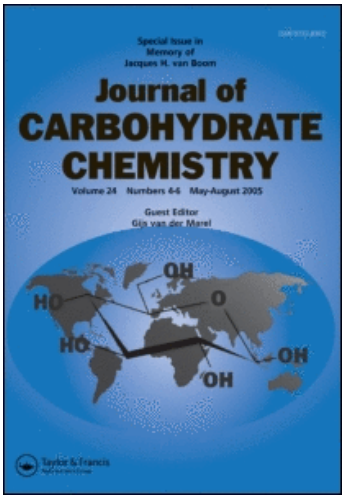

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Convenient Oxidations of Carbohydrate Derived Lactols and of ε-Hydroxy-β-ketophosphonates

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CONVENIENT OXIDATIONS OF CARBOHYDRATE DERIVED LACTOLS AND OF ε-HYDROXY-β-KETOPHOSPHONATES

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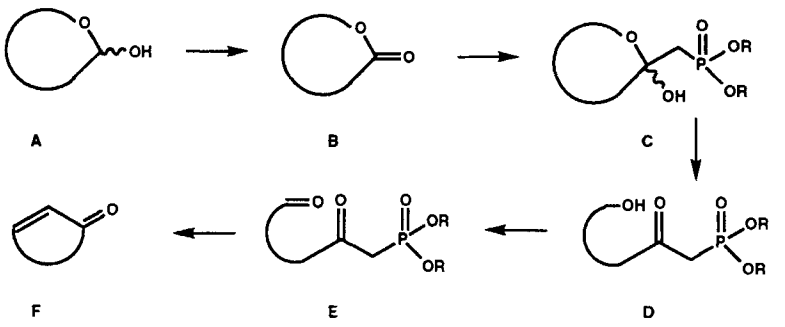
ABSTRACT

Convenient oxidation of carbohydrate derived lactols to lactones as well as the oxidation of ε-hydroxy-β-ketophosphonates to their corresponding β,ε-diketophosphonates can be performed with the *Dess-Martin* periodinane in high yields.

INTRODUCTION

For several years the synthesis of carbocyclic analogs of carbohydrates, nucleosides and nucleotides has been in the focus of interest due to their promising biological properties.[1] Many approaches to these molecules have therefore been devised. A promising route originally proposed by Altenbach[2]



and Marquez,[3, 4] and recently applied by Vasella et al.[5] used chain elongation of an aldonolactone **B** by the addition of a lithiomethylenephosphonate,[6] oxidation of the resulting lactol **C** or **D** (→ **E**) followed by ring closure using a *Horner-Emmons* reaction (→ **F**). The aldonolactone **B**, serving in this sequence as the educt, is usually obtained by the oxidation of a suitably protected aldose **A**.

