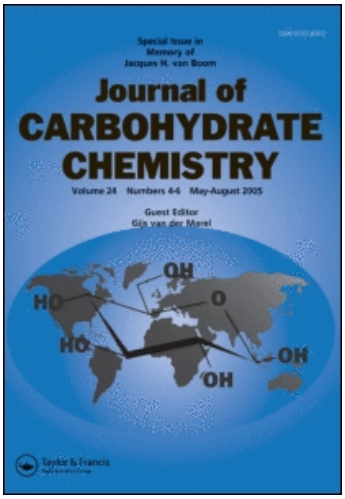


Journal of Carbohydrate Chemistry

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713617200

Addition Reactions of Benzenesulfinic Acid with Glycals and 1,2-Dibromosugars

Vikram Basava[a]; Broc Flores[a]; Matthew Giovine[a]; Thomas Licisyn[a]; Katelyn Walck[a]; Walter Boyko[a]; Robert Giuliano[a]

[a] Department of Chemistry, Villanova University, Villanova, PA, USA

To cite this Article Basava, Vikram , Flores, Broc , Giovine, Matthew , Licisyn, Thomas , Walck, Katelyn , Boyko, Walter and Giuliano, Robert(2008) 'Addition Reactions of Benzenesulfinic Acid with Glycals and 1,2-Dibromosugars', Journal of Carbohydrate Chemistry, 27: 7, 389 — 400

To link to this Article: DOI: 10.1080/07328300802374805

URL: http://dx.doi.org/10.1080/07328300802374805

Journal of Carbohydrate Chemistry, 27:389–400, 2008

ISSN: 0732-8303 print / 1532-2327 online
DOI: 10.1080/07328300802374805

Taylor & Francis
Taylor & Francis Group

Addition Reactions of Benzenesulfinic Acid with Glycals and 1,2-Dibromosugars

Vikram Basava, Broc Flores, Matthew Giovine, Thomas Licisyn, Katelyn Walck, Walter Boyko, and Robert Giuliano

Department of Chemistry, Villanova University, Villanova, PA 19085, USA

The addition of benzenesulfinic acid to glycals was investigated under various conditions, and optimized yields of the glycosyl phenylsulfone products were obtained in the presence of tin tetrachloride as a catalyst. Double bond shift (Ferrier rearrangement) occurred in all cases except amicetal, which lacks a substituent at the allylic carbon. Glycosylation of benzenesulfinic acid with 1,2-dibromides was carried out using silver triflate as the promoter, and gave sulfinate esters as products by reaction at oxygen rather than at sulfur. The sulfinate esters were obtained as mixtures of stereoisomers at the stereogenic sulfur atom. Trapping of the sulfinates with carboxylate nucleophiles was observed during attempted oxidation with MCPBA.

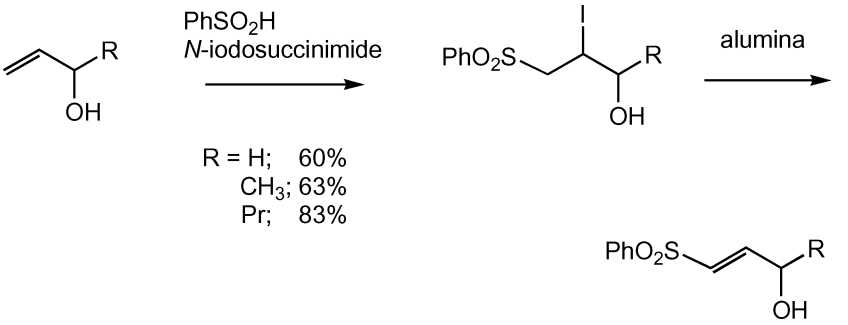
Keywords Benzenesulfinic acid, glycosyl phenylsulfones, carbohydrate sulfinate esters

INTRODUCTION

We have recently developed a new method for the iodosulfonation of alkenes using benzenesulfinic acid and *N*-iodosuccinimide.[1] Treatment of the product iodosulfones with neutral alumina in dichloromethane at rt results in dehydroiodination to give the corresponding vinyl sulfones in high yield and purity (Sch. 1). Carbohydrate-derived sulfones[2] and vinyl sulfones[3] are useful as intermediates in the synthesis of amino[4] and branched-chain[5] sugars, and as precursors to *C*-glycosides via α-lithiaton,[6] α-samariation,[7] and the Ramberg-Backlund reaction.[8] It was of interest to investigate the iodosulfonation of glycals using benzensulfinic acid, in an effort to synthesize carbohydrate

Received January 11, 2008; accepted July 31, 2008.
Address correspondence to Robert Giuliano, Department of Chemistry, Villanova University, 800 Lancaster Avenue, 300D Mendel Science Center, Villanova PA 19085.

sulfones for application in some of these areas, in particular as precursors to *C*-glycosides. In this study, we describe the addition of benzenesulfinic acid to glycals to give glycosyl phenylsulfones, and also the glycosylation of benzenesulfinic acid with sugar dibromides to give sulfinate esters.



