^{1}H NMR Spectra and Conformations of Propane-1,2-diol, *meso*- and Racemic Butane-2,3-diols, and some Alditols in Non-aqueous Media

Frances B. Gallwey,[a] Jane E. Hawkes,[a] Peter Haycock,[b] and David Lewis[*,c]
[a] *Department of Chemistry, King's College, Strand, London WC2R 2LS, UK*
[b] *Department of Chemistry, Queen Mary College, Mile End Road, London E1 4NS, UK*
[c] *Department of Chemistry, Royal Holloway and Bedford New College, Egham Hill, Egham, Surrey TW20 0EX, UK*

The solvent change low polar→protic→very polar aprotic causes a progressive change in the conformation of the three title diols towards the conformer with the two C–O bonds *trans*. Alditols in deuterium oxide have each hydroxymethyl group with the C–O bond extending the chain as the main conformer. In polar aprotic solvents the main conformer has the C–O bond *trans* to the adjacent C–O bond. The carbon chain conformation can be somewhat different in the two solvent types.

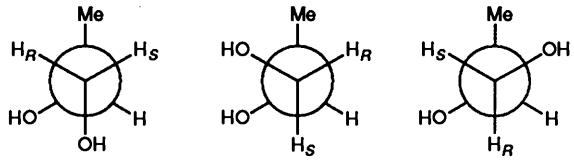
The conformations[1] of several alditols have been determined in the crystalline state. The chain adopts a conformation which minimises parallel 1,3-interactions. The hydroxymethyl end groups often adopt the sterically least-congested conformation in which their oxygen extends the chain, but sometimes the conformation, as at C-1 in arabinitol has the C–O bond *trans* to the adjacent C–O bond. The reasons when this latter case will be preferred are at present unclear. ^{1}H[2–7] and ^{13}C[8,9] NMR spectroscopy of unsubstituted alditols in deuterium oxide often reveals a mixture of conformers for a given alditol, but the main chain conformer is generally that found for the crystalline state. In all the cases studied the main hydroxymethyl group conformer has oxygen extending the chain. Considerably less is known about the conformations[10,11] of alditols in non-aqueous media. Here the different hydrogen bonding patterns should yield different equilibrium populations of chain and hydroxymethyl group conformers. This work looks at this problem.

In order to help the analysis, we first consider the simpler case of 1,2-diols. Propane-1,2-diol may act as a model for a hydroxymethyl group of an alditol, while *meso*-(=*erythro*-) and racemic (=*threo*-) butane-2,3-diols may mimic sections of the chain having *erythro*- and *threo*-hydroxyl groups, respectively. Factors influencing the conformer populations of acyclic vicinal secondary alcohols include hydrogen bonding (inter- and intramolecular), solvent, solute concentration, and the substituents on the carbons carrying the hydroxyl groups.[12] A significant spin off from the diol work should be that for the first time some quantitative experimental results are available against which theoretical calculations of conformer populations can be compared.

Results and Discussion

(±)-*Propane*-1,2-*diol*.—Although the NMR spectroscopy work used racemic diol, the NMR parameters (Table 1) and the discussion are in terms of the *S*-(+)-isomer, in order that the *pro-R* and *pro-S* hydroxymethyl protons can be identified (Fig. 1).

The calculated ^3J values (Fig. 1) were obtained from a Karplus-type equation[13] which allows for the orientation and electronegativity of substituents about the coupling protons. The values are the same as those used previously to determine the rotamer populations of the hydroxymethyl groups of alditols.[2] The propanediol conformer populations (Table 1) were derived by equating the observed $^3J_{2\text{-H},1\text{-H}_R}$ and



	O_e	O_g	O_t
$^3J_{2\text{-H},1\text{-H}_R}$	10.7	0.9	5.0
$^3J_{2\text{-H},1\text{-H}_S}$	3.1	2.8	10.7

Fig. 1. Nomenclature and calculated ^3J values/Hz for conformers of (*S*)-(+)-propane-1,2-diol. H_R and H_S identifies the *pro-R* and *pro-S* protons, respectively.

$^3J_{2\text{-H},1\text{-H}_S}$ values to the sum of the products of the appropriate calculated ^3J value (Fig. 1) of each conformer and its amount (x), and knowing that $\Sigma x = 100$. However, the assignment of the ^3J couplings was not immediately obvious since Table 1 shows that the shifts of the protons are very solvent dependent. The matter was resolved by calculating the O_e, O_g, O_t (oxygen extending the chain, oxygens *gauche*, and oxygen *trans*, respectively) ratios for the two alternative assignments for each solvent, and seeing which ratio best fitted the expected hydrogen bonding patterns [intramolecular hydrogen bonding as present in the O_e and O_g conformers gives a low $^3J_{2\text{-H},1\text{-H}_S}$ value (Fig. 1) whereas intermolecular hydrogen bonding as present in the O_t conformer gives a higher value] and/or the relative shifts of the two protons, based on shielding considerations (see below). Considering the rotamer populations, the O_g conformer remains approximately constant (25–33%). The amount of the O_e conformer progressively falls as that of the O_t conformer rises when the solvent changes from low polar through protic to very polar aprotic. In deuterium oxide, the rotamer ratio is in good agreement with that calculated[14] by molecular mechanics (Table 2).

