Regio- and stereo-selective bromo(alkoxylation)s of (*E*)-α-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyloxymethylene) carbonyl compounds. A route to near-stereopure α-bromo α-dioxymethyl carbonyl compounds†

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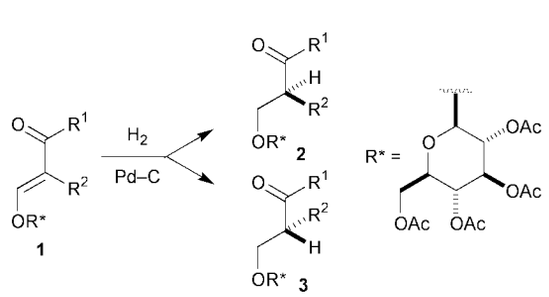
(*E*)-4-Methoxymethoxy-3-methylbut-3-en-2-one **17b** reacts with NBS in propan-1-ol in a highly regio- and *anti*-stereo-selective manner to give (3*R**,4*R**)-3-bromo-4-methoxymethoxy-3-methyl-4-propoxybutan-2-one **18**. Compound **10**, a relative of the butenone **17b** in which the methoxymethyl group is replaced by the 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl unit, undergoes an analogous bromo(propoxylation) reaction with reasonable facial selectivity to give an 86:14 mixture of (3*R*,4*R*)-3-bromo-3-methyl-4-propoxy-4-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)butan-2-one **11c** and its (3*S*,4*S*)-diastereomer **12c**. The major bromo(propoxy) derivative, isolable in 57% yield by fractional crystallisation, is assigned the stereostructure **11c** by single-crystal X-ray crystallographic analysis. Other primary alcohols and methanol participate in the reaction of compound **10** with NBS, leading predominantly (with selectivities ranging from 75:25 to 89:11) to bromo(alkoxy) products of type **11** which are usually separable from their diastereomers of type **12** by fractional crystallisation (in yields ranging from 41 to 64%). A model to account for the role of the 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl unit in the stereoinduction process is proposed.

Related bromo(propoxylation)s are observed with the vinylogous esters **24**, **25a** and **25b**, leading to the isolation of the major products, **28**, **30a** and **30b** (in yields ranging from 39 to 55%), and with the vinylogous carbonates **32a**, **32c**, **37a** and **37b**, providing access to the major products **33a**, **33c**, **38a** and **38b** (in yields ranging from 52 to 73%).

In the presence of trifluoroacetic acid and ethane-1,2-diol, the bromo(propoxy) derivatives **11c**, **28**, **30b** and **33c** undergo transacetalisation to give the ethylene glycol acetals **40a**, **40b**, **41** and **40c** with ees of 94–98%, in yields ranging from 56 to 67%.

Introduction

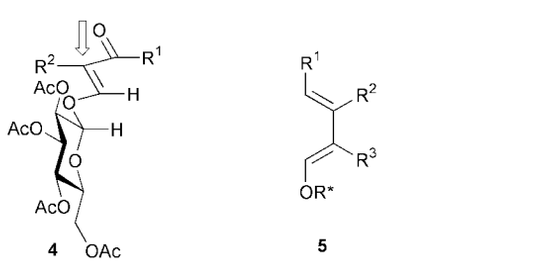
As part of a programme aimed at defining, understanding and exploiting stereocommunication through glycosidic bonds,[2] we have become interested in additions to the olefinic bonds of α-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyloxymethylene) carbonyl compounds of type **1**.[3] In catalytic hydrogenations,[4] dihydro adducts of type **2** have been shown to predominate over those of type **3** (Scheme 1). Although the selectivities were

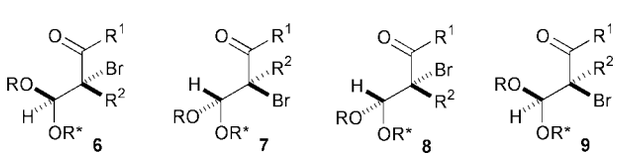


Scheme 1

modest (ranging from 67:33 to 85:15), it was usually possible to isolate the major dihydro derivatives of type **2** in acceptable yields (ranging from 49 to 71%) simply by fractional crystallisation.

The dihydro derivatives were considered to arise by addition of hydrogen to the olefinic units of conformers of type **4**, that were adopted for steric and stereoelectronic reasons. Delivery of hydrogen by the catalyst (in a *syn*-selective manner) to the less-hindered *Re*-face‡ accounted for the selectivity. This model was based upon one developed earlier to explain the *Re*-face reactivity of dienyl glucosides of type **5** in Diels–Alder reactions.[5,6]





† For preliminary communication, see ref. 1.

‡ The stereodescriptor refers to the carbon atom of the olefin bearing the 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyloxy unit.

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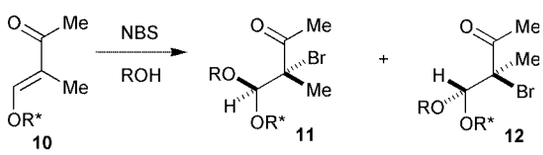
In this paper, we report on the behaviour of systems of type **1** in bromo(alkoxylation)s. At the outset of our studies, very little was known about such reactions involving achiral relatives of our substrates.§ On the assumption that their vinyl ether character would outweigh their α,β-unsaturated carbonyl character,¶ systems of type **1** were expected to react in a regioselective manner (the bromine atom being attached to the oxygen-free olefinic carbon atom). If *anti*-stereoselectivity prevailed, bromo(alkoxy) derivatives of type **6** were predicted to predominate over those of type **7**. Conversely, if *syn*-stereoselectivity was dominant, products of type **8** were anticipated in preference to ones of type **9**.

Results and discussion

The butenone **10**[4] was selected for the initial bromo(alkoxylation) studies. It reacted with NBS in methanol to give, following a standard work-up (in which the residue, obtained after evaporation of the alcohol, was dissolved in CH_2Cl_2 and the solution was washed with aq. $Na_2S_2O_5$ and then concentrated), mainly a 75:25 mixture of bromo(methoxy) derivatives. Two crystallisations of the mixture provided the major product in 47% yield; by processing the mother liquor, it was possible to isolate the minor product (contaminated with ≈5% of the major adduct) in ≈10% yield. There was little doubt that the products possessed the expected regiostructures; thus, the methine hydrogen atoms at position 4 resonated as singlets at δ 4.95 (for the major adduct) and δ 5.03, in accord with their acetal disposition. On the basis of subsequent evidence, the major material was assigned the stereostructure **11a** and the minor one the stereostructure **12a**, indicative of *anti*-stereoselective additions (Scheme 2).



Scheme 2

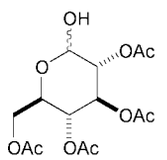
With a view to improving the selectivity and/or the isolated yield of the major bromo(alkoxy) derivative, the reaction of the butenone **10** with NBS and other alcohols was examined (Scheme 2).

The use of ethanol led to the isolation of an 80:20 mixture of the bromo(ethoxy) derivatives **11b** and **12b** after the standard work-up; two crystallisations provided compound **11b** in 38% yield. A more efficient route to compound **11b** became available when it was discovered that the material was relatively insoluble in the reaction mixture; a simple filtration of the cooled mixture then afforded compound **11b** in 64% yield.

An 86:14 mixture of the bromo(propoxy) products **11c** and **12c** was produced in the reaction of the butenone **10** with NBS and propan-1-ol; the standard work-up followed by two crystallisations gave the major material **11c** in 57% yield. A simpler work-up (in which the reaction mixture was partially concentrated, cooled and filtered) provided compound **11c** in 52% yield.

The reaction of the butenone **10** with NBS and butan-1-ol gave rise to an 86:14 of the bromo(butoxy) derivatives **11d** and **12d**, from which the major product **11d** was isolated in 41% yield after crystallisation.

When the butenone **10** was subjected to the action of NBS and propan-2-ol or 2-methylpropan-2-ol, the tetraacetate **13** (as a mixture of α- and β-anomers) was the major product. In the former reaction, there was also evidence for the presence of ≈25% of two dibromo products of type **14** (as an 80:20 mixture) on the basis of the presence of singlets at δ 6.35 and 6.50 (attributed to the 4-H methine signals of the minor and major dibromides).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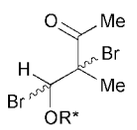
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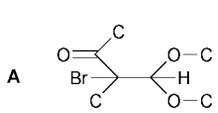
To determine the effect of α-substitution, benzyl alcohol, 2-methylpropan-1-ol and 2,2-dimethylpropan-1-ol were examined in the reaction of the butenone **10** with NBS. Benzyl alcohol provided an 89:11 mixture of the bromo(benzyloxy) derivatives **11e** and **12e**, from which compound **11e** was isolated in 43% yield after crystallisation. 2-Methylpropan-1-ol gave an 88:12 mixture of the bromo(methylpropoxy) products **11f** and **12f**; fractional crystallisation of the mixture led to the isolation of compound **11f** in 55% yield. Mainly three products arose in the reaction with 2,2-dimethylpropan-1-ol, considered to be a 76:10:14 mixture of compounds **11g**, **12g** and **14** by ^{1}H NMR spectroscopy; fractional crystallisation gave a 91:9 mixture of compounds **11g** and **14**.

From the foregoing results, it is clear that methanol and a range of primary alcohols participate in the reaction of the butenone **10** with NBS. Major and minor bromo(alkoxy) derivatives of types **11** and **12** emerge in ratios ranging from 75:25 to 89:11; the major products of type **11** can be isolated by fractional crystallisation in yields ranging from 41 to 64%.

The major product obtained from the reaction of the butenone **10** with NBS and propan-1-ol was assigned the stereostructure **11c** on the basis of a single-crystal X-ray crystallographic analysis. Its molecular structure, together with its crystallographic labelling, is shown in Fig. 1.‖ The stereostructures **11a**,**b** and **11d**–**g** were inferred by analogy and supported by similarities in the ^{1}H NMR spectra of the compounds. Thus, the methyl ketone signals appeared in the δ 2.20–2.32 region for compounds **11a**–**g**; by contrast the corresponding signals for their diastereomers **12a**–**g** were shifted downfield by 0.05–0.13 ppm.

Although there was no doubt that compounds **11a**–**g** were the major products of the bromo(alkoxylation)s of the butenone **10**, the structures of the minor products were not unequivocally defined. As indicated in Scheme 3, if the oxonium ion **15** were to intervene, then the minor products could possess the stereostructures **16a**–**g**. To shed light on this situation, the behaviour of compound **17b** (prepared in 35% yield after chromatography by the action of $ClCH_2OMe$ on the salt **17a**[6] in MeCN) in the bromo(propoxylation) was examined. The formation of a single

§ A sub-structure search in STN International and Beilstein Crossfire of the unit **A** shown below failed to provide any relevant references.


A

¶ A referee has asked for the basis of this assumption. It rests on the knowledge that the reactivity of alkenes towards electrophiles is increased by electron-donating substituents and decreased by electron-withdrawing substituents. Electrophiles, therefore, would be expected to be more responsive to electron-rich character than to electron-deficient character.

‖ In compound **11c**, the torsional angles involving O(5′)–C(1′)–O(1′)–C(4), C(1′)–O(1′)–C(4)–O(4) and O(1′)–C(4)–O(4)–C(6) are −76.2, +121.2 and −86.7°. For two other crystal structures of glycosidic acyclic acetals, see ref. 10.

