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CYCLIC ORGANIC DERIVATIVES OF HYPOPHOSPHOROUS ACID[a]

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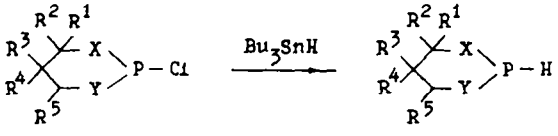
Abstract—2-H-1,3,2-Dioxa-, dithia-, diaza- and oxaazaphosphorinanes have been prepared by reducing corresponding phosphorichloridates; spectral and chemical properties of these compounds have been studied. These compounds were considered as initial members of series when investigating the stereochemistry of heterocycles substituted at the phosphorus. The examination of ^1H, ^{13}C and ^{31}P NMR spectra has shown that substitution of hydrogen at the phosphorus by axial halogen, alkyl, alkoxy and amido-groups is accompanied by shielding of 4,6-C atoms and deshielding of 4,6-axial protons; introduction of an axial Me group into γ-position to the P–H fragment causes a 30–40 ppm up-field shift of the resonance of the phosphorus nucleus.

Organic derivatives of hypophosphorous acid belong to a class of compounds in which only mono-[1–4] and diesters,[5–8] their synthesis and simplest transformations are known. In the present paper dithiol esters, diamides and amidoesters of hypophosphorous acid are described, these being 6-membered cyclic compounds. As cyclic systems are more stable than acyclic ones; this is important for such labile substances as hypophosphorous acid derivatives. Another essential factor is that the cycles under consideration pertain to a novel type of phosphorinanes which are of interest for stereochemical investigations.

I. *Synthesis of* 2-H-1,3,2-*dioxa-, dithia-, diaza- and oxaazaphosphorinanes*

The novel hypophosphorous acid derivatives have been synthesized from phosphorchloridates by reducing the latter with tributyltin hydride (Table 1).



The reaction proceeds easily, the yields are 60–70%. In some cases, however, complications were encountered, associated with difficulties in separating the end products.

II. NMR *spectra of* 2-H-*phosphorinanes*

The structure of the compounds has been confirmed by NMR spectra and chemical properties. In the ^{31}P NMR spectra (Table 2) there is a doublet splitting with the P–H spin-spin coupling constants from 160 to 230 Hz, which is characteristic of a three-coordination atom of P. For IV, V, VII and X two doublet signals correspond to the two geometrical isomers (a and b); for II and IX no second isomer has been observed.

When passing from dioxa- to dithiaphosphorinanes, a substantial up-field shift of the ^{31}P NMR signals takes place into the region characteristic for phosphines. Comparison of the chemical shifts of the P nucleus in the investigated compounds with the electronegativity of the neighbouring atoms shows a dependence close to linear. The proton NMR spectra of the compounds are complicated and in some cases (I–II, VI and X) complete analysis could not be carried out. (Recording of the spectra under the double hetero-nuclear resonance conditions does not lead to sufficient simplification of the spectrum). In the case of III–V, VIII and XI for predominant isomers complete analysis of the PMR spectra has been carried out. The results are presented in Tables 3 and 4.

The data presented in Table 2 show an essential nonequivalence of axial and equatorial protons, which, together with the spin coupling constants (Table 4), indicates that these compounds exist predominantly in a "chair" conformation. The value of the spin-coupling constants of XI indicates the absence of a complete symmetry of the chair, or an increase of the conformational equilibrium of labile forms.

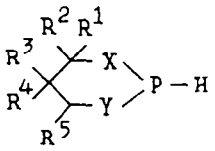
In the ^{13}C NMR spectra of the signals are observed due to all the C atoms in the molecule, split into doublets as a result of the spin-spin interaction with the P nucleus. The assignment of the signals was performed by comparison with the spectra of the known dioxa-, dithia-, diazaphosphorinanes.[10–13] The values of coupling constants $^2J_{CP}$ and $^3J_{CP}$ are typical for the related heterocycles. ^{13}C chemical shifts and coupling constants ^{13}C–^{31}P are given in Table 5.

III. *Stereochemistry of phosphorinanes*

The stereochemistry of phosphorinanes containing in position 1,3 atoms of O, N and S is at present under extensive study.[9–18] Interest in these compounds is due to their high stereochemical originality as compared to cyclohexand derivatives and related heterocycles, particularly, by high axial preference of substituents at the P. In this connection it becomes of special importance to study the influence of various heteroatoms on the

[a]This is a full account of the two preliminary communications (i) *Dokl. Acad. Nauk, USSR* **219**, 881 (1974) and (ii) *Zh Obsch. Khim.* **46**, 1184 (1976).