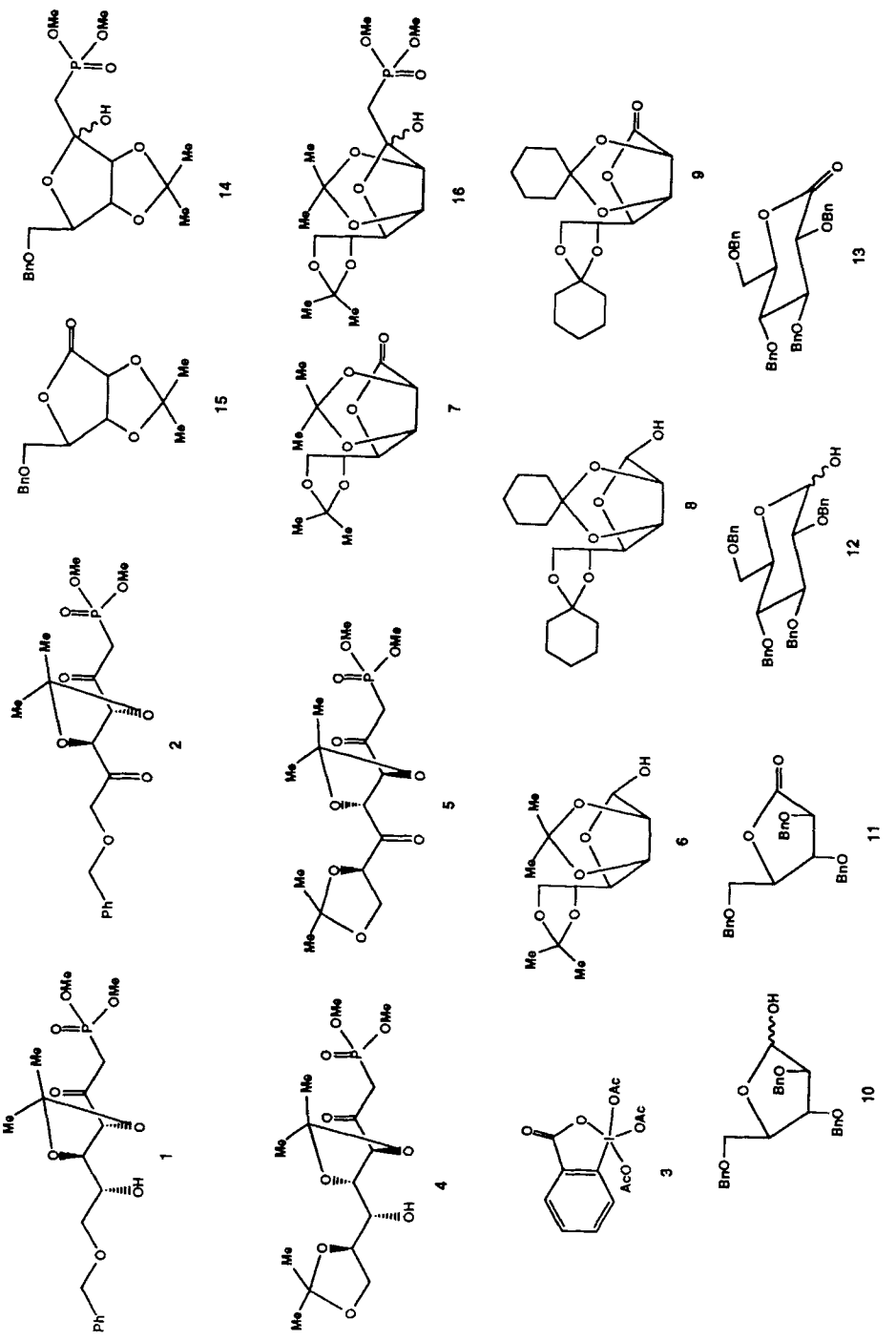
RESULTS AND DISCUSSION

During our own synthetic efforts large scale preparations (> 100 g) were necessary and two problems were encountered: Firstly, the oxidations of the aldoses **A** to the lactones **B** and secondly, the oxidation of the lactol **C** *via* its acyclic form **D** to the dialkyl 1-deoxy-2,5-diulosylphosphonate **E**.

Several reagents have been devised for the latter oxidation on a small preparative scale, amongst them dimethyl sulfoxide (DMSO) - oxalyl chloride-triethylamine,[2] pyridinium chlorochromate,[2] DMSO - trifluoroacetic acid[5] or the chromium trioxide dipyridine complex[3] but all of these reagents failed to give reasonably high yields in large scale preparations.

Therefore we decided to investigate these oxidations in a more systematic way. For reasons of efficiency it seemed logical to look for an oxidant that mastered both oxidations (**A**→ **B** and **D** → **E**) in a satisfactory manner. As shown for the D-*ribo*-2-hexulosylphosphonate **1**, chromium(VI) based reagents [chromium trioxide / pyridine[4] (→ 36.4% yield of **2**), pyridinium chlorochromate[3] (→ 53%), pyridinium dichromate / acetic acid / mol sieves[7] (→ 43%), chromium trioxide / pyridine/ acetic anhydride[8] (→ 55%)] always required the use of an excess of oxidant and gave only inferior yields of the 2,5-hexodiulosylphosphonate **2**. This is probably due to a prolonged contact of the rather sensitive products with the chromium salts during work up, but also to the severe adhesion of the product to the chromium salts. *Swern*-type[9] oxidations gave moderate yields of 40-60%[2,5] even after rigorous drying of starting materials, reagents and solvents; dimanganese heptoxide (Mn_2O_7) in carbon tetrachoride[10] caused serious problems in preparation, handling, application and finally during work up and disposal. Several other reagent systems, amongst them activated manganese dioxide or chromium trioxide/*tert*-butyl-hydroperoxide[11] failed to give satisfactory yields.

