1635.34, 1417.42, 1270.86 cm^{-1}; MS (CI) 182 (MH^+).

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Supplementary Material Available: Description of X-ray diffraction experiments, tables of structure determination data, atomic coordinates, displacement coordinates, and interatomic distances and angles for **4** and **5**, and ORTEP drawings of **4** and **5** (12 pages). Ordering information is given on any current masthead page.

Synthesis and Use of Glycosyl Phosphites: An Effective Route to Glycosyl Phosphates, Sugar Nucleotides, and Glycosides

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Abstract: An efficient and convenient synthetic route to glycosyl phosphites and phosphates has been developed that uses dibenzyl *N,N*-diethylphosphoramidite as a phosphitylating reagent. Glycosyl phosphites and phosphates of 2-acetamido-2-deoxy-D-galactose (GalNAc) (**29**), 2-acetamido-2-deoxy-D-glucose (GlcNAc) (**30**), D-galactose (Gal) (**31**), D-glucose (Glc) (**32**), D-mannose (Man) (**33**), L-rhamnose (Rha) (**34**), L-fucose (Fuc) (**35**), and *N*-acetylneuraminic acid (NeuAc) (**41**) were prepared by this procedure. Compounds **29** and **30** were obtained as α anomers exclusively, whereas compounds **31**, **32**, and **41** were obtained as β anomers, and compounds **33** and **34**, as α anomers, predominately. The phosphates are useful for the synthesis of sugar nucleotides, and the phosphites are effective glycosylation reagents.

Introduction

We report here the use of dibenzyl *N,N*-diethylphosphoramidite (DDP) in the preparation of dibenzyl glycosyl phosphites, which can be easily converted to glycosyl phosphates or used as glycosylation reagents in oligosaccharide synthesis (Scheme I). Glycosyl phosphates are key intermediates in the biosynthesis of carbohydrates.[1] In the Lenoir pathway,[2] sugar is initially activated as a sugar-1-phosphate and transformed into a nucleoside diphosphate sugar, which then functions as a donor substrate for a glycosyltransferase-catalyzed transfer of the sugar moiety to a glycosyl acceptor.

Due to the growing interest in enzymatic oligosaccharide synthesis, the availability of sugar nucleotides has become a subject for investigation. Several enzymatic[3-6] and chemical[7-12] methods for the synthesis of sugar nucleotides have been reported. These methods usually start with glycosyl 1-phosphates, which are generally quite expensive and not all commercially available.

Many elegant and new methods for the synthesis of glycosyl phosphates, either enzymatic[6a,f,13] or chemical,[8,11,12,14-19] have been developed. We have recently reported[12a] the use of DDP in the synthesis of β-L-fucosyl dibenzyl phosphite, which is further converted to fucosyl phosphate and GDP-fucose. To investigate the generality of this phosphitylation reaction, we have carried out the synthesis of glycosyl phosphites of seven important sugars, including GalNAc, GlcNAc, Gal, Glc, Man, Rha, and NeuAc, and conversion of the phosphites to phosphates (Schemes II-IV). The glycosyl phosphites can also be used as glycosylation reagents, as illustrated in the synthesis of α-2,3- and α-2,6-linked sialosides (Scheme V).[12b] The sialyl phosphite is a very effective sialylation reagent,[12b,c] giving the α-2,3- or α-2,6-linked sialosides in 30-80% yield, which is higher than or comparable to that from reactions based on other sialylation reagents.[20,21]

Results and Discussion

Glycosyl Phosphites and Phosphates. The phosphitylating reagent DDP was first introduced in 1980 by Smirnova et al.[22] and was subsequently used by others[23] for phosphorylating alcohols. However, it was only recently that the phosphitylating reagent was characterized.[24]

We chose DDP to prepare the glycosyl phosphates for the following reasons: it is relatively cheap and easy to prepare on

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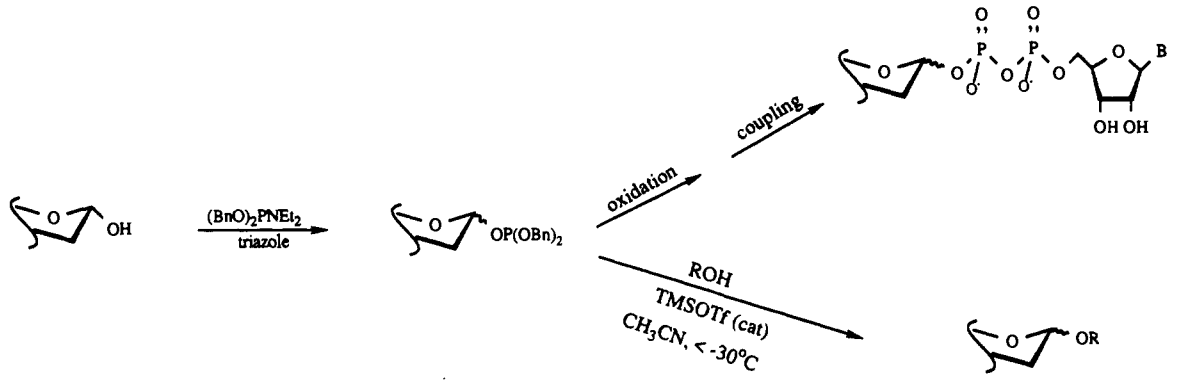
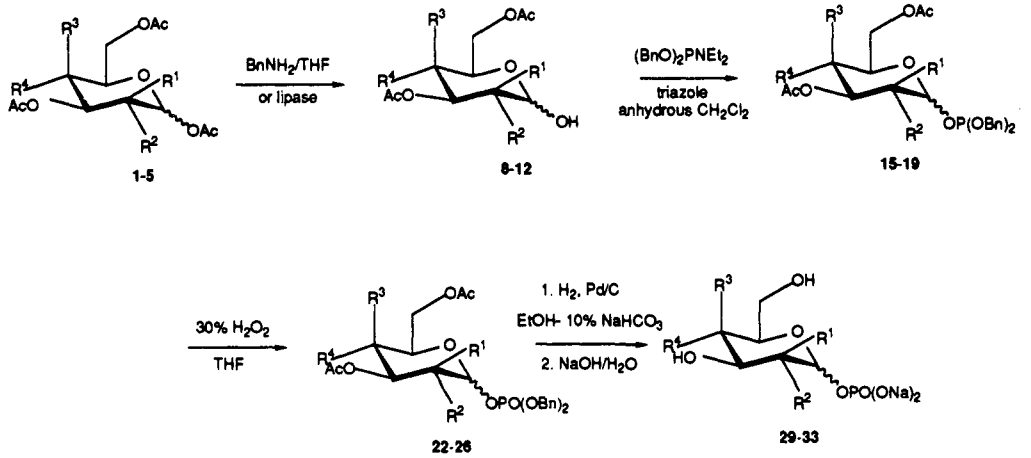
Scheme I. Use of Glycosyl Phosphites for the Synthesis of Sugar Nucleotides and for Glycosylation



