# Uncatalysed preparation of α-amino phosphonates under solvent free conditions

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A simple, efficient and environmentally friendly procedure has been developed for the three component coupling of carbonyl compounds, aromatic and aliphatic amines and dialkyl phosphites to produce α-amino phosphonates. The α-amino phosphonates are synthesised in high yields (74–97%) in a few minutes (1–3 min) by microwave irradiation under solvent-free conditions, avoiding the use of any catalyst.

**Keywords:** α-amino phosphonates, solvent-free, environmentally friendly

α-Amino phosphonates constitute an important class of biologically active compounds, and their synthesis has received increased attention during the last two decades. Their potential as herbicides,[1] insecticides,[2] fungicides,[3] peptidomimetics,[4] enzyme inhibitors[5] (including HIV protease[6]) and antiviral agents[7] as well as their role for antibody generation[8] is well documented. Most synthetic methods reported utilise reactions of imines with phosphorus nucleophiles.[9] However, these methods are not devoid of limitations as many imines are hygroscopic and are not sufficiently stable for isolation. Recently, it has been shown that three-component reactions of aldehydes (or ketones), a amines, and a diethyl phosphite were efficiently promoted by catalytic amounts of $TaCl_5$, $TaCl_5$–$SiO_2$,[10] lanthanide triflate,[11] indium chloride,[12] montmorillonite KSF,[13] and $Al_2O_3$[14] in a solvent (such as $CH_2Cl_2$, $CH_3CN$, toluene and tetrahydrofuran) at reflux conditions.

Although these procedures do not require the isolation of the unstable imines prior to the reactions, reaction times of longer than 10 h are necessary to obtain the desired products in good yields. In addition, the use of harmful organic solvents is undesirable from the viewpoint of today's environmental consciousness, and therefore methods that reduce solvent use are widely sought.

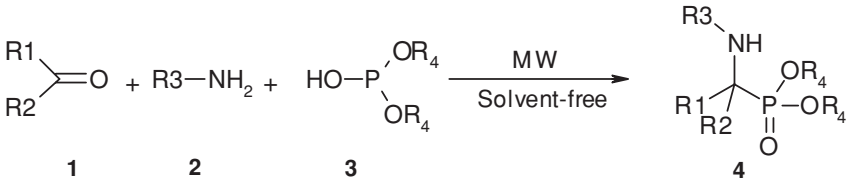
In continuation of our interest in developing environmentally safer methods,[15] we report here a three component coupling of carbonyl compounds, amines and a dialkyl phosphite by microwave irradiation under solvent-free conditions (in dry media), although chromatography could not be avoided for purification.

This method is clean and rapid, affording the corresponding α-amino phosphonates with good to excellent yields in few minutes, avoiding the addition of any catalyst.

## Results and discussions

Recently, Kaboudin[16a] and Yadav[16b] have reported that three-component reactions of aldehydes, amines and triethyl-phosphite were efficiently promoted by acidic alumina and montmorillonite clay, respectively, under solvent-free conditions using microwave irradiation. The better to understand the role of the catalyst (acidic alumina[16a] and montmorillonite clay[16b]), a comparison reaction was performed using benzaldehyde **1a**, aniline **2a** and triethyl phosphite under solvent-free conditions using microwave irradiation without any catalyst. It was surprising to observe that the reaction occurred with similar high yield (95%). To investigate this surprising reactivity we extended this method to the preparation of several α-amino phosphonates. From results summarised in Table 1 the generality of the reaction is evident, as a variety of aromatic, aliphatic and heterocyclic aldehydes react with amine and the dialkyl phosphite in good to excellent yields (74–97 %) with a very short time of irradiation (1–3 min). The conventional approaches for the synthesis of these compounds involves reflux in expensive and often hazardous solvents (such as $CH_2Cl_2$, $CH_3CN$, toluene and tetrahydrofuran). Our method under domestic microwave irradiation (output of 720 W) occur at reasonable temperature ranges (100–110°C, highest observed temperature after irradiation) in the absence of such solvents and without catalyst. The reactions were clean with no tar formation and, interestingly, no product from the 1-hydroxyphosphonate was observed.[17] Also, unlike the conventional approach for this transformation which involves aqueous work-up generating high volumes of toxic effluents, our method is a almost effluent free and safe.

