Isomerism in Bicyclic Diacetals. Part I. 1,3:2,4- and 1,4:2,3-Di-*O*-methylene-erythritol

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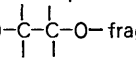
Acid-catalysed methylenation of erythritol affords 1.3:2.4- and 1.4:2.3-di-*O*-methylene-erythritol and a small amount of 1.4-anhydro-2.3-*O*-methylene-erythritol. Constitutional assignments have been made to the diacetals on the basis of their ^{1}H n.m.r. and mass spectra. Deuteriation studies and the lanthanide shift reagent, Eu(fod)$_3$, have been employed to investigate the conformational behaviour of the 1.4:2.3-diacetal in solution by ^{1}H n.m.r. spectroscopy. Acid-catalysed equilibration of the 1.3:2.4- and 1.4:2.3-diacetals indicates that there is a free energy difference of 1·37 kcal mol^{-1} in favour of the former at room temperature. The significance of these results is discussed in terms of electronic effects associated with the  fragments as well as steric effects.

ALDITOLS containing four or more hydroxy-groups can form bicyclic diacetals when they undergo acid-catalysed condensations with aldehydes or ketones. By limiting consideration to those acetalations involving all the hydroxy-groups of the tetritols, four contiguous hydroxy-groups of the pentitols, and all four secondary hydroxy-groups of the hexitols, two categories of constitutionally isomeric bicyclic diacetals can be identified (Figure 1) on the basis of the relative configurations of the inner pair of hydroxy-groups in the alditols. (i) *cis*-Fused 2,4,7,9-tetraoxabicyclo[4.4.0]decane (1) and *trans*-fused 3,5,8,10-tetraoxabicyclo[5.3.0]decane (2) ring systems in addition to a 4,4′-bis-1,3-dioxolan (3) may result when carbon atoms previously associated with hydroxy-groups in the *threo* configuration form the ring junctions. (ii) *trans*-Fused 2,4,7,9-tetraoxabicyclo[4.4.0]decane (4) and *cis*-fused 3,5,8,10-tetraoxabicyclo[5.3.0]decane (5) ring systems in addition to a 4,4′-bis-1,3-dioxolan (6) may result when carbon atoms previously associated with hydroxy-groups in the *erythro* configuration form the ring junctions.

Examples of alditols which fall into the first category of reactivity are D-threitol, D-xylitol, D-arabinitol,† D-glucitol, D-iditol, and D-mannitol; examples of alditols which fall into the second category are erythritol, D-arabinitol, ribitol, galactitol, allitol, and D-altritol.

Bicyclic diacetals containing the *cis*-fused 2,4,7,9-tetraoxabicyclo[4.4.0]decane ring system are known [1] in the *threo*, *xylo*, *arabino*, *gluco*, *ido*, and *manno* configurational series. Acid-catalysed methylenation of L-threitol has yielded [2] 1,3:2,4-di-*O*-methylene-L-threitol (7) with a *cis*-fused [4.4.0] ring system. Although two conformations, which have been termed [3] the '*O*-inside' and the '*H*-inside,' are possible for (7), dipole moment measurements in benzene and ^{1}H n.m.r. spectroscopy in

† D-Arabinitol displays category (i) reactivity if the hydroxy-groups on C-1, -2, -3, and -4 are involved, and category (ii) reactivity if the hydroxy-groups on C-2, -3, -4, and -5 are involved.

[1] J. F. Stoddart, 'Stereochemistry of Carbohydrates,' Wiley, New York, 1971, p. 210.
[2] R. U. Lemieux and J. Howard, *Canad. J. Chem.*, 1963, **41**, 393.
[3] J. A. Mills, *Adv. Carbohydrate Chem.*, 1955, **10**, 1.

deuteriochloroform have shown [2] that (7) exists predominantly as the ' *O*-inside ' conformation in solution. It has also been established [4] that the configurational isomer of 1,3:2,4-di-*O*-benzylidene-L-threitol with equatorial phenyl groups in the ' *O*-inside ' conformation is obtained on acid-catalysed benzylidenation of L-threitol. It was argued [2] some time ago that the ' *O*-inside ' conformation is preferred on the basis of steric considerations. There are three *gauche* oxygen–oxygen interactions associated with the $-O-\overset{|}{C}-\overset{|}{C}-O-$ fragments in this conformation whereas the ' *H*-inside ' conformation incorporates three *anti* oxygen–oxygen orientations. The conformational behaviour of molecules of the type $RO{\cdot}CH_2{\cdot}CH_2{\cdot}OR'$ has been the subject of numerous investigations [5-16] in the last few years. It has been established that *anti–gauche* equilibria in solution depend on the nature of R and R' and also on solvent polarity. Solvent effects suggest that electronic factors as well as steric factors are important in determining the positions of conformational equilibria. Such considerations, however, do not alter the general conclusion [1,2] that the ' *O*-inside ' conformation of 1,3:2,4-di-*O*-methylene-L-threitol (7) should be much more stable than the ' *H*-inside ' conformation, a conclusion which is in agreement with experimental observation.[2]

Molecular models show [1,3] that 1,3:2,4-di-*O*-methylene-DL-xylitol (8),[17] 2,4:3,5-di-*O*-methylene-D-glucitol (9),[18] and 2,4:3,5-di-*O*-methylene-L-iditol (10) [19] must also exist in ' *O*-inside ' conformations, as the ' *H*-inside ' conformations all have axial hydroxymethyl groups which would have to be accommodated in the sterically crowded ' inside ' portion of the molecule.

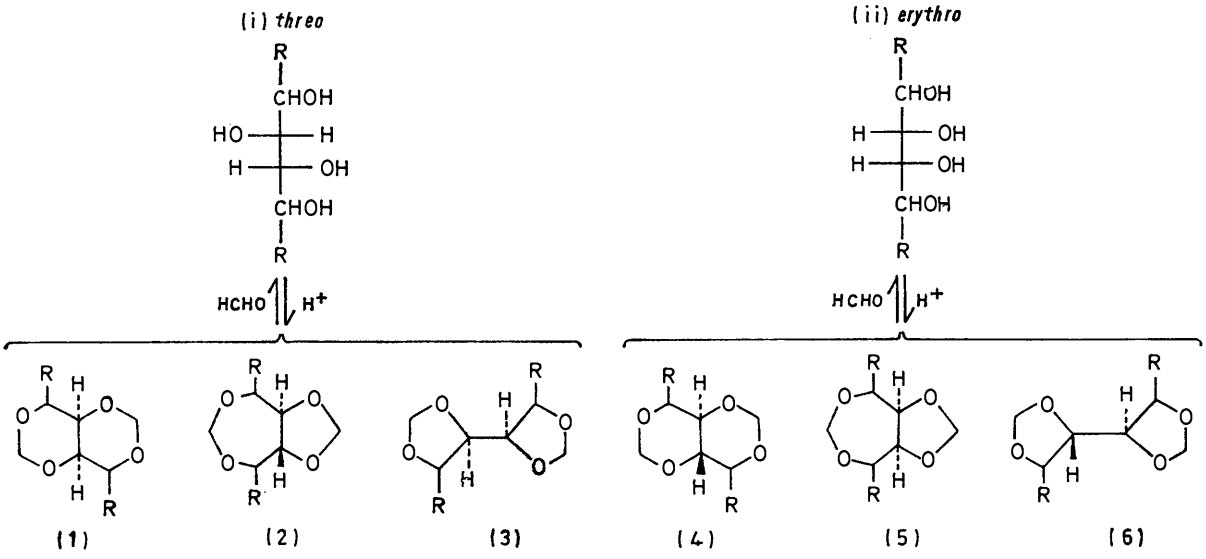


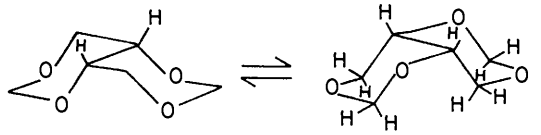
FIGURE 1 The two categories (i) and (ii) of constitutional isomers resulting from bicyclic diacetal formation in (i) the *threo* series, and (ii) the *erythro* series

