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PHOSPHONIC SYSTEMS. I. SYNTHESIS AND ADDITION REACTIONS OF 1-PENTENYLPHOSPHONIC DIAMIDES

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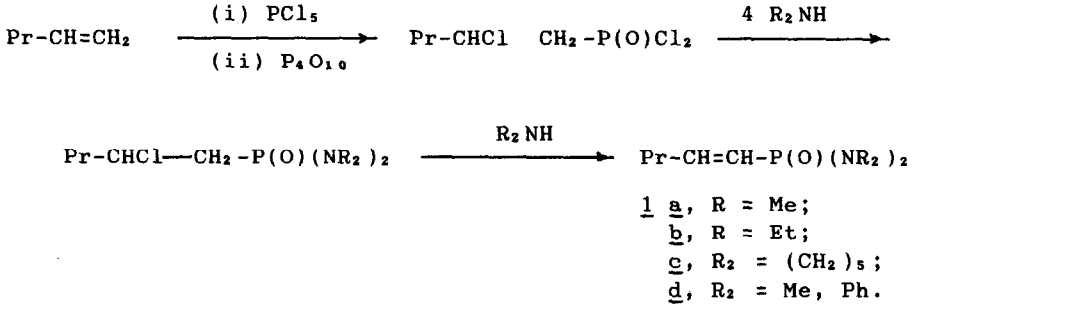
Abstract: *A series of N-substituted 1-pentenylphosphonic diamides was prepared from 1-pentene. These compounds act as acceptors in the conjugate addition of organolithium reagents, yielding 2-substituted pentylphosphonic derivatives. The possibility of a tandem addition - condensation reaction is indicated for these substrates.*

Phosphoryl group - activated olefination constitutes a large part of the carbon skeleton transformations *via* phosphorus - stabilized carbanions.[1] α-Carbanions, stabilized by the phosphoramide group, $P(O)(NR_2)_2$, and derived from alkyl,[2] chloroalkyl,[3] or allylic [4] phosphonodiamidates proved useful substrates in olefination reactions; in properly designed systems stereodifferentiation towards carbon electrophiles has been obtained.[5] Although allylic phosphonodiamidates find increasing synthetic applications as precursors for the stabilized allylic carbanions, the chemistry, and synthetic potential of the 1-alkenylphosphonic (vinylphosphonic) diamides is virtually unknown. For example, in a recent compilation,[6] only the preparation and the n.m.r. spectroscopy are reported for ethenylphosphonic diamides, and 1-propenylphosphonic diamide is not even listed as a known compound. In continuation of our studies on the prototropic equlibria in alkenylphosphonic systems,[7] we turned our attention to the amide derivatives in order to determine the effect of the $P(O)(NR_2)_2$ group on the adjacent olefinic function. We report here the preparation of a series of 1-pentenylphosphonic diamides and the reactivity of these substrates towards organometallic reagents.

Results and Discussion

N,N,N',N'-tetrasubstituted-1-pentenylphosphonodiamidates, 1 have been prepared according to Scheme 1.



Scheme 1

The last two steps (substitution at phosphorus and the dehydrohalogenation) can be achieved in one reaction, using the required molar quantity of the amine. In fact, for the strongly basic amines such as piperidine and diethylamine (pK_a 11.20 and 10.98, respectively), the rates of the elimination and the substitution are comparable, so it was not possible to isolate the intermediate 2-chloropentylphosphonic diamide derivative. In the case of amines of weaker basicity, such as dimethylamine or N-methyl aniline (pK_a 10.64 and 4.85, respectively), both, the 2-chlorosubstituted amides, and the unsaturated products 1 could be prepared. Compounds 1, as demonstrated by the high-resolution ^1H n.m.r. spectroscopy, have exclusively E configuration, and do not contain any measurable quantities of the isomeric 2-pentenyl derivatives.

Treatment of amides 1 with strong bases (MeONa/MeOH; tBuOK/tBuOH; LDA/THF) gave no evidence for the prototropic equlibration to the 2-pentenyl system. Although it is possible that the α,ß-unsaturated phosphonodiamidates represent not only the kinetic, but also the thermodynamic products, the absence of any equilibration may also result from the low acidity of the allylic 3-CH_2 group. When the reactions with sodium methoxide were carried out in deuterated methanol, and the reactions with LDA were followed by quenching with D_2O, no incorporation of deuterium at either the C-1 or C-3 centers was observed.

