SYNTHESIS AND CHARACTERIZATION OF METHYLPHOSPHINEDIACETIC ACID*

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Methylphosphinediacetic acid, a novel carboxyphosphine ligand, was obtained as the hydrochloride after reacting methyldichlorophosphine with ethyl bromozinc acetate, subjecting the ester formed to basic hydrolysis, and treating the disodium salt with excess hydrochloric acid. The substance was characterized by its analytical and spectral data. The protonation of the anion demonstrated that the methyl group, with low electronic and steric demands, induces a pronounced increase in the basicity of the phosphorus atom as compared with other hitherto examined phosphineacetic acids: the first proton bonds exclusively to the phosphorus ($pK = 6{\cdot}19$), whereas protonation of the carboxyl groups only occurs in acid solutions ($pK = 2{\cdot}76$ and $1{\cdot}2$, respectively); hence, the free acid has the zwitterion structure.

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The preceding papers in this series have been concerned with tertiary phosphine ligands containing CH_2COOH and C_6H_5 functional groups. The presence of the phenyl group is advantageous particularly from the synthetic point of view; on the other hand, this group as a sterically demanding electrophilic substituent affects unfavourably the σ-donor ability of the phosphorus atom. The electronic and steric properties of substituents have generally a substantial effect on the coordination behaviour of simple phosphine ligands[1,2], which are of importance, *e.g.*, in homogeneous catalysis[3]. Moreover, in phosphineacetic acids the basicity of the phosphorus gives rise to another, specific effect, *viz.* a competition of the phosphorus atoms with the carboxyl groups in the protonation (formation of zwitterions[4]), which is of crucial importance for the complexing behaviour of the substances. The aim of the present work was to establish the influence of the methyl group, a substituent with modest steric demands and a pronounced $+I$ effect, on the properties of the basic unit of phosphineacetic acids, —$P(CH_2COOH)_2$. The new ligand synthesized for this purpose, methylphosphinediacetic acid (H_2G), is convenient also in that it can be directly compared with its nitrogen analogue, methyliminodiacetic acid, which has been studied extensively.

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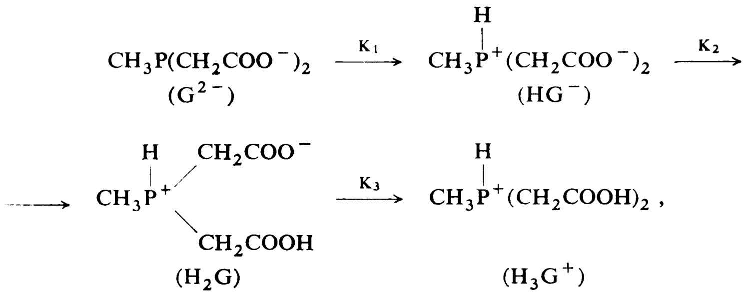
The ligand was prepared by making use of the conventional procedure[5-7] of reacting chlorophosphine with an organometallic substance containing a carboxyl group. The bis(ethyl ester), isolated by distillation, was subjected to basic hydrolysis to afford the disodium salt. As expected, the substance – in contrast to sodium phenylphosphineacetates – is susceptible to air oxidation, and was therefore treated with excess hydrochloric acid to give the crystalline hydrochloride $H_2G.HCl$, which is stable in air and fairly soluble in water. The overall yield from the synthesis was 8% with respect to methyldichlorophosphine; an increase in the yield might probably be achieved by optimizing the first step. The analytical and spectral data of the bis(ethyl ester), the disodium salt, and the hydrochloride of methylphosphinediacetic acid are in agreement with the assumed composition and structure.

If dissolved in water, $H_2G.HCl$ splits off the first of its three protons virtually completely. The dissociation of the second and the third protons can be conveniently followed potentiometrically using a glass electrode. The titration curves were processed[8] to obtain the protonation constant values, *viz.* $\log \beta_1 = \log([HG]/[H][G]) = 6{\cdot}19(1)$ and $\log \beta_2 = \log([H_2G]/[H]^2[G]) = 9{\cdot}05(2)$ at 25°C and $I = 0{\cdot}1$ ($NaClO_4$).

The addition of the third proton is only observable at $pH < 1{\cdot}5$. An approximate value of the constant $K_3 = [H_3G]/([H][H_2G])$ could be determined from the infrared spectra of acid solutions in D_2O. The spectra are of diagnostical use particularly in the region of 1 500 – 1 800 cm^{-1}, where the four possible structures of the carboxyl group absorb in three well resolved bands[4]: $R_2PCH_2COO^-$ at about 1 575 cm^{-1}, $R_2P^+(H)CH_2COO^-$ at about 1 610 cm^{-1}, and R_2PCH_2COOH together with $R_2P^+(H)CH_2COOH$ at about 1 720 cm^{-1}. The integral intensities of these bands (for equal concentrations of the groups concerned) are identical within experimental error[4]. Based on the data of the band intensities for solutions of different acidity (Fig. 1), the mechanism of the association of protons and the third protonation constant were determined. It is clear that the first proton attached is bonded exclusively to the phosphorus, and only the second and third protons bond to the carboxyl groups ($K_i = \beta_i/\beta_{i-1}$):



The relative integral intensities of the bands at 1 610 and 1 720 cm^{-1} in the acid region provided the value of pK_3 = 1·2(1).

