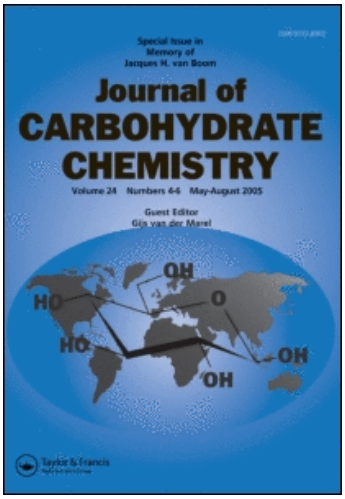

Journal of Carbohydrate Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713617200

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To cite this Article Knapp, Spencer , Naughton, Andrew B. J. , Kukkola, Paivi J. and Shieh, Wen-Chung(1991) 'Mono-Triflation of Carbohydrate Diols and Triols', Journal of Carbohydrate Chemistry, 10: 6, 981 — 993
To link to this Article: DOI: 10.1080/07328309108543967
URL: http://dx.doi.org/10.1080/07328309108543967

J. CARBOHYDRATE CHEMISTRY, 10(6), 981-993 (1991)

MONO-TRIFLATION OF CARBOHYDRATE DIOLS AND TRIOLS

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February 25, 1991 - Final form August 29, 1991

ABSTRACT

For five carbohydrate substrates [methyl 4,6-*O*-(phenylmethylene)-1-thio-α-D-glucopyranoside **1a**, 1-cyano-1-deoxy-4,6-*O*-(phenylmethylene)-α-D-galactopyranose **2a**, methyl α-D-xylopyranoside **3a**, methyl β-D-arabinopyranoside **4a**, and methyl 5-*O*-(*tert*-butyldiphenylsilyl)-α-D-ribofuranoside **5a**], selective mono-triflation was achieved where the reacting hydroxyl is *cis* and vicinal to a heteroatom.

INTRODUCTION

Carbohydrate trifluoromethanesulfonates (triflates) are useful intermediates for the preparation of anhydro, amino, cyano, halo, thio, unsaturated, and deoxy sugars.[1] They are generally described as unstable, prone to rearrangement, or difficult to isolate.[1-3] While selective *p*-toluenesulfonylation of carbohydrate diols and triols has been well studied,[4] much less is known about selective mono-triflation, or the properties of diol and triol mono-triflates.[3,5,6] In conjunction with our interest in the synthesis of amino sugars by benzoylcarbamate *N*-cyclization,[5,6] we have employed a procedure for selective mono-triflation of carbohydrate diols and triols exploiting the greater reactivity of secondary hydroxyls that are flanked by a cis, vicinal heteroatom (ether oxygen or thioether sulfur). We report here the application to five substrates (**1a - 5a**), and the isolation and characterization of the products (Tables I and II).

Table I. Selective Triflation of Carbohydrate Diols and Triols

Starting Material	Product(s)	Yield[a] (%)	mp (°C)[b]	IR (solv.) ν (cm^{-1})	CI-MS (70 ev)[c] *m/z*	[α] ($CHCl_3$)[d] (°), conc.
1a			142-144	(CCl_4) 3391, 3330	299 $(M+1)^+$, 281, 251, 193	+193.2, 1.11 (MeOH)
	1b	57	105.5-107	(CCl_4) 3608, 1417	431 $(M+1)^+$	+157.0, 0.87
	1c	9	102-103	(CCl_4) 3726, 3629, 1412	431 $(M+1)^+$	+22.1, 0.29
	1d	29	92.5-94	($CHCl_3$) 1430	563 $(M+1)^+$	+98.4, 1.00
	1a	5 (recovered)				
2a			205	($CHCl_3$) 3404, 3375, 1602	278 $(M+1)^+$, 251, 172	+37.1, 1.00 (MeOH)
	2b	75	105-107	($CHCl_3$) 3677, 1602	410 $(M+1)^+$, 383, 332, 260, 154	+63.1, 1.10 (MeOH)
	2a	trace				
3a						
	3b	37	84.5-85 (dec)	($CHCl_3$) 3604, 3379, 1415	297 $(M+1)^+$	+93.5, 1.00
	6a	6	oil[e]	(film) 1418	279 $(M+1)^+$	+77.4, 0.80
	3c	6	100-101 (dec)	($CHCl_3$) 3605, 3338, 1422	429 $(M+1)^+$	+73.3, 0.60
	3a	48 (recovered)				
4a						
	4b	48	103-104 (dec)	(CCl_4) 3367, 1405	297 $(M+1)^+$	-95.8, 1.10

