2-Phosphaindolizines

Raj K. Bansal*[a], Konstantin Karaghiosoff[b], Neelima Gupta[a], Alfred Schmidpeter*[b], and Claudia Spindler[b]

Department of Chemistry, University of Rajasthan[a],
Jaipur-302004, India

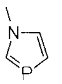
Institut für Anorganische Chemie der Universität München[b],
Meiserstraße 1, D-8000 München 2, Germany

Received July 30, 1990

Key Words: 1,3-Azaphosphole, annulation to pyridine / 2-Phosphaindolizines / Pyridinium bromides, 1,2-dialkyl- / Phosphorus(III) chloride, condensation with CH_2 groups / Calculations, MNDO

Pyridinium bromides **3** prepared by alkylation of 2-methyl-, 2-ethyl-, and 2-benzylpyridines **1** with methyl bromides **2** bearing an electron-withdrawing group (COPh, CN, CO_2Et, $C_6H_4NO_2$) are condensed with PCl_3 in the presence of Et_3N to give 2-phosphaindolizines **4**. The 1-unsubstituted representatives **9** (prepared from **8**) may undergo a substitution reaction at this position with an excess of PCl_3. 1- and 2-phosphaindolizines are 1,3-azaphospholes with a pyridine ring *a*-annulated to the 1,2 and 1,5 bond, respectively. The different types of annulation result in characteristic differences in charge distribution, ^{31}P-NMR shift, and chemical behavior. 2-Phosphaindolizines **4** and **9** are stable in dry air and do not undergo alkylation. Compounds **9** hydrolyze to give zwitterionic (1-alkyl-2-pyridino)methylphosphinates **13**. The phosphorus atom of a 2-phosphaindolizine can act as a ligand atom as shown by the example of a $Cr(CO)_5$ complex.

Azaphospholes constitute a relatively recent group of five-membered aromatic heterocycles[1]. Among these systems representatives with and without a nitrogen atom adjacent to the phosphorus atom in the ring may be distinguished. While the former can usually be prepared by a condensation reaction using PCl_3 or $P(NMe_2)_3$, the latter (1,3-azaphospholes and 1,2,4-diazaphospholes) are obtained by condensation with phosphines or silylphosphines or by cycloaddition reactions. Thus, the monocyclic 1,3-azaphospholes **A**[2–6,27] as well as their benzo and pyrido derivatives **B**[7–12] and **D**[4] have been prepared. The latter may be viewed as 1-phospha analogs of indolizines **E**.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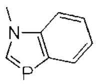
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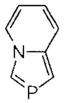
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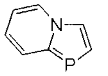
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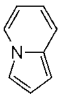
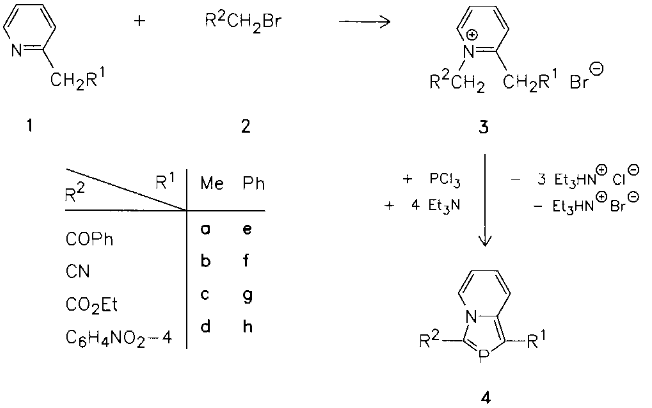

E

The 2-phosphaindolizines ([1,3]azaphospholo[1,5-*a*]pyridines, **C**) are not yet known. In this paper we report on their synthesis by means of a PCl_3 condensation[13]. This is the first example of a heterophosphole with carbon atoms on both sides of the two-coordinate phosphorus atom in the ring being formed in this way[27]. As the positions 1 and 2 of the indolizine ring are different in character[14] the phosphorus ring member in these positions and hence the systems **D** and **C** should differ characteristically, e.g. in their NMR spectra and in their reactivity.

Synthesis

The PCl_3 condensation of a suitable four-membered chain presents a facile route to heterophospholes[15]. For the synthesis of 2-phosphaindolizines of type **C** 1,2-dialkylpyridinium salts **3** offer themselves as the starting material. Their 2-methylene group is sufficiently reactive for a triethylamine-mediated condensation; its deprotonation results in a stable enamine[16]. In contrast, the 1-methylene group needs activation by an electron-withdrawing substituent R^2. COPh, CN, CO_2Et, and $C_6H_4NO_2$-4 have been found to be effective for this purpose. The respective pyridinium salts **3** are readily obtained[17–19] from 2-ethyl- or 2-benzylpyridine (**1a**, **c**) and phenacyl bromide (**2a**), bromoacetonitrile (**2b**), ethyl bromoacetate (**2c**), or 4-nitrobenzyl bromide (**2d**).



R^2 \ R^1	Me	Ph
COPh	a	e
CN	b	f
CO_2Et	c	g
$C_6H_4NO_2$-4	d	h

For the condensation, equimolar amounts of **3** and PCl_3 are treated with a fourfold molar amount of Et_3N in toluene at ambient temperature or preferably in acetonitrile at 0–5°C. The reaction is usually complete within 24 h. The formation of **4c** requires heating in toluene to 60°C. In the reaction of **3a–c** in toluene an intermediate product is observed by its ^{31}P-NMR signal at $\delta \approx 140-150$. This intermediate has been isolated in case of **3c** and has been identified by analysis and NMR spectra as the ylide **5c**. We

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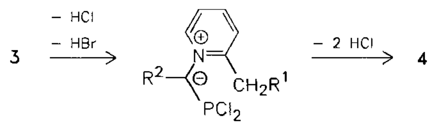
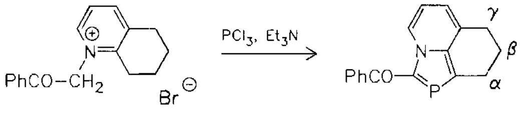
assume that the condensation proceeds also in the other cases via an intermediate **5**.



