C, 56.66; H, 5.17; N, 8.62. Found: C, 56.46; H, 5.19; N, 8.69.

**Compound 11**: yield 0.127 g (29%); mp 91 °C (40–60 °C petroleum ether); $^1$H NMR (DMSO-$d_6$) δ 1.20 (t, $^3J$ = 7.0 Hz, 3 H, $CH_2CH_3$), 1.30 (br s, 3 H, $CH_2CH_3$), 4.24 (m, 2 H, $CH_2CH_3$), 4.35 (br s, 2 H, $CH_2CH_3$), 6.61 (br d, $^3J$ = 6.3 Hz, 1 H, C4-H), 7.06 (br s, 1 H, C3-H), 7.47 (mc, 6 $H_{Ar}$), 7.97 (br d, $^3J$ = 8.0 Hz, 2 H, phenyl-$SO_2$-C2/6-H), 8.08 (d, $^3J$ = 8.4 Hz, 1 H, C5-H); EIMS (*m/z*, rel intensity) 455 ($M^{•+}$, 1), 310 (31), 169 (100). Anal. Calcd for $C_{22}H_{21}N_3O_6S$ (455.49): C, 58.01; H, 4.65; N, 9.26. Found: C, 58.27; H, 4.61; N, 9.06.

**Supplementary Material Available**: Full details of the X-ray analysis of compound 8 and 400-MHz $^1$H NMR spectra of a mixture of **6a** and **7** (from (*E*)-**1a**) and a mixture of **6b** and **7** (from (*Z*)-**1b**) (9 pages). Ordering information is given on any current masthead page.

# Synthesis of α-Methyl 1′,2′-Dideoxycellobioside: A Novel *C*-Disaccharide

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Bromonium ion induced 6-*endo-trig* cyclizations of *E* olefins derived from D-arabinose provide a stereoselective route to 2′-deoxyglucono-β-*C*-glycosides. Use of δ-alkenols containing allylic isopropylidenes (i.e., 1) prevents formation of furan products due to the highly strained transition state necessary for formation of the trans [3.3.0] bicyclic systems. Because the exo-anomeric carbon is not involved in the cyclization, previously established stereocenters at this carbon are left intact. Application of this methodology to the synthesis of α-methyl 1′,2′-dideoxycellobioside (**22**) is presented. The restricted rotation about the bond connecting the two sugars affords a unique staggered conformation of the disaccharide.

Because of the ubiquitous role carbohydrates play in biology, carbohydrate analogues are valuable tools for the study of biochemical systems. Since the chemistry of sugars is dominated by the reactivity of the glycosidic bond, a great deal of effort has gone into the synthesis and study of *C*-glycosides in which the acetal linkage has been replaced by a hydrolytically stable carbon–carbon bond. The best understood *C*-glycosides are a series of *C*-disaccharides synthesized and studied by Kishi[2] and coworkers in which the bridging oxygen of the glycosidic linkage is replaced by a methylene group. They found that the solution conformations of these molecules are similar to those of the corresponding *O*-disaccharides. A general model based on a diamond-lattice analysis[3] has since been developed to predict solution conformations of disaccharides. We became interested in developing a series of *C*-oligosaccharides in which the "floppy" glycosidic linkage has been reengineered to produce a linkage with a predictable restricted conformation. Analysis of molecular models showed that direct connectivity of the two rings (to form a β-1′-deoxydisaccharide) should result in restricted rotation about the connecting bond, due to steric interaction between substituents on the two rings. We therefore set out to synthesize α-methyl 1′,2′-dideoxycellobioside (**22**) which can be considered a prototype for this class of compounds.

Methodology for the generation of *C*-glycosides has found wide application in natural products synthesis[4] and in the synthesis of biologically active carbohydrate analogues.[5] Methods which exploit the steric and/or stereoelectronic effects of pyranose or furanose substrates involve the intermediacy of cations, radicals, anions, or organometallic reagents at the anomeric carbon.[6] Equally productive approaches make use of the de novo synthesis of furanose or pyranose rings via cycloaddition or cyclization reactions on cyclic[7] or acyclic intermediates.[8] We desired a pyranose β-*C*-glycoside synthesis that would allow coupling of preformed glycoside units without disrupting the stereochemistry at the exo carbon adjacent to the anomeric position.[9] The extensive literature describing the electrophile-induced cyclization of carbohydrate-derived alkenols[10] encouraged us to pursue this methodology for the generation of the acyclic precursors. However, we realized that attaining selective 6-endo (versus 5-exo)[11] cyclization would be a problem. Both steric and electronic (inductive) effects can influence the stereo- and regiochemical outcome of the cyclization reaction. For example,

(1) Taken from the Ph.D. thesis of B.R.T.

(2) (a) Babirad, S. A.; Wang, Y.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 1370. (b) Wu, T.-C.; Goekjian, P. G., Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4819. (c) Goekjian, P. G.; Wu, T.-C.; Kang, H.-Y.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4823. (d) Babirad, S. A.; Wang, Y.; Goekjian, P. G.; Kishi, Y. *J. Org. Chem.* **1987**, *52*, 4825. (e) Wang, Y.; Goekjian, P. G.; Ryckman, D. M.; Kishi, Y. *J. Org. Chem.* **1988**, *53*, 4151.

(3) Miller, W. H.; Ryckman, D. M.; Goekjian, P. G.; Wang, Y.; Kishi, Y. *J. Org. Chem.* **1988**, *53*, 5580.

(4) Examples include showdomycin: Barton, D. H. R.; Ramesh, M. *J. Am. Chem. Soc.* **1990**, *112*, 891 and references therein. Palytoxin: Armstrong, R. W.; Beau, J. M.; Cheon, S. H.; Christ, W. J.; Fujioka, H.; Ham, W. H.; Hawkins, L. D.; Kishi, Y.; Jin, H.; Kang, S. H.; Tino, J. A.; Taniguchi, M.; Uenishi, J.; Ueda, K.; Talamas, F. X.; Stutz, A. E.; White, J. B.; Yonaga, M.; Mcwhorter, W. W.; Nakata, M.; Martinelli, M. J.; Mizuno, M. *J. Am. Chem. Soc.* **1989**, *111*, 7525.

(5) (a) Peseke, K.; Abrosi, H. D.; Michalik, M. *Carbohydr. Res.* **1989**, *194*, 87. (b) Bamford, M. J.; Coe, P. L.; Walker, R. T. *J. Med. Chem.* **1990**, *33*, 2494. (c) Related compounds: Danishefsky, S. J.; Pearson, W. H.; Harvey, D. F.; Maring, C. J.; Spring, J. P. *J. Am. Chem. Soc.* **1985**, *107*, 1256.

(6) For a comprehensive listing of methods for C-glycosidation, see: Herscovici, J.; Muleka, K.; Boumaiza, L.; Antonakis, K. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1995.

(7) Ireland, R. E.; Thaisrivongs, S.; Wilcox, C. S. *J. Am. Chem. Soc.* **1980**, *102*, 1155. Burke, S. D.; Armistead, D. M.; Schoenen, F. J. *J. Org. Chem.* **1984**, *49*, 4320. Curran, D. P.; Suh, Y. G. *Carbohydr. Res.* **1987**, *171*, 161.

(8) Myles, D. C.; Danishefsky, S. J.; Schulte, G. *J. Org. Chem.* **1990**, *55*, 1636 and references cited therein.

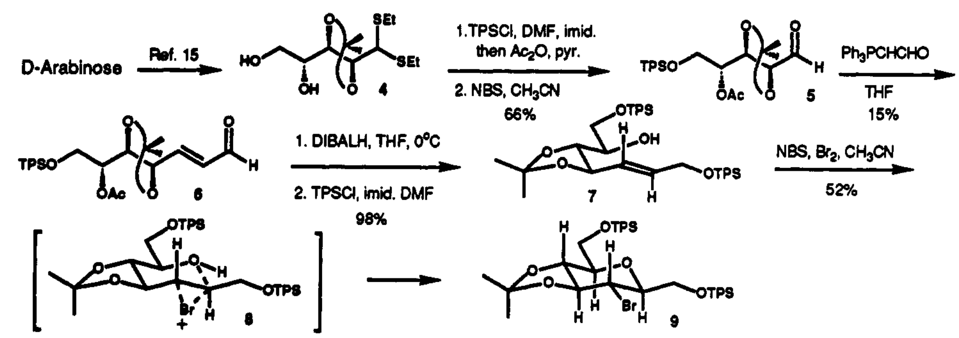
(9) In general, many previously developed methods meet this criteria (i.e., Diels–Alder reactions, Claissen rearrangements, any 6-endo cyclization). However, construction of C-oligosaccharides using carbohydrate precursors provides a complementary route to these targets (vide infra).

(10) Sinay provided one of the first examples of a 6-*exo-trig* cyclization of a glucose-derived δ-hydroxyalkene, with predominant formation of the α-anomer. In general, the directing effect of allylic hydroxy groups in 5- and 6-exo cyclizations result in products with cis relationship between the alcohol and the carbon on the newly formed stereocenter: Pougny, J. R.; Nassr, M. A. M.; Sinay, P. *J. Chem. Soc., Chem. Commun.* **1981**, 375. For comprehensive studies on carbohydrate substrates, see: Reitz, A. B.; Nortey, S. O.; Maryanoff, B. E.; Liotta, D.; Monahan, R. *J. Org. Chem.* **1987**, *52*, 4191 and references cited therein.

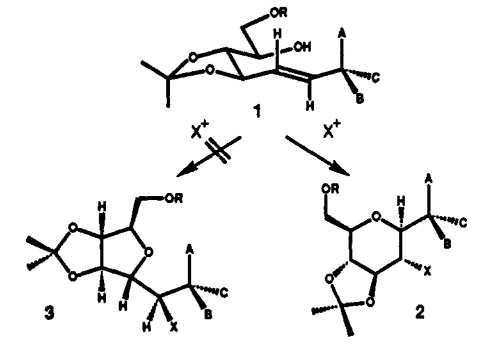
(11) Baldwin, J. E. *J. Chem. Soc., Chem. Comm.* **1976**, 734.

0022-3263/92/1957-0915$03.00/0 

**Scheme I**




Yoshida[12] has found that iodoetherification of some substituted 4-pentene-1,3-diols affords a predominance of tetrahydropyran (over tetrahydrofuran) products when all substituents in the former are equatorial. More predictable and regiospecific 6-endo cyclization of $\gamma$-hydroxyalkenes and hydroxy epoxides[13] has been achieved by inductive stabilization of the developing positive charge in the transition state. These elegant approaches unfortunately place constraints on the nature of the substituents at the exo anomeric carbon. For our purposes, a modification of the cyclization event was necessary to avoid involvement of this atom. We reasoned that electrophile-induced cyclizations[14] of *trans*-acetonide olefins of the type shown in structure 1 should yield exclusively the desired pyranose



product 2, because the competing *5-exo-trig* cyclization to the trans-fused [3.3.0] bicyclic structure 3 requires a highly strained transition state. Olefins of type 1 are readily available through the Wittig condensation, avoiding perturbation of stereocenters contiguous to C1. Furthermore, anomeric configuration can potentially be controlled by the choice of *Z* (to give $\alpha$) or *E* (to give $\beta$)1 as the cyclization precursor. We wish to report the successful application of this strategy to the synthesis of $\alpha$-methyl 1′,2′-dideoxycellobioside (22) via bromonium ion induced cyclization of olefin 17.[15]

## Results and Discussion

Initial cyclization models were generated from D-arabinose since it contains the required stereochemical relationship at C2 and C3. The one-carbon transposition of stereocenters upon homologation affords D-glucose stereochemistry at C3, C4, and C5. Thus, arabinose derivative 4[16] was converted to cyclization precursor 7 in 42% overall yield using standard techniques (Scheme I). When an acetonitrile solution of 7 was exposed to *N*-bromosuccinimide, only starting material was recovered. However, addition of catalytic $Br_2$ to the NBS/$CH_3CN$ solution resulted in a 52% yield of a *single* diastereomer 9, with an equatorial bromine at C2 and the $\beta$-configuration at the anomeric position.[17] The $^1H$ NMR spectrum of 9 shows large H1–H2 and H4–H5 coupling constants (9.7 and 9.1 Hz, respectively), confirming the trans diaxial relationship of these sets of hydrogens. Diastereomer 9 is presumably formed via the six-membered-ring transition state 8.

