Stripping off Water at Ambient Temperature: Direct Atom-Efficient Acetal Formation between Aldehydes and Diols Catalyzed by Water-Tolerant and Recoverable Vanadyl Ttriflate

Chien-Tien Chen,* Shiue-Shien Weng, and Jun-Qi Kao
Chun-Chen Lin* and Mi-Dan Jan

e-mail: chefv043@scc.ntnu.edu.tw for Chien-Tien Chen

SUPPORTING INFORMATION

Representative experimental procedures, spectral data (20 pages)

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1. **General experimental.** ^{1}H NMR and ^{13}C NMR spectra were recorded in deuterochloroform with chloroform as an internal reference unless otherwise stated. Chemical shifts are reported in ppm (d). Coupling constants, *J*, are reported in Hz. Infrared spectra were reported with peaks in units of cm^{-1} with the following relative intensities: br (broad), s (strong 67-100 %), m (medium 33-67 %), or w (weak 0-33 %). Mass spectra were recorded with an ionization voltage of 70 or 20 eV unless otherwise stated. Combustion analyses were performed by the Northern Instrument Center of Taiwan. Fast atom bombardment (FAB) and electrospray (ESI) mass spectra were reported with data in the form m/e (intensity relative to base peak). Analytical TLC was visualized with UV light or with phosphomolybdic acid (PMA) and $KMnO_4$ staining agents. Column (flash) chromatography was performed using 32-63 μm silica gel. Solvents for extraction and chromatography were reagent grade. CH_2Cl_2, CH_3CN, and MeOH were dried over CaH_2 before use. THF and toluene were dried over Na with benzophenone-ketyl intermediate as indicator. All reactions were run under nitrogen and the end products were isolated as chromatographically pure materials. The VOX_2 series of compounds (brand name as *Clip-all*® series, US patent # 6,541,659 B1, **2003**) is now available directly from the institution (e-mail: chefv043@scc.ntnu.edu.tw). 2,3-Dihydroxy-propyl benzoate,[1] monosaccharides **7a,b-8**, **10a, 10b, 11b-13**,[2] **24**,[3] and **26**[4] was synthesized according to the literature procedures. Pentaerythritol-**3**, **9**, and **11a** are commercially available. All aldehydes and ethylene glycol were purified by distillation or re-crystallization before use. 4-Acetoxy-benzaldehyde was synthesized by acetylation of 4-hydroxy benzaldehyde.[5]

2. General Procedure for the preparation of vanadyl triflate-$VO(OTf)_2$

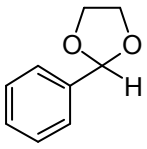
In a flame-dried, 50-mL, two-necked, round-bottomed flask was placed vanadyl sulfate-$VOSO_4$-xH_2O (342 mg, 2.1 mmol) followed by addition of anhydrous MeOH. (2 mL). To the above solution, a solution of $Ba(OTf)_2$ (872 mg, 2 mmol) in MeOH (2 mL) was slowly added at ambient temperature. After having been stirred for 30 min, the reaction mixture became turbid with copious amount of barium sulfate precipitation. The mixture was filtered through a short plug of

Celite. The filtrate was evaporated to give faint blue solid which was further dried at 120 ^{o}C for 4 hours in vacuo to furnish vanadyl triflate in 85% yield (622 mg). It can be stored at ambient temperature for several weeks in dry cabinet and can be used directly.

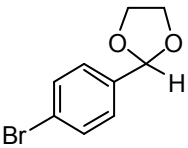
3. General procedure for the acetal formation

In a flame-dried 50-mL, two-necked, round bottomed flask was placed $VO(OTf)_2$-xH_2O (18.5 mg, 0.05 mmol) and aldehyde (1.1-1.3 mmol) in CH_2Cl_2 or CH_3CN (10 mL). After 10 min, a solution of diols (those in Scheme 1) or saccharides (those in Table 1 and Scheme 2) in CH_2Cl_2 or CH_3CN (10 mL) were added at ambient temperature. The resulting reaction mixture was stirred for the indicated time period. After completion of the reaction as judged by TLC analysis, the reaction mixture was quenched by sequential addition of Et_3N (0.5 mL) and cold saturated aqueous $NaHCO_3$ solution (5 mL). The organic layer was separated and the aqueous layer was extracted with EtOAc (10 mL × 3). The combined organic layers were washed with brine solution (10 mL), dried ($MgSO_4$), and evaporated. The crude product was purified by column chromatography on silica gel (pretreated with EtOAc/hexane eluents containing 1% of Et_3N). The obtained product was characterized by routine spectroscopic methods.

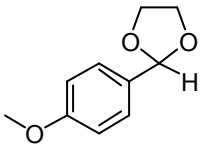
Aanalytical data of acetals



Data for **2-phenyl-1,3-dioxolane (4a)**:[6] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50-7.37 (m, 5H), 5.82 (s, 1H, PhCH), 4.16-4.03 (m, 4H, $H_2C(4)$, $H_2C(5)$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.9, 129.1, 128.3, 126.4, 103.7, 65.2; TLC R_f 0.62 (EtOAc/hexanes, 1/20).

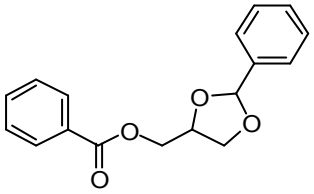


Data for **2-(4-Bromo-phenyl)-1,3-dioxolane (4b)**:[6] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, J = 8.4 , 2H), 7.35 (d, J = 8.4 , 2H), 5.77 (s, 1H, PhCH), 4.14-3.99 (m, 4H, $H_2C(4)$, $H_2C(5)$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.0, 131.5, 128.2, 123.2, 103.0, 65.3; TLC R_f 0.52 (EtOAc/hexanes, 1/15).



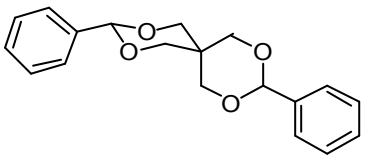
Data for **2-(4-Methoxy-phenyl)-1,3-dioxolane (4c)**:[6] ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, J = 8.7 , 2H), 6.91 (d, J = 8.7 , 2H), 5.76 (s, 1H, PhCH), 4.13-4.01 (m, 4H, $H_2C(4)$, $H_2C(5)$); ^{13}C NMR (100 MHz, $CDCl_3$)?δ 160.2, 129.9, 127.8, 113.6, 103.6, 65.1, 55.1; TLC R_f 0.60 (EtOAc/hexanes, 1/20).

(2-phenyl-1,3-dioxolan-4-ly)methyl benzoate (5)[7]



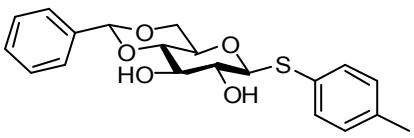
^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (dd, J = 8.2, 1.2, 2H), 7.59-7.38 (m, 8H, aromatic Hs), 5.53 (s, 1H, PhCH), 5.29 (septet, J = 5.2, 1H, HC(4)), 4.56-4.52 (m, 2H, H_2COBz), 3.89-3.84 (m, 2H, $H_2C(5)$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.4, 137.3, 133.4, 129.7, 129.4, 129.2, 128.5, 128.4, 126.2, 110.5, 77.2, 68.7, 63.2; MS (70 eV, $C_{17}H_{16}O_4$) 284 (M^+, 6), 162 (33), 105 (100), 77 (41); TLC R_f 0.34 (EtOAc/hexanes, 1/50).

3,9-Diphenyl-2,4,8,10-tetraoxa-spiro[5,5]undecane (6)[8]



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50-7.48, 7.41-7.36 (m, 10H, 2 × C_6H_5), 5.46 (s, 2H, 2 × PhCH), 4.88 (d, J = 11.6 Hz, 2H), 3.87-3.82 (m, 4H), 3.67 (d, J = 11.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.9, 129.1, 128.3, 126.0, 102.2, 71.0, 70.6, 32.5; MS (70 eV, $C_{19}H_{20}O_4$) 312 (M^+, 87), 311 (100), 205 (24), 175 (40), 105 (60); TLC R_f 0.46 (EtOAc/hexanes, 1/ 50); mp 160-162 °C.

