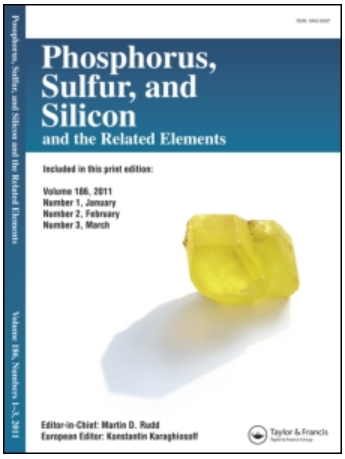

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ORGANOPHOSPHORUS COMPOUNDS AS POTENTIAL FUNGICIDES. PART I. *N*-(ω-GUANI-DINOALKYL)AMINOALKANEPHOSPHONIC ACIDS AND THEIR AMINOPHOSPHONIC PRECURSORS: PREPARATION, NMR SPECTROSCOPY, AND FAST ATOM BOMBARDMENT MASS SPECTROMETRY

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ORGANOPHOSPHORUS COMPOUNDS AS POTENTIAL FUNGICIDES. PART I. *N*-(ω-GUANIDINOALKYL)AMINOALKANEPHOSPHONIC ACIDS AND THEIR AMINOPHOSPHONIC PRECURSORS: PREPARATION, NMR SPECTROSCOPY, AND FAST ATOM BOMBARDMENT MASS SPECTROMETRY

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N-(ω-Aminoalkyl)- and *N*-(ω-guanidinoalkyl)-aminoalkanephosphonic acids have been prepared from α,ω-diaminoalkanes by reaction with chloromethanephosphonic acid (or an ester of a halogenoalkanephosphonic acid), followed by treatment with *S*-methylisothiouronium chloride. Ethylene diamine yielded 1-phosphonomethyl-2-iminoimidazolidine. A number of 1:1 salts of the α,ω-diamines and chloromethanephosphonic acid are also reported. Doubly charged zwitterionic structures are assigned to both ω-amino and ω-guanidino compounds on the basis of ^{31}P and ^{13}C nmr data. Thus the addition of an excess of acid (D_2SO_4) causes the ^{31}P chemical shift to move to higher field, from ca. 8 to 14 ppm, whilst $^1J_{PC}$ increases from ca. 130 to 150 Hz. The ^1H and ^{13}C chemical shifts of the terminal methylene groups in the polymethylene chain are unaffected by acidification.

Fast atom bombardment mass spectrometry gives rise to characteristic $[M + H]^+$ ions, frequently as the base peak, and to fragmentations involving the loss of phosphorous acid, or the formation of ions resulting from carbon–nitrogen or carbon–carbon cleavage. The compounds show activity against a number of fungal pathogens and other microbial organisms.

Key words: Organophosphorus; fungicides; guanidinophosphonic acids; aminophosphonic acids; NMR spectroscopy; FAB mass spectrometry.

Aminophosphonic acids[1] and aminophosphonous acids[2] are of interest as analogues of the amino-carboxylic acids and as structural units in phosphonopeptides.[3] Guanidinophosphonic acids[4] are less well known but a number of examples have attracted interest as analogues of creatine[5] and of other neuroactive biomolecules.[6]

We now report a novel series of fungicidal guanidinophosphonic acids (**5**)[7] derived from polymethylene diamines (**1**) by reaction of an excess of the amine

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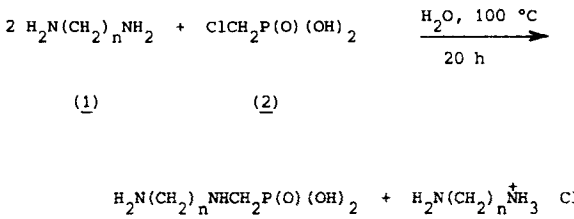