Extension of this cyclization strategy to the synthesis of 1,4-C-disaccharides containing no glycosidic oxygen was then investigated (Scheme II). Aldehyde 12 was generated from D-arabinose in five steps in 43% overall yield. Conversion of 10[18] to the phosphonium salt 11 and condensation with aldehyde 12 afforded a 67% combined yield of 13 and 14 (1:3 *E*/*Z*). The mixture of olefins was photochemically isomerized[19] to a 2:3 *E*/*Z* mixture and then deprotected to the C5′/C6′ diols 15 and 16, which were readily separated by silica gel chromatography. Reprotection of the primary hydroxyl group afforded cyclization precursors 17 and 18 in 81% and 89% yield, respectively. Cyclization studies were initially undertaken on the *cis*-alkenol 18. Assuming a similar transition state as that proposed for the formation of 9, the cis isomer should afford the $\alpha$-anomer at C1′ and an equatorial bromide at C2′. All attempts at cyclization were unsuccessful, probably due to the substantial allylic strain (C3′/C4) required in the transition state. The stereochemical outcome in the cyclization of the trans isomer 17 was predicted to be the same as for model alkenol 7 due to the conformational rigidity facilitated by the isopropylidene group. However, construction of models indicated that formation of the initial bromonium ion intermediate might be difficult because of steric crowding at C4 by the C3 and C5 substituents on the pyran. We were pleased to find that cyclization of 17 with NBS/$Br_2$ in $CH_3CN$ resulted in the formation of disaccharide 19 as a *single* diastereomer in 32% yield. Other products obtained included the noncyclized mixture of isomeric dibromides (~30%) and several compounds resulting from debenzylation at C6 of the benzyl ether (~20%).

(12) Tamaru, T.; Hojo, M.; Kawamaura, S.-I.; Sawada, S.; Yoshida, Z.-I. *J. Org. Chem.* **1987**, *52*, 4062.
(13) A systematic study of acid-catalyzed cyclizations of hydroxy epoxides resulting in stereoselective synthesis of tetrahydrofuran and tetrahydropyran systems has recently appeared, including a thorough citation of previous work: Nicolaou, K. C.; Prasad, C. V. C.; Somers, P. K.; Hwang, C.-K. *J. Am. Chem. Soc.* **1989**, *111*, 5330.
(14) Brominative cyclizations to pyran derivatives directed by inductive stabilization of transition states have been previously reported: (a) Kato, T.; Ichinose, I.; Hosogai, T.; Kitahara, Y. *Chem. Lett.* **1976**, 1187. (b) Ting, P. C.; Bartlett, P. A. *J. Am. Chem. Soc.* **1984**, *106*, 2668. (c) Jung, M. E.; Lew, W. *J. Org. Chem.* **1991**, *56*, 1347.
(15) Carbohydrate-related pyran dimers which are C1 linked have been reported as byproducts: Dubois, E.: Beau, J.-M. *J. Chem. Soc., Chem. Commun.* **1990**, 1191.
(16) Fried, J.; Walz, D. E. *J. Am. Chem. Soc.* **1949**, *71*, 140. Zinner, H.; Tembarz, G.; Klocking, H. P. *Chem. Ber.* **1957**, *90*, 2688.
(17) Addition of bromine vapor to a stirring solution of NBS/$CH_3CN$ was the most reproducible protocol. Slow addition of bromine resulted mostly in dibromide biproducts.
(18) Daly, S. M.; Armstrong, R. W. *Tetrahedron Lett.* **1989**, *30*, 5713.
(19) Lorenz, K.; Lichtenthaler, F. W. *Tetrahedron Lett.* **1987**, *28*, 6437.

Scheme II

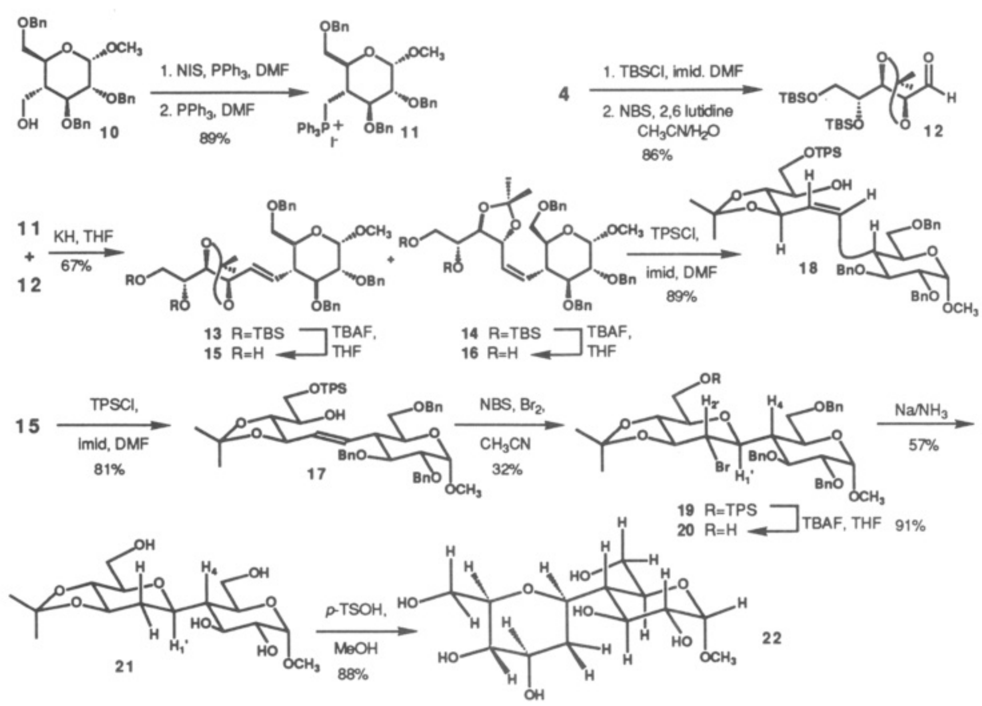
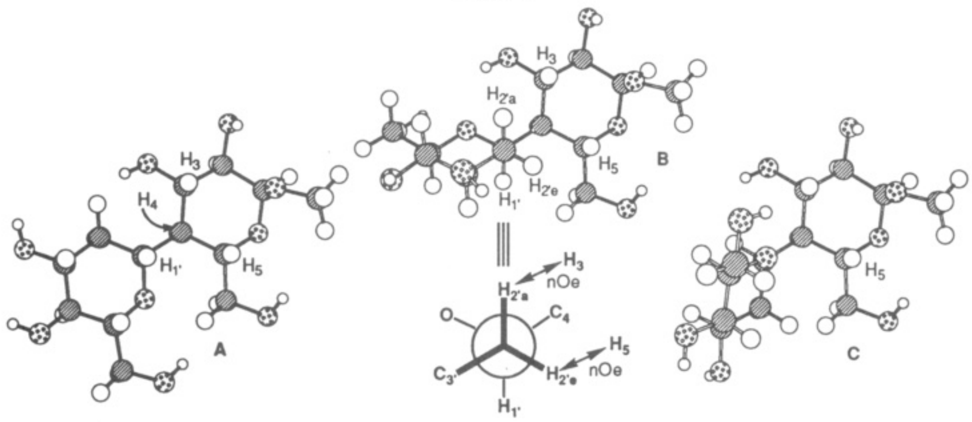


Chart I



In an attempt to increase the efficiency of cyclization and minimize the formation of byproducts, we investigated other conditions with varying success. For instance, 2,4,4,6-tetrabromocyclohexa-2,5-dienone[14c] afforded **19** in acetonitrile (34–38%) and nitromethane (19%) only in the presence of catalytic $Br_2$. *N*-Bromosuccinimide in methylene chloride or acetonitrile gave no reaction. The effect of the C6′ blocking group on the cyclization efficiency was also investigated. Exchange of the TPS protecting group for benzyl or benzoyl resulted in low yields (0–11%) even under the best cyclization conditions. Deprotection of silyl ether **19** afforded bromide **20** which could be directly reduced with sodium in liquid ammonia/THF to tetrol **21**.[20] Acid hydrolysis of the isopropylidene group afforded the α-methyl glycoside of 1′,2′-dideoxycellobiose **22** in 45% yield from **19**. The stereochemistry of the *C*-disaccharide intermediates **19–22** was unambiguously established by $^1$H NMR analysis (Table I). The coupling constant between H1′ and H4 in **19**, **20**, and **21** (in $CDCl_3$) is zero, suggesting that the dihedral angle about C1′/C4 is near 90° in the preferred conformation. As a consequence, H1′ is an apparent doublet with a large coupling constant (**19**: $J_{1',2'a}$ = 10.3 Hz; **20**: $J_{1',2'a}$ = 9.7 Hz; **21**: $J_{1',2'a}$ = 10.5 Hz) reflecting the diaxial relationship to H2′$_a$ and confirming the β stereochemistry at the anomeric carbon. Similarly, the H4 hydrogen is an apparent triplet as a result of the near-identical trans diaxial couplings to H3 and H5. All disaccharides show strong nuclear Overhauser enhancements (NOE) between H1′ and H4. Unlike intermediates **19–21** (in $CDCl_3$), polyol **22** (in $CD_3OD$) exhibits a 2.5-Hz coupling constant between H1′ and H4. Solvent effects play a role in this observation, since comparison of this same coupling constant for **21** in $CD_3OD$ reveals a value of 1.7 Hz. Conformational changes induced by removal of the isopropylidine might also influence this value.

The Karplus relation[22] can be used to correlate the H1′ to H4 coupling constant with the interring conformation of the preferred rotamer. The contribution to the coupling constant should be large for rotamer A because of the anti relationship between these two hydrogens and small for gauche rotamers B and C (60°). The observation of a zero coupling constant for compounds **19–21** in a wide tem-

(20) A small quantity (10%) of reductive elimination products were observed.

(21) Compounds **9**, **19**, and **20** are at a field strength of 360 MHz; **21** and **22** are at 500 MHz.

(22) Karplus, M. *J. Chem. Phys.* **1959**, *30*, 11. Karplus, M. *J. Am. Chem. Soc.* **1963**, *85*, 2870.