It has been reported that on oxidation of an α,ε-diol with the *Dess-Martin* periodinane, 1,1,1-triacetoxy-1,1-dihydro-benziodoxol-3(1*H*)-one (**3**),[12-14] the reaction stopped at the lactol stage.[15] However, this reagent **3** has now been found to react very cleanly in the oxidation of primary and secondary alcohols to



aldehydes and ketones, respectively.[13] The desired transformations **1** → **2** and **4** → **5** proceeded well and in high yields (76 and 74%, respectively). Excellent results were also obtained for the lactol → lactone oxidation of several carbohydrate-derived lactols. Thus, 2,3:5,6-di-*O*-isopropylidene-α-D-mannofuranose (**6**) afforded 2,3:5,6-di-*O*-isopropylidene-D-mannono-1,4-lactone (**7**) in 95% yield and the cyclohexylidene analog **9** was obtained in 95% yield from **8**. The course of the oxidations reflects the mildness of the oxidant since under forced conditions the formation of significant amounts of an isomeric (4 *R,S*)-2,3;5,6-di-*O*-isopropylidene-D-*lyxo*-4-hexulosono lactol is always observed.[16] Although somewhat trivial, the oxidation of **6** represents a good example for comparison of the efficiency of different oxidants. Thus **7** has been obtained by oxidation of **6** with DMSO/acetic anhydride (96%),[17] DMSO/oxalyl chloride,[18] potassium permanganate (60%),[19] *N*-iodo-succinimide/tetra-*n*-butylammonium iodide (91%),[20] pyridinium chlorochromate (84%),[21] chromium trioxide dipyridine complex,[8,22] sodium meta-periodate/ruthenium tetroxide (73%),[23] electrochemically (92%),[24] catalytic hydrogen transfer,[25] and silver carbonate (98%);[26] some of these methods are only applicable on a very small scale.

2,3,5-Tri-*O*-benzyl-D-arabinofuranose (**10**) gave the corresponding arabinono-1,4-lactone **11** (96.5% yield). As an example for the synthesis of a pyranoid lactone 2,3,4,6-tetra-*O*-benzyl-D-glucopyranose (**12**) was chosen and the lactone **13** was obtained in 89% yield.[38]

In summary, the periodinane **3** seems to be superior to many other oxidants hitherto used both for the oxidation of lactols to lactones and for the preparation of β,ε-diketophosphonates from their respective ε-hydroxy-β-keto-phosphonate precursors.

EXPERIMENTAL

General methods. Melting points are uncorrected (*Reichert* hot stage microscope), optical rotations were obtained using a Perkin-Elmer 243B polarimeter (1 cm micro-cell), NMR spectra (internal Me_4Si) were recorded using either a Bruker AM250 or a Varian XL300 instrument (δ given in ppm, *J* in Hz, internal Me_4Si), IR spectra (film or KBr-pellet) on a Perkin-Elmer 298 instrument or on a Perkin-Elmer 1605 FT-IR, MS-spectra were taken either on a MAT311A or a Varian-112S instrument; for elemental analysis a Foss-Heraeus Vario EL instrument was used. TLC was performed on silica gel (Merck 5554, detection by dipping in a solution containing 10% sulfuric acid (400 mL), ammonium molybdate (20 g) and cerium(IV) sulfate (20 mg) followed by heating to 150 °C. The tetrahydrofuran (THF) was freshly distilled from sodium/

benzophenone, the dichloromethane in succession from P_4O_{10} and K_2CO_3; all reactions were performed under dry argon.

CAUTION! The precursor of the *Dess Martin* periodinane **3**, namely 1-hydroxy-1,2-benziodoxol3(1*H*)-one 1-oxide (cyclized 2-iodoxy-benzoic acid)[27] was reported to be explosive under excessive heating (> 200 °C) or impact.[28]

General procedure A. *Oxidations with periodinane* **3**: To a solution of the educt (25 mmol) in dry dichloromethane (100 mL) a solution of **3** (10.7 g, 26 mmol) in dry dichloromethane (100 mL) was added slowly at 25 °C. After the addition of dry *tert*-butyl alcohol (2.0 g, 27 mmol) the mixture was stirred until TLC showed the complete disappearance of the starting material (0.5 - 4 h). The reaction mixture was diluted with diethyl ether (500 mL); this resulted in the precipitation of a white solid. A saturated aqueous solution of $NaHCO_3$ was added until this solid was dissolved, and the mixture was extracted with diethyl ether (7 x 200 mL). The combined organic layers were dried ($MgSO_4$), the solvent was evaporated and the residue subjected to column chromatography (silica gel, hexane/ethyl acetate).

