckering in the two compounds.

(b) *Oxirane ring frequencies.* Bellamy,[3] in summarizing the work of several authors, suggested that three frequency ranges are characteristic of oxirane ring absorption: around 1250, 900 and 830 cm^{-1}. Patterson[15] concluded from a study of a variety of epoxides, epoxyethers, and epoxyesters that two low-frequency absorptions, ranging from 875–950 and 775–850 cm^{-1}, were characteristic of the oxirane ring. All the cyclopentane epoxides examined in this and our earlier work show a strong, sharp absorption band between 825–855 cm^{-1}. The consistent presence of this band, its intensity, and its absence from the spectra of the corresponding olefins support its assignment as an oxirane ring absorption band.[1d, 16] This region of the spectrum contains bands due to C–O stretching and C–H rocking vibrations. Since the band is present in both *cis*-cyclodecene oxide and the corresponding compound in which the oxirane ring H atoms are replaced by deuterium[1d, 16] it cannot be due to C-H rocking, and it was, therefore, tentatively assigned to C–O stretching. However, other modes are also represented in this region of the spectrum, so this band is better ascribed to some as yet unspecified vibration, characteristic of the epoxide group.

TABLE 2. EFFECT OF SUBSTITUTION ON OXIRANE VIBRATIONAL FREQUENCIES OF CYCLOPENTANE EPOXIDES[a]

	Compound	ν (cm^{-1}) *cis*	*trans*	$\Delta\nu$ relative to cyclopentene	oxide	$\Delta\nu$ (*cis-trans*)
	10a	851		+12		
	13a		843		+4	8
	10b + 13b	852	842	+13	+3	10
vicinal	**10c**	852		+13		
	13c		844		+5	8
	10d	846		+7		
	13d		842		+3	4
	10e	846		+7		
	21a	835		−4		
	22a		833		−6	2
trans-annular	**21b + 22b**[b]	840	832	+1	−7	8
	21c	842		+3		
	22c		832		−7	10
	21d	840		+1		

[a] All values given are for dilute solutions in CS_2. The frequency for cyclopentene oxide is 839 cm^{-1}.

[b] These compounds were available only as a mixture of the *cis*- and *trans*-isomers. The higher frequency absorption has been assigned to the *cis*-isomer by analogy with the other compounds.

In Table 2 are presented the frequencies of the oxirane ring for *cis*- and *trans*-isomers of several mono-substituted cyclopentane epoxides. In the case of the vicinally substituted compounds the oxirane ring absorption of both the *cis*- and the *trans*-isomers occurs at higher frequency than in cyclopentene oxide. In each pair ν_{cis} is higher than ν_{trans}. In the transannular compounds ν_{cis} is also higher than ν_{trans}. However, ν_{trans} is lower than $\nu_{\text{cyclopentene oxide}}$, whereas ν_{cis} (except for **21a**) is slightly higher than $\nu_{\text{cyclopentene oxide}}$. The epoxyalcohol **21a** should not be compared with the other compounds in this series, because of the strong intramolecular H-bond noted above. This bond both deforms the oxirane ring and changes its polarity, and it is, therefore, not surprising that the compound behaves in an anomalous manner. The frequency shifts described may be related to those observed in α-haloketones, and may have an analogous basis.[3, 17]

(c) C–Br *Stretching Frequencies.* Altona *et al.*[18] studied the C–halogen stretching frequencies in a number of 5-membered ring systems and concluded that, as in 6-membered rings,[18, 19] axial and equatorial C–Hal bonds can be distinguished spectroscopically. However, the difference in ring size modifies the vibrational properties to a certain extent. Axial C–Br bonds absorb at 510–535 cm^{-1} in secondary monohalogenocyclopentanes and -tetrahydrofurans. The equatorial C–Br stretching mode occurs at 709 cm^{-1} in bromocyclopentane.

The major absorption bands below 775 cm^{-1} in the spectra of the bromo-substituted epoxides we have studied, are listed in Table 3.

TABLE 3. C—Br STRETCHING FREQUENCIES OF BROMO-SUBSTITUTED CYCLOPENTANE EPOXIDES

Compound	(cm^{-1})	Relative % absorption[a]	Assignment
10d	732 (vs)	82	equatorial C–Br
	649 (s)	18	
	598 (br)	9	
13d	604 (s)	45	axial C–Br
21d	730 (s)	38	equatorial C–Br
	645 (br)	15	
	540 (s)	38	axial C–Br
29d	632 (s)	55	axial C–Br
	588 (s)	55	axial C–Br

All values for solutions in CS_2. Abbreviations: (vs) very sharp; (s) sharp; (br) broad.

[a] The intensity is expressed as the % absorption relative to that of the oxirane ring C—O stretching band near 840 cm^{-1}.