For the O_e conformer (Figure 1), the H_R proton is shielded by two *gauche* interactions, while the H_S proton experiences one *gauche* shielding interaction and a deshielding *anti*-oxygen.[15] Thus H_R will be shielded with respect to H_S. However, in the O_t conformer, such arguments mean that H_S is the more shielded

* *Address for correspondence:* 61, Mill Lane, Kirk Ella, Hull, HU10 7JW, UK.

Table 1. ^{1}H NMR parameters and conformational data for propane-1,2-diol[a]

	δ (ppm)					J/Hz					Conformers (%)		
Solvent	CH_3	2-H	1-H_s[b]	1-H_R	OH	H_3C, CH	$2,1_S$	$2,1_R$	$1_R,1_S$	HC,OH	O_e	O_g	O_t
$CDCl_3$[c]	1.40	3.89	3.59	3.38	3.78	6.3	2.9	8.0	−11.3$_5$	*d*	73	28	(−2)
D_2O[e,f]	1.15	3.89	3.54	3.45	*g*	6.5	4.0$_5$	6.6$_5$	−11.6	*g*	53	33	14
C_5D_5N	1.42	4.27	3.90	3.92	6.11 6.28	6.1$_5$	4.5	7.0	−10.8	*d*	54	26	19
CD_3OD[c]	1.20$_5$	3.76	3.40	3.40	*d*	6.2$_5$	5.2	6.3	−11.0	*g*	43	28	29
$(CD_3)_2SO$[c]	0.99$_5$	3.56	3.15	3.25	4.41 2-OH 4.47 2-OH	6.3	5.7$_5$	5.7$_5$	−10.5	4.5 2-OH 5.2$_5$ H_R, 1-OH 6.0 H_S, 1-OH	34	30	36
$[N(CD_3)_2]_3P{=}O$[h]	1.05	3.61	3.10	3.43	5.09 2-OH 5.16 1-OH	6.1$_5$	7.1$_5$	5.1$_5$	−10.1	4.2$_5$ 2-OH 4.7$_5$ H_R, 1-OH 6.2$_5$ H_S, 1-OH	21	25	54

[a] For *S*-(+)-isomer. [b] *R* and *S* identify the *pro-R* and *pro-S* protons. [c] 250 MHz, internal tetramethylsilane. [d] Unresolved, broad peak. [e] 400 MHz, external sodium 3-(trimethylsilyl)propionate. [f] Ref. 3. [g] Absent. [h] 400 MHz, external tetramethylsilane.

Table 2. Conformer populations of various compounds containing a 1,2-disubstituted ethane fragment

Compound	Solvent	Method	Population	
Propane-1,2-diol	ε[a] = 80	mm[b]	O_e, O_g, O_t	54, 30, 16%[c]
	D_2O, 23 °C	^{1}H NMR[d]	O_e, O_g, O_t	53, 33, 14%
meso-Butane-2,3-diol	ε = 1.5	mm[b]	P = 11%[c]	
	CCl_4, 26 °C	^{1}H NMR[d]	P = 9%	
	ε = 80	mm[b]	P = 30%[c]	
	D_2O, 26 °C	^{1}H NMR[d]	P = 37%	
	CCl_4–$CDCl_3$ (3:1)→MeOH	^{13}C NMR[e]	G→P	
	low polar→polar aprotic	^{13}C NMR[f]	G→P	
D-Butane-2,3-diol	ε = 1.5	mm[b]	P,G^-,G^+	27, 2, 71%[c]
	CCl_4, 26 °C	^{1}H NMR[d]	G^+	84–90%
	ε = 80	mm[b]	P,G^-,G^+	55, 8, 38%[c]
	CCl_4–$CDCl_3$ (3:1)→MeOH	^{13}C NMR[e]	mainly G^+→G^-	
	low polar→polar aprotic	^{13}C NMR[f]	P→G^-[g]	
1,2-Dichloropropane	10 vol.% in CCl_4	^{1}H NMR[h]	Cl_e, Cl_g, Cl_t	11, 16, 73%
	25 vol.% in CD_3OD	^{1}H NMR[h]	Cl_e, Cl_g, Cl_t	24, 27, 48%
	25 vol.% in CD_3CN	^{1}H NMR[h]	Cl_e, Cl_g, Cl_t	31, 32, 37%
meso-2,3-Dichlorobutane	n-hexane, 28 °C	IR[i]	P = 74%	
	CH_3CN, 28 °C	IR[i]	P = 30%	
D-2,3-Dichlorobutane	n-hexane, 28 °C	IR[i]	P,G^+,G^-[j]	24, 18, 58%
	CH_3CN, 28 °C	IR[i]	P,G^+,G^-[j]	43, 32, 25%
1,2-Dichloroethane	cyclohexane	IR[k]	C–Cl bonds *trans* = 70%[c]	
	CH_3CN	IR[k]	C–Cl bonds *trans* = 39%[c]	
1,2-Dimethoxyethane	CCl_4, 25 °C	^{1}H NMR[l]	C–OMe bonds *trans* = 18%	
	$HCONMe_2$, 25 °C	^{1}H NMR[l]	C–OMe bonds *trans* = 11%	