Chart II

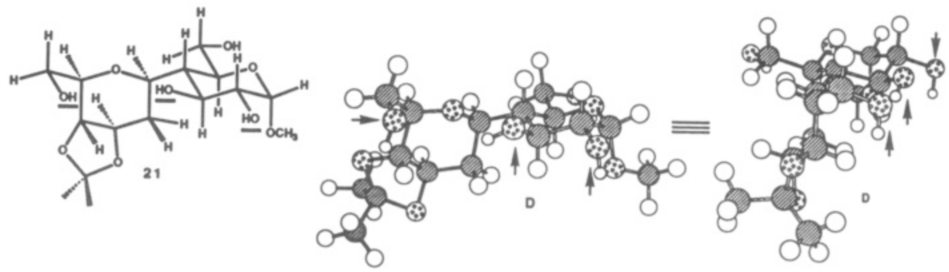
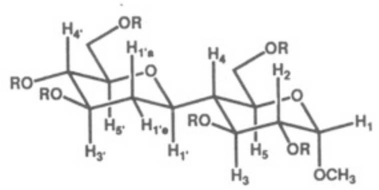



**Table I. Comparison of Coupling Constants (Hz) for Ring Protons of *C*-Disaccharides 19–22 and Monosaccharide 9[21]**



| | 9 ($CDCl_3$) | 19 ($CDCl_3$) | 20 ($CDCl_3$) | 21 ($CDCl_3$) | 21 ($CD_3OD$) | 22 ($CD_3OD$) |
|---|---|---|---|---|---|---|
| $J_{1,2}$ | | 3.8 | 3.7 | 3.9 | 3.7 | 3.8 |
| $J_{2,3}$ | | 9.4 | 9.2 | 8.7 | | 9.5 |
| $J_{3,4}$ | | 10.6 | 9.8 | 9.2 | 10.7 | 10.2 |
| $J_{4,5}$ | | 10.4 | 9.7 | 9.9 | 10.7 | 10.5 |
| $J_{4,1'}$ | | 0 | 0 | 0 | 1.7 | 2.5 |
| $J_{1',2'a}$ | 9.7 | 10.3 | 9.7 | 10.5 | 11.6 | 11.8 |
| $J_{1',2'e}$ | | | | 2.6 | 3.1 | 1.9 |
| $J_{2'a,3'}$ | 10.6 | 9.9 | 10.3 | 10.5 | 11.6 | 11.6 |
| $J_{2'e,3'}$ | | | | 2.6 | 3.4 | 5.0 |
| $J_{3',4'}$ | 8.9 | 9.4 | 8.7 | 9.1 | 9.1 | 8.7 |
| $J_{4',5'}$ | 9.1 | 9.1 | 9.0 | 9.1 | 9.1 | 9.3 |

perature range (−40 to +25 °C) suggests that a conformation resembling structure B or C should be favored. Van der Waals contacts between the C6 and C2′ hydrogens in C effectively rule out rotamers with this general conformation. NOE experiments on **20–22** provide additional support for general structure B. Enhancements between $H2'_{eq}$–H5 and $H2'_{ax}$–H3 are clearly observable.[23] The small distortion induced by the trans bicyclic nature of the sugar containing the ketal might account for a dihedral value larger than 60°. In contrast, the fully deprotected polyol **22** ($CD_3OD$) exhibits an average value more in line with a staggered conformation.

When triol **21** is viewed down the C4/C1′ bond connecting the two sugars and is drawn as rotamer D (same as general structure B), the hydroxyl groups at C2, C3, and C6′ are essentially planar (these groups are underlined and highlighted with arrows). This feature might explain the NMR behavior ($CDCl_3$) of **21** at low temperature. From −20 to −40 °C, the spectrum of **21** gradually converts to a new species which exhibits sharp lines and appears to be an aggregate of **21**. The formation ($CDCl_3$) of hydrogen bonds in a cooperative fashion might facilitate this complexation. No substantial change was observed in the variable temperature spectra of **19** and **20** (in $CDCl_3$) or **22** (in $CD_3OD$).

## Conclusions

The synthesis of α-methyl 1′,2′-dideoxycellobioside (**22**) has been achieved via a cyclization route which does not involve the exo anomeric carbon in the cyclization process. Regiochemical control is achieved by the use of a trans-fused isoproylidene ring involving the erythro allylic and homoallylic oxygens in the starting alkenols. The required erythro relationship of these oxygen substituents limits the scope of this method to the synthesis of glucono-β-*C*-glycosides with the possibility of reduction to the 2′-deoxy derivatives or heteroatom substitution at C2′ (Br → X). Structural demands of the ylide-containing sugar fragment should be less restrictive. For instance, generation of 2′-deoxy-glu-man or 2′-deoxy-glu-gal as well as 2′-deoxy-glu-furan dimers should be possible. Many methods are known for stereospecific synthesis of *C*-glycosides, but the C5 + C7 strategy for the synthesis of C6 + C6 dimers offers a rapid entry into these interesting targets. The apparent conformational lock which compound **22** exhibits provides a unique structural motif which may prove to be useful in controlling localized conformations of larger oligosaccharides. The selective homologation of these disaccharides to oligosaccharides is the focus of current studies in our laboratories.

## Experimental Section

**General Information.** $^1H$ and $^{13}C$ NMR spectra were recorded at the field strength specified in MHz. Chemical shifts are reported in ppm with $CHCl_3$, acetone-$d_6$, or DMSO-$d_6$ as internal standards. Tetrahydrofuran, diethyl ether, and toluene solvents were distilled from sodium benzophenone ketyl under $N_2$. Methylene chloride was distilled from $P_2O_5$. Dimethylformamide, diisopropylamine, and dimethyl sulfoxide were distilled from barium oxide under $N_2$ and stored over 4-Å molecular sieves. Tetrabutylammonium fluoride (TBAF), *tert*-butyldimethylsilyl chloride (TBSCl), and *tert*-butyldiphenylsilyl chloride (TPSCl) as well as all other reagents were used as supplied. All crude organic extracts were dried with sodium sulfate unless noted otherwise. Solvents were removed under reduced pressure using a rotary evaporator. Unless otherwise noted, flash chromatography was performed on Merck silica gel 60 (230–400 mesh) using various gradients of hexanes/ethyl acetate as eluants. Small-scale separations (<60 mg) were done on Fischer Prep-Sep silica columns or MSD preparative thin-layer chromatography (0.25-, 0.5-, 1.0-, and 2.0-mm thicknesses).

**2,3:4,5-Di-*O*-isopropylidene-D-arabinose Diethyl Dithioacetal.** A slurry of arabinose (10.78 g, 71.81 mmol) and ethanethiol (50 mL) was treated with a catalytic amount of concd HCl (3 drops) and shaken vigorously for 30 min. The excess ethanethiol was removed under reduced pressure using a bleach trap, and the resultant cake was dissolved in reagent-grade acetone (100 mL) and shaken for 2 h. The HCl was neutralized with aqueous ammonia and the solvent removed. The residue was chromatographed to provide 13.98 g (58%) of dithioacetal as a pale yellow oil along with dithioacetone: $^1H$ NMR (500 MHz, $CDCl_3$) δ 4.29 (dd, $J_{2,1}$ = 2.7 Hz, $J_{2,3}$ = 6.7 Hz, 1 H, $H_2$), 4.12–4.15 (m, 1 H, $H_5$), 4.05–4.09 (m, 2 H, $H_3$ and $H_5$), 4.03 (s, $J_{1,2}$ = 2.7 Hz, 1 H, $H_1$), 3.96 (dd, $J$ = 4.7, 8.38 Hz, 1 H, $H_5$), 2.66–2.79 (m, 4 H, $CH_3CH_2S$), 1.44 (s, 3 H, $CH_3$), 1.41 (s, 3 H, $CH_3$), 1.37 (s, 3 H, $CH_3$), 1.33, (s, 3 H, $CH_3$), 1.27 (t, $J$ = 8.9 Hz, 3 H, $CH_3CH_2S$), 1.26 (t, $J$ = 8.9 Hz, 3 H, $CH_3CH_2S$).

**2,3-*O*-Isopropylidene-D-arabinose Diethyl Dithioacetal (4).** The diisopropyl arabinose (2.18 g, 6.49 mmol) was dissolved in methanol (20 mL) with water (2 mL). A catalytic quantity of *p*-toluenesulfonic acid (50 mg) was added and the mixture stirred for 36 h at −10 °C. The acid was then neutralized with tri-

(23) NOE data has been successfully applied to the conformational analysis of carbohydrates: Williams, N. R.; Davison, B. E.; Ferrier, R. J.; Furneax, R. H. *Carbohydr. Chem.* 1985, *17*, 205 and ref 2.

ethylamine and the solvent removed under reduced pressure. The resulting syrup was chromatographed to provide 1.65 g (86%) of the diol arabinose 4 as a colorless oil, and 139 mg of starting material were recovered: $[\alpha]_D$ = +56.5° (*c* 0.0092, $CHCl_3$); IR (film, $cm^{-1}$) 3395, 2968; $^1$H NMR (360 MHz, $CDCl_3$) δ 4.32 (dd, $J_{2,1}$ = 3.9 Hz, $J_{2,3}$ = 6.9 Hz, 1 H, $H_2$), 4.11 (dd, $J_{3,4}$ = $J_{3,2}$ = 7.0 Hz, 1 H, $H_3$), 4.10 (dd, $J_{5,4}$ = 7.2 Hz, $J_{gem}$ = 14.2 Hz, 1 H, $H_5$), 4.02 (d, $J_{1,2}$ = 3.9 Hz, 1 H, $H_1$), 3.67–3.85 (m, 2 H, $H_4$ and $H_5$), 3.00 (bd, *J* = 4.4 Hz, 1 H, O*H*), 2.65–2.79 (m, 4 H, $SCH_2CH_3$), 2.46 (bs, 1 H, O*H*), 1.45 (s, 3 H, $CH_3$), 1.38, (s, 3 H, $CH_3$), 1.26 (t, *J* = 7.7 Hz, 3 H, $SCH_2CH_3$), 1.26 (t, *J* = 7.3 Hz, 3 H, $SCH_2CH_3$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 109.9, 83.3, 78.7, 73.1, 63.8, 53.0, 27.1, 26.9, 25.1, 24.8, 14.2; low-resolution MS *m/e* 296 ($M^+$, 15), 217 (18), 177 (15), 135 (100). Anal. Calcd for $C_{12}H_{24}O_4S_2$: C, 48.62 H, 8.16 S, 21.63. Found: C, 48.59 H, 8.11 S, 21.64.

**4-*O*-Acetyl-5-*O*-(*tert*-butyldiphenylsilyl)-2,3-*O*-isopropylidene-D-arabinose Diethyl Dithioacetal.** To a solution of diol arabinose 4 (0.946 g, 3.20 mmol) and imidazole (0.650 g, 9.61 mmol) in DMF (10 mL) was added TDPSCl (1 mL, 3.84 mmol). This solution was stirred 4 h at 25 °C until all starting material was consumed (monitored by TLC). At 0 °C pyridine (5 mL) and then $Ac_2O$ (1.3 ml, 14.2 mmol) were added and stirring continued for 2 d at 60 °C. The solvents were removed under high vacuum and the residue was extracted with aqueous $NaHCO_3$. The aqueous phase was extracted twice with 20 mL portions of $CHCl_3$. The concentrated crude organic extract was chromatographed to provide 1.27 g (69%) of the 5-siloxy-4-acetyl arabinose derivative as a colorless oil. $[\alpha]_D$ = +38.1° (*c* 0.0085, $CHCl_3$); IR (film) $cm^{-1}$: 2930, 2857, 1734; $^1$H NMR (360 MHz, $CDCl_3$) δ, 7.37-7.73 (m, 10 H, Ar*H*), 5.18 (ddd, $J_{4,5}$ = 3.6 Hz, $J_{4,5}$ = 5.6 Hz, $J_{4,3}$ = 6.9 Hz, 1 H, $H_4$), 4.48 (dd, $J_{3,2}$ = $J_{3,4}$ = 6.9 Hz, 1 H, $H_3$), 4.37 (dd, $J_{2,1}$ = 3.6 Hz, $J_{2,3}$ = 6.9 Hz, 1 H, $H_2$), 3.99 (dd, $J_{5,4}$ = 3.6 Hz, $J_{gem}$ = 11.3 Hz, 1 H, $H_5$), 3.91 (dd, $J_{5,4}$ = 5.6 Hz, $J_{gem}$ = 11.3 Hz, 1H, $H_5$), 3.89 (d, $J_{1,2}$ = 3.6 Hz, 1 H, $H_1$), 2.67–2.80 (m, 4 H, $SCH_2CH_3$), 2.07 (s, 3 H, $CH_3$), 1.48 (s, 3 H, $CH_3$), 1.36 (s, 3 H, $CH_3$), 1.28 (t, *J* = 7.43 Hz, 6 H, $SCH_2CH_3$), 1.10 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 169.6, 135.3, 135.3, 134.5, 132.9, 132.9, 129.5, 129.5, 129.2, 127.5, 127.5, 127.3, 110.2, 82.5, 76.8, 74.4, 62.4, 53.2, 27.0, 26.9, 26.5, 26.3, 25.0, 24.7, 20.7, 18.9, 14.1; HR FAB MS Calcd for $C_{30}H_{44}O_5S_2Si$: 577.2478 ($MH^+$), Found 577.2470.