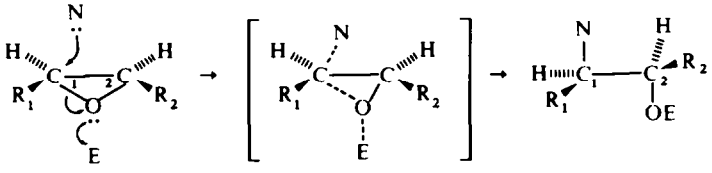
The chemical/geometrical arrangement in the vicinity of the C–Br bond in the bromo-epoxide **21d** is closely analogous to that in bromocyclopentane. In fact, two strong absorptions occur, one at 540 cm^{-1} (axial C–Br) and the other at 730 cm^{-1}

10d (V_4) **13d** (V_4) (V_4) **21d** (V^4)

(equatorial C–Br), suggesting that appreciable amounts of both the V_4 and V^4 conformers are present. The *cis*-vicinal bromo-epoxide **10d** (predominant absorption at 732 cm^{-1}, equatorial C–Br mode) seems to exist mainly in the V_4 conformation shown. The chemical/geometrical arrangement about C–Br for the axial (V_4) conformations in **13d** and **29d** differs from that in **21d**. The former compounds would be expected to absorb in the same range as the diaxial bromohydrins (e.g. diaxial *trans*-4-bromotetrahydrofuran-3-ol: 640 cm^{-1}).[20e] Accordingly the bands at 604 $^{-1}$ (**13d**) and at 588 and 632 cm^{-1} ($\nu_{average}$ = 610 cm^{-1}), (**29d**) are attributed to the axial forms. The weaker bands in the spectra of **10d** and **21d** presently cannot be assigned to particular conformers. Indeed, they may not even be related to C–Br absorption, since there are weak bands in this region of the spectrum of **10a** also.

Epoxide hydrolysis

Epoxide scission by various nucleophilic reagents has been extensively studied.[20, 21] On stereochemical grounds these reactions have generally been classified as SN2 displacements, since, in the majority of cases, inversion of configuration occurs at the reactive C atom.[20] However, in terms of the product ratios obtained under various conditions and the effect of substituents, these reactions behave more like SN1 mechanisms. Swain and Langsdorf's[22] unified treatment of concerted displacement reactions seems most useful in explaining the regiospecificity of the epoxide-opening reactions we have studied. When R_2 is more electron-withdrawing than R_1, attack at C-1 will be favored[23, 24] if, in the formation of the transition state complex, bond-



N = nucleophilic reagent E = electrophilic reagent

breaking has proceeded further than bond-making (i.e. a "partial carbonium ion" has developed). However, if bond-making has proceeded further than bond-breaking in the transition state, then nucleophilic attack at C-2 would be favored. Several factors may tend to increase the extent of bond-breaking in the transition state of oxide scission reactions.[23, 24] These include: polarization of the epoxide group, facilitated by the considerable ring strain in these molecules; coordination of the electrophilic reagent at the epoxide oxygen; and the use of a relatively weak nucleophile which allows a greater diffusion of charge in the transition state. In most of the

reactions, both acid- and base-catalyzed, cited by Parker and Isaacs,[20] as well as in more recent work reported by Franks *et al.*[1b] and Bannard *et al.*,[25] an electronegative substituent in R_2 results in predominant attack of the nucleophile at C-1, the C atom more distant from the electron-withdrawing substituent. These results support a mechanism in which bond-breaking proceeds further than bond-making in the formation of the transition state. Such reactions which conform stereochemically to an SN2 mechanism, but which exhibit substituent effects more characteristic of SN1 mechanisms, have been termed "modified SN2" reactions.[20]

The use of kinetic data, to evaluate the influence of substituents on epoxide-opening, is complicated because the observed hydrolytic constant, k_h, is the sum of $k_1 + k_2$, the constants for reaction at C-1 and C-2 respectively. Since different substituents may affect k_1 and k_2 differently, conclusions based on k_h alone can only be considered tentative. If the product ratio, $[P_1]/[P_2]$, for reaction at C-1 and C-2, is also known, then k_1 and k_2 can be evaluated, since $k_1 + k_2 = k_h$ and $[P_1]/P_2] = k_1/k_2$.

It is evident from the data in Table 4 that the adjacent OH group in **10a** reduces the overall rate ($k_1 + k_2$) about 3-fold compared to the transannular OH group in **21a**. The presence of a second electronegative substituent at the other vicinal position in **15a** results in a further 50-fold decrease in the hydrolytic rate. The more electronegative bromo-substituent in **10d** causes a greater decrease in rate than does the hydroxyl

TABLE 4. HYDROLYTIC CONSTANTS FOR SUBSTITUTED CYCLOPENTANE EPOXIDES[a]

Compound	k_h(Mole^{-1} sec^{-1})[b]	$\frac{k_h(cis)}{k_h(trans)}$	Ref
21a	3·0	0·9	*c*
22a	3·3		*c*
10a	0·93	1·3	*c*
13a	0·71		*c*
10d	0·17	2·8	*c*
13d	0·06		*c*
10e	0·34		*c*
27a	0·26		*d*
15a	0·017	1·5	*d*
40a	0·011		*d*

[a] Hydrolyses conducted in dilute H_2SO_4 at 100°.

[b] k_h is the second-order rate constant obtained by dividing the pseudo-first order constant by the normality of acid.

[c] This work.

