Preparation of diversely protected 2-azido-2-deoxyglycopyranoses from glycals

Stanislas Czernecki and Ebtissam Ayadi

Abstract: A new and efficient preparation of diversely protected 2-azido-2-deoxyglycopyranosides from the corresponding glycals is described. The glycals are first transformed into protected phenyl 2-azido-2-deoxyselenoglycopyranosides by azido-phenylselenylation. Two procedures were employed according to the protecting groups present: sodium azide and diphenyldiselenide in the presence of (diacetoxyiodo)benzene for peracetylated glycals (Procedure A) or trimethylsilyl azide and tetra-*n*-butylammonium fluoride in the presence of *N*-phenylselenophthalimide for perbenzylated glycals (Procedure B). A *gluco–manno* mixture (90%) is obtained from protected D-glucal whereas only the *galacto* isomer is formed from protected D-galactal (75%). The compatibility of the second procedure with one free hydroxyl group and a variety of protecting groups was verified with 1,5-anhydro-2-deoxy-3,4-*O*-isopropylidene-D-*lyxo*-hex-1-enitol and its 6-*O*-acetyl, 6-*O*-allyl, 6-*O*-benzyl, and 6-*O*-*tert*-butyldimethylsilyl derivatives as well as with 1,5-anhydro-4,6-*O*-benzylidene-2-deoxy-D-*lyxo*-hex-1-enitol and its 3-*O*-acetyl and 3-*O*-benzyl derivatives, which were transformed into phenyl 2-azido-2-deoxy-α-D-selenogalactopyranoside derivatives in good yield. In the second step, hydrolysis of these selenoglycosides afforded diversely protected glycopyranoses in high yield. Peracetylated derivatives were hydrolyzed in the presence of *N*-iodosuccinimide, whereas mercury trifluoroacetate was employed for 3,4-*O*-isopropylidene, 4,6-*O*-benzylidene, and perbenzylated derivatives. In some cases the two steps can be carried out without isolation of the intermediate selenoglycoside.

Key words: glycals, 2-azido-2-deoxygalactopyranose, 2-azido-2-deoxyglucopyranose, selenoglycosides.

Résumé : On décrit une nouvelle préparation efficace de divers 2-azido-2-désoxyglycopyranosides protégés de diverses manières à partir des glycals correspondants. Dans la première étape, on transforme les glycals en 2-azido-2-désoxysélénoglycopyranosides de phényle protégés par azidophénylsélénylation. On a utilisé deux méthodes suivant la nature des groupes protecteurs présents : azoture de sodium et diphényldisélénure en présence de (diacétoxyiodo)benzène avec les glycals peracétylés (méthode A) ou azoture de triméthylsilyle et fluorure de tétra-*n*-butylammonium en présence de *N*-phénylsélénophtalimide avec les glycals perbenzylés (méthode B). On obtient un mélange *gluco–manno* (90%) à partir du D-glucal alors que l'on obtient uniquement l'isomère *galacto* à partir du D-galactal (75%). Utilisant le 1,5-anhydro-2-désoxy-3,4-*O*-isopropylidène-D-*lyxo*-hex-1-énitol et ses dérivés 6-*O*-acétyl-, 6-*O*-allyl-, 6-*O*-benzyl- et 6-*O*-*tert*-butyldiméthylsilyl- ainsi que le 1,5-anhydro-4,6-*O*-benzylidène-2-désoxy-D-*lyxo*-hex-1-énitol et ses dérivés 3-*O*-acétyl- et 3-*O*-benzyl- qui ont été transformés en dérivés du 2-azido-2-désoxy-α-galactopyranoside de phényle avec de bons rendements, on a vérifié la compatibilité de la deuxième méthode avec la présence d'un groupe hydroxyle libre et de divers groupes protecteurs. Dans la deuxième étape, l'hydrolyse de ces sélénoglycosides fournit divers glycopyranoses protégés avec des rendements élevés. On a hydrolysé les dérivés peracétylés en présence de *N*-iodosuccinimide alors que l'on a utilisé du trifluoroacétate de mercure pour les dérivés 3,4-*O*-isopropylidène, 4,6-*O*-benzylidène et perbenzylés. Dans certains cas, on a effectueé les deux étapes sans isoler les sélénoglycosides intermédiaires.

Mots clés : glycals, 2-azido-2-désoxygalactopyranose, 2-azido-2-désoxyglucopyranose, sélénoglycosides.

[Traduit par la rédaction]

Introduction

Protected 2-azido-2-deoxy derivatives of galactose and glucose are extensively used for the synthesis of biologically important 2-amino-2-deoxygalactose- (and glucose-) containing oligosaccharides (1, 2). Due to the small size of the azido group, 2-azido-2-deoxyglycopyranosyl donors are generally used as reactive intermediates. Depending on the leaving group and the promotor used, they can induce either a 1,2-*cis* or a 1,2-*trans* stereochemistry (2) and regeneration of the amino function is possible under mild conditions. They are generally prepared in two steps from the corresponding glycals: azidonitration followed by transformation of the obtained 2-azido-1-nitrate adducts into various glycosyl donors by displacement of the anomeric nitrate by halide ions as described by Lemieux and Ratcliffe (3) or by using potas-

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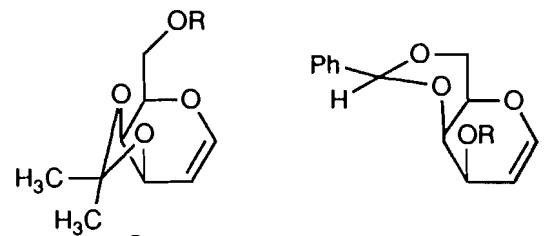
Table 1. Synthesis of diversely protected 2-azido-2-deoxy glycopyranosides.

Entry	Glycal	Azido-phenylselenylation			Hydrolysis			Yield from glycal (%)
		Procedure	Compound	Yield (%)	Procedure	Compound	Yield (%)	
1	**1***a*	A[a]	(**5***a* + **6***a*)[c]	91	C[d]	(**11***a* + **12***a*)[c]	90	82
2	**1***b*	B[b]	(**5***b* + **6***b*)[c]	82	D[e]	(**11***b* + **12***b*)[f]	93	76
3	**2***a*	A	**7***a*	92	C	**13***a*	87	80
4	**2***b*	B	**7***b*	75	D	**13***b*	87	65
5	**3***a*	B	**9***a*	59				
6	**3***b*	B	**9***b*	91	D	**14***a*	79	72
7	**3***b*	A	**9***b*	50				
8	**3***c*	B	**9***c*	84	D	**14***b*	87	73
9	**3***d*	B	**9***d*	66				
10	**3***e*	B	**9***e*	74	D	**14***c*	88	65
11	**4***a*	B	**10***a*	68				
12	**4***b*	B	**10***b*	73	D	**15***a*	86	63
13	**4***c*	B	**10***c*	76	D	**15***b*	82	62

