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Alkylamides of trivalent phosphorus-acids: phosphorus–nitrogen diad tautomerism

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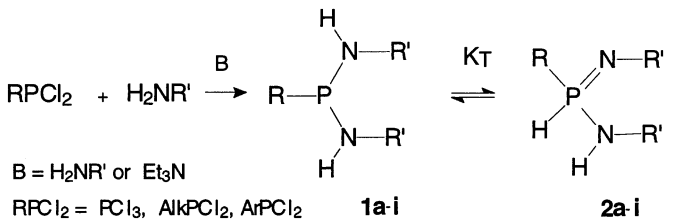
Abstract

Alkylamides of trivalent phosphorus acids **1** exist in prototropic equilibrium with PH–iminophosphoranes **2**. Phosphorus–nitrogen diad tautomeric equilibrium **1** ⇌ **2** depends on the nature of solvents and the substituents at the phosphorus and nitrogen atoms shifting towards the tautomeric form possessing the least mobile proton. © 2000 Published by Elsevier Science Ltd.

Keywords: phosphorus–nitrogen diad prototropic tautomerism; tris(alkylamino)phosphines; bis-alkylamides of phosphonic acids; tris[(*S*)-α-methylbenzylamino]phosphine.

We have recently described chiral symmetric esters of phosphoric acid prepared from optically active natural alcohols (glucofuranose, borneol, menthol, etc.) and demonstrated that these esters are suitable starting materials for asymmetric synthesis.[1–3]

Proceeding with these studies, we have prepared the chiral symmetric alkylamides of trivalent phosphorus acids **1**, R′ = (*S*)-CH(Me)C_6H_5 possessing interesting chemical properties (Scheme



Scheme 1.

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1). Thus, we found that the compounds **1** exist in tautomeric equilibrium with PH–iminophosphoranes **2**. Formerly the phosphorus–nitrogen diad prototropy of trivalent phosphorus compounds **1** containing alkylamino groups was not described, although PH–iminophosphoranes, $R_2P(H)=NR'$, containing electron-accepting substituents $R'=SO_2Ar$, C(O)Ar, $SiMe_3$ are known.[4,5] Bis- and tris(alkylamino)phosphines **1** are in general little-studied compounds. Many years ago Michaelis described an attempt to prepare the tris(*n*-propylamino)phosphine however he came to the conclusion that tris(alkylamino)phosphines are unstable.[6] Therefore, we have studied compounds **1** bearing at the nitrogen, not only in chiral 1-methylbenzylamino groups, but also in other alkyl groups. The compounds **1** were prepared by reaction of PCl_3 or $RPCl_2$ with excess alkylamines or with alkylamines and triethylamine as shown in Scheme 1.[7] Aminophosphines **1** are stable at room temperature and not stable to heating. Sterically hindered groups R and R′ increase the stability of **1**, which can easily be isolated as spectroscopically pure liquids or crystalline compounds. (Table 1).[8]

Table 1
Phosphorus–nitrogen diad prototropy **1** ⇌ **2**

Entry	Compd	R	R′	Solvent	$\delta_{P(III)}$	δ_{HP}	$^1J_{HP}$	K_T	P^{III}/P^{IV}
1	**1a**	C_6H_5	$CH(CH_3)C_6H_5$	$CDCl_3$	60.04	13.63	534	0.59	37:63
2	**1a**	C_6H_5	$CH(CH_3)C_6H_5$	CD_2Cl_2	60.24	8.27	525	0.66	40:60
3	**1a**	C_6H_5	$CH(CH_3)C_6H_5$	C_6D_6	60.04	12.14	528	0.72	42:58
4	**1a**	C_6H_5	$CH(CH_3)C_6H_5$	Et_2O	60.11	11.03	520	1.28	56:44
5	**1b**	4-$Me_2NC_6H_4$	$CH(CH_3)C_6H_5$	$CDCl_3$	61.39	14.67	526	0.89	47:53
6	**1c**	4-FC_6H_4	$CH(CH_3)C_6H_5$	$CDCl_3$	60.11	12.15	538	1.63	62:38
7	**1d**	$C(CH_3)_3$	$CH(CH_3)C_6H_5$	C_6D_6	88.65	−7.27	596	19	95:5
8	**1e**	$NHCH(CH_3)C_6H_5$	$CH(CH_3)C_6H_5$	$CDCl_3$	104.8	7.53	580	0.09	1:11
9	**1f**	$NHCH_2CH(CH_3)_3$	$CH_2CH(CH_3)_3$	$CDCl_3$	115.7	12.49	579	1.4	7:5
10	**1g**	$NHCH(CH_3)_2$	$(CH_3)_2CH$	$CDCl_3$	94.24	5.52	560	0.89	47:53
11	**1h**	$NHCH(CH_3)C_2H_5$	$CH(CH_3)C_2H_5$	$CDCl_3$	92.35	8.31	562	2.03	67:33
12	**1i**	$NHC(CH_3)_3$	$C(CH_3)_3$	$CDCl_3$	88.72	−7.24	581	11.5	92:8