In conclusion we have described a simple and convenient method for the synthesis of α-amino phosphonates without




**1** **2** **3** **4**

$R_1$ = Ph, *p*Me-$C_6H_4$, *p*MeO-$C_6H_4$, $_p$Cl-$C_6H_4$, *p*$NO_2$-$C_6H_4$, *o*HO-$C_6H_4$ and $C_4H_3O$

$R_2$ = H; $R_1$-$R_2$ = -$(CH_2)_5$-

$R_3$ = Ph, $PhCH_2$ and *p*Me-$C_6H_4$; $R_4$ = Me and Et

**Scheme1**

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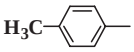
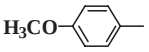
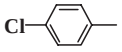
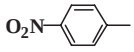
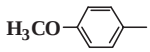
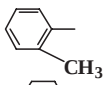
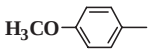
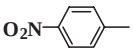
**Table 1** Three component synthesis α-amino phosphonates **4** by microwave irradiation under solvent free-conditions

| α-amino phosphonate | $R_1$ | $R_2$ | $R_3$ | $R_4$ | Yield% (time/min)[a] |
|---|---|---|---|---|---|
| **4a** |  | H |  | Et | 95(1) |
| **4b** |  | H |  | Et | 95(1) |
| **4c** |  | H |  | Et | 97(1) |
| **4d** |  | H |  | Et | 80(2) |
| **4e** |  | H |  | Et | 74(2) |
| **4f** |  | H |  | Et | 76(1) |
| **4g** |  | H |  | Me | 94(1) |
| **4h** |  | H |  | Me | 96(1) |
| **4l** |  | H |  | Et | 87(2) |
| **4j** |  | H |  | Et | 90(2) |
| **4k** |  | H |  | Et | 83(3) |
| **4l** |  | H |  | Et | 77(3) |
| **4m** | |  |  | Et | 80(2) |
| **4n** |  | H |  | Et | 88(2) |

[a]Yields in pure products isolated by chromatography (*n*-hexane/ethyl acetate) and identified by $^1$H, $^{13}$C NMR, IR spectroscopy and melting points.

catalyst under microwave irradiation in solvent-free conditions, thus it is an attractive addition to existing methods.

## Experimental

*General procedure for the syntheses of α-amino phosphonates* (**4a–n**)

In a typical procedure, the aldehyde **1** (1 mmol), aniline **2** (1 mmol) and dialkyl phosphite **3** (1.1 mmol), were mixed in a Pyrex test tube and subjected to microwave irradiation for (1–3 min) using 720 W (a kitchen type microwave was used in all experiments). The crude product was purified by silica gel column chromatography using *n*-hexane/ethyl acetate as eluent. The product structure was determined by $^1$H, $^{13}$C NMR, IR spectrometry and melting points.

$^1$H and $^{13}$C NMR spectra were recorded at 300 MHZ and 75 MHZ, respectively, on a Bruker ultrashield TM 300 MHZ spectrometer in $CDCl_3$, using $CDCl_3$ as internal standard. The chemical shifts (δ) are expressed in ppm relative to $CDCl_3$ and coupling constant (*J*) in Hertz. IR spectra were obtained on a FTIR (ATI Mattson-Genesis Series) instrument and reported in wave numbers (cm$^{-1}$). Melting points were determined with a "Thomas Hoover" melting (capillary method) apparatus and are uncorrected. Flash column chromatography was performed using Merck silica gel 60 (230–400 mesh ASTM).

All reactions were carried out under air. Solvents and starting materials (Aldrich) were used without further purification.

*Spectroscopic–spectrometry data of the reaction products*

*Diethyl(phenyl)-N-(phenyl)aminomethylphosphonate*,[11] **4a:** White solid ; m.p. 92–94 °C (lit. 90–91°C); $R_f$ (35% AcOEt/hexane) 0.38; $^1$H NMR ($CDCl_3$) δ: 1.2 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.4 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 3.73–4.3 (4H, m, $OCH_2CH_3$); 4.9 (1H, d, $J_{HP}$ = 24.6 Hz, C*H*P), 5 (1H, br, N*H*); 6.6–7.8 (10H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.46 (d, $^3J_{CP}$ = 6.03 Hz, $OCH_2CH_3$); 16.7 (d, $^3J_{CP}$ = 6.03 Hz, $OCH_2CH_3$); 56.35 (d, $^1J_{CP}$ = 149 Hz, *C*HP); 63.5 (d, $^2J_{CP}$ = 6.79Hz, $OCH_2CH_3$); 63.53 (d, $^2J_{CP}$ = 6.79 Hz, $OCH_2CH_3$); 114.13 (s); 118.64 (s); 128.1 (s); 128.85 (s); 129.43 (s); 136.2 (s); 146.6 (s). IR (KBr) : 3304 (NH), 2985 (CH), 1605 (C=C), 1514 (C=C), 1240 (P=O), 1020 (P–O) cm$^{-1}$.

