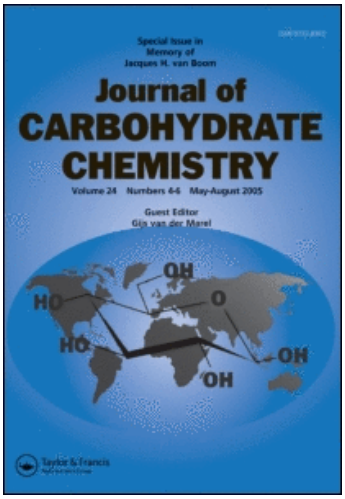

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DIELS-ALDER REACTIONS OF ISOPRENE AND 1,3-BUTADIENE WITH NITROHEPTENES DERIVED FROM SUGARS

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ABSTRACT

The Diels-Alder cycloadditions of 1,3-butadiene and isoprene with D-*galacto*- and D-*manno*-(*E*)-nitroalkenes are described. These reactions showed an *unlike* stereoselectivity, as a consequence of the configuration of the adjacent chiral centre to the dienophilic double bond. For isoprene adducts, the favored regioisomers were those in which the nitro and the methyl groups on cyclohexene rings are in a 1,4-relationship. Assignment of absolute configurations at the new chiral centres in the adducts were based on NMR data and polarimetric correlations with known compounds.

INTRODUCTION

Monosaccharide derivatives are being used increasingly for the construction of enantiomerically pure, polysubstituted carbocycles.[1] Particularly noteworthy for this purpose are the asymmetric Diels-Alder cycloadditions, that have been successfully applied to produce cyclohexane derivatives, the carbohydrate being used either as the dienophilic or as the dienic component.[1,2] In this way, as part of our continuing work on this subject, we have shown that (*E*)-1-deoxy-1-nitroalkenes and α,β-unsaturated aldehydes derived from sugars react with symmetrically substituted or 1-substituted dienes to yield optically active norbornene[3] or cyclohexene[4] derivatives.

Since many important natural and synthetic products are made from chiral cyclohexene rings in which the double bond is unsubstituted[5] or it bears a methyl group,[6] we have now considered of interest the application of our methodology to the synthesis of such systems. In this article, we describe in full the results of uncatalysed Diels-Alder reactions between the nitroalkenes **1a** and **1b** with 1,3-butadiene and isoprene, together with the application to the synthesis of a variety of chiral cyclohexane or cyclohexene rings.

RESULTS AND DISCUSSION

The four cycloadditions were performed with an excess of the dienes, by using toluene or xylene as the solvents, the progress of the reactions being monitored by ^1H NMR spectroscopy. Table 1 summarizes the final composition of the reaction mixtures after heating, as well as the observed stereo- and regioselectivity.

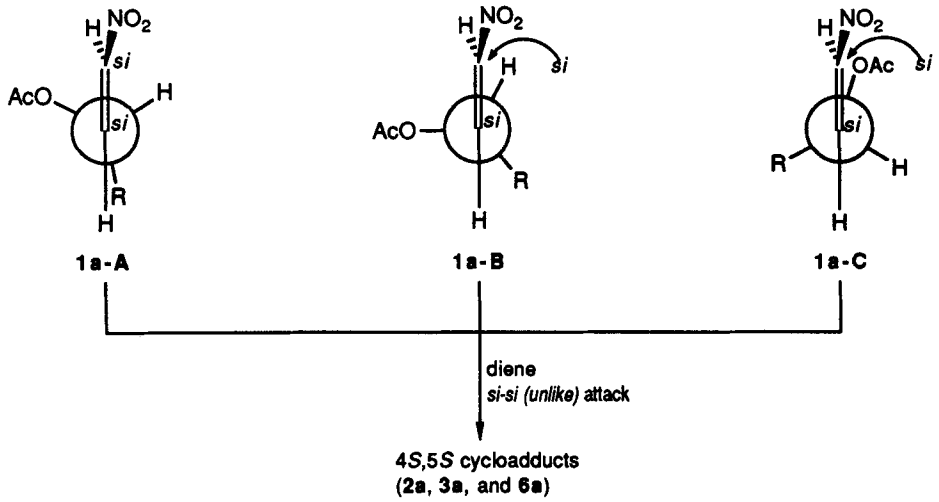
Concerning stereoselectivity, the data show that with both dienes, the D-*galacto*-nitroalkene **1a** led preponderantly to adducts with 4*S*,5*S* configuration, whereas for D-*manno* **1b** the major were the 4*R*,5*R*. These findings are consistent with our previous observations[4b,c] and agree with those of Franck,[7] who proposes that the face selectivity in the intermolecular Diels-Alder reactions is a predictable function of the configuration of the adjacent chiral centre to the dienophilic double bond.[7] However, even though this rationalization is generally assumed, the main differences are found with regard to the choice of conformers which presumably most stabilize the Diels-Alder transition-states. Some of these conformers, as proposed by authors and referred to nitroalkene **1a** are drawn in Scheme 1 as Newman's projections along the C-2—C-3 bond; for any of them, the preference in addition would be unlike, *i.e.* at the *si-si* face of the nitroolefin **1a** (thus leading to **2a**, **3a**, and **6a**), or at the *re-re* face if the nitroolefin were **1b** (thus leading to **4b**, **5b**, and **7b**).

The eclipsed H-alkyl **1a-A** model have been utilised in Diels-Alder reactions of α,β-unsaturated esters derived from sugars,[9] as well as by our own group;[4b] the preponderant stereoisomers produced (as a result of an unlike attack of the diene) were those expected on the basis of Cram's rule.[10] This unlike face selectivity also has been explained by Franck,[7] using a model similar to **1a-B**, which showed the lowest repulsive

Table 1. Composition of Reaction Mixtures from Cycloadditions

Reactants	Cycloadducts (%)[a] (4*S*,5*S*)	(4*R*,5*R*)	Stereoselectivity (*S,S*/*R,R* ratio)	Regioselectivity (*para*/*meta* ratio)[b]
1a + 2-methyl-1,3-butadiene	**2a** (57)	**4a** (8)	5.67	1.86
	3a (28)	**5a** (7)		
1b + 2-methyl-1,3-butadiene	**2b** (23)	**4b** (44)	0.56	2.03
	3b (13)	**5b** (20)		
1a + 1,3-butadiene	**6a** (78)	**7a** (22)	3.54	-----
1b + 1,3-butadiene	**6b** (33)	**7b** (67)	0.49	-----

a. Cycloadduct distribution was determined by ^{1}H NMR analysis. b. *Para* and *meta* indicate the 1,4- or 1,3-relationship between the nitro and the methyl groups on cyclohexene rings.

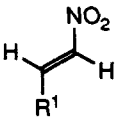


Scheme 1

gauche interactions in the transition state of the cycloaddition. On the other hand, Tronchet *et al.* reported that nitroenoses[11] and other compounds[12] having the general formula RCH(OR′)-CH=CHX (*E* configuration, X = electron withdrawing group) preferentially adopt, in solution, a conformation (as **1a**-C) in which the C-3—O bond eclipses the double bond; this same model was used to justify the high diastereofacial

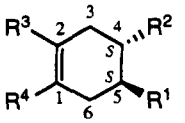
selectivity observed in the addition of dimethylsulfoxonium methylide and a sugar derived nitroalkene.[13]

In agreement with MO predictions,[14] our results for the regioselectivity of the additions of **1a** or **1b** and isoprene indicate that 1,4-disubstituted adducts (see Table 1) were favored over the 1,3-disubstituted. However, the preference in our case was clearly lower than that reported[15] for a related reaction between isoprene and 1-nitro-1-hexene.

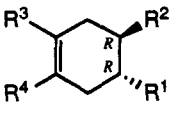


1

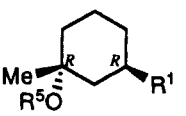
a, R^1 = D-*galacto*-$(CHOAc)_4$-CH_2OAc
b, R^1 = D-*manno*-$(CHOAc)_4$-CH_2OAc
c, R^1 = D-*galacto*-$(CHOH)_4$-CH_2OH
d, R^1 = D-*manno*-$(CHOH)_4$-CH_2OH
e, R^1 = CHO
f, R^1 = CH_2OH



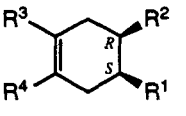
2, R^2 = NO_2, R^3 = H, R^4 = Me
3, R^2 = NO_2, R^3 = Me, R^4 = H
6, R^2 = NO_2, R^3 = R^4 = H
8, R^2 = R^3 = H, R^4 = Me
9, R^2 = R^3 = R^4 = H