2,4:3,5-Di-*O*-methylene-D-mannitol (11) [20] can exist either in the ' *O*-inside ' conformation with two axial hydroxymethyl groups or in the ' *H*-inside ' conformation with two equatorial hydroxymethyl groups. Coupling constant data from the ^1H n.m.r. spectrum of 1,6-dideoxy-2,4:3,5-di-*O*-methylene-D-mannitol (12) indicate [21] that the ' *H*-inside ' conformation is the predominant contributor to the conformational equilibrium at room temperature in deuteriochloroform solution. However, when the temperature is lowered to −59°, the ' *O*-inside ' conformation is preferred. The temperature dependence of this conformational equilibrium has been interpreted [21] in terms of the ' *H*-inside ' conformation being more flexible and thus having a higher entropy than the ' *O*-inside ' conformation.

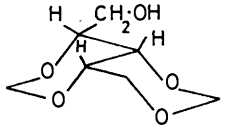
[4] A. B. Foster, A. H. Haines, and J. Lehmann, *J. Chem. Soc.*, 1961, 5011.
[5] J. E. Mark and P. J. Florey, *J. Amer. Chem. Soc.*, 1965, **87**, 1415; 1966, **88**, 3702.
[6] R. G. Snyder and G. Zerbi, *Spectrochim. Acta*, 1967, **23A**, 391.
[7] C. B. Anderson, D. T. Sepp, M. P. Geis, and A. A. Roberts, *Chem. and Ind.*, 1968, 1805.
[8] E. L. Eliel and M. K. Kaloustian, *Chem. Comm.*, 1970, 290.
[9] E. L. Eliel, *Accounts Chem. Res.*, 1970, **3**, 1.
[10] R. J. Abraham and K. Parry, *J. Chem. Soc.* (*B*), 1970, 539.
[11] E. L. Eliel, *Pure Appl. Chem.*, 1971, **25**, 509.
[12] R. J. Abraham, H. D. Banks, E. L. Eliel, O. Hofer, and M. K. Kaloustian, *J. Amer. Chem. Soc.*, 1972, **94**, 1913.
[13] E. L. Eliel and R. M. Enanoza, *J. Amer. Chem. Soc.*, 1972, **94**, 8072.
[14] E. L. Eliel, *Angew. Chem. Internat. Edn.*, 1972, **11**, 739.
[15] E. L. Eliel and O. Hofer, *J. Amer. Chem. Soc.*, 1973, **94**, 8041.
[16] L. Phillips and V. Wray, *J.C.S. Chem. Comm.*, 1973, 90.
[17] R. M. Hann, A. T. Ness, and C. S. Hudson, *J. Amer. Chem. Soc.*, 1944, **66**, 670.
[18] W. N. Haworth and L. F. Wiggins, *J. Chem. Soc.*, 1944, 58; R. M. Hann, J. K. Wolfe, and C. S. Hudson, *J. Amer. Chem. Soc.*, 1944, **66**, 1898.
[19] R. M. Hann and C. S. Hudson, *J. Amer. Chem. Soc.*, 1945, **67**, 602.
[20] W. T. Haskins, R. M. Hann, and C. S. Hudson, *J. Amer. Chem. Soc.*, 1943, **65**, 67; W. N. Haworth and L. F. Wiggins, *J. Chem. Soc.*, 1944, 58.
[21] D. M. Kilburn, M.Sc. Thesis, Queen's University, Kingston, Ontario, 1969.

In principle, D-arabinitol could display category (i) or category (ii) reactivity. In practice, acid-catalysed condensation of D-arabinitol with formaldehyde yields [22] 1,3:2,4-di-*O*-methylene-D-arabinitol (13) *in low yield,** and so category (i) reactivity has been observed. The nature of the potential conformational equilibrium between the '*O*-inside' conformation with an axial hydroxymethyl group and the '*H*-inside' conformation with an equatorial hydroxymethyl group has not been investigated.

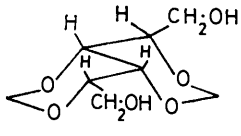
Although no *trans*-fused 3,5,8,10-tetraoxabicyclo-[5.3.0]decane derivatives have been isolated as thermodynamically stable bicyclic diacetals after acid-catalysed



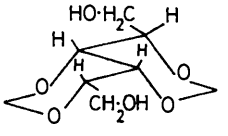
'*O*-inside' (7) '*H*-inside'



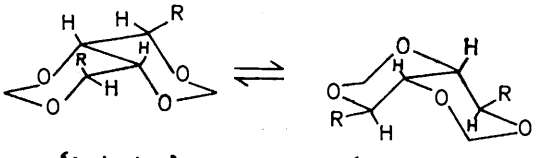
(8)



(9)

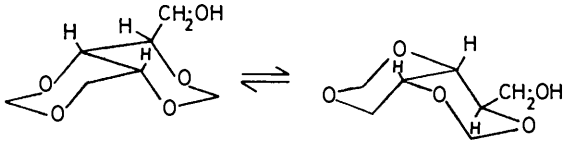


(10)



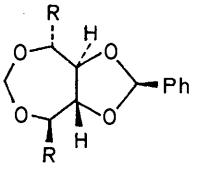
'*O*-inside' '*H*-inside'

(11) R = CH_2OH
(12) R = Me

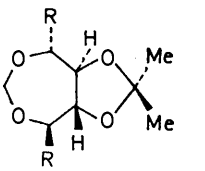


'*O*-inside' (13) '*H*-inside'

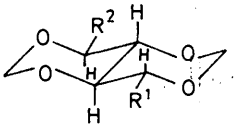
acetalations, a number of derivatives of 3,4-*O*-benzylidene-2,5-*O*-methylene-D-mannitol (14) and 3,4-*O*-isopropylidene-2,5-*O*-methylene-D-mannitol (15) have been prepared indirectly.[23-25]



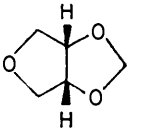
(14)a; R = CH_2OH
b; R = CH_2OBz
c; R = CH_2OTs
d; R = Me



(15)a; R = CH_2OH
b; R = CH_2OBz



(16) $R^1 = CH_2OH$, $R^2 = H$;
or $R^1 = H$, $R^2 = CH_2OH$
(17) $R^1 = R^2 = CH_2OH$



(18)

Bicyclic diacetals containing the *trans*-fused 2,4,7,9-tetraoxabicyclo[4.4.0]decane system have been characterised [1] in only the *ribo* and *allo* series. Acid catalysed methylenation of ribitol and allitol has yielded 1,3:2,4-di-*O*-methylene-DL-ribitol (16) [26] and 2,4:3,5-di-*O*-methylene-allitol (17) [27] with *trans*-fused [4.4.0] ring systems and equatorial hydroxymethyl groups. When our present investigations were initiated no *cis*-fused 3,5,8,10-tetraoxabicyclo[5.3.0]decane derivatives had been fully characterised.

This paper describes results obtained from the acid-catalysed methylenation of erythritol. The succeeding paper discusses some closely related findings in the *galacto*, *arabino*, and *ribo* series. The whole investigation has been the subject of a preliminary communication.[28]

RESULTS AND DISCUSSION

Prolonged acid-catalysed methylenation of erythritol afforded two of the three possible [(4)—(6); R = H] constitutionally isomeric diacetals shown in Figure 1. Both isomers are crystalline and the isomer with m.p. 100° has been reported [29] previously (lit. m.p. 97—98°), although its constitution was not determined. The other isomer, with m.p. 88—89°, is a new compound. A third non-crystalline product, isolated in low yield (7%) by preparative g.l.c., was characterised as 1,4-anhydro-2,3-*O*-methylene-erythritol (18) by spectroscopic methods.