[a] ε = relative permittivity. [b] mm = molecular mechanics, ref. 14. [c] Populations obtained from energy differences of the conformers, and assuming a temperature of 25 °C. [d] This work. [e] Ref. 18. [f] Ref. 19. [g] See text. [h] Ref. 21. [i] S. Kondo and M. Takeda, *Polym. Eng. Sci.*, 1985, **25**, 1026. [j] Nomenclature corresponding to Fig. 3(*b*). [k] N. Oi and J. F. Coetzee, *J. Am. Chem. Soc.*, 1969, **91**, 2478; R. J. Abraham and E. Bretschneider in *Internal Rotation in Molecules*, ed. W. J. Orville-Thomas, Wiley, London, 1974, p. 515–517. [l] V. Viti, P. L. Indovina, F. Podo, L. Radics and G. Nemethy, *Mol. Phys.*, 1974, **27**, 541.

proton. The diol has a high O_e content in deuteriochloroform, and the more shielded (H_R) proton has the larger coupling to 2-H, but in perdeuteriohexamethylphosphotriamide, [$^2H_{18}$]-HMPT, the diol has a high O_t content and now the more shielded proton is H_S, and it has the larger coupling to 2-H. The separation (Δ, $\delta H_S - \delta H_R$, ppm) of the shifts of the hydroxymethyl protons is empirically linearly related to the O_t population [$O_t = (-100.3 \pm 11.8)\Delta + (22.9 \pm 2.0)$; r = 0.974], and somewhat less well to the O_e population.

When oxygen is adjacent to, and antiparallel to, a proton which has a *trans* ^3J coupling to an adjacent proton (Fig. 2), this coupling increases by up to 1 Hz.[16] The O_g conformer is the only one for which this situation holds. Since its population is approximately constant, $^3J_{Me,H}$ should also be constant. The

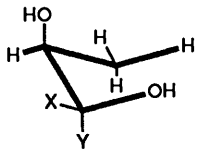


Fig. 2. Enhancement of a $^3J_{Me,H}$ coupling by a suitably orientated oxygen. The required geometry is shown by thickened lines. X = Y = H O_g conformer of (*S*)-propane-1,2-diol; X = H, Y = Me a *gauche* conformer of *meso*-butanediol; X = Me, Y = H P conformer of L-(+)-butanediol.

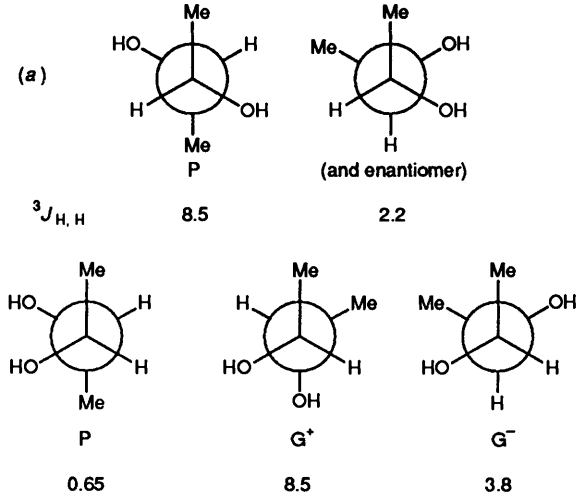


Fig. 3. $^3J_{2H,3H}$ values/Hz for (*a*) *meso*-(*R*,*S*)- and (*b*) D-(−) (2*R*,3*R*)-butane-2,3-diols.

small variations (Table 1) which do occur mirror well the slight changes in O_g.

meso- *and Racemic Butane*-2,3-*diols*.—^{1}H NMR data for the isomers are given in Table 3. Calculations of the $^3J_{2,3}$ couplings (Fig. 3) for the isomers used the Karplus-type equation[13] as previously.

A mixture of *meso*- and racemic diols was used for the NMR spectroscopy, but the discussion is simplified by considering only one [the D-(−), *i.e.*, (2*R*,3*R*)] isomers of the racemate. The signals for the *meso*- and racemic isomer were readily assigned from their relative intensities, as the isomers occurred in a 1:2 ratio. Also, the shifts (Table 3) of similar protons in the two isomers were usually well separated. The population (Table 3) of the planar carbon chain (P) conformer for the *meso*-isomer follows directly using the observed $^3J_{2\text{-}H,3\text{-}H}$ values and those in Fig. 3(*a*). In low polar media, the *gauche*-forms each having an intramolecular hydrogen bond are preferred and on passing through protic to very polar aprotic the planar chain conformer, with 2-O,3-O *trans* disposed, is increasingly favoured. ^{13}C NMR studies[18,19] and molecular mechanics[14] similarly deduced the *gauche*→planar chain form as the solvent changed from apolar to polar (Table 2).

In a *gauche*-form of the *meso*-isomer [Fig. 3(*a*)], an oxygen (*e.g.* 2-O) is antiparallel to 3-H which has a *trans*-coupling to one of the methyl protons. Therefore, as predicted,[16] the $^3J_{Me,H}$ coupling (Table 3) increases as the *gauche*-population rises.