	4c	12	105-106 (dec)	($CHCl_3$) 3560, 3349, 1415	297 $(M+1)^+$	-91, 1.10
	4d	13	oil	(CCl_4) 3611, 3467, 1425	429 $(M+1)^+$	-122.7, 0.83
	4a	25 (recovered)				
5a			oil[e]	($CHCl_3$) 3660, 3545	371 (M+1-MeOH)$^+$, 353, 293	+59.5, 0.84
	5b	47	oil	(CCl_4) 3550, 2900, 1420, 1220, 1100, 1000	534 (M^+) (FAB-MS)	+50.6, 1.00
	5c	26	oil	(CCl_4) 2900, 1420, 1220, 1150	635 (M+1-MeOH)$^+$, 589, 517, 485, 439, 391, 335	+74.4, 1.00
	5a	26 (recovered)				
	5d	quant.	oil	(CCl_4) 1743, 1740 (sh)		+67.8, 1.17

[a] Yield of isolated product based on starting material.

[b] Satisfactory microanalysis obtained (± 0.04) unless otherwise noted. See Table IV.

[c] Spectrum of **5b** was obtained using FAB-MS.

[d] Recorded in chloroform solution except as noted.

[e] Did not give satisfactory elemental analysis.

Table II. NMR Spectra

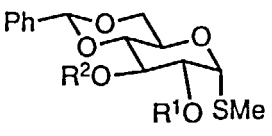
Compound	^{1}H NMR (400-MHz/$CDCl_3$/TMS) d, J (Hz)
1 a	2.19 (s, SCH_3), 2.38 (br s, OH), 2.62 (br s, OH), 3.50 (app t, J = 9.3, 6-H), 3.77 (app t, J = 10.3, 4-H), 3.81 (app t, J = 9.3, 3-H), 3.92 (dd, J = 9.3, 5.7, 2-H), 4.17 (td, J = 9.8, 5.1, 5-H), 4.28 (dd, J = 10.3, 4.9, 6'-H), 5.29 (d, J = 5.4, 1-H), 5.52 (s, Ph-CH), 7.33 - 7.48 (m, 5 H_{arom})
1 b	2.17 (s, SCH_3), 2.74 (d, J = 3.3, 3-OH), 3.55 (app t, J = 9.3, 4-H), 3.78 (app t, J = 9.6, 6-H), 4.14 (td, J = 9.3, 3.18, 3-H), 4.23 (dd, J = 9.9, 5-H), 4.28 - 4.32 (m, 6'-H), 4.92 (dd, J = 9.5, 5.8, 2-H), 5.46 (d, J = 5.8, 1-H), 5.54 (s, Ph-CH), 7.39 - 7.41 (m, 3 H_{arom}), 7.48 - 7.50 (m, 2 H_{arom})