[d] Franks *et al.*[1b]

substituent in **10a**. The product ratio is known accurately only for anhydrotetrol **27a**. NMR spectral analysis of the hydrolytic products of **27a** shows that $[P_1]/[P_2]$ is 9 in this case. Therefore, k_1 is 0·23 M^{-1} sec^{-1} and k_2 is 0·03 M^{-1} sec^{-1}. For the symmetrical epoxide **22a**, $k_h = 2\,k_1$ and thus k_1 is 1·65 M^{-1} sec^{-1}. The introduction of a vicinal OH group in **27a** causes an approximately 7-fold decrease in k_1 and 50-fold

decrease in k_2, compared to k for the transannularly substituted compound **22a**. These substituent effects are consistent with a "modified SN2" mechanism in which the transition state has partial carbonium ion character because bond-breaking has proceeded further than bond-making. The presence of an adjacent electro-negative substituent would oppose the formation of the developing carbonium ion and thus decrease the hydrolytic rate.

The data also show that a *trans*-vicinal OH group as in **13a** and **40a**, causes a small decrease in rate, compared to the *cis* compounds **10a** and **15a**. The considerably larger *trans*-bromo group in **13d** causes an even greater decrease in rate, compared to the *cis*-bromo-epoxide **10d**. This effect most probably results from steric hindrance, by the *trans* oriented substituent, to approach of the nucleophile. The apparent lack of any steric *trans* effect in the transannularly substituted epoxide **22a** is understandable in view of the conformation of this compound in which the *trans*-OH group on C-4 is in an equatorial position and thus directed away from the reactive center.[26]

EXPERIMENTAL

Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn.

Spectra. IR spectra were determined with a Perkin–Elmer 621 spectrophotometer calibrated with various polystyrene absorption bands. The O—H, oxirane ring and C—Br stretching frequencies were determined at slow scan rate using a 2- or 4-fold expanded frequency scale with NaCl or KBr cells. All spectra were determined on dilute solns in CS_2. NMR spectra were measured with Varian Associates A-60 or HA-100 NMR spectrometers, with TMS as internal reference.

Physical constants. M.ps were determined on a Köfler micro hot stage (A. H. Thomas and Co) and are corrected. B.ps are uncorrected. Refractive index was measured with an Abbe refractometer.

Chemicals. All epoxidations were done with *m*-chloroperoxybenzoic acid which was 85% pure and used without further purification. This substance was purchased from FMC Corp., Carteret, N.J. 2-Cyclopentenol was obtained from the Pittsburgh Plate Glass Co., Barberton, Ohio and was redistilled before use, b.p. 37–44°, 10 torr. Molar tetrahydrofuran borane soln purchased from Metal Hydrides, Inc., Beverly, Mass. was used in the hydroboration of cyclopentadiene.

Kinetics of epoxide hydrolysis. Known amounts of the epoxide substrate and standardized H_2SO_4 were mixed in the cold and then heated in a boiling water bath, allowing 30 sec for temp equilibration. At various time intervals, aliquots were removed and quantitatively diluted into cold 0·1 M potassium phosphate buffer, pH 7·2. The amount of glycol product formed during hydrolysis was determined by periodate oxidation. The amount of periodate consumed was determined spectrophotometrically, and from this the amount of glycol present was calculated.[27] The data for each kinetic experiment were plotted semi-logarithmically and the half-times determined graphically. The second order hydrolytic constant, k_h, was calculated as $k/[H^+]$.

DL-(1,2,3/4)-4-*Bromocyclopentane*-1,2,3-*triol* (**2a**)

HBr gas was bubbled for several min through an alcoholic soln of **1a** (7·75 g, 67 mmole, in 200 ml abs EtOH), and the soln was left at room temp overnight. The solvents were evap under reduced press, the residue was dissolved in 95% EtOH and passed over a column of Amberlite CG-4B anion exchange resin. Evap of the eluate yielded 8·44 g (43 mmole, 26%) of crude **2a** as a viscous residue. A portion of this material was passed over a second column of resin, yielding a product which cryst after exposure to air for a few days. The material was dried on a porous plate and recryst twice from EtOAc; m.p. 80·5–82·5°. (Found: C, 30·34; H, 4·56; Br, 40·30; $C_5H_9O_3$ Br requires: C, 30·48; H, 4·60; Br, 40·56%).

DL-(1,2,4/3)-4-*Bromocyclopentane*-1,2,3-triol (**6a**)

HBr gas was bubbled through an alcoholic soln of **5a** for several min, and the soln was stirred overnight. After removal of solvent the residue was dissolved in H_2O and extracted twice with CH_2Cl_2. The aqueous layer was evap to a very viscous residue which cryst over a period of 2 months. This oily material was dried on a porous plate and then recrystallized twice from abs EtOH; m.p. 112·5–114·5°. (Found: C, 30·69; H, 4·80; Br, 40·37: $C_5H_9O_3Br$ requires: C, 30·48; H, 4·60; Br, 40·56%).

DL-1,2,3-*Tri*-O-*benzoyl*-(1,2,4/3)-4-*bromocyclopentane*-1,2,3-*triol* (**6b**)

Bromotriol **6a** (160 mg, 0·81 mmole) was dissolved in 0·5 ml dry pyridine. The soln was chilled in an ice bath, 0·3 ml of BzCl was added with stirring, and the mixture was left at room temp overnight. Excess BzCl was decomposed by addition of H_2O. The mixture was dissolved in CH_2Cl_2 and extracted twice with 1N H_2SO_4, twice with 1N NaOH and once with H_2O. The CH_2Cl_2 layer was dried over Na_2SO_4 and the solvent removed by evap under reduced press. The oily residue crystallized on exposure to abs EtOH (350 mg, 0·74 mmole, 92%). An analytical sample, recrystallized from abs EtOH, melted at 119–121°. (Found: C, 61·32; H, 4·25; Br, 15·52. $C_{26}H_{21}O_6Br$ requires: C, 61·43; H, 4·16; Br, 15·72%).