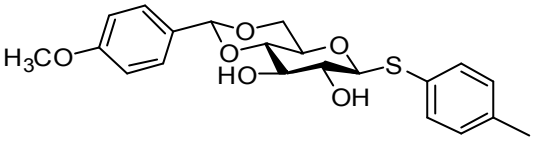
4-Methylphenyl4,6-*O*-benzylidine-1-thio-β-D-glucopyranoside (14a)[9]



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49-7.43 (m, 4H), 7.38-7.35 (m, 3H), 7.15 (d, J = 8.0, 2H), 5.53 (s, 1H, PhCH), 4.58 (d, J = 9.6, 1H, HC(1)), 4.37 (dd, J = 10.4, 4.0, 1H, $H_{eq}C(6)$), 3.85 (dd, J = 9.6, 8.0, 1H, HC(4)), 3.77 (dd, J = 10.4, 9.6, 1H, $H_{ax}C(6)$), 3.52-3.48 (m, 2H, HC(2), HC(3)), 3.43 (dt, J = 9.6, 4.4, 1H, HC(5)), 2.70 (bs, 1H, OH), 2.60 (bs, 1H, OH), 2.36 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.9, 136.9, 133.7, 129.9, 129.3, 128.3, 127.2, 126.3, 101.9, 88.7, 80.3, 74.6,

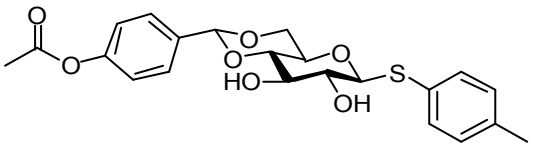
72.5, 70.6, 68.6, 21.2; MS (70 eV, $C_{20}H_{22}O_5S$) 374 (M^+, 34), 250 (100), 145 (10), 127 (19), 124 (77), 107 (71), 91(43), 79 (25); $[\alpha]_D^{25}$ -34.40 (*c* 1.0, $CHCl_3$); TLC R_f 0.21 (EtOAc/hexanes, 1/ 2); mp 171-172 °C.

4-Methylphenyl 4,6-*O*-((4-methoxyphenyl)methylene)-1-thio- β -D-glucopyranoside (14b)[9]



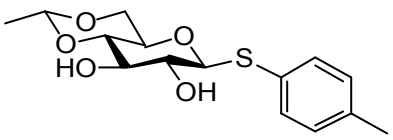
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, *J* = 7.7, 2H), 7.39 (d, *J* = 8.4, 2H), 7.15 (d, *J* = 7.7, 2H), 6.88 (d, *J* = 8.3, 2H), 5.48 (s, 1H, PhCH), 4.56 (d, 1H, *J* = 9.7, HC(1)), 4.35 (dd, *J* = 10.5, 3.9, 1H, $H_{eq}C(6)$), 3.83-3.73 (m, 2H, $H_{ax}C(6)$, HC(4)), 3.82 (s, 3H, OCH_3), 3.50-3.42 (m, 3H, HC(2), HC(3), HC(5)), 2.79 (bs, 1H, OH), 2.66 (bd, *J* = 1.4, 1H, OH), 2.36 (s, $ArCH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.3, 138.9, 133.7, 129.9, 129.4, 127.6, 127.2, 113.7, 101.9, 88.7, 80.2, 74.6, 72.5, 70.6, 68.6, 55.3, 21.2; MS (70 eV, $C_{21}H_{24}O_6S$) 404 (M^+, 8), 309 (23), 281 (32), 267 (13), 165 (14), 137 (100), 123 (69); $[\alpha]_D^{25}$ -35.70 (*c* 1.0, $CHCl_3$); TLC R_f 0.19 (EtOAc/hexanes, 1/ 2); mp 176-178 °C.

4-Methylphenyl 4,6-*O*-((4-acetoxyphenyl)methylene)-1-thio- β -D-glucopyranoside (14c)



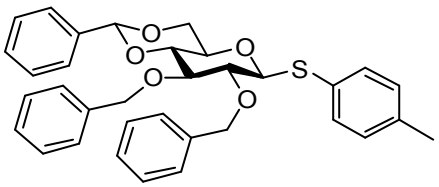
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (d, *J* = 8.4, 2H), 7.43 (d, *J* = 8.0, 2H), 7.15 (d, *J* = 8.0, 2H), 7.09 (d, *J* = 8.4, 2H), 5.51 (s, 1H, PhCH), 4.56 (d, *J* = 9.6, 1H, HC(1)), 4.36 (dd, *J* = 10.4, 4.4, 1H, $H_{eq}C(6)$), 3.78-3.74 (m, 2H, $H_{ax}C(6)$, HC(4)), 3.50-3.47 (m, 2H, HC(2), HC(3)), 3.42 (dt, *J* = 9.6, 4.4, 1H, HC(5)), 2.83 (d, *J* = 2.4, 1H, OH), 2.68 (d, *J* = 2.4, 1H, OH), 2.36 (s, 3H, $COCH_3$), 2.28 (s, 3H, $ArCH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.2, 151.2, 138.8, 134.6, 133.6, 129.8, 127.5, 127.3, 121.4, 101.2, 88.6, 80.2, 74.5, 72.5, 70.4, 68.5, 21.1, 21.0; MS (70 eV, $C_{22}H_{24}O_7S$) 432 (M^+, 8), 308 (32), 267 (31), 165 (29), 123 (100), 91 (24), 69 (19); $[\alpha]_D^{25}$ -19.80 (*c* 1.0, $CHCl_3$); TLC R_f 0.17 (EtOAc/hexanes, 1/ 2); HRMS calcd for ($C_{22}H_{24}O_7S$) 432.1243, found 432.1247; Anal. Calcd. For $C_{22}H_{24}O_7S$: C, 61.10; H, 5.59. Found: C, 60.73; H, 5.61; mp 188-191 °C.

4-Methyl phenyl 4,6-*O*-ethylidene-1-thio-β-D-glucopyranoside (14d)[9]



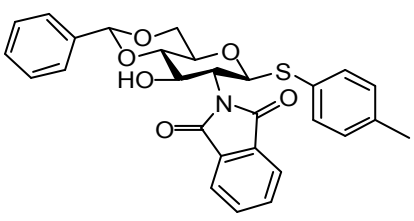
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (d, *J* = 8.0, 2H), 7.13 (d, *J* = 8.0, 2H), 4.71 (q, *J* = 5.0, 1H, *H*CCH_3), 4.52 (d, *J* = 9.6, 1H, HC(1)), 4.19 (dd, *J* = 10.6, 4.6, 1H, $H_{eq}C(6)$), 3.76 (dd, *J* = 9.6, 9.2, 1H, HC(4)), 3.55 (dd, *J* = 10.4, 9.6, 1H, $H_{ax}C(6)$), 3.39-3.31 (m, 2H, HC(2), HC(3)), 3.27 (t, *J* = 9.2, 1H, HC(5)), 3.06 (bs, 1H, OH), 2.81 (bs, 1H, OH), 2.35 (s, 3H, $ArCH_3$), 1.36 (d, *J* = 5.2, 3H, HC*C*H_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.8, 133.6, 129.9, 127.2, 99.7, 88.7, 79.5, 74.5, 72.5, 70.5, 68.0, 21.2, 20.3; MS (ESI) 335 ($M+Na^+$, 9); $[\alpha]_D^{25}$ -77.12 (*c* 1.0, $CHCl_3$); TLC R_f 0.30 (EtOAc/hexanes, 1/ 2); Anal. Calcd for $C_{15}H_{20}O_5S$ (312.4): C, 57.67; H, 6.45. Found: C, 57.46; H, 6.11; mp 180-182 ^oC.

***p*-Methylphenyl 2,3-Di-*O*-Benzyl-4,6-*O*-benzylidene-1-thio-β-D-glucopyranoside (15)**



^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47-7.25 (m, 17H, aromatic Hs), 7.11 (d, *J* = 8.0, 2H), 5.58 (s, 1H, PhCH), 4.93, 4.92 (d, *J* = 11.1, 2H, H_2CPh), 4.82, 4.78 (d, *J* = 11.1, 2H, H_2CPh), 4.69 (d, *J* = 10.0, HC(1)), 4.38 (dd, *J* = 10.5, 5.0, 1H, $H_{eq}C(6)$), 3.82 (dd, *J* = 9.5, 9.0, 1H, HC(3)), 3.81 (dd, *J* = 10.0, 9.0, 1H, $H_{ax}C(6)$), 3.68 (t, *J* = 9.5, 1H, HC(4)), 3.48 (dd, *J* = 10.0, 8.5, 1H, HC(2)), 3.45 (ddd, *J* = 9.5, 9.0, 5.0, HC(5)), 2.34 (s, 3H, $ArCH_3$); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.2, 138.1, 138.0, 137.1, 132.9, 129.7, 129.0, 128.9, 128.3, 128.1, 128.1, 128.0, 127.8, 121.7, 125.9, 101.0, 88.4, 82.9, 81.3, 80.2, 75.7, 75.2, 70.1, 68.6, 21.0; MS (FAB, $C_{34}H_{34}O_5S$) m/z 554 ($M+H^+$, 20); $[\alpha]_D^{25}$ -29.9 (*c* 1.0, $CHCl_3$); TLC R_f 0.25 (EtOAc/hexanes, 1/3); HR-FAB MS calcd for $C_{34}H_{34}O_5S$+H: 555.2192, found 555.2205; mp 123-125^{o}C.