Scheme II. Preparation of D-Glycosyl Phosphites and Phosphates



Scheme III. Preparation of L-Glycosyl Phosphites and Phosphates

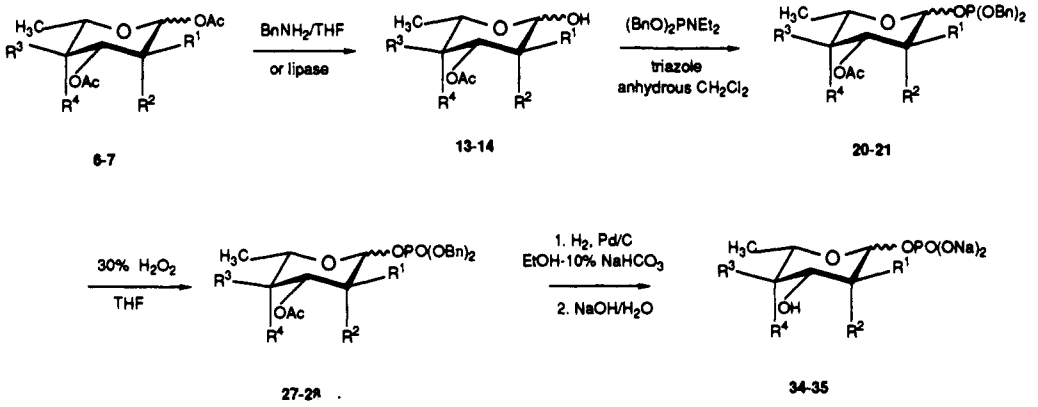


Table I. Identification of R Groups for Compounds in Schemes II and III

compd	R^1	R^2	R^3	R^4	compd	R^1	R^2	R^3	R^4
1	H	NHAc	OAc	H	**19**	OAc	H	H	OAc
2	H	NHAc	H	OAc	**20**	H	OAc	OAc	H
3	H	OAc	OAc	H	**21**	OAc	H	H	OAc
4	H	OAc	H	OAc	**22**	H	NHAc	OAc	H
5	OAc	H	H	OAc	**23**	H	NHAc	H	OAc
6	H	OAc	OAc	H	**24**	H	OAc	OAc	H
7	OAc	H	H	OAc	**25**	H	OAc	H	OAc
8	H	NHAc	OAc	H	**26**	OAc	H	H	OAc
9	H	NHAc	H	OAc	**27**	H	OAc	OAc	H
10	H	OAc	OAc	H	**28**	OAc	H	H	OAc
11	H	OAc	H	OAc	**29**	H	NHAc	OH	H
12	OAc	H	H	OAc	**30**	H	NHAc	H	OH
13	H	OAc	OAc	H	**31**	H	OH	OH	H
14	OAc	H	H	OAc	**32**	H	OH	H	OH
15	H	NHAc	OAc	H	**33**	OH	H	H	OH
16	H	NHAc	H	OAc	**34**	H	OH	OH	H
17	H	OAc	OAc	H	**35**	OH	H	H	OH
18	H	OAc	H	OAc					

Table II. Selected ^{1}H-NMR Data of Compounds **8–12**, **15–19**, **22–26**, and **29–33**[a] Shown in Scheme II

	H-1α	H-1β	H-2	H-3	H-4	H-5	H-6a	H-6b	CH_3CO	NH
8	5.32 (t) $J_{1,2}$ = 3.35		4.53 (dt) $J_{2,3}$ = 11.95	5.26 (dd) $J_{3,4}$ = 3.20	5.39 (dd) $J_{4,5}$ = 0.80	4.45 (t) $J_{5,6}$ = 6.60	4.14 to	4.05 (m)	2.17, 2.06, 2.01, 2.00 (4s)	6.04 (d) $J_{2,NH}$ = 9.50
9	5.30–5.28 (m)		4.32 (dt) $J_{1,2}$ = 4.20 $J_{2,3}$ = 10.30	5.15 (t) $J_{2,3}$ = 10.40	5.30–5.28 (m)	4.15–4.13 (m)	4.22 to	4.20 (m)	2.10, 2.04, 2.05, 1.97 (4s)	5.79 (d) $J_{2,NH}$ = 10.00
10	5.52 (broad)	n.d.[b]	5.19 (dd) $J_{1,2}$ = 3.50 $J_{2,3}$ = 8.80	5.41 (dd) $J_{3,4}$ = 3.40	5.48 (dd) $J_{4,5}$ = 1.25	4.72 (dt) $J_{5,6a}$ = $J_{5,6b}$ = 6.50	4.12 (dd) $J_{6a,6b}$ = 11.50	4.08 (dd)	2.15, 2.10, 2.06, 1.99 (4s)	
11	5.47 (d) $J_{1,2}$ = 3.55	4.76 (d) $J_{1,2}$ = 9.00	4.90 (dd) $J_{2,3}$ = 10.25	5.54 (t) $J_{3,4}$ = 10.00	5.09 (t) $J_{4,5}$ = 10.50	4.29 to	4.22 (m)	4.17–4.12 (m)	2.10, 2.09, 2.04, 2.02 (4s)	
12	5.23 (broad)		5.28 (dd) $J_{1,2}$ = 1.85	5.43 (dd) $J_{3,4}$ = 10.00	5.31 (t) $J_{4,5}$ = 10.00	4.29 to	4.23 (m)	4.16–4.12 (m)	2.17, 2.11, 2.06, 2.00 (4s)	

	H-1α	H-1β	H-2	H-3	H-4	H-5	H-6a	H-6b	CH_3CO_2	CH_3-CONH	NH
15[c]	5.58 (dd) $J_{1,2}$ = 3.40 $J_{1,P}$ = 7.75	5.46 (t) $J_{1,2}$ = 7.00	4.58 (ddd) $J_{2,3}$ = 11.50 $J_{2,P}$ = 3.40	5.13–5.08 (m)	5.36 (bd) $J_{3,4}$ = 2.00	4.24 (dt) $J_{4,5}$ = 0.90 $J_{5,6a}$ = $J_{5,6b}$ = 6.50	4.06 (dd) $J_{6a,6b}$ = 11.30	3.94 (dd)	2.15, 2.00, 1.96 (3s)	1.65 (1s)	5.24 (d) $J_{2,NH}$ = 9.65
16[d]	5.56 (dd) $J_{1,2}$ = 3.35 $J_{1,P}$ = 7.80		4.35 (ddd) $J_{2,3}$ = 10.75	5.21 (t) $J_{3,4}$ = 10.00	5.13 (t) $J_{4,5}$ = 10.00	4.00 (ddd) $J_{5,6a}$ = 4.15 $J_{5,6b}$ = 2.20	4.13 (dd) $J_{6a,6b}$ = 12.45	3.92 (dd)	2.03, 2.02, 2.01 (3s)	1.62 (1s)	5.52 (d) $J_{2,NH}$ = 9.35
17[e]	5.82 (dd) $J_{1,2}$ = 3.40 $J_{1,P}$ = 8.35	5.07 (dd) $J_{1,2}$ = 7.80 $J_{1,P}$ = 8.20	5.35 (dd) $J_{2,3}$ = 10.50	5.05 (dd) $J_{3,4}$ = 3.45	5.41 (dd) $J_{4,5}$ = 1.00	3.97 (dt) $J_{5,6a}$ = 6.40 $J_{5,6b}$ = 7.00	4.16 (dd) $J_{6a,6b}$ = 11.50	4.12 (dd)	2.17, 2.00, 1.99, 1.91 (4s)		
18[e]	5.77 (dd) $J_{1,2}$ = 3.50 $J_{1,P}$ = 8.33	5.15–4.85 (m)	5.15–4.85 (m)	5.23 (t) $J_{2,3}$ = $J_{3,4}$ = 9.50	5.15–4.85 (m)	3.75 (ddd) $J_{4,5}$ = 10.00 $J_{5,6a}$ = 5.00 $J_{5,6b}$ = 2.00	4.24 (dd) $J_{6a,6b}$ = 12.50	4.10 (dd)	2.032, 2.029, 2.01, 1.90 (4s)		
19[e]	5.50 (dd) $J_{1,2}$ = 1.50 $J_{1,P}$ = 8.00	n.d.[b]	5.21 (dd) $J_{2,3}$ = 3.50	5.40 (dd) $J_{4,5}$ = 10.00	5.30 (t) $J_{5,6a}$ = 5.00 $J_{5,6b}$ = 2.50	4.07 (ddd) $J_{6a,6b}$ = 12.50	4.20 (dd)	3.96 (dd)	2.16, 2.05, 2.02, 2.01 (4s)		

