Boron Enolates in Stereoselective Syntheses of 2-Enitols from *O*-Benzyl Aldoses by Reaction with Borohydride in 2-Propanol. Configuration of *E* and *Z* Enols from Proton Relaxation Rates

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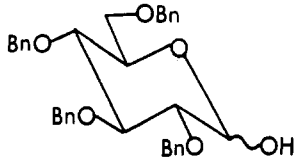
Isomerically pure *E* and *Z* forms of 2,4,6-tri-*O*-benzyl-2-dehydro-3-deoxy-D-*erythro*-hex-2-enitol (**4** and **3**, respectively) were synthesized from 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose by reactions employing sodium borohydride and 2-propanol under differing conditions. A cyclic boron enolate is proposed as a transition state to account for the formation of the *Z* olefin through regio- and stereoselective elimination, followed by hydride reduction. The elimination step was effected in the absence of boron to ensure generation of the *E* isomer. The relative configurations of **3** and **4** were determined by measuring the effects on spin–lattice relaxation rates of replacing specific protons in the vicinity of the double bonds with deuterium. Also described are notable differences between lithium and sodium counterions in their influence on stereo- and regioselectivity and the synthesis of 2-enitols corresponding to **3** and **4** from 2,3,5-tri-*O*-benzyl-D-arabinofuranose.

The reaction of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**1**) with sodium borohydride in 2-propanol has been shown[1] to give not only the normal reduction product, alditol **2**, but also a 50% yield of an elimination product,



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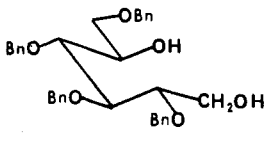

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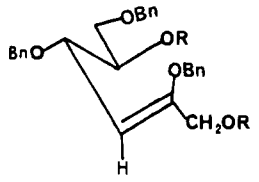
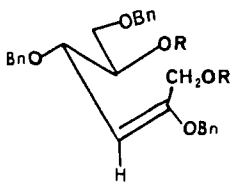


3, R = H

5, R = Ac



4, R = H

6, R = Ac

namely, 2,4,6-tri-*O*-benzyl-2-dehydro-3-deoxy-D-*erythro*-hex-2-enitol (**3**). As there were two reactions in competition, it appeared feasible that the product ratio might be varied selectively by changes in the experimental conditions. It was clear, for example, that the competing reactions had been accompanied by changes in the nature and composition of the reagent, because the borohydride is converted into a mixture of alkoxyborohydrides ($NaBH_{4-n}OR_n$). These latter species may have exerted stereo- and regioselectivities[2] distinct from each other and from those of the borohydride itself. The possible effects of other variables were contemplated as well. Accordingly, the original reaction conditions have been altered within wide limits. It has been found, in fact, that the outcome of the reaction may be controlled rigorously, in ways that substantially enhance its synthetic utility. These modifications, as well as corresponding reactions of aldoses isomeric with **1**, are described here.

Another question remaining from the earlier study,[1] namely, the configuration of the enol function in **3**, has now been resolved by applying proton spin-relaxation measurements to this molecule and related enols. The results of that study are reported as well.

Results and Discussion

As already noted,[1] the formation of **3** from **1** appears to involve enolization of the aldose in the borohydride solution, prior to the reduction step. Consequently, in an attempt to increase the extent of enolization initially, and thus possibly the yield of elimination product **3**, sodium isopropoxide was added to a solution of **1** in 2-propanol, the strongly basic solution was heated briefly, and the sodium borohydride was then introduced. Under these conditions, none of glucitol **2** was formed, and although a quantitative yield of olefinic diol was obtained, this diol proved not to be **3** but its geometric isomer (**4**), which was isolated as a diacetate (**6**).

Product **6** gave ^1H and ^{13}C NMR spectra (Table I) similar to, but distinct from, those of the diacetate of diol **3** prepared earlier[1] (i.e., **5**). The data showed that **6** contains two *O*-acetyl groups, three *O*-benzyl groups, and an olefinic proton on C-3 (doublet at δ 4.68). Also commensurate with the enol–ether structure of **6** were ^{13}C signals at δ 154.4 (C-2) and 101.6 (C-3). Two ^1H doublets (δ 4.70 and 4.53), comprising an AB pair, were attributable to H-1 and H-1′, respectively. These assignments were confirmed by the appearance in their place of two broad singlets when sodium borodeuteride was used[3] in place of borohydride. Consequently, the formation of diol **4** involved not simply hydride reduction of aldose **1** but concomitant losses of H-2 and the 3-benzyloxy substituent of **1**.

