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On the synthesis of vinyl and phenyl *C*-furanosides by stereospecific debenzylative cycloetherification

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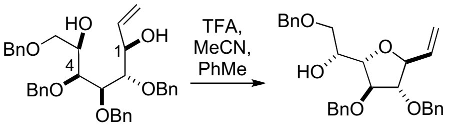
ABSTRACT

Open-chain benzyl-ether-protected polyols in which one of the alcohols is either allylic or benzylic are synthesised by addition of organometallic vinyl or phenyl reagents to benzyl-ether-protected carbohydrate hemiacetals. The diastereoselectivity of addition is dependent on whether a Grignard reagent or a trialkylzincate reagent is used. The open-chain compounds undergo a stereospecific cyclisation reaction on treatment with catalytic strong Brønsted acid with heating to form tetrahydrofurans with inversion of configuration at the allylic or benzylic carbon (C-1) and loss of hydroxyl from this position. A short synthesis of the starting material, 1,2,4,6-tetra-*O*-benzyl-D-galactose, from lactose is described.

1. Introduction

Polyhydroxylated tetrahydrofuran (THF) derivatives occur in nature as substructures of various natural products. *C*-Furanosides are polyhydroxylated THFs and are hydrolytically stable bioisosteres of furanosides, which are widespread in bacterial polysaccharides,[1] hence such compounds may be relevant for the development of new antibacterial treatments.[2] Among the many methods reported for the synthesis of THFs[3] are the acid-catalysed dehydrative ring-closure of activated (e.g., benzylic) diols, often under equilibrating conditions and via carbocationic intermediates to give a thermodynamically stable diastereomer.[4] Alternatively, intramolecular nucleophilic attack onto a good leaving group (e.g., a sulfonate) can give a stereospecific cyclisation with inversion of configuration at the reacting carbon atom to give a single diastereomer of product derived from a single diastereomer of the starting material. Benzyl ethers[5] and alcohols[6] have both been reported as intramolecular nucleophiles in this latter process. Related to this are other diastereoselective debenzylative cycloetherifications that may operate under kinetic control, but that rely on, for example, activation of a diastereotopic C=C double bond to initiate ring-closure.[7]

We recently reported a Brønsted acid (TFA) induced stereospecific debenzylative cyclisation reaction of vinyl-substituted carbohydrate derivatives to give THFs (Scheme 1). The reaction is stereospecific with inversion of configuration at allylic C-1 and loss of OH, OAc or OCH_2Ar as leaving groups.[8] In this paper, we describe a modification using catalytic strong acid, and also show that the phenyl-substituted carbohydrate derivatives react in the same way to give phenyl *C*-furanosides, also stereospecifically. The stereospecific nature of the cyclisation reaction drives the requirement for diastereoselectivity in synthesis to the previous step: formation of the activated diol by organometallic addition to a carbohydrate hemiacetal. With this in mind, we also give the results of our investigation into zinc-modified organometallic additions, which can influence the diastereoselectivity of these reactions. Finally, we also give a short synthesis of the required galactose hemiacetal **2** starting from lactose.



Scheme 1.

2. Results and discussion

2.1. Synthesis of galactose hemiacetal (2)

For this study, we needed gram quantities of the *galacto* hemiacetal **2**. While the easily crystallised *gluco* compound **1** may be prepared on a hundred-gram scale starting from cheap α-methyl glucoside in two steps (benzylation and hydrolysis),[9] the higher price of the galactose methyl glycosides makes this approach less attractive.[10] A very cheap galactoside is available in lactose **3**, and we investigated a benzylation–hydrolysis route starting from this disaccharide. A synthesis of benzylated sugar hemiacetals derived

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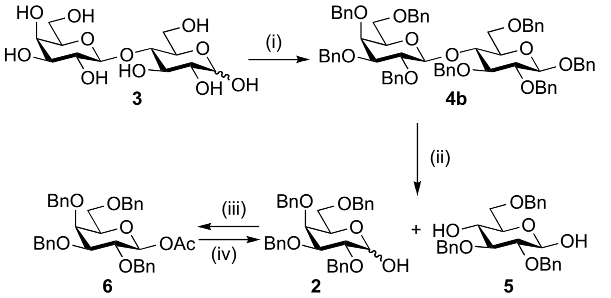


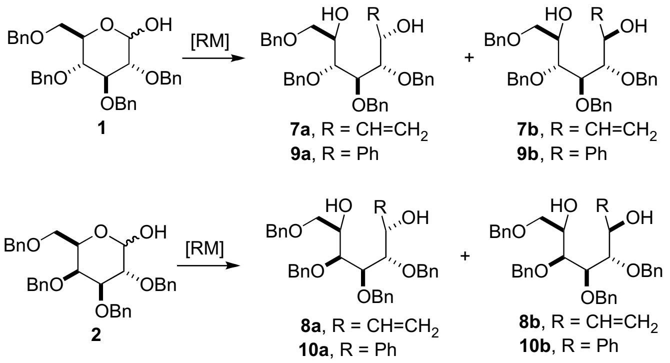
Scheme 2. Reagents and conditions: (i) BnBr, NaH, DMF, 0 °C→rt, 46%; (ii) $H_2SO_{4(aq)}$, AcOH, 85 °C, **5**, 29%; (iii) Ac_2O, Et_3N, 62% from **4b**; (iv) NaOMe, MeOH, 97%.

from the non-reducing disaccharide, sucrose, has recently been published.[11] Benzylation of reducing monosaccharides gives mainly β-pyranosides, but for galactose, the α-furanoside is the major product making this direct route to the *galacto* hemiacetal **2** unfeasible;[12] Schmidt has described alkylation of minimally protected carbohydrate hemiacetals to give β-glycosides.[13] When we attempted perbenzylation of lactose **3** under standard conditions (Scheme 2), we were able to isolate a major perbenzylated β-disaccharide **4b** after chromatography and recrystallisation. Hydrolysis of disaccharide **4b** gave the two hemiacetals **2** and **5**, which were easily separable by chromatography. However, both hemiacetals were contaminated by traces of inseparable by-products. The *gluco* compound was recrystallised to give pure **5** (29%), while the *galacto* compound must be acetylated and recrystallised (**6**, β only, 62% from **4b**),[14] and finally deacetylated (97%) to give the pure *galacto* hemiacetal **2**.

2.2. Organometallic additions

Next, we examined organometallic addition to hemiacetals **1** and **2**: introducing activating groups, vinyl and phenyl, renders the resulting C-1 alcohols allylic or benzylic, respectively. Using vinylmagnesium bromide, diastereomeric product ratios of 1:2 (**7a**/**7b**)[15] and 2:1 (**8a**/**8b**)[8] were obtained from *gluco* **1** and *galacto* **2** hemiacetals, respectively, in good overall yields. We have already reported the results of some attempts to influence the stereoselectivity of the addition to *gluco* hemiacetal **1**.[15] Nicotra found that divinylzinc adds to benzylated pentofuranose hemiacetals with excellent diastereoselectivity in favour of the 1,2-chelate product,[16] but we found that this reagent gave no reaction with either of hemiacetals **1** and **2**. More reactive organozinc derivatives have been described: triorganozincates have been shown to add to α,β-unsaturated carbonyl derivatives[17] diastereoselectively,[18] and to sulfinylimines diastereoselectively.[19] A procedure using catalytic zinc was also reported.[20] We prepared triorganozincates from vinylmagnesium bromide and either a dialkylzinc or zinc bromide.[17–19] These reagents reacted with *gluco* **1** and *galacto* **2** hemiacetals to give the addition products (i.e., **7a**,**b** and **8a**,**b**, respectively) in good yield, and changes in the diastereoselectivity of the reaction were seen compared to the reaction with the Grignard reagent. Indeed, for the *galacto* hemiacetal, the change from vinylmagnesium bromide to a triorganozincate reagent resulted in a reversal of diastereoselectivity in the reaction (Table 1, cf. entries 8–10). The vinyl group was transferred in preference to both ethyl (only tested for hemiacetal **1**) and methyl groups in these addition reactions; while traces of a diol derived from ethyl transfer to **1** could be detected when $ZnEt_2$ was used as zinc source (Table 1, entry 3), we could not see any evidence of methyl transfer when

Table 1
Organometallic additions to *gluco* **1** and *galacto* **2** hemiacetals



	sm	R	Conditions	dr	Product/yield[a]
1	**1**	CH=CH$_2$	VinylMgBr (4), THF, 0 °C→rt, 22 h	**7a**/**7b**, 1:2.5	**7a**/29%; **7b**/65%[15]
2	**1**	CH=CH$_2$	VinylMgBr (10), $ZnBr_2$ (2.5), THF	**7a**/**7b**, 1:4	**7a**/10%; **7b**/57%
3	**1**	CH=CH$_2$	VinylMgBr (5), $ZnEt_2$ (5.5), THF, hexane	**7a**/**7b**, 1:4	**7a**,**b**/60%[b,c]
4	**1**	CH=CH$_2$	VinylMgBr (5), $ZnMe_2$ (5.5), THF, toluene	**7a**/**7b**, 1:4	**7a**/10%; **7b**/53%
5	**1**	Ph	PhMgBr (3), Et_2O, THF	**9a**/**9b**, 1:2	**9a**/25%; **9b**/48%
6	**1**	Ph	PhMgBr (10), $ZnBr_2$ (2.5), Et_2O	**9a**/**9b**, <1:6	**9a**/9%; **9b**/75%
7	**1**	Ph	PhMgBr (5), $ZnMe_2$ (5.5), Et_2O, toluene	**9a**/**9b**, 1:7	**9a**/7%; **9b**/47%
8	**2**	CH=CH$_2$	VinylMgBr (2.5), THF	**8a**/**8b**, 2:1	**8a**/53%; **8b**/31%
9	**2**	CH=CH$_2$	VinylMgBr (10), $ZnBr_2$ (2.5), THF	**8a**/**8b**, 1:2	**8a**/17%; **8b**/40%
10	**2**	CH=CH$_2$	VinylMgBr (5), $ZnMe_2$ (5.5), THF, toluene	**8a**/**8b**, 1:2	**8a**/24%; **8b**/48%
11	**2**	Ph	PhMgBr (10), Et_2O, THF	**10a**/**10b**, 1:1.7	**10a**/28%; **10b**/48%
12	**2**	Ph	PhMgBr (9), Et_2O	**10a**/**10b**, 1:3	**10a**,**b**/80%[c]
13	**2**	Ph	PhMgBr (10), Et_2O, toluene	**10a**/**10b**, 1:3	**10a**,**b**/67%[c]
14	**2**	Ph	PhMgBr (10), $ZnBr_2$ (2.5), Et_2O, toluene	**10a**/**10b**, 1:3	**10a**,**b**/47%[c]
15	**2**	Ph	PhMgBr (5), $ZnMe_2$ (5.5), Et_2O, toluene	**10a**/**10b**, 1:3	**10a**/19%; **10b**/46%

[a] Isolated yields.
[b] A small amount of a compound resulting from ethyl transfer was also seen.
[c] Diastereomers not separated.