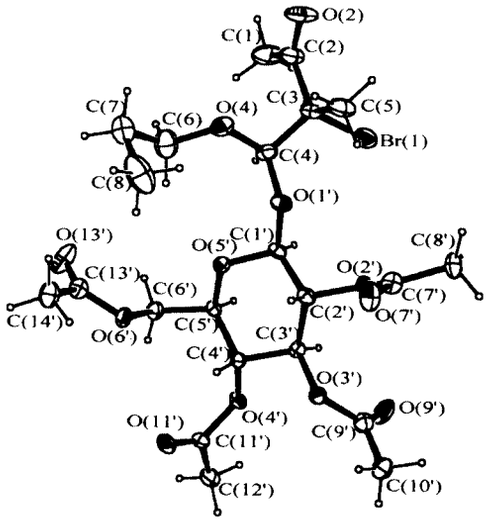
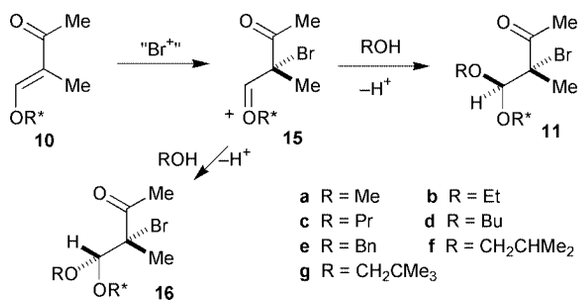
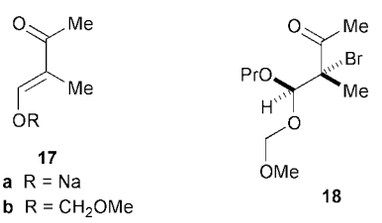


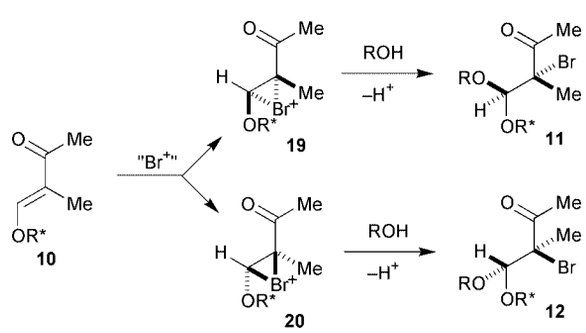
Fig. 1 Molecular structure of compound **11c**.



Scheme 3



bromo(propoxy) derivative, isolated in 57% yield after chromatography and assigned the structure *rac*-**18**, implied that the addition displayed high *anti*-stereoselectivity. It is likely, therefore, that the minor products formed in the bromo(alkoxylation)s of the butenone **10** possess the stereostructures **12a**–**g**, rather than the stereostructures **16a**–**g**, and that they arise by S_N2-like ring openings of the cyclic bromonium ion **20**. Correspondingly, the major bromo(alkoxylation) products are deemed to arise from the cyclic bromonium ion **19** by similar pathways (Scheme 4). It is worth noting that the preferred

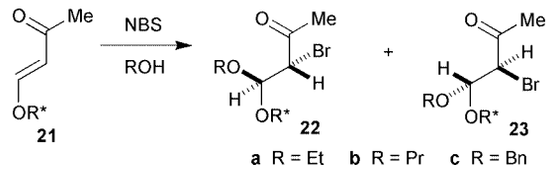


Scheme 4

bromonium ion **19** is that resulting from a selective addition to the *Re*-face of the olefinic bond of compound **10** and consistent with the involvement of a reactive conformation akin to **4** ($R^1 = R^2 = Me$).

Earlier, we had observed[5] that dienes of the type **5** ($R^3 = H$) showed poorer *Re*-face selectivity in Diels–Alder reactions than related dienes of type **5** ($R^3 = Me$). It was of interest therefore to compare the selectivity of the butenone **21**[7] with that of its relative **10** in the bromo(alkoxylation)s.

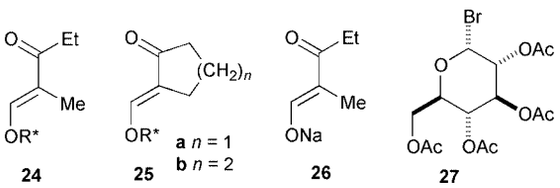
The reactions of the butenone **21** with NBS in ethanol, propan-1-ol and benzyl alcohol were examined (Scheme 5). The



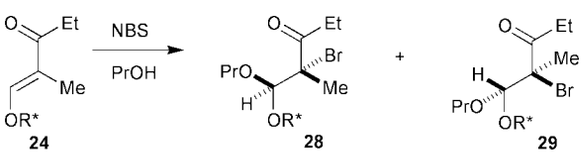
Scheme 5

first reaction afforded a 71:29 mixture of the bromo(ethoxy) derivatives **22a** and **23a**, the second a 72:28 mixture of the bromo(propoxy) products **22b** and **23b**, and the third an 80:20 mixture of the bromo(benzyloxy) derivatives **22c** and **23c**. In each case, the product was contaminated with a significant amount (10–25%) of the tetraacetate **13**, necessitating a chromatographic purification. However, fractional crystallisation of the purified products failed to provide the major bromo(alkoxy) material free of the minor one. The stereostructures of compounds **22a**–**c** and **23a**–**c** were not rigorously established but were assigned by analogy with the results observed for the butenone **10**. It is worth noting, however, that the methyl ketone signals appeared at higher field in the major bromo(alkoxy) products [as was observed in the case of the major bromo(alkoxy) derivatives **11a**–**g** derived from **10**]. Clearly, the bromo(alkoxylation)s of the butenone **21** were less *Re*-face selective than those of its relative **10**.

The bromo(propoxylation) reaction could be extended to the pentenone **24**[6] and compounds **25a**[4] and **25b**.[4] Thus, the acyclic



vinylogous ester **24** [prepared from the salt **26**[8] and the acetobromoglucose **27**[9] in much improved yield (44% *versus* 6%) by using a mixture of Me_2CO and water (in place of Me_2SO) as the reaction medium **] gave rise to the bromo(propoxy) derivatives **28** and **29** (Scheme 6) in the ratio 87:13; compound **28** was

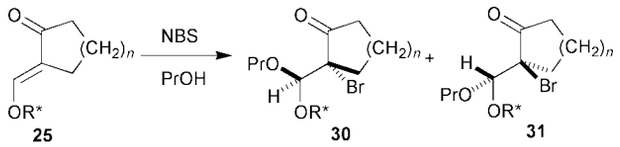


Scheme 6

isolated in 51% yield after the standard work-up and crystallisation (the yield was increased to 55% by simply cooling the reaction mixture, filtering off the product and effecting its recrystallisation). The reactions involving the methylenecyclopentanone **25a** and the methylenecyclohexanone **25b** (Scheme 7) afforded 87:13 mixtures of the bromo(propoxy) adducts **30a**/**31a** and **30b**/**31b**; following crystallisation, compound **30a** was isolated in 52% yield and compound **30b** in 39% yield.

As Schemes 8 and 9 illustrate, vinylogous carbonates also underwent the bromo(propoxylation). Thus, the propenoate

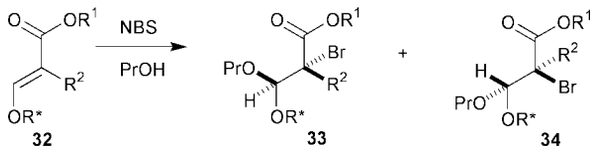
** Earlier, a similar modification was shown to result in an improvement in the yield of the butenone **10** (see ref. 4).



25 30 31

a $n = 1$ **b** $n = 2$

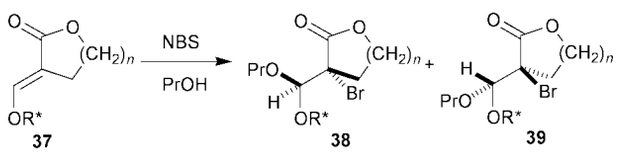
Scheme 7



32 33 34

a $R^1 = R^2 = Me$ **b** $R^1 = Me$, $R^2 = H$ **c** $R^1 = Et$, $R^2 = Me$

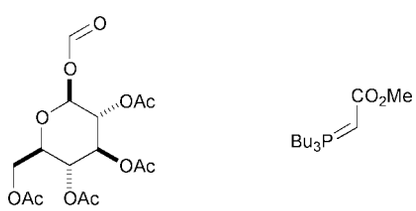
Scheme 8



37 38 39

a $n = 1$ **b** $n = 2$

Scheme 9



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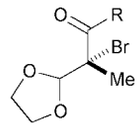
32a[4] furnished an 85:15 mixture of the bromo(propoxy) derivatives **33a** and **34a**; crystallisation of the mixture provided compound **33a** in 52% yield. A 78:22 mixture of the bromo(propoxy) derivatives **33b** and **34b** was produced in the reaction involving the propenoate **32b** [prepared (73% yield after crystallisation) by Wittig condensation of the formyl ester **35**[6] with the phosphorane **36**], from which compound **33b** was isolated in 18% yield after chromatography and crystallisation. Again, it is worth noting that replacement of the 2-methyl group by a hydrogen atom results in a poorer *Re*-face selectivity. Whilst the propenoate **32c**[4] showed a selectivity identical to that of its relative **32a**, it was possible to isolate the major bromo(propoxy) derivative **33c** in a much better yield (73% after crystallisation). The cyclic vinylogous carbonates **37a**[4] and **37b**[4] underwent reaction with NBS in propan-1-ol to give similar ratios of products, the former reaction affording an 85:15 mixture of the bromo(propoxy) derivatives **38a** and **39a** and the latter a 90:10 mixture of compounds **38b** and **39b**. Following crystallisation, compound **38a** was isolated in 54% yield and compound **38b** in 66% yield.

To summarise, a range of acyclic and cyclic vinylogous esters/carbonates of type **1** react with NBS and methanol/primary alcohols to give predominantly bromo(alkoxy) products of type **6**, which can usually be isolated in a near-stereopure state by fractional crystallisation.

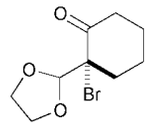
Removal of the auxiliary from bromo(alkoxy) derivatives of type **6** was readily achieved under transacetalisation conditions. Thus, when treated with trifluoroacetic acid (TFA) and ethane-1,2-diol, the bromo(propoxy) derivative **11c** was transformed into mainly a 50:50 mixture of the acetal **40a** and the tetraacetate **13**; a simple work-up [in which the mixture was left in acidic methanol (to convert **13** into D-glucose)] gave the acetal **40a**, as a near-pure oil (by ^{1}H NMR spectroscopy) in 63% yield. A chromatographed sample possessed an ee of 98%.

In a similar manner, the bromo(propoxy) derivatives **28**, **30b** and **33c** were transformed into the acetals **40b** (58% yield; 94% ee), **41** (56% yield; 96% ee) and **40c** (67% yield; 98% ee).



40

a R = Me
b R = Et
c R = OEt



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The aforecited results are of interest in the following respects. In showing that vinylogous esters/carbonates of type **1** undergo highly regioselective bromo(alkoxylation)s in an *anti*-stereoselective manner, they illuminate new reactivity of these synthetically versatile systems. They reveal that the model used to explain the facial reactivity of systems of type **1** in hydrogenations also accounts for their behaviour in bromo(alkoxylation)s. They extend the role of the 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl unit as a cheap and practical auxiliary. Finally, compounds **11c**, **28**, **30a**,**b**, **33c**, **38a**,**b**, **40a**–**c** and **41** are representatives of a new class of 1,2,3-trifunctional chirons and the present technology is capable of making them available in gram quantities. Their clusters of reactive functionality render the compounds of considerable potential in stereoselective synthesis.

Experimental

Light petroleum refers to that fraction boiling in the range 35–60 °C. NBS was recrystallised from ten times its weight of water, dried *in vacuo* (over P_2O_5) and stored in the dark.