[a]Procedure A: $(PhSe)_2$ (0.6 equiv.), NaN_3 (2.4 equiv.), $PhI(OAc)_2$ (1.4 equiv.), CH_2Cl_2, 48 h rt.
[b]Procedure B: *N*-PSP (2 equiv.), $(CH_3)_3SiN_3$ (2 equiv.), $(n-Bu)_4NF$ (0.2 equiv.), CH_2Cl_2, 48 h rt.
[c]Inseparable mixture.
[d]Procedure C: NIS (5 equiv.), $THF-H_2O$, 12 h rt.
[e]Procedure D: $(CF_3COO)_2Hg$ (1.5 equiv.), $THF-H_2O$, CH_2Cl_2, 30 min rt.
[f]66% *gluco*, 12% *manno*, and 15% of a *gluco–manno* mixture.

sium *O*-ethyl dithiocarbonate (4). Efficient glycosyl donors such as trichloroacetimidates (5) and fluorides (6) can also be prepared after hydrolysis of the anomeric *O*-nitrate. Several methods were reported for the latter transformation (5, 7, 8).

We recently disclosed a new route to protected 2-azido-2-deoxyglycopyranoses in which azido-phenylselenylation of protected glycal afforded a phenyl 2-azido-2-deoxyselenoglycoside that was readily hydrolyzed (9). We now report full details with extension of this methodology to several diversely protected glycals to demonstrate its compatibility with a variety of protecting groups employed in oligosaccharide synthesis.



3*a* R=H
3*b* R=Ac
3*c* R=Bn
3*d* R=TBDMS
3*e* R=Allyl

4*a* R=H
4*b* R=Ac
4*c* R=Bn

TBDMS= $Si(Me)_2CMe_3$
Allyl = CH_2-CH=CH_2

Results and discussion

Treatment of 3,4,6-tri-*O*-acetyl-d-glucal (**1***a*) and 3,4,6-tri-*O*-acetyl-d-galactal (**2***a*) with (diacetoxyiodo)benzene (1.4 equiv.) and sodium azide (2.4 equiv.) in the presence of diphenyldiselenide (0.6 equiv.) in methylene chloride at room temperature afforded phenyl 3,4,6-tri-*O*-acetyl-2-azido-2-deoxy-1-seleno-α-d-glycopyranosides in good yield (Table 1, entries 1 and 3). From **1***a* the *gluco* (**5***a*) and *manno* (**6***a*) isomers were obtained in 91% yield as an inseparable mixture. From the integration of H1 signals in the ^1H NMR spectrum of the mixture, the proportion was found to be 3:2. Interestingly, only the α anomers were formed, as indicated by the values of the H1,H2 coupling constants (5.3 Hz for the *gluco* isomer and ≈0 Hz for the *manno* isomer). From **2***a*, only one compound, the α-*galacto* isomer **7***a*, was formed and isolated in crystalline form (92%). No *talo* isomer **8***a* could be detected in the ^1H NMR spectrum of the crude mixture, although it is known that some *talo* azidonitrate (4–8%) is formed in azidonitration of protected d-galactal (3, 4). The regio- and the stereochemistry of this reaction can be rationalized by addition of an electrophilic azido radical (10) formed in situ by oxidation of azide ion (11) to C2 of the electron-rich double bond of the glycal, generating an anomeric radical by the anomeric effect in the α configuration. Further reaction with diphenyldiselenide affords the α-selenoglycosides.

When perbenzylated glycals **1***b* (12) and **2***b* (13) were reacted under the same conditions, perbenzylated phenyl 2-azido-2-deoxy-1-seleno-α-d-glycopyranosides were obtained in low yield, in agreement with recent results (14). This could be due to oxidative cleavage of the benzyl group under reaction conditions. Interestingly, when **1***b* and **2***b* were reacted with azidotrimethylsilane (2 equiv.), tetra-*n*-butylammonium fluoride (0.2 equiv.), and *N*-phenylselenophthalimide (*N*-PSP, 2 equiv.) in methylene chloride, phenyl 2-azido-3,4,6-tri-*O*-benzyl-2-deoxy-1-seleno-α-d-glycopyranosides were obtained in good yield. As above, a mixture of *gluco* (**5***b*) and

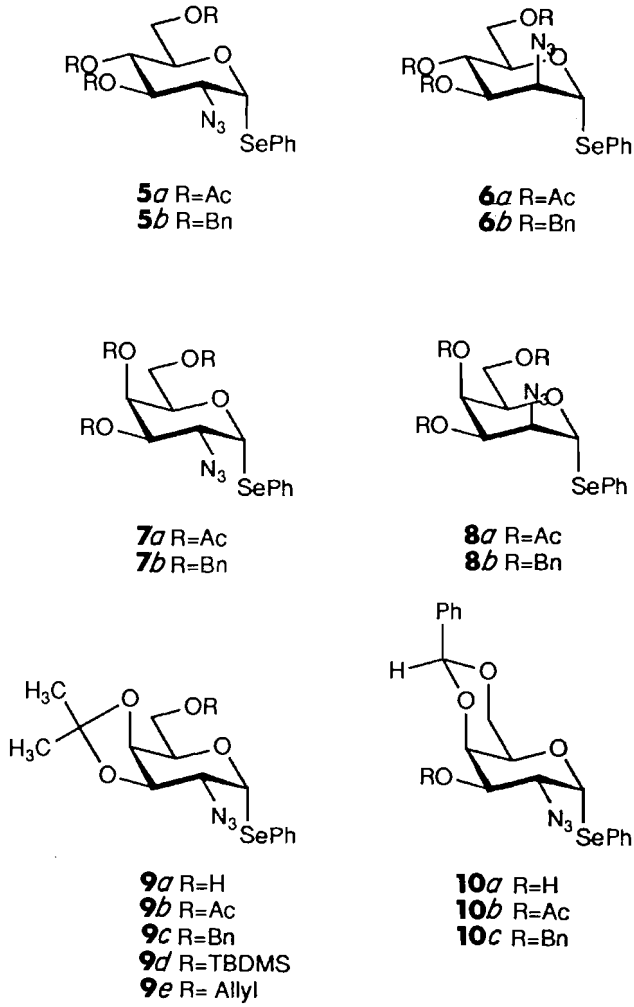
manno (**6***b*) isomers was obtained (82%) with low diastereoselectivity (70:30) from the *glucal* derivative **1***b*, whereas complete diastereocontrol was observed and the α-*galacto* selenoglycoside **7***b* was obtained as the sole product (75%) from **2***b*. The regio- and diastereochemical outcome of the reaction was verified by ^{1}H NMR spectroscopy. The chemical shifts of H1 of **5***b*, **6***b*, and **7***b* (5.95, 5.85, and 5.93 ppm, respectively) are in agreement with the values already reported for selenoglycosides (15–17) and azido sugars (18). the presence of the phenylseleno group of C1 was further confirmed by hydrolysis leading to 2-azido-2-deoxyglycopyranose derivatives (vide infra). Transformation of **7***a* into **7***b* by deacetylation and benzylation (see Experimental) definitively confirmed that the regioselectivity of the reaction was the same as above.