Substrates 1 also proved unreactive with respect to Grignard reagents; treatment of 1b with methylmagnesium iodide or propylmagnesium bromide, as well as of 1c with benzylmagnesium chloride, led to the recovery of unchanged amides in good yields. Similarly, no reaction was observed when 1b was treated with diethyl sodiomalonate.

We have found however that all substrates 1 react easily with alkyl-

and aryllithium reagents yielding, after aqueous work-up, 2-substituted derivatives of 1-pentylphosphonic diamides 2 (Equation 1).

$$\underset{\underline{1}}{Pr\text{-}CH{=}CH\text{-}P(O)(NR_2)_2} \xrightarrow[(ii)\ H_2O]{(i)\ R'Li} \underset{\underline{2}}{Pr\text{-}\overset{R'}{\overset{|}{C}}H\text{—}CH_2\text{-}P(O)(NR_2)_2} \qquad (1)$$

R' = n-Bu, n-Pr, Ph

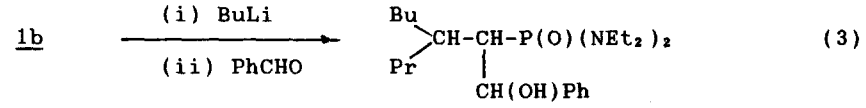
The same results can be obtained with alkyl lithium reagents generated *in situ*, from alkyl halide and metallic lithium. When aqueous work-up was replaced by treatment with D_2O, the phosphonic diamides 2, labelled at carbon-1 with one deuterium atom, were isolated. Products 2 were identified by n.m.r. (^1H, ^{13}C, ^{31}P) spectroscopy, mass spectrometry and elemental (C, H, N) analysis. They were also hydrolytically degraded to the free phosphonic acids 3 (Equation 2), identified as such, or as the crystalline dicyclohexylammonium salts.

$$\underline{2} \xrightarrow{\text{conc. HCl}} \underset{\underline{3}}{Pr\text{-}\overset{R'}{\overset{|}{C}}H\text{—}CH_2\text{-}PO_3H_2} \qquad (2)$$

Reaction (1) represents, to our knowledge, the first example of the conjugate addition of an organometallic reagent to the α,β-unsaturated phosphonodiamidate system. Nucleophilic addition of alkyl lithium reagents was reported [8] for the ethenylphosphonic ester, additionally activated at position α by the trimethylsilyl group. The unsubstituted ethenylphosphonic diesters undergo nucleophilic addition with alkylcopper complexes,[9] however the tetraester of 1,1-ethylidenebisphosphonic acid was reported [10] to undergo Michael-type addition reaction with some, but not with carbon nucleophiles. The addition reaction (1) offers a general synthetic route to the alkylphosphonic acids, branched at position 2. It also provides a method for the structural modifications, by means of nucleophilic reagents, at position 2 of the carbon skeleton of the alkene, initially used for the preparation of the amides 1.

If in reaction (1) the aqueous work-up were replaced by the treatment with an electrophile, the reaction could offer a route for the modification of both, the C-2, and C-1 positions of the substrate's molecule in a single

step. Such a tandem conjugate addition-α-alkylation was applied successfully to the tertiary crotonamides.[11] We have found that quenching the products of the addition of butyl lithium to amides 1 with alkylating (iodomethane, benzyl bromide) or acylating (acetyl chloride) agents resulted in very low yields of the tandem reaction, the 2-substituted compounds 2 being still the main products after the aqueous treatment of the reaction mixtures. However, when 1b was treated with buthyl lithium followed by benzaldehyde, and the mixture refluxed in THF, the expected product of the two carbon - carbon bonds formation reaction was obtained:



(3)

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The experimental conditions and the synthetic scope of the tandem addition/condensation reactions of substrates 1 are being currently investigated in our Laboratory.