DL-1,2-O-*Isopropylidene*-(1,2,3/0)-*cyclopentane*-1,2,3-*triol* (**8a**)

Crude **3a** (6·0 g, 30 mmole) was acetylated by the usual procedure and the produce dist, yielding a mixture of **3a** and **4a** (4·5 g, 19 mmole, 63%) reported previously.[2b] This mixture was dissolved in 100 ml 95% EtOH to which were added several g of Raney Ni and Amberlite CG-4B. This was stirred for four hr at 45–50° while H_2 was bubbled through. The solid was filtered off and the solvent evap; the residue was dissolved in CH_2Cl_2 and the soln extracted once with H_2O. After removal of CH_2Cl_2, the residue was dist, b.p. 53–55° (0·6 torr), $n_D^{25.5}$ 1·4544, (1·5 g, 9·5 mmole, 50%). (Found: C, 60·96; H, 8·87; $C_8H_{14}O_3$ requires: C, 60·74; H, 8·92%).

DL-3-O-*Benzoyl*-1,2-O-*isopropylidene*-(1,2,3/0)-*cyclopentane*-1,2,3-*triol* (**8b**)

A sample of **8a** (500 mg, 3·16 mmole) was benzoylated as usual. The solid product (625 mg, 2·35 mmole, 76%) was recryst from abs EtOH yielding long, white needles, which melted at 103–105°, then resolidified and melted again at 109·5–111°. (Found: C, 68·42; H, 6·77. $C_{15}H_{18}O_4$ requires: C, 68·68; H, 6·92%).

DL-1,2-*Anhydro*-(1,2,3/0)-*cyclopentane*-1,2,3-*triol* (**10a**)

The allylic alcohol **9a** was redistilled (37–44°, 10 torr) before use. Compound **10a** was routinely prepared by epoxidation of **9a** with a 10% molar excess of *m*-chloroperoxybenzoic acid in $CHCl_3$. After two days in the dark, ppt was removed by filtration, and the solvent evap. The residue was shaken with H_2O, the insol material was filtered off and the H_2O layer extracted twice with equal vol of ether. Evap of the water under reduced press left the liquid epoxide which was distilled at 60–64°, 0·6–0·8 torr, n_D^{25} 1·4731. (Found: C, 59·79; H, 8·01; $C_5H_8O_2$ requires: C, 59·98; H, 8·05%).

DL-3-O-*Acetyl*-1,2-*anhydro*-(1,2,3/0)-*cyclopentane*-1,2,3-*triol* (**10c**)

A sample of **10a** (4·0 g, 40 mmole) was acetylated as usual. The crude product was dist yielding 960 mg (6·7 mmole, 17%) of **10c** (b.p. 85–86°, 6–7 torr, n_D^{25} 1·4475. (Found: C, 59·19; H, 7·22: $C_7H_{10}O_3$ requires: C, 59·14; H, 7·09%).

DL-3-O-*Methyl*-1,2-*anhydro*-(1,2,3/0)-*cyclopentane*-1,2,3-triol (**10e**)

Epoxyalcohol **10a** (5 g, 50 mmole) was stirred in 50 ml THF containing 6·7 g powdered NaOH. Me_2SO_4 (10 ml) was added dropwise over $\frac{3}{4}$ hr and the mixture was stirred for 7 hr at room temp. The mixture was then heated for $1\frac{1}{2}$ hr at 60–70° with N_2 bubbling through. H_2O was added to dissolve the solid, and the soln was extracted with equal vol of CH_2Cl_2. The combined organic extracts were dried over Na_2SO_4 and the solvent removed under reduced press. Distillation yielded 2·5 g (21 mmole, 42%) of **10e** (b.p. 82·5–85·5°, 40 torr, $n_D^{26.5}$ 1·4457). (Found: C, 62·96; H, 8·80. $C_6H_{10}O_2$ reguires: C, 63·13; H, 8·83%).

DL-1,2-O-*Isopropylidene*-(1,2/3)-*cyclopentane*-1,2,3-*triol* (**12a**)

(A) *From anhydrotriol* **10a**. A soln of **10a** (3·7 g, 37 mmole) in 50 ml 0·5N H_2SO_4 was heated in a boiling water bath for 45 min. The soln was neutralized with $Ba(OH)_2$ soln and then filtered over a bed of charcoal. Evap of water under reduced press left a viscous residue which was dissolved in dry acetone, a drop of conc H_2SO_4 and several g of anhyd $CuSO_4$ were added, and the mixture was stirred at room temp for 3 days. The mixture was neutralized with a little conc NH_4OH, filtered, and evap under reduced press. The residue was dissolved in water and the soln was extracted twice with ether. The ether layer was dried over Na_2SO_4 and evap leaving an oily residue which cryst on chilling in dry ice (3·05 g, 19·3 mmole, 52%). A portion of this crude material was sublimed (bath temp 45–50°, 0·1 torr, condenser at 0°) yielding a sublimate which melted at 50–52°. (Found: C, 60·73; H, 9·02. $C_8H_{14}O_3$ requires: C, 60·74; H, 8·92%).