Considering the (±)-isomers, it is not possible to assign definite populations to the conformers, but from the observed $^3J_{2\text{-}H,3\text{-}H}$ values and the expected ^3J values [Fig. 3(*b*)], population limits can be given. Using the D-(−)-isomer, the G^+ conformer population falls in the sequence carbon tetrachloride→deuterium oxide→[$^2H_{18}$]HMPT (84–90, 47–68 and 24–55%, respectively). From molecular rotation work,[17] the planar chain (P) conformer population is shown to be approximately constant at 6–20%. The $^3J_{Me,H}$ values (Table 3) for the D-isomer show no definite trend and are fairly constant. This is to be expected if the P conformer (Fig. 2 shows the enantiomer) population is fairly constant. The overall conclusion is that in passing from a low polar solvent, in which there is 84–90% of the G^+ conformer, through protic to very polar aprotic solvents, the G^+ conformer decreases as the G^- conformer increases and the P conformer is constant at 6–20%.

A ^{13}C NMR spectroscopy study has reported[18] ^{13}C shift values for the diol in carbon tetrachloride–deuteriochloroform, 3:1, and in methanol, and inferred from the substituent shielding effects an increase in the population of the G^- conformer (for the D-isomer). A more comprehensive study[19] concluded that as the solvent changes from low polar to polar aprotic, the population changes from the P to the G^- conformer, but on the reasoning presented, an equally valid option is $G^+ \rightarrow G^-$.

Thus we conclude that both ^{13}C NMR studies are consistent with our interpretation from ^{1}H NMR spectroscopy. A molecular mechanics study[14] agrees with the present work *i.e.* in a low polar solvent the G^+ conformer is the main conformer, but it states that the change low polar→aqueous solution involves the change P→G^+. However, this is not consistent with their values (Table 2) which in fact show $G^+ \rightarrow$P, but the authors note that the calculations for aqueous solution 'cannot result in a good description of compounds dissolved in polar interactive solvents.'

Since measurements were performed on a mixture of the *meso*- and (±)-isomers, the separation [$\delta_{meso} - \delta_{(\pm)}$ ppm] between the methyl or between the methine protons of the *meso*- and (±)-isomers could be accurately determined in each solvent. The methyl proton separation changes from carbon tetrachloride (−0.039) to [$^2H_{18}$]HMPT (+0.1171), while the methine proton separation (x) in the two solvents is +0.288 and −0.239 ppm. The interactions experienced by the 2-H and 3-H protons in the P, G^- and G^+ conformers of the D-isomer are: 2 *anti*-oxygens + 2 *gauche*-carbons; 2-*gauche*-oxygens; and 2 *gauche*-carbons + 2 *gauche*-oxygens (Fig. 3). The methine proton shifts of the conformers should therefore be progressively shielded. A similar analysis for the *meso*-isomer predicts the P conformer to have the same net interactions as those of the G^+ conformer of the D-isomer, and to be shielded relative to a *meso-gauche*-conformer. In a low polar solvent the D-isomer is mainly the G^+ conformer and the *meso*-isomer is mainly the *gauche*-conformer. Thus x is positive, as observed. In a polar aprotic solvent, the main forms are $G^+ + G^-$ and P respectively, giving x as negative. This analysis of the change of the conformer populations with solvent in terms of shifts is therefore consistent with that deduced from vicinal coupling constants.

To summarise the results for the three diols: each prefers an intramolecularly hydrogen bonded form in low polar solvents,[20] while in polar aprotic media the form with the oxygen atoms *trans* predominates for propane-1,2-diol and for *meso*-butane-2,3-diol. By analogy, this arrangement also occurs significantly for D-butane-2,3-diol. This behaviour can be contrasted to that shown by other acyclic compounds (Table 2) containing an X–C–C–X structure, where X is a strong electronegative atom or group, but which cannot provide a hydrogen for hydrogen bonding. For the *S*-isomer of 1,2-dichloropropane, the calculated[13] coupling constants corresponding to Fig. 1 are $^3J_{2\text{-}H,1\text{-}H_s}$ 3.3, 3.0 and 11.1 Hz, and for $^3J_{2\text{-}H,1\text{-}H_a}$ 11.1, 2.0 and 4.3 Hz. Using these values with the observed ^3J values[21] gives the Cl_e, Cl_g, Cl_t (chlorine extending the carbon chain, chlorines *gauche*, and chlorines *trans*, respectively) ratios in Table 2. For the last five compounds

Table 3. ^{1}H NMR parameters and conformational data for the butane-2,3-diols[a]

	meso							(±)					
	δ(ppm)			^3J/Hz				δ(ppm)			^3J/Hz		
Solvent	CH_3	C*H*OH	OH	H_3C,CH	2-H,3-H	HC,OH	P conformer (%)	CH_3	C*H*OH	OH	H_3C,CH	2-H,3-H	HC,OH
CCl_4[b]	1.06	3.69	3.97	6.4_5	2.7_5	*c*	9	1.10	3.40	4.24	6.1	7.7_5	*c*
$CDCl_3$[b]	1.13_5	3.80	2.66	6.4	3.3_5	*c*	18	1.17	3.52	2.92	6.1_5	7.2	*c*
C_6D_6[d]	1.15	3.80	4.36	6.4	3.3	4.5	17	1.13	3.54_5	4.57	5.9_5	6.9_5	4.2
[$^2H_5$]Pyridine[b]	1.49	4.06	5.03	6.2_5	5.7_5	*c*	56	1.38	3.92	5.88	6.1	6.5	*c*
D_2O[b]	1.14_5	3.72	—	6.3	4.5	*c*	37	1.14_5	3.63	—	6.3	6.0	*c*
$(CD_3)_2SO$[b]	1.01	3.32	4.31_5	6.1_5	5.5	4.9_5	52	0.96	3.28	4.34	6.1_5	5.6_5	4.4
$[N(CD_3)_2]_3P{=}O$[d]	1.09	3.27	5.04_5	6.0_5	7.0	4.8_5	76	0.97	3.51	5.01	6.2_5	4.9_5	3.7_5

[a] Mixture of *meso*- and (±)-isomers (1:2). [b] 250 MHz, internal tetramethylsilane. [c] Absent. [d] 400 MHz, external tetramethylsilane.

