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SYNTHESIS AND STEREOCHEMISTRY OF 6-DEOXY-6-HALOGENO-D-GLUCOFURANOSE CYCLIC PHOSPHATES

NIKOLAY K. KOCHETKOV, EDUARD E. NIFANT'EV, MICHAIL P. KOROTEEV, ZAUR K. ZHANE, AND ANATOLIY A. BORISENKO

N. D. Zelinsky Institute of Organic Chemistry, Academy of Sciences of U.S.S.R., Moscow (U.S.S.R.)

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ABSTRACT

1,2-*O*-Cyclohexylidene- and 1,2-*O*-isopropylidene-α-D-glucofuranose react with hexa-alkylphosphorous triamides to give the corresponding 3,5,6-phosphites. Treatment of the latter compounds with chlorine and bromine affords 1,2-substituted 6-deoxy-6-halogeno-α-D-glucofuranose 3,5-phosphorohalogenidates. Replacement of halogen at phosphorus by hydroxyl and amino groups has been investigated. Cyclic phosphorohalogenidates isomerize in *N,N*-dimethylformamide. The stereochemistry of the compounds investigated was established by using ^{1}H- and ^{13}C-n.m.r. data.

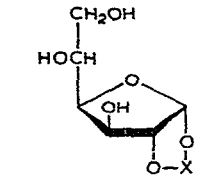
INTRODUCTION

This paper is concerned with the synthesis and stereochemical investigation of a new type of sugar derivative, namely sugar phosphites, which are easily formed by treatment of 1,2-*O*-cyclohexylidene-α-D-glucofuranose (**1**) and 1,2-*O*-isopropylidene-α-D-glucofuranose (**2**) with hexaethylphosphorous triamide.

RESULTS AND DISCUSSION

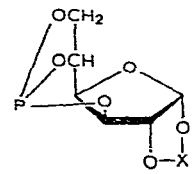
Reaction of **1**[1] and **2** with hexaethylphosphorous triamide proceeds smoothly to give the corresponding crystalline phosphites **3** and **4** in yields of 80–85%. Due to the geometry of the molecules, **3** and **4** are unreactive towards electrophilic reagents. For example, they could not be oxidised to the respective phosphates and did not undergo an Arbuzov reaction with alkyl halides. Treatment of **3** and **4** with chlorine selectively opened the five-membered phosphorus-containing ring to give the corresponding phosphorochloridates **5** and **6**. These reactions probably do not follow the conventional Arbuzov scheme *via* a quasiphosphonium salt, but involve pentacovalent phosphorus. This assumption is favoured by the fact that the ^{31}P-n.m.r. spectrum of each reaction mixture at −75° contains a signal at 24.5 p.p.m. corresponding to pentacovalent phosphorus. This signal disappears on increasing the temperature, with concomitant, pronounced enhancement of the intensity of the

halogen phosphate signal. The phosphorochloridates **5** and **6** are reactive and the phosphorus halogen is smoothly displaced by various nucleophiles. Thus, 6-bromo (**7**) and 6-chloro-6-deoxy-1,2-*O*-isopropylidene-α-D-glucofuranose 3,5-phosphoropiperididate (**9**), 6-chloro-1,2-*O*-cyclohexylidene-6-deoxy-α-D-glucofuranose 3,5-phosphoropiperididate (**8**) and 3,5-phosphoramidate (**10**), and 6-chloro-6-deoxy-1,2-*O*-isopropylidene-α-D-glucofuranose 3,5-phosphate (**11**) were prepared. Removal of the cyclohexylidene or isopropylidene groups of **8a** or **9** with trifluoroacetic acid gave 6-chloro-6-deoxy-D-glucofuranose 3,5-phosphoropiperididate (**12**).



