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Palladium-Catalyzed P-Arylation of Hydrophosphoryl Derivatives of Protected Monosaccharides

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Abstract—Palladium-catalyzed arylation of hydrophosphorylated protected monosaccharides of the pyranose and furanose series gave the corresponding *P*-aryl derivatives.

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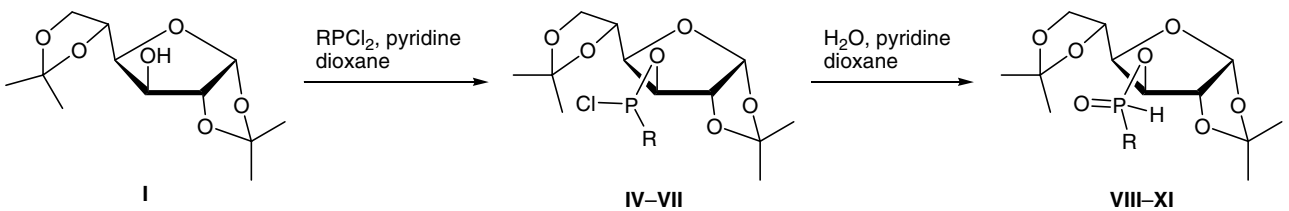
Palladium-catalyzed arylation and vinylation of compounds containing a P–H bond with formation of a new C_{sp^2}–P bond have been extensively studied [1]. These reactions include primarily arylation and vinylation of dialkyl phosphonates [2], and various procedures were proposed to accomplish such processes [3]. Apart from common dialkyl phosphonates, phosphorylated derivatives of thymidine [4] and dinucleoside [5] were used as substrates. Arylation and vinylation were also performed under analogous conditions with alkyl(phenyl)phosphonous acid esters [6] to give aryl(vinyl)phosphinates, as well as with phosphinous acid esters [7] and phosphinous acid itself [8]. Increasing interest in the synthesis of compounds having a C_{sp^2}–P bond via arylation and vinylation of hydrophosphoryl compounds in the presence of copper complexes should also be noted [9].

In the present work we examined the arylation of phosphorylated derivatives of a number of sugars of the pyranose and furanose series having different phosphorus-containing groups: (SugO)P(OR')(O)H, $(SugO)_2P(O)H$, and (SugO)PPh(O)H; these groups turned out to strongly differ in their reactivity. As substrates we used phosphinates and phosphonates derived from the following accessible monosaccharides: 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (**I**), methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside (**II**), and benzoylated mannopyranose **III**.

Phosphorus-containing sugars **VIII**–**XI** and **XIII** were synthesized in two steps. In the first step, the substrate was treated with dichlorophosphine. Intermediate P(III) chlorides were detected by ^{31}P NMR spectroscopy: the spectra contained singlets in the region δ_P 168–174 ppm due to compounds **IV**–**VII** and **XII**. Chlorides **IV**–**VII** and **XII** are very labile, and they were subjected to controlled hydrolysis by addition of an equimolar amount of water to the reaction mixture (Schemes 1, 2). Ethyl 2,3,4,6-tetra-*O*-benzoyl-

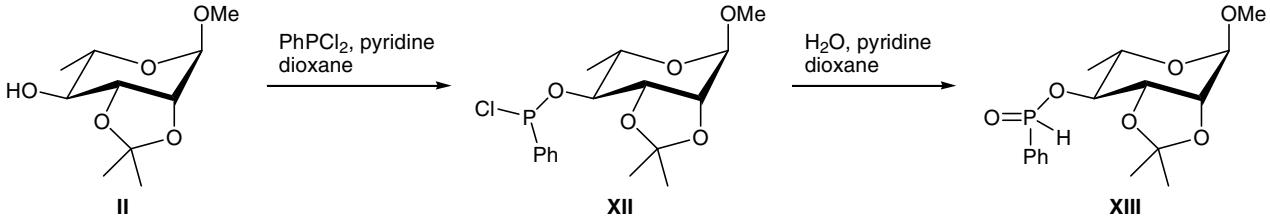
Scheme 1.



I **IV–VII** **VIII–XI**

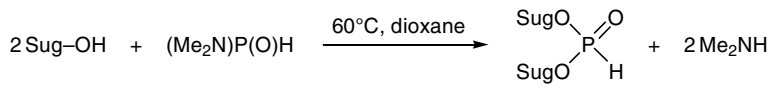
IV, **VIII**, R = EtO; **V**, **IX**, R = BuO; **VI**, **X**, R = *cyclo*-$C_6H_{11}O$; **VII**, **XI**, R = Ph.