**4-*O*-Acetyl-5-*O*-(*tert*-butyldiphenylsilyl)-2,3-*O*-isopropylidene-D-arabinose (5).** A solution of the dithioacetal (1.213 g, 2.10 mmol) and 2,6-lutidine (1.71 mL, 14.72 mmol) in $CH_3CN/H_2O$ (25 mL/10 mL) was treated with NBS (2.25 g, 12.62 mmol), and the mixture was stirred at 25 °C for 10 min. Excess NBS was destroyed with aqueous $NaHSO_3$, and the solution was extracted with aqueous $NaHCO_3$. The aqueous phase was extracted three times with 40-mL portions of $CHCl_3$. The combined organic extracts were concentrated and purified by flash chromatography (20% EtOAc in hexanes) to provide 936 mg (95%) of aldehyde 5 as a pale yellow oil: $^1$H NMR (360 MHz, $CDCl_3$) δ 9.72 (d, $J_{1,2}$ = 1.8 Hz, 1 H, $H_1$), 7.40–7.70 (m, 10 H, Ar*H*), 5.21 (ddd, $J_{4,5}$ = 3,3 Hz, $J_{4,5}$ = 4.4 Hz, $J_{4,3}$ = 5.8 Hz, 1 H, $H_4$), 4.41 (dd, ABX, $J_{3,2}$ = $J_{3,4}$ = 6.4 Hz, 1 H, $H_3$), 4.37 (dd, ABX, $J_{2,1}$ = 1.8 Hz, $J_{2,3}$ = 6.4 Hz, 1 H, $H_2$), 3.91 (dd, ABX, $J_{5,4}$ = 3.3 Hz, $J_{gem}$ = 10.7 Hz, 1 H, $H_5$), 3.87 (dd, ABX, $J_{5,4}$ = 4.4 Hz, $J_{gem}$ = 10.7 Hz, 1 H, $H_5$), 2.09 (s, 3 H, $CH_3$), 1.45 (s, 3 H, $CH_3$), 1.41 (s, 3 H, $CH_3$), 1.07 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 199.8, 170.1, 135.5, 135.5, 133.0, 132.9, 129.8, 129.7, 127.7, 111.6, 62.2, 74.7, 73.3, 62.6, 26.7, 26.6, 26.0, 20.8, 19.1.

**(*E*)-5-*O*-Acetyl-6-*O*-(*tert*-butyldiphenylsilyl)-1-formyl-3,4-*O*-isopropylidene-1,2-dideoxy-D-*gluco*-hex-1-enose (6).** To a solution of the arabinose aldehyde 5 (0.604 g, 1.28 mmol) in THF (10 mL) was added acetylmethylene–triphenylphosphorane (0.812 g, 2.67 mmol) at 25 °C. Stirring was continued for 12 h, and the solution was then extracted with saturated $NH_4Cl$. The aqueous phase was extracted three times with $CHCl_3$. The combined organic extracts were concentrated and chromatographed on silica (hexanes/ethyl acetate) to provide 75 mg (12%) of the (*E*)-α,β-unsaturated aldehyde 6 as a colorless oil (the major product is polymeric material): $[\alpha]_D$ = +12.0° (*c* 0.0377, $CHCl_3$); IR (film, $cm^{-1}$) 2932, 2858, 1746, 1700; $^1$H NMR (360 MHz, $CDCl_3$) δ 9.58 (d, $J_{1,2}$ = 7.9 Hz, 1 H, $H_1$), 7.39–7.67 (m, 10 H, Ar*H*), 6.75 (dd, $J_{3,4}$ = 5.2 Hz, $J_{trans}$ = 15.7 Hz, 1 H, $H_3$), 6.36 (ddd, $J_{w(2,4)}$ = 1.4 Hz, $J_{2,1}$ = 7.9 Hz, $J_{trans}$ = 15.7 Hz, 1 H, $H_2$), 5.16 (ddd, $J_{6,5}$ = 6.5 Hz, $J_{6,7}$ = 4.1 Hz, $J_{6,7}$ = 4.9 Hz, 1 H, $H_6$), 4.64 (ddd, $J_{w(4,2)}$ = 1.4 Hz, $J_{4,3}$ = 5.2 Hz, $J_{4,5}$ = 7.9 Hz, 1 H, $H_4$), 4.11 (dd, $J_{5,6}$ = 6.5 Hz, $J_{5,4}$ = 7.9 Hz, 1 H, $H_5$), 3.84–3.92 (m, AB, 2 H, $H_7$), 2.04 (s, 3 H, $CH_3$), 1.42 (s, 6 H, $CH_3$), 1.06 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 192.9, 169.9, 152.5, 135.5, 135.4, 132.9, 132.4, 129.8, 129.8, 127.7, 127.7, 110.6, 78.3, 77.5, 73.6, 62.6, 26.7, 26.6, 26.5, 20.8, 19.1.

**(*E*)-6-*O*-(*tert*-Butyldiphenylsilyl)-3,4-*O*-isopropylidene-1,2-dideoxy-1-(hydroxymethyl)-D-*gluco*-hex-1-enose.** The unsaturated aldehyde 6 (69 mg, 0.139 mmol) was dissolved in THF (2 mL) and cooled to −78 °C. DIBALH (0.5 mL, 0.75 mmol, 1.5 M in toluene) was added, and the solution was stirred for 25 min. The excess DIBALH was destroyed with methanol and the solution extracted with saturated $NH_4Cl$. The aqueous phase was extracted with two 5-mL portions of $CHCl_3$. The combined organic phase was concentrated and chromatographed (hexanes/ethyl acetate) to provide 63 mg (99%) of diol as a clear colorless oil: $[\alpha]_D$ = +2.1° (*c* 0.0313, $CHCl_3$); IR (film, $cm^{-1}$) 3417, 2931, 2858; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.39–7.67 (m, 10 H, Ar*H*), 5.97 (dt, $J_{2,1}$ = 5.2 Hz, $J_{trans}$ = 15.6 Hz, 1 H, $H_2$), 5.79 (ddt, $J_{w(3,1)}$ = 1.5 Hz, $J_{3,4}$ = 6.8 Hz, $J_{trans}$ = 15.6 Hz, 1 H, $H_3$), 4.46 (dd, $J_{4,3}$ = 6.8 Hz, $J_{4,5}$ = 7.2 Hz, 1 H, $H_4$), 4.10–4.14 (m, 2 H, $H_1$), 3.72–3.83 (m, AB, 4 H, $H_5$, $H_6$, $H_7$), 2.57 (d, *J* = 4.4 Hz, 1 H, OH), 1.40 (s, 3 H, $CH_3$), 1.36 (s, 3 H, C $H_3$), 1.06 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 135.5, 135.5, 133.1, 133.0, 132.8, 129.8, 129.8, 128.8, 127.8, 127.7, 109.1, 80.1, 79.2, 77.2, 72.6, 64.9, 62.5, 26.9, 26.8, 26.8, 19.2; FAB MS *m/e* 455 ($M^+$ − H, 1), 441 ($M^+$ − $CH_3$, 4), 399 ($M^+$ − *tert*-butyl, 6); HR FAB MS calcd for $C_{26}H_{35}O_5Si$ 455.2254 ($M^+$ − H), found 455.2263. Anal. Calcd for $C_{26}H_{36}O_5Si$: C, 68.39; H, 7.95. Found: C, 68.45; H, 7.70.

**(*E*)-6-*O*-(*tert*-Butyldiphenylsilyl)-3,4-*O*-isopropylidene-1,2-dideoxy-1-[(*tert*-butyldiphenylsiloxy)methyl]-D-*gluco*-hex-1-enose (7).** A solution of the alcohol (41 mg, 0.090 mmol) and imidazole (30 mg, 0.444 mmol) in DMF (2 mL) was treated with *tert*-butylchlorodiphenylsilane (25 μL, 0.096 mmol). This solution was allowed to stir for 2 h at 25 °C. The excess silane was decomposed with methanol and the solvent removed under high vacuum to provide a crude yellow paste. The crude material was directly chromatographed (hexanes/ethyl acetate) to provide 63 mg (100%) of disilyl olefin 7 as a clear colorless oil: $[\alpha]_D$ = +3.5° (*c* 0.0313, $CHCl_3$); IR (film, $cm^{-1}$) 3444, 3070, 2930; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.40–7.77 (m, 20 H, Ar*H*), 5.91–5.92 (m, 2 H, $H_2$, $H_3$), 4.51–4.54 (m, 1 H, $H_4$), 4.24 (m, 2 H, $H_1$), 3.80–3.86 (m, AB, 4 H, $H_5$, $H_6$, $H_7$), 2.61 (s, 1 H, O*H*), 1.44 (s, 3 H, $CH_3$), 1.41 (s, 3 H, $CH_3$), 1.11 (s, 9 H, $(CH_3)_4CSi$), 1.10 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 135.5, 135.5, 135.5, 135.2, 134.8, 133.5, 133.0, 132.9, 132.6, 129.8, 129.6, 129.6, 127.8, 127.7, 127.6, 127.6, 127.6, 109.0, 80.3, 79.1, 72.7, 64.8, 63.6, 26.9, 26.8, 26.8, 26.5, 19.2, 19.2, 19.0; FAB MS *m/e* 693 ($M^+$ − H, 1), 637 ($M^+$ − *tert*-butyl, 2), 199 (100); HR FAB MS calcd for $C_{42}H_{53}O_5Si_2$ 693.3432 ($M^+$ − H), found 693.3456.