	H-1α	H-1β	H-2	H-3	H-4	H-5	H-6a	H-6b	CH_3CO_2	CH_3CON	NH
22	5.72 (dd) $J_{1,2}$ = 3.50 $J_{1,P}$ = 6.00		4.61 (ddd) $J_{2,P}$ = 3.50 $J_{2,3}$ = 11.50	5.12–5.07 (m)	5.37 (dd) $J_{3,4}$ = 3.15 $J_{4,5}$ = 1.20	4.24 (dt) $J_{5,6a}$ = $J_{5,6b}$ = 6.50	4.06 (dd) $J_{6a,6b}$ = 11.50	3.93 (dd)	2.13, 1.98, 1.92 (3s)	1.72 (1s)	5.74 (d) $J_{2,NH}$ = 9.50
23[f]	5.67 (dd) $J_{1,2}$ = 3.30 $J_{1,P}$ = 5.95		4.39–4.35 (m)	5.17	5.10 (m)	3.98 (ddd) $J_{4,5}$ = 10.00	4.13 (dd) $J_{5,6a}$ = 3.95 $J_{6a,6b}$ = 12.50	3.92 (dd) $J_{5,6b}$ = 2.25	2.03, 2.02, 2.01 (3s)	1.71 (1s)	5.59 (d) $J_{2,NH}$ = 9.25
24[g]	5.96 (dd) $J_{1,2}$ = 3.40 $J_{1,P}$ = 6.80	5.35–5.31 (m)	5.35–5.31 (m)	5.03 (dd) $J_{3,4}$ = 3.50 $J_{2,3}$ = 10.00	5.42 (dd) $J_{4,5}$ = 0.85	4.03 (dt) $J_{5,6a}$ = $J_{5,6b}$ = 6.50	4.16 (dd) $J_{6a,6b}$ = 11.30	4.09 (dd)	2.18, 1.99, 1.97, 1.92 (4s)		
25[g]	5.91 (dd) $J_{1,2}$ = 3.30 $J_{1,P}$ = 7.50	5.35 (t) $J_{1,2}$ = $J_{1,P}$ = 7.50	5.13–5.08 (m)	5.22 (t) $J_{3,4}$ = 9.50	5.15–5.09 (m)	3.81 (ddd) $J_{4,5}$ = 10.95 $J_{5,6a}$ = 5.00 $J_{5,6b}$ = 2.00	4.24 (dd) $J_{6a,6b}$ = 12.50	4.12 (dd)	2.04, 2.01, 2.00, 1.90 (4s)		

26	5.61 (dd)	5.44 (dd)	5.23 (t)	5.30 to	5.28 (m)	4.04 (ddd)	4.18 (dd)	3.92 (dd)	2.14, 2.03,		
	$J_{1,2}$ = 1.80	$J_{1,2}$ = 1.50	$J_{2,3}$ = 2.80			$J_{4,5}$ = 9.00	$J_{6a,6b}$ = 12.45		3.00, 1.99		
	$J_{1,P}$ = 6.40	$J_{1,P}$ = 6.80				$J_{5,6a}$ = 4.60			(4s)		
						$J_{5,6b}$ = 2.30					
29	5.33 (dd)		4.14 (ddd)	3.89 (dd)	3.95 (bd)	4.16 (ddd)	3.73 (dd)	3.68 (dd)		2.02 (1s)	
	$J_{1,2}$ = 3.60		$J_{2,3}$ = 10.85	$J_{3,4}$ = 3.20		$J_{5,6a}$ = 7.60	$J_{6a,6b}$ = 11.65				
	$J_{1,P}$ = 7.55		$J_{2,P}$ = 2.00			$J_{5,6b}$ = 4.55					
30	5.34 (dd)		3.90 (ddd)	3.77 (dd)	3.47 (t)	3.92 (ddd)	3.86 (dd)	3.76 (dd)		2.04 (1s)	
	$J_{1,2}$ = 3.30		$J_{2,3}$ = 8.50	$J_{3,4}$ = 10.50	$J_{4,5}$ = 9.50	$J_{5,6a}$ = 2.50	$J_{6a,6b}$ = 12.50				
	$J_{1,P}$ = 7.55		$J_{2,P}$ = 2.00			$J_{5,6b}$ = 5.00					
31	5.44 (dd)	4.78 (t)	3.47 (dd)	3.62 (dd)	3.83 (bd)	3.67 to	3.65 (m)	3.74 (dd)			
	$J_{1,2}$ = 3.65	$J_{1,2}$ =	$J_{2,3}$ = 11.50	$J_{3,4}$ = 3.75				$J_{5,6b}$ = 10.00			
		$J_{1,P}$ = 9.22						$J_{6a,6b}$ = 12.50			
	$J_{1,P}$ = 7.40										
32	5.42 (dd)	4.86 (t)	3.27 (t)	3.49 (t)	3.30 (t)	3.48–3.45 (m)	3.87 (dd)	3.64 (dd)			
	$J_{1,2}$ = 3.60	$J_{1,2}$ =	$J_{2,3}$ = 8.50	$J_{3,4}$ = 9.50	$J_{4,5}$ = 9.50		$J_{5,6a}$ = 1.50	$J_{5,6b}$ = 7.00			
		$J_{1,P}$ = 7.75									
	$J_{1,P}$ = 7.60						$J_{6a,6b}$ = 12.50				
33	5.27 (dd)	5.11 (dd)	3.89–3.81 (m)	3.54 (t)	3.89–3.81 (m)	3.67 (dd)	3.89 to	3.81 (m)			
	$J_{1,2}$ = 1.65	$J_{1,2}$ = 1.50		$J_{2,3}$ =		$J_{4,5}$ = 12.50					
				$J_{3,4}$ = 10.00							
	$J_{1,P}$ = 8.73	$J_{1,P}$ = 8.90				$J_{5,6a}$ =					
						$J_{5,6b}$ = 6.78					

[a] Chemical shifts are in ppm, and coupling constants (J) are in Hz. [b] Not determined due to spectral overlap. [c] HRMS calcd for $C_{28}H_{34}PO_{11}NCs$ ($M + Cs^+$): 724.0924. Found: 724.0931. [d] HRMS calcd for $C_{28}H_{34}PO_{11}NNa$ ($M + Na^+$): 614.1767. Found: 614.1798. [e] HRMS calcd for $C_{28}H_{33}PO_{12}Cs$ ($M + Cs^+$): 725.0764. Found: 725.0764 for **17**, 725.0760 for **18**, and 725.0766 for **19**. [f] The ^{1}H-NMR data were in good agreement with those reported.[3c] [g] The ^{1}H-NMR data were in good agreement with those reported.[16]

a large scale (100 g) based on our new procedure; the reagent is very stable at room temperature and can be kept for at least six months; and the phosphitylating reaction is very effective, going to completion within 30 min at room temperature in an N_2 atmosphere.

All hexoses were prepared as peracetates and treated with benzylamine oralipase to selectively deprotect the C-1 ester for subsequent phosphitylation. For Glc and Gal, the less stable β-phosphates were the major products regardless of the anomeric ratios of the 2,3,4,6-tetra-*O*-acetylhexopyranoses. On the other hand, Man and Rha gave predominantly α-phosphates. The anomeric configuration was determined from the $J_{1,2}$ coupling constants and the NOE study. The 2-acetamido-2-deoxy sugars, such as GlcNAc and GalNAc, gave only α-phosphates, but the NeuAc derivative gave only the β-phosphate.