As seen from the close analogies between the NMR spectral characteristics of **3** and **4** [in the form of diacetates **5** and **6** (Table I)], these two products must be geometric isomers. On the basis of evidence presented later, the *Z* configuration is assigned to **3** and the *E* configuration to **4**. The fact that each was obtained under a different set of experimental conditions prompted an examination of other modifications to the experimental procedure.

One variant that proved to favor the formation of **3** exclusively involved a reversal of the order of addition of the reactants. That is, although the preceeding experiment had shown that **4** is produced when the borohydride is introduced *after* the base-catalyzed enolization step, isomer **3** was known to have been formed in the *presence* of bo-

(1) Rao, V. S.; Perlin, A. S. *Can. J. Chem.* **1981**, *59*, 333.
(2) Gemal, A. L.; Luche, J. L. *J. Am. Chem. Soc.* **1981**, *103*, 5454 and references cited.
(3) Introduction of deuterium at C-1 resulted in an upfield shift (0.015 ppm) for the remaining proton on C-1: Hall, L. D.; Wong, K. F.; Hull, W. E. *J. Chem. Soc., Chem. Commun.* **1979**, 953.

0022-3263/82/1947-3265$01.25/0

Table I. NMR Parameters for 2-Enitol Derivatives[a]

^{1}H NMR Parameters

	chemical shift								coupling constants, Hz				
compd	H-1	H-1′	H-3	H-4	H-5	H-6	H-6′	CH_3	CH_2Ph	$J_{1,1'}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6}$	$J_{5,6'}$	$J_{6,6'}$
6	4.70	4.53	4.68	4.34	5.14	3.68	3.61	2.03, 2.05	4.77 (s), 4.55, 4.34 (AB), 4.50, 4.33 (AB)	12.8	9.6	6.4	5.6[b]	4.0[b]	10.4
5	4.72	4.65	4.97	4.69	5.26	~3.70	~3.66	2.08, 2.11	4.87 (s), 4.58, 4.48 (AB), 4.50, 4.34 (AB)	13.6	9.2	5.5	5.5[b]	4.5[b]	10.4
13	4.96	4.66	4.79	5.76	3.56			2.02, 2.04	4.74 (s), 4.59, 4.53 (AB)	12.5	10.0	5.0			
14[c]			4.97	6.00	3.50			2.07, 2.09			8.7	5.1			

^{13}C NMR Parameters

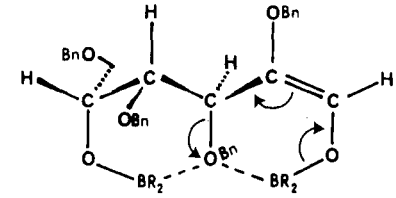
	chemical shift						
compd	C-1	C-2	C-3	C-4,5,6 and CH_2Ph	CH_3	CO
6	60.9	154.4	101.6	68.4, 69.3, 70.1, 73.1, 73.8 (2)	20.8, 21.1	170.3, 170.5
5	62.3	153.2	111.4	68.7, 70.5, 71.3, 71.6, 73.0, 73.2	20.9, 21.1	170.3 (2)
13	61.3	155.1	99.2	69.3, 69.6, 71.9, 73.0	20.6, 21.1	170.1, 170.2
14[b]	62.14	151.5	109.9		20.9, 21.2	

[a] Chemical shifts (δ) in parts per million from Me_4Si. [b] Observed spacings. [c] Spectrum partially obscured by admixed alditol.

rohydride. Consequently, aside from the need for a strong base, it appeared that the borohydride was required, perhaps incorporated into a transient complex, to induce the selective production of **3**. Therefore, instead of adding the borohydride to the solution of **1**, as done originally, the aldose was added to a cold solution prepared previously by heating sodium borohydride under reflux in 2-propanol for 24 h. In this way, **1** was exposed from the outset to a strongly basic medium, as well as to an equilibrated mixture of alkoxyborohydrides from which the hypothetical boron complex could be generated. Under these circumstances, the yield of enediol **3** (isolated as diacetate **5**) was increased from 50% to almost 100%.

