3. Synthesis of 1,2-*cis*-Configurated Glycosylphosphonates

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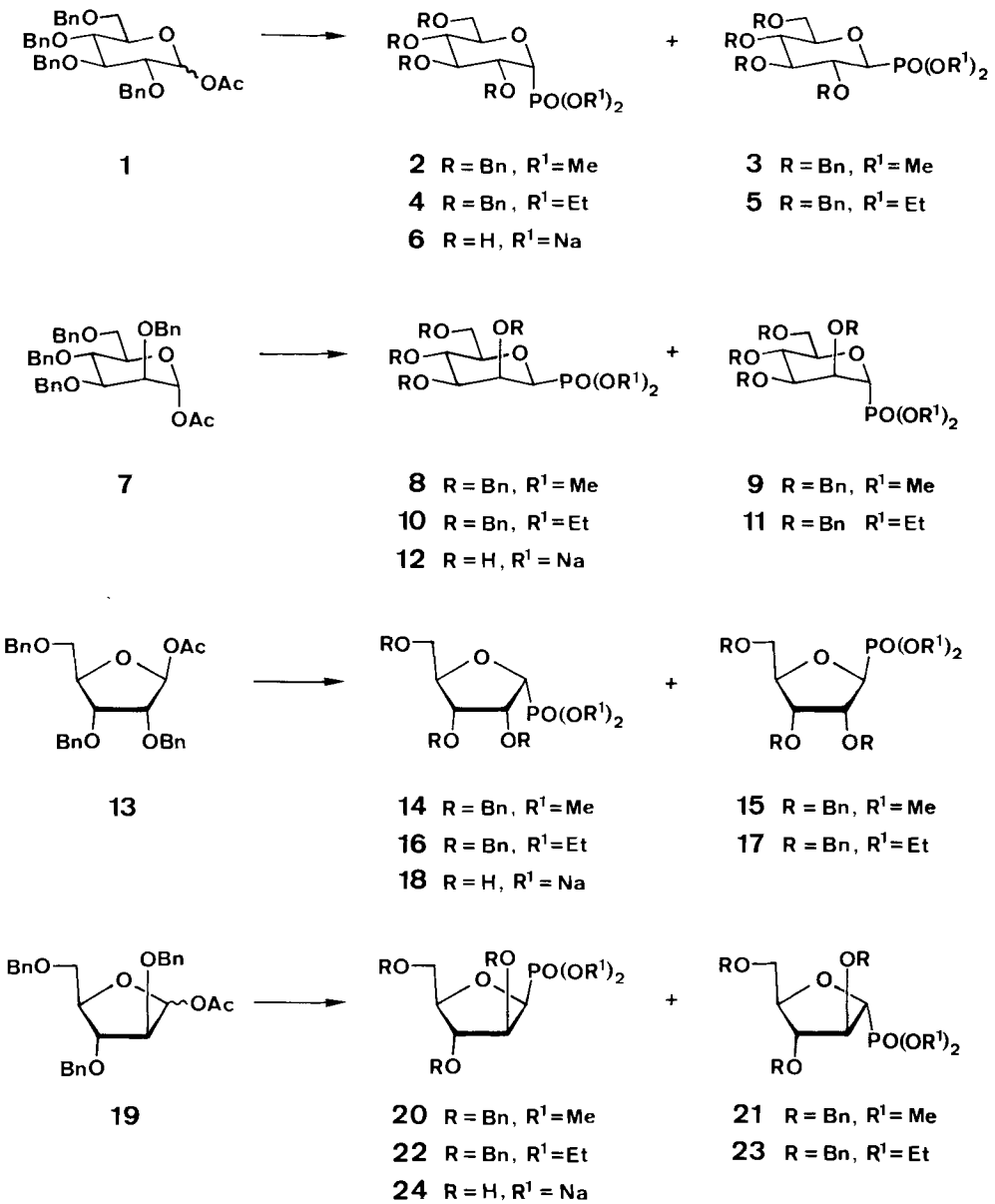
A synthesis of 1,2-*cis*-configurated, non-isosteric phosphonate analogues of aldose-1-phosphates is described. Treatment of 1-*O*-acyl-glycoses **1**, **7**, **13**, and **19** with trialkyl phosphite in the presence of trimethylsilyl trifluoromethanesulfonate gave the 1,2-*cis*-configurated glycosylphosphonates **2**, **4**, **8**, **10**, **14**, **16**, **20**, and **22** as the major anomers and the 1,2-*trans*-configurated glycosylphosphonates **3**, **5**, **9**, **11**, **15**, **17**, **21**, and **23** as the minor anomers. The 1,2-*cis*-configurated phosphonates **4**, **10**, **16**, and **22** were deprotected to give the (α-D-glucopyranosyl)phosphonate **6**, the (β-D-mannopyranosyl)phosphonate **12**, the (α-D-ribofuranosyl)phosphonate **18**, and the (β-D-arabinofuranosyl)phosphonate **24**, respectively, in high yields. The preferred formation of 1,2-*cis*-configurated phosphonates is explained by postulating an equilibrium between the anomeric phosphonium-salt intermediates (such as **25** and **26**) and a stabilization of the *cis*-configurated salts through formation of a pentacoordinated species (such as **28**).

Introduction. – There is no general method for the synthesis of non-isosteric but isopolar glycosylphosphonate analogues of aldose-1-phosphates, *i.e.* compounds carrying a phosphono group at the anomeric center such as **6** *(Scheme 1)*. *Paulsen* [1] has described some derivatives of these compounds, which could not be transformed into the desired analogues, and the scope of our multistep synthesis of the (β-D-mannofuranosyl)phosphonate seems to be limited [2], so that an evaluation of the biological properties of these phosphate analogues has not been possible so far.

We now report a short and efficient route to glycosylphosphonates. Our scheme is based on the known reactions of carbocations with trialkyl phosphites leading to dialkyl phosphonates [3] [4]. In a similar way, 1-*O*-acyl-glycoses should react *via* the corresponding oxonium ions to give glycosylphosphonates. This was checked by treating benzylated 1-*O*-acetyl-glycoses with $P(OMe)_3$ and $P(OEt)_3$ in the presence of a suitable catalyst. The choice of the glycoses was dictated both by the importance of their phosphates (glucose and ribose) and by the desire to probe the influence of the configuration at C(2) (mannose and arabinose) on the stereochemical outcome of the phosphonoylation. The benzyl group is known as a 'non-participating' and easily removable protective group in the synthesis of glycosides [5]. Preliminary experiments established the advantage of trimethylsilyl trifluoromethanesulfonate [6–8] as catalyst in combination with a C(1) acetoxy group in obtaining high yields of the desired phosphonates.

Results and Discussion. – Treatment of a mixture of the glucopyranoses **1** ($\alpha/\beta = 4:1$) [9] (*Scheme 1* and *Table 1*) with 1.5 equiv. of $P(OMe)_3$ and 1.2 equiv. of trimethylsilyl trifluoromethanesulfonate in CH_2Cl_2 at room temperature gave the 1,2-*cis*-configurated dimethyl (α-D-glucopyranosyl)phosphonate **2** (92%) and its anomer **3** (5%). Under similar conditions, **1** reacted with $P(OEt)_3$ to yield the diethyl phosphonates **4** (93%) and

Scheme 1



5 (5%). The anomers were separated by column chromatography, and the major diethyl phosphonate **4** was deprotected. Thus, treatment of **4** with bromotrimethylsilane followed by hydrogenolysis and passage through a column of *Dowex CCR-2* (Na^+ form) gave the disodium (α-D-glucopyranosyl)phosphonate (**6**, 95%).

Table 1. *Phosphonoylation of 1-O-Acetyl-glycoses with Trialkyl Phosphites* (1.5 equiv.) *and Trimethylsilyl Trifluoromethanesulfonate* (1.2 equiv.)

Starting material	Phosphite	Products and yields
1 (α/β = 4:1)	$P(OMe)_3$	**2** (92%), **3** (5%)
1 (α/β = 4:1)	$P(OEt)_3$	**4** (93%), **5** (5%)
7	$P(OMe)_3$	**8** (89%), **9** (6%)
7	$P(OEt)_3$	**10** (90%), **11** (5%)
13	$P(OMe)_3$	**14** (88%), **15** (6%)
13	$P(OEt)_3$	**16** (90%), **17** (5%)
19 (α/β = 58:42)	$P(OMe)_3$	**20** (86%), **21** (9%)
19 (α/β = 58:42)	$P(OEt)_3$	**22** (84%), **23** (9%)

Surprisingly, under analogous conditions, the α-D-mannopyranose **7**[1]) also yielded the 1,2-*cis*-configurated dimethyl and diethyl phosphonates **8** (89%) and **10** (90%), respectively, as the major and the 1,2-*trans*-configurated anomers **9** (6%) and **11** (5%) as the minor products. A very similar behaviour was observed in the case of the furanoses **13** [11] and **19** [12] giving mainly the 1,2-*cis*-configurated phosphonates **14**, **16**, **20**, and **22** respectively. In each case, the 1,2-*trans*-isomers **15**, **17**, **21**, and **23** were isolated as the minor products *(Table 1)*. The 1,2-*cis*-configurated diethyl phosphonates **10**, **16**, and **22** were deprotected as indicated above to give the (β-D-mannopyranosyl)phosphonate **12** (96%), the (α-D-ribofuranosyl)phosphonate **18** (98%) and the (β-D-arabinofuranosyl)phosphonate **24** (97%), respectively.

