A One-Step Synthesis of Azide-Tagged Carbohydrates: Versatile Intermediates for Glycotechnology

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Abstract: Herein we describe a simple and practical methodology for accessing both the α-anomers (D-mannose, *N*-acetyl-D-glucosamine, *N*-acetyl-D-galactosamine, D-lactose) and α- and β-anomers (D-glucose, D-galactose, L-fucose) of 2′-azidoethyl and azidotriethylene glycol glycosides using free sugars and Dowex 50 (resin) as an efficient catalyst. These azidoalkyl glycosides are increasingly useful synthetic intermediates for glycotechnology.

Key words: azidoethyl glycosides, azidotriethylene glycol glycosides, glycotechnology, resin-catalyzed glycosylation

Azidoalkyl glycosides have become synthetic intermediates of increased importance due in part to the recent discovery of chemoselective ligation reactions utilizing alkyl azides as a reaction partner, including the 'Staudinger ligation'[1] and 'Click' chemistry (also known as the copper-catalyzed Huisgen reaction).[2] This chemistry has been exploited for the generation of carbohydrate arrays,[3] glycodendrimers[4] and defined glycoproteins.[5] In addition, the aminoalkyl glycosides, which are typically derived from the corresponding azidoalkyl glycosides, have seen widespread use in the areas of a) synthesis of neoglycoconjugates, glycopolymers, and glycodendrimers,[6] b) modification and synthesis of glycolipids, glycosphingolipids, oligosaccharides and polysaccharides,[7] c) spacer-arm photoaffinity glycosides, cluster glycosides, multivalent carbohydrate ligands, calixarene scaffolds (protein binding carbohydrates), and supramolecular gelators[8] and most recently d) in the generation of carbohydrate microarrays.[9]

A review of the literature shows that the most common methods for the synthesis of azidoalkyl glycosides involve reaction of an activated sugar donor (peracetates, glycosyl halides or trichloroacetimidates) with an alcohol/glycol bearing a leaving group (halogen or tosyl) followed by displacement of the latter by the azide anion to yield the azidoalkyl glycoside.[10] The typical synthesis of each azidoalkyl sugar derivative is thus lengthy, requiring four to five steps including protection of the hydroxyls, activation of the sugar, glycosylation with the alcohol, displacement of the leaving group by the azide and deprotection. Typical overall yields for these reaction sequences range from 27–55%. We have found only a single report in the literature of a one-step conversion of a free sugar to the corresponding 2′-azidoethyl glycoside, using $BF_3{\cdot}OEt_2$ as the catalyst.[7b] However, purification of the product in this report was laborious. There is no general, and simple methodology in the literature for the synthesis of an array of azidoalkyl glycosides in a single reaction.

Herein we report a simple, one-step reaction for the synthesis of azidoalkyl glycosides using resin-catalyzed glycosylation. Resin-catalyzed glycosylation has been known in the literature for decades, though its use has mostly been limited to the preparation of methyl glycosides.[11] We found no examples where resin-catalyzed glycosylation was used as a methodology for the synthesis of 2′-azidoethyl or azidotriethylene glycol glycosides. It is a convenient method for glycoside synthesis, as the catalyst is stable to hydrolysis, unlike most glycosylation catalysts, and is easily removed by filtration. Our results on the resin-catalyzed glycosylation of 2-azidoethanol and azidotriethylene glycol with a selected set of biologically important free sugars are detailed below.

We began our initial study with a panel of commercially available and biologically relevant sugars including D-glucose (**I**), D-mannose (**II**), D-galactose (**III**), *N*-acetyl-D-galactosamine (**V**), L-fucose (**VI**) and the α-isomers of *N*-acetyl-D-glucosamine (**IV**), and D-lactose (**VII**) as the starting materials (Figure 1).