Scheme 2.



II **XII** **XIII**

Scheme 3.



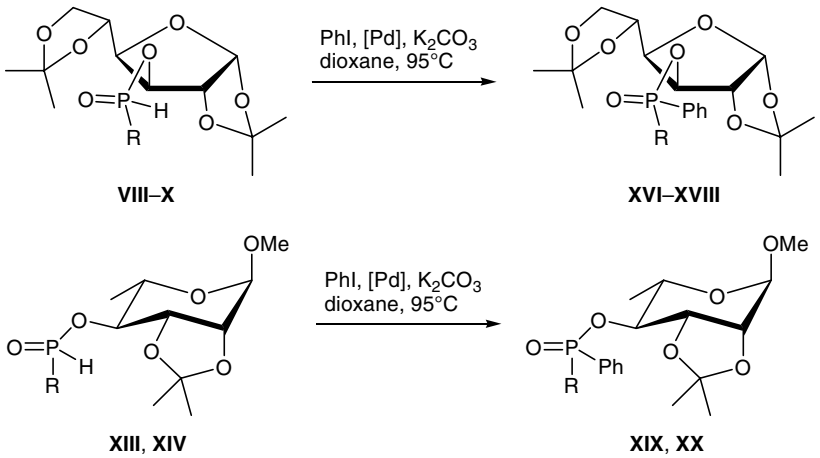
I, **II** **XIV**, **XV**

α-D-mannopyranosyl phosphonate **III** was synthesized by reaction of 2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranozyl hydrogen phosphonate with ethanol in the presence of pivaloyl chloride according to the procedure described in [10]. Diglycosyl phosphonates **XIV** and **XV** were prepared by phosphorylation of monosaccharides **I** and **II**, respectively, with phosphonic bis(dimethylamide) (Scheme 3). Phosphorylated sugars **VIII**–**XI** and **XIII**–**XV** were purified by column chromatography. Compound **III** was subjected to arylation without additional purification. According to the ^{31}P and ^{13}C NMR data, compounds **III**, **VIII**–**XI**, and **XIII** were approximately equimolar mixtures of two diastereoisomers.

Phosphorylated monosaccharide derivatives **III**, **VIII**–**XI**, and **XIII**–**XV** were brought into reaction with iodobenzene in the presence of zero-valent palladium complex. The reactions were carried out under conditions of phase-transfer catalysis (K_2CO_3–$Et_3BzlN^+Cl^-$) at 90–95°C using $Pd(PPh_3)_2Cl_2$ as precursor of Pd(0). The arylation readily occurred with compounds **III**, **VIII**–**X**, and **XIII** (Schemes 4, 5). Usually, the reaction was complete in 3 h; however, the reaction with pyranose derivative **XIII** required only 1.5 h. Sterically more hindered phosphonate **XV** required heating for 5 h at 100°C. The arylation products were formed in ~80% yield (according to the ^{31}P NMR data), and they were isolated in 60–70% yield by column chromatography. In all cases, the reactions were accompanied by partial hydrolysis of the initial phosphorylated monosaccharides, so that the ^{31}P NMR spectra contained signals from the P-arylated hydrolysis products. For example, the ^{31}P NMR spectrum of the reaction mixture obtained from compound **VIII** contained low-intensity signals at δ_P 28.5 and 3.9 ppm [EtO(HO)P(O)Ph and EtO(HO)P(O)H, respectively].

The arylation of butyl glucofuranosyl phosphonate **IX** was also performed under conditions of microwave activation. The application of microwave irradiation to accelerate organic reactions is well known [11]. This

Scheme 4.

