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Photoreaction of methyl and phenyl 4,6-*O*-benzylidene-2,3-dideoxy-2-*C*-*p*-tolylsulfonyl-β-D-*erythro*-hex-2-enopyranosides in methanol

Tohru Sakakibara,* Tetsuya Shindo, Hiroshi Hirai

Graduate School of Integrated Science, Yokohama City University, 22-2, Seto, Kanazawa-ku, Yokohama 236-0027, Japan

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Dedicated to Professor Derek Horton on the occasion of his 70th birthday

Abstract

The title compounds were irradiated with a high-pressure mercury lamp in methanol to give 2-*C*-hydroxymethyl derivatives having the *gluco*, *altro*, and *allo* configurations as well as an S_N2' product. Equatorial attack of a hydroxymethyl radical slightly predominated over axial attack. During chromatographic separation on a silica gel column, partial migration of the 4,6-*O*-benzylidene group in the *gluco* and *altro* products occurred to yield the 3′,4-*O*-benzylidene derivatives.

Keywords: Photoreaction; Sulfonyl sugars; Benzylidene group

1. Introduction

α,β-Unsaturated sulfones are compounds of potential utility because a host of nucleophiles added to the electron-deficient β-carbon atom.[1] The sulfonyl group is replaced by a hydrogen atom[2] or changed to other functional group.[3]

Previously, we showed that nucleophiles added from the equatorial side of methyl 4,6-*O*-benzylidene-2,3-dideoxy-2-*C*-*p*-tolylsulfonyl-β-D-*erythro*-hex-2-enopyranoside (**1**) with high stereoselectivity to give the *gluco* adducts.[4] On the other hand, a similar reaction of the phenyl analog **2** afforded the S_N2' products, that is, the glucal derivatives.[4] Sodium borodeuteride also added from the equatorial side of **1**, and the stereochemistry of the subsequent protonation was strongly affected by the solvents employed.[5]

However, photoaddition reactions to α,β-unsaturated sulfones have been extremely limited.[6] Therefore, we have performed such reactions by irradiation of **1** and **2** in methanol in the presence of benzophenone.

2. Results and discussion

2-Sulfonyl-2-enopyranoside **1** was irradiated with a high-pressure mercury lamp in methanol in the presence of benzophenone (added as a sensitizer) for 10 h at ~8 °C to give three new spots on TLC. By silica gel column chromatography, the glucal **3** (4%), the β-D-*allo* product **6** (9%), and a mixture (55%) of the β-D-*gluco* **7** and β-D-*altro* **9** products were isolated. After acetylation of the mixture, compounds **7** and **9** could be separated by column chromatography. The isolated acetates, β-D-*gluco* **8** and β-D-*altro* isomers **10**, were deacetylated to afford the alcohols **7** and **9**, respectively. The *allo* and *gluco* configurations with the $^4C_1$ conformations for **6** and **7**, respectively, were readily assigned by the coupling constants; $J_{1,2}$ 8.7, $J_{2,3} = J_{3,4} = 5.0$, $J_{4,5}$ 9.6 Hz for **6** and $J_{1,2}$ 6.7, $J_{2,3}$ 9.2 Hz, $J_{3,4} = J_{4,5} = 10.1$ Hz for **7**. The twist-boat conformation ($^1S_5$) for the *altro* isomer **9** was suggested by the coupling constants ($J_{1,2}$ 2.6, $J_{2,3}$ 8.1, $J_{3,4}$ 7.9, and $J_{4,5}$

* Corresponding author. Tel. +81 45 787 2183; fax: +81 45 787 2370

E-mail address: baratoru@yokohama-cu.ac.jp (T. Sakakibara).

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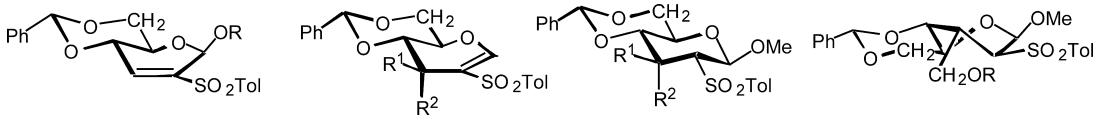
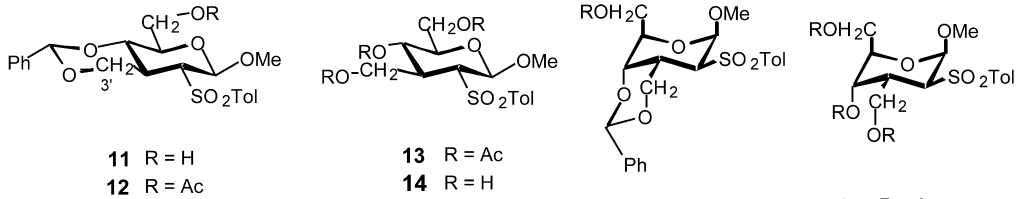


1 R = Me
2 R = Ph

3 $R^1 = CH_2OH$, $R^2 = H$
4 $R^1 = CH_2OAc$, $R^2 = H$
5 $R^1 = H$, $R^2 = CH_2OAc$

6 $R^1 = H$, $R^2 = CH_2OH$
7 $R^1 = CH_2OH$, $R^2 = H$
8 $R^1 = CH_2OAc$, $R^2 = H$

9 R = H
10 R = Ac

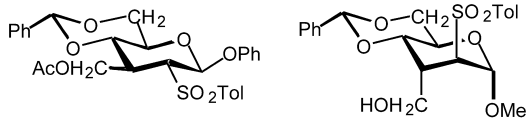


11 R = H
12 R = Ac

13 R = Ac
14 R = H

15 R = H
16 R = Ac

17 R = Ac
18 R = H



19

20

10.4 Hz) and confirmed by correlation between H-2 and H-5 in the NOESY spectrum. The *altro* configuration for **9** was chemically confirmed by treatment of the *allo* isomer **6** with DBU in THF, in which a 1:2 mixture of **6** and **9** was obtained. The same treatment, except in the presence of small amount of deuterium oxide, gave a similar result in which H-1 appeared as singlet, indicating the epimerization at C-2. The glucal structure for **3** was determined by IR (hydroxyl group at 3490 cm^{-1} and strong absorption band at 1605 cm^{-1} for O–C=C–SO_2Tol) and ^{1}H NMR spectra (olefinic proton at δ 7.74, $J_{3,4}$ 10.9 Hz). The configuration at C-3 was confirmed by transformation of **3** into the β-D-glucopyranoside **7** as a major product by treatment with methanolic sodium methoxide.

