Carbohydrate Research, 136 (1985) 335–345
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

SYNTHESIS OF 2-DEOXY, 3-DEOXY, AND 2,3-DIDEOXY ANALOGS OF α,α-TREHALOSE BY REDUCTIVE DESULFONYLOXYLATION OF *p*-TOLUENESULFONATES WITH LITHIUM TRIETHYLBOROHYDRIDE

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(Received June 19th, 1984; accepted for publication, August 6th, 1984)

ABSTRACT

Lithium triethylborohydride reacts readily with the 2-tosylate, the 2,2′-ditosylate, the 2,3,2′-tritosylate, and the 2,3,2′,3′-tetratosylate of 4,6;4′,6′-di-*O*-benzylidene-α,α-trehalose (**1**), to give products resulting both from *O*-desulfonylation and from reductive *C*-desulfonyloxylation. Among the products obtained were the known, symmetrically modified, 2,2′- and 3,3′-dideoxytrehalose analogs (as bis-benzylideneacetals) having the α-D-*ribo*,α-D-*ribo* and α-D-*arabino*,α-D-*arabino* configurations, respectively, as well as three new, crystalline, unsymmetrical analogs, namely, the 2,3′-dideoxy isomer with the α-D-*ribo*,α-D-*arabino* configuration, a 2-monodeoxy analog (α-D-*ribo*,α-D-*gluco*), and a 3-monodeoxy analog (α-D-*arabino*,α-D-*gluco*). The α-D-*altro*,α-D-*gluco* isomer of **1** was isolated as a crystalline by-product in one of the reactions.

INTRODUCTION

We have recently reported[1] that lithium triethylborohydride (LTBH) is an efficient reagent for the reductive desulfonyloxylation of certain secondary *p*-toluenesulfonates of glycosides. Thus, the 4,6-*O*-benzylidene-α- and -β-D-glucopyranoside 2- and 3-tosylates (and 2,3-ditosylates) were converted with excellent yields into 2- and 3-deoxyglycosides, and it was noted that the action of this hydride differs in its mechanism and, consequently, with respect to the stereochemistry of the major products formed, from that of the less-efficient, if more familiar reagent, lithium aluminum hydride (LAH). We now describe an extension of this work to sulfonic esters of α,α-trehalose. Deoxy derivatives of that disaccharide are of interest as substrate analogs for the study of the mechanism of action and specificity of the important and widespread enzyme, trehalase[2], and they may find use elsewhere in biochemical research, as other synthetic trehalose derivatives and analogs have done, for example, in studies examining structure–biological function relationships of mycobacterial cord factor[3].

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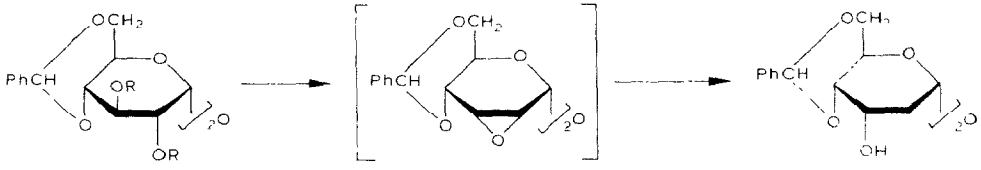
0008-6215/85/$ 03.30

RESULTS AND DISCUSSION

In their exemplary work during the early 1970's on the chemical modification of trehalose, Hough, Richardson, and their co-workers prepared[4] the *allo,allo*-diepoxide **3** from the 2,3,2′,3′-tetramesylate of 4,6;4′,6′-di-*O*-benzylidene-α,α-trehalose (**1**) by the action (24 h) of base, and, in a second step[5], reduced it with LAH (18 h) to give the symmetrically deoxygenated derivative, 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranosyl 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranoside (**4**, 52% overall yield). Employing the corresponding 2,3,2′,3′-tetratosylate **2**, we have now obtained **4** in a single operation, by a 3-h treatment with an excess of LTBH in boiling oxolane. Although the yield (65%) of isolated deoxygenated sugar was not as high as that (96%) for the analogous, monosaccharidic methyl glycoside 2,3-ditosylate[1], the example demonstrated that the method is suitable, at least in principle, for use with larger molecules.