Table 1. 2H-1,3,2-X,Y-phosphorinanes



No.	X	Y	R^1	R^2	R^3	R^4	R^5
I*	O	O	H	H	H	H	H
II	O	O	CH_3	H	H	H	H
III	O	O	H	H	CH_3	CH_3	H
IV	O	O	CH_3	CH_3	H	H	CH_3
V	O	O	$i\text{-}C_3H_7$	H	CH_3	CH_3	H
VI	S	S	H	H	H	H	H
VII	S	S	CH_3	H	H	H	H
VIII	$N\text{-}tC_4H_9$	$N\text{-}tC_4H_9$	H	H	H	H	H
IX	"	"	CH_3	H	H	H	H
X	$N\text{-}CH_3$	$N\text{-}CH_3$	CH_3	H	H	H	H
XI	$N\text{-}i\text{-}C_3H_7$	O	H	H	H	H	H

*) Compound I exists only in tributylstannane solution.

balance of vicinal interactions of unshared electron pairs, this balance being, evidently, responsible for the axial preference in 1,3,2-dioxaphosphorinanes.[14]

In each series of the heterocycles there is an initial member, i.e. a compound having an H atom at the P, in other words, a corresponding derivative of hypophosphorous acid. Many stereochemical regularities in the NMR spectra have been established, as a rule, by comparing the spectral parameters of the substituted and of the initial members of the series. For instance, cyclohexane is a "reference point" in determining the increments of substituents for calculating chemical shifts of ^{13}C in accordance with an additive scheme for cyclohexane derivatives.[19] The study of the ^{13}C NMR spectra of cyclohexanes has shown α, β and γ-effects of substituents to be promising for stereochemical investigations, particularly as regards the γ-effect, the nature of which is now discussed.[21-24]

The configuration at P in 2-H-1,3,2-dioxaphosphorinanes was studied by Stec *et al.*[9] The hydrogen at P was shown to occupy predominantly an axial position. Quantitative estimates of the axial preference of the hydrogen have been made on IV and V. Equilibrium relation of the thermodynamically more stable and less stable isomers (close to the relation of the forms with the axial and equatorial orientation of H at the P) amounts to 62:1 and 82:1, which gives $G^0_{25} = -2.6$ kcal/mole. The value obtained is close to the conformation energy of other substituents at the P (Me, OMe),[14,29] and hence, it is determined by the equatorial preference of the unshared electron pair of the phosphorus.

Having at our disposal the initial members i.e. the hypophosphorous acid derivatives, we have successively studied the influence of H substitution at the P on the chemical shifts of ^1H, ^{13}C and ^{31}P nuclei with a view to establishing stereochemical regularities which could furnish a basis for further study of the structure and conformations of P-containing heterocycles.

γ-Effects in ^{13}C spectra. Comparison of chemical shifts of $C_{4,6}$ of P-substituted 1.3-2-dioxaphosphorinanes with those of 2-H-1,3,2-phosphorinanes makes it possible to determine γ-effects of the substituent at the P (Table 5). In the series of 4-Me-2-R-1,3,2-dioxaphosphorinanes it is shown that for R=Cl, OMe, Me *trans*-isomers with the axial orientation of the substituent at the P atom are thermodynamically more stable, while for R=NMe_2 thermodynamically more stable are *cis*-isomers with the equatorial orientation of the substituent.[14,17,25] Thermodynamically less stable isomers are conformationally heterogeneous systems.[25] As can be seen from the data presented in Table 5, for 1,3,2-dioxaphosphorinanes the substitution of H at the P by Cl, F, Me, OME, NMe_2 groups is accompanied by a 6.5–13.7 ppm up-field shift of C_4 and C_6 (γ-effect). The value of the C_4 shift for *trans*-isomers with the axial orientation of the substituent at the P is 1.3–7 ppm greater than that for *cis*-isomers. A high γ-effect is also observed for the C_6 atom; in a number of cases this effect in the *cis*-isomer is complemented by the γ-effect of the 4-Me group. A similar manifestation of the γ-influence of the substituent at the P is displayed in other series of phosphorinanes as well, which may be considered as an argument in favour of the statement that thermodynamically more stable isomers of 4-Me-2R-1,3,2-dithia-, diaza-, oxaaza-

Table 2. Parameters of P–H bonds in ^{31}P and ^{1}H NMR spectra

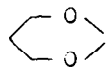
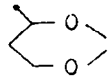
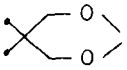
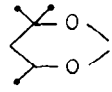
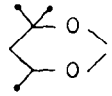
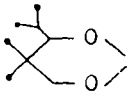
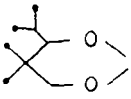
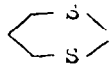
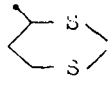
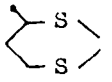
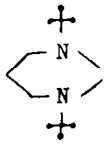
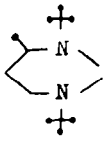
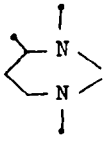
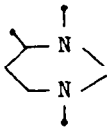
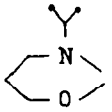
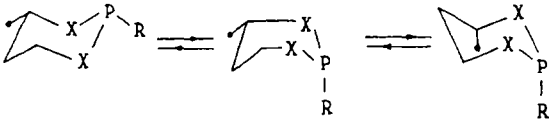
No.	Compound	$\delta_{^{31}P}$, ppm from 85% H_3PO_4	$^{1}J_{PH}$, Hz ±0.02 Hz	δ_{PH}, ppm from TMS ±0.01 ppm
1	2	3	4	5
I		+154.0	169.0	7.08
II		+149.2	169.4	7.02
III		+147.3	168.7	6.97
IVa		+119.1 (98.4%)	164.2	7.24
IVb		+105.4 (1.6%)	158.1	7.39
Va		+151.9 (98.8%)	166.0	7.02
Vb		+131.8 (1.2%)	164.2	7.14
VI		-1.5	203.0	6.41
VIIa		-4.5 (92.7%)	204.0	6.28
VIIb		-45.3 (7.3%)	201.0	6.52
VIII		+49.6	214.0	5.70
IX		+12.7	229.0	6.00
Xa		+82.2 (81%)	192.0	-