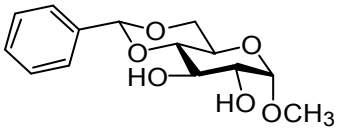
***p*-Methylphenyl-4,6-*O*-benzylidine-2-deoxy-2-phthalimido-1-thio-β-D-glucopyranoside (16)**[10]



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.94 (bd, *J* = 5.6, 2H), 7.76 (dd, *J* = 5.6, 2.8, 2H), 7.47 (dd, *J* = 7.6, 4.0, 2H), 7.38-7.36 (m, 3H), 7.28 (d, *J* = 8.4, 2H), 7.07 (d, *J* = 8.0, 2H), 5.63 (d, *J* = 10.5, 1H,

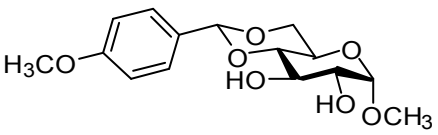
HC(1)), 5.56 (s, 1H, PhCH), 4.62 (dt, *J* = 9.6, 3.2, 1H, HC(3)), 4.39 (dd, *J* = 10.4, 4.8, 1H, $H_{eq}C(6)$), 4.31 (t, *J* = 10.0, 1H, HC(2)), 3.82 (t, *J* = 10.4, 1H, $H_{ax}C(6)$), 3.69 (td, *J* = 9.3, 4.8, 1H, HC(5)), 3.47 (t, *J* = 9.2, 1H, HC(4)), 2.55 (bd, *J* = 1.6, 1H, OH), 2.31 (s, 3H, CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 168.2, 167.5, 138.5, 136.9, 134.2, 133.4, 131.6, 129.7, 129.4, 128.4, 127.8, 126.3, 123.9, 123.4, 102.0, 84.5, 82.0, 70.3, 69.8, 68.6, 55.6, 21.1; MS (70 eV, $C_{28}H_{25}NO_6S$) 503 (M^+, 97), 502 (91), 430 (67), 399 (100), 387 (28), 386 (35); $[\alpha]_D^{25}$ +33.4 (*c* 0.5, $CHCl_3$); TLC R_f 0.23 (EtOAc/hexanes, 1/ 2); mp 121-122 °C.

Methyl 4,6-*O*-benzylidene-α-D-glucopyranoside (17a)[11]



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.51-7.48 (m, 2H), 7.39-7.36 (m, 3H), 5.54 (s, 1H, HC-acetal), 4.81 (d, *J* = 4.0, 1H, HC(1)), 4.30 (dd, *J* = 9.6, 4.0, 1H, $H_{eq}C(6)$), 3.94 (t, *J* = 9.2, 1H, HC(4)), 3.84-3.75 (m, 1H, C(2)), 3.74 (t, *J* = 9.5, 1H, $H_{ax}C(6)$), 3.64 (dd, *J* = 9.0, 4.0, 1H, HC(5)), 3.49 (dt, *J* = 9.2, 4.0, 1H, HC(5)), 3.47 (s, 3H, OCH_3), 2.66 (d, *J* = 2.0, 1H, OH), 2.23 (d, *J* = 9.6, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 137.1, 129.3, 128.3, 126.3, 102.0, 99.8, 80.9, 72.9, 71.9, 68.9, 62.4, 55.6; MS (70 eV, $C_{14}H_{18}O_6$) 282 (M^+, 5), 123 (100), 91 (24); $[\alpha]_D^{25}$ +139.00 (*c* 2.0, $CHCl_3$); TLC R_f 0.15 (EtOAc/hexanes, 1/ 2); mp 168-169 °C.

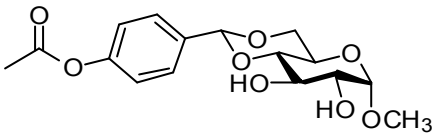
Methyl-4,6-*O*-((4-methoxyphenyl)methylene)-α-D-glucopyranoside (17b)[12]



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.41 (d, *J* = 8.8, 2H), 6.88 (d, *J* = 8.8, 2H), 5.48 (s, 1H, HC-acetal), 4.78 (d, *J* = 4.0, 1H, HC(1)), 4.27 (dd, *J* = 9.6, 4.4, 1H, $H_{eq}C(6)$), 3.90 (t, *J* = 9.2, 1H, HC(4)), 3.80 (s, 3H, $ArOCH_3$), 3.78-3.76 (m, 1H, HC(2)), 3.72 (dd, *J* = 9.6, 9.4, 1H, $H_{ax}C(6)$), 3.61 (dt, *J* = 9.2, 3.9, 1H, HC(5)), 3.46 (t, *J* = 9.2,1H, HC(3)), 3.45 (s, 3H, OCH_3), 2.86 (bs, 1H, OH), 2.38 (d, *J* = 8.8, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 160.2, 129.5, 127.6, 113.7, 101.9, 99.8, 80.9, 72.9, 71.8, 68.9, 62.4, 55.5, 55.3; MS (70 eV, $C_{15}H_{20}O_7$) 312 (M^+, 28), 311 (31), 137 (93), 135 (100);

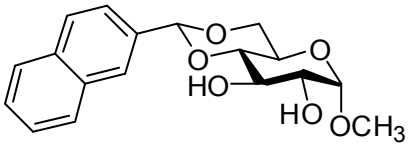
$[\alpha]_D^{25}$ +105.68 (*c* 1.0, $CHCl_3$); TLC R_f 0.45 (MeOH/CH_2Cl_2, 1/ 10); mp 197-198 °C.

Methyl -4,6-*O*-((4-acetoxyphenyl)methylene)- α -D-glucopyranoside (17c)



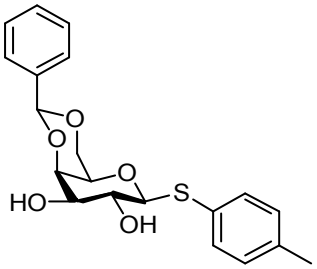
^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.51 (d, *J* = 8.6, 2H,), 7.10 (d, *J* = 8.6, 2H), 5.53 (s, 1H, HC-acetal), 4.81 (d, *J* = 4.0, HC(1)), 4.29 (dd, *J* = 9.2, 4.0, 1H, $H_{eq}C(6)$), 3.92 (t, *J* = 9.2, 1H, HC(4)), 3.78 (dd, *J* = 9.2, 4.4, 1H, HC(2)), 3.76 (dd, *J* = 10.0, 9.2, 1H, $H_{ax}C(6)$), 3.63 (dd, *J* = 9.2, 4.0, 1H, HC(5)), 3.51-3.49 (m, 1H, HC(3)), 3.46 (s, 3H, OCH_3), 2.29 (s, 3H, $OC(O)CH_3$), 1.95 (br, 2H, 2 × OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 169.2, 151.2, 137.7, 127.6, 121.4, 101.2, 99.8, 80.9, 72.8, 71.6, 68.9, 62.3, 55.5, 21.1; MS (70 eV, $C_{16}H_{20}O_8$) 340 (M^+, 11), 298 (30), 297 (17), 281 (12), 165 (44), 123 (100), 122(62), 121 (75); $[\alpha]_D^{25}$ +105.36 (*c* 1.0, $CHCl_3$); TLC R_f 0.13 (EtOAc/hexanes, 1/ 2); Anal. Calcd For $C_{16}H_{20}O_8$: C, 56.47; H, 5.92. Found: C, 56.20; H, 6.10; mp 202-204 °C.

Methyl -4,6-*O*-((2-naphthyl)methylene)- α -D-glucopyranoside (17d)[13]



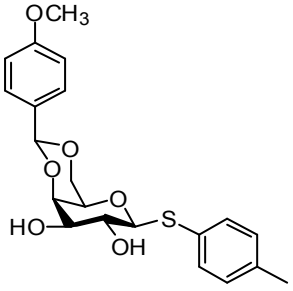
^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.97 (s, 1H), 7.87-7.82 (m, 3H), 7.60 (dd, *J* = 8.5, 1.4, 1H), 7.51-7.48 (m, 2H), 5.70 (s, 1H, HC-acetal), 4.81 (d, *J* = 3.9, 1H, HC(1)), 4.34 (dd, *J* = 9.5, 4.1, 1H, $H_{eq}C(6)$), 3.96 (dd, *J* = 9.2, 8.0, 1H, HC(4)), 3.87-3.78 (m, 2H, $H_{ax}C(6)$, HC(2)), 3.67 (dt, *J* = 9.6, 3.9, 1H, HC(5)), 3.54 (t, *J* = 9.2, 1H, HC(3)), 3.47 (s, 3H, $OC(O)CH_3$), 2.78 (bs, 1H, OH), 2.30 (d, *J* = 9.1, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 134.4, 133.8, 132.9, 128.4, 128.2, 127.7, 126.5, 126.2, 125.8, 123.7, 102.0, 99.8, 81.0, 72.9, 71.9, 69.0, 62.4, 55.6; MS (70 eV, $C_{18}H_{20}O_6$) 332 (M^+, 31), 157 (34), 156 (100), 155 (82), 141(12), 129 (19), 128 (31), 127 (68), 126 (19), 101 (13), 87 (11), 86 (25), 85 (18), 75 (13), 74 (54), 73 (38), 71 (38), 69 (15), 61 (25), 60 (69), 57 (55), 56 (27), 55 (15); $[\alpha]_D^{25}$ +82.8 (*c* 1.0, $CHCl_3$); TLC R_f 0.35 (MeOH/CH_2Cl_2, 1/15); mp 193-194°C.