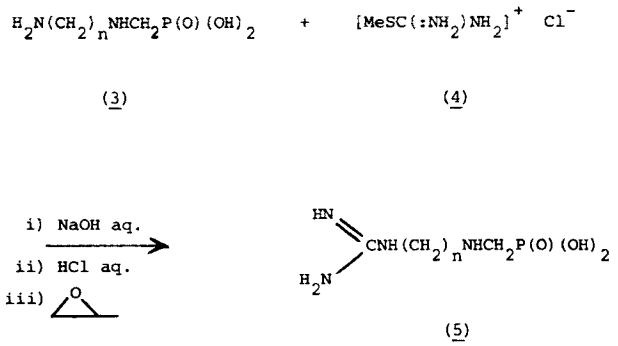
SCHEME 1

with chloromethanephosphonic acid (**2**) (Scheme 1) followed by treatment of the so-formed *N*-(ω-aminoalkyl)aminoalkanephosphonic acid (**3**) with *S*-methylisothiouronium chloride (**4**) in the presence of alkali (Scheme 2). The products were isolated as the hydrochlorides which were then treated with propylene oxide (as hydrogen chloride acceptor) to liberate the free guanidinophosphonic acids.

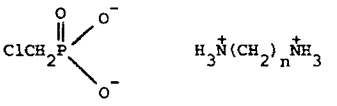
The initial interaction between an α,ω-diamine and chloromethanephosphonic acid gives a 1:1 salt (**6**) but nucleophilic displacement of chlorine by amino occurs on heating an aqueous solution in the presence of an excess of the diamine. The presence of added alkali, as used in previously described reactions of this type,[8–11] was found to be unnecessary; competing hydrolysis of the chloromethanephosphonic acid[12] was thereby avoided. A five mole excess of the diamine was used in order to limit reaction to the formation of the mono-*N*-phosphonomethyl derivative (**3**). Displacement of halogen similarly occurred on heating diethyl 2-bromoethanephosphonate[13] with an excess of 1,8-diamino-octane in water, the corresponding phosphonic acid (**7**, $n = 8$) being obtained by subsequent hydrolysis followed by treatment with propylene oxide (Scheme 3). The *N*-(ω-aminoalkyl)aminoalkanephosphonic acids were separated from the excess of diamine and diamine hydrochloride by the addition of ethanol in which they are insoluble and were recrystallised from aqueous ethanol as white microcrystalline monohydrates.

Di-, tri-, and tetra-phosphonomethylated diamines[9,11] and other related phosphonic derivatives of di- and poly-amines have been reported elsewhere,[14] especially in connection with their use as chelating agents, corrosion inhibitors, and additives for epoxy resins, etc.

The guanidino compounds described in the present work (**5**, **8**) were isolated as



SCHEME 2



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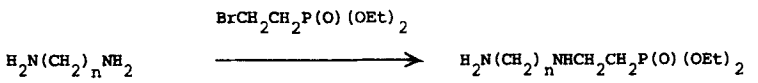
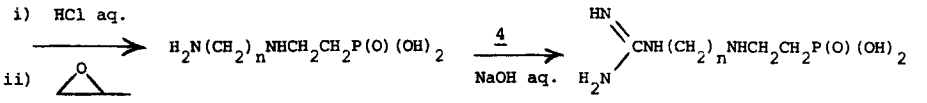




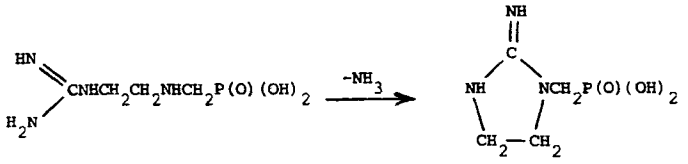
(7) (8)

SCHEME 3

dihydrates after acidification with hydrochloric acid followed by propylene oxide treatment (Scheme 2). In the case of the ethylene diamine derivative (**3**, $n = 2$), however, 1-phosphonomethyl-2-iminoimidazolidine (**9**) was obtained, presumably as a result of cyclisation of the intermediate guanidine (Scheme 4). Similar cyclisations occur in the formation of 2-imino-5-hydroxypyrimidinium sulphate by the reaction of 1,3-diaminopropan-2-ol with *S*-methylisothiouronium sulphate[15] and in the formation of carbendazim from *o*-phenylenediamine and methyl cyanocarbamate.[16]

