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C-Phosphorylated Pyrazoles. Reaction of N-Methyl- and N-Phenylpyrazoles with Phosphorus(III) Halides

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ABSTRACT

The reactions of N-methyl- and N-phenylpyrazole derivatives with phosphorus(III) halides have been studied. The preparative method for synthesis of a variety of 4-phosphorylated pyrazoles, including pyrazolyl substituted halo- and dihalophosphines, has been elaborated. Migration of an alkyl group from O to P(III) in 4-phosphorylated 5-alkoxypyrazoles was found to give a P-ylides in a vinylogous manner with respect to the Arbuzov reaction. © 1995 John Wiley & Sons, Inc.

INTRODUCTION

Recently, we have shown that electron-rich heteroaromatic compounds, such as pyrrole [1], indole [2], furan [3], thiophene [4], and indolizine [5], as well as some aromatic compounds [6], undergo C-phosphorylation with phosphorus (III) halides in basic medium. As a result, we have elaborated a preparative method for the synthesis of a wide range of substances having a direct phosphorus to heterocycle bond.

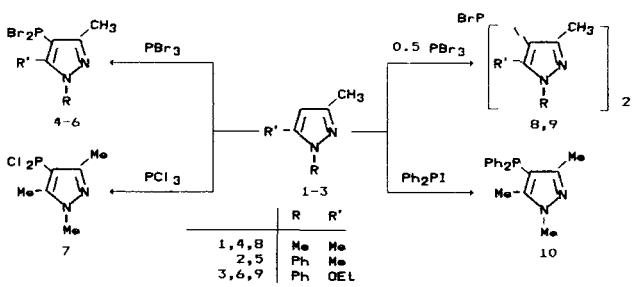
It was of specific interest to involve in this reaction π-electron-amphoteric heterocycles, in particular pyrazoles. Up to now, practically all known methods for the synthesis of phosphorylated pyrazoles have been based on cyclization of acyclic phosphorylated compounds, and there are a scarcity of methods known for the synthesis of nonphosphorylated pyrazoles [7–17].

Phosphorylation of the pyrazoles that are the most reactive in electrophilic substitution reactions with phosphorus oxychloride [18] and in the formation of ylides by the action of Ph_3PBr_2 [19] have been reported.

All enumerated methods have offered the possibility for the synthesis only of pyrazoles with pentacovalent phosphorus, and, up to now, the sole known pyrazole in which a trivalent phosphorus is attached directly to a heterocycle has been prepared by reduction of the corresponding phosphine oxide [17]. Recently, we have published preliminary reports about the possibility of phosphorylation of pyrazoles with phosphorus(III) halides in the presence of organic bases [20].

RESULTS AND DISCUSSION

We have previously found that phosphorus(III) halides react with N-methylpyrazole, as well as with less active N-phenylpyrazoles, to form dihalo phosphine derivatives (**4–10**).



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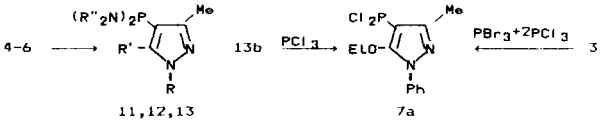
When a mixture of 1,3,5-trimethylpyrazole and phosphorus tribromide in a 3:1 molar ratio was allowed to stand for 3 months, the ^{31}P NMR spectrum of the reaction mixture showed a signal δ −81 that can be attributed to a trispyrazolylphosphine, but we failed to isolate the compound.

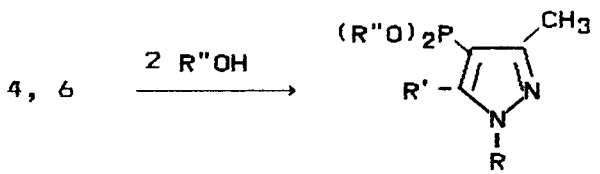
Contrary to the results with other triheteroarylphosphines [21], an attempt to phosphorylate 1,3,5-trimethylpyrazole by the action of trichloromethyldichlorophosphine failed, with destruction of starting materials being observed.

In the case of less active N-phenylpyrazoles, direct electrophilic substitution can be carried out only with the use of phosphorus tribromide. Formation of dibromophosphine (**6**) required 2 days at 20°C, whereas formation of (**5**) was completed only in 4 days. One month was necessary for formation of bromophosphine **9**. As mentioned previously, dichlorophosphine **7a** could not be prepared by the attempted reaction of N-phenylpyrazole with phosphorus trichloride. Because of this, compound **7a** was prepared by the alternative method of the reaction of phosphorus trichloride with diaminophosphine **13b**, but it was found to be far more convenient to prepare this compound by reaction of 5-ethoxypyrazole with a mixture of phosphorus trichloride and phosphorus tribromide in a 2:1 molar ratio. In this case, the time necessary to complete the reaction was three times greater than that in the case of phosphorus tribromide.