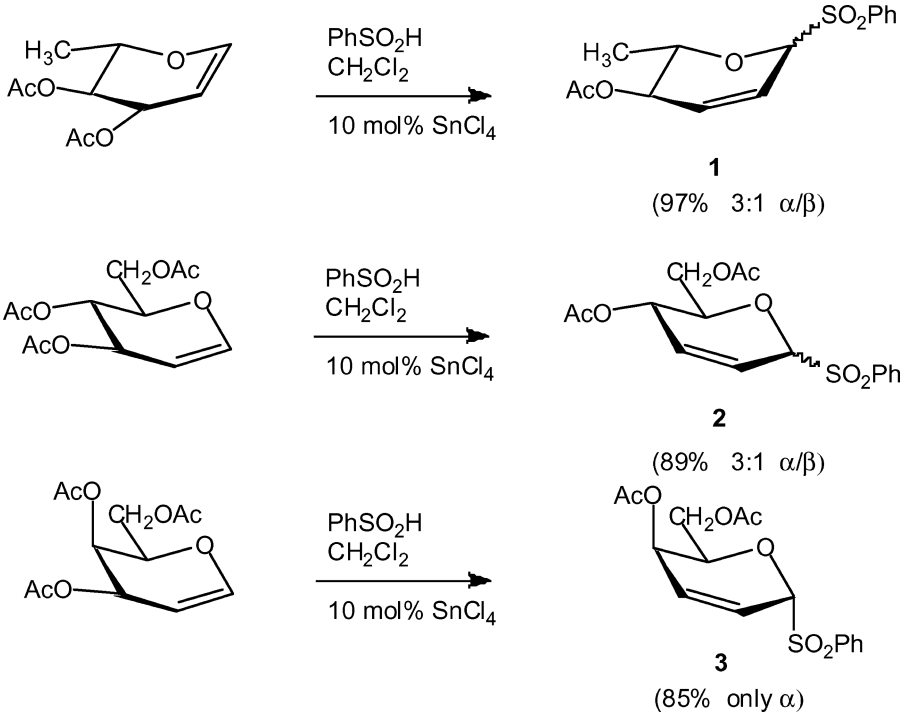
Scheme 1. Iodosulfonation-dehydrohalogenation with $PhSO_2H$/NIS/alumina.

RESULTS AND DISCUSSION

Previously, we observed that iodosulfonaton of 3,4-di-*O*-acetyl-L-rhamal with benzenesufinic acid and *N*-iodosuccinimide gave a mixture of glycosyl phenylsulfones **1** with no evidence of iodination. The double bond had shifted to C2-C3 to give a Ferrier-type rearrangement product.[9] Repeating the experiment with a different iodinating reagent (IDCP) produced the same result, again with no addition of iodine. The addition of benzenesulfinic acid to tri-*O*-acetyl-D-glucal had previously been reported by Ley and coworkers, with improvement in yields when the reaction was carried out using boron trifluoride-etherate as a catalyst.[10] We had also observed that simple treatment of a glycal, 3,4-di-*O*-acetyl-L-rhamnal, with excess benzenesulfinic acid in dichloromethane gave the mixture of sulfones (3:1 α β) in yields ranging from 54% to 86%. A four- to fivefold excess of benzenesulfinic acid was used in these reactions.

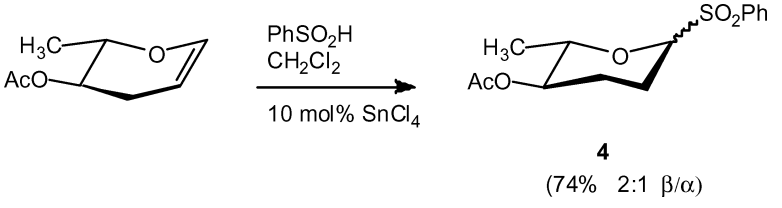
The use of tin tetrachloride as a catalyst in Ferrier reactions involving the addition of alcohols to glycals was reported by Horton and coworkers.[11] We decided to attempt the tin-catalyzed addition of benzenesulfinic acid to glycals in an effort to prepare the glycosyl phenylsulfones more efficiently. Results for the addition of benzenesulfinic acid to glycals using these conditions are summarized in Scheme 2. The amount of catalyst used was 10 mole percent; however, excess benzenesulfinic acid (three equivalents) was still required to get high yields of products. The glycosyl phenylsulfones **1** and **2** were obtained as mixtures of anomers. In the case of 3,4,6-tri-*O*-acetyl-D-galactal, only the α-anomer **3** of the phenylsulfone product was obtained. The products of these reactions were purified by flash chromatography but the mixtures of anomers were

inseparable. The products were stable when stored at 0°C; however, it was observed that anomerization to give a product mixture enriched in the α-anomer occurred upon chromatography and also on standing for extended periods.



Scheme 2. $SnCl_4$-Catalyzed Addition of $PhSO_2H$ to Glycals.

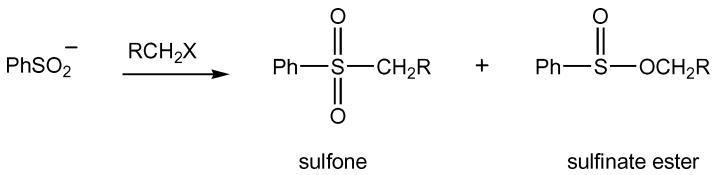
The addition to of benzenesulfinic acid to 4-*O*-acetyl-L-amicetal[12] gives an anomeric mixture of glycosyl phenylsulfones **4**, with a preference for the α-anomer (2:1). When iodosulfonation of this glycal was attempted using *N*-iodosuccinimide/benzenesulfinic acid, there was no iodosulfone product obtained.