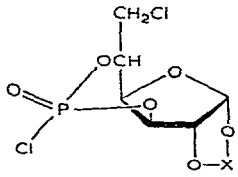
1 X = 

2 X = Me_2C 



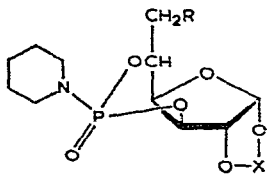
3 X = 

4 X = Me_2C 



5 X = 

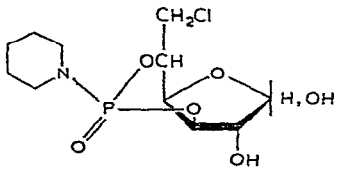
6 X = Me_2C 



7 R = Br, X = Me_2C 

8 R = Cl, X = 

9 R = Cl, X = Me_2C 



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The foregoing phosphorochloridates tended to isomerize. Thus, **5**, obtained as the stereoisomer **5a** (^{31}P, δ +8.0 p.p.m.), gave a new isomer **5b** (^{31}P, δ +17.0 p.p.m.) on dissolution in *N*,*N*-dimethylformamide. The rate and degree of the isomerization was concentration-dependent. In a saturated solution, isomerization was complete within 1 h to give **5a** and **5b** in the ratio 1:2. In dilute solution, the transformation of **5a** into **5b** was almost complete. Addition of piperidine then gave **8b**, which is the geometrical isomer of **8a**. These data confirm earlier results[2] for 2-chloro-2-oxo-1,3,2-dioxaphosphorinanes.

The structure and stereochemistry of the foregoing compounds were investigated by n.m.r. spectroscopy. The resulting ^{13}C-n.m.r. data may be of general value in the stereochemical analysis of other carbohydrates which possess cyclic phosphorus-containing moieties.

^{1}H-N.m.r. spectra were sufficiently simple for first-order analysis. In order to identify the P-H coupling constants, ^{1}H/^{31}P double-resonance was used. Fig. 1 shows the ^{1}H/^{31}P mono- and double-resonance spectra of **3**. The appropriate data

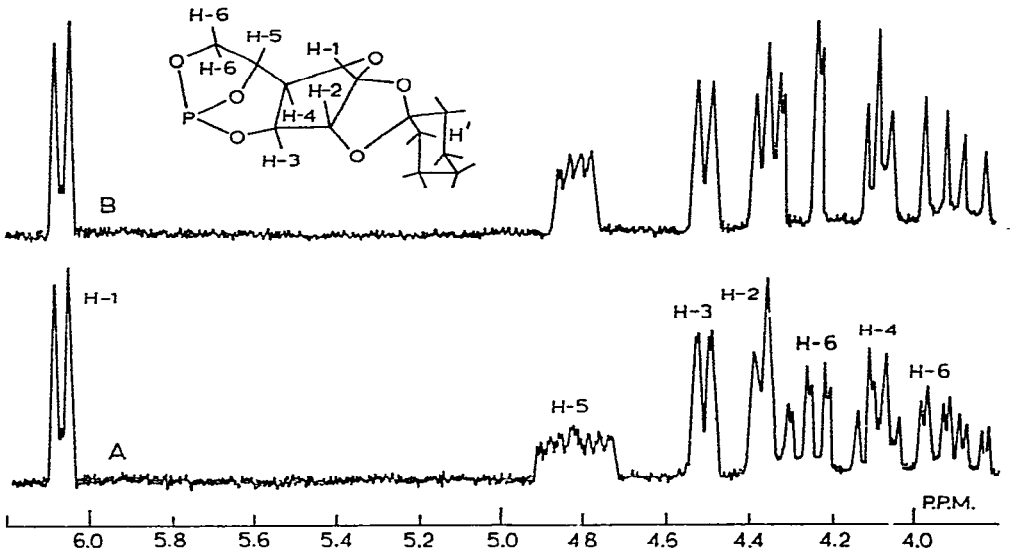


Fig. 1. Partial ^{1}H-n.m.r. spectrum (100 MHz) of **3** in chloroform solution: *A* normal spectrum; *B* spectrum measured with simultaneous irradiation at the ^{31}P-resonance frequency.

are listed in Table I, together with that for the model compound 2,7,8-trioxa-1-phosphabicyclo[3.2.1]octane (**13**), for which the six-membered ring has a chair conformation[3]. A comparison of the H–H and P–H coupling constants for **3** and **13** showed agreement of the parameters for H-4,5,6,6'. Thus, the geometry of the five-membered ring of **3** resembles that of **13**. The differences in the coupling constants involving H-3 were used to estimate the change of the conformation of the six-membered ring in **3**. Using a Karplus-like dependence of the coupling constant ^3J(POCH) on the dihedral angle[3,4], a decrease of the H-3/P coupling of 3 to ~0 Hz (*cf.* 3.5 Hz in **13**) demonstrates an increase in P–O–C–H-3 dihedral angle of up to 90°. This results in an almost planar distribution of O-3, C-3, C-4, and C-5 with non-parallel C-5–O and C-3–O bonds and a twist conformation of the six-membered ring. The H–C–C–H and H–C–O–P dihedral angles measured from Dreiding models are in good agreement with the values found from Karplus-like dependences and confirm the proposed twist conformation of **3**.