The phosphitylation reaction proceeds very rapidly, even at 0 °C. From the anomeric ratio of the products obtained, it appears that β-2,3,4,6-tetra-*O*-acetyl sugars of Glc and Gal are more reactive than the corresponding α-anomers, resulting in the formation of β-anomers as the predominant products. In the case of Man and Rha, however, the β-1-hydroxyl group is hindered due to the C-2 acetyl group; thus, the 1,2-trans product, α-phosphate, was preferred. The 2-acetamido-2-deoxy sugars gave only α-phosphates. It is generally believed[19] that a trans 2-acetamido group will destabilize the β-phosphate by neighboring-group participation. For example, **15** was obtained as an α/β (7.4:1) mixture upon phosphitylation. However, only the α-phosphate **22** was isolated after oxidation. In the case of NeuAc, the α position is blocked by the methyl ester, and as a result, only the β-phosphate **41** was obtained.

Solvents were found to affect the anomeric ratio of the phosphitylated products. When **10** was phosphitylated in THF, the α:β ratio was found to be 1:6; in CH_2Cl_2, the ratio changed to 1:2. Control of the anomeric ratio by Lewis acid[11] and mild base[19] have also been reported. An attempt to increase the α:β ratio of **24** using boron trifluoride etherate as the Lewis acid[11] was not successful.

Compound **40** can also be prepared by using dibenzyl phosphate (Scheme IV).[25a] However, the procedure was more tedious, and the yield was low compared to our method. Our attempt to phosphorylate **42** yielded a mixture of eliminated compound and hydrolyzed compound **36**.

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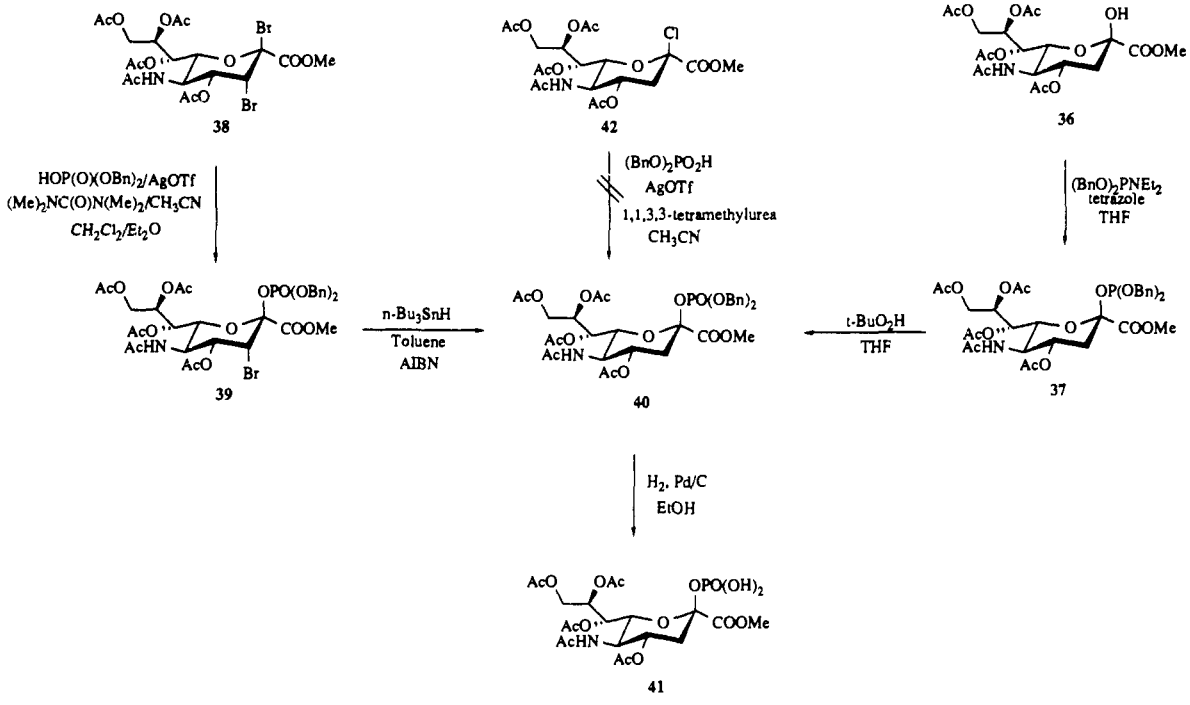
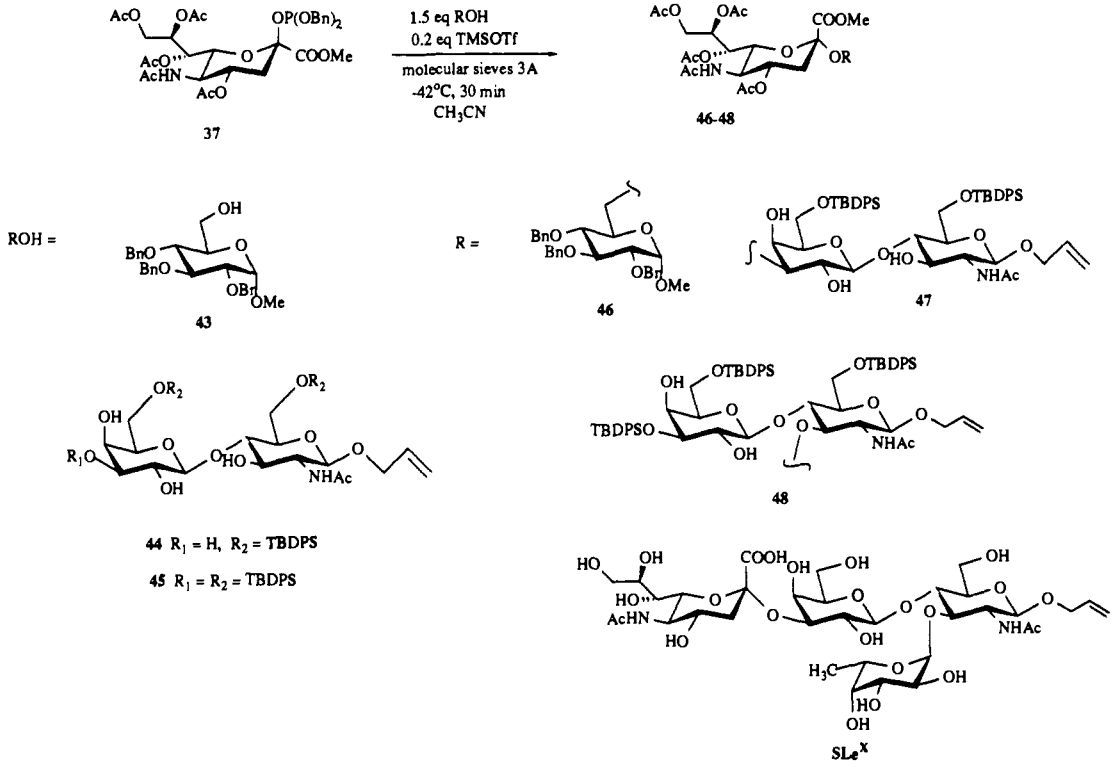
Scheme IV. Preparation of Sialyl Phosphite and Phosphate