Experimental

N.m.r. spectra were recorded on a Bruker AC 300 MHz spectrometer in $CDCl_3$, and the chemical shift values are given relative to TMS (^1H) and trimethyl phosphate (^{31}P). Melting points were obtained on a Gallenkamp apparatus, and are uncorrected. Mass spectra were recorded on a Varian MAT-212 double focusing direct inlet spectrometer at a ionization potential of 70 eV. Only the values for M^+ are given. "Bulb to bulb" distillations were performed on a Buchi GKR-50 apparatus. For column chromatography Merck Kieselgel 60 (0.063 - 0.200 mm) was used as a stationary phase. Sovents and commercially available substrates were purified by conventional methods immediately before use. All reactions involving organometallic reagents were carried out in an atmosphere of dry nitrogen.

2-Chloropentylphosphonic dichloride was prepared as described before.[7]

N,N,N',N'-tetramethyl-1-pentenylphosphonodiamidate (1a).

2-Chloropentylphosphonodichloridate (5.1 g, 0.0228 mol) was dissolved in CCl_4 (50 mL), and dry dimethylamine was passed through this solution with stirring at room temperature for 2 h. The precipitate was filtered off and washed with CCl_4. The CCl_4 solution (total 100 mL) was evaporated under reduced pressure and the residue was purified by distillation on a

Kugelrohr apparatus (oven temp. 100-120°C/0.005 mm) yielding N,N,N',N'-tetramethyl-2-chloropentylphosphonodiamidate; 4.6 g, 84%. ^{1}H n.m.r.: δ 0.88 (3H, t, J_{HH} 7.5 Hz, 5-CH_3); 1.35 - 1.53 (2H, m, 4-CH_2); 1.53 - 1.90 (2H, m, 3-CH_2); 2.22 (2H, d of d, J_{HP} 14.1 Hz, J_{HH} 6.3 Hz, 1-CH_2); 2.54 (6H, d, J_{HP} 9.7 Hz, 2 x NMe); 2.58 (6H, d, J_{HP} 11.8 Hz, 2 x NMe); 4.16 - 4.24 (1H, m 2-CH). ^{31}P n.m.r.: δ 31.1.

The dichloridate (1.53 g, 0.0063 mol) was added to a solution of KOH (0.65 g, 0.0116 mol) in water (4 mL) and stirred at room temperature for 24 h. The mixture was extracted with chloroform (4 x 5 mL), the chloroform solution was dried and evaporated under reduced pressure. The crude product was purified by distillation using a Kugelrohr apparatus (oven temp. 150-160°C/0.05 mm); 1a, 1.0 g (78%). ^{1}H n.m.r.: δ 0.89 (3H, t, J_{HH} 7.4 Hz, 5-CH_3); 1.45 (2H, sext, J_{HH} 7.5 Hz, 4-CH_2); 2.15 (2H, d of t, J_{HH} 7.5, 7.0 Hz, 3-CH_2); 2.55 (12H, d, J_{HP} 9.9 Hz, 4 x NMe); 5.63 (1H, d of d of t, J_{HP} 20.5, J_{HH} 16.5, 1.5 Hz, 1-CH); 6.61 (1H, d of d of t, J_{HP} 19.5, J_{HH} 16.5, 7.0, 2-CH). ^{31}P n.m.r.: δ 26.0. Anal. Calcd for $C_9H_{21}N_2OP$: C, 52.9; H, 10.4; N, 13.7. Found: C, 53.0; H, 10.2; N, 13.4%.

N,N,N',N'-tetraethyl-1-pentenylphosphonodiamidate (1b).