Table 2. (*Contd*).

1	2	3	4	5
Xb	 P–H	+47.3 (19%)	202.5	–
XI	 P–H	+112.0	201.0	7.0

phosphorinanes have a predominantly axial orientation of the substituent at the P.

Additional shielding of C atoms in accordance with the γ-effect rule manifests itself also when an axial Me group is present in position 4. For instance, in the *cis*-isomer of 4-Me-2-methoxy-1,3,2-dioxaphosphorinane the value of the γ-effect on C_6 for the *cis*-isomer exceeds this value for the *trans*-isomer. This is associated with an additional γ-effect on C_6 from the 4-Me group in the diaxial conformation, which makes a considerable contribution to the conformation equilibrium.[29] A similar difference in the γ-effects is observed for *cis*-isomers in the series of 4-Me-1,3,2,-dithia- and 4-Me-N,N-dimethyl-1,3,2-diazaphosphorinanes. Probably, the conformation state of the *cis*-isomers of all the above-cited compounds is close and can be expressed in the following general form:



X = O, $N(CH_3)$, S

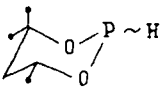
Of particular interest is the analysis of the γ-effect of the 4-Me group in the series of diazaphosphorinanes with *t*-Bu substituents at the N. Evidently, a Me group is predominantly axially oriented in both isomers because of steric hindrances created by two equatorial t-Bu radicals.

In addition to the influence of axial substitution on the chemical shifts of ^{13}C, in the configuration analysis one must exercise caution when using the γ-rule, since the γ-effect value cannot be the only reliable criterion of differences in the orientation of the substituents.[21–24] In Table 6 are the values of γ-effects from the same substitutnts at the P atom for acyclic compounds and similar cyclic compounds. A series of 4-Me-2-R-1,3,2-dioxaphosphorinanes is taken for the sake of comparison. The values of γ_{C_1} in the non-cyclic series are also sufficiently great and they are close to the mean arithmetic value of the γ-effects for the *cis*- and *trans*-isomers of the corresponding phosphorinane. Probably, it is reasonable to consider only the difference between the γ-effects in the structures when applying the γ-rule in the configuration assignment:[26]

$$\Delta\gamma_{C^4} = \gamma_{C^4 trans} - \gamma_{C^4 cis}$$

Chemical shifts of ^{31}P NMR. Analysis of the data presented in Table 2 shows that the predominant *trans*-isomers of IV, V, VII and IX have a stronger down-field shift than the *cis*-isomers, i.e. an inversion of shifts is observed, compared with the isomers of P-substituted compounds.

The influence of the substitution of H at the P by Cl, OR and NR_2 groups on the chemical shifts of ^{31}P has been studied on derivatives of IV (Table 7). The results show that in all cases of P–H→P–R substitution an up-field shift takes place, i.e. the γ-effect is negative. This is, at least, opposite to the direction of the ^{31}P shift in phosphines in case of Me substitution and also in the ^{13}C NMR spectra for the same substituents. Structural changes in the cycle, as a rule, influence but little the chemical shifts of ^{31}P in 2-R-phosphorinanes, but in contrast, 2-H-phosphorinanes proved to be extremely sensitive to such changes. Analysis of the ^{31}P NMR spectra (Table 2) shows that these changes produce maximum effect if they occur in accordance with the γ-effect rule. Thus, in the series of dioxaphosphorinanes only the transition from I to IV is accompanied by a considerable change of the resonance conditions of the P nucleus, since in both isomers one of the 4-Me groups always has to be in the axial position ($\Delta\delta \geq 30$ ppm).