5

A ^{31}P-NMR signal in the same region (δ = 144) is observed when 1-phenacylpyridinium bromide is treated in the above way with PCl_3; it is attributed to a product of type **5** with the 2-alkyl group missing. No reaction is found to occur with 1-benzylpyridinium bromide. The formation of **4** via the intermediate **5** would parallel the pathway suggested by Kröhnke for the formation of indolizines[20)]. He has found that 2-methyl-1-phenacyl- and 2-methyl-1-(4-nitrobenzyl)-pyridinium bromides are first acylated at the *N*-methylene group.

Starting from 5,6,7,8-tetrahydro-1-phenacylquinolinium bromide (**6**) the tricyclic phosphaindolizine derivative **7** has been obtained.



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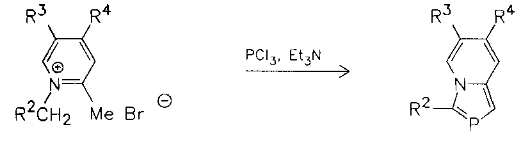
A complication arises in the synthesis of the 1-unsubstituted 2-phosphaindolizines **9**, because it is frequently accompanied by the formation of the 1-dichlorophosphino derivatives **10**. In separate reactions compounds **10** have been shown to be secondary products generated by substitution of **9**[21)]. The formation of **10** can be avoided if the reaction leading to **9** is carried out at 0°C in acetonitrile.

Analogously, from 2,5-dimethyl-1-phenacylpyrazinium bromide (**11**) 3-benzoyl-6-methyl-7-aza-2-phosphaindolizine (**12**) is obtained in low yield.



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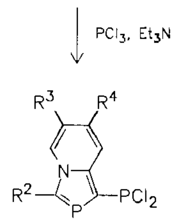
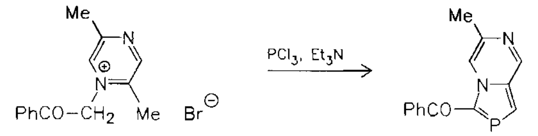
R² \ R³, R⁴	H, H	H, Me	Bu, H
COPh	a	d	f
CO_2Et	b	e	–
$C_6H_4NO_2$-4	c	–	–



10



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Charge Density Determination by MNDO Calculations

Indolizines **E** and their 1- and 2-phospha derivatives **D** and **C** represent heteroaromatic 10π-electron systems with a π-electron deficiency in the six-membered and a π-electron excess in the five-membered ring[4,14)]. MNDO calculations[26)] for the unsubstituted systems show that this π-charge separation increases in the order indolizine < 2-phosphaindolizine < 1-phosphaindolizine (Figure 1). In indolizine the π-charge is highest in the positions 1 and 3. These two positions are also known to be most susceptible to electrophilic attack[14)]. The introduction of a phosphorus atom into the position 2 lowers the π-electron density at the adjacent carbon atoms somewhat, suggesting that they will undergo electrophilic substitution less easily.

The total charge distribution in the phosphaindolizines resembles that in the parent indolizine except for the immediate local effect of the CH/P exchange: The phosphorus

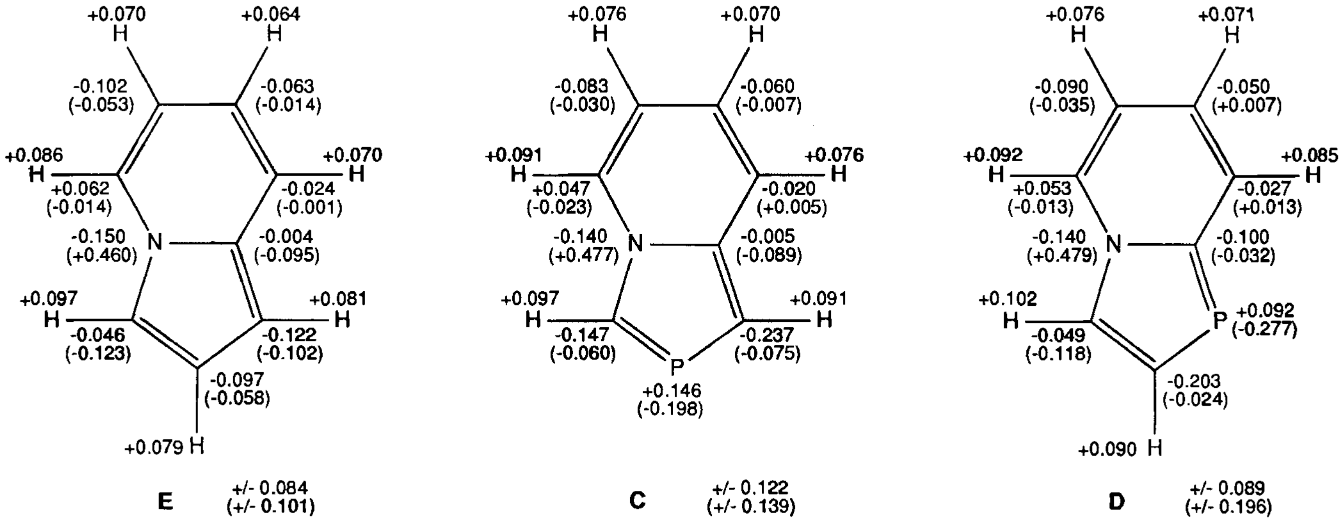


Figure 1. MNDO-calculated distribution of the total charge (π-electron charge) and the resulting relative charges of the six- and five-membered rings in indolizine **E** as well as 2- and 1-phosphaindolizines **C**, **D**