Dichloridate (10 g. 0.045 mol), dissolved in dry benzene (60 mL) was added dropwise to a stirred and cooled solution of diethylamine (23.4 g, 0.32 mol) in benzene (40 mL) at 0-5°C over a period of two hours. The mixture was then stirred for additional two hours at room temperature and left overnight. The precipitate was filtered off, washed with benzene, solvent was removed under reduced pressure and the crude product was purified by distillation using a Kugelrohr apparatus (oven temp. 170-200°C/0.05 mm); 1b, 6.0 g (51%). ^{1}H n.m.r.: δ 0.88 (3H, t, J_{HH} 7.5 Hz, 5-CH_3); 1.04 (12H, t, J_{HH} 7.1 Hz, 4 x Me of NEt); 1.44 (2H, sext, J_{HH} 7.4 Hz, 4-CH_2); 2.15 (2H, d of t, J_{HH} 7.4, 7.1 Hz, 3-CH_2); 3.00 (8H, d of q, J_{HP} 11.0, J_{HH} 7.1 Hz, 4 x CH_2 of NEt); 5.68 (1H, d of d of t, J_{HP} 21.2, J_{HH} 16.9, 1.7 Hz, 1-CH); 6.63 (1H, d of d of t, J_{HP} 19.4, J_{HH} 16.9, 6.7 Hz, 2-CH). ^{31}P n.m.r.: δ 23.9. ^{13}C n.m.r.: δ 13.5 (s, 5-CH_3); 14.0 (d, J_{CP} 2.7 Hz, 4 x Me of NEt); 21.3 (s, 4-CH_2); 36.0 (s, 3-CH_2); 38.1 (d, J_{CP} 4.8 Hz, 4 x CH_2 of NEt); 121.0 (d, J_{CP} 153.0 Hz, 1-CH); 150.1 (d, J_{CP} 3.7 Hz, 2-CH). M.S. (EI): m/z 260 (M^+, 5.0%). Anal. Calc for $C_{13}H_{29}N_2OP$: C, 60.0; H, 11.2; N, 10.8. Found: C, 59.1; H, 11.6; N, 10.0%.

The same product (yield 35%) could be obtained by reacting the phosphorodichloridate with five mole-equivalents on diethylamine, followed by treatment with 30% aqueous sodium hydroxide solution.

N,N'-bis-piperydyl-1-pentylphosphonodiamidate (1c).

Piperidine (11.1 mL, 0.11 mol) was added dropwise with stirring at room temperature to a solution of the dichloridate (5.0 g, 0.02 mol) in CCl_4 (30 mL), and the stirring was continued for 2 hours. The precipitate was filtered off and the solvent was removed under reduced pressure. Aqueous potassium hydroxide solution (50%, 30 mL) was added to the residue and the mixture was stirred at room temperature for 24 hours. The product was extracted with CCl_4 (2 x 15 mL), CCl_4 solution was washed with water (2 x 30 mL), dried ($MgSO_4$), and evaporated under reduced pressure. 1c was obtained as a yellow oil; 4.11 g (65%). ^1H n.m.r.: δ 0.88 (3H, t, J_{HH} 7.4 Hz, 5-CH_3); 1.45 (14H, m, 4-CH_2, 6 x CH_2 of piperydyl groups); 2.15 (2H, q, J_{HH} = $J_{HH'}$ 7.1 Hz, 3-CH_2); 2.98 (8H, m, 4 x CH_2 of piperydyl groups); 5.61 (1H, d of d of t, J_{HP}(gem) 20.6 Hz, J_{HH}(tr) 17.0 Hz, 1.5 Hz, 1-CH); 6.61 (1H, d of d of t, J_{HP}(cis) 18.9 Hz, J_{HH} 17.0, 7.1 Hz, 2-CH). ^{31}P n.m.r.: δ 21.6. ^{13}C n.m.r.: δ 13.6 (s, 5-CH_3); 21.3 (s, 4-CH_2); 24.9 (s, 2 x CH_2 of piperydyl group); 26.3 (d, J_{CP} 5.2 Hz, 4 x CH_2 of piperydyl groups); 36.1 (s, 3-CH_2); 44.7 (d, J_{CP} 2.3 Hz, 4 x NCH_2); 119.6 (d, J_{CP} 151.0 Hz, 1-CH); 151.1 (d, J_{CP} 7.6 Hz, 2-CH). M.S. (EI): m/z 284 (M^+, 0.5%). Anal. Calcd for $C_{15}H_{29}N_2OP$: C, 63.4; H, 10.3; N, 9.9. Found: C, 62.5; H, 10.4; N, 9.2%.

N,N'-dimethyl-N,N'-diphenyl-1-pentylphosphonodiamidate (1d)

Dichloridate (2.0 g, 0.009 mol) in benzene (10 mL) was added dropwise with stirring and cooling to the solution of N-methylaniline (5.0 mL, 0.047 mol) in benzene (10 mL) at 5-10°C, and the mixture was left stirred at room temperature for 48 h. After filtration and evaporation of the solvent, the crude product was purified by column chromatography (Kieselgel 60, ethyl acetate-benzene, 95:5).