Although the amounts were variable, another *gluco* isomer **11** was almost always isolated as crystals from the fraction mainly containing the β-D-*gluco* isomer **7** after column chromatography. Before column chromatography, however, compound **11** could not be detected. The *gluco* structure for **11** was determined from the coupling constants and confirmed chemically as follows. Debenzylidenation and subsequent acetylation of the monoacetates **8** and **12** (derived by acetylation of **11**) gave the same peracetate **13**. Thus compound **11** should be formed from **7** by migration of the 4,6-*O*-benzylidene group to O-4 and the newly introduced hydroxymethyl group (3′,4-*O*-benzylidene). It was noteworthy that the benzylidenation of trihydroxy derivative **14**, followed by acetylation, afforded a 1:3 mixture of the 4,6-*O*-benzylidene **8** and 3′,4-*O*-benzylidene derivative **12**.

After acetylation of a fraction that mainly consisted of **7**, a small amount of the transbenzylidenated *altro* product **16** was isolated. Different from the alternative *altro* isomer **10**, compound **16** has the $^1C_4$ conformation ($J_{2,3}$ 11.8 Hz). The *altro* configuration for **16** was confirmed by transformation into the peracetate **17**, identical with a sample prepared from the β-D-allopyranoside **10**. The peracetate **17** and trihydroxy derivative **18** exist in the $^1C_4$ conformation. Benzylidenation of **18** afforded the 3′,4-*O*-benzylidene derivative **15** in 89% yield.

Similar photoreaction of the phenyl analog **2**, followed by acetylation and subsequent separation by column chromatography afforded the glucal **4**, allal **5**, and the *gluco* adduct **19** in 37%, 24%, and 11% yields, respectively. The *gluco* structure for **19** was assigned by the coupling constants ($J_{1,2}$ 5.0, $J_{2,3}$ 7.9, $J_{3,4} = J_{4,5}$ 9.9 Hz). The allal structure for **5** was suggested by the IR (1620 cm^{-1} for O–C=C–SO_2Tol) and ^{1}H NMR spectra (olefinic proton at δ 7.74, $J_{3,4}$ 5.9 Hz) and confirmed by conversion into the α-D-altropyranoside **20** ($J_{1,2}$ 0, $J_{2,3} < 1.0$ Hz) in almost quantitative yield by treatment with methanolic sodium methoxide. Thus a methoxide ion predominantly added from the same side of the substituent at C-3 of 1-enitols **4** and **5**. Similar stereoselectivity was observed in the S_N2' reaction of 3-*O*-acetyl-1,5-anhydro-4,6-*O*-benzylidene-2-deoxy-2-C-*p*-tolylsulfonyl-D-*arbino*- and -*ribo*-hex-1-enitol with methanolic sodium methoxide.[7]

The ratios of glycal derivatives (S_N2' product) to adducts were 1:16 for the methyl derivative **1** and 5.5:1 for the phenyl derivative **2**. These results are reasonable because a phenoxy radical generated by formation of

glycal derivatives is much more stable than a methoxy radical.[8]

The stereoselectivities of the present hydroxymethyl radical addition reaction to methyl and phenyl derivatives (**1** and **2**) were 2.4:1 and 2.0:1, respectively, where equatorial attack slightly predominated over axial attack.

3. Experimental

General methods.—Melting points are uncorrected. Optical rotations were determined with a Horiba High Sensitive Polarimeter (SEPA-200). ^{1}H NMR spectra were recorded with JEOL EX-270 or Bruker AVANCE 400 instruments in $CDCl_3$ with Me_4Si as the internal standard. Only important correlations for structural determination observed in the NOESY spectrum are described. The integration values in NOE difference spectra are roughly estimated, because measurement conditions were not completely optimized. IR spectra were recorded for KBr pellets. Solutions were dried over $MgSO_4$ and evaporated under diminished pressure. Column chromatography was conducted on silica gel (Wakogel C-300) with 12:1 toluene–EtOAc.

*Irradiation of **1** in methanol.*—To a solution of **1** (Ref. 9, 500 mg, 1.24 mmol) in methanol (distilled over Mg, 160 mL) in the presence of benzophenone (37 mg, 0.20 mmol) was cooled at ~ 8 °C and irradiated in a Riko photoreactor with a high-pressure mercury lamp in an H_2O–ethylene glycol cooled Pyrex immersion-well for 10 h under N_2. The mixture was then evaporated, and the resulting syrup was chromatographed to give the 1-enitol derivative **3** (22 mg, 4%) as the front-running fraction, the *allo* isomer **6** (46 mg, 9%) as the second one, and a 4:1 mixture (298 mg, 55%) of the *gluco* and *altro* isomers (**7** and **9**), as judged from ^{1}H NMR spectroscopy as the third one.