4-Methylphenyl 4,6-*O*-benzylidine-1-thio- β -D-galactopyranoside (18a)[9]



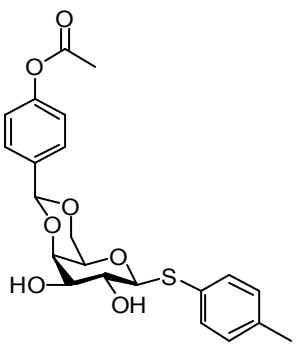
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 (dd, *J* = 7.6, 2.0, 2H), 7.39-7.36 (m, 5H, aromatic Hs), 7.12 (d, *J* = 8.0, 2H), 5.51 (s, 1H, PhCH), 4.47 (d, *J* = 9.2, 1H, HC(1)), 4.40 (dd, *J* = 12.4, 1.6, 1H, $H_{eq}C(6)$), 4.22 (d, *J* = 2.4, 1H, HC(4)), 4.04 (dd, *J* = 12.4, 1.6, 1H, $H_{ax}C(6)$), 3.71-3.63 (m, 2H, HC(2), HC(3)), 3.56 (d, *J* = 1.4, 1H, HC(5)), 2.46 (d, *J* = 1.6, 1H, OH), 2.42 (d, *J* = 8.4, 1H, OH), 2.36 (s, 3H, $ArCH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.5, 137.6, 134.3, 129.7, 129.3, 128.2, 126.7, 126.6, 101.4, 87.1, 75.4, 73.8, 70.0, 69.3, 68.7, 21.2; MS (70 eV, $C_{20}H_{224}O_5S$) 374 (M^+, 98), 251 (36), 124 (31), 107 (100), 91 (43), 79 (38); $[\alpha]_D^{25}$ -72.8 (*c* 1.0, MeOH); TLC R_f 0.31 (EtOAc/hexanes, 1/ 2); mp 154-155 °C.

4-Methylphenyl 4,6-*O*-((4-methoxyphenyl)methylene)-1-thio- β -D-galatopyranoside (18b)[14]



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 (d, *J* = 8.0, 2H), 7.31 (d, *J* = 8.6, 2H), 7.12 (d, *J* = 8.0, 2H), 6.87 (d, *J* = 8.6, 2H), 5.45 (s, 1H, PhCH), 4.44 (d, *J* = 8.8, 1H, HC(1)), 4.35 (d, *J* = 12.4, 1H, $H_{eq}C(6)$), 4.18-4.16 (m, 1H, HC(4)), 4.00 (d, *J* = 12.4, 1H, $H_{ax}C(6)$), 3.82 (s, 3H, OCH_3), 3.69-3.59 (m, 2H, HC(2), HC(3)), 3.52-3.50 (bs, 1H, HC(5)), 2.56 (br, 1H, OH), 2.37 (s, $ArCH_3$); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.3, 138.5, 134.3, 130.2, 129.7, 127.9, 126.7, 113.5, 101.2, 87.1, 75.3, 73.8, 70.0, 69.3, 68.8, 55.3, 21.3; MS (70 eV, $C_{21}H_{24}O_6S$) 404 (M^+, 7), 309 (19), 281 (32), 267 (9), 137 (100), 123 (79), 91 (30), 69 (19); $[\alpha]_D^{25}$ -9.80 (*c* 1.0, $CHCl_3$); TLC R_f 0.23 (EtOAc/hexanes, 1/ 2); HR-MS calcd for $C_{21}H_{24}O_6$ 404.1294, found 404.1293; mp 156-158 °C.

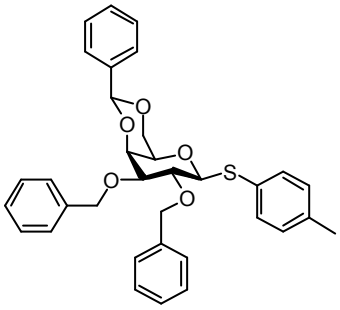
4-Methylphenyl-4,6-*O*-((4-acetoxyphenyl)methylene)-1-thio- β -D- galatopyranoside (18c)



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.57 (d, *J* = 8.0, 2H), 7.40 (d, *J* = 8.4, 2H), 7.10 (d, *J* = 8.0, 2H), 7.07 (d, *J* = 8.4, 2H), 5.50 (s, 1H, PhCH), 4.45 (d, *J* = 9.2, 1H, HC(1)), 4.37 (d, *J* = 12.0, 1H, $H_{eq}C(6)$), 4.20 (d, *J* = 2.8, 1H, HC(4)), 4.02 (d, *J* = 12.0, 1H, $H_{ax}C(6)$), 3.72-3.59 (m, 2H, HC(2), HC(3)), 3.55-3.54 (bs, 1H, HC(5)), 2.50 (bs, 1H, OH), 2.46 (d, *J* = 8.4, 1H, OH),

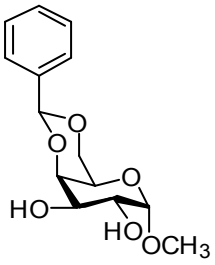
2.38 (s, 3H, $ArCH_3$), 2.31 (s, 3H, $OC(O)CH_3$); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 169.1, 151.2, 138.3, 135.3, 134.0, 129.6, 127.7, 127.0, 121.2, 100.5, 87.0, 75.4, 73.6, 69.8, 69.2, 68.6, 21.1, 21.0; MS (70 eV, $C_{22}H_{24}O_7S$) 432 (M^+, 8), 308 (35), 267 (33), 165 (24), 123 (100), 91 (24); $[\alpha]_D^{25}$ -38.80 (*c* 1.0, $CHCl_3$); TLC R_f 0.18 (EtOAc/hexanes, 1/ 2); HR-MS calcd for $C_{22}H_{24}O_7S$ 432.1243, found 432.1231; Anal. Calcd for $C_{22}H_{24}O_7S$: C, 61.10; H, 5.59. Found: C, 60.89; H, 5.34; mp 162-164 °C.

_p_-Methylphenyl 2,3-Di-*O*-Benzyl-4,6-*O*-benzylidene-1-thio-D-galactopyranoside (19)[10]



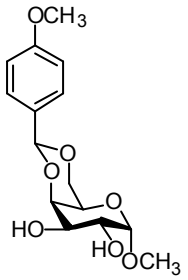
^1H NMR (400MHz, $CDCl_3$) δ 7.64 (d, *J* = 8.0, 2H,), 7.55-7.30 (m, 15H, aromatic Hs), 7.02 (d, *J* = 8.0, 2H), 5.50 (s, 1H, PhCH), 4.75-4.73 (m, 4H, 2 × H_2CPh), 4.60 (d, *J* = 9.2, 1H, HC(1)), 4.38 (d, *J* = 12.4, 1H, $H_{eq}C(6)$), 4.16 (d, *J* = 3.2, 1H, HC(4)), 3.98 (dd, *J* = 12.4, 1H, $H_{ax}C(6)$), 3.87 (t, *J* = 9.2, 1H, HC(2)), 3.63 (dd, *J* = 9.2, 3.2, 1H, HC(3)), 3.39 (bs, 1H, HC(5)), 2.32 (s, 3H, CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.5, 138.1, 137.9, 137.6, 133.4, 129.6, 129.0, 128.6, 128.33, 128.27, 128.11, 128.05, 127.74, 127.73, 127.6, 126.6, 101.2, 86.5, 81.4, 75.34, 75.28, 73.6, 71.7, 69.7, 69.4, 21.1; ESI-MS ($C_{34}H_{34}O_5S$, 554) m/z 577 ($M+Na^+$, 85); mp 129-131 °C.