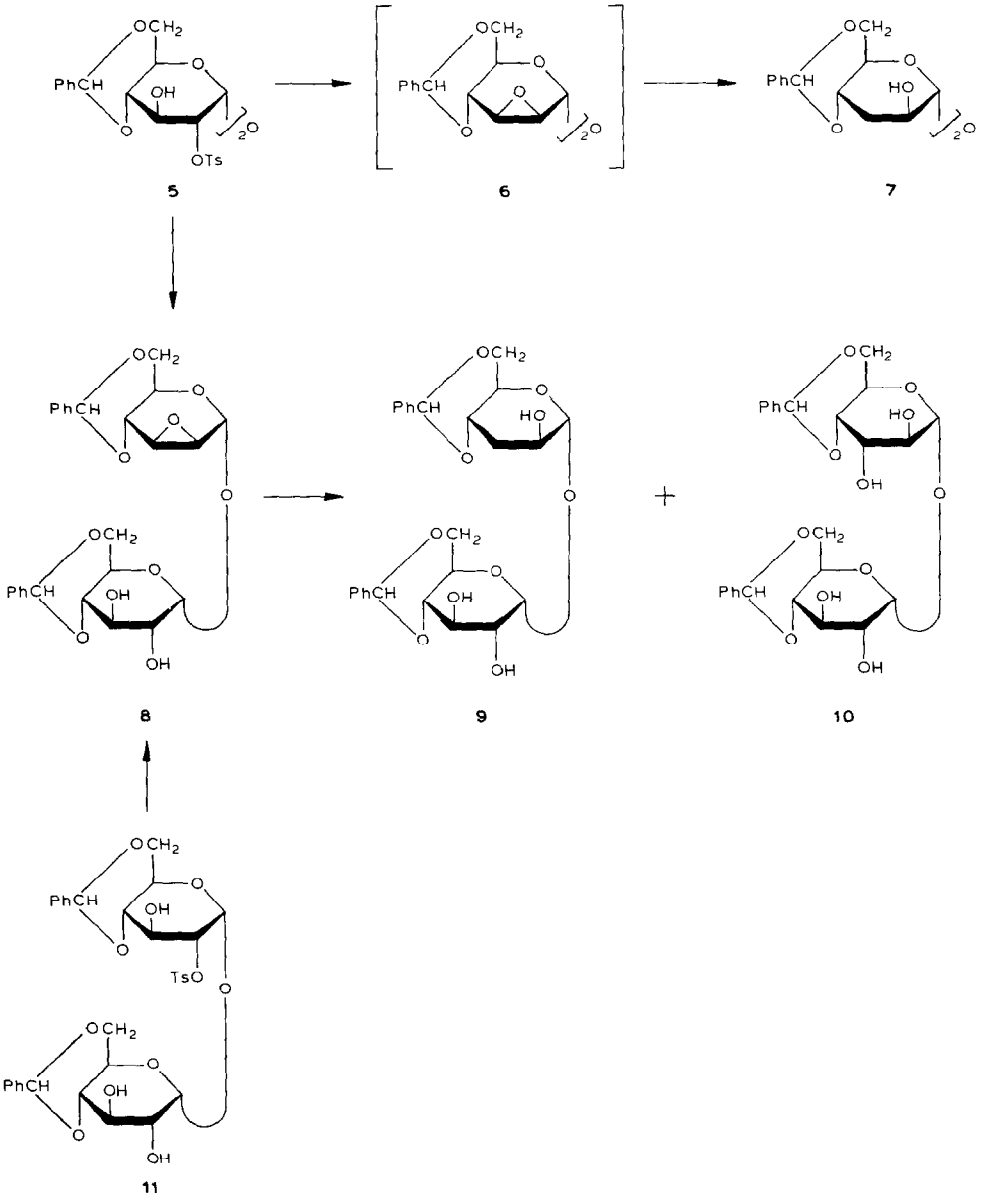
1 R = H
2 R = Ts

3 4

However, it was hardly surprising that a more-complex course of reaction can be observed in the disaccharide series. Such was the case for the desulfonyloxylation of the 2,2′-ditosylate **5**. It gave a mixture of several products, from which the expected, symmetrical dideoxy sugar, 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranoside (**7**), could be isolated crystalline in a yield of only 45%, whereas the corresponding, monosaccharidic methyl glycoside 2-tosylate had furnished[1] a 90% yield of 3-deoxyglycoside. In the latter instance, a small proportion (~5%) of the desulfonylated, parent diol had been isolated as a by-product (and >50% of diol was formed by action of LAH), reflecting the known susceptibility to S–O fission of the tosyloxy group in position 2 of glucopyranosides, and it appears likely for that reason that the parent tetraol **1** was among the products generated from **5***. The two-fold desulfonyloxylation of **5** doubtless proceeded by way of an intermediary epoxide structure in each moiety, just as the corresponding *manno*-epoxide was[1] an intermediate in the monosaccharide reaction mentioned. Intermediacy of the *manno,manno*-di-epoxide **6** is but one suggestion; it is also possible that the oxirane ring formed in the first moiety is reductively opened before that in the

