The Preparation of 1-Tributylstannyl Glycals from 1-Phenylsulfonyl Glycals via Ni(0)-Catalysed Coupling with Tributylstannylmagnesium Bromide

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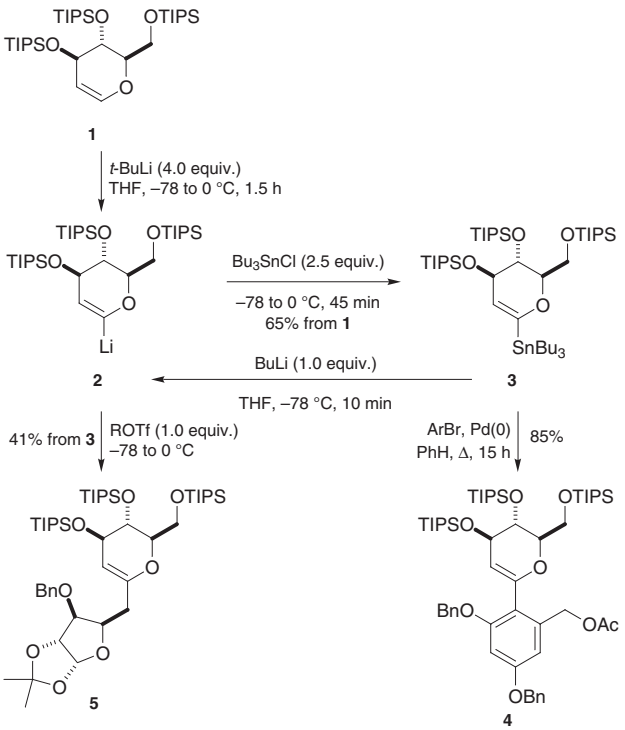
Dedicated to Professor Jean-François Normant on the occasion of his 65th birthday

Abstract: 1-Phenylsulfonyl glycals undergo an easy Ni(0)-catalysed coupling with tributylstannylmagnesium bromide to give the corresponding 1-tributylstannyl glycals in good yield.

Key words: nickel, catalysis, coupling, sulfones, stannanes, glycals, carbohydrates

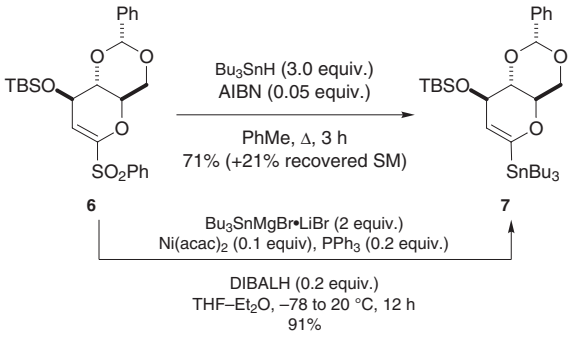
The easy interconversion of 1-tributylstannyl glycals such as **3** with their corresponding lithium derivatives **2** (Scheme 1) makes them valuable precursors for *C*-glycosidation reactions.[1,2] For example, 1-tributylstannyl glycals undergo Pd-catalysed coupling with aryl or alkenyl halides[3-10] whilst the lithium derivatives participate in nucleophilic addition and substitution reactions[1,2,11-15] illustrated here by the formation of **4** and **5**. Unfortunately, the conditions typically used to metallate 3,4-dihydro-2*H*-pyrans (*t*-BuLi/THF, −78 °C to −20 °C) are limited to a narrow range of carbohydrate-derived substrates because (a) the presence of polar oxygen substituents frequently require excess *t*-BuLi for complete metallation, as in the conversion of **1** to **2** and (b) convenient and common protecting groups such as benzyl ethers and *tert*-butyldimethylsilyl (TBS) groups are metallated under the strongly basic conditions.[1,16-19] The only general and mild method[6] reported to date for the synthesis of 1-tributylstannyl glycals from carbohydrate precursors entails substitution of 1-phenylsulfonyl glycals by tributylstannyl radicals illustrated by the conversion of **6** to **7** (Scheme 2). The method is attractive because the sulfone **6** is readily available in good yield and the radical substitution reaction occurs under neutral conditions albeit at elevated temperature. However, in our hands, the radical substitution frequently requires up to 10 equivalents of tributylstannane, and even then unreacted sulfone remains. We now report an efficient and easy synthesis of 1-tributylstannyl glycals which is based on the Ni(0)-catalysed coupling of tributylstannylmagnesium bromide with 1-phenylsulfonyl glycals.

Our method was inspired by a report that alkenyl sulfones undergo Ni(0)-catalysed substitution by Grignard reagents devoid of β-hydrogens.[20] We reasoned that tributylstannylmagnesium bromide, easily prepared from hexabutyldistannane in two steps, should undergo an analogous coupling with 1-phenylsulfonyl glycals. To test our idea, we converted sulfone **6** to stannane **7** in 91% yield (1 mmol scale) with no recovered starting material. The experimental procedure is very easy: the $Bu_3SnMgBr$•LiBr was prepared by addition of $MgBr_2$•OEt_2 to Bu_3SnLi.[21] In a separate flask, DIBALH (0.2 equivalent) was added to a suspension of $Ni(acac)_2$ (0.1 equivalent) and Ph_3P (0.2 equivalent) at 0−5 °C. The resultant brown solution of the Ni(0) catalyst[22] was added to $Bu_3SnMgBr$•LiBr at −78 °C and after 5 minutes, the sulfone **6** was added. The dark mixture was allowed to warm gradually to room temperature overnight whereupon a standard extractive work-up and chromatographic purification returned the desired stannane **7**.



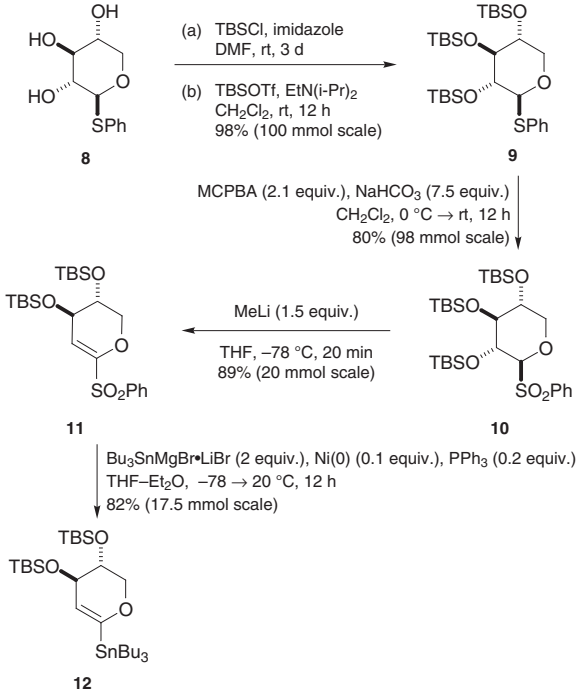
Scheme 1

A large scale synthesis of 1-tributylstannyl-D-xylal **12** (Scheme 3) demonstrates the ready accessibility of the 1-phenylsulfonyl glycals using the Beau protocol[6] and the practicality of the Ni(0)-catalysed coupling. Thus, 1-phenylthio-D-xylopyranoside (**8**) was silylated using TBSCl and imidazole in DMF but the reaction did not go to completion, even with a large excess of TBSCl at elevated temperature; hence, a second silylation using TBSOTf and Hünig's base was required to complete the silylation (98% yield). Oxidation of the thioether **9** with *m*-chloro-



Scheme 2

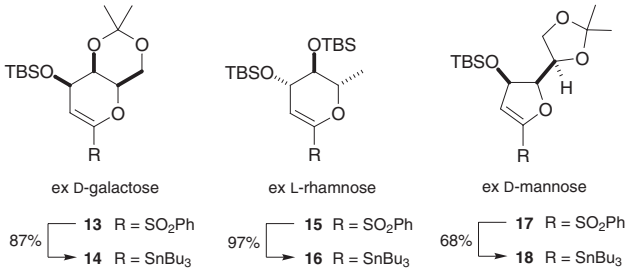
peroxybenzoic acid (MCPBA) gave the sulfone **10** (80%) which then underwent elimination on treatment with MeLi to give the desired 1-phenylsulfonyl xylal **11** (89%). Finally, the Ni(0) catalysed coupling of **11** with $Bu_3SnMgBr$•LiBr as described above gave the stannane **12** in 82% yield on a 17.5 mmol scale (57% overall).