$ZnMe_2$ was used, which is in agreement with reported results that methyl is a less transferrable group than ethyl.[19]

To introduce a phenyl group, hemiacetals **1** and **2** were treated with phenylmagnesium bromide to give the respective diols **9a**,**b**, and **10a**,**b**. Both pairs of diastereomers could be separated by chromatography. Phenyl-substituted triorganozincates prepared as for the vinyl derivatives gave the *gluco*-derived diol **9b** with a much enhanced diastereoselectivity over that seen with the Grignard reagent (cf. Table 1, entries 5–7). For the galactose case, little change in diastereoselectivity was seen (entries 11–15).

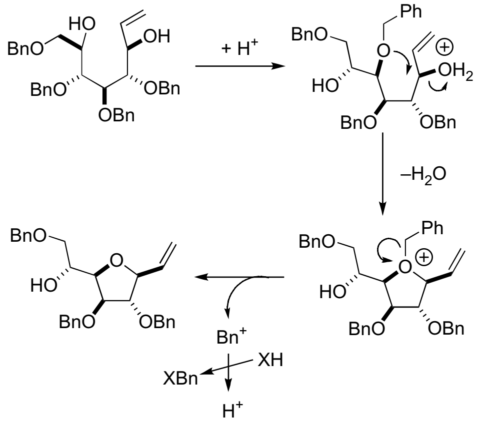
The stereochemical assignment of the diastereomeric diols resulting from phenyl Grignard addition could be made as follows: Marco-Contelles has used empirical trends in H-1 ^{1}H NMR chemical shifts and $J_{1,2}$ coupling constants to assign the stereochemistry of pairs of diastereomers resulting from organometallic addition (methyl[21] or phenylethynyl substituents) to tetrabenzyl glucose **1**.[22] It is to be expected that glucose and galactose derivatives should follow similar trends, as the compounds are isostructural around C-1. Indeed, our own data for vinyl derivatives **7a**,**b**,[23] **8a**,**b** (whose stereochemistry we have assigned previously)[8] fits these trends, as do Vasella's data for glucose- and galactose-derived trimethylsilylethynyl and bromoethynyl compounds:[24] 1*R* compounds invariably have a lower chemical shift for H-1 (by 0.1–0.2 ppm) than do the corresponding 1*S* compounds. The vicinal ^{1}H–^{1}H coupling $J_{1,2}$ for the 1*R* compounds is 2.7–3.3 Hz, while for the 1*S* epimers $J_{1,2}$ is bigger, in the range 4.6–5.3 Hz. We found that the phenyl-substituted glucose derivatives also fitted these trends, and **9a** (H-1 5.08 ppm, $J_{1,2}$ 5.8 Hz) was assigned with the 1*S* configuration, and **9b** (H-1 4.92 ppm, $J_{1,2}$ 2.8 Hz) was assigned as 1*R*. For the galactose phenyl derivatives also, **10a** (H-1 5.00 ppm, $J_{1,2}$ 6.4 Hz) was assigned as 1*S*, and **10b** (H-1 4.94 ppm, $J_{1,2}$ 2.3 Hz) was assigned as 1*R*.[25]

This means that for most of the examples we tested, the triorganozincate reagents give more of the product predicted from a 1,2-chelation model[26] than do the Grignard reagents. This is manifested in a selectivity enhancement for the *gluco* cases (**7b**/**7a**; 2.5:1→4:1) and (**9b**/**9a**; 2:1→6:1), while for the *galacto* vinyl system, it gives a reversal of diastereoselectivity (**8b**/**8a**; 1:2→2:1). But for the *galacto* phenyl reactions, (formation of **10a**,**b**) little change in diastereoselectivity was seen in changing between Grignard and zinc reagents.

2.3. Debenzylative cyclisations

We have previously described a stereospecific debenzylative cyclisation reaction of the vinyl-substituted diols **7a**,**b** and **8a**,**b** to give *C*-glycosides with retention of configuration at C-4 and inversion at C-1.[8] A likely mechanism involves protonation of the allylic alcohol, converting it into a better leaving group, which can then undergo an intramolecular substitution by O-4 with Walden inversion to give the heterocycle (Scheme 3). A benzyl group is lost from O-4, and this may be quenched either by an external scavenger, or by nucleophiles from within the molecule (e.g., OH-5), resulting in the formation of by-products. In any case, a proton may be regenerated, implying that the reaction could be run with catalytic acid. Sanz has recently reported Brønsted acid catalysed nucleophilic substitution reactions of activated alcohols.[27]

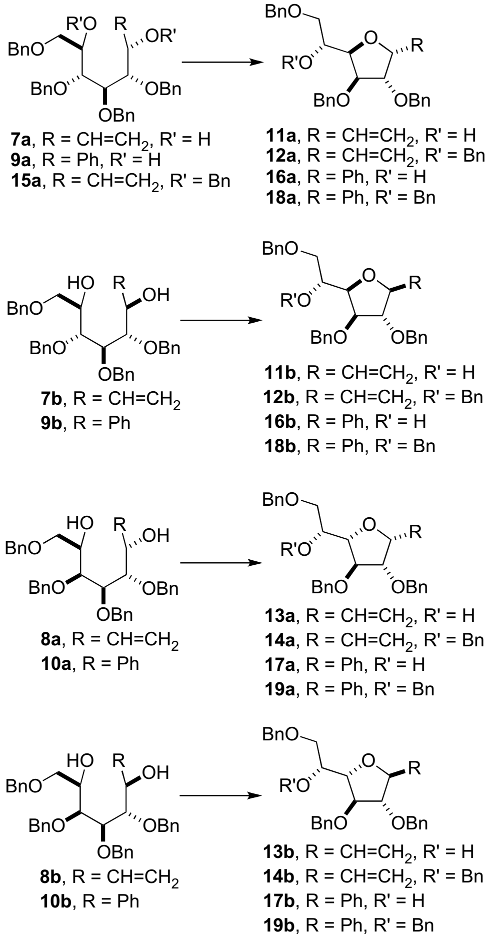
When **7a** was treated with a catalytic quantity (0.5 equiv) of TsOH in acetonitrile, some product formation (**11a**) could be detected by TLC, but even after heating at 50 °C for 6 days, only a low conversion of the starting material was seen. With a stronger sulfonic acid, 2,4-dinitrobenzenesulfonic acid (DNBSA, 0.5 equiv)[28] some starting material still remained after 48 h at rt, but heating the mixture drove the reaction to completion, and diol **7a** was converted into two major products, THFs **11a** and **12a**. Subsequent reactions were therefore all carried out with heating. The cyclisation of **7a** with 0.1 equiv DNBSA in acetonitrile was complete after 21 h (Table 2, entry 1), giving clean conversion to the two products **11a** and **12a** (obtained as single diastereomers) without formation of impurities due to benzylation of the benzyl ether protecting groups (S$_E$Ar) as we had seen earlier.[8] We tested different solvents (Table 2, entries 3–5): the reaction could be carried out in acetone (60 °C) with a comparable yield of the major product **11a**, but the reaction was much less clean than for acetonitrile, the mixture quickly turned dark brown, whereas for acetonitrile only a very slight colouration was seen. The reaction in acetone was somewhat faster than that in acetonitrile however. In dichloromethane (40 °C), more of the benzylated by-product **12a** was seen, while in toluene (80 °C), we found that the reaction was not stereospecific: traces of the C-1 epimer **11b** were found to contaminate the major product **11a**. Microwave heating could be used to accelerate the reaction (Table 2, entries 2 and 6). Heating diol **7a** in acetone gave complete conversion and a major cyclised product **11a** after a very short reaction time (15 min) in a sealed tube at 100 °C. In acetonitrile, the reaction was slower (1 h), but cleaner conversion to THFs **11a** and **12a** was seen.



Scheme 3. A reasonable mechanism for the cyclisation reaction, illustrated for the formation of **11b** from **7b**. XH represents a scavenger, e.g., toluene, water, OH-5, or MeCN–H_2O or acetone–H_2O.

The glucose- and galactose-derived vinyl-substituted diols **7a**,**b** and **8a**,**b** were heated (conventional heating and/or microwave heating) in acetonitrile and in acetone using 0.1 equiv DNBSA as catalytic activator, and in all cases, vinyl *C*-glycosides **11a**,**b** and **13a**,**b** were formed as major products, along with the perbenzyl by-products **12a**,**b** and **14a**,**b**, which were easily isolated when acetonitrile was used as solvent (Table 2, entries 1, 2, 5–14). In each case, a single diastereomer of the starting material gave a single diastereomer of product. Reactions in acetonitrile were cleaner than those in acetone, and isolation of the products was invariably easier; when acetone was used as solvent, some formation of the perbenzylated by-products **12a**,**b** and **14a**,**b** was seen but these were not obtained pure, and the major products **11a**,**b** and **13a**,**b** were still contaminated after chromatography by benzyl alcohol, which must be removed by high vacuum. The cyclisations of both of the galactose-derived diols **8a** and **8b** were somewhat slower than those of the glucose-derived compounds **7a** and **7b**, and some starting material still remained after longer reaction times. We also showed that the perbenzylated open-chain derivative **15a** (obtained by benzylation of diol **7a**, NaH, BnBr, THF, 93%) cyclised under microwave heating with DNBSA to give the perbenzylated THF **12a** (Table 2, entries 15, 16). Perbenzylated **15a** cyclised more slowly than did diol **7a** under the same reaction conditions in both acetonitrile and acetone, presumably due to a sterically more congested transition state.