Methyl-4,6-*O*-benzylidene-α-D–galatopyranoside (20a)[11]



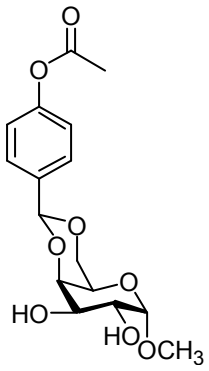
^1H NMR ($CDCl_3$, 400 MHz) δ 7.51-7.49 (m, 2H), 7.39-7.36 (m, 3H), 5.56 (s, 1H, PhCH), 4.93 (d, *J* = 3.2, 1H, HC(1)), 4.29 (dd, *J* = 12.6, 1.4, 1H, $H_{eq}C(6)$), 4.28 (d, *J* = 3.6, 1H, HC(4)), 4.09 (dd, *J* = 12.4, 1.6, 1H, $H_{ax}C(6)$), 3.92-3.87 (m, 2H, HC(2), HC(3)), 3.71 (bs, 1H, HC(5)), 3.47 (s, 3H, OCH_3), 2.09 (bs, 2H, 2 × OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 137.5, 129.0, 128.2, 126.3, 101.3, 100.2, 75.9, 69.9, 69.8, 69.3, 62.7, 55.7; EI-MS (20 eV, $C_{14}H_{18}O_6$) 282 (M^+,12), 251 (7), 179 (19), 162 (8), 133 (22), 107 (100),105(87), 73 (39); $[\alpha]_D^{25}$ -110.20 (*c* 2.0, $CHCl_3$); TLC R_f 0.15 (EtOAc/hexanes, 1/ 2); mp 202-204 °C.

Methyl-4,6-*O*-((4-methoxyphenyl)methylene)-α-D-galatopyranoside (20b)[12]



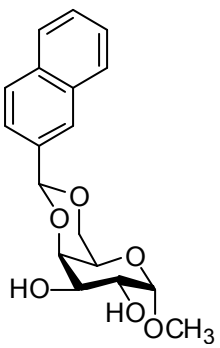
^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.42 (d, *J* = 8.6, 2H), 6.89 (d, *J* = 8.6, 2H,), 5.51 (s, 1H, PhCH), 4.93 (d, *J* = 3.2, 1H, HC(1)), 4.29-4.24 (m, 2H, HC(4), $H_{eq}C(6)$), 4.07 (dd, *J* = 12.6, 1.7, 1H, $H_{ax}C(6)$), 3.92-3.88 (m, 2H, HC(2), HC(3)), 3.81 (s, 3H, $ArOCH_3$) 3.69 (s, 1H, HC(5)), 3.46 (s, 3H, OCH_3), 2.43 (d, *J* = 8.8, 1H, OH), 2.18 (d, *J* = 7.6, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 160.3, 130.1, 127.6, 113.6, 101.2, 100.2, 75.8, 69.9, 69.8, 69.3, 62.7, 55.7, 55.3; EI-MS (70 eV, $C_{15}H_{20}O_7$) 312 (M^+, 24), 137 (63), 136 (62), 135 (100), 121 (25); $[\alpha]_D^{25}$ +122.60 (*c* 1.0, $CHCl_3$); TLC R_f 0.45 ($MeOH/CH_2Cl_2$, 1/ 10); mp 139-140 °C.

Methyl - 4, 6 -*O*- ((4-acetoxyphenyl)methylene)-α-D-galatopyranoside (20c)



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.51 (d, *J* = 8.6, 2H), 7.10 (d, *J* = 8.6, 2H), 5.56 (s, 1H, PhCH), 4.93 (d, *J* = 2.4, 1H, HC(1)), 4.31-4.28 (m, 2H, HC(4), $H_{eq}C(6)$), 4.09 (dd, *J* = 12.6, 1.5, 1H, $H_{ax}C(6)$), 3.91-3.89 (m, 2H, HC(2), HC(3)), 3.71 (s, 1H, HC(5)), 3.47 (s, 3H, OCH_3), 2.33 (d, *J* = 4.6, 1H, OH), 2.29 (s, 3H, $OC(O)CH_3$), 2.09 (d, *J* = 2.5, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 169.3, 151.2, 135.2, 127.5, 121.4, 100.6, 100.2, 75.9, 69.83, 69.75, 69.3, 62.7, 55.7, 21.1; EI-MS (70 eV, $C_{16}H_{20}O_8$) 340 (M^+, 12), 298 (33), 297 (17), 281 (13), 165 (43), 123 (100), 122 (62), 121 (79); $[\alpha]_D^{25}$ +90.24 (*c* 1.0, $CHCl_3$); TLC R_f 0.45 ($MeOH/CH_2Cl_2$, 1/ 10); Anal. calcd for $C_{16}H_{20}O_8$: C, 56.47; H, 5.92. Found: C, 56.22; H, 6.10; mp 227-230 °C.

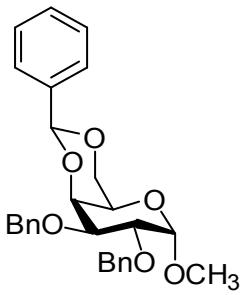
Methyl - 4, 6 -*O*- ((2-naphthyl)methylene)-α-D-galatopyranoside (20d)[13]



^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.97 (s, 1H), 7.87-7.82 (m, 3H), 7.60 (dd, *J* = 8.6, 1.6, 1H), 7.51-7.48 (m, 2H), 5.70 (s, 1H, NpCH), 4.96 (d, *J* =3.3, 1H, HC(1)), 4.35-4.30 (m, 2H, HC(4), $H_{eq}C(6)$), 4.12 (dd, *J* = 12.6, 1.5, 1H, $H_{ax}C(6)$), 3.96-3.90 (m, 2H, HC(2), HC(3)), 3.72 (bs, 1H, HC(5)), 3.47 (s, 3H, OCH_3); ^{13}C NMR

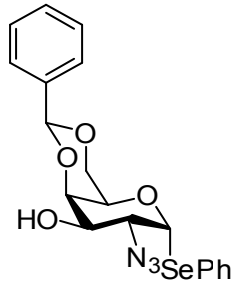
($CDCl_3$, 100 MHz) δ 134.8, 133.8, 132.9, 128.4, 128.1, 127.7, 126.5, 126.2, 125.7, 123.8, 101.4, 100.2, 76.0, 70.0, 69.9, 69.4, 62.8, 55.8; EI-MS (70 eV $C_{18}H_{20}O_6$) 332 (M^+, 29), 157 (36), 156 (86), 155 (77), 141 (16), 129 (24), 128 (35), 127 (59), 101 (13), 87 (15), 86 (24), 85 (18), 74 (73), 73 (51), 71 (43), 69 (16), 61 (35), 60 (100), 57 (48); $[\alpha]_D^{25}$ +99.36 (*c* 1.0, $CHCl_3$); TLC R_f 0.45 (MeOH/CH_2Cl_2, 1/ 10); mp 179-182 °C.

Methyl-2,3-Di-*O*-Benzyl-4,6-*O*-benzylidene-1-α-D-galactopyranoside (21)[15]



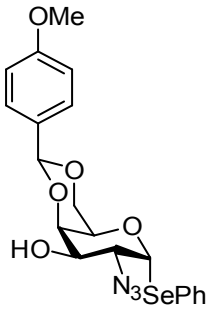
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (dd, *J* = 7.5, 1.5, 2H), 7.42-7.24 (m, 13H, aromatic Hs), 5.48 (s, 1H, PhCH), 4.88 (d, *J* = 12.0, 1H, H_aH_bCPh), 4.83 (d, *J* = 10.0, 1H, H_aH_bCPh), 4.77 (d, *J* = 3.5, 1H, HC(1)), 4.76 (dd, *J* = 10.0, 2H, H_aH_bCPh), 4.68 (d, *J* = 12.0, 1H, H_aH_bCPh), 4.22 (dd, *J* = 12.4, 1.3, 1H, $H_{eq}C(6)$), 4.18 (d, 1H, *J* = 3.1, HC(4)), 4.08 (dd, *J* = 10.1, 3.5, 1H, HC(3)), 3.97-4.02 (m, 2H, HC(2), $H_{ax}C(6)$), 3.59 (bs, 1H, HC(5)), 3.30 (s, 3H, OCH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.8, 138.6, 137.8, 128.8, 128.3, 128.1, 128.0, 127.7, 127.6, 127.5, 126.3, 101.1, 99.5, 76.0, 75.4, 74.8, 73.8, 72.2, 69.4, 62.5, 55.5; FAB-MS ($C_{28}H_{30}O_6$, 462) m/z 463 ($M+H^+$, 26); TLC R_f 0.25 (EtOAc/hexanes, 1/2); mp 132-133 °C.