Scheme 3

In order to further probe the scope and generality of our method (Scheme 4), we prepared the 1-phenylsulfonyl glycals **13** (from D-galactose), **15** (from L-rhamnose) and **17** (from D-mannose) and converted them to the corresponding stannanes **14**, **16** and **18** in 87%, 97% and 68% yields, respectively. The lower yield of the furanoid stannane **18** reflects its high lability.

In conclusion, we have devised a simple, practical and efficient synthesis of 1-tributylstannyl glycals from readily available 1-phenylsulfonyl glycals using a Ni(0)-catalysed coupling with $Bu_3SnMgBr$•LiBr. Our procedure offers new opportunities for *C*-glycosidation and transmetallation reactions of the glycals derived from the common monosaccharides glucose, xylose, galactose, mannose and rhamnose.



Scheme 4

Et_2O and THF were freshly distilled from sodium benzophenone ketyl under N_2 prior to use. CH_2Cl_2 and toluene were freshly distilled from CaH_2 under N_2. DMF was distilled from CaH_2 under reduced pressure (approx. 10 mmHg). MeOH was freshly distilled from magnesium methoxide under N_2 prior to use. Alumina refers to activated neutral alumina, purchased from Acros and was deactivated with 5% H_2O. Flash chromatography was performed on Fisher Scientific 'Matrex Silica 60' silica gel (35–70 micron particle size). Specific optical rotations were measured at ambient temperature (21±3 °C) on an Optical Activity Polaar 2000 polarimeter using a 5 mL cell with a 1 dm path length. IR spectra were recorded on a Jasco 410 FT-IR spectrometer using a thin film supported between NaCl plates, a KBr disk or a solution cell. ^1H and ^{13}C NMR spectra were recorded in Fourier Transform mode on a Bruker DPX 400 spectrometer. All spectra were obtained in $CDCl_3$ or C_6D_6 in 5 mm diameter tubes, and the chemical shift (ppm) is quoted relative to the residual signals of $CDCl_3$ (δ_H = 7.27 ppm) or C_6D_6 (δ_H = 7.4 ppm). In case of ^{13}C NMR spectra, the chemical shift (ppm) is quoted relative to the middle signal of $CDCl_3$ (δ_C = 77.2 ppm) or C_6D_6 (δ_C = 128.7 ppm). Multiplicities in ^1H NMR spectra are quoted as: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. Coupling constants (*J*) are reported in Hz. Numbers in parenthesis following the chemical shift in the ^{13}C spectra refer to the number of protons attached to the carbon as disclosed by the Distortionless Enhancement by Phase Transfer (DEPT) technique, with secondary pulses at 90° and 135°. Signal assignments are based on COSY, HMQC and HMBC correlations. Low and high resolution mass spectra were run on a JEOL MStation JMS-700 spectrometer.

1,5-Anhydro-4,6-*O*-benzylidene-3-*O*-*tert*-butyldimethylsilyl-2-deoxy-1-tributylstannyl-D-*arabino*-hex-1-enitol (7) (Scheme 2)

To a magnetically stirred solution of hexabutyldistannane (1.16 g, 1.01 mL, 2 mmol) in THF (10 mL), was added dropwise *n*-BuLi (0.87 mL, 2.30 M in hexanes, 2 mmol) at a rate sufficient to maintain the internal temperature below 5 °C. After the addition was complete, the yellow solution containing Bu_3SnLi was stirred at 0–5 °C for 30 min whereupon a heterogeneous mixture of $MgBr_2$•Et_2O in Et_2O (10 mL), prepared from 1,2-dibromoethane (0.376 g, 0.17 mL, 2 mmol) and Mg (0.058 g, 2.4 mmol), was added by cannula and the yellow suspension stirred at 0–5 °C for 5 min.

In a separate flask, a solution of DIBALH (0.13 mL, 1.5 M in toluene, 0.2 mmol) was added dropwise to a mixture of $Ni(acac)_2$ (0.026 g, 0.1 mmol) and Ph_3P (0.052 g, 0.2 mmol) in toluene (2.3 mL), at 0–5 °C. The dark brown mixture was stirred at r.t. for 15 min and then transferred by cannula, with the aid of a further 1 mL of Et_2O, to the previously prepared $Bu_3SnMgBr$•LiBr, cooled

to −78 °C. The brown mixture was stirred at −78 °C for 5 min and then a solution of the sulfone **6** (0.489 g, 1 mmol) in THF (5 mL) was added by cannula with the aid of a further 1 mL of THF. The brown mixture was allowed to warm gradually to r.t. overnight, then poured into rapidly stirred H_2O (100 mL) and extracted with Et_2O (2 × 50 mL). Filtration through Celite was necessary to separate the layers. The combined organic layers were treated with Et_3N (1 mL), dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by column chromatography on SiO_2 (hexanes/Et_2O containing 0.5% of Et_3N) to give stannane **7** (0.580 g, 0.91 mmol, 91%) as a colourless oil: $[\alpha]_D$ −32.1° (*c* 1.6, $CHCl_3$); Lit.[6] $[\alpha]_D$ −32° (*c* 1.6, $CHCl_3$).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.3 (0, C1), 137.9 (0, Ph), 128.9 (1, Ph), 128.3 (1, 2C, Ph), 126.2 (1, 2C, Ph), 116.2 (1, C2), 101.3 (1), 81.1 (1), 69.2 (1), 68.9 (2, C6), 68.4 (1), 29.1 (2, 3C, C_4H_9Sn, J_{Sn-C} 21.4), 27.3 (2, 3C, C_4H_9Sn, J_{Sn-C} 54.4), 26.0 (3, 3C, *t*-Bu), 18.5 (0, CSi), 13.9 (3, 3C, C_4H_9Sn), 9.9 (2, 3C, C_4H_9Sn, J_{Sn-C} 347.9, 332.3), −4.1 (3, CH_3Si), −4.5 (3, CH_3Si).

Stannane 12 (Scheme 3)

Phenyl 2,3,4-Tris-*O*-(*tert*-butyldimethylsilyl)-1-thio-β-D-xylopyranoside (9)

To a solution of phenyl 1-thio-β-D-xylopyranoside[23] (**8**) (24.23 g, 100 mmol) in DMF (280 mL) were added imidazole (51.10 g, 750 mmol) and TBSCl (54.30 g, 360 mmol). After 3 days at r.t., the mixture was poured into H_2O (1.4 L) and extracted with Et_2O. The organic layer was washed with H_2O, dried (Na_2SO_4) and concentrated in vacuo. The colourless residue (61 g) was purified by column chromatography (SiO_2, hexanes/Et_2O, 20:1) to yield a mixture of di- and tri-protected compounds as a clear oil (51 g). The mixture was dissolved in anhyd CH_2Cl_2 (200 mL). *i*-Pr_2NEt (40.5 mL, 231.1 mmol) was added followed by TBSOTf (dropwise) (31.9 mL, 139.0 mmol). After 12 h at r.t., the reaction was washed with 5% HCl (2 × 260 mL) then H_2O (2 × 260 mL), and the aqueous layers extracted with CH_2Cl_2. The organic extracts were dried (Na_2SO_4). The solvent was evaporated in vacuo to give a red oil, which was purified by column chromatography (SiO_2, hexanes/Et_2O, 50:1 to 10:1) to give **9** as a colourless oil (57.2 g, 98 mmol, 98%, 2 steps): $[\alpha]_D$ −70.5° (*c* 1, $CHCl_3$).