Table 2
Debenzylative cycloetherification with catalytic DNBSA



7a, R = CH=CH$_2$, R' = H
9a, R = Ph, R' = H
15a, R = CH=CH$_2$, R' = Bn

11a, R = CH=CH$_2$, R' = H
12a, R = CH=CH$_2$, R' = Bn
16a, R = Ph, R' = H
18a, R = Ph, R' = Bn

7b, R = CH=CH$_2$
9b, R = Ph

11b, R = CH=CH$_2$, R' = H
12b, R = CH=CH$_2$, R' = Bn
16b, R = Ph, R' = H
18b, R = Ph, R' = Bn

8a, R = CH=CH$_2$
10a, R = Ph

13a, R = CH=CH$_2$, R' = H
14a, R = CH=CH$_2$, R' = Bn
17a, R = Ph, R' = H
19a, R = Ph, R' = Bn

8b, R = CH=CH$_2$
10b, R = Ph

13b, R = CH=CH$_2$, R' = H
14b, R = CH=CH$_2$, R' = Bn
17b, R = Ph, R' = H
19b, R = Ph, R' = Bn

Entry	sm	Solvent	T/°C	t	Products/yield[a]
1	**7a**	MeCN	80	21 h	**11a**/72%; **12a**/23%
2	**7a**	MeCN	100[b]	1 h	**11a**/67%; **12a**/23%
3	**7a**	DCM	40	24 h	**11a**/54%; **12a**/33%
4	**7a**	Toluene	80	24 h	Not stereospecific
5	**7a**	Acetone	60	4 h	**11a**/65%
6	**7a**	Acetone	100[b]	15 min	**11a**/69%
7	**7b**	MeCN	80	20 h	**11b**/60%; **12b**/13%
8	**7b**	MeCN	100[b]	15 min	**11b**/67%; **12b**/12%
9	**7b**	Acetone	60	20 h	**11b**/58%
10	**7b**	Acetone	100[b]	30 min	**11b**/68%[c]
11	**8a**	MeCN	80	38 h	**13a**/69%; **14a**/19%
12	**8a**	Acetone	60	24 h	**13a**/31%
13	**8b**	MeCN	80	23 h	**13b**/43%; **14b**/16%
14	**8b**	Acetone	60	22 h	**13b**/51%
15	**15a**	MeCN	100[b]	3.5 h	**12a**/75%
16	**15a**	Acetone	100[b]	2 h	**12a**/73%
17	**9a**	MeCN	80	21 h	**16a**/58%; **18a**/21%
18	**9a**	Acetone	60	26 h	**16a**/65%
19	**9a**	Acetone	100[b]	15 min	**16a**/66%
20	**9b**	MeCN	80	23 h	**16b**/70%; **18b**/13%
21	**9b**	Acetone	60	20 h	**16b**/65%
22	**9b**	Acetone	100[b]	15 min	**16b**/78%
23	**10a**	MeCN	80	26 h	**17a**/63%; **19a**/16%
24	**10a**	Acetone	60	24 h	**17a**/30%[d]
25	**10b**	MeCN	80	21 h	**17b**/51%; **19b**/19%
26	**10b**	Acetone	60	36 h	**17b**/37%

Reactions carried out with 0.1 equiv DNBSA unless otherwise stated.
[a] Isolated yields.
[b] Microwave heating.
[c] Used 0.02 equiv DNBSA.
[d] Used 0.3 equiv DNBSA.

The phenyl-substituted diols **9a**,**b** and **10a**,**b** also each cyclised stereospecifically on heating with DNBSA in either acetone or acetonitrile to give phenyl *C*-glycosides **16a**,**b** and **17a**,**b** as single diastereomers (Table 2, entries 17–26). Just as in the vinyl series, we found that the reactions were cleaner in acetonitrile than in acetone, and that when acetonitrile was used, the perbenzyl derivatives **18a**,**b** and **19a**,**b** were easily isolated in addition to the major products **16a**,**b** and **17a**,**b**. We confirmed that the stereochemistry of the benzylated by-products **18a**,**b** and **19a**,**b** was the same as the respective major reaction products **16a**,**b** and **17a**,**b** in each case by standard benzylation (NaH, BnBr, DMF, 67–95%).

We assigned the stereochemistry of the phenyl-substituted THFs by comparison of the ^{13}C NMR chemical shifts of **16a**,**b** and **17a**,**b** with those of compounds of similar constitution and known configuration, i.e., the vinyl *C*-hexofuranosides **11a**,**b** and **13a**,**b**, and also the previously described benzyl-ether-protected vinyl *C*-pentofuranosides.[29] Significant differences between α- and β-epimers were seen in the shifts for C-1 and C-2: these carbons appear at higher chemical shift in *C*-furanosides with a β (*gluco* or *galacto*) configuration than in those with an α (*gluco* or *galacto*) configuration.[30] Glucose and galactose epimers were distinguished by differences in the shifts of C-4: this carbon resonates at higher chemical shift in *C*-furanosides with a *galacto* configuration than in those with a *gluco* configuration. These trends were clearly followed by our compounds, which allowed an assignment of the stereochemistry.[31] This means that the cyclisation reactions of the phenyl derivatives had the same stereochemical outcome as for the vinyl derivatives: retention of configuration at C-4 and inversion at C-1. It is well known that in S_N2-type reactions, allylic and benzylic secondary carbons are substituted more quickly than other secondary carbons.[32,33]

Schmidt has reported a similar cyclisation of glucose-derived benzylic alcohols. A diastereomeric mixture of open-chain alcohols cyclised under mildly acidic conditions to give a diastereomeric mixture of aryl *C*-furanosides.[34] The highly oxygenated aryl groups used by Schmidt would be more able to stabilise a carbocationic intermediate, making an S_N1-type cyclisation more likely, and also enabling the subsequent observed isomerisation to the thermodynamically more stable β-*C*-pyranosides. A very similar acid-catalysed cyclisation of phenyl-substituted carbohydrate-derived diols in benzene has also been reported,[35] but here the reaction does not appear to be stereospecific as the authors describe the formation of more than one furanoside product from a single diastereomer of starting material. The origin of the difference between this report and our results is not clear, but it is possible that a different solvent is the cause (as we have seen, Table 2, entry 4), or simply that the dominance of the stereospecific reaction pathway over other non-stereospecific cyclisation mechanisms is substrate dependent.

A similar report of acid-catalysed cyclisation of open-chain carbohydrate-derived compounds to give vinyl *C*-pentofuranosides has been published.[36]

3. Conclusions

We have shown that the stereospecific debenzylative cycloetherification reaction of some *C*-1-activated carbohydrate derivatives with inversion of configuration at C-1 and loss of OH as a leaving group to give THF derivatives may be run under catalytic Brønsted acidic conditions. The reaction is stereospecific for both vinyl- and phenyl-substituted derivatives under the reported reaction conditions, and it may be valuable in stereocontrolled syntheses of vinyl or aryl *C*-furanosides or other polyhydroxylated THF derivatives. We may also conclude that triorganozincates add to benzyl-protected carbohydrate hemiacetals giving addition products with altered diastereoselectivity compared to Grignard reagents, and hence may be a useful alternative reagent.

4. Experimental section

4.1. General methods

Melting points were recorded on a Gallenkamp melting point apparatus and are uncorrected. Proton nuclear magnetic resonance (^{1}H) spectra were recorded on Bruker Avance II 400 (400 MHz), Bruker Avance II 500 (500 MHz) or Varian Mercury 400 (400 MHz) spectrometers; multiplicities are quoted as singlet (s), broad singlet (br s), doublet (d), doublet of doublets (dd), triplet (t), apparent triplet (at), apparent triplet of doublets (atd), doublet of apparent triplets (dat), quartet (q), apparent quartet (aq), AB quartet (ABq) or multiplet (m). Carbon nuclear magnetic resonance (^{13}C) spectra were recorded on Bruker Avance II 400 (100 MHz), Bruker Avance II 500 (125 MHz) or Varian Mercury 400 (100 MHz) spectrometers, and multiplicities assigned by DEPT. Spectra were assigned using COSY, HSQC and DEPT experiments. All chemical shifts are quoted on the δ-scale in parts per million (ppm). Residual solvent signals ($CHCl_3$, δ_H 7.26, δ_C 77.16) were used as an internal reference. Low- and high-resolution (HRMS) electrospray (ES^+) mass spectra were recorded using a Bruker Microtof instrument. Infra-red spectra were recorded on a Perkin–Elmer Spectrum One FT-IR spectrometer using the thin film method on NaCl plates. Optical rotations were measured on a Perkin–Elmer 241 polarimeter with a path length of 1 dm; concentrations are given in g/100 mL. Microanalysis was carried out by the Elemental Analysis Unit at the University of Santiago de Compostela, Spain. Thin layer chromatography (TLC) was carried out on Merck Kieselgel sheets, pre-coated with $60F_{254}$ silica. Plates were visualised with UV light and developed using 10% sulfuric acid, or an ammonium molybdate (10% w/v) and cerium(IV) sulfate (2% w/v) solution in 10% sulfuric acid. Flash column chromatography was carried out on silica gel (35–70 micron, Grace). Acetonitrile (puriss) was bought from Riedel de Hahn, acetone (Normapur) from VWR, and used as supplied. Dinitrobenzenesulfonic acid was bought from Alfa Aesar and used as supplied. Organometallic reagents were bought from Sigma–Aldrich (phenylmagnesium bromide (3 M in Et_2O)) or Acros (vinylmagnesium bromide (0.7 M in THF); dimethylzinc (1.2 M in toluene); diethylzinc (1 M in hexane)) and used as supplied. Anhydrous zinc bromide was from Fluka and was not purified before use. Diethyl ether was dried over sodium. THF was distilled from sodium benzophenone ketyl radical or purified on a Vacuum Atmospheres solvent purification column. Toluene was purified on a Vacuum Atmospheres solvent purification column. Reactions performed under an atmosphere of hydrogen, nitrogen or argon were maintained by an inflated balloon. Characterisation data for compounds **8a**,**b**, **11a**,**b**–**14a**,**b** is found in the Supplementary data of our preliminary communication (Ref. 8).

