Oxidative Hydrolysis of Conformationally Restrained Pent-4-enyl Glycosides: Formation of *N*-Acetyl-α-D-Glucopyranosylamines

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The α- and β-anomers of the conformationally restrained pent-4-enyl D-glucopyranosides (**5**) and (**6**) have been synthesised, and each anomer found to give stereospecifically the corresponding *N*-acetyl-α-D-glucopyranosylamines (**7**) and (**8**) as the major products on treatment with *N*-bromosuccinimide in 1% aqueous acetonitrile. In contrast, the strain free α- and β-anomers of pent-4-enyl 2,3,4,6-tetra-*O*-benzyl-D-glucopyranoside (**10**) yield only the corresponding pyranose (**11**). The α-configuration of the acetamide substituent in (**7**) and (**8**) was established by derivatisation of (**8**) to the 4,6-di-*O*-acetate (**12**α), subsequent ^{1}H n.m.r. nuclear Overhauser enhancement (n.O.e.) experiments, and by independent synthesis of the 4,6-di-*O*-acetate-β-anomeric acetamide (**12**β).

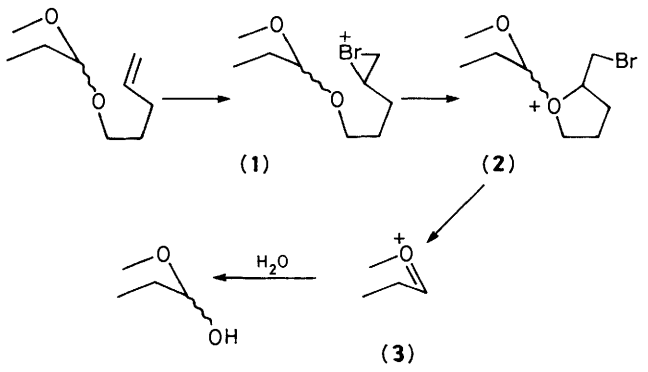
We have recently shown that treatment of pent-4-enyl glycosides with *N*-bromosuccinimide in 1% aqueous acetonitrile leads to specific hydrolysis of the glycosidic acetal, leaving a wide range of protecting groups unaffected.[1] Mechanistically, it is thought that the hydrolysis results from cascade of the bromonium ion (**1**) to the oxolanium ion (**2**), and then oxocarbenium ion (**3**), which is trapped by water to generate the requisite pyranose (Scheme 1). Subsequently, this process has been adapted to the synthesis of oligosaccharides, intermediate (**3**) being trapped by a sugar alcohol.[2,3] In this paper, we disclose our findings that treatment of the conformationally restrained pent-4-enyl glycosides (**5**) and (**6**) (both α- and β-anomers), with *N*-bromosuccinimide in 1% aqueous acetonitrile, leads to the corresponding *N*-acetyl-α-D-glucopyranosylamines, (**7**) and (**8**), respectively.

The 6:6:5 *trans-anti-trans* tricyclic α- and β-anomers (**5**α) and (**5**β) were prepared from the previously described pent-4-enyl glycoside (**4a**).[1] Kinetic acetonation of (**4a**) gave (**4b**) (57%) with return of (**4a**) (37%). Careful chromatographic fractionation gave the anomers (**4b**α) and (**4b**β), and treatment of each according to the method of Debost and co-workers[4] furnished pure (**5**α) (88%) and (**5**β) (91%). Reaction of (**4b**α) and (**4b**β) with 1,2-dichloroethane under phase transfer conditions using a modified procedure of Gross and Cesare[5] gave the corresponding 6:6:6 *trans-anti-trans* tricyclic anomers (**6**α) (66%) and (**6**β) (83%), along with a small amount of unreacted starting material in each case (Scheme 2).

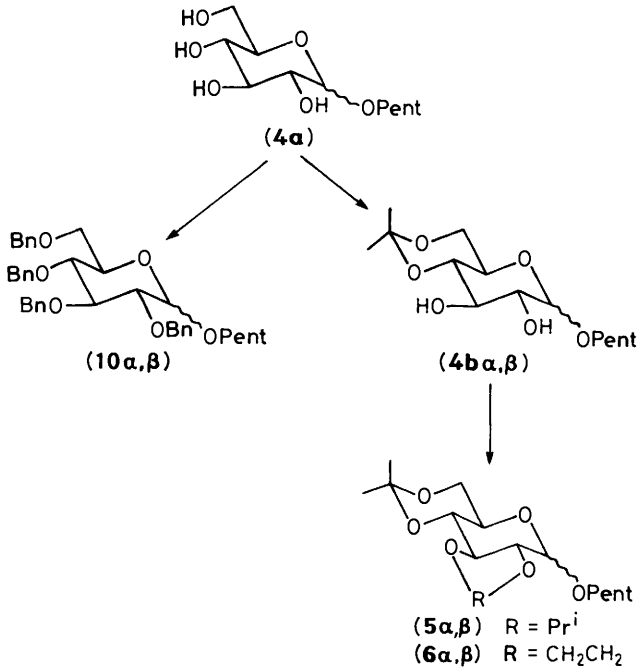
Treatment of either anomer of (**5**) and (**6**) with *N*-bromosuccinimide in 1% aqueous acetonitrile gave the *N*-acetyl-α-D-glucopyranosylamines (**7**) and (**8**), respectively as the major products isolated, with none of the corresponding β-glycosylamides being detected (Table 1). Accompanying formation of (**8**) from both (**6**α) and (**6**β) was the pyranose (**9a**), whose structure was confirmed by conversion to the corresponding glycosyl acetate (**9b**) and subsequent ^{1}H n.m.r. analysis.

In the reactions of (**5**α) and (**5**β), the ^{1}H n.m.r. spectrum of the crude mixtures showed no evidence of an aldose [comparable to (**9a**)] among several minor products that were not identified. The poor overall material balance from (**5**) may be a reflection of the strain imposed on the oxocarbenium ion intermediate by the 6:6:5 *trans-anti-trans* ring arrangement. This torsional strain was evident in the relatively long reaction times required for disappearance of starting material.