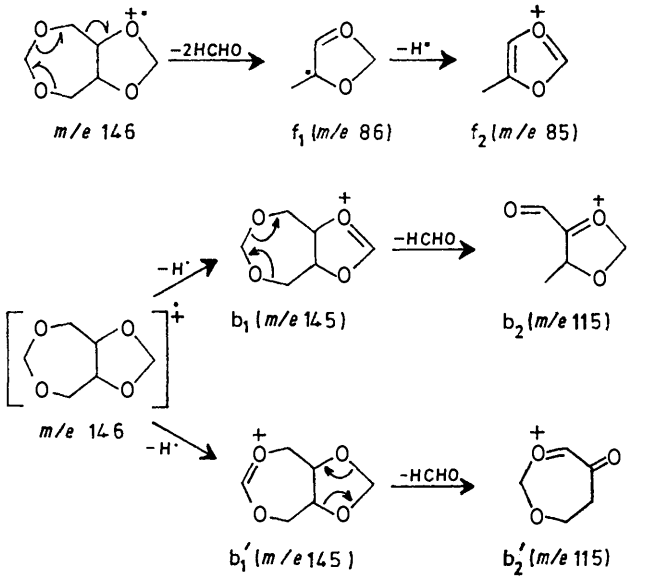
* Recently, one [1] of us has been incorrectly attributed [16] the elaim that the 1,3 : 2,4-diacetal (13) is the thermodynamically favoured product in this reaction. It should be emphasised that Zissis and Richtmeyer [22] isolated this diacetal from the acid-catalysed methylenation of D-arabinitol in 49% yield *only after three successive equilibrations of the same reaction mixture.* Other products may be present in the reaction mixture under equilibrium conditions and it is our belief that this work should be repeated before conclusions are drawn about the nature of the thermodynamically favoured product.

[22] E. Zissis and N. K. Richtmeyer, *J. Amer. Chem. Soc.*, 1954, **76**, 5515.
[23] A. T. Ness, R. M. Hann, and C. S. Hudson, *J. Amer. Chem. Soc.*, 1943, **65**, 2215.
[24] B. Wickberg, *Acta Chem. Scand.*, 1958, **12**, 1187.
[25] J. F. Stoddart and W. A. Szarek, *J. Chem. Soc.* (*B*), 1971, 437.
[26] R. M. Hann and C. S. Hudson, *J. Amer. Chem. Soc.*, 1944, **66**, 1906.
[27] M. L. Wolfrom, B. W. Lew, and R. M. Goepp, *J. Amer. Chem. Soc.*, 1946, **68**, 1443.
[28] I. J. Burden and J. F. Stoddart, *J.C.S. Chem. Comm.*, 1974, 863.
[29] M. Schulz and B. Tollens, *Annalen*, 1896, **289**, 20.

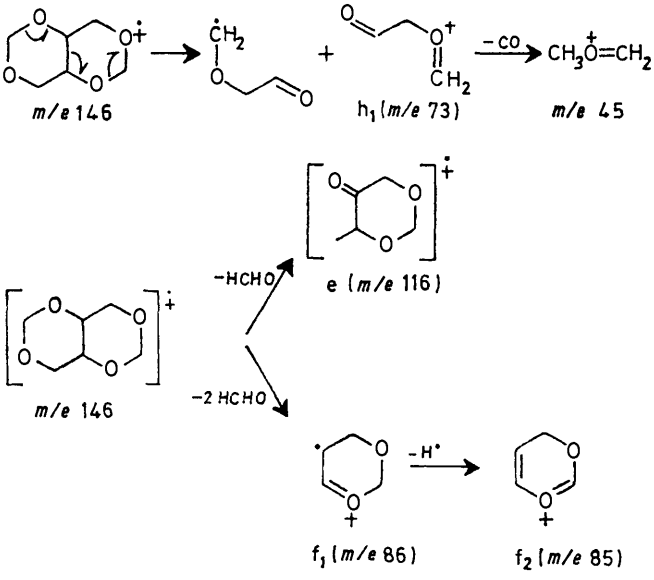
Constitutional assignments of the diacetals were based upon the nature of the ^{1}H n.m.r. signals for their dioxymethylene protons [30] and were confirmed [31] by mass spectrometry. The chemical shift patterns characterise the topic relationships [32] between the dioxymethylene groups, and the magnitudes of the geminal coupling constants between the dioxymethylene protons are also diagnostic of a given bicyclic diacetal. It is well established [30] that the geminal coupling constant for dioxymethylene protons in 1,3-dioxolan rings is close to 0, whereas in 1,3-dioxan and 1,3-dioxepan rings numerical values * of around 6 Hz are to be expected.

The ^{1}H n.m.r. spectrum of the compound with m.p. 88—89° exhibits *two anisochronous* [32] AB systems with $J_{AB} < 1{\cdot}0$ Hz and J_{AB} 6·1 Hz for the *constitutionally heterotopic* [32] dioxymethylene groups and so this isomer is identified as 1,4:2,3-di-*O*-methylene-erythritol (5; R = H). The *two isochronous* [32] AB systems in the ^{1}H n.m.r. spectrum of the compound with m.p. 100° with J_{AB} 6·0 Hz for the *enantiotopic* [32] dioxymethylene groups necessitate that this isomer be 1,3:2,4-di-*O*-methylene-erythritol (4; R = H). No evidence was obtained for the formation of the other possible constitutional isomer, 1,2:3,4-di-*O*-methylene-erythritol (6; R = H), under the conditions of thermodynamic control employed in this investigation.

Analysis of the fragmentation patterns produced in the mass spectrum of the bicyclic diacetals often allow [31] a distinction to be made between constitutional isomers. The important aspects of the fragmentation pattern (see Experimental section) of the 1,4:2,3-diacetal (5; R = H) are accounted for in Scheme 1. Loss of two formaldehyde molecules from the molecular ion (*m/e* 146) by rupture of three bonds gives a fragment f_1 (*m/e* 86) which may subsequently lose a hydrogen atom to yield fragment f_2 (*m/e* 85). There are also important peaks to be found in the high mass range particularly at *m/e* 145 (fragment b_1/b'_1) and 115 (fragment b_2/b'_2). As shown in Scheme 1, fragments b_1 and b'_1 result from loss of a hydrogen atom from the 1,3-dioxolan and 1,3-dioxepan rings respectively of the molecular ion. Both these fragments may then lose formaldehyde to give fragments b_2 and b_2', respectively, with *m/e* 115. A significant feature of the mass spectrum of the 1,4:2,3-diacetal (5; R = H) is the relatively *low* abundance of a ' half-ion ' peak at *m/e* 73. In the case of the 1,3:2,4-diacetal (4; R = H), this is the most intense peak in the mass spectrum (see Experimental section) and arises [31] from electron shifts which result in the rupture of three bonds to give a stable ' half-radical ' and the ' half-ion ' (h_1) at *m/e* 73. Loss of carbon monoxide from the fragment h_1 gives an ion with *m/e* 45. Loss of formaldehyde from the molecular ion gives fragment e (*m/e* 116). Loss of two formaldehyde molecules from the molecular ion gives fragment f_1



SCHEME 1 Fragmentation patterns for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H)



SCHEME 2 Fragmentation patterns for 1,3:2,4-di-*O*-methylene-erythritol (4; R = H)

(*m/e* 86) which can eliminate a hydrogen atom to yield fragment f_2 (*m/e* 85).