Although more work is necessary to understand and to rationalize these results, similar changes in regioselectivity in azido-phenylselenylation have already been observed with exocyclic alkenes (19).

The compatibility of this methodology with many protecting groups was further demonstrated with diversely protected D-galactal derivatives, which are often employed in oligosaccharide synthesis: 1,5-anhydro-2-deoxy-3,4-*O*-isopropylidene-D-*lyxo*-hex-1-enitol (**3***a*) (20) and its 6-*O*-acetylated (**3***b*) (20), 6-*O*-benzylated (**3***c*) (20), and 6-*O*-*tert*-butyldimethylsilylated (**3***d*) derivatives. The compatibility with the benzylidene group, which is very sensitive to oxidation and to radical reactions, was also demonstrated with 1,5 anhydro-4,6-*O*-benzylidene-2-deoxy-D-*lyxo*-hex-1-enitol (**4***a*) (20) and its 3-*O*-acetyl (**4***b*) (4) and 3-*O*-benzyl (**4***c*) (20) derivatives.

Azido-phenylselenylation of acetylated derivative **3***b* according to procedure A was very slow, but the same diastereocontrol was observed and the α-*galacto* selenoglycoside **9***b* was obtained (Table 1, entry 7). Better results were obtained with procedure B, which was employed for the transformation of **3***b*, **3***c*, **3***d*, **4***b*, and **4***c* into protected 2-azido-2-deoxy-1-seleno-α-D-galactopyranosides in good yield (see Table 1). For **3***d*, in which a *tert*-butyldimethylsilyl group was present, tetra-*n*-butylammonium fluoride was omitted, the reaction time was longer than with other glycals, and the yield of **9***d* slightly lower (66%). Transformation of **9***d* into **9***b* by desilylation and acetylation further confirmed that the regioselectivity was the same with both methods. The *galacto* configuration of the resulting 2-azido-2-deoxyselenoglycosides was confirmed by ^{1}H NMR spectroscopy. For **9***b*, **9***c*, **9***d*, and **9***e*, the values of coupling constants of H2 with H1 (≈5 Hz indicating a *cis* relationship) and with H3 (6–7 Hz) were in agreement with values already reported for such 3,4-*O*-isopropylidene *galacto* derivatives (20). For **10***b* and **10***c* the corresponding coupling constants ($J_{1,2}$ = 5.2 Hz and $J_{2,3}$ = 10.5 Hz) clearly indicated the α-D-*galacto* configuration.

Interestingly, azido-phenylselenylation by procedure B was also possible in the presence of one unprotected hydroxyl group and compounds **3***a* and **4***a* were transformed into **9***a*[2] and **10***a* (Table 1, entries 5 and 11). Although the reaction was not as clean and the yield was lower, this possibility is interesting because **9***a* and **10***a* could eventually serve as glycosyl acceptors as well as glycosyl donors.



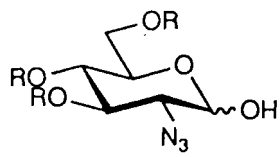
Furthermore, it was verified that the reaction can be successfully carried out in the presence of an *O*-allyl ether. For that purpose, 6-*O*-allyl-1,5-anhydro-2-deoxy-3,4-*O*-isopropylidene-D-*lyxo*-1-enitol **3***e* was prepared from **3***a*. Azido-phenylselenylation of **3***e* according to procedure B was highly selective and protected 2-azido-2-deoxy-1-seleno-α-D-galactopyranoside **9***e* was obtained in 74% yield. The product formed by double azido-phenylselenylation was isolated (3%) and characterized by ^{1}H NMR.[3]

These easily obtained 2-azido-2-deoxyselenoglycosides were subjected to hydrolysis to generate the anomeric hydroxyl. Owing to the *soft* nature of the selenium atom, *soft* catalysts such as heavy metal salts were evaluated.

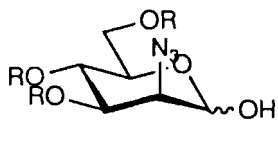
When ether-oxides or acetals were present as protecting group, hydrolysis was complete in 30 min at room temperature in the presence of mercury trifluoroacetate in wet tetrahydrofuran and the protected 2-azido-2-deoxyglycopyranoses were obtained in good yield (see Table 1). When mercury acetate was employed, some 1-*O*-acetyl derivative was also

[2] In this case the regioselectivity was not complete and a small amount (7%) of 3,4-*O*-isopropylidene-2-phenylseleno-β-D-galactopyranosyl azide was also formed, isolated, and characterized by analysis and spectroscopic methods (see experimental).

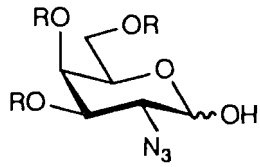
[3] ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.20 (s, 3H, CH_3), 1.40 (s, 3H, CH_3), 3.10-3.80 (m, 6H), 3.90-4.30 (m, 4H), 4.50 (m, 1H, $J_{2,3}$ = 7.2 Hz, H2), 5.80 (d, 1H, $J_{1,2}$ = 5 Hz, H1), 7.10-7.70 (m, 10 H, aromatic).



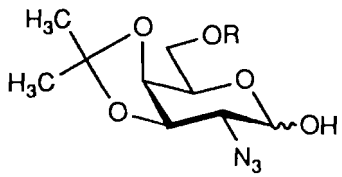
11*a* R=Ac
11*b* R=Bn

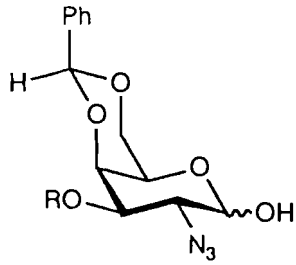


12*a* R=Ac
12*b* R=Bn



13*a* R=Ac
13*b* R=Bn





14*a* R=Ac
14*b* R=Bn
14*c* R=Allyl

15*a* R=Ac
15*b* R=Bn

formed. Hydrolysis of the *gluco–manno* mixture of **5***b* and **6***b* afforded a mixture of **11***b* and **12***b* that could be separated by flash chromatography, and **11***b* was obtained in crystalline form (66%).

Under these conditions, the hydrolysis of acetylated derivatives **5***a*, **6***a*, and **7***a* was very slow, presumably because the electron-withdrawing effect of the acetoxy group does not favor the formation of the carbenium ion. When *N*-iodosuccinimide (5 equiv.) was employed instead of mercury trifluoroacetate, the reaction was complete in 12 h at room temperature. From **5***a*–**6***a*, an inseparable mixture of **11***a* and **12***a* was obtained, whereas the *galacto* azido-selenoglycoside **7***a* was transformed into **13***a* (87%).