We were somewhat surprised to observe the absence of products of iodosulfonation in the reactions of glycals with $PhSO_2H$/NIS. Evidently, protonation of the nucleophilic double bond in the vinyl ether moiety is more rapid than iodonium transfer, unlike the cases of the simple alkenes that were used as

substrates in our previous studies of iodosulfonation. When alternate sources of benzenesulfinate, such as tetra-*n*-butylammonium benzenesulfinate,[13] were used in place of benzensulfinic acid in an attempted iodosulfonation of 3,4-di-*O*-acetyl-L-rhamal, no significant reaction took place. Glycosyl phenylsulfones have been used in several approaches to *C*-glycosides. Since those obtained here are allylic, it is expected that they will be suitable substrates for activation and coupling to aldehydes or other electrophilic reagents.

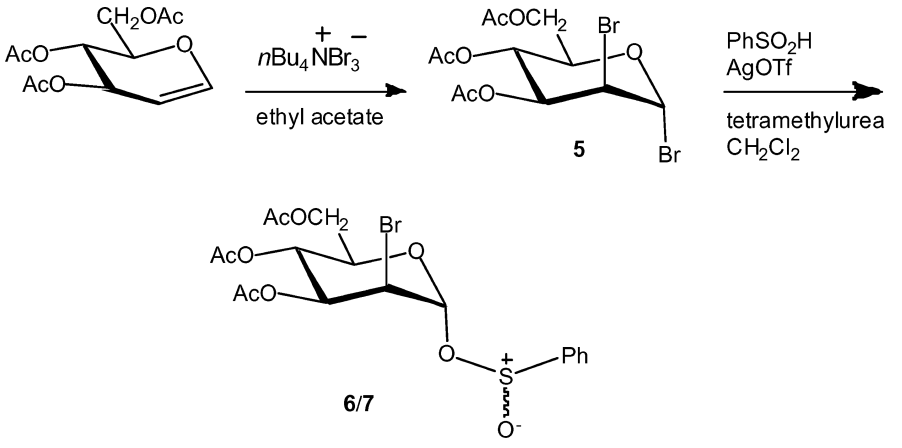
The reaction of benzenesulfinic acid with sugar dibromides was also investigated in this study. The direct glycosylation of benzenesulfinic acid with donors other than glycals has not been reported. Our experience with the addition reactions of benzenesulfinic acid to glycals had suggested to us that as an acceptor, benzenesulfinate might be relatively unreactive in the glycosylation reaction. In addition, benzenesulfinate anion is an ambident nucleophile and it is known to react with alkylating agents at either sulfur or oxygen to give sulfones or sulfinate esters, respectively.[14] The nature of the alkylating agent and solvent appear to be involved in determining the outcome, the latter due to the extent of hydrogen bonding to the nucleophilic sulfinate ion. Soft electrophiles such as alkyl halides have been shown to favor alkylation at sulfur, while hard electrophiles such as diazomethane favor the formation of sulfinate esters. For this study, sugar dibromides were selected as donors, since products of glycosylation at sulfur might be transformed into vinyl sulfones, or other synthetically useful intermediates.



The glycosylation method we selected for coupling the sugar dibromides with benzenesulfinic acid in this study was that of Hanessian and Banoub,[15] in which silver triflate is used as the promoter and tetramethylurea serves as an acid scavenger. It was considered that silver benzenesulfinate could be generated in situ under these conditions. Silver salts of benzenesulfinic acid are known to undergo both *S*- and *O*-alkylation,[14] but in the absence of examples with carbohydrate substrates, we could not predict the preferred mode of attack of sulfinate on the glycosyl bromide.

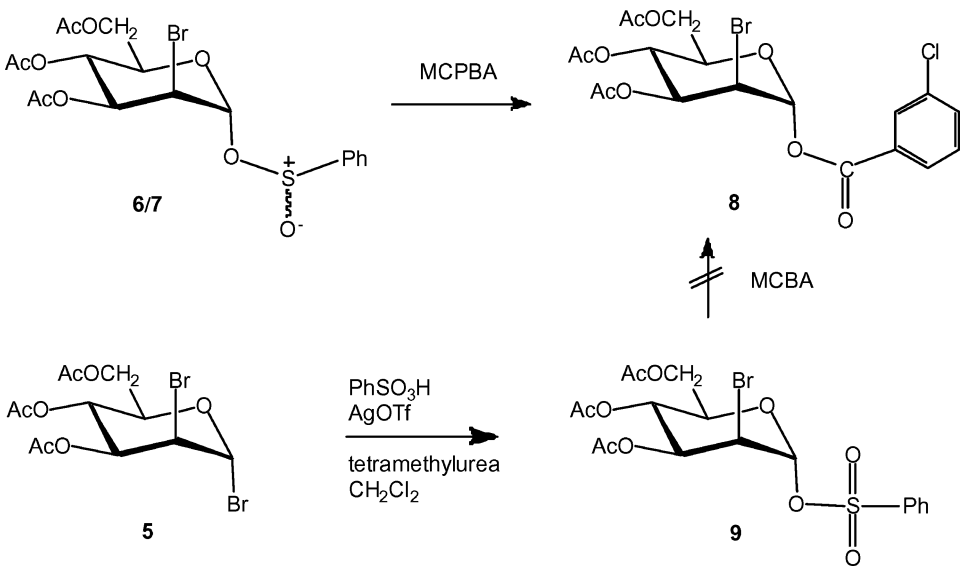
The sugar dibromide 3,4,6-tri-*O*-acetyl-2-bromo-2-deoxy-α-D-mannopyranosyl bromide was prepared using tetra-*n*-butylammonium tribromide, as described by Descotes.[16] Crystallization of the product mixture from ether-hexane gave anomerically pure *α-manno* dibromide. Results of the coupling of the dibromide to benzenesulfinic acid in the presence of silver triflate and tetramethylurea are shown in Scheme 3. The outcome of this experiment was sensitive to the reaction conditions, in particular the exclusion of air, and the