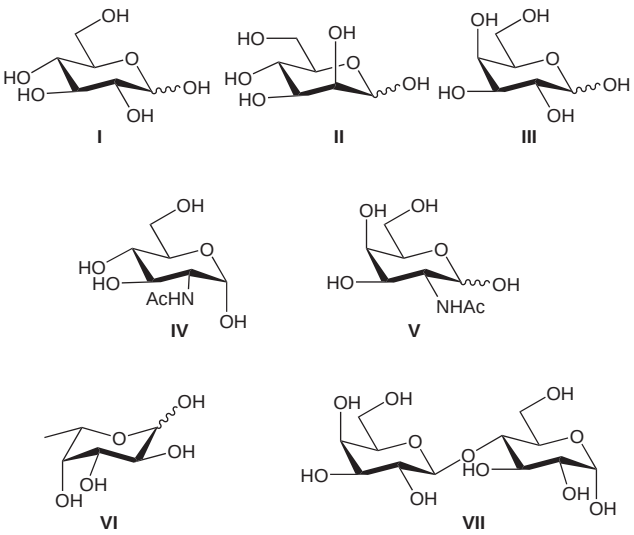

Figure 1 Panel of sugars for resin-catalyzed glycosylation

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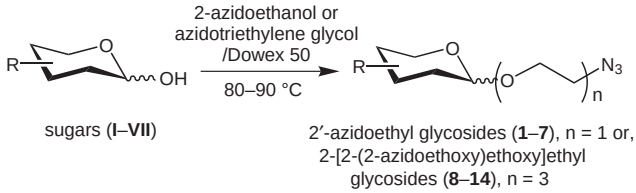
In general, the reaction was carried out by mixing the free sugar with anhydrous Dowex 50 (120 mg/mmol of substrate) in neat 2-azidoethanol or azidotriethylene glycol (4 mL/mmol) at temperatures ranging from 80–90 °C (Scheme 1). The results are summarized in Table 1.

Yields ranged from 33–56%, which were comparable to or better than yields obtained using the previously described multi-step methodology.[10] D-Mannose (**II**), *N*-acetyl-α-D-glucosamine (**IV**), *N*-acetyl-D-galactosamine (**V**), and α-D-lactose (**VII**) afforded single isomers (α) **2**, **4**, **5** and **7** in 49%, 45%, 40% and 56% yields, respectively, as the sole products, whereas D-glucose (**I**), D-galactose (**III**) and L-fucose (**VI**) generated a mixture of anomers **1** (46%, α:β = 2.6:1), **3** (33%, α:β = 2:1) and **6** (51%, α:β = 2:1) based on ^{1}H NMR (Table 1).



Scheme 1 Resin-catalyzed glycosylation of 2-azidoethanol and azidotriethylene glycol

Compounds **1**,[6d,7e] **2**,[7c,e] **3β**,[6d,7e] **4**,[6e] **5**,[7b,e] and **6α**,[7e] have previously been characterized. Compounds **7**, **3α** [^{1}H NMR (DMSO-d_6 + D_2O): δ = 4.67 (1 H, d, *J* = 3.3 Hz, H-1)] and **6β** [^{1}H NMR (DMSO-d_6 + D_2O): δ = 4.09 (1 H, d, *J* = 7.5 Hz, H-1)] were unknown in the literature. Compound **7** was characterized as its amino derivative (**7a**)[12] after reduction via hydrogenation (Scheme 2). As might be expected, the α/β-mixtures of **1**, **3** and **6** were not separable by flash chromatography. Therefore they were separated after conversion to their corresponding peracetylated derivatives in good yields **15** (97%), **16** (95%) and **17** (95%, Scheme 2).[15,16]