The progress of reactions was monitored by TLC, using Merck plastic or aluminium sheets coated with silica gel (60 F_{254}); chromatograms were initially examined under UV light (Mineralight UVG2-58) and then visualised with a *p*-anisaldehyde stain [plates were sprayed with *p*-$MeOC_6H_4$-CHO–conc. H_2SO_4–EtOH (1:4:95) and heated]. Column chromatography was effected, under positive pressure from a compressed-air line, with Crossfield Sorbsil C60 flash silica. HPLC analyses were carried out with a Chiralpak AD column (25 × 0.46 cm) employing either a Kontron system [420 pump and 742 UV detector (set at 215 nm)] fitted with a Rheodyne 7125 injector or a Shimadzu system (LC-10AT pump, SPD-10AV UV/vis detector, SIL-10AD autoinjector and SCL-10A controller).

Evaporations were conducted under reduced pressure (using a water-pump or an oil-pump) at ≤40 °C with a Büchi rotary evaporator (fitted with a water or Me_2CO–solid CO_2 condenser). Mps were determined with a Büchi 512 melting point apparatus. Specific optical rotations, given in 10^{-1} deg cm^2 g^{-1}, were measured at ≈20 °C using a Thorn Automation Type 243 or an Optical Activity 1000 polarimeter with a cell of path length 0.1 dm.

Carbon, hydrogen and nitrogen contents were determined with a Carlo Erba Model 1108 analyser; bromine content was measured by oxygen combustion followed by automatic argentometric titration on a Mettler DL25 titrator. A Perkin-Elmer Lambda 15 spectrometer was used to determine UV spectra; extinction coefficients (ε) are presented in cm^2 mmol^{-1}. IR spectra were recorded using a Perkin-Elmer 783 spectrometer. NMR spectra were measured using a Bruker AM 300 or a Bruker AM 400 [with distortionless enhancement by polarisation transfer (DEPT) editing for ^{13}C spectra]; *J*-values and separations are given in Hz. FAB mass spectra (*m*-$NO_2C_6H_4$-CH_2OH as matrix) and CI mass spectra (NH_3 as carrier gas) were measured using a Kratos MS 50 spectrometer; high-

resolution mass spectra were recorded on a Kratos Concept IS spectrometer. A Rigaku AFC6S diffractometer was used for the single-crystal X-ray analysis.

(*E*)-4-Methoxymethoxy-3-methylbut-3-en-2-one 17b

Chloromethyl methyl ether (2.00 g, 24.8 mmol) was added to a stirred mixture of the sodium salt **17a**[6] (2.44 g, 20.0 mmol) and acetonitrile (20 cm^3). After 15 h, the mixture was concentrated and the product partitioned between dichloromethane and water. Evaporation of the dried ($MgSO_4$) organic phase left a syrup that was predominantly compound **17b**. Subjection of the material to column chromatography [hexanes–EtOAc (4:1) as eluent] gave the *title compound* **17b** (1.01 g, 35%); λ_{max} (EtOH)/nm 249 (ε 10000); ν_{max} (film)/cm^{-1} 1720 (vinylogous ester C=O) and 1650 (C=C); δ_H (300 MHz; $CDCl_3$) 1.73 (3 H, d, *J* 1, 3-Me), 2.22 (3 H, s, 1-H_3), 3.44 (3 H, s, MeO), 5.00 (2 H, s, OCH_2O) and 7.41 (1 H, apparent d, separation 1, 4-H); δ_C (100 MHz; $CDCl_3$) 8.3 (CH_3C), 25.3 (1-CH_3), 56.3 (CH_3O), 97.4 (OCH_2O), 119.5 (3-C), 156.1 (4-CH) and 197.7 (2-CO); *m*/*z* (CI) 145 (MH^+, 100%) (Found: MH^+, 145.0867. $C_7H_{13}O_3$ requires *m*/*z* 145.0865).

(*E*)-2-Methyl-1-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-gluocopyranosyloxy)pent-1-en-3-one 24

A solution of the salt **26**[8] (6.80 g, 50 mmol) in water (20 cm^3) and the acetobromoglucose **27**[9] (10.3 g, 25 mmol) in acetone (40 cm^3) was stirred for 3 days. After partial concentration (to remove Me_2CO), the mixture was extracted twice with dichloromethane. Evaporation of the dried ($MgSO_4$) organic phase and crystallisation of the residue from dichloromethane–diethyl ether gave compound **24** (4.91 g, 44%) in a pure state; mp 107–108 °C (lit.,[6] 97–99 °C); δ_H (300 MHz; $CDCl_3$) 1.10 (3 H, t, *J* 7, 5-H_3), 1.72 (3 H, d, *J* 1, 2-Me), 2.03, 2.05, 2.06 and 2.09 (each 3 H, s, 4 × $MeCO_2$), 2.56 (2 H, q, *J* 7, 4-H_2), 3.83 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.16 and 4.30 [each 1 H, dd (*J* 2.5 and 12.5) and dd (*J* 5 and 12.5), 6′-H_2], 4.90 (1 H, d, *J* 8, 1′-H), 5.13–5.30 (3 H, m, 2′-, 3′ and 4′-H) and 7.36 (1 H, apparent d, separation 1, 1-H).

Methyl (*E*)-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)prop-2-enoate 32b

A solution of the formyl ester **35**[6] (4.00 g, 10.6 mmol) and the phosphorane **36** [obtained by washing a solution of $Bu_3P^+CH_2CO_2Me\ Br^-$ (5.10 g, 14.4 mmol) in CH_2Cl_2 with 10% aq. NaOH and removing the solvent by evaporation] in toluene (100 cm^3) was heated under reflux for 30 min. The solid, obtained after concentration, was washed with light petroleum and the product crystallised from dichloromethane–light petroleum to give the *title compound* **32b** (3.34 g, 73%); mp 142–143 °C; $[\alpha]_D$ −21 (*c* 0.27, CH_2Cl_2) (Found: C, 49.7; H, 5.6. $C_{18}H_{24}O_{12}$ requires C, 50.0; H, 5.6%); λ_{max} (EtOH)/nm 223 (ε 16000); ν_{max} (KBr)/cm^{-1} 1750 (ester C=O), 1720 and 1710 (vinylogous carbonate C=O), and 1630 (C=C); δ_H (300 MHz; $CDCl_3$) 2.04, 2.06, 2.07 and 2.12 (each 3 H, s, 4 × $MeCO_2$), 3.73 (3 H, s, MeO_2C), 3.83 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.17 and 4.29 [each 1 H, dd (*J* 2.5 and 12.5) and dd (*J* 5 and 12.5), 6′-H_2], 4.92 (1 H, d, *J* 8, 1′-H), 5.14 (1 H, t, *J* 9.5, 4′-H), 5.16 (1 H, dd, *J* 8 and 9, 2′-H), 5.27 (1 H, t, *J* 9, 3′-H), 5.51 (1 H, d, *J* 12.5, 2-H) and 7.52 (1 H, d, *J* 12.5, 3-H); δ_C (100 MHz; $CDCl_3$) 20.9 and 21.0 (4 × CH_3CO_2), 51.7 (CH_3O), 61.9 (6′-CH_2), 68.1, 71.0, 72.7 and 73.0 (2′-, 3′-, 4′- and 5′-CH), 100.3 (1′-CH), 102.1 (2-CH), 158.9 (3-CH), 167.6 (CO_2Me) and 169.4, 169.6, 170.4 and 170.9 (4 × MeCO); *m*/*z* (FAB) 433 (MH^+, 10%), 331 ($C_{14}H_{19}O_9^+$, 45), 169 (70), 109 (55) and 43 (100) [(after addition of KI) 471 (MK^+, 40%)].

Bromo(alkoxylation) studies

General procedure. NBS (0.214 g, 1.2 mmol) was added to a stirred mixture of the vinylogous ester/carbonate (1 mmol) in the appropriate alcohol. After the time specified, the mixture was concentrated and a solution of the residue in ethyl acetate or dichloromethane was washed successively with 1% aq. sodium metabisulfite and water. Evaporation of the dried ($MgSO_4$) organic phase gave a residue, which was analysed by NMR spectroscopy and then purified in the manner described.

*Reaction involving the butenone **10** and methanol.* The reaction of the butenone **10**[4] (0.225 g, 0.52 mmol) in methanol (5 cm^3) for 1 h gave rise to a product comprising mainly a 75:25 mixture of the bromo(methoxy) adducts **11a** and **12a** [the ratio was estimated from the integrals of the singlets at δ 2.32 and 2.38 (attributed to the 1-H_3 signals of **11a** and **12a**) and of the singlets at δ 3.46 and 3.59 (ascribed to the methoxy signals of **11a** and **12a**)]; ≈5% of succinimide (δ 2.72) was also present.

Crystallisation of the material from dichloromethane–diethyl ether–light petroleum gave a 96:4 mixture of the bromo(methoxy) adducts **11a** and **12a** (0.153 g, 54%). A further crystallisation from methanol provided *(3R,4R)-3-bromo-4-methoxy-3-methyl-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)butan-2-one* **11a** (0.133 g, 47%); mp 150–152 °C; $[\alpha]_D$ −20 (*c* 2.0, CH_2Cl_2) (Found: C, 44.5; H, 5.4; Br, 15.3. $C_{20}H_{29}BrO_{12}$ requires C, 44.4; H, 5.4; Br, 14.8%); λ_{max} (EtOH)/nm 294 (ε 85); ν_{max} (KBr)/cm^{-1} 1750 (ester C=O) and 1725 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.78 (3 H, s, 3-Me), 2.02, 2.05, 2.06 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.32 (3 H, s, 1-H_3), 3.46 (3 H, s, MeO), 3.79 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.18 and 4.25 [each 1 H, dd (*J* 5 and 12) and dd (*J* 2.5 and 12), 6′-H_2], 4.83 (1 H, d, *J* 8, 1′-H), 4.95 (1 H, s, 4-H), 5.08 (1 H, t, *J* 9.5, 4′-H), 5.13 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.28 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 19.3 (CH_3C), 20.7, 20.8, 21.0 and 21.2 (4 × CH_3CO_2), 24.9 (1-CH_3), 57.4 (CH_3O), 62.1 (6′-CH_2), 66.4 (3-C), 68.6, 71.1, 72.1 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 100.8 (1′-CH), 106.4 (4-CH), 169.4, 169.5, 170.3 and 170.5 (4 × MeCO) and 200.2 (2-CO); *m*/*z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 80%), 195 and 193 ($C_6H_{10}BrO_2^+$, each 15), and 169 (100).

The filtrate from the first crystallisation was concentrated and the residue was triturated with light petroleum to give mainly (3*S*,4*S*)-3-bromo-4-methoxy-3-methyl-4-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)butan-2-one **12a** (0.028 g, ≈10%); δ_H(300 MHz; $CDCl_3$) *inter alia* 1.77 (3 H, s, 3-Me), 2.01, 2.03, 2.05 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.38 (3 H, s, 1-H_3), 3.59 (3 H, s, MeO), 3.73 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.15 and 4.24 [each 1 H, dd (*J* 2.5 and 12.5) and dd (*J* 5 and 12.5), 6′-H_2], 4.83 (1 H, dd, *J* 8, 1′-H), 5.03 (1 H, s, 4-H), 5.08 (1 H, d, *J* 8 and 9.5, 2′-H), 5.09 (1 H, t, *J* 9.5, 4′-H) and 5.24 (1 H, t, *J* 9.5, 3′-H).

*Reaction involving the butenone **10** and ethanol.* (*a*) The reaction of the butenone **10** (0.225 g, 0.52 mmol) in ethanol (5 cm^3) for 1 h gave rise to a product comprising mainly an 80:20 mixture of the bromo(ethoxy) adducts **11b** and **12b** [the ratio was estimated from the heights of the singlets at δ 2.32 and 2.39 (ascribed to the 1-H_3 signals of **11b** and **12b**)]; ≈8% of succinimide was also present.