results were difficult to interpret. If the coupling reaction was carried out under an inert atmosphere, a nearly equal mixture of two major sulfinate esters **5** and **6** was obtained, both assigned as α-anomers on the basis of the major starting dibromide stereochemistry and the small and identical $J_{1,2}$ of 1.6 Hz. Sulfur is stereogenic in the sulfinate esters, so mixtures of diastereomers are obtained. In addition, there were minor amounts of other side-products that included sulfonate ester **9**. Formation of the latter could be suppressed by exclusion of air from the reaction. However, no evidence of sulfone formation that would result from glycosylation of benzenesulfinic acid at sulfur, rather than oxygen, was observed. The downfield shifts of the anomeric proton resonances in the ^{1}H NMR spectra occur at 5.8 to 6.0 ppm, while the alternate, sulfone products would be expected to exhibit shifts for H-1 at 4.5 to 5.0 ppm.[17]



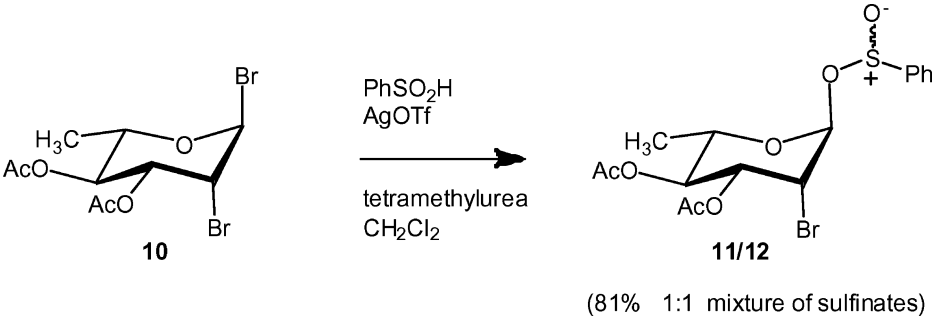
Scheme 3. Glycosylation of a Sugar Dibromide with Benzenesulfinic Acid.

Glycosyl phenylsulfonate **9** was synthesized from the dibromide **5** by coupling with benzenesulfonic acid, using the same reaction conditions. Having **9** in hand helped us to confirm its formation in minor amounts when the coupling of **5** with benzenesulfinic acid was not conducted under an inert atmosphere. We also attempted to prepare **9** by oxidation of the sulfinate esters **6/7** with MCPBA. The only appreciable product isolated from this experiment was the glycosyl aryl ester **8** (Sch. 4). This raises questions as to whether oxidation of sulfinate to sulfonate occurs prior to aryl ester formation, and whether both sulfintate and sulfonate undergo coupling to form the ester. Treatment of neither the sulfinate esters nor **9** with excess MCBA gave ester **8**. Further experiments would be required to elucidate the details of the sulfinate esterification, or to demonstrate that sulfinate esters may serve as glycosyl donors toward other nucleophiles. In the present study, reaction conditions were developed for the reproducible synthesis of sulfinate esters from readily available sugar dibromides.



Scheme 4. Oxidation/Esterification of Phenylsulfinate Esters.

The *α-manno* dibromide **10**, obtained from 3,4-di-*O*-acetyl-L-rhamnal by bromination with tetra-*n*-butylammonium tribromide, also underwent glycosylation with benzenesulfinic acid to provide bromosulfinate esters **11/12** as a 1:1 mixture of sulfinate diastereomers, both assigned as *α*-anomers (Sch. 5). Again, the formation of sulfones was not detected. Also, the formation of sulfonate by-products was not observed when the reaction was carried out under argon. Purification by chromatography and by crystallization were attempted on the mixtures of sulfinate esters without success.



Scheme 5. Synthesis of Phenylsulfinate Esters from a Rhamnal-Derived Dibromosugar.

Sulfinate esters derived from carbohydrates are not well known and their chemistry has not been well studied. Benzenesulfinate esters derived from menthol have previously been synthesized and shown to react with organometallic reagents to give chiral sulfoxides by Harpp.[18] Applications

of sulfinate esters in carbohydrate chemistry are under investigation in our laboratory.