Physical data for **3**: mp 185–186 °C (EtOH), $[\alpha]_D^{25}$ + 141° (*c* 0.6, $CHCl_3$); ν_{max} 3490 (OH), 1605 (O–C=C–SO_2), 1280 and 1140 cm^{-1} (SO_2); ^{1}H NMR: δ 7.74 (d, 1 H, $J_{1,3}$ 1.7 Hz, H-1), 2.28 (m, 1 H, $J_{3,4}$ 10.9 Hz, H-3), 4.10 (broad t, 1 H, $J_{4,5}$ 10.9 Hz, H-4), 4.46 (dd, 1 H, ABX, H-6*e*), 3.90–3.83 (m, 2 H, H-5, H-6*a*), 4.02 (dd, 1 H, $J_{3,3'}$ 3.0, $J_{3',OH}$ 4.6 Hz, H-3′), 3.82 (m, 1 H, $J_{3,3''} \sim 0$, $J_{3'',OH}$ 10.9 Hz, H-3″), 2.73 (dd, 1 H, OH), 5.62 (s, 1 H, PhCH), and 2.44 (s, 3 H, SO_2Tol). Anal. Calcd for $C_{21}H_{22}O_6S$: C, 62.67; H, 5.51; S, 7.97. Found: C, 62.87; H, 5.61; S, 7.78.

Physical data for **6**: mp 157–158 °C (EtOH), $[\alpha]_D^{25}$ − 76° (*c* 1, $CHCl_3$); ν_{max} 3520 and 3475 (OH), 1280, and 1130 cm^{-1} (SO_2); ^{1}H NMR (400 MHz): δ 5.21 (d, 1 H, $J_{1,2}$ 8.7 Hz, H-1), 3.40 (dd, 1 H, $J_{2,3}$ 5.0 Hz, H-2), 3.06 (m, 1 H, H-3), 3.71 (dd, 1 H, $J_{3,4}$ 5.0, $J_{4,5}$ 9.6 Hz, H-4), 4.17 (sextet, 1 H, $J_{5,6a}$ 10.1, $J_{5,6e}$ 5.0 Hz, H-5), 3.62 (t, 1 H, $J_{6a,6e}$ 10.5 Hz, H-6*a*), 4.32 (dd, 1 H, H-6*e*), 4.43–4.35 (m, 2 H, H-3′, H-3″), 2.89 (dd, 1 H, $J_{3',OH}$ 5.8, $J_{3'',OH}$ 8.2 Hz, OH), 5.56 (s, 1 H, PhCH), 3.30 (s, 3 H, OMe), and 2.44 (s, 3 H, SO_2Tol). Anal. Calcd for $C_{22}H_{26}O_7S$: C, 60.81; H, 6.03; S, 7.38. Found: C, 60.69; H, 5.98; S, 7.32.

Separation of **7** and **9** could be achieved after acetylation. To a mixture (300 mg, 0.69 mmol) of **7** and **9** in CH_2Cl_2 (60 mL) was added alternatingly and portionwise AcCl (900 mg, 11.46 mmol) and pyridine (900 mg, 11.38 mmol). After stirring for 2 h at room temperature, the mixture was partitioned between AcOEt and H_2O. The organic layer was separated and washed with H_2O, dried, and evaporated to give a residue that was chromatographed to afford successively **8** (235 mg, 71%) and **10** (59 mg, 18%).

Physical data for **8**: mp 121–122 °C (2-PrOH), $[\alpha]_D^{25}$ − 54° (*c* 1, $CHCl_3$); ν_{max} 1740 (OAc), 1300, and 1140 cm^{-1} (SO_2); ^{1}H NMR (400 MHz): δ 4.91 (d, 1 H, $J_{1,2}$ 6.2 Hz, H-1), 3.59 (dd, 1 H, $J_{2,3}$ 9.2 Hz, H-2), 2.74 (m, 1 H, H-3), 3.75 (t, 1 H, $J_{3,4}$ 9.7, $J_{4,5}$ 9.3 Hz, H-4), 3.60 (sextet, 1 H, $J_{5,6a}$ 10.1, $J_{5,6e}$ 4.3 Hz, H-5), 3.66 (t, 1 H, $J_{6a,6e}$ 10.0 Hz, H-6*a*), 4.31 (dd, 1 H, H-6*e*), 4.44 (dd, 1 H, $J_{3,3'}$ 3.1, $J_{3',3''}$ 11.4 Hz, H-3′), 4.62 (dd, 1 H, $J_{3,3''}$ 3.4 Hz, H-3″), 5.51 (s, 1 H, PhCH), 3.30 (s, 3 H, OMe), and 2.46 (s, 3 H, SO_2Tol), and 1.99 (s, 3 H, OAc). Anal. Calcd for $C_{24}H_{28}O_8S$: C, 60.49; H, 5.92; S, 6.73. Found: C, 60.40; H, 5.83; S, 6.92.

Physical data for **10**: mp 141–142 °C (EtOH), $[\alpha]_D^{25}$ − 46° (*c* 1, $CHCl_3$); ν_{max} 1730 (OAc), 1315, and 1150 cm^{-1} (SO_2); ^{1}H NMR: δ 5.03 (d, 1 H, $J_{1,2}$ 2.6 Hz, H-1), 3.83 (dd, 1 H, $J_{2,3}$ 7.3 Hz, H-2), 3.11 (m, 1 H, H-3), 4.38 (dd, 1 H, $J_{3,4}$ 7.6, $J_{4,5}$ 10.2 Hz, H-4), 3.86 (td, 1 H, $J_{5,6a}$ 10.2, $J_{5,6e}$ 4.6 Hz, H-5), 3.60 (t, 1 H, $J_{6a,6e}$ 10.2 Hz, H-6*a*), 4.31 (dd, 1 H, H-6*e*), 4.55 (dd, 1 H, $J_{3,3'}$ 4.6 Hz, $J_{3',3''}$ 11.6 Hz, H-3′), 4.39 (dd, 1 H, $J_{3,3''}$ 4.0 Hz, H-3″), 5.50 (s, 1 H, PhCH), 3.35 (s, 3 H, OMe), 2.46 (s, 3 H, SO_2Tol), and 2.04 (s, 3 H, OAc). Anal. Calcd for $C_{24}H_{28}O_8S$: C, 60.49; H, 5.92; S, 6.73. Found: C, 60.69; H, 5.78; S, 6.81.