*A chromatographically slow-moving product, migrating like **1** in t.l.c., was observed but not investigated further

second moiety arises (the same consideration applies of course to the sequence **2**→**3**→**4**). Hough and his co-workers prepared[4] **6** by base treatment of **5**, and converted[5] it subsequently into **7** by reduction with LAH, achieving an overall yield of 70%, superior to the yield of the present, one-step procedure. However, in addition to 45% of **7**, we were able to isolate, from the LTBH reaction of **5**, two previously unknown, crystalline products, namely **9** (11%) and **10** (7.6%), which, as non-sym-



metrically modified trehalose analogs, should command particular interest. Their precursor probably was the known[4] mono-epoxide **8**, arising through internal displacement of tosylate in one hexoside moiety, and desulfonylation in the other. In the light of the aforementioned, relative proneness of 2-tosylate groups to S–O fission, the occurrence of such a side-reaction appears plausible. The unsymmetrical structure of 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-α-D-glucopyranoside (**9**) was readily apparent from the ^{1}H-n.m.r. spectrum that showed individual signals for corresponding, but non-equivalent, protons in the two halves of the molecule, with the benzylidene methine and anomeric protons being particularly diagnostic. The C-3 methylene group gave the same multiplet, at δ 2.1 but with half the intensity, as that present in the spectrum of the 3,3′-dideoxy sugar **7**. Upon acetylation of **9**, the spectrum indicated incorporation of 3 *O*-acetyl groups. Chemical proof for the structure of **9** was provided by LAH reduction of independently prepared epoxide **8**, which furnished **9** in good yield*.

The structure of the *altro,gluco* tetraol **10** followed from elemental and spectral analysis. As for **9**, separate sets of signals were observed in the ^{1}H-n.m.r. spectrum for the two hexose units. The *altro* moiety was characterized by two narrow multiplets for H-2 and H-3 (one of which showed a 4.4-Hz coupling with OH), and doublets of doublets for H-4 (*J* 2.4 and 11.5 Hz) and H-6*e* (*J* 5.4 and 9.7 Hz), all in the range of δ 4.1–4.5 where the corresponding signals in methyl 4,6-*O*-benzylidene-α-D-altropyranoside occur[6]. The H-1 and H-5 signals, a singlet and a doublet of triplets, were deshielded by ~0.35 p.p.m. relative to those for the monosaccharide model. The *gluco* moiety of **10** was characterized by a doublet for H-1 (*J* 3.9 Hz), a doublet of doublets for H-2 (*J* 3.9 and 8.9 Hz), and triplets (*J* ~9 Hz) for H-3 and H-4. Before deuterium exchange, the H-3 triplet was doubled by coupling with HO-3 which gave a sharp, 4.5-Hz doublet at δ 4.76. This phenomenon was not observed in the *gluco,gluco* isomer **1**, and its significance will be considered elsewhere.

As regards the origin of **10**, it is assumed that part of the epoxide **8** may have escaped reductive ring-opening during the action of LBTH and subsequently may have undergone hydrolysis in the aqueous, alkaline medium of the processing operations.

The mono-epoxide **8** had first been synthesized[4], in 56% yield, by base treatment of the 2-monotosylate (**11**) of **1**. When we treated **11** with 5 molar equivalents of LTBH in boiling oxolane for 70 min, it was completely consumed, and several products were formed (t.l.c.). Among those was the epoxide **8**, isolated crystalline in 9% yield. The survival of a significant proportion of this intermediate under the conditions of LTBH reduction that were employed is noteworthy. We believe it was not due to any intrinsic refractoriness to the reagent, for epoxides in general

*This experiment, performed for the sole purpose of obtaining a sample for comparison, gave 54% of **9**, with 23% of unchanged **8** being recovered. The conditions could probably be optimized, to make this reaction the route of choice for the preparation of **9**.

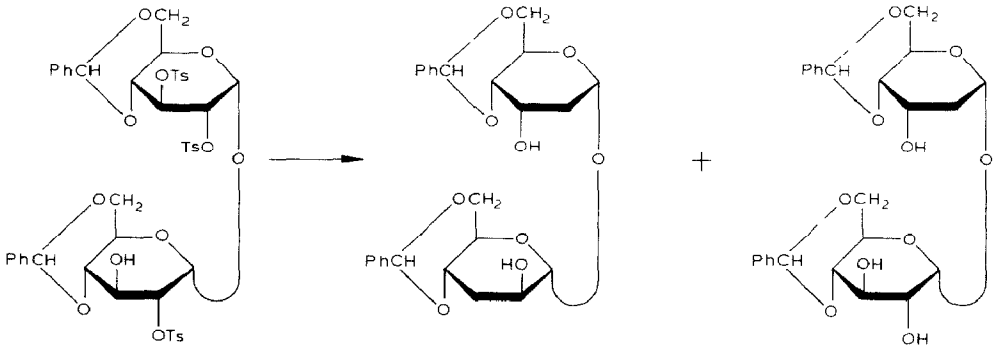
are known to react with LTBH rapidly and quantitatively[7,8]. Rather, the provision of only 5 mol. equiv. of LTBH, even though corresponding to the presumed stoichiometry of interaction with **11**, may have been a borderline measure perhaps because of an inadvertent entry of moisture or the use of an aged reagent. The result re-emphasizes our previous observation[1] that carbohydrate desulfonyloxylations require an adequate excess of the reductant*.