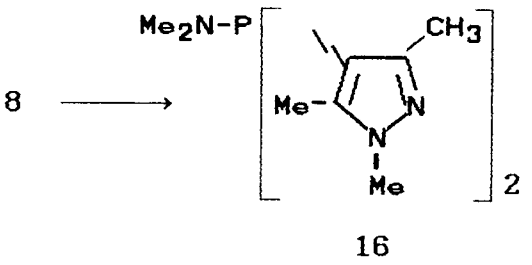
	R	R'	R"
11a	Me	Me	Me
12a	Ph	Me	Me
13a	Ph	OEt	Me
11b	Me	Me	Et
12b	Ph	Me	Et
13b	Ph	OEt	Et

From the dibromophosphines **4–6** obtained, we synthesized dioxy and diaminophosphines by usual methods. Similarly to some other alkoxy heteroarylphosphines [22], compound **14** is unstable, probably because of alkylation.



	R	R'	R"
14	Ph	Me	Ph
15	Ph	Me	Me

Compound **15** was identified only by its ^{31}P NMR spectrum and was transformed into the corresponding thiophosphonate (shown later). Contrary to **14** the phenoxy and aminophosphines are stable in the absence of moisture. Bromophosphine **8** reacts with dimethylamine in the usual manner. It has been found that even a slight increase of steric hindrance, as found in the bromophosphine **8**, results in a sharp decrease of reactivity; thus, this compound did not react with dimethylamine even on prolonged heating. However, hydrolysis of bromophoshine **9** proceeded easily giving the phosphinous acid **17**.



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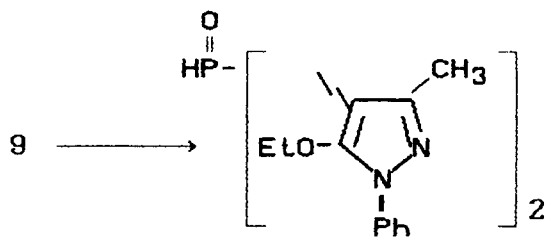

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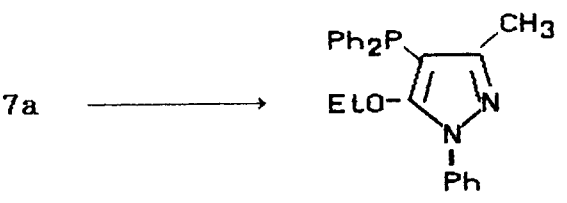
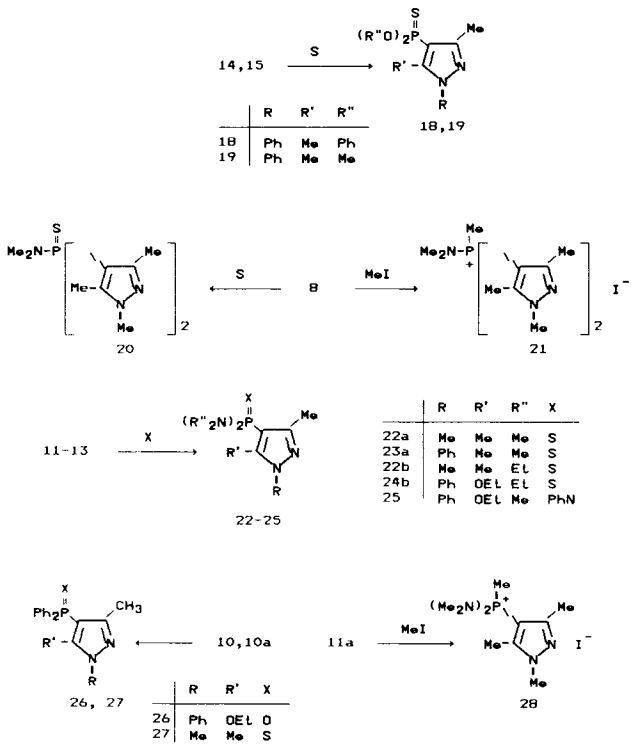
Phosphine **10a** was obtained from dichlorophosphine **7a**.



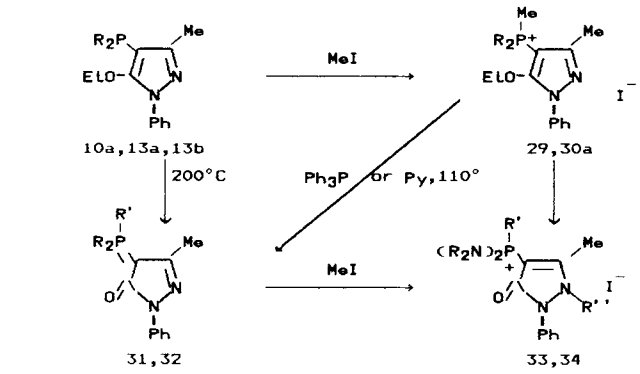
10a

Syntheses of a variety of phosphorylated pyrazoles with trivalent phosphorus enables preparation from them of thiophosphonates, iminophosphonates, amidophosphinates, phosphonium salts, and phosphonates.

However, the attempted preparation of phosphonates derived from 5-alkoxypyrazoles failed because of dealkylation. In the next report, we shall



discuss this situation in detail. 4-Phosphorylated 5-alkoxypyrazoles display some specific properties caused by mobility of alkyl group at the **5** position of the heterocycles. Compounds of types **10a** and **13** can be considered as vinylogs of ethoxy phosphines. When heated to 200°C, they almost completely transform into ylides **32**. Alkyl halides and salts **30** catalyze these transformations. The structures of the compounds have been determined by ^{1}H, ^{13}C, and ^{31}P NMR spectroscopy (Tables 2 through 5). The yields as well as the data of the elemental analyses and ^{31}P NMR spectra are given in Table 1.