Most glycotechnology applications are biological in origin, thus the prevention of non-specific binding by proteins to the synthesized epitope is often desired. Polyethylene glycol linkers are widely known to prevent protein absorption and are often used to link biologically relevant molecules.[13] We therefore examined the reaction of 2-[2-(2-azidoethoxy)ethoxy]ethanol (azidotriethylene glycol) with the sugar panel shown in Figure 1. The anomeric mixtures observed for the sugars under consideration were similar to those previously described for the 2′-azidoethyl glycosides with a single exception, *N*-acetyl-D-galactosamine (**V**), which yielded a mixture of isomers **12** [30%, α:β (2.4:1), Table 2], of which only the α-isomer **12α**[16] (21%) could be separated in pure form via column chromatography. D-Mannose (**II**), *N*-acetyl-α-D-glucosamine (**IV**) and α-D-lactose (**VII**) produced only the α-isomers **9** (54%),[14] **11** (30%) and **14** (60%), respectively (Table 2). D-Glucose (**I**), D-galactose (**III**) and L-fucose (**VI**) yielded mixtures of α- and β-isomers **8** (53%, α:β = 2:1), **10** (44%, α:β = 3:1) and **13** (51%, α:β = 2:1), respectively, based on ^{1}H NMR (Table 2).[17]

Compounds **8**, **10**, **11**, **12**, **13** and **14** were colorless gums and unknown in the literature. Single compounds **11**, **12** and **14** were characterized as the unprotected carbohydrates[16,17] whereas the anomeric mixtures of **8**, **10** and **13** were characterized as their corresponding peracetylated derivatives **18** (98%), **19** (97%) and **20** (96%).[15,16] Initial yields obtained with *N*-acetyl-α-D-glucosamine (**IV**) and α-D-lactose (**VII**) were low (14% and 35%, respectively). We believe that this was due to their poor solubility in azidotriethylene glycol as discussed below.

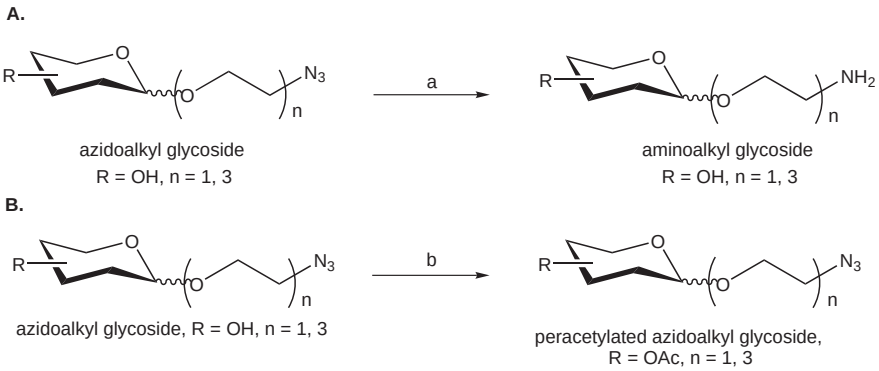
In most cases, the reactions did not go to completion at the glycosylation stage and a portion of starting material remained unreacted. No significant by-products were observed as analyzed by thin-layer chromatography. It was initially thought that the starting material contained moisture, causing the reaction not to proceed to completion, however, drying the starting material, using increasing amounts of catalyst (resin), an increased excess of 2-azidoethanol, and prolonged reaction times did not significantly increase glycoside formation. Furthermore, increasing the temperature did not aid product formation. Instead, we observed destruction of the resin with

Table 1 2′-Azidoethyl Glycosides

Starting sugars	Products	Time (h)	Ratio (α:β)	Yield (%)
D-Glucose (**I**)	**1**	2–3	2.6:1	46
D-Mannose (**II**)	**2**	2–3	α	49
D-Galactose (**III**)	**3**	2–3	2:1	33
N-Acetyl-α-D-glucosamine (**IV**)	**4**	2–3	α	45
N-Acetyl-D-galactosamine (**V**)	**5**	2–3	α	40
L-Fucose (**VI**)	**6**	2–3	2:1	51
α-D-Lactose (**VII**)	**7**	2–3	α	56