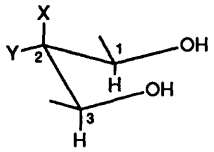
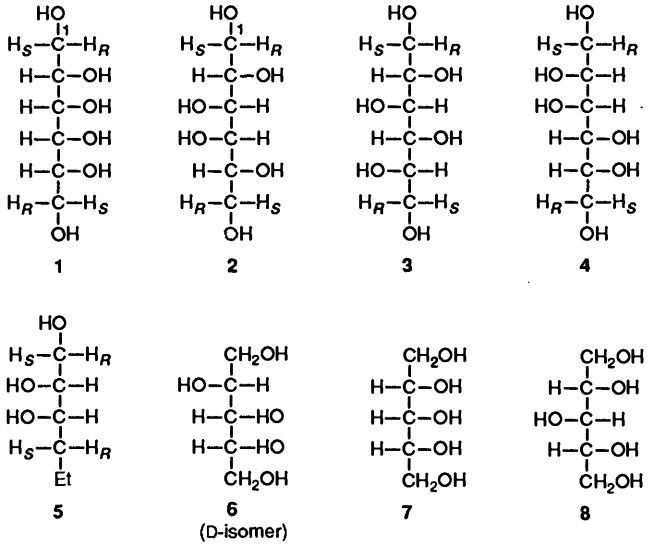


Fig. 4 Planar carbon chain fragment with a *xylo*-(X = OH, Y = H) or *ribo*-(X = H, Y = OH) hydroxy unit.

in Table 2, the change low polarity→polar aprotic solvent increases, as expected,[22] the amount of the more polar conformer(s), *i.e.*, with the C–X bonds *gauche*, and for all the dichloro-compounds, low polarity solvents give a majority of the conformer with the C–Cl bonds *trans*. These results are the opposite of the situation in the diols. Presumably, the energies due to hydrogen bonding involving the hydroxy proton(s) of the diols outweigh the electrostatic energies due to dipolar effects. The position of protic solvents in the ranking between low polar, and very polar aprotic solvents (Tables 1 and 3) clearly suggests that relative permittivity is not a dominant factor determining this ranking for the diols or for 1,2-dichloropropane (Table 2).

Alditols and Hexane-1,2,3-*triol*.—The alditols chosen for study were two (galactitol **2** and D-mannitol **4**) which have only one preferred chain conformation each in deuterium oxide, and two (allitol **1** and L-iditol **3**) which have more than one main chain conformer each in this solvent.[2] Alditols are insoluble in low polar solvents, so to study the chain conformation of a polyol in such solvent (chloroform), a more hydrophobic compound (L-*erythro*-hexane-1,2,3-triol **5**) was used. Table 4 lists the NMR data on the compounds studied and the solvents used.



Approximate alditol[2] and hexanetriol[7] conformer populations were obtained as previously, using the appropriate observed ^3J values and ^3J values calculated for C–C units in which the torsion angles were assumed to be 60°. The C(1)–C(4) [=C(3)–C(6)] chain of D-mannitol **4** in perdeuteriodimethylsulphoxide, [$^2H_6$]DMSO, and in [$^2H_{18}$]HMPT is *ca.* 80% planar, and in [$^2H_5$]pyridine it is 70%. This compares with 90% deuterium oxide. The $^3J_{3,4}$ coupling in all four solvents was too small to observe, indicating a complete planarity for the C(2)–C(5) chain. For galactitol **2** the C(1)–C(4) [=C(3)–C(6)] chain in the three non-aqueous solutions is 70–90% planar, which is the same value as for deuterium oxide solution. Unfortunately, the ^3J value for the *erythro*-C(3)–C(4) section was unobservable, so the conformation about the C(2)–C(5) chain could not be determined. But there is no reason to suspect that it is not essentially planar, as in deuterium oxide solution, since the chain of *erythro*-butane-2,3-diol in [$^2H_6$]DMSO, [$^2H_5$]pyridine or [$^2H_{18}$]HMPT is more planar than in deuterium oxide (Table 3). Allitol **1** and L-iditol **3** have similar types of conformers (Table 5). The published figures (Table 5) for allitol and L-iditol in deuterium oxide were derived assuming that the amount of the planar chain (P) conformer for each was zero. This assumption is essentially correct for allitol since the amount of the $_2G^-$ (for nomenclature see ref. 8) conformer is only 8%, and the amount of the P form should be less than this (calculation gives P <3%). HMPT as solvent gives virtually identical populations. However, the assumption for L-iditol now seems incorrect since if the $_2G^-$ conformer were as high as 24%, there could well be some P form. Recalculating the results allowing for the P conformer and assuming that its amount is less than or equal to the amount of $_2G^-$ conformer gives the limits shown in Table 5. In HMPT there is a significant shift towards the P and $_2G^-$ conformers which contain two and one *xylo*-units, with 1,3-parallel C–O bonds (O‖O) respectively. Thus it seems that (*a*) HMPT can accommodate a *xylo*-O‖O unit better than deuterium oxide and (*b*) both solvents can accommodate *xylo*-O‖O units better than *ribo*-O‖O units; the latter occur in the P and $_2G^-$ conformers of allitol. For a 1,3-*xylo*-O‖O unit (Fig. 4), the 1-H,2-H and 2-H,3-H are *anti* to the oxygens, a situation giving rise to an attractive O/O

Table 4. ^{1}H NMR parameters[b] and conformational data for polyols.