NMR spectra allow us to observe NH–phosphine and PH–iminophosphorane tautomeric forms (Fig. 1). Thus, the ^{31}P NMR spectrum of tris[(*S*)-α-methylbenzylamino]phosphine **1e** exhibits two signals: the first at 104.2 ppm, quartet, $^3J_{PH}$ 18 Hz, belonging to the NH–phosphine form, and the second at 7.53 ppm, double triplet with a very large coupling constant $^1J_{PH}$ 580

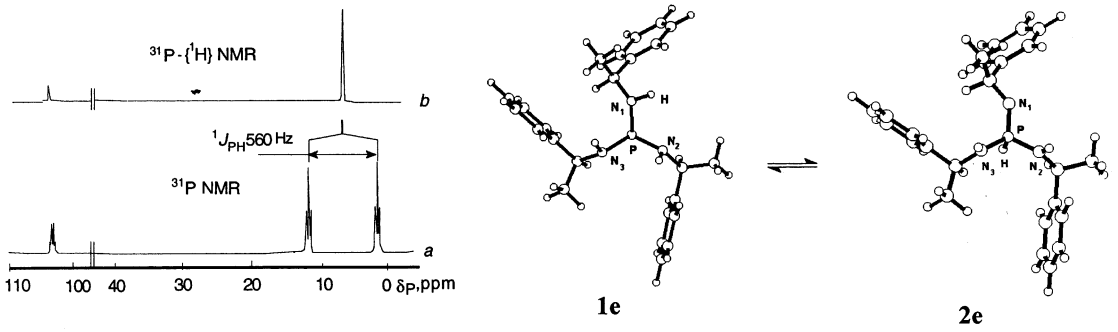


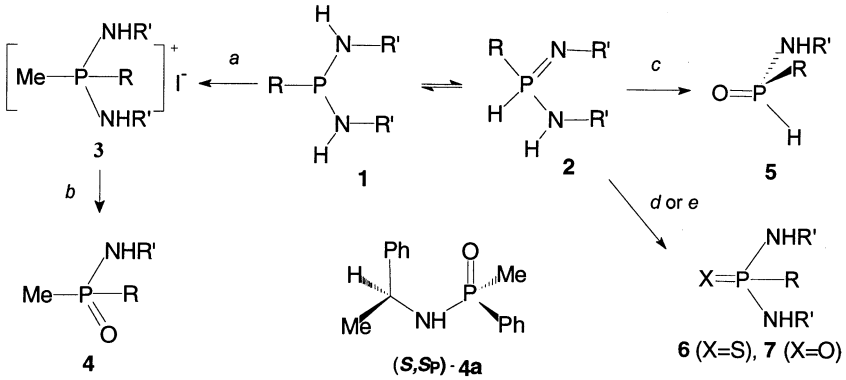
Figure 1. (a) ^{31}P NMR spectrum of tris[(*S*)-α-methylbenzylamino]phosphine **1e** in $CDCl_3$ solution; (b) ^{31}P-{^1H} NMR spectrum of **1e** in $CDCl_3$ solution; (c) MOPAC-97 molecular modelling of **1e** ⇌ **2e**

Hz (PH-group) and the coupling constant $^3J_{PH}$ 10 Hz (PNH groups) corresponding to the PH–iminophosphorane form. In the ^{31}P-{^1H} NMR spectra the double triplet converts into a singlet that confirms the structure of the PH–iminophosphorane **2e** (Fig. 1b). The ^1H NMR spectra show a doublet with the same constant $^1J_{PH}$ belonging to the PH group. The IR spectra of compounds **2** reveal the absorption at 2380 cm^{-1}, corresponding to the P–H vibration.

The results presented in Table 1 show that the position of the prototropic equilibrium **1** ⇌ **2** depends strongly on the solvent used and substituents at the phosphorus and nitrogen atoms, which, evidently, influence the mutual acidity of the PH and NH forms:

1. Electron-donating substituents X = F<H<Me_2N of the *para*-substituted bis(alkylamino)arylphosphines **1a–c**, 4-$XC_6H_4P(NHR')_2$, displace the prototropic equilibrium **1** ⇌ **2** towards the NH–phosphine form (entries 1, 5, 6). Evidently, these substituents reduce the acidity of the PH-form;
2. Branched alkyl substituents at the nitrogen atom of compounds **1d–i**, R′ = $(CH_3)_3C$> $CH_3CH_2(CH_3)CH \sim (CH_3)_2CH$>$(CH_3)_2CHCH_2$>$C_6H_5(CH_3)CH$, stabilize the NH–phosphine form and displace the tautomeric equilibrium towards this form (entries 8–12). It is well known that more branched alkyl groups possess a higher electron-donating effect and therefore they reduce the NH-acidity of compounds.[9a,b]
3. The position of the tautomeric equilibrium depends also on the solvent. In the following solvent sequence: chloroform>methylene chloride>benzene>ether, the tautomeric equilibrium is shifted towards the PH–iminophosphoranes **2** (entries 1–4).

The chemical properties of compounds **1** are similar to those of other trivalent phosphorus compounds, confirming their structure (Scheme 2).