1 c	2.26 (s, SCH_3), 2.39 (d, J = 10.1, 2-OH), 3.75 (app t, J = 9.5, 4-H), 3.83 (app t, J = 10.1, 6-H), 4.12 (dt, J = 10.1, 6.3, 2-H), 4.21 (dt, J = 9.7, 4.8, 5-H), 4.35 (dd, J = 10.2, 4.9, 6'-H), 4.83 (t, J = 9.5, 3-H), 5.37 (d, J = 5.5, 1-H), 5.57 (s, Ph-CH), 7.36 - 7.38 (m, 3 H_{arom}), 7.46 - 7.48 (m, 2 H_{arom})
1 d	2.20 (s, SCH_3), 3.80 - 3.86 (m, 4-H and 6-H), 4.31 - 4.38 (m, 5-H and 6'-H), 5.08 (dd, J = 9.5, 5.8, 2-H), 5.19 (app t, J = 9.6, 3-H), 5.60 (s, Ph-CH), 5.63 (d, J = 5.6, 1-H),7.37 - 7.40 (m, 3 H_{arom}), 7.48 - 7.50 (m, 2 H_{arom})
2 a	2.51 (d, J = 10, 3-OH), 2.75 (s, 2-OH), 3.52 (s, 5-H), 3.52 - 3.62 (m, 3-H), 4.02 - 4.08 (m, 2-H, 6-H and 6'-H), 4.25 (d, J = 3.4, 4-H), 4.43 (d, J = 12.8, 1-H), 5.52 (s, Ph-CH), 7.25 - 7.45 (m, 5 H_{arom})
2 b	3.42 (d, J = 5.6, 2-OH), 3.55 (d, J = 1.1, 5-H), 4.05 (dd, J = 12.9, 1.7, 6- H), 4.17 (d, J = 9.7, 1-H), 4.36 (dd, J = 12.9, 1.7, 6'-H), 4.40 - 4.45 (m, 2-H), 4.48 (dd, J = 3.7, 0.9, 4-H), 4.76 (dd, J = 9.5, 3.7, 3-H), 5.55 (s, Ph-CH), 7.35 - 7.50 (m, 5 H_{arom})
3 b	2.88 (br s, OH), 3.27 (br s, OH), 3.44 (s, OCH_3), 3.54 (app t, J = 12.7, 5-H), 3.70 - 3.77 (m, 4-H and 5'-H), 4.00 (dd, J = 9.6, 8.3, 3-H), 4.58 (dd, J = 9.6, 3.7, 2-H), 4.89 (d, J = 3.6, 1-H)