IR (film): ν = 2929, 2857, 1133 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.51−7.46 (m, 2H, Ph), 7.31−7.23 (m, 2H, Ph), 7.23−7.15 (m, 1H, Ph), 5.36 (apparent s, 1H), 4.58 (d, 1H, *J* = 10.8 Hz, H-5), 3.86 (apparent s, 1H), 3.71 (apparent s, 1H), 3.57 (d, 1H, *J* = 11.9 Hz, H-5), 3.55 (apparent s, 1H), 0.99, 0.94, 0.92 (3 × s, 9H each, *t*-Bu), 0.16, 0.13, 0.10 (3 × s, 3H each, CH_3Si), 0.11 (s, 9H, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.0 (0, Ph), 130.5 (1, 2C, Ph), 128.9 (1, 2C, Ph), 126.5 (1, Ph), 88.7 (1, C1), 73.3 (1), 71.3 (1), 69.9 (1), 61.4 (2, C5), 26.3 (9, 3C, *t*-Bu), 26.3 (9, 3C, *t*-Bu), 25.9 (9, 3C, *t*-Bu), 18.6 (0, CSi), 18.5 (0, CSi), 18.1 (0, CSi), −4.3 (3, CH_3Si), −4.4 (3, CH_3Si), −4.5 (3, 2C, CH_3Si), −4.5 (3, CH_3Si), −4.6 (3, CH_3Si).

HRMS (FAB$^+$mode): *m/z* calcd for $C_{29}H_{56}O_4SSi_3Na$ $(M+Na)^+$: 607.3105. Found: 607.3099.

2,3,4-Tris-*O*-(*tert*-butyldimethylsilyl)-β-D-xylopyranosyl Phenyl Sulfone (10)

Thioglycoside **9** (57.23 g, 97.9 mmol) was dissolved in CH_2Cl_2 (1500 mL) and the solution cooled in an ice-bath. Sodium bicarbonate (61.3 g, 730 mmol) was added followed by 50% MCPBA was (71.4 g, 206 mmol). The reaction mixture was allowed to warm to r.t. overnight. The solution was then washed with sat. sodium sulfite (2 × 1.25 L), then sat. sodium sulfite/bicarbonate (1:1, 2 × 1.25 L). The organic layer was dried (Na_2SO_4) and the solvent evaporated in vacuo to give a white solid which was recrystallised from EtOH (150 mL) to yield sulfone **10** as white cubic crystals (48.6 g, 78.7 mmol, 80%), mp: 99−100 °C; $[\alpha]_D$ −73.1° (*c* 0.9, $CHCl_3$).

IR (KBr): ν = 2929, 2858, 1576, 1328, 1252, 1140 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.94−7.89 (m, 2H, Ph), 7.64−7.58 (m, 1H, Ph), 7.56−7.50 (m, 2H, Ph), 4.76 (d, 1H, *J* = 10.2 Hz), 4.64 (s, 1H, H1), 4.49 (s, 1H), 3.80−3.77 (m, 1H), 3.66−3.58 (m, 2H), 0.96, 0.91, 0.89 (3 × s, 9H each, *t*-Bu), 0.18, 0.17, 0.15, 0.12, 0.08, 0.07 (6 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 139.6 (0, Ph), 133.5 (1, Ph), 129.1 (2, 2C, Ph), 128.8 (2, 2C, Ph), 94.3 (1, C1), 70.8 (1), 68.9 (1), 66.7 (1), 64.6 (2, C5), 26.2 (3, 3C, *t*-Bu), 26.1 (3, 3C, *t*-Bu), 25.8 (3, 3C, *t*-Bu), 18.4 (0, CSi), 18.3 (0, CSi), 18.1 (0, CSi), −4.3 (3, CH_3Si), −4.4 (3, CH_3Si), −4.5 (3, CH_3Si), −4.5 (3, CH_3Si), −4.6 (3, CH_3Si), −4.7 (3, CH_3Si).

HRMS (FAB$^+$mode): *m/z* calcd for $C_{29}H_{56}O_6SSi_3Na$ $(M+Na)^+$: 639.3003. Found: 639.3010.

1,5-Anhydro-3,4-bis-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-1-phenylsulfonyl-D-*threo*-pent-1-enitol (11)

To a solution of sulfone **10** (12.4 g, 20.0 mmol) in anhyd THF (200 mL), at −78 °C, was added MeLi•LiBr (20.0 mL, 1.5 M, 30.0 mmol) dropwise and the yellow solution stirred at −78 °C for 20 min. The reaction mixture was then poured into a mixture of sat. sodium bicarbonate (550 mL) and Et_2O (100 mL). The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (100 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated in vacuo to give a white solid. The crude product was recrystallised from hexanes (60 mL) to give unsaturated sulfone **11** as white crystals (8.6 g, 17.7 mmol, 89%), mp: 111−112 °C: $[\alpha]_D$ −93.8° (*c* = 1.0, $CHCl_3$).

IR (KBr): ν = 2956, 2928, 2896, 2856, 1645, 1327, 1254, 1117, 1077 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.95−7.90 (m, 2H, Ph), 7.64−7.58 (m, 1H, Ph), 7.54−7.48 (m, 2H, Ph), 6.06 (dd, 1H, *J* = 5.2, 1.2 Hz, H2), 4.03 (dd, 1H, *J* = 11.2, 1.5 Hz, H5), 4.00 (ddd, 1H, *J* = 11.3, 3.0, 1.2 Hz, H5), 3.97−3.92 (m, 1H, H3), 3.65 (quintet, 1H, *J* = 1.4 Hz, H4), 0.88, 0.70 (2 × s, 9H each, *t*-Bu), 0.12, 0.11, 0.00, −0.06 (4 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.0 (0, C1), 138.6 (0, Ph), 133.8 (1, Ph), 129.2 (2, 2C, Ph), 128.6 (2, 2C, Ph), 107.0 (1, C2), 68.7 (2, C5), 68.3 (1, C4), 65.1 (1, C3), 25.9 (9, 3C, *t*-Bu), 25.6 (9, 3C, *t*-Bu), 18.1 (0, CSi), 17.9 (0, CSi), −4.2 (3, CH_3Si), −4.5 (3, CH_3Si), −4.7 (3, CH_3Si), −4.8 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 502 (MNH_4^+, 100).

Anal. Calcd for $C_{23}H_{40}O_5Si_2S$: C, 56.98; H, 8.32. Found: C, 57.07; H, 8.31.

1,5-Anhydro-3,4-bis-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-1-tributylstannyl-D-*threo*-pent-1-enitol (12)

Stannane **12** (9.06 g, 14.35 mmol, 82%) prepared from sulfone **11** (8.5 g, 17.5 mmol), using the procedure described above for the preparation of stannane **7**, was obtained as a colourless oil: $[\alpha]_D$ −83.7° (*c* 1, *n*-hexane).

IR (film): ν = 2956, 2929, 2857, 1600, 1112, 1092 cm^{-1}.

^{1}H NMR (400 MHz, C_6D_6): δ = 5.30 (dd, 1H, *J* = 3.8, 1.0 Hz, J_{Sn-H} = 27.7 Hz, H2), 4.33 (dt, 1H, *J* = 1.1, 4.1 Hz, H3), 4.28 (dd, 1H, *J* = 10.7, 2.3 Hz, H5), 4.13−4.07 (m, 1H, H4), 4.04 (ddd, 1H, *J* = 10.7, 6.0, 1.2 Hz, H5), 2.05−1.01 (m, 27H, C_4H_9Sn), 1.26, 1.21 (2 × s, 9H each, *t*-Bu), 0.42, 0.41, 0.33, 0.27 (4 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, C_6D_6): δ = 165.5 (0, C1), 114.6 (1, C2), 71.3 (1, C4), 68.7 (1, C3), 68.2 (2, C5), 30.1 (2, 3C, J_{Sn-C} 21.4, C_4H_9Sn), 28.3 (2, 3C, J_{Sn-C} 55.4, C_4H_9Sn), 26.8 (3, 3C, *t*-Bu), 26.7 (3, 3C,

t-Bu), 19.0 (0, CSi), 18.9 (0, CSi), 14.6 (3, 3C, C_4H_9Sn), 10.6 (2, 3C, J_{Sn-C} 345.1, 329.5, C_4H_9Sn), −3.2 (3, CH_3Si), −3.4 (3, CH_3Si), −3.7 (3, CH_3Si), −3.9 (3, CH_3Si).