The assignment of the configuration at the anomeric center of the glycosylphosphonates was based on their spectroscopic properties.

1. *^{1}H-NMR Spectra.* 1.1. *Chemical Shifts.* The application of the rule, according to which in pyranoses the ^{1}H-NMR signal of the anomeric proton of the β-D-anomer occurs at a higher field than the one of the corresponding α-D-anomer [13] [14] leads to the assignment of the indicated configurations of the phosphonates (see *Table 2*). In anomeric furanose derivatives, the H–C(1) signal of the 1,2-*cis*-configurated anomer usually occurs at lower field [15]. This rule again leads to the indicated configuration fo the phosphonates *(Table 2)*.

In the $^4C_1$ conformation of the (α-D-glucopyranosyl)phosphonate **2** and the (α-D-mannopyranosyl)phosphonate **9**, the dimethoxyphosphoryl group, H–C(3), and H–C(5) are in a 1,3-diaxial orientation. A

Table 2. *Spectroscopic Data of the Glycosylphosphonates*

Compound	^{1}H-NMR					^{13}C-NMR	
	δ (H–C(1))	δ (H–C(3))	δ (H–C(5))[a]) or δ (H–C(4))[a])	J (1,2)	J (P,H–C(2))	δ (C(1))	J (P,C(1))
2	4.50	4.31	4.05	7.0	32.0	71.55	152.9
3	< 3.73	< 3.73	3.47	⩾ 9.0	9.0–10.0	74.83	171.5
8	3.83	3.62	3.45	0.8	2.7	75.57	171.8
9	4.37	4.13	4.15	2.5	2.5	71.97	167.1
14	4.48	4.11	4.25	4.2	2.0	77.24	173.1
15	4.37	3.97	4.26	3.8	9.0	77.51	167.2
20	4.45	4.05	4.22	4.2	2.5	77.37	171.9
21	4.33	4.15	4.27	4.8	...	78.21	166.0

[a]) For pyranoses, δ (H–C(5)) and for furanoses, δ (H–C(4)) is reported.

[1]) Obtained by acetylation (Ac_2O, pyridine) of 2,3,4,6-tetra-*O*-benzyl-D-mannopyranose. The α-D-configuration of **7** was deduced from its ^{13}C-NMR spectra (^1J(C(1),H) = 175.3 Hz) (*cf.* [10]).

deshielding effect of the dimethoxyphosphoryl group on these H-atoms is expected [16] [17]. Indeed, the chemical shifts of H–C(3) and H–C(5) of the anomeric glucose derivatives **2** and **3** differ by $\Delta\delta > 0.58$ and 0.58 ppm, respectively, the signals of the α-D-anomer(= major) **2** occurring at lower field. Similarly, the chemical shifts of H–C(3) and H–C(5) of the anomeric mannose derivatives **9** and **8** differ by $\Delta\delta = 0.51$ and 0.7 ppm, respectively, the signals of the α-D-anomer(= minor) **9** occurring at lower field.

1.2. *Coupling Constants.* Another indication relevant to the assignment of the configuration at C(1) was obtained by the examination of the values of the coupling constants ^3J(H–C(1), H–C(2)) (see *Table 2*). In the *gluco*-series, the coupling constant for the α-D-anomer **2** is relatively large (7 Hz). This is presumably due to a distortion of the chair conformation, the dimethoxyphosphoryl group tending towards a pseudo-equatorial orientation. Such a behaviour is not unexpected considering the small anomeric effect ($AE = 0.56$ kcal/mol) and the large A value ($A = 2$ kcal/mol) of the dimethoxyphosphoryl group [16]. In spite of this, the differentiation between the two *gluco*-anomers **2** and **3** remains unambiguous considering $^3J(1,2) \geq 9$ Hz for the β-D-anomer **3**. The interpretation of the corresponding coupling constants in mannopyranosides is more difficult, but usually the β-D-anomers display smaller $^3J(1,2)$ values than the α-D-derivatives [18]. The application of this rule to **8** and **9** ($^3J(1,2) = 0.8$ and 2.5 Hz, respectively) leads to the same configurational assignment as the interpretation of the chemical shifts. In the furanose series, the difference in the values of $^3J(1,2)$ are too small to be of diagnostic value.

The configuration at the anomeric centre was also deduced from an examination of the ^3J(P, *H*–C(2)) values. There are many reports relating the *'Karplus-like'* dependence of ^3J(P, H) of phosphonates to the dihedral angles [17] [19] [20]. The value of ^3J(P, H) has a maximum at a dihedral angle of 0° ($^3J = 15$–20 Hz) and of 180° ($^3J = 35$–40 Hz) and a minimum at 90° ($^3J = 0$ Hz). The values of ^3J(P, H) in the (α-D-glycopyranosyl)phosphonate **2** (32 Hz) and in the (β-D-glucopyranosyl)phosphonate **3** (9–10 Hz) agree well with the indicated configuration (dihedral angle H–C(2)–C(1)–P of *ca.* 150° for **2** and 60° for **3**). In both the (β- and α-D-mannopyranosyl)phosphonates **8** and **9**, respectively, the dimethoxyphosphoryl group and H–C(2) are in a synclinal relationship; the corresponding dihedral angle and, by consequence, the values of ^3J(P, H) are *ca.* the same ($J = 2.7$ Hz in **8** and $J = 2.5$ Hz in **9**). In the (α- and β-D-ribofuranosyl)phosphonates **14** and **15**, respectively, the dimethoxyphosphoryl group is presumably pseudo-equatorially oriented. *Dreiding* models of **14** and **15** (pseudo-equatorial position of the dimethoxyphosphoryl group) show a value for the dihedral angle H–C(2)–C(1)–P of 80° to 100° and 0° to 20°, respectively. This agrees well with ^3J(P, H) = 2.0 and 9.0 Hz for **14** and **15**, respectively. For the (β-D-arabinofuranosyl)phosphonate **20**, a *Dreiding* model (pseudo-equatorial position of the dimethoxyphosphoryl group) shows a value of *ca.* 90° for the dihedral angle in conformity with ^3J(P, H) = 2.5 Hz.

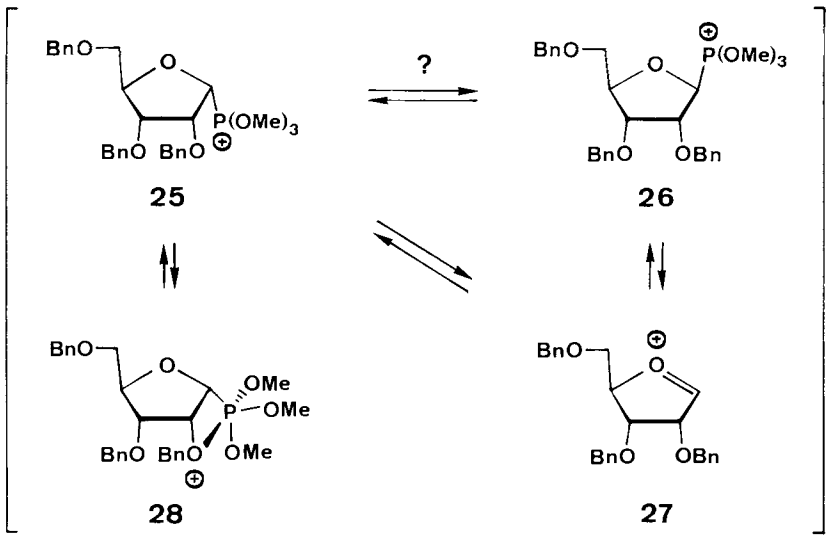
2. *^{13}C-NMR Spectra.* 2.1. *Chemical Shifts.* In pyranoses, the signal for C(1) of the α-D-anomer appears at a higher field than the one of the corresponding β-D-anomer [14] [21], hence, the α-D-configuration has to be assigned to **2**, **4**, **9**, and **11** (*Table 2* and *Exper. Part*). In cyclohexanes, the C-atoms bearing an axial dialkyloxyphosphoryl group are more strongly shielded than the C-atoms bearing an equatorial dialkyloxyphosphoryl group [22] [23]. A similar situation has been found for partially deoxygenated glycosylphosphonates [16]. A comparison of the relative chemical-shift values of C(1) of the α- and β-D-ribo- and arabinofuranosylphosphonates (*Table 2* and *Exper. Part*) with those of alkyl furanosides [21] agrees with the indicated configuration.