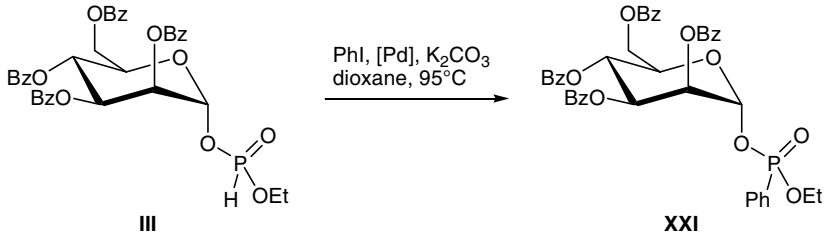


VIII–X **XVI–XVIII**

XIII, **XIV** **XIX**, **XX**

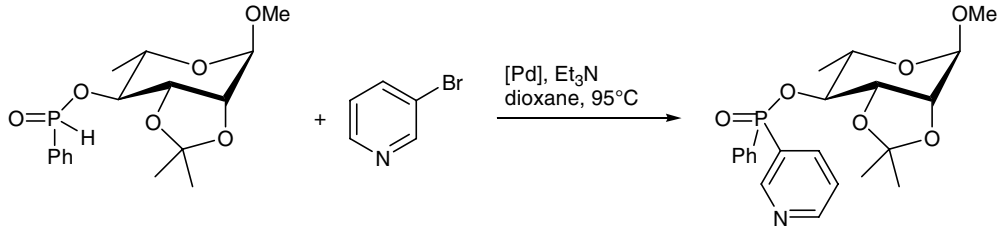
VIII, **XVI**, R = EtO; **IX**, **XVII**, R = BuO; **X**, **XVIII**, R = *cyclo*-$C_6H_{11}O$; **XIII**, **XIX**, R = Ph; **XV**, **XX**, R = SugO.

Scheme 5.



III XXI

Scheme 6.



XIII XXII

technique is also used in the chemistry of organophosphorus compounds [12]. We have found that catalysis by $Pd(PPh_3)_2Cl_2$ in combination with microwave activation makes it possible to strongly shorten the reaction time (from 3 h to 14 min).

Glucofuranosyl derivatives **XI** and **XIV** turned out to be considerably less stable than their pyranose analogs **XIII** and **XV**; their arylation resulted in formation of a mixture of phosphorus-containing products.

Unexpected results were obtained while attempting to effect arylation with different bromopyridines. The reactions were carried out in the presence of $Pd(PPh_3)_4$ using triethylamine as a base. In all cases, except for the reaction with compound **XIII**, the desired P-arylation products were formed in an amount of 3–5%, while the main process was reduction of bromopyridine and formation of (SugO)P(OR')(O)Br (up to 62%, according to the ^{31}P NMR data). By reaction of **XIII** with 3-bromopyridine at 85°C in 50 min we obtained the corresponding arylation product **XXII** in almost quantitative yield (>90%; ^{31}P NMR) (Scheme 6).

On the other hand, compound **XIII** almost failed to react with other hetaryl bromides; in the reaction with 2-bromothiophene, the conversion of **XIII** was as low as 3% in 6 h at 95–100°C, and decomposition of **XIII** was observed.

EXPERIMENTAL

The ^{13}C NMR spectra were measured on a Bruker AC-200 spectrometer at 50.32 MHz. The ^{31}P NMR spectra were recorded on a Bruker WP-80SY instrument at 32.4 MHz and on a Bruker Avance-400 spectrometer at 162 MHz; 85% phosphoric acid was used as external reference. The mass spectra were obtained on a Bruker Autoflex II instrument. Silica gel L (100–160 and 40–60 μm) was used for column chromatography. Analysis by thin-layer chromatography was performed on Silufol UV-254 plates using the following solvent systems: benzene–dioxane, 7:1 (A), 8:1 (B); hexane–dioxane, 3:1 (C), 5:1 (D), 6:1 (E); petroleum ether–dioxane, 2:1 (F); spots were visualized by treatment with iodine vapor and by calcination. All syntheses were carried out in pure dehydrated solvents under dry oxygen-free argon.

Phosphonates VIII–X (*general procedure*). A solution of 1 equiv of monosaccharide **I** and 2.5 equiv of pyridine in 5 ml of dioxane was added dropwise to a solution of 1.1 equiv of the corresponding alkyl phosphorodichloridite in 3 ml of dioxane at a bath temperature of 12°C. The mixture was stirred for 30 min at room temperature, cooled, and a solution of 1.1 equiv of water in 3 ml of dioxane was slowly added in a dropwise manner. The mixture was stirred for 30 min at room temperature and left overnight, the precipitate of pyridine hydrochloride was filtered off, the filtrate was evaporated, and the residue was subjected to column chromatography on silica gel.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(ethyl phosphonate) (VIII) was synthesized from 0.66 g of ethyl phosphorodichloridite, 1.06 g of monosaccharide **I**, 0.81 g of pyridine, and 0.08 g of water. The product was purified by chromatography on silica gel L (100–160 μm) using solvent system B as eluent.