Molecular models of 1,4:2,3-di-*O*-methylene-erythritol

* Geminal coupling constants usually assume negative values; in this paper, however, we shall present numerical values only.

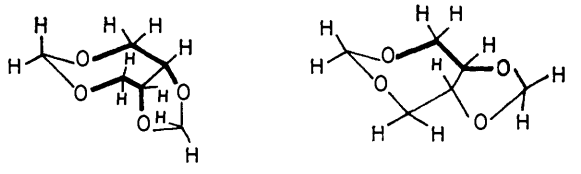
[30] J. A. Pople and A. A. Bothner-By, *J. Chem. Phys.*, 1965, **42**, 1339; A. A. Bothner-By, *Adv. Magnetic Resonance*, 1965, **1**, 195; R. C. Cookson and T. A. Crabb, *Tetrahedron Letters*, 1964, 679; *Tetrahedron*, 1968, **24**, 2385; R. C. Cookson, T. A. Crabb, J. J. Frenkel, and J. Hudec, *Tetrahedron*, Suppl. No. 7, pp. 355, 1966; R. Cahill, R. C. Cookson, and T. A. Crabb, *Tetrahedron*, 1969, **25**, 4681.

[31] O. S. Chizov, L. S. Golovkina, and N. S. Wulfson, *Carbohydrate Res.*, 1968, **6**, 138, 143; N. S. Wulfson, O. S. Chizov, and L. S. Golovkina, *Zhur. org. khim.*, 1968, **4**, 744.

[32] K. Mislow and M. Raban, *Topics Stereochem.*, 1967, **1**, 1; E. L. Eliel, ' Elements of Stereochemistry,' Wiley, New York, 1969, p. 20; D. Arigoni and E. L. Eliel, *Topics Stereochem.*, 1969, **4**, 127; E. L. Eliel, *J. Chem. Educ.*, 1971, **48**, 163; H. Hirschmann and K. R. Hanson, *J. Org. Chem.*, 1971, **36**, 3293; *European J. Biochem.*, 1971, **22**, 301; J. F. Stoddart, MTP International Review of Science, Organic Chemistry, Series One, vol. 1, ed. W. D. Ollis, 1973, p. 1.

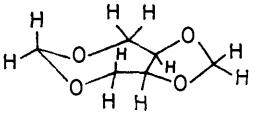
(5; R = H) reveal that there are *three* conformations where torsional energy and nonbonded interactions appear to be approximately minimal. In all these conformations, the 1,3-dioxepan ring adopts a favourable twist-chair conformation with the *cis*-fused 1,3-dioxolan ring in a twist conformation. If attention is focused on the relative conformational dispositions of the oxygen atoms in the $-O-\overset{|}{C}-\overset{|}{C}-O-$ units between the five- and seven-membered rings, then the three conformations (Figure 2) may be identified as the *gauche,gauche* (19), *gauche,anti* (20), and *anti,anti* (21) conformations. The *gauche,gauche* conformation (19) may be regarded as a ' conformational relative ' of the ' *O*-inside ' conformation [2] of 1,3:2,4-di-*O*-methylene-L-threitol (7).

In view of this situation it was of interest to investigate the conformational behaviour of 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in solution by ^{1}H n.m.r. spectroscopy. The partial ^{1}H n.m.r. spectra in deuteriochloroform and in carbon disulphide are shown in Figures 3 and 4, respectively. In order to aid the assignment of chemical shifts to the bridgehead and *C*-methylene protons, 1,4:2,3-di-*O*-methylene[1,1,4,4-$^2H_4$]erythritol (26) was prepared by the procedure outlined in Scheme 3. Comparisons of the experimental spectra in Figures 3 and 4 with computed spectra have provided the coupling constant data summarised in Table 1. The problem now arises of equating this information with the conformational behaviour of the molecule. The possibility must be recognised that the *gauche,gauche* (19), *gauche,anti* (20),



gauche , gauche (19)

gauche, anti (20)



anti , anti (21)

FIGURE 2 The *gauche,gauche* (19), *gauche,anti* (20), and *anti, anti* (21) conformations of 1,4 : 2,3-di-*O*-methylene-erythritol (5; R = H); the *gauche* $-O-\overset{|}{C}-\overset{|}{C}-O-$ fragments are identified by the thickened bonds

and *anti,anti* (21) conformations—and for that matter, other conformations—may be of approximately equal energies and, in view of the conformational flexibility of the molecule, may also be undergoing rapid interconversion.* If this is the case, then the calculation of

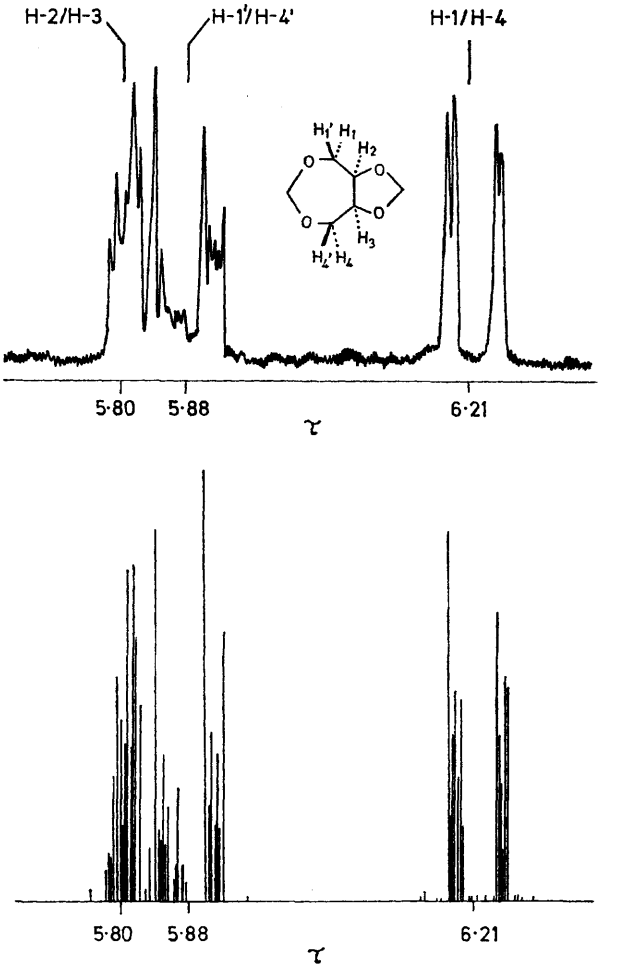


FIGURE 3 The experimental and computed partial ^{1}H n.m.r. spectra of 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in deuteriochloroform

specific coupling constants would be imprudent,[33] since coupling constants should be summed [34] over the whole pseudorotational itinerary and not just over the most stable conformations. In addition, the dependence [35] of coupling constants on the orientation of the protons with

TABLE 1

Vicinal coupling constants observed for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in deuteriochloroform and carbon disulphide

Vicinal protons	*J*/Hz $CDCl_3$	*J*/Hz CS_2
1,2	3·0	4·0
1', 2	5·0	7·0
2, 3	8·0	8·0
3, 4	3·0	4·0
3, 4'	5·0	7·0

* Such a process involves boat-like intermediates for the seven-membered ring.

[33] W. E. Willy, G. Binsch, and E. L. Eliel, *J. Amer. Chem. Soc.*, 1970, **92**, 5394.

[34] V. Tabacik, *Tetrahedron Letters*, 1968, 555, 561.