atom bears a positive charge, which is roughly 0.15 electron charges above that of the replaced CH group while the two atoms adjacent to the phosphorus atom in the ring at the same time become more negative by roughly 0.10 electron charges. In the same way as the CH group in the position 2 of **E** is less negatively charged than the CH group in the position 1, the phosphorus atom in **C** is more positively charged than in **D**. It will consequently less likely act as a donor. The different situation of the phosphorus atom in **D** and **C** parallels that in phosphamethinecyanines $(R_2N[CH]_n)_2P^{\oplus}$ with $n = 1$ and 2, respectively[22].

NMR Spectra

^{31}P*:* The chemical shifts of carbon-bonded two-coordinate phosphorus atoms in five-membered delocalized rings cover a wide range[23] with the majority of shifts at $\delta \approx 50-185$. The shifts of 1- and 2-phosphaindolizines are found well separated in different regions of this range, the former at the high-field end ($\delta = 68-76$)[4] and the latter at the low-field end ($\delta = 131-184$; see Tables 1, 2). They thus clearly reflect the difference in charge density at the phosphorus atom as calculated. Within the 2-phosphaindolizines the shifts strongly depend on the substituents R^2 and increase in the order $C_6H_4NO_2$-4 ($\delta \approx 132$) < CO_2Et, CN ($\delta \approx 163$) < COPh ($\delta \approx 182$). They depend only weakly on R^1: Ph < H < Me.

The phosphorus coupling of 1-H ($J \approx 36$ Hz; see Table 2) is characteristic of its position in the plane of the two-coordinate phosphorus atom and *cis* to the phosphorus atom lone pair of electrons[24].

Table 1. ^{31}P- and ^{1}H-NMR data of compounds **4**, **7**

δ J [Hz]	**4a**	**4b**	**4c**	**4d**	**4e**	**4f**	**4g**	**4h**	**7**
P	183.6	165.2	165.5	136.0	178.5	160.5	160.0	130.6	174.0
5-H	10.49	8.42	9.83	8.25	10.34	8.51	9.90	8.27	10.07
^4J(P,5-H)	1.4	1.5	1.8	0.9	1.1	1.1	1.8	1.1	0.8
^3J(5-H,6-H)	7.2	7.1	7.3	7.2	7.3	7.0	7.3	7.3	6.7
^4J(5-H,7-H)	1.1	1.1	1.1	0.9	1.2	1.1	1.2	1.1	1.6
^5J(5-H,8-H)	<0.5	0.5	0.5	<0.5	0.5	0.5	<0.5	0.5	
6-H	7.14	6.89	6.84	6.60	7.00	6.95	6.89	6.65	6.88
^5J(P,6-H)	1.1	1.1	1.0	0.7	0.8	1.0	0.9	0.5	1.0
^3J(6-H,7-H)	6.2	6.6	6.6	6.4	6.7	6.6	6.6	6.9	6.8
^4J(6-H,8-H)	1.3	1.3	1.5	1.5	1.5	1.3	1.5	1.3	
7-H	7.44	7.11	7.09	6.86	7.26	7.13	7.09	6.89	6.92
^5J(P,7-H)	0.7	0.8	0.7	0.9	0.6	0.7	0.6	0.5	1.1
^3J(7-H,8-H)	8.6	9.0	8.9	9.1	9.0	9.1	9.1	9.2	
8-H	7.68	7.47	7.44	7.42	7.75	7.71	7.69	7.68	
^4J(P,H-8)		1.1	1.0	1.1	1.0	1.1	1.1	1.1	
R^1: CH_3[a]	2.75	2.57	2.57	2.60					[b]
^3J(P,H)	12.5	12.7	12.0	11.7					
R^2: OCH_2			4.36				4.40		
CH_3			1.39				1.42		
^3J(H,H)			7.1				7.1		
o-H	8.0			7.7	7.9			7.8	7.9
m-,*p*-H	ca.7.2			8.3	ca.7.5			8.3	ca.7.6

[a] The ^{1}H-NMR signals of R^1 = Ph were found in the range of $\delta = 7.3-7.6$. – [b] α-H_2: $\delta = 3.14$ [td, ^3J(P,H) = 5.9 Hz]; β-H_2: $\delta = 2.01$ [quint of d, ^4J(P,H) = 1.1 Hz]; γ-H_2: $\delta = 2.94$ [t, ^3J(H,H) = 6.0 Hz].

Table 2. ^{31}P- and ^{1}H-NMR data of compounds **9**, **12**

δ J [Hz]	**9a**	**9b**	**9c**	**9d**	**9e**	**9f**	**12**
P	179.8	162.0	132.2	184.4	163.3	180.0	181.5
1-H	7.20	7.48	7.40	7.41	7.29	7.57	7.91
^2J(P,1-H)	35.4	36.4	37.5	36.1	33.0	36.1	35.4
^5J(1-H,5-H)	0.8		0.6	0.6			
5-H	10.39	9.68	8.24	10.14	9.67	9.99	9.77
^4J(P,5-H)	2.1			0.8			
^3J(5-H,6-H)	7.2	7.1	7.3	7.5	7.4		
^4J(5-H,7-H)	1.1		1.1				
^5J(5-H,8-H)	0.4		0.3	0.5			
6-H	6.19	6.87	6.61	6.75	6.65	[a]	[b]
^5J(P,6-H)	1.0		0.6				
^3J(6-H,7-H)	6.7	6.8	6.5				
^4J(6-H,8-H)	1.5		1.5	1.8	1.9		
7-H	6.41	7.08	6.84	[c]	[d]	7.15	
^5J(P,7-H)	0.6		0.5				
^3J(7-H,8-H)	9.0	8.8	9.0			9.0	
8-H	6.83	7.50	7.44	7.25	7.21	7.51	8.96
^4J(P,8-H)	1.0		1.1				
R^2: OCH_2		4.29			4.34		
CH_3		1.31			1.37		
^3J(H,H)		7.1			7.1		
o-H	8.0		7.7	7.9		7.8	7.9
m-,*p*-H	ca.7.2		8.3	ca.7.5		ca.7.4	ca.7.5

