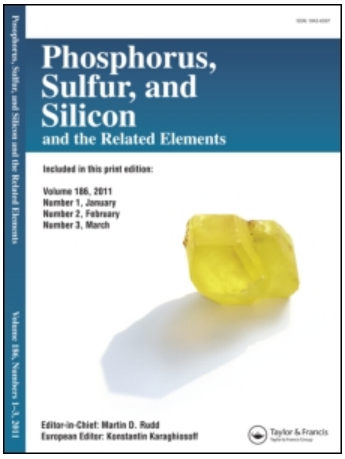

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N-*Benzhydryl-protected diethyl esters of 1-amino-1-aryl- (phenyl, cumyl, p-dimethylaminophenyl, piperonyl, 1′-naphthyl, 9′-anthryl, 1′-pyrenyl) and 1-amino-1-heteroaryl- (furyl, 2′-thienyl, 3′-thienyl, 2′-pyrrolyl)-methanephosphonic acids, prepared by the addition of diethyl phosphite to the corresponding benzhydryl imines, have been isolated, purified, and characterized. The presence of chiral α-carbon and prochiral phosphorus in these esters gives rise to complicated features in their NMR spectra, which are discussed. Hydrolysis of the crude 1-aryl compounds in situ gave modest yields of the corresponding aminophosphonic acids (except for 1′-pyrenyl). Of the 1-heteroaryl derivatives, only the 2′-thienyl compound gave the expected aminophosphonic acid; in other cases, alternative modes of decomposition may occur under hydrolytic conditions. NMR and mass spectral data are given for all products.*

Keywords: Aminophosphonate; aminophosphonic acids; aryl; heteroaryl; mass spectrometry; NMR

INTRODUCTION

Aminophosphonic acids and their derivatives have attracted widespread interest in the agrochemical and biomedical fields.[1] Among the aralkyl types, derivatives of α-aminophenylmethanephosphonic

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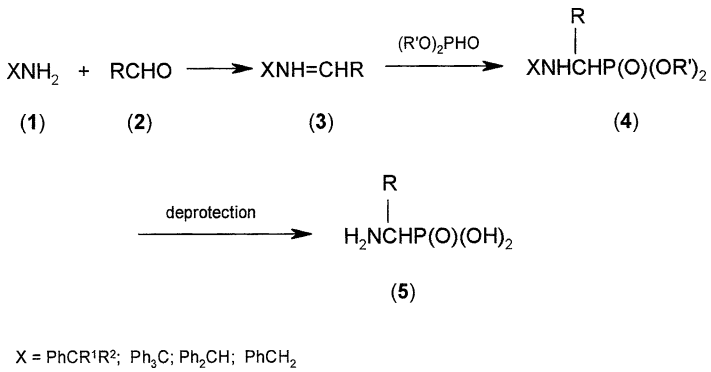
acid (**5**, R = Ph), the phosphonic analogue of α-phenylglycine, have been shown to exhibit activity as herbicides and plant growth regulators,[2] agrochemical fungicides,[3,4] and glutamate receptor agonists and antagonists in the pharmacological field.[5] Also, a number of heteroaromatic analogues (**5**, R = furyl, thienyl, pyrrolyl, or pryidyl) have attracted interest as potential herbicides and as structural units in phosphonopeptides with enzyme inhibitory properties.[6]

A common method for the synthesis of aminophosphonates involves the addition of dialkyl phosphite to an imine (**3**) giving, in the first instance, an *N*-protected ester (**4**) of the corresponding amino acid (Scheme 1).[7] Addition is both acid- and base-catalyzed but may also occur simply on heating. The use of an imine derived from a tertiary benzylic amine (X = $PhCR^1R^2$),[8] tritylamine (X = Ph_3C),[9]or benzhydrylamine (X = Ph_2CH)[10,11] has the advantage that *N*-deprotection can be carried out by hydrolysis rather than hydrogenolysis, which is necessary for the removal of *N*-benzyl groups (X = $PhCH_2$).[12] Thus, the in situ hydrolysis of *N*-benzhydrylaminophosphonate esters (**4**, X = Ph_2CH) has been used by various workers[10,11,13–17] in a convenient "one-pot" procedure for the preparation of free aminophosphonic acids (**5**).

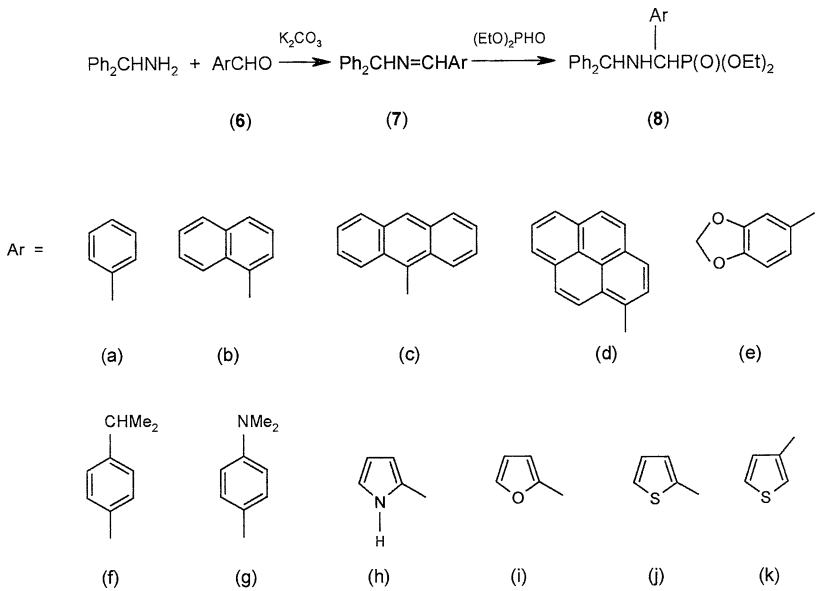


SCHEME 1

In addition, the *N*-protected esters (**4**) may undergo selective ester hydrolysis (via the use of trimethylsilyl bromide) to give *N*-protected aminophosphonic acids,[18,19] or selective *N*-deprotection, by hydrogenolysis[12] or by reaction with hydrogen bromide in acetic acid[9,20,21] to give aminophosphonic esters, which are important intermediates in the synthesis of phophonopeptides.[22]

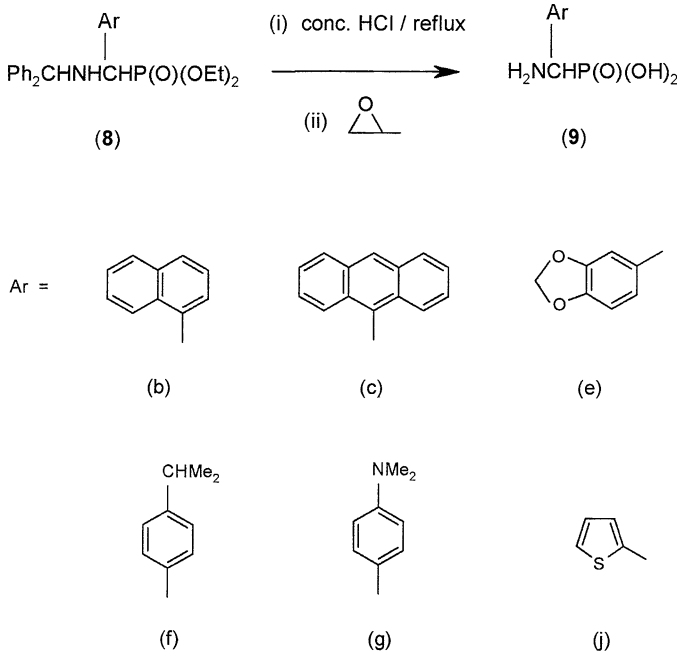
DISCUSSION

We have previously used imines derived from benzhydrylamine in the one-pot synthesis of fluorinated 1-amino-1-phenylmethanephosphonic acids, and for the first time we isolated, purified, and characterized the intermediate *N*-benzhydryl-protected esters.[13] In continuation of these studies, we now report the synthesis and characterization of a further series of *N*-benzhydryl-protected 1-amino-1-aryl- and 1-amino-1-heterocyclyl-methanephosphonates (**8**, Scheme 2). In addition we report our investigations of the in situ hydrolysis of these esters as a method for obtaining the corresponding aminophosphonic acids (**9**, Scheme 3), several of which are novel compounds. None of the *N*-benzhydryl–protected esters (**8a–8k**) has previously been isolated and characterized, although two examples, the 1-phenyl (**8a**) and 1-(2′-thienyl) (**8j**) derivatives, were obtained as intermediates that were hydrolyzed in situ during the course of one-pot syntheses involving benzhydrylamine.[10,15]