Scheme V. Synthesis of Sialosides



Determination of Anomeric Ratio. ^{1}H-NMR was used to determine the anomeric ratio, on the basis of the coupling of H-1 and H-2. The trans diaxial coupling constant is around 10 Hz, whereas the cis or trans ax–eq coupling is around 2 Hz. For the NeuAc derivatives, the chemical shift of H-3eq was used to determine the anomeric configuration; typical α-linked sialyl derivatives are in the range of 2.6–2.8 ppm, whereas the β-anomers show an upfield shift.[25b]

Use of Glycosyl Phosphites as Glycosylation Reagents. For sialylation, compound **37** was reacted with **43** in the presence of 0.2 equiv of TMSOTf in CH_3CN at –42 °C for 30–40 min to give a 5:1 (α/β) mixture of the 2,6-linked sialoside **46** in 80% yield based on **37** (85% based on consumed **43**) and the elimination product 2,3-dehydrosialic acid derivative in 5% yield. No sialylation was observed under such conditions using phosphate **40** as a glycosylation reagent; however, some glycosylation (~35%, $\alpha:\beta$ = 3:1) and elimination (~12%) occurred in the presence of stoichiometric amounts of TMSOTf. Compound **37** was then used in the sialylation of the chemoenzymatically[26] synthesized **44** under the same conditions to give a 6:1 (α/β) mixture of the 2,3-linked

(26) Prepared (46% isolated yield) from the β-galactosyltransferase reaction product β-*O*-allyl-*N*-acetyllactosamine. By reaction with 2 equiv of *t*-BuPh$_2$SiCl and imidazole in DMF at room temperature: Wong, C.-H.; Ichikawa, Y.; Krach, T.; Gautheron, C.; Dumas, D. P.; Look, G. C. *J. Am. Chem. Soc.* **1991**, *113*, 8137.

Table III. Selected ^{1}H-NMR Data of Compounds **13**, **20**, **27**, and **34**[a] Shown in Scheme III

compd	H-1α	H-1β	H-2	H-3	H-4	H-5	CH_3	CH_3CO_2
13	5.17 (dd) $J_{1,2}$ = 1.78 $J_{1,OH}$ = 3.89	n.d.[b]	5.29 (dd) $J_{2,3}$ = 3.42	5.38 (dd) $J_{3,4}$ = 10.08	5.09 (t) $J_{4,5}$ = 9.98	4.15–4.09 (m)	1.23 (d) J_{5,CH_3} = 6.18	2.16, 2.06, 2.00 (3s)
20[c]	4.23 (dd) $J_{1,2}$ = 1.80 $J_{1,P}$ = 7.80	n.d.[b]	5.22 (dd) $J_{2,3}$ = 3.40	5.36 (dd) $J_{3,4}$ = 10.20	5.08 (t) $J_{4,5}$ = 10.00	4.02–3.98 (m)	1.14 (d) J_{5,CH_3} = 6.25	2.15, 2.05, 2.00 (3s)
27[d]	5.55 (dd) $J_{1,2}$ = 1.60 $J_{1,P}$ = 6.35	5.40 (dd) $J_{1,2}$ = 1.05 $J_{1,P}$ = 7.45	5.23 (dd) $J_{2,3}$ = 3.50	5.26 (dd) $J_{3,4}$ = 9.50	5.11–5.08 (m)	3.99–3.93 (m)	1.11 (d) J_{5,CH_3} = 6.25	2.14, 2.05, 1.99 (3s)
34	5.20 (dd) $J_{1,2}$ = 2.00 $J_{1,P}$ = 8.30	5.00 (dd) $J_{1,2}$ = 0.90 $J_{1,P}$ = 8.75	3.91 (dd) $J_{2,3}$ = 3.35	3.86 (dd) $J_{3,4}$ = 8.90	3.35 (t) $J_{4,5}$ = 9.75	3.40–3.30 (m)	1.22 (d) J_{5,CH_3} = 6.30	

[a] Chemical shifts are in ppm, and coupling constants (J) are in Hz. [b] Not determined due to spectral overlap. [c] HRMS calcd for $C_{26}H_{31}PO_{10}Cs$ ($M + Cs^+$): 557.1553. Found: 557.1542. [d] The ^{1}H-NMR data were in good agreement with those reported.[31]

product **47** in 27% yield (78% yield based on consumed **44**). Interestingly, sialylation of **45** occurred regioselectively at the 3-OH group of GlcNAc to give a 6:1 (α/β) mixture of the α-2,3-linked sialoside **48** in 44% yield (80% yield based on consumed **45**). Deprotection of **47** (Bu_4NF, then 0.1 N LiOH) followed by enzymatic fucosylation using α-1,3-fucosyltransferase[27] and GDP-fucose gave the unprotected and anomerically pure SLe^X in 85% yield.[28]

In summary, we have developed a new procedure for the synthesis of dibenzyl glycosyl phosphites. These glycosyl phosphites are useful for the preparation of glycosyl phosphates and for glycosylation reactions. Of particular interest is the sialyl phosphite, which is easy to prepare and stable to handle, and the yields of sialylation are higher than or comparable to those based on other sialylation reagents.[20] To further improve the stereoselectivity in the sialylation reaction, one may use the benzyl ester instead of the methyl ester of the NeuAc derivative.[28c] Other acetylated glycosyl phosphites can be easily prepared from their peracetates via selective deprotection at C-1 with benzylamine or lipases.[12,21m] The strategy described here, combined with the readily available sugar analogues prepared from aldolase reactions,[21m] should enable us to incorporate unnatural sugars, particularly sialic acid analogues, into oligosaccharides. Work is in progress to determine the mechanism and scope of the new glycosylation reaction and to extend this chemoenzymatic strategy to the synthesis of SLe^X analogues and other glycoconjugates.

Experimental Section

The ^{1}H-NMR data of compounds **8–41** (except **14**, **21**, **28**, **35**, **36**, and **38**) and the HRMS data for compounds **15–20** are summarized in Tables II–IV, and their respective yields and anomeric ratios are shown in Table V.

The procedures described below were also applied to the other glycosyl 1-phosphates, **29–35**. The only modification occured at the purification step of **8**, **9**, **15**, and **16**. EtOAc was used as the eluent for **8** and **9**, EtOAc/hexane (2:3) was used for **15**, and $CHCl_3$/EtOAc/MeOH (15:0.5:0.2) was used for **16**.

2,3,4,6-Tetra-*O*-acetyl-D-glucose (11). A solution of pentaacetate **4** (5.0 g, 12.8 mmol) and $BnNH_2$[32] (19.2 mmol) in THF (30 mL) was maintained at room temperature overnight. The mixture was diluted with cold water and extracted with $CHCl_3$ (3 × 50 mL). The combined organic layer was successively washed with ice-cold dilute HCl, saturated $NaHCO_3$, saturated NaCl, and water, dried over anhydrous Na_2SO_4, and concentrated in vacuo. The residual syrup was purified by silica gel chromatography with EtOAc/hexane (2:3) to give **11** (3.80 g, 85%) as a 3:1 (α/β) mixture of anomers as judged by ^{1}H-NMR ($CDCl_3$).

Dibenzyl 2,3,4,6-Tetra-*O*-acetyl-D-glucopyranosyl Phosphite (18). Dibenzyl *N*,*N*-diethylphosphoramidite (0.86 g, 7.3 mmol) was added to a solution of **11** (1.0 g, 2.9 mmol) and 1,2,4-triazole (0.8 g, 11.5 mmol) in anhydrous CH_2Cl_2 under a nitrogen atmosphere at room temperature. The mixture was allowed to stir at room temperature for 1–2 h before being diluted with ether. The mixture was successively washed with ice-cold saturated $NaHCO_3$, saturated NaCl, and water, dried over anhydrous Na_2SO_4, and concentrated in vacuo. The residual syrup was chromatographed on silica gel with EtOAc/hexane (1:4) to give **18** (1.73 g, 97%) as a 1:4 (α/β) mixture of anomers.