Polyol	Perdeuteriated solvent	δ(ppm) H-1	H-2	H-3	HO-x[d]	Other	J/Hz $1_R,1_S$	1,2	2,3	3,4	HO-x[d]	Other	CH_2OH group (%) O_e	O_g	O_t
Allitol[c] **1**	HMPT	3.63 *R*[a] 3.46 *S*	3.67	3.59	1 4.76 2 4.98 3 5.03		−10.9	4.5 *R* 5.7_5 *S*	5.9	6.3_5	1_R 6.2 1_S 5.0 2 4.2_5 3 3.9		41	39	20
Galactitol[c] **2**	HMPT	3.49 *R*[e] 3.51 *S*	3.81	3.59	1 4.98 2 4.36 3 4.28		−10.5	6.4_5 *R* 6.5 *S*	~1.6	?	1_R 5.5_5 1_S 5.5_5 2 6.5 3 6.8		38	17	45
L-Iditol **3**	HMPT	3.48 *R*[e] 3.53 *S*	3.68	3.72	1 4.97 2 4.79 3 4.34		−10.8	5.7_5 *R* 5.8_5 *S*	2.6	3.7_5	1_R ~5.5 1_S ~5.5 2 4.2_5 3 5.2_5		35	29	36
D-Mannitol **4**	HMPT	3.44 *R* 3.66 *S*	3.58_5	3.62	1 4.81 2 4.75 3 4.33		-10.4_5	6.1 *R* 4.1_5 *S*	8.2	~0	1_R 5.0_5 1_S 6.4_5 2 4.5 3 6.7_5		47	38	15
L-*erythro*-Hexane-1,2,3-triol **5**	HMPT	3.46_5 *R*[e] 3.59 *S*	3.28	3.34	1 4.92 2 4.84 3 5.02	H-4, 1.54_5 1.64_5 H-5_R ~ H-5_S ~ 1.33_5 H-6 0.86	-10.8_5	5.8 *R* 5.3 *S*	7.4	8.2_5 *R* 2.7 *S*	1_R 5.2_5 1_S 5.2_5 2 4.2_5 3 5.2	5_R,6 7.1 5_S,6 7.1	29	34	37
Galactitol[c]	DMSO	3.41 *R*[e] 2.38 *S*	3.70	3.45	1 4.40 2 4.10 3 4.03		−10.6	6.3 *R* 6.5 *S*	~1.2	?	1_R 5.5_5 1_S 5.5_5 2 6.6_5 3 7.2_5		39	18	43
D-Mannitol	DMSO	3.38 *R* 3.60 *S*	3.45	3.54	1 4.30_5 2 4.39 3 4.12		−10.8	6.0 *R* 3.5 *S*	8.2_5	~0	1_R 5.7_5 1_S 5.7_5 2 5.5 3 7.0		54	39	7
Galactitol[c]	Pyridine	4.38 *R*[e] 4.36 *S*	4.88	4.67_5	1 6.37 2 6.14 3 6.08		−10.7	6.0_5 *R* 6.1 *S*	~1.4_5	?	1_R 5.2_5 1_S 5.2_5 2 ~6.5_5 3 ~3.6_5		36	24	40
D-Mannitol	Pyridine	4.35 *R* 4.52 *S*	4.60_5	4.82	1 6.21 2 6.54[f] 3 6.10[f]		-10.8_5	5.9 *R* 3.9 *S*	7.5	~0	1_R 5.3_5 1_S 5.3_5 2 6.7^f 3 5.7_5[f]		46	42	13
L-*erythro*-Hexane 1,2,3-triol	$CDCl_3$	3.83 *R* 3.77 *S*	3.60	3.79	*g*	H-4, 1.48_5, 1.48_5 H-5, 1.38_5, 1.57 H-6 0.96	−11.5	5.5 *R* 3.4 *S*	4.4	6.7_5 *R*[g] 5.5 *S*		5_R,6 7.1 5_S,6 7.1	44	50	6

[a] *R* and *S* identify the *pro-R* and *pro-S* protons. [b] 400 MHz, internal tetramethylsilane. [c] *meso*-compounds have been numbered in such a way that the highest numbered asymmetric carbon atom has the D-configuration. [d] x refers to the carbon position of the hydroxy group. [e] The *R* and *S* protons may need interchanging. [f] Assignments may need interchanging. [g] Absent.

interaction.[23] The attractive O/O situation is absent for the *ribo*-O‖O case. In partially acetylated polyols in chloroform, when the free hydroxy groups are in a 1,3-*erythro*-arrangement, a *xylo*-sequence at carbons 1–3 has the carbon chain two thirds planar, but for a *ribo*-sequence only one fifth of the chain is planar.[24] The attractive O/O interaction can operate for the *xylo*-case, but not for the *ribo*-case.