SCHEME 2

In the present investigations imine intermediates (**7a–7k**) were prepared (Scheme 2) by the interaction of equimolar quantities of benzhydrylamine (or its hydrochloride) and the corresponding aldehyde (**6a–6k**) in the presence of an excess of anhydrous potassium carbonate.[8,23] Products were recrystallized from a mixture of toluene



SCHEME 3

and light petroleum spirit before use in the next stage of the synthesis. The diethyl phosphonate esters (**8a**–**8k**) were prepared by heating equimolar mixtures of diethyl phosphite and the corresponding imine in the absence of solvent, usually at temperatures between 90 and 100°C. The use of a solvent is known to reduce the rate of addition.[24] Reactions were monitored by ^{31}P NMR until optimum conversion was achieved, and the products (δ_P 21–26 ppm) were recrystallized from ethyl acetate to give yields of 50–90%. A higher reaction temperature (125–140°C) was necessary in the synthesis of diethyl 1-(1′-pyrenyl)-1-benzhydrylaminomethanephosphonate (**8d**) because of the high melting point of the imine, which failed to form a liquid reaction mixture with diethyl phosphite at lower temperatures. In most cases, extended reaction times of more than 6 h resulted in some decomposition of the desired products and the appearance of a new signal (δ_P 4 ppm) in addition to that of the starting diethyl phosphite (δ_P 7 ppm). It is likely that the initial addition reaction is reversible and that prolonged heating allows for alternative reactions of the starting materials. The by-product (δ_P 4 ppm) has not been identified unambiguously, but the chemical shift suggests that it is monoethyl phosphite[25,26] formed by monodealkylation of the dialkyl ester.

The *N*-benzhydryl–protected diethyl phosphonate eters (**8**) are well-defined crystalline solids which were characterized by elemental analysis, NMR, and mass spectrometry.

Preparation of the Free Aminophosphonic Acids

Free α-aminoarylmethanephosphonic acids have previously been obtained by the hydrochloric acid-catalyzed hydrolysis of the corresponding *N*-benzhydryl-protected dialkyl esters, prepared as described above, but without isolation and purification of the latter (Scheme 1).[10,11,13–17] However, certain types of aminophosphonic acid derivative, including a number of *N*-benzhydryl types, have been found to undergo phosphorus-carbon fission under the conditions of acid hydrolysis, a factor that might account for the small or modest yields of final products that are obtained in certain cases.[27]

In the present work, in situ hydrolysis using concentrated hydrochloric acid under reflux (Scheme 3) was found to be suitable for the preparation of most of the α-aryl derivatives, including the α-naphthyl (**9b**) and 9-anthryl (**9c**) compounds, but in the heterocyclic series only the 2′-thienyl compound (**9j**) was obtainable by this procedure. 1-Aminobenzylphosphonic acid (**9a**) has been prepared previously by this method.[10,14] No free aminophosphonic acids were isolable from the hydrolysis products of the 1′-pyrenyl, 2′-pyrrolyl, furyl, or 3′-thienyl esters (**8d**, **8h**, **8i**, and **8k**, respectively). Further work is necessary to establish the exact cause in the case of the 1′-pyrenyl and 3′-thienyl systems, although the failure to obtain free aminophosphonic acids from the furyl and 2′-pyrrolyl derivatives may be due to the instability of the furyl and pyrrolyl rings under acid conditions. Similar difficulties have been reported elsewhere in attempts to prepare 1-amino-1-furyl- and 1-amino-1-(2′-pyrrolyl)-methanephosphonic acid by procedures that involve acid hydrolysis.[15,16] In addition, the possibility of phosphorus–carbon fission, as reported for 2- and 4-pyridyl systems,[17] and for 9-fluorenyl–substituted aminophosphonates,[27] might be a determining factor. In these cases, alternative methods for deprotection and deesterification of the *N*-protected aminophosphonates are necessary if the free aminophosphonic acids are required.[15,16,28]

Spectroscopic Characterization

NMR Spectroscopy

The diethyl phosphonate esters (**8a**–**8k**) exhibit ^{31}P chemical shifts in the range of 21–26 ppm. Chemicals shifts for the phenyl, substituted phenyl, and polycyclic aromatic derivatives are all in the range of δ_P

23–24 ppm. Only the 9-anthryl derivative resonates at slightly lower field (δ_P 26 ppm). The highest field signal among the compounds under investigation is shown by the furan derivative (δ_P 21 ppm), possibly because of shielding by the ring oxygen atom.

^1H and ^{13}C NMR spectra of the diethyl phosphonate esters are complicated by several structural factors. In addition to splitting due to phosphorus coupling, the presence of a chiral carbon atom attached to phosphorus causes the two ethoxy goups in each ester to be anisochronous,[29] as also are the two phenyl rings of the diphenylmethylamino moiety. In addition, the fact that the phosphorus atom is prochiral results in the methylene protons within each ethyl group being anisochronous,[30] although in the examples given here chemical shift nonequivalence is seen clearly for the protons of only one of the two methylene groups. Thus, one of the CH_2 groups gives rise to two distinct and separate multiplets, whereas the other appears as only one complex region of overlapping peaks (Table I). This difference in behavior of the two methylene groups in any one diethyl ester may be attributed to differences in orientation of the ethoxy groups with respect to the 1-benzhydrylamino and 1-aryl substituents, and to the differing influences of associated ring currents.[31–35]

The ^{13}C spectra show, as expected, two methyl and two methylene signals for each diethyl ester, all of which appear as doublets due to phosphorus–carbon coupling (Table II).

TABLE I ^1H NMR Parameters (δ/ppm, J/Hz) for the Ethoxy Group Protons of Diethyl Phosphonate Esters (**8a**–**8k**)

Compound	Upfield CH_3	Downfield CH_3	CH^A of upfield CH_2	CH^B of upfield CH_2	Downfield CH_2
8a	1.07, $^3J_{HH}$ 7.06, $^4J_{PH}$ 0.57	1.36, $^3J_{HH}$ 7.07, $^4J_{PH}$ 0.56	3.62–3.78	3.83–3.99	4.12–4.29
8b	0.76, $^3J_{HH}$ 7.06	1.36, $^3J_{HH}$ 7.06	3.34–3.43	3.70–3.79	4.14–4.35
8c	0.62, $^3J_{HH}$ 7.10	1.35, $^3J_{HH}$ 7.12	3.27–3.37	3.61–3.71	4.12–4.31
8d	0.75, $^3J_{HH}$ 7.05	1.38, $^3J_{HH}$ 7.04	3.35–3.45	3.67–3.80	4.18–4.39
8e	1.12, $^3J_{HH}$ 7.03, $^4J_{PH}$ 0.43	1.35, $^3J_{HH}$ 6.98, $^4J_{PH}$ 0.43	3.76–3.90	3.93–4.14	4.19–4.23
8f	1.01, $^3J_{HH}$ 7.07	1.25, $^3J_{HH}$ 7.01	3.61–3.77	3.82–3.97	4.07–4.27
8g	1.07, $^3J_{HH}$ 7.11	1.35, $^3J_{HH}$ 7.05	3.62–3.75	3.85–3.95	4.14–4.29
8h	1.01, $^3J_{HH}$ 6.96	1.33, $^3J_{HH}$ 7.06	3.41–3.51	3.67–3.76	4.00–4.21
8i	1.15, $^3J_{HH}$ 6.97	1.36, $^3J_{HH}$ 7.19	3.80–4.00	4.01–4.09	4.17–4.33
8j	1.15, $^3J_{HH}$ 7.01	1.35, $^3J_{HH}$ 7.12	3.80–3.93	3.97–4.09	4.13–4.30
8k	1.11, $^3J_{HH}$ 7.05, $^4J_{PH}$ 0.47	1.36, $^3J_{HH}$ 7.05, $^4J_{PH}$ 0.46	3.69–3.84	3.88–4.03	4.10–4.33

TABLE II ^{13}C NMR Parameters (δ/ppm, J/Hz) for the Ethoxy Groups of Diethyl Phosphonates (**8a–8k**)