**2-Bromo-6-*O*-(*tert*-butyldiphenylsilyl)-1,2-dideoxy-3,4-*O*-isopropylidene-1-*C*-[(*tert*-butyldiphenylsiloxy)methyl]-β-D-*gluco*-hexopyranose (9).** To a solution of the olefin 7 (24 mg, 0.035 mmol) in $CH_3CN$ (2 mL) was added NBS (19 mg, 0.105 mmol). The cyclization was initiated by the addition of a catalytic amount of $Br_2$ vapors applied directly to the top of the stirring solution. After 5 min the excess halogen was decomposed with aqueous $NaHSO_3$ and then extracted with aqueous $NaHCO_3$. The aqueous phase was extracted with two 10-mL portions of $CHCl_3$. The combined organic extracts were concentrated and chromatographed to provide 14 mg (52%) of the cyclic bromide 9 as a clear colorless oil: $[\alpha]_D$ = +2.7° (*c* 0.0140, $CHCl_3$); IR (film, $cm^{-1}$) 3071, 2930; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.3–7.7 (m, 20 H, Ar*H*), 4.24 (dd, $J_{2,1}$ = 9.7 Hz, $J_{2,3}$ = 10.6 Hz, 1 H, $H_2$), 4.09 (dd, $J_{1',1}$ = 3.3 Hz, $J_{gem}$ = 11.3 Hz, 1 H, $H_{1'}$), 4.04 (dd, $J_{1',1}$ = 1.4 Hz, $J_{gem}$ = 11.3 Hz, 1 H, $H_{1'}$), 3.94 (dd, $J_{6,5}$ = 2.4 Hz, $J_{gem}$ = 11.4 Hz, 1 H, $H_6$), 3.85 (dd, $J_{6,5}$ = 4.9 Hz, $J_{gem}$ = 11.4 Hz, 1 H, $H_6$), 3.71 (dd, $J_{3,4}$ = 8.9 Hz, $J_{3,2}$ = 10.6 Hz, 1 H, $H_3$), 3.67 (ddd, $J_{5,6}$ = 2.4 Hz, $J_{5,6}$ = 4.9 Hz, $J_{5,4}$ = 9.1 Hz, 1 H, $H_5$) 3.54 (ddd, $J_{1,1'}$ = 1.4 Hz, $J_{1,1'}$ = 3.3 Hz, $J_{1,2}$ = 9.7 Hz, 1 H, $H_1$), 3.50 (dd, $J_{4,3}$ = 8.9 Hz, $J_{4,5}$ = 9.1 Hz, 1 H, $H_4$), 1.56 (s, 3 H, $CH_3$), 1.49 (s, 3 H, $CH_3$), 1.05 (s, 9 H, $(CH_3)_4CSi$), 1.04 (s, 9 H, $(CH_3)_4CSi$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 135.7, 135.3, 134.8, 129.6, 129.6, 127.6, 127.6, 110.8, 83.7, 81.6, 79.5, 75.7, 64.1, 63.1, 45.6, 26.8, 26.7, 19.3, 19.3; FAB MS *m/e* 773 ($MH^+$, 1), 319 (2), 199 (23); HR FAB MS calcd for $C_{42}H_{54}$-

$BrO_5Si_2$ 773.2693 ($MH^+$), found 773.2719. Anal. Calcd for $C_{42}H_{53}BrO_5Si_2$: C, 65.18; H, 6.90; Br, 10.32. Found: C, 65.27; H, 6.89; Br, 9.99.

**Methyl 4-Deoxy-4-*C*-(iodomethylene)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside.** A solution of alcohol 10 (3.33 g, 6.96 mmol), $PPh_3$ (3.62 g, 13.8 mmol), and DMF (50 mL) was treated with NIS (3.16 g, 14.0 mmol) at 50 °C with stirring for 2 h. The DMF was removed under reduced pressure and the residue chromatographed on silica (4:1 hexane/EtOAc) to provide 3.66 g (90%) of the iodomethyleneglucose as a colorless oil: $[\alpha]_D$ = +10.7° (*c* 0.015, $CHCl_3$); IR (film, $cm^{-1}$) 3027, 2905, 2858; $^1H$ NMR (360 MHz, $CDCl_3$) δ 7.25–7.37 (m, 15 H, Ph*H*), 5.07 (d, *J* = 10.7 Hz, 1 H, PhC*H*), 4.77 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.76 (d, *J* = 10.7 Hz, 1 H, bz*H*), 4.69 (d, $J_{1,2}$ = 3.5 Hz, 1 H, $H_1$), 4.66 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.65 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 4.45 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 3.92 (dd, $J_{3,2} = J_{3,4}$ = 9.7 Hz, 1 H, $H_3$), 3.79 (dt, $J_{5,4}$ = 9.9 Hz, $J_{5,6}$ = 2.7 Hz, 1 H, $H_5$), 3.68 (dd, $J_{2,3}$ = 9.7 Hz, $J_{2,1}$ = 3.5 Hz, 1 H, $H_2$), 3.64 (dd, $J_{4',4}$ = 2.5 Hz, $J_{gem}$ = 10.6 Hz, 1 H, $H_{4'}$), 3.59 (d, $J_{6,5}$ = 2.7 Hz, 2 H, $H_6$), 3.40 (s, 3 H, $OCH_3$), 2.98 (dd, $J_{4',4}$ = 2.7 Hz, $J_{gem}$ = 10.6 Hz, 1 H, $H_{4'}$), 1.49 (tt, $J_{4,4'}$ = 2.5–2.7 Hz, $J_{4,3/4,5}$ = 9.7–9.9 Hz, 1 H, $H_4$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 138.6, 138.1, 137.7, 128.5, 128.4, 128.1, 127.9, 127.8, 127.7, 98.6, 81.1, 77.6, 75.9, 73.5, 72.9, 71.0, 68.6, 55.3, 41.1; FAB MS *m/e* 587 ($M^+$ – H, 3), 557 ($M^+$ – $CH_3O$, 2), 341 (3), 219 (4), 181 (8); HR FAB MS calcd for $C_{29}H_{32}IO_5$ 587.1295 ($M^+$ – H), found 587.1280. Anal. Calcd for $C_{29}H_{33}IO_5$: C, 59.19; H, 5.65; I, 21.56. Found: C, 58.92; H, 5.46; I, 21.46.

**Methyl 4-Deoxy-4-*C*-(triphenylmethylenephosphonium iodide)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (11).** A solution of iodide (3.64 g, 6.18 mmol) in DMF (50 mL) was treated with triphenylphosphine (8.68 g, 33.10 mmol) for 15 h at 100 °C. The DMF was removed under reduced pressure and the residue chromatographed on silica (10% MeOH/EtOAc) to provide 5.36 g (100%) of the phosphonium iodide 11 as a colorless foam. A small quantity was recrystallized from EtOAc to give pure phosphonium iodide as colorless crystals: mp = 161 °C; $[\alpha]_D$ = +56.1° (*c* 0.161, $CHCl_3$); IR (film, $cm^{-1}$) 3056, 3041, 2903; $^1H$ NMR (500 MHz, $CDCl_3$) δ 6.78–7.66 (m, 30 H, Ph*H*), 4.85 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 4.56 (d, $J_{1,2}$ = 3.4 Hz, 1 H, $H_1$), 4.27 (s, 2 H, PhC*H*), 4.24 (bd, $J_{5,4}$ = 10.3 Hz, 1 H, $H_5$), 4.14 (d, *J* = 11.4 Hz, 1 H, PhC*H*), 4.01 (dd, $J_{6,5}$ = 2.8 Hz, $J_{gem}$ = 11.9 Hz, 1 H, $H_6$), 4.00 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 3.92 (dd, $J_{3,2}$ = 9.1 Hz, $J_{3,4}$ = 10.3 Hz, 1 H, $H_3$), 3.84 (d, *J* = 11.4 Hz, 1 H, PhC*H*), 3.78 (ddd, $J_{4',4}$ = 3.4 Hz, $J_{gem}$ = 13.9 Hz, $J_{4',P}$ = 16.8 Hz, 1 H, $H_{4'}$), 3.67 (ddd, $J_{4',4}$ = 6.56 Hz, $J_{gem}$ = 13.9 Hz, $J_{4',P}$ = 16.8 Hz, 1 H, $H_{4'}$), 3.45 (dd, $J_{6,5}$ = 2.1 Hz, $J_{gem}$ = 11.9 Hz, 1 H, $H_6$), 3.25 (s, 3 H, $CH_3O$), 3.19 (dd, $J_{2,1}$ = 3.39 Hz, $J_{2,3}$ = 8.95 Hz, 1 H, $H_2$), 2.14–2.23 (m, 1 H, $H_4$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 138.5, 137.7, 137.5, 134.3, 133.9, 133.7, 129.9, 129.8, 128.2, 128.0, 127.8, 127.7, 127.3, 127.0, 119.8, 118.9, 97.4, 81.9, 79.4, 74.1, 73.2, 72.0, 70.3, 55.3, 37.8; FAB MS *m/e* 723 ($M^+$ – I, 100), 631 (7), 262 (11). Anal. Calcd for $C_{47}H_{48}IO_5P$: C, 66.35; H, 5.69; I, 14.92. Found: C, 66.12; H, 5.58; I, 14.74.

**4,5-Di-*O*-(*tert*-butyldimethylsilyl)-2,3-*O*-isopropylidene-D-arabinose Diethyl Dithioacetal.** A solution of diol arabinose 4 (2.09 g, 7.04 mmol) and imidazole (2.40 g, 35.25 mmol) in DMF (40 mL) was treated with *tert*-butylchlorodimethylsilane (3.17 g, 21.05 mmol) and stirred for 18 h at 25 °C under dry $N_2$. The DMF was removed under reduced pressure and the thick oil extracted with $NH_4Cl$ (aq) into $CHCl_3$. The aqueous phase was washed twice more with 25-mL portions of $CHCl_3$. The combined organic extracts were chromatographed using 20% EtOAc in hexanes as the eluting solvent to provide 3.29 g (89%) of pure disilyl arabinose as a colorless oil: $[\alpha]_D$ = +37.7° (*c* 0.0391, $CHCl_3$); IR (film, $cm^{-1}$) 2954, 2932, 2856; $^1H$ NMR (360 MHz, $CDCl_3$) δ 4.29 (dd, $J_{2,1}$ = 2.6 Hz, $J_{2,3}$ = 7.5 Hz, 1 H, $H_2$), 4.14 (dd, $J_{3,4}$ = 6.2 Hz, $J_{3,2}$ = 7.5 Hz, 1 H, $H_3$), 3.90 (d, $J_{1,2}$ = 2.6 Hz, 1 H, $H_1$), 3.71–3.75 (m, ABB'X, 1 H, $H_4$), 3.69 (dd, $J_{5,4}$ = 4.1 Hz, $J_{gem}$ = 10.5 Hz, 1 H, $H_5$), 3.57 (dd, $J_{5,4}$ = 4.5 Hz, $J_{gem}$ = 10.5 Hz, 1 H, $H_5$), 2.63–2.72 (m, 4 H, $SCH_2CH_3$), 1.38 (s, 3 H, $CH_3$), 1.31 (s, 3 H, $CH_3$), 1.20 (t, *J* = 7.48 Hz, 3 H, $SCH_2CH_3$), 1.19 (t, *J* = 7.45 Hz, 3 H, $SCH_2CH_3$), 0.845 (s, 9 H, $(CH_3)_4CSi$), 0.843 (s, 9 H, $(CH_3)_4CSi$), 0.0632 (s, 3 H, $SiCH_3$), 0.0557 (s, 3 H, $SiCH_3$), 0.0069 (s, 3 H, $SiCH_3$), –0.0004 (s, 3 H, $SiCH_3$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 109.3, 83.0, 78.6, 75.0, 65.0, 53.9, 27.3, 26.9, 25.8, 25.8, 25.3, 24.5, 18.2, 18.0, 14.4, 14.2, –4.4, –4.5, –5.6, –5.6; low-resolution MS *m/e* 524 ($M^+$, 5), 409 (33), 347 (25), 289 (100), 257 (100), 73 (96). Anal. Calcd for $C_{24}H_{52}O_4S_2Si_2$: C, 54.91; H, 9.98; S, 12.21. Found: C, 55.01; H, 10.07; S, 12.37.