*Diethyl(4-methylphenyl)- N-(phenyl)aminomethylphosphonate*,[11] **4b:** White solid; m.p. 63–65°C; $R_f$ (35% AcOEt/hexane) 0.4; $^1$H NMR ($CDCl_3$) δ: 1.25 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.4 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 2.45 (3H, s, $C_6H_5CH_3$ ) ; 3.79–4.31 (4H, m, $OCH_2CH_3$); 4.87 (1H, d, $J_{HP}$ = 24.6 Hz, C*H*P), 5 (1H, br, N*H*); 6.71–7.5 (9H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.5 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$); 16.71 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$); 21.4 (s; $C_6H_5CH_3$); 56 (d, $^1J_{CP}$ = 150 Hz, *C*HP); 63.48 (d, $^2J_{CP}$ = 6.94Hz, $OCH_2CH_3$); 114.14 (s); 118.57 (s); 128 (s); 129.4 (s); 129.55 (s); 129.58 (s); 133 (s); 137.8 (s);146.8 (s). IR (KBr) : 3326 (NH), 2987 (CH), 1608 (C=C), 1505 (C=C), 1237 (P=O), 1017 (P–O) cm$^{-1}$.

*Diethyl(4-methoxyphenyl)-N-(phenyl)aminomethylphosphonate*,[11] **4c:** White solid; m.p. 102–103 °C; $R_f$ (35% AcOEt/hexane) 0.26; $^1$H NMR ($CDCl_3$) δ: 1.25 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.39 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 3,86 (3H, s, $C_6H_5OCH_3$); 3.8–4.26 (4H, m, $OCH_2CH_3$); 4.85 (1H, d, $J_{HP}$ = 23.1 Hz, C*H*P), 4.95 (1H, br, N*H*); 6.7–7.53 (9H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.53 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 16.72 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 55.44 (s, $C_6H_5OCH_3$); 55.62 (d, $^1J_{CP}$ = 151.2 Hz, *C*HP); 63.43 (d, $^2J_{CP}$ = 6.9Hz, $OCH_2CH_3$); 63.47 (d, $^2J_{CP}$ = 6.9 Hz, $OCH_2CH_3$); 114.15 (s); 114.32 (s); 118.57 (s); 128 (s); 129.2 (s); 129.33 (s); 146.67 (s);

159.56 (s). IR (KBr) : 3304 (NH), 2985 (CH), 1605 (C=C), 1514 (C=C), 1240 (P=O), 1021 (P–O) $cm^{-1}$.

*Diethyl(4-chlorophenyl)-N-(phenyl)aminomethylphosphonate,*[18] **4d:** White solid; m.p. 83–84 °C; $R_f$ (35% AcOEt/hexane) 0.41; $^1$H NMR ($CDCl_3$) δ: 1.29 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.4 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 3.85–4.8 (4H, m, $OCH_2CH_3$); 4.9 (1H, d, $J_{HP}$ = 24.6 Hz, C*H*P), 5 (1H, br, N*H*); 6.6–7.6 (9H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.56 (d, $^3J_{CP}$ = 5.25 Hz, $OCH_2CH_3$); 16.69 (d, $^3J_{CP}$ = 5.25 Hz, $OCH_2CH_3$); 56 (d, $^1J_{CP}$ = 148.5 Hz, *C*HP); 63.64 (d, $^2J_{CP}$ = 7.5 Hz, $OCH_2CH_3$); 114.11 (s); 118.92 (s); 129 (s); 129.5 (s); 133.94 (s); 134.91 (s); 146.27 (s). IR (KBr) : 3294 (NH), 2987 (CH), 1608 (C=C), 1498 (C=C), 1237 (P=O), 1040 (P–O) $cm^{-1}$.