[35] K. L. Williamson, *J. Amer. Chem. Soc.*, 1963, **85**, 516; P. Laszlo and P. von R. Schleyer, *ibid.*, p. 2709; D. H. Williams and N. S. Bhacca, *ibid.*, 1964, **86**, 2742; H. Booth, *Tetrahedron Letters*, 1965, 411; S. Sternhell, *Quart. Rev.*, 1969, **23**, 236.

respect to the electronegative oxygen atoms is also uncertain. These factors render the Karplus relationship [36] unreliable for the *quantitative* determination of torsion

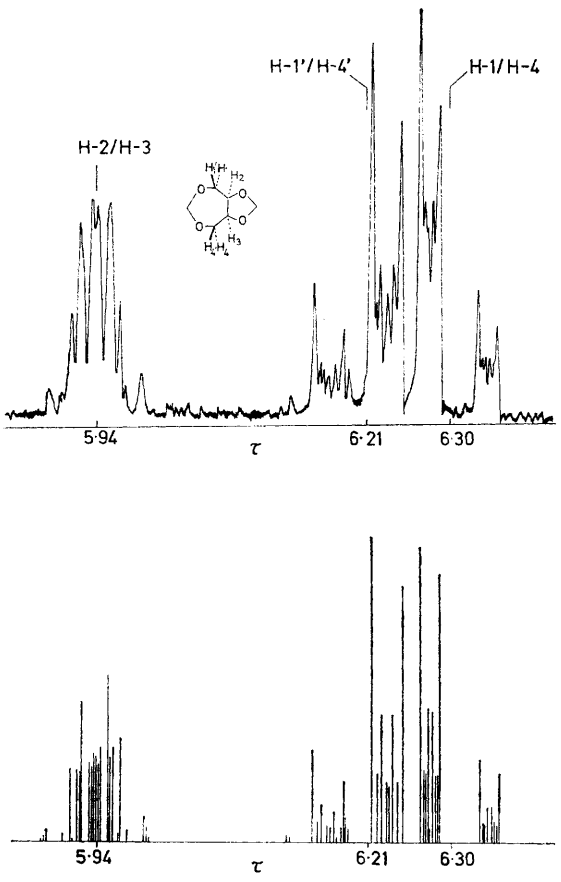


FIGURE 4 Experimental and computed partial ^1H n.m.r. spectra of 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in carbon disulphide

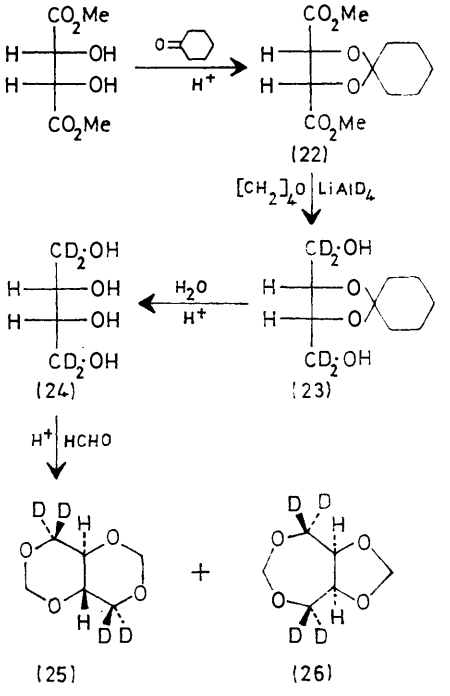
angles, and hence of conformation, in 1,4:2,3-di-*O*-methylene-erythritol (5; R = H). In six-membered rings, and to some extent in five-membered rings, this problem may be circumvented by employing the *R*-value method [37] provided certain structural criteria are fulfilled. Unfortunately, 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) is not amenable to such an analysis. However, the significant difference amongst conformations (19)—(21) in Figure 2, lies in the torsion angles involving the H(1')–C–C–H(2) and H(3)–C–C–H(4') fragments. If these are directly associated with *gauche* –O–C–C–O– fragments, then the torsion angle relating the protons to each other is [38,39] *synclinal*; * if they are associated with *anti* –O–C–C–O– fragments, then the torsion angle relating the protons to each other is [38,39] *antiperiplanar*.*

* Conformations are described as *synclinal* or *antiperiplanar* if the torsion angle is within ±30° of ±60° or ±180°, respectively.

† Tris-(1,1,1,2,2,3,3-heptafluoro-7,7-dimethyloctane-4,6-dionato)europium(III).

Thus, by applying the Karplus equation in a *qualitative* sense and making allowance for the conformational averaging which is presumably occurring between enantiomeric conformations, it would be expected that the coupling constant $J_{1',2}$ (≡ $J_{3.4'}$) would increase in magnitude on going from the *gauche,gauche* (19), through the *gauche,anti* (20), to the *anti,anti* (21) conformation. Thus, qualitatively at least, an increase in the magnitude of observed values for $J_{1',2}$ (≡ $J_{3.4'}$) from 5·0 to 7·0 Hz (Table 1) on going from deuteriochloroform to carbon disulphide solution indicates that contributions from conformations with oxygen atoms in the –O–C–C–O– fragments in the *anti* relationship is more important in carbon disulphide.

This conclusion is supported by results obtained for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in the presence of the lanthanide shift reagent, Eu(fod)$_3$,† in deuteriochloroform and in carbon disulphide solution. Although comparison (Table 2) of the lanthanide-induced shifts indicates that a similar conformational picture pertains in both solvents in the presence of Eu(fod)$_3$, the dramatic change (Table 3) in the magnitude of $J_{1',2}$ (≡ $J_{3.4'}$) from 7·0 to 4·0 Hz, as Eu(fod)$_3$ is added progressively to the carbon disulphide solution, is consistent



SCHEME 3 Preparation of 1,3:2,4- (25) and 1,4:2,3- (26) di-*O*-methylene[1,1,4,4-$^2H_4$]erythritol

only with a perturbation in the conformational equilibrium towards the *gauche,gauche* conformation (19).

[36] M. Karplus, *J. Chem. Phys.*, 1959, **30**, 11; *J. Amer. Chem. Soc.*, 1963, **85**, 2870.
[37] J. B. Lambert, *Accounts Chem. Res.*, 1971, **4**, 87.
[38] W. Klyne and V. Prelog, *Experientia*, 1960, **16**, 521.
[39] IUPAC 1968 Tentative Rules, Section E, Fundamental Stereochemistry. *J. Org. Chem.*, 1970, **35**, 2849.

Interactions between substrates and lanthanide shift reagents are known [40] to influence the positions of conformational equilibria involving diastereoisomeric conformations. The *gauche,gauche* conformation (19) provides the best geometrical situation for simultaneous co-ordination of all four oxygen atoms with the europium ion and is presumably stabilised as a consequence.

TABLE 2

Comparison of the lanthanide-induced shifts for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) with $Eu(fod)_3$ in deuteriochloroform and in carbon disulphide

	$CDCl_3$		CS_2	
Proton	$\delta^0_{solvent}$	$\Delta\delta^{0.5}$ [a]	$\delta^0_{solvent}$	$\Delta\delta^{0.5}$ [a]
H-1/H-4	3·79	4·18	3·70	5·34
H-1′/H-4′	4·12	5·16	3·79	6·73
H-2/H-3	4·20	4·14	4·06	5·24
H_A/1,4-O·CH_2·O	4·96	2·10	4·60	3·14
H_B/1,4-O·CH_2·O	4·61	2·88	4·60	3·65
H_A/2,3-O·CH_2·O	5·22	1·55	5·01	2·24
H_B/2,3-O·CH_2·O	4·86	2·33	4·72	3·92

[a] Plots of lanthanide-induced shifts against molar ratios (ρ) of complex to substrate gave excellent linear relationships up to at least ρ = 0·5. Thus, we have defined $\Delta\delta^{0.5} = \delta^0_{solvent} - \delta^{\rho=0.5}_{Eu(fod)_3}$.