**4,5-Di-*O*-(*tert*-butyldimethylsilyl)-2,3-*O*-isopropylidene-D-arabinose (12).** A solution of the dithioacetal of arabinose (0.782 g, 1.49 mmol) and 2,6-lutidine (1.20 mL, 10.30 mmol) in $CH_3CN/H_2O$ (45 mL/10 mL) was treated with NBS (1.58 g, 8.89 mmol) and stirred at 25 °C for 10 min. The excess NBS was destroyed with aqueous $NaHSO_3$ and the solution extracted with aqueous $NaHCO_3$. The combined organic extracts were concentrated and chromatographed (20% EtOAc in hexanes) providing 607 mg (97%) of aldehyde 12 as a pale yellow oil: IR (film, $cm^{-1}$) 2954, 2932, 2867, 1736; $^1H$ NMR (360 MHz, $CDCl_3$) δ 9.7 (d, $J_{1,2}$ = 1.8 Hz, 1 H, $H_1$), 4.47 (dd, $J_{2,1}$ = 1.8 Hz, $J_{2,3}$ = 7.0 Hz, 1 H, $H_2$), 4.27 (dd, $J_{3,4}$ = 3.7 Hz, $J_{3,2}$ = 7.0 Hz, 1 H, $H_3$), 3.92 (ddd, $J_{4,5}$ = 1.7 Hz, $J_{4,3}$ = 3.7 Hz, $J_{4,5}$ = 7.40 Hz, 1 H, $H_4$), 3.57 (d, AB, *J* = 5.6 Hz, 2 H, $H_5$), 1.46 (s, 3 H, $CH_3$), 1.34 (s, 3 H, $CH_3$), 0.881 (s, 9 H, $(CH_3)_4CSi$), 0.869 (s, 9 H, $(CH_3)_4CSi$), 0.0933 (s, 3 H, $SiCH_3$), 0.0852 (s, 3 H, $SiCH_3$), 0.0420 (s, 6 H, $SiCH_3$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 201.0, 110.6, 80.3, 77.44, 72.4, 64.4, 26.6, 25.8, 25.8, 25.7, 18.26, 18.1, –4.5, –4.7, –5.5, –5.6.

**(*E*)- and (*Z*)-6,5-Di-*O*-(*tert*-butyldimethylsilyl)-1,2-dideoxy-3,4-*O*-isopropylidene-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-*gluco*-hexopyranosid-4-yl)-D-*gluco*-hex-1-enose (13, 14).** To a stirred mixture of the phosphonium salt 11 (1.17 g, 1.37 mmol) and aldehyde 12 (0.730 g, 1.74 mmol) in THF (35 mL) under dry $N_2$ was slowly added KH (81 mg, 2.03 mmol) at 0 °C. After 90 min the excess KH was destroyed at 0 °C with aqueous $NH_3Cl$. The aqueous phase was extracted three times with 15-mL portions of $CHCl_3$. The combined organic phases were dried over $Na_2SO_4$, filtered, and concentrated under reduced pressure to yield a crude paste. The crude material was purified by flash chromatography on silica (20% hexanes in EtOAc) to provide 0.797 g (67%) of an inseparable mixture (1:3 *E*/*Z*) by $^1H$ NMR) of olefins 13, 14 as a colorless oil: $^1H$ NMR (360 MHz, $CDCl_3$, mixture of diastereomers, olefinic region only) δ 5.82 (dd, $J_{2,3}$ = 6.0 Hz, $J_{trans}$ = 15.4 Hz, 1 H, $H_{2E}$), 5.66 (dd, $J_{2,3}$ = 8.7 Hz, $J_{cis}$ = 10.7 Hz, 1 H, $H_{2Z}$), 5.60 (dd, $J_{1,4'}$ = 9.1 Hz, $J_{trans}$ = 15.4 Hz, 1 H, $H_{1E}$), 5.35 (dd, $J_{1,4'} = J_{cis}$ = 10.7 Hz, 1 H, $H_{1Z}$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 138.9, 138.3, 138.0, 133.1, 131.6, 128.2, 128.1, 128.1, 128.1, 128.0, 127.9, 127.9, 127.8, 127.7, 127.5, 127.3, 127.3, 127.1, 126.8, 108.4, 107.6, 98.4, 98.0, 81.1, 80.8, 80.4, 80.0, 78.5, 78.4, 76.7, 75.1, 74.0, 73.3, 73.2, 73.0, 72.9, 72.8, 71.3, 71.1, 70.8, 70.4, 69.9, 69.6, 64.8, 63.8, 60.0, 54.9, 54.8, 47.7, 44.1, 31.7, 29.5, 29.1, 27.0, 26.9, 26.7, 25.8, 25.7, 25.7, 25.5, 22.5, 20.7, 18.1, 17.9, 17.9, 17.9, 14.0, –4.5, –4.7, –4.8, –4.9, –5.5, –5.5, –5.7, –5.7; FAB MS *m/e* 861 ($M^+$ – H, 2), 665 (3), 359 (4), 301 (7).

**(*E*)-1,2-Dideoxy-3,4-*O*-isopropylidene-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-*gluco*-hexopyranosid-4-yl)-D-*gluco*-hexo-1-enose (16) and (*Z*)-1,2-Dideoxy-3,4-*O*-isopropylidene-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-*gluco*-hexopyranosid-4-yl)-D-*gluco*-hex-1-enose (15).** The mixture of *E* and *Z* olefins 13, 14 (769 mg, 0.891 mmol) was dissolved in toluene (40 mL) in a quartz vessel. The solution was purged with argon and irradiated with stirring using a Hanovia lamp (8 h). The solvent was removed under reduced pressure and the residue dissolved in THF (5 mL) and treated with a 1.0 M solution of tetrabutylammonium floride in THF (3.60 mL, 3.56 mmol). After 30 min the solvent was removed under reduced pressure and the resultant oil chromatographed (hexanes/ethyl acetate) to provide 195 mg (35%) of the *E* olefin 16 and 325 mg (58%) of the *Z* olefin 15 as colorless oils. 16 (*E*): $[\alpha]_D$ = +21.8° (*c* 0.0090, $CHCl_3$); IR (film, $cm^{-1}$) 3454, 2984, 2900, 1497, 1456; $^1H$ NMR (360 MHz, $CDCl_3$) δ 7.25–7.41 (m, 15 H, Ph*H*), 5.66 (dd, $J_{2',3'}$ = 7.0 Hz, $J_{trans}$ = 15.3 Hz, 1 H, $H_{2'}$), 5.49 (dd, $J_{1',4}$ = 9.2 Hz, $J_{trans}$ = 15.3 Hz, 1 H, $H_{1'}$), 4.83 (d, *J* = 9.6 Hz, 1 H, PhC*H*), 4.81 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.69 (d, $J_{1,2}$ = 3.3 Hz, 1 H, $H_1$), 4.67 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.61 (d, *J* = 9.6 Hz, 1 H, PhC*H*), 4.58 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.46 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.30 (dd, $J_{3'2'} = J_{3',4'}$ = 7.5 Hz, 1 H, $H_{3'}$), 3.68–3.75 (m, ABB', 3 H, $H_{5'}$ and $H_{6'}$), 3.48–3.57 (m, 5 H, $H_{4'}$, $H_2$, $H_3$, $H_5$, $H_6$), 3.45 (dd, $J_{6,5}$ = 4.63 Hz, $J_{gem}$ = 10.7 Hz, 1 H, $H_6$), 3.40 (s, 3 H, $OCH_3$), 2.55 (bdd, *J* = 10.43, 9.90 Hz, 1 H, $H_4$), 1.41 (s, 3 H, $CH_3$), 1.39 (s, 3 H, $CH_3$); $^{13}C$ NMR (90 MHz, $CDCl_3$) δ 138.2, 138.0, 137.9, 132.9, 129.8, 128.2, 128.1, 128.0, 127.9, 127.8, 127.5, 127.4, 127.3, 127.3, 108.8, 98.3, 80.5, 79.9, 78.8, 78.3, 75.0, 73.1, 72.8, 72.1, 70.0, 69.7, 63.3, 60.1, 54.9, 47.7, 26.7, 26.7;

FAB MS *m/e* 633 ($M^+$ − H, 3), 603 ($M^+$ − $CH_3O$, 4), 537 (3), 495 (3), 371 (14). Anal. Calcd for $C_{37}H_{46}O_9$: C, 70.01; H, 7.30. Found: C, 69.48; H, 7.23.

**15** (*Z*): $[\alpha]_D$ = +64.1° (*c* 0.0170, $CHCl_3$); IR (film, $cm^{-1}$) 3460, 2985, 2932, 2893, 1454, 1370, 1211, 1051, 739, 699; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.26–7.37 (m, 15 H, Ph*H*), 5.64 (dd, $J_{2',3'}$ = 9.4 Hz, $J_{cis}$ = 10.8 Hz, 1 H, $H_{2'}$), 5.20 (dd, $J_{1',4}$ = $J_{cis}$ = 10.8 Hz, 1 H, $H_{1'}$), 4.93 (d, *J* = 11.0 Hz, 1 H, PhC*H*), 4.79 (dd, $J_{3',2'}$ = $J_{3',4'}$ = 7.8 Hz, 1 H, $H_{3'}$), 4.77 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.71 (d, $J_{1,2}$ = 3.4 Hz, 1 H, $H_1$), 4.65 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.64 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.60 (d, *J* = 11.0 Hz, 1 H, PhC*H*), 4.48 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 3.76 (dd, $J_{4',3'}$ = $J_{4',5'}$ = 9.68 Hz, 1 H, $H_{4'}$), 3.65 (dd, $J_{2,1}$ = 3.4 Hz, $J_{2,3}$ = 9.3 Hz, 1 H, $H_2$), 3.49–3.62 (m, 5 H, $H_{5'}$, $H_{6'}$, $H_3$, $H_5$, and $H_6$), 3.47 (dd, $J_{6,5}$ = 4.1 Hz, $J_{gem}$ = 10.7 Hz, 1 H, $H_6$), 3.35 (s, 3 H, OC$H_3$), 3.22 (bdd, $J_{6',5'}$ = 5.16 Hz, $J_{gem}$ = 11.04 Hz, 1 H, $H_{6'}$). 3.00 (bddd, $J_{4,1'}$ = $J_{4,5}$ = $J_{4,3}$ = 10.42 Hz, 1 H, $H_4$), 1.38 (s, 3 H, C$H_3$), 1.24 (s, 3 H, C$H_3$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 137.7, 133.0, 129.0, 128.5, 128.3, 128.2, 128.1, 128.0, 127.5, 109.5, 98.4, 81.6, 81.1, 78.2, 75.6, 75.2, 73.7, 73.4, 72.1, 69.8, 64.0, 55.2, 43.0, 27.1, 26.9; FAB MS *m/e* 633 ($M^+$ H, 3), 577 (4), 545 (4). Anal. Calcd for $C_{37}H_{46}O_9$: C, 70.01 H, 7.30. Found: C, 69.98 H, 7.27.