Compound	Upfield CH_3	Downfield CH_3	Upfield CH_2	Downfield CH_2
8a	16.14, $^3J_{PC}$ 6.23	16.29, $^3J_{PC}$ 6.29	62.59, $^2J_{PC}$ 6.92	62.97, $^2J_{PC}$ 7.23
8b	15.73, $^3J_{PC}$ 5.85	16.43, $^3J_{PC}$ 6.10	62.46, $^2J_{PC}$ 6.98	62.90, $^2J_{PC}$ 6.92
8c	15.90, $^3J_{PC}$ 5.72	16.68, $^3J_{PC}$ 5.98	62.64, $^2J_{PC}$ 6.98	62.78, $^2J_{PC}$ 7.42
8d	16.15, $^3J_{PC}$ 5.66	16.77, $^3J_{PC}$ 5.91	62.83, $^2J_{PC}$ 6.79	63.35, $^2J_{PC}$ 6.78
8e	16.28, $^3J_{PC}$ 5.97	16.57, $^3J_{PC}$ 5.85	62.65, $^2J_{PC}$ 7.25	63.02, $^2J_{PC}$ 7.33
8f	16.42, $^3J_{PC}$ 5.84	16.84, $^3J_{PC}$ 5.99	62.86, $^2J_{PC}$ 6.37	63.21, $^2J_{PC}$ 7.20
8g	16.26, $^3J_{PC}$ 5.79	16.57, $^3J_{PC}$ 5.91	62.54, $^2J_{PC}$ 6.86	62.80, $^2J_{PC}$ 6.86
8h	16.14, $^3J_{PC}$ 6.89	16.56, $^3J_{PC}$ 6.16	62.68, $^2J_{PC}$ 6.79	63.07, $^2J_{PC}$ 6.79
8i	16.28, $^3J_{PC}$ 5.85	16.55, $^3J_{PC}$ 6.35	62.19, $^2J_{PC}$ 6.86	62.53, $^2J_{PC}$ 6.79
8j	16.26, $^3J_{PC}$ 6.23	16.55, $^3J_{PC}$ 6.23	62.96, $^2J_{PC}$ 6.73	63.31, $^2J_{PC}$ 6.98
8k	16.35, $^3J_{PC}$ 6.14	16.69, $^3J_{PC}$ 5.82	62.79, $^2J_{PC}$ 6.82	63.20, $^2J_{PC}$ 6.84

Apart from the complex overlapping peaks associated with the ethoxy and aryl (or heteroaryl) goups, the NMR spectra of the esters exhibit well-separated and characteristic signals for the two CH groups in each molecule (Table III). For the methine proton of the benzhydryl group the chemical shift is almost constant for all compounds (δ_H 4.41–4.86 ppm), and is upfield from the corresponding signal of the parent imine (δ_H 5.43–5.91 ppm). In one example (**8a**) it is split by 4-bond coupling to phosphorus ($^4J_{PH}$ 1.13 Hz), although this is unusual. The proton of the α-CH group (adjacent to phosphorus) shows more variation in chemical

TABLE III Proton and Carbon-13 NMR Parameters for the Methine Groups (P–CH–NH–CH) in Compounds **8a–8k**

Compound	δ(P-CH)	$^2J_{PCH}$	δ(N-CH)	δ(P-C)	$^1J_{PC}$	δ(N-C)	$^3J_{PCNC}$
8a	3.93	22.47	4.68[a]	57.99[a]	155.3	63.56	17.04
8b	4.86	23.31	4.65	52.05[a]	155.0	63.76	16.67
8c	5.62	26.78	4.41	53.84	157.3	64.53	15.41
8d	5.41	22.80[b]	4.61	52.95	158.4	64.09	16.98
8e	3.84	20.07	4.70	57.69	156.7	63.56	16.86
8f	3.91	22.01	4.71	57.75	155.6	63.89	17.05
8g	3.83	22.05	4.72	57.22	157.4	63.35	17.23
8h	3.94	22.52	4.81	51.53	161.8	63.87	17.17
8i	4.04	23.73	4.74	52.02	163.0	64.47	16.29
8j	4.21	22.40	4.86	53.45	130.5	63.79	15.79
8k	4.05	22.01	4.74	53.74	157.9	64.05	16.35

[a]Doublet $^4J_{PH}$ 1.13.

[b]Doublet of doublets; the coupling of this proton to the NH proton ($^3J_{HH}$) was not resolved well enough to measure.

[c]Doublet $^4J_{PH}$ 2.67.

TABLE IV ^{1}H, ^{13}C and ^{31}P NMR Parameters for Aminophosphonic Acids (**9**)

Compound	δ(P—C<u>H</u>)	$^{2}J_{P\text{-}CH}$	δ(P—<u>C</u>)	$^{1}J_{PC}$	δ_P
9b	4.76	16.1	52.6	131.1	18.8
9c	5.54	22.3	54.3	130.1	18.4
9e	3.73	15.2	58.1	132.5	18.2
9f	3.79	15.5	58.0	131.6	18.4
9g	3.74	15.0	57.6	132.8	18.6
9j	4.19	15.1	53.9	133.6	17.3

shift according to the substitutent group present, ranging from 3.83–4.05 ppm for the heterocyclic (**8h**–**8k**) and phenyl (**8a**) or substituted phenyl derivatives (**8e**–**8g**) but lying further downfield (4.86–5.62 ppm) for the polycyclic aromatic compounds (**8b**–**8d**). All are at significantly higher field than the signal for the corresponding imino proton of the precursor (δ_H 8.13–9.49 ppm) and appear as characteristic doublets ($^{2}J_{PH}$ 20–27 Hz). In the ^{13}C spectra, both methine carbon atoms are split by phosphorus to give characteristic doublets in the region 51.53–57.99 ppm ($^{1}J_{PC}$ 130.5–163.0 Hz) for the carbon atom attached to phosphorus and 63.35–64.53 ppm ($^{1}J_{PC}$ 15.41–17.23 Hz) for the methine carbon of the benzhydryl group.

Because of the low aqueous solubility of the free amino acids (**9b**, **9c**, **9e**–**9g**, and **9j**), their NMR spectra were recorded in NaOD solution in D_2O. Under these conditions the ^{31}P chemical shift, which is pH-dependent, is in the range 17–19 ppm. The ^{1}H and ^{13}C NMR spectra are relatively simple, showing the expected aromatic region for the α-substituent in each case, and simple doublets for the carbon and hydrogen of the α-CH group (Table IV).

Mass Spectrometry

Electron impact mass spectral data are shown in Table V for the *N*-protected diethyl esters and LSIMS data are given for the aminophosphonic acids in Table VI. Molecular (or pseudomolecular) ions, although variable in intensity, were observed in all cases. Fragmentation of the esters involves either C-N fission, to give the stable benzhydryl cation (m/z 167), usually as the base peak, or P-C fission, with or without hydrogen transfer, and the consequent loss of diethyl phosphite or the diethoxyphosphonyl radical. As noted previously in other cases,[13,36,37] LSIMS spectra of the aminophosphonic acids are relatively simple; the major fragmentation occurs by loss of phosphorous acid from the protonated molecular ion, and in several cases the loss of a hydroxyl group is observed.

TABLE V Principal Fragments (m/z, %) in the EI Mass Spectra of Diethyl Phosphonate Esters (**8a**–**8k**)

Compound	$M^{+\cdot}$	$[M–(EtO)_2PO]^+$	$[M – (EtO)_2PHO]^{+\cdot}$	Ph_2CH^+(m/z 167)
8a	409, (10)	272, (62)	271, (47)	(100)
8b	459, (1)	322, (22)	321, (8)	(100)
8c	509, (38)	372, (67)	371, (55)	(100)
8d	534, (3)	397, (13)	396, (55)	(100)
8e	453, (4)	316, (0)	315, (74)	(100)
8f	451, (7)	314, (56)	313, (74)	(100)
8g	452, (3)	314, (33)	313, (13)	(67)[a]
8h	398, (20)	261, (81)	260, (21)	(100)
8i	399, (8)	263, (0)	262, (44)	(100)
8j	415, (4)	278, (65)	277, (48)	(100)
8k	415, (3)	278, (10)	277, (57)	(100)

[a]Base peak m/z 65.

EXPERIMENTAL

Materials and Instrumentation

Starting materials, solvents, and reagents were obtained commercially and were mainly used as supplied. Diethyl ether was dried over sodium wire. ^{1}H NMR spectra were obtained on a Bruker AM250 spectrometer operating at 250.133 MHz. ^{13}C NMR spectra (broad-band proton decoupled, DEPT-135 and DEPT-90) were obtained on a Bruker AM250 spectrometer operating at 62.896 MHz. Samples were dissolved in $CDCl_3$ containing tetramethylsilane (TMS) as the internal reference, or in $NaOD/D_2O$ containing sodium 3-trimethylsilylpropionate-d_4 ($Me_3SiCD_2CD_2CO_2Na$; TSP) as the internal reference. $^{31}P\{^1H\}$ NMR spectra were recorded on Bruker AM250 and WP80-SY instruments operating at 101.256 MHz and 32.44 MHz, respectively. Samples were

TABLE VI Principal Ions (m/z, %) in the LSIMS of Aminophosphonic Acids (**9**)[a]

Compound	$[MH – (H_3PO_3)]^+$	$[MH – (OH)]^+$	$[(MH)]^+$	$[MH + (G)]^+$
9b	—	221 (15)	238 (100)	—
9c[b]	206 (34)	271 (26)	288 (11)	—
9e	150 (100)	215 (17)	232 (6)	324 (2)
9f	148 (100)	—	230 (18)	322 (4)
9g	149 (100)	214 (96)	231 (12)	323 (2)
9j	—	—	194 (100)	286 (72)

[a]G represents a molecule of glycerol matrix.
[b]Base peak m/z 149.

dissolved in $CDCl_3$ or $NaOD/D_2O$, with H_3PO_4 as the external reference. Microanalysis for carbon, hydrogen, nitrogen, and sulfur was carried out on a Carlo Erba 1106 elemental analyzer. Low-resolution electron impact mass spectra were obtained using a Kratos Profile HV3 spectrometer with an ionizing energy of 70 eV. LSIMS data were obtained on the same instrument using a glycerol matrix and with a primary beam of caesium ions generated in an ion gun operating at 10 kV. Melting points were recorded on an electrothermal digital melting point apparatus and are uncorrected.