Yield 0.49 g (31%), colorless oily substance, R_f 0.60 (B). ^{13}C NMR spectrum ($CDCl_3$), δ_C, ppm: 15.4 s, 15.5 s ($OCH_2\mathbf{C}H_3$); 24.4–26.2 s [$C(\mathbf{C}H_3)_2$]; 61.2 d, 61.4 d ($O\mathbf{C}H_2CH_3$, $^2J_{PC}$ = 6.5, 7.6 Hz); 66.3 s (C^6); 71.3 s, 71.6 s (C^5); 77.6 d (C^3, $^2J_{PC}$ = 4.8 Hz); 79.6 d, 79.7 d (C^4, $^3J_{PC}$ = 5.0 Hz); 83.0 d, 83.2 d (C^2, $^3J_{PC}$ = 9.7 Hz); 104.4 s, 104.6 s (C^1); 108.0 s, 110.6 s, 108.6 s [$\mathbf{C}(CH_3)_2$]. ^{31}P NMR spectrum ($CHCl_3$), δ_P, ppm: 7.4 d ($^1J_{PH}$ = 715.8 Hz), 8.3 d ($^1J_{PH}$ = 715.8 Hz). Calculated, %: C 47.73; H 7.15; P 8.79. $C_{14}H_{25}O_8P$. Found, %: C 47.49; H 7.05; P 8.61.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(butyl phosphonate) (IX) was synthesized from 0.75 g of butyl phosphorodichloridite, 1.01 g of compound **I**, 0.77 g of pyridine, and 0.08 g of water. The product was purified by chromatography on silica gel L (100–160 μm) using solvent system E as eluent. Yield 0.52 g (35%), colorless oily substance, R_f 0.16 (E). ^{13}C NMR spectrum ($CDCl_3$), δ_C, ppm: 12.6 s ($CH_2\mathbf{C}H_3$); 17.7 s ($CH_2\mathbf{C}H_2CH_3$); 24.2–25.9 s [$C(\mathbf{C}H_3)_2$]; 31.4 s ($OCH_2\mathbf{C}H_2$); 64.7 d ($O\mathbf{C}H_2CH_2$, $^2J_{PC}$ = 7.5 Hz); 66.3 s, 66.4 s (C^6); 71.2 s, 71.5 s (C^3); 77.2 s (C^5); 79.5 d, 79.6 d (C^4, $^3J_{PC}$ = 5.6, $^3J_{PC}$ = 5.1 Hz); 82.9 d (C^2, $^3J_{PC}$ = 9.9 Hz); 104.3 s (C^1); 108.3 s, 111.2 s [$\mathbf{C}(CH_3)_2$]. ^{31}P NMR spectrum (C_6H_6), δ_P, ppm: 8.1 d ($^1J_{PH}$ = 717.6 Hz), 7.2 d ($^1J_{PH}$ = 728.8 Hz). Found, %: C 50.43; H 7.77; P 8.10. $C_{16}H_{29}O_8P$. Calculated, %: C 50.52; H 7.68; P 8.14.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(cyclohexyl phosphonate) (X) was synthesized from 0.86 g of cyclohexyl phosphorodichloridite, 1.02 g of compound **I**, 0.77 g of pyridine, and 0.08 g of water. The product was purified by chromatography on silica gel L (100–160 μm) using solvent system D as eluent. Yield 0.47 g (30%), colorless oily substance, R_f 0.40 (D). ^{13}C NMR spectrum (CCl_4–$CDCl_3$), δ_C, ppm: 22.8 s, 23.5 s ($C^{3'}$); 25.3–25.4 s [$C(\mathbf{C}H_3)_2$]; 26.5 s, 27.0 s ($C^{4'}$); 31.7 s, 33.7 s ($C^{2'}$); 67.4 s (C^6); 72.2 s, 72.5 s (C^5); 75.4 d (C^3, $^2J_{PC}$ = 4.5 Hz); 77.9 d ($C^{1'}$, $^2J_{PC}$ = 4.3 Hz); 80.6 d, 80.7 d (C^4, $^3J_{PC}$ = 5.1 Hz); 84.0 d (C^2, $^3J_{PC}$ = 12.0 Hz); 105.2 s, 105.3 s (C^1); 109.1 s, 111.9 s, 109.2 s, 112.0 s [$\mathbf{C}(CH_3)_2$]. ^{31}P NMR spectrum (CH_2Cl_2), δ_P, ppm: 6.7 d ($^1J_{PH}$ = 705.1 Hz), 5.5 d ($^1J_{PH}$ = 708.7 Hz). Calculated, %: C 53.20; H 7.69; P 7.62. $C_{18}H_{31}O_8P$. Found, %: C 53.02; H 7.49; P 7.52.