Table 2 2-[2-(2-Azidoethoxy)ethoxy]ethyl Glycosides

Starting sugars	Product	Time (h)	Ratio (α:β)	Yield (%)
D-Glucose (**I**)	**8**	1.5	2:1	53
D-Mannose (**II**)	**9**	3	α	54
D-Galactose (**III**)	**10**	2	3:1	44
N-Acetyl-α-D-glucosamine (**IV**)	**11**	1.5	α	30
N-Acetyl-D-galactosamine (**V**)	**12**	4	2.4:1	30
L-Fucose (**VI**)	**13**	2	2:1	51
α-D-Lactose (**VII**)	**14**	2	α	60



Scheme 2 Hydrogenation and acetylation of azidoalkyl glycosides. *Reagents and conditions*: a) Pd/C, H_2, MeOH, 12 h, quant.; b) Ac_2O, pyridine, DMAP, r.t., 2–12 h, for n = 1, **15** = 97%, **16** = 95%, **17** = 95%; for n = 3, **18** = 98%, **19** = 97%, and **20** = 96%.

prolonged stirring at high temperatures (above 100 °C). Attempts to pull water out of the reaction mixture using vacuum distillation resulted in the loss of 2-azidoethanol. A significant improvement in yield was obtained for the glycosylation of *N*-acetyl-α-D-glucosamine (**IV**) and α-D-lactose (**VII**) with azidotriethylene glycol by the addition of anhydrous DMSO as a co-solvent (30% and 60%, compared to 14% and 35%, respectively). With both nucleophiles (2-azidoethanol and azidotriethylene glycol) the anomeric ratio (α/β) varies from 100% α to 2:1 α:β. Results from these glycosylation reactions are consistent with both the existing data on methyl glycosides[11] and with theoretical predictions that the most thermodynamically stable compounds (α-isomers) will be formed preferentially.

Herein we present a simple synthesis of 2′-azidoethyl and azidotriethylene glycol glycosides of both mono and disaccharides using resin-catalyzed glycosylation. Although the panel presented here is a simplified one, it can be extended to the synthesis of more complicated glycans. For example, the glycosides formed can serve as scaffolds for chemoenzymatic synthesis of diverse epitopes. Recent developments in the use of azidoalkyl glycosides to create tools for glycotechnology highlight the importance of facile and practical methodologies for the synthesis of this compound class.

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(12) **Procedure for the Reduction of Azidoalkyl Glycosides.**
To a well-stirred solution of the azidoalkyl glycoside in MeOH (4 mL/mmol) was added Pd/C (40 mg/mmol) and a balloon of H_2 (g). The reaction mixture was monitored for 12 h. After completion of the reaction (TLC), the mixture was filtered through Celite® and the filtrate was concentrated to dryness to give the title compound quantitatively.
2′-Aminoethyl-α-D-lactoside(7a): yield: 100%; a yellow fluffy material (hygroscopic). IR (KBr plate): 3370 (br, OH + NH_2) cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6 + D_2O): δ = 4.65 (1 H, d, *J* = 3.9 Hz, H-1), 4.12 (1 H, d, *J* = 8.1 Hz, H-1′), 4.09 (1 H, d, *J* = 7.5 Hz), 3.71–3.30 (10 H, m), 3.23–2.96 (3 H, m), 2.67 (2 H, m). HRMS (EI): *m/z* calcd for $C_{14}H_{28}NO_{11}$ $[M + H]^+$: 386.1662; found: 386.1662.

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(15) **General Procedure for the Acetylation of Azidoalkyl Glycosides.**
To a well-stirred solution of the azidoalkyl glycoside in dry pyridine (4 mL/mmol) under N_2 was added DMAP (catalytic amount). Then, Ac_2O (10–12 equiv) was added to the mixture dropwise by syringe and the reaction was stirred for 2–12 h at ambient temperature. After completion (TLC, charred in 2% methanolic H_2SO_4), a small amount of ice was added and the reaction was stirred for ca. 30 min. The reaction mixture was then poured into H_2O (30 mL/mmol) and extracted with $CHCl_3$ (3 × 40 mL). The combined organic layers were dried over anhydrous Na_2SO_4, filtered and the filtrate was concentrated to dryness in vacuo. Column chromatography (230–400 mesh) was carried out using acetone–$CHCl_3$–hexanes (1:1:8) to separate both α- and β-isomers.