Dibenzyl 2,3,4,6-Tetra-*O*-acetyl-D-glucopyranosyl Phosphate (25). To a solution of **18** (1.2 g, 2.2 mmol) in THF (50 mL) cooled to −78 °C with a dry ice–acetone bath was added dropwise 30% H_2O_2 (10 mL). The mixture was allowed to warm up to room temperature and was stirred for 1.5 h at room temperature. The mixture was diluted with ether and successively washed with ice-cold saturated $Na_2S_2O_3$, saturated $NaHCO_3$, saturated NaCl, and water. The organic phase was dried over anhydrous Na_2SO_4 and concentrated to give an α/β (1:4) mixture of **25** (1.36 g, 98%) as judged by ^{1}H-NMR ($CDCl_3$). This product was used for the next step without further purification.

Glucose 1-Phosphate (32). Compound **25** (1.0 g, 1.8 mmol) was hydrogenated (14.7 psi) over 5% Pd/C (200 mg) in EtOH (30 mL) and 10% $NaHCO_3$ (20 mL) for 10 h at room temperature. The mixture was filtered and the filtrate concentrated. The residue was treated with 1 N NaOH (10 mL) at room temperature for 3 h. The mixture was neutralized with ice-cold 1 N AcOH to pH 7.5, and the insoluble material was removed by filtration. Alternatively, a solution of MeOH/H_2O (1:1 v/v) in 10% Et_3N was used instead of NaOH, so that the subsequent neutralization step was eliminated. The filtrate was concentrated, diluted with water, and passed through a column of Dowex 50W-X8 [Na^+] (1 × 15 cm) with water as the eluent. The appropriate fractions were pooled and lyophilized to give **32**.

Occasionally, a small amount of dephosphorylated product was observed. It was removed by passing the diluted filtrate through a column of Dowex 1W-X8 [HCO_2^-] (1 × 30 cm). The column was first eluted with water to remove the neutral product, and then a linear gradient of NH_4HCO_3 (0.1–0.3 M) was applied to elute the desired product. The appropriate fractions were pooled and lyophilized. The lyophilized powder was dissolved in water (10 mL), cooled to 0 °C, and neutralized to pH 7.0 with Dowex 50W-X8 [H^+] resin. The resin was filtered off, and the filtrate was again lyophilized to yield **32** (0.30 g, 59%) as an α/β (1:4) mixture as judged by ^{1}H-NMR (D_2O).

Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-2-(dibenzylphosphityl)-3,5-dideoxy-β-D-*glycero*-D-*galacto*-2-nonulopyranosonate (37). DDP (0.25 g, 0.78 mmol) was added dropwise to a solution of **36**[29] (0.166 g, 0.34 mmol) and 1*H*-tetrazole (0.10 g, 1.43 mmol) in THF (5 mL) under a nitrogen atmosphere, and the mixture was maintained for 4 h at room temperature. CH_2Cl_2 (10 mL) was added to the mixture, and the organic phase was washed with ice-cold dilute HCl, aqueous $NaHCO_3$, and ice–water and dried over anhydrous Na_2SO_4. The solution was evaporated in vacuo to give a crude material, which was chromatographed on a silica gel column with EtOAc/hexane (5:1) to give **37** (0.17 g, 68%)

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Table IV. Selected ^{1}H-NMR Data of Compounds **37**–**41**[a] Shown in Scheme IV

	H-3eq	H-4	H-5	H-6	H-7	H-8	H-9a	H-9b	COOMe	CH_3COO	CH_3CON
37	2.39 (dd)	4.83–4.91 (m)	3.99 (ddd)	3.74 (dd)	5.14 (dd)	4.83–4.91 (m)	4.10 (dd)	4.57 (dd)	3.73 (s)	1.96, 2.01,	1.79 (s)
	$J_{3eq,4}$ = 4.90		$J_{5,NH}$ =	$J_{5,6}$ = 10.60	$J_{7,8}$ = 2.40		$J_{8,9a}$ = 7.40	$J_{8,9b}$ = 2.00		2.06, 2.07	
	$J_{3eq,3ax}$ = 13.00		$J_{4,5}$ = 10.40	$J_{6,7}$ = 2.00			$J_{9a,9b}$ = 12.40			(4s)	
39	4.56 (d)	5.13 (dd)	4.50 (ddd)	4.33 (dd)	5.31 (dd)	5.37 (ddd)	4.32 (dd)	4.73 (dd)	3.58 (s)	1.94, 2.09,	1.87 (s)
	$J_{3eq,4}$ = 3.60	$J_{4,5}$ = 10.60	$J_{5,6}$ = 10.50	$J_{6,7}$ = 2.10	$J_{7,8}$ = 2.20	$J_{8,9a}$ = 7.78	$J_{9a,9b}$ = 12.40			2.10, 2.14	
			$J_{5,NH}$ = 10.00			$J_{8,9b}$ = 2.10				(4s)	
40	2.60 (dd)	4.98–5.04 (m)	4.12 (ddd)	4.07 (dd)	5.32 (dd)	5.30 (ddd)	4.23 (dd)	4.60 (dd)	3.67 (s)	1.99, 2.00,	1.87 (s)
	$J_{3eq,4}$ = 4.90		$J_{5,NH}$ =	$J_{5,6}$ = 10.60	$J_{7,8}$ = 2.00	$J_{8,9a}$ = 2.40	$J_{9a,9b}$ = 12.30			2.05, 2.12	
	$J_{3eq,3ax}$ = 13.40		$J_{4,5}$ = 9.60	$J_{6,7}$ = 2.00		$J_{8,9b}$ = 7.60				(4s)	
41	2.73 (dd)	5.40 (ddd)	3.88 (dd)	4.52 (dd)	5.45 (dd)	5.30–5.34 (m)	4.40 (dd)	4.54 (dd)	3.80 (s)	2.03, 2.09,	1.89 (s)
	$J_{3eq,4}$ = 4.80	$J_{3ax,4}$ = 10.40	$J_{5,6}$ = 10.40	$J_{6,7}$ = 2.12	$J_{7,8}$ = 2.16		$J_{8,9a}$ = 6.00	$J_{8,9b}$ = 3.00		2.13, 2.15	
	$J_{3eq,3ax}$ = 13.00	$J_{4,5}$ = 10.80					$J_{9a,9b}$ = 12.60			(4s)	

[a] Chemical shifts are in ppm, and coupling constants (J) are in Hz.

Table V. Anomeric Ratios and Chemical Yields of Each Step in Scheme II–V

compd	α:β ratio	yield (%)	compd	α:β ratio	yield (%)
8	α only	71	**26**	3:1	98
9	α only	83	**27**	6:1	98
10	2:1	81	**29**	α only	64
11	3:1	85	**30**	α only	39
12	α only	87	**31**	1:2	42
13	18:1	88	**32**	1:4	59
15	7.4:1	47	**33**	3:1	72
16	α only	93	**34**	6:1	76
17	1:2	88	**37**	β only	68
18	1:4	97	**39**	β only	24
19	3:1	80	**40**	β only	95, 46[a]
20	6:1	97	**41**	β only	99
22	α only	93	**46**	5.6:1	80
23	α only	97	**47**	6:1	27
24	1:2	94	**48**	6:1	44
25	1:4	98			

[a] Chemical yield obtained with respect to compound **39**.

as a colorless syrup. ^{13}C-NMR ($CDCl_3$): δ 20.7, 20.8, 20.9, 21.0, 23.1, 36.0, 49.5, 53.5, 62.6, 67.3, 67.4, 67.8, 69.3, 70.8, 94.8, 128.0, 128.7, 135.5, 141.8, 153.0, 169.1, 170.2, 170.4, 170.8, 171.0. HRMS calcd for $C_{34}H_{42}NO_{15}PCs$ (M + Cs^+) 868.1346, found 868.1346.