4.2. Benzyl 2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranoside (4b)

Lactose monohydrate **3** (10 g, 27.8 mmol) was suspended in benzyl bromide (50 mL, 418 mmol) and DMF (250 mL), and cooled to 0 °C under N_2. Sodium hydride (60% in oil, 18.9 g, 473 mmol) was added in portions over 15 min, and the well-stirred reaction mixture was left in the cooling bath and allowed to warm to rt as the ice melted. NOTE: the reaction mixture should not be removed from the cooling bath until after the reaction has neared completion. Failure to follow this may result in rapid exothermic reaction. After 44 h, TLC (pentane/EtOAc 4:1) showed the presence of a major product (R_f 0.2). The reaction mixture was cooled to 0 °C, quenched with MeOH (50 mL) and stirred for 30 min at rt. The solvent was then removed under reduced pressure, and the residue dissolved in EtOAc (200 mL) and washed with water (200 mL). The aqueous phase was re-extracted with EtOAc (200 mL), and the combined extracts were washed with brine (200 mL), dried (Na_2SO_4) and concentrated in vacuo. The residue was partially purified by dry flash column chromatography (pentane/EtOAc 15:1 (1 L)→pentane/EtOAc 10:1 (500 mL)→pentane/EtOAc 4:1 (1.5 L)) to give a pale yellow oil (19 g), which was then recrystallised from EtOAc (25 mL)/pentane (80 mL) to give perbenzylated β-lactoside **4b** (13.4 g, 46%) as white crystals. Mp 83–86 °C, lit. mp 74–76 °C;[37] $[\alpha]_D^{25}$ +0.9 (*c* 1.0, $CHCl_3$), lit. $[\alpha]_D^{20}$ +0.1 ($CHCl_3$);[37] ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 3.37–3.41 (m, 3H, H-5^{I}, H-5^{II}, H-6), 3.44 (dd, $J_{2,3}$ 9.8 Hz, $J_{3,4}$ 3.0 Hz, 1H, H-3^{II}), 3.51 (dd, $J_{1,2}$ 7.7 Hz, $J_{2,3}$ 9.2 Hz, 1H, H-2^{I}), 3.56–3.60 (m, 2H, H-3^{I}, H-6′), 3.76–3.81 (m, 2H, H-2^{II}, H-6), 3.84 (dd, $J_{5,6'}$ 4.5 Hz, $J_{6,6'}$ 11.0 Hz, 1H, H-6′), 3.94 (d, $J_{3,4}$ 3.0 Hz, 1H, H-4^{II}), 3.99 (dd, *J* 8.9 Hz, *J* 9.8 Hz, 1H, H-4^{I}), 4.27, 4.37 (ABq, J_{AB} 11.8 Hz, 2H, PhC*H*$_2$), 4.43 (d, *J* 12.1 Hz, 1H, PhC*H*H′), 4.47 (d, $J_{1,2}$ 7.7 Hz, 1H, H-1^{II}), 4.51 (d, $J_{1,2}$ 7.7 Hz, 1H, H-1^{I}), 4.57–4.60 (m, 2H, PhC*H*H′, PhCH*H*′), 4.68 (d, *J* 12.0 Hz, 1H, PhC*H*H′), 4.72–4.80 (m, 5H, PhC*H*$_2$, 3×PhC*H*H′), 4.83 (d, *J* 11.1 Hz, 1H, PhCH*H*′), 4.93 (d, *J* 10.8 Hz, 1H, PhCH*H*′), 4.96 (d, *J* 11.9 Hz, 1H, PhCH*H*′), 4.98 (d, *J* 11.3 Hz, 1H, PhCH*H*′), 5.05 (d, *J* 10.7 Hz, 1H, PhCH*H*′), 7.13–7.41 (m, 40H, Ar–CH); ^{13}C NMR (125 MHz, $CDCl_3$) δ_C 68.2, 68.4 (2×t, C-6^{I}, C-6^{II}), 71.1, 72.7, 73.2, 73.5, 74.8, 75.2, 75.4, 75.5 (8×t, 8×PhCH$_2$), 73.1, 75.3 (2×d, C-5^{I}, C-5^{II}), 73.8 (d, C-4^{II}), 76.9 (d, C-4^{I}), 80.1 (d, C-2^{II}), 81.9 (d, C-2^{I}), 82.7 (d, C-3^{II}), 83.2 (d, C-3^{I}), 102.7 (C-1^{I}), 102.9 (C-1^{II}), 127.2, 127.5, 127.6, 127.6, 127.7, 127.7, 127.8, 127.8, 127.9, 127.9, 128.0, 128.0, 128.0, 128.1, 128.2, 128.2, 128.3, 128.3, 128.3, 128.4, 128.4, 128.5, 128.5, 128.5, 128.5 (25×d, Ar–CH), 137.7, 138.2, 138.6, 138.7, 138.8, 139.0 (6×s, Ar–C).

The mother liquor contains (according to NMR spectroscopy) further **4b** as the major component, along with another disaccharide likely to be the perbenzylated α-lactoside, with anomeric carbon resonances at δ_C 96.0 and 102.9 ppm.

4.3. 2,3,4,6-Tetra-*O*-benzyl-D-galactopyranose (2), 2,3,6-tri-*O*-benzyl-D-glucopyranose (5) and 1-*O*-acetyl-2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranose (6)

Benzyl lactoside **4b** (6.84 g, 6.4 mmol) was suspended in a mixture of acetic acid (75 mL) and H_2SO_4 (1 M, 10 mL), and the mixture stirred at 85 °C. After 5 h, TLC (pentane/EtOAc, 3:1) showed complete consumption of the starting material (R_f 0.8) into three products (R_f 0.6, 0.4 (**1**), 0.2 (**5**)). The reaction mixture was allowed to cool to rt, then quenched by addition to water (250 mL). The mixture was extracted with toluene (2×250 mL), and the organic extracts washed with $NaHCO_3$ (satd aq, 250 mL), dried (Na_2SO_4), filtered and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc 2:1→5:4) to give impure galactose hemiacetal **2** (3.24 g), and impure glucose hemiacetal **5** (α/β, 1:1; 1.32 g). The glucose hemiacetal **5** was recrystallised from EtOAc/pentane to give white crystals, **5** (α/β, 7:1; 834 mg, 29%);[38] ^{1}H NMR (400 MHz, $CDCl_3$) selected data α-anomer: δ_H 2.40 (br s, 1H, OH), 3.03 (br s, 1H, OH), 3.55 (dd, $J_{1,2}$ 3.5 Hz, $J_{2,3}$ 9.3 Hz, 1H, H-2), 3.60 (at, *J* 9.4 Hz, 1H, H-3 or H-4), 3.67–3.68 (m, 2H, H-6, H-6′), 3.79 (at, *J* 9.2 Hz, H-3 or H-4), 4.00 (dat, *J* 4.5, 9.3 Hz, 1H, H-5), 4.54, 4.59 (ABq, J_{AB} 12.3 Hz, 2H, PhC*H*$_2$), 4.69, 4.76 (ABq, J_{AB} 11.7 Hz, 2H, PhC*H*$_2$), 4.76, 4.98 (ABq, J_{AB} 12.3 Hz, 2H, PhC*H*$_2$), 5.23 (br s, 1H, H-1), 7.27–7.37 (m, 15H, Ar–H); selected data β-anomer: δ_H 3.37 (dd, *J* 7.6, 9.0 Hz, 1H), 3.46 (at, *J* 8.7 Hz, 1H).

Impure galactose hemiacetal **2** (3.24 g) was dissolved in CH_2Cl_2 (70 mL), and triethylamine (21 mL) and acetic anhydride (4.2 mL) were added. After 2 h, TLC (pentane/EtOAc, 4:1) indicated complete conversion of starting material (R_f 0.1) into a major product (R_f 0.6). The reaction mixture was cooled to 0 °C, and MeOH (30 mL) was slowly added, after which the mixture was concentrated in vacuo. The residue was dissolved in EtOAc (100 mL) and washed with HCl (1 M, 100 mL). The aqueous phase was re-extracted with EtOAc (100 mL), and the combined extracts were dried ($MgSO_4$), filtered and concentrated in vacuo. The resulting yellow oil was recrystallised from EtOAc/pentane to give the β-acetate **6** (2.32 g, 62% from

4b) as a white solid. Mp 98–101 °C (EtOAc/pentane), lit. mp 101–102 °C (EtOH);[39] $[\alpha]_D^{28}$ +2.5 (*c* 1.0, $CHCl_3$), lit. +5.3 (*c* 1.0, $CHCl_3$);[39] ^1H NMR (400 MHz, $CDCl_3$) δ_H 2.03 (s, 3H, CH_3), 3.54–3.63 (m, 3H, H-3, H-6, H-6′), 3.69 (m, 1H, H-5), 3.95 (dd, $J_{1,2}$ 8.0 Hz, $J_{2,3}$ 9.7 Hz, 1H, H-2), 3.98 (m, 1H, H-4), 4.39, 4.44 (ABq, J_{AB} 11.8 Hz, 2H, $PhCH_2$), 4.62, 4.94 (ABq, J_{AB} 11.6 Hz, 2H, $PhCH_2$), 4.72–4.74 (m, 3H, $PhCH_2$, PhC*H*H′), 4.84 (d, *J* 11.3 Hz, 1H, PhCH*H*′), 5.56 (d, $J_{1,2}$ 8.0 Hz, 1H, H-1), 7.26–7.34 (m, 20H, Ar–H).

Acetate **6** (2.30 g, 4.0 mmol) was suspended in MeOH (50 mL), and a solution of sodium methoxide (prepared from sodium (17 mg) and MeOH (5 mL)) was added. After 3 h, all the starting material had dissolved, and TLC (3:1 pentane/EtOAc) showed complete conversion of starting material (R_f 0.6) into a single product (R_f 0.2). Dowex 50X 8 (H^+) ion-exchange resin (2 mL) was added, then the mixture was filtered and concentrated in vacuo. The residue was passed through a pad of silica eluting with pentane/EtOAc, 1:1, to give hemiacetal **2** (2.06 g, 97%) as a colourless oil that crystallised on standing;[40] selected data, ^1H NMR (400 MHz, $CDCl_3$) δ_H 2.93 (br s, 1H, OH-1α), 3.14 (d, $J_{OH,1}$ 6.4 Hz, 1H, OH-1β), 3.76 (dd, *J* 7.4, 9.6 Hz, 1H, β), 3.97 (dd, *J* 1.1, 2.8 Hz, 1H, H-4α), 4.03 (dd, *J* 3.6, 9.8 Hz, 1H, α), 4.15 (at, *J* 6.4 Hz, 1H, α), 5.28 (d, $J_{1,2}$ 3.5 Hz, 1H, H-1α).

4.4. General methods for organometallic additions

General procedure 1, Grignard reagents. A solution of the hemiacetal (ca. 0.2 mM in anhydrous THF) under N_2 was cooled in an ice-water bath. The organometallic reagent (4 equiv) was added dropwise. The reaction mixture was allowed to reach rt over ca. 1 h, and stirring was continued for a further 20 h. The reaction was quenched by careful addition of NH_4Cl (satd aq). The mixture was diluted with water and EtOAc. The phases were separated and the aqueous layer was extracted twice with EtOAc. The combined organic extracts were washed with water twice, and then dried (Na_2SO_4) filtered and concentrated in vacuo. The crude product was purified by repeated column chromatography (pentane/EtOAc, 3:1) to give the diols as colourless oils.

General procedure 2, Grignard+$ZnBr_2$. A solution of anhydrous $ZnBr_2$ (2.5 equiv) in anhydrous THF (vinylmagnesium bromide) or Et_2O (phenylmagnesium bromide) was cooled under N_2 in an ice-water bath. The solution was treated dropwise with the Grignard reagent (10 equiv). After 5 min, the cooling bath was removed. If necessary, additional solvent was added until a clear solution was obtained. Once all the solids had dissolved, the solution was re-cooled in an ice-water bath. The hemiacetal was added as a ca. 1 M solution in THF (or ether) by syringe. The reaction mixture was allowed to warm to rt over ca. 1 h, and stirring was continued for a further 20 h. The reaction was quenched by careful addition of NH_4Cl (satd aq). The mixture was diluted with water and EtOAc. The phases were separated and the aqueous layer was extracted twice with EtOAc. The combined organic extracts were washed with water twice, and then dried (Na_2SO_4) filtered and concentrated in vacuo. The crude product was purified by repeated column chromatography (pentane/EtOAc, 3:1) to give the diols as colourless oils. NOTE: PhMgBr addition in Et_2O resulted in a biphasic reaction mixture, whereas a homogeneous solution was obtained with THF. The diols were isolated in similar yields and diastereomeric ratios in both cases.