The major reaction product obtained from **11** was the 3-deoxy sugar **9**. The crystalline material (46%) that was isolated by column chromatography of the crude, crystalline mixture of reaction products (88%, containing **8** as mentioned, and a few percent of **1**), gave correct microanalytical data but was not isomerically homogeneous. T.l.c. showed **9** to be accompanied by a marginally faster-moving component, and separation by repeated chromatography remained unsatisfactory. The major component, roughly three-quarters of the mixture, gave 200-MHz n.m.r. signals completely matching those of pure **9**. The minor component exhibited separate signals for an axial and an equatorial proton of a deoxy group, straddling the two-proton multiplet for the 3-deoxy function in **9**. These signals were octets whose splittings closely agreed with those reported[1,6] for H-2*e* and H-2*a* in methyl 4,6-*O*-benzylidene-2-deoxy-α-D-*arabino*-hexopyranoside, and it is therefore tentatively suggested that the compound was the 2-deoxy derivative of **1**, having arisen by anti-Fürst–Plattner opening of the oxirane **8**. Such diminished regioselectivity has also been encountered in the monosaccharide series, but only for β-glycosides, whereas the α-glycosides appeared to obey the Fürst–Plattner rule strictly.

Finally, the LTBH reduction of the 2,3,2′-tritosylate **12** was examined. The formation of a complex mixture of products was revealed by a multitude of spots in t.l.c. Of these, three appeared to represent prominent products, one was comparatively weak but still significant, and the remaining four or five were traces. On column chromatography, the most mobile of the three major components emerged as a non-crystallizable oil whose spectral features placed it outside the category of products previously encountered in this study. Although it appeared to be a carbohydrate derivative, it lacked benzylidene acetal groupings and showed strong, proton resonances in the δ 2.0 region, possibly due to an organoboron moiety. The material was not investigated further. The other two, chief components, each present to ~30%, fitted nicely the pattern of reactivity found in the preceding experiments. One of them proved to be the non-symmetrical dideoxy sugar 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranoside (**13**). Its structure as a hybrid of **4** and **7** was established by its

*In the case of **11**, 3 equiv. of LTBH are instantly consumed by the hydroxyl groups, which are converted into alkoxytriethylboronate groupings, with release of H_2. Triethylborane liberated in the subsequent, epoxide-forming step complexes, and thereby deactivates[7], a 4th equivalent, and a 5th is needed to reduce the epoxide. In processing the reaction mixture from **11**, protracted exposure of the products to aqueous alkali was avoided, which probably prevented residual **8** from being converted into **10**.

^{1}H-n.m.r. spectrum, representing an almost perfect superposition of the spectra of the symmetrical counterparts, with but minor, chemical-shift differences for certain signals. The other product isolated and identified was the monodeoxy disaccharide 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranosyl 4,6-*O*-benzylidene-α-D-glucopyranoside (**14**). Its formation again reflects the differential stabilities of tosylate groups in positions 2 and 3 of glucopyranose systems.



12 13 14

In summary, the action of LTBH upon various, bis-benzylidenated α,α-trehalose tosylates constitutes a simple and useful means for the synthesis of certain deoxygenated trehalose analogs. In addition to the previously described, symmetrical 2,2′- and 3,3′-dideoxy disaccharides **4** and **7**, the hitherto unknown 2- and 3-monodeoxy analogs **14** and **9**, as well as the unsymmetrical 2,3′-dideoxy sugar **13** have been obtained. The products were those predicted on the basis of a course of reaction analogous to that established for methyl 4,6-*O*-benzylidene-D-glucopyranoside tosylates. In view of the remarkably different results obtained under similar conditions with *non-benzylidenated* hexopyranoside tosylates, where the dominant feature was the occurrence of ring-contraction[9], the present study lends support to the notion that structural rigidity, as imparted by the *trans*-fused acetal ring, is an important factor in permitting LTBH to generate unrearranged deoxyglycosides.