Therefore, conditions have been found for inducing regioselective and stereoselective elimination reactions, whereby **1** is converted into either the *E* or *Z* isomer of the 2-enitol in virtually quantitative yield. As both isomers, either as diols **3** and **4** or as diacetates **5** and **6**, were liquid and not differentiable chromatographically, evidence as to their isomeric purity was available only from NMR spectroscopy. In fact, it was clear from the ^{13}C NMR spectra of **5** and **6**, and especially from their 400-MHz ^{1}H NMR spectra (Figure 1), that each product represented a single (>95%) geometric isomer.

The formation of **3** and **4** likely involves an initial enolization of **1** and migration of the double bond together with elimination of the 3-benzyloxy group, as well as hydride reduction. One plausible way to account specifically for the *Z* isomer **3** is through the formation of a transient boron–enolate[4] of the 1,2-*trans*-enediol, in which elimination of the 3-benzyloxy group and migration of the double bond are facilitated, e.g., as in **7**. The product then would be an α,β-unsaturated *aldehydo* analogue of **3**, i.e., **8**, which is reduced subsequently to **3**.



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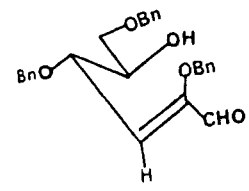

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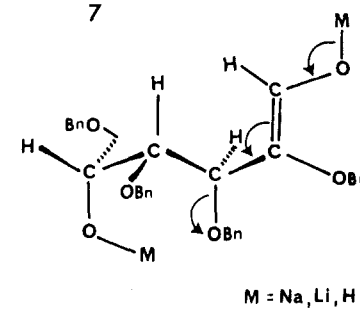

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Compound **8** need not be formed per se if hydride is transferred intramolecularly (within **7**) in concert with the elimination process. To examine this possibility, we made attempts to detect intermediate species through isotope incorporation. As previously, a suspension of sodium bo-

(4) Masamune, S.; Choy, W.; Kerdesky, F. A. J.; Imperiali, B. *J. Am. Chem. Soc.* **1981**, *103*, 1566. For boron aza enolates see: Meyers, A. I.; Yamamoto, Y. *Ibid.* **1981**, *103*, 4278. For zirconium enolates see: Evans, D. A.; McGee, L. R. *Ibid.* **1981**, *103*, 2876. For stereoselective generation of ester enolates see: Ireland, R. E.; Willard, A. K. *Tetrahedron Lett.* **1975**, 3975.

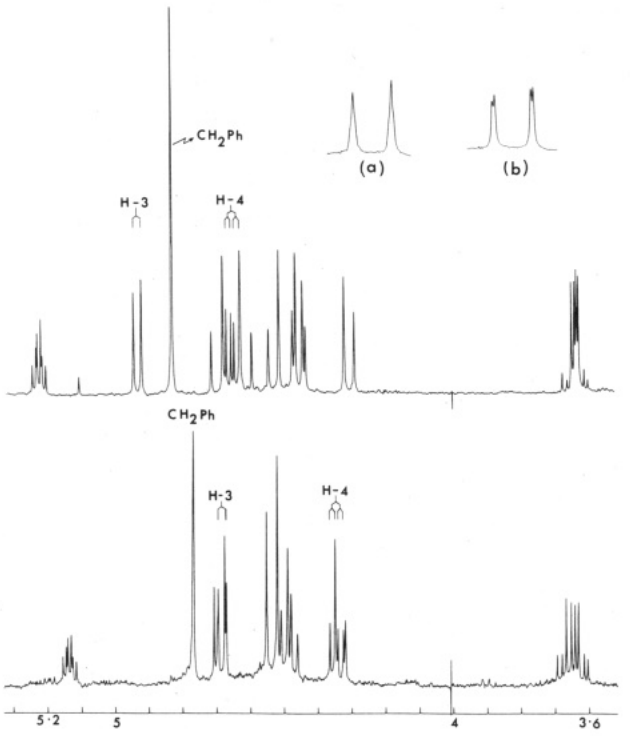


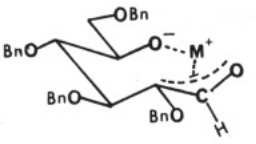
Figure 1. Partial ^1H NMR spectra (400 MHz; solvent, $CDCl_3$) of geometric isomers of 1,5-di-*O*-acetyl-2,4,6-tri-*O*-benzyl-2-dehydro-3-deoxy-D-*erythro*-hex-2-enitol: *Z* isomer (**5**), upper; *E* isomer (**6**), lower. The figure insets are expansions of signal H-3 of **5** (a) and of **5**-*1-d* (b), depicting $^4J_{H\text{-}3,H\text{-}1}$. The signals designated are those utilized in measurements of spin–lattice relaxation rates (see Figure 2); the other signal assignments are given in Table I. The minor peak at δ 5.12 (upper spectrum) is attributable to the benzylic protons of benzyl acetate.