Two crystallisations of the mixture from chloroform–diethyl ether–light petroleum gave *(3R,4R)-3-bromo-4-ethoxy-3-methyl-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)-butan-2-one* **11b** (0.110 g, 38%); mp 152–153 °C; $[\alpha]_D$ −29 (*c* 0.53, CH_2Cl_2) (Found: C, 45.1; H, 5.5; Br, 14.5. $C_{21}H_{31}BrO_{12}$ requires C, 45.4; H, 5.6; Br, 14.4%); λ_{max} (EtOH)/nm 293 (ε 90); ν_{max} (KBr)/cm^{-1} 1760 (ester C=O) and 1730 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.11 (3 H, t, *J* 7, $MeCH_2$), 1.78 (3 H, s, 3-Me), 2.02, 2.04, 2.06 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.32 (3 H, s, 1-H_3), 3.49 and 3.94 (each 1 H, dq, *J* 9.5 and 7, $MeCH_2O$), 3.77 (1 H, ddd, *J* 2.5, 5.5 and 10, 5′-H), 4.16 and 4.24 [each 1 H, dd (*J* 5.5 and 12) and dd (*J* 2.5 and 12), 6′-H_2], 4.84 (1 H, d, *J* 8, 1′-H), 5.05 (1 H, s, 4-H), 5.06 (1 H, t, *J* 9.5, 4′-H), 5.12 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.27 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 14.8 (CH_3CH_2), 19.5 (CH_3C), 20.7, 20.8 and 21.1 (4 × CH_3CO_2), 25.0 (1-CH_3), 62.2 (6′-CH_2), 65.5

(Me*C*H$_2$), 66.8 (3-C), 68.6, 71.2, 72.1 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 100.8 (1′-CH), 104.9 (4-CH), 169.4, 169.6, 170.3 and 170.5 (4 × Me*C*O) and 200.2 (2-CO); *m*/*z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 80%), 209 and 207 ($C_7H_{12}BrO_2^+$, each 50), and 169 (100).

(*b*) The reaction of the butenone **10** (4.30 g, 10.0 mmol) in ethanol (50 cm^3) for 15 h deposited a solid. The mixture was cooled (−30 °C) and the solid collected by filtration. After having been washed with a small volume of cold ethanol and dried, the solid (3.57 g, 64%) was identified as the bromo(ethoxy) adduct **11b**.

*Reaction involving the butenone **10** and propan-1-ol.* (*a*) The reaction of the butenone **10** (2.00 g, 4.7 mmol) in propan-1-ol (40 cm^3) for 1 h gave rise to a product comprising mainly an 86:14 mixture of the bromo(propoxy) adducts **11c** and **12c** [the ratio was estimated from the integrals of the singlets at δ 2.31 and 2.37 (ascribed to the 1-H$_3$ signals of **11c** and **12c**)]; ≈10% of succinimide was also present.

Two crystallisations of the mixture from chloroform–diethyl ether–light petroleum gave *(3R,4R)-3-bromo-3-methyl-4-propoxy-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)-butan-2-one* **11c** (1.51 g, 57%); mp 134–136 °C; $[\alpha]_D$ −28 (*c* 1.2, CH_2Cl_2) (Found: C, 46.3; H, 6.0; Br, 14.1. $C_{22}H_{33}BrO_{12}$ requires C, 46.4; H, 5.8; Br, 14.0%); λ_{max} (EtOH)/nm 294 (ε 90); ν_{max} (KBr)/cm^{-1} 1760 (ester C=O) and 1730 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.82 (3 H, t, *J* 7.5, *Me*CH$_2$), 1.44–1.56 (2 H, m, MeC*H*$_2$), 1.77 (3 H, s, 3-Me), 2.01, 2.04, 2.06 and 2.07 (each 3 H, s, 4 × MeCO$_2$), 2.31 (3 H, s, 1-H$_3$), 3.33 and 3.87 (each 1 H, dt, *J* 9.5 and 6.5, EtC*H*$_2$O), 3.76 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.15 and 4.23 [each 1 H, dd (*J* 5 and 12) and dd (*J* 2.5 and 12), 6′-H$_2$], 4.84 (1 H, d, *J* 8, 1′-H), 5.03 (1 H, s, 4-H), 5.06 (1 H, t, *J* 10, 4′-H), 5.11 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.26 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.2 (*C*H$_3$CH$_2$), 19.2 (*C*H$_3$C), 20.4, 20.5 and 20.7 (4 × *C*H$_3$CO$_2$), 22.3 (Me*C*H$_2$), 24.7 (1-CH$_3$), 61.8 (6′-CH$_2$), 66.4 (3-C), 68.3, 70.9, 71.7 and 72.3 (2′-, 3′-, 4′- and 5′-CH), 71.3 (Et*C*H$_2$), 100.5 (1′-CH), 104.7 (4-CH), 169.1, 169.2, 170.0 and 170.2 (4 × Me*C*O) and 199.8 (2-CO); *m*/*z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 70%), 223 and 221 ($C_8H_{14}BrO_2^+$, each 40), 181 and 179 ($C_5H_8BrO_2^+$, each 20), and 169 (100).

(*b*) The reaction of the butenone **10** (0.430 g, 1.00 mmol) in propan-1-ol (50 cm^3) was left for 1 h at 38 °C and 60 h at ≈20 °C. After concentration to ≈50% of its volume, the mixture was allowed to crystallise (first at ≈20 °C and then at −30 °C); filtration gave the bromo(propoxy) adduct **11c** (0.298 g, 52%).

*Reaction involving the butenone **10** and butan-1-ol.*—The reaction of the butenone **10** (0.225 mmol, 0.52 mmol) in butan-1-ol (18 cm^3) for 1 h gave rise to a product comprising mainly an 86:14 mixture of the bromo(butoxy) adducts **11d** and **12d** [the ratio was estimated from the integrals of the singlets at δ 2.32 and 2.39 (ascribed to the 1-H$_3$ signals of **11d** and **12d**)].

Crystallisation of the mixture from chloroform–diethyl ether–light petroleum gave *(3R,4R)-3-bromo-4-butoxy-3-methyl-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)-butan-2-one* **11d** (0.125 g, 41%); mp 75–77 °C; $[\alpha]_D$ −12 (*c* 0.08, CH_2Cl_2) (Found: C, 47.4; H, 6.1; Br, 13.8. $C_{23}H_{35}BrO_{12}$ requires C, 47.3; H, 6.0; Br, 13.7%); λ_{max} (EtOH)/nm 294 (ε 110); ν_{max} (KBr)/cm^{-1} 1760 (ester C=O) and 1730 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.86 (3 H, t, *J* 7.5, *Me*CH$_2$), 1.19–1.33 and 1.35–1.52 (each 2 H, m, MeC*H*$_2$C*H*$_2$), 1.78 (3 H, s, 3-Me), 2.02, 2.04, 2.06 and 2.08 (each 3 H, s, 4 × MeCO$_2$), 2.32 (3 H, s, 1-H$_3$), 3.37 and 3.92 (each 1 H, dt, *J* 9.5 and 6.5, PrC*H*$_2$O), 3.76 (1 H, ddd, *J* 3, 5 and 10, 5′-H), 4.16 and 4.23 [each 1 H, dd (*J* 5 and 12) and dd (*J* 3 and 12), 6′-H$_2$], 4.84 (1 H, d, *J* 8, 1′-H), 5.03 (1 H, s, 4-H), 5.07 (1 H, t, *J* 9.5, 4′-H), 5.12 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.27 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 13.8 (*C*H$_3$CH$_2$), 19.2 (Me*C*H$_2$), 19.4 (*C*H$_3$C), 20.7 and 21.0 (4 × *C*H$_3$CO$_2$), 25.0 (1-CH$_3$), 31.4 (Et*C*H$_2$), 62.1 (6′-CH$_2$), 66.7 (3-C), 68.5, 71.1, 72.0 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 69.7 (Pr*C*H$_2$), 100.7 (1′-CH), 105.0 (4-CH), 169.4, 169.5, 170.3 and 170.5 (4 × Me*C*O) and 200.1 (2-CO); *m*/*z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 50%), 237 and 235 ($C_9H_{16}BrO_2^+$, each 20), 181 and 179 ($C_5H_8BrO_2^+$, each 15) and 169 (100); *m*/*z* (CI) 602 and 600 (MNH_4^+, 15 and 10%), 331 ($C_{14}H_{19}O_9^+$, 20) and 157 (100).

*Reaction involving the butenone **10** and propan-2-ol.* The reaction of the butenone **10** (0.215 g, 0.50 mmol) in propan-2-ol (60 cm^3) for 2 h gave rise to a product comprising mainly the tetraacetylglucose **13** as a 1:1 mixture of α- and β-anomer [on the basis of the triplets (*J* 10) at δ 5.22 and 5.52 (attributable to the 3-H signals of the β- and α-anomer]; there was also evidence for the presence of ≈25% of the dibromide **14** as an 80:20 mixture of diastereomers [on the basis of the singlets at δ 6.35 and 6.50 (attributed to the 4-H signals of the minor and major dibromides)].

*Reaction involving the butenone **10** and 2-methylpropan-2-ol.* The reaction of the butenone **10** (0.215 g, 0.50 mmol) in 2-methylpropan-2-ol (30 cm^3) at ≈30 °C for 2 h gave rise to a product containing largely the tetraacetylglucose **13** as a 2:1 mixture of α- and β-anomer; there was also evidence for the presence of ≈10% of the dibromide **14** as an 80:20 mixture of diastereomers.

*Reaction involving the butenone **10** and benzyl alcohol.* The reaction of the butenone **10** (0.225 g, 0.52 mmol) in benzyl alcohol (2 cm^3) for 1 h gave rise (after removal of PhCH$_2$OH by azeotropic distillation with water) to a product comprising mainly an 89:11 mixture of the bromo(benzyloxy) adducts **11e** and **12e** [the ratio was estimated from the integrals of the singlets at δ 2.20 and 2.38 (attributed to the 1-H$_3$ signals of **11e** and **12e**)]; ≈2% of succinimide was also present.

Crystallisation of the mixture from diethyl ether–hexanes gave *(3R,4R)-4-benzyloxy-3-bromo-3-methyl-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)butan-2-one* **11e** (0.139 g, 43%); mp 118–120 °C; $[\alpha]_D$ −41 (*c* 0.57, CH_2Cl_2) (Found: C, 50.8; H, 5.3; Br, 12.9. $C_{26}H_{33}BrO_{12}$ requires C, 50.6; H, 5.4; Br, 13.0%); λ_{max} (EtOH)/nm 206 (ε 9700), 251 (210), 257 (230), 263 (180), 267 (120) and 294 (65); ν_{max} (KBr)/cm^{-1} 1755 (ester C=O) and 1725 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.81 (3 H, s, 3-Me), 2.00, 2.03, 2.06 and 2.10 (each 3 H, s, 4 × MeCO$_2$), 2.20 (3 H, s, 1-H$_3$), 3.83 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.20 and 4.28 [each 1 H, dd (*J* 5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H$_2$], 4.53 and 4.91 (each 1 H, d, *J* 11.5, PhC*H*$_2$), 4.93 (1 H, d, *J* 8, 1′-H), 5.11 (1 H, t, *J* 10, 4′-H), 5.17 (1 H, dd, *J* 8 and 9.5, 2′-H), 5.19 (1 H, s, 4-H), 5.30 (1 H, t, *J* 9.5, 3′-H) and 7.22–7.35 (m, C_6H_5 and $CHCl_3$); δ_C (100 MHz; $CDCl_3$) 19.5 (*C*H$_3$C), 20.6, 20.7 and 20.9 (4 × *C*H$_3$CO$_2$), 24.9 (1-CH$_3$), 62.0 (6′-CH$_2$), 66.8 (3-C), 68.4, 71.1, 72.1 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 71.1 (Ph*C*H$_2$), 100.7 (1′-CH), 104.2 (4-CH), 127.9, 128.0 and 128.4 (5 × phenyl CH), 136.9 (phenyl C), 169.3, 169.4, 170.2 and 170.4 (4 × Me*C*O) and 200.0 (2-CO); *m*/*z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 60%), 169 (70), 109 (70) and 91 ($C_7H_7^+$, 100).