General procedure 3, Grignard+$ZnMe_2$. The Grignard reagent (5.0 equiv) was added under N_2 to ice-cold anhydrous THF (to afford a ca. 0.5 mM solution). $ZnMe_2$ (5.5 equiv) was added dropwise, and the mixture was stirred at 0 °C for 10 min. (NOTE: addition of the reagents in any other order resulted in the spontaneous combustion of the $ZnMe_2$ solution.) The hemiacetal in THF (0.2–0.4 mM) was added to this solution by syringe. The reaction mixture was allowed to slowly warm to room temperature (approx. 1 h). Stirring was continued for 20 h at room temperature. The reaction was quenched by careful addition of NH_4Cl (satd aq). The mixture was diluted with water and EtOAc. The phases were separated and the aqueous layer was extracted twice with EtOAc. The combined organic extracts were washed twice with water, and then dried (Na_2SO_4), filtered and concentrated in vacuo. Repeated column chromatography (pentane/EtOAc, 3:1) gave the diols as colourless oils.

4.5. General methods for cyclisation with catalytic DNBSA

General procedure 4, conventional heating. The substrate (**7a**,**b**–**10a**,**b**) was dissolved in acetone or acetonitrile. DNBSA (0.1 equiv) was added, and the mixture was heated with a reflux condenser at 60 °C or 80 °C until TLC showed disappearance of the starting material. The reaction was then quenched by addition of Et_3N (ca. 1.5 mL), and the mixture was concentrated in vacuo, and the residue purified by flash column chromatography to give the C-glycosides (**11a**,**b**–**14a**,**b**, **16a**,**b**–**19a**,**b**).

General procedure 5, microwave heating. The substrate (**7a**,**b**, **9a**,**b**, **15a**) was weighed into a microwave vial (2.5 mL or 5 mL as appropriate) and dissolved in acetone or acetonitrile. DNBSA (0.1 equiv) was added, and then the vial was sealed and heated in the microwave apparatus (Emrys Creator) at 100 °C for the stated time (fixed hold time, normal absorption). The reaction was then quenched by addition of triethylamine (ca. 1.5 mL), and the mixture was concentrated in vacuo, and the residue purified by flash column chromatography to give *C*-glycosides (**11a**,**b**, **12a**,**b**, **16a**,**b**).

4.6. (2*R*,3*R*,4*R*,5*S*,6*S*)-1,3,4,5-Tetra-*O*-benzyl-oct-7-ene-1,2,3,4,5,6-hexaol (7a) and (2*R*,3*R*,4*R*,5*S*,6*R*)-1,3,4,5-tetra-*O*-benzyl-oct-7-ene-1,2,3,4,5,6-hexaol (7b)

Following general procedure 2, hemiacetal **1** (540 mg, 1.00 mmol) was converted into a mixture of diols **7a** and **7b** (1:4), which was separated (pentane/EtOAc, 3:1) to give **7a** (58 mg, 10%) and **7b** (325 mg, 57%).

Following general procedure 3, hemiacetal **1** (400 mg, 0.74 mmol) was converted into a mixture of diols **7a** and **7b** (1:4), which was separated (pentane/EtOAc, 3:1) to give **7a** (40 mg, 10%) and **7b** (223 mg, 53%).

Following general procedure 3 but using Et_2Zn in place of Me_2Zn, traces of a compound consistent with ethyl addition to the hemiacetal was seen along with **7a** and **7b**: *m*/*z* (ES^+) 1163 (2M+Na^+, 40), 593 (M+Na^+, 100%); HRMS (ES^+) calcd for $C_{36}H_{42}O_6Na$ (MNa^+) 593.2874, found 593.2889.

4.7. (2*R*,3*S*,4*R*,5*S*,6*S*)-1,3,4,5-Tetra-*O*-benzyl-oct-7-ene-1,2,3,4,5,6-hexaol (8a) and (2*R*,3*S*,4*R*,5*S*,6*R*)-1,3,4,5-tetra-*O*-benzyl-oct-7-ene-1,2,3,4,5,6-hexaol (8b)

Following general procedure 1, hemiacetal **2** (1.6 g, 2.9 mmol) was converted into a mixture of diols **8a** and **8b** (2:1), which was separated (toluene/EtOAc, 10:1) to give **8b** (523 mg, 31%) and **8a** (884 mg, 53%).

Following general procedure 2, hemiacetal **2** (540 mg, 1.0 mmol) was converted into a mixture of diols **8a** and **8b** (1:2), which was separated to give **8b** (228 mg, 40%) and **8a** (98 mg, 17%).

Following general procedure 3, hemiacetal **2** (351 mg, 0.65 mmol) was converted into a mixture of diols **8a** and **8b** (1:2), which was separated to give **8b** (178 mg, 48%) and **8a** (87 mg, 24%).

4.8. (1*S*,2*S*,3*R*,4*R*,5*R*)-2,3,4,6-Tetra-*O*-benzyl-1-phenyl-hexane-1,2,3,4,5,6-hexaol (9a) and (1*R*,2*S*,3*R*,4*R*,5*R*)-2,3,4,6-tetra-*O*-benzyl-1-phenyl-hexane-1,2,3,4,5,6-hexaol (9b)

Following general procedure 1, hemiacetal **1** (1.0 g, 1.9 mmol) was converted into a mixture of diols **9a** and **9b** (1:2), which was separated (7:2→5:2 pentane/EtOAc) to give **9a** (283 mg, 25%) and **9b** (545 mg, 48%).

Following general procedure 2, hemiacetal **1** (1.0 g, 1.85 mmol) was converted into a mixture of diols **9a** and **9b** (<1:6), which was separated (pentane/EtOAc, 3:1, repeated) to give **9a** (97 mg, 9%) and **9b** (860 mg, 75%).

Following general procedure 3, hemiacetal **1** (400 mg, 0.74 mmol) was converted into a mixture of diols **9a** and **9b** (1:7), which was separated to give **9a** (34 mg, 7%) and **9b** (213 mg, 47%).

Compound **9a**, a colourless oil, R_f 0.5 (pentane/EtOAc, 2:1); $[\alpha]_D^{22}$ +17.8 (*c* 1.0, $CHCl_3$); ν_{max} 3453 (br, OH) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 3.10 (br s, 1H, OH), 3.63–3.64 (m, 3H, H-6, H-6′, OH), 3.85–3.87 (m, 3H, H-2, H-3, H-4), 4.04 (dat, *J* 4.2, 6.4 Hz, 1H, H-5), 4.39, 4.42 (ABq, J_{AB} 11.3 Hz, 2H, PhCH_2), 4.46, 4.49 (ABq, J_{AB} 11.3 Hz, 2H, PhCH_2), 4.55, 4.61 (ABq, J_{AB} 12.0 Hz, 2H, PhCH_2), 4.57, 4.68 (ABq, J_{AB} 11.2 Hz, 2H, PhCH_2), 5.08 (d, $J_{1,2}$ 5.8 Hz, 1H, H-1), 7.13–7.41 (m, 25H, Ar–H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 71.2 (t, C-6), 71.5 (d, C-5), 72.9, 73.4, 73.6 (3×t, 4×PhCH_2), 73.7 (d, C-1), 76.3, 78.1, 80.2 (3×d, C-2, C-3, C-4), 126.8, 127.6, 127.8, 127.9, 128.0, 128.2, 128.3, 128.4, 128.4, 128.5, 128.5, 128.6, 128.8 (13×d, Ar–CH), 137.5, 137.6, 137.8, 138.3 (4×s, 4×Bn-C), 141.8 (s, Ar–C); *m*/*z* (ES$^+$) 1259 (2M+Na$^+$, 7), 641 (M+Na$^+$, 100%); HRMS (ES$^+$) calcd for $C_{40}H_{42}O_6Na$ (MNa$^+$) 641.2874, found 641.2859.

Compound **9b**, a colourless oil, R_f 0.4 (pentane/EtOAc, 2:1); $[\alpha]_D^{22}$ −12.5 (*c* 1.0, $CHCl_3$); ν_{max} 3440 (br, OH) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 3.04 (br s, 2H, OH-1, OH-5), 3.66 (dd, $J_{5,6}$ 5.0 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6), 3.70 (dd, $J_{5,6'}$ 3.6 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6′), 3.81 (dd, $J_{3,4}$ 3.1 Hz, $J_{4,5}$ 7.0 Hz, 1H, H-4), 4.02 (dd, $J_{2,3}$ 6.9 Hz, $J_{3,4}$ 3.1 Hz, 1H, H-3), 4.05 (dd, $J_{1,2}$ 2.8 Hz, $J_{2,3}$ 6.9 Hz, 1H, H-2), 4.13–4.18 (m, 2H, H-5, PhC*H*H′), 4.54–4.62 (m, 4H, PhC*H*H′, PhCH*H*′, PhCH_2), 4.65 (d, *J* 11.4 Hz, 1H, PhCH*H*′), 4.70, 4.75 (ABq, J_{AB} 11.3 Hz, 2H, PhCH_2), 4.92 (d, $J_{1,2}$ 2.8 Hz, 1H, H-1), 7.10–7.41 (m, 25H, Ar–H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 71.0 (d, C-5), 71.4 (t, C-6), 73.2, 73.4, 73.6, 74.8, 75.3 (4×t, d, 4×PhCH_2, C-1), 77.5 (d, C-4), 79.8, 83.4 (2×d, C-2, C-3), 126.3, 127.5, 127.8, 127.9, 128.0, 128.0, 128.0, 128.3, 128.4, 128.4, 128.6, 128.6 (12×d, Ar–CH), 137.9, 138.0, 138.1, 138.1 (4×s, 4×Bn-C), 142.0 (s, Ar–C); *m*/*z* (ES$^+$) 1259 (2M+Na$^+$, 20), 641 (M+Na$^+$, 100%); HRMS (ES$^+$) calcd for $C_{40}H_{42}O_6Na$ (MNa$^+$) 641.2874, found 641.2865.

4.9. (1*S*,2*S*,3*R*,4*S*,5*R*)-2,3,4,6-Tetra-*O*-benzyl-1-phenyl-hexane-1,2,3,4,5,6-hexaol (10a) and (1*R*,2*S*,3*R*,4*S*,5*R*)-2,3,4,6-tetra-*O*-benzyl-1-phenyl-hexane-1,2,3,4,5,6-hexaol (10b)

Following general procedure 1, hemiacetal **2** (565 mg, 1.05 mmol) was converted with PhMgBr (3.2 mL, 3 M in Et_2O, 9.6 mmol), in Et_2O (3 mL) into a mixture of diols **10a** and **10b** (1:3), which was purified (pentane/EtOAc, 3:1) to give **10a**,**b** (519 mg, 80%).