2.2. *Coupling Constants.* The assignment of the configuration at C(1) was also based on the values of ^1J(P, C). The values of ^1J(P, C) have been reported to depend on the axial or equatorial orientation of the P-substituent; for dialkyloxyphosphoryl groups, $^1J(P_{eq}, C) > {}^1J(P_{ax}, C)$ [16] [17] [24]. We found ^1J(P, C) = 166.3–171.8 Hz for the (β-D-glycopyranosyl)phosphonates (equatorial position of the dialkyloxyphosphoryl group) and ^1J(P, C) = 151.0–167.1 Hz for the (α-D-glycopyranosyl)phosphonates (axial position of the dialkyloxyphosphoryl group) (*Table 2* and *Exper. Part*). These data agree with the previously reported values for compounds possessing equatorial and axial phosphoryl groups, respectively.

The assignment of the configuration at C(1) of the glycosylphosphonates based on their spectroscopic properties agree with their chiroptical properties, assuming the validity of *Hudson*'s rules for glycosylphosphonates (*cf.* [16]). In all pairs of anomeric glycosylphosphonates described here, the α-D-anomer is more strongly dextrorotatory than the corresponding β-D-anomer (see *Exper. Part*).

The stereochemistry of this *Michaelis-Arbuzov*-type reaction [25] does not depend on the anomeric configuration of the starting 1-*O*-acetyl-glycoses. The almost exclusive formation of the 1,2-*cis*-configurated phosphonates in both the pyranose and the furanose series is striking. It is explained on the basis of the postulates, that the anomeric

Scheme 2



phosphonium-ion intermediates such as **25** and **26** are in (direct or indirect) equilibrium with each other and that the C(2)-alkoxy group stabilizes the 1,2-*cis*-isomers such as **25** by coordination with the phosphonium centre *(Scheme 2)*. The equilibrium of the phosphonium salts is not unexpected in view of the stability of the presumed oxonium-ion intermediates such as **27** and of the weakness of the nucleophiles (trimethylsilyl acetate and trifluoromethanesulfonate) generated during the reaction. Indeed, with $BF_3 \cdot OEt_2$ as a catalyst, a higher proportion of the 1,2-*trans*-isomer was obtained from **19** (→51% of **22** and 19% of **23**). Under these conditions, the more highly nucleophilic [$BF_3 \cdot AcO^-$] is formed, and the anomeric phosphonium salts are dealkylated before they reach equilibrium. Pentacoordinated phosphorous compounds similar to **28** are known [26].

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Experimental Part

General. See [27]. $P(OMe)_3$ *(Fluka, pract.)*, $P(OEt)_3$ *(Fluka, purum)* and CH_2Cl_2 were destilled before use (CH_2Cl_2 from P_2O_5). Trimethylsilyl trifluoromethanesulfonate *(purum)* and bromotrimethylsilane *(purum)* were obtained from *Fluka*. Chromatography: A = AcOEt/CH_2Cl_2/hexane 1:1:1. ^1H-, ^{13}C-, and ^{31}P-NMR spectra were recorded on a *Varian-XL-200* (^1H(200 MHz), ^{13}C(50 MHz), ^{31}P(80 MHz)) or *Bruker-AM-400* spectrometer (^1H(400 MHz), ^{13}C(100 MHz), ^{31}P(160 MHz)); in $CDCl_3$ soln. unless otherwise specified; δ in ppm relative to TMS (for ^1H-NMR and ^{13}C-NMR) as internal standard or relative to H_3PO_4 (for ^{31}P-NMR) as external reference (uncorrected). MS: *Varian-112S* (Cl: isobutan) and *Varian-711* spectrometer (FAB, bombardement with 8-keV Xe-atoms, glycerol matrix).

1. Protected Dialkyl Glycosylphosphonates. – 1.1. *General Procedure.* Under Ar, trimethylsilyl trifluoromethanesulfonate (1.2 mmol) was added dropwise during 10 min to a soln. of the 1-*O*-acetyl-glycose (1 mmol) and trialkyl phosphite (1.5 mmol) in 2 ml of CH_2Cl_2 at 0°. The soln. was left to return to r.t. and stirred until the starting material had disappeared (1–2 h). The mixture was quenched with 0.3 ml of H_2O, diluted with 500 ml of AcOEt and processed in the usual way (sat. aq. $NaHCO_3$, sat. aq. NaCl soln.) to give a residue which was purified by chromatography on SiO_2.

1.2. *Dimethyl (2,3,4,6-Tetra-*O*-benzyl-α- and β-*D*-glucopyranosyl)phosphonates* (**2** and **3**, resp.). Treatment of 1 g (1.71 mmol) of a mixture of 1-*O*-acetyl-2,3,4,6-tetra-*O*-benzyl-D-glucopyranoses (**1**, α/β = 4:1) [9] with 319 mg (303 µl, 2.57 mmol) of $P(OMe)_3$ and 457 mg (373 µl, 2.05 mmol) of trimethylsilyl trifluoromethanesulfonate in 3.4 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 999 mg (92%) of **2** and 54 mg (5%) of **3**.

Data of **2**. R_f (A) 0.33, $[\alpha]_D^{25}$ = +48.4° (*c* = 1.47). IR: 3085*w*, 3060*w*, 2990*m*, 2950*m*, 2910*m*, 2860*m*, 1495*w*, 1450*m*, 1360*m*, 1250*m*, 1090*s*, 1060*s*, 1035*s*, 1028*s*, 910*w*, 830*m*. ^{1}H-NMR (400 MHz): 7.38–7.14 (*m*, 20 arom. H); 4.96–4.40 (*m*, 8 H); 4.50 (*dd*, *J*(P,H) = 11.5, *J* = 7.0, H–C(1)); 4.31 (*t*, *J* = 8.8, H–C(3)); 4.05 (*ddt*, *J*(P,H) = 1.0, *J* = 9.5, 2.7, 2.7, H–C(5)); 3.92 (*ddd*, *J*(P,H) = 32.0, *J* = 8.8, 7.0, H–C(2)); 3.78 (*d*, *J*(P,H) = 10.8, $POCH_3$); 3.71 (*d*, *J*(P,H) = 10.8, $POCH_3$); 3.67 (*d*, *J* = 2.7, 2 H–C(6)); 3.58 (*dd*, *J* = 9.5, 8.8, H–C(4)). ^{13}C-NMR (50 MHz): 138.54 (*s*); 138.24 (*s*); 137.85 (*s*); 137.54 (*s*); 128.16 (*d*); 128.13 (*d*); 128.08 (*d*); 127.99 (*d*); 127.72 (*d*); 127.65 (*d*); 127.59 (*d*); 127.47 (*d*); 127.34 (*d*); 81.62 (*d*); 78.19 (*d*); 77.35 (*d*); 75.71 (*d*); 75.00 (*t*); 74.31 (*t*); 73.41 (*t*); 73.21 (*t*); 71.55 (*dd*, *J*(P,C) = 152.9, *J*(C,H) = 145, C(1)); 68.91 (*t*); 53.09 (*dq*, *J*(P,C) = 6.9); 52.35 (*dq*, *J*(P,C) = 6.6). ^{31}P-NMR (80 MHz): +25.02. Anal. calc. for $C_{36}H_{41}O_8P$ (632.71): C 68.34, H 6.53, P 4.89; found: C 68.12, H 6.56, P 4.69.

Data of **3**. R_f (A) 0.25, $[\alpha]_D^{25}$ = +35.1° (*c* = 1.12). IR: 3085*w*, 3060*w*, 2990*m*, 2970*m*, 2910*w*, 2860*m*, 1495*w*, 1450*m*, 1395*w*, 1360*m*, 1328*w*, 1248*m*, 1130 (sh), 1095*s*, 1060*s*, 1035*s*, 910*w*, 830*m*. ^{1}H-NMR (400 MHz): 7.35–7.16 (*m*, 20 arom. H); 4.91–4.79 (*m*, 5 H); 4.59–4.53 (*m*, 3 H); 3.89 (*dt*, *J* = 9.0, 10.0, H–C(2)); 3.82 (*d*, *J*(P,H) = 11.6, $POCH_3$); 3.70 (*d*, *J*(P,H) = 11.6, $POCH_3$); 3.73–3.59 (*m*, 5 H); 3.47 (*ddd*, *J* = 9.5, 4.8, 2.0, H–C(5)). ^{13}C-NMR (50 MHz): 138.39 (*s*); 138.09 (2*s*); 137.92 (*s*); 128.38 (*d*); 128.31 (*d*); 128.23 (*d*); 127.95 (*d*); 127.85 (*d*); 127.77 (*d*); 127.64 (*d*); 127.57 (*d*); 127.38 (*d*); 127.33 (*d*); 127.27 (*d*); 87.13 (*dd*, *J*(P,C) = 18.2); 80.99 (*dd*, *J*(P,C) = 17.2); 78.85 (*d*); 77.81 (*d*); 75.64 (*t*); 75.09 (2*t*); 74.83 (*dd*, *J*(P,C) = 171.5, C(1)); 73.38 (*t*); 69.11 (*t*); 54.26 (*dq*, *J*(P,C) = 6.1); 52.56 (*dq*, *J*(P,C) = 7.0). ^{31}P-NMR (80 MHz): +22.75. Anal. calc. for $C_{36}H_{41}O_8P$ (632.71): C 68.34, H 6.53, P 4.89; found: C 68.13, H 6.31, P 4.80.