TABLE 3

Vicinal coupling constants $J_{1'.2}$ (≡ $J_{3.4'}$) in CS_2 for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) at various different molar ratios (ρ) of $Eu(fod)_3$

ρ	$J_{1'.2}$ (≡$J_{3.4'}$)/Hz
0·00	7·0
0·15	5·9
0·34	5·0
0·55	4·0
0·80	4·0

It is instructive to compare these results with those obtained (Table 4) for 1,3:2,4-di-*O*-methylene-L-threitol (7) and 1,6-dideoxy-2,4:3,5-di-*O*-methylene-D-mannitol (12) in deuteriochloroform on addition of $Eu(fod)_3$. The '*O*-inside' conformations of these molecules resemble the *gauche,gauche* conformation (19) of 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in as far as they also provide a good disposition of the oxygen atoms for simultaneous co-ordination with europium ions. The lanthanide-induced shifts for (5; R = H) and (7) are similar in as much as the signals due to protons on C-1, -2, -3, and -4 are shifted downfield more rapidly than those of the *O*-methylene protons. Coupling constant data from the ^1H n.m.r. spectrum of 1,6-dideoxy-2,4:3,5-di-*O*-methylene-D-mannitol (12) show [21] that the '*H*-inside' conformation is an important contributor to the conformational equilibrium at room temperature in deuteriochloroform solution. However, when $Eu(fod)_3$ is added, a decrease in the magnitude of $J_{2.3}$ (≡ $J_{4.5}$) is observed (Table 5) indicating a perturbation in the conformational equilibrium towards the '*O*-inside' conformation. This behaviour appears to have a close analogy with that already noted for 1,4:2,3-di-*O*-methylene-erythritol (5; R = H) in carbon disulphide solution.

TABLE 4

Lanthanide-induced shifts for 1,3:2,4-di-*O*-methylene-L-threitol (7) and 1,6-dideoxy-2,4:3,5-di-*O*-methylene-D-mannitol (12) in deuteriochloroform

Compound (7)			Compound (12)		
Proton	$\delta^0_{solvent}$	$\Delta\delta^{0.5}$ [a]	Proton	$\delta^0_{solvent}$	$\Delta\delta^{0.5}$ [a]
H-2/H-3	3·62	4·22	H-2/H-5	4·21	3·62
H-1*ax*/H-4*ax*	3·78	4·27	H-3/H-4	3·67	2·83
H-1*eq*/H-4*eq*	4·15	5·35	H_B	4·83	2·50
H_B	4·77	3·36	H_A	4·83	2·60
H_A	5·15	3·43	CH_3	1·34	1·46

[a] Footnote as for Table 2.

TABLE 5

Vicinal coupling constants $J_{2.3}$ (≡ $J_{4.5}$) for 1,6-dideoxy-2,4:3,5-di-*O*-methylene-D-mannitol (12) at various molar ratios (ρ) of $Eu(fod)_3$

ρ	$J_{2.3}$(≡ $J_{4.5}$)/Hz
0·00	5·9
0·11	5·5
0·27	4·8
0·43	4·7
0·58	4·2
0·74	3·8

Acid-catalysed equilibration of the 1,3:2,4- (4; R = H) and 1,4:2,3- (5; R = H) diacetals indicates that there is a free energy difference of 1·37 kcal mol^{-1} in favour of the 1,3:2,4-diacetal (4; R = H) at room temperature. Coupling constant data (see Experimental section) for the 1,3:2,4-diacetal (4; R = H) are consistent with a *trans*-decalin-like conformation (27) which incorporates three *anti* oxygen–oxygen orientations.

(27)

It is known that formaldehyde [41] and acetaldehyde [42,43] will condense with glycerol to give approximately equimolar mixtures of 1,3-dioxan and 1,3-dioxolan derivatives at equilibrium. Thermodynamic data obtained from the polymerisation of 1,3-dioxolan [44] and 1,3-dioxepan [45] indicate (*cf.* ref. 46) that the strain energies are of the same order of magnitude in these ring systems as well. Thus, the relatively small free energy difference between the 1,3:2,4- (4; R = H) and 1,4:2,3- (5; R = H)

[40] R. R. Fraser and Y. Y. Wigfield, *Chem. Comm.*, 1970, 1471; J. F. Caputo and A. R. Martin, *Tetrahedron Letters*, 1971, 4547; W. G. Bentrude, H.-W. Tan, and K. C. Yee, *J. Amer. Chem. Soc.*, 1972, **94**, 3265; T. Sato and K. Goto, *J.C.S. Chem. Comm.*, 1973, 494; B. L. Shapiro, M. D. Johnstone, jun., and M. J. Shapiro, *J. Org. Chem.*, 1974, **39**, 796; K. L. Williamson, D. R. Clutter, R. Erich, M. Alexander, A. E. Burroughs, C. Chua, and M. E. Bogel, *J. Amer. Chem. Soc.*, 1974, **96**, 1471.

[41] H. Hibbert and N. M. Carter, *J. Amer. Chem. Soc.*, 1928, **50**, 3120.

[42] H. S. Hill and H. Hibbert, *J. Amer. Chem. Soc.*, 1923, **45**, 3117; H. S. Hill, H. C. Hill, and H. Hibbert, *ibid.*, 1928, **50**, 2242.

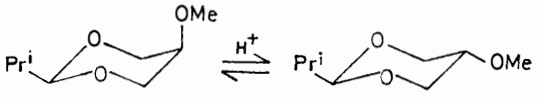
[43] G. Aksnes, P. Albriktsen, and P. Juvvik, *Acta Chem. Scand.*, 1965, **19**, 920.

[44] P. H. Plesch and P. H. Westermann, *J. Polymer Sci.*, 1968. **C16**, 3837; W. K. Bushfield, R. M. Lee. and D. Merigold, *Makromol. Chem.*, 1972, **156**, 183.

[45] P. H. Plesch and P. H. Westermann, *Polymer*, 1969, **10**, 105; W. K. Bushfield and R. M. Lee, *Makromol. Chem.*, 1973, **169**, 199.

[46] G. Borgen and J. Dale, *J.C.S. Chem. Comm.*, 1974, 484.

diacetals is not surprising.* It would certainly appear that the *gauche* oxygen–oxygen interactions in the *gauche,gauche* (19) and *gauche,anti* (20) conformations of the 1,4:2,3-diacetal (5; R = H) do *not* result in any *appreciable* relative stabilisation of this isomer under the equilibrium conditions employed. This is in spite of the fact that the *gauche,anti* conformation (20) also accommodates a favourable orientation for the dioxymethylene group in the seven-membered ring. This is the only conformation in Figure 2 where the 1,3-dioxa-grouping in the seven-membered ring avoids an unfavourable *syn*-axial lone pair interaction.[9,11,47,48] There are, of course, two *syn*-axial interactions associated with the 1,3-dioxa-groupings in the *trans*-decalin-like conformation (27) of the 1,3:2,4-diacetal (4; R = H). This problem does not arise in 2-isopropyl-5-methoxy-1,3-dioxan (28) which is probably the most suitable model compound available [8,12,14,15] at present with which to compare the stereochemical behaviour of the di-*O*-methylene derivatives [(4) and (5); R = H] of erythritol. Studies on the position of the configurational equilibrium between *cis*- (28a) and *trans*- (28b) 2-isopropyl-5-methoxy-1,3-dioxan in 17 different solvents indicate [8,12,14,15] values for the conformational free energies of the methoxy-group ranging from −0·01 in acetonitrile to 1·06 in n-hexane. These data seem to suggest that there is an *unfavourable* electronic interaction [8,12,14,15] resulting in a *small* relative destabilisation of isomers with *gauche* oxygen–oxygen interactions and leading to a *small* preference for the *anti* arrangement of vicinal oxygen substituents.