L-*erythro*-Hexane-1,2,3-triol **5** gives a complex mixture of conformers (Table 6). As the solvent changes from chloroform to deuterium oxide to HMPT, the molecule increasingly prefers the *erythro*-C(2)–C(3) unit with *anti* oxygens, as is the case for *meso*-butane-2,3-diol. Thus the planar (P + $_3$G$^-$) to *gauche* ($_2$G$^+$/$_2$G$^-$ + $_2$G$^+$,$_3$G$^+$) ratio about the C(1)–C(4) portion changes progressively from 30:70 to 75:25. Doubly-twisted chains are always unfavoured, so it is unclear why the $_2$G$^+$,$_3$G$^+$ population (30%) is so high in chloroform.

Considering now the approximate hydroxymethyl group rotamer populations, galactitol and D-mannitol have essentially planar chains in deuterium oxide. The C(1)–C(4) chain of mannitol is somewhat less planar in the three non-aqueous solvents used above, so the rotamer ratios will change somewhat to reflect this. However an important factor determining the ratios seems to be the solvent. Mannitol in deuterium oxide has an $O_eO_gO_t$ ratio[2] of 54:46:0 but, like propane-1,2-diol, in polar aprotic solvents, it prefers to have the O-1 and O-2 oxygens *anti*, by O_e or $O_g \rightarrow O_t$ (Table 4), even

Table 5. Conformers (%) of allitol and L-iditol

	Conformer[a]	D_2O[b]	HMPT
(*a*) Allitol			
	P	[0]	[0]
	$_2G^-$	8	8
	$_2G^-,_4G^+$	49	47
	$_3G^+/_3G^-$	43	45
(*b*) Iditol			
	P	[0] (0–8)	19–28
	$_2G^-$	24 (8–24)	28–46
	$_2G^-,_4G^-$	26 (26–34)	0–9
	$_3G^-$	49 (49)	35

[a] For nomenclature, see ref. 8. [b] Ref. 2; revised in parentheses for iditol.

Table 6. L-*erythro*-Hexane-1,2,3-triol

	Conformer[a] population (%)			
Solvent	P	$_2G^+/_2G^-$	$_3G^-$	$_2G^+,_3G^+$
$CDCl_3$	5	40	25	30
D_2O[b]	25	50	20	5
HMPT	40	25	35	0

[a] C(1)–C(4) portion. For nomenclature, see ref. 8. [b] Ref. 7.

though this leads to an O-1||O-3 interaction. Likewise galactitol in deuterium oxide has a 53:16:31 ratio which moves to a larger O_t component in polar aprotic solvents. Allitol and L-iditol also increase their O_t populations by $O_e \rightarrow O_t$. The L-*erythro*-hexanetriol ratio in deuterium oxide is 64:32:4.[7] It is unclear why the O_e population rises in passing from chloroform to deuterium oxide only to fall again in HMPT. However, the O_t population (37%) as expected, is highest in the last named solvent.

In deuterium oxide the separation (Δ, ppm) of the shifts of the primary protons of the hydroxymethyl group of an alditol is empirically linearly related to the lesser of the two ^3J couplings of the protons to the adjacent proton.[2] Similarly the five polyols in HMPT (Table 4) also give a good straight line $J_{1,2} = (-11.3 \pm 1.1)\Delta + (6.5 \pm 0.15)$; $r = 0.986$. The gradient of this line, and the gradients of the two lines obtained from the galactitol and mannitol values in DMSO and pyridine are all approximately the same and equal to the gradient of the line for deuterium oxide.

^3J values for the pentitols[11] in non-aqueous solution can be converted into conformer populations. For arabinitol **6** in [$^2H_5$]pyridine the C(1)–C(4) chain has virtually the same conformation as in deuterium oxide. The C(3)–C(5) chain is very slightly less conformationally pure than when in deuterium oxide. The two chain segments are galactitol- and mannitol-like, respectively, and so the results mirror well the behaviour of galactitol and mannitol in [$^2H_5$]pyridine. The hydroxymethyl ratios (37:22:41 and 45:40:15) at C-1 and C-5 agree well with the galactitol and mannitol ratios (Table 4) in [$^2H_5$]pyridine. Ribitol **7** and xylitol **8** in [$^2H_5$]pyridine have 19 and 31% of planar chain (P) conformers, compared to 8 and 15% in deuterium oxide,[2] and in [$^2H_6$]acetone, xylitol has 36% P conformer. The P conformers have an O||O interaction, and again it seems that an O||O interaction is better accommodated in a *xylo*-unit than in a *ribo*-unit. In passing from deuterium oxide to pyridine the hydroxymethyl group ratios (49:40:11 and 36:33:31 respectively) show, as expected, a shift $O_e \rightarrow O_t$.

Of the three rotamers of the hydroxy proton, the one with a HOCH unit planar and the protons *anti* has a $^3J_{HC,OH}$ *ca.* 12.5 Hz.[25] The observed $^3J_{HC,OH}$ values (usually 4–6 Hz) for the diols and alditols are consistent with a mixture of rotamers.