EXPERIMENTAL

General methods. — General preparative, instrumental, and chromatographic methods were the same as those previously employed[1,9]. Oxolane refers to a reagent-grade product that was dried, immediately before use, by boiling it, under nitrogen, over potassium metal in the presence of benzophenone. Lithium triethylborohydride (LTBH) was purchased from Aldrich Chemical Co. as a M solution in oxolane. Optical rotations were measured at ~25° with a Perkin–Elmer 241 polarimeter, and refer to chloroform solutions, unless otherwise specified. ^{1}H-N.m.r. spectra were recorded at 200 or 300 MHz for solutions in $CDCl_3$ unless

stated otherwise, using a Varian XL-200 or XL-300 instrument. Chromatography was performed with ethyl acetate–hexane mixtures *A* 1:2, *B* 1:1, *C* 3:2, and *D* 2:1. The starting tosylates **2, 5, 11,** and **12** were prepared essentially as reported[4], although some procedural improvements[10] were employed.

Reaction of 4,6:4',6'-di-O-benzylidene-α,α-trehalose 2,3,2',3'-tetratosylate (**2**) *with LTBH.* — To a stirred suspension of **2** (2.0 g, 1.76 mmol) in oxolane (20 mL), under nitrogen, was added LTBH solution (20 mL) by syringe, and the mixture was then boiled under reflux for 3 h, with further portions of LTBH solution (10 and 5 mL) being added after 2 and 2.5 h, respectively. After that period, **2** (R_F 0.70) was no longer detectable in t.l.c. (solvent *B*), and product spots were seen with R_F 0.2–0.4 (strong, elongated), 0.55, and 0.65 (both weak). The mixture was allowed to cool, poured into ice–water, stirred for 1 h, concentrated until most of the oxolane had been removed, and extracted with dichloromethane (3 × 50 mL). The combined extracts were washed with water, dried ($MgSO_4$), and concentrated, with several portions of ethanol being added towards the end. The white solid (0.84 g) obtained upon evaporation of the solvent was recrystallized from ethanol–hexane, to give the 2,2'-dideoxy compound **4** (460 mg, R_F 0.27). A second crop (96 mg) was obtained from the mother liquor after chromatography (solvent *A*) on a short column of silica gel (10 g), followed by recrystallization (total yield, 556 mg, 65%); m.p. 177–179°, $[\alpha]_D$ +126° (*c* 0.6); lit.[5a] m.p. 179–180°, $[\alpha]_D$ +127°. The ^{1}H-n.m.r. data (300 MHz) were in essential agreement with the 100-MHz data reported[5a]. ^{13}C-N.m.r. data ($CDCl_3$, internal Me_4Si): δ 137.4, 129.0, 128.2, and 126.3 (aromatic), 102.0 (*Ph*-CH), 93.9 (C-1,1'), 79.8, 64.6, and 59.2 (C-3,3',4,4',5,5'), 69.2 (C-6,6'), and 35.6 (C-2,2'). Mass spectrum (c.i.): *m/z* 487, 486, and 485 (calc. for M^+, 486.5).

Reaction of 4,6:4',6'-di-O-benzylidene-α,α-trehalose 2,2'-ditosylate (**5**) *with LTBH.* — A solution of **5** (ethanolate; 2.36 g, 2.7 mmol) in oxolane (20 mL) was allowed to react with LTBH solution (25 mL) at the reflux temperature for 2 h, after which a further 10 mL of reductant was added and boiling was continued for 1 h. T.l.c. (solvent *D*) then indicated the complete consumption of **5** (R_F 0.8) and the formation of several, slow-moving products. The cooled mixture was stirred with ice–water (150 mL) for 2 h and then concentrated. The residue was exhaustively extracted with dichloromethane, and the combined extracts were washed (water), dried ($MgSO_4$), and concentrated, to give a solid residue (1.332 g). The latter showed (t.l.c., solvent *D*) three main spots corresponding to **7** (R_F 0.6), **10** (R_F 0.4), and **9** (R_F 0.3), and a weak spot that migrated like **1** (R_F 0.2). The mixture was eluted from a column of silica gel (40 g) with solvent *B*. Fractions (5 mL) were combined as follows: 10–24 contained fast-moving, unidentified material (42 mg, discarded); 25–37 contained **7** (555 mg); 38–53 contained **7** and **10** (176 mg); 54–61 contained **10** (19 mg); 62–65 contained **10** and **9** (13 mg); 66–78 contained **9** (150 mg); 79–83 contained **9** and **1** (?) (18 mg); 84–95 contained **1** (?) mainly (75 mg); and 96–105 contained unidentified material (50 mg, discarded). The material from fractions 38–53 gave, on fractional crystallization from 2-propanol, **10** (100 mg)

and, from the mother liquor, **7** (70 mg). No attempts were made to separate the products in the other mixed fractions. Hence, the following were isolated pure: **7** (625 mg, 45%), **9** (150 mg, 11%), and **10** (119 mg as the 2-propanolate, 7.6%).