rohydride in 2-propanol was heated under reflux for 24 h before introducing aldose **1**. Two hours later, when the reaction was about half-complete,[5a] sodium borodeuteride was added. Diacetate **5** was then found, by comparison of its ^1H NMR spectrum with that of Figure 1, to contain about 0.2 deuterium atom at C-1. Analogously, by using sodium borodeuteride at the outset and introducing borohydride after 2 h, **5** was found to be about 80% deuterated. Hence the distribution of deuterium (or hydrogen) corresponded approximately to that due simply to the reaction of **1** remaining after the 2-h period. Although inconclusive, these experiments suggest that once the initial enolization has occurred, migration of the double bond and elimination follow rapidly and that intermediates (represented by **7**) do not accumulate.

Attempts to isolate **8** also were unsuccessful.[5b] However, evidence in favor of sequence **1** → **7** → **8** → **3** was provided by another modification to the experimental procedure. That is, the aldose **1** in 2-propanol was treated with a suspension of sodium tetrakis(2-oxopropyl)borate[6] for 2 h, sodium borohydride was then added, and 44 h later the mixture was processed. As this procedure gave diacetate **5** in quantitative yield, it indicated that the elimination step had been largely effected by the tetrakis(2-oxopropyl)borate to yield **8** having *Z* geometry.

Formation of the *E* isomer **4**, in contrast to that of **3** which is dependent on complexation with boron, appears to be determined prior to the introduction of borohydride. That is, base-catalyzed elimination by isopropoxide ion probably generates solely the α,β-unsaturated analogue of **8** which is then reduced by borohydride. In various possible pathways, depicted by **9** and **10**, the 1,2-cis enolate assumes an extended W conformation[7] or pseudocyclic[8] geometry for the enol. Loss of the benzyloxy group then is accompanied by migration of the double bond to the 2,3-position in a concerted manner to give the geometrically pure *E* isomer.[9]

Other Aldoses. It was reported previously that the C-2 epimer of **1**, namely, 2,3,4,6-tetra-*O*-benzyl-D-mannose (**11**),



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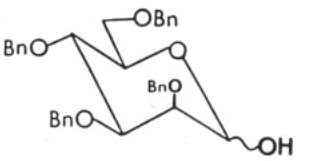

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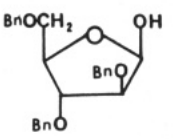

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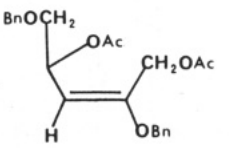

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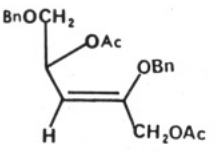

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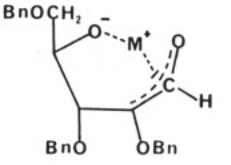

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when added to a boiling solution of sodium borohydride in 2-propanol, gave 90% of the corresponding alditol (in contrast to 50% with **1** under these conditions) and 10% of olefin **3**. The latter is now known to be the *Z* isomer. However, paralleling the result obtained with **1**, the course of the reaction was altered so as to favor production of the *E* isomer by initially promoting enolization with sodium isopropoxide, followed by treatment with borohydride. This gave, after acetylation, a 1:9 mixture of *Z* and *E* isomers **5** and **6**. Furthermore, no tetra-*O*-benzylmannitol was detected.

A furanose derivative, i.e., 2,3,5-tri-*O*-benzyl-D-arabinofuranose (**12**), was examined as well. Added to a boiling solution of sodium borohydride in 2-propanol, this aldose afforded only tri-*O*-benzylpentitol, perhaps because

(5) (a) When, in a parallel experiment, the reaction mixture was processed at this stage, the ^1H NMR spectrum of the O-acetylated product suggested that approximately 40% of **I** remained, admixed with **5** and unidentified material. (b) These involved quenching of the reaction by acidification with an ion-exchange resin, at stages when substantial enolization and elimination was expected to have occurred, followed by acetylation of the material isolated. ^1H NMR spectra of the products obtained were highly complex and suggested that extensive polymerization had occurred. The same procedure was adopted, again unsuccessfully, in an attempt to detect the geometric isomer of **8** (expected to exist as the cyclic lactol) as well as a possible intermediate generated by a furanose derivative (**12**) to be described later.