	10a	13a	13b	29	30a	31	32a	32b	33	34
R	Ph	Me_2N	Et_2N	Ph	Me_2N	Ph	Et_2N	Me_2N	Me	Et
R'						Et	Et	Me	Me	Et
R''									Et	Me

Thus, vinylogs of ethyl esters of phosphorus(III) acids **10** and **13** were found to undergo transformations analogous to those found in the Arbuzov reaction. Developing the indicated analogy, phosphonium salts **29** and **30** can be considered as vinylogs of Arbuzov reaction intermediates. Really, when heated to 110°C in a solution of pyridine or fused with triphenylphosphine, substance **30a** undergoes dealkylation giving ylide **32**. It should be noted that, in the case of **30a**, judging from its ^{31}P NMR spectral changes, this transformation proceeds very slowly at 20°C in a solution of dimethylformamide, namely, at the rate of 25% per 15 days, even in the absence of dealkylating reagents. However, heating of phosphonium salt **30a** in the absence of solvent at 150°C in a sealed tube gave rise to a phosphonium salt of different structure, **33**. In this case, 5-alkoxypyrazoles transformed into pyrazolones by the usual scheme. Heating of this salt at the same temperature in vacuo gave rise to a mixture of substance **32** and **33**, with predominance of **32**. Alkylation of ylides **31** and **32** proceeds at nitrogen (not at oxygen, as happened with some similar compounds [23]) giving phosphonium salts **33** and **34**, respectively. It was confirmed by ^{1}H, ^{13}C, and ^{31}P NMR spectroscopy. The closest analogy of this rearrangement are found in works of Singh devoted to dealkylation of p-methoxyarylphosphonium salts [24] as well as in a work of Lutsenko [25] where compounds of trivalent phosphorus containing an alkoxy group separated from the phosphorus atom by a triple bond are considered.

EXPERIMENTAL

A Bruker WP-200 spectrometer was used to take the ^{31}P NMR spectra and a Varian Gemini-200 to take the ^{1}H and ^{13}C NMR spectra. The ^{1}H and ^{13}C signals were registered with respect to the internal standard, tetramethylsilane, and the ^{31}P signals to the external standard, 85% H_3PO_4.

Dibromo(1,3,5-trimethylpyrazol-4-yl) phosphine **4**

To a solution of phosphorus tribromide (0.02 mol) in pyridine (20 mL), a solution of 1,3,5-trimethylpyrazole (0.02 mol) in pyridine (15 mL) was added with cooling. The reaction mixture was allowed to stand overnight. The ^{31}P NMR resonance, δ = 133.5, corresponded to the presence of the desired dibromophosphine. This reaction mixture was used for further transformations.

Dibromo(3,5-dimethyl-1-phenylpyrazol-4-yl)phosphine **5**

To a solution of 3,5-dimethyl-1-phenylpyrazole (0.026 mol) in pyridine (20 mL), a solution of phos-

TABLE 1 Yields, Analytical Data, and ^{31}P NMR Spectra of the Compounds **5–34**

Compound	Mp (°C) Bp (°C/mm)	Yield (%)	Formula	$\partial^{31}P$ (Solvent)	Found (%) (Calculated) N	P
5	102–104	88	$C_{11}H_{11}Br_2N_2P$	131.4[a]	7.41 (7.74)	8.21 (8.56)
6	oil	79	$C_{12}H_{13}Br_2N_2OP$	126.6[a]	7.01 (7.15)	7.54 (7.90)
7a	oil	78	$C_{12}H_{13}Cl_2N_2O$	145.6[b]	9.01 (9.24)	9.87 (10.22)
7 [20]	100/0.01	41	$C_6H_9Cl_2N_2P$	151.4	13.10 (13.27)	14.33 (14.68)
8	oil	45	$C_{12}H_{18}BrN_4P$	53.8[a]	16.51 (17.02)	9.02 (9.41)
9	69–71	54	$C_{14}H_{22}BrN_4O_2P$	35.5[b]	13.91 (14.39)	7.61 (7.96)
10 [20]	86–89	91	$C_{18}H_{19}N_2P$	−32.8[b]	9.15 (9.52)	10.21 (10.52)
10a	oil	53	$C_{24}H_{23}N_2OP$	−35.5[b]	7.11 (7.25)	8.12 (8.02)
11a [20]	49–50	39	$C_{10}H_{21}N_4P$	94.2[b]	23.91 (24.54)	14.13 (13.57)
11b	110/0.02	54	$C_{14}H_{29}N_4P$	92.2[a]	19.70 (19.70)	10.82 (10.89)
12a	oil	60	$C_{15}H_{23}N_4P$	97.3[b]	18.87 (19.30)	10.37 (10.67)
12b	oil	56	$C_{19}H_{31}N_4P$	89.5[b]	16.43 (16.17)	8.14 (8.94)
13a [20]	oil	88	$C_{16}H_{25}N_4OP$	87.1[b]	17.11 (17.49)	9.67 (9.67)
13b [20]	oil	82	$C_{20}H_{33}N_4OP$	81.2[b]	14.52 (14.88)	8.02 (8.23)
14	oil	52	$C_{23}H_{21}N_2O_2P$	161.2[b]	6.93 (7.21)	7.53 (7.97)
16 [20]	67–70	51	$C_{14}H_{24}N_5P$	20.1[b]	23.83 (23.87)	10.11 (10.56)
17	oil	55	$C_{14}H_{23}N_4O_3P$	10.4[bc]	16.7 (17.17)	(9.07) (9.49)
18	oil	61	$C_{23}H_{21}N_2O_2PS$	73.3[c]	6.28 (6.66)	6.94 (7.37)
19	oil	46	$C_{13}H_{17}N_2O_2PS$	83.3[b]	9.18 (9.45)	10.12 (10.45)
20	101–103	57	$C_{14}H_{24}N_5PS$	49.0[c]	20.97 (21.52)	9.43 (9.52)
21	130–133	58	$C_{15}H_{27}IN_5P$	32.1[d]	15.49 (16.09)	6.65 (7.12)
22a	52–55	64	$C_{10}H_{21}N_4PS$	73.1[b]	21.41 (21.52)	11.91 (11.90)
22b	oil	48	$C_{14}H_{29}N_4PS$	68.3[b]	18.24 (17.70)	10.1 (9.79)
23a	72–74	46	$C_{13}H_{23}N_4PS$	73.4[b]	16.93 (17.38)	9.20 (9.61)
24b	80–81	42	$C_{20}H_{33}N_4OPS$	64.0[b]	13.85 (13.71)	7.87 (7.58)
25	oil	45	$C_{22}H_{30}N_5OP$	13.1[b]	16.90 (17.02)	7.23 (7.53)
26	112–115	34	$C_{24}H_{23}N_2O_2P$	19.1[c]	7.10 (6.96)	7.97 (7.70)
27	107–110	49	$C_{18}H_{19}N_2PS$	30.2[b]	8.40 (8.58)	9.64 (9.49)
28	168–169	71	$C_{11}H_{24}IN_4P$	52.9[c]	14.84 (15.13)	7.92 (8.37)
29	170–173	67	$C_{25}H_{26}IN_2OP$	9.7[c]	5.76 (5.30)	6.27 (5.86)