[a] 6-Bu: α-H_2: $\delta = 2.60$ (t); β-H_2: $\delta = 1.58$ (quint); γ-H_2: $\delta = 1.33$ (sext); CH_3: $\delta = 0.90$ [t, ^3J(H,H) = 7.5 Hz]. – [b] 6-CH_3: $\delta = 2.56$ (s). – [c] 7-CH_3: $\delta = 2.35$ (s). – [d] 7-CH_3: $\delta = 2.30$ (s).

^{13}C*:* The shifts and P,C coupling constants of the five-membered ring of 2-phosphaindolizines compare well with those of monocyclic 1,3-azaphospholes[2–4,9,25]. The one-bond P coupling to C-3 (formal double bond; $J = 45-63$ Hz) is always larger than that to C-1 (formal single bond; $J = 38-47$ Hz). The two-bond P coupling to C-9 is found at $J = 6.8-11.0$ Hz. The three-bond P coupling to C-8 ($J = 5.2-7.7$ Hz) is larger than that to C-5 ($J = 1.6-4.9$ Hz) while the four-bond P couplings to C-7 and C-6 are similar ($J = 2.1-4.5$ Hz). The four-bond P coupling to C-*o* of the benzoyl substituent ($J = 7.1-7.7$ Hz) is unusually large (see Tables 3, 4).

Properties and Reactivity

The 2-phosphaindolizines **4**, **7**, **9**, **12** are mostly crystalline, in some cases oily products. Their colors range from pale to dark yellow to even brown in the case of R^2 = $C_6H_4NO_2$-4. A strong green fluorescence is observed for an acetonitrile solution of **9d** when irradiated with UV light. On standing for several days solutions of 2-phosphaindolizines turn intensely green. This is always observed when these compounds are hydrolyzed (see below). Sometimes even crystalline samples not exposed to air or moisture turn green, while others do not.

In contrast to 1-phosphaindolizines which readily decompose during oxidation in air[4] the 2-phosphaindolizines are stable in dry air. Moreover, in contrast to 1-phosphaindolizines[4], 2-phosphaindolizines cannot be alkylated. This is in accord with their higher positive charge at the phosphorus

Table 3. ^{13}C-NMR data of compounds **4**, 7

δ J [Hz]	**4a**	**4b**	**4c**	**4d**	**4e**	**4f**	**4g**	**4h**	**7**
C-1	139.0	136.2	136.5	133.5	145.0	142.6	142.9	139.8	142.0
^{1}J(P,C)	39.2	42.5	38.5	40.4	39.8	41.9	38.8	40.9	42.1
^{2}J(C,H)	6.2	6.2	6.2	6.2					
^{3}J(C,H)	1.9	1.5	2.2	2.4		2.1	2.2		
C-3	141.4	136.6	133.6	149.6	143.9	116.9	136.2	151.9	141.6
^{1}J(P,C)	55.3	53.5	51.3	47.2	55.1	47.2	51.3	47.2	58.3
^{3}J(C,H)						2.7	2.2		
C-5	130.7	127.5	128.9	123.7	130.8	127.8	129.0	123.9	128.4
^{3}J(P,C)	4.0	4.4	4.0	2.1	3.8	4.2	4.4	1.6	4.9
^{1}J(C,H)	190.1	185.0	189.4	189.0		190.3	193.4		
^{2}J(C,H)	5.8	5.8	4.4	5.2		4.0	4.8		
^{3}J(C,H)	5.8	6.2	6.2	5.2		7.0	6.8		
^{4}J(C,H)	1.2	1.5	1.8	<1.0		1.2	1.1		
C-6	114.2	114.0	113.1	112.6	114.8	114.7	113.8	113.2	115.0
^{4}J(P,C)	4.4	4.4	4.0	3.1	3.9	3.2	3.7	2.6	4.3
^{1}J(C,H)	169.0	168.2	166.7	165.9		168.8	167.1		
^{2}J(C,H)	4.2	3.3 1.8	4.0 1.8	3.7 1.9		4.0 1.5	3.8 1.6		
^{3}J(C,H)	8.4	9.2	8.4	9.0		8.2	8.4		
C-7	124.6	122.5	121.8	119.1	126.0	123.9	123.2	120.6	121.5
^{4}J(P,C)	3.3	2.9	2.9	2.1	3.9	2.1	2.9	2.1	3.4
^{1}J(C,H)	167.6	167.8	166.3	165.4		167.5	167.0		
^{2}J(C,H)	2.0	1.5	1.5	<1.0		1.0	1.8		
^{3}J(C,H)	7.5	7.3	7.7	7.3		7.3	7.3		
C-8	116.3	117.4	116.3	118.0	117.6	118.6	117.5	118.9	129.4
^{3}J(P,C)	7.7	6.6	7.3	6.3	7.6	5.2	5.9	5.2	7.6
^{1}J(C,H)	166.6	167.0	165.6	164.0		169.4	168.3		
^{2}J(C,H)	1.5	1.1	1.5	1.4		1.5	1.5		
^{3}J(C,H)	7.9	7.0	7.3	7.0		6.6	6.9		
C-9	144.7	141.6	143.3	141.1	143.6	140.5	142.2	139.9	143.7
^{2}J(P,C)	10.3	11.0	9.9	8.9	7.7	9.4	8.1	6.8	9.8
R^{1}: CH$_3$	13.1	12.7	12.8	12.7					[a]
^{2}J(P,C)	25.3	25.7	25.3	25.2					
C-*i*					136.1	135.2	136.4	136.7	
^{2}J(P,C)					19.2	19.9	19.1	19.4	
C-*o*					129.4	129.4	129.3	129.4	
^{3}J(P,C)					7.7	7.4	7.3	7.3	
C-*m*					128.8	128.9	128.6	128.8	
C-*p*					127.2	127.5	126.8	126.7	
^{5}J(P,C)							1.5	1.1	
R^{2}: CO,CN	187.4	115.9	163.6		187.9	115.6	163.6		187.6
^{2}J(P,C)	25.3	24.2	19.8		25.6	24.1	19.8		25.6
OCH$_2$			59.8				60.2		
^{4}J(P,C)			1.1				0.7		
CH$_3$			14.4				14.4		
C-*i*	142.1			141.3	141.9			140.9	142.0
$^{2,3}J$(P,C)	0.6			18.4				17.8	
C-*o*	129.5			128.9	129.7			129.2	129.5
$^{3,4}J$(P,C)	7.3			7.3	7.7			7.8	7.3
C-*m*	127.6			124.5	127.8			124.5	127.6
C-*p*	130.8			146.6	131.1			146.9	130.7
^{5}J(P,C)								1.6	