*Reaction involving the butenone **10** and 2-methylpropan-1-ol.* The reaction of the butenone **10** (0.225 g, 0.52 mmol) in 2-methylpropan-1-ol (10 cm^3) for 3 h gave rise to a product comprising mainly an 88:12 mixture of the bromo(methylpropoxy) adducts **11f** and **12f** [the ratio was estimated from the integrals of the singlets at δ 2.32 and 2.38 (attributed to the 1-H$_3$ signals of **11f** and **12f**)]; ≈11% of succinimide was also present.

Crystallisation of the mixture from chloroform–diethyl ether–light petroleum gave *(3R,4R)-3-bromo-3-methyl-4-(2-methylpropoxy)-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)butan-2-one* **11f** (0.167 g, 55%); mp 124–126 °C; $[\alpha]_D$ −24 (*c* 0.5, CH_2Cl_2) (Found: C, 47.1; H, 5.9; Br, 14.0. $C_{23}H_{35}BrO_{12}$ requires C, 47.3; H, 6.0; Br, 13.7%); λ_{max} (EtOH)/nm 294 (ε 100); ν_{max} (KBr)/cm^{-1} 1760 and 1740 (ester C=O) and 1730 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.80 and 0.81 (each 3 H, d, *J* 7, *Me*$_2$CH), 1.72–1.82 (1 H, m, Me$_2$C*H*), 1.78 (3 H, s, 3-Me), 2.02, 2.04, 2.07 and 2.08 (each 3 H, s, 4 × MeCO$_2$), 2.32 (3 H, s, 1-H$_3$), 3.08 and 3.72 (each 1 H, dd, *J* 7 and 9, Me$_2$CHC*H*$_2$O), 3.73–3.79 (1 H, m, 5′-H), 4.16 and 4.24 [each 1 H,

dd (*J* 5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H_2], 4.84 (1 H, d, *J* 8, 1′-H), 5.02 (1 H, s, 4-H), 5.08 (1 H, t, *J* 10, 4′-H), 5.11 (1 H, dd, *J* 8 and 10, 2′-H) and 5.26 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 19.1, 19.2 and 19.3 [(CH_3)$_2$CH and CH_3C], 20.6, 20.7 and 20.9 (4 × CH_3CO_2), 24.9 (1-CH_3), 28.2 (Me_2CH), 62.0 (6′-CH_2), 66.6 (3-C), 68.4, 71.1, 71.9 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 76.4 (CH_2O), 100.6 (1′-CH), 104.9 (4-CH), 169.3, 169.4, 170.2 and 170.4 (4 × MeCO) and 200.0 (2-CO); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 90), 235 and 233 ($C_9H_{16}BrO_2^+$, each 30), and 169 (100).

Reaction involving the butenone ***10*** *and 2,2-dimethylpropan-1-ol.* The reaction of the butenone **10** (0.157 g, 0.37 mmol) in 2,2-dimethylpropan-1-ol (3.0 cm^3) at ≈55 °C for 1 h gave rise to a product comprising mainly a 76:10:14 mixture of compounds **11g**, **12g** and **14** [the proportions were estimated from the integrals of the singlets at δ 2.32, 2.38 and 2.41 (attributed to the 1-H_3 signals of **11g**, **12g** and **14**)].

Crystallisation of the material from dichloromethane–diethyl ether–light petroleum gave a 91:9 mixture of (3*R*,4*R*)-3-bromo-4-(2,2-dimethylpropoxy)-3-methyl-4-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)butan-2-one **11g** and 3,4-dibromo-3-methyl-4-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)butan-2-one **14** (as a single diastereomer) (0.043 g); δ_H (300 MHz; $CDCl_3$) (for **11g**) 0.82 (9 H, s, Me_3C), 1.78 (3 H, s, 3-Me), 2.02, 2.05, 2.07 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.32 (3 H, s, 1-H_3), 2.95 and 3.63 (each 1 H, d, *J* 9, CH_2O), 3.76 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.16 and 4.25 [each 1 H, dd (*J* 5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H_2], 4.83 (1 H, d, *J* 8, 1′-H), 5.01 (1 H, s, 4-H), 5.06–5.14 (2 H, m, 2′- and 4′-H) and 5.27 (1 H, t, *J* 9.5, 3′-H).

Reaction involving the butenone ***17b*** *and propan-1-ol.* The reaction of butenone **17b** (0.225 g, 1.56 mmol) in propan-1-ol (18 cm^3) for 1 h gave rise to a product that was mainly the bromo(propoxy) adduct **18**. Column chromatography [hexanes–EtOAc (9.1) as eluent] provided *(3R*,4R*)-3-bromo-4-methoxymethoxy-3-methyl-4-propoxybutan-2-one* **18** (0.250 g, 57%) as a clear oil (Found: C, 42.1; H, 7.0; Br, 28.5. $C_{10}H_{19}BrO_4$ requires C, 42.4; H, 6.8; Br, 28.2%); λ_{max} (EtOH)/nm 291 (ε 95); ν_{max} (film)/cm^{-1} 1725 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.86 (3 H, t, *J* 7.5, *Me*CH_2), 1.54 (2 H, sextet, separation 7, MeCH_2), 1.81 (3 H, s, 3-Me), 2.35 (3 H, s, 1-H_3), 3.43 (3 H, s, MeO), 3.46 and 3.74 (each 1 H, dt, *J* 9 and 6.5, EtCH_2O), 4.81 (2 H, AB q, *J* 7, separation of inner lines 3, OCH_2O) and 4.98 (1 H, s, 4-H); δ_C (100 MHz; $CDCl_3$) 10.6 (CH_3CH_2), 20.6 (CH_3C), 23.0 (MeCH_2), 25.6 (1-CH_3), 56.3 (CH_3O), 67.6 (3-C), 72.2 (EtCH_2O), 96.1 (OCH_2O), 103.7 (4-CH) and 200.9 (2-CO); *m/z* (CI) 302 and 300 (MNH_4^+, each 100%), 240 and 238 ($C_7H_{11}BrO_4^+$, each 25), 180 and 178 ($C_5H_7BrO_2^+$, each 35), 160 (45) and 143 (95).

Reaction involving the butenone ***21*** *and ethanol.* The reaction of the butenone **21**[7] (0.217 g, 0.52 mmol) in ethanol (3 cm^3) for 0.5 h gave rise to a product comprising mainly a 71:29 mixture of the bromo(ethoxy) adducts **22a** and **23a** [the ratio was estimated from the integrals of the singlets at δ 2.32 and 2.35 (attributed to the 1-H_3 signals of **22a** and **23a**)]; ≈20% of the tetraacetylglucose **13** was also present.

Subjection of the mixture to column chromatography ($CHCl_3$ as eluent) gave an orange oil (0.211 g) comprising mainly a 75:25 mixture of the bromo(ethoxy) adducts **22a** and **23a**. Three crystallisations of the material from ethyl acetate–light petroleum gave a 97:3 mixture of *(3R,4R)-3-bromo-4-ethoxy-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)-butan-2-one* **22a** and its *(3S,4S)-diastereomer* **23a** (0.020 g, 7%); mp 90–93 °C; $[\alpha]_D$ −9 (*c* 0.27, CH_2Cl_2) (Found: C, 44.2; H, 5.4; Br, 15.2. $C_{20}H_{29}BrO_{12}$ requires C, 44.4; H, 5.4; Br, 14.8%); λ_{max} (EtOH)/nm 294 (ε 90); ν_{max}(KBr)/cm^{-1} 1755 (ester C=O) and 1745 (ester and ketone C=O); δ_H (300 MHz; $CDCl_3$) (for **22a**) 1.14 (3 H, t, *J* 7, *Me*CH_2), 2.01, 2.04, 2.06 and 2.07 (each 3 H, s, 4 × $MeCO_2$), 2.32 (3 H, s, 1-H_3), 3.54 and 3.87 (each 1 H, dq, *J* 9.5 and 7, MeCH_2O), 3.74 (1 H, ddd, *J* 3, 5.5 and 10, 5′-H), 4.15 and 4.22 [each 1 H, dd, (*J* 5.5 and 12) and dd (*J* 3 and 12), 6′-H_2], 4.29 (1 H, d, *J* 7.5, 3-H), 4.81 (1 H, d, *J* 8, 1′-H), 4.95 (1 H, d, *J* 7.5, 4-H), 5.06 (1 H, t, *J* 10, 4′-H), 5.07 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.24 (1 H, t, *J* 9.5, 3′-H); *m/z* (FAB) 565 and 563 (MNa^+, each 1%), 543 and 541 (MH^+, each 1), 331 ($C_{14}H_{19}O_9^+$, 100), 195 and 193 ($C_6H_{10}BrO_2^+$, each 60) and 169 (90).

Reaction involving the butenone ***21*** *and propan-1-ol.* The reaction of the butenone **21** (0.279 g, 0.67 mmol) in propan-1-ol (3 cm^3) gave rise to a product comprising mainly a 72:28 mixture of the bromo(propoxy) adducts **22b** and **23b** [the ratio was estimated from the integrals of the singlets at δ 2.31 and 2.35 (attributed to the 1-H_3 signals of **22b** and **23b**)]; ≈25% of the tetraacetylglucose **13** was also present.

Subjection of the mixture to column chromatography ($CHCl_3$ as eluent) gave an orange oil (0.238 g) comprising mainly a 75:25 mixture of the bromo(propoxy) adducts **22b** and **23b**. Crystallisation of the material from ethyl acetate–light petroleum gave a 50:50 mixture of the bromo(propoxy) adducts **22b** and **23b** (0.044 g, 12%) as an off-white solid; evaporation of the mother liquor gave a residue (0.140 g, 38%) comprising a 80:20 mixture of the bromo(propoxy) adducts **22b** and **23b**. A further crystallisation of the 80:20 mixture failed to provide pure material; on storage, however, the filtrate deposited another crop of crystals (0.016 g, 4%) comprising a 94:6 mixture of *(3R,4R)-3-bromo-4-propoxy-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)butan-2-one* **22b** and its *(3S,4S)-diastereomer* **23b**; mp 62–73 °C; $[\alpha]_D$ −6 (*c* 0.33, CH_2Cl_2) (Found: C, 45.7; H, 5.9; Br, 14.1. $C_{21}H_{31}BrO_{12}$ requires C, 45.5; H, 5.6; Br, 14.4%); λ_{max} (EtOH)/nm 291 (ε 150); ν_{max} (KBr)/cm^{-1} 1755 (ester C=O) and 1740sh (ketone C=O); δ_H (300 MHz; $CDCl_3$) (for **22b**) 0.86 (3 H, t, *J* 7.5, *Me*CH_2), 1.47–1.57 (2 H, m, MeCH_2), 2.01, 2.04, 2.06 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.31 (3 H, s, 1-H_3), 3.40 (1 H, dt, *J* 9.5 and 7, EtCHHO), 3.71–3.82 (2 H, m, 5′-H and EtCH*H*O), 4.16 and 4.21 [each 1 H, dd (*J* 5.5 and 12.5) and dd (*J* 3 and 12.5), 6′-H_2], 4.29 (1 H, d, *J* 7.5, 3-H), 4.81 (1 H, d, *J* 8, 1′-H), 4.94 (1 H, d, *J* 7.5, 4-H), 5.06 (1 H, t, *J* 10, 4′-H), 5.07 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.23 (1 H, t, *J* 9.5, 3′-H); *m/z* (FAB) 579 and 577 (MNa^+, each 2%), 331 ($C_{14}H_{19}O_9^+$, 60), 209 and 207 ($C_7H_{12}BrO_2^+$, each 50) and 169 (100).