N,N'-dimethyl-N,N'-diphenyl-2-chloropentylphosphonodiamidate was obtained as a colorless oil, 1.4 g (43%). ^1H n.m.r.: δ 0.81 (3H, t, J_{HH} 7.3 Hz, 5-CH_3); 1.20 - 1.48 (2H, m, 4-CH_2); 1.49 - 1.62 (1H, m, 3-CH); 1.68 - 1.81 (1H, m, 3-CH'); 2.26 (2H, sixteen lines, 1-CH_2); 3.07 (6H, d, J_{HP} 8.1 Hz, 2 x NMe); 3.15 (6H, d, J_{HP} 8.5 Hz, 2 x NMe); 4.12 - 4.25 (1H, m, 2-CH); 7.12 - 7.34 (10H, m, 2 x Ph). ^{31}P n.m.r: δ 24.8. Anal. Calc. for $C_{19}H_{26}ClN_2OP$: C, 62.5; H, 7.2; N, 7.7. Found: C, 61.6; H, 6.7; N, 7.4%.

To this product (0.45 g, 0.0012 mol) was added a solution of potassium t-butoxide (0.18 g, 0.0016 mol) in t-butanol (1.5 mL), and the mixture was stirred at room temperature for 22 h. Volatile components were removed under reduced pressure, water (17 mL) was added and extracted with chloroform (10 x 5 mL). The chloroform extract was dried and evaporated

under reduced pressure yielding pure (1d), colorless oil, 0.40 g (100%). ^{1}H n.m.r.: δ 0.80 (3H, t, J_{HH} 7.4 Hz, 5-CH_3); 1.36 (2H, sext, J_{HH} 7.3 Hz, 4-CH_2); 2.09 (2H, d of t, J_{HH} 7.3, 7.1 Hz, 3-CH_2); 3.06 (6H, d, J_{HP} 8.8 Hz, 2 x NMe); 5.73 (1H, d of d of t, J_{HP} 23.6, J_{HH} 16.9, 1.4 Hz, 1-CH); 6.77 (1H, d of d of t, J_{HP} 20.5, J_{HH} 16.9, 6.7 Hz, 2-CH); 7.04 (2H, t, J_{HH} 6.6 Hz, 2 x H_{para} of NPh); 7.16 (4H, d, J_{HH} 7.9 Hz, 4 x H_{ortho} of NPh); 7.23 (4H, t, J_{HH} 5.2 Hz, 4 x H_{meta} of NPh). ^{31}P n.m.r.: δ 17.7.
Anal. Calc for $C_{19}H_{25}N_2OP$: C, 69.5; H, 7.7; N, 8.5. Found: C, 69.8; H, 7.5; N, 8.8%.

Preparation of phosphonodiamidates 2. General procedure.

A. A solution of the organolithium reagent (2 - 3 mole-equivalents) was added slowly with cooling and stirring to one mole-equivalent of 1. The mixture was then stirred at room temperature for 3 - 22 h, and evaporated under reduced pressure. Water was added and the mixture was extracted with tetrachloromethane or chloroform. After drying and evaporating the solvent, crude 2 was purified by column chromatography.

B. Exccess of metallic lithium was added to a solution of 1 in bezene, followed by the addition of two mole-equivalents of the corresponding haloalkane. The flask was sealed and the mixture was stirred at room temperature for 24 h. After filtration the volatile components were removed under reduced pressure, water was added and the mixture was extracted with tetrachloromethane. Pure products 2 were obtained in the same way as in A.

Hydrolysis of 2. A sample of 2 was added to a large exccess of conc. aq. HCl and the mixture was heated under reflux for 1 h, then stirred at elevated temperature overnight. The oily product was extracted with ether, followed by chloroform. The combined organic extracts were dried and evaporated, yielding 3 as colorless oil. The dicycloammonium salts of 3 were prepared by adding the solution of one mole-equivalent of dicyclohexylamine in ether to the etheral solution of 3. The precipitated product was washed with ether and dried.