Although no evidence for formation of **11** was obtained by ^{1}H NMR spectroscopy and TLC of the crude product just after evaporation, transbenzylidenation of **7** into **11** frequently occurred during crystallization of the mixture of **7** and **9** or during separation by column chromatography on silica gel. While the conditions for the transbenzylidenation have not yet been established, the rearrangement also occurred in chloroform-*d*. An analytical sample of **11**, which readily crystallized from the mixture, was prepared by recrystallization from ethanol: mp 198–199 °C, $[\alpha]_D^{25}$ + 3° (*c* 1, $CHCl_3$); ν_{max} 3480 (OH), 1285, and 1140 cm^{-1} (SO_2); ^{1}H NMR (400 MHz): δ 4.69 (d, 1 H, $J_{1,2}$ 7.2 Hz, H-1), 3.07 (dd, 1 H, $J_{2,3}$ 11.9 Hz, H-2), 2.63 (qd, 1 H, $J_{3,4}$ 10.5 Hz, H-3), 3.82 (dd, 1 H, $J_{4,5}$ 9.0 Hz, H-4), 3.65 (ddd, 1 H, $J_{5,6}$ 4.2, $J_{5,6'}$ 3.1 Hz, H-5), 3.76 (ddd, 1 H, $J_{6,6'}$ 12.1 Hz, H-6′), 3.83 (m, 1 H, H-6), 3.89 (t, 1 H, $J_{3,3'a}$ 10.5, $J_{3'a,3'e}$ 11.6

Hz, H-3′*a*), 5.17 (dd, 1 H, $J_{3,3'e}$ 4.1 Hz, H-3′*e*), 5.59 (s, 1 H, PhCH), 3.17 (s, 3 H, OMe), 2.46 (s, 3 H, SO_2Tol), and 1.92 (dd, 1 H, $J_{6,OH}$ 5.3, $J_{6',OH}$ 7.8 Hz, OH). Anal. Calcd for $C_{22}H_{26}O_7S$: C, 60.81; H, 6.03; S, 7.38. Found: C, 60.74; H, 5.93; S, 7.28.

The same compound **11** was prepared by benzylidenation of **14** as described later.

The filtrate was evaporated and acetylated by AcCl and pyridine to give the acetate **12**, together with a small amount of the *altro* isomer **16**, identical with an authentic sample prepared from **15**.

Acetylation of **11**.—Similar acetylation of **11** (45 mg, 0.10 mmol) with AcCl and pyridine in CH_2Cl_2 as had been described for the preparation of **8** and **10** gave a crystalline residue of **12** in almost quantitative yield.

Physical data for **12**: mp 142–143 °C (EtOH), $[\alpha]_D^{25}$ + 14° (*c* 1, $CHCl_3$); ν_{max} 1735 (OAc), 1295, and 1150 cm^{-1} (SO_2); ^1H NMR (400 MHz): δ 4.70 (d, 1 H, $J_{1,2}$ 6.6 Hz, H-1), 3.09 (dd, 1 H, $J_{2,3}$ 11.8 Hz, H-2), 2.60 (m, 1 H, H-3), 3.8–3.7 (m, 2 H, H-4 -5), 4.18 (dd, 1 H, $J_{5,6}$ 5.5, $J_{6,6'}$ 12.0 Hz, H-6), 4.35 (dd, 1 H, $J_{5,6'}$ 2.1 Hz, H-6′), 3.88 (dd, 1 H, $J_{3,3'a}$ 10.5, $J_{3'a,3'e}$ 11.6 Hz, H-3′*a*), 5.12 (dd, 1 H, $J_{3,3'e}$ 4.1 Hz, H-3′*e*), 5.56 (s, 1 H, PhCH), 3.18 (s, 3 H, OMe), 2.46 (s, 3 H, SO_2Tol), and 2.04 (s, 3 H, OAc); the n.O.e. difference spectrum (270 MHz), H-5 (11%), H-3 (6%), and OMe (10%) appeared by irradiation at H-1. Anal. Calcd for $C_{24}H_{28}O_8S$:C, 60.49; H, 5.92; S, 6.73. Found: C, 60.49; H, 5.95; S, 6.59.

Epimerization of **6**.—To a solution of the *allo* isomer **6** (15 mg, 0.03 mmol) in oxolane (5 mL) was added DBU (720 mg, 4.73 mmol), and the mixture was allowed to stand for 1 week at room temperature. The mixture was then partitioned between AcOEt and H_2O. The organic layer was washed with dil aq HCl and H_2O, dried, and evaporated. The ^1H NMR spectrum showed that it was a 1:2 mixture of **6** and the *altro* isomer **9**. The same reaction was performed one more time, and the combined residue was chromatographed to give **6** (9 mg, 30%) as the fast-running fraction and **9** (20 mg, 67%) as the second one.

Physical data for **9**; syrup, $[\alpha]_D^{25}$ − 38° (*c* 0.8, $CHCl_3$); ν_{max} 3520 (OH), 1300, 1140 and 1130 cm^{-1} (SO_2); ^1H NMR (400 MHz): δ 5.00 (d, 1 H, $J_{1,2}$ 2.6 Hz, H-1), 3.66 (dd, 1 H, $J_{2,3}$ 8.1 Hz, H-2), 2.89 (m, 1 H, H-3), 4.49 (dd, 1 H, $J_{3,4}$ 7.9, $J_{4,5}$ 10.4 Hz, H-4), 3.91 (td, 1 H, $J_{5,6a}$ 10.4, $J_{5,6e}$ 4.9 Hz, H-5), 3.58 (t, 1 H, $J_{6a,6e}$ 10.5 Hz, H-6*a*), 4.34 (dd, 1 H, H-6*e*), 4.02 (m, 2 H, H-3′, -3″), 2.35 (broad s, 1 H, OH), 5.49 (s, 1 H, PhCH), 3.34 (s, 3 H, OMe), and 2.47 (s, 3 H, SO_2Tol); NOESY: correlation between H-2 and H-5; PhCH and H-4; PhCH and H-6*a*. Anal. Calcd for $C_{22}H_{26}O_7S{\cdot}0.5\ H_2O$: C, 59.58; H, 6.14; S, 7.23. Found: C, 59.56; H, 5.87; S, 7.00.