*Diethyl(4-nitrophenyl)-N-(phenyl)aminomethylphosphonate,*[11] **4e:** Yellow solid; m.p. 153–154 °C; $R_f$ (35% AcOEt/hexane) 0.28; $^1$H NMR ($CDCl_3$) δ: 1.3 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 1.41 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 3.95–4.32 (4H, m, $OCH_2CH_3$); 4.99 (1H, d, $J_{HP}$ = 24.3 Hz, C*H*P), 5 (1H, br, N*H*); 6.64–8.35 (9H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.51 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$); 16.68 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$); 56.26 (d, $^1J_{CP}$ = 147.4 Hz, *C*HP); 63.72 (d, $^2J_{CP}$ = 6.9Hz, $OCH_2CH_3$); 64 (d, $^2J_{CP}$ = 6.94 Hz, $OCH_2CH_3$); 114 (s); 119.31 (s); 124 (s); 128.9 (s); 129.6 (s); 144.5 (s); 146 (s);148 (s). IR (KBr) : 3295 (NH), 2994 (CH), 1605 (C=C), 1349 (C=C), 1249 (P=O), 1039 (P–O) $cm^{-1}$.

*Diethyl(2-hydroxyphenyl)-N-(phenyl)aminomethylphosphonate,*[10] **4f:** $R_f$ (35% AcOEt/hexane) 0.23; $^1$H NMR ($CDCl_3$) δ: 1.1 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.25 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 2.2 (s; H; $C_6H_5OH$); 3.84–4.18 (4H, m, $OCH_2CH_3$); 5.01 (1H, d, $J_{HP}$ = 23.1 Hz, C*H*P), 5 (1H, br, N*H*); 6.59–7.19 (9H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.52 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 16.68 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 54.25 (d, $^1J_{CP}$ = 151.6 Hz, *C*HP); 63.91 (d, $^2J_{CP}$ = 7 Hz, $OCH_2CH_3$); 64.42 (d, $^2J_{CP}$ = 7.2 Hz, $OCH_2CH_3$); 114.77 (s); 118.65 (s); 119.63 (s); 120.94 (s); 121.9 (s); 129.55 (s); 146.5 (s); 159 (s). IR (KBr) : 3405 (NH), 2987 (CH), 1608 (C=C), 1505 (C=C), 1222 (P=O), 1025 (P–O) $cm^{-1}$.

*Dimethyl(phenyl)-N-(phenyl)aminomethylphosphonate,** **4g:** White solid; m.p. 93–95°C; $R_f$ (35% AcOEt/hexane) 0.37; $^1$H NMR ($CDCl_3$) δ: 3.62 (3H, d, $J_{HP}$ = 15 Hz, $OCH_3$); 3.93 (3H, d, $J_{HP}$ = 15 Hz, $OCH_3$); 4.92 (1H, d, $J_{HP}$ = 24.6 Hz, C*H*P), 5 (1H, br, N*H*); 6.71–7.61 (10H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 54.1 (d, $^2J_{CP}$ = 6.75 Hz, $OCH_3$); 55.96 (d, $^1J_{CP}$ = 150.75 Hz, *C*HP); 114.15 (s); 118.83 (s); 128 (s); 128.36 (s); 129.4 (s); 135.9 (s); 146.3 (s). IR (KBr) : 3310 (NH), 2955 (CH), 1608 (C=C), 1498 (C=C), 1237 (P=O), 1040 (P–O) $cm^{-1}$.

*Dimethyl(4-methoxyphenyl)-N-(phenyl)aminomethylphosphonate,*[11] **4h**: White solid; m.p. 84–86 °C; $R_f$ (35% AcOEt/hexane) 0.29; $^1$H NMR ($CDCl_3$) δ: 3.6 (3H, d, $J_{HP}$ = 15 Hz, $OCH_3$); 3.87 (3H, d, $J_{HP}$ = 15 Hz, $OCH_3$); 3,9 (3H, s, $C_6H_5OCH_3$); 4.95 (1H, d, $J_{HP}$ = 24.6 Hz, C*H*P), 5 (1H, br, N*H*); 6.7–7.7 (9H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 54.05 (d, $^2J_{CP}$ = 6 Hz, $OCH_3$); 55.26 (d, $^1J_{CP}$ = 151.5 Hz, *C*HP); 55.48 (s, $C_6H_5OCH_3$); 114.19 (s); 114.48 (s); 118.78 (s); 127.63 (s); 129.63 (s); 129.15 (s); 129.23 (s); 146.39 (s); 159.69 (s). IR (KBr) : 3304 (NH), 2957 (CH), 1605 (C=C), 1505 (C=C), 1249 (P=O), 1030 (P–O) $cm^{-1}$.