The $J_{1,2}$, $J_{2,3}$, $J_{3,4}$, and $J_{4,5}$ values for **5a** and **5b** were similar to those of **3**. Thus, the geometry of the carbohydrate part of **5a** and **5b** was unchanged and there is no inversion of the six-membered ring (Scheme 1, A⇌C); for the inverted ring, $J_{4,5}$ must be 10–12 Hz (*ax–ax* orientation). Hence, the chloromethyl group is axial

TABLE I

$^{1}H^{a}$- AND $^{31}P^{b}$-N.M.R. DATA AND DIHEDRAL ANGLES

	3			5a	5b	8a	13
	δ	Dihedral angles H–C–C–H and H–C–O–P		δ	δ	δ	δ
		Dreiding model	from Karplus equation				
H-1	6.07	—	—	6.02	5.61	6.05	—
H-2	4.51	—	—	4.76	4.28	4.10	—
H-3ax	4.57	—	—	5.08	4.45	4.10	4.21
H-4eq	4.09	—	—	4.54	3.97	4.47	—
H-5eq	4.82	—	—	3.88	4.12	4.76	4.64
H-6	4.28	—	—	3.88	3.62	3.80	4.32
H-6	3.91	—	—	3.88	3.62	3.80	3.86
$J_{1,2}$	3.6	40°	53°	3.7	3.7	3.5	—
$J_{2,3}$	0	100°	90°	0	0	0	—
$J_{3ax,4eq}$	3.0	50°	57°	2.9	2.7	3.3	4.0
$J_{3ax,P}$	0	100°	90°	6.0	1.7	5.6	3.5
$J_{4eq,5eq}$	2.7	80°	58°	2.9	3.3	3.6	2.8
$J_{4eq,P}$	3.9	—	—	2.3	3.6	1.4	3.8
$J_{5eq,6}$	0.7	90°	93°	4.4	6.2	3.6	0.7
$J_{5eq,P}$	9.8	165°	170°	8.2	12.5	3.6	9.6
$J_{6,6'}$	9.2	—	—	—	—	—	8.8
$J_{6,P}$	4.5	135°	—	—	—	—	4.4
$J_{6',P}$	1.6	100°	—	—	—	—	1.7
$\delta(^{31}P)$		−117.0		+8.0	+17.4	0.0	—

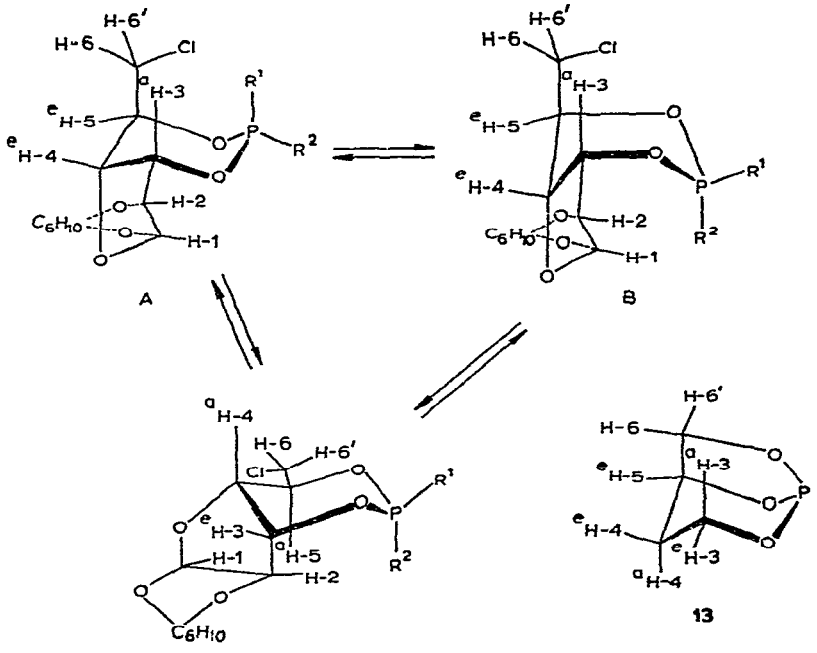
[a]In p.p.m. with respect to Me_4Si; solutions, 10% in $CHCl_3$ (**3**, **5a**, **8a**, **13**) and 10% in *N*,*N*-dimethylformamide (**5b**). [b]In p.p.m. with respect to H_3PO_4; solutions, 10% in *N*,*N*-dimethylformamide (**5a**, **5b**) and 10% in CH_2Cl_2 (**3**, **8a**); **8b** $\delta(^{31}P)$ +10.1 p.p.m.

and the isomerization is accounted for by differences in the phosphorus moiety (Scheme 1, A⇌B).