(B) *From* 2-*cyclopentenol*. A soln of **9a** (10·5 g, 124 mmole) in 300 ml acetone was cooled to −10 to −20°. A soln of 20 g $KMnO_4$ and 1·7 g K_2CO_3 in 300 ml of H_2O was added over 1 hr, with stirring. After an addi-

tional 15 min the mixture was centrifuged, the supernatant soln was decanted, and after addition of 60% $HClO_4$ to pH 5, was recentrifuged. The supernatant was conc to 50 ml, 200 ml of 95% EtOH was added and the pptd salts were filtered off. This procedure was repeated again, and then all solvents were evap off, leaving a yellow oily residue (6·08 g, 51 mmole, 41%). A portion of this crude product was acetylated in the usual manner. The product, m.p. 47–51°, had an IR spectrum identical with that of **12a** obtained above.

DL-(1,2/3)-*cyclopentane*-1,2,3-*triol* (**11a**)

A soln of **12a** (1·0 g, 6·3 mmole in 0·1N H_2SO_4) was heated in a boiling water bath for one hr, and was then neutralized with satd $Ba(OH)_2$aq, filtered over charcoal and evaporated to dryness. The residue was dissolved in abs EtOH, and dried over Na_2SO_4. The solvent was evap and the residue dissolved in a minimum hot acetone. Crystallization occurred in the cold overnight. Filtration in the cold yielded crystals which melted below room temp (350 mg, 3·0 mmole, 47%). On analysis by periodate titration, 2·5 mg (21·1 μmole) consumed 43·8 μmole of periodate, as predicted for a 1,2,3-triol. ((Found: C, 50·70; H, 8·71. $C_5H_{10}O_3$ requires: C, 50·83; H, 8·53%).

DL-1,2,3-*Tri*-O-*benzoyl*-(1,2/3)-*cyclopentane*-1,2,3-*triol* (**11b**)

A sample of the crude product (4 gr, 34 mmole) obtained from $KMnO_4$ oxidation of **9a** was benzoylated in the usual manner. The tribenzoate, which did not crystallize from EtOH, was dissolved in benzene, absorbed in an Al_2O_3 column (2 × 21 cm), and eluted with benzene. After evaporation of benzene from the eluates, crystallization occurred. The product (2·32 g, 5·5 mmole, 16%) was recrystallized twice from EtOH to give an anal sample, m.p. 97·5–99°. (Found: C, 72·31; H, 5·20. $C_{26}H_{22}O_6$ requires: C, 72·54; H, 5·15%.)

DL-1,2-*Anhydro*-(1,2/3)-*cyclopentane*-1,2,3-*triol* (**13a**)

The allylic alcohol **9a** was acetylated with Ac_2O in dry pyridine (40 g, 475 mmole), and the product was purified as described for benzoylations. The crude product was dist (69–72°, 40 torr) yielding 50 g of **9c** (398 mmole, 83%) $n_D^{25.5}$ 1·4459. (Found: C, 66·80; H, 8·19. $C_7H_{10}O_2$ requires: C, 66·64; H, 7·99%.)

40 g (318 mmole) of **9c** were dissolved in 250 ml THF and 70 g of *m*-chloroperoxybenzoic acid were added. The reaction mixture was left in the dark at room temp for 6 days. The THF was evaporated, 200 ml CH_2Cl_2 was added to the residue and the ppt was removed by filtration. The filtrate was then washed with two 150 ml portions 1 N NaOH and the organic layer dried over Na_2SO_4. After evaporation of the solvent under reduced press the residue was distilled. A low-boiling fraction, consisting of unreacted starting material was collected, followed by 20 g of **13c** (140 mmole, 44%), b.p. 100–110°, 38 torr. A portion of this material was redist through a small Vigreux column (b.p. 94·5–95°, 20 torr, $n_D^{24.5}$ 1·4485). (Found: C, 59·30; H, 6·98. $C_7H_{10}O_3$ requires: C, 59·12; H, 7·09%.)

10 g (70 mmole) of **13c** were dissolved in 50 ml of abs MeOH to which 25 ml of 0·33% Na methylate was added, and the soln was heated at 60–70° for 1 hr. The soln was stirred with Amberlite MB-1 until neutral to pH paper. After filtration and evaporation of solvent, the residue was dist yielding 4·0 g (40 mmole, 57%) of **13a** (b.p. 45–47°, 0·25 torr, $n_D^{24.5}$ 1·4694). (Found: C, 59·73; H, 8·09. $C_5H_8O_2$ requires: C, 59·98; H, 8·05%.)