(16) **Characterization of Compounds.**
The full characterization for one representative compound for each glycoside (**16α** for the 2′-azidoethyl glycosides and **18α**,**β** for the azidotriethylene glycosides) is given. Key data are shown for all other unknown compounds. For ^{13}C NMR all methylenes (CH_2) were identified by DEPT. NMR exchange data for the anomeric protons of the unprotected mixtures are shown in ref. 17.
2′-Azidoethyl-2,3,4,6-tetra-*O*-acetyl-α-D-galactoside (16α).
An amorphous hygroscopic solid. IR ($CHCl_3$): 2931, 2108 (N_3), 1747 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 5.47 (1 H, m), 5.36 (1 H, dd, *J* = 3.3, 10.5 Hz), 5.16 (1 H, s, H-1), 5.13 (1 H, dd, *J* = 8.4, 15.0 Hz), 4.25 (1 H, t, *J* = 6.6 Hz), 4.10 (2 H, d, *J* = 6.9 Hz), 3.86 (1 H, m), 3.63 (1 H, m), 3.52–3.34 (2 H, m), 2.14 (3 H, s, CH_3), 2.08 (3 H, s, CH_3), 2.04 (3 H, s, CH_3), 1.98 (3 H, s, CH_3). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.5 (C=O), 170.4 (C=O), 170.2 (C=O), 169.9 (C=O), 96.4 (C-1), 68.0, 67.8, 67.4, 67.3 (CH_2), 66.5, 61.7 (CH_2), 50.4 (CH_2), 20.7 (CH_3), 20.7 (CH_3), 20.62 (CH_3), 20.6 (CH_3). HRMS (EI): *m/z* calcd for $C_{16}H_{24}N_3O_{10}$ $[M + H]^+$: 418.1462; found: 418.1451.
2′-Azidoethyl-2,3,4-tri-*O*-acetyl-β-L-fucoside (17β).
A colorless gum. IR ($CHCl_3$): 2106 (N_3), 1752 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.52 (1 H, d, *J* = 8.1 Hz, H-1). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.6 (C=O), 170.1 (C=O), 169.5 (C=O), 100.8 (C-1), 68.2 (CH_2), 50.5 (CH_2). HRMS (EI): *m/z* calcd for $C_{14}H_{22}N_3O_8$ $[M + H]^+$: 360.1407; found: 360.1411.
2-[2-(2-Azidoethoxy)ethoxy]ethyl-2,3,4,6-tetra-*O*-acetyl-α-D-glucoside (18α) and 2-[2-(2-Azidoethoxy)ethoxy]ethyl-2,3,4,6-tetra-*O*-acetyl-β-D-glucoside (18β).
Compound **18α**: a colorless gum. IR ($CHCl_3$): 2109 (N_3), 1750 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 5.43 (1 H, t, *J* = 10.2 Hz), 5.08 (1 H, d, *J* = 3.6 Hz, H-1), 5.01 (1 H, t, *J* = 10.2 Hz), 4.81 (1 H, dd, *J* = 3.6, 10.2 Hz), 4.21 (1 H, dd, *J* = 3.9, 12.0 Hz), 4.06 (2 H, m), 3.74 (1 H, m), 3.62 (9 H, m), 3.35 (2 H, t, *J* = 5.4 Hz), 2.03 (3 H, s, CH_3), 2.01 (3 H, s, CH_3), 1.97 (3 H, s, CH_3), 1.95 (3 H, s, CH_3). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.4 (C=O), 169.9 (C=O), 169.4 (C=O), 95.6 (C-1), 70.6 (CH_2), 70.5 (CH_2), 69.9, 68.3, 67.5 (CH_2), 67.0, 61.7 (CH_2), 50.5 (CH_2), 20.5 (CH_3), 20.49 (CH_3), 20.42 (CH_3). HRMS (EI): *m/z* calcd for $C_{20}H_{32}N_3O_{12}$ $[M + H]^+$: 506.1986; found: 506.1982.