Following general procedure 2, hemiacetal **2** (260 mg, 0.48 mmol) was converted with $ZnBr_2$ (285 mg, 1.3 mmol), PhMgBr (1.6 mL, 3 M in Et_2O, 4.8 mmol), in Et_2O (5 mL) and toluene (3.2 mL) into a mixture of diols **10a** and **10b** (1:3), which was purified (pentane/EtOAc, 3:1) to give **10a**,**b** (141 mg, 47%).

Following general procedure 3, hemiacetal **2** (371 mg, 0.69 mmol) was converted into a mixture of diols **10a** and **10b** (1:3), which was separated to give **10b** (194 mg, 46%) and **10a** (80 mg, 19%).

Compound **10a**, a colourless oil; $[\alpha]_D^{25}$ −6.3 (*c* 1.0 $CHCl_3$); ν_{max} 3430 (OH) cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ_H 2.92 (br s, 1H, OH), 3.01 (br s, 1H, OH), 3.49–3.53 (m, 2H, H-6, H-6′), 3.80 (dd, $J_{1,2}$ 6.4 Hz, $J_{2,3}$ 3.4 Hz, 1H, H-2), 3.87 (dd, $J_{3,4}$ 5.2 Hz, $J_{4,5}$ 2.0 Hz, 1H, H-4), 3.94 (dd, $J_{3,4}$ 5.2 Hz, $J_{3,2}$ 3.4 Hz, 1H, H-3), 4.15 (dat, $J_{5,6}$ 6.2 Hz, $J_{4,5}$ 2.0 Hz, 1H, H-5), 4.28, 4.36 (ABq, J_{AB} 11.2 Hz, 2H, PhCH_2), 4.40–4.53 (m, 4H, 2×PhCH_2), 4.70, 4.74 (ABq, J_{AB} 11.6 Hz, 2H, PhCH_2), 5.00 (d, $J_{1,2}$ 6.4 Hz, 1H, H-1), 7.12–7.41 (m, 25H, Ar–H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ_C 69.7 (d, C-5), 71.2 (t, C-6), 73.1, 73.3 (2×t, PhCH_2), 73.5 (d, C-1), 73.3, 74.0 (2×t, PhCH_2), 78.0 (d, C-4), 79.1 (d, C-3), 81.5 (d, C-2), 126.9, 127.7, 127.7, 127.8, 127.9, 127.9, 128.1, 128.3, 128.3, 128.4, 128.4, 128.4, 128.5 (13×d, Ar–CH), 137.8, 137.9, 138.0, 138.0, 141.6 (5×s, Ar–C); HRMS (ES$^+$) calcd for $C_{40}H_{43}O_6$ (MH$^+$) 619.3054, found 619.3054; calcd for $C_{40}H_{42}O_6Na$ (MNa$^+$) 641.2874, found 641.2883.

Compound **10b**, a colourless oil; $[\alpha]_D^{25}$ +32.0 (*c* 1.0 $CHCl_3$); ν_{max} 3446 (br, OH) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 3.40 (d, $J_{OH,1}$ 5.5 Hz, 1H, OH-1), 3.49 (d, $J_{OH,5}$ 3.1 Hz, 1H, OH-5), 3.54 (dd, $J_{5,6}$ 6.6 Hz, $J_{6,6'}$ 9.4 Hz, 1H, H-6), 3.58 (dd, $J_{5,6'}$ 5.4 Hz, $J_{6,6'}$ 9.4 Hz, 1H, H-6′), 3.86 (dd, $J_{1,2}$ 2.3 Hz, $J_{2,3}$ 6.3 Hz, 1H, H-2), 3.96–3.99 (m, 2H, H-3, H-4), 4.10 (m, 1H, H-5), 4.16, 4.44 (ABq, J_{AB} 10.8 Hz, 2H, PhCH_2), 4.44, 4.49 (ABq, J_{AB} 11.8 Hz, 2H, PhCH_2), 4.55 (d, *J* 11.5 Hz, 1H, PhC*H*H′), 4.70 (d, *J* 11.3 Hz, 1H, PhC*H*H′), 4.72–4.78 (m, 2H, 2×PhCH*H*′), 4.94 (dd, $J_{1,2}$ 2.3 Hz, $J_{OH,1}$ 5.5 Hz, 1H, H-1), 7.04–7.38 (m, 25H, Ar–H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 70.3 (d, C-5), 70.9 (t, C-6), 72.4 (d, C-1), 73.5, 73.7, 74.7, 75.0 (4×t, 4×PhCH_2), 77.9, 81.1 (2×d, C-3, C-4), 83.2 (d, C-2), 126.3, 127.5, 127.8, 127.9, 128.0, 128.0, 128.3, 128.3, 128.4, 128.4, 128.5, 128.6, 128.6 (13×d, Ar–CH), 137.7, 137.9, 138.2, 138.2 (4×s, 4×Bn-C), 142.2 (s, Ar–C); *m*/*z* (ES$^+$) 1259 (2M+Na$^+$, 100), 641 (M+Na$^+$, 95%); HRMS (ES$^+$) calcd for $C_{40}H_{42}O_6Na$ (MNa$^+$) 641.2874, found 641.2871.

4.10. (2,3,6-Tri-*O*-benzyl-α-D-glucofuranosyl)ethene (11a) and (2,3,5,6-tetra-*O*-benzyl-α-D-glucofuranosyl)ethene (12a)

Using conventional heating (general procedure 4), diol **7a** (250 mg, 0.44 mmol) in acetone (3 mL) was converted with DNBSA (11 mg, 0.04 mmol) into *C*-glycoside **11a** (131 mg, 65%).

Using conventional heating (general procedure 4), diol **7a** (50 mg, 0.088 mmol) in acetonitrile (2 mL) was converted with DNBSA (2 mg, 0.009 mmol) into *C*-glycosides **12a** (11 mg, 23%) and **11a** (29 mg, 72%).

Using microwave heating (general procedure 5), diol **7a** (575 mg, 1.0 mmol) in acetone (4 mL) was converted with DNBSA (25 mg, 0.1 mmol) into *C*-glycoside **11a** (322 mg, 69%).

Using microwave heating (general procedure 5), diol **7a** (50 mg, 0.088 mmol) in acetonitrile (2 mL) was converted with DNBSA (2 mg, 0.009 mmol) into *C*-glycosides **12a** (11 mg, 23%) and **11a** (27 mg, 67%).

4.11. (2,3,6-Tri-*O*-benzyl-β-D-glucofuranosyl)ethene (11b) and (2,3,5,6-tetra-*O*-benzyl-β-D-glucofuranosyl)ethene (12b)

Using conventional heating (general procedure 4), diol **7b** (150 mg, 0.26 mmol) in acetone (3 mL) was converted with DNBSA (7 mg, 0.026 mmol) into *C*-glycoside **11b** (83 mg, 68%).

Using conventional heating (general procedure 4), diol **7b** (120 mg, 0.21 mmol) in acetonitrile (2.5 mL) was converted with DNBSA (5.2 mg, 0.021 mmol) into *C*-glycosides **12b** (17 mg, 15%) and **11b** (64 mg, 66%).

Using microwave heating (general procedure 5), diol **7b** (262 mg, 0.46 mmol) in acetone (2 mL) was converted with DNBSA (2 mg, 0.009 mmol) into *C*-glycoside **11b** (144 mg, 68%).

Using microwave heating (general procedure 5), diol **7b** (50 mg, 0.088 mmol) in acetonitrile (2 mL) was converted with DNBSA (2 mg, 0.009 mmol) into *C*-glycosides **12b** (6 mg, 12%) and **11b** (27 mg, 67%).

4.12. (2,3,6-Tri-*O*-benzyl-α-D-galactofuranosyl)ethene (13a) and (2,3,5,6-tetra-*O*-benzyl-α-D-galactofuranosyl)ethene (14a)

Using conventional heating (general procedure 4), diol **8a** (96 mg, 0.17 mmol) in acetone (3 mL) was converted with DNBSA (4 mg, 0.017 mmol) into *C*-glycoside **13a** (26 mg, 33%).

Using conventional heating (general procedure 4), diol **8a** (173 mg, 0.31 mmol) in acetonitrile (3.8 mL) was converted with DNBSA (8 mg, 0.031 mmol) into *C*-glycosides **14a** (26 mg, 16%) and **13a** (86 mg, 61%).

4.13. (2,3,6-Tri-*O*-benzyl-β-D-galactofuranosyl)ethene (**13b**) and (2,3,5,6-tetra-*O*-benzyl-β-D-galactofuranosyl)ethene (**14b**)

Using conventional heating (general procedure 4), diol **8b** (145 mg, 0.26 mmol) in acetone (3 mL) was converted with DNBSA (6 mg, 0.025 mmol) into *C*-glycoside **13b** (60 mg, 51%).

Using conventional heating (general procedure 4), diol **8b** (131 mg, 0.23 mmol) in acetonitrile (2 mL) was converted with DNBSA (6 mg, 0.023 mmol) into *C*-glycosides **14b** (25 mg, 20%) and **13b** (49 mg, 46%).

4.14. (2*R*,3*R*,4*R*,5*S*,6*S*)-1,2,3,4,5,6-Hexa-*O*-benzyl-oct-7-ene-1,2,3,4,5,6-hexaol (**15a**)

Diol **7a** (500 mg, 0.88 mmol) was dissolved in THF (4 mL), and BnBr (0.54 mL, 2.11 mmol) and sodium hydride (60% in oil, 100 mg, 2.11 mmol) were added. After 17 h, work-up and column chromatography (pentane/EtOAc, 5:1) gave the fully protected compound **15a** (614 mg, 93%) as a colourless oil. ^{1}H NMR (CDCl$_3$, 400 MHz) δ_H 3.72 (m, 1H), 3.85–3.95 (m, 5H), 4.00 (dd, *J* 4.5, 7.9 Hz, 1H), 4.17, 4.54 (ABq, J_{AB} 11.8 Hz, 2H, PhC*H*$_2$), 4.41 (d, *J* 11.8 Hz, 1H, PhC*H*H′), 4.50 (s, 2H, PhC*H*$_2$), 4.59–4.72 (m, 6H, PhC*H*H′, PhCH*H*′, 2×PhC*H*$_2$), 4.80 (d, *J* 11.3 Hz, 1H, PhCH*H*′), 4.32–4.39 (m, 2H, H-1b, H-1b′), 5.97 (ddd, $J_{1,1a}$ 7.9 Hz, $J_{1a,1b}$ 17.3 Hz, $J_{1a,1b'}$ 10.3 Hz, 1H, H-1a), 7.23–7.32 (m, 30H, Ar–H); ^{13}C NMR (CDCl$_3$, 100 MHz) δ_C 70.1, 70.2, 72.1, 73.4, 74.1, 74.2, 75.3 (7×t, C-6, 6×PhCH$_2$), 79.3, 79.7, 79.8, 81.2, 81.9 (5×d, C-1, C-2, C-3, C-4, C-5), 119.7 (t, C-1b), 127.4, 127.4, 127.5, 127.6, 127.6, 127.7, 127.7, 127.8, 128.1, 128.1, 128.3, 128.3, 128.3, 128.3, 128.4, 128.4 (16×d, Ar–CH), 136.0 (d, C-1a), 138.6, 138.8, 138.8, 138.9, 139.0, 139.2 (6×s, 6×Ar–C); HRMS (ES$^+$) calcd for C$_{50}$H$_{52}$O$_6$Na (MNa$^+$) 771.3656, found 771.3654.