TABLE 1 (Continued) Yields, Analytical Data, and ^{31}P NMR Spectra of the Compounds **5–34**

Compound	Mp (°C) Bp (°C/mm)	Yield (%)	Formula	$\delta^{31}P$ (Solvent)	Found (%) (Calculated) N	P
30a	110–111	87	$C_{17}H_{28}IN_4OP$	50.9[c]	12.49 (12.12)	6.55 (6.70)
31	oil	27	$C_{24}H_{23}N_2OP$	14.1[b]	7.15 (7.25)	7.74 (8.02)
32a [20]	oil	37	$C_{20}H_{33}N_4OP$	59.5[b]	14.51 (14.88)	8.01 (8.23)
32b [20]	101–105	38	$C_{15}H_{23}N_4OP$	54.6[b]	18.46 (18.29)	9.98 (10.11)
33 [20]	51–55	31	$C_{17}H_{28}IN_4OP$	53.1[c]	11.9 (12.12)	6.3 (6.70)
34 [20]	67–72	35	$C_{21}H_{36}IN_4OP$	54.8[c]	10.52 (10.81)	5.53 (5.97)

Solvents: [a]pyridine; [b]benzene; [c]chloroform; [d]methanol; [e]doublet, $^1J_{PH}$ = 492 Hz.

TABLE 2 4-Phosphorylated 1,3,5-Trimethylpyrazoles: ^1H NMR δ (Multiplicity), J (Hz)

	1-CH_3	3-CH_3	5-CH_3	N-$CH_{2,3}$	CH_2-$\underline{CH_3}$	P-CH_3	P-Ph
7[a]	3.74s	2.48s	2.46s				
8[a]	3.70s	2.18s	1.86s				
10[a]	3.76s	2.18s	1.86s				7.20–7.85 m
11b[b]	2.48s	1.70s	1.20s	2.25m (7.0)	0.26t (7.0)		
11a[b]	3.23s	2.46s	1.92s	2.66d (9.2)			
16[b]	3.20s	2.30s	1.92s	2.53d (10.8)			
20[b]	3.20s	2.23s	1.92s	2.53d (10.8)			
21[c]	3.83s	2.29s	2.15s	2.81d (10.8)		2.54d (13.4)	
22a[a]	3.73s	2.52s	2.39s	2.61d (12.4)			
22b[a]	3.76s	2.53s	2.40s	3.14m (7.0)	1.10t (7.0)		
27[a]	3.73s	1.99s	1.88s				7.49–7.96 m
28[a]	2.47s	2.32s	1.90s			2.51d (13)	

Spectrum were taken in [a]$CDCl_3$; [b]C_6O_6; [c]CD_3OD.

phorus tribromide (0.026 mol) in pyridine (30 mL) was added. After 4 days the precipitated solid was filtered off, and the solvent was removed in vacuo. To the residue, petroleum ether (70 mL) was added and the mixture was filtered. The solvents were evaporated from the filtrate to give an oil, which solidified on standing.

Dibromo(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphine **6**

To a solution of 3-methyl-1-phenyl-5-ethoxypyrazole (0.04 mol) in pyridine (15 mL), a solution of phosphorus tribromide (0.04 mol) in pyridine (10 mL) was added. After 2 days the reaction mixture was diluted with petroleum ether (60 mL). The precipitated solid was filtered off. The filtrate was maintained at 5°C overnight. The newly precipitated yellow product was filtered off and dried in vacuo.