Reaction involving the butenone ***21*** *and benzyl alcohol.* The reaction of the butenone **21** (0.635 g, 1.53 mmol) in benzyl alcohol (16 cm^3) for 40 min gave (after removal of $PhCH_2OH$ by azeotropic distillation with water) a product comprising mainly an 80:20 mixture of the bromo(benzyloxy) adducts **22c** and **23c** [the ratio was estimated from the integrals of the singlets at δ 2.25 and 2.31 (attributed to the 1-H_3 signals of **22c** and **23c**)]; ≈10% of the tetraacetylglucose **13** was also present.

Subjection of the mixture to column chromatography ($CHCl_3$ as eluent) and crystallisation of the product from methanol gave an 84:16 mixture of *(3R,4R)-4-benzyloxy-3-bromo-4-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)-butan-2-one* **22c** and its *(3S,4S)-diastereomer* **23c** (0.411 g, 45%); mp 84–86 °C; $[\alpha]_D$ −5 (*c* 0.35, CH_2Cl_2) (Found: C, 49.8; H, 5.2; Br, 13.3. $C_{25}H_{31}BrO_{12}$ requires C, 49.8; H, 5.1; Br, 13.1%); λ_{max} (EtOH)/nm 205 (ε 9100), 252 (250), 257 (280), 263 (230), 267 (170) and 294 (90); ν_{max} (KBr)/cm^{-1} 1760 (ester C=O) and 1740 (ester and ketone C=O); δ_H (300 MHz; $CDCl_3$) (for **22c**) 2.01, 2.02, 2.04 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.25 (3 H, s, 1-H_3), 3.75 (1 H, dt, *J* 10 and 4, 5′-H), 4.19 (2 H, d, separation 4, 6′-H_2), 4.33 (1 H, d, *J* 7.5, 3-H), 4.55 and 4.85 (each 1 H, d, *J* 11.5, $PhCH_2O$), 4.86 (1 H, d, *J* 8, 1′-H), 5.07–5.15 (3 H, m, 4-, 2′- and 4′-H), 5.25 (1 H, t, *J* 9.5, 3′-H) and 7.24–7.39 (m, C_6H_5 and $CHCl_3$); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 60%), 169 (75) and 91 ($C_7H_7^+$, 100).

Reaction involving the pentenone ***24*** *and propan-1-ol.* (*a*) The reaction of the pentenone **24**[6] (0.225 g, 0.51 mmol) in propan-1-ol (15 cm^3) for 5 h gave rise to a product comprising mainly an 87:13 mixture of the bromo(propoxy) adducts **28**

and **29** [the ratio was estimated from the heights of the singlets at δ 203.3 and 204.9 (attributed to the 3-CO groups of **28** and **29**)].

Crystallisation of the mixture from methanol afforded *(1R,2R)-2-bromo-2-methyl-1-propoxy-1-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)pentan-3-one* **28** (0.150 g, 51%); mp 174–175 °C; $[\alpha]_D$ −24 (*c* 0.9, CH_2Cl_2) (Found: C, 47.4; H, 6.0; Br, 14.0. $C_{23}H_{35}BrO_{12}$ requires C, 47.4; H, 6.1; Br, 13.7%); λ_{max} (EtOH)/nm 295 (ε 80); ν_{max}(KBr)/cm^{-1} 1760 (ester C=O) and 1730 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.80 (3 H, t, *J* 7.5, *Me*CH_2), 1.09 (3 H, t, *J* 7, 5-H_3), 1.48 (2 H, sextet, separation 7, MeCH_2), 1.79 (3 H, s, 2-Me), 2.01, 2.03, 2.05 and 2.06 (each 3 H, s, 4 × $MeCO_2$), 2.52–2.81 (2 H, m, 4-H_2), 3.31 and 3.85 (each 1 H, dt, *J* 9.5 and 7, EtCH_2O), 3.76 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.15 and 4.23 [each 1 H, dd (*J* 5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H_2], 4.83 (1 H, d, *J* 8, 1′-H), 5.02–5.14 (2 H, m, 2′- and 4′-H), 5.06 (1 H, s, 1-H) and 5.26 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 8.1 (5-CH_3), 10.4 (*C*$H_3$$CH_2$), 19.3 (*C*$H_3$C), 20.6, 20.7 and 21.0 (4 × *C*H_3CO_2), 22.5 (Me*C*H_2), 30.3 (4-CH_2), 62.1 (6′-CH_2), 66.5 (2-C), 68.5, 71.1, 71.9 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 71.5 (Et*C*H_2), 100.7 (1′-CH), 105.0 (1-CH), 169.3, 169.5, 170.2 and 170.4 (4 × Me*C*O) and 203.3 (3-CO); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 100%), 237 and 235 ($C_9H_{16}BrO_2^+$, each 25), and 169 (70).

(*b*) The reaction of the pentenone **24** (1.54 g, 3.5 mmol) in propan-1-ol (170 cm^3) was left for 6 h at 30 °C and overnight at −30 °C. Filtration and recrystallisation of the product from hot propan-1-ol gave the bromo(propoxy) adduct **28a** (1.11 g, 55%).

Reaction involving the methylenecyclopentanone ***25a*** *and propan-ol.* The reaction of the cyclopentanone **25a**[4] (0.442 g, 1.00 mmol) in propan-1-ol (50 cm^3) for 2 h gave rise to a product comprising mainly an 87:13 mixture of the bromo(propoxy) adducts **30a** and **31a** [the ratio was estimated from the heights of the singlets at δ 22.4 and 22.8 (attributed to the Me*C*H_2 signals of **30a** and **31a**)].

Crystallisation of the material from ethyl acetate–hexanes gave *(2R)-2-bromo-2-[(R)-propoxy-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyloxy)methyl]cyclopentanone* **30a** (0.304 g, 52%); mp 112 °C; $[\alpha]_D$ −12 (*c* 0.63, CH_2Cl_2) (Found: C, 47.2; H, 5.5; Br, 13.4. $C_{23}H_{33}BrO_{12}$ requires C, 47.5; H, 5.7; Br, 13.7%); ν_{max}(KBr)/cm^{-1} 1760 (easter C=O) and 1750 (ester and ketone C=O); δ_H (300 MHz; $CDCl_3$) 0.82 (3 H, t, *J* 7.5, *Me*CH_2), 1.50 (2 H, sextet, separation 7, MeCH_2), 2.04, 2.06, 2.08 and 2.09 (each 3 H, s, 4 × $MeCO_2$), 2.41–2.53 and 2.58–2.71 (each 1 H, m, 5-H_2), 3.38 and 3.87 (each 1 H, dt, *J* 9 and 6.5, EtCH_2O), 3.77 (1 H, ddd, *J* 2.5, 5.5 and 10, 5′-H), 4.17 and 4.23 [each 1 H, dd (*J* 5.5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H_2], 4.86 (1 H, d, *J* 8, 1′-H), 4.98 (OCHO), 5.07 (1 H, t, *J* 9.5, 4′-H), 5.12 (1 H, dd, *J* 8 and 10, 2′-H) and 5.29 (1 H, t, *J* 10, 3′-H) (the 3- and 4-H_2 signals appeared in the δ 1.97–2.21 region and were partly obscured by the $MeCO_2$ signals); δ_C (100 MHz; $CDCl_3$) 10.3 (*C*$H_3$$CH_2$), 18.7 (4-$CH_2$), 20.5 and 20.9 (4 × *C*H_3CO_2), 22.4 (Me*C*H_2), 32.6 (3-CH_2), 36.5 (5-CH_2), 62.1 (6′-CH_2), 66.0 (2-C), 68.4, 71.0, 71.8 and 72.4 (2′-, 3′-, 4′- and 5′-CH), 71.9 (Et*C*H_2), 100.7 (1′-CH), 105.1 (OCHO), 169.1, 169.4, 170.0 and 170.3 (4 × Me*C*O) and 209.7 (1-CO); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 100%), 235 and 233 ($C_9H_{14}BrO_2^+$, each 25), 193 and 191 ($C_6H_8BrO_2^+$, each 65) and 169 (95) [(after addition of KI) 621 and 619 (MK^+, each 100%)].

Reaction involving the methylenecyclohexanone ***25b*** *and propan-1-ol.* (*a*) The reaction of the cyclohexanone **25b**[4] (0.456 g, 1.00 mmol) in propan-1-ol (50 cm^3) for 2 h gave rise to a product comprising mainly an 87:13 mixture of the bromo(propoxy) adducts **30b** and **31b** [the ratio was estimated from the integrals of the singlets at δ 202.4 and 202.8 (attributed to the 1-CO signals of **30b** and **31b**)]; ≈20% of the tetraacetylglucose **13** was also present.

Crystallisation of the material from ethanol gave *(2R)-2-bromo-2-[(R)-propoxy-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)methyl]cyclohexanone* **30b** (0.120 g, 20%); mp 110 °C; $[\alpha]_D$ +70 (*c* 0.44, CH_2Cl_2) (Found: C, 48.3; H, 5.9; Br, 13.2. $C_{24}H_{35}BrO_{12}$ requires C, 48.4; H, 5.9; Br, 13.4%); ν_{max} (KBr)/cm^{-1} 1760 and 1745sh (ester C=O) and 1720 (ketone C=O); δ_H (400 MHz; $CDCl_3$) 0.84 (3 H, t, *J* 7.5, *Me*CH_2), 1.45–1.61 (2 H, m, MeCH_2), 1.80–2.40 (≈7 H, m, 3-, 4- and 5-H_2 and 6-H_{eq}), 2.03, 2.06, 2.07 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 2.96 (1 H, ddd, *J* 6.5, 14 and 16, 6-H_{ax}), 3.50 and 3.93 (each 1 H, dt, *J* 9 and 6.5, EtCH_2O), 3.78 (1 H, ddd, *J* 2.5, 5.5 and 10, 5′-H), 4.18 and 4.24 [each 1 H, dd (*J* 5.5 and 12) and dd (*J* 2.5 and 12), 6′-H_2], 4.82 (1 H, d, *J* 8, 1′-H), 5.06 (1 H, t, *J* 9.5, 4′-H), 5.13 (1 H, dd, *J* 8 and 9.5, 2′-H), 5.15 (1 H, s, OCHO) and 5.28 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.5 (*C*$H_3$$CH_2$), 20.3 (4- or 5-$CH_2$), 20.7 and 21.1 (4 × *C*H_3CO_2), 22.7 (Me*C*H_2), 24.8 (5- or 4-CH_2), 31.7 (3-CH_2), 36.8 (6-CH_2), 62.3 (6′-CH_2), 68.6, 71.2, 72.0 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 68.7 (2-C), 71.9 (Et*C*H_2), 101.0 (1′-CH), 105.2 (OCHO), 169.3, 169.5, 170.2 and 170.5 (4 × Me*C*O) and 202.4 (1-CO); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 65), 249 and 247 ($C_{10}H_{16}BrO_2^+$, each 35), 207 and 205 ($C_7H_{10}BrO_2^+$, each 45), 179 and 177 ($C_6H_{10}BrO^+$, each 30) and 169 (100) [(after addition of KI) 635 and 633 (MK^+, each 90%)].

(*b*) The aforecited reaction of the cyclohexanone **25b** (2.53 g, 5.5 mmol) was repeated but, additionally, the solution was washed with 5% aq. sodium hydroxide. Evaporation left a brown residue (containing no tetraacetate **13** by ^{1}H NMR spectroscopy), which was dissolved in boiling ethanol, treated with charcoal and filtered. On cooling, the filtrate deposited compound **30b** (0.670 g, 20%). The filtrate was evaporated and the residue crystallised from ethyl acetate–light petroleum to give a further quantity (0.640 g, 19%) of compound **30b**.