The above protonation mechanism was confirmed by the ^{1}H and ^{31}P{^{1}H} NMR spectra patterns. The variations in the chemical shifts in dependence on the solution acidity are summarized in Fig. 2 and Table I. The ^{1}H NMR spectra reflect the changes in the shielding of the nonlabile hydrogen atoms due to protonation of neighbouring sites[4,9]. In the ^{31}P{^{1}H} NMR spectra this effect is still more pronounced since the resonant atom is one of the possible protonation sites; however, similarly as for the systems investigated previously[4], the measurements are somewhat complicated by the fact that in the region of formation of zwitterions a slow proton exchange takes place between the phosphine and phosphonium structures, inducing a considerable broadening of the resonance signal of phosphorus.

It can be concluded that as expected, the new carboxyphosphine ligand, methylphosphinediacetic acid, exhibits an increased basicity of the phosphorus atom due to the electronic and steric properties of the methyl group. The mechanism of its acid-base reactions differs from that for the phenyl-substituted derivatives but is identical with that for the nitrogen analogue. The coordination properties of this ligand can be expected to be specific in some respects.

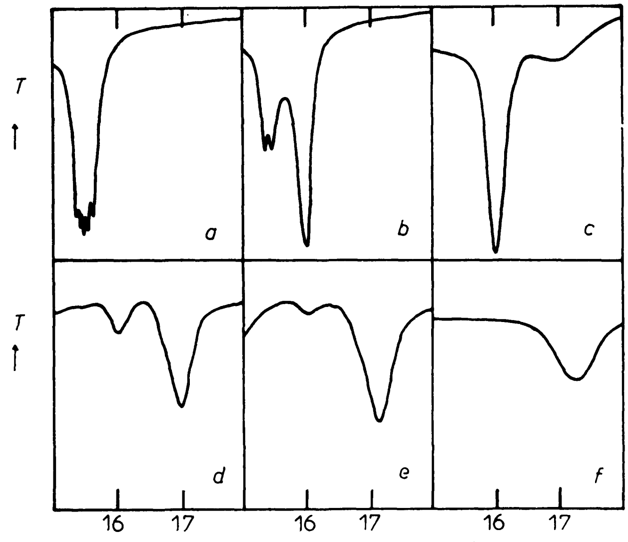


FIG. 1

Infrared spectra of the ligand in D_2O solutions (c = 0·2 mol l^{-1}) at various acidities. pD: *a* 11·81, *b* 5·52, *c* 3·22, *d* 1·21, *e* 0·76, *f* 0·35

EXPERIMENTAL

The procedures for handling phosphines and the measurements have for the most part been described[4-7]. The NMR spectra were taken on Tesla BS 487 A (^1H) and Varian XL 200 (^{13}C and ^{31}P) instruments. The signal positions, in δ units (ppm), are given with respect to tetramethylsilane as the internal standard or 85% H_3PO_4 as the external standard; downfield shifts are regarded as positive. The chemicals were reagent or pure grade preparations of Lachema, Meck, or Pierce Inorganics, and were purified by standard methods if necessary. Methyldichlorophosphine was synthesized according to Soroka[10].

TABLE I

Limiting chemical shifts for the various acid-base forms of the ligand

Group	Chemical shift, ppm, of the species			
	G^{2-}	HG^-	H_2G	H_3G^+
CH_3	1·16	1·87	2·15	2·20
CH_2COO	2·47	3·35	3·78	3·90
P	−39·8	−19·4	−3·1	−2·2

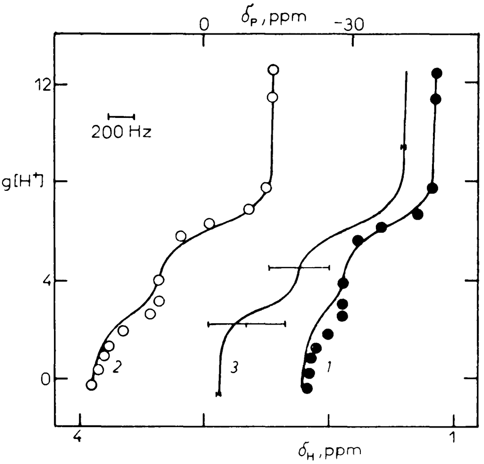


FIG. 2

Chemical shifts of protons and phosphorus at various acidities. The experimental points are fitted by curves calculated from data of Table I and the protonation constants. *1* CH_3, *2* CH_2COO, *3* P

Synthesis of the ligand. Methyldichlorophosphine (94·5 g, 0·808 mol) in ether (150 ml) was added at −30 to −40°C to the Reformatsky reagent, prepared[11] from zinc chips activated with iodine (107 g, 1·64 mol) and freshly distilled ethyl bromoacetate (187 ml, 1·64 mol) in ether (220 ml). The stirred mixture was allowed to warm to room temperature, and water (300 ml) was added under ice cooling. The ether layer was washed with water and dried with sodium sulphate. Distillation at 104−106°C/0·2 kPa afforded diethyl methylphosphinediacetate (37·8 g) as a colourless liquid, n_D^{25} = 1·4694, oxidizing slowly in air.