Dichloro(1,3,5-trimethylpyrazol-4-yl)phosphine **7** [20]

To a solution of 1,3,5-trimethylpyrazole (0.1 mol) in pyridine (14 mL) cooled to −30–40°C, a solution of phosphorus trichloride (0.11 mol) in pyridine (16 mL) was added. The reaction mixture was allowed

TABLE 3 4-Phosphorylated 3,5-Dimethyl-1-phenylpyrazoles: ^{1}H NMR δ (Multiplicity), *J* (Hz)

	5-CH$_3$	*3-CH$_3$*	*1-Ph*	*N–CH$_{2,3}$*	*CH$_2$–CH$_3$*	*P–OCH$_3$*
5[a]	2.54s	2.66s	7.52m			
12a[b]		2.41s	7.47–8.20m	2.68d		
12b[b]	2.26s	2.61s	7.6m	3.10q (7)	1.08t (6.8)	
14[a]	2.44s	2.53s	7.05–7.58m			
18[a]	2.56s	2.63s	7.10–7.65m			
19[a]	2.49s	2.44s	7.36–7.71m			3.78d (12)
23a[a]	2.48s	2.51s	7.27–7.45m	2.67d (12.4)		

Spectrum were taken in [a]$CDCl_3$; [b]CD_3CN.

to stand for 5 days at ambient temperature. Then the reaction mixture was diluted with benzene (17 mL). The precipitated solid was filtered off, and the residue was dissolved in petroleum ether (30 mL). The residual oil that had not dissolved was removed by filtration through glass fiber. The solvent was evaporated in vacuo, giving a light oil that crystallized at 0°C.

Dichloro(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphine **7a**

To a solution of the pyrazole **3** (0.03 mol) in pyridine (20 mL), a mixture of phosphorus trichloride (0.02 mol) and tribromide (0.01 mol) in pyridine (10 mL) was added. After 6 days a solution of phosphorus trichloride (15 mL) in petroleum ether (20 mL) was added. After 0.5 hours the precipitated solid was filtered off and washed with benzene (20 mL). The solvents and the excess phosphorus trichloride were evaporated. The oil that remained was treated with boiling heptane (30 mL). The hot transparent solution was separated, the solvent was evaporated, and the residue was dried in vacuo.

To a solution of phosphorus trichloride (0.06 mol) in benzene (30 mL), a solution of diamidophosphonite **13b** (0.01 mol) in benzene (10 mL) was added dropwise with stirring. After 1 hour, the solvent and excess phosphorus trichloride were evaporated. The residue was reprecipitated with heptane from benzene. Yield 70%.

Bromobis(1,3,5-trimethylpyrazol-4-yl)phosphine **8**

To a solution of phosphorus tribromide (0.01 mol) in pyridine (10 mL), a solution of 1,3,5-trimethylpyrazole (0.025 mol) in pyridine (15 mL) was added with cooling. Then the reaction mixture was kept at 100°C for 8 hours. The ^{31}P NMR resonance, δ = 53.3, corresponded to the presence of bromophosphine **8**. This reaction mixture was used for further transformations.

Bromobis(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphine **9**

To a solution of phosphorus tribromide (0.01 mol) in pyridine (15 mL), a solution of 3-methyl-1-phenyl-5-ethoxypyrazole (0.025 mol) in pyridine (20 mL) was added. After 1 month, the reaction mixture was diluted with benzene (20 mL) and filtered. The solvents were evaporated, and the residue was dissolved in a mixture of benzene (20 mL) and petroleum ether (40 mL). The precipitated solid was filtered off, and the solvents were evaporated. The product was extracted with boiling heptane and precipitated by freezing at −30°C. The product was filtered off and dried.

Diphenyl(1,3,5-trimethylpyrazol-4-yl)phosphine **10** [*20*]

To a solution of diphenyliodophosphine (0.08 mol) in pyridine (5 mL), a solution of 1,3,5-trimethylpyrazole (0.08 mol) in pyridine (7 mL) was added. After 1 hour, benzene (7 mL) was added. The precipitated solid was filtered off, and the solvent was evaporated. The product was recrystallized from n-octane.

Diphenyl(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphine **10a**

A 0.5 L four-necked flask equipped with a thermometer, reflux condenser, mechanical stirrer, and dropping funnel was charged with diethyl ether (200 mL), magnesium (0.03 mol), iodomethane (2 mL), and a catalytic amount of iodine. After the reaction had started, bromobenzene (0.25 mol) was added to the reaction mixture dropwise with cooling. After the addition had been completed, the reaction mixture was refluxed for 0.5 hours and cooled to ambient temperature. Then dichlorophospine **7a** (0.12 mol) was added dropwise with cooling. After completion of the addition, the reaction mixture was refluxed for 1 hour and then poured into a so-

TABLE 4 4-Phosphorylated 3-Methyl-1-phenyl-5-ethoxypyrazoles: ^{1}H NMR δ (Multiplicity), J (Hz)