To establish the conformation of the phosphorus-containing ring, the ^{13}C-n.m.r. data shown in Table II were used. The signals were assigned on the basis of the additivity of the parameters of the various substituents. Unequivocal assignment of the signals for **3** and **5** was performed by means of selective $^{13}C/^{1}H$ double-resonance, together with the use of p.m.r. data.

$^{3}J(^{1}H–^{31}P)$ spin-coupling constants are widely used in conformational analysis, in conjunction with the Karplus-like equation[3,4]. Likewise, we have used $^{3}J(^{13}C–^{31}P)$ spin-coupling constants. A correlation with dihedral angle was first established by using the results for 4,4,6-trimethyl-2*H*-2-oxo-1,3,2-dioxaphosphorinanes[5] and 4-ethyl-2,6,7-trioxa-1-oxo-1-phosphabicyclo[2.2.2]octane[6] (Table III, Fig. 2). On this basis, the values $J_{C-2,P}$ 6.0, $J_{C-4,P}$ 5.8*, and $J_{C-6,P}$ 4.8 Hz

*The dihedral angle is determined by dividing the constant into two, in accordance with the number of ways of spin–spin interaction.



5a $R^1 = O$, $R^2 = Cl$

5b $R^1 = Cl$, $R^2 = O$

8a $R^1 =$  , $R^2 = O$

8b $R^1 = O$, $R^2 =$ 

Scheme 1

correspond to the dihedral angles 145°, 55°, and 46°, respectively, which are consistent with a chair form having the chloromethyl group axial. This result is confirmed by the analysis of the $J_{H-3,P}$ and $J_{H-5,P}$ values on the basis of the known dependence[4].

The corresponding dihedral angles of 163°, 46°, and 32° for **5a** indicate a flattening of the six-membered ring at the phosphorus end, or the presence of a conformational equilibrium between chair and boat forms; the boat form of 1,3,2-dioxaphosphorinanes is associated with only 1 kcal/mol more energy than that of the chair form[8]. Likewise, the data for **8a** and **8b** reveal the similarity of the conformations **5a** and **8a**, and **5b** and **8b**.

We have also used these constants to determine the configuration at phosphorus. This method has been employed to determine the configuration at phosphorus in some isomers of 2(*R*)-4-methyl-1,3,2-dioxaphosphorinanes[9], and reference data for

TABLE II

THE ^{13}C CHEMICAL SHIFTS[a] AND $^{13}C-^{31}P$ SPIN-COUPLING CONSTANTS[b]

	1	3		4		5a		5b		8a		8b		13	
	δ	δ	J	δ	J	δ	J	δ	J	δ	J	δ	J	δ	J
C-1	105.45	106.00	<0.6	106.10	<0.6	104.87	<0.6	105.31	<0.6	105.39	<0.6	104.99	<0.6	—	—
C-2	85.41	84.30	<0.6	84.21	<0.6	81.37	8.2	79.70	6.0	82.98	6.9	83.76	4.3	—	—
C-3	75.02	73.80	2.6	73,32	2.5	85.40	8.2	84.32	12.1	84.72	8.3	84.18	10.0	59.56	1.4
C-4	81.21	78.10	4.4	77.71	4.4	75.78	9.7	75.76	5.8	76.75	7.9	74.60	4.4	32.60	5.2
C-5	70.00	71.98	4.5	71.40	4.5	84.02	9.1	81.72	5.2	77.38	5.4	75.60	4.5	72.20	3.8
C-6	65.03	67.46	6.0	67.01	6.0	44.91	8.6	44.22	4.8	46.10	2.7	45.54	4.2	68.64	5.9
C-1′	113.38	113.19	0	129.0	0	114.43	0	114.10	0	114.25	0	114.12	0	—	—
C-2′	36.02	36.30	0	26.4	0	36.23	0	36.86	0	36.72	0	36.89	0	—	—
C-3′	24.23	24.18	0	26.4	0	24.09	0	25.28	0	25.17	0	25.27	0	—	—
C-4′	25.38	25.44	0	—	—	25.29	0	24.41	0	24.40	0	24.40	0	—	—
C-5′	24.59	24.52	0	—	—	24.44	0	24.07	0	24.10	0	24.10	0	—	—
C-6′	36.80	37.12	0	—	—	36.87	0	36.20	0	36.15	0	36.15	0	—	—