4.15. (2,3,6-Tri-*O*-benzyl-α-D-glucofuranosyl)benzene (**16a**)

Using conventional heating (general procedure 4), diol **9a** (45 mg, 0.073 mmol) in acetone (2 mL) was converted with DNBSA (2 mg, 0.007 mmol) into *C*-glycoside **16a** (24 mg, 65%).

Using conventional heating (general procedure 4), diol **9a** (129 mg, 0.21 mmol) in acetonitrile (2.5 mL) was converted with DNBSA (5 mg, 0.021 mmol) into *C*-glycosides **18a** (30 mg, 24%) and **16a** (70 mg, 66%).

Using microwave heating (general procedure 5), diol **9a** (237 mg, 0.38 mmol) in acetone (3 mL) was converted with DNBSA (10 mg, 0.04 mmol) into *C*-glycoside **16a** (129 mg, 66%).

Compound **16a**, a colourless oil; $[\alpha]_D^{22}$ −29.3 (*c* 1.0, CHCl$_3$); ν_{max} 3461 (br, OH) cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ_H 3.70 (dd, $J_{5,6}$ 6.0 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6), 3.81 (dd, $J_{5,6'}$ 3.1 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6′), 3.95 (dd, $J_{1,2}$ 3.5 Hz, $J_{2,3}$ 0.9 Hz, 1H, H-2), 4.04, 4.12 (ABq, J_{AB} 12.1 Hz, 2H, PhC*H*$_2$), 4.22 (ddd, $J_{4,5}$ 8.6 Hz, $J_{5,6}$ 6.0 Hz, $J_{5,6'}$ 3.1 Hz, 1H, H-5), 4.22 (dd, $J_{2,3}$ 0.9 Hz, $J_{3,4}$ 3.7 Hz, 1H, H-3), 4.35 (dd, $J_{3,4}$ 3.7 Hz, $J_{4,5}$ 8.6 Hz, 1H, H-4), 4.57 (d, *J* 11.8 Hz, 1H, PhC*H*H′), 4.60–4.63 (m, 3H, PhCH*H*′, PhC*H*$_2$), 5.22 (d, $J_{1,2}$ 3.5 Hz, 1H, H-1), 6.90–6.92 (m, 2H, Ar–H), 7.21–7.39 (m, 18H, Ar–H); ^{13}C NMR (100 MHz, CDCl$_3$) δ_C 68.9 (d, C-5), 72.2, 72.5, 72.8, 73.6 (4×t, C-6, 3×PhCH$_2$), 80.8 (d, C-4), 82.9, 83.1, 83.2 (3×d, C-1, C-2, C-3), 127.4, 127.6, 127.7, 127.8, 127.8, 127.9, 128.0, 128.1, 128.4, 128.6, 128.7 (11×d, Ar–CH), 137.8, 137.8, 137.9, 138.4, (4×s, 4×Ar–C); *m/z* (ES$^+$) 1043 (2M+Na$^+$, 55), 533 (M+Na$^+$, 100%); HRMS (ES$^+$) calcd for C$_{33}$H$_{34}$O$_5$Na (MNa$^+$) 533.2298, found 533.2296.

4.16. (2,3,6-Tri-*O*-benzyl-β-D-glucofuranosyl)benzene (**16b**)

Using conventional heating (general procedure 4), diol **9b** (244 mg, 0.40 mmol) in acetone (4.7 mL) was converted with DNBSA (10 mg, 0.040 mmol) into *C*-glycoside **16b** (130 mg, 65%).

Using conventional heating (general procedure 4), diol **9b** (358 mg, 0.58 mmol) in acetonitrile (8.6 mL) was converted with DNBSA (14 mg, 0.06 mmol) into *C*-glycosides **18b** (47 mg, 14%) and **16b** (211 mg, 71%).

Using microwave heating (general procedure 5), diol **9b** (496 mg, 0.80 mmol) in acetone (4 mL) was converted with DNBSA (20 mg, 0.08 mmol) into *C*-glycoside **16b** (319 mg, 78%).

Compound **16b**, a colourless oil; $[\alpha]_D^{22}$ −23.9 (*c* 1.0, CHCl$_3$); ν_{max} 3479 (br, OH) cm^{-1}; ^{1}H NMR (400 MHz, CDCl$_3$) δ_H 3.72 (dd, $J_{5,6}$ 6.1 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6), 3.84 (dd, $J_{5,6'}$ 3.3 Hz, $J_{6,6'}$ 9.8 Hz, 1H, H-6′), 4.02 (dd, $J_{1,2}$ 3.6 Hz, $J_{2,3}$ 1.0 Hz, 1H, H-2), 4.15 (dd, $J_{3,4}$ 3.9 Hz, $J_{4,5}$ 8.0 Hz, 1H, H-4), 4.22 (dd, $J_{2,3}$ 1.0 Hz, $J_{3,4}$ 3.9 Hz, 1H, H-3), 4.39 (ddd, $J_{4,5}$ 8.0 Hz, $J_{5,6}$ 6.1 Hz, $J_{5,6'}$ 3.3 Hz, 1H, H-5), 4.48–4.58 (m, 4H, 2 × PhC*H*$_2$), 4.58, 4.63 (ABq, J_{AB} 11.8 Hz, 2H, PhC*H*$_2$), 4.88 (d, $J_{1,2}$ 3.6 Hz, 1H, H-1), 7.22–7.45 (m, 20H, Ar–H); ^{13}C NMR (100 MHz, CDCl$_3$) δ_C 68.8 (d, C-5), 71.8, 72.1, 72.4, 73.7 (4×t, C-6, 3×PhCH$_2$), 81.4 (d, C-4), 83.4 (d, C-3), 86.5 (d, C-1), 89.6 (d, C-2), 126.7, 127.8, 127.8, 127.9, 128.0, 128.0, 128.5, 128.5, 128.6, 128.6 (10×d, Ar–CH), 137.7, 137.8, 138.3 (3×s, 3×Bn-C), 140.7 (s, Ar–C); *m/z* (ES$^+$) 533 (M+Na$^+$, 100%); HRMS (ES$^+$) calcd for C$_{33}$H$_{34}$O$_5$Na (MNa$^+$) 533.2298, found 533.2293. Analysis, found: C, 78.00; H, 6.70. C$_{33}$H$_{34}$O$_5$ requires C, 77.62; H, 6.71%.

4.17. (2,3,6-Tri-*O*-benzyl-α-D-galactofuranosyl)benzene (**17a**)

Using conventional heating (general procedure 4), diol **10a** (122 mg, 0.20 mmol) in acetone (2 mL) was converted with DNBSA (15 mg, 0.06 mmol) into *C*-glycoside **17a** (30 mg, 30%).

Using conventional heating (general procedure 4), diol **10a** (95 mg, 0.154 mmol) in acetonitrile (2 mL) was converted with DNBSA (4 mg, 0.015 mmol) into *C*-glycosides **19a** (15 mg, 16%) and **17a** (49 mg, 63%).

Compound **17a**, a colourless oil; $[\alpha]_D^{25}$ −44.3 (*c* 1.0 CHCl$_3$); ν_{max} 3424 (OH) cm^{-1}; ^{1}H NMR (CDCl$_3$, 400 MHz) δ_H 3.07 (br s, 1H, OH-5), 3.55–3.63 (m, 2H, H-6, H-6′), 3.70 (d, $J_{1,2}$ 3.2 Hz, 1H, H-2), 3.93 (m, 1H, H-5), 3.97, 4.09 (ABq, J_{AB} 12.0 Hz, 2H, PhC*H*$_2$), 4.10 (d, $J_{3,4}$ 2.8 Hz, 1H, H-3), 4.18 (dd, $J_{3,4}$ 2.8 Hz, $J_{4,5}$ 3.2 Hz, 1H, H-4), 4.44 (s, 2H, PhC*H*$_2$), 4.50 (s, 2H, PhC*H*$_2$), 5.03 (d, $J_{1,2}$ 3.2 Hz, 1H, H-1), 6.82–6.84 (m, 2H, Ar–H), 7.12–7.34 (m, 18H, Ar–H); ^{13}C NMR (CDCl$_3$, 100 MHz) δ_C 70.8 (d, C-5), 71.6 (t, C-6), 71.8, 71.9, 73.4 (3×t, 3×PhCH$_2$), 83.0 (d, C-1), 83.1 (d, C-2), 84.0 (d, C-4), 84.6 (d, C-3), 127.3, 127.6, 127.7, 127.7, 127.7, 127.7, 127.8, 127.9, 128.0, 128.2, 128.3, 128.5 (12×d, Ar–CH), 136.2, 137.0, 137.5, 138.2 (4×s, 4×Ar–C); HRMS (ES$^+$) calcd for C$_{33}$H$_{34}$O$_5$Na (MNa$^+$) 533.2298, found 533.2301.

4.18. (2,3,6-Tri-*O*-benzyl-β-D-galactofuranosyl)benzene (**17b**)

Using conventional heating (general procedure 4), diol **10b** (194 mg, 0.31 mmol) in acetone (3.7 mL) was converted with DNBSA (8 mg, 0.031 mmol) into *C*-glycoside **17b** (59 mg, 37%).

Using conventional heating (general procedure 4), diol **10b** (134 mg, 0.22 mmol) in acetonitrile (2.6 mL) was converted with DNBSA (5 mg, 0.022 mmol) into *C*-glycosides **19b** (25 mg, 19%) and **17b** (56 mg, 51%).