EXPERIMENTAL

General Procedure for the Addition of Benzenesulfinic Acid to Glycals

Benzenesulfinic acid was prepared by acidification of the sodium salt with 12M HCl and drying of the product in a vacuum oven (25 mm Hg) at rt overnight, then stored at 0°C.[1] To a stirring solution of the glycal in anhydrous dichloromethane at 0°C was added benzenesulfinic acid (see individual examples below for equivalents of $PhSO_2H$). Ten mole percent of tin tetrachloride (1 M solution in dichloromethane) was added and the reaction was allowed to warm to rt and monitored by TLC using mixtures of ethyl acetate-hexane as noted. Reactions were typically completed in 1 to 3 h, after which additional dichloromethane was added and the mixture washed with 10% aqueous sodium bicarbonate solution, water, and brine; dried (Na_2SO_4); and concentrated. Products were obtained as oils, which were further purified by flash chromatography using the solvent mixtures indicated in each example. Assignments of NMR chemical shifts to the phenyl sulfinate and sulfonate esters were made with HETCOR analysis.

Phenylsulfonyl 4-*O*-acetyl-2,3,6-trideoxy-α.β-L-*threo*-hex-2-enopyranoside (1)

From 2.14 g (10 mmol) of glycal, treated with benzenesulfinic acid 4.06 g (29 mmol, 2.9 eq) and 1.0 mL tin tetrachloride solution in 60 mL anhydrous dichloromethane, there was obtained 2.87 g (97%) of product as a 3:1 $\alpha\beta$ anomeric mixture after purification by flash chromatography with 1:4 ethyl acetate-hexane. R_f 0.4 (40% ethyl acetate-hexanes). The anomers were not separated. NMR and other analytical data for **1** α have previously been reported from this laboratory.[1]

Phenylsulfonyl 4,6-di-*O*-acetyl-2,3-dideoxy-α, β-D-*threoo*-hex-2-enopyranoside (2)

From 0.287 g (1.05 mmol) of glycal, treated with benzenesulfinic acid (0.398 g, 2.8 mmol) and 0.2 mL tin tetrachloride solution in 6 mL dichloromethane, there was obtained 0.34 g (89%) of product as a 3:1 α β anomeric mixture after purification by flash chromatography with 1:2 ethyl acetate-hexane. The anomers were not separated. R_f 0.5. The ^{1}H NMR for **2**α matched that reported.[10]

Phenylsulfonyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (3)

From 0.289 g (1.06 mmol) of glycal, treated with benzenesulfinic acid (0.457 g, 3.2 mmol) and 0.2 mL tin tetrachloride solution in 6 mL dichloromethane, there was obtained 0.317 g (85%) of product as a white solid after purification by flash chromatography with 1:3 ethyl acetate-hexane: mp 148–150°C. R_f 0.48. $[\alpha]_D^{23}$ –61.1° (*c*, 1.8, methanol). ^{1}H NMR (300 MHz, $CDCl_3$): α 8.00 (m, 2H, Ph-H), 7.72 (m, 1H, Ph-H), 7.59 (m, 2H, Ph-H), 6.56 (m, 1H, $J_{3,4}$ 5.6 Hz, H-3), 6.49 (dd, 1H, $J_{2,3}$ 10.3 Hz, H-2), 5.21 (dd, 1H, $J_{1,2}$ 2,9 Hz, $J_{1,3}$ 2.0 Hz, H-1), 5.14 (dd, 1H, $J_{4,5}$ 2.4 Hz, H-4), 4.91 (m, 1H, $J_{5,6}$ 6.1 Hz, H-5), 4.14 (m, 2H, H-6), 2.14 (s, 3H, CH_3), 2.05 (s, 3H, CH_3). ^{13}C NMR α 170.5, 170.2, 137.1, 134.5, 129.5, 129.4, 128.3, 122.9, 88.6, 70.8, 63.3, 62.4, 21.2, 21.0. HRMS calcd for $C_{16}H_{18}O_7NaS$ $(M + Na)^+$: 377.0671. Found: 377.0673.

Phenylsulfonyl 4-*O*-acetyl-2,3,6-trideoxy-α, β-L-*threo*-hexopyranoside (4)

To a solution of 4-*O*-acetyl-6-deoxy-L-amicetal (39 mg, 0.25 mmol) in anhydrous dichloromethane (3 mL) was added benzenesulfinic acid (213 mg, 1.5 mmol) and the mixture was stirred at 0°C initially then overnight at rt. The reaction was diluted with excess dichloromethane (40 mL); washed with 10% $NaHSO_3$ (40 mL), water (40 mL), and brine (40 mL); dried over anhydrous Na_2SO_4; and concentrated. The crude product was then purified by flash chromatography over silica gel by the gradient elution method using 40% to 50% ethyl acetate. The product **4** (55 mg, 74%), a 2:1 mixture of β/α anomers, is obtained as a colorless oil. R_f0.44 (40% ethyl acetate/hexanes). ^{1}H NMR (α-anomer) β, α7.92 (m, 2H, Ph-H); 7.69 (m, 1H, P-H), 7.57 (m, 2H, Ph-H), 4.38 (dd, 1H, $J_{1,2e}$ 2.1 Hz, $J_{1,2a}$ 11.8 Hz, H-1), 3.43 (m, 1H, $J_{4,5}$ 9.6 Hz, $J_{5,6}$ 6.2 Hz H-5), 2.02 (s, 3H, CH_3), 1.16 (d, 3H, CH_3). Analytical MW calculated for $C_{14}H_{18}O_5S$ is 298.08. Found by ESI MS $(M + NH_4)^+$ 314.3 (38%), 155.3 (100%).