1.3. *Diethyl (2,3,4,6-Tetra-*O*-benzyl-α- and β-*D*-glucopyranosyl)phosphonates* (**4** and **5**, resp.). Treatment of 1 g (1.71 mmol) of **1** (α/β = 4:1) with 426 mg (446 µl, 2.57 mmol) of $P(OEt)_3$ and 457 mg (373 µl, 2.05 mmol) of trimethylsilyl trifluoromethanesulfonate in 3.4 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 1.05 g (93%) of **4** and 56 mg (5%) of **5**.

Data of **4**. R_f (A) 0.5, $[\alpha]_D^{25}$ = +44.6° (*c* = 1.24). IR: 3090*m*, 3060*m*, 2995*s*, 2910*m*, 2865*m*, 1494*w*, 1452*m*, 1390*m*, 1363*m*, 1308*m*, 1246*s*, 1156*m*, 1050*s* (br.), 970*s*, 910*w*, 865*w*. ^{1}H-NMR (200 MHz): 7.40–7.10 (*m*, 20 arom. H); 5.00–3.95 (*m*, 15 H); 3.85 (*dd*, *J* = 9.2, 7.0, 1 H); 3.67 (*d*, *J* = 2.9, 2 H); 3.59 (*dd*, *J* = 9.8, 8.5, 1 H); 1.29 (*t*, *J* = 6.9, CH_3); 1.25 (*t*, *J* = 6.9, CH_3). ^{13}C-NMR (100 MHz): 138.63 (*s*); 138.38 (*s*); 137.89 (*s*); 137.76 (*s*); 128.21 (*d*); 127.95 (*d*); 127.84 (*d*); 127.73 (*d*); 127.65 (*d*); 127.51 (*d*); 127.42 (*d*); 81.76 (*d*); 78.37 (*d*); 77.20 (*d*); 75.60 (*d*); 75.18 (*t*); 74.36 (*t*); 73.31 (2*t*); 71.65 (*dd*, *J*(P,C) = 152.0, C(1)); 68.90 (*t*); 62.60 (*dt*, *J*(P,C) = 6.0); 61.88 (*dt*, *J*(P,C) = 6.0); 16.35 (*q*); 16.29 (*q*). ^{31}P-NMR (160 MHz): +22.40. Anal. calc. for $C_{38}H_{45}O_8P$ (660.77): C 69.07, H 6.86, P 4.68; found: C 68.80, H 7.05, P 4.50.

Data of **5**. R_f (A) 0.38, $[\alpha]_D^{25}$ = +35.1° (*c* = 1.02). IR: 3090*w*, 3060*w*, 2995*m*, 2910*m*, 2870*m*, 1497*w*, 1452*m*, 1390*w*, 1360*m*, 1330*w*, 1245*m*, 1095*s*, 1055*s*, 1028*s*, 975*m*, 909*m*. ^{1}H-NMR (400 MHz): 7.37–7.14 (*m*, 20 arom. H); 5.01–4.86 (*m*, 5 H); 4.66–4.55 (*m*, 3 H); 4.30–4.10 (*m*, 4 H); 3.95 (*q*, *J* = 9.5, 1 H); 3.80–3.65 (*m*, 5 H); 3.51 (*ddd*, *J* = 9.5, 4.5, 1.5, 1 H); 1.27 (*t*, *J* = 7.1, CH_3); 1.21 (*t*, *J* = 7.1, CH_3). ^{13}C-NMR (100 MHz): 138.39 (*s*); 138.19 (*s*); 138.10 (*s*); 137.94 (*s*); 128.36 (*d*); 128.27 (*d*); 128.15 (*d*); 127.93 (*d*); 127.86 (*d*); 127.75 (*d*); 127.62 (*d*); 127.58 (*d*); 127.48 (*d*); 87.17 (*dd*, *J*(P,C) = 18.1); 80.87 (*dd*, *J*(P,C) = 17.1); 78.96 (*d*); 77.81 (*d*); 75.64 (*t*); 75.06 (*t*); 74.99 (*t*); 74.81 (*dd*, *J*(P,C) = 166.3, C(1)); 73.33 (*t*); 69.05 (*t*); 63.48 (*dt*, *J*(P,C) = 6.2); 62.18 (*dt*, *J*(P,C) = 6.2); 16.36 (*dq*, *J*(P,C) = 5.5); 16.18 (*dq*, *J*(P,C) = 5.5). ^{31}P-NMR (160 MHz): +20.52. Anal. calc. for $C_{38}H_{45}O_8P$ (660.77): C 69.07, H 6.86, P 4.68; found: C 68.97, H 6.84, P 4.61.

1.4. *1-*O*-Acetyl-2,3,4,6-tetra-*O*-benzyl-α-*D*-mannopyranose* (**7**). A mixture containing 10 g (18.4 mmol) of 2,3,4,6-tetra-*O*-benzyl-D-mannose, 50 ml of Ac_2O and 50 ml of pyridine was stirred at 10° for 3 h and then evaporated *i.v.* Traces of pyridine were removed by co-evaporation with toluene. Chromatography of the residue on silica gel (800 g, AcOEt/hexane 1:3) gave 10.5 g (98%) of **7** as a colourless solid. Recrystallisation from AcOEt/hexane, m.p. 58–59°, R_f (A) 0.72, $[\alpha]_D^{25}$ = +28.8° (*c* = 0.96). IR: 3080*w*, 3060*w*, 3030*w*, 3000*m*, 2900*m*, 2870*m*, 1747*s*, 1494*m*, 1452*m*, 1368*m*, 1150*s*, 1090*s*, 1045*s*, 1025*s*, 1013*s*, 950*s*. ^{1}H-NMR (400 MHz): 7.41–7.16 (*m*, 20 arom. H); 6.21 (*d*, *J* = 2.0, H–C(1)); 4.90–4.40 (*m*, 8 H); 4.07 (*t*, *J* = 4.5, H–C(4)); 3.87–3.78 (*m*, H–C(5)); 3.84 (*dd*, *J* = 9.5, 3.2, H–C(3)); 3.74 (*dd*, *J* = 11.0, 4.6, H–C(6)); 3.73 (*dd*, *J* = 3.2, 2.0, H–C(2)); 3.70 (*dd*, *J* = 11.0, 1.8, H–C(6)); 2.01 (*s*, CH_3). ^{13}C-NMR (50 MHz): 168.79 (*s*); 138.29 (2*s*); 138.14 (*s*); 137.85 (*s*); 128.28 (*d*); 128.21 (*d*); 127.92 (*d*); 127.86 (*d*); 127.64 (*d*); 127.40 (*d*); 127.27 (*d*); 127.21 (*d*); 91.93 (*d*, *J*(C,H) = 175.3, C(1)); 79.12 (*d*); 75.14 (*t*); 74.48 (*d*); 74.30 (*d*); 73.61 (*d*); 73.43 (*t*); 72.43 (*t*); 72.08 (*t*); 68.98 (*t*); 20.89 (*q*). MS (Cl): 583 (M^+ + 1), 582 (M^+), 523 (M^+ – OAc). Anal. calc. for $C_{36}H_{38}O_7$ (582.72): C 74.20, H 6.57; found: C 74.08, H 6.66.

1.5. *Dimethyl (2,3,4,6-Tetra-*O*-benzyl-β- and α-*D*-mannopyranosyl)phosphonates* (**8** and **9**, resp.). Treatment of 1 g (1.71 mmol) of **7** with 319 mg (303 µl, 2.57 mmol) of $P(OMe)_3$ and 457 mg (357 µl, 2.05 mmol) of trimethylsilyl trifluoromethanesulfonate in 3.4 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 966 mg (89%) of **8** and 65 mg (6%) of **9**.