**(*E*)-6-*O*-(*tert*-Butyldiphenylsilyl)-1,2-dideoxy-3,4-*O*-isopropylidene-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-*gluco*-hexopyranosid-4-yl)-D-*gluco*-hex-1-enose (17).** To a stirred solution of diol **15** (232 mg, 0.365 mmol) and imidazole (112 mg, 1.65 mmol) in DMF (15 mL) under dry $N_2$ was added *tert*-butyldiphenylsilyl chloride (TPSCl, 105 μL, 0.402 mmol) at 50 °C. Stirring was continued for 8 h and the excess silyl chloride decomposed with dry methanol. The solvent was removed under reduced pressure and the resultant yellow paste chromatographed on silica (25% EtOAc in hexanes) to yield 258 mg (81%) of the primary protected olefin **17** as a colorless oil: $[\alpha]_D$ = +20.0° (*c* 0.0136, $CHCl_3$); IR (film, $cm^{-1}$) 3504, 2930; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.24–7.72 (m, 25 H, Ph*H*), 5.68 (dd, $J_{2',3'}$ = 6.8 Hz, $J_{trans}$ = 15.4 Hz, 1 H, $H_{2'}$), 5.42 (dd, $J_{1',4}$ = 9.3 Hz, $J_{trans}$ = 15.4 Hz, 1 H, $H_{1'}$), 4.81 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.80 (d, *J* = 10.5 Hz, 1 H, PhC*H*), 4.68 (d, $J_{1,2}$ = 3.32 Hz, 1 H, $H_1$), 4.66 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 4.62 (d, *J* = 10.5 Hz, 1 H, PhC*H*), 4.49 (d, *J* = 12.1 Hz, 1 H, PhC*H*), 4.36 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.34 (dd, $J_{3',2'}$ = 6.8 Hz, $J_{3',4'}$ = 6.9 Hz, 1 H, $H_{3'}$), 3.58–3.77 (m, 5 H, $H_{4'}$, $H_{5'}$, $H_2$, $H_3$ and $H_5$), 3.54 (dd, $J_{6,5}$ = 3.5 Hz, $J_{gem}$ = 9.4 Hz, 1 H, $H_6$), 3.47–3.50 (m, 2 H, $H_6$ and $H_{6'}$), 3.40 (s, 3 H, OC$H_3$), 3.67 (dd, $J_{6',5'}$ = 4.6 Hz, $J_{gem}$ = 10.6 Hz, 1 H, $H_{6'}$), 2.57 (ddd, *J* = 10.14, 10.09, 10.09 Hz, 1 H, $H_4$), 2.44 (bd, *J* = 3.85 Hz, 1 H, O*H*), 1.34 (s, 6 H, C$H_3$), 1.05 (s, 9 H, $(CH_3)_4$CSi); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 138.3, 138.1, 138.0, 135.3, 135.2, 132.9, 132.7, 132.7, 129.7, 129.6, 128.2, 128.1, 128.0, 127.9, 127.8, 127.6, 127.6, 127.4, 127.3, 127.2, 108.8, 98.5, 79.8, 79.7, 78.5, 75.1, 73.1, 72.9, 72.9, 69.8, 69.7, 65.3, 60.0, 54.9, 47.5, 26.7, 26.7, 26.6, 20.7, 19.0; FAB MS *m/e* 871 ($M^+$ − H, 39), 815 (19), 675 (54). Anal. Calcd for $C_{53}H_{64}O_9Si$: C, 72.90; H, 7.39. Found: C, 72.77; H, 7.58.

**(*Z*)-6-*O*-(*tert*-Butyldiphenylsilyl)-1,2-dideoxy-3,4-*O*-isopropylidene-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-*gluco*-hexopyranosid-4-yl)-D-*gluco*-hex-1-enose (18).** To a stirred solution of diol **16** (77 mg, 0.122 mmol) and imidazole (37 mg, 0.544 mmol) in DMF (5 mL) under dry $N_2$ was added TPSCl (35 μL, 0.134 mmol) at 50 °C. Stirring was continued for 3 h and the excess silyl chloride decomposed with dry methanol. The solvent was removed under reduced pressure and the resultant yellow paste was chromatographed (25% EtOAc in hexanes) to yield 95 mg (89%) of the protected olefin **18** as a colorless oil: $[\alpha]_D$ = +40.3° (*c* 0.0340, $CHCl_3$); IR (film, $cm^{-1}$) 3455, 2930; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.23–7.72 (m, 25 H, Ph*H*), 5.64 (dd, $J_{2',3'}$ = 8.8 Hz, $J_{cis}$ = 10.9 Hz, 1 H, $H_{2'}$), 5.17 (dd, $J_{1',4}$ = $J_{cis}$ = 10.9 Hz, 1 H, $H_{1'}$), 4.82 (d, *J* = 11.3 Hz, 1 H, PhC*H*), 4.77 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.73–4.78 (m, 1 H, $H_{3'}$), 4.68 (d, *J* = 11.3 Hz, 1 H, PhC*H*), 4.68 (d, $J_{1,2}$ = 3.45 Hz, 1 H, $H_1$), 4.61 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.61 (d, *J* = 13.2 Hz, 1 H, PhC*H*), 4.48 (d, *J* = 12.2 Hz, 1 H, PhC*H*), 3.56–3.80 (m, 8 H, $H_{4'}$, $H_{5'}$, $H_{6'}$, $H_2$, $H_3$, $H_5$, $H_6$, and $H_6$), 3.48 (dd, $J_{6',5'}$ = 5.1 Hz, $J_{gem}$ = 10.7 Hz, 1 H, $H_{6'}$), 3.37 (s, 3 H, OC$H_3$), 3.00 (ddd, *J* = 10.4, 10.4, 10.4 Hz, 1 H, $H_4$), 2.72 (bd, *J* = 4.8 Hz, 1 H, O*H*), 1.34 (s, 3 H, C$H_3$), 1.18 (s, 3 H, C$H_3$), 1.07 (s, 9 H, $(CH_3)_4$CSi); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 138.3, 138.2, 138.2, 135.6, 135.5, 134.8, 133.5, 133.4, 132.8, 131.3, 129.6, 129.6, 128.8, 128.4, 128.1, 128.1, 128.0, 127.8, 127.6, 127.6, 127.3, 127.3, 109.2, 98.3, 80.9, 80.8, 78.2, 75.8, 75.0, 73.3, 73.2, 73.1, 70.3, 69.8, 65.5, 55.1, 43.4, 27.2, 26.9, 26.8, 26.5, 19.2; FAB MS *m/e* 871 ($M^+$ − H, 2), 815 (3), 675 (2). Anal. Calcd for $C_{53}H_{64}O_9Si$: C, 72.90; H, 7.39. Found: C, 72.89; H, 7.15.

**Methyl 4-Deoxy-2,3,6-tri-*O*-benzyl-4-*C*-(2-bromo-6-*O*-(*tert*-butyldiphenylsilyl)-1,2-dideoxy-3,4-*O*-isopropylidene-β-D-*gluco*-hexopyranos-1-yl)-α-D-*gluco*-hexopyranoside (19).** To a stirred solution consisting of *E* olefin **17** (15 mg, 0.017 mmol) and NBS (9 mg, 0.053 mmol) in anhydrous $CH_3CN$ (2 mL) was added a catalytic amount of $Br_2$ vapors at 25 °C. After 15 min the excess $Br_2$/NBS was decomposed with aqueous $NaHSO_3$ and the solution was extracted with $CH_2Cl_2$. The combined crude extracts were concentrated and chromatographed to provide 5 mg (32%) of the cyclic bromide **19** as a pale yellow oil: $[\alpha]_D$ = +28.4° (*c* 0.0045, $CHCl_3$); IR (film, $cm^{-1}$) 2929, 2857; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.26–7.64 (m, 25 H, Ph*H*), 5.04 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.83 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.76 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.70 (d, $J_{1,2}$ = 3.8 Hz, 1 H, $H_1$), 4.69 (d, *J* = 11.9 Hz, 1 H, PhC*H*), 4.67 (d, *J* = 12.3 Hz, 1 H, PhC*H*), 4.37 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.09 (bd, $J_{5,4}$ = 10.1–10.4 Hz, 1 H, $H_5$), 3.92 (dd, $J_{3,2}$ = 9.4 Hz, $J_{3,4}$ = 10.6 Hz, 1 H, $H_3$), 3.72 (dd, $J_{2',3'}$ = 9.9 Hz, $J_{2',1'}$ = 10.3 Hz, 1 H, $H_{2'}$), 3.68 (dd, $J_{2,1}$ = 3.8 Hz, $J_{2,3}$ = 9.4 Hz, 1 H, $H_2$), 3.65 (dd, $J_{6,5}$ = 2.5 Hz, $J_{gem}$ = 10.9 Hz, 1 H, $H_6$), 3.63 (dd, $J_{6',5'}$ = 2.0 Hz, $J_{gem}$ = 11.4 Hz, 1 H, $H_{6'}$), 3.57 (dd, $J_{6',5'}$ = 3.13 Hz, $J_{gem}$ = 11.4 Hz, 1 H, $H_{6'}$), 3.52 (d, $J_{1',2'}$ = 10.3 Hz, 1 H, $H_{1'}$), 3.48 (dd, $J_{6,5}$ = 1.8 Hz, $J_{gem}$ = 10.9 Hz, 1 H, $H_6$), 3.35 (s, 3 H, OC$H_3$), 3.26 (dd, $J_{3',2'}$ = 9.9 Hz, $J_{3',4'}$ = 9.4 Hz, 1 H, $H_{3'}$), 3.14 (dd, $J_{4',3'}$ = 9.4 Hz, $J_{4',5'}$ = 9.1 Hz, 1 H, $H_{4'}$), 2.70 (bd, $J_{5',4'}$ = 9.1 Hz, 1 H, $H_{5'}$), 2.58 (dd, $J_{4,3}$ = $J_{4,5}$ = 10.4 Hz, 1 H, $H_4$), 1.44 (s, 3 H, C$H_3$), 1.42 (s, 3 H, C$H_3$), 0.99 (s, 9 H, $(CH_3)_4$CSi); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 138.7, 138.4, 137.0, 135.5, 135.4, 133.1, 129.7, 129.6, 128.8, 128.6, 128.5, 128.4, 128.3, 128.1, 127.9, 127.8, 127.8, 127.7, 127.6, 110.3, 98.6, 83.8, 81.7, 78.5, 77.2, 76.8, 76.3, 74.9, 74.1, 74.1, 73.0, 70.2, 67.2, 62.6, 55.2, 49.0, 41.6, 26.7, 26.6, 26.5, 19.2; FAB MS *m/e* (951 ($M^+$ − H, 1), 949 ($M^+$ − H, 1)), (921 (1), 919 (1)), (813 (2), 811 (2)); HR FAB MS calcd for $C_{53}H_{62}BrO_9Si$ 949.3346 ($M^+$ − H), found 949.3345.