4, R^2 = NO_2, R^3 = H, R^4 = Me
5, R^2 = NO_2, R^3 = Me, R^4 = H
7, R^2 = NO_2, R^3 = R^4 = H
13, R^2 = R^3 = R^4 = H



10, R^5 = H
12, R^5 = Ac



11, R^2 = NO_2, R^3 = H, R^4 = Me

The structures assigned to adducts **2-7** were supported by elemental analyses, spectroscopic evidence (IR, and ^1H and ^{13}C NMR), and correlation of their degradation products with known compounds. Conformations of cyclohexene rings and sugar side chains were deduced from vicinal $^3J_{H,H}$ couplings, being similar to described[4b] for closely related compounds. Placement of methyl group at C-1 or C-2 in isoprene-derived adducts[16] was based on ^{13}C NMR spectral comparison with those of cyclohexene analogues in which the double bond was unsubstituted or dimethyl-substituted; thus C-3 and/or C-6 are more deshielded[17] if there is a methyl group on the olefinic vicinal carbons C-2 or C-1, respectively. Moreover, we have found a clear and useful relation between ^{13}C NMR chemical shifts of the sugar side chains in pentaacetoxypentyl-cyclohexenes[18] and the absolute configurations at their chiral centers C-4 and C-5; in this way, when the adducts are 4*S*,5*S* and they have a D-*galacto* chain, the signals for C-1′ are clearly distinguishable (and at lower field) than those of C-2′—C-5′; this same pattern was encountered in the case of D-*manno*-(4*R*,5*R*) adducts (see Figure 1a). On the

contrary, the signals for C-1′ are at higher field (and intermixed with those of C-2′—C-4′) in D-*galacto*-(4*R*,5*R*) or D-*manno*-(4*S*,5*S*) compounds (see Figure 1b).

Treatment of adducts **2a**, **6a**, and **7b** with Bu_3SnH in the presence of azoisobutyronitrile (AIBN)[15] led to their respective denitrated derivatives **8a**, **9a**, and **13b** in 46-55% yields. These compounds showed (^1H NMR) similar conformations in their sugar chains and cyclohexene rings to those of their precursors; however, the lack of the nitro group was evident from NMR upfield shifts of H-4 and C-4.

Deacetylation of cyclohexene pentaacetates were carried out in acidic or alkaline media. On acid treatment, the expected pentahydroxypentyl nitrocyclohexenes **2c**, **6c**, and **7d**[19] were obtained from **2a**, **6a**, and **7b**, whereas on potassium carbonate deacetylation of **2a** (4*S*,5*S*), partial epimerization at C-4 occurred as a consequence of the formation of a carbanion at this carbon; in this way, compounds **2c** (4*S*,5*S*) and **11c** (4*R*,5*S*) were formed in a 46:54 ratio. The *cis* arrangement of the nitro group and the sugar chain in **11c** and its acetyl derivative **11a** was supported on their $J_{4,5}$ values (2.6 and 2.4 Hz, respectively).

On the other hand, when denitrated **8a** was subjected to the acid deacetylation conditions, the cyclohexane derivative **10c** was obtained. Formation of this compound may be explained by a stereospecific Markovnikov addition of water to the olefinic bond in **8a**; this behaviour was in contrast with that cited above for **2a** under the same treatment, as well as with that observed in other cyclohexene derivatives, where the double bond remained unchanged[4b] or it suffered an intramolecular nucleophilic attack[4a] from the hydroxyl group at C-1′. The presence of an additional hydroxyl group in **10c** was supported by the ^1H NMR spectrum of its acetyl derivative **12a**, for which six acetate methyl groups could be observed; furthermore, methyl at C-1 appeared as a sharp singlet, thus indicating its equatorial orientation on the cyclohexane ring (no possible W-path for long-range coupling[20]), as well as the location of the hydroxyl group at this same carbon.

Oxidative cleavage of the pentitols **2c**, **6c**, **7d**, and **11c** with sodium metaperiodate yielded their respective nitroaldehydes **2e**, **6e**, **7e**, and **11e**, which were characterised by spectral data, polarimetric correlations and, in the case of **2e** and **11e**, by the preparation of their corresponding (2,4-dinitrophenyl)hydrazones. The absolute stereochemistry at chiral centres C-4 and C-5 follows from that of their starting materials through

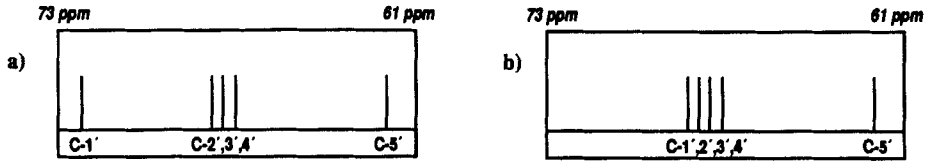


Figure 1. ^{13}C NMR signals of sugar-side chain carbons of pentaacetoxypentyl-cyclohexenes.

reactions where these carbons did not change their configurations. Moreover, optical rotations for **2e** (4*S*,5*S*; $[\alpha]_D$ +59.5°), **6e** (4*S*,5*S*; $[\alpha]_D$ +64°), and **7e** (4*R*,5*R*; $[\alpha]_D$ -69°), were similar to that of known[4b] (4*S*,5*S*)-1-*C*-(1,2-dimethyl-4-nitro-1-cyclohexen-5-yl)carbaldehyde ($[\alpha]_D$ +56°) or its 4*R*,5*R* enantiomer. The *cis* nitro aldehyde **11e**, which was obtained from **2a** (4*S*,5*S*) through deacetylation-epimerization and oxidation must present the 4*R*,5*S* configuration, as is also supported by $J_{4,5}$ values for this compound and its hydrazone derivative (3.1 Hz and 3.4 Hz, respectively).

On the other hand, potassium carbonate deacetylation of denitrated **9a**, followed by oxidative cleavage of the non-isolated glycosyl cyclohexene **9c**, led to aldehyde **9e**. $NaBH_4$ reduction of the later afforded previously described[21,22] (cyclohexene)methanol **9f**. The *R* stereochemistry of this alcohol additionally supports the absolute configuration assigned to butadiene adducts **6** and **7** (**a** and **b**).

In conclusion, we have described in this paper a series of chiral nitrocyclohexenes, their absolute configurations being based on NMR data and polarimetric comparison with related compounds. Acid-catalysed deacetylation of denitrated **8a** to yield **10c** supposes a result that is in contrast with our previous findings[4d] with 4-(hydroxymethyl)-5-glycocyclohexenes, in which the acid treatment yielded substituted 6-oxabicyclo-[3.2.1]octanes. Preparation of these later compounds from denitrated cyclohexenes is currently under investigation in our laboratory.

EXPERIMENTAL

Melting points were determined with an Electrothermal 8100 apparatus and are uncorrected. Optical rotations were obtained at 20±2 °C with a Perkin-Elmer 241 polarimeter. Infrared spectra were recorded in the range 4000-600 cm^{-1} with a Perkin-

Elmer 399 or Midac FT-IR spectrophotometers. ^{1}H NMR (200.13 MHz) and ^{13}C NMR (50.33 MHz) were obtained on a Bruker AC 200 E instrument with tetramethylsilane as the internal reference. NMR assignments were confirmed by homo- and heteronuclear double-resonance experiments, and DEPT. TLC was performed on silica gel 60 GF_{254} (Merck), with visualisation of spots by UV light or iodine vapour; solvents were ether-light petroleum, 1:1 (solvent a) or benzene-methanol, 3:1 (solvent b). Elemental analyses were determined by the Servicio de Microanálisis de la Universidad de Extremadura with a Perkin-Elmer 240 C Elemental Analyser.

Diels-Alder Reaction of the Nitroalkene 1a and 2-Methyl-1,3-butadiene. To a solution of (*E*)-3,4,5,6,7-penta-*O*-acetyl-1,2-dideoxy-1-*C*-nitro-D-*galacto*-hept-1-enitol[23] (**1a**; 10.0 g, 23.1 mmol) in dry toluene (50 mL) was added 2-methyl-1,3-butadiene (6.9 mL, 69.0 mmol) and hydroquinone (catalytic amount). The reaction mixture was heated at 105 °C in a closed glass container, and additional 2-methyl-1,3-butadiene (21.5 mL, 215 mmol) was added in 5 portions. After seven days, ^{1}H NMR showed disappearance of the starting nitroalkene and formation of the adducts **2a**, **3a**, **4a**, and **5a** in a respective ratio 57:28:8:7. Decolourisation with charcoal and evaporation of the solvent led to an oily residue that crystallised (ethanol) to yield a mixture of the four adducts (7.44 g, 66%).

Anal. Calcd for $C_{22}H_{31}NO_{12}$: C, 52.70; H, 6.23; N, 2.79. Found: C, 52.63; H, 6.29; N, 2.80.