Similar treatment of **6**, except for addition of D_2O (200 mg), gave a similar result in which deuteration at C-2 occurred; this is indicated by appearance of H-1 signals as a singlet in both products.

Deacetylation of **8**.—To a solution of **8** (20 mg, 0.04 mmol) in methanol (8 mL) was added 1.8 M NaOMe (3 mL). After stirring for 3 h at room temperature, the mixture was partitioned between H_2O and AcOEt, and then the organic layer was washed with dil aq HCl and H_2O, dried, and evaporated to give **7** in almost quantitative yield.

Physical data for **7**: mp 110–111 °C (2-PrOH), $[\alpha]_D^{25}$ − 36° (*c* 1, $CHCl_3$); ν_{max} 3550–3400 (OH), 1290, and 1130 cm^{-1} (SO_2); ^1H NMR (400 MHz): δ 4.78 (d, 1 H, $J_{1,2}$ 6.7 Hz, H-1), 3.66 (dd, 1 H, $J_{2,3}$ 9.2 Hz, H-2), 2.59 (m, 1 H, H-3), 3.82 (t, 1 H, $J_{3,4} = J_{4,5}$ 10.1 Hz, H-4), 3.55 (sextet, 1 H, $J_{5,6a}$ 10.1, $J_{5,6e}$ 4.8 Hz, H-5), 3.67 (t, 1 H, $J_{6a,6e}$ 10.2 Hz, H-6*a*), 4.28 (dd, 1 H, H-6*e*), 4.17 (dd, 1 H, $J_{3,3'}$ 3.7, $J_{3',3''}$ 11.5 Hz, H-3′), 3.99 (dd, 1 H, $J_{3,3''}$ 2.3 Hz, H-3″), 5.56 (s, 1 H, PhCH), 3.14 (s, 3 H, OMe), and 2.46 (s, 3 H, SO_2Tol). Anal. Calcd for $C_{22}H_{26}O_7S$: C, 60.81; H, 6.03; S, 7.38. Found: C, 61.00; H, 5.99; S, 7.39.

Deacetylation of **10**.—Similar deacetylation of **10** (20 mg, 0.04 mmol) afforded **9**, identical with an authentic sample by its ^1H NMR spectrum and TLC.

Reaction of **3** *with methanolic sodium methoxide*.—To a solution of **3** (10 mg, 0.02 mmol) in methanol (5 mL) was added 1.2 M NaOMe (2 mL) and the mixture was heated under reflux for 2 h and allowed to stand overnight at room temperature. The mixture was partitioned between AcOEt and H_2O. The organic layer was washed with dil aq HCl and H_2O, dried, and evaporated, from which **7**, identical with an authentic sample, was separated in 57% yield, as the major product, after column chromatography.

Methyl 4,6-di-O-*acetyl-3*-C-*acetoxymethyl-2*-C-p-*tolylsulfonyl-β*-D-*glucopyranoside* (**13**).—A solution of **8** (30 mg, 0.06 mmol) in 70% aq AcOH (10 mL) was kept for 2 h at 80–90 °C. After cooling, the mixture was evaporated, and the evaporation was repeated azeotropically with ethanol, toluene, and ethanol. The residue was then dried over P_2O_5 in vacuo at 40 °C. Its ^1H NMR was different from that obtained from **12**. To the syrup dissolved in CH_2Cl_2 (5 mL) was added Ac_2O (300 mg, 2.94 mmol) and $BF_3{\cdot}OEt_2$ (50 mg, 0.35 mmol). After keeping for 1 h at room temperature, the mixture was partitioned between AcOEt and H_2O. The organic layer was washed with dil aq HCl and H_2O, dried, and evaporated. The residue was chromatographed to give 23 mg (77%) of **13** as syrup; $[\alpha]_D^{25}$ − 4° (*c* 1.2, $CHCl_3$); ν_{max} 1740 (OAc), 1290, and 1140 cm^{-1} (SO_2); ^1H NMR (400 MHz): δ 4.87 (d, 1 H, $J_{1,2}$ 5.4 Hz, H-1), 3.53 (dd, 1 H, $J_{2,3}$ 8.1 Hz, H-2), 2.69 (m, 1 H, H-3), 5.19 (t, 1 H, $J_{3,4} = J_{4,5}$ 9.6 Hz, H-4), 3.77 (ddd, 1 H, H-5), 4.20 (dd, 1 H, $J_{5,6}$ 4.9, $J_{6,6'}$ 12.2 Hz, H-6), 4.03 (dd, 1 H, $J_{5,6'}$ 2.9 Hz, H-6′), 4.49 (dd, 1 H, $J_{3,3'}$ 3.6, $J_{3',3''}$ 11.7 Hz, H-3′), 4.09 (dd, 1 H, $J_{3,3''}$ 4.4 Hz, H-3″), 3.30 (s, 3 H, OMe), 2.46 (s, 3 H, SO_2Tol), 2.09 (s, 3 H, OAc), 2.06 (s, 3 H, OAc), and 1.99 (s, 3 H, OAc). Anal. Calcd. for

$C_{21}H_{28}O_{10}S$: C, 53.38; H, 5.97; S, 6.79. Found: C, 53.58; H, 5.85; S, 6.96.

The same debenzylidenation of **12**, except the reaction time was prolonged to 3 h, and subsequent acetylation gave in 80% yield the peracetate **13**, which was identical with an authentic sample by its ^{1}H NMR spectrum and TLC.