1,2,3-*Tri*-O-*benzoyl*-(1,3/2)-*cyclopentane*-1,2,3-*triol* (**14b**)

Anhydrotriol **13a** was dissolved in 0·1 N H_2SO_4 and the soln was heated in a boiling water bath for 1 hr. Excess $BaCO_3$ was added, the mixture was filtered through a bed of charcoal, and the solvent was removed by evaporation. TLC indicated the presence of two triol components (R_f 0·53 and 0·13) with a preponderance of the slower moving material. This product was treated with acetone in the usual manner in order to convert the 1,2/3 isomer into an isopropylidene derivative. The crude acetonide was dissolved in water and the soln was extracted with ether. The aqueous soln was again evap to dryness, and part of the residue (1·53 g, 13 mmole) was benzoylated in the usual manner. The crude tribenzoate was chromatographed on an Al_2O_3 (1 × 20 cm) column with benzene as eluent. Evap of solvent from the eluate yielded a material which cryst on exposure to air. This material was pressed on a porous plate and dried overnight (2·0 g, 4·65 mmole, 36%). Recrystallization twice from abs EtOH gave an anal sample of **14b**, m.p. 95·5–96°. Mixed m.p. with **11b** was depressed, m.p. 77–88°. (Found: C, 72·70; H, 5·00. $C_{26}H_{22}O_6$ requires: C, 72·54; H, 5·15%).

DL-3-*Bromo*-(1,2,3/0)-*cyclopentene oxide* (**10d**)

The allylic acetate **9c** (30 g, 240 mmole) was dissolved in 75 ml CCl_4, and the soln cooled to $-5°$ to $-10°$. A soln of Br_2 (280 mmole in 40 ml of CCl_4) was added dropwise, with stirring, during 1·5 hr. The reaction soln was left stirring an additional 1·5 hr at room temp. The solvent was then evap under reduced press, the residue dissolved in 200 ml ether and filtered through a bed of charcoal. Distillation (b.p. 65–74°, 0·05 torr) gave 41 g (154 mmole, 64%) of material which analyzed correctly for an acetoxy-dibromocyclopentane. Integration of the acetyl signals in the NMR spectrum indicated that this material was a mixture of the two possible *trans*-dibromo isomers, **36** and **37**, in the ratio of about 3 : 1. A soln of this mixture (20 g, 70 mmole in 50 ml THF) was added dropwise over 1·5 hr, with stirring, to 200 ml of 1 N NaOH. The mixture was then heated at 45–50° for 0·5 hr, and then continuously extracted with ether for 8 hr. The ether extract was dried, evap under reduced press, and the residue distilled (b.p. 52–55°, 1·75 torr) yielding 1·5 g (9·2 mmole, 13%; n_D^{24} 1·5106) of **10d**. (Found: C, 37·10; H, 4·35; Br, 48·76. C_5H_7OBr requires: C, 36·84; H, 4·33; Br, 49·02%).

DL-3-*Bromo*-(1,2/3)-*cyclopentene oxide* (**13d**)

Cyclopentene (15·3 g, 225 mmole) was dissolved in 150 ml dry CCl_4 to which 13·5 g (76 mmole) N-bromosuccinimide was added.[28] The mixture was refluxed for 1 hr, cooled, filtered, and the filtrate washed with equal vols of sat $NaHCO_3$aq and water. The soln containing the allylic bromide was dried over Na_2SO_4, diluted with 350 ml $CHCl_3$ and then 55 *m*-chloroperoxybenzoic acid were dissolved in the soln. After 7 days the reaction mixture was filtered and the solvents removed. The residue was dissolved in ether, washed twice with 1N NaOH and once with water. The ether was removed and the residue distilled (b.p. 43–46·5°, 0·85 torr) yielding 1·33 g (8·3 mmole, 11%, $n_D^{24.5}$ 1·5059) of **13d**. The IR and NMR spectra of this material were different from those of the *cis*-isomer **10d**. (Found: C, 36·74; H, 4·46; Br, 49·22. C_5H_7OBr requires: C, 36·84; H, 4·33; Br, 49·02%).

3,5-*Dibromo*-(1,2/3,5)-*cyclopentene oxide* (**29d**)

This material was prepared in very low yield by the direct epoxidation of *cis*-3,5-dibromocyclopentene[8] in $CHCl_3$. The reaction conditions and work-up were similar to those described above. The product was dist at 69–71·5°, 0·2 torr ($n_D^{24.5}$ 1·5643). On standing at room temp crystallization occurred giving a white solid, m.p. 33–34·5°. The NMR spectrum indicated that only one isomer was present, and this has been assigned the *trans*-configuration **29d** on the basis of the *trans*-directing effect of large, dipolar groups in epoxidation reactions.[5a,b] (Found: C, 24·98; H, 2·54; Br, 66·24. $C_5H_6OBr_2$ requires: C, 24·82; H, 2·50; Br, 66·06%).

1,2-O-*Isopropylidene*-(1,2,4/0)-*cyclopentane*-1,2,4-*triol* (**19a**)

Bromotriol acetonide **18a** (700 mg, 3 mmole) prepared as previously described,[1b] was dissolved in 150 ml 95% EtOH and reduced with H_2 and Raney Ni, by the method used for the preparation of **8a**. After the usual isolation procedure, a liquid product was obtained (170 mg, 1·08 mmole, 36%), b.p. 53–55° (0·4 torr). (Found: C, 61·00; H, 9·10. $C_8H_{14}O_3$ requires: C, 60·74; H, 8·92%).