(6) Prepared from sodium borohydride and acetone in 2-propanol. See: Wigfield, D. C.; Gowland, F. W. *Tetrahedron Lett.* **1976**, 3373 and references cited therein.

(7) Grob, C. A.; Schiess, P. W. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 1.

(8) Isbell, H. S.; Frush, H. L.; Wade, C. W. R.; Hunter, C. E. *Carbohydr. Res.* **1969**, *9*, 163.

(9) Interactions involving sodium 2-propoxide ion pairs and aggregates of them in 2-propanol may occur in the transition state leading to formation of the *E* isomer. See, e.g.: Bartsch, R. A.; Cho, B. R.; Day, J. C. *J. Org. Chem.* **1980**, *45*, 4057.

hydride reduction of furanoses is faster than for pyranoses. When, however, **12** was first dissolved in sodium or lithium isopropoxide, the borohydride then introduced, and the product acetylated an enitol diacetate **13** was obtained. From a comparison of its ^1H and ^{13}C NMR parameters with those of **5** and **6**, as shown later, it was concluded that **13** possesses the *E* configuration. The geometric isomer of **13** was obtained under the same experimental conditions described for the formation of the *Z* olefin from **1**. That is, furanose derivative **12** then gave a 3:7 mixture of *Z* enitol and normal pentitol, the enitol being characterized as its diacetate (**14**).

Other Observations. A noteworthy characteristic of these reactions is the fact that their stereochemistry can be highly sensitive to the cation present. Hence, when 2,3,4,6-tetra-*O*-benzyl-D-glucose (**1**) was subjected to enolization with *lithium* (rather than sodium) isopropoxide[10] solution followed by reduction with either sodium or lithium borohydride, the *Z* isomer was produced in addition to the *E* isomer. With 3 equiv of lithium the *E*/*Z* ratio was 2:3,[11] and with 8 equiv the ratio was 1:3. Possibly, due to the stronger coordinating ability of the lithium counterion, as compared with sodium, a cyclic complex somewhat analogous to **7** is favored, and consequently also a high proportion of intramolecular elimination leading to **3**. This difference between the effect of sodium and lithium did not apply, however, with furanose derivative **12**. Hence, the mechanism for the formation of **13** may be regarded as analogous to that for the *E* isomer **4** produced from aldopyranoses **1** and **11** under analogous conditions. However, the fact that lithium did not promote the formation of the *Z* isomer from **12** suggests that this cation coordinates more strongly with an enolate derived from the furanose (e.g., as in **15**) than that from a larger pyranose ring (e.g., **10**). As a consequence, only the *E* isomer **13** was obtained in the absence of borohydride or boronate. When the latter were present before elimination had commenced, it appears likely that a boron enolate intermediate corresponding to **7** was formed, ensuring that the stereochemistry was directed toward formation of the *Z* isomer **14**.

In marked contrast to all of these findings, associated originally with the attempted reduction of **1** to alditol **2** with sodium borohydride in 2-propanol, it has now been found that *lithium* borohydride is far more effective. Hence, the addition of lithium borohydride to a suspension of **1** in 2-propanol at room temperature led to the formation of **2** exclusively. Possibly this is attributable to an increase in the solubility of the initial aldose–borohydride adduct having lithium as the counterion rather than sodium. An enhancement in the solubility of **1** may also be invoked to account for the fact that **2** again was the sole product when the use of *sodium* borohydride was accompanied by the addition of 20% of methanol to the suspension of **1** in 2-propanol.

Configuration of Enol Derivatives 5, 6, 13, and 14. Measurements of spin–lattice relaxation rates (R_1),[12] as well as other NMR data, provided a basis for assigning the configuration of the double bonds in **5** and **6**. The principal evidence came from a comparison between R_1 values