Methyl 5-Acetamido-3-bromo-2-(dibenzylphosphoryl)-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-β-D-*glycero*-D-*galacto*-2-nonulopyranosonate (39). To a stirred solution of **38**[25] (0.15 g, 0.23 mmol) was added dibenzyl phosphate (79 mg, 0.28 mmol) and 1,1,3,3-tetramethylurea (61 mg, 0.52 mmol) in CH_2Cl_2 (1 mL) at room temperature under a nitrogen atmosphere. The mixture was stirred for 7 h and filtered by passing it through a Celite 545 bed, and the solid was washed with CH_2Cl_2. The combined filtrates and washings were evaporated in vacuo to give a crude material, which was chromatographed on a silica gel column with EtOAc/MeOH (100:1) to give **39** (47 mg, 24%) as a colorless syrup. HRMS calcd for $C_{34}H_{41}NO_{16}PBrNa$ (M + Na^+) 854.1244, found 854.1266.

Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-2-(dibenzylphosphoryl)-3,5-dideoxy-β-D-*glycero*-D-*galacto*-2-nonulopyranosonate (40). To a cooled solution of **37** (0.13 g, 0.17 mmol) in THF (2 mL) was added *t*-BuO_2H (0.4 mL) at −10 °C. The mixture was allowed to warm up to room temperature and was stirred for 1 h at room temperature. The mixture was diluted with CH_2Cl_2, washed with ice-cold aqueous $NaHCO_3$ and water, and then dried over anhydrous Na_2SO_4. The organic phase was evaporated in vacuo to give a crude material, which was chromatographed on silica gel with $CHCl_3$/MeOH (25:1) to give **40** (0.126 g, 95%) as a colorless syrup. HRMS calcd for $C_{34}H_{42}NO_{16}PCs$ (M + Cs^+) 884.1396, found 884.1305.

Alternatively, a solution of **39** (35 mg, 0.04 mmol) and tributyltin hydride (12 mg, 0.04 mmol) in toluene in the presence of a catalytic amount of AIBN was heated at 100 °C for 1 h under a nitrogen atmosphere. The reaction mixture was filtered by passing it through a Celite 545 bed, and the solid was washed with toluene. The combined filtrates and washings were evaporated in vacuo to give a crude material, which was chromatographed on a silica gel column with EtOAc/MeOH (100:1) to give **40** (13.6 mg, 43%) as a colorless syrup. An attempt to synthesize **40** from **42**[31,32] using the reaction protocol indicated in Scheme IV was not successful.

Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-β-D-*glycero*-D-*galacto*-2-nonulopyranosonate 2-Phosphate (41). Compound **40** (0.22 g, 0.25 mmol) was hydrogenated (14.7 psi) over 5% Pd/C (10 mg) under a hydrogen atmosphere for 7 h at room temperature. The catalyst was filtered off through a Celite 545 bed, and the filtrate was concentrated in vacuo. The crude material was chromatographed on a reversed-phase silica gel column with CH_3CN/H_2O (5:1) to give **41** (0.164 g, 99%) as a colorless syrup. HRMS calcd for $C_{20}H_{30}NO_{16}PCs$ (M + Cs^+) 704.0356, found 704.0356.

Coupling Reaction of Sialyl Phosphite and Glycosyl Donor. A solution of phosphite **37** (51 mg, 0.07 mmol), methyl glucopyranoside **42** (48 mg, 0.10 mmol), and 3-Å molecular sieves in CH_3CN (1.5 mL) was cooled to −42 °C, and TMSOTf (3.0 mg, 0.01 mmol) was added. After the mixture was stirred for 30 min at −42 °C, the reaction was quenched with saturated aqueous $NaHCO_3$ and the mixture warmed to room temperature. The mixture was added to EtOAc and washed with saturated $NaHCO_3$. The organic solvents were dried over Na_2SO_4, filtered, and

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concentrated under reduced pressure. The residue was chromatographed on silica gel (CH_2Cl_2/MeOH, 25:1) to provide **46α** (42.1 mg, 68%) and **46β** (7.9 mg, 12%) as colorless syrups. The ^{1}H-NMR spectra of **46α** and **46β** were in good agreement with a previous report.[29]

α-Anomer: ^{1}H-NMR ($CDCl_3$) δ 1.80, 1.85, 2.00, 2.01, 2.12 (3 H each, s, OAc and NAc), 1.96 (1 H, t, J = 12.9 Hz, H-3ax), 2.65 (1 H, dd, J = 4.76, 12.96 Hz, H-3eq), 3.35 (3 H, s, OMe), 3.41 (1 H, dd, J = 1.70, 10.6 Hz, Glc-H-6), 3.51 (1 H, dd, J = 3.52, 9.68 Hz, Glc-H-2), 3.59 (1 H, dd, J = 9.1, 10.0 Hz, Glc-H-4), 3.74 (3 H, s, $COOCH_3$), 3.73–3.79 (2 H, m, Glc-H-5 and NeuAc-H-9), 3.94 (1 H, dd, J = 9.2, 9.6 Hz, Glc-H-3), 3.99 (1 H, ddd, J = 10.4, 10.8, 9.8 Hz, NeuAc-H-5), 4.03 (1 H, dd, J = 2.6, 12.6 Hz, NeuAc-H-9′), 4.09 (1 H, dd, J = 2.1, 10.8 Hz, NeuAc-H-6), 4.22 (1 H, dd, J = 4.0, 10.6 Hz, Glc-H-6′), 4.60 (1 H, d, J = 3.6 Hz, Glc-H-1), 4.74 (1 H, d, J = 10.8 Hz, $PhCH_2$), 4.77 (1 H, d, J = 10.7 Hz, $PhCH_2$), 4.79 (1 H, d, J = 12.2 Hz, $PhCH_2$), 5.09 (1 H, d, J = 9.8 Hz, NeuAc-NH), 5.25 (1 H, dd, J = 2.1, 9.4 Hz, NeuAc-H-7), 5.32 (1 H, ddd, J = 2.6, 4.7, 9.4 Hz, NeuAc-H-8), 7.25–7.36 (15 H, m, Ph). HRMS calcd for $C_{48}H_{59}NO_{18}Cs$ (M + Cs^+) 1070.2786, found 1070.2788.

Allyl 6-*O*-(*tert*-Butyldiphenylsilyl)-D-galactopyranosyl-β-(1,4)-2-acetamido-2-deoxy-6-*O*-(*tert*-butyldiphenylsilyl)-β-D-glucopyranoside (44). To a cooled mixture of β-*O*-allyl-*N*-acetyllactosamine (890 mg, 2.1 mmol) and imidazole (315 mg, 4.62 mmol) in DMF (30 mL) was added dropwise t-Bu$(Ph)_2$SiCl (1.21 g, 4.41 mmol; 1.15 mL) at 0–5 °C, and the mixture was stirred for 10 h at room temperature. Water (2 mL) was added to the cooled mixture, and the mixture was stirred for 30 min at room temperature and concentrated. The residue was chromatographed on silica gel with $CHCl_3$/EtOAc/MeOH (12:7:1) to give **44** (871 mg, 46%) and **45** (152 mg, 7%): ^{1}H-NMR ($CDCl_3$) δ 1.017 (9 H, s, t-Bu), 1.023 (9 H, s, t-Bu), 1.95 (3 H, s, NHAc), 3.37–3.40 (1 H, m, H-5), 3.47 (1 H, dd, J = 2.93, 9.17 Hz, H-3′), 3.65 (1 H, br t, J = 8.4 Hz, H-2′), 3.96 (1 H, br d, J = 2.6 Hz, H-4′), 4.46 (1 H, d, J = 7.8 Hz, H-1′), 4.62 (1 H, d, J = 8.3 Hz, H-1). HRMS calcd for $C_{49}H_{65}NO_{11}Si_2Na$ (M + Na)$^+$: 1032.4096. Found: 1032.0439.