Preparations of Imines (7): General Procedure

Equimolar quantities (0.03–0.1 mol) of benzhydrylamine and the aromatic aldehyde (**6a**–**6d**) or of benzhydrylamine hydrochloride and the aldehyde (**6e**–**6k**) were dissolved in dichloromethane or anhydrous ether to give a solution (15–40% w/v) which was stirred for 6 h at room temperature in the presence of an excess of anhydrous potassium carbonate. The solution was filtered, the solvent was removed under reduced pressure, and the residue was recrystallized from toluene and petroleum spirit (b.p. 40–60°C), to give the following products.

N-Benzylidene-1,1-diphenylmethylamine[14] (**7a**) (4.89 g, 66.7%), as a white crystalline solid, m.p. 104–105°C (Calculated for $C_{20}H_{17}N$: C, 88.5; H, 6.3; N, 5.2%. Found: C, 88.5; H, 6.4; N, 5.2). δ_H ($CDCl_3$) 5.59 (1H, s, $Ph_2C\underline{H}$), 7.17–7.42 (13H, m, Ar), 7.81–7.85 (2H, m, Ar), 8.40 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.77 ($Ph_2\underline{C}$), 126.88, 127.58, 128.34, 128.40, 130.63, 136.18, 143.83 (Ar), 160.63 (N=$\underline{C}$); EI ms: m/z 271 (M^+, 66.7%).

N-(1′-Naphthylmethylidene)-1,1-diphenylmethylamine (**7b**) (29.71 g, 92.2%), as a yellow crystalline solid, m.p. 109–110°C ($C_{24}H_{19}N$ requires: C, 89.7; H, 6.0; N, 4.4%. Found: C, 89.8; H, 6.0; N, 4.3). δ_H ($CDCl_3$) 5.59 (1H, s, $Ph_2C\underline{H}$), 7.12–7.52 (14H, m, Ar), 7.71–7.75 (2H, m, Ar), 8.92 (1H, s, N=C$\underline{H}$), 9.09 (1H, m, Ar); δ_C ($CDCl_3$) 79.23 ($Ph_2\underline{C}$), 124.66, 125.05, 125.93, 126.92, 127.14, 127.61, 128.43, 128.48, 129.78, 131.14, 131.28, 131.37, 133.72, 143.97 (Ar), 160.85 (s, N=$\underline{C}$); EI ms: m/z 321 (M^+, 21.8%).

N-(9′-Anthrylmethylidene)-1,1-diphenylmethylamine (**7c**) (6.45 g, 87.0%), as a yellow crystalline solid, m.p. 139°C ($C_{28}H_{21}N$requires: C, 90.5; H, 5.7; N, 3.8%. Found: C, 90.3; H, 5.6; N, 3.7). δ_H ($CDCl_3$) 5.83 (1H, s, $Ph_2C\underline{H}$), 7.20–7.41 (10H, m, Ar), 7.50–7.53 (4H, m, Ar), 7.86–7.90 (2H, m, Ar), 8.33 (1H, s, Ar) 8.37–8.43 (2H, m, Ar), 9.49 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 80.29 ($Ph_2\underline{C}$), 125.01, 125.35, 126.82, 127.32, 127.94, 128.80, 128.98, 129.69, 130.29, 131.39, 143.94 (Ar), 160.70 (N=$\underline{C}$); EI ms: m/z 371 (M^+, 22.8%).

N-(1′-Pyrenylmethylidene)-1,1-diphenylmethylamine (**7d**) (26.85 g, 67.9%), as a yellow crystalline solid, m.p. 180–181°C ($C_{28}H_{21}N$ requires: C, 91.1; H, 5.4; N, 3.5%. Found: C, 90.9; H, 5.6; N, 3.4). δ_H ($CDCl_3$) 5.80 (1H, $Ph_2C\underline{H}$), 7.23–7.57 (10H, m, Ar), 7.98–8.18 (5H, m, Ar), 8.14 (1H, d, $^3J_{HH}$ 8.07, Ar), 8.20 (1H, d, $^3J_{HH}$ 9.21, Ar) 8.65 (1H, d, Ar), 9.01 (1H, d, Ar), 9.42 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 79.27 (s, $Ph_2\underline{C}$), 122.84, 124.84, 125.64, 125.87, 126.08, 127.10, 127.04, 127.43, 127.74, 128.70, 124.59, 130.02, 130.57, 131.22, 132.91, 144.14 (Ar), 159.84 (s, N=$\underline{C}$); EI ms: m/z 395 (M^+, 2.0%).

N-Piperonylidene-1,1-diphenylmethylamine (**7e**) (16.73 g, 53.1%), as a white crystalline solid, m.p. 115–116°C ($C_{21}H_{17}NO_2$ requires: C, 80.0; H, 5.4; N, 4.4%. Found: C, 80.1; H, 5.4; N, 4.4). δ_H ($CDCl_3$) 5.55 (1H, s, $Ph_2C\underline{H}$), 5.97 (2H, s, O$C\underline{H}_2$O), 6.80 (1H, d, Ar), 7.14 (1H, dd, Ar), 7.18–7.40 (10H, m, Ar) 7.52 (1H, d, Ar), 8.29 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.63 (s, $Ph_2\underline{C}$), 101.41, 106.92, 107.96, 124.73, 126.93, 127.65, 128.41, 131.27, 144.07 (Ar), 148.22 (Ar-O), 149.94 (Ar-O), 159.83 (s, N=$\underline{C}$); EI ms: m/z 315 (M^+, 30.0%).

N-(4′-Isopropylbenzylidene)-1,1-diphenylmethylamine[43] (**7f**) (16.54 g, 52.8%), as a white crystalline solid, m.p. 63–64°C (Calculated for $C_{23}H_{23}N$: C, 88.1; H, 7.4; N, 4.5%. Found: C, 88.2; H, 7.5; N, 4.4). δ_H ($CDCl_3$) 1.21 (6H, d, $^3J_{HH}$ 6.81, 2 × CH_3), 2.87 (1H, septet, C$\underline{H}CH_3$), 5.55 (1H, $Ph_2C\underline{H}$), 7.13–7.76 (14H, m, Ar), 8.34 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 23.79 (2 × CH_3), 34.08 ($\underline{C}HCH_3$), 77.79 (s, $Ph_2\underline{C}$), 123.58, 126.86, 127.67, 128.34, 128.52, 134.13, 143.99, 151.86 (Ar), 160.59 (N=$\underline{C}$); EI ms: m/z 313 (M^+, 48.8%).

N-(4′-Dimethylaminobenzylidene)-1,1-diphenylmethylamine (**7g**) (28.98 g, 92.3%), as an orange crystalline solid, m.p. 140–141°C (Calculated for $C_{22}H_{22}N_2$: C, 84.0; H, 7.0; N, 8.9%. Found: C, 84.0; H, 7.1; N, 8.9). δ_H ($CDCl_3$) 2.92 (6H, s, 2 × CH_3), 5.51 (1H, s, $Ph_2C\underline{H}$), 6.64 (2H, d, Ar), 7.13–7.40 (10H, m, Ar), 7.69 (2H, d, Ar), 8.82 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 40.12 (2 × CH_3), 77.69 ($Ph_2\underline{C}$), 111.49, 124.61, 126.68, 127.74, 128.26, 129.79, 144.47, 152.07 (Ar), 160.56 (N=$\underline{C}$); EI ms: m/z 314 (M^+, 20.7%).

N-(2′-Pyrrolylmethylidene)-1,1-diphenylmethylamine (**7h**) (8.30 g, 55.3%), as a yellow crystalline solid, m.p. 160–162°C ($C_{18}H_{16}N$ requires: C, 83.0; H, 6.2; N, 10.8%. Found: C, 82.9; H, 6.3; N, 10.9). δ_H ($CDCl_3$) 5.56 (1H, $Ph_2C\underline{H}$), 6.22 (1H, dd, $^3J_{H3-H4}$ 3.65 and $^3J_{H4-H5}$ 2.56, pyrrolyl 4-H), 6.51 (1H, dd, $^4J_{H3-H5}$ 1.10, pyrrolyl 3-H), 6.84 (1H, dd, pyrrolyl 5-H), 7.18–7.35 (10H, m, Ar), 8.13 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.66 ($Ph_2\underline{C}$), 110.16 (pyrrolyl 4-C), 115.54 (pyrrolyl 3-C), 122.68 (pyrrolyl 5-C), 127.10, 127.82, 128.47, 129.76 (Ar), 143.37 (pyrrolyl 2-C), 151.34 (N=$\underline{C}$); EI ms: m/z 260 (M^+, 21.7%).