Phenylsulfinyl 3,4,6-tri-*O*-acetyl-2-bromo-2-deoxy-α-D-mannopyranosides (6/7)

To a stirring solution of tri-*O*-acetyl-D-glucal (0.27 g, 1 mmol) in ethyl acetate (6 mL) under argon was added tetra-*n*-butylammonium tribromide (0.485 g, 1 mmol) and the yellow solution was stirred under argon at rt for 1.5 h. Ethyl acetate (5 mL) was added and the reaction was filtered through Celite and the filtrate washed with water (2 × 5 mL) and sat'd aqueous sodium chloride, dried (Na_2SO_4), and concentrated to a syrup, which was composed of a 9:1 mixture of *α-manno*/*α-gluco* 1,2-dibromides, R_f = 0.52 (40:60 ethyl acetate/hexanes). Crystallization from ether-hexane gave anomerically pure

^{1}H NMR of 6/7 (300 MHz, $CDCl_3$):			^{13}C NMR of 6/7 (70.4 MHz $CDCl_3$):		
Assignment	6	7	Assignment	6	7
1	5.979	5.840	1	95.40	96.95
2	4.454	4.362	2	48.60	48.60
3	5.195	5.121	3	68.36	68.09
4	5.445	5.435	4	65.47	65.20
5	3.988	4.058	5	70.50	70.24
6a	4.097	4.245	6	61.05	61.71
6b	3.689	4.150	Acetate methyl	ND	ND
CH_3CO	2.085, 2 × 2.033	2.135, 2.082, 2.066	Phenyl, *i*	144.23	143.72
Phenyl, *o*	~7.77	~7.77	Phenyl, *o*	124.41	124.31
Phenyl, *m*	~7.60	~7.60	Phenyl, *m*	128.96	129.15
Phenyl, *p*	~7.60[b]	~7.60	Phenyl, *p*	132.69	132.95
$J_{I,K}$,Hz			Acetate carbonyl	ND	ND
1, 2	1.6	1.6			
2, 3	4.0	4.0			
3, 4	9.8	9.8			
4, 5	9.7	10.0			
5, 6a	3.8	4.9			
5, 6b	2.3	2.5			
6a, b	12.5	12.5			

α-manno dibromide; yield, 0.307 g (71%). The ^{1}H NMR data matched that reported.[16] A sample of the dibromide (0.307 g, 0.71 mmol) was taken up in dry dichloromethane (12 mL) and 4 Å molecular sieves (0.20 g) were added, followed by (at 0°C under argon) benzenesulfinic acid (0.607 g, 4.27 mol) and TMU (0.248 g, 2.14 mol). After stirring 10 min, silver triflate (0.407 g, 1.58 mmol) was added. The mixture was stirred for 1.5 hr at 0°C under argon, then diluted with 15 mL dichloromethane and transferred to a separatory funnel and washed with sat'd aqueous sodium bicarbonate solution (10 mL). The mixture was washed with water, dried (Na_2SO_4), and concentrated to an oil (0.199 g). The crude product contained two major components that were assigned as two diastereomeric α-sulfinates (**6/7**) in an approximate 1:1 ratio; yield, 57%. When the reaction was carried out without rigorous maintenance of an inert argon atmosphere, the formation of sulfonate **9** and other by-products was observed. Sulfinates **6/7** had R_f 0.34 (40% ethyl acetate/hexanes).

HRMS calcd for $C_{18}H_{21}O_9SBrNa$ $(M + Na)^+$: 514.9987. Found 515.0015.

3,4,6-Tri-*O*-acetyl-2-bromo-2-deoxy-1-*O*-*m*-chlorobenzoyl-a-D-mannopyranose (8)

To a solution of sulfinate esters **6/7** (0.25 g, 0.5 mmol) in dichloromethane (5 mL) was added with MCPBA (0.15 g of 77%, 0.65 mmol, 1.3 equiv) over 7 hr while stirring at rt for 1 h. An additional three portions of MCPBA (0.15 g) were added over a period of 7 hr and the reaction was stirred at 35°C. The reaction was quenched by the addition of aqueous NaOH solution and the organic phase was separated, washed with 10% aqueous NaI solution (4 mL), dried (Na_2SO_4), and concentrated to yield the ester **8** as a white powder (0.13 g, 51%). $[\alpha]_D^{23} = -3.9$ (*c*, 1.0, dichloromethane). ^{1}H NMR (300 MHz, $CDCl_3$): α 8.09, 7.99, 7.59, 7.43, 5.51 (d, 1H, $J_{1,2}$1.6 Hz, H-1), 5.44 (dd, $J_{3,4}$9.6 Hz, $J_{4,5}$ 9.6 Hz, H-4), 5.32 (dd, $J_{2,3}$3.8 Hz, H-3), 4.49 (dd, 1H, H-2), 4.27 (m, 1H, H-5), 4.20 (m, 2H, H-6), 2.11 (s, 3H, CH_3), 2.10, (s, 3H, CH_3), 2.07 (s, 3H, CH_3). HRMS calcd for $C_{19}H_{20}ClBrO_9Na$: 528.9877 (M + Na). Found: 528.9891.