To confirm that the formation of the glucopyranosylamines (**7**) and (**8**) was associated with the strain imposed on the pyranose ring, we re-investigated the oxidative hydrolysis of the



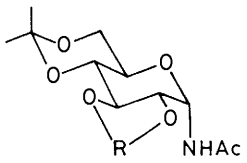
Scheme 1.



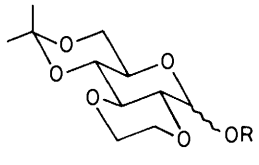
Scheme 2.

Table 1. Reaction of (**5**), (**6**), and (**10**) with *N*-bromosuccinimide in 1% aqueous acetonitrile

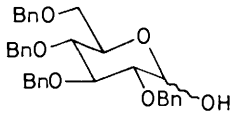
Starting material	Time (h)	Products isolated (%)
(**5**α)	65	(**7**) (34)
(**5**β)	65	(**7**) (27)
(**6**α)	43	(**8**) (45), (**9a**) (13)
(**6**β)	20	(**8**) (75), (**9a**) (4)
(**10**α)	2	(**11**) (71)
(**10**β)	3	(11) (71)



(**7**) R = Pr^i
(**8**) R = CH_2CH_2



(**9a**) R = OH
(**9b**) R = Ac



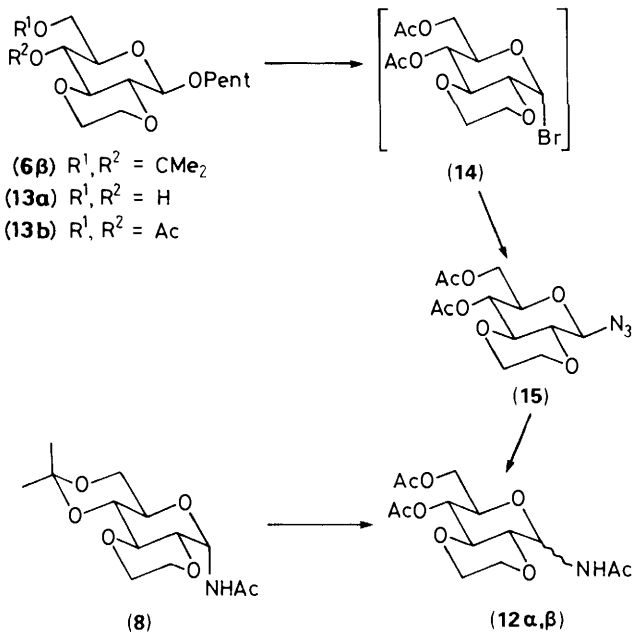
(**11**)

perbenzylated pent-4-enyl glycoside (**10**), formed from benzylation of (**4a**) in 70% yield (Scheme 2). Careful separation of the (**10**α) and (**10**β) anomers, and reaction of each with *N*-bromosuccinimide in 1% aqueous acetonitrile generated the pyranose (**11**) cleanly, with no evidence (^{1}H n.m.r.) of acetamide formation.

The values $J_{1,2}$ 4.6 and 5.6 Hz observed for proton H-1 [after deuterium exchange of the NHAc protons in (**7**) and (**8**), respectively] suggested α-configurations for these acetamides in line with reports for other *N*-acetyl-α-D-pyranosylamines.[6,7] However we felt that these assignments required clarification in view of the fact that $J_{1,2}$ values of similar magnitude had been reported for some β-glucopyranosylamides by Sinay and Pougny,[8] and Schmidt and Michel.[9] The latter assignments are in contrast with many analogues whose parameters, $J_{1,2}$ 8—10 Hz, were deemed to be indicative of β-configuration,[7,10,11]

Consequently, the isopropylidene group in (**8**) was removed by acid hydrolysis and the resulting diol acetylated *in situ* to give the 4,6-di-*O*-acetate (**12**α) (74%) (Scheme 3). N.O.e. difference studies showed a 12% enhancement for H-2 upon irradiation of proton H-1, which supports the assignment of α-configuration of the anomeric acetamide in (**7**) and (**8**).

For further confirmation, the 4,6-di-*O*-acetate, containing the anomeric acetamide in β-configuration, (**12**β), was synthesised unambiguously by the following route. The isopropylidene group in (**6**β) was removed by acid hydrolysis and the resulting diol (**13a**) acetylated to afford the 4,6-di-*O*-acetate (**13b**) (83% overall). Treatment with bromine in dichloromethane afforded the glucopyranosyl bromide (**14**), whose n.m.r. spectrum showed the value $J_{1,2}$ 3.6 Hz, diagnostic of an equatorial H-1.[12] We presume that (**14**) results from a similar cascade mechanism as that depicted in Scheme 1, except the oxocarbenium ion (**3**) is trapped by bromide to give the more thermodynamically stable α-anomer, in accord with ample precedents.[13] However, sequential treatment of (**13b**) with bromine, then sodium azide in *N*,*N*-dimethylformamide, led exclusively to the β-D-glucopyranosyl azide (**15**) (77%) by S_N2 displacement.[14] Reduction and acylation then afforded (**12**β) (Scheme 3).



(**6**β) R^1,R^2 = CMe_2
(**13a**) R^1, R^2 = H
(**13b**) R^1, R^2 = Ac

(**14**)

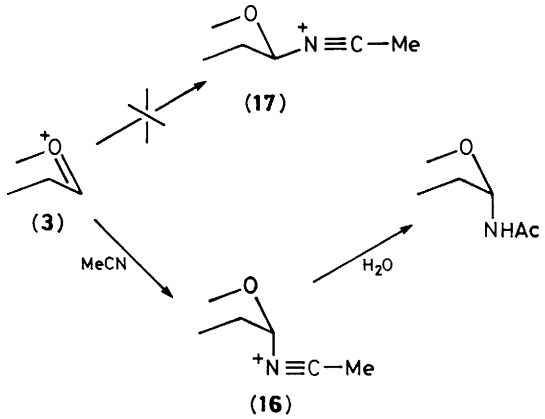
(**15**)

(**8**)

(**12**α,β)

Scheme 3.