[a] C-α: δ = 26.1 [^{2}J(P,C) = 16.6 Hz]; C-β: δ = 22.6 [^{3}J(P,C) = 5.8 Hz]; C-γ: δ = 28.6 [^{4}J(P,C) = 0.9 Hz].

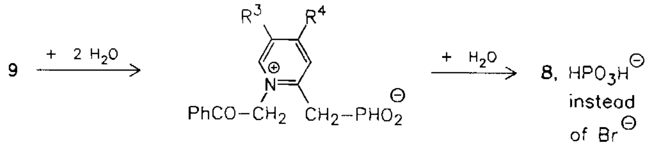
Table 4. ^{13}C-NMR data of compounds **9**, **12**

δ J [Hz]	**9a**	**9b**	**9c**	**9d**[a]	**9e**[b]	**9f**[c]	**12**[d]
C-1	126.3	125.4	121.2	125.3	122.9	127.4	129.3
^{1}J(P,C)	43.3	42.0	44.1	42.7	41.8	42.0	46.7
^{1}J(C,H)	172.7	171.7		171.2			172.0
^{3}J(C,H)		2.4		2.4			
C-3	145.8	137.9	152.2	143.9	136.2	145.1	146.0
^{1}J(P,C)	58.6	53.0	45.1	57.1	52.8	56.9	62.9
^{3}J(C,H)	7.2	7.6		7.5			7.3
C-5	130.7	129.6	124.5	129.8	128.3	136.7	119.2
^{3}J(P,C)	4.3	3.7	4.2	4.0	3.7	4.5	4.7
^{1}J(C,H)	189.8	189.6		189.3			193.0
^{2}J(C,H)		4.5		4.9			
^{3}J(C,H)		5.8					
^{4}J(C,H)		1.1		<1.0			
C-6	114.1	114.9	112.8	116.8	116.2	128.9	140.8
^{4}J(P,C)	4.3	4.2	2.6	4.3	4.4	4.5	4.2
^{1}J(C,H)	170.0	168.1		164.7			
^{2}J(C,H)		3.9, 1.3		4.2			
^{3}J(C,H)		8.7		7.3, 4.2			
C-7	124.9	124.2	120.1	136.7	133.7	129.0	
^{4}J(P,C)	3.1	3.1	2.1	3.1	2.9	3.2	
^{1}J(C,H)	166.5	166.5					
^{2}J(C,H)		<1.0		6.2, 1.1			
^{3}J(C,H)		7.3		7.3			
C-8	119.2	120.6	120.8	117.8	118.0	119.9	144.2
^{3}J(P,C)	7.0	6.8	5.8	7.0	6.6	7.1	7.3
^{1}J(C,H)	166.6	167.0		164.1			185.1
^{2}J(C,H)		1.3					
^{3}J(C,H)		7.6, 2.3		6.8, 2.6 4.2[e]			
C-9	146.9	147.1	144.0	147.3[f]	146.5	147.0	138.7
^{2}J(P,C)	10.4	11.0	9.4	10.7	11.0	10.5	10.5
R^{2}: CO	187.7	164.3		187.4	163.9	188.2	188.7
^{2}J(P,C)	25.3	19.9		25.9	20.5	26.0	23.6
OCH$_2$		60.9			60.0		
^{4}J(P,C)		0.8					
CH$_3$		14.8			15.5		
C-*i*	142.6		141.2	141.8		143.1	
^{2}J(P,C)			17.8				
C-*o*	130.2		129.1	129.5		130.4	129.7
$^{3,4}J$(P,C)	7.6		7.9	7.3		7.1	7.3
C-*m*	127.7		124.4	127.6		128.7	128.0
C-*p*	131.1		146.7	130.8		131.8	131.8
^{5}J(P,C)			2.1				