The complete stereocontrol obtained in the *galacto* series makes this procedure very useful. For convenience, it was verified with **2***b* that the two steps can be carried out without purification of the intermediate azido-selenoglycoside **7***b*. In this case, after azido-phenylsenylation, the precipitate was filtered off and the solvent evaporated. Hydrolysis of the crude **7***b* afforded **13***b* after flash chromatography (72% overall yield).

Conclusion

The presently described transformation of protected glycals into 2-azido-2-deoxyglycopyranosides represents a new and very efficient method for the preparation of these important intermediates in oligosaccharide synthesis (21). The overall yield obtained for the preparation of these 2-azido-2-deoxyglycopyranoses compares favorably with yields previously reported for azidonitration followed by hydrolysis. The success of the process in the case of D-galactal derivatives is particularly remarkable because only the *galacto* isomer is obtained in high yield, affording an easy access to galactosamine donors. Another advantage of this methodology is its compatibility with a variety of protecting groups including acetates, acetals, allyl ethers, benzyl ethers, benzylidene groups, and silyl ethers as well as with one nonprotected hydroxyl group. The mild conditions employed would also allow extension of this methodology to glycals derived from disaccharides.

Experimental

General procedures

Melting points were measured with a Thomas–Hoover apparatus and are uncorrected. IR spectra were recorded with a Unicam spectrometer. ^{1}H NMR spectra were recorded on a Bruker AM 200 spectrometer. Optical rotations were measured on a Perkin–Elmer 141 polarimeter in a 10 cm cell at 22°C. Analytical TLC was performed on Merck aluminum precoated plates of silica gel 60 F-254 with detection by UV and by spraying with 6 N H_2SO_4 and heating about 2 min at 300°C. For flash chromatography, Merck silica gel 60 (230–400 mesh) and anhydrous solvents were employed. Solvents were evaporated under reduced pressure in a rotary evaporator below 30°C.

Microanalyses were performed at the Service de Microanalyse de l'Université Pierre et Marie Curie.

N-Phenylselenophthalimide (*N*-PSP) was prepared according to Nicolaou et al. (22).

*1,5-Anhydro-2-deoxy-3,4-*O*-isopropylidene-6-*O*-tert-butyldimethylsilyl-*D*-lyxo-hex-1-enitol* **3***d*

To a solution of **3***a* (20) (500 mg, 2.68 mmol) and imidazole (456 mg, 6.7 mmol) in DMF (5 mL), *tert*-butyldimethylsilylchloride (505 mg, 3.35 mmol) was added. The reaction was stirred at 46°C for 48 h. The solvent was evaporated and the residue partitioned between H_2O and Et_2O (20 mL, 1:1) and

the aqueous phase extracted with ether (2 × 10 mL). The combined Et_2O layer was washed with H_2O (2 × 10 mL) and dried ($MgSO_4$). After evaporation, the residue was purified by flash chromatography. Elution with CH_2Cl_2–hexane (1:4 and 3:7) afforded **3***d* (677 mg, 84%), solid, mp 38–40°C; R_f 0.77 (EtOAc–hexane 1:9); $[\alpha]_D$ −2.6 (*c* 1, CH_2Cl_2); ^{1}H NMR (200 MHz, $CDCl_3$) δ: 0.10 (s, 6H, $2CH_3$, silyl), 0.90 (s, 9H, $3CH_3$, silyl), 1.40 (s, 3H, CH_3), 1.45 (s, 3H, CH_3), 3.90 (m, 3H, H5, H6, H6′), 4.35 (ddd, 1H, $J_{3,4}$ = 6 Hz, H4), 4.60 (dd, 1H, $J_{2,3}$ = 2.7 Hz, H3), 4.75 (ddd, 1H, $J_{1,2}$ = 6.2 Hz, $J_{2,4}$ = 1.6 Hz, H2), 6.30 (d, 1H, H1). Anal. calcd. for $C_{15}H_{28}O_4Si$: C 59.96, H 9.39; found: C 60.27, H 9.12.

*6-O-Allyl-1,5-anhydro-2-deoxy-3,4-O-isopropylidene-*d*-lyxo-hex-1-enitol* **3**e

Sodium hydride (60%, 146 mg, 3.48 mmol) was added in small portions to a solution of **3***a* (590 mg, 3.17 mmol) in DMF (10 mL) under stirring and cooling in ice-water. The mixture was then stirred for 30 min at room temperature, allyl bromide (304 μL, 3.48 mmol) was added dropwise, and the mixture was stirred overnight at room temperature. Excess NaH was destroyed with MeOH and the reaction mixture partitioned between H_2O and CH_2Cl_2 (30 mL, 1:1). The aqueous layer was reextracted with CH_2Cl_2 (2 × 5 mL). The combined organic phase was washed with H_2O until the pH was neutral and then dried ($MgSO_4$). Evaporation afforded a residue, which was chromatographed on silica gel. Elution with EtOAc–hexane (1:10) afforded **3***e*: 584 mg (81%) as an oil. R_f 0.63 (EtOAc–hexane 1:9); $[\alpha]_D$ 14.2 (*c* 1, CH_2Cl_2); ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.30 (s, 3H, CH_3), 1.50 (s, 3H, CH_3), 3.65–3.85 (2dd, 2H, $J_{5,6}$ = 5 Hz $J_{5,6'}$ = 7.6 Hz, $J_{6,6'}$ = 10.2 Hz, H6, H6′), 4.10 (m, 1H, H4), 4.20 (m, 3H, CH_2 allyl, H5), 4.7 (dd, 1H, $J_{3,4}$ = 6.2 Hz, H3), 4.80 (m, 1H, $J_{2,4}$ = 1.5 Hz, $J_{2,3}$ = 2.8 Hz, H2), 5.30 (m, 2H, CH=*CH*$_2$), 5.90 (m, 1H, *CH*=CH_2), 6.40 (d, 1H, $J_{1,2}$ = 6.3 Hz, H1). Anal. calcd. for $C_{12}H_{18}O_4$: C 63.69, H 8.01; found: C, 63.43, H 8.16.

Typical procedures for azido-phenylselenylation

Procedure A

To a stirred solution of glycal (1 mmol), diphenyldiselenide (0.6 mmol), and sodium azide (2.4 mmol) in dichloromethane (4 mL) under argon, (diacetoxyiodo)benzene (1.4 mmol) was added. The mixture was stirred at room temperature during 48 h until TLC indicated completion of the reaction. The solution was diluted with dichloromethane (20 mL) and washed with 5% aqueous $NaHCO_3$ (2 × 8 mL). The aqueous layer was reextracted with dichloromethane (2 × 5 mL), the organic layer was washed until neutral pH, dried over $MgSO_4$, filtered, and evaporated. The crude product was purified by column chromatography on silica gel.