There are many examples of the formation of nitrilium salts by nucleophilic attack on an electrophilic carbon by a nitrile.[15] Consequently, a possible mechanism for formation of the *N*-acetyl-α-D-glucopyranosylamines may parallel that for the α-D-glucopyranosyl bromide (**14**), except the oxocarbenium ion (**3**) is trapped by acetonitrile to give the α-acetonitrilium ion (**16**). Reaction of (**16**) with water then yields the α-anomeric acetamide found in (**7**) and (**8**) (Scheme 4).



Scheme 4.

It is unclear why the oxocarbenium ion resulting from the constrained pent-4-enyl glycosides traps acetonitrile so effectively. It may be that the reactivity of the oxocarbenium ion is greatly enhanced by the ring strain. However, ring strain of the oxocarbenium ion intermediate may not be the only factor. From Table 1 it is seen that the anomeric pair (**6**α) and (**6**β) give very different ratios of products (**8**) and (**9a**). This suggests that there may be differences in the ease of formation of the intermediate [*e.g.*, (**3**)] for both anomers. These differences are not yet reconciled and are topics of continued investigations.

A further interesting point of issue is the α-anomeric configuration of the acetonitrilium ion (**16**). In similar circumstances, formation of a β-acetonitrilium ion (**17**) has been suggested[8,9] as a consequence of the reverse anomeric effect.[16]

Furthermore, general evidence has indicated that the acetamide moiety possesses little anomeric effect[16] and would therefore prefer equatorial orientation on steric grounds. Hence, it is unlikely that a thermodynamic driving force is responsible for the axial orientation of the anomeric acetamide in (**7**) and (**8**), which suggests the result is kinetic in origin. It is noteworthy that Pavia and co-workers,[10] and Lemieux and Ratcliffe[6] have reported carbohydrate acetonitrilium ions adopting an α-anomeric configuration as in (**16**). Further studies are in progress.

Experimental

Column chromatography was carried out on Kieselgel (230—400 mesh) with the eluant specified in parentheses. All reactions requiring anhydrous conditions were conducted in an oven-dried apparatus under a static atmosphere of argon. Organic extracts were dried over $MgSO_4$ and evaporated at aspirator pressure using a rotary evaporator, unless otherwise stated. Light petroleum refers to the fraction boiling between 35 to 60 °C. Dichloromethane, pyridine, and *N*,*N*-dimethylformamide (DMF) were dried and distilled before use using standard methods.[17] *N*-Bromosuccinimide (NBS) was recrystallised from hot water and dried *in vacuo* over phosphorus pentoxide. Chemical shifts are reported in δ values relative to tetramethylsilane or chloroform as an internal standard. ^1H N.m.r. spectra were recorded in deuteriochloroform on a Varian XL-300 spectrometer. I.r. spectra were recorded in chloroform on a Perkin-Elmer 297 instrument. Optical rotations were measured for chloroform solutions using a Perkin-Elmer 241 instrument. Mass spectra were recorded on a Hewlett-Packard 59-88A GCMS by chemical ionisation (with methane–ammonia as the reagent gas). Accurate mass determinations were recorded on a VG-705 by chemical ionisation (with ammonia as the reagent gas, an accelerating voltage of 8 kV, and ~10 000 resolution). T.l.c. was conducted on precoated Kieselgel 60 F254 (Art. 5554; Merck) and spots visualised using a mixture of ammonium molybdate(VI) tetrahydrate and cerium(IV) sulphate tetrahydrate in 10% aqueous sulphuric acid. M.p.s were recorded with a Buchi 510 apparatus and are uncorrected. Elemental combustion analyses were performed by M-H-W Laboratories, Phoenix, Arizona.

Pent-4-enyl 4,6-O-*Isopropylidene*-α-D-*glucopyranoside* (**4b**α) *and Pent-4-enyl* 4,6-O-*Isopropylidene*-β-D-*glucopyranoside* (**4b**β).—To a stirred solution of the pent-4-enyl glycoside (**4a**), (2.06 g, 8.31 mmol) in dry DMF (20 ml) was added (1*S*)-(+)-10-camphorsulphonic acid (0.09 g, 0.39 mmol) and 2,2-dimethoxypropane (2 ml, 16.29 mmol). The resulting mixture was stirred at room temperature for 45 min before adding 1.2M sodium methoxide in methanol (1 ml, 1.20 mmol). Evaporation of the solvent under reduced pressure (0.1 mmHg) without heating and flash chromatography of the residue (light petroleum–ethyl acetate, 1:1) gave first *pent-4-enyl* 4,6-O-*isopropylidene*-β-D-*glucopyranoside* (**4b**β) as a colourless oil (0.41 g, 17%), $[\alpha]_D^{21}$ 34.5° (*c* 0.17); δ_H 5.80 (1 H, qt, J_1 16.9 Hz, J_2 10.2 Hz, J_3 6.6 Hz, C*H*=CH$_2$), 5.05—4.94 (2 H, m, CH=CH_2), 4.31 (1 H, d, *J* 7.7 Hz, 1-H), 3.93—3.82 (2 H, m, 6eq-H and OCH_AH$_B$CH$_2$CH$_2$), 3.78 (1 H, t, *J* 10.5 Hz, 6ax-H), 3.66 (1 H, td, J_1 8.9 Hz, J_2 2.1 Hz, addition of D_2O caused td to collapse to t, 3-H), 3.59—3.50 (2 H, m, 4-H and OCH$_A$H$_B$CH$_2$CH$_2$), 3.43 (1 H, td, J_1 8.2 Hz, J_2 2.5 Hz, addition of D_2O caused td to collapse to t, 2-H), 3.25 (1 H, td, J_1 9.8 Hz, J_2 5.3 Hz, 5-H), 2.62 (1 H, d, *J* 2.0 Hz, exchanged with D_2O, OH), 2.47 (1 H, d, *J* 2.5 Hz, exchanged with D_2O, OH), 2.16—2.09 (2 H, m, CH_2CH=CH$_2$), 1.77—1.69 (2 H, m, CH$_2$CH_2CH$_2$), 1.49 (3 H, s, CH$_3$), and 1.42 (3 H, s, CH$_3$) (Found: C, 58.5; H, 8.2. $C_{14}H_{24}O_6$ requires C, 58.3; H, 8.4%).