**Methyl 4-Deoxy-2,3,6-tri-*O*-benzyl-4-*C*-(2-bromo-1,2-dideoxy-3,4-*O*-isopropylidene-β-D-*gluco*-hexopyranos-1-yl)-α-D-*gluco*-hexopyranoside (20).** To a solution of disaccharide **19** (35 mg, 0.037 mmol) in THF (2 mL) was added TBAF/THF (2 mL, 1 M, 2 mmol). This mixture was allowed to stir at 25 °C for 3 h. The solvent was removed under reduced pressure and the resultant syrup was chromatographed on silica (hexanes/ethyl acetate) to provide 24 mg (91%) of alcohol **20** as a colorless oil: $[\alpha]_D$ = +26.7° (*c* 0.0165, $CHCl_3$); IR (film, $cm^{-1}$) 3479, 2926; $^1$H NMR (360 MHz, $CDCl_3$) δ 7.27–7.37 (m, 15 H, Ph*H*), 5.05 (d, *J* = 12.2 Hz, 1 H, PhC*H*), 4.80 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.67 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 4.66 (d, *J* = 12.0–12.2 Hz, 2 H, PhC*H*), 4.64 (d, $J_{1,2}$ = 3.7 Hz, 1 H, $H_1$), 4.43 (d, *J* = 12.0 Hz, 1 H, PhC*H*), 3.87–3.89 (dm, $J_{5,4}$ = 9.7 Hz, 1 H, $H_5$), 3.81 (dd, $J_{3,2}$ = 9.2 Hz, $J_{3,4}$ = 9.8 Hz, 1 H, $H_3$), 3.72 (dd, $J_{2',3'}$ = 10.3 Hz, $J_{2',1'}$ = 9.7 Hz, 1 H, $H_{2'}$), 3.64 (dd, $J_{2,1}$ = 3.7 Hz, $J_{2,3}$ = 9.2 Hz, 1 H, $H_2$), 3.56–3.60 (m, 1 H, $H_{6'}$), 3.48–3.51 (m, AB, 2 H, $H_6$), 3.50 (d, $J_{1',2'}$ = 9.7 Hz, 1 H, $H_{1'}$), 3.44–3.48 (m, 1 H, $H_{6'}$), 3.36 (s, 3 H, OC$H_3$), 3.23 (dd, $J_{3',2'}$ = 10.3 Hz, $J_{3',4'}$ = 8.7 Hz, 1 H, $H_{3'}$), 2.79 (dd, $J_{4',3'}$ = 8.7 Hz, $J_{4',5'}$ = 9.0 Hz, 1 H, $H_{4'}$), 2.71–2.75 (m, 1 H, $H_{5'}$), 2.48 (dd, $J_{4,3}$ = 9.8 Hz, $J_{4,5}$ = 9.7 Hz, 1 H, $H_4$), 1.41 (s, 3 H, C$H_3$), 1.37 (s, 3 H, C$H_3$); $^{13}$C NMR (90 MHz, $CDCl_3$) δ 138.6, 138.2, 137.1, 128.8, 128.6, 128.5, 128.5, 128.4, 128.2, 127.9, 127.9, 127.8, 110.9, 98.4, 83.7, 81.7, 78.6, 77.2, 76.2, 75.1, 75.0, 73.9, 73.1, 70.3, 67.0, 62.7, 55.4, 48.4, 41.9, 29.7, 26.7, 26.4; FAB MS *m/e* (711 ($M^+$ − H, 55), 713 ($M^+$ − H, 65)), (681 (60), 683 (55)), (573 (64), 575 (55)); HR FAB MS calcd for $C_{37}H_{44}BrO_9$ 711.2169 ($M^+$ − H), found 711.2146.

**Methyl 4-Deoxy-4-*C*-(1,2-dideoxy-3,4-*O*-isopropylidene-β-D-*gluco*-hexopyranos-1-yl)-α-D-*gluco*-hexopyranoside (21).** A solution of the bromo disaccharide **20** (14.9 mg, 0.021 mmol) in THF (500 μL) was cooled to −78 °C. Liquid ammonia was condensed into the reaction vessel until a total volume of 2.5 mL was achieved. Sodium metal was added until a blue color persisted. Stirring was continued for 15 min, and the excess sodium was decomposed with aqueous $NH_4Cl$. The vessel was warmed to 25 °C, and the solvent was removed under reduced pressure. The residue was triturated with 10% methanol in $CHCl_3$ and the solvent removed under reduced pressure. The resultant film was chromatographed (15% MeOH/$CHCl_3$) to provide 4.3 mg (57%) of the dehalogenated tetraol **21** as a colorless film; $[\alpha]_D = +55.5°$ (*c* 0.0059, $CHCl_3$); IR (film, $cm^{-1}$) 3391, 2922; $^1H$ NMR (500 MHz, $CDCl_3$) $\delta$ 4.79 (d, $J_{1,2} = 3.9$ Hz, 1 H, $H_1$), 3.94 (dd, $J_{3,2} = 8.7$ Hz, $J_{3,4} = 9.2$ Hz, 1 H, $H_3$), 3.93 (dd, $J_{1',2'eq} = 2.6$ Hz, $J_{1',2'ax} = 10.5$ Hz, 1 H, $H_{1'}$), 3.85 (dd, $J_{6',5'} = 3.2$ Hz, $J_{gem} = 11.9$ Hz, 1 H, $H_{6'}$), 3.81 (dd, $J_{6,5} = 2.0$ Hz, $J_{gem} = 11.3$ Hz, 1 H, $H_6$), 3.64–3.74 (m, 3 H, $H_{6'}$, $H_5$, $H_6$), 3.57–3.63 (m, 2 H, $H_{3'}$, $H_{5'}$), 3.51 (dd, $J_{2,1} = 3.9$ Hz, $J_{2,3} = 8.7$ Hz, 1 H, $H_2$), 3.42 (s, 3 H, $OCH_3$), 3.22 (dd, $J_{4',3'} = J_{4',45'} = 9.1$ Hz, 1 H, $H_{4'}$), 2.08 (ddd, $J_{2'eq,1'} = J_{2'eq,3'} = 2.6$ Hz, $J_{gem} = 11.4$ Hz, 1 H, $H_{2'eq}$), 2.07 (dd, $J_{4,3} = 9.2$ Hz, $J_{4,5} = 9.9$ Hz, 1 H, $H_4$), 1.95 (ddd, $J_{2'ax,1'} = J_{2'ax,3'} = J_{gem} = 10.4$–$11.5$ Hz, 1 H, $H_{2'ax}$), 1.43 (s, 6 H, isopropylidene $CH_3$'s); $^{13}C$ NMR (90 MHz, $CDCl_3$) $\delta$ 110.8, 99.4, 79.8, 77.9, 76.2, 74.7, 73.9, 70.0, 68.8, 63.1, 62.9, 55.5, 45.4, 33.2, 26.8, 26.7; FAB MS *m/e* 365 ($MH^+$, 2), 333 (2), 242 (100); HR FAB MS calcd for $C_{16}H_{29}O_9$ 365.1812 ($MH^+$), found 365.1815. Anal. Calcd for $C_{16}H_{28}O_9$: C, 52.74; H, 7.75. Found: C, 52.45; H, 7.50.

**Methyl 4-Deoxy-4-*C*-(1,2-dideoxy-$\beta$-D-*gluco*-hexopyranos-1-yl)-$\alpha$-D-*gluco*-hexopyranoside (22).** A solution of disaccharide **21** (5.5 mg, 0.015 mmol) in methanol (2 mL) was treated with *p*-toluenesulfonic acid. After 15 min, the solution was treated with mildly basic ion exchange resin, filtered, and concentrated under reduced pressure. The residue was chromatographed (20% MeOH/$CHCl_3$) to provide 4.3 mg (88%) of the fully deprotected disaccharide **22** as a white film: $[\alpha]_D = +73.8°$ (*c* 0.0037, $CHCl_3$); IR (film, $cm^{-1}$) 3398, 2923; $^1H$ NMR (500 MHz, $CD_3OD$) $\delta$ 4.67 (d, $J_{1,2} = 3.8$ Hz, 1 H, $H_1$), 3.86 (dm, $J_{1',2'ax} = 11.8$ Hz, 1 H, $H_{1'}$), 3.83 (dd, $J_{3,2} = 9.5$ Hz, $J_{3,4} = 10.2$ Hz, 1 H, $H_3$), 3.82 (dd, $J_{6',5'} = 2.0$ Hz, $J_{gem} = 11.3$ Hz, 1H, $H_{6'}$), 3.79 (dd, $J_{6,5} = 2.3$ Hz, $J_{gem} = 11.5$ Hz, 1 H, $H_6$), 3.74 (ddd, $J_{5,6} = 2.3$ Hz, $J_{5,6} = 4.8$ Hz, $J_{5,4} = 10.5$ Hz, 1 H, $H_5$), 3.66 (dd, $J_{6,5} = 5.8$ Hz, $J_{gem} = 11.5$ Hz, 1 H, $H_6$), 3.65 (dd, $J_{6',5'} = 5.3$ Hz, $J_{gem} = 11.3$ Hz, 1 H, $H_{6'}$). 3.52 (ddd, $J_{3',2'eq} = 5.0$ Hz, $J_{3',4'} = 8.7$ Hz, $J_{3',2'ax} = 11.6$ Hz, 1 H, $H_{3'}$), 3.37 (dd, $J_{2,1} = 3.8$ Hz, $J_{2,3} = 9.5$ Hz, 1 H, $H_2$), 3.37 (s, 3 H, $OCH_3$), 3.18 (dd, $J_{4',3'} = J_{4',5'} = 8.7$–$9.3$ Hz, 1 H, $H_{4'}$), 3.13 (ddd, $J_{5',6'} = 2.0$ Hz, $J_{5',6'} = 5.3$ Hz, $J_{5',4'} = 9.3$ Hz, 1 H, $H_{5'}$), 1.90 (ddd, $J_{2'eq,1'} = 1.9$ Hz, $J_{2'eq,3'} = 5.0$ Hz, $J_{gem} = 12.6$ Hz, 1 H, $H_{2'eq}$), 1.80 (ddd, $J_{4,1'} = 2.5$ Hz, $J_{4,3} = J_{4,5} = 10.2$–$10.5$ Hz, 1 H, $H_4$), 1.66 (ddd, $J_{2'ax,1'} = J_{2'ax,3'} = 11.6$–$11.8$ Hz, $J_{gem} = 12.6$ Hz, 1 H, $H_{2'ax}$); $^{13}C$ NMR (90 MHz, $CD_3OD$) $\delta$ 101.3, 82.3, 75.4, 75.0, 74.2, 73.1, 70.8, 70.7, 64.1, 63.0, 55.5, 47.6, 38.5. Anal. Calcd for $C_{13}H_{24}O_9 \cdot H_2O$: C, 45.61; H, 7.66. Found: C, 45.60; H, 7.40.

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# Silicon-Promoted Ring Contractions in the Formation of Carbocyclic Spiro Compounds. Total Synthesis of (−)-Solavetivone

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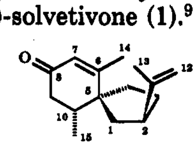
A new method involving silicon-promoted ring contraction was developed for the synthesis of carbocyclic spiro compounds. In the presence of a Lewis acid, (trimethylsilyl)decalinol **12** and (trimethylsilyl)decalin epoxide **11** underwent ring contraction in a highly stereoselective manner to afford spiro[4.5]dec-6-enes **14** and **19**, respectively. The first total synthesis of optically active solavetivone ((−)-**1**) was accomplished in 13 steps by use of this new type of reaction as the key step. Utilization of the silicon-promoted ring contraction solves three problems associated with spiro compound synthesis: (1) efficient generation of the quaternary carbon spiro center, (2) full control of the stereoconfiguration of the spiro center during its formation, and (3) stereospecific establishment of chiral centers on both rings of the spiro unit.

## Introduction

Many carbocyclic spiro compounds possess valuable biological or physical properties. Chemical and pharmaceutical industries use some of these compounds extensively. Whereas the spiro moiety exists among alkaloids, steroids, and polycyclic hydrocarbons, the spiro[4.5]decane sesquiterpenes make up the majority of naturally occurring spiro carbocycles.

Several synthetic methods can lead to spiro carbocycles;[1–3] however, few of them give high yields with control of stereochemistry at the spiro center as well as in both rings. Acid-catalyzed rearrangement involving ring contraction can generate spiro compounds stereoselectively,[2] but examples of this method with high yields are rare. We undertook the development of a new synthetic method that can provide good yields of isomerically pure spiro products.

Silicon can direct organic reactions in various ways.[4–6] Recently, Kuwajima[7,8] reported a silicon-directed ring enlargement reaction. Herein, we report a novel silicon-promoted ring contraction reaction and its application as the key step in a total synthesis of a spirocyclic natural product, (−)-solvetivone (1).[9]




(−)-Solavetivone (1)

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