[a]Given in p.p.m. downfield from internal Me_4Si; accuracy ±0.05 p.p.m. Solutions: **1** 20% in pyridine; **3**, **4**, **5a**, **8a**, **8b**, and **13** 20% in CH_2Cl_2; **8b** 20% in *N,N*-dimethylformamide. [b]Given in Hz; accuracy ±0.1 Hz.

TABLE III

DIHEDRAL ANGLE DEPENDENCE OF $^3J(^{13}C-^{31}P)$

θ	J (Hz)	Ref.	Type of atom
0° [a]	12.2[b]	6	CH_2
55.5° [c]	3.0[d]	5	5-CH_2
100° [e]	1.8	5	6-CH_3^{ax}
140° [e]	5.9	5	6-CH_3^{eq}
178° [c]	8.9	5	4-CH_3^{eq}

[a]The value of the angle is determined by the symmetry of the molecule. [b]The experimental value of $^3J(^{13}C-^{31}P)$ is divided into three, in accordance with the number of ways of spin–spin interaction. [c]X-Ray data[7]. [d]The experimental value of $^3J(^{13}C-^{31}P)$ is divided into two, in accordance with the number of ways of spin–spin interaction. [e]From Dreiding models.

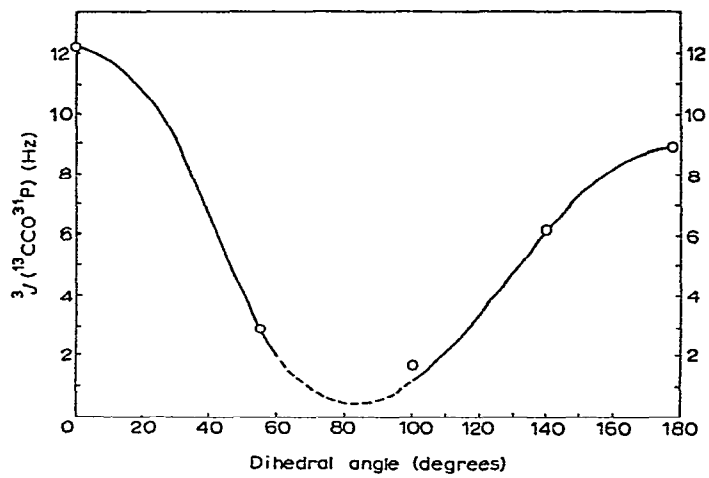


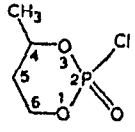
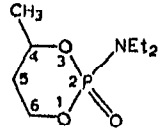
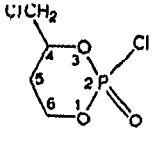
Fig. 2. Plot of coupling constants against dihedral angle.

the *cis* and *trans* isomers of 4-methyl-2-chloro-2-oxo- (**14a,b**) and 4-methyl-2-diethylamino-2-oxo-1,3,2-dioxaphosphorinanes (**15a,b**) are recorded in Table IV; the configuration at phosphorus in these compounds has been established[10,11]. Data are also included for the *trans* phosphorochloridate **16** (the product of ring-scission of **13** by chlorine), the stereochemistry of which is determined by the route of synthesis.

Comparison of the $J_{C-5,P}$ value of *cis*- and *trans*-**14** with the $J_{C-4,P}$ values of **5a** and **5b** (Table II) reveals an identical configuration at phosphorus for the pairs **5b**/*trans*-**14** and **5a**/*cis*-**14**. Comparison of the phosphoramidates reveals an identical configuration for the pairs **8a**/*cis*-**15** and **8b**/*trans*-**15**. Hence, **5a** and **8b** are the *cis* isomers and **5b** and **8a** are *trans* isomers. Thus, replacement of chlorine by piperidine leads to inversion of configuration at phosphorus, which accords with the data obtained on the mechanism of nucleophilic substitution for 2-chloro-2-oxo-1,3,2-dioxaphosphorinanes[2,10,12] and phosphorochloridates of carbohydrates[13].