Data of **8**. R_f (A) 0.25, $[\alpha]_D^{25} = -27.8°$ (c = 1.05). IR: 3090*w*, 3070*w*, 2990*m*, 2960*m*, 2870*m*, 1495*w*, 1455*m*, 1360*m*, 1265*m*, 1245*m*, 1130*s*, 1105*s*, 1060*s*, 1040*s*, 1030*s*, 985*w*, 910*w*, 865*w*, 830*w*. ^{1}H-NMR (400 MHz): 7.47–7.19 (*m*, 20 arom. H); 5.09–4.50 (*m*, 8 H); 4.35 (*dt*, J(P,H) = 2.7, J = 2.7, 0.8, H–C(2)); 4.04 (*t*, J = 9.6, H–C(4)); 3.83 (*dd*, J(P,H) = 14.8, J = 0.8, H–C(1)); 3.76 (*d*, J = 3.3, 2 H–C(6)); 3.76 (*d*, J = 10.6, $POCH_3$); 3.65 (*d*, J = 10.6, $POCH_3$); 3.62 (*dd*, J = 9.6, 2.7, H–C(3)); 3.45 (*dt*, J = 9.6, 3.3, 3.3, H–C(5)). ^{13}C-NMR (50 MHz): 138.61 (*s*); 138.49 (*s*); 138.20 (*s*); 137.92 (*s*); 128.43 (*d*); 128.31 (*d*); 128.17 (*d*); 128.11 (*d*); 127.94 (*d*); 127.76 (*d*); 127.56 (*d*); 127.51 (*d*); 127.43 (*d*); 127.23 (*d*); 84.18 (*dd*, J(P,C) = 17.8); 81.87 (*dd*, J(P,C) = 16.4); 75.57 (*dd*, J(P,C) = 171.8, J(C,H) = 136.0, C(1)); 75.16 (*t*); 74.57 (*t*, *d*); 74.04 (*d*); 73.22 (*t*); 72.20 (*t*); 69.25 (*t*); 53.79 (*dq*, J(P,C) = 6.5); 52.68 (*dq*, J(P,C) = 6.5). ^{31}P-NMR (80 MHz): +20.99. Anal. calc. for $C_{36}H_{41}O_8P$ (632.71): C 68.34, H 6.53, P 4.89; found: C 68.12, H 6.66, P 4.78.

Data of **9**. R_f (A) 0.32, $[\alpha]_D^{25} = +12.9°$ (c = 1.0). IR: 3090*w*, 3060*w*, 2990*m*, 2950*w*, 2860*w*, 1490*w*, 1450*m*, 1365*w*, 1245*m*, 1090*s*, 1050*s*, 1035*s*, 1025*s*, 830*m*. ^{1}H-NMR (400 MHz): 7.39–7.16 (*m*, 20 arom. H); 4.83–4.48 (*m*, 8 H); 4.37 (*dd*, J(P,H) = 15.1, J = 2.5, H–C(1)); 4.15 (*m*, H–C(5)); 4.13 (*dd*, J = 8.7, 2.5, H–C(3)); 4.02 (*q*, J(P,H) = 2.5, J = 2.5, H–C(2)); 3.91 (*t*, J = 8.7, H–C(4)); 3.76 (*d*, J = 10.6, $POCH_3$); 3.71 (*d*, J = 4.0, 2 H–C(6)); 3.62 (*d*, J = 10.6, $POCH_3$). ^{13}C-NMR (50 MHz): 138.45 (*s*); 138.34 (*s*); 138.28 (*s*); 137.80 (*s*); 128.42 (*d*); 128.31 (*d*); 128.24 (*d*); 128.13 (*d*); 127.94 (*d*); 127.76 (*d*); 127.71 (*d*); 127.64 (*d*); 127.57 (*d*); 127.49 (*d*); 127.44 (*d*); 79.01 (*d*); 76.79 (*dd*, J(P,C) = 1.7); 74.54 (*d*); 74.42 (*t*); 73.32 (*d*); 73.24 (*t*); 72.46 (*t*); 72.04 (*t*); 71.97 (*dd*, J(P,C) = 167.1, C(1)); 69.45 (*t*); 53.73 (*dq*, J(P,C) = 7.0); 52.49 (*dq*, J(P,C) = 7.0). ^{31}P-NMR (80 MHz): +23.14. Anal. calc. for $C_{36}H_{41}O_8P$ (632.71): C 68.34, H 6.53, P 4.89; found: C 68.05, H 6.80, P 4.70.

1.6. *Diethyl (2,3,4,6-Tetra-*O*-benzyl-β- and α-*D*-mannopyranosyl)phosphonates* (**10** and **11**, resp.). Treatment of 1 g (1.71 mmol) of **7** with 426 mg (446 µl, 2.57 mmol) of $P(OEt)_3$ and 457 mg (373 µl, 2.05 mmol) of trimethylsilyl trifluoromethanesulfonate in 3.4 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 1.02 g (90%) of **10** and 56 mg (5%) of **11**.

Data of **10**. R_f (A) 0.20, $[\alpha]_D^{25} = -31.8°$ (c = 1.26). IR: 3065*w*, 3030*w*, 2990*m*, 2910*m*, 2865*m*, 1494*w*, 1452*m*, 1390*m*, 1360*m*, 1290*w*, 1234*m*, 1160*m*, 1095*s*, 1050*s*, 1028*s*, 970*s*, 910*m*. ^{1}H-NMR (200 MHz): 7.41–7.22 (*m*, 20 arom. H); 4.93–4.49 (*m*, 8 H); 4.36 (*m*, 1 H); 4.19–4.00 (*m*, 5 H); 3.79 (*dd*, J = 14.7, 1.1, 1 H); 3.78 (*d*, J = 3.3, 2 H); 3.63 (*dd*, J = 9.8, 2.7, 1 H); 3.45 (*dt*, J = 9.8, 3.3, 1 H); 1.30 (*t*, J = 7.1, CH_3); 1.11 (*t*, J = 7.1, CH_3). ^{13}C-NMR (100 MHz): 138.91 (*s*); 138.70 (*s*); 138.47 (*s*); 138.17 (*s*); 128.42 (*d*); 128.30 (*d*); 128.22 (*d*); 128.06 (*d*); 128.02 (*d*); 127.67 (*d*); 127.59 (*d*); 127.34 (*d*); 127.27 (*d*); 84.49 (*dd*, J(P,C) = 17.2); 81.02 (*dd*, J(P,C) = 16.3); 76.04 (*dd*, J(P,C) = 171.7, C(1)); 75.28 (*t*); 74.78 (*d*); 74.69 (*t*); 74.41 (*d*); 73.36 (*t*); 72.33 (*t*); 69.47 (*t*); 63.35 (*dt*, J(P,C) = 6.4); 62.37 (*dt*, J(P,C) = 6.4); 16.39 (*q*); 16.21 (*q*). ^{31}P-NMR (80 MHz): +18.39. Anal. calc. for $C_{38}H_{45}O_8P$ (660.77): C 69.07, H 6.86, P 4.68; found: C 69.05, H 6.77, P 4.50.

Data of **11**. R_f (A) 0.26, $[\alpha]_D^{25} = +14.5°$ (c = 1.66). IR: 3090*w*, 3063*w*, 2995*m*, 2930*m*, 2910*m*, 2870*m*, 1494*m*, 1452*m*, 1391*m*, 1366*m*, 1336*w*, 1280*m*, 1241*m*, 1159*m*, 1095*s*, 1048*s*, 1028*s*, 970*s*, 910*m*. ^{1}H-NMR (200 MHz): 7.40–7.17 (*m*, 20 arom. H); 4.90–4.45 (*m*, 8 H); 4.33 (*dd*, J = 16.0, 2.0, 1 H); 4.21–3.88 (*m*, 8 H); 3.71 (*d*, J = 3.8, 2 H); 1.23 (*t*, J = 7.1, CH_3); 1.19 (*t*, J = 7.1, CH_3). ^{13}C-NMR (100 MHz): 138.58 (*s*); 138.40 (*s*); 138.30 (*s*); 137.81 (*s*); 128.25 (*d*); 128.16 (*d*); 127.85 (*d*); 127.64 (*d*); 127.48 (*d*); 127.36 (*d*); 79.34 (*d*); 76.69 (*d*); 74.61 (*d*); 74.42 (*t*); 73.32 (*d*); 73.20 (*t*); 72.35 (*t*); 72.16 (*dd*, J(P,C) = 151.0, C(1)); 71.80 (*t*); 69.61 (*t*); 63.20 (*dt*, J(P,C) = 6.7); 61.90 (*dt*, J(P,C) = 6.7); 16.36 (*dq*, J(P,C) = 6.3); 16.28 (*dq*, J(P,C) = 6.3). ^{31}P-NMR (160 MHz): +20.36. Anal. calc. for $C_{38}H_{45}O_8P$ (660.77): C 69.07, H 6.86, P 4.68; found: 68.78, H 6.94, P 4.50.

1.7. *Dimethyl (2,3,5-Tri-*O*-benzyl-α- and β-*D*-ribofuranosyl)phosphonates* (**14** and **15**, resp.). Treatment of 1 g (2.16 mmol) of *1-*O*-acetyl-2,3,5-tri-*O*-benzyl-β-*D*-ribofuranose* (**13**) [11] with 402 mg (382 µl, 3.24 mmol) of $P(OMe)_3$ and 576 mg (470 µl, 2.59 mmol) of trimethylsilyl trifluoromethanesulfonate in 4.3 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 975 mg (88%) of **14** and 66 mg (6%) of **15**.