HRMS (CI): *m/z* calcd for $C_{29}H_{63}O_3Si_2{}^{120}Sn$ $(M+H)^+$: 635.3338. Found: 635.3328

Stannanes 14, 16 and 18 (Scheme 4)

Stannanes **14**, **16** and **18** were prepared on a 1 mmol scale using the procedure described above for the preparation of stannane **7**. All stannanes decomposed gradually on storage at ≥ 0 °C but their lifetime could be increased to months by storage in the freezer (approx. −10 °C) with a few drops of Et_3N per mmol.

2,6-Anhydro-4-*O*-(*tert*-butyldimethylsilyl)-5-deoxy-1,3-*O*-isopropylidene-6-tributylstannyl-D-*arabino*-hex-5-enitol (14)

Stannane **14** was obtained in 87% yield as a colourless oil: $[\alpha]_D$ −8.8° (*c* 1.04, $CHCl_3$).

IR (film): ν = 2955, 2927, 2855, 1609, 1463, 1378, 1338, 1252, 1187, 1142, 1071 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 4.66 (t, 1H, *J* = 1.7 Hz, J_{Sn-H} = 28.6 Hz, H5), 4.59 (ddd, 1H, *J* = 4.7, 1.6, 0.8 Hz, H4), 4.06 (ddd, 1H, *J* = 4.7, 1.7, 1.5 Hz, H3), 3.98 (dd, 1H, *J* = 12.5, 1.9 Hz, H1), 3.92 (dd, 1H, *J* = 12.5, 2.0 Hz, H1), 3.68 (br s, 1H, H2), 1.60−0.86 (m, 27H, C_4H_9Sn), 1.48 (s, 3H, CH_3C), 1.46 (s, 3H, CH_3C), 0.92 (s, 9H, *t*-Bu), 0.12, 0.11 (2 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 163.2 (0, C6), 112.5 (1, C5), 98.9 (0), 68.4 (1, C2), 66.2 (1, C3), 65.5 (1, C4), 63.9 (2, C1), 29.5 (3), 29.1 (2, 3C, J_{Sn-C} 20.6, C_4H_9Sn), 27.4 (2, 3C, J_{Sn-C} 56.4, C_4H_9Sn), 26.2 (3, 3C, *t*-Bu), 19.1 (3), 18.7 (0, CSi), 13.9 (3, 3C, C_4H_9Sn), 9.8 (2, 3C, J_{Sn-C} 347.1, 331.5, C_4H_9Sn), −3.9 (3, CH_3Si), −4.0 (3, CH_3Si).

HRMS (CI, isobutane): *m/z* calcd for $C_{27}H_{55}O_4Si^{120}Sn$ $(M+H)^+$: 591.2897. Found: 591.2899

1,5-Anhydro-3,4-bis-*O*-(*tert*-butyldimethylsilyl)-2,6-dideoxy-1-tributylstannyl-L-*arabino*-Hex-1-enitol (16)

Stannane **16** was obtained in 97% yield as a colourless oil: $[\alpha]_D$+38.2° (*c* 1.03, $CHCl_3$).

IR (film): ν = 2956, 2929, 2857, 1607, 1462, 1377, 1361, 1255, 1112, 1072, 1048 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 4.68 (d, 1H, *J* = 2.7 Hz, J_{Sn-H} = 27.7 Hz, H2), 4.11 (dd, 1H, *J* = 2.8, 5.7 Hz, H3), 3.74 (dq, 1H, *J* = 7.4, 6.6 Hz, H5), 3.49 (dd, 1H, *J* = 5.8, 7.8 Hz, H4), 1.62−0.87 (m, 27H, C_4H_9Sn), 1.26 (d, 3H, *J* = 6.6 Hz, H6), 0.92, 0.90 (2 × s, 9H each, *t*-Bu), 0.11 (s, 3H, CH_3Si), 0.11 (s, 3H, CH_3Si), 0.10 (s, 3H, CH_3Si), 0.09 (s, 3H, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.8 (0, C1), 114.7 (1, C2), 75.7 (1, 2C, C4,C5), 71.4 (1, C3), 29.1 (2, 3C, J_{Sn-C} 21.1, C_4H_9Sn), 27.4 (2, 3C, J_{Sn-C} 55.4, C_4H_9Sn), 26.4 (3, 3C, *t*-Bu), 26.2 (3, 3C, *t*-Bu), 18.5 (0, CSi), 18.2 (0, CSi), 18.0 (3, C6), 13.9 (3, 3C, C_4H_9Sn), 9.8 (2, 3C, J_{Sn-C} 344.1, 330.9, C_4H_9Sn), −3.2 (3, CH_3Si), −3.3 (3, CH_3Si), −3.8 (3, CH_3Si), −4.0 (3, CH_3Si).

HRMS (CI, isobutane): *m/z* calcd for $C_{30}H_{65}O_3Si_2{}^{120}Sn$ $(M+H)^+$: 649.3499. Found: 649.3495

1,4-Anhydro-3-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-5,6-*O*-isopropylidene-1-tributylstannyl-D-*arabino*-hex-1-enitol (18)

Stannane **18** was obtained in 68% yield as a colourless oil by a slight modification of the procedure used for the preparation of stannane **7**. The high lability of **18** required Al_2O_3 deactivated with 5% H_2O and a mixture of hexanes/Et_2O, 50:1 to 10:1 containing 0.5% of Et_3N for the chromatography.

$[\alpha]_D$ −30.9° (*c* 1.15, $CHCl_3$).

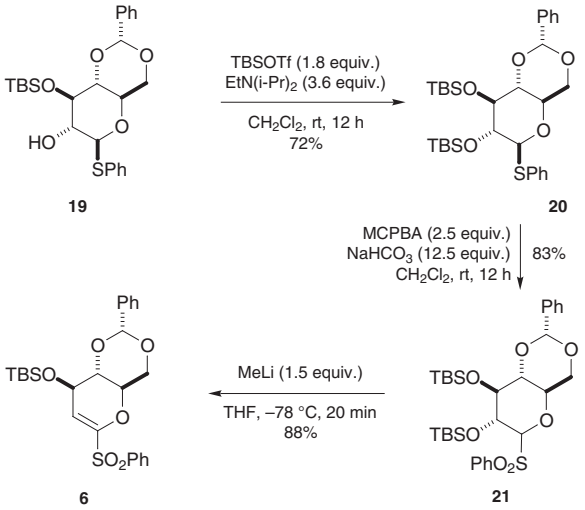
IR (film): ν = 2956, 2928, 2856, 1576, 1463, 1378, 1369, 1254, 1212, 1098, 1065 cm^{-1}.

^1H NMR (400 MHz; C_6D_6): δ = 5.61 (d, 1H, *J* = 2.6 Hz, J_{Sn-H} = 10.1 Hz, H2), 5.00 (dd, 1H, *J* = 6.7, 2.5 Hz, H3), 4.91 (dt, 1H, *J* = 5.9, 6.4 Hz, H5), 4.56 (t, 1H, *J* = 6.3 Hz, H4), 4.50 (d, 2H, *J* = 6.5 Hz, H6), 1.98−1.16 (m, 27H, C_4H_9Sn), 1.77, 1.63 (2 × s, 3H each), 1.19 (s, 9H, *t*-Bu), 0.32, 0.31 (2 × s, 3H each, Me_2Si).