Compound **18β**: a colorless gum. IR ($CHCl_3$): 2108 (N_3), 1755 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 5.17 (1 H, t, *J* = 9.3 Hz), 5.04 (1 H, t, *J* = 9.6 Hz), 4.95 (1 H, dd, *J* = 8.1, 9.6 Hz), 4.58 (1 H, d, *J* = 8.1 Hz, H-1), 4.22 (1 H, dd, *J* = 4.5, 12.3 Hz, C_6-H′), 4.09 (1 H, dd, *J* = 2.4, 12.3 Hz, C_6-H), 3.90 (1 H, m, C_5-H), 3.75–3.56 (10 H, m), 3.36 (2 H, t, *J* = 5.1 Hz), 2.05 (3 H, s, CH_3), 2.01 (3 H, s, CH_3), 1.98 (3 H, s, CH_3), 1.96 (3 H, s, CH_3). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.7 (C=O), 170.3 (C=O), 169.5 (C=O), 169.4 (C=O), 100.9 (C-1), 72.9, 71.8, 71.3, 70.8 (CH_2), 70.5 (CH_2), 70.1 (CH_2), 69.1 (CH_2), 68.5, 62.0 (CH_2), 50.7 (CH_2), 20.8 (CH_3), 20.7 (CH_3), 20.7 (CH_3), 20.6 (CH_3). HRMS (EI): *m/z* calcd for $C_{20}H_{32}N_3O_{12}$ $[M + H]^+$: 506.1986; found: 506.1999.
2-[2-(2-Azidoethoxy)ethoxy]ethyl-2,3,4,6-tetra-*O*-acetyl-α-D-galactoside (19α) and 2-[2-(2-azidoethoxy)ethoxy]ethyl-2,3,4,6-tetra-*O*-acetyl-β-D-galactoside (19β).
Compound **19α**: a brown-colored gum. IR ($CHCl_3$): 2108 (N_3), 1747 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 5.12 (1 H, d, *J* = 1.8 Hz, H-1). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.5 (C=O), 170.3 (C=O), 170.1 (C=O), 96.3 (C-1), 70.82 (CH_2), 70.8 (CH_2), 67.7 (CH_2), 61.7 (CH_2), 50.7 (CH_2). HRMS (EI): *m/z* calcd for $C_{20}H_{32}N_3O_{12}$ $[M + H]^+$: 506.1986; found: 506.1987.
Compound **19β**: a colorless gum. IR ($CHCl_3$): 2106 (N_3), 1747 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.55 (1 H, d, *J* = 8.1 Hz, H-1). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.6 (C=O), 170.4 (C=O), 170.32 (C=O), 169.6 (C=O), 101.5 (C-1), 70.9 (CH_2), 70.85 (CH_2), 70.8 (CH_2), 69.2 (CH_2), 61.5 (CH_2), 50.8 (CH_2). HRMS (EI): *m/z* calcd for $C_{20}H_{32}N_3O_{12}$ $[M + H]^+$: 506.1986; found: 506.1997.
2-[2-(2-Azidoethoxy)ethoxy]ethyl-2,3,4-tri-*O*-acetyl-α-L-fucoside (20α) and 2-[2-(2-Azidoethoxy)ethoxy]ethyl-2,3,4-tri-*O*-acetyl-β-l-fucoside (20β).
Compound **20α**: a colorless gum. IR ($CHCl_3$): 2107 (N_3), 1743 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 5.03 (1 H, d, *J* = 1.5 Hz, H-1). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.4 (C=O), 170.2 (C=O), 169.8 (C=O), 96.0 (C-1), 70.5 (CH_2), 70.4 (CH_2), 70.0 (CH_2), 67.8 (CH_2), 50.4 (CH_2). HRMS (EI): *m/z* calcd for $C_{18}H_{30}N_3O_{10}$ $[M + H]^+$: 448.1931; found: 448.1944.
Compound **20β**: a colorless gum. IR ($CHCl_3$): 2106 (N_3), 1751 (C=O) cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.49 (1 H, d, *J* = 8.1 Hz, H-1). ^{13}C NMR (75.47 MHz, $CDCl_3$): δ = 170.7 (C=O), 170.2 (C=O), 169.6 (C=O), 101.1 (C-1), 70.7 (CH_2), 70.6 (CH_2), 70.4 (CH_2), 70.0 (CH_2), 69.1 (CH_2), 50.6 (CH_2). HRMS (EI): *m/z* calcd for $C_{18}H_{30}N_3O_{10}$ $[M + H]^+$: 448.1931; found: 448.1933.
2-[2-(2-Azidoethoxy)ethoxy]ethyl-2-*N*-acetamido-2-deoxy-α-D-glucoside (11).
A colorless gum. IR (KBr plate): 3290 (br, OH), 2111 (N_3), 1652 (C=O) cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ = 4.68 (2 H, t, *J* = 4.8 Hz, H-1 and 1 H). ^{13}C NMR (75.47 MHz,