Phenylsulfonyl 3,4,6-tri-*O*-acetyl-2-bromo-2-deoxy-α-D-mannopyranoside (9)

To a solution of 3,4,6-tri-*O*-acetyl-2-bromo-2-deoxy-a-D-mannopyranosyl bromide (0.421 g, 0.9744 mmol), prepared from tri-*O*-acetyl-D-glucal as described above, in dichloromethane (10 mL) at 0°C under argon were added 4 Å molecular sieves (0.2 g) followed by benzenesulfonic acid (0.639 g, 4.04 mmol) and 1,1,3,3-tetramethylurea (0.344 g, 2.96 mmol). The mixture was stirred 10 min and then silver triflate (0.251 g, 0.97 mmol) was added and stirring was continued for 3 h. The mixture was filtered through a Celite pad, the solid washed with dichloromethane, and the filtrate washed with sat'd aqueous sodium bicarbonate solution and water, dried (Na_2SO_4), and concentrated to a yellow oil that contained the sulfonate **9** (0.471 g, 95%) as a mixture of α- and β-anomers (6:1) that was not purified further. R_f 0.42 (40% ethyl acetate/hexanes. ^{1}H NMR (a-anomer, 300 MHz, $CDCl_3$): α 7.98, 7.60, 7.71, 6.13 (d, 1H, $J_{1,2}$1.5 Hz, H-1), 5.42 (dd,1H, $J_{3,4}$9.8 Hz, $J_{4,5}$ 10.2 Hz, H-4), 5.15 (dd, 1H, $J_{2,3}$4.0 Hz, H-3), 4.50 (dd, 1H, H-2), 3.99 (dd, 1H, $J_{6\alpha,6b}$12.7 Hz, H-6a), 3.70 (m, 1H, $J_{5,6\alpha}$3.6 Hz, $J_{5,6b}$2.4 Hz, H-5), 3.56 (dd, 1H, H-6b), 2.08 (s, 3H, CH_3), 2.06, (s, 3H, CH_3), 2.07 (s, 3H, CH_3).

Phenylsulfinyl 3,4-di-*O*-acetyl-2-bromo-2,6-di-deoxy-α-L-mannopyranosides (11/12)

To a solution of crystalline 3,4-di-*O*-acetyl-2-bromo-2,6-di-deoxy-α-L-mannopyranosyl bromide **10** (0.226 g, 0.61 mmol), prepared from 3,4-di-*O*-acetyl-6-deoxy-L-glucal by bromination with tetra-*n*-butylammonium tribromide as described[16] in anhydrous dichloromethane (10 mL) at 0°C under argon, were added 4 Å molecular sieves (0.2 g), benzenesulfinic acid (0.449 g, 2.84 mmol), and 1,3,3-tetramethylurea (0.175 g, 1.51 mmol). After stirring for

10 min, silver triflate (0.268 g, 1.04 mmol) was added and the reaction was stirred 2.5 hr at 0°C. The reaction was diluted with dichloromethane (15 mL), washed with sat'd sodium bicarbonate solution and water, dried (Na_2SO_4), and concentrated to an oil that contained phenylsulfinate esters **11/12** in an approximate 1:1 ratio; yield, 0.214 g (81%). R_f 0.39 (40% ethyl acetate in hexanes). Analytical MW calculated for $C_{16}H_{19}O_7SBr$: 434.99. Found by ESIMS $(M + NH_4)^+$452.2 (100%), 293.2 (22%), 233.2 (13%).

^{1}H NMR of 11/12 (300 MHz, $CDCl_3$):			^{13}C NMR of 11/12 (70.4 MHz $CDCl_3$):		
Assignment	11	12	Assignment	11	12
1	5.90 d	5.79 d	1	94.94	96.88
2	4.45 dd	4.36 dd	2	49.24	49.19
3	~5.14 cm	5.06 dd	3	68.42	68.17
4	~5.14 cm	5.20 t	4	70.38	70.38
5	3.86 dq	3.94 dq	5	68.42	68.71
6	0.94 d	1.21 d	6	16.82	17.20
C*H*$_3$CO	2.03–2.11	2.03–2.11	*C*H$_3$CO	20.5–20.7	20.5–20.7
Phenyl-*o*	7.74–7.78	7.74–7.78	Phenyl-*i*	144.35	143.99
Phenyl-*m/p*	7.52–7.63	7.52–7.63	Phenyl-*o*	124.38	124.26
$J_{I,K}$, Hz			Phenyl-*m*	128.85	129.09
1, 2	1.5	1.7	Phenyl-*p*	132.42	132.72
1, 5	0.7	0.6	CH$_3$*C*O	169.2–169.7	169.2–169.7
2, 3	3.5	3.9			
3, 4	ND	9.7			
4, 5	9.7	9.7			
5, 6	6.3	6.4			

REFERENCES

1. Wolff, R.R.; Basava, V.; Giuliano, R.M.; Boyko, W.J.; Schauble, J.H. Iodosulfonatioin of alkenes with benzenesulfinic acid-N-iodosuccinimide-Facile preparation of a,b-uunsaturated sulfones. Can. J. Chem. **2006**, *84*, 667–675.

2. Ferrier, R.J.; Furneaux, R.H.; Tyler, P.C. Observations on the possible application of glycosyl disulphides and sulphenic esters and sulphones in the synthesis of glycosides. Carbohydr. Res. **1977**, *58*, 397–404.