Fractional crystallisation from ethanol gave pure **2a** (3.97 g, 35%) and mixed fractions in which each one of the other three stereoisomers was, however, clearly preponderant. The pure compound **2a**, (4*S*,5*S*)-1,2,3,4,5-penta-*O*-acetyl-1-*C*-(1-methyl-4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol, had mp 136-138 °C, R_F 0.37 (solvent a), $[\alpha]_D$ +34° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1740 (C=O), 1545, 1360 (NO_2) and 1220 (C-O-C); δ_H ($CDCl_3$) 5.32-5.20 (2 H, m, H-2,4'), 5.34 (1 H, dd, $J_{1',2'}$ ~ 1, $J_{2',3'}$ 9.8, H-2'), 5.19 (1 H, dd, $J_{3',4'}$ 1.0, H-3'), 4.46 (1 H, q, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 7.9, H-4), 4.27 (1 H, dd, $J_{4',5'}$ 4.4, $J_{5',5''}$ 11.7, H-5'), 3.80 (1 H, dd, $J_{4',5''}$ 7.1, H-5''), 2.66 (1 H, m, $J_{5,6a}$ 8.3, $J_{5,6b}$ 7.1, H-5), 2.60-2.45 (2 H, m, H-3a,3b), 2.36 (1 H, dd, $J_{6a,6b}$ 17.9, H-6b), 2.18, 2.10, 2.05, 2.01, 1.99 (each 3 H, each s, 5 OAc), 1.99 (1 H, dd, H-6a) and 1.69 (3 H, br s, Me-1); δ_C ($CDCl_3$) 171.1-169.6 ($OCOCH_3$), 131.7 (C-

1), 116.4 (C-2), 82.6 (C-4), 72.1 (C-1'), 67.7, 67.5 (C-2',3',4'), 62.1 (C-5'), 36.4 (C-5), 31.5, 30.4 (C-3,6), 22.7 (Me-1), and 20.7-20.2 ($OCOCH_3$).

Anal. Calcd for $C_{22}H_{31}NO_{12}$: C, 52.70; H, 6.23; N, 2.79. Found: C, 52.67; H, 6.28; N, 2.82.

δ_C ($CDCl_3$) for **3a**: 171.2-169.5 ($OCOCH_3$), 129.7 (C-2), 117.9 (C-1), 82.9 (C-4), 71.4 (C-1'), 67.7, 67.5 (C-2',3',4'), 62.1 (C-5'), 35.7 (C-5), 33.9 (C-3), 25.8 (C-6), 22.4 (Me-1) and 20.7-20.3 ($OCOCH_3$).

δ_C ($CDCl_3$) for **4a**: 171.2-169.5 ($OCOCH_3$), 132.5 (C-1), 115.7 (C-2), 82.6 (C-4), 69.0, 68.6, 68.1, 67.7 (C-1',2',3',4'), 62.1 (C-5'), 37.9 (C-5), 30.0, 28.4 (C-3,6), 22.9 (Me-1) and 20.7-20.3 ($OCOCH_3$).

δ_C ($CDCl_3$) for **5a**: 171.2-169.5 ($OCOCH_3$), 129.5 (C-2), 119.0 (C-1), 83.4 (C-4), 69.0-67.7 (C-1',2',3',4'), 62.4 (C-5'), 37.6 (C-5), 34.6 (C-3), 23.6 (C-6), 22.5 (Me-1) and 20.7-20.3 ($OCOCH_3$).

Diels-Alder Reaction of the Nitroalkene 1a and 1,3-Butadiene. To a solution of compound **1a**[23] (10.0 g, 23.1 mmol) in dry xylene (150 mL) were added 1,3-butadiene sulfone (7.8 g, 65.8 mmol) and hydroquinone (catalytic amount). The reaction mixture was heated at 125-130 °C in a closed glass container, and additional butadiene sulfone (26.7 g, 226 mol) was added in 8 portions. After twenty-four days, ^1H NMR showed the disappearance of the starting nitroalkene and formation of the adducts **6a** and **7a** in a 78:22 ratio. Decolourisation with charcoal and concentration of the solvent gave a mixture of the adducts (7.6 g, 68%). Fractional crystallisation from xylene yielded (4*S*,5*S*)-1,2,3,4,5-penta-*O*-acetyl-1-*C*-(4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol **6a** (3.0 g, 27%), mp 149-150 °C, R_F 0.36 (solvent a), $[\alpha]_D$ +37° (*c* 0.55, chloroform); ν_{max} (KBr)/cm^{-1} 1755 (C=O), 1560, 1380 (NO_2) and 1230 (C-O-C); δ_H ($CDCl_3$) 5.66 (2 H, m, H-1,2), 5.36 (1 H, dd, $J_{1',2'}$ 1.4, $J_{2',3'}$ 9.8, H-2'), 5.25 (1 H, ddd, $J_{4',5'}$ 4.7, $J_{4',5''}$ 6.9, H-4'), 5.19 (1 H, dd, $J_{3',4'}$ 1.8, H-3'), 5.02 (1 H, dd, $J_{1',5}$ 9.5, H-1'), 4.52 (1 H, ddd, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 7.5, H-4), 4.28 (1 H, dd, $J_{5',5''}$ 11.6, H-5'), 3.79 (1 H, dd, $J_{4',5''}$ 7.2, H-5''), 2.64 (1 H, m, H-5), 2.61 (2 H, m, H-3a,3b), 2.43 (1 H, m, $J_{6a,6b}$ 17.8, H-6b), 2.18, 2.07, 2.02 (each 3 H, each s, 3 OAc), 2.14 (1 H, m, H-6a) and 2.10 (6 H, s, 2 OAc); δ_C ($CDCl_3$) 171.1-169.7 ($OCOCH_3$), 124.1, 122.3 (C-1,2), 82.5 (C-4), 71.6 (C-1'), 67.7, 67.6, 67.5 (C-2',3',4'), 62.2 (C-5'), 35.9 (C-5), 29.6 (C-3), 26.1 (C-6) and 20.7-20.4 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{29}NO_{12}$: C, 51.74; H, 5.95; N, 2.87. Found: C, 51.43; H, 6.03; N, 2.91.

The mixture of adducts was chromatographed on silica gel (flash chromatography, solvent a) to afford pure (4*R*,5*R*)-1,2,3,4,5-penta-*O*-acetyl-1-*C*-(4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol **7a** (1.30 g, 12%), mp 138-140 °C, R_F 0.29 (solvent a), $[\alpha]_D$ +4.5° (*c* 0.36, chloroform); ν_{max} (KBr)/cm^{-1} 1755 (C=O), 1570, 1390 (NO_2) and 1235 (C-O-C); δ_H ($CDCl_3$) 5.60 (2 H, m, H-1,2), 5.31 (1 H, dd, $J_{1',2'}$ 2.6, $J_{2',3'}$ 9.3, H-2'), 5.25 (1 H, m, $J_{3',4'}$ 2.5, H-3'), 5.21 (1 H, ddd, $J_{4',5'}$ 4.7, $J_{4',5''}$ 7.3, H-4'), 4.96 (1 H, dd, $J_{1',5}$ 4.0, H-1'), 4.60 (1 H, dt, $J_{4,5}$ 9.4, $J_{4,3a} \sim J_{4,3b}$ 7.1, H-4), 4.25 (1 H, dd, $J_{5',5''}$ 11.7, H-5'), 3.79 (1 H, dd, $J_{4',5''}$ 7.3, H-5''), 2.68 (1 H, m, $J_{5,6a}$ 6.3, $J_{5,6b} < 1$, H-5), 2.59 (2 H, m, H-3a,3b), 2.12 (2 H, m , H-6a,6b), 2.10, 1.98 (each 3 H, each s, 2 OAc) and 2.05 (9 H, s, 3 OAc); δ_C ($CDCl_3$) 170.3-169.6 ($OCOCH_3$), 125.1, 121.9 (C-1,2), 82.9 (C-4), 69.0, 68.5, 68.1, 67.5 (C-1',2',3',4'), 62.0 (C-5'), 37.6 (C-5), 30.1 (C-3), 23.8 (C-6) and 20.6-20.3 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{29}NO_{12}$: C, 51.74; H, 5.95; N, 2.87. Found: C, 51.48; H, 5.92; N, 2.63.