4-O-*Benzoyl*-1,2-O-*isopropylidene*-(1,2,4/0)-*cyclopentane*-1,2,4-*triol* (**19b**)

The acetonide **19a** (115 mg, 0·73 mmole) was benzoylated as usual. The oily product cryst from abs EtOH (80 mg, 0·31 mmole, 42%). Recryst from EtOH gave an anal sample, m.p. 75·5–76·5°. (Found: C, 68·66; H, 6·89. $C_{15}H_{18}O_4$ requires: C, 68·68; H, 6·92%).

1,2,4-*Tri*-O-*benzoyl*-(1,2,4/0)-*cyclopentane*-1,2,4-*triol* (**17b**)

Bromotriol tribenzoate **16b** (450 mg, 0·88 mmole) prepared as previously reported[1b] was dissolved in abs EtOH and reduced with H_2 and Raney Ni as described. The crude product crystallized from EtOH (165 mg, 0·38 mmole, 43%), and was recrystallized from EtOH, m.p. 68–69·5°. (Found: C, 72·79; H, 5·20. $C_{26}H_{22}O_6$ requires: C, 72·54; H, 5·15%).

1,2-O-*Isopropylidene*-(1,2/4)-*cyclopentane*-1,2,4-*triol* (**25a**)

The alcohol **20a** (6·0 g, 72 mmole), prepared by hydroboration of cyclopentadiene,[29] was dissolved in 300 ml acetone. The soln was maintained at -10 to $-20°$ while a soln of 12 g $KMnO_4$ and 1·0 g K_2CO_3 in 250 ml of H_2O was added, dropwise, with strong stirring, during a period of 0·5 hr. Stirring was continued for 0·5 hr, and the product was isolated as described above, yielding a yellow oil (1·4 g, 11·8 mmole, 16%).

A portion of this triol **24a** was treated with acetone in the usual manner; the crude acetonide was dissolved in ether and extracted twice with H_2O. The ethereal soln was dried over Na_2SO_4, the solvent was evap, and the crude acetonide was sublimed (bath temp 45–55°, 0·3 torr, condenser at 0°) yielding **25a**, m.p. 57–62°. (Found; C, 60·58; H, 8·88. $C_8H_{14}O_3$ requires: C, 60·74; H, 8·92%).

4-O-*Benzoyl*-1,2-O-*isopropylidene*-(1,2/4)-*cyclopentane*-1,2,4-*triol* (**25b**)

Compound **25a** (150 mg, 0·95 mmole) was benzoylated as usual. The viscous product was dissolved in a minimum of hot abs EtOH and stored at 0°. Crystallization occurred overnight, yielding 110 mg (0·42 mmole, 44%). Recrystallization from EtOH gave an anal sample, m.p. 106–109°. (Found: C, 68·40; H, 6·73. $C_{15}H_{18}O_4$ requires: C, 68·68; H, 6·92%).

1,2,4-*Tri*-O-*benzoyl*-(1,2/4)-*cyclopentane*-1,2,4-*triol* (**24b**)

Part of the crude product obtained from the $KMnO_4$ oxidation of **20a** was benzoylated as usual. The crude tribenzoate **24b** was chromatographed on Al_2O_3 (1 × 20 cm) with benzene as eluent. The combined eluates were evap and the residue was precipitated from abs EtOH. Two recrystallization gave an analytical sample, m.p. 110–112°. (Found: C, 72·25; H, 5·12. $C_{26}H_{22}O_6$ requires: C, 72·54; H, 5·15%).

DL-1,2,4-*Tri*-O-*benzoyl*-(1,4/2)-*cyclopentane*-1,2,4-*triol* (**23b**)

Epoxidation of **20a** in $CHCl_3$ by the usual procedure yielded a mixture of anhydrotriols **21a** and **22a**. Dist gave two fractions: one, b.p. 35–44°, 0·2 torr, had an IR spectrum with a sharp band at 3552 cm^{-1} and a small shoulder on the high-frequency side; the other fraction b.p. 45–58°, 0·2 torr, showed two distinct peaks, in the IR at 3552 cm^{-1} and 3618 cm^{-1} and was, therefore, a mixture of the two isomers, **21a** and **22a**. The high-boiling fraction (1·2 g, 12 mmole), dissolved in 0·05 N H_2SO_4, was heated 45 min in a boiling water bath. The crude triol **23a** (660 mg, 5·5 mmole, 46%) was benzoylated as usual. The crude tribenzoate **23b** cryst on exposure to air (2·0 g, 4·65 mmole, 85%). Recryst twice from abs EtOH gave an anal sample, m.p. 111·5–112·5°. (Found: C, 72·39; H, 5·11. $C_{26}H_{22}O_6$ requires: C, 72·54; H, 5·15%).

1,2-*Anhydro*-(1,2,4/0)-*cyclopentane*-1,2,3-triol (**21a**)

The lower boiling fraction from the epoxidation of **20a** was redist through a small Vigreux column, giving a sample of **21a** (b.p. 26–26·5°, 0·1 torr). The IR spectrum showed only the H-bonded OH at 3552 cm^{-1}. (Found: C, 59·75; H, 8·20. $C_5H_8O_2$ requires: C, 59·98; H, 8·05%).