Phenylphosphinates XI and XIII (*general procedure*). A solution of 1 equiv of monosaccharide **I** or **II** and 2.5 equiv of pyridine in 5 ml of dioxane was added dropwise over a period of 20–30 min to a solution of 1.1 equiv of phenylphosphonous dichloride in 3 ml of dioxane at a bath temperature of 12°C. The mixture was stirred for 30 min at room temperature and cooled, and a solution of 1.1 equiv of water in 3 ml of dioxane was slowly added dropwise. The mixture was stirred for 30 min at room temperature and left overnight, the precipitate of pyridine hydrochloride was filtered off, the filtrate was evaporated, and the residue was subjected to column chromatography on silica gel.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-phenylphosphinate (XI) was synthesized from 0.80 g of phenylphosphonous dichloride, 1.06 g of monosaccharide **I**, 0.81 g of pyridine, and 0.08 g of water. The product was purified by chromatography on silica gel L (100–160 μm) using solvent system A as eluent. Yield 0.67 g (43%), colorless powder, mp 115–117°C, R_f 0.51 (A). ^{13}C NMR spectrum ($CDCl_3$), δ_C, ppm: 24.9–26.5 s [$C(\mathbf{C}H_3)_2$]; 67.0 s, 67.4 s (C^6); 72.4 s (C^5); 74.0 s, 74.6 s (C^3); 81.1 s, 83.4 s (C^4); 83.5 s, 84.9 s (C^2); 104.8 s, 105.0 s (C^1); 108.9 s, 111.3 s, 109.2 s, 112.2 s [$\mathbf{C}(CH_3)_2$]; 128.4 s, 128.7 s ($C^{3'}$); 130.6 s ($C^{2'}$); 131.3 s ($C^{4'}$); 131.9 d ($C^{1'}$, $^1J_{PC}$ = 153.0 Hz). ^{31}P NMR spectrum ($CHCl_3$), δ_P, ppm: 28.2 d ($^1J_{PH}$ = 578.0 Hz), 26.5 d ($^1J_{PH}$ = 577.3 Hz). Found, %: C 56.15; H 6.66; P 7.98. $C_{18}H_{25}O_7P$. Calculated, %: C 56.25; H 6.56; P 8.06.

Methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside 4-phenylphosphinate (XIII) was synthesized from 0.59 g of phenylphosphonous dichloride, 0.65 g of monosaccharide **II**, 0.59 g of pyridine, and 0.06 g of water. The product was purified by chromatography on silica gel L (100–160 μm) using solvent system C as eluent. Yield 0.28 g (27%), Colorless oily substance, R_f 0.32 (C). ^{13}C NMR spectrum ($CDCl_3$), δ_C, ppm: 18.2 s (C^6); 26.5–28.7 s [$C(\mathbf{C}H_3)_2$]; 54.8 s (OCH_3); 63.9 s, 64.0 s (C^5); 75.9 s, 76.0 s (C^2); 78.3, 78.6 s (C^3); 79.1 d (C^4, $^2J_{PC}$ = 7.2 Hz); 97.7 s (C^1); 109.5 s, 110.0 s [$\mathbf{C}(CH_3)_2$]; 128.5 d, 128.8 d ($C^{2'}$, $^2J_{PC}$ = 7.1, 7.0 Hz); 130.5 s, 130.8 s ($C^{3'}$); 131.0 s, 131.3 s ($C^{4'}$); 132.2 d ($C^{1'}$, $^1J_{PC}$ = 93.4 Hz). ^{31}P NMR spectrum ($CHCl_3$), δ_P, ppm: 26.6 d, 27.1 d ($^1J_{PH}$ = 572.3 Hz). Found, %: C 56.25; P 8.93. $C_{16}H_{23}O_6P$. Calculated, %: C 56.14; P 9.05.