General procedure B. *Reaction of dimethyl lithiomethylphosphonate with lactones*:[3] A solution of freshly distilled dimethyl methylphosphonate (24.0 g, 193.5 mmol) in dry THF (200 mL) was cooled to -78 °C and *n*-butyllithium (120 mL, 1.6 M in hexane) was slowly added. After completion of the addition, the mixture was stirred for an additional 30 min at -78 °C. A solution of the lactone (77 mmol) in dry THF (200 mL) was slowly added and the stirring was continued for 15 min. The cooling bath was removed and the mixture allowed to warm to 0 °C. The excess of the reagent was destroyed by careful and dropwise addition of a saturated aqueous NH_4Cl solution. The mixture was diluted by the addition of diethyl ether (500 mL) and the organic layer was separated. The aqueous layer was extracted with diethyl ether (8 x 100 mL) and the combined organic phases were washed with brine (50 mL) and dried ($MgSO_4$). The solvent was removed and the residue subjected to column chromatography (silica gel, hexane/ethyl acetate).

General procedure C. *Synthesis of the 2,5-hexo-(or -hepto)-ulosylphosphonates*:[3,4] To a solution of the educt from procedure **B** (40 mmol) in dry methanol (80 mL) a methanolic solution of sodium methoxide [prepared from 2.4 g sodium and dry methanol (100 mL)] was added and the mixture was stirred for two days, then neutralized with glacial acetic acid and the solvents were evaporated under reduced pressure. The residue was dissolved in a mixture of ethyl acetate (500 mL) and water (250 mL), thereby the organic layer was separated. The aqueous phase was extracted with ethyl acetate (10 x 100 mL) and the combined organic phases were dried ($MgSO_4$). The solvent was

removed under reduced pressure and the residue subjected to column chromatography (silica gel, hexane/ethyl acetate gradient 3:1 → 1:1 → 0:1).

Dimethyl (6-*O*-benzyl-3,4-*O*-isopropylidene-α-D-*ribo*-2-hexulofuranosyl)phosphonate (14). According to procedure **B** from **15** (21.35 g, 77 mmol)[4] **14** (25.9 g, 84%) was obtained: mp 56 °C (lit:[4] 54-56 °C); $[\alpha]_D^{20}$ -13.8° (*c* 1.1, $CHCl_3$) (lit:[4] -14.0° (*c* 0.93, $CHCl_3$)); IR (KBr) cm^{-1} 3340br m, 2990m, 2960m, 2860w, 1740w, 1455m, 1375m, 1230br s, 1050 br s; ^1H NMR (250 MHz, DMSO-d_6) δ 1.27 (s, 3 H, Me^i), 1.39 (s, 3 H, Me^i), 2.30-2.40 (m, 2 H, H-1a, H-1b), 3.55-3.70 (m, 8 H, H-6a, H-6b, 2 x POMe), 4.15 (t, $J_{3,4}$ = 6.2 Hz, H-4), 4.50 (d, $J_{5,6}$ = 5.0 Hz, H-5), 4.52 (s, 2 H, CH_2-aryl), 4.75 (d, H-3), 6.25 (s, exchangeable with D_2O, OH), 7.38 (br s, 5 H, H_{aryl}); ^{13}C NMR (62 MHz, DMSO-d_6) δ 25.13 (q, Me^i); 26.47 (q, Me^i), 31.53 (dt, $J_{C,P}$ = 139.2 Hz, C-1), 51.62 (dq, $J_{C,P}$ = 6.2 Hz, POMe), 52.48 (dq, $J_{C,P}$ = 6.1 Hz, POMe), 71.50, 72.32 (2 t, C-6, CH_2-aryl), 82.85, 83.71 (2 d, C-4, C-5), 85.18 (dd, $J_{C,P}$ = 4.2 Hz, C-3), 104.96 (s, C_q^i); 111.68 (s, C_q^i), 127.50, 127.57, 128.28 (3 d, C_{aryl}), 138.25 (s, C_q of aryl); FABMS (glycerol) 385; FABMS (glycerol + LiCl) 409.