4,6-*O*-Benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranoside (**7**), after recrystallization from 2-propanol–light petroleum, was obtained apparently as a hydrate, m.p. 200–202°, $[\alpha]_D$ +95° (*c* 0.7); lit.[5b] m.p. 209–210° (anhydrous compound), $[\alpha]_D$ +95°. The ^{1}H-n.m.r. spectrum was identical with that of a sample (m.p. 203–205°, $[\alpha]_D$ +94°) prepared by reduction of the di-epoxide **6** with LAH as described[5b], and agreed with the reported[5b] data.

Anal. Calc. for $C_{26}H_{30}O_9 \cdot 1.5\ H_2O$: C, 60.82; H, 6.48; for $C_{26}H_{30}O_9 \cdot 2\ H_2O$: C, 59.76; H, 6.56. Found: C, 60.21; H, 6.06.

A sample of **7** was acetylated with acetic anhydride and pyridine, to give the diacetate, m.p. 162–164°, $[\alpha]_D$ +89° (*c* 0.35); lit.[5b] m.p. 167–168°, $[\alpha]_D$ +90°.

4,6-*O*-Benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-α-D-glucopyranoside (**9**), after crystallization from 2-propanol–light petroleum, did not show a distinct melting-point but foamed at ~90°, possibly because of loss of solvent of crystallization, and melted with decomposition at 115–130; $[\alpha]_D$ +81° (*c* 0.7). ^{1}H-N.m.r. data (200 MHz): δ 7.4 (m, 10 H, 2 Ph), 5.58 (s, *Ph*-CH), 5.51 (s, *Ph*-CH′), 5.21 (d, 1 H, $J_{1',2'}$ 3.9 Hz, H-1′), 4.97 (t, 1 H, $J_{1,2} = J_{1,3} = 0.4$ Hz, H-1), 4.30–4.25 (m, 2 H, H-2,4), 3.95 (t, $J_{2',3'} = J_{3',4'} = 9.3$ Hz, H-3′, partially overlapped by an unresolved 3-H m adjoining downfield), 3.8 (m, 3 H, unresolved), 3.70 (dd, 1 H, *J* 3.8 and 9.3 Hz, H-2′), 3.50 (t, 1 H, *J* 9.3 Hz, H-4′), and 2.17 (m, 2 H, H-3*a*,3*e*). Exchangeable, broad HO signals were present at δ 3.0, 2.5, and 1.65 (3 bs, each 1 H, 3 OH); after D_2O exchange, the H-1 signal became a 1.0-Hz d. A small proportion of 2-propanol was present in the sample, as revealed by a 6.1-Hz d at δ 1.20.

Anal. Calc. for $C_{26}H_{30}O_{10}$ (502.5): C, 62.14; H, 6.02. Found: C, 62.01; H, 6.24 (for sample dried at 56° in a high vacuum).

A sample of mono-epoxide[4] **8** (200 mg) was reduced with LAH (150 mg) in boiling oxolane (10 mL) during 1 h. Customary processing followed by chromatography gave **9** (111 mg, 54%), $[\alpha]_D$ +81° (*c* 0.5), identical (i.r. spectra, R_F values, m.p.) with the compound obtained from **5**.

Acetylation of **9** gave a triacetate, m.p. 123–125°, $[\alpha]_D$ +78°; ^{1}H-n.m.r. data: δ 2.20, 2.18, and 2.12 (3 s, each 3 H, 3 OAc).

4,6-*O*-Benzylidene-α-D-altropyranosyl 4,6-*O*-benzylidene-α-D-glucopyranoside (**10**) crystallized from 2-propanol as a monosolvate, m.p. 247–251° (dec.), $[\alpha]_D$ +68° (*c* 0.8). The non-solvated compound was obtained by repeated evaporation of carbon tetrachloride from the solvate. ^{1}H-N.m.r. data (acetone-d_6): δ 7.4 (m, 10 H, 2 Ph), 5.68 and 5.57 (2 s, 2 *Ph*-CH), 5.46 (d, 1 H, $J_{1',2'}$ 3.9 Hz, H-1′), 5.01 (s, 1 H, H-1), 4.83 (dt, 1 H, $J_{5,6e}$ 5.4, $J_{4,5} = J_{5,6a} = 10.2$ Hz, H-5), 4.73 (d, 1 H, *J* 4.4 Hz, HO-3′), 4.62 (d, 1 H, *J* 4.3 Hz, HO-3), 4.42 (dd, 1 H, $J_{5,6e}$ 5.4, $J_{6a,6e}$ 9.8 Hz, H-6*e*), 4.28 (nm, H-2), 4.23 (nm, H-3), 4.12 (dd, 1 H, $J_{3,4}$ 2 Hz, H-4), 4.04 (dt, 1 H, $J_{2',3'}$

$\approx J_{3',4'} \approx 9$ Hz, $J_{3',OH}$ 4.4 Hz, H-3'), 3.70 (m, 3 H, unresolved), 3.61 (dd, 1 H, $J_{1',2'}$ 3.9, $J_{2',3'}$ 8.9 Hz, H-2'), 3.44 (t, 1 H, J 9 Hz, H-4'), and 2.90 (s, 2 HO). The spectrum of the 2-propanolate additionally showed a 6-proton d (J 6.1 Hz) at δ 1.11, a sharp HO d (J 4.4 Hz) at δ 3.46 superposed on the H-4' signal, and a d of quin at δ 3.90, collapsing to a quin on exchange with D_2O. The assignments were made with the aid of spin-decoupling experiments.