	3-CH_3	*O–CH_2–*	*N–CH_2–*	*OCH_2CH_3*	*NCH_2–CH_3*	**o**-*Ph*	**m**-*Ph*	**P**-*Ph*	*Others*
		4.27q		1.41t			7.38–7.68m		
6[a]	2.62s	(7.0)	—	(7.0)	—				
		4.24q		1.34t		7.65d	7.54t	7.26t	
7[a]	2.59s	(7.0)	—	(6.8)	—	(7.2)	(7.0)	(7.2)	
		4.28q		1.47t					
	2.55s	4.10q		1.20t			7.30–7.71m		
9[a]	2.37s	(7.0)	—	(7.0)	—				
		4.23q		1.43t					
	1.83s	3.98q		1.11t			7.25–7.92m		
10a[a]	2.28s	(7.2)	—	(7.0)	—				
		3.88q	2.73d	1.14t		7.65d	7.46t	7.29t	
13a[b]	2.11s	(7.6)	(9.4)	(7.6)	—	(8.8)	(8.9)	(8.9)	
		3.76q	3.10q	1.07t	0.92t	8.00d	7.16t	6.96t	
13b[b]	2.47s	(7.3)	(7.3)	(7.3)	(7.3)	(8.2)	(7.9)	(7.9)	
	2.38s			1.43s			7.40–7.69m		P–H 8.2d
17[a]	2.28s	4.13q	—	1.21	—				(492)
				1.26t	1.12t	7.96d	7.37t	7.15t	
24b[a]	2.44s	3.11–3.44m		(7.2)	(7.2)	(7.6)	(7.6)	(7.6)	
									o-Ph′ 6.8d (7.0)
									m-Ph′ 7.1t (7.0)
		4.05q	2.91d	1.22t		7.69d	7.35t		
25[a]	2.41s	(7.0)	(11)	(7.0)	—	(7.2)	(7.2)	7.25t	*p*-Ph′ 6.7t
				0.88t					
	1.98s	3.53q		0.66t			7.21–7.90m		
26[a]	1.26s	(7.0)	—	JHH6.9	—				
							7.32–7.96m		P–CH_3 3.15d (14)
29[a]	1.88s	3.78q	—	0.90t					
		3.98q	2.95d	1.26t			7.61–7.28m		P–CH_3 2.54d (14)
30a[a]	2.35s	(7.0)	(11)	(7.0)	—				P–CH_2 3.12m
							7.25–8.20m		PCH_2CH_3 1.39t (7.3)
31[a]	1.62s								P–CH_2 2.52dq (6.8, 23.8)
							6.98–8.07m		
			3.14q		1.13t				PCH_2CH_3 1.28t (7.5)
32a[a]	2.18s		(7.8)		(7.5)				
			2.71d				7.01–8.07		P–Me 1.99d (13.8)
32b[a]	2.15s		(10.2)						P–Me 2.26d (13.8)
							7.28–7.56		N^+CH_2 3.98q (7)
			2.80d						$N^+CH_2CH_3$ 1.28t (7)
33[a]	2.65s		(10)						PCH_2 2.68m
				1.24t			7.34–7.59		PCH_2CH_3 1.37t (8)
34[a]	2.76s		3.25m	(7.3)					

Spectrum were taken in [a]$CDCl_3$; [b]CD_3CN; [c]C_6D_6.

lution of ammonium chloride (40 g) in water (300 mL). The organic layer was separated, and the water layer was washed with benzene (2 × 50 mL). The combined organic layer was dried over Na_2SO_4, and the solvents were evaporated. The residue was dissolved in petroleum ether (100 mL) and purified by freezing. After removal of the solvent, the residue was dried in vacuo.

General method of synthesizing the compounds **11–13**

Bis(dimethylamino)-1,3,5-trimethylpyrazol-4-ylphosphine **11a** [20]

Bis(diethylamino)-1,3,5-trimethylpyrazol-4-ylphosphine **11b**

Bis(dimethylamino)-3,5-dimethyl-1-phenylpyrazol-4-ylphosphine **12a**

TABLE 5 4-Phosphorylated Pyrazoles ^{13}C {^1H} NMR δ (Multiplicity), J (P–C, Hz)

	C-3	*C-4*	*C-5*	*1-CH_3*	*3-CH_3*	*5-CH_3*	*PN–CH_2–*	*CH_2–CH_3*
	145.1d	113.0d	151.1d		13.4d	10.9d		
7[a]	(41.2)	(55.5)	(13.4)	35.9s	(4.5)	(9.5)	—	—
	139.9d		149.0d			10.7d	43.4d	14.7d
11b[b]	(19.4)	112.1s	(13.6)	35.3s	14.4s	(2.3)	(17.7)	(4.1)
							43.5d	13.7
12b[b]	140.6s	114.5s	150.9s	—	14.6s	—	(17.1)	(22)
	151.0d		153.9d				43.6d	14.6d
13b[b]	(9.4)	103.7s	(7.4)	—	15.0s	—	(11.7)	(2.8)
	148.6d	97.3d	152.2d				37.6d	
21[c]	(14.7)	(86.6)	(8.7)	37.1s	14.3s	11.8s	(3.5)	—
	143.5d	105.0d	149.4d				37.3d	
22a[a]	(25.9)	(152)	(12)	35.6s	—	—	(22)	
	143.9d	108.0d	149.7d				39.5d	13.6d
22b[a]	(23.6)	(154)	(11.4)	36.0s	14.5s	12.0s	(4.5)	(3.9)
	150.5d	87.6d	157.6d				37.8d	
30a[a]	(9.1)	(150)	(18.9)	—	12.4s	—	(4.1)	—