Anal. Calcd for $C_{18}H_{27}O_8P$ (402.38): C, 53.73; H, 6.76. Found: C, 53.89; H, 6.97.

Dimethyl (3,4:6,7-di-*O*-isopropylidene-α-D-*manno*-2-heptulofuranosyl)phosphonate (16). According to procedure **B** from **7** (19.9 g, 77 mmol) **16** (25.6 g, 87%) was obtained: mp 71-73 °C; $[\alpha]_D^{20}$ +6.2° (*c* 1.8, $CHCl_3$); IR (KBr) cm^{-1} 3366s, 2991s, 2956m, 2904m, 2855m, 1735m, 1701m, 1685m, 1654m, 1560m, 1458s, 1391s, 1373s, 1331s, 1228s, 1188s, 1162s, 1045s, 1000s; ^1H NMR (300 MHz, $CDCl_3$) δ 1.30, 1.35, 1.41, 1.44 (4 s, 12 H, Me^i), 2.20 (dd, $J_{1a,1b}$ = 15.5, $J_{H,P}$ = 18.3 Hz, H-1a), 2.38 (dd, $J_{H,P}$ = 17.6 Hz, H-1b), 3.72 (d, $J_{H,P}$ = 11.1 Hz, 3 H, POMe), 3.78 (d, $J_{H,P}$ = 11.2 Hz, 3 H, POMe), 3.97 (dd, $J_{6,7}$ = 5.1, $J_{7a,7b}$ = 8.3 Hz, H-7a), 4.03 (dd, $J_{6,7b}$ = 6.3 Hz, H-7b), 4.15 (dd, $J_{4,5}$ = 3.7, $J_{5,6}$ = 7.3 Hz, H-5), 4.37 (ddd, H-6), 4.46 (d, $J_{3,4}$ = 5.8 Hz, H-3), 4.82 (ddd, $J_{H,P}$ = 1.2 Hz, H-4), 5.47 (bs, 1 H, exchangeable with D_2O, OH); ^{13}C NMR (62 MHz, $CDCl_3$) δ 24.46, 25.12, 25.90, 26.78 (4 q, Me^i), 30.29 (dt, $J_{C,P}$ = 136.7 Hz, C-1), 51.97 (dq, $J_{C,P}$ = 6.6 Hz, POMe), 53.54 (dq, $J_{C,P}$ = 6.5 Hz, POMe), 66.69 (t, C-7), 73.08 (d, C-6), 79.53, 80.25 (2 d, C-4, C-5), 85.87 (dd, $J_{C,P}$ = 10.7 Hz, C-3), 103.54 (d, $J_{C,P}$ = 7.3 Hz, C-2), 109.09, 112.86 (2 s, C_q^i); FABMS (glycerol) 384, 383.

Anal. Calcd for $C_{15}H_{27}O_9P$ (382.35): C, 47.12, H, 7.12. Found: C, 47.42, H, 7.06.

Dimethyl (6-*O*-benzyl-3,4-*O*-isopropylidene-α-D-*ribo*-2-hexulosyl)phosphonate (1). According to procedure **C** from **14** (16.0 g, 40 mmol) **1** (14.2 g, 89%) was obtained as an oil: $[\alpha]_D^{20}$ -8.0° (*c* 1.0, $CHCl_3$) (lit:[4]