Anal. Calc. for $C_{26}H_{30}O_{11}$ (518.5): C, 60.22; H, 5.83. Found: C, 60.17; H, 5.52.

Reaction of 4,6:4',6'-di-O-benzylidene-α,α-trehalose 2-tosylate (**11**) *with LTBH.* — A mixture of the monotosylate **11** (2.00 g, 3 mmol), oxolane (20 mL), and LTBH (15 mL) was boiled under reflux for 70 min. T.l.c. (solvent *D*) then revealed two products, R_F 0.50 (major) and 0.70 (minor) but no **11** (R_F 0.63). The mixture was stirred with ice–water (200 mL) for 20 min and then neutralized to pH 7–8 with sodium hydrogensulfate. Stirring was continued for 1 h, and, after concentration to ~100 mL, the solution was extracted with dichloromethane (3 × 100 mL). The combined extracts were washed, dried, and concentrated. Crystallization of the resulting, colorless foam (1.38 g) from ethanol afforded the mono-epoxide **8** (130 mg, 8.7%), R_F 0.70, slightly contaminated by the slower-moving product(s), but which had m.p. 148–150°, $[\alpha]_D$ +90° (*c* 0.9); lit.[4] m.p. 152–155°, $[\alpha]_D$ +88.5°. The i.r. spectrum was identical with that of an authentic sample[10]. The ^{1}H-n.m.r. data agreed essentially with those reported[4].

The ethanolic mother liquor of crystallization was concentrated, and the residue was applied to a column of silica gel (40 g), and eluted with solvent *C*. The fractions that contained chiefly the substance(s) having R_F 0.5 yielded material that crystallized on trituration with carbon tetrachloride. The product (695 mg, 46%) had m.p. 97–98°, $[\alpha]_D$ +59° (*c* 0.5). Although the microanalysis agreed with structure **9**, the product was not homogeneous since t.l.c. (solvent *B*) revealed a double spot in the region of R_F 0.2 (with the lower part being stronger). The i.r. spectrum was virtually identical with those of **9** obtained from **5** (with LTBH) or from **8** (with LAH), and the 200-MHz, ^{1}H-n.m.r. spectrum showed a major component the signals of which matched those of **9**. The minor component visible in the spectrum gave an H-1 doublet (J 3.9 Hz) at δ 5.15, and two methylenic octets suggesting a 2-deoxy-α-D-*arabino*-hexopyranose structure, namely at δ 2.22 ($J_{1,2e}$ ~1, $J_{2e,3}$ ~5, $J_{2a,2e}$ ~13 Hz, H-2*e*) and 1.90 ($J_{1,2a}$ 3.9, $J_{2a,3}$ 11, $J_{2a,2e}$ 13 Hz, H-2*a*). The *Ph*-CH signal (δ 5.52) coincided with one of the *Ph*-CH signals of **9**.

Anal. Calc. for $C_{26}H_{30}O_{10}$ (502.5): C, 62.14; H, 6.02. Found: C, 62.13; H, 6.09.

Reaction of 4,6:4',6'-di-O-benzylidene-α,α-trehalose 2,3,2'-tritosylate (**12**) *with LTBH.* — A solution of **12** (1.54 g, 1.57 mmol) in oxolane (15 mL) was allowed to react with LTBH solution (15 mL) at the reflux temperature for 2 h and, after the addition of another 15 mL of reductant, for a further 2 h. The consumption of **12** (R_F 0.83) was monitored by t.l.c. (solvent *D*). To the cooled mixture was added dropwise a small amount of methanol, until gas evolution ceased. The mix-

ture was then boiled for 15 min, cooled, stirred with ice–water (200 mL) for 1 h, and concentrated, and the residue was extracted with dichloromethane (3 × 50 mL). The combined extracts were washed, dried, and concentrated. The resulting, yellow syrup contained 3 major products (*A*–*C*, R_F 0.70, 0.57, and 0.23), a minor product (R_F 0.38), and several traces (R_F 0.91, 0.76, 0.65, and 0.27). The material was eluted from a column of silica gel (50 g) with hexane–ethyl acetate (19:1, then 9:1, 4:1, and 1:1). The fractions containing *A* and the faster-moving trace-products yielded an oily material that was not investigated further, as its n.m.r. spectrum lacked the features characteristic for a benzylidenated sugar. (A similar reduction of **12**, for only 1.5 h, gave a similar mixture of products, but containing very little, if any, of *A*.) The fractions containing chiefly *B* (0.24 g) and *C* (0.22 g) were purified further by flash chromatography on small columns with hexane–ethyl acetate (7:3, then 1:1 for *B*, and 2:3 for *C*), to give *B* (130 mg) and *C* (180 mg).