1,2-*Anhydro*-(1,2/4)-*cyclopentane*-1,2,4-*triol* (**22a**)

The homoallylic alcohol **20a** (15 g, 180 mmole) was acetylated as usual yielding 19·2 g (170 mmole, 94%) of **20c**. Redist of a small portion gave an anal sample (b.p. 61–62°, 22 torr, n_D^{23} 1·4441). (Found: C, 66·43; H, 8·05. $C_7H_{10}O_2$ requires: C, 66·64; H, 7·99%).

A soln of **20c** (14 g, 123 mmole, in 250 ml of MeOH) was treated with *m*-chloroperoxybenzoic acid for 7 days. The product was isolated as described for **13c** and was distilled to give 8·7 g of **22c** b.p. 102·5–105·5°, 25 torr, $n_D^{24.5}$ 1·4500 (61 mmole, 50%). (Found: C, 59·09; H, 7·07. $C_7H_{10}O_3$ requires: C, 59·12; H, 7·09%).

The acetylated epoxide **22c** (2·5 g, 17·5 mmole) was dissolved in 40 ml abs MeOH to which 10 ml 0·33% NaOMe was added and the soln was heated for 1 hr at 50–60°. After isolation as described previously, the crude **22a** (1·0 g, 10 mmole, 57%) was dist (b.p. 50–51·5°, 0·2 torr). (Found: C, 60·19; H, 7·96. $C_5H_8O_2$ requires: C, 59·98; H, 8·05%).

DL-O-*Acetyl*-2,4-*dibromo*-(1,4/2)-*cyclopentanol* (**38**)

4-Bromocyclopentene was prepared by treatment of 3-cyclopentenol **20a** (10 g, 120 mmole) with 5 ml PBr_3 in 50 ml dry CCl_4 at 0° for 2 hr. The soln was cautiously poured over 150 ml dil acid, and the organic layer was washed once with H_2O and dried over Na_2SO_4. A soln of AcOBr was prepared by stirring 180 mmole of AgOAc with a slight excess Br_2 in 300 ml dry CCl_4 for 15 min and then removing the AgBr by filtration. The AcOBr was added to the soln of 4-bromocyclopentene. The mixture was stirred 18 hr at room temp and then was poured into 300 ml dil HCl-ice water. The organic phase was separated, washed once with H_2O, and dried. The product was dist to give 8·6 g (30 mmole, 25%) of O-acetyl-2,4-dibromocyclopentanol (b.p. 72–73°, 0·2 torr, n_D^{23} 1·5232). (Found: C, 29·24; H, 3·58; Br, 55·67. $C_7H_{10}O_2Br_2$ requires: C, 29·40; H, 3·52; Br, 55·89%).

Integration of the acetyl signals in the NMR spectrum of this material indicated that it contained at least 90% of one of the two isomers **38** and **39**. The major component was assigned the structure **38** on the basis of detailed analysis of the spectrum.[30]

4-Bromo-(1,2,4/0)-*cyclopentene oxide* (**21d**)

The acetoxydibromocyclopentane **38** (1·4 g, 4·9 mmole) was dissolved in 40 ml of a 0·33% NaOMe soln, and was refluxed for 45 min. Excess water was added, and the soln was then extracted twice with equal volumes of ether. The ether extracts were dried and the solvent was removed. Distillation yielded 150 mg (0·86 mmole, 17%) of **21d** (b.p. 83–86°, 1·5 torr). (Found: C, 35·66; H, 4·10; Br, 51·45. C_5H_7OBr requires: C, 36·82; H, 4·33; Br, 49·03%).

The IR spectrum of this material showed a small band in the carbonyl region; the product was probably contaminated with a small amount of the starting material which would account for the deviation in the elemental analysis.

DL-2,3-O-*Isopropylidene*-(1,2,3/4)-*cyclopentane*-1,2,3,4-*tetrol* (**31a**)

DL-1,3-Di-O-acetyl-*trans*-cyclopentene-1,3-diol was prepared as previously described.[2c] This material (11·0 g, 60 mmole) was dissolved in 300 ml acetone, cooled to −10 to −20°, and a soln 10 g $KMnO_4$ in 200 ml water was added over 1·5 hr, with stirring. After 0·5 hr additional stirring the mixture was centrifuged, and the brownish supernatant fluid filtered through a bed of charcoal. The filtrate was evap to dryness under reduced press, the residue was acetylated in the usual manner. The product was dist to give 3·9 g (b.p. 115–130°, 1·0 torr) (15 mmole, 25%) of **31c**. This material was deacetylated with NaOMe as usual. The oily product crystallized on standing. Sublimation (bath temp 80–90°, 0·25 torr) and subsequent recrystallization from butanone–ligroine gave **31a** m.p. 137–138·5°. The IR spectrum showed bands at 3607 and 3548 cm^{-1} (free and intramolec H-bonded OH). (Found: C, 55·16; H, 8·08. $C_8H_{14}O_4$ requires: C, 55·14; H, 8·10%).

Cyclopentene oxide was prepared by the method of Goodman *et al.*;[29] b.p. 101–102°; $n_D^{22} = 1·4348$.

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Note added in proof—Cheer and Johnson[31] have pointed out that the strength of intramolecular OH···O bonds is related not only to the interatomic distances but also to the possibility that the atoms are so related spatially that there is maximum endwise overlap between the s-orbital of the hydrogen and the directed orbitals on the oxirane oxygen. These considerations are directly applicable to the H-bonding described in the present work.

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