Data of **14**. R_f (A) 0.19, $[\alpha]_D^{25} = +74.4°$ (c = 1.12). IR: 3060*w*, 3000*m*, 2960*m*, 2860*m*, 1495*w*, 1453*m*, 1363*m*, 1246*s*, 1124*s*, 1043*s*, 1029*s*, 913*w*, 884*w*. ^{1}H-NMR (400 MHz): 7.48–7.21 (*m*, 15 arom. H); 4.86, 4.81 (*AB*, J = 11.0, PhCH_2); 4.58, 4,46 (*AB*, J = 11.7, PhCH_2); 4.57, 4.47 (*AB*, J = 12.1, PhCH_2); 4.48 (*t*, J = 4.2, H–C(1)); 4.40 (*dt*, J(P,H) = 2.0, J = 4.2, 4.2, H–C(2)); 4.25 (*ddd*, J = 8.8, 3.0, 2.0, H–C(4)); 4.11 (*dd*, J = 8.8, 4.2, H–C(3)); 3.78 (*dd*, J = 10.5, 2.0, H–C(5)); 3.76 (*d*, J(P,H) = 10.8, $POCH_3$); 3.62 (*d*, J(P,H) = 10.8, $POCH_3$); 3.60 (*dd*, J = 10.5, 3.0, H–C(5)). ^{13}C-NMR (100 MHz): 138.08 (*s*); 137.91 (*s*); 137.53 (*s*); 128.41 (*d*); 128.36 (*d*); 128.26 (*d*); 128.12 (*d*); 127.85 (*d*); 127.72 (*d*); 127.60 (*d*); 127.54 (*d*); 79.87 (*dd*, J(P,C) = 4.0); 79.34 (*dd*, J(P,C) = 7.9); 77.47 (*dd*, J(P,C) = 4.2); 77.24 (*dd*, J(P,C) = 173.1, C(1)); 74.25 (*t*); 73.39 (*t*); 72.92 (*t*); 68.68 (*t*); 53.91 (*dq*, J(P,C) = 5.8);

52.05 (*dq*, *J*(P,C) = 6.8). ^{31}P-NMR (160 MHz): +21.78. Anal. calc. for $C_{28}H_{33}O_7P$ (512.56): C 65.61, H 6.49, P 6.04; found: C 65.47, H 6.46, P 5.91.

Data of **15**. R_f (A) 0.25, $[\alpha]_D^{25}$ = +48.4° (*c* = 1.0). IR: 3060*w*, 3000*m*, 2960*m*, 2920*w*, 2860*w*, 1495*w*, 1453*m*, 1360*w*, 1250*s*, 1125*s*, 1085*s*, 1050*s* (br.), 1030 (sh), 830*m*, 692*m*. ^{1}H-NMR (400 MHz): 7.36–7.25 (*m*, 15 arom. H); 4.69–4.45 (*m*, 6 H); 4.37 (*dd*, *J*(P,H) = 2.0, *J* = 3.8, H–C(1)); 4.27 (*ddd*, *J*(P,H) = 9.0, *J* = 5.1, 3.8, H–C(2)); 4.26 (*ddd*, *J* = 7.0, 5.2, 3.4, H–C(4)); 3.97 (*dd*, *J* = 7.0, 5.1, H–C(3)); 3.73 (*d*, *J*(P,H) = 10.4, $POCH_3$); 3.72 (*d*, *J*(P,H) = 10.4, $POCH_3$); 3.66 (*dd*, *J* = 10.9, 3.4, H–C(5)); 3.57 (*dd*, *J* = 10.9, 5.2, H–C(5)). ^{13}C-NMR (100 MHz): 138.14 (*s*); 137.60 (*s*); 137.39 (*s*); 128.34 (*d*); 128.26 (*d*); 128.16 (*d*); 127.94 (*d*); 127.86 (*d*); 127.79 (*d*); 127.61 (*d*); 127.52 (*d*); 81.17 (*dd*, *J*(P,C) = 6.6); 78.20 (*dd*, *J*(P,C) = 4.8); 77.51 (*dd*, *J*(P,C) = 167.2, C(1)); 77.22 (*dd*, *J*(P,C) = 4.1); 73.31 (*t*); 72.24 (*t*); 71.98 (*t*); 69.77 (*t*); 53.76 (*dq*, *J*(P,C) = 6.6); 53.03 (*dq*, *J*(P,C) = 6.6). ^{31}P-NMR (160 MHz): +22.90. Anal. calc. for $C_{28}H_{33}O_7P$ (512.56): C 65.61, H 6.49, P 6.04; found: C 65.76, H 6.69, P 5.88.

1.8. *Diethyl (2,3,5-Tri-*O*-benzyl-*α*- and β-*D*-ribofuranosyl)phosphonates* (**16** and **17**, resp.). Treatment of 1 g (2.16 mmol) of **13** with 538 mg (563 µl, 3.24 mmol) of $P(OEt)_3$ and 576 mg (470 µl, 2.59 mmol) of trimethylsilyl trifluoromethanesulfonate in 4.3 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 1.05 g (90%) of **16** and 58 mg (5%) of **17**.

Data of **16**. R_f (A) 0.3, $[\alpha]_D^{25}$ = +76.8° (*c* = 1.34). IR: 2990*m*, 2910*m*, 2870*m*, 1494*w*, 1452*m*, 1390*w*, 1360*w*, 1290*w*, 1243*m*, 1125*s*, 1090*s*, 1047*s*, 1029*s*, 972*m*. ^{1}H-NMR (200 MHz): 7.48–7.20 (*m*, 15 arom. H); 4.82–4.35 (*m*, 8 H); 4.27–3.80 (*m*, 6 H); 3.78 (*dd*, *J* = 11.5, 2.5, H–C(5)); 3.58 (*dd*, *J* = 11.5, 3.5, H–C(5)); 1.32 (*t*, *J* = 7.0, CH_3); 1.10 (*t*, *J* = 7.0, CH_3). ^{13}C-NMR (100 MHz): 138.01 (*s*); 137.88 (*s*); 137.45 (*s*); 128.35 (*d*); 128.23 (*d*); 128.14 (*d*); 127.94 (*d*); 127.72 (*d*); 127.61 (*d*); 127.47 (*d*); 127.44 (*d*); 79.68 (*dd*, *J*(P,C) = 4.5); 79.30 (*dd*, *J*(P,C) = 8.9); 77.30 (*dd*, *J*(P,C) = 4.3); 77.49 (*dd*, *J*(P,C) = 173.4, C(1)); 74.06 (*t*); 73.24 (*t*); 72.76 (*t*); 68.61 (*t*); 63.19 (*dt*, *J*(P,C) = 6.2); 61.59 (*dt*, *J*(P,C) = 6.2); 16.24 (*dq*, *J*(P,C) = 5.8); 16.10 (*dq*, *J*(P,C) = 5.8). ^{31}P-NMR (160 MHz): +19.26. Anal. calc. for $C_{30}H_{37}O_7P$ (540.60): C 66.65, H 6.90, P 5.72; found: C 66.38, H 7.18, P 5.50.

Data of **17**. R_f (A) 0.23, $[\alpha]_D^{25}$ = +36.4° (*c* = 1.03). IR: 3060*w*, 2995*m*, 2930*m*, 2913*m*, 2870*m*, 1497*w*, 1453*w*, 1392*w*, 1368*w*, 1290*w*, 1245*m*, 1123*s* (br.), 1029*s* (br.), 980*m*, 964*m*, 915*w*, 884*w*. ^{1}H-NMR (200 MHz): 7.40–7.20 (*m*, 15 arom. H); 4.70–4.40 (*m*, 6 H); 4.35 (*dd*, *J* = 3.4, 2.3, 1 H); 4.30–4.00 (*m*, 6 H); 3.95 (*dd*, *J* = 7.7, 5.0, 1 H); 3.67 (*dd*, *J* = 11.0, 3.5, H–C(5)); 3.60 (*dd*, *J* = 11.0, 5.3, H–C(5)); 1.26 (*t*, *J* = 6.9, CH_3); 1.23 (*t*, *J* = 6.9, CH_3). ^{13}C-NMR (100 MHz): 138.05 (*s*); 137.49 (*s*); 137.33 (*s*); 128.19 (*d*); 128.11 (*d*); 128.04 (*d*); 127.82 (*d*); 127.69 (*d*); 127.64 (*d*); 127.51 (*d*); 127.37 (*d*); 80.75 (*dd*, *J*(P,C) = 6.5); 78.09 (*dd*, *J*(P,C) = 4.6); 77.75 (*dd*, *J*(P,C) = 164.7, C(1)); 76.93 (*d*); 73.15 (*t*); 72.06 (*t*); 71.68 (*t*); 69.73 (*t*); 62.99 (*dt*, *J*(P,C) = 6.7); 62.39 (*dt*, *J*(P,C) = 6.7); 16.25 (*q*); 16.20 (*q*). ^{31}P-NMR (160 MHz): +20.44. Anal. calc. for $C_{30}H_{37}O_7P$ (540.60): C 66.65, H 6.90, P 5.72; found: C 66.60, H 6.88, P 5.65.