Eluted second was *pent-4-enyl* 4,6-O-*isopropylidene*-α-D-*glucopyranoside* (**4b**α) as a colourless oil (0.76 g, 32%), $[\alpha]_D^{22}$ +117.4° (*c* 0.08); δ_H 5.79 (1 H, qt, J_1 16.9 Hz, J_2 10.2 Hz, J_3 6.7 Hz, C*H*=CH$_2$), 5.07—4.96 (2 H, m, CH=CH_2), 4.83 (1 H, d, *J* 3.9 Hz, 1-H), 3.84 (1 H, dd, J_1 10.3 Hz, J_2 5.1 Hz, 6eq-H), 3.78—3.40 (7 H, m, 2-H, 3-H, 4-H, 5-H, 6ax-H, and OCH_2CH$_2$CH$_2$), 2.56 (1 H, d, *J* 2.0 Hz, exchanged with D_2O, OH), 2.16—2.09 (3 H, m, CH_2CH=CH$_2$ and OH, addition of D_2O caused the integral of this signal to decrease to that corresponding to 2 H), 1.77—1.67 (2 H, m, CH$_2$CH_2CH$_2$), 1.50 (3 H, s, CH$_3$), and 1.43 (3 H, s, CH$_3$) (Found: C, 58.05; H, 8.5. $C_{14}H_{24}O_6$ requires C, 58.3; H, 8.4%).

A mixed fraction comprising of (**4b**α) and (**4b**β) was also collected (0.19 g, 8%).

Final elution of the column [with dichloromethane–methanol (20:3)] returned (**4a**) (0.77 g, 37%).

Pent-4-enyl 2,3:4,6-*Di*-O-*isopropylidene*-α-D-*glucopyranoside* (**5**α).—To a stirred solution of the diol (**4b**α) (257 mg, 0.89 mmol) in dry DMF (1 ml) was added (1*S*)-(+)-10-camphorsulphonic acid (4 mg) and 2-methoxypropene (0.13 ml, 1.36 mmol). The resulting mixture was stirred at room temperature for 45 min before adding solid sodium hydrogen carbonate. After evaporation of the solvent under reduced pressure (0.1 mmHg) with no heating, the residue was partitioned between water (50 ml) and dichloromethane (50 ml). The layers were thoroughly stirred, separated, and the aqueous layer further extracted with dichloromethane (2 × 50 ml). The combined dried extracts were evaporated under reduced pressure and the oily residue purified by flash chromatography (light petroleum–ethyl acetate, 1:1) to give the *title compound* as a colourless oil (259 mg, 88%), $[\alpha]_D^{21}$ +94.5° (*c* 0.96), δ_H 5.80 (1 H, qt, J_1 17.1 Hz, J_2 10.4 Hz, J_3 6.7 Hz, C*H*=CH$_2$), 5.11 (1 H, d, *J* 3.0 Hz, 1-H), 5.08—4.95 (2 H, m, CH=CH_2), 4.03 (1 H, t, *J* 9.3 Hz, 3-H), 3.90—3.47 (7 H, m, 2-H, 4-H, 5-H, 6ax-H, 6eq-H, and OCH_2CH$_2$CH$_2$), 2.17—2.10 (2 H, m, CH_2CH=CH$_2$), 1.78—1.68 (2 H, m, CH$_2$CH_2CH$_2$), 1.53 (3 H, s, CH$_3$), 1.45 (3 H, s, CH$_3$), and 1.44 (6 H, s, 2 × CH$_3$) (Found: C, 62.1; H, 8.3. $C_{17}H_{28}O_6$ requires C, 62.2; H, 8.6%).

Pent-4-enyl 2,3:4,6-*Di*-O-*isopropylidene*-β-D-*glucopyranoside* (**5**β).—In the same way, the diol (**4b**β) (255 mg) gave the *title compound* (264 mg, 91%) as a colourless oil that slowly solidified to a white solid, m.p. 69—71 °C (from light petroleum–ether); $[\alpha]_D^{22}$ −40.7° (*c* 0.59); δ_H 5.78 (1 H, qt, J_1 17.1 Hz, J_2 10.2 Hz, J_3 6.6 Hz, C*H*=CH$_2$), 5.04—4.93 (2 H, m, CH=CH_2), 4.67 (1 H, d, *J* 7.9 Hz, 1-H), 3.97—3.81 (4 H, m, 4-H, 6ax-H, 6eq-H, and OCH_AH$_B$CH$_2$CH$_2$), 3.65—3.56 (2 H, m, 3-H and OCH$_A$H$_B$CH$_2$CH$_2$), 3.39 (1 H, dd, J_1 8.9 Hz, J_2 7.9 Hz, 2-H), 3.24 (1 H, td, J_1 9.4 Hz, J_2 5.6 Hz, 5-H), 2.15—2.07 (2 H, m, CH_2CH=CH$_2$), 1.79—1.69 (2 H, CH$_2$CH_2CH$_2$), 1.52 (3 H, s, CH$_3$), 1.45 (6 H, s, 2 × CH$_3$), and 1.42 (3 H, s, CH$_3$) (Found: C, 62.3; H, 8.6. $C_{17}H_{28}O_6$ requires C, 62.2; H, 8.6%).