*Diethyl(phenyl)-N-(2-methylphenyl)aminomethylphosphonate,* **4i:** White solid; m.p. 43–46 °C; $R_f$ (35% AcOEt/hexane) 0.45; $^1$H NMR ($CDCl_3$) δ: 1.25 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 1.43 (3H, t, $J_{HH}$ = 7.2 Hz, $OCH_2CH_3$); 2.45 (3H, s, $C_6H_5CH_3$); 3.79–4.32 (4H, m, $OCH_2CH_3$); 4.9 (1H, d, $J_{HP}$ = 24.3 Hz, C*H*P), 5 (1H, br, N*H*); 6.5–7.7 (9H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.47 (d, $^3J_{CP}$ = 5.77 Hz, $OCH_2CH_3$); 17.78 (d, $^3J_{CP}$ = 5.77 Hz, $OCH_2CH_3$); 17.82 (s, $C_6H_5CH_3$), 55.41 (d, $^1J_{CP}$ = 149 Hz, *C*HP); 63.54 (d, $^2J_{CP}$ = 7 Hz, $OCH_2CH_3$); 111.55 (s); 118.32 (s); 123.17 (s); 127.21 (s); 128 (s); 128.8 (s); 130.45 (s) 136.24 (s); 144.7 (s). IR (KBr): 3342 (NH), 2979 (CH), 1608 (C=C), 1521 (C=C), 1237 (P=O), 1017 (P–O) $cm^{-1}$.

*Diethyl(4-methoxyphenyl)-N-(2-methylphenyl)aminomethylphosphonate,** **4j:** Yellow solid; m.p. 67–69 °C; $R_f$ (35% AcOEt/hexane) 0.38; $^1$H NMR ($CDCl_3$) δ: 1.18 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 1.3 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 2.3 (3H, s, $C_6H_5CH_3$); 3.78 (3H, s, $C_6H_5OCH_3$); 3.75–4.17 (4H, m, $OCH_2CH_3$); 4.78 (1H, d, $J_{HP}$ = 23.7 Hz, C*H*P), 5 (1H, br, N*H*); 6.43–7.43 (8H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.48 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 16.65 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 17.74 (s, $C_6H_5CH_3$), 55.41 (s, $C_6H_5OCH_3$); 55.67 (d, $^1J_{CP}$ = 150.7 Hz, *C*HP); 63.4 (d, $^2J_{CP}$ = 6.8 Hz, $OCH_2CH_3$); 63.46 (d, $^2J_{CP}$ = 6.8 Hz, $OCH_2CH_3$); 111.58 (s); 114.26 (s); 118.26 (s); 123.14 (s); 127.14 (s); 127,94 (s); 129.23 (s); 130.38 (s); 144.51 (s); 159.56 (s). IR (KBr) : 3436 (NH), 2987 (CH), 1608 (C=C), 1513 (C=C), 1245 (P=O), 1033 (P–O) $cm^{-1}$.

* The charactersation of **4g**, **i**, **j** and **l** must be regarded as formally tentative based on the awardable electroscopic and other evidance.

*Diethyl(phenyl)-N-(benzyl)aminomethylphosphonate,*[11] **4k:** $R_f$ (35% AcOEt/hexane) 0.27; $^1$H NMR ($CDCl_3$) δ: 1.12 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 1.29 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 2.67 (1H, br, N*H*); 3.97 (1H, d, $J_{HP}$ = 24.3 Hz, C*H*P), 3.76–4.14 (6H, m, $OCH_2CH_3$ and $C_6H_5CH_2$); 6.19–7.45 (10H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.3 (d, $^3J_{CP}$ = 5.81 Hz, $OCH_2CH_3$); 16.5 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 51.38 (s, $C_6H_5CH_2$); 59.65 (d, $^1J_{CP}$ = 153,7 Hz, *C*HP); 62.88 (d, $^2J_{CP}$ = 6.9 Hz, $OCH_2CH_3$); 63 (d, $^2J_{CP}$ = 6.9 Hz, $OCH_2CH_3$); 127.2 (s); 128 (s); 128.4 (s); 128.5 (s); 128.57 (s); 128.7 (s); 128.8 (s); 135.8 (s); 139.4 (s). IR (KBr) : 3452 (NH), 2987 (CH), 1608 (C=C), 1498 (C=C), 1245 (P=O), 1040 (P–O) $cm^{-1}$.