Reaction involving the propenoate ***32a*** *and propan-1-ol.* The reaction of the propenoate **32a**[4] (0.500 g, 1.12 mmol) in propan-1-ol (20 cm^3) for 1 h gave rise to a residue comprising mainly an 85:15 mixture of the bromo(propoxy) adducts **33a** and **34a** [the ratio was estimated from the heights of the singlets at δ 22.4 and 23.0 (attributed to the Me*C*H_2 signals of **33a** and **34a**)].

Crystallisation of the material from diethyl ether gave *methyl (2R,3R)-2-bromo-2-methyl-3-propoxy-3-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)propanoate* **33a** (0.343 g, 52%); mp 155–157 °C; $[\alpha]_D$ −16 (*c* 0.1, CH_2Cl_2) (Found: C, 45.4; H, 5.8; Br, 14.2. $C_{22}H_{33}BrO_{13}$ requires C, 45.1; H, 5.7; Br, 13.7%); ν_{max}(KBr)/cm^{-1} 1760 and 1730 (ester C=O); δ_H (300 MHz; $CDCl_3$) 0.82 (3 H, t, *J* 7, *Me*CH_2), 1.40–1.60 (2 H, m, MeCH_2), 1.80 (3 H, s, 2-Me), 2.02, 2.04, 2.06 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 3.35 and 3.87 [each 1 H, dt (*J* 9.5 and 7) and dt (*J* 9.5 and 6), EtCH_2O], 3.73–3.81 (1 H, m, 5′-H), 3.79 (3 H, s, MeO), 4.16 and 4.24 [each 1 H, dd (*J* 5 and 12.5) and dd (*J* 5 and 12.5), 6′-H_2], 4.85 (1 H, d, *J* 8, 1′-H), 5.06 (1 H, t, *J* 10, 4′-H), 5.08 (1 H, s, 3-H), 5.13 (1 H, dd, *J* 8 and 10, 2′-H) and 5.28 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.3 (*C*$H_3$$CH_2$), 19.4 (*C*$H_3$C), 20.5, 20.6 and 20.9 (4 × *C*H_3CO_2), 22.4 (Me*C*H_2), 52.9 (*C*H_3O), 60.0 (2-C), 62.0 (6′-CH_2), 68.5, 71.0, 71.8 and 72.4 (2′-, 3′-, 4′- and 5′-CH), 71.6 (Et*C*H_2), 100.8 (1′-CH), 105.0 (3-CH) and 169.2, 169.3, 169.4, 170.0 and 170.2 (1-CO and 4 × Me*C*O); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 80), 239 and 237 ($C_8H_{14}BrO_3^+$, each 90), 197 and 195 ($C_5H_8BrO_3^+$, each 90) and 169 (100).

Reaction involving the propenoate ***32b*** *and propan-1-ol.* (*With P. M. Cowley*.) The reaction of the propenoate **32b** (0.500 g, 1.16 mmol) in propan-1-ol (70 cm^3) for 3 h gave rise to a residue comprising mainly a 78:22 mixture of the bromo(propoxy) adducts **33b** and **34b** [the ratio was estimated from the heights of the singlets at δ 22.8 and 23.1 (attributed to the Me*C*H_2 signals of **33b** and **34b**)].

Subjection of the product to column chromatography [Et_2O–light petroleum (2:1) as eluent] and crystallisation of the chromatographed material (from Et_2O–light petroleum) gave *methyl (2R,3R)-2-bromo-3-propoxy-3-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyloxy)propanoate* **33b** (0.118 g, 18%); mp 67–68 °C; $[\alpha]_D$ −27 (*c* 0.2, CH_2Cl_2) (Found: C, 44.1; H, 5.4;

Br, 14.4. $C_{21}H_{31}BrO_{13}$ requires C, 44.1; H, 5.5; Br, 14.0); ν_{max} (KBr)/cm^{-1} 1750 (ester C=O); δ_H (300 MHz; $CDCl_3$) 0.86 (3 H, t, *J* 7.5, *Me*CH_2), 1.40–1.60 (2 H, m, MeCH_2), 2.01, 2.04, 2.06 and 2.09 (each 3 H, s, 4 × $MeCO_2$), 3.43 (1 H, dt, *J* 9.5 and 7, EtC*H*HO), 3.72–3.83 (2 H, m, 5′-H and EtCH*H*O), 3.78 (3 H, s, MeO), 4.15 and 4.21 [each 1 H, dd (*J* 6 and 12.5) and dd (*J* 3 and 12.5), 6′-H_2], 4.27 (1 H, d, *J* 8, 2-H), 4.86 (1 H, d, *J* 8, 1′-H), 4.97–5.12 (3 H, m, 2′-, 3- and 4′-H) and 5.24 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.7 (*C*H_3CH_2), 20.9 and 21.1 (4 × *C*H_3CO_2), 22.8 (Me*C*H_2), 45.6 (2-CH), 53.3 (CH_3O), 62.5 (6′-CH_2), 68.9, 71.4, 72.4 and 73.1 (2′-, 3′-, 4′- and 5′-CH), 71.8 (Et*C*H_2), 98.6 (1′-CH), 103.1 (3-CH) and 168.3, 169.5, 169.8, 170.6 and 170.8 (1-CO and 4 × Me*C*O); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 80%), 225 and 223 ($C_7H_{12}BrO_3^+$, each 50), 183 and 181 ($C_4H_6BrO_3^+$, each 100) and 169 (100).

Reaction involving the propenoate ***32c*** *and propan-1-ol.* The reaction of the propenoate **32c**[4] (2.30 g, 5.0 mmol) in propan-1-ol (25 cm^3) for 18 h gave rise to a residue comprising mainly an 85:15 mixture of the bromo(propoxy) adducts **33c** and **34c** [the ratio was estimated from the heights of the singlets at δ 22.6 and 23.2 (attributed to the Me*C*H_2CH_2 signals of **33c** and **34c**)].

Crystallisation of the material from propan-2-ol gave *ethyl (2R,3R)-2-bromo-2-methyl-3-propoxy-3-(2′,3′,4′,6′-tetra-O-acetyl-β-*D*-glucopyranosyloxy)propanoate* **33c** (2.18 g, 73%); mp 127 °C; $[\alpha]_D$ −15 (*c* 0.9, CH_2Cl_2) (Found: C, 46.0; H, 6.2; Br, 13.4. $C_{23}H_{35}BrO_{13}$ requires C, 46.1; H, 5.9; Br, 13.3%); ν_{max} (KBr)/cm^{-1} 1760, 1740 and 1730 (ester C=O); δ_H (300 MHz; $CDCl_3$) 0.82 (3 H, t, *J* 7.5, *Me*CH_2CH_2), 1.30 (3 H, t, *J* 7, *Me*CH_2O), 1.43–1.58 (2 H, m, MeCH_2CH_2), 1.79 (3 H, s, 2-Me), 2.02, 2.04, 2.06 and 2.08 (each 3 H, s, 4 × $MeCO_2$), 3.34 and 3.88 (each 1 H, dt, *J* 9 and 6.5, Et*C*H_2O), 3.77 (1 H, ddd, *J* 2.5, 5 and 10, 5′-H), 4.13–4.27 (4 H, m, 6′-H_2 and MeCH_2O), 4.85 (1 H, d, *J* 7.5, 1′-H), 5.03–5.15 (2 H, m, 2′- and 4′-H), 5.07 (1H, s, 3-H) and 5.27 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.5 (*C*$H_3CH_2CH_2$), 14.0 (*C*H_3CH_2O), 19.5 (*C*H_3C), 20.7 and 21.1 (4 × *C*H_3CO_2), 22.6 (Me*C*H_2CH_2), 60.5 (2-C), 62.2 (6′-CH_2), 68.6, 71.2, 72.0 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 71.7 (2 × CH_2O), 100.9 (1′-CH), 105.2 (3-CH) and 169.1, 169.4, 169.5, 170.3 and 170.5 (1-CO and 4 × Me*C*O); *m/z* (FAB) 623 and 621 (MNa^+, each 30%), 331 ($C_{14}H_{19}O_9^+$, 100), 253 and 251 ($C_9H_{16}BrO_3^+$, each 70), 211 and 209 ($C_6H_{10}BrO_3^+$, each 95) and 169 (55).

Reaction involving the methylenebutyrolactone ***37a*** *and propan-1-ol.* The reaction of the butyrolactone **37a**[4] (0.500 g, 1.13 mmol) in propan-1-ol (20 cm^3) for 2 h gave rise to a product comprising mainly an 85:15 mixture of the bromo-(propoxy) adducts **38a** and **39a** [the ratio was estimated from the heights of the singlets at δ 22.6 and 23.1 (attributed to the Me*C*H_2 signals of **38a** and **39a**)]; ≈11% of succinimide was also present.

Crystallisation of the mixture from cold methanol gave *(αR)-α-bromo-α-[(R)-propoxy-(2′,3′,4′,6′-tetra-O-acetyl-β-*D*-gluco-pyranosyloxy)methyl]-γ-butyrolactone* **38a** (0.357 g, 54%); mp 145–148 °C; $[\alpha]_D$ −17 (*c* 0.5, CH_2Cl_2) (Found: C, 45.0; H, 5.3; Br, 13.8. $C_{22}H_{31}BrO_{13}$ requires C, 45.3; H, 5.4; Br, 13.7%); ν_{max}(KBr)/cm^{-1} 1775 (γ-lactone C=O) and 1755 and 1745 (ester C=O); δ_H (300 MHz; $CDCl_3$) 0.84 (3 H, t, *J* 7.5, *Me*CH_2), 1.53 (2 H, sextet, separation 7, MeCH_2), 2.02, 2.05 and 2.06 (3, 3 and 6 H, each s, 4 × $MeCO_2$), 2.31 and 3.07 [each 1 H, ddd (*J* 2.5, 5.5 and 15) and dt (*J* 15 and 9), β-H_2], 3.47 and 3.89 [each 1 H, dt (*J* 9 and 7) and dt (*J* 9 and 6.5), Et*C*H_2O], 3.77 (1 H, ddd, *J* 2.5, 5.5 and 10, 5′-H), 4.15 and 4.22 [each 1 H, dd (*J* 5.5 and 12.5) and dd (*J* 2.5 and 12.5), 6′-H_2], 4.32–4.47 (2 H, m, γ-H_2), 4.85 (1 H, d, *J* 8, 1′-H), 5.03 (1 H, s, OCHO), 5.05 (1 H, t, *J* 9.5, 4′-H), 5.10 (1 H, dd, *J* 8 and 9.5, 2′-H) and 5.27 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.4 (*C*H_3CH_2), 20.7 and 21.1 (4 × *C*H_3CO_2), 22.6 (Me*C*H_2), 32.7 (β-CH_2), 58.0 (α-C), 62.2 (6′-CH_2), 66.2 (γ-CH_2), 68.5, 71.3, 72.2 and 72.5 (2′-, 3′-, 4′- and 5′-CH), 72.5 (Et*C*H_2), 100.9 (1′-CH), 104.4 (OCHO), 169.2, 169.5, 170.2 and 170.5 (4 × Me*C*O) and 172.4 (γ-lactone CO); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 90%), 237 and 235 ($C_8H_{12}BrO_3^+$, each 20), 195 and 193 ($C_5H_6BrO_3^+$, each 50) and 169 (100).

Reaction involving the methylenevalerolactone ***37b*** *and propan-1-ol.* The reaction of valerolactone **37b**[4] (0.450 g, 0.98 mmol) in propan-1-ol (20 cm^3) for 2 h gave rise to a product comprising mainly a 90:10 mixture of the bromo(propoxy) adducts **38b** and **39b** [the ratio was estimated from the heights of the singlets at δ 22.6 and 23.1 (attributed to the Me*C*H_2 signals of **38b** and **39b**)].