(5*R*)-1,2,3,4,5-Penta-*O*-acetyl-1-*C*-(1-methyl-1-cyclohexen-5-yl)-D-*galacto*-pentitol (8a). A mixture of **2a** (5.0 g, 11.0 mmol), tributyltin hydride (14.4 mL, 53.5 mmol), and azobisisobutyronitrile (0.75 g, 4.57 mmol) in dry toluene (100 mL) was refluxed for 30 min. TLC (solvent a) then showed the complete absence of starting material (R_F 0.37) and the presence of only one product with R_F 0.44. Evaporation of the solvent yielded an oily residue which was partitioned between 1:1 acetonitrile-petroleum ether (100 mL). The acetonitrile layer was dried (Na_2SO_4) and concentrated, to yield the *title compound* as an amorphous solid that crystallised from methanol (2.9 g, 55%), mp 142-144 °C, $[\alpha]_D$ +89.5° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1747 (C=O), 1460, 1377 (CH_3) and 1224 (C-O-C); δ_H ($CDCl_3$) 5.40 (1 H, dd, $J_{1',2'}$ 1.6, $J_{2',3'}$ 9.9, H-2'), 5.37 (1 H, m, H-2), 5.23 (1 H, dd, $J_{3',4'}$ 1.5, H-3'), 5.21 (1 H, m, H-4'), 4.88 (1 H, dd, $J_{1',5}$ 9.1, H-1'), 4.31 (1 H, dd, $J_{4',5'}$ 4.6, $J_{5',5''}$ 11.8, H-5'), 3.79 (1 H, dd, $J_{4',5''}$ 7.6, H-5''), 2.21-1.85 (2 H, m, H-6a,6b), 2.11, 2.10, 2.09, 2.08, 2.00 (each 3 H, each s, 5 OAc), 2.07 (1 H, m, H-3b), 1.80-1.50 (2H, m, H-3a,4b), 1.64 (1H, m, H-5), 1.63 (3 H, br s, Me-1) and 1.14 (1 H, m, H-4a); δ_C ($CDCl_3$) 170.6-169.6 ($OCOCH_3$), 131.9 (C-1), 120.8 (C-2), 73.6 (C-1'), 67.8, 67.7,

67.6 (C-2′,3′,4′), 62.4 (C-5′), 34.6 (C-5), 32.6 (C-6), 24.7, 24.4 (C-3,4), 23.5 (Me-1) and 20.8-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{22}H_{32}O_{10}.0.5\ CH_3OH$: C, 57.19; H, 7.25. Found: C, 57.27; H, 6.93.

(5*R*)-1,2,3,4,5-Penta-*O*-acetyl-1-*C*-(1-cyclohexen-5-yl)-D-*galacto*-pentitol (9a). As described for **8a**, denitration of **6a** gave **9a** (46% yield), after purification through a silica gel column (solvent a), mp 140-141 °C, R_F 0.44 (solvent a), $[\alpha]_D$ +74° (*c* 0.46, chloroform); ν_{max} (KBr)/cm^{-1} 1745 (C=O) and 1220 (C-O-C); δ_H ($CDCl_3$) 5.67 (1 H, br d, H-2), 5.58 (1 H, br d, H-1), 5.39 (1 H, dd, $J_{1',2'}$ 1.2, $J_{2',3'}$ 9.8, H-2′), 5.23 (1 H, dd, $J_{3',4'}$ 1.9, H-3′), 5.22 (1 H, ddd, $J_{4',5'}$ 4.4, $J_{4',5''}$ 7.4, H-4′), 4.88 (1 H, dd, $J_{1',5}$ 9.3, H-1′), 4.31 (1 H, dd, $J_{5',5''}$ 11.7, H-5′), 3.79 (1 H, dd, H-5′′), 2.22 (1 H, br d, $J_{6a,6b}$ 16.2, H-6b), 2.1-1.5 (4 H, m, H-3a,3b,4b,6a), 2.09 (12 H, s, 4 OAc), 2.01 (3 H, s, 1 OAc), 1.63 (1 H, m, H-5) and 1.24 (1 H, m, H-4a); δ_C ($CDCl_3$) 170.7-169.8 ($OCOCH_3$), 126.9, 124.9 (C-1,2), 73.5 (C-1′), 67.9, 67.8, 67.6 (C-2′,3′,4′), 62.4 (C-5′), 34.1 (C-5), 27.8 (C-6), 24.7, 24.6 (C-3,4) and 20.8-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{30}O_{10}$: C, 57.00; H, 6.83. Found: C, 56.93; H, 6.87.

Acid-catalysed Deacetylation of 2a. A solution of **2a** (1.5 g, 2.99 mmol) in methanol-4 mol dm^{-1} HCl (6:1, 72 mL) was refluxed for 3.5 h. TLC (solvent b) then showed the complete absence of starting material (R_F 0.81) and the presence of only one product with R_F 0.48. Decolourisation with charcoal and evaporation of the solvent yielded (4*S*,5*S*)-1-*C*-(1-methyl-4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol (**2c**) as an oil, that crystallised from methanol (0.51 g, 59%), mp 154-156 °C, $[\alpha]_D$ -26.5° (*c* 0.5, pyridine); ν_{max} (KBr)/cm^{-1} 3421, 3336 (OH), 1552, 1382 (NO_2), 1104 and 1035 (C-O); δ_H (DMSO-d_6) 5.33 (1 H, m, H-2), 4.87 (1 H, q, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 4.8, H-4), 4.27 (5 H, m, D_2O exchangeable OH′s), 3.74 (1 H, t, $J_{3',4'} < 1$, $J_{4',5'} \sim J_{4',5''}$ 6.4, H-4′), 3.57 (1 H, d, $J_{1',5}$ 10.3, $J_{1',2'} < 1$, H-1′), 3.5-3.3 (4 H, m, H-2′,3′,5′,5′′), 2.74 (1 H, m, $J_{5,6a} \sim J_{5,6b}$ 4.8, H-5), 2.65 (1 H, m, H-3a), 2.45 (1 H, m, $J_{3a,3b}$ 18.0, H-3b), 1.95 (1 H, m, $J_{6a,6b}$ 16.6, H-6a), 1.76 (1 H, m, H-6b) and 1.60 (3 H, br s, Me-1); δ_C (DMSO-d_6) 131.5 (C-1), 116.7 (C-2), 82.9 (C-4), 70.0, 69.8, 69.1, 69.0 (C-1′,2′, 3′,4′), 63.3 (C-5′), 38.2 (C-5), 28.0 (C-3), 25.9 (C-6) and 25.3 (Me-1).

Anal. Calcd for $C_{12}H_{21}NO_7$: C, 49.48; N, 7.26; N, 4.81. Found: C, 49.66; H, 7.29; N, 4.70.

Acid-catalysed Deacetylation of 8a. Using the same procedure as for the acid-catalysed deacetylation of **2a**, compound **8a** gave crystalline (1*R*,5*R*)-1-*C*-(1-hydroxy-1-methylcyclohex-5-yl)-D-*galacto*-pentitol (**10c**, 54%). Recrystallised from methanol, mp 151-153 °C, R_F 0.44 (solvent b), $[\alpha]_D$ -7° (*c* 0.5, pyridine); ν_{max} (KBr)/cm^{-1} 3305 (OH), 1428 (CH_3), 1073 and 1027 (C-O); δ_H (DMSO-d_6) 4.02 (6 H, m, D_2O exchangeable OH's), 3.72 (1 H, t, $J_{3',4'}$ 1, $J_{4',5'} \sim J_{4',5''}$ 6.3, H-4'), 3.5-3.3 (5 H, m, H-1',2',3',5',5'') and 2.1-0.9 (12 H, m, H-2a,2b,3a,3b,4a,4b,5,6a,6b,Me-1); δ_C (DMSO-d_6) 74.1 (C-1), 72.7 (C-1'), 70.0, 69.5, 69.1 (C-2',3',4'), 63.2 (C-5'), 43.6 (C-6), 40.6 (C-2), 36.4 (C-5), 34.5 (Me-1), 28.0 (C-4) and 21.9 (C-3).

Anal. Calcd for $C_{12}H_{24}NO_7.0.5\ CH_3OH$: C, 48.38; H, 8.44; N, 4.51. Found: C, 48.22; H, 8.37; N, 4.25.

Acid-catalysed Deacetylation of 6a. Using the same procedure as for the acid-catalysed deacetylation of **2a**, compound **6a** gave (4*S*,5*S*)-1-*C*-(4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol (**6c**) as an amorphous solid that was recrystallised from ethanol and dried over phosphorus pentoxide (90%), mp 144-145 °C, R_F 0.35 (solvent b), $[\alpha]_D$ -28° (*c* 0.48, pyridine); ν_{max} (KBr)/cm^{-1} 3440, 3300 (OH), 1560, 1385 (NO_2) and 1050 (C-O); δ_H (DMSO-d_6) 5.58 (1 H, br d, H-1), 5.65 (1 H, br d, H-2), 4.94 (1 H, q, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 3.8, H-4), 3.90 (5 H, m, D_2O exchangeable OH's), 3.73 (1 H, t, $J_{3',4'} < 1$, $J_{4',5'} \sim J_{4',5''}$ 5.7, H-4'), 3.62 (1 H, dd, $J_{1',5}$ 10.3, $J_{1',2'} < 1$, H-1'), 3.5-3.3 (4 H, m, H-2',3',5',5''), 2.74 (1 H, m, H-5), 2.69 (1 H, br d, $J_{3a,3b}$ 17.3, H-3b), 2.46 (1 H, br d, H-3a), 2.00 (1 H, br d, $J_{6a,6b}$ 17.3, H-6b) and 1.87 (1 H, br d, H-6a); δ_C (DMSO-d_6) 124.6, 123.0 (C-1,2), 82.8 (C-4), 70.0, 69.4, 69.1, 68.9 (C-1',2',3',4'), 63.3 (C-5'), 37.5 (C-5), 25.6 (C-3) and 23.0 (C-6).

Anal. Calcd for $C_{11}H_{19}NO_7$: C, 47.65; H, 6.91; N, 5.05. Found: C, 47.62; H, 6.86; N, 4.97.