N,N,N',N'-Tetramethyl-2-propylhexylphosphonodiamidate, 2a:

61%, oil, purified by column chromatography (ethyl acetate/acetone, 1:1). ^{1}H n.m.r.: δ 0.867, 0.872 (6H, two t, J_{HH} 6.7, 2 x CH_3); 1.10 - 1.45 (11H, m, 5 x CH_2, 2-CH); 1.65 (2H, d of d, J_{HP} 16.5, J_{HH} 6.2 Hz, 1-CH_2); 2.58 (12H, d, J_{HP} 9.2 Hz, 4 x NMe). ^{31}P n.m.r.: δ 36.3. MS (EI): m/z 262 (M^+, 5.3%). Anal. Calcd for $C_{13}H_{31}N_2OP$: C, 59.5; H, 11.9; N, 10.7. Found: C, 60.0; H, 11.3; N, 10.4%.

N,N,N',N'-Tetraethyl-2-propylhexylphosphonodiamidate, 2b:

72%, oil, purified by column chromatography (acetone). ^{1}H n.m.r.: δ 0.760, 0.765 (6H, two t, J_{HH} 7.0 Hz, 2 x CH_3); 0.97 (12H, t, J_{HH} 5.9 Hz, 4 x Me of NEt); 1.07 - 1.28 (10H, m, 5 x CH_2); 1.32 - 1.56 (1H, m, 2-CH); 1.50 (2H, d of d, J_{HP} 13.8, J_{HH} 5.7 Hz, 1-CH_2); 2.89 (8H, d of q, J_{HP} 8.3, J_{HH} 7.1 Hz, 4 x CH_2 of NEt). ^{31}P n.m.r.: δ 34.7. MS (EI): m/z 318 (M^+, 4.0%). Anal. Calcd for $C_{17}H_{39}N_2OP$: C, 64.1; H, 12.3; N, 8.8. Found: C, 63.4; H, 12.1; N, 8.4%.

2b was also prepared ((53%) by heating the benzene solution of equimolar quantities of 1b and 1-bromobutane under reflux in the presence of the exccess of lithium metal for 8 h. The usual work-up gave the product, the ^{1}H and ^{31}P n.m.r. spectra of which were identical to those of 2b prepared from 1b and BuLi.

2b was hydrolysed with conc. HCl (1 h of reflux followed by 12 h at 50°C); extraction with ether gave 2-propylhexylphosphonic acid, 3a (57%); ^{1}H n.m.r.: δ 0.87 (6H, two overlapping t, 2 x Me); 0.95-1.42 (11H, m, 5 x CH_2, CH); 1.73 (2H, d of d, J_{HP} 19.4, J_{HH} 6.3 Hz, 1-CH_2); 9.69 (2H, br s, PO_3H_2). ^{31}P n.m.r.: δ 35.4. Dicyclohexylammonium salt (85%): mp 138-139°C. ^{31}P n.m.r. (D_2O): δ 27.6. Anal. Calcd for $C_{21}H_{44}NO_3P$: C, 64.75; H, 11.4; N, 3.6. Found: C, 63.9; H, 11.8; N, 3.7%.

N,N'-bis-piperydyl-2-propylhexylphosphonodiamidate, 2c:

73%, oil, purified by column chromatography (ethyl acetate/acetone, 1:1). ^{1}H n.m.r.: δ 0.88 (6H, t, J_{HH} 6.9 Hz, 2 x CH_3); 1.18 - 1.40 (10H, m, 5 x CH_2 of 2-propylhexyl group); 1.40 - 1.60 (13H, m, 6 x CH_2 of piperydyl groups, 2-CH); 1.61 (2H, d of d, J_{HP} 14.0, J_{HH} 6.2 Hz, 1-CH_2); 2.90 - 3.08 (8H, m, 4 x NCH_2). ^{31}P n.m.r.: δ 32.2. ^{13}C n.m.r.: δ 14.1 (s, 6-CH_3); 14.4 (s, 5-CH_2, 5'-CH_2); 23.0 (s, 4-CH_2, 4'-CH_2); 24.7 (s, 2 x 4-CH_2 of piperydyl groups); 26.4 (d, J_{CP} 5.6 Hz, 4 x 3,5-CH_2 of piperydyl groups); 28.6 (s, 3-CH_2, 3'-CH_2); 32.4 (d, J_{CP} 2.8 Hz, 2-CH); 36.9 (d, J_{CP} 8.4 Hz, 1-CH_2); 44.9 (d, J_{CP} 2.1 Hz, 4 x NCH_2); MS (EI): m/z 342 (M^+, 3.7%). Anal. Calcd. for $C_{19}H_{39}N_2OP$: C, 66.6; H, 8.2; N, 11.5. Found: C, 66.9; H, 8.1; N, 11.4%.