No other transitions (of the type I→II, III, V) where there is no predominant axial γ-substituent can lead to a greater change in the shielding of the P nucleus. A similar change of $\delta^{31}P$ occurs in Me substitution in the predominant isomer of 4-Me-1,3-di-t-Bu-2-H-1,3,2-diazaphosphorinane because of the axial orientation of the 4-Me group and also in the minor isomer of 4-Me-2-H-

Table 3. Chemical shifts of ^1H NMR in ppm (± 0.01 ppm) from TMS

No.	H_a^5	H_e^5	H_a^4	H_e^4	H_a^6	H_e^6	$4CH_3$	$5CH_3^a$	$5CH_3^e$	Solvent	Notes
II	1.96	1.60	3.77	–	3.77	4.25	1.21	–	–	pure	compd. is described in [9]
III	–	–	3.42	3.81	3.42	3.81	–	1.17	0.66	pure	
IV	1.70	1.52	–	–	3.92	–	1.32^a 1.28^e	–	–	pure pure	$6CH_3^e$ 1.18
V	–	–	3.26	–	3.40	3.71	–	1.17	0.74	pure	$CH_3^I = 1.00$ $CH_3^{II} = 0.98$ $\rangle CH- = 1.94$
VII	1.79	2.12	2.92	–	2.96	3.10	1.20	–	–	30% benz.	
VIII	1.86	1.52	2.92	3.51	2.92	3.51	–	–	–	pure	$C(CH_3)_3 = 1.26$
IX	1.87	–	–	3.36	3.04	3.00	–	–	–	pure	$C(CH_3)_3 = 1.22$
XI	1.87	1.10	2.96	2.96	3.50	4.13	–	–	–	pure	$\rangle CH- = 3.27$ $C(CH_3)_3 = 1.04$

Table 4. Spin-spin coupling constants of H–H and P–H (±0.2 Hz)

	4a4e	5a5e	4a5a	4a5e	4e5a	4e5e	4aP	4eP	5eP	5aP	6a6e	5a6a	5a6e	5e6a	5e6e	6eP	6aP
II[1]	–	-14.2	*	*	–	–	*	–	2.5	1.2	-11.2	11.5	4.3	2.4	2.0	7.3	3.8
III	-10.8	–	–	–	–	–	3.7	7.3	–	–	-10.8	–	–	–	–	7.3	3.7
IV[2]	–	-14.0	–	–	–	–	–	–	3.1	0.7	–	10.2	–	3.1	–	–	3.0
V[3]	–	–	–	–	–	–	4.0	–	–	–	-10.8	–	–	–	–	7.4	3.7
VII	–	-14.6	10.6	2.3	–	–	<0.3	–	9.4	3.0	-13.6	*	4.3	*	4.3	2.2	<0.3
VIII[4]	-13.0	-12.8	11.6	3.0	4.2	3.3	2.6	3.4	0.6	<0.3	–	–	–	–	–	–	–
IX	–	-13.0	–	–	5.2	3.5	–	4.5	*	*	*	*	*	*	*	3.2	<0.3
XI	-13.8	-13.6	12.8	2.6	3.6	2.6	1.9	1.9	<0.5	0.9	-11.0	12.2	4.3	2.3	2.0	7.4	4.2

1. $^{4}J_{4e-6e} = 2.5$ Hz; $J_{4a-CH_3^a} = 0.8$ Hz

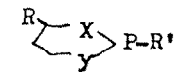
2. $J_{5a-4CH_3^a} = 0.6$ Hz; $J_{5e-CH_3} \simeq 0$ Hz; $^{4}J_{4CH_3^e-4CH_3^a} = 0.5$ Hz; $^{3}J_{6a-6CH_3} = 6.15$ Hz

3. $^{3}J_{4a-CH(CH_3)_2} = 3.3$ Hz; $J_{CH-CH_3'} = 0$ Hz; $J_{CH-CH_3} = 6.8$ Hz

4. $^{4}J_{P-N-C-CH} = 1.8$ Hz

* – constants are not determined

Table 5. Chemical shifts of ^{13}C, spin-spin interaction constants of ^{13}C–^{31}P. γ-Effects of phosphorus substituent on chemical shifts of ^{13}C in ppm



No.	R	R'	X	Y	para-meter	C_4	C_5	C_6	4–CH_3	γ-eff. of R substitution		Effects of methyl substitution		
										C_4	C_6	α C_4	β C_5	γ C_6
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	H	H	O	O	δ	72.60	-	72.60		0	0	0	0	0
					γ	4.6		4.6						
	H	Cl	O	O	δ	62.7	28.9	62.7	-					
					γ	2.6	5.3	2.6	-					
	H	OCH_3	O	O	δ	59.5	29.4	59.5	-					
					γ	1.6	5.5	1.6	-					
	CH_3	H	O	O	δ	79.6	37.2	72.6	24.1	0	0	7.0	-	0
					γ	4.8	4.8	5.4	1.2					
	CH_3	Cl	O	O	δ	69.6	35.8	62.7	22.9	-9.9	-9.9	6.9	6.9	0
					γ	3.0	4.5	3.7	2.8					
	$CH_3^{(a)}$	OCH_3	O	O	δ	65.8	36.5	59.8	23.4	-13.7	-12.8	6.3	7.1	0.3
					γ	3.6	4.7	2.5	3.2					
	$CH_3^{(b)}$	OCH_3	O	O	δ	69.8	33.9	59.0	23.4	-9.7	-13.6	10.3	4.5	-0.5
					γ	3.6	10.8	1.8	1.6					
	CH_3	F	O	O	δ	67.7	35.7	61.1	22.9	-11.8	-11.5			
					γ	2.2	5.1	2.6	3.4					