1.9. *Dimethyl (2,3,5-Tri-*O*-benzyl-β- and* α*-*D*-arabinofuranosyl)phosphonates* (**20** and **21**, resp.). Treatment of 1 g (2.16 mmol) of a mixture of *1-*O*-acetyl-2,3,5-tri-*O*-benzyl-*D*-arabinofuranose* (**19**) (α/β = 58:42) [12] with 402 mg (382 µl, 3.24 mmol) of $P(OMe)_3$ and 576 mg (470 µl, 2.59 mmol) of trimethylsilyl trifluoromethanesulfonate in 4.3 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 952 mg (86%) of **20** and 99 mg (9%) of **21**.

Data of **20**. R_f (A) 0.21, $[\alpha]_D^{25}$ = +1.8° (*c* = 1.15). IR: 3000*m*, 2960*m*, 2925*w*, 2860*m*, 1495*w*, 1452*m*, 1390*w*, 1362*w*, 1243*m*, 1095*s*, 1055*s*, 1040*s*, 940*w*, 825*m*, 692*m*. ^{1}H-NMR (400 MHz): 7.35–7.24 (*m*, 15 arom. H); 4.60–4.46 (*m*, 6 H); 4.45 (*dd*, *J*(P,H) = 6.0, *J* = 4.2, H–C(1)); 4.30 (*ddd*, *J*(P,H) = 2.5, *J* = 4.2, 1.0, H–C(2)); 4.22 (*ddd*, *J* = 7.4, 5.7, 2.3, H–C(4)); 4.05 (*dt*, *J*(P,H) = 2.3, *J* = 2.3, 1.0, H–C(3)); 3.76 (*d*, *J*(P,H) = 10.8, $POCH_3$); 3.69 (*dd*, *J* = 9.9, 5.7, H–C(5)); 3.64 (*d*, *J*(P,H) = 10.8, $POCH_3$); 3.57 (*dd*, *J* = 9.9, 7.4, H–C(5)). ^{13}C-NMR (100 MHz): 138.12 (*s*); 137.40 (*s*); 137.23 (*s*); 128.39 (*d*); 128.32 (*d*); 128.28 (*d*); 128.10 (*d*); 127.82 (*d*); 127.62 (*d*); 84.44 (*dd*, *J*(P,C) = 11.1); 83.24 (*dd*, *J*(P,C) = 3.8); 82.96 (*dd*, *J*(P,C) = 6.9); 77.37 (*dd*, *J*(P,C) = 171.9, C(1)); 73.23 (*t*); 72.39 (*t*); 71.45 (*t*); 69.88 (*t*); 53.80 (*dq*, *J*(P,C) = 5.1); 52.25 (*dq*, *J*(P,C) = 6.6). ^{31}P-NMR (160 MHz): +21.61. Anal. calc. for $C_{28}H_{33}O_7P$ (512.56): C 65.61, H 6.49, P 6.04; found: C 65.72, H 6.63, P 5.84.

Data of **21**. R_f (A) 0.28, $[\alpha]_D^{25}$ = +25.2° (*c* = 1.05). IR: 3000*m*, 2960*m*, 2920*w*, 2860*m*, 1494*w*, 1454*m*, 1363*m*, 1260*s*, 1080 (sh), 1050*s* (br.), 910*w*, 860*w*, 820*m*, 693*m*. ^{1}H-NMR (400 MHz): 7.38–7.22 (*m*, 15 arom. H); 4.66–4.48 (*m*, 7 H); 4.33 (*dd*, *J*(P,H) = 2.8, *J* = 4.8, H–C(1)); 4.27 (*dt*, *J* = 4.7, 5.0, H–C(4)); 4.15 (*dd*, *J* = 5.0, 3.5, H–C(3)); 3.81 (*d*, *J*(P,H) = 10.6, $POCH_3$); 3.80 (*d*, *J*(P,H) = 10.6, $POCH_3$); 3.63 (*dd*, *J* = 10.7, 4.7, H–C(5)); 3.57 (*dd*, *J* = 10.7, 5.0, H–C(5)). ^{13}C-NMR (100 MHz): 137.99 (*s*); 137.65 (*s*); 137.49 (*s*); 128.32 (*d*); 128.11 (*d*); 127.90 (*d*); 127.81 (*d*); 127.75 (*d*); 127.66 (*d*); 127.60 (*d*); 84.79 (*dd*, *J*(P,C) = 5.4); 84.48 (*dd*, *J*(P,C) = 5.7); 82.27 (*dd*, *J*(P,C) = 3.0); 78.21 (*dd*, *J*(P,C) = 166.0, C(1)); 73.36 (*t*); 72.26 (*t*); 72.03 (*t*); 68.90 (*t*); 53.65 (*dq*, *J*(P,C) = 6.9); 53.13 (*dq*, *J*(P,C) = 6.7). ^{13}P-NMR (160 MHz): +23.77. Anal. calc. for $C_{28}H_{33}O_7P$ (512.56): C 65.61, H 6.49, P 6.04; found: C 65.63, H 6.63, P 5.90.

1.10. *Diethyl (2,3,5-Tri-O-benzyl-β- and α-D-arabinofuranosyl)phosphonates* (**22** and **23**, resp.). *A) With trimethylsilyl trifluoromethanesulfonate*[2]). Treatment of 1 g (2.16 mmol) of **19** (α/β = 58:42) with 538 mg (563 µl, 3.24 mmol) of $P(OEt)_3$ and 576 mg (470 µl, 2.59 mmol) of trimethylsilyl trifluoromethanesulfonate in 4.3 ml of CH_2Cl_2 gave, after chromatography (100 g SiO_2, A), 980 mg (84%) of **22** and 105 mg (9%) of **23**.

B) With $BF_3 \cdot OEt_2$. Treatment of 5 g (10.8 mmol) of **19** (α/β = 58:42) with 8.27 g (8.67 ml, 49.8 mmol) of $P(OEt)_3$ and 3.97 g (3.52 ml, 28 mmol) of $BF_3 \cdot OEt_2$ gave, after chromatography (500 g SiO_2, A), 3.01 g (51%) of **22** and 1.15 g (19%) of **23**.

Data of **22**. R_f (A) 0.41, $[\alpha]_D^{25}$ = −2.8° (*c* = 1.11). IR: 3070*w*, 2997*m*, 2935*w*, 2915*w*, 2870*w*, 1494*w*, 1453*m*, 1390*w*, 1368*m*, 1290*w*, 1240*m*, 1160*w*, 1110 (sh), 1095*s*, 1028*s* (br.), 963*m*. ^{1}H-NMR (400 MHz): 7.35–7.23 (*m*, 15 arom. H); 4.59, 4.51 (*AB*, *J* = 11.9, PhCH_2); 4.57, 4.50 (*AB*, *J* = 11.5, PhCH_2); 4.46 (*s*, PhCH_2); 4.41 (*dd*, *J*(P,H) = 6.1, *J* = 4.3, H–C(1)); 4.30 (*ddd*, *J* = 4.3, 2.6, 1.2, H–C(2)); 4.22 (*ddd*, *J* = 7.5, 5.7, 2.5, H–C(4)); 4.17–3.96 (*m*, 5 H); 3.69 (*dd*, *J* = 9.9, 5.7, H–C(5)); 3.57 (*dd*, *J* = 9.9, 7.5, H–C(5)); 1.31 (*t*, *J* = 7.1, CH_3); 1.13 (*t*, *J* = 7.1, CH_3). ^{13}C-NMR (50 MHz): 138.19 (*s*); 137.49 (*s*); 137.37 (*s*); 128.38 (*d*); 128.26 (*d*); 128.11 (*d*); 127.76 (*d*); 127.62 (*d*); 127.55 (*d*); 84.35 (*dd*, *J*(P,C) = 11.3); 83.38 (*d*); 83.29 (*d*); 83.13 (*d*); 82.98 (*d*); 77.65 (*dd*, *J*(P,C) = 172.0, C(1)); 73.26 (*t*); 72.40 (*t*); 71.44 (*t*); 70.00 (*t*); 63.02 (*dt*, *J*(P,C) = 6.4); 61.77 (*dt*, *J*(P,C) = 6.7); 16.36 (*dq*, *J*(P,C) = 5.8); 16.23 (*dq*, *J*(P,C) = 6.3). ^{31}P-NMR (80 MHz): +19.17. Anal. calc. for $C_{30}H_{37}O_7P$ (540.60): C 66.65, H 6.90, P 5.72; found: C 66.53, H 6.96, P 5.60.