N,N'-dimethyl-N,N'-diphenyl-2-propylhexylphosphonodiamidate, 2d: 82%, oil. ^{1}H n.m.r.: δ 0.75, 0.77 (6H, two t, J_{HH} 6.9, 7.2 Hz, 2 x CH_3); 0.99 - 1.25 (11H, m, 5 x CH_2, 2-CH); 1.70 (2H, d of d, J_{HP} 14.1, J_{HH} 5.4 Hz, 1-CH_2); 3.10 (6H, d, J_{HP} 7.8 Hz, 2 x NMe); 7.06 - 7.31 (10H, m, 2 x NPh). ^{31}P n.m.r.: δ 30.0. Anal. Calcd for $C_{23}H_{35}N_2OP$: C, 71.5; H, 9.1; N, 7.3. Found: C, 71.2; H, 9.1; N, 7.4%.

2d was hydrolysed as 2b yielding 3a (61%); n.m.r. spectra identical to those obtained before. Dicyclohexylammonium salt (88%); mp 139.5-140.5°C; mixed mp 140-142°C. ^{31}P n.m.r. (D_2O): δ 27.6.

N,N'-bis-piperydyl-2-propylpentylphosphonodiamidate, 2e:

82%, oil. ^{1}H n.m.r.: δ 0.88 (6H, t, J_{HH} 13.3 Hz, 2 x Me); 1.05-1.62 (21H, m, 4 x CH_2, CH of the 2-propylpentyl group; 6 x CH_2 of the piperydyl groups); 1.62-1.92 (2H, m, 1-CH_2); 2.99 (8H, m, 4 x NCH_2 of the piperydyl groups). ^{31}P n.m.r.: δ 32.2. M.S.: m/z 328 (M^+, 1%).

2e was hydrolysed as before yielding 2-propylpentylphosphonic acid, 3b (42%). ^{1}H n.m.r.: δ 0.87 (6H, two overlapping t, 2 x Me); 1.10-1.45 (9H, m, 4 x CH_2, CH); 1.74 (2H, d of d, J_{HP} 19.8, J_{HH} 6.3 Hz, 1-CH_2) 8.80 (2H, br s, PO_3H_2). ^{31}P n.m.r.: δ 35.9. Dicyclohexylammonium salt (70%); mp 151-152°C. ^{31}P n.m.r.(D_2O): δ 22.9. Anal. Calcd for $C_{20}H_{42}NO_3P$: C, 64.0; H, 11.3; N, 3.7. Found: C, 63.9; H, 11.3; N, 3.6%.

N,N,N',N'-tetramethyl-2-phenylpentylphosphonodiamidate, 2f:

42%, oil, purified by column chromoatography (benzene, followed by methanol). ^{1}H n.m.r.: δ 0.80 (3H, t, J_{HH} 7.4 Hz, CH_3); 0.85 - 1.20 (2H, m, 4-CH_2); 1.48 - 1.66 (2H, m, 3-CH_2); 1.94 - 2.14 (2H, m, 1-CH_2); 2.21 (6H, d, J_{HP} 8.7 Hz, 2 x NMe); 2.53 (6H, d, J_{HP} 9.7 Hz, 2 x NMe); 2.55 - 2.68 (1H, m, 2-CH); 7.1 - 7.28 (5H, m, Ph). ^{31}P n.m.r.: δ 34.5. ^{13}C n.m.r.: δ 13.9 (s, 5-CH_3); 20.5 (s, 4-CH_2); 31.4 (s, 3-CH_2); 35.5 (d, J_{CP} 4.2 Hz, 4 x NMe), 35.9 (d, J_{CP} 2.8 Hz, 2-CH); 40.9 (d, J_{CP} 26.2 Hz, 1-CH_2); 126.1, 127.6, 128.2 (aromatic carbons). Anal. Calcd. for $C_{15}H_{27}N_2OP$: C, 63.8; H, 9.6; N, 9.9. Found: C, 63.6; H, 9.1; N, 9.7%. M.S.: m/z 282 (M^+, 18%).