3. a) Alonso-Cruz, C.R.; Leon, E.I.; Ortiz-Lopez, F.J.; Rodriguez, M.S.; Suarez, E. Fragmentation of carbohydrate anomeric alkoxyl radicals. Synthesis of highly functionalized chiral vinyl sulfones. Tetrahedron Lett. **2005**, *46*, 5265–5268; b) Chery, F.; Desroses, M.; Tatibouet, A.; De Lucchi, O.; Rollin, P. Synthesis of sugar-based ethenyl ethers through a vinyl. bis-sulfone methodology. Tetrahedron **2003**, *59*, 4563–4572; c) Cassidy, J.F.; Williams, J.M. Vinyl sulphones derived from thioglycosides: synthesis and alkylation. Tetrahedron Lett. **1986**, *36*, 4359–4362; d) Simpkins, N.S. *Sulphones in Organic Synthesis.* Pergamon Press: Oxford, U.K., 1993.

4. Ravindran, B.; Sakthivel, K.; Cheravakkattu, G.S.; Pathak, T. Diastereoselective addition of amines to vinyl sulfone modified carbohydrates: a highly flexible methodology for the synthesis of new classes of deoxyaminosugars. J. Org. Chem. **2000**, *65*, 2637–2641.

5. Sanki, A.K.; Cheravakkattu, G.S.; Falgune, U.D.; Pathak, T. Anomeric configuration-directed diastereoselective C-C bond formation in vinyl sulfone-modified carbohydrates: a general route to branched-chain sugars. Org. Lett. **2003**, *5*, 1285–1288.

6. Beau, J.-M.; Sinay, P. Preparation and reductive lithiation of 2-deoxy-D-glucopyranosyl phenylsulfones: a highly stereoselective route to *C*-glycosides. Tetrahedron Lett. **1985**, *26*, 6185–6188.

7. a) Miquel, N.; Doisneau, G.; Beau, J.-M. Reductive samariation of anomeric 2-pyridyl sulfones with catalytic nickel: an unexpected improvement in the synthesis of 1,2-*trans* diequatorial *C*-glycosyl compounds. Angew. Chem. Int. Ed. **2000**, *39*, 4111–4114; b) Du, Y.; Linhardt, R.J. Stereospecific synthesis of α-*C*-glycosyl derivatives ("α-*C*-glycosides") of *N*-acetylneuraminic acid by samarium-mediated reductive desulfonylation of a glycosyl phenylsulfone. Carbohydr. Res. **1998**, *308*, 161–164.

8. a) Chen, G.; Franck, R.W.; Yang, G.; Blumenstein, M. Anomeric effect of sulfones. Can. J. Chem. **2002**, *80*, 894–899; b) Taylor, R.J.; McAllister, G.D.; Franck, R.W. The Ramberg-Backlund reaction for the synthesis of *C*-glycosides, *C*-linked-disaccharides and related compounds. Carbohydr. Res. **2006**, *341*, 1298–1311.

9. Ferrier, R.J.; Prasad, N. Unsaturated carbohydrates. Part IX. Synthesis of 2,3-dideoxy-α-D-erythro-hex-2-enopyranosides from tri-*O*-acetyl-D-glucal. J. Chem. Soc. C **1969**, 570–575.

10. Brown, D.S.; Bruno, M.; Davenport, R.J.; Ley, S.V.; Substitution reactions of 2-benzenesulphonyl cyclic ethers with carbon nucleophiles. Tetrahedron **1989**, *45*, 4293–4308.

11. Bhate, S.; Horton, D.; Priebe, W. Allylic rearrangement of 6-deoxy glycals having practical utility. Carbohydr. Res. **1985**, *144*, 331–337.

12. Martin, A.; Pais, M.; Monneret, C. Synthese de disaccharides naturels, fragments d'anthracyclines oligosaccharideques. Carbohydr. Res. **1983**, *113*, 21–29.

13. Vennstra, G.E.; Zwaneburg, B. An improved synthesis of sulfones using tetrabutylammonium sulfinates. Synthesis **1975**, 519–520.

14. a) Meek, J.S.; Fowler, J.S. O and S methylation of the ambident *p*-toluenesulfinate anion. J. Org. Chem. **1968**, *33*, 3422–3424; b) Kondratenko, N.V.; Sambur, V.P.; Yagupol'skii, L.M. Double reactivity of silver salts of sulfinic acids. Z. Organich. Khim. **1971**, *7*, 2382–2388, CAN 76:58544.

15. Hanessian, S.; Banoub, J. Chemistry of the glycosidic linkage. An efficient synthesis of 1,2-trans-disaccharides. Carbohydr. Res. **1976**, *53*, C13–C16.

16. Tiechmann, M.; Descotes, G.; Lafont, D. Bromination of 1,5-anhydrohex-1-enitols (glycals) using quaternary ammonium tribromides as bromine donors: synthesis of α-1,2-*trans*-2-brono-2-deoxyglyhcopyranosyl bromides and fluorides. Synthesis **1993**, 889–894.

17. Diez, D.; Beneitez, M.T.; Marcos, I.S.; Garrido, N.M.; Basabe, P.; Sanz, F.; Broughton, H.B.; Urones, J.G. Chemistry of epoxysulfones: straightforward synthesis of versatile chiral building blocks. Org. Lett. **2003**, *5*, 4361–4364.

18. Harpp, D.N.; Vines, S.M.; Montiller, J.P.; Chan, T.H. Reaction of sulfinate esters with Grignard and organocopper lithium reagents. A useful route to chiral sulfoxides. J. Org. Chem. **1976**, *41*, 3987–3992.