Table 5. (*Contd*).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	$CH_3^{(a)}$	H	O	O	α γ	66.0 5.0	37.2 4.4	60.3 5.5	24.2 2.8	-13.5	-12.3			
	$CH_3^{(b)}$	H	O	O	α γ	73.0 5.3	37.0 9.9	65.7 5.2	24.1 7.0	-6.5	-6.9			
	$CH_3^{(a)}$	$N(CH_3)_2$	O	O	α γ	66.8 3.0	36.1 5.8	60.3 2.0	23.5 3.4	-12.7	-12.3			
	$CH_3^{(b)}$	$N(CH_3)_2$	O	O	α γ	71.2 6.2	36.1 9.9	63.9 6.2	23.8 5.8	-8.3	-8.7			
	H	OC_2H_5	N-CH_3	N-CH_3	α γ	45.5 6.4	26.3 0.5	45.5 6.4						
	H	$(C_2H_5)_2$	N-CH_3	N-CH_3	α γ	47.6 3.0	27.3 0.5	47.6 3.0						
	CH_3	H	N-CH_3	N-CH_3	α γ	59.6 8.7	30.8 1.5	57.7 8.4	0	0	0			
	$CH_3^{(a)}$	OC_2H_5	N-CH_3	N-CH_3	α γ	48.2 6.2	33.7 1.0	46.3 5.8		-11.4	-11.4	2.7	7.4	±0.8
	$CH_3^{(b)}$	OC_2H_5	N-CH_3	N-CH_3	α γ	52.1 8.0	32.4 1.0	42.4 6.5		-7.5	-15.3	6.6	6.1	-3.1
	$CH_3^{(a)}$	$(C_2H_5)_2$	N-CH_3	N-CH_3	α γ	50.8 6.4	34.6 1.0	47.7 5.6		-8.8	-10.0	3.2	7.3	+0.1
	$CH_3^{(b)}$	$(C_2H_5)_2$	N-CH_3	N-CH_3	α γ	54.3 0.7	35.2 1.2	49.1 3.7		-5.3	-8.6	6.7	7.9	+1.5
	H	H	N-tBu	N-tBu	α γ	49.7 7.1	30.7 0.6	49.7 7.1	-	0	0	0	0	0
	H	Cl	N-tBu	N-tBu	α γ	40.1 5.5	26.7 1.0	40.1 1.0	-	-9.3	-9.3			
	H	OC_2H_5	N-tBu	N-tBu	α γ	38.7 3.9	28.4 0.6	38.7 3.9		-10.7	-10.7			

Table 5. (*Contd*).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	CH_3	H	N-tBu	N-tBu	δ	46.8	35.1	43.3	19.4	0	0	-2.9	4.4	-6.4
					J	5.3	0.6	6.0	0.6					
	CH_3	Cl	N-tBu	N-tBu	δ	46.7	30.5	36.3	21.8	-0.1	-7.0	6.3	3.5	-4.1
					J	8.9	2.0	5.6	4.2					
	$CH_3^{(a)}$	OC_2H_5	N-tBu	N-tBu	δ	46.7	35.1	35.8	24.8	-0.1	-7.4	7.7	6.4	-3.1
					J	5.0	0.6	4.5	0.6					
	$CH_3^{(b)}$	OC_2H_5	N-tBu	N-tBu	δ	46.3	31.9	35.9	22.6	-0.5	-7.4	7.3	3.2	-3.1
					J	7.9	5.2	4.7	1.7					
	H	H	S	S	δ	34.0	27.6	34.0	-	0	0	0	0	0
					J	10.5	0.7	10.5						
	H	Cl	S	S	δ	24.8	25.3	24.8	-	-9.2	-9.2	-	-	-
					J	14.6	1.7	14.6						
	H	OC_2H_5	S	S	δ	25.1	27.1	25.1		-8.9	-8.9			
					J	13.9	1.0	13.9						
	CH_3	H	S	S	δ	43.9	36.7	36.5	26.3	0	0	9.9	9.1	2
					J	9.4	1.2	9.2	4.3					
	$CH_3^{(a)}$	Cl	S	S	δ	35.9	35.4	28.7	25.8	-8.0	-7.8	11.1	10.1	3.9
					J	13.6	1.7	13.6	3.8					
	$CH_3^{(b)}$	Cl	S	S	δ	39.3	31.7	22.8	25.1	-4.6	-13.7	14.5	6.4	-2.0
					J	13.0	1.2	12.8	1.2					
	$CH_3^{(a)}$	OC_2H_5	S	S	δ	33.9	35.7	26.7	25.3	-10.0	-9.8	8.8	8.6	1.6
					J	14.0	1.5	13.8	3.6					
	$CH_3^{(b)}$	OC_2H_5	S	S	δ	37.1	33.0	22.2	24.7	-6.8	-14.3	12.0	5.9	-2.9
					J	11.3	1.3	12.1	0.5					
	H	H	N-iPr	O	δ	48.6	29.8	73.1	-	0	0	0	0	0
					J	5.4	4.2	6.4						
	H	Cl	N-iPr	O	δ	38.2	27.4	63.2	-	-10.4	-5.9	-	-	-
					J	5.2	1.8	4.4						
	H	OC_2H_5	N-iPr	O	δ	37.3	28.6	59.6	-	-11.3	-13.5			
					J	4.0	1.6	2.8						