Pent-4-enyl 2,3-O-*Ethylene*-4,6-O-*isopropylidene*-α-D-*glucopyranoside* (**6**α).—To a stirred solution of the diol (**4b**α) (346 mg, 1.20 mmol) and tetrabutylammonium bromide (79 mg, 0.25 mmol) in 1,2-dichloroethane (5.5 ml) was added 35% aqueous sodium hydroxide (7.5 ml). The two resulting layers were thoroughly stirred at between 50—55 °C for 48 h, with a further portion of 1,2-dichloroethane (2 ml) added after 24 h. After allowing to cool, the mixture was added to water (50 ml) and extracted with ether (4 × 50 ml). The combined extracts were washed with brine (100 ml), dried, and the solvent removed under reduced pressure. Flash chromatography of the oily residue gave two components. The first component (eluted with light petroleum–ethyl acetate, 65:35), corresponding to the *title compound* was a colourless oil (248 mg, 66%), $[\alpha]_D^{23}$ +71.8°

(*c* 0.61); δ_H 5.79 (1 H, qt, J_1 17.0 Hz, J_2 10.4 Hz, J_3 6.6 Hz, C*H*=CH_2), 5.06—4.95 (2 H, m, CH=CH_2), 4.82 (1 H, d, *J* 3.7 Hz, 1-H), 3.88—3.62 (10 H, m, 3-H, 4-H, 5-H, 6ax-H, 6eq-H, OCH_2CH_2O, and O$CH_AH_BCH_2CH_2$), 3.53—3.44 (2 H, m, 2-H and O$CH_AH_BCH_2CH_2$), 2.17—2.09 (2 H, m, CH_2CH=CH_2), 1.81—1.70 (2 H, m, $CH_2CH_2CH_2$), 1.51 (3 H, s, CH_3), and 1.45 (3 H, s, CH_3) (Found: C, 61.4; H, 8.3. $C_{16}H_{26}O_6$ requires C, 61.1; H, 8.3%).

The second component (eluted with light petroleum–ethyl acetate, 1:1) was returned starting material (**4b**α) (65 mg, 19%).

Pent-4-enyl 2,3-O-*Ethylene*-4,6-O-*isopropylidene*-β-D-*glucopyranoside* (**6**β).—In the same way, the diol (**4b**β) (364 mg) gave an 8% yield of returned (**4b**β) (28 mg) and the *title compound* (329 mg, 83%) as a colourless oil; $[\alpha]_D^{21}$ −64.8° (*c* 0.85); δ_H 5.78 (1 H, qt, J_1 17.0 Hz, J_2 10.3 Hz, J_3 6.6 Hz, C*H*=CH_2), 5.04—4.92 (2 H, m, CH=CH_2), 4.44 (1 H, d, *J* 7.8 Hz, 1-H), 3.92—3.75 (7 H, m, 6ax-H, 6eq-H, OCH_2CH_2O and O$CH_AH_BCH_2CH_2$), 3.70 (1 H, t, *J* 9.4 Hz, 4-H), 3.60—3.52 (1 H, m, O$CH_AH_BCH_2CH_2$), 3.47 (1 H, t, *J* 9.2 Hz, 3-H), 3.35—3.24 (2 H, m, 2-H and 5-H), 2.14—2.03 (2 H, m, CH_2CH=CH_2), 1.77—1.68 (2 H, m, $CH_2CH_2CH_2$), 1.50 (3 H, s, CH_3), and 1.44 (3 H, s, CH_3) (Found: C, 61.2; H, 8.5. $C_{16}H_{26}O_6$ requires C, 61.1; H, 8.3%).

Pent-4-enyl 2,3,4,6-*Tetra*-O-*benzyl*-α-D-*glucopyranoside* (**10**α) *and Pent-4-enyl* 2,3,4,6-*Tetra*-O-*benzyl*-β-D-*glucopyranoside* (**10**β).—A stirred solution of (**4a**) (0.51 g, 2.05 mmol) in dry DMF (15 ml) was treated with tetrabutylammonium iodide (148 mg, 0.40 mmol), sodium hydride (60% dispersion in oil; 249 mg, 10.38 mmol), and benzyl bromide (1.1 ml, 9.25 mmol) for 2 h at 0 °C. After allowing to warm to room temperature and stirring for another 3 h, the solvent was removed under reduced pressure (0.1 mmHg) with no heating. The residue was added to water (50 ml) and extracted with chloroform (5 × 50 ml). Evaporation of the combined, dried extracts, and flash chromatography of the resulting oily residue (gradient of 0.5—1% ethyl acetate in chloroform) gave first *pent-4-enyl* 2,3,4,6-*tetra*-O-*benzyl*-α-D-*glucopyranoside* (**10**α) (533 mg, 43%) as a colourless oil, $[\alpha]_D^{20}$ +34.4° (*c* 0.25); δ_H 7.37—7.11 (20 H, 4 × CH_2Ph), 5.81 (1 H, qt, J_1 17.1 Hz, J_2 10.2 Hz, J_3 6.6 Hz C*H*=CH_2), 5.06—4.45 (11 H, m, 4 × CH_2Ph, CH=CH_2 and 1-H), 3.99 (1 H, t, *J* 9.2 Hz, 3-H), 3.79—3.60 (5 H, m, 4-H, 5-H, 6-H, 6′-H, and O$CH_AH_BCH_2CH_2$), 3.56 (1 H, dd, J_1 9.6 Hz, J_2 3.6 Hz, 2-H), 3.47—3.39 (1 H, m, O$CH_AH_BCH_2CH_2$), 2.17—2.09 (2 H, m, CH_2CH=CH_2), and 1.78—1.68 (2 H, m, $CH_2CH_2CH_2$) (Found: C, 77.1; H, 7.5. $C_{39}H_{44}O_6$ requires C, 76.95; H, 7.3%).