N-Furfurylidene-1,1-diphenylmethylamine (**7i**) (21.0 g, 80.4%), as a pale yellow crystalline solid; m.p. 110–112°C ($C_{18}H_{15}NO$ requires: C, 82.7; H, 5.8; N, 5.4%. Found: C, 82.8; H, 5.8; N, 5.4). δ_H ($CDCl_3$) 5.53 (1H, s, $Ph_2C\underline{H}$), 6.36 (1H, dd, $^3J_{H4-H3}$ 3.42 and $^3J_{H4-H5}$ 1.75, furyl 4-H), 6.72 (1H, dd, $^4J_{H3-H5}$ 0.67, furyl 3-H), 7.17–7.37 (10H, m, Ar), 7.44 (CH, dd, furyl 5-H), 8.13 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.92 ($Ph_2\underline{C}$), 111.61 (furyl 4-C), 114.5 (furyl 3-C), 126.99, 127.73, 128.38, 143.27 (Ar), 144.79 (furyl 5-C), 149.63 (N=$\underline{C}$), 151.54 (furyl 2-C); EI ms: m/z 261 (M^+, 61.9).

N-(2′-Thienylmethylidene)-1,1-diphenylmethylamine (**7j**) (4.30 g, 35.3%); m.p. 95°C ($C_{18}H_{15}NS$ requires: C, 77.9; H, 5.4; N, 5.0; S, 11.6%. Found: C, 77.9; H, 5.4; N, 5.0; S, 11.7). δ_H ($CDCl_3$) 5.57 (1H, s, $Ph_2C\underline{H}$), 7.01 (1H, dd, $^2J_{H3-H4}$ 5.00 and $^2J_{H4-H5}$ 3.62, thienyl 4-H), 7.17–7.38 (12H, m, Ar overlapping with thienyl 3-H and 5-H), 8.43 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.21 ($Ph_2\underline{C}$), 127.09 (Ar), 127.41 (thienyl 4-C), 127.82, 128.54 (Ar), 129.25 (thienyl 3-C), 130.77 (thienyl 5-C), 142.85 (thienyl 2-C), 143.76 (Ar), 154.12 (N=$\underline{C}$); EI ms: m/z 277 (M^+, 80.7%).

N-(3′-Thienylmethylidene)-1,1-diphenylmethylamine (**7k**) (6.0 g, 49.6%); m.p. 80–81°C ($C_{18}H_{15}NS$ requires: C, 77.9; H, 5.4; N, 5.0; S, 11.6%. Found: C, 77.9; H, 5.4; N, 5.0; S, 11.7). δ_H ($CDCl_3$) 5.52 (1H, s, $Ph_2C\underline{H}$), 7.14–7.38 (11H, m, Ar overlapping with thienyl 5-H), 7.55 (1H, dd, thienyl 4-H), 7.63 (1H, dd, thienyl 2-H), 8.35 (1H, s, N=C$\underline{H}$); δ_C ($CDCl_3$) 77.63 ($Ph_2\underline{C}$), 125.95 (thienyl 5-C), 126.10 (thienyl 4-C), 126.85, 127.58, 128.31 (Ar), 128.63 (thienyl 2-C), 140.51 (Ar), 143.70 (thienyl 3-C), 154.98 (N=$\underline{C}$); EI ms: m/z 277 (M^+, 23.0%).

Preparations of Diethyl Phosphonate Esters (8): General Procedure

An equimolar mixture (0.003–0.07 mol) of diethyl phosphite and imine (**7**) was heated (100°C, except for **7d**, for which a temperature of 140°C was necessary). Reactions were monitored by ^{31}P NMR until optimum conversion had been achieved: 4 h (**7a**, **7d**), 5 h (**7f**), 6h (**7e**, **7g**, **7h**, **7i**, **7j**), 8 h (**8c**, **8k**), and 10 h (**8b**). The oily product was triturated with ethyl acetate and the precipitate, which formed was washed with the minimum of diethyl ether and recrystallized from ethyl acetate to give the following products.

Diethyl 1-phenyl-1-(diphenylmethylamino)methanephosphonate (**8a**) (3.52 g, 71.6%), as a white crystalline solid, m.p. 98–99°C ($C_{24}H_{28}NO_3P$ requires: C, 70.4; H, 6.9; N, 3.3%. Found: C, 70.4; H, 6.9; N, 3.3). δ_H ($CDCl_3$) 1.07 (3H, d of t, $^3J_{HH}$ 7.06 and $^4J_{PH}$ 0.57, CH_3), 1.36 (3H, d of t, $^3J_{HH}$ 7.07 and $^4J_{PH}$ 0.56, CH_3), 2.56 (1H, br s, NH), 3.62–3.78 (1H, m, H^A of CH_2), 3.83–3.99 (1H, m, H^B of CH_2), 3.93 (1H, d, $^2J_{PH}$ 22.47, P–C$\underline{H}$), 4.12–4.29 (2H, m, CH_2), 4.68 (1H, d, $^4J_{PH}$ 1.13, $Ph_2C\underline{H}$),

7.14–7.40 (15H, m, Ar); δ_C ($CDCl_3$) 16.14 (d, $^3J_{PC}$ 6.23, CH_3), 16.29 (d, $^3J_{PC}$ 6.29, CH_3), 57.99 (d, $^1J_{PC}$ 155.29, P-C), 62.59 (d, $^2J_{PC}$ 6.92, CH_2), 62.97 (d, $^2J_{PC}$ 7.23, CH_2), 63.65 (d, $^3J_{PC}$ 17.04, Ph_2C), 127.11, 127.29, 127.92, 128.38, 128.56, 128.50, 128.66 (Ar), 135.89 (d, J_{PC} 1.57), 142.00, 143.66 (Ar); δ_P ($CDCl_3$) 23.70; EI ms: m/z 409 (M^+, 9.7%).

Diethyl 1-(1′-naphthyl)-1-(diphenylmethylamino)methanephosphonate (**8b**) (18.12 g, 53.3%), as a white crystalline solid, m.p. 102–103°C ($C_{28}H_{30}NO_3P$ requires: C, 73.2; H, 6.6; N, 3.0%. Found: C, 73.3; H, 6.7; N, 3.0). δ_H ($CDCl_3$) 0.76 (3H, t, $^3J_{HH}$ 7.06, CH_3), 1.36 (3H, t, $^3J_{HH}$ 7.06, CH_3), 2.74 (1H, br s, NH), 3.34–3.43 (1H, m, H^A of CH_2), 3.70–3.79 (1H, m, H^B of CH_2), 4.14–4.35 (2H, m, CH_2), 4.65 (1H, s, Ph_2CH), 4.86 (1H, br d, $^2J_{PH}$ 23.01, P-CH), 7.13–7.87 (17H, m, Ar); δ_C ($CDCl_3$) 15.73 (d, $^3J_{PC}$ 5.85, CH_3), 16.43 (d, $^3J_{PC}$ 6.10, CH_3), 52.05 (d, $^1J_{PC}$ 155.03, P-C), 62.46 (d, $^2J_{PC}$ 6.98, CH_2), 62.90 (d, $^2J_{PC}$ 6.92, CH_2), 63.76 (d, $^3J_{PC}$ 16.67, Ph_2C), 122.99, 125.36 (d, J_{PC} 3.33), 125.46, 125.77, 128.28, 126.48, 127.19, 127.03, 127.84, 128.25, 128.36, 128.53, 128.55, 132.14, 132.24, 133.55, 142.09, 143.50 (Ar); δ_P ($CDCl_3$) 23.90; EI ms: m/z 459 (M^+, 1.4%).