* - Data are given for ring carbon atoms only.
** - Absence of β-effect on C_4 is, probably, associated with the presence of axial methyl group in this position
(a) and (b) - geometrical isomers

Table 6. γ-Effects of phosphorus substituent in cyclic and acyclic compounds

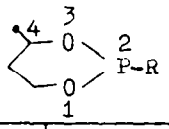
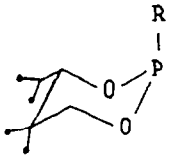
R	$(CH_2CH_3O)_2PR$			
	δ_{C^1}	δ_{C^1}	δ_{C^4} trans	δ_{C^4} cis
H	69.0	0	0	0
Cl	61.5	-7.5	-9.9	-
F	58.6	-10.2	-11.8	-
OCH_2CH_3	58.0	-11.0	-13.7	-9.9
CH_3	61.9	-7.1	-13.5	-6.5
$N(C_2H_5)_2$	58.9	-10.1	-12.7	-8.3

Table 7. Influence of substitution of hydrogen at phosphorus on chemical shifts of ^{31}P NMR

(α-effect) 

R	δ_{P^*}		α-effect	
	cis	trans	cis	trans
H	131.8	151.9		0
Cl	-	151.3		-0.6
OCH_3	132.8	127.1	-19.1	-24.8
OC_2H_5	133.1	126.1	-18.8	-25.8
$N(CH_3)_2$	144.9	136.4	-7.0	-15.5

*) Within δ-scale, i.e., down-field from H_3PO_4.

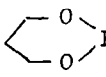
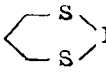
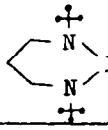
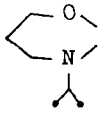
1,3,2-dithiaphosphorinane, for the reason described. Thus, γ-effect manifests in the serise of 2-H-phosphorinanes and on the nucleus of ^{31}P.

Change of chemical shifts of ^1H *as a consequence of* γ-*effect.* After the change in shielding of the recorded nuclei of ^{13}C and ^{31}P, if it is the consequence of the electron density redistribution in the C–H and P–H bonds, one should expect corresponding changes in δ^1H as well. Shielding of ^{13}C and ^{31}P will be accompanied by deshielding of the H atoms bonded with them.[27] Though the change of shielding is not directly related with the change of the electron density, factual data on such relationship in chemical shifts have been reported.[19,27]

In a number of 6-membered saturated heterocycles, equatorial protons have been shown to resonate down-field compared with the axial ones.[28] Contrary to the case of cyclohexanes and 6-membered saturated heterocycles, in the series of P-substituted phosphorinanes the fact of down-field arrangement of axial protons was established.[12–16] At the same time for 4-Me-2-H-1,3,2-dioxa-[9] and for 1,3-di-t-Bu-2-H-1,3,2-diazaphosphorinanes[13] the arrangement of the axial and equatorial protons was shown to be the same as for cyclohexane, though this phenomenon was not discussed.

Since we had phosphorinanes containing at the P atom both hydrogen and various substituents, we studied the chemical shifts of protons for C_4 and C_6. The results are presented in Table 8. Not only does the general

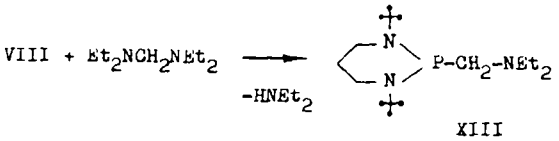
Table 8. ^1H Chemical shifts in ppm of different phosphorinanes

Phosphorinane	R	H_4^a	H_6^a	H_6^e	H_4^a	H_6^a	H_6^e
	H	3.85	3.77	4.25	0	0	0
	Cl	4.80	4.69	4.07	0.95	0.92	-0.18
	CH_3	4.39	4.29	3.92	0.49	0.52	-0.33
	OCH_3	4.55	4.44	3.79	0.70	0.67	-0.46
	H	-	2.12	2.91	-	0	0
	Cl	-	3.62	2.28	-	1.50	-0.63
	OC_2H_5	-	3.39	2.61	-	1.27	-0.30
	H	-	2.92	3.51	-	0	0
	OC_2H_5	-	3.23	2.82	-	0.31	-0.69
	H	2.96	3.50	4.12	0	0	0
	Cl	2.87	4.29	3.55	-0.09	1.26	-0.57
	$N(CH_3)_2$	2.29	4.01	3.55	0.33	0.51	-0.57

regularity of deshielding the sterically perturbed axial protons hold, but the phenomenon of inversion of the chemical shifts of the axial and equatorial protons is observed: for P-hydrides up-field resonance is displayed by the axial protons and for P-substituted compounds, by the equatorial ones. A similar change occurs in the PMR spectrum for the protons bonded with the perturbed P nucleus. The data presented in Table 2 indicate that in all the cases where the γ-effect from the Me group on the P nucleus (30–40 ppm) is recorded (transitions I→IV; VI→VIIb, VIII→IX), proton deshielding by the value $\Delta\delta \approx 0.1$–0.3 ppm is observed.