Crystallisation of the mixture from dichloromethane–diethyl ether–hexanes gave *(αR)-α-bromo-α-[(R)-propoxy-(2′,3′,4′,6′-tetra-O-acetyl-β-*D*-glucopyranosyloxy)methyl]-δ-valerolactone* **38b** (0.390 g, 66%); mp 155 °C; $[\alpha]_D$ −35 (*c* 0.8, CH_2Cl_2) (Found: C, 46.3; H, 5.5; Br, 13.1. $C_{23}H_{33}BrO_{13}$ requires C, 46.2; H, 5.6; Br, 13.4%); ν_{max} (KBr)/cm^{-1} 1750br (ester and δ-lactone C=O); δ_H (400 MHz; $CDCl_3$) 0.86 (3 H, t, *J* 7, *Me*CH_2), 1.54 (2 H, sextet, separation 7, MeCH_2), 1.83–1.93, 2.14–2.35 and 2.55–2.68 (1, 2 and 1 H, each m, β- and γ-H_2), 2.04, 2.07 and 2.08 (3, 3 and 6 H, each s, 4 × $MeCO_2$), 3.47 and 3.93 [each 1 H, dt (*J* 9 and 7) and dt (*J* 9 and 6), Et*C*H_2O], 3.79 (1 H, ddd, *J* 2.5, 5.5 and 10, 5′-H), 4.18 and 4.23 [each 1 H, dd (*J* 5.5 and 12) and dd (*J* 2.5 and 12), 6′-H_2], 4.33 and 4.50–4.60 [each 1 H, dt (*J* 3.5 and 11.5) and m, δ-H_2], 4.88 (1 H, d, *J* 8, 1′-H), 5.07 (1 H, t, *J* 9.5, 4′-H), 5.13 (1 H, dd, *J* 8 and 9.5, 2′-H), 5.27 (1 H, s, OCHO) and 5.29 (1 H, t, *J* 9.5, 3′-H); δ_C (100 MHz; $CDCl_3$) 10.4 (*C*H_3CH_2), 19.7 (γ-CH_2), 20.6, 20.7 and 21.1 (4 × *C*H_3CO_2), 22.6 (Me*C*H_2), 29.2 (β-CH_2), 60.6 (α-C), 62.2 (6′-CH_2), 68.5, 71.2, 72.2 and 72.6 (2′-, 3′-, 4′- and 5′-CH), 70.8 (δ-CH_2), 72.4 (Et*C*H_2), 101.1 (1′-CH), 105.9 (OCHO), 166.9 (δ-lactone CO) and 169.3, 169.5, 170.1 and 170.4 (4 × Me*C*O); *m/z* (FAB) 331 ($C_{14}H_{19}O_9^+$, 25%), 251 and 249 ($C_9H_{14}BrO_3^+$, each 10), 209 and 207 ($C_6H_8BrO_3^+$, each 20), 169 (40) and 43 ($C_3H_7^+$, 100) [(after addition of KI) 637 and 635 (each MK^+, 15%)].

Auxiliary-detachment studies

General procedure. A mixture of the bromo(alkoxy) compound (1 mmol), ethane-1,2-diol (0.62 g, 10 mmol) and TFA (5 cm^3) was stirred for 2 h and then partitioned between dichloromethane and water.The organic phase was washed successively with aq. sodium hydrogen carbonate and water, dried ($MgSO_4$) and concentrated to leave mainly a 50:50 mixture of the ethylene glycol acetal and the tetraacetate **13** by ^{1}H NMR spectroscopy. A solution of the product in methanol (20 cm^3) containing toluene-*p*-sulfonic acid monohydrate (0.200 g) was left overnight and concentrated. The residue was then partitioned between dichloromethane and water. Evaporation of the dried ($MgSO_4$) organic phase gave the ethylene glycol acetal.

(3R)-3-Bromo-3-(1′,3′-dioxolan-2′-yl)butan-2-one ***40a****.* (*a*) The reaction involving the bromo(propoxy) compound **11c** (0.500 g, 0.88 mmol) gave rise to the *title compound* **40a** (0.123 g, 63%) as a near-pure oil. A chromatographed sample showed $[\alpha]_D$ −33 (*c* 0.85, CH_2Cl_2) (Found: C, 37.7; H, 5.0; Br, 36.0. $C_7H_{11}BrO_3$ requires C, 37.7; H, 5.0; Br, 35.8%); λ_{max} (EtOH)/nm 296 (ε 90); ν_{max} (film)/cm^{-1} 1720 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.77 (3 H, s, 4-H_3), 2.44 (3 H, s, 1-H_3), 3.96–4.13 (4 H, m, 4′- and 5′-H_2) and 5.30 (1 H, s, 2′-H); δ_C (100 MHz; $CDCl_3$) 20.9 (4-CH_3), 26.3 (1-CH_3), 66.1 and 66.4 (4′- and 5′-CH_2), 67.2 (3-C), 105.0 (2′-CH) and 201.6 (2-CO); *m/z* (CI) 242 and 240 (MNH_4^+, each 100%).

By HPLC analysis, the sample possessed an ee of 98% [hexanes–Me_2CHOH (99:1) as eluent with a flow rate of 0.75 cm^3 min^{-1}; retention times: 9.0 min for **40a** and 10.0 min for *ent*-**40a**].

(*b*) The aforecited reaction was repeated but the mixture was partitioned between dichloromethane and 5% aq. sodium

hydroxide. After having been washed with water (2 ×), the organic phase was dried ($MgSO_4$) and concentrated to leave compound **40a** (0.102 g, 52%) with an ee of 95%.

(2R)-2-Bromo-2-(1′,3′-dioxolan-2′-yl)pentan-3-one ***40b***. The reaction involving the bromo(propoxy) compound **28** (1.24 g, 2.1 mmol) gave rise to the *title compound* **40b** (0.290 g, 58%) as a near-pure oil. A chromatographed sample showed $[\alpha]_D$ −18 (*c* 0.5, CH_2Cl_2) (Found: C, 40.8; H, 5.6; Br, 33.4. $C_8H_{13}BrO_3$ requires C, 40.5; H, 5.5; Br, 33.7%); λ_{max} (EtOH)/nm 295 (ε 100); ν_{max} (film)/cm^{-1} 1720 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.10 (3 H, t, *J* 7, 5-H_3), 1.79 (3 H, s, 1-H_3), 2.70–2.98 (2 H, m, 4-H_2), 3.95–4.13 (4 H, m, 4′- and 5′-H_2) and 5.31 (1 H, s, 2′-H); δ_C (100 MHz; $CDCl_3$) 8.4 (5-CH_3), 21.2 (1-CH_3), 31.8 (4-CH_2), 66.2 and 66.5 (4′- and 5′-CH_2), 67.6 (3-C), 105.1 (2′-CH) and 204.9 (3-CO); *m*/*z* (FAB) 239 and 237 (MH^+, each 100%) and 157 ($C_8H_{13}O_3^+$, 90).

By HPLC analysis, the sample possessed an ee of 94% [hexanes–Me_2CHOH (99 : 1) as eluent with a flow rate of 0.75 cm^3 min^{-1}; retention times: 7.9 min for **40b** and 8.7 min for *ent*-**40b**].

(2R)-2-Bromo-2-(1′,3′-dioxolan-2′-yl)cyclohexan-1-one ***41***. TFA (2.75 cm^3) was added to the bromo(propoxy) compound **30b** (0.549 g, 0.92 mmol) followed, after 20 min, by ethane-1,2-diol (0.544 g, 8.8 mmol). After 15 min, the mixture was diluted with dichloromethane and washed successively with water (3 ×) and aq. sodium hydrogen carbonate. Evaporation of the dried ($MgSO_4$) organic phase and subjection of the product to column chromatography [light petroleum–EtOAc (1 : 1) as eluent] gave the *title compound* **41** (0.128 g, 56%) as an oil that solidified; mp 33 °C; $[\alpha]_D$ +225 (*c* 0.75, CH_2Cl_2) (Found: C, 43.3; H, 5.3; Br, 31.9. $C_9H_{13}BrO_3$ requires C, 43.4; H, 5.3; Br, 32.1%); ν_{max} (film)/cm^{-1} 1720 (ketone C=O); δ_H (300 MHz; $CDCl_3$) 1.59–1.77, 1.82–1.92, 1.98–2.14 and 2.27–2.45 (1, 1, 3 and 2 H, each m, 3-, 4- and 5-H_2 and 6-H_{eq}), 3.14 (1 H, dt, *J* 6.5 and 14.5, 6-H_{ax}), 3.96–4.15 (4 H, m, 4′- and 5′-H_2) and 5.45 (1 H, s, 2′-H); δ_C (100 MHz; $CDCl_3$) 21.3, 26.3, 33.6 and 37.6 (3-, 4-, 5- and 6-CH_2), 66.3 and 66.9 (4′- and 5′-CH_2), 68.2 (2-C), 104.2 (2′-CH) and 203.7 (1-CO); *m*/*z* (FAB) 251, 249 and 247 (MH^+ and $M - H^+$, 6, 12 and 6%) and 73 (100) [(after addition of KI) 289 and 287 (MK^+, 100 and 70%)].

By HPLC analysis, the sample possessed an ee of 96% [hexanes–Me_2CHOH (98 : 2) as eluent with a flow rate of 1 cm^3 min^{-1}; retention times: 11.2 min for **41** and 10.8 min for *ent*-**41**].

Ethyl (2R)-2-bromo-2-(1′,3′-dioxolan-2′-yl)propanoate ***40c***. The reaction involving the bromo(propoxy) compound **33c** (0.599 g, 1.00 mmol) gave rise to the *title compound* **40c** (0.169 g, 67%) as a near-pure oil. A chromatographed sample showed $[\alpha]_D$ +9 (*c* 1.67, CH_2Cl_2) (Found: C, 38.1; H, 5.0; Br, 32.0. $C_8H_{13}BrO_4$ requires C, 38.0; H, 5.2; Br, 31.6%); ν_{max} (film)/cm^{-1} 1740 (ester C=O); δ_H (300 MHz; $CDCl_3$) 1.31 (3 H, t, *J* 7, *Me*CH_2), 1.82 (3 H, s, 3-H_3), 3.97–4.14 (4 H, m, 4′- and 5′-H_2), 4.27 (2 H, q, *J* 7, MeCH_2O) and 5.45 (1 H, s, 2′-H); δ_C (100 MHz; $CDCl_3$) 14.0 (CH_3CH_2), 21.0 (3-CH_3), 60.0 (2-C), 62.5 (MeCH_2), 66.4 and 66.8 (4′- and 5′-CH_2), 105.2 (2′-CH) and 169.4 (1-CO); *m*/*z* (CI) 272 and 270 (MNH_4^+, each 100%), 255 and 253 (MH^+, each 20), 192 (80) and 175 (50).

By HPLC analysis, the sample possessed an ee of 98% [hexanes–Me_2CHOH (99 : 1) as eluent with a flow rate of 0.75 cm^3 min^{-1}; retention times: 8.7 min for **40c** and 10.0 min for *ent*-**40c**].

Crystal structure determination of compound 11c

Crystal data. $C_{22}H_{33}BrO_{12}$, $M = 569.39$, orthorhombic, $a = 11.952(2)$, $b = 13.551(2)$, $c = 17.076(3)$ Å, $V = 2765.8(8)$ Å^3, $T = 293(2)$ K, space group $P2_12_12_1$, $Z = 4$, μ(Mo-Kα) = 1.542 mm^{-1}, 1879 reflections measured, 1824 unique ($R_{int} = 0.043$) which were used in all calculations. The final $wR(F^2)$ was 0.144 (all data). CCDC reference number 207/435. See http://www.rsc.org/suppdata/p1/b0/b002749i/ for crystallographic files in .cif format.

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