	P–CH_3	**i**-*Ph*	**o**-*Ph*	**m**-*Ph*	**p**-*Ph*	*O–CH_2–*	*$OCH_2\underline{CH_3}$*
	—	—	—	—	—	—	—
	—	—	—	—	—	—	—
			125.9	128.6	129.0		
	—	140.0s	126.0	128.9	129.2	—	—
						70.7	
	—	139.9s	122.2s	129.0s	126.0s	70.8	15.5s
	15.0d						
	(51.3)	—	—	—	—	—	—
	—	—	—	—	—	—	—
	—	—	—	—	—	—	—
	15.2d						
	(18.5)	136.9s	123.5s	129.6s	129.0s	73.2s	13.1s

Spectrum were taken in [a]$CDCl_3$; [b]C_6D_6; [c]CD_3OD.

Bis(diethylamino)-3,5-dimethyl-1-phenylpyrazol-4-ylphosphine **12b**

Bis(dimethylamino)-3-methyl-1-phenyl-5-ethoxypyrazol-4-yl-phosphine **13a** [20]

Bis(diethylamino)-3-methyl-1-phenyl-5-ethoxypyrazol-4-yl-phosphine **13b** [20]

To a solution of the corresponding dichloro- or dibromophosphine **4–7** (0.05 mol) in pyridine (10 mL), a solution of dialkylamine (0.21 mol) in benzene (10 mL) was added with cooling. After 1 hour, the precipitated solid was filtered off, and the solvents were evaporated. The residue was taken up in petroleum ether (40 mL). The solution was cooled to −70°C and decanted from an oily residue. The solvent was evaporated, and the product was dried in vacuo.

Diphenoxy(3,5-dimethyl-1-phenylpyrazol-4-yl)phosphine **14**

To a solution of dibromophosphine **5** (5 mmol) in benzene (10 mL), a solution of phenol (10 mmol) and triethylamine (25 mmol) in benzene (10 mL) was added. After 10 minutes, the precipitated solid was filtered off, and the solvent was evaporated. The residue was boiled with petroleum ether (30 mL). The solution was filtered, and the solvent was evaporated. The residual oil was kept in vacuo.

Dimethylaminobis(1,3,5-trimethylpyrazol-4-yl)phosphine **16** [20]

To a solution of phosphorus tribromide (0.024 mol) in pyridine (10 mL), a solution of 1,3,5-trimethylpyrazole (0.05 mol) in pyridine (15 mL) was added with cooling. Then the reaction mixture was kept at 100°C for 8 hours. The ^{31}P NMR resonance, δ = 53.3, corresponded to the presence of bromophosphine **8**. After having been cooled to −5°C, a solution of dimethylamine (0.12 mol) in benzene (100 mL) was added dropwise. After 1 hour, the reaction mixture was diluted with petroleum ether (20 mL). The precipitated solid was filtered off, and the solvents were evaporated. The residue was taken up in petroleum ether (40 mL), and the solution was decanted from the residual oil. The solvent was evaporated, and the product was dried in vacuo.

Bis(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphinous acid **17**

A solution of bromophosphine **9** (0.02 mol) in dichloromethane (20 mL) was shaken with water (10 mL) in a separatory funnel and then with 25% aqueous ammonia solution. The organic layer was frozen in liquid nitrogen to destroy the colloid. The mixture was filtered, and the filtrate was dried over anhydrous Na_2SO_4. The solvent was evaporated, and the residue was dried in vacuo.

Diphenoxy(3,5-dimethyl-1-phenylpyrazol-4-yl)thiophosphonate **18**

To a solution of phosphine **14** (2 mmol) in benzene (10 mL), finely ground sulfur (2 mmol) was added. After dissolution of sulfur, the solvent was evaporated. The residual yellow oil was refluxed with petroleum ether (10 mL) for 5 minutes. The boiling transparent solution was separated from the residue. After cooling to room temperature, the precipitated oil was separated and dried in vacuo.

Dimethoxy(3,5-dimethyl-1-phenylpyrazol-4-yl)thiophosphonate **19**

To a solution of dibromophosphine **5** (5 mmol) in benzene (10 mL), a solution of methyl alcohol (0.01 mol) and triethylamine (0.011 mol) in benzene (10 mL) was added. After 1 hour, the precipitated solid was filtered off, and the ^{31}P NMR spectrum of the reaction mixture showed δ = 167.7. This signal was attributed to dimethoxy(3,5-dimethyl-1-phenylpyrazol-4-yl)phosphine **15**. To the reaction mixture, finely ground sulfur (5 mmol) was added. After 0.5 hours, the reaction mixture was filtered. The product was precipitated by portionwise addition of petroleum ether. The precipitated oil was dried in vacuo.

Dimethylamidobis(1,3,5-trimethylpyrazol-4-yl)thiophosphinate **20**

The same procedure as in the case of **22–24** was applied.

Methyldimethylaminobis(1,3,5-trimethylpyrazol-4-yl)phosphonium iodide **21**

To a solution of aminophosphine **16** (2 mmol) in benzene (8 mL), iodomethane (4 mmol) was added. After 1 hour, the solvent was decanted, and the residue was scratched with petroleum ether until the desired product solidified. The product was filtered off and dried.