IV. *Chemical properties of* 2-H-1,3,2-*diazaphosphorinanes.* We have investigated the chemical properties of the novel derivatives of hypophosphorous acid using 2-H-1,3,2-diazaphosphorinanes, containing an interesting structural fragment, namely, a trivalent P atom bonded simultaneously with the amido group and with the H atom. For these compounds one should expect reactions typical for P-H and P-N groups.

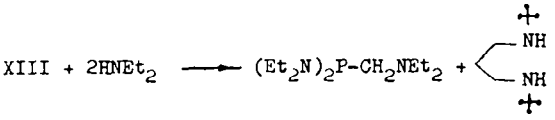
Addition of methacrylate to the activated C=C bond has shown an increased reactivity of hypophosphorous acid diamedes as compared to secondary phosphines and dialkylphosphites: the addition taking place either upon slight heating to 60° during 2–3 hr or at room temperature during 12 hr. The addition proceeds contrary to Markovnikoff's rule.



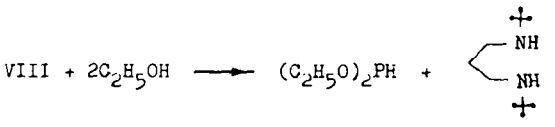
XIII

The addition products were distilled in vacuum and were characterized by high chromatographic mobility on aluminium oxide and were easily oxidized in air. This reaction offers a synthesis of functionally substituted phosphorous acids which cannot be obtained by known methods.

Compounds VIII and IX react with aminals; aminomethylation along the P–H bond in this case is accompanied by a partial reamidation of hypophosphorous acid diamide and two α-aminophosphonates of a cyclic and acyclic strucutre are formed in a ratio of 1:1.



In order to elucidate the phosphorylating capacity of hypophosphorous acid diamides, we conducted an alcoholysis of 2-H-1,3,2-diazaphosphorinane with ethyl alcohol:



The reaction proceeded easily, with a small exothermal effect; the resultant diethoxyphosphine was stable only in solution and therefore its presence was determined from the ^{31}P spectra of the reaction mixture. The doublet of P–H bond of the initial compound with δ_{31P} = 49.5 ppm was fully transformed into a similar doublet down-field, $\delta_{31P} = +160$ ppm and J_{PH} 170 Hz, which

characterized the P–H fragment of the diethoxyphosphine.

EXPERIMENTAL

All the syntheses were carried out in dry, deoxygenated argon. ^1H, ^{13}C and ^{31}P NMR spectra have been recorded on a Varian XL-100-15 spectrometer; chemical shifts of ^1H and ^{13}C are given down-field from the TMS ^1H and ^{13}C signals. ^{31}P shifts are given in ppm down field from 85% H_3PO_4.

5,5-Dimethyl-2-H-1,3,2-dioxaphosphorinane (III). To 8 g (0.047 g mol) of 5,5-dimethyl-2-Cl-1,3,2-dioxaphosphorinane 28 g (0.094 g mol) of tri-n-butylstannane were added and the mixture heated for 4 hr at 100° and then distilled. The yield is 4.7 g (75%); b.p. 36–37°/1 mm; n_D^{20} 1.468; δ_{31_P} 147.3 ppm; J_{PH} 166 Hz. Elementary analysis is given for the addition product of sulphur to III: (Found: C, 36.81; H, 6.72; P, 18.24. Calc. for $C_5H_{11}O_2PS$: C, 36.14; H, 6.63; P, 18.67%.

5,5-Dimethyl-4-isopropyl-2-H-1,3,2-dioxaphosphorinane (V). Similarly, from 4 g (0.02 g mol) of the corresponding and 13 g (0.05 g mol) of tri-n-butylstannane 2.9 g, 65% of V was obtained, b.p. 37–39°/1 mm; n_D^{20} 1.468; δ_{31P} 151.9 ppm; J_{P-H} 166.3 Hz. Elementary analysis for the oxidized product: (Found: C, 49.5; H, 8.60; P, 15.75. Calc. for $C_8H_{17}O_3P$: C, 50.0; H, 8.85; P, 16.4%).

4,4,6-Trimethyl-2-H-1,3,2-dioxaphosphorinane (IV). To 6.9 g (0.038 g mol) of 4,4,6-trimethyl-2-Cl-1,3,2-dioxaphosphorinane, 22.1 g (0.076 g mol) of tri-n-butylstannate were added. The mixture was kept for 48 hr at room temp and then distilled in vacuum. The yield was 2.9 g (53%), b.p. 26–28°/1 mm. Analysis for the product with added sulphur: Found: C, 39.67; H, 7.05; P, 16.83. Calc. for $C_6H_{13}O_2PS$: C, 40.00; H, 7.22; P, 17.22%).