-8.2° (*c* 1.02, $CHCl_3$); IR (film) cm $^{-1}$ 3990 br m, 3070w, 3040w, 3000m, 2960m, 2940m, 2870m, 1730s, 1457m, 1385m, 1375m, 1250s, 1050s; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.37 (s, 3 H, Me^i), 1.45 (s, 3 H, Me^i), 2.68 (br s, 1 H, exchangeable with D_2O, OH), 3.33 (dd, $J_{1a,1b}$ = 14.3, $J_{H,P}$ = 22.4 Hz, H-1a), 3.47 (dd, $J_{H,P}$ = 22.4 Hz, H-1b), 3.56 (dd, $J_{5,6a}$ = 6.0, $J_{6a,6b}$ = 9.9 Hz, H-6a), 3.70 (dd, $J_{5,6b}$ = 3.2 Hz, H-6b), 3.76 (d, $J_{H,P}$ = 2.7 Hz, 3 H, POMe), 3.80 (d, $J_{H,P}$ = 2.7 Hz, 3 H, POMe), 3.90 (ddd, $J_{4,5}$ = 6.5 Hz, 1 H, H-5), 4.24 (dd, $J_{3,4}$ = 6.2 Hz, H-4), 4.57 (s, 2 H, CH_2-aryl), 4.63 (d, H-3), 7.28-7.38 (m, 5 H, H_{aryl}); ^{13}C NMR (75 MHz, $CDCl_3$) δ 25.97 (q, Me^i), 26.93 (q, Me^i), 37.19 (dt, $J_{C,P}$ = 131.0 Hz, C-1), 53.03 (dq, $J_{C,P}$ = 6.7 Hz, POMe), 53.14 (dq, $J_{C,P}$ = 5.4 Hz, POMe), 70.82 (t, C-6), 71.52 (d, C-3), 73.42 (t, CH_2-aryl), 77.36 (d, C-5), 82.63 (dd, $J_{C,P}$ = 2.3 Hz, C-4), 111.19 (s, C_q^i), 127.58, 127.61, 128.24 (3 d, C_{aryl}), 137.67 (s, C_q of aryl), 201.31 (d, $J_{C,P}$ = 6.7 Hz, C-2); MS (FAB, glycerol): 403; FABMS (glycerol + LiCl): 409.

Anal. Calcd for $C_{18}H_{27}O_8P$ (402.38): C, 53.73, H, 6.76. Found: C, 53.58, H, 6.93.

Dimethyl (3,4:6,7-di-*O*-isopropylidene-α-D-*manno*-2-heptulosyl)phosphonate (4). According to procedure **C** from **16** (15.3 g, 40 mmol) **4** (13.8 g, 90%) was obtained): mp 62-63 °C, $[\alpha]_D^{20}$ +32° (*c* 1.2, $CHCl_3$); IR (KBr) cm $^{-1}$ 3380 br m, 2995m, 2960m, 2940m, 1720s, 1460m, 1385s, 1375s, 1255s, 1215s, 1162s, 1130s, 1050s; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.32, 1.38, 1.39, 1.46 (4 s, 12 H, Me^i), 2.38 (bs, 1 H, exchangeable with D_2O, OH), 3.22 (dd, $J_{1a,1b}$ = 14.3, $J_{H,P}$ = 22.3 Hz, H-1a), 3.54 (dd, $J_{H,P}$ = 22.7 Hz, H-1b), 3.61 (m, H-6), 3.76 (d, $J_{H,P}$ = 4.3 Hz, 3 H, POMe), 3.80 (d, $J_{H,P}$ = 4.3 Hz, 3 H, POMe), 4.00-4.07 (m, 3 H, H-5, H-7a, H-7b), 4.34 (dd, $J_{4,5}$ = 2.4, $J_{3,4}$ = 7.5 Hz, H-4), 4.51 (d, H-3); ^{13}C NMR (62 MHz, $CDCl_3$): δ 25.36, 26.29, 26.66, 26.84 (4 q, Me^i), 36.78 (dt, $J_{C,P}$ = 131.78 Hz, C-1), 53.07 (dq, $J_{C,P}$ = 6.5 Hz, POMe), 53.25 (dq, $J_{C,P}$ = 6.4 Hz, POMe), 66.89 (t, C-7), 70.51, 76.25, 77.28, 80.80 (4 d, C-3, C-4, C-5, C-6), 109.43, 111.17 (2 s, C_q^i), 202.30 (d, $J_{C,P}$ = 6.8 Hz, C-2); FABMS (glycerol/lithium chloride) 391 (39), 389 (3).

Anal. Calcd for $C_{15}H_{27}O_9P$ (382.35): C, 47.12, H, 7.12. Found: C, 47.32, H, 7.29.