*Diethyl(4-nitrophenyl)-N-(benzyl)aminomethylphosphonate,** **4l.** $R_f$ (35% AcOEt/hexane) 0.25; $^1$H NMR ($CDCl_3$) δ: 1.11 (3H, t, $J_{HH}$ = 6.8 Hz, $OCH_2CH_3$), 1.27 (3H, t, $J_{HH}$ = 6.8 Hz, $OCH_2CH_3$), 2.65 (1H, br, N*H*), 3.95 (1H, d, $J_{HP}$ = 24.5 Hz, C*H*P), 3.73–4.12 (6H, m, $OCH_2CH_3$ and $C_6H_5CH_2$), 6.21–7.48 (9H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.31 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$), 16.6 (d, $^3J_{CP}$ = 5.8 Hz, $OCH_2CH_3$), 51.4 (s, $C_6H_5CH_2$), 59. (d, $^1J_{CP}$ = 153,7 Hz, *C*HP), 62.8 (d, $^2J_{CP}$ = 7 Hz, $OCH_2CH_3$), 63 (d, $^2J_{CP}$ = 7 Hz, $OCH_2CH_3$), 127 (s), 128.4 (s), 128.5 (s), 128.6 (s), 128.8 (s), 128.9 (s), 130 (s), 136 (s), 139.4 (s). IR (KBr) 3452 (NH), 2987 (CH), 1608 (C=C), 1498 (C=C), 1245 (P=O), 1040 (P–O) $cm^{-1}$.

*Diethyl N-(phenyl)aminocyclohexylphosphonate,*[10] **4m:** White solid; m.p. 102–105 °C; $R_f$ (35% AcOEt/hexane) 0.36; $^1$H NMR ($CDCl_3$) δ: 1.25 (6H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 1.5–2.21 (11H, m, $–(CH_2)_5–$ and N*H*); 4.06 (4H, m, $OCH_2CH_3$); 6.81–7.28 (5H, m, *H*Ar).$^{13}$C NMR ($CDCl_3$) δ: 16.83 (d, $^3J_{CP}$ = 5.47 Hz, $OCH_2CH_3$); 20.37 (s, $–(CH_2)_5–$); 25.7 (s, $–(CH_2)_5–$); 30.63 (s, $–(CH_2)_5–$); 57.53 (d, $^1J_{CP}$ = 159.1 Hz, *C*P); 62.48 (d, $^2J_{CP}$ = 7.65 Hz, $OCH_2CH_3$); 118.85 (s); 119.75 (s); 129 (s); 146.22 (s). IR (KBr) : 3318 (NH), 2987 (CH), 1608 (C=C), 1505 (C=C), 1222 (P=O), 1017 (P–O) $cm^{-1}$.

*Diethyl(furfuryl)-N-(phényl)aminométhylphosphonate,*[11] **4n:** White solid; m.p. 50–52 °C; $R_f$ (35% AcOEt-hexane) 0.35; $^1$H NMR ($CDCl_3$) δ: 1.22 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 1.31 (3H, t, $J_{HH}$ = 6.9 Hz, $OCH_2CH_3$); 3.85–4.25 (4H, m, $OCH_2CH_3$); 4.56 (1H, br, N*H*); 4.91 (1H, d, $J_{HP}$ = 23.7 Hz, C*H*P); 6.33–7.39 (8H, m, *H*Ar). $^{13}$C NMR ($CDCl_3$) δ: 16.39 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 16.54 (d, $^3J_{CP}$ = 5.7 Hz, $OCH_2CH_3$); 50.39 (d, $^1J_{CP}$ = 158.4 Hz, *C*HP); 63.38 (d, $^2J_{CP}$ = 6.9 Hz, $OCH_2CH_3$); 63.6 (d, $^2J_{CP}$ = 6.9 Hz, $OCH_2CH_3$); 108.82 (s, furan); 110.87 (s, Ph); 114 (s, Ph); 119 (s, furan); 129 (s, Ph); 142.59 (s, furan); 146.21 (s, furan); 149.54 (s, Ph). IR (KBr): 3035(NH), 2983(CH), 1603(C=C), 1499(C=C), 1244(P=O), 1027(P–O) $cm^{-1}$.

*Received 26 November 2004; accepted 3 March 2005*
*Paper 04/2900*

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