Compound **17b**, a colourless oil; $[\alpha]_D^{25}$ −27.3 (*c* 1.0 CHCl$_3$); ν_{max} (OH) 3455 cm^{-1}; ^{1}H NMR (CDCl$_3$, 400 MHz) δ_H 2.70 (br s, 1H, OH-5), 3.60–3.63 (m, 2H, H-6, H-6′), 4.00 (aq, *J* 5.3 Hz, 1H, H-5), 4.18 (dd, $J_{1,2}$ 5.2 Hz, $J_{2,3}$ 3.6 Hz, 1H, H-2), 4.27–4.33 (m, 2H, H-3, H-4), 4.45, 4.45 (ABq, J_{AB} 11.6 Hz, 2H, PhC*H*$_2$), 4.52 (s, 2H, PhC*H*$_2$), 4.55, 4.58 (ABq, J_{AB} 12.0 Hz, 2H, PhC*H*$_2$), 5.06 (d, $J_{1,2}$ 5.2 Hz, 1H, H-1), 7.17–7.42 (m, 20H, Ar–H); ^{13}C NMR (CDCl$_3$, 100 MHz) δ_C 70.5 (d, C-5), 71.5 (t, C-6), 72.0, 72.2, 73.5 (3×t, 3×PhCH$_2$), 83.1 (d, C-4), 84.5 (d, C-3), 84.5 (d, C-1), 89.7 (d, C-2), 126.3, 127.6, 127.7, 127.7, 127.7, 127.9, 128.4, 128.4, 128.4, 128.5 (10×d, Ar–CH), 137.4, 137.7, 138.0, 140.4 (4×s, 4×Ar–C); HRMS (ES$^+$) calcd for C$_{33}$H$_{35}$O$_5$ (MH$^+$) 511.2479, found 511.2480; calcd for C$_{33}$H$_{34}$O$_5$Na (MNa$^+$) 533.2298, found 533.2294.

4.19. (2,3,5,6-Tetra-*O*-benzyl-α-D-glucofuranosyl)benzene (**18a**)

Alcohol **16a** (53 mg, 0.10 mmol) was dissolved in DMF (2 mL), and the solution was placed under a N$_2$ atmosphere. NaH (60%, 8 mg, 0.21 mmol) was added in one portion. After 30 min, the mixture was treated with BnBr (37 mL, 0.31 mmol) and the mixture stirred overnight. After this time, the mixture was concentrated in vacuo and the residue dissolved in a mixture of EtOAc and water. The phases were separated and the aqueous layer was extracted twice with EtOAc. The combined organic extract was washed with water twice, dried (Na_2SO_4), filtered and concentrated. The residue was purified by flash column chromatography (pentane/ethyl acetate, 7:1) to give the perbenzylated compound **18a** (59 mg, 95%) as a colourless oil; $[\alpha]_D^{25}$ −23.0 (*c* 1.0 $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ_H 3.60 (dd, $J_{5,6}$ 5.6 Hz, $J_{6,6'}$ 10.6 Hz, 1H, H-6), 3.94 (d, $J_{1,2}$ 3.6 Hz, 1H, H-2), 4.00 (m, 1H, H-6′), 4.01, 4.14 (ABq, J_{AB} 12.0 Hz, 2H, PhC*H*$_2$), 4.10 (m, 1H, H-5), 4.24 (d, $J_{3,4}$ 3.6 Hz, 1H, H-3), 4.50 (dd, $J_{3,4}$ 3.6 Hz, $J_{4,5}$ 9.2 Hz, 1H, H-4), 4.54–4.65 (m, 5H, 2×PhC*H*$_2$, PhC*H*H′), 4.87 (d, *J* 11.6 Hz, 1H, PhCH*H*′), 5.23 (d, $J_{1,2}$ 3.6 Hz, 1H, H-1), 6.88–6.90 (m, 2H, Ar–H), 7.20–7.38 (m, 23H, Ar–H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ_C 71.9 (t, C-6), 72.2, 72.6, 72.7, 73.6 (4×t, 4×Ph*C*H$_2$), 76.6 (d, C-5), 80.3 (d, C-4), 82.9 (d, C-3), 83.0 (2×d, C-1, C-2), 127.5, 127.5, 127.6, 127.6, 127.7, 127.7, 127.8, 127.8, 128.0, 128.1, 128.4, 128.5, 128.5, 128.7 (14×d, Ar–CH), 138.0, 138.1, 138.3, 139.0, 139.3 (5×s, 5×Ar–C); HRMS (ES$^+$) calcd for $C_{40}H_{41}O_5$ (MH$^+$) 601.2949, found 601.2968; calcd for $C_{40}H_{40}O_5Na$ (MNa$^+$) 623.2768, found 623.2774.

4.20. (2,3,5,6-Tetra-*O*-benzyl-β-D-glucofuranosyl) benzene (18b)

Prepared as described for **18a**: alcohol **16b** (211 mg, 0.41 mmol), benzyl bromide (147 mL, 0.24 mmol), sodium hydride (60%, 33 mg, 0.83 mmol), DMF (2 mL) was converted into perbenzylated **18b** (215 mg, 87%), a colourless oil. $[\alpha]_D^{25}$ −24.3 (*c* 1, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ_H 3.79 (dd, $J_{5,6}$ 5.4 Hz, $J_{6,6'}$ 10.6 Hz, 1H, H-6), 3.90–4.01 (m, 2H, H-2, H-6′), 4.18 (d, *J* 3.2 Hz, 1H, H-3), 4.25–4.31 (m, 2H, H-4, H-5), 4.38, 4.46 (ABq, J_{AB} 11.2 Hz, 2H, PhC*H*$_2$), 4.52–4.60 (m, 5H, 2×PhC*H*$_2$, PhC*H*H′), 4.85 (d, *J* 11.6 Hz, 1H, PhCH*H*′), 4.93 (d, $J_{1,2}$ 2.8 Hz, 1H, H-1), 7.10–7.12 (m, 2H, Ar–H), 7.21–7.41 (m, 23H, Ar–H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ_C 71.3 (t, C-6), 71.5, 71.8, 72.8, 73.5 (4×t, 4×Ph*C*H$_2$), 76.1, 81.0 (2×d, C-4, C-5), 82.8 (d, C-3), 86.7 (d, C-1), 88.9 (d, C-2), 126.5, 127.4, 127.4, 127.5, 127.6, 127.6, 127.9, 128.3, 128.3, 128.5 (10×d, Ar–CH), 137.7, 137.9, 138.7, 139.0, 140.9 (5×s, 5×Ar–C); HRMS (ES$^+$) calcd for $C_{40}H_{41}O_5$ (MH$^+$) 601.2949, found 601.2961; calcd for $C_{40}H_{40}O_5Na$ (MNa$^+$) 623.2768, found 623.2776.

4.21. (2,3,5,6-Tetra-*O*-benzyl-α-D-galactofuranosyl) benzene (19a)

Prepared as described for **18a**: alcohol **17a** (46 mg, 0.090 mmol), benzyl bromide (46 mL, 0.27 mmol), sodium hydride (60%, 7 mg, 0.18 mmol), DMF (2 mL) was converted into perbenzylated **19a** (36 mg, 67%), a colourless oil. $[\alpha]_D^{25}$ −11.5 (*c* 1, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ_H 3.66 (dd, $J_{5,6}$ 6.6 Hz, $J_{6,6'}$ 10.4 Hz, 1H, H-6), 3.82 (dd, $J_{5,6'}$ 3.6 Hz, $J_{6,6'}$ 10.4 Hz, 1H, H-6′), 3.94 (d, $J_{1,2}$ 3.6 Hz, 1H, H-2), 3.98–4.01 (m, 2H, H-5, PhC*H*H′), 4.10 (d, *J* 12.0 Hz, 1H, PhCH*H*′), 4.15–4.16 (m, 2H, H-3, H-4), 4.45–4.54 (m, 4H, 2×PhC*H*$_2$), 4.79, 4.87 (ABq, J_{AB} 11.6 Hz, 2H, PhC*H*$_2$), 5.03 (d, $J_{1,2}$ 3.6 Hz, 1H, H-1), 6.90–6.93 (m, 2H, Ar–H), 7.18–7.42 (m, 23H, Ar–H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ_C 71.0 (t, C-6), 71.5, 71.6, 73.1, 73.2 (4×t, 4×Ph*C*H$_2$), 78.0 (d, C-5), 82.9 (d, C-1), 84.0 (d, C-3, C-4), 84.1 (d, C-2), 127.5, 127.5, 127.5, 126.6, 127.6, 127.7, 127.8, 128.0, 128.1, 128.2, 128.3, 128.4 (12×d, Ar–*C*H), 136.5, 137.8, 138.4, 138.8 (4×s, Ar–C); HRMS (ES$^+$) calcd for $C_{40}H_{41}O_5$ (MH$^+$) 601.2949, found 601.2937; calcd for $C_{40}H_{40}O_5Na$ (MNa$^+$) 623.2768, found 623.2776.

4.22. (2,3,5,6-Tetra-*O*-benzyl-β-D-galactofuranosyl) benzene (19b)

Prepared as described for **18a**: alcohol **17b** (61 mg, 0.12 mmol), benzyl bromide (42 mL, 0.36 mmol), sodium hydride (60%, 10 mg, 0.24 mmol), DMF (2 mL) was converted into perbenzylated **19b** (57 mg, 79%), a colourless oil. $[\alpha]_D^{25}$ −29.5 (*c* 1.0 $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ_H 3.78–3.82 (m, 3H, H-6, H-6′, H-4 or H-5), 4.17 (dd, $J_{1,2}$ 6.8 Hz, $J_{2,3}$ 4.0 Hz, 1H, H-2), 4.34–4.37 (m, 2H, H-3 and H-4 or H-5), 4.42–4.50 (m, 4H, 2×PhC*H*$_2$), 4.53 (s, 2H, PhC*H*$_2$), 4.63, 4.83 (ABq, J_{AB} 12.0 Hz, 2H, PhC*H*$_2$), 5.03 (d, $J_{1,2}$ 6.8 Hz, 1H, H-1), 7.21–7.46 (m, 25H, Ar–H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ_C 71.1 (t, C-6), 72.3, 72.4, 73.4, 73.7 (4×t, 4×Ph*C*H$_2$), 78.1, 82.7, 84.5 (3×d, C-3, C-4, C-5), 84.0 (d, C-1), 90.7 (d, C-2), 126.8, 127.8, 127.9, 128.0, 128.0, 128.5, 128.6, 128.6, 128.6, 128.7 (10×d, Ar–CH), 138.1, 138.2, 138.5, 138.8, 141.0 (5×s, 5×Ar–C); HRMS (ES$^+$) calcd for $C_{40}H_{41}O_5$ (MH$^+$) 601.2949, found 601.2946; calcd for $C_{40}H_{40}O_5Na$ (MNa$^+$) 623.2768, found 623.2756.

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Supplementary data

^{13}C NMR data for stereochemical assignment of *C*-furanosides. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2009.01.014.

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