[a] 7-CH$_3$: δ = 20.8 [qdd, ^{1}J(C,H) = 127.4 Hz, ^{3}J(C,H) = 5.0, 3.7 Hz]. – [b] 7-CH$_3$: δ = 14.5 (s). – [c] 6-Bu: C-α: δ = 33.5 [d, ^{5}J(P,C) = 0.8 Hz]; C-β: δ = 33.1 (s); C-γ: δ = 22.9 (s); CH$_3$: δ = 14.1 (s). – [d] 6-CH$_3$: δ = 21.1 (s). – [e] Coupling with methyl protons. – [f] ^{2}J(C,8-H) ≈ ^{2}J(C,1-H) ≈ ^{3}J(C,5-H) ≈ 5.5 Hz.

atom (see above). A first test shows, however, that 2-phosphaindolizines can form complexes with transition metals. Thus, **9d** replaces the olefin in pentacarbonyl[(*Z*)-cyclooctene]chromium. The observed ^{31}P-NMR coordination shift of Δδ = 7.5 is in compliance with a P coordination of **9d** and is of the same order of magnitude as for other azaphospholes P-coordinated to Cr(CO)$_5$[23].

2-Phosphaindolizines are more or less susceptible to hydrolysis. The representatives **4** with R^{1} = Me may be handled in moist media for a short time without detectable harm. After 3 weeks in acetonitrile solution containing an equimolar amount of water only 5% of these compounds are hydrolyzed yielding HPO$_3$H$^{\ominus}$ [^{31}P NMR: δ ≈ 3, d, ^{1}J(P,H) ≈ 640 Hz]. The 1-unsubstituted representatives **9** are hydrolyzed more readily and completely within a few days.



R^3, R^4	H, H	H, Me	Bu, H
	13a	**13b**	**13c**

Table 5. ^{31}P- and ^1H-NMR data of compounds **13** (coupling constants J in Hz)

		13a	**13b**	**13c**
$\delta^{31}P$ (dt)		13.2	12.3	15.5
	$^1J(P,H)$	537.0	535.2	542.0
	$^2J(P,H)$	15.5	15.3	15.8
	$^4J(P,3\text{-}H)$	1.5		2.0
δ^1H	PH	7.04		7.03
	PCH_2	3.27		3.23
	NCH_2	6.58		6.54
	3-H	7.93		7.85
	$^3J(3\text{-}H,4\text{-}H)$	8.0		7.9
	4-H	8.41		8.26
	$^4J(4\text{-}H,6\text{-}H)$	1.2		1.8
	5-H	7.81[a]		[b]
	6-H	8.53		8.38
	o-H	8.1		8.1
	m-H	7.6		7.6
	p-H	7.7		7.7

[a] $^3J(4\text{-}H,5\text{-}H) = 7.6$; $^3J(5\text{-}H,6\text{-}H) = 6.4$; $^4J(3\text{-}H,5\text{-}H) = 1.5$. – [b] 5-Bu: α-H_2: $\delta = 2.73$ (t); β-H_2: $\delta = 1.60$ (quint); γ-H_2: $\delta = 1.32$ (sext); CH_3: $\delta = 0.98$ [t, $^3J(H,H) \approx 7.4$].

The predominant product results from the hydrolytic cleavage of the bond between P and C-3 and is unequivocally identified by its NMR spectra (see Table 5 and Experimental) as the zwitterion **13**. In a slower second step it decomposes further to give the corresponding pyridinium phosphite.

We thank the *Alexander von Humboldt Foundation* and the *Fonds der Chemischen Industrie* for their support and the *University Grants Commission* (New Delhi) for the award of a Junior Research Fellowship to N. G.

Experimental

All reactions were carried out under dry oxygen-free argon by using the Schlenk technique. – Melting points were determined with a Lintström apparatus and are uncorrected. – ^{31}P NMR: Jeol GSX-270. – ^1H and ^{13}C NMR: Jeol EX-400. – IR: Perkin-Elmer 881. – Compounds **3** are prepared as described in the literature (**3a, b, c, e, f**[17], **3g**[17,19], **8a, b, c**[18], **8d**[17], **8e**[17,19]) or in an analogous manner: To 0.1 mol of **2** in 100 ml diethyl ether 0.1 mol of **1** is added at ambient temperature with stirring. After 24–36 h, the colorless to cream-colored solid formed is separated, washed with diethyl ether, and dried. The salts are obtained in 75–95% yield and used without further purification.

2-Ethyl-1-(4-nitrobenzyl)pyridinium Bromide (**3d**): Mp 181 to 182°C.

$C_{14}H_{15}BrN_2O_2$ (323.2)	Calcd.	C 52.03	H 4.60	N 8.67
	Found	C 51.35	H 4.76	N 8.45

2-Benzyl-1-(4-nitrobenzyl)pyridinium Bromide (**3h**): Mp 178 to 180°C.

$C_{19}H_{17}BrN_2O_2$ (385.3)	Calcd.	C 59.24	H 4.45	N 7.27
	Found	C 59.00	H 4.34	N 7.16

5,6,7,8-Tetrahydro-1-phenacylquinolinium Bromide (**6**): Mp 200 to 202°C.