^{13}C NMR (100 MHz, C_6D_6): δ = 169.0 (0, C1), 117.6 (1, C2), 109.5 (0), 86.9 (1, C4), 74.8 (1, C3), 74.4 (1, C4), 67.6 (2, C6), 30.0 (2, 3C, J_{Sn-C} 21.9, C_4H_9Sn), 28.2 (2, 3C, J_{Sn-C} 55.7, C_4H_9Sn), 27.7 (3), 26.7 (3, 3C, *t*-Bu), 26.4 (3), 10.8 (2, 3C, J_{Sn-C} 353.9, 338.3, C_4H_9Sn), 14.6 (3, 3C, C_4H_9Sn), −3.6 (3, CH_3Si), −4.1 (3, CH_3Si).

HRMS (CI, isobutane): *m/z* calcd for $C_{27}H_{55}O_4Si^{120}Sn$ $(M+H)^+$: 591.2897. Found: 591.2897.

Unsaturated Sulfone 6 (Scheme 5).



Scheme 5

Phenyl 2,3-Bis-(*O*-*tert*-butyldimethylsilyl)-4,6-*O*-benzylidene-1-thio-β-D-glucopyranoside (20)

To a solution of alcohol **19**[6] (3.62 g, 7.6 mmol) and *i*-Pr_2NEt (3.53 g, 4.7 mL, 27.36 mmol) in CH_2Cl_2 (76 mL) was added dropwise at 0 °C TBSOTf (3.61 g, 3.1 mL, 13.68 mmol). The solution was stirred at r.t. overnight, poured into H_2O, the organic layer separated, and the aqueous layer extracted with CH_2Cl_2 (50 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated in vacuo. The residue was purified by column chromatography (SiO_2, hexanes/Et_2O, 20:1 to 2:1) to give thioglycoside **20** (3.22 g, 5.47 mmol, 72%) as a white solid, mp: 63−64 °C (90% EtOH/H_2O); $[\alpha]_D$ −70.8° (*c* 1, $CHCl_3$).

IR (CCl_4): ν = 2955, 2930, 2857, 1471, 1381, 1251, 1217 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.52−7.42 (m, 4H, Ph), 7.40−7.24 (m, 6H, Ph), 5.46 (s, 1H, CHPh), 4.89 (d, 1H, *J* = 7.3 Hz, H1), 4.33 (dd, 1H, *J* = 10.3, 4.6 Hz, H6), 3.87 (dd, 1H, *J* = 8.2, 5.7 Hz, H3), 3.78−3.69 (m, 3H, H6, H2, H4), 3.66 (dt, 1H, *J* = 4.4, 9.6 Hz, H5), 0.95, 0.84 (2 × s, 9H each), 0.22, 0.15, 0.05, 0.03 (4 × s, 3H each).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.4 (0, Ph), 135.2 (0, Ph), 131.4 (1, 2C, Ph), 129.3 (1, Ph), 129.1 (1, 2C, Ph), 128.3 (1, 2C, Ph), 127.5 (1, Ph), 126.7 (1, 2C, Ph), 102.4 (1), 89.7 (1, C1), 81.7 (1, C4), 77.3 (1, C3), 76.3 (1, C2), 69.4 (2, C6), 68.7 (1, C5), 26.4 (3, 3C, *t*-Bu), 26.4 (3, 3C, *t*-Bu), 18.6 (0, C-Si), 18.4 (0, C-Si), −2.6 (3, CH_3Si), −2.8 (3, CH_3Si), −3.2 (3, CH_3Si), −3.2 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 589 ($M+H^+$, 6), 606 (MNH_4^+, 7).

Anal. Calcd for $C_{31}H_{48}O_5SSi_2$: C, 63.22; H, 8.21. Found: C, 63.10; H, 8.35.

2,3-Di-*O*-(*tert*-butyldimethylsilyl)-4,6-*O*-benzylidene-β-D-glucopyranosyl Phenyl Sulfone (21)

To a solution of 1-thioglycoside **20** (2.92 g, 4.96 mmol) in CH_2Cl_2 (55 mL), cooled in an ice-bath, was added $NaHCO_3$ (5.25 g, 62.5 mmol) followed by dropwise addition of a dried (Na_2SO_4) solution of MCPBA (50%, 4.3 g, 12.5 mmol) in CH_2Cl_2 (55 mL). The mixture was allowed to warm gradually to r.t. overnight, then washed twice with a mixture of sat. $NaHCO_3$ and sodium thiosulfate (1:1, 100 mL) and the aqueous layers were extracted with CH_2Cl_2 (50 mL). The combined organic extracts were treated with Et_3N (5 mL), dried (Na_2SO_4), and concentrated in vacuo. The crude product was purified by column chromatography (SiO_2, hexanes/Et_2O, 10:1 to 2:1 containing 0.5% of Et_3N to give sulfone **21** (2.55 g, 4.11 mmol, 83%) as a pale yellow amorphous solid: $[\alpha]_D$ −52.5° (*c* 1, $CHCl_3$).

IR (CCl_4): ν = 2955, 2930, 2858, 1471, 1377, 1329, 1257 cm^{-1}.

^1H NMR(400 MHz, $CDCl_3$): δ = 7.97−7.92 (2H, Ph), 7.72−7.65 (1H, Ph), 7.50−7.43 (2H, Ph), 7.53−7.48 (2H, Ph), 7.43−7.35 (3H, Ph), 5.58 (s, 1H, CHPh), 4.71 (dd, 1H, *J* = 1.6, 1.2 Hz, H1), 4.58 (t, 1H, *J* = 1.6 Hz, H2), 4.32 (dd, 1H, *J* = 10.3, 5.1 Hz, H6), 4.26 (dd, 1H, *J* = 10.5, 6.6 Hz, H4), 3.99 (dt, 1H, *J* = 5.1, 10.2 Hz, H5), 3.94 (dt, 1H, *J* = 6.7, 1.2 Hz, H3), 3.75 (t, 1H, *J* = 10.2 Hz, H6), 0.95, 0.90 (2 × s, 9H each), 0.16, 0.12 (2 × s, 3H each), 0.13 (s, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.3 (0, Ph), 137.5 (0, Ph), 134.1 (1, Ph), 129.4 (1, 2C, Ph), 129.2 (1, 2C, Ph), 129.1 (1, Ph), 128.4 (1, 2C, Ph), 126.2 (1, 2C, Ph), 101.5 (1), 94.8 (1, C1), 81.2 (1, C4), 76.1 (1, C3), 72.9 (1, C2), 69.5 (2, C6), 65.0 (1, C5), 25.9 (3, 3C, *t*-Bu), 25.9 (3, 3C, *t*-Bu), 18.2 (0, C-Si), 18.1 (0, C-Si), −3.9 (3, CH_3Si), −4.4 (3, CH_3Si), −4.6 (3, CH_3Si), −4.9 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 621 ($M+H^+$, 100), 638 (MNH_4^+, 30).

Anal. Calcd for $C_{31}H_{48}O_7SSi_2$: C, 59.96; H, 7.79. Found: C, 59.95; H, 8.00.

1,5-Anhydro-4,6-*O*-benzylidene-3-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-1-phenylsulfonyl-D-*arabino*-hex-1-enitol (6)

Sulfone **21** (2.3 g, 3.7 mmol) treated with MeLi•LiBr[6,24] gave unsaturated sulfone **6** (1.60 g, 3.27 mmol, 88%) as a white solid after recrystallisation from hexanes/Et_2O, mp: 160−161 °C (Lit.[6] mp: 160−161 °C); $[\alpha]_D$ −54.9° (*c* 1.3, $CHCl_3$); Lit.[6] $[\alpha]_D$ −54° (*c* 1.3, $CHCl_3$).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.8 (0, C1), 138.0 (0, Ph), 136.9 (0, Ph), 134.3 (1, Ph), 129.4 (1, 2C, Ph), 129.3 (1, Ph), 128.8 (1, 2C, Ph), 128.4 (1, 2C, Ph), 126.1 (1, 2C, Ph), 111.7 (1, C2), 101.7 (1), 79.3 (1), 71.5 (1), 67.9 (2, C6), 67.6 (1), 25.9 (3, 3C, *t*-Bu), 18.3 (0, CSi), −4.3 (3, CH_3Si), −4.7 (3, CH_3Si).