TABLE IV

^{13}C-CHEMICAL SHIFTS AND ^{13}C-^{31}P COUPLING CONSTANTS

			C-4	C-5	C-6	$CH_3(CH_2Cl)$	$N-CH_2$	$N\cdots CH_3$	$\delta\,^{31}P$
 14	*trans*[a]	δ	81.5	33.7	71.9	22.5	—	—	+2.9
		J	8.1	6.1	7.8	10.6	—	—	
	cis	δ	82.5	33.1	69.8	21.4	—	—	+5.4
		J	8.8	12.6	8.0	3.0	—	—	
 15	*trans*	δ	76.3	33.1	66.6	22.6	39.6	14.6	−3.5
		J	7.0	9.0	6.4	5.1	4.7	2.6	
	cis	δ	74.8	34.8	66.6	23.0	40.25	14.9	−6.6
		J	5.6	4.6	5.6	9.5	5.6	1.6	
 16	*trans*	δ	81.8	29.4	70.2	46.3	—	—	+3.0
		J	7.7	6.1	8.1	12.1	—	—	

[a]The *cis,trans* assignments refer to the orientation of the $CH_3(CH_2Cl)$ and $P-Cl(NR_2)$ groups.

The comparison of ^{31}P-chemical shifts for the isomers of **5** and **8** with those for the model compounds **14** and **15** shows that there is a high-field shift of the resonance signals of >10 p.p.m., which is accompanied by a reversal of the chemical shifts for each pair of isomers. These facts may be accounted for by non-bonded interactions between the phosphorus atom and the substituents at positions 3 and 5. This interaction (γ-effect) is well-known in ^{13}C-n.m.r. spectra[14] and has also been observed in ^{31}P-n.m.r. spectra[15]. The reversal of chemical shifts is explained by a weaker non-bonded interaction for **5a** and **8a**, in the conformation of which the boat form plays an important role.

EXPERIMENTAL

N.m.r. spectra were determined with a Varian XL-100 instrument. Optical rotations were measured with a Perkin–Elmer 141 polarimeter on solutions in dichloromethane unless stated otherwise. Melting points were determined on a Leitz microscope heating-stage and are corrected. All the experiments with trivalent phosphorus compounds were carried out under argon. T.l.c. was performed on Silica Gel L 100/250, using *A* benzene or *B* 3:1 benzene–*p*-dioxane, and detection by charring with sulphuric acid.

1,2-O-Cyclohexylidene-α-D-glucofuranose 3,5,6-phosphite (**3**). — A mixture of **1** (10.4 g) and hexaethylphosphorous triamide (9.8 g) was heated for 2 h at 80–90° with distillation of the liberated diethylamine. The mixture was then kept at 10 mmHg for 0.5 h at the same temperature. Crystallization of the residue from tetrahydrofuran gave **3** (9.8 g, 85%), m.p. 169–170°, $[\alpha]_D^{20}$ +30.5° (*c* 0.3, chloroform); lit.[1] m.p. 169–170°.

1,2-O-Isopropylidene-α-D-glucofuranose 3,5,6-phosphite (**4**). — In a manner similar to that for **1**, **2** (11 g) and hexaethylphosphorous triamide (12.4 g) reacted to give, after crystallisation from toluene, **4** (9.6 g, 81%), m.p. 155–156°, $[\alpha]_D^{20}$ +45° (*c* 0.3)*.

Anal. Calc. for $C_9H_{13}O_6P$: C, 43.5; H, 5.3; P, 12.5. Found: C, 43.8; H, 5.2; P, 12.3.

6-Chloro-1,2-O-cyclohexylidene-6-deoxy-α-D-glucofuranose 3,5-phosphorochloridate (**5a,b**). — A stream of chlorine was passed at −25° through a solution of **3** (1.4 g) in dichloromethane (25 ml) until a green colour appeared. The temperature was then slowly increased to room temperature, the mixture was stirred for 0.5 h, the solvent was then evaporated, and the residue was crystallized from carbon tetrachloride to give **5a** (1.6 g, 90%), m.p. 150–151°, $[\alpha]_D^{20}$ +36° (*c* 0.04).