DMSO-d_6): δ = 169.4 (C=O), 97.0 (C-1), 69.9 (CH_2), 69.7 (CH_2), 69.5 (CH_2), 69.3 (CH_2), 66.5 (CH_2), 60.8 (CH_2), 50.0 (CH_2). HRMS (EI): *m/z* calcd for $C_{14}H_{27}N_4O_8$, $[M + H]^+$: 379.1829; found: 379.1833.

2-[2-(2-Azidoethoxy)ethoxy]ethyl-2-*N*-acetamido-2-deoxy-α-D-galactoside (12*α*).

A brown-colored gum. IR (KBr-plate): 3305 (OH), 2110 (N_3), 1646 (C=O) cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ = 4.67 (1 H, d, *J* = 3.6 Hz, H-1). ^{13}C NMR (75.47 MHz, DMSO-d_6): δ = 169.6 (C=O), 97.4 (C-1), 69.8 (CH_2), 69.7 (CH_2), 69.5 (CH_2), 69.3 (CH_2), 66.5 (CH_2), 60.6 (CH_2), 50.0 (CH_2). HRMS (EI): *m/z* calcd for $C_{14}H_{27}N_4O_8$ $[M + H]^+$: 379.1829; found: 379.1830.

2-[2-(2-Azidoethoxy)ethoxy]ethyl-α-D-lactoside (14).

A yellow gum. IR (KBr plate): 3387 (br, OH), 2109 (N_3), 1652 (C=O) cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6): δ = 4.65 (1 H, t, *J* = 3.0 Hz, H-1), 4.10 (1 H, d, *J* = 7.8 Hz, H-1′). ^{13}C NMR (75.47 MHz, DMSO-d_6): δ = 102.5 (C-1), 98.4 (C-1′). HRMS: *m/z* calcd for $C_{18}H_{34}N_3O_{13}$ $[M + H]^+$: 500.2092; found: 500.2086.

(17) **^{1}H NMR Exchange Data for the Anomeric Position of *α*/*β*-Mixtures 8, 10, 13 and α-Glycosides 11 and 14.**

Compound **8*α***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.63 (1 H, d, *J* = 3.9 Hz, H-1).

Compound **8*β***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.12 (1 H, d, *J* = 7.5 Hz, H-1).

Compound **10*α***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.66 (1 H, d, *J* = 3.0 Hz, H-1).

Compound **10*β***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.08 (1 H, d, *J* = 7.5 Hz, H-1).

Compound **13*α***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.59 (1 H, d, *J* = 2.7 Hz, H-1).

Compound **13*β***: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.07 (1 H, d, *J* = 7.2 Hz, H-1).

Compound **11**: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.68 (1 H, d, *J* = 3.3 Hz, H-1).

Compound **14**: ^1H NMR (DMSO-d_6 + D_2O): δ = 4.64 (1 H, d, *J* = 3.9 Hz, H-1 and 4.13 (1 H, d, *J* = 7.8 Hz, H-1′).