*Methyl 3-*C*-acetoxymethyl-4,6-di-*O*-acetyl-2,3-dideoxy-2-*C*-p-tolylsulfonyl-β-*D*-altropyranoside* (**17**).—A solution of **10** (15 mg, 0.03 mmol) in 70% aq AcOH (10 mL) was heated for 2 h at 80–90 °C. After cooling and evaporation, the mixture was azeotropically evaporated with ethanol and then toluene. The resulting syrup was dissolved in CH_2Cl_2 (5 mL), to which Ac_2O (300 mg, 1.65 mmol) and $BF_3{\cdot}OEt_2$ (50 mg) was added. The same workup described for the preparation of **13** gave **17** in 78% yield; syrup, $[\alpha]_D^{25}$ −73° (*c* 1.8, $CHCl_3$); ν_{max} 1740 (C=O), 1310, and 1130 cm^{-1} (SO_2); ^{1}H NMR (400 MHz, C_6D_6): δ 4.80 (d, 1 H, $J_{1,2}$ 3.3 Hz, H-1), 3.88 (dd, 1 H, $J_{2,3}$ 11.9 Hz, H-2), 3.31 (m, 1 H, H-3), 5.49 (broad t, 1 H, $J_{3,4}$ 2.6, $J_{4,5}$ 2.0 Hz, H-4), 5.06 (dd, 1 H, $J_{3,3'}$ 4.5, $J_{3',3''}$ 11.4 Hz, H-3′), 4.25–4.30 (m, 2 H, H-6, -6′), 4.60 (dd, 1 H, $J_{3,3''}$ 10.2 Hz, H-3″), ~4.20 (m, 1 H, H-5), 2.97 (s, 3 H, OMe), 1.88 (s, 3 H, SO_2Tol), 1.74 (s, 3 H, OAc), 1.71 (s, 3 H, OAc), and 1.66 (s, 3 H, OAc); NOESY: correlation between H-3 and H-6; H-1 and OMe. Anal. Calcd for $C_{21}H_{28}O_{10}S{\cdot}H_2O$: C, 51.42; H, 6.16; S, 6.54. Found: C, 51.84; H, 5.63; S, 7.02.

Similar debenzylidenation, except that the reaction time was 3 h, and subsequent acetylation of **16** gave the same peracetate **17** in ~80% yield.

*Methyl 2,3-dideoxy-3-*C*-hydroxymethyl-2-*C*-p-tolylsulfonyl-β-*D*-glucopyranoside* (**14**).—A solution of **7** (15 mg, 0.03 mmol) in 70% aq. AcOH (10 mL) was kept for 2 h at 80–90 °C. After cooling, the mixture was evaporated, and evaporation was repeated azeotropically with toluene and with EtOH. The residue was dried over P_2O_5 in vacuo at 40 °C to give **14** in 90% yield.

Physical data for **14**; syrup, $[\alpha]_D^{25}$ −10° (*c* 1.6, $CHCl_3$); ν_{max} 3370 (OH), 1280, and 1140 cm^{-1} (SO_2); ^{1}H NMR (CD_3OD): δ 4.83 (d, 1 H, $J_{1,2}$ 7.3 Hz, H-1), 3.82–3.70 (m, 3 H, H-2, -4, -6′), 2.34 (tt, 1 H, $J_{2,3} = J_{3,4}$ 10.2, $J_{3,3'}$ 3.3, $J_{3,3''}$ 2.3 Hz, H-3), 4.34 (dd, 1 H, $J_{3,3''}$ 10.9 Hz, H-3′), 4.13 (dd, 1 H, H-3″), 3.46 (m, 1 H, H-5), 3.99 (dd, 1 H, $J_{5,6}$ 2.7, $J_{6,6'}$ 12.2 Hz, H-6), 3.30 (s, 3 H, OMe) and 2.59 (s, 3 H, SO_2Tol). Anal. Calcd for $C_{15}H_{22}O_7S$: C, 52.01; H, 6.40; S, 9.26. Found: C, 51.89; H, 6.24; S, 8.97.

Benzylidenation of **14**.—To a solution of **14** (15 mg, 0.04 mmol) in DMF (2 mL) and benzaldehyde dimethyl acetal (0.05 mL, 0.33 mmol) was added TsOH until pH ~2, and the mixture was stirred at 60 °C under diminished pressure. After 2 h, the mixture was extracted with AcOEt, and the extracts were washed with aq $NaHCO_3$, aq NaCl, dried, and evaporated. To the syrup dissolved in $CHCl_3$ (3 mL) was added pyridine (0.04 mL, 0.49 mmol), and the mixture was cooled to −20 °C. To the cooled solution was added dropwise AcCl (0.04 mL, 0.56 mmol). After 2 h, the mixture was extracted with CH_2Cl_2, and the extracts were washed with aq HCl, aq NaCl, dried, and evaporated. The contaminating benzaldehyde was removed by column chromatography with toluene and then toluene and AcOEt (15:1) to give a 1:3 mixture (18 mg, 96%) of **8** and **12**, as judged from NMR spectroscopy.

*Methyl 2,3-dideoxy-2-*3*-C-hydroxymethyl-*C*-p-tolylsulfonyl-β-*D*-altropyranoside* (**18**).—A solution of **9** (163 mg, 0.38 mmol) in 70% aq AcOH (48 mL) was kept for 2 h at 80 °C. After cooling, the mixture was evaporated, and evaporation was repeated azeotropically three times with toluene. The residue was then dried over P_2O_5 in vacuo at 40 °C to give **18** as a syrup (112 mg, 84%).

Physical data for **18**; syrup, $[\alpha]_D^{25}$ −35° (*c* 1.0, $CHCl_3$); ν_{max} 3330 (OH), and 1280 cm^{-1} (SO_2); ^{1}H NMR (D_2O): δ 4.37 (d, 1 H, $J_{1,2}$ 3.6 Hz, H-1), 3.87 (dd, 1 H, $J_{2,3}$ 10.4 Hz, H-2), 2.60 (m, 1 H, H-3), 4.19 (t, 1 H, $J_{3,4} = J_{4,5}$ 3.0 Hz, H-4), 3.82–3.52 (m, 4 H, H-5, -6, -6′, 3″), 3.98 (dd, 1 H, $J_{3,3'}$ 5.0, $J_{3',3''}$ 11.2 Hz, H-3′), 3.09 (s, 3 H, OMe), and 2.35 (s, 3 H, SO_2Tol). Anal. Calcd for $C_{15}H_{22}O_7S{\cdot}0.5H_2O$: C, 50.69; H, 6.52; S, 9.02. Found: C, 50.80; H, 6.17; S, 9.49.