N,N'-bis-piperydyl-2-phenylpentylphosphonodiamidate, 2g:

41%, pale-yellow powder, purified by column chromatography (benzene, followed by ethyl acetate-ethanol, 2:1). ^{1}H n.m.r.: δ 0.73 (3H, t J_{HH} 7.3 Hz, Me); 0.80-1.15 (2H, m, 4-CH_2); 1.15-1.65 (12H, m, 6 x CH_2 of the piperydyl groups); 1.78 (2H, m, 3-CH_2); 1.87-2.07 (2H, twelve lines, 1-CH_2); 2.45-3.10 (9H, m, 4 x NCH_2 of the piperydyl groups, 2-CH); 7.05-7.26 (5H, m, Ph). ^{31}P n.m.r.: δ 30.5. ^{13}C n.m.r.: δ 15.6 (s, Me); 20.3 (s, 4-CH_2); 22.0 (s, 2 x $NCH_2CH_2\underline{C}H_2$ of the piperydyl groups); 24.4 (d, J_{CP} 9.4 Hz, 3-CH_2); 25.9 (two d, J_{CP} 12.9 Hz, 4 x $NCH_2\underline{C}H_2$ of the piperydyl groups); 32.0 (d, J_{CP} 114.0 Hz, 1-CH_2); 39.8 (d, J_{CP} 46.9 Hz, 2-CH); 44.2 (two d, J_{CP} 32.7 Hz, 4 x NCH_2 of the piperydyl groups); 125.9 (s, 4-C_{arom}); 127.2, 128.1 (two s, 2 x 2-C_{arom}, 2 x 3-C_{arom}); 128.3 (s, 1-C_{arom}). M.S.: m/z 362 (M^+, 4%). Anal. Calcd for $C_{21}H_{35}N_2OP$: C, 69.6; H, 9.7; N, 7.7. Found: C, 69.3; H, 9.9; N, 7.2%.

N,N,N',N'-tetraethyl-1-phenyl-1-hydroxy-3-propyl-2-heptylphosphonodiamidate, 4:

A solution of BuLi in hexane (4.8 mL, 4.0 mmol) was added dropwise with stirring to a solution of 1b (1.02 g, 3.9 mmol) in THF (5 mL). After 30 min a solution of benzaldehyde (2.15 g, 20 mmol) in THF (5 mL) was added at -70°C. The mixture was then heated under reflux for 18 h. Most of the THF was distilled off, water (5 mL) was added, and the mixture was extracted with CCl_4 (3 x 5 mL). The residue was purified by column chromatography (ethyl acetate, followed by acetone). 4; 0.17 g (10.3%); ^1H n.m.r.: δ 0.73 (6H, two t, J_{HH} 7.2 Hz, Me of 7-C, and of 3-Pr group); 1.00 (12H, two t, J_{HH} 7.0, 7.2 Hz, 4 x Me of NEt_2 groups); 0.85 - 1.70 (12H, overlapping m, 6-CH_2, 5-CH_2, 4-CH_2, 2 x CH_2 of the Pr group, 3-CH, 2-CH); 2.35 - 2.45 (1H, br. s, OH); 2.65 - 3.20 (8H, m, 4 x CH_2 of NEt_2 groups); 4.27 (1H, d of d, J_{HP} 18.7 Hz, J_{HH} 8.4 Hz, 1-CH); 7.43 (2H, t, J_{HH} 7.2 Hz, 2 x meta-H); 7.53 (1H, t, J_{HH} 7.2 Hz, para-H); 8.01 (2H, d, J_{HH} 7.2 Hz, 2 x ortho-H). ^{31}P n.m.r.: δ 27.75 (two signals). M.S.: m/z 424 (M^+, 3%). Anal. Calcd for $C_{24}H_{45}N_2O_2P$: C, 67.9; H, 10.7; N, 6.6. Found: C, 67.9; H, 10.8; N, 6.0%.

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