Base-catalysed Deacetylation of 2a with Partial Epimerization. To a solution of **2a** (1.0 g, 2.0 mmol) in 90% methanol (27 mL) was added potassium carbonate (0.61 g, 4.45 mmol), and the mixture was stirred for 20 h at room temperature. TLC (solvent b) then showed the complete absence of starting material (R_F

0.81) and the presence of two products with R_F 0.58 (**11c**, 4*R*,5*S*, major) and R_F 0.48 (**2c**, 4*S*,5*S*, minor) in a ratio of 54:46 (^{1}H NMR). The reaction mixture was neutralised with Amberlite IR-120 (H^+) resin, and concentrated to give an oil that crystallised from methanol-10^{-2} *N* HCl, yielding (4*R*,5*S*)-1-*C*-(1-methyl-4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol (**11c**; 0.26 g, 45%), mp 177-179 °C, $[\alpha]_D$ -63° (*c* 0.5, pyridine); ν_{max} (KBr)/cm^{-1} 3325 (OH), 1550, 1370 (NO_2), 1100 and 1030 (C-O); δ_H (DMSO-d_6) 5.30 (1 H, m, H-2), 5.10 (1 H, m, $J_{4,5}$ 2.6, $J_{4,3a} \sim J_{4,3b}$ 4.1, H-4), 4.7-4.0 (5 H, m, D_2O exchangeable OH's), 3.8-3.3 (5 H, m, H-2',3',4',5',5''), 3.70 (1 H, d, $J_{1',5}$ 11.4, $J_{1',2'}$ < 1, H-1'), 2.65 (1 H, m, $J_{3a,3b}$ 17.4, H-3b), 2.54 (1 H, m, H-3a), 2.31 (1 H, m, H-5), 2.06 (1 H, dd, $J_{5,6b}$ 5.7, $J_{6a,6b}$ 17.4, H-6b), 1.88 (1 H, dd, $J_{5,6a}$ 9.8, H-6a) and 1.65 (3 H, br s, Me-1); δ_C (DMSO-d_6) 133.2 (C-1), 116.3 (C-2), 79.8 (C-4), 70.1 (C-1'), 69.1, 68.9, 68.7 (C-2',3',4'), 63.3 (C-5'), 38.2 (C-5), 29.3, 29.1 (C-3,6) and 23.3 (Me-1).

Anal. Calcd for $C_{12}H_{21}NO_7$: C, 49.48; N, 7.26; N, 4.81. Found: C, 49.48; H, 7.30; N, 4.81.

(1*R*,5*R*)-1,2,3,4,5-Penta-*O*-acetyl-1-*C*-(1-*O*-acetyl-1-methyl-cyclohex-5-yl)-D-*galacto*-pentitol (12a). Conventional acetylation of **10c** (0.74 g, 3.0 mmol) with pyridine (5 mL) and acetic anhydride (5 mL) led to the *title compound* as an oil that crystallised from methanol (1.1 g, 68%), mp 148-150 °C, R_F 0.37 (solvent a), $[\alpha]_D$ +29.5° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1753 (C=O), 1374 (CH_3) and 1228 (C-O-C); δ_H ($CDCl_3$) 5.41 (1 H, dd, $J_{2',3'}$ 9.7, H-2'), 5.26 (1 H, dd, $J_{3',4'}$ 1.9, H-3'), 5.20 (1 H, m, H-4'), 4.86 (1 H, dd, $J_{1',5}$ 9.7, $J_{1',2'}$ 2.0, H-1'), 4.30 (1 H, dd, $J_{4',5'}$ 4.8, $J_{5',5''}$ 11.8, H-5'), 3.79 (1 H, dd, $J_{4',5''}$ 7.3, H-5'') and 2.2-0.9 (30 H, m, H-2a,2b,3a, 3b,4a,4b,5,6a,6b,Me-1 and 6 OAc); δ_C ($CDCl_3$) 170.8-169.5 ($OCOCH_3$), 73.3 (C-1'), 71.3 (C-1), 67.9, 67.7, 67.1 (C-2',3',4'), 62.3 (C-5'), 42.3 (C-6), 40.8 (C-2), 34.3 (C-5, Me-1), 27.6 (C-4), 21.6 (C-3) and 20.9-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{24}H_{36}O_{12}$ .CH_3OH: C, 54.73; H, 7.34. Found: C, 54.53; H, 7.07.

(4*R*,5*S*)-1,2,3,4,5-Penta-*O*-acetyl-1-*C*-(1-methyl-4-nitro-1-cyclohexen-5-yl)-D-*galacto*-pentitol (11a). Conventional acetylation of **11c** (0.6 g, 2.1 mmol) with pyridine (4 mL) and acetic anhydride (4 mL) led to the *title compound* as a white solid, that was recrystallised from ethanol (0.9 g, 87%), mp 137-139 °C, R_F 0.42

(solvent a), $[\alpha]_D$ +43.5° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1740 (C=O), 1550, 1365 (NO_2) and 1220 (C-O-C); δ_H ($CDCl_3$) 5.36 (1 H, dd, H-2′), 5.33 (1 H, m, H-2), 5.31 (1 H, dd, $J_{1',5}$ 10.3, $J_{1',2'}$ 1.0, H-1′), 5.23 (1 H, m, H-4′), 5.11 (1 H, dd, $J_{2',3'}$ 9.7, $J_{3',4'}$ 2.0, H-3′), 4.54 (1 H, td, $J_{4,3a} \sim J_{4,3b}$ 5.5, $J_{4,5}$ 2.4, H-4), 4.35 (1 H, dd, $J_{4',5'}$ 4.4, $J_{5',5''}$ 11.8, H-5′), 3.78 (1 H, dd, $J_{4',5''}$ 7.6, H-5′′), 2.70 (1 H, m, $J_{3a,3b}$ 18.1, H-3a), 2.50 (1 H, m, H-3b), 2.30 (2 H, m, H-6a,6b), 2.13, 2.11, 2.10, 2.05, 2.00 (each 3 H, each s, 5 OAc) and 1.71 (3 H, br s, Me-1); δ_C ($CDCl_3$) 170.3-169.9 ($OCOCH_3$), 132.7 (C-1), 115.8 (C-2), 79.1 (C-4), 69.2 (C-1′), 67.7 (C-2′,3′,4′), 62.5 (C-5′), 36.9 (C-5), 29.9, 28.5 (C-3,6), 28.0 (Me-1) and 20.6-20.2 ($OCOCH_3$).

Anal. Calcd for $C_{22}H_{31}NO_{12}$: C, 52.70; H, 6.23; N, 2.79. Found: C, 52.40; H, 6.38; N, 2.79.

(4*S*,5*S*)-1-*C*-(1-Methyl-4-nitro-1-cyclohexen-5-yl)carbaldehyde (2e). To a solution of **2c** (0.20 g, 0.69 mmol) in water (17 mL) at 0 °C was added a solution of sodium metaperiodate (0.71 g, 3.32 mmol) in water (4.3 mL), and the mixture was stirred for 10 min at 0 °C. TLC (solvent b) then showed complete conversion of the starting material (R_F 0.48) into only one product with R_F 0.72. Then, the solution was extracted with chloroform (4 x 30 mL), and the extracts were washed with water, dried ($MgSO_4$), and concentrated to give the *title compound* as a chromatographically pure, colourless oil (0.11 g, 95%), $[\alpha]_D$ +59.5° (*c* 0.5, chloroform); ν_{max} (film)/cm^{-1} 2857, 2727 (CH), 1722 (C=O), 1544 and 1374 (NO_2); δ_H ($CDCl_3$) 9.65 (1 H, s, C*H*O), 5.33 (1 H, m, H-2), 4.83 (1 H, td, $J_{4,5} \sim J_{4,3b} \sim 8.6$, $J_{4,3a}$ 6.2, H-4), 3.39 (1 H, td, $J_{2,5}$ 0.8, $J_{5,6a}$ 8.6, $J_{5,6b}$ 6.4, H-5), 2.69 (1 H, m, $J_{3a,3b}$ 17.3, H-3b), 2.39 (1 H, dd, $J_{6a,6b}$ 17.5, H-6b), 2.10 (1 H, m, H-6a) and 1.68 (3 H, br s, Me-1); δ_C ($CDCl_3$) 194.3 (*C*HO), 131.8 (C-1), 117.3 (C-2), 79.9 (C-4), 48.2 (C-5), 29.0, 28.0 (C-3,6) and 22.6 (Me-1).