Benzylidenation of **18**.—Similar benzylidenation of **18** (110 mg, 0.31 mmol) afforded 200 mg of **15** that was contaminated with small amount of benzaldehyde. Half amount of the syrup was similarly chromatographed to give 60 mg (89%) of **15**, which was pure as judged from ^{1}H NMR spectroscopy.

Physical data for **15**: mp 173.5–175 °C (2-PrOH–acetone), $[\alpha]_D^{25}$ −81° (*c* 1.1, $CHCl_3$); ν_{max} 3460 (OH), 1290, and 1130 cm^{-1} (SO_2); ^{1}H NMR (400 MHz): δ 4.85 (d, 1 H, $J_{1,2}$ 3.4 Hz, H-1), 4.30 (dd, 1 H, $J_{2,3}$ 11.8 Hz, H-2), 2.60 (dd, 1 H, H-3), 4.28 (broad s, 1 H, $J_{3,4}$ 2.2, $J_{4,5}$ ~0 Hz, H-4), 3.94 (t, 1 H, $J_{5,6} = J_{5,6'}$ 4.5 Hz, H-5), 3.7–3.85 (m, 2 H, H-6, -6′), 4.78 (d, 1 H, $J_{3,3'e}$ ~0, $J_{3'a,3'e}$ 12.3 Hz, H-3′*e*), 3.99 (dd, 1 H, $J_{3,3'a}$ 2.4 Hz, H-3′*a*), 5.55 (s, 1 H, PhCH), 3.38 (s, 3 H, OMe), and 2.45 (s, 3 H, SO_2Tol), 2.72 (bdd, $J_{6,OH}$ 4.1, $J_{6',OH}$ 8.2 Hz, OH); NOESY: correlation between PhCH and H-3′*a*; H-1 and OMe; H-3 and H-6. Anal. Calcd for $C_{22}H_{26}O_7S$: C, 60.81; H, 6.03; S, 7.38. Found: C, 61.06; H, 6.01; S, 7.21.

The remaining syrup was dissolved in CH_2Cl_2 (5 mL), and pyridine (0.04 mL, 0.49 mmol) and AcCl (0.04 mL, 0.56 mmol) were added at −20 °C. After 2 h at ambient temperature, similar workup gave **16** (45 mg, 61% from **18**).

Physical data for **16**: mp 84–85 °C (2-PrOH), $[\alpha]_D^{25}$ −69° (*c* 1.1, $CHCl_3$); ν_{max} 1740 (CO), 1315, and 1140 cm^{-1} (SO_2); ^{1}H NMR (400 MHz, C_6D_6): δ 4.76 (d, 1 H, $J_{1,2}$ 3.3 Hz, H-1), 4.57 (dd, 1 H, $J_{2,3}$ 11.8 Hz, H-2), 3.53 (broad dd, 1 H, $J_{3,4}$ 1.7, $J_{3,3'e}$ ~0, $J_{3,3'a}$ 2.0 Hz,

H-3), 3.83 (dd, 1 H, $J_{4,5}$ ~0 Hz, H-4), 4.2–4.4 (3 H, m, H-5, -6, 6′), 5.09 (d, 1 H, $J_{3'a,3'e}$ 12.0 Hz, H-3′*e*), 3.53 (dd, 1 H, H-3′*a*), 5.28 (s, 1 H, PhCH), 3.03 (s, 3 H, OMe), 1.86 (s, 3 H, SO_2Tol), and 1.68 (s, 3 H, OAc); NOESY: correlation between H-2 and H-3′*e*; PhCH and H-3′*a*. Anal. Calcd for $C_{24}H_{28}O_8S$: C, 60.49; H, 5.92; S, 6.73. Found: C, 60.70; H, 5.92; S, 6.60.

Irradiation of **2** *in methanol*.—To a solution of **2** (Ref. 9, 570 mg, 1.23 mmol) in methanol (distilled over Mg, 540 mL) in the presence of benzophenone (36 mg, 0.20 mmol) was cooled at ~10 °C and irradiated in a Riko photoreactor with a high-pressure mercury lamp in an H_2O–ethylene glycol cooled Pyrex immersion-well for ~10 h under N_2. After evaporation, the syrup was dissolved in CH_2Cl_2 (50 mL) and pyridine (1.84 mL, 22.7 mmol) and cooled to −20 °C. AcCl (1.63 mL, 22.9 mmol) was added dropwise to the solution. After 2.5 h, the mixture was extracted with CH_2Cl_2, and the extracts were washed with aq HCl, aq NaCl, aq $NaHCO_3$, dried, and evaporated. The syrup was chromatographed with 30:1 hexane–AcOEt to give **19** (75 mg, 11%) and a 3:2 mixture (334 mg, 61%) of **4** and **5**. Compounds **4** and **5** were separated by fractional crystallization from 2-propanol; the first crop was **5**.