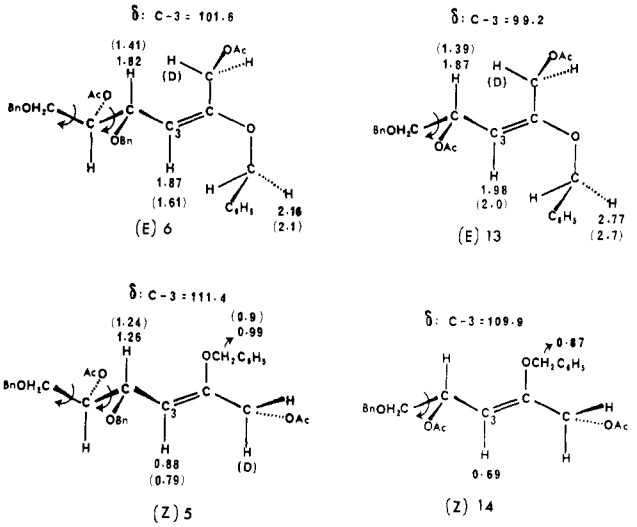

Figure 2. Spin–lattice relaxation rates (R_1) for isomeric 2-enitols **5**, **6**, **13**, and **14**. R_1 values in parentheses are those measured for the 1-deuterio analogues of the compounds. Chemical shifts of C-3 are included for comparison.

for appropriate protons and the corresponding values obtained when a proton on C-1 had been replaced by deuterium (Figure 2). This showed that the relaxation rate for H-4 of **5** was unaffected by the presence of deuterium, whereas H-4 of **6** exhibited a marked decrease in rate.[13] Consequently, only in the latter isomer is H-1 or H-1′ sufficiently close to H-4 to contribute importantly to its relaxation rate. As shown in Figure 2, therefore, compound **6** must possess the *E* configuration and **5** the *Z* configuration. Also consistent with these assignments is the fact that the R_1 values for H-3 and H-4 of **6** are much larger than for **5**, because this should be a reflection of the greater proximity of these protons to a number of other protons, as depicted for the *E* isomer. Justification for a preponderance of the anti orientation of H-4 with respect to H-3, shown in Figure 2 for both isomers, is afforded (Table I) by the large values[14] of $J_{3,4}$, which are 9.6 and 9.2 Hz for **5** and **6**, respectively.

Other NMR data[15] clearly support the assignments proposed. Thus, the fact that C-3 of **6** is much more strongly shielded than C-3 of **5** is consistent[16] with greater steric crowding about the double bond anticipated for the *E* isomer. Furthermore, an allylic coupling of 0.65 Hz was observed (inset, Figure 1) between H-3 and H-1 of **5**,[17] but no such coupling was detected for **6**. Comparable data for geometric pairs of known olefins[18] indicate that this coupling observed with **5** is to be expected for a *Z* isomer.

Of the two olefins obtained from the reactions of the arabinofuranose derivative **12**, product **13** resembled the *E* isomer **6** in its NMR characteristics, and the data for **14** resembled those of the *Z* isomer **5**. Thus, the C-3 chemical shifts for **13** and **6** (δ 99.2 and 101.6, respectively) were displaced equally far upfield of those of **14** and **5** (at δ 109.9 and 111.4, respectively). Moreover, the R_1 values

(10) Lithium bases may exist as aggregates which alter the stereospecific course of the reaction. See, e.g.: Jackman, L. M.; Lange, B. C. *J. Am. Chem. Soc.* **1981**, *103*, 4494.

(11) Although sodium borohydride was used in some reactions and lithium borohydride in others, we attribute this effect to the influence of lithium ion in the elimination step, rather than to a difference in reducing properties between sodium and lithium borohydrides.

(12) These measurements were made on undegassed samples, as the compounds are isomeric, and only *relative*, rather than absolute, R_1 values were required for the present purpose.

(13) See, e.g.: Bock, K.; Hall, L. D.; Pedersen, C. *Can. J. Chem.* **1980**, *58*, 1916.

(14) Garbisch, E. W., Jr. *J. Am. Chem. Soc.* **1964**, *86*, 5561.

(15) The additivity of substituent constants for proton chemical shifts (Tobey, S. W. *J. Org. Chem.* **1969**, *34*, 1281) was not definitive in the present instance.

(16) Perlin, A. S. "Isotopes in Organic Chemistry"; Bruncel, E., Lee, C. C., Eds.; Elsevier: Amsterdam, 1977; Vol. 3, Chapter 4.

(17) This was more clearly evident (inset b, Figure 1) after a deuterium atom had been introduced at C-1 through the use of borodeuteride in the synthesis of **5**.

(18) Gordon, A. J.; Ford, R. A. "The Chemist's Companion"; Wiley-Interscience: New York, 1972; p 278.

for **13** were so closely akin to those of **6** as to verify that **13** also possesses the *E* configuration. Hence, Figure 2 shows that not only were the R_1 values for H-3 and H-4 similar to those of **6** but there also was a comparable impact on R_1 of H-4 of **13** when C-1 was monodeuterated. Although only partial data are available for **14** (Figure 2), its R_1 values suggest that it is equivalent sterically to *Z* isomer **5**.