6a	3.34 (dd, J = 3.9, 1.7, 4-H), 3.43 (d, J = 3.9, 3-H), 3.50 (s, OCH_3), 4.00 (d, J = 13.4, 5-H), 4.06 (dd, J = 13.5, 1.7, 5'-H), 4.73 (d, J = 3.7, 2-H), 4.88 (d, J = 3.7, 1-H)
3c	2.49 (d, J = 6.6, 4-OH), 3.47 (s, OCH_3), 3.63 (app t, J = 10.9, 5-H), 3.85 (dd, J = 11.5, 6.1, 5'-H), 3.99 (ddd, J = 10.6, 9.0, 6.1, 4-H), 4.72 (dd, J = 9.7, 3.6, 2-H), 5.06 (d, J = 3.4, 1-H), 5.11 (app t, J = 9.5, 3-H)
4b	2.48 (br s, 3-OH and 4-OH), 3.43 (s, OCH_3), 3.73 (dd, J = 12.8, 1.9, 5-H), 3.85 (dd, J = 12.8, 1.6, 5'-H), 4.09 (app dd, J = 3.4, 1.7, 4-H), 4.14 (dd, J = 9.3, 3.7, 3-H), 4.90 - 4.95 (m, 1-H and 2-H)
4c	2.44, (d, J = 2.4, 4-OH), 2.58 (d, J = 7.3, 2-OH), 3.45 (s, OCH_3), 3.75 (dd, J = 12.8, 1.8, 5-H), 3.87 (dd, J = 12.7, 1.0, 5'-H), 4.10 (app d, J = 1.6, 4-H), 4.13 - 4.18 (m, 2-H), 4.94 (dd, J = 9.3, 3.7, 3-H), 4.96 (d, J = 3.5, 1-H)
4d	2.74 (d, J = 4.0, 4-OH), 3.48 (s, OCH_3), 3.80 (dd, J = 12.9, 2.1, 5-H_{eq}), 3.92 (dd, J = 12.9, 1.0, 5-H_{ax}), 4.41 (br s, 4-H), 5.11 (d, J = 2.3, 2-H), 5.21 (d, J = 2.6, 1-H), 5.22 (s, 3-H)
5a	1.05 (s, t-C_4H_9), 2.47 (d, J = 8.2, 3-OH), 2.82 (d, J = 9.5, 2-OH), 3.47 (s, OCH_3), 3.74 (dd, J = 1.3, 3.3, 4-H and 5-H), 4.05 - 4.12 (m, 3-H and 5'-H), 4.20 (s, 2-H), 4.93 (d, J = 4.5, 1-H), 7.3 - 7.7 (m, 10 H_{arom})
5b	1.05 (s, t-C_4H_9), 2.91 (d, J = 11.5, 3-OH), 3.50 (s, OCH_3), 3.75 (d, J = 1.5, 5-H and 5'-H), 4.20 (s, 4-H), 4.37 (dd, J = 5.2, 11.6, 3-H), 5.12 - 5.18 (m, 1-H, 2-H), 7.3 - 7.7 (m, 10 H_{arom})
5c	1.05 (s, t-C_4H_9), 3.50 (s, OCH_3), 3.81 (dd, J = 1.9, 5.9, 5-H and 5'-H), 4.42 (d, J = 1.7, 4-H), 5.13 (t, J = 6.1, 2-H), 5.16 (d, J = 6.3, 1-H), 5.36 (d, J = 6.2, 3-H), 7.35 - 7.70 (m, 10 H_{arom})
5d	1.06 (s, t-C_4H_9), 2.13 (s, AcO), 2.15 (s, AcO), 3.45 (s, OCH_3), 3.80 (dd, J= 11.2, 2.9, 5-H), 3.88 (dd, 1H, J = 11.2, 2.9, 5'-H), 4.15 (dd, J = 5.9, 2.9, 4-H), 5.12 - 5.16 (m, 1-H and 2-H), 5.43 (dd, J = 6.6, 2.9, 3-H), 7.3-7.7 (m, 10 H_{arom})

RESULTS AND DISCUSSION

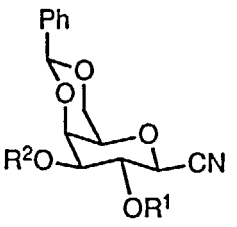
Carbohydrate diols and triols undergo triflation with slightly more than 1 equiv of trifluoromethanesulfonic anhydride in dichloromethane / pyridine solution at -20 °C. The triflate products are described in Table I. Isolated yields are given, hence the ratios of mono-triflates do not accurately convey the kinetic selectivity. Nevertheless, some interesting trends are apparent, as discussed below. For one example, **1a**, additional triflic anhydride slightly improved the isolated yield of the monotriflates. For the other substrates, however, additional triflic anhydride led to the formation of increased amounts of di-triflate, even with remaining starting material. Thus in general, triflation of one hydroxyl in a vicinal diol does not seem to greatly diminish the reactivity of the other. As a result, the reactions were not run to completion. Two equiv of pyridine are normally adequate unless more is needed to dissolve the substrate. A typical procedure is given in the Experimental section, and variations on the typical procedure are listed in Table III.