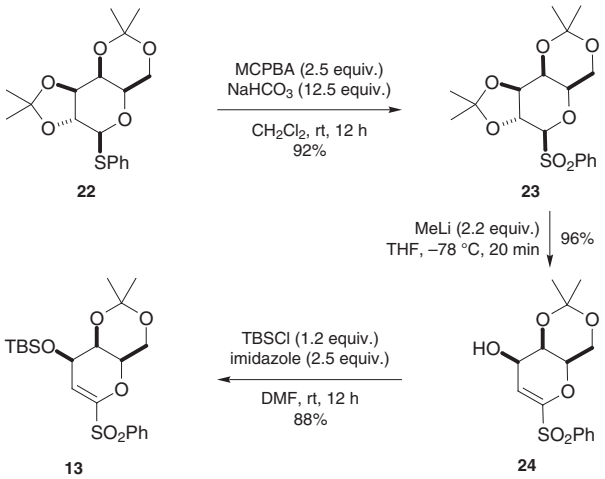
Unsaturated Sulfone 13 (Scheme 6)

2,3:4,6-Di-*O*-isopropylidene-β-D-galactopyranosyl Phenyl Sulfone (23)

Oxidation of **22**[25] (5.28 g, 15 mmol) according to the procedure described for the preparation of **21** gave sulfone **23** (5.28 g, 13.8 mmol, 92%) as a pale yellow solid, mp: 131−132 °C (hexanes/Et_2O): $[\alpha]_D$ −33.4° (*c* 1.04, $CHCl_3$)

IR (CCl_4): ν = 3069, 2990, 2887, 1586, 1448, 1382, 1330, 1276, 1225 cm^{-1}.

^1H NMR(400 MHz, $CDCl_3$): δ = 8.06−8.01 (m, 2H, Ph), 7.73−7.67 (m, 1H, Ph), 7.62−7.55 (m, 2H, Ph), 4.56 (dd, 1H, *J* = 7.5, 1.5 Hz, H1), 4.37 (t, 1H, *J* = 1.6 Hz, H4), 4.02 (dd, 1H, *J* = 13.1, 2.1 Hz, H6), 3.98 (dd, 1H, *J* = 13.1, 1.6 Hz, H6), 3.67−3.58 (m, 2H, H2, H3), 3.43 (d, 1H, *J* = 1.4 Hz, H5), 1.48, 1.39, 1.37, 1.10 (4 × s, 3H each).



Scheme 6

^{13}C NMR (100 MHz, $CDCl_3$): δ = 135.0 (0, Ph), 134.4 (1, Ph), 130.4 (1, 2C, Ph), 128.9 (1, 2C, Ph), 112.1 (0), 98.5 (0), 91.0 (1, C1), 79.0 (1, C2), 70.5 (1, C5), 68.8 (1, C3), 66.0 (1, C4), 62.6 (2, C6), 28.7 (3), 26.7 (3), 26.3 (3), 18.7 (3).

MS (CI, isobutane): *m/z* (%) = 385 ($M+H^+$, 100).

Anal. Calcd for $C_{18}H_{24}O_7S$: C, 56.23; H, 6.29. Found: C, 56.20; H, 6.32.

2,6-Anhydro-5-deoxy-1,3-*O*-isopropylidene-phenylsulfonyl-D-*arabino*-hex-5-enitol (24)

Sulfone **23** (5 g, 13 mmol) treated with MeLi•LiBr (29 mmol, 2.2 equiv)[6,24] gave alcohol **24** (4.08 g, 12.5 mmol, 96%) as a white solid. The crude product was sufficiently pure to use in the next step without further purification. An analytical sample was recrystallised from EtOH, mp: 73−74 °C; $[\alpha]_D$ −85.3° (*c* 1.21, $CHCl_3$).

IR ($CHCl_3$): ν = 3562, 3031, 3017, 2997, 2921, 1651, 1586, 1448, 1383, 1353, 1327 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.02−7.97 (m, 2H, Ph), 7.67−7.61 (m, 1H, Ph), 7.59−7.52 (m, 2H, Ph), 6.02 (t, 1H, *J* = 1.7 Hz, H5), 4.51 (ddd, 1H, *J* = 11.5, 4.5, 1.9 Hz, H4), 4.18 (dt, 1H, *J* = 4.6, 1.2 Hz, H3), 4.04−3.95 (m, 3H, H2, H1), 2.55 (d, 1H, *J* = 11.5 Hz, OH), 1.42, 1.04 (2 × s, 3H each).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.4 (0, C6), 138.6 (0, Ph), 133.9 (1, Ph), 129.1 (1, 2C, Ph), 128.5 (1, 2C, Ph), 108.1 (1, C5), 99.3 (0), 71.0 (1, C2), 64.3 (1, C3), 63.8 (1, C4), 62.2 (2, C1), 28.8 (3), 18.7 (3).

MS (CI, isobutane): *m/z* (%) = 327 ($M+H^+$, 55).

2,6-Anhydro-4-*O*-(*tert*-butyldimethylsilyl)-5-deoxy-1,3-*O*-isopropylidene-6-phenylsulfonyl-D-*arabino*-hex-5-enitol (13)

To a solution of the crude sulfone **24** (3.96 g, 12 mmol) in DMF (80 mL) was added imidazole (2.04 g, 30 mmol) followed by TBSCl (2.18 g, 14.4 mmol). The solution was stirred at r.t. overnight, then poured into H_2O (200 mL) and extracted with Et_2O (2 × 100 mL). The combined organic extracts were dried (Na_2SO_4), concentrated in vacuo, and the residue purified by chromatography to give the unsaturated sulfone **13** as an amorphous white solid (4.64 g, 10.5 mmol, 88%): $[\alpha]_D$ −84.8° (*c* 1.16, $CHCl_3$).

IR (CCl_4): ν = 3070, 2993, 2952, 2929, 2858, 1732, 1651, 1471, 1448, 1382, 1340 cm^{-1}.

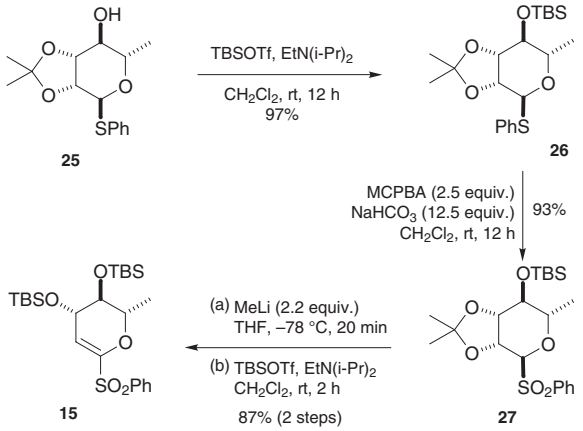
^1H NMR (400 MHz, $CDCl_3$): δ = 8.02−7.97 (m, 2H, Ph), 7.65−7.59 (m, 1H, Ph), 7.56−7.50 (m, 2H, Ph), 5.96 (t, 1H, *J* = 1.7 Hz, H5), 4.67 (ddd, 1H, *J* = 4.1, 1.8, 0.7), 4.06 (dt, 1H, *J* = 4.1, 1.5 Hz), 4.02 (br s, 1H), 3.99 (dd, 1H, *J* = 12.9, 1.6 Hz), 3.95 (dd, 1H, *J* = 12.9, 2.0 Hz, H1), 1.38, 1.02 (2 × s, 3H each), 0.90 (s, 9H, *t*-Bu), 0.10, 0.09 (2 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.5 (0, C6), 138.5 (0, Ph), 133.8 (1, Ph), 129.1 (1, 2C, Ph), 128.6 (1, 2C, Ph), 109.5 (1, C5), 98.9 (0), 71.4 (1), 66.2 (1), 65.5 (1), 62.5 (2, C1), 28.9 (3), 25.9 (3, 3C, *t*-Bu), 18.6 (3), 18.5 (0, CSi), −4.1 (3, CH_3Si), −4.2 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 458 (MNH_4^+, 100).