Conclusions

We have shown that acyclic vicinal diols prefer a *gauche*-arrangement of C–O bonds in low polar and protic solvents and a *trans* arrangement in very polar aprotic solvents; this behaviour is the opposite to that given by acyclic compounds having polar vicinal substituents which cannot use a hydrogen for hydrogen bonding. Certain alditols crystallise with the oxygen of the hydroxymethyl group extending the chain—this is the main conformer of the group when alditols are dissolved in water. Arabinitol crystallises with the C–O bond of the C–I hydroxymethyl group *trans* to the adjacent C–O bond and this is the main conformer of the group when alditols are dissolved in very polar aprotic solvents.

There is limited evidence to show that very polar aprotic solvents stabilise a *xylo*-O||O interaction better than water and that *xylo*-O||O interactions are stabilised better than *ribo*-O||O interactions in both aprotic and aqueous solvents.

Experimental

(±)-Propane-1,2-diol, the mixed butane-2,3-diols, galactitol, D-mannitol, and the perdeuterio solvents were commercially available. L-Iditol was obtained[2] as previously and allitol was prepared as described[2] for the [3-^{2}H]compound. The synthesis of L-*erythro*-hexane-1,2,3-triol will be published elsewhere. Solutions were generally 1–4 g compound per 100 cm^3 solvent. Spectra were recorded using either a Bruker WH-400 or a Bruker WM-250 spectrometer at temperatures of 23 ± 2 and 26 ± 1 °C, respectively. Where necessary, the hydroxyl protons were irradiated individually to both identify the C–H protons coupled to them and to simplify the spectrum for computing.[2] Gaussian resolution-enhanced spectra showed typically $w_{\frac{1}{2}}$ 0.5–1.0 Hz for the diols and 2 Hz for the alditols. Spectra were normally simulated with an error of *ca.* 0.25 Hz in the shifts and coupling constants.

Acknowledgements

The 400 MHz ^{1}H NMR spectra were obtained from the University of London Intercollegiate Research Service (ULIRS) WH-400 spectrometer at Queen Mary College. The 250 MHz ^{1}H NMR spectra were obtained from the ULIRS WM 250 spectrometer of King's College.

References

1 G. A. Jeffrey and H. S. Kim, *Carbohydr. Res.*, 1970, **14**, 207.
2 G. E. Hawkes and D. Lewis, *J. Chem. Soc., Perkin Trans. 2*, 1984, 2073.
3 D. G. Gillies and D. Lewis, *J. Chem. Soc., Perkin Trans. 2*, 1985, 1155.
4 D. Lewis, *J. Chem. Soc., Perkin Trans. 2*, 1986, 467.
5 D. Lewis and S. J. Angyal, *J. Chem. Soc., Perkin Trans. 2*, 1989, 1763.
6 S. J. Angyal, J. K. Saunders, C. T. Grainger and P. G. Williams, *Carbohydr. Res.*, 1986, **150**, 7.
7 D. Lewis, *J. Chem. Soc., Perkin Trans. 2*, 1990, 1349.
8 S. J. Angyal and R. Le Fur, *Carbohydr. Res.*, 1980, **84**, 201.
9 S. J. Angyal and R. Le Fur, *Carbohydr. Res.*, 1984, **126**, 15.
10 G. W. Schnarr, D. M. Vyas and W. A. Szarek, *J. Chem. Soc., Perkin Trans. 1*, 1979, 496.
11 F. Franks, R. L. Kay and J. Dadok, *J. Chem. Soc., Faraday Trans. 1*, 1988, **84**, 2595.
12 C. A. Kingsbury, *J. Org. Chem.*, 1970, **35**, 1319.
13 C. A. G. Haasnoot, F. A. A. M. de Leeuw and C. Altona, *Tetrahedron*, 1980, **36**, 2783.
14 M. Van Duin, J. M. A. Baas and B. Van de Graaf, *J. Org. Chem.*, 1986, **51**, 1298.

15 N. S. Bhacca and D. H. Williams, *Applications of NMR Spectroscopy in Organic Chemistry. Illustrations from the Steroid Field*, Holden-Day, San Francisco, 1964, p. 185.
16 C. Altona and C. A. G. Haasnoot, *Org. Magn. Reson.*, 1980, **13**, 417.
17 D. Lewis, *J. Chem. Soc., Perkin Trans. 2*, submitted (paper 0/03690K).
18 H-J. Schneider and M. Lonsdorfer, *Org. Magn. Reson.*, 1981, **16**, 133.
19 G. C. Levy, T. Pehk and E. Lippmaa, *Org. Magn. Reson.*, 1980, **14**, 214.
20 M. Tichý, *Adv. Org. Chem.*, 1965, **5**, 125.
21 T. Spoormaker and M. J. A. de Bie, *Recl. Trav. Chim. Pays-Bas*, 1980, **99**, 154.
22 E. L. Eliel, N. L. Allinger, S. J. Angyal and G. A. Morrison, *Conformational Analysis*, J. Wiley, New York, 1965, p. 159.
23 A. J. Kirby, *The Anomeric Effect and Related Stereoelectronic Effects at Oxygen, Reactivity and Structure Concepts in Organic Chemistry*, Springer-Verlag, Berlin, 1983, vol. 15, p. 32.
24 S. J. Angyal and R. Le Fur, *J. Org. Chem.*, 1989, **54**, 1927.
25 N. L. Bauld and Y. S. Rim, *J. Org. Chem.*, 1968, **33**, 1303.

Paper 0/02341H
Received 25*th May* 1990
Accepted 6*th August* 1990