Eluted second was *pent-4-enyl* 2,3,4,6-*tetra*-O-*benzyl*-β-D-*glucopyranoside* (**10**β) (289 mg, 23%) as a colourless oil that slowly solidified to a white solid, m.p. 70—71 °C (from dichloromethane–hexane), $[\alpha]_D^{20}$ +6.1° (*c* 0.53); δ_H 7.36—7.14 (20 H, m, 4 × CH_2Ph), 5.83 (1 H, qt, J_1 17.0 Hz, J_2 10.2 Hz, J_3 6.6 Hz, C*H*=CH_2), 5.06—4.51 (10 H, m, 4 × CH_2Ph and CH=CH_2), 4.39 (1 H, d, *J* 7.8 Hz, 1-H), 4.02—3.94 (1 H, m, O$CH_AH_BCH_2CH_2$), 3.74 (1 H, dd, J_1 10.8 Hz, J_2 1.9 Hz, 6-H), 3.72—3.52 (4 H, m, 3-H, 4-H, 6′-H, and O$CH_AH_BCH_2$), 3.48—3.42 (2 H, m, 2-H and 5-H), 2.21—2.14 (2 H, m, CH_2CH=CH_2), and 1.81—1.72 (2 H, m, $CH_2CH_2CH_2$) (Found: C, 76.8; H, 7.1. $C_{39}H_{44}O_6$ requires C, 76.95; H, 7.3%).

A mixed fraction comprising of (**10**α) and (**10**β) was also collected (52 mg, 4%).

General Procedure for the Reaction of Pent-4-enyl Glycosides with NBS.—NBS (2.5 equivalents) was added to a solution of the pent-4-enyl glycoside in 1% aqueous acetonitrile (20 ml/mmol of pent-4-enyl glycoside). The reaction flask was wrapped in silver foil and progress of the reaction was monitored by t.l.c. When the starting material had disappeared, the reaction was quenched with 10% aqueous sodium thiosulphate (1 ml) and the solvent removed under reduced pressure. The resulting residue was partitioned between water (25 ml) and dichloromethane (25 ml), the layers thoroughly stirred, separated, and the aqueous layer further extracted with dichloromethane (4 × 25 ml). The combined extracts were washed with water (2 × 25 ml), dried, and the solvent removed under reduced pressure. Flash chromatography of the residue using light petroleum–ethyl acetate solvent mixtures afforded the following products.

N-*Acetyl*-2,3:4,6-*di*-O-*isopropylidene*-α-D-*glucopyranosylamine* (**7**) as a colourless glass, $[\alpha]_D^{22}$ +97.2° (*c* 0.62); $\nu_{max.}$ 3 450 (NH), 1 700 ($NCOCH_3$), and 1 495 ($NCOCH_3$) cm^{-1}; δ_H 6.03 (1 H, d, *J* 6.3 Hz, exchanged with D_2O, NH), 5.86 (1 H, dd, J_1 6.6 Hz, J_2 4.8 Hz, addition of D_2O caused dd to collapse to d, *J* 4.6 Hz, 1-H), 3.93—3.86 (2 H, m, 4-H and 6eq-H), 3.81 (1 H, t, *J* 10.5 Hz, 6ax-H), 3.73 (1 H, dd, J_1 9.3 Hz, J_2 4.7 Hz, 2-H), 3.65 (1 H, t, *J* 9.3 Hz, 3-H), 3.36 (1 H, td, J_1 9.7 Hz, J_2 5.1 Hz, 5-H), 2.09 (3 H, s, $NCOCH_3$), 1.53 (3 H, s, CH_3), 1.47 (3 H, s, CH_3), 1.46 (3 H, s, CH_3), and 1.41 (3 H, s, CH_3); *m*/*z* 302 (18%, M^+ + 1) and 106 (100) (Found: M^+ + 1, 302.1600. $C_{14}H_{23}NO_6$ requires M + 1, 302.1604).

N-*Acetyl*-2,3-O-*ethylene*-4,6-O-*isopropylidene*-α-D-*glucopyranosylamine* (**8**) as a colourless glass, $[\alpha]_D^{22}$ +55.0° (*c* 0.15); $\nu_{max.}$ 3 450 (NH), 1 695 ($NHCOCH_3$) and 1 495 ($NHCOCH_3$) cm^{-1}; δ_H 6.13 (1 H, d, *J* 5.5 Hz, exchanged with D_2O, NH), 5.58 (1 H, t, *J* 6.0 Hz, addition of D_2O caused t to collapse to d, *J* 5.6 Hz, 1-H), 3.90—3.49 (10 H, m, 2-H, 3-H, 4-H, 5-H, 6eq-H, 6ax-H, OCH_2CH_2O), 2.08 (3 H, s, $NCOCH_3$), 1.50 (3 H, s, CH_3), and 1.43 (3 H, s, CH_3); *m*/*z* 305 (24%, M^+ + 18) and 288 (100, M^+ + 1) (Found: M^+ + 1, 288.1438. $C_{13}H_{21}NO_6$ requires M + 1, 288.1447).

2,3-O-*Ethylene*-4,6-O-*isopropylidene*-D-*glucopyranose* (**9a**) as a gum; δ_H 5.22 (d, *J* 3.5 Hz, 1-H for the α-anomer), 4.77 (d, *J* 7.7 Hz, 1-H for the β-anomer). The remaining spectrum was complicated owing to the mixture of anomers. The ratio of α- to β-anomers was ~3:2 from both (**6**α) and (**6**β).