Diethyl 1-(9′-anthryl)-1-(diphenylmethylamino)methanephosphonate (**8c**) (21.14 g, 51.9%), as a white crystalline solid, m.p. 122–123°C ($C_{32}H_{32}NO_3P$ requires: C, 75.4; H, 6.3; N, 2.7%. Found: C, 75.3; H, 6.1; N, 2.6). δ_H ($CDCl_3$) 0.62 (3H, t, $^3J_{HH}$ 7.10, CH_3), 1.35 (3H, t, $^3J_{HH}$ 7.12, CH_3), 3.04 (1H, br s, NH), 3.27–3.37 (1H, m, H^A of CH_2), 3.61–3.71 (1H, m, H^B of CH_2), 4.12–4.31 (2H, m, CH_2), 4.41 (1H, s, Ph_2CH), 5.62 (1H, d, $^2J_{PH}$ 26.78, P-CH), 7.00–7.57 (15H, m, Ar), 7.93–7.98 (2H, 2 × d, Ar), 8.39 (1H, d, $^3J_{HH}$ 2.45, anthryl 13-H), 9.33 (1H, d, $^3J_{HH}$ 9.02, anthryl 3-H); δ_C ($CDCl_3$) 15.90 (d, $^3J_{PC}$ 5.72, CH_3), 16.68 (d, $^3J_{PC}$ 5.98, CH_3), 53.84 (d, $^1J_{PC}$ 157.24, P-C), 62.64 (d, $^2J_{PC}$ 6.98, CH_2), 62.78 (d, $^2J_{PC}$ 7.42, CH_2), 64.53 (d, $^3J_{PC}$ 15.41, Ph_2C), 123.47, 124.80, 125.36, 125.99, 126.13, 127.05 (d), 127.09, 127.48, 127.52, 128.30, 128.26, 128.62, 128.97 (d, J_{PC} 4.09), 129.36, 130.90 (d, J_{PC} 4.09), 131.35 (d, J_{PC} 1.95), 131.68, 131.83, 131.95 (d, J_{PC} 3.40), 142.09, 143.39 (Ar); δ_P ($CDCl_3$) 25.60; EI ms: m/z 509 (M^+, 37.9%).

Diethyl 1-(1′-pyrenyl)-1-(diphenylmethylamino)methanephosphonate (**8d**) (0.93 g, 69.7%), as a white crystalline solid, m.p. 107–108°C ($C_{34}H_{32}NO_3P$ requires: C, 76.5; H, 6.0; N, 2.6%. Found: C, 76.5; H, 6.1; N, 2.5). δ_H ($CDCl_3$) 0.75 (3H, t, $^3J_{HH}$ 7.05, CH_3), 1.38 (3H, t, $^3J_{HH}$ 7.04, CH_3), 3.02 (1H, br s, NH), 3.35–3.45 (1H, m, H^A of CH_2), 3.67–3.80 (1H, m, H^B of CH_2), 4.18–4.39 (2H, m, CH_2), 4.61 (1H, s, Ph_2CH), 5.41 (1H, br dd, $^2J_{PH}$ 22.80, P-CH), 7.10–7.33 (10H, Ar), 7.76–8.45 (9H, Ar); δ_C ($CDCl_3$) 16.15 (d, $^3J_{PC}$ 5.66, CH_3), 16.77 (d, $^3J_{PC}$ 5.91, CH_3), 52.95 (br d, $^1J_{PC}$ 158.37, P-C), 62.83 (d, $^2J_{PC}$ 6.79, CH_2), 63.35 (d, $^2J_{PC}$ 6.98, CH_2), 64.09 (d, $^3J_{PC}$ 16.98, Ph_2C), 122.65, 124.86, 124.95, 125.15,

125.42, 125.62, 126.12, 127.28, 127.55, 127.63, 127.70, 127.34, 128.23, 128.55, 128.74, 130.02, 130.80, 130.17 (d, J_{PC} 7.67), 131.02 (d, J_{PC} 2.70), 131.48, 142.26, 143.75 (Ar); δ_P ($CDCl_3$) 23.74; EI ms: m/z 534 (M^+, 3.0%).

Diethyl 1-(piperonyl)-1-(diphenylmethylamino)methanephosphonate (**8e**) (18.9 g, 93.0%), as a white crystalline solid, m.p. 119–120°C ($C_{25}H_{28}NO_5P$ requires: C, 66.2; H, 6.2; N, 3.1%. Found: C, 66.4; H, 6.4; N, 3.0). δ_H ($CDCl_3$) 1.12 (3H, d of t, $^3J_{HH}$ 7.03 and $^4J_{PH}$ 0.43, CH_3), 1.35 (3H, d of t, $^3J_{HH}$ 6.98 and $^4J_{PH}$ 0.43, CH_3), 2.52 (1H, br s, NH), 3.76–3.90 (1H, m, H^A of CH_2), 3.84 (1H, d, $^2J_{PC}$ 20.07, P-C<u>H</u>) 3.93–4.14 (1H, m, H^B of CH_2), 4.19–4.23 (2H, m, CH_2), 4.70 (1H, s, $Ph_2C\underline{H}$), 5.93 (2H, s, $OC\underline{H}_2O$), 6.74–6.80 (2H, Ar), 6.90 (1H, Ar), 7.15–7.35 (10H, m, 2 × Ph); δ_C ($CDCl_3$) 16.28 (d, $^3J_{PC}$ 5.79, CH_3), 16.57 (d, $^3J_{PC}$ 5.85, CH_3), 57.69 (d, $^1J_{PC}$ 156.70, P-<u>C</u>), 62.65 (d, $^2J_{PC}$ 7.25, ester CH_2), 63.02 (d, $^2J_{PC}$ 7.33, ester CH_2), 63.56 (d, $^3J_{PC}$ 16.86, $Ph_2\underline{C}$), 101.92 (s, $O\underline{C}H_2O$), 108.22 (d, J_{PC} 1.76), 108.71 (d, J_{PC} 5.41), 122.23, 122.35, 127.15, 127.25, 127.34, 127.85, 128.51 (d, J_{PC} 12.39), 129.68, 142.01, 143.69 (Ar), 147.96 (Ar-O), 147.99 (Ar-O); δ_P ($CDCl_3$) 23.67; EI ms: m/z 453 (M^+, 4.5%).

Diethyl 1-(4′-isopropylphenyl)-1-(diphenylmethylamino)methanephosphonate (**8f**) (14.6 g, 62.4%), as a white crystalline solid, m.p. 88–90°C ($C_{27}H_{34}NO_3P$ requires: C, 71.8; H, 7.6; N, 3.1%. Found: C, 71.9; H, 7.6; N, 3.1). δ_H ($CDCl_3$) 1.01 (3H, t, $^3J_{HH}$ 7.07, $C\underline{H}_3CH_2$), 1.25 [6H, d, $^3J_{HH}$ 7.01 $(C\underline{H}_3)_2CH$], 1.33 (3H, t, $^3J_{HH}$ 7.05, $C\underline{H}_3CH_2$), 2.59 (1H, br s, NH), 2.89 [1H, septet, $C\underline{H}(CH_3)_2$], 3.61–3.77 (1H, m, H^A of CH_2), 3.82–3.97 (1H, m, H^B of CH_2), 3.91 (1H, d, $^2J_{PH}$ 22.01, P-C<u>H</u>), 4.07–4.27 (2H, m, CH_2), 4.71 (1H, s, $Ph_2C\underline{H}$), 7.10–7.37 (14H, m, Ar); δ_C ($CDCl_3$) 16.42 (d, $^3J_{PC}$ 5.84, CH_3), 16.84 (d, $^3J_{PC}$ 5.99, CH_3), 24.0 (s, $\underline{C}H_3CH$), 33.62 (s, $CH_3\underline{C}H$), 57.75 (d, $^1J_{PC}$ 155.6, P-<u>C</u>), 62.86 (d, $^2J_{PC}$ 6.37, CH_2), 63.21 (d, $^2J_{PC}$ 7.20, CH_2), 63.89 (d, $^3J_{PC}$ 17.05, $Ph_2\underline{C}$), 126.87 (d, J_{PC} 2.14), 127.37, 127.56, 128.18, 128.66, 128.76, 128.83, 128.86, 133.33, 142.47, 144.10, 148.82 (d, J_{PC} 3.14) (Ar); δ_P ($CDCl_3$) 24.63; EI ms: m/z 451 (M^+, 7.0%).

Diethyl 1-(4′-dimethylaminophenyl)-1-(diphenylmethylamino)methanephosphonate (**8g**) (12.09 g, 87.6%), as a red-orange crystalline solid, m.p. 108–109°C ($C_{26}H_{33}N_2O_3P$ requires: C, 69.1; H, 7.4; N, 6.2%. Found: C, 69.3; H, 7.3; N, 6.3). δ_H ($CDCl_3$) 1.07 (3H, t, $^3J_{HH}$ 7.11, $C\underline{H}_3CH_2$), 1.35 (3H, t, $^3J_{HH}$ 7.05, $C\underline{H}_3CH_2$), 2.92 [6H, s, $N(C\underline{H}_3)_2$], 3.62–3.75 (1H, m, H^A of CH_2), 3.85–3.95 (1H, m, H^B of CH_2), 3.83 (1H, d, $^2J_{PH}$ 22.05, P-C<u>H</u>), 4.14–4.29 (2H, m, CH_2), 4.72 (1H, s, $Ph_2C\underline{H}$), 6.70 (2H, d, Ar), 7.13–7.38 (13H, m, Ar); δ_C ($CDCl_3$), 16.26 (d, $^3J_{PC}$ 5.79, $C\underline{H}_3CH_2$), 16.57 (d, $^3J_{PC}$ 5.91, $C\underline{H}_3CH_2$), 40.40 [$N(C\underline{H}_3)_2$], 57.22 (d, $^1J_{PC}$ 157.36, P-<u>C</u>), 62.54 (d, $^2J_{PC}$ 6.86, CH_2), 62.80 (d, $^2J_{PC}$ 6.86, CH_2), 63.35 (d, $^3J_{PC}$ 17.23, $Ph_2\underline{C}$), 112.37, 122.86, 126.99, 127.16, 127.27,

127.88, 128.32, 128.48, 129.38 (d, J_{PC} 6.54), 142.25, 143.98, 150.17 (d, J_{PC} 1.87) (Ar); δ_P ($CDCl_3$) 25.12; EI ms: m/z 452 (M^+, 3.0%).