Acetylation of **44** with Ac_2O and pyridine gave the corresponding acetate quantitatively: ^{1}H-NMR ($CDCl_3$) δ 1.03 (9 H, s, t-Bu), 1.07 (9 H, s, t-Bu), 1.78, 1.79, 1.95, 2.00, 2.02 (5 × 3 H, s, 4 × OAc, NHAc), 3.30–3.34 (1 H, m, H-5), 3.53 (1 H, t, J = 8.8 Hz, H-6′a), 3.62–3.68 (1 H, m, H-5′), 3.71–3.78 (1 H, m, H-6′b), 3.87 (1 H, dd, J = 2.9, 11.27 Hz, H-6a), 3.92 (1 H, dd, J = 2.5, 11.27 Hz, H-6b), 4.02–4.13 (3 H, m, allylic, H-2,4), 4.27–4.34 (1 H, m, allylic), 4.40 (1 H, d, J = 7.6 Hz, H-1), 4.68–4.71 (1 H, m, H-1′), 4.94 (1 H, t, J = 9.2 Hz, H-3), 5.01–5.03 (2 H, m, H-2′,3′), 5.57 (1 H, d, J = 1.3 Hz, H-4′), 5.68 (1 H, d, J = 9.5 Hz, NH).

[Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosonate]-(2,3)-[6-*O*-(*tert*-butyldiphenylsilyl)-β-D-galactosyl]-(1,4)-allyl 2-Acetamido-2-deoxy-6-*O*-(*tert*-butyldiphenylsilyl)-β-D-glucopyranoside (47). To a stirred solution of **44** (102 mg, 0.11 mmol) and 3-Å molecular sieves in dry CH_3CN (0.5 mL) was added TMSOTf (4 mg) at 0 °C under an argon atmosphere. The reaction mixture was cooled to −40 °C, and phosphite **37** (56 mg, 0.076 mmol) was added dropwise over 20 min. After the addition was over, the mixture was allowed to warm up to −32 to −30 °C and was stirred for 1 h at the same temperature. The reaction mixture was diluted with cold EtOAc and quenched with cold saturated aqueous $NaHCO_3$. The organic layer was separated and dried over anhydrous sodium sulfate. The solution was evaporated in vacuo to give a crude material, which was chromatographed on a silica gel column ($CHCl_3$/CH_3OH, gradient elution from 25:1 to 15:1) to give unreacted **44** (75 mg) and **47** (28 mg, 27%) as a colorless syrup: ^{1}H-NMR ($CDCl_3$) δ 1.04, 1.09 (9 H each, s, t-Bu), 1.52, 1.82, 1.83, 1.99, 2.06, 2.13 (3 H each, s, OAc and NHAc), 2.70 (1 H, dd, J = 4.6, 13.1 Hz, H-3eq of NeuAc), 3.28–3.31 (2 H, m), 3.40–3.48 (1 H, m), 3.54–3.59 (1 H, m), 3.69 (3 H, s, $COOCH_3$), 3.75–3.98 (7 H, m), 4.02–4.15 (3 H, m), 4.18–4.30 (4 H, m), 4.82–4.90 (2 H, m), 4.92 (1 H, ddd, J = 5.2, 10.7, 11.3 Hz, H-4 of NeuAc), 4.98 (1 H, dd, J = 1.7, 12.3 Hz, H-9′ of NeuAc), 4.99 (1 H, m), 5.13–5.32 (1 H, m), 5.21–5.32 (2 H, m), 5.45–5.50 (1 H, m), 5.65–5.78 (2 H, m), 6.55 (1 H, bd), 7.03 (1 H, bd), 7.27–7.48 (12 H, m, phenyl protons), 7.57–7.62 (2 H, m, phenyl protons), 7.70–7.78 (6 H, m, phenyl protons). HRMS calcd for $C_{69}H_{92}N_2O_{23}Si_2Cs$ (M + Cs^+) 1505.4684, found 1505.4696.

[Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosonate]-(2,3)-[3,6-di(*tert*-butyldiphenylsilyl)-β-D-galactosyl]-(1,4)-allyl 2-Acetamido-2-deoxy-6-*O*-(*tert*-butyldiphenylsilyl)-β-D-glucopyranoside (48). To a stirred solution of **45** (36 mg, 0.032 mmol) and 3-Å molecular sieves in dry CH_3CN (0.5 mL) was added TMSOTf (2 mg) at 0 °C under an argon atmosphere. The reaction mixture was cooled at −40 °C, and phosphite **37** (28 mg, 0.038 mmol) was added dropwise over 20 min. After the addition was over, the mixture was allowed to warm up to −32 to −30 °C and was stirred for 2 h at the same temperature. The reaction mixture was diluted with cold EtOAc and quenched with cold saturated aqueous $NaHCO_3$. The organic layer was separated and dried over anhydrous Na_2SO_4. The solution was evaporated in vacuo to give a crude material, which was chromatographed on a silica gel column ($CHCl_3$/CH_3OH, gradient elution from 25:1 to 15:1). Unreacted **45** (9 mg) was recovered, and **48** (27 mg, 44%) was obtained as a colorless syrup: ^{1}H-NMR ($CDCl_3$) δ 0.95, 0.97, 1.15 (9 H each, s, t-Bu), 1.81, 1.86, 2.01, 2.06, 2.16 (3 H each, s, OAc and NHAc), 2.67 (1 H, dd, J = 4.9, 13.1, H-3eq of NeuAc), 2.78 (1 H, bs), 3.26 (1 H, m), 3.50–3.58 (2 H, m), 3.62–3.67 (1 H, m), 3.68 (3 H, s, $COOCH_3$), 3.75–4.12 (11 H, m), 4.26–4.30 (2 H, m), 4.78–5.10 (5 H, m), 5.45–5.55 (2 H, m), 5.60 (1 H, m, H-8 of NeuAc), 5.78–5.82 (1 H, m), 6.99 (1 H, d, J = 10.1 Hz), 7.04 (1 H, d, J = 6.0 Hz), 7.16–7.42 (20 H, m), 7.50 (2 H, bd), 7.60 (2 H, bd), 7.68 (4 H, bd), 7.77 (2 H, bd). HRMS calcd for $C_{85}H_{110}N_2O_{23}Si_3Cs$ (M + Cs^+) 1743.5862, found 1743.5747. ^{1}H-NMR ($CDCl_3$) for compound **45**: δ 0.98, 0.99, 1.10 (9 H, s, t-Bu), 1.91 (3 H, s, NHAc), 3.98–4.05 (2 H, m), 4.25–4.33 (1 H, m), 4.40–4.45 (1 H, m), 4.72 (1 H, d, J = 8.4 Hz, H-1), 5.14–5.18 (1 H, m), 5.21–5.27 (1 H, m), 5.41 (1 H, d, J = 7.72 Hz, H-1′), 5.32–5.42 (1 H, m).

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