Dimethyl (6-*O*-benzyl-3,4-*O*-isopropylidene-D-*erythro*-2,5-hexodiulosyl) phosphonate (2). According to procedure **A** from **1** (10.1 g, 25 mmol) **2** (7.6 g, 76%) was obtained as an oil: $[\alpha]_D^{20}$ -17.7° (*c* 1.5, $CHCl_3$); lit:[4] -14.1° (*c* 1, $CHCl_3$); IR (film) cm $^{-1}$ 2990m, 2956m, 2855m, 1736s, 1732s, 1602w, 1497w, 1455m, 1385s, 1262s, 1212s, 1154m, 1030s; ^{1}H NMR (250 MHz, $CDCl_3$) δ 1.41 (s, 6 H, 2 x Me^i), 3.28 (dd, $J_{1a,1b}$ = 14.2, $J_{H,P}$ = 22.5 Hz, H-1a), 3.51 (dd, $J_{H,P}$ = 22.4 Hz, H-1b), 3.77 (d, $J_{H,P}$ = 1.9 Hz, 3 H, POMe), 3.81 (d, $J_{H,P}$ = 1.9 Hz, 3 H, POMe), 4.38 (d, $J_{6a,6b}$ = 18.4 Hz, H-6a), 4.49 (d, H-6b), 4.61

(s, 2 H, CH_2-aryl), 4.78, 4.82 (AB, $J_{3,4}$ = 5.7 Hz, H-3, H-4), 7.35 (m, 4 H, H_{aryl}); ^{13}C NMR (75 MHz, $CDCl_3$) δ 25.98 (q, Me^i), 26.14 (q, Me^i), 36.95 (dt, $J_{C,P}$ = 130.1 Hz, C-1), 53.15 (dq, $J_{C,P}$ = 2.9 Hz, POMe), 53.17 (dq, $J_{C,P}$ = 4.6 Hz, POMe), 72.55 (t, C-6), 73.30 (t, CH_2-aryl), 79.34, 81.47 (2 d, C-2, C-3), 112.90 (s, C_q^i), 127.85, 127.88, 128.33 (3 d, C_{aryl}), 136.79 (s, C_q of aryl), 199.36 (d, $J_{C,P}$ = 7.0 Hz, C-2), 204.47 (s, C-5); MS (EI, 80 eV, 180 °C): 385 (0.4), 324 (0.2), 309 (0.2), 292 (6.4), 251 (12.4), 193 (18.2), 151 (37.4), 124 (16.3), 109 (19.0), 91 (100).

Anal. Calcd for $C_{18}H_{25}O_8P$ (400.36): C, 54.00, H, 6.29. Found: C, 53.82, H, 6.43.

Dimethyl (3,4:6,7-di-*O*-isopropylidene-D-*glycero*-L-*erythro*-2,5-heptodiulosyl) phosphonate (5). According to procedure **A** from **4** (9.6 g, 25 mmol) **5** (7.1 g, 74%) was obtained as an oil: $[\alpha]_D^{20}$ +16.8° (*c* 1.0, $CHCl_3$); IR (film) cm $^{-1}$ 2990s, 2959m, 2940m, 2856m, 2339w, 1846w, 1799m, 1732s, 1456m, 1383s, 1261s, 1215s, 1154s, 1033s; ^1H NMR (250 MHz, $CDCl_3$) δ 1.40, 142, 1.45, 1.46 (4 s, 12 H, Me^i), 3.26 (dd, $J_{1a,1b}$ = 14.2, $J_{H,P}$ = 22.6 Hz, H-1a), 3.58 (dd, $J_{H,P}$ = 22.4 Hz, H-1b), 3.79 (d, $J_{H,P}$ = 3.4 Hz, 3 H, POMe), 3.84 (d, $J_{H,P}$ = 3.4 Hz, 3 H, POMe), 4.13 (dd, $J_{6,7a}$ = 5.4, $J_{7a,7b}$ = 8.7 Hz, H-7a), 4.26 (dd, $J_{6,7b}$ = 7.5 Hz, H-7b), 4.8-4.9 (m, H-4, H-6), 5.02 (d, $J_{3,4}$ = 5.5 Hz, H-3); ^{13}C NMR (62 MHz, $CDCl_3$): δ 25.21, 25.86, 26.02, 26.18 (4 q, Me^i), 37.00 (dt, $J_{C,P}$ = 131.07 Hz, C-1), 53.27 (dq, $J_{C,P}$ = 6.6 Hz, POMe), 53.38 (dq, $J_{C,P}$ = 6.5 Hz, POMe), 65.79 (t, C-6), 78.40, 78.80, 81.37 (3 d, C3, C-4, C-6), 111.24, 113.05 (2 s, C_q^i), 200.14 (s, C-2), 204.62 (s, C-5); MS (EI, 80 eV, 148 °C): 381 (0.2), 380 (0.1), 365 (7.4), 251 (28.4), 194 (41.4), 193 (48.5), 166 (52.9), 165 (35.2), 151 (99.9), 124 (70.1), 109 (42.2), 101 (62.2).