Data of **23**. R_f (A) 0.46, $[\alpha]_D^{25}$ = +21.2° (*c* = 1.5). IR: 3090*w*, 3065*w*, 2995*s*, 2930*m*, 2910*m*, 2870*m*, 1605*w*, 1495*m*, 1452*s*, 1391*m*, 1362*m*, 1295*m*, 1244*s*, 1160*m*, 1100*s*, 1050*s* (br.), 1028*s*, 970*m*, 910*m*, 860*m*. ^{1}H-NMR (400 MHz): 7.36–7.24 (*m*, 15 arom. H); 4.67–4.48 (*m*, 8 H); 4.29–4.13 (*m*, 6 H); 3.63 (*dd*, *J* = 10.8, 4.5, H–C(5)); 3.57 (*dd*, *J* = 10.8, 5.0, H–C(5)); 1.33 (*t*, *J* = 6.0, CH_3); 1.30 (*t*, *J* = 6.0, CH_3). ^{13}C-NMR (50 MHz): 138.22 (*s*); 137.94 (*s*); 137.80 (*s*); 128.50 (*d*); 128.07 (*d*); 127.98 (*d*); 127.95 (*d*); 127.90 (*d*); 127.84 (*d*); 127.72 (*d*); 85.17 (*dd*, *J*(P,C) = 5.9); 84.74 (*dd*, *J*(P,C) = 5.9); 82.26 (*dd*, *J*(P,C) = 3.8); 78.65 (*dd*, *J*(P,C) = 166.1, C(1)); 73.53 (*t*); 72.45 (*t*); 72.21 (*t*); 69.14 (*t*); 63.23 (*dt*, *J*(P,C) = 6.8); 62.79 (*dt*, *J*(P,C) = 6.8); 16.72 (*q*); 16.62 (*q*). ^{31}P-NMR (80 MHz): +21.51. Anal. calc. for $C_{30}H_{37}O_7P$ (540.60): C 66.65, H 6.90, P 5.72; found: C 66.38, H 6.71, P 5.91.

2. Disodium Glycosylphosphonates. – 2.1. *General Procedure*. Under N_2, bromotrimethylsilane (4 mmol) was added dropwise over 10 min to a soln. of the protected glycosylphosphonate (1 mmol) in 15 ml of dry CH_2Cl_2 at 0°. The mixture was stirred at r.t. for 4 h and then concentrated. The residue was taken up in 10 ml of MeOH and hydrogenolysed in the presence of 100 mg of 10% Pd/C under normal pressure (1–1.5 h). After filtration of the catalyst and concentration of the filtrate *i.v.*, the residue was taken up in 10 ml of H_2O and washed with AcOEt (2 × 2 ml). The aq. phase was treated with *Dowex CCR-2* (Na^+ form), lyophilised, and dried *i.v.* over P_2O_5.

2.2. *Disodium (α-D-Glucopyranosyl)phosphonate* (**6**). Deprotection of 3 g (4.54 mmol) of **4** gave 1.05 g of the free acid, which was converted to 1.23 g (95%) of **6**. R_f (PrOH/NH_3/H_2O 4:3:1) 0.24, $[\alpha]_D^{25}$ = +46.8° (*c* = 0.95 H_2O). ^{1}H-NMR (400 MHz, D_2O): 4.18 (*ddd*, *J* = 8.4, 5.9, 2.0, H–C(5)); 4.07 (*dd*, *J*(P,H) = 11.8, *J* = 6.2, H–C(1)); 4.01 (*t*, *J* = 8.4, H–C(3)); 3.82 (*dd*, *J* = 10.0, 2.0, H–C(6)); 3.76 (*ddd*, *J*(P,H) = 22.0, *J* = 8.4, 6.2, H–C(2)); 3.75 (*dd*, *J* = 10.0, 5.9, H–C(6)); 3.34 (*t*, *J* = 8.4, H–C(4)). ^{13}C-NMR (50 MHz, D_2O): 80.11 (*d*); 77.82 (*d*); 76.36 (*dd*, *J*(P,C) = 142.0, C(1)); 74.91 (*d*); 73.66 (*d*); 64.50 (*t*). MS (FAB of the free acid): 245 (*M* + 1), 267 (*M* + Na). ^{31}P-NMR (160 MHz, D_2O): +14.53. Anal. calc. for $C_6H_{11}Na_2O_8P$ (288.11): C 25.01, H 3.85, P 10.75; found: C 24.72, H 3.95, P 10.63.

2.3. *Disodium (β-D-Mannopyranosyl)phosphonate* (**12**). Deprotection of 2 g (3.02 mmol) of **10** gave 709 mg of the free acid, which was converted to 836 mg (96%) of **12**. R_f (PrOH/NH_3/H_2O 4:3:1) 0.19, $[\alpha]_D^{25}$ = −16.3° (*c* = 1.18 H_2O). ^{1}H-NMR (400 MHz, D_2O): 4.18 (br. *s*, H–C(1)); 3.91 (*d*, *J* = 12.0, H–C(3)); 3.70 (*dd*, *J* = 12.0, 7.0, H–C(4)); 3.67–3.60 (*m*, 2 H–C(6)); 3.55 (*d*, *J*(P,H) = 13.0, H–C(2)); 3.34 (*t*, *J* = 7.1, H–C(5)). ^{13}C-NMR (50 MHz, D_2O): 81.70 (*dd*, *J*(P,C) = 13.3); 74.90 (*dd*, *J*(P,C) = 14.2); 75.81 (*dd*, *J*(P,C) = 149.9, C(1)); 69.87 (*d*); 67.54 (*d*); 61.79 (*t*). ^{31}P-NMR (80 MHz, D_2O): +13.80. MS (FAB of the free acid): 245 (*M* + 1), 267 (*M* + Na). Anal. calc. for $C_6H_{11}Na_2O_8P$ (288.11): C 25.01, H 3.85, P 10.75; found: C 24.83, H 3.99, P 10.58.

2.4. *Disodium (α-D-Ribofuranosyl)phosphonate* (**18**). Deprotection of 2.0 g (3.69 mmol) of **16** gave 780 mg of the free acid, which was converted to 935 mg (98%) of **18**. R_f (PrOH/NH_3/H_2O 4:3:1) 0.24, $[\alpha]_D^{25}$ = +27.4° (*c* = 1.08 H_2O). ^{1}H-NMR (400 MHz, D_2O): 4.27 (*ddd*, *J*(P,H) = 2.0, *J* = 4.0, 3.0, H–C(2)); 4.07 (*dd*, *J* = 8.0, 4.0, H–C(3)); 3.96 (*dd*, *J*(P,H) = 7.0, *J* = 3.0, H–C(1)); 3.95 (*ddd*, *J* = 8.0, 5.4, 2.5, H–C(4)); 3.84 (*dd*, *J* = 12.3, 2.5, H–C(5)); 3.66 (*dd*, *J* = 12.3, 5.4, H–C(5)). ^{13}C-NMR (50 MHz, D_2O): 81.73 (*dd*, *J*(P,C) = 5.0); 77.31 (*dd*, *J*(P,C) = 148.5, C(1)); 74.00 (*dd*, *J*(P,C) = 9.9)); 72.30 (*d*); 62.08 (*t*). ^{31}P-NMR (160 MHz, D_2O): +13.5. MS (FAB of the free acid): 215 (*M* + 1), 237 (*M* + Na). Anal. calc. for $C_5H_9Na_2O_7P$ (258.10): C 23.26, H 3.51, P 11.99; found: C 22.99, H 3.70, P 11.70.

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[2]) In the presence of 1.2 equiv. of $SnCl_4$, only traces of **22** and **23** were obtained from **19** and 1.5 equiv. of $P(OEt)_3$.

2.5. *Disodium (β-D-Arabinofuranosyl)phosphonate* (**24**). Deprotection of 1.9 g (3.5 mmol) of **22** gave 734 mg of the free acid, which was converted to 880 mg (97%) of **24**. R_f ($PrOH/NH_3/H_2O$ 4:3:1) 0.25, $[\alpha]_D^{25} = +21.2°$ ($c = 1.19$ H_2O). ^{1}H-NMR (400 MHz, D_2O): 4.21 (*d*, $J = 3.0$, H–C(1)); 4.03 (*m*, H–C(3)); 4.01 (*dd*, $J(P,H) = 7.1$, $J = 3.0$, H–C(2)); 3.90 (*ddd*, $J = 6.4, 4.4, 2.5$, H–C(4)); 3.77 (*dd*, $J = 12.0, 4.4$, H–C(5)); 3.71 (*dd*, $J = 12.0, 6.4$, H–C(5)). ^{13}C-NMR (100 MHz, D_2O): 87.75 (*d*); 79.12 (*d*); 78.75 (*dd*, $J(P,C) = 145.0$, C(1)); 78.03 (*d*); 62.89 (*t*). ^{31}P-NMR (160 MHz, D_2O): +13.05. MS (FAB of the free acid): 215 ($M + 1$), 237 ($M + Na$). Anal. calc. for $C_5H_9Na_2O_7P$ (258.10): C 23.26, H 3.51, P 11.99; found: C 23.02, H 3.64, P 11.90.

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