Methyl 4,6-*O*-(phenylmethylene)-1-thio-α-D-glucopyranoside (**1a**) showed roughly 6:1 selectivity for the C-2 hydroxyl, a result that parallels the triflation[5,6] of the parent pyranoside (no sulfur, >20:1 C-2 hydroxyl selectivity), the larger size of the sulfur atom notwithstanding. The mono-triflates **1b** and **1c** were independently shown to be stable to the reaction conditions. The role of the sulfur atom in directing nearby triflation may be to "trap" by proton exchange,[4,7] or promote by hydrogen bonding,[4] the formation of the initial hydroxyl-derived *O*-sulfonyl-oxonium ion. Alternatively, the selectivity may reflect a lone pair - lone pair repulsive interaction[8] with the hydroxyl group. Delivery[9,10] of the electrophile [*N*-(trifluoromethanesulfonyl)-pyridinium[1]] by the sulfur atom is another possibility. Hydrogen bonding of an alcohol to thioether sulfur, although significant, is typically 1.0-1.6 kcal/mol weaker (for the intermolecular case) than the corresponding hydrogen bond to an ether oxygen.[11]



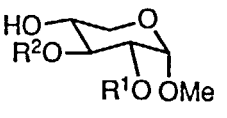
1

a: $R^1 = R^2 = H$
b: $R^1 = Tf, R^2 = H$
c: $R^1 = H, R^2 = Tf$
d: $R^1 = R^2 = Tf$



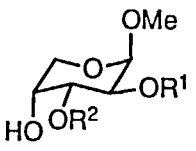
2

a: $R^1 = R^2 = H$
b: $R^1 = H, R^2 = Tf$



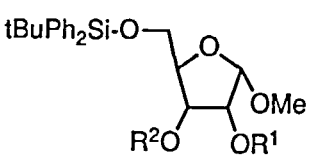
3

a: $R^1 = R^2 = H$
b: $R^1 = Tf, R^2 = H$
c: $R^1 = R^2 = Tf$



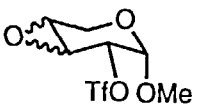
4

a: $R^1 = R^2 = H$
b: $R^1 = Tf, R^2 = H$
c: $R^1 = H, R^2 = Tf$
d: $R^1 = R^2 = Tf$



5

a: $R^1 = R^2 = H$
b: $R^1 = Tf, R^2 = H$
c: $R^1 = R^2 = Tf$
d: $R^1 = R^2 = Ac$



6

a: *arabino* epoxide
b: *ribo* epoxide

Triflation of the galactopyranosyl cyanide **2a** shows the same high preference for the galactose C-3 hydroxyl demonstrated in other studies.[1,6] Presumably the nearby ether oxygen at C-4 is responsible for the selectivity (> 20:1). The examples **1a** and **2a**, along with previous results,[5,6] confirm that selectivity in triflation of pyranoside diols is not simply a function of the acidity or steric environment of the reacting hydroxyl, nor due any special property of the anomeric center.[12]

The xylopyranoside and arabinopyranoside triols (**3a** and **4a**, respectively) exhibit good selectivity for mono-triflation at the C-2 hydroxyl, with significant quantities of recovered starting material. Analogous selectivity has been observed for tosylation of these same substrates.[13,14] A small amount of an epoxy 2-triflate was isolated from triflation of **3a**, according to its IR spectrum (no -OH), NMR spectrum (2-H at δ 4.73), and mass spectrum (molecular weight 278). Its structure was assigned as methyl 3,4-anhydro-2-*O*-trifluoromethanesulfonyl-α-L-arabinopyranoside (**6a**) based on the absence of the 2,4-ditriflate from the reaction mixture, and on the independent conversion of the 2,3-ditriflate **3c** to an isomeric epoxy 2-triflate, methyl 3,4-anhydro-2-*O*-trifluoromethanesulfonyl-α-D-ribopyranoside (**6b**), using tetra-*n*-butylammonium fluoride in benzene solution (see Experimental section). Ditriflate **3c** was also shown to be stable to the triflation conditions. Satisfactory elemental analysis could not be obtained for either epoxy triflate. Interestingly, **6a** is the only epoxide isolated from a pyridine-promoted carbohydrate triflation reaction in this or previous work[5,6] from our laboratory.