Diglycosyl phosphonates XIV and XV (*general procedure*). Monosaccharide **I** or **II**, 2 equiv, was dissolved in 3 ml of dioxane, 1.3 equiv of phosphonic bis(dimethylamide) was added, and the mixture was heated for 6 h at a bath (glycerol) temperature of 60°C. The solvent was evaporated, and the residue was purified by column chromatography.

Bis(1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose) 3,3'-phosphonate (XIV) was synthesized from 0.94 g of 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose and 0.32 g of phosphonic bis(dimethylamide). The product was purified by chromatography on silica gel L (100–160 μm) using solvent system F as eluent. Yield 0.25 g (12%), colorless oily substance, R_f 0.41 (F). ^{1}H NMR spectrum (C_6D_6), δ, ppm: 1.05–1.34 s [24H, $C(CH_3)_2$], 4.0 m (4H, 4-H, 6'-H), 4.3 m (4H, 5-H, 6-H), 4.8 d.d (2H, 2-H, $^3J_{2,1}$ = 3.4 Hz), 5.2 d (2H, 3-H, $^3J_{HP}$ = 10.1 Hz), 5.8 d and 5.9 d (2H, $^3J_{1,2}$ = 3.4 Hz), 7.0 d (1H, PH, $^1J_{PH}$ = 721.1 Hz). ^{31}P NMR spectrum (C_6H_6): δ_P 7.1 ppm, d.d ($^1J_{PH}$ = 721.1, $^3J_{PH}$ = 10.1 Hz). Found, %: C 50.30; H 7.05; P 4.91. $C_{24}H_{39}O_{13}P$. Calculated, %: C 50.88; H 6.94; P 5.47.

Bis(methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside) 4,4'-phosphonate (XV) was synthesized from 1.11 g of methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside and 0.44 g of phosphonic bis(dimethylamide). The product was purified by chromatography on silica gel L (100–160 μm) using solvent system D as eluent. Yield 0.60 g (24%), colorless oily substance, R_f 0.37 (D). ^{1}H NMR spectrum (C_6D_6), δ, ppm: 1.2 s (6H, C^6H_3), 1.4–1.6 s [12H, $C(CH_3)_2$], 3.03 s and 3.05 s (3H each, OCH_3), 3.7 m (2H, 4-H), 4.1 d.d (2H, 3-H, $^3J_{3,2}$ = 5.5, $^3J_{3,4}$ = 4.3 Hz), 4.2 d.d (2H, 2-H, $^3J_{2,1}$ = 6.1, $^3J_{2,3}$ = 5.5 Hz), 4.4 m (2H, 4-H, $^2J_{HP}$ = 10.5, $^3J_{4,5}$ = 7.3, $^3J_{4,3}$ = 4.3 Hz), 4.8 d (2H, 1-H, $^3J_{1,2}$ = 6.1 Hz), 7.4 d (1H, PH, $^1J_{PH}$ = 713.8 Hz). ^{31}P NMR spectrum (C_6H_6): δ_P 7.1 ppm, d.d ($^1J_{PH}$ = 713.8, $^3J_{PH}$ = 10.5 Hz). Found, %: C 51.0; H 7.54; P 6.91. $C_{20}H_{35}O_{11}P$. Calculated, %: C 49.79; H 7.31; P 6.42.

Palladium-catalyzed arylation of phosphorylated sugars with iodobenzene. An ampule was evacuated, filled with argon, and charged with a solution of 0.26 mmol of compound **III**, **VIII**–**X**, **XIII**, or **XV** in 0.5 ml of dioxane, and 0.04 g (0.29 mmol) of calcined K_2CO_3, 0.004 g (2 mmol %) of $Pd(PPh_3)_2Cl_2$, 0.006 g (0.025 mmol) of benzyltriethylammonium chloride, and 0.051 g (0.25 mmol) of iodobenzene were added in succession. The ampule was sealed, and the mixture was stirred and heated at 90–95°C with intermittent shaking. The ampule was then opened, 1 ml of water and 5 ml of chloroform were added to the mixture, the mixture was stirred, and the aqueous phase was separated and extracted with chloroform. The extracts were combined with the organic phase, dried over calcined Na_2SO_4, and filtered through a thin (~3 mm) layer of silica gel on a glass filter (to remove palladium black), the sorbent was washed with chloroform (2× 6 ml), the solvent was distilled off from the filtrate under reduced pressure, and the oily residue was subjected to column chromatography on silica gel L (40–60 μm).