For $C_9H_{17}O_4P$ (220·2) calculated: 48·91% C, 7·70% H, 14·07% P; found: 49·29% C, 7·74% H, 13·72% P. IR spectrum, cm^{-1} (neat): 1 120 s ν_s(C—O—C), 1 260 s ν_{as}(C—O—C), 1 470 m $\delta(CH_3)$, 1 735 vs ν(C=O), 2 880−2 990 w $\nu(CH_2 + CH_3)$. NMR spectrum, δ (ppm) (C_6D_6): ^1H: 1·16 d, 3 H, ^2J(P, H) 3 (PCH_3); 1·23 t, 6 H, ^3J(H, H) 7 (CH_2CH_3); 2·53 b, s 4 H (PCH_2.COO); 4·11 q, 4 H, ^3J(H, H) 7 (OCH_2). $^{13}C\{^1H\}$: 16·15 d, ^1J(P, C) 17·6 (PCH_3); 19·56 s (CH_2CH_3); 38·90 d, ^1J(P, C) 24·0 (PCH_2); 65·90 s (OCH_2); 175·37 s (C=O). $^{31}P\{^1H\}$: −39·28 s.

The ester (36·0 g, 0·16 mol) was dissolved in petroleum ether (220 ml), and a solution of NaOH obtained by dissolving sodium metal (9·1 g, 0·4 mol) in 96% ethanol (300 ml) was added. The precipitate separated was allowed to stand for several hours, collected, washed with ethanol and ether, and dried at 50°C/1 kPa. The crude disodium salt obtained (31·0 g) contained, by TLC, IR, and ^1H NMR data, about 2% impurities (phosphine oxide, nonhydrolyzed ester, and NaOH; the content of trivalent phosphorus decreased rapidly on standing in air). Attempted purification of the salt failed because of its easy oxidation by atmospheric oxygen and its high solubility in water.

For $C_5H_7Na_2O_4P$ (208·2) calculated: 28·81% C, 3·36% H, 22·09% Na, 14·87% P; found: 28·58% C, 3·37% H, 21·01% Na, 12·86% P(III). IR spectrum, cm^{-1} (KBr, hexachlorobutadiene): 445 w ν_s(P—C), 585 w ν_{as}(P—C), 1 590 vs ν_{as}(COO), 2 880−2 990 w $\nu(CH_2 + CH_3)$. NMR spectra, δ(ppm) (D_2O): ^1H: 1·14 d, 3 H, ^2J(H, H) 3 (PCH_3); 2·45 m, 4 H (PCH_2 and impurities). $^{13}C\{^1H\}$: 14·62 d, ^1J(P, C) 13·1 (P—CH_3); 41·99 d, ^1J(P, C) 17·4 (PCH_2); 182·52 s (C=O). $^{31}P\{^1H\}$: −39·92 s. Under strictly anaerobic conditions, the crude disodium salt (30 g) was vacuum evaporated at 50°C to dryness with 6M-HCl (75 ml). The product was extracted with boiling anhydrous acetic acid (200 ml), the filtrate was vacuum evaporated to dryness and repeatedly evaporated with small volumes of benzene. Final crystallization from anhydrous acetic acid afforded the hydrochloride $H_2G.HCl$ (12·8 g) as colourless crystals, m.p. 122°C, stable in air and fairly soluble in water.

For $C_5H_{10}ClO_4P$ (200·6) calculated: 29·91% C, 4·98% H, 1·49% H^+, 17·66% Cl, 15·43% P; found: 30·11% C, 5·02% H, 1·44% H^+, 17·81% Cl, 15·28% P(III). IR spectrum, cm^{-1} (nujol, hexachlorobutadiene): 445 w ν_s(P—C), 585 w ν_{as}(P—C), 1 405 s, 1 470 sh $\delta(CH_3)$, 1 740 vs ν(C=O), 2 460 s ν(P—H), 2 500−3 400 s, b $\nu(CH_2 + CH_3) + \nu(OH)$. NMR spectra, δ (ppm) (10% HCl): ^1H: 1·99 d, 3 H, ^2J(P, H) 13 (PCH_3); 3·60 d, 4 H, ^2J(P, H) 12 (PCH_2COO). $^{13}C\{^1H\}$: 6·96 d, ^1J(P, C) 53·8 (PCH_3); 32·40 bd, ^1J(P, C) ~100 (PCH_2); 171·73 s (C=O). $^{31}P\{^1H\}$: −2·84 s.

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