Anal. Calc. for $C_{12}H_{17}Cl_2O_6P$: C, 40.1; H, 4.7; Cl, 19.8; P, 8.8. Found: C, 40.4; H, 4.7; Cl, 20.0; P, 8.7.

*Editor's footnote: S. Inokawa, K. Seo, H. Yoshida, and T. Ogata, *Bull. Chem. Soc. Jap.*, 44 (1971) 1431, described the preparation of compound **4**, m.p. 155°, $[\alpha]_D$ −24.3° (*N,N*-dimethylformamide), by a different route.

When the reaction was carried out using tetrahydrofuran as solvent and the product was crystallised from chloroform, then **5b** (20%) was obtained; m.p. 180–181°, $[\alpha]_D$ +42° (*c* 0.05).

Anal. Found: C, 40.2; H, 4.7; Cl, 19.9; P, 8.7.

6-Chloro-6-deoxy-1,2-O-isopropylidene-α-D-glucofuranose 3,5-phosphorochloridate (**6**). — In a manner similar to that for **3**, **4** (1.24 g) reacted with chlorine to give **6** (1.4 g, 92%), m.p. 116–117°, $[\alpha]_D^{20}$ +32° (*c* 0.15).

Anal. Calc. for $C_9H_{13}Cl_2O_6P$: C, 33.9; H, 4.1; Cl, 22.3; P, 9.7. Found: C, 33.7; H, 4.1; Cl, 21.9; P, 9.9.

6-Bromo-1,2-O-cyclohexylidene-6-deoxy-α-D-glucofuranose 3,5-phosphoropiperididate (**7**). — A solution of bromine (0.8 g) in dichloromethane (10 ml) was added to a solution of **3** (1.44 g) in the same solvent (20 ml) at −20°, with vigorous stirring. The temperature was slowly increased to room temperature and piperidine (0.86 g) was added. After stirring for 1 h, the solvent was evaporated; the residue was then washed with 0.1M HCl and water, and crystallized from carbon tetrachloride to give **7** (1.5 g, 65%), m.p. 168–169°, $[\alpha]_D^{20}$ +42° (*c* 0.02); R_F 0.06 (solvent *A*) and 0.65 (solvent *B*).

Anal. Calc. for $C_{17}H_{27}BrNO_6P$: C, 41.5; H, 5.9; Br, 12.9; N, 3.9; P, 6.7. Found: C, 41.1; H, 5.7; Br, 12.5; N, 3.9; P, 6.8.

6-Chloro-1,2-O-cyclohexylidene-6-deoxy-α-D-glucofuranose 3,5-phosphoropiperididate (**8a,b**). — Freshly distilled piperidine (0.86 g) was added at 0°, with vigorous stirring, to a solution of **5a** (1.8 g) in dry tetrahydrofuran (15 ml). The mixture was stirred for 1 h at room temperature, the solvent was then evaporated, and the residue was washed with 0.1M HCl and water, and crystallized from carbon tetrachloride to give **8a** (1.4 g, 72%), m.p. 154–155°, $[\alpha]_D^{20}$ +37.5° (*c* 0.02), R_F 0.07 (solvent *A*) and 0.67 (solvent *B*).

Anal. Calc. for $C_{17}H_{27}ClNO_6P$: C, 49.7; H, 6.6; Cl, 8.7; N, 3.4; P, 7.6. Found: C, 49.6; H, 6.6; Cl, 8.8; N, 3.3; P, 7.5.

In a similar manner, **5b** (1.8 g) was converted into **8b** (1.3 g, 72%), m.p. 125–126°, $[\alpha]_D^{20}$ +30° (*c* 0.02). Addition of piperidine to a 10% solution of **5a** in *N,N*-dimethylformamide also gave **8b**. N.m.r. data (^{31}P): +10.1 p.p.m.

Anal. Found: C, 49.6; H, 6.6; Cl, 8.8; N, 3.23; P, 7.5.

6-Chloro-6-deoxy-1,2-O-isopropylidene-α-D-glucofuranose 3,5-phosphoropiperididate (**9**). — In a manner similar to that described for **8a**, **6** (1.24 g) gave **9** (1.5 g, 75%), m.p. 138–140°, $[\alpha]_D^{20}$ +32° (*c* 0.15), R_F 0.1 (solvent *A*) and 0.86 (solvent *B*).

Anal. Calc. for $C_{14}H_{23}ClNO_6P$: C, 45.6; H, 6.5; Cl, 10.0; N, 3.7; P, 8.4. Found: C, 45.8; H, 6.6; Cl, 10.2; N, 3.7; P, 8.8.