1,3-Di-t-butyl-2-H-1,3,2-diazaphosphorinane (VIII). 16.8 g (0.067 g mol) of 1,3-di-t-butyl-2-Cl-1,3,2-diazaphosphorinane were placed in a Claisen flask and 19.5 g (0.067 g mol) of tri-n-butylstannane added. The mixture was heated for 15 min at 50–60° and distilled in vacuum, yield 8.1 g (57%), b.p. 60–62°/1 mm; n_D^{20} 1.4854; δ_{31_P} 49.6 ppm; δ_{P-H} 214 Hz.

1,3-Di-t-butyl-4-methyl-2-H-1,3,2-diazaphosphorinane (IX). By a similar procedure, from 4.2 g of 1,3-di-t-butyl-4-methyl-2-Cl-1,3,2-diazaphosphorinane and 4.62 g of tri-n-butylstannane, 2.05 g (56%) of 1,3-di-t-buthy-4-methyl-2-H-1,3,2-diazaphosphorinane was obtained, b.p. 63–64° (1 mm); n_D^{20} 1.4850; δ_{31_P} 12.7 ppm; δ_{P-H} 7 ppm; $^1J_{P-H}$ 229 Hz. (Found: C, 62.01; H. 11.09. Calc. for $C_{12}H_{27}N_2P$: C, 62.5; H, 11.7%).

2-H-1,3,2-Dithiaphosphorinane (VI). By a similar procedure, from 17.3 g (0.1 g mol) of 2-Cl-1,3,2-dithiaphosphorinane and 29.1 g (0.1 g mol) of tri-n-butylstannane, 4.14 g (30%) of 2-H-1,3,2-dithiaphosphorinane was obtained, b.p. 50–53° (1 mm); m.p. 40°; δ_{32_P} 1.54 ppm; δ_{P-H} 6.41 ppm; J_{P-H} 200 Hz.

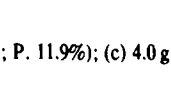
3-Isopropyl-2-H-1,3,2-oxaazaphosphorinane (XI). To 5.58 g (0.003 g mol) of chlorophosphite in 5 ml absolute benzene, 9.4 g (0.032 g mol) tri-n-butylstannane were added. The mixture was kept at room temp for 1 hr. Then the solvent was distilled off. The residue was twice distilled under vacuum and yielded 2.37 g (50%) of the product, b.p. 34–35°/1 mm; δ_{31_P} 112 ppm; J_{P-H} 201 Hz.

Analysis is given for the oxidized product: (Found: C, 44.1; H, 8.6; P, 18.8. Calc. for $C_6H_{14}NO_2P$: C, 44.2; H, 8.6; P. 19.02%).

1,3 - Di - t - butyl - 2 - (3 - carbomethoxyethyl) - 1,3,2-diazaphosphorinane. To 3.5 g of VIII 1.38 g methyl acrylate were added. The mixture was kept at room temp for 12 hr and then heated for 2–3 hr at 60° and distilled. The yield of the adduct was 0.8 g (20%); b.p. 115–116°/1 mm; n_D^{20} 1.4898; d_4^{20} 0.9709; δ_{31_P} 59.6 ppm; IR spectrum (νC=O 1752 cm^{-1} v.s.); (Found: C, 59.64; H, 10.42: P, 9.47. Calc. for $C_{15}H_{31}PN_2O_2$: C, 59.6; H, 10.26; P, 10.26%).

1,3 - Di - t - butyl - 4 - methyl - 2 - (3 - carbomethoxyethyl) - 1,3,2 - diazaphosphorinane. By a similar procedure, from 1.9 g of IX and 0.71 g methyl acrylate, 1.05 g (40%) of the adduct were obtained, b.p. 117°/1 mm; n_D^{20} 1.4927; δ_{31_P} 62.8 ppm; IR spectrum (νC=O 1752 cm^{-1} v.s.); (Found: C, 60.6; H, 10.7. Calc. for $C_{16}H_{34}PN_2O_2$: C, 59.2; H, 10.55%).

Interaction of N,N'-di-t-butyl-2-H-1,3,2-diazaphosphorinane with tetraethyl diaminomethylene. In a Claisen flask 5.32 g tetraethyl diaminomethylene were added to 7.2 g of VIII. The mixture was heated at 75° for 25 min and then at 120° for 30 min. After distilling-off 0.9 ml (59%) diethylamine, the residue was distilled in vacuum yielding:

(a) 1.5 g of 1,3-di-t-butyl-1,3-propylenediamine, b.p. 65°/1 mm; (b) 2.1 g of $(Et_2N)P-CH_2-NEt_2$, b.p. 105°/1 mm; n_D^{20} 1.4875; δ_{31_P} 52.2 ppm. (Found: C, 59.08; H, 11.5; P, 11.10. Calc. for: C, 59.8; H, 12.2; P. 11.9%); (c) 4.0 g (45%) of  PCH_2-NEt_2, b.p. 118–120°/1 mm; δ_{31_P} 47.1 ppm. (Found: C, 63.5; H, 11.5; P, 10.0. Calc. for: C, 63.8; H, 11.98; P, 10.8%).

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