Procedure B

To a stirred solution of glycal (1 mmol), azidotrimethylsilane (2 mmol), and tetra-*n*-butylammonium fluoride (0.2 mmol) in dichloromethane (10 mL) under argon, was added *N*-PSP (2 mmol). The mixture was stirred at room temperature during 48 h. The solvent was evaporated, toluene (15 mL) was added, the precipitated salts were filtered off, and the crude mixture was concentrated and purified by column chromatography on silica gel. The following 2-azido-2-deoxy-1-seleno-α-d-glycopyranosides were prepared using one of these procedures.

*Phenyl 3,4,6-tri-*O*-acetyl-2-azido-2-deoxy-1-seleno-*α*-*d*-glucopyranoside* **5**a *and* α-*d*-*mannopyranoside* **6**a

Procedure A: yield (91%), oil; R_f 0.75 (CH_2Cl_2–Et_2O 9:1); IR (neat): 2119 (N_3), 1757 (OAc) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) *gluco* isomer δ: 2.00–2.20 (3s, 9H, OAc), 3.90–4.00 (dd, 1H, $J_{6',6}$ = 12.21 Hz, $J_{6,5}$ = 1.96 Hz, H6), 4.00–4.10 (dd, 1H, $J_{2,3}$ = 10.15 Hz, H2), 4.25–4.35 (dd, 1H, $J_{6',5}$ = 4.89 Hz, H6′), 4.50 (m, 1H, $J_{5,4}$ = 10.4 Hz, H5), 5.20–5.50 (m, 2H, H3, H4), 5.95 (d, 1H, $J_{1,2}$ = 5.39 Hz, H1), 7.15–7.20 (m, 5H, aromatic); *manno* isomer δ: 2.10–2.30 (3s, 9H, OAc), 4.20 (2dd, 2H, $J_{6,6'}$ = 12.24 Hz, $J_{6,5}$ = 2.16 Hz, $J_{6',5}$ = 5.15 Hz, H6, H6′), 4.37 (dd, 1H, $J_{2,3}$ = 2.95 Hz, H2), 4.45 (m, 1H, H5), 5.25–5.45 (m, 2H, H3, H4), 5.80 (d, 1H, $J_{1,2}$ = 1.27 Hz, H1), 7.20–7.70 (m, 5H, aromatic). Anal. calcd. for $C_{18}H_{21}O_7N_3Se$: C 45.96, H 4.50, N 8.93; found: C 46.35, H 4.47, N 9.00.

*Phenyl 3,4,6-tri-*O*-acetyl-2-azido-2-deoxy-1-seleno-*α*-*d*-galactopyranoside* **7**a

Procedure A: yield (92%), solid, mp 104–105°C; R_f 0.75 (CH_2Cl_2–Et_2O 9:1); $[\alpha]_D$ +170 (*c* 1, CH_2Cl_2); IR (KBr): 2119 (N_3), 1757 (OAc) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 2.20 (3s, 9H, OAc), 4.05 (2dd, 2H, $J_{6,5}$ = 7.1 Hz, $J_{6,6'}$ = 11.4 Hz, H6, H6′), 4.30 (dd, 1H, $J_{2,3}$ = 10.8 Hz, H2), 4.70 (bt, 1H, H5), 5.15 (dd, 1H, $J_{3,4}$ = 3.2 Hz, H3), 5.50 (dd, 1H, $J_{4,5}$ = 1.1 Hz, H4), 6.00 (d, 1H, $J_{1,2}$ = 5.4 Hz, H1), 7.20–7.70 (m, 5H, aromatic). Anal. calcd. for $C_{18}H_{21}O_7N_3Se$: C 45.96, H 4.50, N 8.93; found: C 46.06, H 4.50, N 9.08.

*Phenyl 2-azido-3,4,6-tri-*O*-benzyl-2-deoxy-1-seleno-*α*-*d*-glucopyranoside* **5**b *and* -α-*d*-*mannopyranoside* **6**b

Procedure B: yield (82%), oil; R_f 0.75 (CH_2Cl_2–hexane 9:1); IR (neat): 2119 (N_3) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 3.50–4.30 (m, 6H, H2, H3, H4, H5, H6, H6′), 4.40–5.00 (m, 6H, $3CH_2$ benzyl), 5.85 (bs, 0.3H, H1 *manno*), 5.95 (d, 0.7 H, $J_{1,2}$ = 4.98 Hz, H1 *gluco*), 7.00–7.70 (m, 20H, aromatic). Anal. calcd. for $C_{33}H_{33}O_4N_3Se$: C 64.49, H 5.41, N 6.83; found: C 64.43, H 5.48, N 7.00.

*Phenyl 2-azido-3,4,6-tri-*O*-benzyl-2-deoxy-1-seleno-*α*-*d*-galactopyranoside* **7**b

Procedure B: yield (75%), oil; R_f 0.75 (CH_2Cl_2–hexane 9:1); $[\alpha]_D$ +157 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 3.40–3.65 (m, 3H, H5, H6, H6′), 3.75 (dd, 1H, $J_{3,2}$ = 10.48 Hz, $J_{3,4}$ = 2.65 Hz, H3), 4.05 (d, 1H, H4), 4.30–5.00 (m, 7H, $3CH_2$ benzyl, H2), 5.93 (d, 1H, $J_{1,2}$ = 5.22 Hz, H1) 7.10–7.70 (m, 20H, aromatic) Anal. calcd. for $C_{33}H_{33}O_4N_3Se$: C 64.49, H 5.41, N 6.83; found: C 64.59, H 5.59, N 7.02.

*Phenyl 6-*O*-acetyl-2-azido-2-deoxy-3,4-*O*-isopropylidene-1-seleno-*α*-*d*-galactopyranoside* **9**b

Procedure B: yield (91%), solid, mp 86–88°C; R_f 0.59 (EtOAc–hexane 1:4); $[\alpha]_D$ +237.7 (*c* 1, CH_2Cl_2); IR (KBr): 2119 (N_3), 1750 (CO) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.15 (1s, 3H, CH_3), 1.25 (1s, 3H, CH_3), 2.00 (1s, 3H, OAc), 4.00 (t, 1H, $J_{4,5}$ = 1.65 Hz, $J_{5,6}$ = 5.5 Hz, $J_{5,6'}$ = 4.91 Hz, H5), 4.10–4.20 (m, 4H, H3, H4, H6, H6′), 4.30 (dd, 1H, $J_{2,3}$ = 6.05

Hz, H2), 5.90 (d, 1H, $J_{1,2}$ = 4.95 Hz, H1), 7.10–7.80 (m, 5H, aromatic). Anal. calcd. for $C_{17}H_{21}O_5N_3Se$: C 47.89, H 4.96, N 9.86; found: C 47.98, H 4.96, N 9.99.