Diethyl 1-(2′-pyrrolyl)-1-(diphenylmethylamino)methanephosphonate (**8h**) (1.88 g, 59.2%), as a pale yellow crystalline solid, m.p. 88–90°C ($C_{22}H_{27}N_2O_3P$ requires: C, 66.3; H, 6.8; N, 7.0%. Found: C, 66.3; H, 6.8; N, 7.0). δ_H ($CDCl_3$) 1.01 (3H, t, $^3J_{HH}$ 6.96, CH_3), 1.33 (3H, t, $^3J_{HH}$ 7.06, CH_3), 2.67 (1H, br s, NH), 3.41–3.51 (1H, m, H^A of CH_2), 3.67–3.76 (1H, m, H^B of CH_2), 3.94 (1H, d, $^2J_{PH}$ 22.52, P-C<u>H</u>), 4.00–4.21 (2H, m, CH_2), 4.81 (1H, s, Ph_2C<u>H</u>), 6.01 (1H, m, pyrrolyl 4-H), 6.13 (1H, m, pyrrolyl 3-H), 6.76 (1H, m, pyrrolyl 5-H), 7.13–7.41 (10H, m, Ar), 9.78 (1H, br s, pyrrolyl N<u>H</u>); δ_C ($CDCl_3$) 16.14 (d, $^3J_{PC}$ 6.89, CH_3), 16.56 (d, $^3J_{PC}$ 6.16, CH_3), 51.53 (d, $^1J_{PC}$ 161.83, P-<u>C</u>), 62.68 (d, $^2J_{PC}$ 6.79, CH_2), 63.07 (d, $^2J_{PC}$ 6.79, CH_2), 63.87 (d, $^3J_{PC}$ 17.17, Ph_2<u>C</u>), 107.68 (s, pyrrolyl 4-C), 109.52 (d, $^4J_{CP}$ 9.56, pyrrolyl 3-C), 118.62 (s, pyrrolyl 5-C), 125.27 (d, $^2J_{CP}$ 3.40, pyrrolyl 2-C), 126.88, 127.16, 127.29, 127.90, 128.24, 128.48, 142.56, 144.16 (Ar); δ_P ($CDCl_3$) 23.96; EI ms: m/z 398 (M^+, 19.8%).

Diethyl 1-furyl-1-(diphenylmethylamino)methanephosphonate (**8i**) (10.64 g, 87%), as a white crystalline solid, m.p. 82–84°C ($C_{22}H_{26}NO_4P$ requires: C, 66.2; H, 6.6; N, 3.5%. Found: C, 66.4; H, 6.6; N, 3.5). δ_H ($CDCl_3$) 1.15 (3H, t, $^3J_{HH}$ 6.97, CH_3), 1.36 (3H, t, $^3J_{HH}$ 7.19, CH_3), 2.53 (1H, br s, NH), 3.80–4.00 (1H, m, H^A of CH_2), 4.01–4.09 (1H, m, H^B of CH_2), 4.04 (1H, d, $^2J_{PH}$ 23.79, P-C<u>H</u>), 4.17–4.33 (2H, m, CH_2), 4.74 (1H, s, Ph_2C<u>H</u>), 6.29 (1H, m, furyl 4-H), 6.38 (1H, m, furyl 3-H), 7.15–7.44 (11H, m, Ar and furyl 5-H); δ_C ($CDCl_3$) 16.28 (d, $^3J_{PC}$ 5.85, CH_3), 16.55 (d, $^3J_{PC}$ 6.35, CH_3), 52.02 (d, $^1J_{PC}$ 163.0, P-<u>C</u>), 62.19 (d,$^2J_{PC}$ 6.86, CH_2), 62.53 (d, $^2J_{PC}$ 6.79, CH_2), 64.42 (d, $^3J_{PC}$ 16.29, Ph_2<u>C</u>), 109.48 (d, $^3J_{PC}$ 7.86, furyl 3-C), 110.54 (s, furyl 4-C), 127.22 (s, furyl 5-C), 127.38, 127.77, 128.46, 128.58, 142.38, 142.68, 141.89, 143.59 (Ar), 149.88 (d, $^2J_{PC}$ 2.70, furyl 2-C); δ_P ($CDCl_3$) 21.00; EI ms: m/z 399 (M^+, 8.4%).

Diethyl 1-(2′-thienyl)-1-(diphenylmethylamino)methanephosphonate (**8j**) (1.96 g, 87.5%), as a pale yellow crystalline solid, m.p. 93–95°C ($C_{22}H_{26}NO_3PS$ requires: C, 63.6; H, 6.3; N, 3.4; S, 7.7%. Found: C, 63.7; H, 6.2; N, 3.4; S, 7.6). δ_H ($CDCl_3$) 1.15 (3H, t, $^3J_{HH}$ 7.01, CH_3), 1.35 (3H, t, $^3J_{HH}$ 7.17, CH_3), 2.76 (1H, br s, NH), 3.80–3.93 (1H, m, H^A of CH_2), 3.97–4.09 (1H, m, H^B of CH_2), 4.21 (1H, d, $^2J_{PH}$ 22.40, P-C<u>H</u>), 4.13–4.30 (2H, m, CH_2), 4.86 (1H, s, Ph_2C<u>H</u>), 6.98–7.02 (2H, m, thienyl 3-H and 4-H), 7.02–7.41 (11H, m, Ar and thienyl 5-H); δ_C ($CDCl_3$), 16.26 (d, $^3J_{PC}$ 6.23, CH_3), 16.55 (d, $^3J_{PC}$ 6.23, CH_3), 53.45 (d, $^1J_{PC}$ 130.51, P-<u>C</u>), 62.96 (d, $^2J_{PC}$ 6.73, CH_2), 63.31 (d, $^2J_{PC}$ 6.98, CH_2), 63.79 (d, $^3J_{PC}$ 15.79, Ph_2<u>C</u>), 125.51 (d, $^3J_{PC}$ 3.21, thienyl 3-C), 126.96, 127.21 (Ar), 127.08 (thienyl 4-C), 127.43 (thienyl 5-C), 127.88, 128.65, 128.43, 128.85 (Ar), 139.64 (thienyl 2-C), 141.80, 143.45 (Ar); δ_P ($CDCl_3$) 21.93; EI ms: m/z 415 (M^+, 4.5%).

Diethyl 1-(3′-thienyl)-1-(diphenylmethylamino)methanephosphonate (**8k**) (5.77 g, 50.2%), as a cream crystalline solid, m.p. 90–92°C ($C_{22}H_{26}NO_3PS$ requires: C, 63.6; H, 6.3; N, 3.4; S, 7.7%. Found: C, 63.7; H, 6.3; N, 3.4; S, 7.6). δ_H ($CDCl_3$) 1.11 (3H, d of t, $^3J_{HH}$ 7.05 and $^4J_{PH}$ 0.47, CH_3), 1.36 (3H, d of t, $^3J_{HH}$ 7.05 and $^4J_{PH}$ 0.46, CH_3), 2.33 (1H, br s, NH), 3.69–3.84 (1H, m, H^A of CH_2), 3.88–4.03 (1H, m, H^B of CH_2), 4.05 (1H, d, $^2J_{PH}$ 22.01, P-C<u>H</u>), 4.10–4.33 (2H, m, CH_2), 4.74 (1H, s, Ph_2C<u>H</u>), 7.07–7.40 (13H, m, Ar and thienyl 2-H, 4-H and 5-H); δ_C ($CDCl_3$), 16.35 (d, $^3J_{PC}$ 6.14, CH_3), 16.69 (d, $^3J_{PC}$ 5.82, CH_3), 53.74 (d, $^1J_{PC}$ 157.90, P-<u>C</u>), 62.79 (d, $^2J_{PC}$ 6.82, CH_2), 63.20 (d, $^2J_{PC}$ 6.84, CH_2), 64.05 (d, $^3J_{PC}$ 16.35, Ph_2<u>C</u>), 123.90 (d, $^3J_{PC}$ 10.38, thienyl 2-C), 126.16 (s, thienyl 5-C), 127.29, 127.37, 127.37, 127.91 (Ar), 127.56 (d, $^3J_{PC}$ 3.84, thienyl 4-C), 128.55, 128.72 (Ar), 137.08 (thienyl 3-C), 142.2, 143.77 (Ar); δ_P ($CDCl_3$) 23.18; EI ms: m/z 415 (M^+, 3.4%).