Experimental Section

Solutions were generally evaporated below 40 °C under diminished pressure. Silica gel for column chromatography was obtained from Macherey Nagel and Co. (Germany). 2,3,4,6-Tetra-*O*-benzyl-D-glucopyranose and 2,3,5-tri-*O*-benzyl-D-arabinofuranose were obtained from Pfanstiehl Laboratories (Waukegan, IL). 2,3,4,6-Tetra-*O*-benzyl-D-mannopyranose was prepared by R. G. S. Ritchie. Proton magnetic resonance spectra were recorded with a Varian XL-200 spectrometer or a Bruker WH-400 spectrometer with $CDCl_3$ as the solvent. Chemical shifts (δ) are reported with reference to tetramethylsilane and, together with the coupling constants given (in hertz), were obtained by first-order analysis with the aid of homonuclear decoupling. Proton spin–lattice relaxation rates (R_1) were measured by the inversion recovery $(180°-\tau-90°-t)_x$ pulse sequence[19] by utilizing the Varian XL-200 T_1 program. Carbon-13 NMR spectra were recorded with a Bruker WH-90 spectrometer.

1,5-Di-*O*-acetyl-2,4,6-tri-*O*-benzyl-2-dehydro-3-deoxy-D-*erythro*-hex-2(*Z*)-enitol (5). A suspension of sodium borohydride (1.0 g) in 2-propanol (10 mL), protected from moisture, was heated under reflux for 24 h and cooled to 5 °C, and 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**1**) (1.0 g) was introduced in one portion. The suspension was stirred at room temperature for 60 h and evaporated almost to dryness, water (60 mL) was introduced, followed by chloroform (50 mL), and the chloroform layer was washed successively with cold 5% hydrochloric acid, saturated sodium hydrogen carbonate, and water, dried (anhydrous sodium sulfate), and evaporated. The syrupy product (yield, 0.98 g) was acetylated with 1:2 acetic anhydride–pyridine, affording the title compound (yield 0.97 g). The ^1H and ^{13}C NMR data are given in Table I, and the ^1H NMR spectrum is shown in Figure 1.

When the reaction mixture was stirred for only 2 h after the addition of **1**, rather than 60 h as above, the workup afforded **5** (~60%), together with unreacted **1** (as its α,β-1-*O*-acetyl derivatives) and a minor proportion of unidentified material. By addition of sodium borodeuteride (1.0 g) after the 2-h period, followed by additional stirring for 48 h, the yield of **5** was essentially quantitative, although this product contained ~0.2 atom of ^2H (^1H NMR evidence). Partially deuterated **5** (containing ~0.8 atom of ^2H) was also obtained by using sodium borodeuteride (1.0 g) at the outset and then introducing sodium borohydride (1.0 g) after the 2-h period.

Use of Sodium Tetrakis(2-oxopropyl)borate in the Synthesis of 5. Acetone (8.6 mL, 116 mmol) was added with stirring to a slurry of sodium borohydride (1.03 g, 27 mmol) in 2-propanol (25 mL) cooled with ice, and after 3 h the mixture was evaporated. The crystalline residue was suspended in 2-propanol (25 mL), and 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (1.0 g) was added with stirring followed, 2 h later, by sodium borohydride (1.0 g). Processing of the reaction mixture and acetylation of the product, as above, afforded **5** (yield 0.99 g).

1,5-Di-*O*-acetyl-2,4,6-tri-*O*-benzyl-2-dehydro-3-deoxy-D-*erythro*-hex-2(*E*)-enitol (6). (A) Enolization with Sodium 2-Propoxide. 2,3,4,6-Tetra-*O*-benzyl-D-glucopyranose (**1**; 1.08 g, 2.0 mmol) was dissolved in 2-propanol (10 mL) by heating under reflux, and a warm solution of sodium (0.14 g, 6 mmol) in 2-propanol (10 mL) was added, whereupon a dark brown color developed. Sodium borohydride (or borodeuteride, 1.0 g) was introduced, the solution was heated under reflux for 22 h and evaporated, and water (60 mL) was added, followed by chloroform (50 mL). The organic layer was washed successively with cold 5% hydrochloric acid, saturated sodium hydrogen carbonate, and saturated sodium chloride, dried (anhydrous sodium sulfate), and evaporated. Acetylation of the syrupy residue (yield, 0.8 g) with 1:2 acetic anhydride–pyridine afforded **6** as an oil that was purified on a column of silica gel with chloroform as the eluent; $[\alpha]_D$ +14.4° (*c* 2.9, $CHCl_3$). The ^1H and ^{13}C NMR data are given in Table I, and the ^1H NMR spectrum is shown in Figure 1.