*Phenyl 2-azido-6-*O*-benzyl-2-deoxy-3,4-*O*-isopropylidene-1-seleno-*α*-*D*-galactopyranoside* **9**c

Procedure B: yield (84%), oil; R_f 0.57 (EtOAc–hexane 1:9); $[\alpha]_D$ +202.8 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.40 (1s, 3H, CH_3) 1.55 (1s, 3H, CH_3), 3.70–3.90 (m, 2H, $J_{5,6}$ = 6.61 Hz, $J_{5,6'}$ = 5.11 Hz, $J_{6,6'}$ = 12.3 Hz, H6, H6′), 4.00 (t, 1H, $J_{4,5}$ = 1.4 Hz, H5), 4.05–4.45 (m, 2H, H3, H4), 4.60 (dd, 2H, CH_2 benzyl), 4.70 (1H, $J_{2,3}$ = 6.91 Hz, H2), 5.9 (d, 1H, $J_{1,2}$ = 4.95 Hz, H1), 7.00–7.60 (m, 10H, aromatic). Anal. calcd. for $C_{22}H_{25}O_4N_3Se$: C 55.69, H 5.31, N 8.86; found: C 55.62, H 5.28, N 9.00.

*Phenyl 2-azido-2-deoxy-3,4-O-isopropylidene-6-*O*-tert-butyldimethylsilyl-1-seleno-*α*-*D*-galactopyranoside* **9***d*

Procedure B: yield (66%), oil; R_f 0.56 (EtOAc–hexane 1:12); $[\alpha]_D$ +170.3 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.00 (1s, 6H, $2CH_3$, silyl), 0.80 (1s, 9H, $3CH_3$, silyl) 1.35 (1s, 3H, CH_3), 1.50 (1s, 3H, CH_3), 3.65–3.95 (m, 3H, $J_{6,6'}$ = 10.2 Hz, $J_{5,6}$ = 6.6 Hz, $J_{5,6'}$ = 6.4 Hz, H6, H6′, $J_{2,3}$ = 7.7 Hz, H2), 4.10–4.30 (m, 2H, $J_{3,4}$ = 5.3 Hz, H3, $J_{4,5}$ = 2.36 Hz, H4), 4.45 (m, 1H, H5), 5.75 (d, 1H, $J_{1,2}$ = 5.02 Hz, H1), 7.1–7.7 (m, 5H, aromatic). Anal. calcd. for $C_{21}H_{33}O_4N_3SeSi$: C 50.59, H 6.67, N 8.42; found: C 50.33, H 6.77, N 8.34.

*Phenyl 2-azido-3,4,6-tri-O-benzyl-2-deoxy-1-seleno-*α*-*D*-galactopyranoside* **7**b *from* **7**a

A solution of ***7a*** (235 mg, 0.5 mmol) and NaOMe (1 M, 0.8 mL) in MeOH (1 mL) was stirred at room temperature until deacetylation was complete (15 h). After neutralization with Amberlite resin IRN 77 (H^+ form) and filtration, evaporation of the solvent afforded a crude product (197 mg), which was dissolved in DMF (2.5 mL). After cooling at 0°C, NaH (60%, 80 mg, 2 mmol) was added. After stirring 1 h, benzyl bromide (200 μL, 1.65 mmol) was added and the mixture stirred at room temperature until TLC indicated completion of the reaction (15 h). Excess NaH was destroyed with MeOH and the reaction mixture partitioned between H_2O and CH_2Cl_2 (30 mL, 1:1). The aqueous layer was reextracted with CH_2Cl_2 (2 × 5 mL). The combined organic phase was washed with H_2O until neutral pH, and dried ($MgSO_4$). Evaporation afforded a residue, which was chromatographed on silica gel. Elution with CH_2Cl_2–hexane (1:1) afforded **7***b*: 253 mg (82%) as an oil identical to **7***b* prepared by azido-phenylselenylation of **2***b*.

*Phenyl 6-*O*-acetyl-2-azido-2-deoxy-3,4-*O*-isopropylidene-1-seleno-*α*-*D*-galactopyranoside* **9**b *from* **9**d

To a solution of ***9d*** (20 mg, 0.04 mmol) in THF (100 μL) was added *n*-Bu_4NF (1.1 M THF solution, 35 mL). Completion of the reaction was observed after stirring 30 min at room temperature. After evaporation, the residue was dissolved in pyridine (25 μL), and Ac_2O (12 μL, 0.12 mmol) was added. After stirring overnight at room temperature, evaporation and coevaporation with toluene afforded a residue, which was chromatographed on silica gel. Elution with EtOAc–hexane (1:16) afforded crude ***9b*** (12 mg, 70%). Recrystallization from absolute EtOH afforded an analytical sample identical to ***9b*** prepared by azido-phenylselenylation of ***3b***.

*Phenyl 2-azido-2-deoxy-3,4-*O*-isopropylidene-1-seleno-*α*-*D*-galactopyranoside* **9**a

Procedure B: yield (59%), oil; R_f 0.79 (EtOAc–hexane 1:9); $[\alpha]_D$ +167.7 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3), 3400 (OH) cm^{-1}, ^1H NMR (200 MHz, $CDCl_3$) δ: 1.38 (1s, 3H, CH_3), 1.55 (1s, 3H, CH_3), 1.78 (1s, 1H, OH), 3.70–3.90 (m, 2H, H6, H6′), 3.90–4.00 (dd, 1H, $J_{2,3}$ = 7.5 Hz, H2), 4.15–4.35 (m, 2H, $J_{3,4}$ = 5.34 Hz, H3, H4), 4.40–4.60 (m, 1H, H5), 5.80 (d, 1H, $J_{1,2}$ = 5.15 Hz, H1), 7.10–7.60 (m, 5H, aromatic). Anal. calcd. for $C_{15}H_{19}O_4N_3Se$: C 46.88, H 4.98, N 10.93; found: C 46.86, H 5.28, N 10.93.

*3,4-*O*-Isopropylidene-2-phenylseleno-*β*-*D*-galactopyranosyl azide*

Procedure B: yield (7%), oil; R_f 0.56 (EtOAc–hexane 1:9); $[\alpha]_D$ +31.4 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3), 3400 (OH) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.30 (1s 3H, CH_3), 1.40 (1s, 3H, CH_3), 2.50 (1s, 1H, OH), 3.40 (dd, 1H, $J_{1,3}$ = 6.7 Hz, H2), 3.70–4.20 (m, 5H, H3, H4, H5, H6, H6′), 4.60 (d, 1H, $J_{1,2}$ = 10.5 Hz, H1), 7.10–7.80 (m, 5H, aromatic). Anal. calcd. for $C_{15}H_{19}O_4N_3Se$: C 46.88, H 4.98, N 10.93; found: C 47.82, H 5.27, N 10.66.