$C_{17}H_{18}BrNO$ (332.2)	Calcd.	C 61.46	H 5.46	N 4.22
	Found	C 61.23	H 5.57	N 4.37

(Dichlorophosphino)(ethoxycarbonyl)(2-ethyl-1-pyridinio)methanide (**5c**): To 3.2 g (11.7 mmol) of **3c**, suspended in 50 ml of toluene under dry argon, 3.3 ml (23.3 mmol) of Et_3N is added with stirring. **3c** dissolves to give a yellow solution from which ammonium bromide precipitates. 1.6 g (11.7 mmol) of PCl_3 in 10 ml of toluene is slowly added, and the solution is stirred at ambient temperature for 24 h. ^{31}P NMR indicates that all the PCl_3 has been consumed and **5c** ($\delta = 149.1$) been formed. After filtration and washing the residue three times with toluene, the solvent of the combined solutions is removed in vacuo. The residue is extracted three times with diethyl ether. The ethereal extracts are combined and concentrated to afford a sticky mass which is washed with pentane to give 2.2 g (63%) of brownish-yellow crystals, mp 125–128°C (after shrinking at 102–104°C). – ^1H NMR (C_6D_6): $\delta = 0.85$ (t), 2.94 [q, $^3J(H,H) = 7.3$ Hz, CEt]; 1.16 (t), 4.23 [q, $^3J(H,H) = 7.0$ Hz, OEt]; 6.46 [dd, $^3J(H,H) = 5.9$ Hz, 5-H]; 6.70 [d, $^3J(H,H) = 7.6$ Hz, 3-H]; 6.96 [t, $^3J(H,H) = 7.3$ Hz, 4-H]; 8.42 (d, 6-H). – ^{13}C NMR (C_6D_6): $\delta = 11.6$, 26.1 (CEt); 15.2, 59.3 [d, $^4J(P,C) = 2.9$ Hz, OEt]; 149.9 [d, $^3J(P,C) = 4.4$ Hz, C-6]; 165.8 [d, $^2J(P,C) = 35.2$ Hz, CO]. – ^{31}P NMR (C_6D_6): $\delta = 151.2$.

$C_{11}H_{14}Cl_2NO_2P$ (294.1)	Calcd.	C 44.92	H 4.80	N 4.76
	Found	C 44.20	H 5.62	N 4.99

When to a solution of **5c** in toluene two equivalents of Et_3N are added and the solution is heated to 60°C for 4 d **4c** is formed.

2-Phosphaindolizines **4**, **7**, **9**, **12**: 0.1 mol of the pyridinium bromides **3a–h**, 6, **8a–f**, or pyrazinium bromide **11** is suspended in 200 ml of toluene or acetonitrile under argon. When toluene is used, the reaction is generally performed at ambient temperature, in the case of acetonitrile at 0–5°C. To the well-stirred suspension 56 ml (0.4 mol) of Et_3N is added slowly, and an intense yellow color develops indicating the formation of the pyridinium ylide. Then 8.7 ml (0.1 mol) of PCl_3 in 10 ml of the respective solvent is added within about 1 h. The reaction mixture turns pale within the first few minutes and turns brown afterwards. When acetonitrile is used, the mixture is now allowed to warm to ambient temperature. After stirring for ca. 12 h (in case of **4c** and **7** after heating the toluene solution at 60–65°C for 6 d or 5 h, respectively), the reaction mixture is filtered and the solid thoroughly washed three times with the solvent. The solvent of the combined solutions is evaporated to dryness in vacuo and the residue extracted with diethyl ether (three times with 100 ml). The ethereal extracts are combined, concentrated, and left in the refrigerator (ca. 4°C) when crystals separate (see Table 6), or the diethyl ether is evaporated completely, as in the case of **9b**.

Alternatively, the reaction mixture is not filtered, but the acetonitrile is evaporated. After this, the residue is extracted three times with vigorous stirring with 200 ml of diethyl ether. We consider this workup and the reaction performed in acetonitrile the method of choice. Products which do not crystallize after evaporation of diethyl ether can be purified by extracting them again with hexane.

In the case of $R^2 = C_6H_4NO_2$-4 the yields obtained by use of the above workup are very low (see **9c** in Table 6; in the case of R^3, R^4 = H, Me no 2-phosphaindolizine is obtained at all). The yields are improved (see **4d, h**) if the residue obtained after removal of the acetonitrile is extracted continuously with toluene for several days using a device in which the solvent is recycled by distillation from the extract.

9d·*Cr(CO)*$_5$: A sample was prepared qualitatively. To a solution of **9d** (0.020 g; 0.08 mmol) in hexane/diethylether (1:1) (5 ml) at −60°C under argon an equimolar amount of pentacarbonyl[(*Z*)-cyclooctene]chromium (0.024 g, 0.08 mmol) is added. After warming the reaction mixture to ambient temperature and stirring for 1 h, the solvent is removed by evaporation and the residue extracted with hexane. After evaporation of the solvent, yellow crystals are obtained. — IR (hexane): $\tilde{\nu}$ = 2075 cm^{-1} (w), 2001 (vw), 1964 (s), 1956 (m) [$\tilde{\nu}$(CO)]. — ^{31}P NMR ($CDCl_3$): δ = 191.9.