A stirred solution of (**9a**) (7 mg) in ethyl acetate was treated with 4-dimethylaminopyridine (~1 mg) and acetic anhydride (~0.1 ml). After 1 h, the solvent was removed under reduced pressure and the residue partitioned between saturated aqueous sodium hydrogen carbonate (5 ml) and dichloromethane (5 ml). The layers were thoroughly stirred, separated, and the organic layer dried. Evaporation of the solvent under reduced pressure and flash chromatography of the crude product afforded 1-O-*acetyl*-2,3-O-*ethylene*-4,6-O-*isopropylidene*-D-*glucopyranose* (**9b**) (6.4 mg, 78%) as a gum; δ_H 6.12 (d, *J* 3.9 Hz, 1-H), and 2.16 (s, $COCH_3$) for the α-anomer; 5.67 (d, *J* 8.2 Hz, 1-H) and 2.14 (s, $COCH_3$) for the β-anomer. The remaining spectrum was complicated owing to a mixture of anomers; *m*/*z* 306 (16%, M^+ + 18), 289 (7, M^+ + 1), and 266 (100).

2,3,4,6-*Tetra*-O-*benzyl*-D-*glucopyranose* (**11**) as a white solid; δ_H 5.23 (br t, addition of D_2O caused br t to collapse to d, *J* 3.4 Hz, 1-H for the α-anomer), 3.09 (d, *J* 5.5 Hz, exchanged D_2O, OH for the β-anomer) and 2.85 (d, *J* 2.5 Hz, exchanged D_2O, OH for the α-anomer). The remaining spectrum was complicated owing to the mixture of anomers. The ratio of α- to β-anomers was ~1:1 from both (**10**α) and (**10**β) (Found: C, 75.5; H, 6.7. $C_{34}H_{36}O_6$ requires C, 75.5; H, 6.7%).

N-*Acetyl*-4,6-*di*-O-*acetyl*-2,3-O-*ethylene*-α-D-*glucopyranosylamine* (**12**α).—A solution of (**8**) (10.6 mg) in methanol (2 ml) was treated with toluene-*p*-sulphonic acid (1 mg) for 2.5 h at room temperature. The mixture was evaporated under reduced pressure and the residue taken up in dry pyridine (1 ml) containing acetic anhydride (0.3 ml). The resulting solution was stirred at room temperature for 12 h before removing the solvent under reduced pressure (0.1 mmHg) with no heating.

The residue was partitioned between saturated aqueous sodium hydrogen carbonate (20 ml) and chloroform (25 ml), and the layers thoroughly stirred and separated. The aqueous layer was further extracted with chloroform (25 ml) and the combined dried extracts were evaporated under reduced pressure. Flash chromatography of the crude product (ethyl acetate) gave the compound (**12**α) (9.1 mg, 74%) as a colourless glass, $[\alpha]_D^{20}$ +63.7° (*c* 0.16); $\nu_{max.}$ 3 450 (NH), 1 745 (CO_2CH_3), 1 700 ($NCOCH_3$), and 1 495 ($NCOCH_3$) cm^{-1}; δ_H 6.12 (1 H, d, *J* 5.6 Hz, exchanged with D_2O, NH), 5.59 (1 H, br t, addition of D_2O caused br t to collapse to d, *J* 4.7 Hz, 1-H), 5.02 (1 H, t, *J* 9.9 Hz, 4-H), 4.27 (1 H, dd, J_1 12.2 Hz, J_2 4.6 Hz, 6′-H), 3.99 (1 H, dd, J_1 12.4 Hz, J_2 2.2 Hz, 6-H), 3.86—3.65 (6 H, m, 2-H, 5-H, and OCH_2CH_2O), 3.52 (1 H, t, *J* 9.7 Hz, 3-H), 2.08, 2.06, and 2.04 (9 H, 3 × s, 2 × $COCH_3$, and $NCOCH_3$); *m*/*z* 349 (16%, M^+ + 18) and (332, M^+ + 1) (Found: C, 50.4; H, 6.4; N, 4.0. $C_{14}H_{21}NO_8$ requires C, 50.75; H, 6.4; N, 4.2%).

Pent-4-enyl 2,3-O-*Ethylene*-β-D-*glucopyranoside* (**13a**).—A solution of (**6**β) (214 mg, 0.68 mmol) in 33% aqueous acetic acid (2 ml) was warmed at between 50—55 °C for 45 min. On cooling, the reaction mixture was basified with saturated aqueous sodium hydrogen carbonate and extracted with dichloromethane (3 × 50 ml). The combined dried extracts were evaporated under reduced pressure and the residue purified by flash chromatography (light petroleum—ethyl acetate, 1:4) to afford compound (**13a**) (162 mg, 87%) as a colourless oil, $[\alpha]_D^{21}$ −52.4° (*c* 0.5); δ_H 5.78 (1 H, qt, J_1 17.1 Hz, J_2 10.3 Hz, J_3 6.6 Hz, C*H*=CH_2), 5.05—4.93 (2 H, m, CH=CH_2), 4.45 (1 H, d, *J* 7.7 Hz, 1-H), 3.91—3.70 (7 H, m, 6-H, 6′-H, OCH_2CH_2O and $OCH_AH_BCH_2CH_2$), 3.65 (1 H, t, *J* 9.2 Hz, 4-H), 3.60—3.52 (1 H, m, $OCH_AH_BCH_2CH_2$), 3.44—3.38 (1 H, m, 5-H), 3.33 (1 H, t, *J* 9.2 Hz, 3-H), 3.19 (1 H, dd, J_1 9.2 Hz, J_2 7.7 Hz, 2-H), 2.59 (1 H, br s, exchanges with D_2O, OH), 2.15—2.06 (3 H, m, CH_2CH=CH_2 and OH, addition of D_2O causes integral of this signal to decrease to that corresponding to 2 H), and 1.78—1.69 (2 H, m, $CH_2CH_2CH_2$) (Found: C, 56.8; H, 8.1. $C_{13}H_{22}O_6$ requires C, 56.9; H, 8.1%).