Anal. Calcd for $C_{21}H_{32}O_6SSi$: C, 57.24; H, 7.32. Found: C, 57.13; H, 7.28.

Unsaturated Sulfone 15



Scheme 7

Phenyl 4-*O*-(*tert*-Butyldimethylsilyl)-2,3-*O*-isopropylidene-1-thio-α-L-rhamnopyranoside (26)

To a solution of alcohol **25**[26] (2.96 g, 10 mmol) and *i*-Pr_2NEt (3.10 g, 4.2 mL, 24 mmol) in CH_2Cl_2 (100 mL) was added dropwise at 0 °C TBSOTf (3.17 g, 2.7 mL, 12 mmol). The solution was allowed to warm to r.t. overnight and then poured into H_2O (200 mL). The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (50 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated in vacuo. The residue was purified by column chromatography (SiO_2, hexanes followed by hexanes/Et_2O, 2:1) to give thioglycoside **26** (4.0 g, 9.7 mmol, 97%) as a colourless oil: $[\alpha]_D$ −186° (*c* 1.01, $CHCl_3$).

IR (film): ν = 3060, 2932, 2896, 2857, 1584, 1474, 1462, 1440, 1381 cm^{-1}.

^1H NMR (400 MHz; C_6D_6): δ = 7.68−7.63 (m, 2H, PhS), 7.26−7.15 (m, 3H, PhS), 6.19 (s, 1H, H1), 4.58 (d, 1H, *J* = 5.6 Hz, H2), 4.49 (dq, 1H, *J* = 9.6, 6.2 Hz, H5), 4.32 (dd, 1H, *J* = 7.1, 5.7 Hz, H3), 3.83 (dd, 1H, *J* = 9.6, 7.2 Hz, H4), 1.68, 1.39 (2 × s, 3H each), 1.50 (d, 3H, *J* = 6.2 Hz, H6), 1.26 (s, 9H, *t*-Bu), 0.54, 0.37 (2 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 133.93 (0, PhS), 131.94 (1, 2C, PhS), 129.15 (1, 2C, PhS), 127.62 (1, PhS), 109.35 (0), 84.16 (1, C1), 79.08 (1, C3), 76.94 (1, C2), 76.42 (1, C4), 67.81 (1, C5), 28.32 (3), 26.73 (3), 26.08 (3, 3C, *t*-Bu), 18.29 (0, C-Si), 17.83 (3, C6), −3.77 (3, CH_3Si), −4.69 (3, CH_3Si).

HRMS (EI): *m/z* calcd for $C_{21}H_{34}O_4SiS$ (M^+): 410.1947. Found: 410.1945

4-*O*-(*tert*-Butyldimethylsilyl)-2,3-*O*-isopropylidene-α-L-rhamnopyranosyl Phenyl Sulfone (27)

Oxidation of **26** (3.77 g, 9.2 mmol) with 50% MCPBA according to the procedure described above for the preparation of **21** gave sulfone **27** (3.80 g, 8.58 mmol, 93%) as a pale yellow solid, mp 138−139 °C (hexanes/Et_2O): $[\alpha]_D$ −58.8° (*c* 1.04, $CHCl_3$).

IR (CCl_4): ν = 3070, 2933, 2895, 2895, 1448, 1382, 1341, 1321 cm^{-1}.

^1H NMR(400 MHz, $CDCl_3$): δ = 7.96−7.90 (m, 2H, Ph), 7.75−7.69 (m, 1H, Ph), 7.65−7.58 (m, 2H, Ph), 4.98 (s, 1H, H1), 4.93 (d, 1H, *J* = 6.1 Hz, H2), 4.23 (dd, 1H, *J* = 7.3, 6.1 Hz, H3), 4.17 (dq, 1H, *J* = 6.2, 9.6 Hz, H5), 3.31 (dd, 1H, *J* = 7.4, 9.6 Hz, H4), 1.52, 1.41 (2 × s, 3H each), 1.10 (d, 3H, *J* = 6.2 Hz, H6), 0.90 (s, 9H, *t*-Bu), 0.16, 0.08 (2 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 136.4 (0, Ph), 134.5 (1, Ph), 129.4 (1, 2C, Ph), 129.2 (1, 2C, Ph), 109.2 (0), 91.0 (1, C1), 78.9 (1, C3), 75.2 (1, C4), 71.4 (1, C5), 70.3 (1, C2), 28.1 (3), 26.4 (3), 26.0 (3, 3C, *t*-Bu), 18.3 (0, C-Si), 18.0 (3, C6), −3.8 (3, CH_3Si), −4.7 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 460 (MNH_4^+, 100).

Anal. Calcd for $C_{21}H_{34}O_6SSi$: C, 56.98; H, 7.74. Found: C, 56.93; H, 7.75.

1,5-Anhydro-3,4-bis-*O*-(*tert*-butyldimethylsilyl)-2,6-dideoxy-1-phenylsulfonyl-L-*arabino*-hex-1-enitol (15)

Sulfone **27** (3.50 g, 7.9 mmol) was treated with MeLi•LiBr (17.4 mmol, 2.2 equiv) to give the elimination product (3.14 g) as a mixture of two regioisomeric alcohols (1:1) as a result of silyl group migration. The crude product was dissolved in CH_2Cl_2 (52 mL) and *i*-Pr_2NEt (2.53 g, 3.14 mL, 19.6 mmol) was added. The solution was then cooled in an ice-bath and TBSOTf (2.60 g, 2.22 mL, 9.8 mmol) was added dropwise. The solution was stirred in an ice-bath for 2 h and then poured into H_2O (100 mL). The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (50 mL). The combined organic extracts were dried (Na_2SO_4) and concentrated in vacuo. The residue was purified by column chromatography (SiO_2, hexanes/Et_2O, 50:1 to 1:1) to give unsaturated sulfone **15** (3.44 g, 6.89 mmol, 87% for two steps) as a colourless solid, mp 70−71 °C (90% EtOH/H_2O): $[\alpha]_D$+64.9° (*c* 1.19, $CHCl_3$)

IR (CCl_4): ν = 2955, 2894, 2857, 1649, 1471, 1447, 1382, 1377, 1362, 1340, 1257 cm^{-1}.

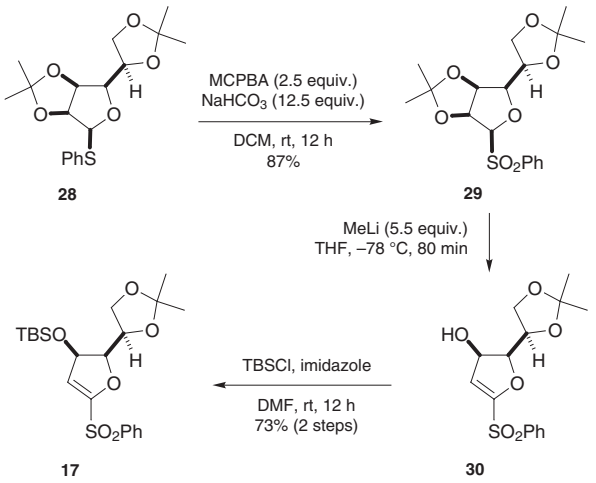
^1H NMR (400 MHz, $CDCl_3$): δ = 7.96−7.91 (m, 2H, Ph), 7.65−7.59 (m, 1H, Ph), 7.55−7.49 (m, 2H, Ph), 6.05 (dd, 1H, *J* = 4.5, 1.1 Hz, H2), 4.21 (ddq, 1H, *J* = 7.0, 3.8, 1.5 Hz, H5), 4.05 (ddd, 1H, *J* = 4.5, 3.2, 1.4 Hz, H3), 3.61 (ddd, 1H, *J* = 3.6, 3.4, 1.2 Hz, H4), 1.20 (d, 3H, *J* = 6.9 Hz, H6), 0.89, 0.76 (2 × s, 9H each, *t*-Bu), 0.14, 0.11, 0.04, 0.00 (4 × s, 3H each, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.9 (0, C1), 138.6 (0, Ph), 133.7 (1, Ph), 129.1 (1, 2C, Ph), 128.6 (1, 2C, Ph), 107.2 (1, C2), 78.3 (1, C5), 72.9 (1, C4), 67.6 (1, C3), 25.9 (3, 3C, *t*-Bu), 25.8 (3, 3C, *t*-Bu), 18.1 (0, CSi), 18.0 (0, CSi), 15.5 (3, C6), −4.2 (3, 2C, CH_3Si), −4.4 (3, CH_3Si), −4.6 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 516 (MNH_4^+, 100).