Table 6. Yields, physical, and analytical data of compounds **4, 7, 9, 12**

	Yield %	Color m.p.[°C]	Formula *M*	Calcd. Found	C	H	N
4a	68 [a)]	pale yellow 124-25	$C_{15}H_{12}NOP$ 252.2		71.43	4.40	5.55
4b	32 [a)]	pale yellow 151-52	$C_9H_7N_2P$ 174.1		62.08 60.53	4.05 4.43	16.09 15.81
4c	51 [b)]	dark yellow 71-73	$C_{11}H_{12}NO_2P$ 221.2		59.74 59.04	5.47 5.66	6.33 6.36
4d	53 [c)]	brown 188-89	$C_{14}H_{11}N_2O_2P$ 270.2		62.23 61.88	4.10 4.20	10.37 10.36
4e	49 [a)]	yellow 135-36	$C_{20}H_{14}NOP$ 315.3		76.19 77.03	4.47 5.18	4.44 4.37
4f	33 [a)]	pale yellow 158-59	$C_{14}H_9N_2P$ 236.2		71.19 71.66	3.84 4.47	11.89 11.89
4g	64 [a)]	canary yellow 73-75	$C_{16}H_{14}NO_2P$ 283.2		67.84 67.58	4.98 5.28	4.94 4.89
4h	36 [c)]	brown 177-78	$C_{19}H_{13}N_2O_2P$ 332.3		68.67 68.64	3.94 3.95	8.43 8.51
7	60 [b)]	yellow 116-18	$C_{17}H_{14}NOP$ 279.3		73.11 73.22	5.05 5.48	5.02 4.92
9a	36 [c)]	pale yellow 114-19	$C_{14}H_{10}NOP$ 239.2		70.22 70.39	4.22 4.32	5.86 5.89
9b	19 [c)]	orange oil	$C_{10}H_{10}NO_2P$ 207.2		57.98 59.69	4.87 5.31	6.76 6.57
9c	5 [c)]	brown					
9d	46 [c)]	yellow 117-18	$C_{15}H_{12}NOP$ 253.2		71.14 69.19	4.78 4.95	5.53 5.55
9e	10 [c)]	yellow 34	$C_{11}H_{12}NO_2P$ 221.2		59.73 59.66	5.47 5.77	6.33 6.09
9f	10 [c)]	yellow 51-52	$C_{18}H_{18}NOP$ 295.3		73.21 72.18	6.14 6.32	4.74 4.71
12	6 [c)]	dark yellow 120-130	$C_{14}H_{11}N_2OP$ 254.2		66.14 66.54	4.36 4.58	11.02 10.94

Synthesis performed in: [a)] toluene at 25°C; [b)] toluene at 60−65°C; [c)] acetonitrile at 0−5°C.

Hydrolysis of **9f**: When an equimolar amount of water (23 μl) is added to 384 mg (1.3 mmol) of **9f** in 25 ml of acetonitrile and the mixture is allowed to stand at room temperature for 2 d, its ^{31}P-NMR spectrum shows only the signal of **9f** (δ = 181.4). With 10 mmol (180 μl) of water after 7 d the ^{31}P-NMR spectrum shows the formation of $HPO_3H^{\ominus}$ {δ = 3.6 [d, ^1J(P,H) = 642.0 Hz]} and of **13c** (see Table 5, also for ^{1}H NMR) with the relative intensities 1:10.5. ^{1}H- and ^{13}C-NMR signals of **13c** are assigned unambiguously from a ^{1}H-/^{13}C-correlated spectrum. — ^{13}C NMR (CD_3CN): δ = 14.0 [q of quint, ^1J(C,H) = 124.5 Hz, ^2J(C,H) = ^3J(C,H) = 4.2 Hz, CH_3], 22.6 [t, ^1J(C,H) = 123.0 Hz, Bu, γ-H_2], 32.3 [t, ^1J(C,H) = 129.3 Hz, Bu, β-H_2], 32.7 [t, ^1J(C,H) = 121.9 Hz, Bu, α-H_2], 39.8 [tddd, ^1J(C,H) = 131.1 Hz, ^1J(P,C) = 66.1 Hz, ^2J(C,H) = 23.6 Hz, ^3J(C,H) = 2.1 Hz, PCH_2], 65.3 [td, ^1J(C,H) = 145.0 Hz, ^3J(C,H) = 3.7 Hz, NCH_2], 129.5 [dt, ^1J(C,H) = 162.3 Hz, ^3J(C,H) = 7.3 Hz, C-*o*], 130.2 [dd, ^1J(C,H) = 164.1 Hz, ^3J(C,H) = 7.9 Hz, C-*m*], 135.9 [dt, ^1J(C,H) = 162.8 Hz, ^3J(C,H) = 7.5 Hz, C-*p*], 134.7 (s, C-*i*), 191.4 (s, CO), 152.4 [d, ^2J(P,C) = 8.9 Hz, C-2], 130.8 [dd, ^1J(C,H) = 174.1 Hz, ^3J(P,C) = 4.2 Hz, C-3], 146.9 [d, ^1J(C,H) = 169.4 Hz, C-4], 141.5 (s, C-5), 146.7 [d, ^1J(C,H) = 194.7 Hz, C-6].

CAS Registry Numbers

1 R′ = Me): 100-71-0 / **1** (R′ = Ph): 101-82-6 / **2d**: 100-11-8 / **3a**: 5994-36-5 / **3b**: 131354-15-9 / **3c**: 70257-97-5 / **3d**: 131354-16-0 / **3e**: 1094-77-5 / **3f**: 131354-17-1 / **3g**: 74360-64-8 / **3h**: 131354-18-2 / **4a**: 131354-19-3 / **4b**: 131354-20-6 / **4c**: 131354-21-7 / **4d**: 131354-22-8 / **4e**: 131354-23-9 / **4f**: 131354-24-0 / **4g**: 131354-25-1 / **4h**: 131354-26-2 / **5c**: 131354-39-7 / 6: 102408-79-7 / **7**: 131354-27-3 / **8a**: 32896-98-3 / **8b**: 55814-02-3 / **8c**: 85108-55-0 / **8d**: 26557-57-3 / **8e**: 95047-62-4 / **8f**: 131354-28-4 / **9a**: 131354-29-5 / **9b**: 131354-30-8 / **9c**: 131354-31-9 / **9d**: 131354-32-0 / **9d** · $Cr(CO)_5$: 131354-41-1 / **9e**: 131354-33-1 / **9f**: 131354-34-2 / **11**: 109101-58-8 / **12**: 131354-38-6 / **13a**: 131354-35-3 / **13b**: 131354-36-4 / **13c**: 131354-37-5 / **C**: 131354-40-0 / **D**: 113894-72-7 / **E**: 274-40-8 / PCl_3: 7719-12-2 / Pentacarbonyl[(*Z*)-cyclooctene]chromium: 92889-73-1

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[257/90]