The α-D-ribofuranoside **5a** showed selective triflation at the C-2 hydroxyl. Selective C-2 tosylation of a related α-D-ribofuranoside using activation with dibutyltin oxide has been reported.[15] Since fluoride-promoted trifluoromethanesulfonyl migration has been observed in a ribofuranoside,[16] the 2-*O*-triflate **5b** was resubjected to the reaction

conditions and shown to be stable. In this furanoside example, the *cis*, vicinal ether oxygen apparently promotes the triflation of the nearby hydroxyl in the same way that has been observed for the pyranoside examples.

To summarize, several stable, well-characterized carbohydrate mono-triflates have been prepared, and are available for study of their reactions with bases and nucleophiles.

EXPERIMENTAL

Apparatus and Reagents. Melting points were determined in sealed evacuated capillary tubes using an Electrothermal apparatus, and are uncorrected. Infrared spectra were recorded using a Mattson Instruments Expert FT-IR spectrometer. Proton nuclear magnetic resonance spectra were obtained with a Varian Associates XL-400 instrument. Elemental analyses were obtained from Robertson Laboratories, Madison, New Jersey. Specific rotations [α] were determined on a Perkin-Elmer model 141 polarimeter at the sodium D line at 23 °C. Desorption chemical ionization mass spectra (CI-MS) were obtained on a Finnegan model MAT 8230 spectrometer at 70 eV using isobutane as the reagent gas. The fast atom bombardment mass spectrum (FAB-MS) of **5b** was recorded at 70 eV on a VG 7070 EQ spectrometer with dithiothreitol / dithioerythritol matrix. Reaction temperatures below 0 °C were maintained using a Neslab model cc-100 II immersion cooler. Dichloromethane and pyridine were distilled from calcium hydride. Commercial trifluoromethanesulfonic anhydride was stored at -10 °C in 1.5-mL vials under argon in reaction size portions. Methyl D-xylopyranoside (78% α-anomer and 18% β-anomer) was purchased from Sigma Chemical Company, and the α-anomer (**3a**) was purified through its tri-*O*-acetyl derivative.[17] Methyl α-D-ribofuranoside was purchased from Sigma Chemical Company and converted to its 5-*O*-*tert*-butyldiphenylsilyl ether **5a** (70%) by a literature method.[18] While satisfactory elemental analysis could not be obtained for **5a**, its 2,3-di-*O*-acetyl derivative **5d** analyzed correctly. Methyl 1-thio-α-D-glucopyranoside was prepared from D-glucose by the method of Pacsu,[19] then converted to its 4,6-*O*-benzylidene derivative **1a** by a standard procedure.[20] 1-Cyano-1-deoxy-2,3,4,6-*O*-tetraacetyl-β-D-galactopyranose was synthesized from D-galactose pentaacetate according to de las Heras,[21] then deacetylated[22] and converted[20] to its 4,6-*O*-benzylidene derivative **2a**. Methyl β-D-arabinopyranoside **3a** and all other reagents were purchased from Aldrich Chemical Company and used as received unless otherwise specified above. The purified

Table III. Chromatography Conditions and Variations on Typical Procedure

St. mat.	Eluants (order of product elution)	Variations on typical procedure
1a	1:9 ether/petr. ether (**2a**, **4a**, **3a**)	Initial 1.4 equiv of Tf_2O, then 3 aliquots of 0.1 equiv; 3.5 equiv of pyridine
1b	1:1 ethyl acetate/*n*-hexane (**2b**)	
1c	1:6 ether/petr. ether (**3c**, **4c**, **2c**) 2:1 ether/petr. ether (**1c**)	2 equiv of pyridine
1d	1:3 ether/petr. ether (**4d**, mix of **3d** and **2d**) 2:1 ether/petr. ether (**1d**)	120 equiv of pyridine was used for solubility; **2d** crystallized using dichloromethane/petr. ether
1e	1:7 ether/petr. ether (**4e**, **2e**) 2:1 ether/petr. ether (**1e**)	2 equiv of pyridine