Compound *B* was identified as 4,6-*O*-benzylidene-3-deoxy-α-D-*arabino*-hexopyranosyl 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranoside (**13**), double m.p. 84–86° and 100–105° (dec.), possibly due to the presence of solvent of crystallization; $[\alpha]_D$ +119° (*c* 0.7). Mass spectrum (f.a.b.): *m/z* 487 (M + 1). ^{1}H-N.m.r. data: δ 7.4 (m, 10 H, 2 Ph), 5.63 (s, 1 H, *Ph*-CH′), 5.57 (s, 1 H, *Ph*-CH), 5.25 (nm 1 H, width ~4 Hz, H-1′), 5.00 (s, 1 H, H-1), 4.32 (dd, 1 H, $J_{5',6e'}$ 5.1, $J_{6a',6e'}$ 10.0 Hz, H-6*e*′), 4.23 (m, 3 H, consisting of dd with $J_{5,6a}$ 10 and $J_{6a,6e}$ 15 Hz for H-6*a*, superposed on H-3′,5′), 4.0 [m, unresolved, 2 H, H-2,4 (or -5)], 3.9–3.7 [m, 3 H, consisting of t with $J_{5',6a'} = J_{6a',6e'} = 10$ Hz for H-6*a*′, superposed on H-5 (or -4) and H-6*e*], 3.64 (dd, 1 H, $J_{3',4'}$ 2.7, $J_{4',5'}$ 9.5 Hz, H-4′), 2.20 [d of narrow (~4 Hz) m, 1 H, $J_{2a',2e'}$ 15 Hz, H-2*e*′], and 2.1–2.0 (m, 3 H, H-2*a*′,3*a*,3*e*). The assigments were made by comparison with the spectra of **4** and **7**, and corroborated by the chemical-shift and coupling data[1] of the methyl glycosides corresponding to the two deoxyhexopyranosyl moieties.

Anal. Calc. for $C_{26}H_{30}O_9$ (486.5): C, 64.18; H, 6.22. Found: C, 64.03; H, 6.32.

Compound *C* was identified as 4,6-*O*-benzylidene-2-deoxy-α-D-*ribo*-hexopyranosyl 4,6-*O*-benzylidene-α-D-glucopyranoside (**14**), and was obtained as a monohydrate even after recrystallization from chloroform–light petroleum, and drying *in vacuo* at 65°. It had a double m.p. 106–107° and 126–127°, $[\alpha]_D$ +101° (*c* 0.9). Mass spectrum (f.a.b.): *m/z* 503 (M + 1). ^{1}H-N.m.r. data: δ 7.4 (m, 10 H, 2 Ph), 5.62 (s, *Ph*-CH), 5.46 (s, *Ph*-CH′), 5.19 (nm, 2 H, H-1,1′), 4.40–4.30 (m, 2 H, unresolved, H-3,5), 4.23 (dd, 1 H, $J_{5,6e}$ 4.4, $J_{6a,6e}$ 9.9 Hz, H-6*e*), 4.16 (bs, HO), 4.00 (t, with broadened lines, 1 H, $J_{2',3'} \approx J_{3',4'} \approx 9$ Hz, H-3′), 3.79 (dt, 1 H, $J_{5',6e'}$ 5, $J_{4',5'} = J_{5'6a'} = 10$ Hz, H-5′), 3.75–3.55 (2 t and 2 d, partially overlapping, H-4,6*a*,2′,6*a*′), 3.48 (t, 1 H, $J_{3',4'} = J_{4',5'} = 9.5$ Hz, H-4′), 3.13 (bs, HO), 2.14 (d of narrow m, 1 H, $J_{2a,2e}$ 15 Hz, H-2*e*), and 1.98 (dt, H-2*a*). The H-2*a*,2*e* signal pattern was the same as in the spectrum of **4** and in that of the corresponding[1], monosaccharidic methyl glycoside.

Anal. Calc. for $C_{26}H_{30}O_{10} \cdot H_2O$ (520.5): C, 59.99; H, 6.20. Found: C, 59.93; H, 6.21.

ACKNOWLEDGMENTS

This work was financially supported by the Natural Sciences and Engineering Research Council of Canada and, in part, by the Medical Research Council of Canada. Dr. Bruno Radatus is thanked for valuable assistance and advice in the preparation and chromatographic purification of tosylated trehalose derivatives.

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