Anal. Calcd for $C_{15}H_{25}O_9P$ (380.33): C, 47.37, H, 6.63. Found: C, 47.57, H, 6.69.

2,3:5,6-Di-*O*-isopropylidene-D-mannono-1,4-lactone (7). According to procedure **A** from **6** (6.51 g, 25 mmol)[29] **7** (6.14 g, 95%) was obtained: mp 124-125 °C; $[\alpha]_D^{20}$ +54° (*c* 1.2, $CHCl_3$); lit:[17] mp 126 °C, $[\alpha]_D^{20}$ +50° ($CHCl_3$).

2,3:5,6-Di-*O*-cyclohexylidene-D-mannono-1,4-lactone (9). According to procedure **A** from **8** (8.5 g, 25 mmol)[34] **9** (8.0 g, 95%) was obtained: mp 101-102 °C; $[\alpha]_D^{20}$ +42.9° (*c* 1.2, $CHCl_3$); lit:[35] mp 108-110 °C, $[\alpha]_D^{20}$ +43.9° ($CHCl_3$); IR (KBr) cm $^{-1}$ 2937s, 2862s, 2668w, 2365w, 1777s, 1700w, 1684w, 1653w, 1635w, 1576w, 1559w, 1450s, 1368s, 1344m, 1286s, 1244m, 1233s, 1197s, 1164s, 1127s, 1074s, 1041s, 1002s; ^1H NMR (300 MHz, $CDCl_3$): δ 1.33-1.65 (m, 20 H, CH_2 of cyclohexylidene), 4.03 and 4.12 (dxAB, $J_{A,B}$ = 8.8 Hz, J = 3.6 and 5.0 Hz, 2 H), 4.44 (m, 2 H), 4.84 (bs, 2 H); ^{13}C NMR

(75 MHz, $CDCl_3$): δ 23.69, 23.86, 24.03, 24.74, 25.08, 34.69, 35.48, 36.39, 36.51 (9 t, CH_2 of cyclohexylidene), 65.82 (t, C-6), 72.71 (d, C-5), 75.49, 75.85, 78.43 (3 d, C-2, C-3, C-4), 110.29, 115.06 (2 s, C_q of cyclohexylidene), 173.76 (s, C-1); MS (EI, 80 eV, 113 °C): 339 (9.5), 338 (48.24), 309 (13.5), 296 (16.9), 295 (100), 141 (28.8), 126 (19.2).

Anal. Calcd for $C_{18}H_{26}O_6$ (338.40): C, 63.89, H, 7.74. Found: C, 63.64, H, 7.92.

2,3,5-Tri-*O*-benzyl-D-arabinono-1,4-lactone (11). According to procedure **A** from **10** (10.5 g, 25 mmol)[38] **11** (10.2 g, 96.5%) was obtained: mp 66-68 °C; $[\alpha]_D^{20}$ +7.1° (*c* 1.4, $CHCl_3$); lit: mp 67 °C,[30] 67-68°C,[31] $[\alpha]_D^{20}$ +6.8° (*c* 1.1, $CHCl_3$).[30]

2,3,4,6-Tetra-*O*-benzyl-D-glucono-1,5-lactone (13). According to procedure **A** from **12** (13.5 g, 25 mmol)[32] **13** (12.0 g, 89%) was obtained as an oil: $[\alpha]_D^{20}$ +77.7° (*c* 1.7, $CHCl_3$), lit: $[\alpha]_D^{20}$ +73.2° (*c* 4, $CHCl_3$),[33] +76.7° (*c* 1.35, $CHCl_3$).[39]

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