The (2,4-dinitrophenyl)hydrazone of **2e** showed mp 143-145 °C, $[\alpha]_D$ +96.5° (*c* 0.50, chloroform); ν_{max} (KBr)/cm^{-1} 3297 (NH), 1621, 1591 (C=N, C=C), 1513 and 1336 (NO_2); δ_H ($CDCl_3$) 11.06 (1 H, s, NH), 9.11 (1 H, d, H-3arom), 8.34 (1 H, dd, *J* 2.6 and 9.6, H-5arom), 7.78 (1 H, d, H-6arom), 7.53 (1 H, d, $J_{1',5}$ 4.1, C*H*=N), 5.44 (1 H, m, H-2), 4.92 (1 H, td, $J_{4,3b}$ 6.1, $J_{4,5} \sim J_{4,3a}$ 9.8, H-4), 3.46 (1 H, m, $J_{5,6a}$ 10.9, H-5), 2.74 (2 H, m, H-3a,3b), 2.45 (1 H, dd, $J_{5,6b}$ 5.9, $J_{6a,6b}$ 17.4, H-6b), 2.18 (1 H, m, H-6a) and 1.76 (3 H, br s, Me-1); δ_C ($CDCl_3$) 148.5 (*C*H=N), 144.8 (C-1arom),

138.5 (C-4arom), 132.3 (C-1), 130.2 (C-5arom), 129.3 (C-2arom), 123.2 (C-3arom), 117.2 (C-2), 116.5 (C-6arom), 83.6 (C-4), 40.3 (C-5), 33.0 (C-3), 30.6 (C-6) and 22.8 (Me-1).

Anal. Calcd for $C_{14}H_{15}N_5O_6$: C, 48.14; H, 4.33; N, 20.05. Found: C, 47.95; H, 4.45; N, 19.86.

(4*R*,5*S*)-1-*C*-(1-Methyl-4-nitro-1-cyclohexen-5-yl)carbaldehyde (11e). Using the same procedure as for the preparation of **2e**, degradation of the pentahydroxypentyl side-chain of **11c** gave the *title compound* as a chromatographically pure, colourless oil (97%), R_F 0.69 (solvent b), $[\alpha]_D$ -2.0° (*c* 0.5, chloroform); ν_{max} (film)/cm^{-1} 2857, 2734 (CH), 1737 (C=O), 1552 and 1382 (NO_2); δ_H ($CDCl_3$) 9.82 (1 H, s, C*H*O), 5.41 (1 H, m, H-2), 5.06 (1 H, td, $J_{4,5}$ 3.1, $J_{4,3b} \sim J_{4,3a}$ 5.2, H-4), 3.14 (1 H, m, $J_{2,3a}$ 1.7, H-3a), 3.08 (1 H, td, $J_{5,6a} \sim J_{5,6b}$ 7.5, H-5), 2.68 (1 H, m, $J_{2,3b}$ 2.6, $J_{3a,3b}$ 18.3, H-3b), 2.67 (2 H, br s, H-6a,6b), 1.76 (3 H, br s, Me-1); δ_C ($CDCl_3$) 199.4 (*C*HO), 132.5 (C-1), 116.9 (C-2), 79.1 (C-4), 47.2 (C-5), 27.7, 27.4 (C-3,6), 23.0 (Me-1).

The (2,4-dinitrophenyl)hydrazone of **11e** showed mp 154-156 °C, $[\alpha]_D$ -16.5° (*c* 0.57, chloroform); ν_{max} (KBr)/cm^{-1} 3289 (NH), 1621 (C=N, C=C), 1513 and 1336 (NO_2); δ_H ($CDCl_3$) 11.09 (1 H, s, NH), 9.09 (1 H, d, H-3arom), 8.31 (1 H, dd, *J* 2.6 and 9.6, H-5arom), 7.78 (1 H, d, H-6arom), 7.56 (1 H, d, $J_{1',5}$ 4.6, C*H*=N), 5.43 (1 H, m, H-2), 4.88 (1 H, td, $J_{4,5}$ 3.4, $J_{4,3a}$ 6.0, $J_{4,3b}$ 7.4, H-4), 3.52 (1 H, m, $J_{5,6a} \sim J_{5,6b}$ 4.6, H-5), 2.89 (1 H, m, $J_{3a,3b}$ 16.2, H-3b), 2.68 (1 H, m, H-3a), 2.42 (2 H, m, $J_{6a,6b}$ 13.2, H-6a,6b) and 1.78 (3 H, br s, Me-1); δ_C ($CDCl_3$) 148.7 (*C*H=N), 144.8 (C-1arom), 138.3 (C-4arom), 132.4 (C-1), 130.1 (C-5arom), 129.2 (C-2arom), 123.6 (C-3arom), 117.0 (C-2), 116.5 (C-6arom), 81.8 (C-4), 39.2 (C-5), 32.0 (C-3), 27.0 (C-6) and 23.1 (Me-1).

Anal. Calcd for $C_{14}H_{15}N_5O_6$: C, 48.14; H, 4.33; N, 20.05. Found: C, 48.07; H, 4.29; N, 19.98.

Diels-Alder Reaction of the Nitroalkene 1b and 2-Methyl-1,3-butadiene. To a solution of (*E*)-3,4,5,6,7-penta-*O*-acetyl-1,2-dideoxy-1-*C*-nitro-D-*manno*-hept-1-enitol[24] (**1b**; 10.0 g, 23.1 mmol) in dry toluene (50 mL) was added 2-methyl-1,3-butadiene (6.9 mL, 69.0 mmol) and hydroquinone (catalytic amount). The

reaction mixture was heated at 105 °C in a closed glass container, and additional 2-methyl-1,3-butadiene (21.5 mL, 215 mmol) was added in 5 portions. After eight days, ^{1}H NMR showed the disappearance of the starting nitroalkene and formation of the adducts **2b**, **3b**, **4b**, and **5b** in a respective ratio 23:13:44:20. Decolourisation with charcoal and evaporation of the solvent led to an oil that crystallised from ethanol to give a mixture of the four adducts, R_F 0.32-0.40 (solvent a) (7.35 g, 65%).

Anal. Calcd for $C_{22}H_{31}NO_{12}$: C, 52.70; H, 6.23; N, 2.79. Found: C, 53.01; H, 6.36; N, 2.83.

Fractional crystallisation from ethanol yielded mixed fractions in which one stereoisomer was, however, clearly preponderant.

δ_H ($CDCl_3$) for **4b**, 5.43 (2 H, m, H-2′,3′), 5.32 (1 H, m, H-2), 5.04 (1 H, dd, $J_{1',2'}$ 8.5, $J_{1',5}$ 5.4, H-1′), 5.00 (1 H, m, H-4′), 4.50 (1 H, q, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 7.2, H-4), 4.22 (1H, dd, $J_{4',5'}$ 2.6, $J_{5',5''}$ 12.7, H-5′), 4.05 (1 H, dd, $J_{4',5''}$ 4.8, H-5′′), 2.78 (1 H, m, $J_{5,6a}$ 7.2, $J_{5,6b}$ 12.4, H-5), 2.61 (2 H, m, H-3a,3b), 2.3-2.0 (2 H, m, H-6a,6b), 2.13, 2.05, 2.00, (each 3 H, each s, 3 OAc), 2.09 (6 H, s, 2 OAc) and 1.65 (3 H, br s, $J_{Me,2}$ 0.9, Me-1); δ_C ($CDCl_3$) 170.4-169.5 ($OCOCH_3$), 132.1 (C-1), 116.6 (C-2), 82.2 (C-4), 71.4 (C-1′), 68.6, 67.8, 66.9 (C-2′,3′,4′), 61.6 (C-5′), 36.6 (C-5), 31.7 (C-3), 30.0 (C-6), 22.8 (Me-1) and 20.8-20.3 ($OCOCH_3$).

δ_C ($CDCl_3$) for **2b**, 170.4-169.5 ($OCOCH_3$), 133.0 (C-1), 116.0 (C-2), 82.7 (C-4), 68.4-66.8 (C-1′,2′,3′,4′), 61.6 (C-5′), 36.6 (C-5), 31.9 (C-3), 27.3 (C-6), 22.2 (Me-1) and 20.8-20.3 ($OCOCH_3$).

δ_C ($CDCl_3$) for **3b**, 170.4-169.5 ($OCOCH_3$), 129.3 (C-2), 116.0 (C-1), 83.1 (C-4), 68.4-66.8 (C-1′2′,3′,4′), 61.6 (C-5′), 36.6 (C-5), 36.5 (C-3), 31.9 (C-6), 22.6 (Me-1) and 20.8-20.3 ($OCOCH_3$).

δ_C ($CDCl_3$) for **5b**, 170.4-169.5 ($OCOCH_3$), 130.1 (C-2), 118.5 (C-1), 83.1 (C-4), 71.4 (C-1′), 68.5, 67.8, 66.9 (C-2′,3′,4′), 61.6 (C-5′), 36.2 (C-5), 34.5 (C-3), 27.1 (C-6), 22.5 (Me-1) and 20.8-20.3 ($OCOCH_3$).