Phenyl-3-*O*-acetyl-2-azido-4,6-benzylidiene-2-deoxy-1-seleno-D-galactopyranoside (22a)[2]



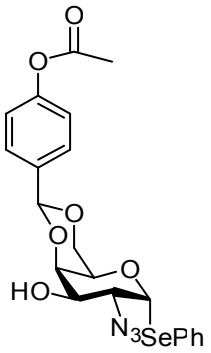
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59-7.57 (m, 2H), 7.51-7.49 (m, 2H), 7.40-7.39 (m, 3H), 7.30-7.26 (m, 3H), 6.03 (d, *J* = 5.2, 1H, HC(1)), 5.60 (s, 1H, PhCH), 4.29 (d, *J* = 3.6, 1H, HC(4)), 4.18-4.12 (m, 3H, HC(2), HC(5), $H_{eq}C(6)$), 4.07 (dd, *J* = 12.8, 2.0, 1H, $H_{ax}C(6)$), 3.92 (dd, *J* = 10.4, 3.6, 1H, HC(3)), 2.41 (bs, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 137.1, 133.7, 129.4, 129.2, 128.9, 128.3, 127.7, 126.2, 101.3, 85.2, 74.9, 70.6, 69.0, 65.0, 61.9; FAB-MS ($C_{19}H_{19}N_3O_4Se$, 432) m/z 433 ($M+H^+$, 11); TLC R_f 0.21(EtOAc/hexanes, 1/3).; mp: 120-122°C.

Phenyl-3-*O*-acetyl-2-azido-4,6-((4-methoxyphenyl)methylene)-2-deoxy-1-seleno-D-galactopyranoside (22b)



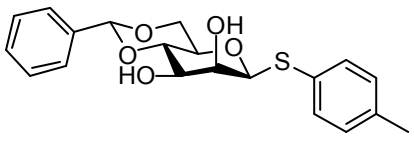
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58-7.56 (m, 2H), 7.41 (d, *J* = 8.5, 2H), 7.28-7.26 (m, 3H), 6.90 (d, *J* = 8.5, 2H), 6.03 (d, *J* = 5.5, 1H, HC(1)), 5.56 (s, 1H, PhCH), 4.30 (d, *J* = 3.5, 1H, HC(4)), 4.17-4.11 (m, 3H, HC(2), HC(5), H_{eq}C(6)), 4.07 (dd, 1H, *J* = 12.8, 1.8, H_{ax}C(6)), 3.94-3.92 (m, 1H, HC(3)), 3.81 (s, 3H, OCH_3), 2.58 (bs, 1H, OH); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 160.4, 133.8, 129.6, 129.2, 128.5, 127.8, 127.6, 113.7, 101.3, 85.2, 74.9, 70.7, 69.1, 65.0, 62.1, 55.3; FAB-MS ($C_{20}H_{21}N_3O_5Se$, 463) m/z 464 ($M+H^+$, 15); $[\alpha]_D^{25}$ +164.5 (*c* 1.0, $CHCl_3$) TLC R_f 0.24 (EtOAc/hexanes, 1/3); High Resolution FAB-MS calcd for $C_{20}H_{21}N_3O_5Se$+H: 464.0718, found: 404.0725; mp 149-151 °C.

Phenyl-3-*O*-acetyl-2-azido-4,6-((4-acetoxyphenyl)methylene)-2-deoxy-α-seleno-D-galactopyranoside (22c)



^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58-7.56 (m, 2H), 7.50 (d, *J* = 9.0, 2H), 7.31-7.26 (m, 3H), 7.11 (d, *J* = 8.6, 2H), 6.03 (d, *J* = 5.0, 1H, HC(1)), 5.59 (s, 1H, PhCH), 4.30 (d, *J* = 3.0, 1H, HC(4)), 4.17-4.11 (m, 3H, HC(2), HC(5), H_{eq}C(6)), 4.07 (dd, 1H, *J* = 12.8, 1.8 Hz, H_{ax}C(6)), 3.94-3.92 (m, 1H, HC(3)), 2.56 (bs, 1Hh, OH), 2.29 (s, 3H, OCH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 169.2, 151.4, 134.8, 133.8, 129.2, 128.5, 127.8, 127.5, 121.5, 100.7, 85.2, 74.9, 70.6, 69.1, 65.09, 62.0, 21.1; FAB-MS ($C_{21}H_{21}N_3O_6Se$, 491) m/z 492 ($M+H^+$, 15); $[\alpha]_D^{25}$ +169.9 (*c* 1.0, $CHCl_3$); TLC R_f 0.24 (EtOAc/hexanes, 1/3); High Resolution FAB-MS calcd for $C_{21}H_{21}N_3O_6Se$+H: 492.0681, found: 492.0674; mp 155-157 °C.

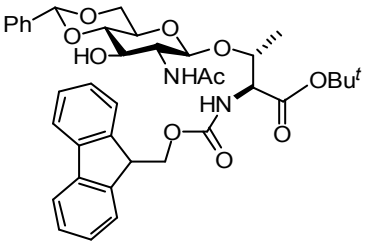
***p*-Methylphenyl 4,6-*O*-benzylidene-1-thio-α-D-mannopyranoside (23)**



^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52-7.50 (m, 2H), 7.41-7.36 (m, 5H), 7.14 (d, *J* = 8.0, 2H), 5.58 (s,1H, PhCH), 5.52 (d, *J* = 1.2, 1H,

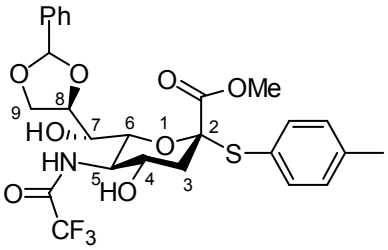
HC(1)), 4.35 (dt, *J* = 10.0, 5.2, 1H, HC(5)), 4.31 (dd, *J* = 3.6, 1.2, 1H, HC(2)), 4.23 (dd, *J* = 10.4, 5.2, 1H, $H_{eq}C(6)$), 4.14 (dd, *J* = 9.6, 3.2, 1H, HC(3)), 4.00 (t, *J* = 9.6, 1H, HC(4)), 3.83 (t, *J* = 10.4, 1H, $H_{ax}C(6)$), 2.62-2.82 (bd, 1H, OH), 2.34 (s, 3H, CH_3), 2.33 (bs, 1H, OH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.1, 137.1, 132.4, 130.0, 129.43, 129.35, 128.4, 126.3, 102.3, 88.3, 79.0, 72.2, 69.1, 68.5, 64.1, 21.1; FAB-MS ($C_{20}H_{22}O_5S$, 374) m/z 375 ($M+H^+$, 27); TLC R_f 0.17 (EtOAc/hexanes, 1/2); High Resolution FAB-MS calcd for $C_{20}H_{22}O_5S$+H: 375.1259, found: 375.1266; mp 189-191 °C.

Fmoc-Thr(4,6-*O*-benzylidene-1-β-GulNAc)-O-*t*-Bu (26)



^{1}H NMR (400 MHz, MeOD) δ 7.71 (d, *J* = 7.5, 2H, Fmoc-HC(4'), HC(5')), 7.61 (dd, *J* = 6.8, 2H, Fmoc-HC(1'), HC(8')), 7.41-7.39 (m, 2H), 7.32-7.21 (m, 7H, Fmoc-HC(2', 3', 6', 7') and aromatic Hs), 6.87 (d, *J* = 8.8, 1H, NH(Thr)), 5.49 (s, 1H, PhCH), 4.50 (s, 1H), 4.44 (d, *J* = 8.3, 1H, HC(1)), 4.32-4.25 (m, 3H, Fmoc-CH_2, ThrHC_β), 4.18-4.14 (m, 2H, Fmoc-HC(9'), HC(3)), 4.04-4.01 (m, 1H, ThrHC_α), 3.70-3.55 (m, 3H, $H_{eq}C(6)$, HC(5), HC(2)), 3.41-3.30 (m, 2H, $H_{ax}C(6)$, HC(4)), 1.90 (s, 3H, $COCH_3$), 1.39 (s, 9H, $C(CH_3)_3$), 1.06 (d, *J* = 6.3, 3H, CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 171.7, 169.2, 156.8, 144.0, 143.8, 141.3, 137.0, 129.2, 128.3, 127.7, 127.1, 126.3, 125.2, 119.9, 101.8, 97.7, 82.2, 81.6, 73.7, 70.3, 68.5, 66.9, 66.1, 58.9, 58.6, 47.2, 28.0, 23.6, 16.4; FAB-MS ($C_{38}H_{44}N_2O_{10}$, 688) m/z 689 ($M+H^+$, 28); $[\alpha]_D^{25}$ –28.1 (*c* 1.0, $CHCl_3$); TLC R_f 0.23 (EtOAc/hexanes, 1/1); High Resolution FAB MS $[M+H]^+$ calcd for $C_{38}H_{44}N_2O_{10}$+H: 689.3066, found: 689.3074; mp 190-192 °C.