Table IV. Elemental Analyses of Products

Compound	Formula		C	H	N
1a	$C_{14}H_{18}O_5S \cdot 1/4H_2O$	calcd:	55.52	6.16	
		found:	55.53	6.10	
1b	$C_{15}H_{17}F_3O_7S_2$	calcd:	41.86	3.98	
		found:	42.00	4.03	
1c	$C_{15}H_{17}F_3O_7S_2$	calcd:	41.86	3.98	
		found:	42.16	3.90	
1d	$C_{16}H_{16}F_6O_9S_3$	calcd:	34.16	2.87	
		found:	34.03	2.87	
2a	$C_{14}H_{15}NO_5 \cdot H_2O$	calcd:	56.95	5.80	4.74
		found:	57.04	5.75	4.63
2b	$C_{15}H_{14}F_3NO_7S$	calcd:	44.01	3.45	3.42
		found:	43.99	3.66	3.10
3b	$C_7H_{11}F_3O_7S$	calcd:	28.38	3.74	
		found:	28.69	3.51	
3c	$C_8H_{10}F_6O_9S_2$	calcd:	22.44	2.35	
		found:	22.73	2.27	
4b	$C_7H_{11}F_3O_7S$	calcd:	28.38	3.74	
		found:	28.68	3.57	
4c	$C_7H_{11}F_3O_7S$	calcd:	28.38	3.74	
		found:	28.53	3.54	
4d	$C_8H_{10}F_6O_9S_2$	calcd:	22.44	2.35	
		found:	22.82	2.34	
5b	$C_{23}H_{29}F_3O_7Si$	calcd:	51.67	5.47	
		found:	51.32	5.40	
5c	$C_{24}H_{28}F_6O_9Si$	calcd:	43.24	4.23	
		found:	43.39	4.25	
5d	$C_{26}H_{34}O_7Si$	calcd:	64.17	7.04	
		found:	63.88	6.72	

carbohydrate triflate products are generally sensitive to prolonged handling but can be stored for months at -5 °C. Precoated silica gel plates (Baker Si250F) were used for analytical thin-layer chromatography (TLC). Machery Nagel silica gel 60 (230-400 mesh) was employed for column chromatography. Organic solutions were dried over anhydrous magnesium sulfate, and all reactions were run under an atmosphere of argon.

Typical Procedure: 1-Cyano-1-deoxy-4,6-*O*-(phenylmethylene)-3-*O*-trifluoromethanesulfonyl-β-D-galactopyranose (2b). A solution of 1-cyano-1-deoxy-4,6-*O*-(phenylmethylene)-β-D-galactopyranose (**2a**, 693 mg, 2.5 mmol) in pyridine (2 mL, 25 mmol) and dichloromethane (50 mL) was stirred and cooled to -20 °C. Trifluoromethanesulfonic anhydride (0.485 mL, 2.88 mmol) was added all at once. The reaction was stirred at -20 °C for 1 h, then 0 °C for 2 h. The reaction was quenched by adding water (20 mL), then slowly warming to room temperature. The organic phase was washed with additional water (2 x 20 mL), dried, and concentrated to a residue (970 mg). Chromatography on silica (20 g) gave analytically pure **2b** (770 mg, 75% yield). Spectra are listed in Tables I and II. For chromatography conditions and variations on the typical procedure see Table III. For elemental analyses see Table IV.