Diels-Alder Reaction of the Nitroalkene 1b and 1,3-Butadiene. To a solution of compound **1b**[24] (10.0 g, 23.1 mmol) in dry xylene (150 mL) were added 1,3-butadiene sulfone (7.8 g, 65.8 mmol) and hydroquinone (catalytic amount). The reaction mixture was heated at 125-130 °C in a closed glass container, and additional 1,3-butadiene sulfone (26.71 g, 0.226 mol) was added in 4 portions. After twelve days, ^{1}H

NMR showed that the reaction had been completed in 65% and the presence of the adducts **7b** and **6b** in a 67:33 ratio. Decolourisation with charcoal and concentration of the solvent gave compound **7b** (4.12 g, 37%) and **6b** (1.35 g, 12%) by fractional crystallisation. After recrystallisation from ethanol, **7b** showed mp 159-161°C, R_F 0.38 (solvent a), $[\alpha]_D$ +16° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1760 (C=O), 1570, 1380 (NO_2) and 1235 (C-O-C); δ_H ($CDCl_3$) 5.65 (2 H, m, H-1,2), 5.43 (2 H, m, $J_{1',2'} \sim J_{3',4'}$ 8.7, $J_{2',3'}$ 1.0, H-2',3'), 5.06 (1 H, dd, $J_{1',5}$ 5.5, H-1'), 5.03 (1 H, ddd, $J_{4',5'}$ 2.7, $J_{4',5''}$ 4.9, H-4'), 4.53 (1 H, dt, $J_{4,5}$ 8.8, $J_{4,3a} \sim J_{4,3b}$ 6.8, H-4), 4.21 (1 H, dd, $J_{5',5''}$ 12.6, H-5'), 4.06 (1 H, dd, H-5''), 2.77 (1 H, m, $J_{5,6a} \sim J_{5,6b}$ 8.8, H-5), 2.65 (2 H, m, H-3a,3b), 2.31 (1 H, m, H-6b), 2.25 (1 H, m, H-6a), 2.12, 2.06, 2.01 (each 3 H, each s, 3 OAc) and 2.09 (6 H, s, 2 OAc); δ_C ($CDCl_3$) 170.6-169.7 ($OCOCH_3$), 124.8, 122.6 (C-1,2), 82.7 (C-4), 71.5 (C-1'), 68.7, 68.0, 67.1 (C-2',3',4'), 61.7 (C-5'), 36.5 (C-5), 30.3 (C-3), 27.3 (C-6) and 20.9-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{29}NO_{12}$: C, 51.74; H, 5.95; N, 2.87. Found: C, 51.65; H, 6.04; N, 2.85.

Data for minor adduct **6b** are as follows: Mp 129-130 °C, R_F 0.32 (solvent a), $[\alpha]_D$ +63° (*c* 0.5, chloroform); ν_{max} (KBr)/cm^{-1} 1760 (C=O), 1570, 1380 (NO_2) and 1230 (C-O-C); δ_H ($CDCl_3$) 5.72 (1 H, br d, $J_{1,2}$ 8.5, H-2), 5.58 (1 H, br d, $J_{1,6a}$ 5.0, H-1), 5.43 (1 H, dd, $J_{1',2'}$ 9.6, $J_{2',3'}$ 2.0, H-2'), 5.36 (1 H, dd, $J_{3',4'}$ 9.0, H-3'), 5.05 (1 H, m, $J_{4',5'}$ 3.0, $J_{4',5''}$ 5.2, H-4'), 5.04 (1 H, dd, $J_{1',5} < 1$, H-1'), 4.41 (1 H, td, $J_{4,3a} \sim J_{4,5}$ 10.1, $J_{4,3b}$ 5.6, H-4), 4.20 (1 H, dd, $J_{5',5''}$ 12.6, H-5'), 4.02 (1 H, dd, H-5''), 2.76 (1 H, dt, $J_{2,3b}$ 5.6, $J_{3a,3b}$ 17.2, H-3b), 2.51 (1 H, m, H-3a), 2.46 (1 H, m, $J_{5,6b}$ 5.7, H-6b), 2.42 (1 H, td, $J_{5,6a}$ 10.1, $J_{1',5}$ 1.0, H-5), 2.17, 2.08 (each 3 H, each s, 2 OAc), 2.16 (1 H, m, H-6a) and 2.05 (9 H, s, 3 OAc); δ_C ($CDCl_3$) 170.5-169.8 ($OCOCH_3$), 125.8, 121.8 (C-1,2), 82.8 (C-4), 68.0, 67.6, 67.4, 67.0 (C-1',2',3',4'), 61.8 (C-5'), 36.4 (C-5), 32.0 (C-3), 23.0 (C-6) and 20.8-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{29}NO_{12}$: C, 51.74; H, 5.95; N, 2.87. Found: C, 51.49; H, 5.92; N, 2.63.

(5*S*)-1,2,3,4,5-Penta-*O*-acetyl-1-*C*-(1-cyclohexen-5-yl)-D-*manno*-pentitol (13b). As described for **8a**, denitration of **7b** gave **13b** as an oil that crystallised from methanol (51% yield), mp 123-125 °C, R_F 0.46 (solvent a), $[\alpha]_D$ +8°

(*c* 0.33, chloroform); ν_{max} (KBr)/cm^{-1} 1750 (C=O) and 1240 (C-O-C); δ_H ($CDCl_3$) 5.68 (1 H, br d, H-2), 5.62 (1 H, br d, H-1), 5.44 (1 H, dd, $J_{1',2'}$ 8.6, $J_{2',3'}$ 1.4, H-2'), 5.40 (1 H, dd, $J_{3',4'}$ 8.6, H-3'), 5.07 (1 H, ddd, $J_{4',5'}$ 2.7, $J_{4',5''}$ 5.3, H-4'), 5.02 (1 H, dd, $J_{1',5}$ 3.1, H-1'), 4.21 (1 H, dd, $J_{5',5''}$ 12.5, H-5'), 4.04 (1 H, dd, H-5''), 2.1-1.8 (5 H, m, H-3a,3b,4b,6a,6b), 2.10, 2.09, 2.08 (each 3 H, each s, 3 OAc), 2.05 (6 H, s, 2 OAc), 1.70 (1 H, m, H-5) and 1.26 (1 H, m, $J_{4a,5}$ 8.6, H-4a); δ_C ($CDCl_3$) 170.5-169.8 ($OCOCH_3$), 127.1, 125.6 (C-1,2), 72.3 (C-1'), 68.0, 67.7, 67.3 (C-2',3',4'), 61.9 (C-5'), 34.2 (C-5), 28.7 (C-6), 25.1 (C-3), 22.6 (C-4) and 20.8-20.6 ($OCOCH_3$).

Anal. Calcd for $C_{21}H_{30}O_{10}$: C, 57.00; H, 6.83. Found: C, 57.10; H, 6.94.

Acid-catalysed Deacetylation of 7b. Using the same procedure as for the acid-catalysed deacetylation of **2a**, compound **7b** yielded (4*R*,5*R*)-1-*C*-(4-nitro-1-cyclohexen-5-yl)-D-*manno*-pentitol (**7d**, 87%). Recrystallised from ethanol:water and dried over phosphorus pentoxide, showed mp 178-179 °C, R_F 0.45 (solvent b), $[\alpha]_D$ -55° (*c* 0.4, pyridine); ν_{max} (KBr)/cm^{-1} 3400-3200 (OH), 1567, 1385 (NO_2) and 1100 (C-O); δ_H (DMSO-d_6) 5.70 (1 H, br d, $J_{1,2}$ 11.0, H-1), 5.61 (1 H, br d, H-2), 4.99 (1 H, d, $J_{H,OH}$ 5.6, D_2O exchangeable OH), 4.93 (1 H, m, $J_{4,5} \sim J_{4,3a} \sim J_{4,3b}$ 7.3, H-4), 4.46 (1 H, d, $J_{H,OH}$ 4.2, D_2O exchangeable OH), 4.39 (1 H, t, $J_{H,OH}$ 5.2, D_2O exchangeable OH-5'), 4.25 (1 H, d, $J_{H,OH}$ 7.1, D_2O exchangeable OH), 4.17 (1 H, d, $J_{H,OH}$ 6.8, D_2O exchangeable OH), 3.7-3.3 (6 H, m, H-1',2',3',4',5',5''), 2.56 (3 H, m, H-3a,3b,4) and 2.17 (2 H, m, H-6a,6b); δ_C (DMSO-d_6) 126.1, 122.8 (C-1,2), 83.7 (C-4), 71.2, 70.5, 69.9, 69.8 (C-1',2',3',4'), 63.7 (C-5'), 39.9 (C-5), 30.0 (C-3) and 25.8 (C-6).

Anal. Calcd for $C_{11}H_{19}NO_7$: C, 47.64; H, 6.90; N, 5.05. Found: C, 47.92; H, 6.94; N, 5.00.