(B) Enolization with Lithium 2-Propoxide. To a refluxing solution of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**1**, 1.08 g) in 2-propanol (20 mL) was added lithium (40 mg, 6 mmol; small pieces), whereupon the solution became dark brown. Five minutes later, sodium borohydride (or lithium borohydride,[20] 1.0 g) was introduced, and refluxing was continued for 24 h. Processing of the reaction mixture as in part A gave 0.85 g of a 3:2 mixture of **5** and **6** (^1H NMR evidence).

1,5-Di-*O*-acetyl-2,3,4,6-tetra-*O*-benzyl-D-glucitol. Method A. Lithium borohydride (1.0 g) was added to a stirred suspension of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**1**, 1.08 g) in 2-propanol (15 mL). The aldose dissolved, accompanied by vigorous frothing, and the colorless solution was stirred for 4 h and then heated briefly, which caused more frothing and the formation of a gel. Following an additional period of 12 h at room temperature, the suspension was evaporated, water (60 mL) and chloroform (50 mL) were added, and the organic layer was washed successively with cold 5% hydrochloric acid, saturated sodium hydrogen carbonate, and water, dried (anhydrous sodium sulfate), and evaporated, affording **2** (yield 1.15 g). Product **2** was acetylated with 1:2 acetic anhydride–pyridine to give the title compound as an oil (yield 1.3 g).

Method B. Sodium borohydride (1.0 g) was added to a stirred suspension of 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (1.0 g) in 2-propanol (50 mL), followed by methanol (10 mL). The suspension cleared, and after 24 h the solution was processed as in method A, affording the title compound (yield 1.2 g).

1,4-Di-*O*-acetyl-2,5-di-*O*-benzyl-2-dehydro-3-deoxy-D-pent-2(*E*)-enitol (13). By use of the procedure described for the synthesis of **6**, 2,3,5-tri-*O*-benzyl-D-arabinofuranose (**12**; 1.0 g, 2.4 mmol) was subjected to enolization in 2-propanol (10 mL) containing sodium (0.15 g, 7.2 mmol) or lithium (0.13 g, 19.2 mmol). The product (yield 0.8 g), after acetylation, afforded syrupy **13** (yield 0.7 g). The ^1H and ^{13}C NMR data are presented in Table I.

1,4-Di-*O*-acetyl-2,5-di-*O*-benzyl-2-dehydro-3-deoxy-D-pent-2(*Z*)-enitol (14). By use of the procedure described for the synthesis of **5**, a product, characterized by NMR spectroscopy as a 3:7 mixture of **14** and the normal pentitol diacetate, was obtained. Partial ^1H and ^{13}C NMR data for **14** are presented in Table I. Reference ^1H NMR data for the pentitol diacetate were furnished by preparing the compound, as described in the following section.

1,4-Di-*O*-acetyl-2,3,5-tri-*O*-benzyl-D-arabinitol. A mixture of 2,3,5-tri-*O*-benzyl-D-arabinofuranose (**12**, 1.0 g), sodium borohydride (1.0 g), and 2-propanol (15 mL) was heated under reflux for 24 h, and the product obtained by a workup as above was acetylated to give the title compound: 0.96 g; ^1H NMR δ 2.00 and 2.02 (2 × 3 H, s, CH_3), 3.7–3.82 (3 H, m, H-2, H-5, H-5′), 3.87 (1 H, dd, H-3, $J_{2,3}$ = 4.0, $J_{3,4}$ = 5.84), 4.15 (1 H, dd, H-1′, $J_{1,1'}$ = 11.2, $J_{1',2}$ = 5.28), 4.28 (1 H, dd, H-1, $J_{1,1'}$ = 11.2, $J_{1,2}$ = 5.92), 4.43–4.69 (6 H, m, OCH_2), 5.23 (1 H, m, H-4, $J_{3,4}$ = 5.84), 7.27–7.43 (15 H, m, C_6H_5).

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(19) Freeman, R.; Hill, H. D. W. *J. Chem. Phys.* **1970**, *53*, 4103.

(20) When lithium borohydride was added a vigorous reaction occurred, and a few minutes later a gel formed. The reaction mixture was then stored for 18 h at room temperature and processed as usual.