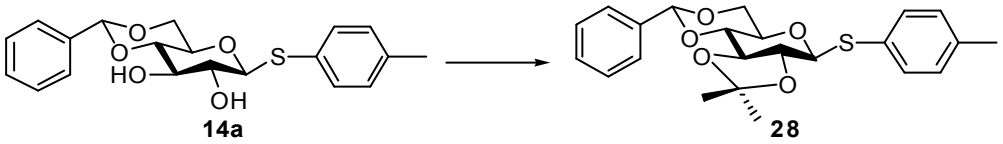
Methyl-(2-(*p*-methylphenyl)-8,9-*O*-benzylidene-3,5-dideoxy-5-trifluoroacetamido-2-thio-D-glycero-α-galacto-2-nonulopyranosid)onate (27)[16]



^{1}H NMR (500 MHz, CD_3OD): Integration of the intensities of PhCH at δ 5.78 (s, 1H) and 5.62 (s, 1H) showed 1:1 mixture of exo/endo isomers; δ 7.44 (d, *J* = 8.0, 2H), 7.38 (dd, *J* = 5.0, 3.0, 1H), 7.33-7.30 (m, 4H), 7.15 (d, *J* = 7.5, 4.0, 2H), 5.81 (s, 0.5H, $PhCH_{exo}$), 5.65 (s, 0.5H, $PhCH_{endo}$), 4.27-4.24 (m, 1H, HC(8)), 4.18 (d, *J* = 8.4. 4.9, 1H, $H_aH_bC(9)$),

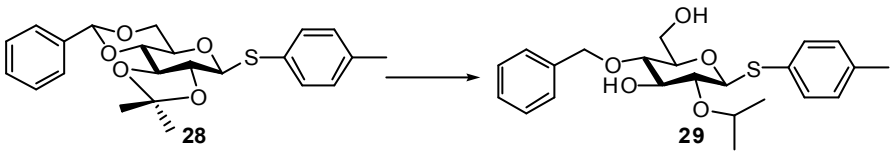
4.08 (d, J = 8.7, 6.3, 1H, $H_aH_bC(9)$), 3.97-3.91 (m, 2H, HC(5), HC(6)), 3.63-3.56 (m, 2.5H, HC(4), 0.5 × HC(7)), 3.48 (d, J = 7.2, 0.5H, 0.5 × HC(7)), 3.43 (s, 1.5H, OCH_3), 3.35 (s, 1.5H, OCH_3), 2.77 (dd, J = 12.7, 4.8, 1H, $H_{eq}C(3)$, 2.35 (s, 3H, $SC_6H_4CH_3$), 1.78 (dd, J = 12.7, 9.0, 1H, $H_aC(3)$); ^{13}C NMR (CD_3OD, 125 MHz) δ (two isomers) 170.6, 170.5, 141.8, 141.7, 140.1, 139.1, 138.2, 138.1, 130.7, 130.6, 130.5, 130.2, 129.39, 129.38, 128.0, 127.7, 127.3, 127.2, 105.6, 105.3, 88.88, 88.85, 77.70, 76.93, 71.0, 70.9, 69.5, 69.1, 68.9, 68.7, 53.8, 53.7, 52.8, 52.7, 42.0, 21.6, 21.5; FAB-MS ($C_{26}H_{28}F_3NO_8S$, 571) m/z 572 ($M+H^+$, 10); TLC R_f 0.23 (EtOAc/hexanes, 1/2); High resolution FAB-MS calcd for $C_{26}H_{28}F_3NO_8S$+H: 572.1557, found: 572.1566.

2,3-Di-*O*-isopropylidene-4-methyl phenyl 4, 6- *O*-benzylidine-1-thio-β-D-glucopyranoside (28)



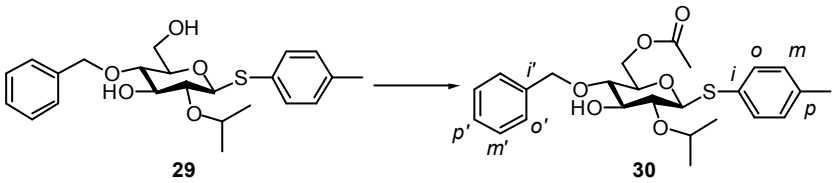
To a solution of **14a** (748 mg, 2 mmol) and D-camphorsulfonic acid (23 mg, 0.1 mmol, 5 mol%) in anhydrous THF (5mL) was added 2-methoxypropene (576 mg, 766 μL, 8 mmol). The mixture was stirred under Ar at ambient temperature for 1.5 hours and then quenched with saturated aqueous $NaHCO_3$ (5 mL) at 0 °. The whole mixture was extracted with EtOAc (3 × 10 mL). The combined organic extracts were dried (Na_2SO_4), filtered, and evaporated. The crude residue was recrystallized from hot diethyl ether (20 mL) to give 780 mg (94%) of **28** as a white solid: ^1H NMR ($CDCl_3$, 400 MHz) δ 7.49-7.47 (m, 3H, aromatic Hs), 7.36-7.33 (m, 2H, aromatic Hs), 7.15 (d, J = 7.9, 2H), 5.55 (s, 1H, PhCH), 4.86 (d, J = 9.8, 1H, HC(1)), 4.40 (dd, J = 10.5, 4.8, 1H, $H_{eq}C(6)$), 3.87 (t, J = 10.4, 1H, HC(4)), 3.84-3.80 (m, 2H, $H_{ax}C(6)$, HC(2)), 3.54-3.47 (m, 1H, HC(3)), 3.31-3.28 (m, 1H, HC(5)), 2.37 (s, 3H, CH_3), 1.50, 1.46 (s, 6H, $C(CH_3)_2$); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.8, 136.7, 134.0, 129.6, 129.1, 128.2, 127.1, 126.3, 111.7 ($C(CH_3)_2$), 101.5 (Ph*C*H), 85.5 (C(1)), 79.9, 78.7, 76.1, 72.0, 68.6 (C(2-6)), 26.6 and 26.4 ($C(CH_3)_2$), 21.2 ($SC_6H_4CH_3$); ESI-MS ($C_{23}H_{26}O_5S$, 415) m/z 438 ($M+Na^+$, 37); TLC R_f 0.15 (EtOAc/hexanes, 1/ 8); Anal. Calcd for $C_{23}H_{26}O_5S$: C, 66.64; H, 6.32. Found: C, 66.38; H, 6.37; mp 176-178 °C.

4-*O*-Benzyl-2-*O*-isopropyl-4-methylphenyl 4,6-*O*-benzylidine-1-thio-β-D-glucopyranoside (29)



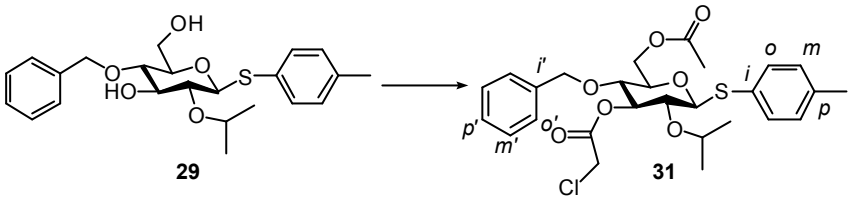
To a solution of **28** (830 mg, 2 mmol) in CH_2Cl_2 (10 mL) under Ar atmosphere at 0 °C was added dropwise a solution of BH_3-THF (1.0 M in THF, 7mL, 7 mmol). The mixture was stirred for 10 minutes and then treated with a solution of dried $VO(OTf)_2$ (250 mg, 0.6 mmol, 0.15 equiv) in CH_2Cl_2. The resulting reaction mixture was gradually warmed to ambient temperature and stirred for 16 hours till the complete consumption of the starting material **28** as judged by TLC analysis. Anhydrous Et_3N (1.0 mL) was then added to the reaction flask at 0 °C followed by slow addition of MeOH (10 equiv) with evolution of H_2. The reaction mixture was co-evaporated two more times with methanol (10 mL). The crude residue was purified by column chromatography on silica gel (EtOAc/hexanes, 5/1) to give the pure diol **29** as a white needle solid (607 mg, 72%) along with recovery of **14a** (16%): ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.38 (d, J = 8.1, 2H), 7.35-7.28 (m, 5H, aromatic Hs), 7.12 (d, J = 8.0, 2H), 4.89 (d, J = 11.3, 1H, H_aH_bCPh), 4.69 (d, J = 11.3, 1H, H_aH_bCPh), 4.54 (d, J = 9.7, 1H, HC(1)), 4.05 (septet, J = 6.1, 1H, HC$(CH_3)_2$), 3.85 (dd, J = 11.7, 2.5, 1H, H_aH_bC(6)), 3.70-3.65 (m, 2H, H_aH_bC(6), HC(3)), 3.48 (t, J = 9.4, 1H, HC(4)), 3.35-3.33 (m, 1H, HC(5)), 3.23 (t, J = 9.2, 1H, HC(2)), 2.60 (d, J = 2.0, 1H, OH), 2.33 (s, 3H, $SC_6H_4CH_3$), 1.97 (t, J = 6.7, 1H, OH), 1.28 (d, J = 6.2, 3H, CHC$(CH_3)_2$), 1.21 (d, J = 6.1, 3H, CHC$(CH_3)_2$); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.1, 136.7, 132.0, 130.0, 129.8, 128.5. 128.0, 127.9, 88.2 (C(1)), 79.1 (C(2)), 78.9 (C(5)), 78.20 (C(4)), 77.1 (C(3)), 74.7 (PhCH_2), 73.8 (O$CH(CH_3)_2$), 62.3 (C(6)), 23.1 and 22.4 (OCH$(CH_3)_2$), 21.1 (CH_3); ESI-MS ($C_{23}H_{30}O_5S$, 418) m/z 441 ($M+Na^+$, 100); $[\alpha]_D^{25}$ -38.8 (*c* 1.0, $CHCl_3$); TLC R_f 0.27 (EtOAc/hexanes, 1/4); Anal. Calcd for $C_{23}H_{30}O_5S$: C, 66.00; H, 7.22. Found: C, 65.62; H, 7.05; mp 66-67 °C.