Physical data for **19**: mp 146–148 °C (EtOH), $[\alpha]_D^{25}$ −63° (*c* 1.0, $CHCl_3$); ν_{max} 1740 (OAc), 1300, 1140 cm^{-1} (SO_2); ^{1}H NMR: δ 5.84 (d, 1 H, $J_{1,2}$ 5.0 Hz, H-1), 3.87 (dd, 1 H, $J_{2,3}$ 7.9 Hz, H-2), 2.85 (m, 1 H, H-3), 3.95 (t, 1 H, $J_{3,4} = J_{4,5}$ 9.9 Hz, H-4), 3.78 (dt, 1 H, $J_{5,6a}$ 10.1, $J_{5,6e}$ 4.6 Hz, H-5), 3.60 (t, 1 H, $J_{6a,6e}$ 10.2 Hz, H-6*a*), 4.29 (dd, 1 H, H-6*e*), 4.47 (dd, 1 H, $J_{3,3'}$ 4.0 Hz, $J_{3',3''}$ 11.5 Hz, H-3′), 4.60 (dd, 1 H, $J_{3,3''}$ 4.0 Hz, H-3″), 5.51 (s, 1 H, PhCH), 2.43 (s, 3 H, SO_2Tol), and 2.02 (s, 3 H, OAc). Anal. Calcd for $C_{29}H_{30}O_8S$: C, 64.67; H, 5.61; S, 5.95. Found: C, 64.70; H, 5.68; S, 5.80.

Physical data for **4**: mp 159–161 °C (2-PrOH), $[\alpha]_D^{25}$ +19° (*c* 1.0, $CHCl_3$); ν_{max} 1740 (OAc), 1610 (O–C=C–SO_2), 1300, 1140 cm^{-1} (SO_2); ^{1}H NMR (C_6D_6): δ 7.77 (d, 1 H, $J_{1,3}$ 1.7 Hz, H-1), 2.75 (m, 1 H, H-3), 3.69 (t, 1 H, $J_{3,4} = J_{4,5}$ 9.5 Hz, H-4), 3.15 (dt, 1 H, $J_{5,6a}$ 10.4, $J_{5,6e}$ 4.9 Hz, H-5), 3.26 (t, 1 H, $J_{6a,6e}$ 10.1 Hz, H-6*a*), 3.95 (dd, 1 H, H-6*e*), 4.63 (dd, 1 H, $J_{3,3'}$ 3.8 Hz, $J_{3',3''}$ 11.9 Hz, H-3′), 4.50 (dd, 1 H, $J_{3,3''}$ 2.6 Hz, H-3″), 5.15 (s, 1 H, PhCH), 1.85 (s, 3 H, SO_2Tol), and 1.42 (s, 3 H, OAc). Anal. Calcd for $C_{23}H_{24}O_7S$: C, 62.15; H, 5.44; S, 7.21. Found: C, 62.38; H, 5.49; S, 7.45.

Physical data for **5**: mp 220–222 °C (2-PrOH), $[\alpha]_D^{25}$ +121° (*c* 0.5, $CHCl_3$); ν_{max} 1740 (OAc), 1620 (O–C=C–SO_2), 1300, 1150 cm^{-1} (SO_2); ^{1}H NMR: δ 7.74 (d, 1 H, $J_{1,3}$ 1.7 Hz, H-1), 3.07 (m, 1 H, $J_{3,4}$ 5.9 Hz, H-3), 3.81 (dd, 1 H, $J_{4,5}$ 9.9 Hz, H-4), 4.30–4.21 (m, 3 H, H-5, H-3′ × 2), 3.74 (t, 1 H, $J_{5,6a} = J_{6a,6e}$ 10.5 Hz, H-6*a*), 4.50 (dd, 1 H, $J_{5,6e}$ 5.3 Hz, H-6*e*), 5.52 (s, 1 H, PhCH), 2.44 (s, 3 H, SO_2Tol), and 1.83 (s, 3 H, OAc). Anal. Calcd for $C_{23}H_{24}O_7S$: C, 62.15; H, 5.44; S, 7.21. Found: C, 61.89; H, 5.20; S, 7.05.

Reaction of **3** *with methanolic sodium methoxide*.—To a solution of **3** (10 mg, 0.025 mmol) in methanol (5 mL) was added 1.2 M NaOMe (2 mL), and the mixture was heated under reflux for 2 h and allowed to stand overnight. The mixture was partitioned between AcOEt and H_2O. The organic layer was washed with dil aq HCl and H_2O, dried, and evaporated to give a 4:1 mixture (8 mg, 74%) of **7** and an unidentified product as judged from the ^{1}H NMR spectrum.

Reaction of **5** *with methanolic sodium methoxide*.—To a solution of **5** (15 mg, 0.034 mmol) in methanol (10 mL) was added 1.8 M NaOMe (3 mL), and the mixture was heated under reflux for 2 h. The mixture was partitioned between AcOEt and H_2O. The organic layer was washed with dil aq HCl and H_2O, dried, and evaporated to give 15 mg (98%) of **20**, which was pure as judged from ^{1}H NMR spectroscopy.

Physical data for **20**; syrup, $[\alpha]_D^{25}$ +49° (*c* 1.8, $CHCl_3$); ν_{max} 3520 (OH), 1300, 1120 cm^{-1} (SO_2); ^{1}H NMR: δ 5.28 (s, 1 H, H-1), 3.46 (broad s, 1 H, $J_{2,3} < 1.0$ Hz, H-2), 2.84 (broad dd, 1 H, H-3), 4.36 (dd, 1 H, $J_{3,4}$ 5.9, $J_{4,5}$ 9.7 Hz, H-4), 4.07 (td, 1 H, $J_{5,6a}$ 9.7, $J_{5,6e}$ 5.1 Hz, H-5), 3.77 (t, 1 H, $J_{6a,6e}$ 10.2 Hz, H-6*a*), 4.28 (dd, 1 H, H-6*e*), 4.17 (dd, 1 H, $J_{3,3'}$ 6.1, $J_{3',3''}$ 9.8 Hz, H-3′), 3.60 (broad dd, 1 H, $J_{3,3''}$ 7.5 Hz, H-3″), 5.53 (s, 1 H, PhCH), 3.37 (s, 3 H, OMe), and 2.48 (s, 3 H, STol). Anal. Calcd for $C_{22}H_{26}O_7S{\cdot}H_2O$: C, 58.39; H, 6.24; S, 7.09. Found: C, 57.91; H, 5.81; S, 7.12.

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