Anal. Calcd for $C_{24}H_{42}O_5SSi_2$: C, 57.79; H, 8.49. Found: C, 57.85; H, 8.75.

Unsaturated Sulfone 17



Scheme 8

2,3:5,6-Di-*O*-isopropylidene-β-D-mannofuranosyl Phenyl Sulfone (29)

Oxidation of thioglycoside **28**[27] (6.69 g, 19 mmol) with 50% MCPBA according to the procedure used for the preparation of **21** gave sulfone **29** (6.32 g, 16.4 mmol, 87%) as a pale yellow solid, mp: 118–119 °C (hexanes/Et_2O) (Lit.[28] mp: 119.5–120.5 °C): $[\alpha]_D$+56.6° (*c* 1.08, $CHCl_3$) {Lit.[28] $[\alpha]_D$+46.6° (*c* 0.98, $CHCl_3$)}

IR (CCl_4): ν = 3070, 2989, 2939, 2880, 1479, 1448, 1381, 1330, 1262 cm^{-1}.

^1H NMR(400 MHz, $CDCl_3$): δ = 8.00–7.95 (m, 2H, Ph), 7.68–7.61 (m, 1H, Ph), 7.56–7.50 (m, 2H, Ph), 5.10 (dd, 1H, *J* = 6.0, 4.1 Hz, H2), 4.77 (dd, 1H, *J* = 6.0, 3.9 Hz, H3), 4.57 (d, 1H, *J* = 4.0 Hz, H1), 4.34 (dt, 1H, *J* = 6.3, 4.9 Hz, H5), 4.02 (dd, 1H, *J* = 8.8, 6.2 Hz, H6), 3.99 (dd, 1H, *J* = 8.9, 4.9 Hz, H6), 3.74 (dd, 1H, *J* = 6.5, 3.9 Hz, H4), 1.42, 1.34, 1.26,1.03 (4 × s, 3H each).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.8 (0, Ph), 133.9 (1, Ph), 129.9 (1, 2C, Ph), 128.6 (1, 2C, Ph), 114.3 (0), 109.4 (0), 94.4 (1, C1), 82.8 (1, C4), 80.2 (1), 79.9 (1), 72.9 (1, C5), 66.4 (2, C6), 26.9 (3), 25.4 (3), 24.6 (3), 24.1 (3).

MS (CI, NH_3): *m/z* (%) = 402 (MNH_4^+, 100).

Anal. Calcd for $C_{18}H_{24}O_7S$: C, 56.23; H, 6.29. Found: C, 56.12; H, 6.28.

1,4-Anhydro-3-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-5,6-*O*-isopropylidene-1-phenylsulfonyl-D-*arabino*-hex-1-enitol (17)

To a rapidly stirred solution of MeLi•LiBr (34 mL, 1.3 M in Et_2O, 44 mmol) in THF (80 mL) at −78 °C was added over 1 h a solution of sulfone **29** (3.07 g, 8.0 mmol) in THF (80 mL). After the addition was complete, the solution was stirred at −78 °C for 10 min, and then transferred slowly by cannula, under N_2, into a rapidly stirred solution of sat. $NaHCO_3$ (200 mL) placed in a 1 L flask and cooled in an ice-bath (very vigorous reaction). The mixture was then extracted with Et_2O (2 × 100 mL), dried (Na_2SO_4), and concentrated in vacuo. The crude product (2.75 g) was then dissolved in DMF (54 mL), whereupon imidazole (1.36g, 20 mmol) was added followed by TBSCl (1.45 g, 9.6 mmol). The solution was stirred at r.t. overnight, then poured into H_2O (300 mL), and extracted with Et_2O (2 × 100 mL). The combined extracts were dried (Na_2SO_4) and concentrated in vacuo. The residue was purified by column chromatography (SiO_2, hexanes/Et_2O, 10:1 to 1:1 containing 0.5% Et_3N) to give **17** (2.58 g, 5.86 mmol, 73%) as a white solid, mp 50–51 °C (EtOH/H_2O): $[\alpha]_D$ −97.7° (*c* 1.14, $CHCl_3$). The compound slowly decomposes at r.t. and should be kept in a freezer.

IR (CCl_4): ν = 2990, 2887, 1448, 1381, 1341, 1225, 1155, 1083 cm^{-1}.

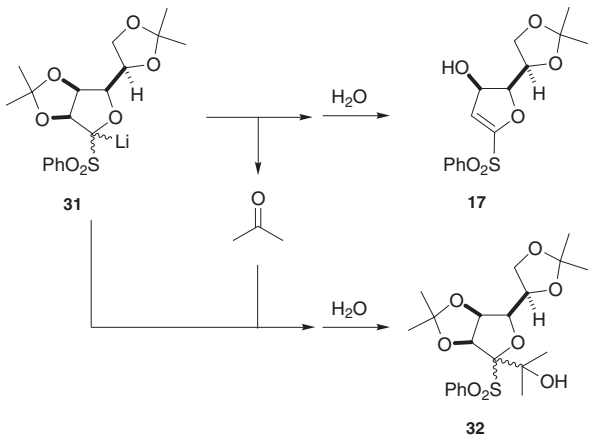
^1H NMR (400 MHz, $CDCl_3$): δ = 7.92–7.85 (m, 2H, Ph), 7.65–7.58 (m, 1H, Ph), 7.53–7.46 (m, 2H, Ph), 5.99 (d, 1H, *J* = 2.7 Hz, H2), 5.02 (dd, 1H, *J* = 6.9, 2.7 Hz, H3), 4.50 (dd, 1H, *J* = 6.0, 6.7 Hz, H4), 4.39 (q, 1H, *J* = 6.2 Hz, H5), 3.99 (dd, 1H, *J* = 8.7, 6.5 Hz, H6), 3.73 (dd, 1H, *J* = 8.7, 6.0 Hz, H6), 1.34, 1.32 (2 × s, 3H each), 0.86 (s, 9H, *t*-Bu), 0.08 (s, 6H, CH_3Si).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 157.7 (0, C1), 138.2 (0, Ph), 134.5 (1, Ph), 129.4 (1, 2C, Ph), 128.7 (1, 2C, Ph), 111.0 (1, C2), 109.2 (0), 88.3 (1, C4), 73.0 (1, C3), 72.5 (1, C5), 65.9 (2, C6), 26.6 (3), 25.8 (3, 3C, *t*-Bu), 25.5 (3), 18.3 (0, C-Si), −4.6 (3, CH_3Si), −4.9 (3, CH_3Si).

MS (CI, NH_3): *m/z* (%) = 458 (MNH_4^+, 100).

Anal. Calcd for $C_{21}H_{32}O_6SSi$: C, 57.24; H, 7.32. Found: C, 57.36; H, 7.29.

When 2.2 equiv of MeLi•LiBr was used in the β-elimination reaction, the desired unsaturated sulfone **17** was accompanied by a second product **32** (**17**:**32** ~ 1:1) corresponding to the adduct derived from addition of the metallated sulfone **31** to the acetone released in the β-elimination reaction as shown in Scheme 9. However, by increasing the amount of MeLi to 5.5 equiv, changing the order of addition and increasing the reaction time, the acetone was presumably trapped by the excess MeLi leading to an increase in yield of **17** from 51% to 73% and a decrease in the amount of **32** (**17**:**32** = 6:1).



Scheme 9

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