4-Methylphenyl (6-*O*-acetyl-4-*O*-benzyl-3-*O*-2-*O*-isopropyl)-1-thio-ß-D-glucopyranoside (30)



In a 25-mL, two-necked, round-bottomed flask was charged with $VO(OTf)_2$ (9.2 mg, 0.025 mmol) in anhydrous CH_2Cl_2 (1 mL). To the above catalyst solution, acetic anhydride (56 mg, 52 µL, 0.55 mmol) was added at ambient temperature. After having been stirred for 20 min, the green solution was cooled to 0 °C and treated with a solution of diol-**29** (210 mg, 0.5 mmol) in CH_2Cl_2 (2 mL). After having been stirred for 40 min till complete consumption of **29**, the reaction mixture was then cooled to ambient temperature and quenched with cold saturated aqueous $NaHCO_3$ solution (3 mL). The aqueous layer was separated and extracted with EtOAc (3 × 10mL). The combined organic extracts were dried (Na_2SO_4), filtered, and evaporated. The crude product was purified by chromatography on silica gel (EtOAc/hexane, 1/4) to give 221 mg (yield 96%) of **30** as a white solid:^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.43 (d, *J* = 7.8, 2H), 7.41-7.26 (m, 5H, aromatic Hs), 7.10 (d, *J* = 8.0, 2H), 4.90 (d, *J* = 11.2, 1H, OC*H*$_a$H$_b$Ph), 4.68 (d, *J* = 11.2, 1H, OCH$_a$*H*$_b$Ph), 4.48 (d, *J* = 10.0, 1H, HC(1)), 4.34 (dd, *J* = 11.8, 2.0, 1H, *H*$_a$H$_b$C(6)), 4.21 (dd, *J* = 11.8, 5.6, 1H, H$_a$*H*$_b$C(6)), 4.05 (septet, *J* = 6.1, 1H, *H*C(CH$_3$)$_2$), 3.67 (dt, *J* = 8.4, 2.4, 1H, HC(3)), 3.52-3.42 (m, 1H, HC(5)), 3.36 (dd, *J* = 11.6, 8.4, 1H, HC(4)), 3.25 (t, *J* = 9.2, 1H, HC(2)), 2.56 (d, *J* = 2.4, 1H, OH), 2.33 (s, 3H, OC(O)CH$_3$), 2.04 (s, 3H, SC$_6$H$_4$C*H*$_3$), 1.28 (d, *J* = 6.0, 3H, OCHC(C*H*$_3$)$_2$), 1.20 (d, *J* = 6.0, 3H, OCHC(C*H*$_3$)$_2$); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.7 (*C*(O)CH$_3$), 137.9 (C$_i$), 137.7 (C$_p$), 132.1 (C$_m$), 130.3 (C$_{i'}$), 129.6 (C$_o$), 128.5, 128.1, 128.0 (C$_{p'}$), 88.3 (C(1)), 78.8 (C(2)), 78.5 (C(3)), 76.9 (C(4)), 76.6 (C(5)), 74.6 (OCH$_2$Ph), 73.7 (O*C*H(CH$_3$)$_2$), 63.5 (C(6)), 23.2 (OC(O)*C*H$_3$), 22.3 (SC$_6$H$_4$*C*H$_3$), 21.1 (OCH(*C*H$_3$)$_2$), 20.8 (OCH(*C*H$_3$)$_2$); ESI-MS ($C_{25}H_{32}O_6S$, 460) m/z 483 (M+Na$^+$, 100);$[\alpha]_D^{25}$ -32.6 (*c* 1.0, $CHCl_3$); TLC R_f 0.35 (EtOAc/hexanes, 1/4); Anal. Calcd for $C_{25}H_{32}O_6S$: C, 65.19; H, 7.00. Found: C, 65.25; H, 6.70; mp 99-101 °C.

4-Methylphenyl (6-*O*-acetyl-4-*O*-benzyl-3-*O*-(2-chloro)acetyl-2-*O*-isopropyl)-1-thio-ß-D-gluco-pyranoside (31)



In a 25-mL, two-necked, round-bottomed flask was charged with $VO(OTf)_2$ (18.5 mg, 0.05 mmol) in anhydrous CH_2Cl_2 (2 mL). To the above catalyst solution, acetic anhydride (112 mg, 104 µL, 1.1 mmol) was added at ambient temperature. After having been stirred for 20 min, the green solution was cooled to 0 °C and treated with a solution of diol-**29** (419 mg, 1 mmol) in CH_2Cl_2 (3 mL). After having been stirred for 40 min till complete consumption of **29**, the reaction mixture was further treated with a solution of chloroacetic anhydride (257 mg, 1.5 mmol) in CH_2Cl_2 (1 mL). The resulting reaction mixture was warmed to 40 °C and stirred for 8 hours with complete disappearance of the 4-methylphenyl (6-*O*-acetyl-4-*O*-benzyl-3-*O*-2-*O*-isopropyl)-1-thio-ß-D-glucopyranoside. The reaction mixture was then cooled to ambient temperature and quenched with cold saturated aqueous $NaHCO_3$ solution (3 mL). The aqueous layer was separated and extracted with EtOAc (3 × 10mL). The combined organic extracts were dried (Na_2SO_4), filtered, and evaporated. The crude product was purified by chromatography on silica gel (EtOAc/hexane, 1/8) to give 472 mg (88 %) of **31** as a colorless oil: ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.42 (d, *J* = 8.1, 2H), 7.35 (d, *J* = 6.9, 2H), 7.32 (t, *J* = 6.9, 1H), 7.25 (t, *J* = 6.9, 2H), 7.11 (d, *J* = 8.0, 2H), 5.20 (t, *J* = 8.8, 1H, HC(3)), 4.58-4.53 (m, 3H, HC(1), OCH_2Ph), 4.35 (dd, *J* = 12.0, 1.7, 1H, $H_aH_bC(6)$), 4.20 (dd, *J* = 11.9 , 4.9, 1H, $H_aH_bC(6)$), 3.94-3.88 (m, 1H, $HC(CH_3)_2$), 3.93 (d, *J* = 14.9, 1H, ClH_aH_bC), 3.85 (d, *J* = 14.9, 1H, ClH_aH_bC), 3.59-3.53 (m, 2H, HC(5), HC(4)), 3.36 (t, *J* = 9.4, 1H, HC(2)), 2.34 (s, 3H, $C(O)CH_3$), 2.07 (s, 3H, $SC_6H_4CH_3$), 1.23 (d, *J* = 6.2, 3H, $OCHC(CH_3)_2$), 1.05 (d, *J* = 6.1, 3H, $OCHC(CH_3)_2$); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.5 ($C(O)CH_3$), 166.0 ($C(O)CH_2Cl$) 138.0 (C_i), 137.2 (C_p), 132.5 (C_m), 129.8 ($C_{i'}$), 129.6 (C_o), 128.6 ($C_{o'}$), 128.2 ($C_{p'}$), 128.0 ($C_{m'}$), 88.8 (C(1)), 79.0 (C(3)), 76.9 (C(2)), 76.6 (C(4)), 76.1 (C(5)), 74.6 ($PhCH_2$), 74.0 ($OCH(CH_3)_2$), 63.0 (C(6)),

40.7 (CH_2Cl), 23.0 ($OCH(CH_3)_2$), 22.1 ($OCH(CH_3)_2$), 21.1 ($C(O)CH_3$), 20.8 ($SC_6H_4CH_3$); ESI-MS ($C_{27}H_{33}ClO_7S$, 537) m/z 561 ($M+Na^+$, 9); $[\alpha]_D^{25}$ -29.2 (*c* 1.0, $CHCl_3$); TLC R_f 0.20 (EtOAc/hexanes, 1/ 4); Anal. Calcd for $C_{27}H_{33}ClO_7S$: C, 60.38; H, 6.19. Found: C, 60.75; H, 6.06.

References:

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