(28a) (28b)

Although it has been claimed [16] that in solution the *gauche* arrangement is always preferred for vicinal oxygen substituents, there is no evidence that vicinal oxygen substituents are a stabilising feature in any of the compounds discussed in this paper.

EXPERIMENTAL

M.p.s were determined using a Reichart hot-stage apparatus. Optical rotations were measured using a Perkin-Elmer 141 automatic polarimeter at ambient temperatures. T.l.c. was carried out on glass plates (20 × 5 cm) coated with Merck silica gel G. Developed plates were air-dried, sprayed with a cerium(IV) sulphate–sulphuric acid reagent, and heated at about 110°. Hopkin and Williams silica gel (MFC) was used as the chromatographic medium for all column separations. G.l.c. analyses were carried out using a Perkin-Elmer F 11 gas chromatograph equipped with a flame-ionisation detector. Low resolution mass spectra were determined with an A.E.I. MS12 spectrometer, and high resolution spectra with an A.E.I. MS 9 instrument. I.r. spectra were recorded for KBr discs using a Perkin-Elmer 137 spectrophotometer (NaCl optics). ^{1}H N.m.r. spectra were recorded on a Varian HA-100 or HR-220 spectrometer with tetramethylsilane as ' lock ' and internal standard. Theoretical ^{1}H n.m.r. spectra were calculated with an ICL 1907 computer by use of the LAOCOON II program.[49]

1,3:2,4- (4; R = H) *and* 1,4:2,3- (5; R = H) *Di-O-methylene-erythritol.*—Concentrated sulphuric acid (6 ml) was added to erythritol (10·0 g) and paraformaldehyde (10·0 g). After 3 days at room temperature, the mixture was refluxed with methanol (180 ml) for 2 h. On cooling, the solution was neutralised with barium carbonate, the barium salts were filtered off, and the methanol was removed to give a white solid (4·0 g). T.l.c. indicated the presence of two major components, R_F 0·90 and 0·67 in ethyl acetate–light petroleum (b.p. 60—80°) (3 : 1 v/v). A portion (2·0 g) of this product was chromatographed on a silica gel column (75 × 2·5 cm) with ethyl acetate–light petroleum (b.p. 60—80°) (1 : 4 v/v) as eluant to give three fractions.

Fraction 1, on recrystallisation from ethyl acetate–light petroleum (b.p. 60—80°), yielded long needles of the 1,3:2,4-*diacetal* (4; R = H) (757 mg), m.p. 100° (lit.,[29] 97—98°) (Found: C, 49·1; H, 6·6%; $M^{+\cdot}$, 146. $C_6H_{10}O_4$ requires C, 49·3; H, 6·9%; *M*, 146), τ (100 MHz; $CDCl_3$) 5·00 and 5·30 (4H, AB systems, J_{AB} 6·0 Hz, O·CH_2·O), 5·86 (2H, m, $J_{1eq.1ax} = J_{4eq.4ax} = 8{\cdot}0$, $J_{1eq.2} = J_{3.4eq} = 1{\cdot}6$ Hz, H-1*eq* and -4*eq*), 6·46 (2H, m, $J_{1eq.1ax} = J_{4eq.4ax} = 8{\cdot}0$, $J_{1ax.2} = J_{3.4ax} = 9{\cdot}2$ Hz, H-1*ax* and -4*ax*), and 6·47 (2H, m, $J_{1eq.2} = J_{3.4eq} = 1{\cdot}6$, $J_{1ax.2} = J_{3.4ax} = 9{\cdot}2$, $J_{2.3} = 9{\cdot}2$ Hz, H-2 and -3), *m/e* 146 (5%), 116 (36), 85 (58), 83 (91), 73 (100), and 45 (38).

Fraction 2, on recrystallisation from ethyl acetate–light petroleum (b.p. 60—80°), yielded the 1,4:2,3-*diacetal* (5; R = H) (106 mg), m.p. 88—89° (Found: C, 48·8; H, 6·7%; $M^{+\cdot}$, 146), τ (220 MHz; $CDCl_3$) 4·78 and 5·14 (2H, AB system, $J_{AB} < 1{\cdot}0$ Hz, 2,3-O·CH_2·O), 5·08 and 5·39 (2H, AB system, J_{AB} 6·1 Hz, 1,4-O·CH_2·O), 5·80 (2H, m, $J_{2.3}$ 8·0, $J_{1'.2} = J_{3.4'} = 5{\cdot}0$, $J_{1.2} = J_{3.4} = 3{\cdot}0$ Hz, H-2 and -3), 5·88 (2H, m, $J_{1'.2} = J_{3.4'} = 5{\cdot}0$, $J_{1.1'} = J_{4.4'} = 13{\cdot}0$ Hz, H-1′ and -4′), and 6·21 (2H, q, $J_{1.2} = J_{3.4} = 3{\cdot}0$, $J_{1.1'} = J_{4.4'} = 13{\cdot}0$ Hz, H-1 and -4), τ (220 MHz; CS_2) 4·99 and 5·28 (2H, AB system, $J_{AB} < 1{\cdot}0$ Hz, 2,3-O·CH_2·O), 5·40 (2H, s, 1,4-O·CH_2·O), 5·94 (2H, m, $J_{2.3}$ 8·0, $J_{3.4}$ 4·0, $J_{1'.2} = J_{3.4'} = 7{\cdot}0$ Hz, H-2 and -3), 6·21 (2H, m, $J_{1.1'} = J_{4.4'} = 13{\cdot}0$, $J_{1'.2} = J_{3.4'} = 7{\cdot}0$ Hz, H-1′ and -4′), and 6·30 (2H, m, $J_{1.1'} = J_{4.4'} = 13{\cdot}0$, $J_{1',2} = J_{3.4'} = 4{\cdot}0$ Hz, H-1 and -4), *m/e* 146 (4%), 145 (6), 115 (85), 101 (21), 86 (100), 85 (17), 83 (21), 73 (30), 70 (60), and 55 (92).

Dimethyl 2,3-O-*Cyclohexylidene*-meso-*tartrate* (22).—A mixture of dimethyl *meso*-tartrate (4·5 g), cyclohexanone

* Two other factors should be considered. They are (i) the favouring of the 1,4 : 2,3-diacetal (5; R = H) on entropy grounds on account of its greater flexibility, and (ii) the destabilisation of the 1,3 : 2,4-diacetal (4; R = H) relative to *trans*-decalin due to the incompatibility of flattening of the C(4)–C(5)–C(6) regions [9,11,14,47] of the 1,3-dioxan rings because of the *trans* ring junction between them. Flattening of one 1,3-dioxan ring would have to be accompanied by unfavourable puckering in the other. Presumably a compromise situation pertains where a considerable amount of strain energy is associated centrosymmetrically with the *trans* ring junction.

[47] E. L. Eliel and Sr. M. C. Knoeber, *J. Amer. Chem. Soc.*, 1968, **90**, 3444; E. L. Eliel, *Svensk kem. Tidskr.*, 1969, **81**, 6/7, 22; F. W. Nader and E. L. Eliel, *J. Amer. Chem. Soc.*, 1970, **92**, 3050; A. J. de Kok and C. Romers, *Rec. Trav. chim.*, 1970, **89**, 313.

[48] J. F. Stoddart, MTP International Review of Science, Organic Chemistry, Series One, vol. 7, ed. G. O. Aspinall, 1973, p. 1.

[49] S. Castellano and A. A. Bothner-By, *J. Chem. Phys.*, 1964, **41**, 3863.