Scheme 2. (a) MeI; (b) Na_2CO_3/H_2O; (c) HCO_2H; (d) $(Me_3Si)_2O_2$; (e) S_8/toluene

Compounds **1** are alkylated by methyl iodide to furnish phosphonium salts **3**, the alkaline hydrolysis of which results in the formation of the optically active amidophosphinates **4**. The major diastereomer (S,S_P)-**4a** was isolated and purified by crystallization from hexane. The reaction of aminophosphines **1** with formic acid resulted in amides of phosphinic acid **5** with very high stereoselectivity. The compounds **1** are easily oxidized by bis(trimethylsilyl)peroxide or add sulfur with the formation of P=S or P=O derivatives **6**, **7**. As a result of these reactions a number of optically active compounds **3–7** bearing chiral (*S*)- or (*R*)-1-methylbenzylamino groups have been prepared. These compounds have been studied as catalysts for asymmetric reduction of C=O and C=N groups as well as a chiral matrix for preparation of optically active dendrimers. The results of these studies will be reported separately.

Acknowledgements

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7. As representative example the synthesis of tris(*tert*-butylamino)phosphine (**1i**) is described: A solution of phosphorus trichloride (0.1 mol) in 10 ml of ether was added dropwise with stirring and cooling up to −70°C to a solution of *tert*-butylamine (0.6 mol) in 25 ml of diethyl ether. The temperature was raised to room temperature and the reaction mixture was left stirring for 2 hours. The triethylamine chlorohydrate was filtered off, the solvent was evaporated and the solid residue was crystallized from diethyl ether at −20°C. Yield 75%, mp 121°C. ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.26 s [27H, $(CH_3)_3C$]; 2.46 m (3H, NH).
8. (a) Kolodiazhnyi, O. I. *Tetrahedron Lett.* **1980**, *21*, 2269–2272. (b) Tolman, Ch. A. *Chem. Rev.* **1977**, *77*, 313.
9. The compounds **1**, **3**–**7** are described in: Kolodiazhnyi, O. I.; Prynada, N. *Zh. Obshch. Khim*, in press. In this paper we give representative information concerning the compounds **3**–**7**. (**3g**): Yield 60%, mp 142°C. ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 41.87. (*S*,S_P)-**4a**: mp 136°C (hexane), $[\alpha]_D^{20}$−46 (*c* 0.3, $CHCl_3$), ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.11 d ($^3J_{HP}$ 14, 3H, CH_3C); 1.11 d ($^3J_{HH}$ 7.5, 3H, CH_3P); 2.09 m (1H, NH); 3.97 m (1H, CH); 7.28, m (5H, C_6H_5). ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 26.99. (*S*,R_P)-**4a**: δ_P 28.33 ppm. (**5d**): Yield 80%, ∼100% de, bp 140°C (0.05 mmHg). $[\alpha]_D^{20}$−91 (*c* 0.3, toluene). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 0.93 d [$^3J_{HP}$ 17.5, 9H, $(CH_3)_3C$]; 1.26 d ($^3J_{HP}$ 9, 3H, CH_3CH); 4.27 m (1H, NH); 6.32 d (1H, $^1J_{HP}$ 495, PH); 7.28 m (5H, C_6H_5). ^{31}P NMR (δ, ppm, $CDCl_3$). δ_P: 39.31 dd, $^1J_{HP}$ 490, $^3J_{HP}$ 17. (**6b**): Yield 60%, mp 132°C (toluene+hexane). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.25 d ($^3J_{HP}$ 7.5, 3H, CH_3); 1.35 d ($^3J_{HP}$ 7.5, 3H, CH_3); 2.55 m (2H, CH); 2.99 s (6H, CH_3N); 4.44 m (2H, NH); 6.53–7.84 m (9H, C_6H_5+C_6H_4). ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 64.42. (**6c**): Yield 50%, mp 106°C (toluene+hexane). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.28 d ($^3J_{HP}$ 7.0, 3H, CH_3); 1.42 d ($^3J_{HP}$ 7.0, 3H, CH_3); 2.65 m (2H, CH); 4.3 m (2H, NH); 6.8–7.7 m (9H, C_6H_5+C_6H_4). ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 62.33. (**6e**): Yield 60%, mp 105–106°C (ethyl acetate–hexane). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.62 d ($^3J_{HP}$ 6.5, 9H, CH_3); 2.52 m (3H, CH); 4.33 m (3H, NH); 7.17 m (15H, C_6H_5); ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 58.76. (**6g**): Yield 80%, mp 91–92°C (petrol). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 1.13 d ($^3J_{HP}$ 6.5, 12H, CH_3); 2.15 m (2H, CH); 3.466 m (3H, NH). ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 58.76. (**7g**): Yield 62%, mp 41–42°C (hexane). ^{1}H NMR (δ, ppm, *J*, Hz, $CDCl_3$): 0.80 d ($^3J_{HP}$ 6.5, 12H, CH_3); 2.45 m (2H, CH); 3.41 m (3H, NH). ^{31}P NMR (δ, ppm, $CDCl_3$): δ_P 17.90.