6-Chloro-1,2-O-cyclohexylidene-6-deoxy-α-D-glucofuranose 3,5-phosphoroamidate (**10**). — Gaseous ammonia was passed through a solution of **5** (1.8 g) in dry tetrahydrofuran (15 ml) at 0° for 1 h. The solvent was then evaporated, and the residue was washed with water and crystallized from carbon tetrachloride to give **10**

(1.2 g, 56%), m.p. 148–149°, $[\alpha]_D^{20}$ +49.5° (*c* 0.01), R_F 0.08 (solvent *A*) and 0.75 (solvent *B*).

Anal. Calc. for $C_{12}H_{19}ClNO_6P$: C, 42.4; H, 5.6; N, 4.2; P, 9.1. Found: C, 41.9; H, 5.7; N, 4.1; P, 9.2.

6-Chloro-6-deoxy-1,2-O-isopropylidene-α-D-glucofuranose 3,5-phosphate (**11**). — Water (0.02 g) was added to a solution of **6** (0.3 g) and triethylamine (0.1 g) in tetrahydrofuran (15 ml). The mixture was boiled under reflux for 0.5 h, cooled, filtered, and then concentrated, and the residue was dried at 0.1 mmHg for 1 h to give **11** as a colourless oil (0.12 g, 65%), $[\alpha]_D^{20}$ +25° (*c* 0.02).

Anal. Calc. for $C_{19}H_{14}O_7P$: C, 53.8; H, 5.8; Cl, 18.4; P, 20.8. Found: C, 53.5; H, 5.7; Cl, 19.0; P, 20.4.

6-Chloro-6-deoxy-D-glucofuranose 3,5-phosphoropiperididate (**12**). — A solution of **8a** (0.2 g) in 90% trifluoroacetic acid was stirred for 10 min and then concentrated at 10 mmHg. The residue was triturated to crystallisation with dry ether to give **12** (0.15 g, 90%), $[\alpha]_D^{20}$ +3° (*c* 0.05, *N,N*-dimethylformamide).

Similar treatment of **9** also gave **12**.

Anal. Calc. for $C_{11}H_{19}ClNP$: C, 31.2; H, 4.5; N, 3.3; P, 7.3. Found: C, 31.0; H, 4.5; N, 3.3; P, 7.4.

REFERENCES

1 E. E. Nifant'ev and J. M. Petrova, *Zh. Obshch. Khim.*, 40 (1970) 2196–2202.
2 W. Wadsworth, Jr., S. Larsen, and H. Horton, *J. Org. Chem.*, 38 (1975) 256–264.
3 M. Kainosho and A. Nakamura, *Tetrahedron*, 25 (1969) 4071–4081.
4 D. W. White and J. G. Verkade, *J. Magn. Resonance*, 3 (1970) 111–116.
5 A. A. Borisenko, N. M. Sergeyev, E. Ye. Nifant'ev, and Yu. A. Ustynyuk, *Chem. Commun.*, (1972) 406–407.
6 E. G. Finer and R. K. Harris, *Progr. NMR Spectrom.*, 6 (1971) 61–92.
7 W. Saengur and M. Mikolajczyk, *Chem. Ber.*, 106 (1973) 3519–3523.
8 W. G. Bentrude and K. C. Yee, *Chem. Commun.*, (1972) 169–170.
9 E. E. Nifant'ev, A. A. Borisenko, and N. M. Sergeyev, *Dokl. Akad. Nauk SSSR, Ser. Chim.*, 208 (1973) 651–653.
10 R. S. Edmundson, *J. Chem. Soc. Perkin I*, (1972) 1660–1666.
11 J. A. Mosbo and J. G. Verkade, *J. Amer. Chem. Soc.*, 95 (1973) 4659–4665.
12 D. W. White, G. K. McEwen, R. D. Bertrand, and J. G. Verkade, *J. Chem. Soc., B*, (1971) 1454–1461.
13 D. B. Cooper, T. D. Inch, and G. J. Lewis, *J. Chem. Soc. Perkin I*, (1974) 1043–1068.
14 D. M. Grant and B. V. Cheney, *J. Amer. Chem. Soc.*, 89 (1967) 5315–5318.
15 L. D. Quin and J. J. Breen, *Org. Magn. Resonance*, 5 (1973) 17–19.