*Phenyl 6-*O*-allyl-2-azido-2-deoxy-3,4-*O*-isopropylidene-1-seleno-*α*-*D*-galactopyranoside* **9**e

Procedure B: yield (74%), oil; R_f 0.42 (EtOAc–hexane 1:12); $[\alpha]_D$ +223.8 (*c* 1, CH_2Cl_2); IR (neat): 2119 (N_3) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.30 (1s, 3H, CH_3), 1.50 (1s, 3H, CH_3), 3.50–3.80 (2dd, 2H, $J_{5,6}$ = 7.10 Hz, $J_{5,6'}$ = 5 Hz, $J_{6,6'}$ = 10.5 Hz, H6, H6′), 3.85–4.00 (m, 3H), 4.15 (m, 2H, CH_2 allyl), 4.60 (m, 1H), 5.05–5.25 (m, 2H, CH=CH_2), 5.75 (d, 1H, $J_{1,2}$ = 5.1 Hz, H1), 5.80–5.90 (m, 1H, CH=CH_2), 7.10–7.70 (m, 5H, aromatic). Anal. calcd. for $C_{18}H_{23}O_4N_3Se$: C 50.94, H 5.46, N 9.90; found: C 51.15, H 5.29, N 9.93.

*Phenyl 2-azido-4,6-*O*-benzylidene-2-deoxy-1-seleno-*α*-*D*-galactopyranoside* ***10***a

Procedure B: yield (68%), solid; mp 116–117°C; R_f 0.57 (ether–hexane 1:4); $[\alpha]_D$ +155.8 (*c* 1, CH_2Cl_2); IR (KBr): 2119 (N_3), 3400 (OH) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.6 (1s, 1H, OH), 4.00 (dd, 1H, $J_{5,6}$ = 3.41 Hz, $J_{6,6'}$ = 10 Hz, H6), 4.05 (m, 3H H3, H5, H6′), 4.20 (d, 1H, $J_{4,5}$ = 1 Hz, H4), 5.55 (s, 1H, PhCH), 4.30 (dd, 1H, $J_{2,3}$ = 10.05 Hz, H2), 6.05 (d, 1H, $J_{1,2}$ = 5.03 Hz, H1), 7.20–7.60 (m, 10H, aromatic). Anal. calcd. for $C_{19}H_{19}O_4N_3Se$: C 52.78, H 4.43, N 9.72; found: C 52.93, H 4.45, N 9.46.

*Phenyl 3-*O*-acetyl-2-azido-4,6-*O*-benzylidene-2-deoxy-1-seleno-*α*-*D*-galactopyranoside* ***10***b

Procedure B: yield (73%), solid; mp 135–137°C; R_f 0.50 (EtOAc–hexane 1:4); $[\alpha]_D$ +307.9 (*c* 1, CH_2Cl_2); IR (KBr): 2119 (N_3), 1750 (OAc) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 2.20 (1s, 3H, OAc), 4.00–4.30 (m, 3H, $J_{5,6}$ = 1.8 Hz, $J_{5,6'}$ = 1.45 Hz, $J_{6,6'}$ = 12.75 Hz, H5, H6, H6′), 4.40–4.60 (m, 2H, H2, H4), 5.10 (dd, 1H, $J_{2,3}$ = 10.8 Hz, $J_{3,4}$ = 3.38 Hz, H3), 5.60 (1s, 1H, PhCH), 6.10 (d, 1H, $J_{1,2}$ = 5.2 Hz, H1), 7.20–7.70 (m, 10H, aromatic). Anal. calcd. for $C_{21}H_{21}O_5N_3Se$: C 53.16, H 4.46, N 8.85; found: C 53.18, H 4.55, N 8.88.

Phenyl 2-azido-3-O-benzyl-4,6-O-benzylidene-2-deoxy-1-seleno-α-D-galactopyranoside ***10***c

Procedure B: yield (76%), solid; mp 141–143°C; R_f 0.63 (EtOAc–hexane 1:4); $[\alpha]_D$ +143.3 (*c* 1, CH_2Cl_2); IR (KBr): 2119 (N_3) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 3.80 (dd, 1H, $J_{2,3}$ = 10.37 Hz, $J_{3,4}$ = 3.35 Hz, H3), 3.95–415 (m, 3H, H5, H6, H6′), 4.25 (d, 1H, H4), 4.40 (dd, 1H, H2), 4.80 (dd, 2H, *J* = 12.08 Hz, $PhCH_2$), 5.50 (1s, 1H, PhCH), 6.05 (d, 1H, $J_{1,2}$ = 5.20 Hz, H1), 7.20–7.60 (m, 15H, aromatic). Anal. calcd. for $C_{26}H_{25}O_4N_3Se$: C 59.77, H 4.82, N 8.04; found: C 60.01, H 4.97, N 7.82.

Typical procedures for hydrolysis

Procedure C

A solution of the protected phenyl 2-azido-2-deoxy-α-D-selenoglycopyranoside (1 mmol) in THF–H_2O (2 mL, 1:1) was treated at room temperature with *N*-iodosuccinimide (5 mmol). After 12 h the mixture was diluted with EtOAc (10 mL), and washed with saturated K_2CO_3 (10 mL). The aqueous layer was reextracted with EtOAc (2 × 5 mL). The organic layer was washed until neutral pH, dried over $MgSO_4$, filtered, and evaporated. The crude product was purified by column chromatography on silica gel.

Procedure D

A solution of the protected phenyl 2-azido-2-deoxy-α-D-selenoglycopyranoside (1 mmol) in THF–H_2O (2 mL, 1:1), was treated at room temperature with mercury trifluoroacetate (1.5 mmol). After 30 min the mixture was diluted with EtOAc (10 mL), and washed with saturated K_2CO_3 (10 mL). The aqueous layer was reextracted with EtOAc (2 × 5 mL). The combined EtOAc layer was washed with 5% aqueous Na_2S (10 mL). The aqueous layer was reextracted with EtOAc (2 × 10 mL), the organic layer was washed until neutral pH, dried over $MgSO_4$, filtered, and evaporated. The crude product was purified by column chromatography on silica gel.

3,4,6-Tri-O-acetyl-2-azido-2-deoxy-D-glucopyranose ***11***a *and mannopyranose* ***12***a

Procedure C was applied to the mixture of **5***a* and **6***a* to give a mixture of **11***a* and **12***a* (5) in 90% yield. Anal. calcd. for $C_{12}H_{17}O_8N_3$: C 43.50, H 5.17, N 12.68; found: C 43.68, H 4.98, N 12.66.

3,4,6-Tri-O-acetyl-2-azido-2-deoxy-D-galactopyranose ***13***a

Procedure C was applied to **7***a* to give known **13***a* (5) in 87% yield. Anal. calcd. for $C_{12}H_{17}O_8N_3$: C 43.50, H 5.17, N 12.68; found: C 43.59, H 5.32, N 12.69.