Methyl 3,4-Anhydro-2-*O*-trifluoromethanesulfonyl-α-D-ribopyranoside (6b): A solution of tetra-*n*-butylammonium fluoride (11.0 mg, 0.042 mmol) in benzene (0.1 mL) was added to a solution of 2,3-ditriflate **3c** (9.0 mg, 0.021 mmol) in dry benzene (1 mL). After 2 h TLC analysis indicated consumption of **3c** and the emergence of a single spot. The reaction mixture was concentrated under reduced pressure and chromatographed directly on 1 g of silica using 1:1 petroleum ether/ ether as the eluant; yield 4.2 mg (72%); mp 73-74 °C (dec); MS (DCI): *m/z* = 279 (M + 1), 261 (-H_2O), 247 (-CH_3OH), 129 (-CF_3SO_3H); IR (film): ν = 1407 cm^{-1}; ^{1}H-NMR ($CDCl_3$): δ = 3.47 (s, 3 H, OCH_3), 3.53 (br s, 2 H, 3-H and 4-H), 3.93 (ddd, 1 H, *J* = 13.43, 1.41, 1.38, 5-H), 4.12 (d, 1 H, *J* = 13.50, 5'-H), 4.71 (d,1 H, J = 4.34, 1-H), 5.11 (dd, 1 H, *J* = 4.02, 2.44, 2-H).

ACKNOWLEDGMENT

We are grateful to the Charles and Johanna Busch Memorial Fund for financial support, to Lever Bothers, Johnson and Johnson, and Ciba-Geigy for fellowship assistance, and to NSF (CHEM-8300444) and NIH (1510 RR0148601A) for support of instrumentation.

REFERENCES

1. R. W. Binkley and M. G. Ambrose, *J. Carbohydr. Chem.*, **3**, 1 (1984).
2. R. W. Binkley and M. A. Abdulaziz, *J. Org. Chem.*, **52**, 4713 (1987).
3. G. J. Englebrecht, C. W. Holzapfel, and G. H. Verdoorn, *S. Afr. J. Chem.*, **42**, 123 (1989).
4. A. H. Haines, *Adv. Carbohydr. Chem. Biochem.*, **33**, 11 (1976).
5. S. Knapp, P. J. Kukkola, S. Sharma, and S. Pietranico, *Tetrahedron Lett.*, **28**, 5399 (1987).
6. S. Knapp, P. J. Kukkola, S. Sharma, T. G. Murali Dhar, and A. B. J. Naughton, *J. Org. Chem.*, **55**, 5700 (1990).
7. W. P. Jencks, *Acc. Chem. Res.*, **9**, 425 (1976).
8. V. G. S. Box, *Heterocycles*, **20**, 677 (1983).
9. J. M. Knoblich, J. Sugihara, and T. Yamazaki, *J. Org. Chem.*, **36**, 3407 (1971).
10. A. R. Chamberlin, R. L. Mulholland, S. D. Kahn, and W. J. Hehre, *J. Am. Chem. Soc.*, **109**, 672 (1987).
11. V. K. Pogorelyi, *Russ. Chem. Rev.*, **46**, 316 (1977).
12. M. Dejter-Juszynski and H. M. Flowers, *Carbohydr. Res.*, **28**, 61 (1973).
13. Y. Kondo, *Carbohydr. Res.*, **110**, 339 (1982).
14. Y. Kondo, *Carbohydr. Res.*, **162**, 159 (1987).
15. M. Kawana, T. Koresawa, and H. Kuzuhara, *Bull. Chem. Soc. Jpn.*, **56**, 1095 (1983).
16. B. Nawrot, K. W. Pankiewicz, R. A. Zepf, and K. A. Watanabe, *J. Carbohydr. Chem.*, **7**, 95 (1988).
17. R. L. Whistler, K. A. Kimmel, and D. F. Durso, *J. Am. Chem. Soc.*, **73**, 3530 (1951).
18. T. W. Hart, D. A. Metcalfe, and F. Scheinmann, *J. Chem. Soc., Chem. Comm.*, 156 (1979).
19. E. Pacsu, *Methods Carbohydr. Chem., Vol. II*, 354 (1963).

20. H. G. Fletcher, Jr., *Methods Carbohydr. Chem., Vol. II*, 307 (1963).

21. F. G. de las Heras and P. Fernandez-Resa, *J. Chem. Soc., Perkin Trans. I*, **4**, 903 (1982).

22. H. Weidmann, *Liebigs Ann. Chem.*, **679**, 186 (1964).