(15·0 ml), toluene-*p*-sulphonic acid (150 mg), and light petroleum (b.p. 40—60°) (15·0 ml) was refluxed in a Soxhlet extractor containing molecular sieves for 48 h. On cooling, the mixture was washed with sodium carbonate solution, and after the light petroleum had been removed by evaporation, the residue was subjected to fractional distillation. The second fraction collected was characterised as *dimethyl* 2,3-O-*cyclohexylidene*-meso-*tartrate* (22) (3·36 g, 52%), b.p. 110—120° at 2 mmHg (Found: $M^{+\cdot}$, 258·1104. $C_{12}H_{18}O_6$ requires M, 258·1103).

2,3-O-*Cyclohexylidene*[1,1,4,4-$^2H_4$]*erythritol* (23).—A solution of dimethyl 2,3-*O*-cyclohexylidene-*meso*-tartrate (22) (1·0 g) in dry tetrahydrofuran (2·0 ml) was added to a solution of lithium aluminium deuteride (346 mg) in dry tetrahydrofuran (10·0 ml) during 10 min. The mixture was refluxed for 30 min before the excess of lithium aluminium deuteride was destroyed with ethyl acetate (2·0 ml). Potassium hydroxide (1·0 g) in water (4·0 ml) was added and after stirring the residue was isolated by decantation. This residue was extracted with ether (3 × 5·0 ml) and the combined organic layers were washed, dried, and concentrated to give the *tetradeuteriated derivative* (23) (860 mg), b.p. 175—180° at 1·5 mmHg (Found: $M^{+\cdot}$, 206·1456. $C_{10}H_{14}D_4O_4$ requires M, 206·1456) as a viscous oil which was used in the next step without further purification.

[1,1,4,4-$^2H_4$]*Erythritol* (24).—A solution of the crude 2,3-*O*-cyclohexylidene[1,1,4,4-$^2H_4$]erythritol (23) (860 mg) in hydrochloric acid (0·1M; 15·0 ml) was refluxed for 2 h, cooled, and extracted with ether (10·0 ml) to remove cyclohexanone. The ether was removed under reduced pressure to leave an oil, which, on addition of ether–ethanol (1 : 1 v/v; 7 ml) crystallised to give [1,1,4,4-$^2H_4$]*erythritol* (24) (260 mg, 45%), m.p. 119—121°. Erythritol has [50] m.p. 121·5°.

1,3:2,4- (25) *and* 1,4:2,3- (26) *Di*-O-*methylene*[1,1,4,4-$^2H_4$]-*erythritol*.—Tetradeuteriated erythritol (24) (300 mg) was mixed with paraformaldehyde (300 mg) and concentrated sulphuric acid (0·18 ml). The mixture was kept for 3 days at room temperature. Chloroform (20 ml) was added and then sodium hydrogen carbonate solution until the mixture was alkaline. The chloroform layer was separated, extracted with more sodium hydrogen carbonate solution (10 ml), dried ($MgSO_4$), and evaporated to yield a white solid (220 mg). T.l.c. revealed the same spectrum of products as obtained from the methylenation of erythritol. The diacetal components were separated chromatographically by the procedure described for the undeuteriated analogues.

Fraction 1 contained 1,3:2,4-*di*-O-*methylene*[1,1,4,4-$^2H_3$]-*erythritol* (25) (75 mg), m.p. 100°, τ (100 MHz; $CDCl_3$) 5·00 and 5·28 (4H, AB systems, J_{AB} 6·0 Hz, O·CH_2·O) and 6·47 (2H, s, H-2 and -3) ,τ (100 MHz; CS_2) 5·15 and 5·43 (4H, AB systems, J_{AB} 6·0 Hz, O·CH_2·O) and 6·65 (2H, s, H-2 and -3), τ (100 MHz; C_6D_6) 5·26 and 5·80 (4H, AB systems, J_{AB} 6·0 Hz, O·CH_2·O) and 6·77 (2H, s, H-2 and -3).

Fraction 2 contained 1,4:2,3-*di*-O-*methylene*[1,1,4,4-$^2H_4$]-*erythritol* (26) (44 mg), m.p. 88—90°, τ (100 MHz; $CDCl_3$) 4·78 and 5·15 (2H, AB system, J_{AB} <1·0 Hz, 2,3-O·CH_2·O), 5·04 and 5·37 (2H, AB system, J_{AB} 6·0 Hz, 1,4-O·CH_2·O), and 5·81 (2H, s, H-2 and -3), τ (100 MHz; CS_2) 4·99 and 5·28 (2H, AB system, J_{AB} <1·0 Hz, 2,3-O·CH_2·O), 5·40 (2H, s, 1,4-O·CH_2·O), and 5·94 (2H, s, H-2 and -3), τ (100 MHz; C_6D_6) 4·99 and 5·41 (2H, AB system, J_{AB} <1·0 Hz, 2,3-O·CH_2·O), 5·49 and 5·65 (2H, AB system, J_{AB} 6·0 Hz, 1,4-O·CH_2·O), and 6·24 (2H, s, H-2 and -3).

Acid-catalysed Equilibration of the Methylene Diacetals (4; R = H) *and* (5; R = H) *of Erythritol*.—Six reaction mixtures were prepared containing erythritol (500 mg), paraformaldehyde (500 mg), and concentrated sulphuric acid (0·3 ml) and stored at *ca.* 25°. Periodically (4—7 weeks) two samples were quenched by addition of sodium hydrogen carbonate followed by extraction with chloroform. The extracts were analyed by g.l.c. on columns (0·125 in × 6 ft) containing 20% Carbowax 20M washed with 2% potassium hydroxide. A minimum of three analyses were carried out on each sample. The g.l.c. system was calibrated by analysing known mixtures of methylene diacetals of erythritol. The experimental data are summarised in Table 6 together with the calculated K and $\Delta G°$ values.

TABLE 6

Acid-catalysed equilibration of the methylene diacetals (4; R = H) and (5; R = H) of erythritol

Sample no.	Equilibration time (weeks)	No. of analyses	Isomer ratio [1,3:2,4-] : [1,4:2,3-]	K	$\Delta G°$/ kcal mol^{-1}
1	4	3	91·3 : 8·7	10·50	1·36
2	4	3	90·9 : 9·1	9·99	1·37
3	5	3	91·6 : 8·4	10·90	1·42
4	5	3	91·6 : 8·4	10·90	1·42
5	7	6	90·4 : 9·6	9·42	1·33
6	7	5	90·4 : 9·6	9·42	1·33
				Average value = 1·37	

During the g.l.c. analyses a small amount (*ca.* 7%) of a volatile fast-moving component was observed. Since it was suspected that this component might correspond to the so-far undetected 1,2:3,4-di-*O*-methylene-erythritol, it was isolated by preparative g.l.c. Spectroscopic examination indicated however that it was 1,4-*anhydro*-2,3-O-*methylene-erythritol* (18) (Found: $M^{+\cdot}$, 116·0469. $C_5H_8O_3$ requires M, 116·0473), τ (100 MHz; $CDCl_3$) 4·98 and 5·14 (2H, AB system, J_{AB} <1·0 Hz, 2,3-O·CH_2·O) and 5·24—6·66 (6H, AA'MM'XX' system).

1,3:2,4-*Di*-O-*methylene*-L-*threitol* (7).—Compound (7) {m.p. 173—174°, $[\alpha]_D$ −5·1° (*c* 0·8 in $CHCl_3$)} was prepared according to ref. 2.

1,6-*Dideoxy*-2,4:3,5-*di*-O-*methylene*-D-*mannitol* (11).—Compound (11) {m.p. 57—59°, $[\alpha]_D$ +61·8° (*c* 2·0 in $CHCl_3$)} was prepared according to ref. 20.

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[50] 'Heilbron's Dictionary of Organic Compounds,' vol. 3, 1965, Eyre and Spottiswoode, London, p. 1354.