(4*S*,5*S*)-1-*C*-(4-Nitro-1-cyclohexen-5-yl)carbaldehyde (6e). Using the same procedure as for the preparation of **2c**, degradation of pentahydroxypentyl side-chain of **6c** gave the *title compound* as a chromatographically pure, colourless oil (95%), R_F 0.70 (solvent b), $[\alpha]_D$ +64° (*c* 0.5, chloroform); ν_{max} (film)/cm^{-1} 2841, 2733 (CH), 1722 (C=O), 1544 and 1374 (NO_2); δ_H ($CDCl_3$) 9.72 (1 H, s, C*H*O), 5.78 (1 H, d, $J_{1,2}$ 9.9, H-1), 5.71 (1 H, d, H-2), 4.94 (1 H, td, $J_{4,3a}$ 6.4, $J_{4,5} \sim J_{4,3b}$ 8.6, H-4), 3.42 (1 H, td, $J_{5,6a}$ 6.3, $J_{5,6b}$ 8.4, H-5), 2.81 (1 H, m, $J_{3a,3b}$ 17.7, $J_{2,3a}$ 2.6, H-3a), 2.63 (1 H, m,

$J_{2,3b}$ < 1, H-3b), 2.58 (1 H, m, $J_{1,6a}$ 2.3, H-6a) and 2.24 (1 H, m, $J_{6a,6b}$ 18.5, $J_{1,6b}$ < 1, H-6b); δ_C ($CDCl_3$) 199.4 (*C*HO), 124.1, 123.5 (C-1,2), 79.9 (C-4), 47.9 (C-5), 28.7 (C-3) and 23.6 (C-6).

(4*R*,5*R*)-1-*C*-(4-Nitro-1-cyclohexen-5-yl)carbaldehyde (7e). Using the same procedure as for the preparation of **2e**, degradation of pentahydroxypentyl side-chain of **7d** gave the *title compound* as a chromatographically pure, colourless oil (87%), $[\alpha]_D$ -69° (*c* 0.5, chloroform); IR, ^1H and ^{13}C NMR spectra for **7e** were identical with those described for its enantiomer **6e**.

(*R*)-1-*C*-(1-Cyclohexen-5-yl)carbaldehyde (9e). To a solution of **9a** (0.27 g, 0.61 mmol) in 90% methanol was added potassium carbonate (0.19 g, 1.41 mmol), and the mixture was stirred for 1 h at room temperature. TLC (solvent b) then showed the complete absence of starting material (R_F 0.83) and the presence of one product of R_F 0.38. The reaction mixture was neutralised with 2% HCl and concentrated to yield an oil (0.13 g) that was dissolved in water at 0 °C (34 mL) and treated with sodium metaperiodate (0.31 g, 1.2 mmol). After 15 min, the solution was extracted with chloroform (3 x 10 mL), and the extracts were washed with water, dried ($MgSO_4$), and concentrated to give the *title compound* as a chromatographically pure, colourless oil (0.06 g, 89%), R_F 0.67 (solvent b); δ_H ($CDCl_3$) 9.67 (1 H, d, $J_{5,CHO}$ 1.0, C*H*O), 5.68 (2 H, m, H-1,2), 2.49 (1 H, m, $J_{4a,5}$ 9.7, $J_{4b,5}$ 3.3 Hz, $J_{5,6a} \sim J_{5,6b}$ 7, H-5), 2.21 (1 H, m, H-6a,6b), 2.07 (2 H, m, H-3a,3b), 1.94 (1 H, m, $J_{3a,4a} \sim J_{3b,4a} \sim 5.5$, H-4a) and 1.63 (1 H, m, $J_{3a,4b} \sim J_{3b,4b}$ 7, H-4b); δ_C ($CDCl_3$) 204.4 (*C*HO), 127.1, 124.7 (C-1,2), 45.9 (C-5), 24.2, 23.6 and 22.0 (C-3,4,6).

(*R*)-1-*C*-(1-Cyclohexen-5-yl)methanol (9f). To a solution of **9e** (0.04 g, 0.36 mmol) in methanol was added sodium borohydride (0.014 g, 0.36 mmol) and the mixture was stirred for 15 min at room temperature. TLC (solvent b) then showed the complete absence of starting material (R_F 0.67) and the presence of only one product of R_F 0.56. The solution was diluted with water, then extracted with chloroform, dried ($MgSO_4$), and concentrated, to yield the *title compound* (0.035 g, 87%), $[\alpha]_D$ +65.5° (*c* 1.14, methanol) {lit.[21] $[\alpha]_D$ +96.0° (*c* 3.0, methanol); *S* enantiomer reported as $[\alpha]_D$ -100.4° (*c* 1.71, methanol) by Masamune *et al.*[22]}.

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REFERENCES AND NOTES

1. R. J. Ferrier and S. Middleton, *Chem. Rev.*, **93**, 2779 (1993).
2. R. M. Giuliano, A. D. Jordan, Jr., A. D. Gauthier, and K. Hoogsteen, *J. Org. Chem.*, **58**, 4979 (1993).
3. (a) E. Román, D. J. Hodgson, Y. Yokomori, E. L. Eliel, M. Bueno, and J. A. Serrano, *Carbohydr. Res.*, **180**, 263 (1988); (b) J. A. Serrano and E. Román, *J. Org. Chem.*, **54**, 6114 (1989).
4. (a) M. Ch. Moreno, J. Plumet, E. Román, J. A. Serrano, M. L. Rodríguez, and C. Ruiz-Pérez, *Tetrahedron Lett.*, **30**, 3179 (1989); (b) J. A. Serrano, M. Ch. Moreno, E. Román, O. Arjona, J. Plumet, and J. Jiménez, *J. Chem. Soc., Perkin Trans.*, 3207 (1991); (c) J. A. Serrano, L. E. Cáceres, and E. Román, *J. Chem. Soc., Perkin Trans.*, 941 (1992); (d) E. Román, M. J. Chamizo, and J. A. Serrano, *Tetrahedron Lett.*, **34**, 1811 (1993); (e) J. A. Serrano, E. G. García, and E. Román, *J. Carbohydr. Chem.*, **13**, 1121 (1994).
5. (a) M. Toyota, Y. Nishikawa, K. Motoki, N. Yoshida, and K. Fukumoto, *Tetrahedron*, **49**, 11189 (1993); (b) J. S. Prasad, D. L. J. Clive, and G. V. J. da Silva, *J. Org. Chem.*, **51**, 2717 (1986); (c) W. Skuballa, B. Buchmann, J. Heindl, W. Froehlich, and R. Ekerdt, *Eur. Pat. Appl.*, EP 399,633: *Chem. Abstr.*, **115**, 8417f (1991).
6. (a) D. A. Evans, K. T. Chapman, and J. Bisaha, *J. Am. Chem. Soc.*, **106**, 4261 (1984); **110**, 1238 (1988); (b) Y-J. Chen and W-Y. Lin, *Tetrahedron*, **49**, 10263 (1993).
7. R. Franck in *Cycloaddition Reactions in Carbohydrate Chemistry*, R. M. Giuliano (Ed.); *ACS Symposium Series 494*, Washington DC, 1992; Chapter 2.
8. It has been demonstrated that diastereofacial selectivity was negligible if the allylic carbon is achiral: D. Horton and D. Koh, *Tetrahedron Lett.*, **34**, 2283 (1993).
9. D. Horton, T. Machinami, and Y. Takagi, *Carbohydr. Res.*, **121**, 135 (1983).
10. D. J. Cram and F. A. Abd Elhafez, *J. Am. Chem. Soc.*, **74**, 3210, 5828 (1952).
11. J. M. J. Tronchet, K. D. Pallie and F. Barbalat-Rey, *J. Carbohydr. Chem.*, **4**, 29 (1985).
12. J. M. Tronchet and T. N. Xuan, *Carbohydr. Res.*, **67**, 469 (1978).
13. B. Radatus, U. Williams, and H. H. Baer, *Carbohydr. Res.*, **157**, 242 (1986).
14. I. Fleming, *Frontier Orbitals and Chemical Reactions*, Wiley, London, 1976, p 86.

15. N. Ono, H. Miyake, A. Kamimura, and A. Kaji, *J. Chem. Soc., Perkin Trans. 1*, 1929 (1987).
16. The same numbering system is maintained through all compounds in this paper to clarify discussion.
17. S. Alunni, L. Minuti, P. Pasciuti, A. Taticchi, M. Guo, and E. Wenkert, *J. Org. Chem.*, **56**, 5353 (1991).
18. These also include 3-*O*-substituted- and 1,2-dimethyl-cyclohexenes described in ref. 4; the structures of the second were proved by X-ray data.
19. Reacetylation of these led to the original acetates, thus establishing that no epimerization had occurred.
20. L. M. Jackman and S. Sternhell, *Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, 2nd ed, Pergamon Press, New York, 1969, p 337.
21. O. Ceder and B. Hansson, *Acta Chem. Scand.; Ser. B.*, **31**, 189 (1977).
22. S. Masamune, L. A. Reed, J. T. Davis, and W. Choy, *J. Org. Chem.*, **48**, 4441 (1983).
23. J. C. Sowden and D. R. Strobach, *J. Am. Chem. Soc.*, **82**, 954 (1960).
24. J. C. Sowden and R. Schaffer, *J. Am. Chem. Soc.*, **73**, 4662 (1950).