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(ethyl phenylphosphonate) (XVI) was synthesized from 0.09 g of compound **VIII**. The product was purified by chromatography using solvent system F as eluent. Yield 0.055 g (55%), colorless oily substance, R_f 0.5 (F). ^{31}P NMR spectrum (dioxane), δ_P, ppm: 17.9, 19.5. Found, %: P 7.44 $C_{20}H_{29}O_8P$. Calculated, %: P 7.23.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(butyl phenylphosphonate) (XVII). *a*. Compound **XVII** was synthesized from 0.1 g of phosphonate **IX**. The product was purified by chromatography using solvent system B as eluent. Yield 0.128 g (64%), colorless oily substance.

b. The cross coupling with iodobenzene was carried out in a microwave furnace (2450 MHz, 290 W). The reaction was complete in 14 min. Yield 0.13 g (66%), R_f 0.51 (B). ^{31}P NMR spectrum (dioxane), δ_P, ppm: 17.9, 19.6. Found, %: P 6.60. $C_{22}H_{33}O_8P$. Calculated, %: P 6.79.

1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose 3-(cyclohexyl phenylphosphonate) (XVIII) was synthesized from 0.11 g of compound **X**. The product was purified by chromatography using solvent system B as eluent. Yield 0.07 g (62%), colorless oily substance, R_f 0.56 (B). ^{31}P NMR spectrum (dioxane), δ_P, ppm: 16.5, 17.9. Found, %: P 6.29. $C_{24}H_{35}O_8P$. Calculated, %: P 6.42.

Methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside 4-diphenylphosphinate (XIX) was synthesized from 0.09 g of compound **XIII**. The reaction mixture was heated for 1.5 h at 90–95°C, and the product was purified by chromatography using solvent system F as eluent. Yield 0.073 g (67%), colorless oily substance, R_f 0.51 (F). ^{31}P NMR spectrum (dioxane): δ_P 31.3 ppm. Found, %: P 7.15. $C_{22}H_{27}O_6P$. Calculated, %: P 7.40.

Bis(methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside 4,4'-phenylphosphonate (XX) was synthesized from 0.12 g of compound **XV**. The reaction mixture was heated for 5 h at 100°C, and the product was purified by chromatography on silica gel L (100–160 μm) using solvent system D as eluent. Yield 0.076 g (58%), R_f 0.42 (D). ^{31}P NMR spectrum (dioxane): δ_P 17.74 ppm. Found, %: P 5.16. $C_{26}H_{39}O_{11}P$. Calculated, %: P 5.54.

2,3,4,6-Tetra-*O*-benzoyl-α-D-mannopyranose 1-(ethyl phenylphosphonate) (XXI) was synthesized from 0.14 g (0.2 mmol) of compound **III** (^{31}P NMR spectrum of **III** in $CDCl_3$: δ_P 6.13, 6.85 ppm). The product was purified by chromatography on silica gel L (40–60 μm) using petroleum ether–ethyl acetate (5:2) as eluent (development with UV light). Yield 0.094 g (63%), R_f 0.15 (petroleum ether–ethyl acetate, 5:2). ^{31}P NMR spectrum (dioxane), δ_P, ppm: 16.9, 17.2. Mass spectrum (MALDI-TOF, anthracene matrix): *m*/*z*: 803 $[M + K]^+$.

Methyl 2,3-*O*-isopropylidene-α-L-ramnopyranoside 4-phenyl(3-pyridyl)phosphinate (XXII). A mixture of 0.1 g (0.26 mmol) of compound **XIII**, 0.6 ml of dry oxygen-free dioxane, 0.036 ml (0.26 mmol) of triethylamine, 0.04 g (0.25 mmol) of 3-bromopyridine, and 0.014 g (5 mol %) of $Pd(PPh_3)_4$ was heated for 50 min at 85°C. The mixture was then diluted with 6 ml of anhydrous petroleum ether, the precipitate was filtered off, the solvent was distilled off from the filtrate, and the oily residue was subjected to column chromatography on silica gel (100–160 μm) using benzene–dioxane, 8:2 as eluent. Yield 0.077 g (68%), partially crystallizing oily substance, R_f 0.35. ^{31}P NMR spectrum ($CDCl_3$), δ_P, ppm: 29.32, 31.65. Mass spectrum: *m*/*z* 458 $[M + K]^+$.

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