General method of synthesizing the compounds **22–24**

Bis(dimethylamido)-1,3,5-trimethylpyrazol-4-ylthiophosphonate **22a**

Bis(diethylamido)-1,3,5-trimethylpyrazol-4-ylthiophosphonate **22b**

Bis(dimethylamido)-3,5-dimethyl-1-phenylpyrazol-4-ylthiophosphonate **23a**

Bis(diethylamido)-3-methyl-1-phenyl-5-ethoxypyrazol-4-yl-thiophosphonate **24b**

To a solution of the corresponding diaminophosphine **11–13** (0.04 mol) in benzene, finely ground sulfur was added, and the mixture was stirred until the sulfur had dissolved. The mixture was filtered, and the solvent was evaporated from the filtrate. The product was purified by reprecipitation with petroleum ether from benzene.

Bis(dimethylamido)-3-methyl-1-phenyl-5-ethoxypyrazol-4-yl-phenyliminophosphonate **25**

To a solution of diamidophosphonite **13a** (0.04 mol) in benzene (7 mL), a solution of phenyl azide (0.04 mol) in benzene (5 mL) was added. The reaction mixture was heated under reflux for 1 hour, accompanied by nitrogen evolution. Then the solvent was evaporated, and the residue was purified by reprecipitation with petroleum ether from benzene.

Diphenyl(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl)phosphine oxide **26**

To a solution of diphenylphosphine **10a** (0.01 mol) in benzene (10 mL), a solution of chlorine (0.01 mol) in benzene (50 mL) was added. The precipitated oil was separated and dissolved in dichloromethane (20 mL). To the solution, a 10% solution of Na_2CO_3 (20 mL) was added. The mixture was shaken several times in a separatory funnel. The organic layer was separated, dried over anhydrous Na_2SO_4, and then evaporated in vacuo. The product was recrystallized from n-decane.

Diphenyl(1,3,5-trimethylpyrazol-4-yl)phosphine sulfide **27**

To a solution of diphenylphosphine 10 (2 mmol), finely ground sulfur was added. The reaction mixture was refluxed for 1 hour. The mixture was filtered, and the solvent was evaporated from the filtrate. The product was purified by reprecipitation from benzene with petroleum ether.

Methyl-bis(dimethylamino)-1,3,5-trimethylpyrazol-4-yl-phosphonium iodide **28**

To a solution of diaminophosphine **11a** (0.01 mol) in benzene (5 mL), a solution of iodomethane (0.02

mol) in benzene (7 mL) was added. After 1 day, the white precipitate that had formed was filtered off, washed with benzene, and dried in vacuo.

Methyldiphenyl(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl) phosphonium iodide **29**

To a solution of diphenylphosphine **10a** (3 mmol) in benzene (5 mL), a solution of iodomethane (4.5 mmol) in benzene (4 mL) was added. After 1 day the precipitated oil was separated and scratched with petroleum ether until the desired product solidified. The product was filtered off, washed with benzene, and dried in vacuo.

Methylbis(dimethylamino)(3-methyl-1-phenyl-5-ethoxypyrazol-4-yl) phosphonium iodide **30a**

The same procedure as in the case of **28** was applied.

Diphenylethyl 3-methyl-1-phenyl-pyrazolin-5-on-4-ylidene phosphorane **31**

The same procedure as in the case of **32a** was applied.

Bis(diethylamino)ethyl 3-methyl-1-phenyl-pyrazolin-5-on-4-ylidene phosphorane **32a** [20]

Diaminophosphine **13b** (6 mmol) was kept at 200–220°C for 1 hour in the presence of a catalytic amount of iodomethane. The dark oil that had formed was subjected to chromatography on an alumina column using benzene as the eluent.

Methyl-bis(dimethylaminophosphine)-3-methyl-1-phenylpyrazolin-5-on-4-ylidene phosphorane **32b** [20]

Method a: A solution of phosphonium iodide **30a** (4 mmol) in pyridine (15 mL) was kept at 100°C for 7 hours. The solvent was evaporated, and the residue was dissolved in benzene (15 mL). The precipitated solid was filtered off. The product was precipitated from benzene with petroleum ether, filtered off, and dried. Yield 21%.

Method b: A mixture of phosphonium iodide **30a** (3.4 mmol) and triphenylphosphine (3.4 mmol) was kept at 120°C for 8 hours. The product was extracted with boiling benzene (3 × 20 mL) and purified by reprecipitation from benzene with petroleum ether, filtered off, and dried.

Methyl(5-methyl-2-phenyl-1-ethylpyrazol-3-on-4-yl)bis(dimethylamino)phosphonium iodide **33** [20]

Methylphosphonium iodide **30a** (5 mmol) was heated at 150°C for 4 hours. The residue was dissolved in dichloromethane and reprecipitated portionwise with diethyl ether. The product was filtered off and dried.

Ethyl bis(diethylamino)-5-methyl-2-phenyl-1-methylpyrazol-3-on-4-yl phosphonium iodide **34** [20]

To a solution of **32a** (3 mmol) in benzene (10 mL), iodomethane (5 mmol) was added. After 1 day, the precipitated oil was separated and dissolved in dichloromethane (10 mL). The solution was filtered, and the product was precipitated from the solution with diethyl ether, filtered off, and dried.

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