Pent-4-enyl 4,6-*Di*-O-*acetyl*-2,3-O-*ethylene*-β-D-*glucopyranoside* (**13b**).—A mixture of (**13a**) (107 mg, 0.39 mmol), dry pyridine (1 ml), and acetic anhydride (0.6 ml) was stirred at room temperature for 29 h. The solvent was removed under reduced pressure (0.1 mmHg) with no heating, then the residue was diluted with saturated aqueous sodium hydrogen carbonate (25 ml) and extracted with dichloromethane (4 × 50 ml). The combined dried extracts were evaporated under reduced pressure and the residue purified by flash chromatography (light petroleum–ethyl acetate, 3:2) to afford the *title compound* (133 mg, 95%) as a colourless oil that slowly solidified to a white solid, m.p. 72 °C; $[\alpha]_D^{22}$ −38.0 (*c* 0.25); δ_H 5.79 (1 H, qt, J_1 17.1 Hz, J_2 10.3 Hz, J_3 6.7 Hz, C*H*=CH_2), 5.28—4.93 (3 H, m, CH=CH_2 and 4-H), 4.41 (1 H, d, *J* 7.6 Hz, 1-H), 4.24 (1 H, dd, J_1 12.2 Hz, J_2 5.2 Hz, 6′-H), 4.09 (1 H, dd, J_1 12.2 Hz, J_2 2.3 Hz, 6-H), 3.89—3.52 (7 H, m, 5-H, OCH_2CH_2O and $OCH_2CH_2CH_2$), 3.42 (1 H, t, *J* 9.4 Hz, 3-H), 3.32 (1 H, dd, J_1 9.3 Hz, J_2 7.7 Hz, 2-H), 2.16—2.02 (8 H, m, 2 × $COCH_3$ and CH_2CH=CH_2), and 1.78—1.68 (2 H, $CH_2CH_2CH_2$) (Found: C, 56.9; H, 7.3. $C_{17}H_{26}O_8$ requires C, 57.0; H, 7.3%).

4,6-*Di*-O-*acetyl*-2,3-*di*-O-*ethylene*-β-D-*glucopyranosyl Azide* (**15**).—To a solution of (**13b**) (119 mg, 0.33 mmol) in dry dichloromethane (5 ml) at 0 °C was added dropwise 0.98M bromine in dry dichloromethane (0.38 ml, 0.37 mmol). The resulting solution was further stirred at 0 °C for 35 min, the solvent removed under reduced pressure with no heating, the residue taken up in dry DMF (2 ml), and treated with sodium azide (24 mg, 0.37 mmol). After 20 h, the solvent was removed under reduced pressure (0.1 mmHg) with no heating and the residue was partitioned between water (30 ml) and dichloromethane (50 ml). The layers were thoroughly stirred, separated, and the aqueous layer further extracted with dichloromethane (2 × 50 ml). The combined dried extracts were evaporated under reduced pressure and the crude product purified by flash chromatography (acetone–chloroform, 5:195) to give the *azide* as a white solid (81 mg, 77%), m.p. 106 °C; $[\alpha]_D^{23}$ −41.5° (*c* 0.23); $\nu_{max.}$ 2 120 (N_3) and 1 740 (CO_2CH_3) cm^{-1}; δ_H 5.03 (1 H, t, *J* 9.8 Hz, 4-H), 4.61 (1 H, d, *J* 8.6 Hz, 1-H), 4.25 (1 H, dd, J_1 12.4 Hz, J_2 5.0 Hz, 6′-H), 4.11 (1 H, dd, J_1 12.4 Hz, J_2 2.2 Hz, 6-H), 3.86—3.66 (5 H, m, 5-H and OCH_2CH_2O), 3.44 (1 H, t, *J* 9.5 Hz, 3-H), 3.27 (1 H, t, *J* 8.9 Hz, 2-H), 2.08 (3 H, s, $COCH_3$), and 2.07 (3 H, s, $COCH_3$); *m*/*z* 333 (100%, M^+ + 18) and 316 (8, M^+ + 1).

N-*Acetyl*-4,6-*di*-O-*acetyl*-2,3-*di*-O-*ethylene*-β-D-*glucopyranosylamine* (**12**β).—A solution of (**15**) (20.3 mg) in absolute methanol containing acetic anhydride (0.3 ml) and platinum(VI) oxide (2 mg) was hydrogenated at atmospheric pressure and room temperature. After 17 h, the mixture was filtered through Celite, which was washed with ethyl acetate (2 × 10 ml). The combined filtrates were evaporated under reduced pressure (0.1 mmHg) with no heating, and the residue purified by flash chromatography (ethyl acetate) to give the *title compound* (14.6 mg, 69%) as a white solid, m.p. 206 °C (from dichloromethane–light petroleum); $[\alpha]_D^{22}$ −21.6° (*c* 0.15); $\nu_{max.}$ 3 440 (NH), 1 740 (CO_2CH_3), 1 700 ($NCOCH_3$), and 1 500 ($NCOCH_3$) cm^{-1}; δ_H 5.98 (1 H, d, *J* 8.9 Hz, exchanged with D_2O, NH), 5.19 (1 H, t, *J* 9.2 Hz, addition of D_2O caused t to collapse to d, *J* 9.1 Hz, 1-H), 5.01 (1 H, t, *J* 9.8 Hz, 4-H), 4.28 (1 H, dd, *J* 12.5 Hz, J_2 4.7 Hz, 6′-H), 4.02 (1 H, dd, J_1 12.5 Hz, J_2 2.0 Hz, 6-H), 3.84—3.68 (5 H, m, 5-H and OCH_2CH_2O), 3.50 (1 H, t, *J* 9.4 Hz, 3-H), 3.23 (1 H, t, *J* 9.1 Hz, 2-H), 2.08, 2.05, and 2.04 (9 H, 3 × s, 2 × $COCH_3$ and $NHCOCH_3$); *m*/*z* 349 (35%, M^+ + 18) and 332 (100, M^+ + 1) (Found: C, 50.5; H, 6.3; N, 4.1. $C_{14}H_{21}NO_8$ requires C, 50.75; H, 6.4; N, 4.2%).

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