2-Azido-3,4,6-tri-O-benzyl-2-deoxy-D-glycopyranose ***11***b *and mannopyranose* ***12***b

Procedure D was applied to the mixture of **5***b* and **6***b* to give a mixture of **11***b* and **12***b*, which was chromatographed on silica gel. The first fraction gave known **11***b* (23) (66%) as a solid; mp 97°C. Anal. calcd. for $C_{27}H_{29}O_5N_3$: C 68.19, H 6.14, N 8.83; found: C 67.99, H 6.14, N 8.95.

The second fraction afforded **12***b* (12%) as a syrup, R_f 0.52 (ether–hexane 2:1); IR (neat): 2119 (N_3), 3400 (OH) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 3.40 (m, 1H), 3.50–3.95 (m, 7H), 4.00–4.30 (m, 4H, $J_{2,3}$ = 3.56 Hz, $J_{3,4}$ = 9.12 Hz, H4), 4.45–5.00 (m, 9H, $J_{1,2}$ = 1.63 Hz, H2), 5.15 (s, 1H, H2), 7.10–7.60 (15H, aromatic). Anal. calcd. for $C_{27}H_{29}O_5N_3$: C 68.19, H 6.14, N 8.83; found: C 68.62, H 6.16, N 8.79.

A mixture of **11***b* and **12***b* was obtained in 15% yield.

2-Azido-3,4,6-tri-O-benzyl-2-deoxy-D-galactopyranose ***13***b

Procedure D was applied to **7***b* to give known **13***b* (5) in 87% yield. Anal. calcd. for $C_{27}H_{29}O_5N_3$: C 68.19, H 6.14, N 8.83; found: C 68.17, H 6.10, N 8.68.

6-O-Acetyl-2-azido-2-deoxy-3,4-O-isopropylidene-D-galactopyranose ***14***a

Procedure D was applied to **9***b* to give known **14***a* (8) in 79% yield. Anal. calcd. for $C_{11}H_{17}O_6N_3$: C 45.98, H 5.82, N 14.62; found: C 46.12, H 5.82, N 14.63.

2-Azido-6-O-benzyl-2-deoxy-3,4-O-isopropylidene-D-galactopyranose ***14***b

Procedure D was applied to **9***c* to give known **14***b* (7) in 87% yield. Anal. calcd. for $C_{16}H_{21}O_5N_3$: C 57.30, H 6.31, N 12.53; found: C 57.45, H 6.42, N 12.66.

3-O-Acetyl-2-azido-4,6-O-benzylidene-2-deoxy-D-galactopyranose ***15***a

Procedure D was applied to **10***b* to give known **15***a* (7) in 87% yield. Anal. calcd. for $C_{15}H_{17}O_6N_3$: C 57.73, H 5.11, N 12.53; found: C 57.62, H 5.17, N 12.52.

2-Azido-3-O-benzyl-4,6-O-benzylidene-2-deoxy-D-galactopyranose ***15***b

Procedure D was applied to **10***c* to give **15***b* in 82% yield as a syrup; R_f 0.52 (EtOAc–hexane 2:3); IR (neat): 2119 (N_3), 3400 (OH) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 2.90 (1s, 1H, OH), 3.35 (1s, 1H, OH), 3.40 (dd, 1H, $J_{2,3}$ = 10.2 Hz, $J_{1,2}$ = 3.45 Hz, H2), 3.80–4.40 (m, 11H), 4.50 (1H, d, $J_{1,2}$ = 8.01 Hz, H1β), 1.75 (1s, 4H, $PhCH_2$), 5.40 (1s, 1H, H1α), 5.50 (1s, 2H, PhCH), 7.20–7.60 (m, 20H, aromatic). Anal. calcd. for $C_{20}H_{21}O_5N_3$: C 62.65, H 5.52, N 10.96; found: C 62.62, H 5.36, N 11.09.

6-O-Allyl-2-azido-2-deoxy-3,4-O-isopropylidene-D-galactopyranose ***14***c

Procedure D was applied to **9***e* to give **14***c* in 88% yield as a syrup; R_f 0.53 (EtOAc–hexane 1:3); IR (neat): 2119 (N_3), 3400 (OH) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.20–1.30 (2s, 6H, 2 CH_3), 1.50–1.70 (2s, 6H, $2CH_3$), 2.50 (s, 1H, OH), 3.20–4.20 (m, 14 H), 4.30–4.45 (m, 3H), 4.50 (d, 1H, $J_{1,2}$ = 8.2 Hz, H1β), 5.20 (m, 4H, $2CH{=}CH_2$), 5.25 (d, 1H, $J_{1,2}$ = 3.3 Hz, H1α), 5.8 (m, 2H, $2CH{=}CH_2$). Anal. calcd. for $C_{12}H_{19}O_5N_3$: C 50.51, H 6.71, N 14.72; found: C 50.33, H 6.86, N 14.79.

Note added in proof

Since the submission of this paper the separation of **5***b* and **6***b* was made possible by using a less polar eluent (ether–hexane 1:11) for column chromathography on silica gel. From **1***b* (1.248 g, 3 mmol), **6***b* was obtained as a syrup (518 mg, 28%), oil; R_f 0.60 (ether–hexane 1:4); $[\alpha]_D$ +83 (*c* 1, $CHCl_3$); IR (neat): 2119 (N_3) cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ: 3.75 (dd, 1H, $J_{5,6}$ = 1.75 Hz, $J_{6,6'}$ = 10.9 Hz, H6), 3.85 (dd, 1H $J_{5,6'}$ = 4.5 Hz, H6′), 4.00–4.15 (m, 3H, H3, H4, H5), 4.21 (dd, 1H,

$J_{2,3}$ = 3Hz, H2), 4.60–4.79 (m, 6H, $3CH_2$ benzyl), 5,85 (d, 1H, $J_{1,2}$ = 1.4 Hz, H1), 7.10–7.50 (m, 20H, aromatic) and **5***b* as crystals (1.135 g, 61.6%), mp 86–89°C; R_f 0.45 (ether–hexane 1:4); $[\alpha]_D$ +99 (*c* 1, $CHCl_3$); IR (KBr): 2119 (N_3) cm^{-1}; ^1H NMR (250 MHz, $CDCl_3$) δ: 3.88 (dd, 1H, $J_{5,6}$ = 2 Hz, $J_{6,6'}$ = 10.1 Hz, H6), 4.05–4.25 (m, 4H, H2, H3, H4, H6′), 4.58 (m, 1H, H5), 4.88–5.3 (m, 6H, $3CH_2$ benzyl), 5.95 (d, 1H, $J_{1,2}$ = 5 Hz, H1), 7.20–7.70 (m, 20H, aromatic).

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