Preparations of Aminophosphonic Acids (9): General Procedure

Equimolar quantities (0.02–0.08 mol) of diethyl phosphite and imine (**7**) were heated together as described above to give the ester (**8**) as a crude oily product. Concentrated hydrochloric acid was then added (1 ml per millimole) and the mixure was heated under reflux (3 h). By-products were removed by extraction with toluene, the aqueous solution was evaporated to dryness under reduced pressure, and the residue was dissolved in methanol at 50°C. Dropwise addition of propylene oxide (precooled in ice) caused precipitation of the free aminophosphonic acid, which was filtered off, washed with acetone, and recrystallized from water and acetone (**9b**, **9c**, **9e**, **9g**, and **9j**), or ethanol and acetone (**9f**), to give the following:

1-Amino-1-(1′-naphthyl)methanephosphonic acid (**9b**) (7.54 g, 31.8%), as a white solid, m.p. 257°C ($C_{11}H_{12}NO_3P$ requires: C, 55.7; H, 5.1; N, 5.9%. Found: C, 55.6; H, 5.1; N, 5.7). δ_H (D_2O/NaOD) 4.76 (1H, d, $^2J_{PH}$ 16.06, P-C<u>H</u>), 7.52–7.65 (3H, m, Ar-3H, 7H, and 8H), 7.71 (1H, d, $^3J_{HH}$ 7.45, Ar-9H), 7.84 (1H, d, $^3J_{HH}$ 8.15, Ar-6H), 7.94 (1H, d, $^3J_{HH}$ 7.90, Ar-4H), 8.31 (1H, d, $^3J_{HH}$ 8.38, Ar-2H); δ_C (D_2O/NaOD) 52.65 (d, $^1J_{PC}$ 131.08, P-<u>C</u>), 127.19, 128.34, 128.52, 128.56, 128.62, 129.25, 131.27, 134.23 (d, J_{PC} 5.66), 136.06, 141.56 (Ar); δ_P (D_2O/NaOD) 18.77; LSIMS: m/z 238 (MH^+, 100).

1-Amino-1-(9′-anthryl)methanephosphonic acid (**9c**) (10.74 g, 37.4%), as a yellow solid, m.p. 286–287°C (decomp.) (Calculated for $C_{15}H_{14}NO_3P$: C, 62.7; H, 4.9; N, 4.9%. Found: C, 62.0; H, 5.1; N, 4.5). δ_H (D_2O/NaOD) 5.54 (1H, d, $^2J_{PH}$ 22.25, P-C<u>H</u>), 7.49–7.65 (4H, m, Ar-4H, 5H, 11H, and 12C), 8.04 (2H, d, $^3J_{HH}$ 7.30, Ar-6H, and 10H), 8.42 (1H,

s, Ar-8H), 8.49 (1H, d, $^3J_{HH}$ 9.02, Ar-13H), 8.96 (1H, d, $^3J_{HH}$ 9.71, Ar-3H); δ_C (D_2O/NaOD) 54.32 (d, $^1J_{PC}$ 130.13, P-C), 127.30, 127.72, 127.78, 127.88, 129.19, 129.24, 130.96, 131.59, 131.85, 132.20, 134.09, 132.84 (d, J_{PC} 7.48), 134.54 (d, J_{PC} 2.77), 139.12 (Ar); δ_P (D_2O/NaOD) 18.44; LSIMS: m/z 288 (MH^+, 11.4), 206 [MH^+-(H_3PO_3), 34%].

1-Amino-1-piperonylmethanephosphonic acid (**9e**) (1.54 g, 41.6%), as a cream solid, m.p. 242–245°C (Calc. for $C_8H_{10}NO_5P$: C, 41.6; H, 4.4; N, 5.1%. Found: C, 41.1; H, 4.4; N, 5.0). δ_H (D_2O/NaOD) 3.73 (1H, d, $^2J_{PH8}$ 15.18, P-CH), 5.95 (2H, s, OCH_2O), 6.86–6.97 (3H, m, piperonyl 2-H, 5-H, and 6-H); δ_C (D_2O/NaOD) 58.08 (d, $^1J_{PC}$ 132.46, P-C), 103.54 (OCH_2O), 110.76 (d, J_{PC} 1.82), 111.17 (d, J_{PC} 4.59), 123.77 (d, J_{PC} 5.79), 139.07 (d, J_{PC} 2.33), 148.07 (d, J_{PC} 2.83), 149.34 (d, J_{PC} 1.89) (Ar); δ_P (D_2O/NaOD) 18.23; LSIMS: m/z 232 (MH^+, 5.5), 150 [MH^+-(H_3PO_3), 100].

1-Amino-4′-isopropylbenzylphosphonic acid (**9f**) (2.33 g, 40.7%), as a white solid, m.p. 308°C (decomp.) (Calc. for $C_{10}H_{16}NO_3P$: C, 52.4; H, 7.0; N, 6.1%. Found: C, 52.5; H, 7.0; N, 6.0). δ_H (D_2O/NaOD) 1.23 (6H, d, $^3J_{HH}$ 6.90, 2 × CH_3), 2.92 [1H, septet, $(CH_3)_2CH$], 3.79 (1H, d, $^2J_{P\text{-}H6}$ 15.49, P-CH), 7.29 (2H, d, Ar-3H), 7.35 (2H, dd, $^3J_{H2-H3}$ 8.30 and $^4J_{P\text{-}H2}$ 1.50, Ar-2H); δ_C (D_2O/NaOD) 26.15 (s, 2 × CH_3), 35.82 [s, $(CH_3)_2C$], 57.95 (d, $^1J_{PC}$ 131.58, P-C), 128.66 (d, J_{PC} 1.38), 130.48 (d, J_{PC} 4.90), 142.35 (d, J_{PC} 2.45), 150.12 (d, J_{PC} 2.64) (Ar); δ_P (D_2O/NaOD) 18.40; LSIMS: m/z 230 (MH^+, 17.7), 148 [MH^+-(H_3PO_3), 100].

1-Amino-4′-dimethylaminobenzylphosphonic acid (**9g**) (1.42 g, 41.1%), as a pale yellow solid, m.p. 230–234°C (Calc. for $C_9H_{15}N_2O_3P$. $^3/_4H_2O$: C, 44.4; H, 6.8; N, 11.5%. Found: C, 44.9; H, 7.0; N, 11.4). δ_H (D_2O/NaOD) 2.83 (6H, s, 2 × CH_3), 3.74 (1H, d, $^2J_{PH}$ 15.03, P-CH), 7.01 (2H, d, $^3J_{H2-H3}$ 8.68, Ar-3H), 7.34 (2H, dd, $^4J_{P\text{-}H2}$ 1.83, Ar-2H); δ_C (D_2O/NaOD) 44.35 (2 × CH_3), 57.56 (d, $^1J_{PC}$ 132.77, P-C), 118.44 (d, J_{PC} 1.45), 131.21 (d, J_{PC} 5.03), 136.27 (d, J_{PC} 2.70), 152.64 (d, J_{PC} 1.95) (Ar); δ_P (D_2O/NaOD) 18.65; LSIMS: m/z 231 (MH^+, 12.3%), 149 [MH^+-(H_3PO_3), 100%].

1-Amino-1-(2′-thienyl)methanephosphonic acid (**9j**) (3.74 g, 71.5%), as a pale pink solid, m.p. 250–252°C [lit.[38] 248–250°C (decomp.), lit.[15] 239–242°C (decomp.)] (Calc. for $C_5H_8NO_3PS.^1/_3H_2O$: C, 30.2; H, 4.4; N, 7.0%. Found: C, 30.2; H, 4.4; N, 6.9). δ_H (D_2O/NaOD) 4.19 (1H, d, $^2J_{P\text{-}H6}$ 15.11, P-CH), 7.04 (1H, dd, $^3J_{H4-H5}$ 5.04 and $^3J_{H4-H3}$ 3.56, thienyl 4-H), 7.11 (1H, dd, $^4J_{H3-H5}$ 1.12, thienyl 3-H), 7.35 (1H, dd, thienyl 5-H); δ_C (D_2O/NaOD) 53.93 (d, $^1J_{PC}$ 133.59, P-C), 127.44 (d, $^4J_{PC}$ 1.38, thienyl 4-C), 128.40 (d, $^3J_{PC}$ 6.29, thienyl 3-C), 129.58 (d, $^4J_{PC}$ 1.45, thienyl 5-C), 145.94 (d, $^2J_{PC}$ 3.08, thienyl 2-C); δ_P (D_2O/NaOD) 17.31; LSIMS: m/z 194 (MH^+, 100%).

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