S-Methylisothiouronium salts are known to react more rapidly with primary than with secondary amino groups[17] and we found no evidence for reaction at the secondary amino group in our examples. Nor did reaction of the secondary amino group occur with cyanamide although this is generally a less selective reagent.[18] Under the strongly alkaline conditions of our experiment, however, hydrolysis led to the formation of the ω-ureido compound (**10**; Scheme 5).

The identities of all products were confirmed by elemental analysis, ^1H, ^{13}C,



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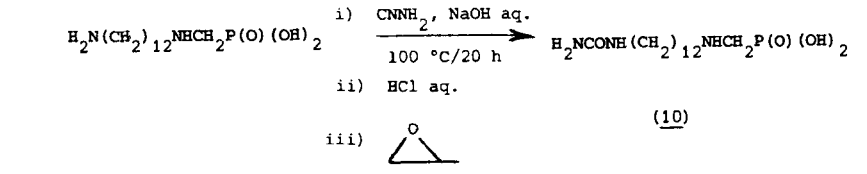
SCHEME 4



SCHEME 5

and ^{31}P nmr spectroscopy, and by positive ion fast-atom bombardment mass spectrometry which gave characteristic $[M + H]^+$ ions, usually as the base peak.

In the above mentioned reaction schemes the amino and guanidino compounds are represented conventionally as non-ionic structures although a number of zwitterionic forms are possible. pK_a values for various stages of neutralisation have been reported elsewhere for the 2-aminoethyl derivative (**3**, $n = 2$).[11] On the basis of known values of pK for phosphonic acids[19] and for amines[20] and guanidines,[21] the compounds reported here may be expected to exist mainly in the doubly zwitterionic form (**11**, **12**) under neutral conditions. This view is confirmed by various aspects of the n.m.r. spectroscopy of these compounds. Thus, the proton and carbon-13 chemical shifts for the terminal methylene groups of the alkylene chain (Table I) do not change significantly on acidification (Tables II and III). Results for a number of simple ω-aminoalkanephosphonic acids[22] indicate that the proton signals for the ω-methylene group would be expected to move downfield by ca. 0.4 ppm on protonation whilst the carbon-13 resonances would move slightly upfield. The effects of protonation on the carbon-13 chemical shifts of amino compounds are complex and may correspond either to shielding or deshielding of the nuclei according to circumstances.[23] For straight-chain amino compounds and polymethylene diamines, however, the α-carbon atoms generally exhibit upfield shifts on protonation of 1–2 ppm.[24]

Also, in the presence of an excess of D_2SO_4, the phosphonate groups become fully protonated. Under these conditions the protons of the phosphorus-bonded CH_2 group become more deshielded [$\Delta(\delta_H) = 0.3$–0.5 ppm] but the carbon-13 resonance moves upfield by 1–3 ppm. The most marked effect is on the one-bond J_{PC} coupling which increases on protonation by *ca.* 20 ppm (Table III). At the same time δ_p moves downfield from *ca.* 8 to 14 ppm with J_{HCP} increasing from 12 to 14 Hz (see Experimental section). Similar increases in J_{PC} (from 131 to 149) and in δ_p (from 9 to 14) have been reported during the corresponding two stages of protonation of α-aminomethanephosphonic acid (**13** to **14** to **15**)[22] whereas the final single stage of protonation only (**14** to **15**) involves an increase of from 141–2 to 149–50 in J_{PC} and of from 11 to 15 in δ_p.[22,25] ω-Guanidino-[25] and ω-amino-alkanephosphonic acids[22,25] in general exhibit ^{31}P chemical shifts that are at significantly higher field than for the unsubstituted alkanephosphonic acids, although the differences decrease with increasing length of the alkyl chain. The influence of amino substituents has been attributed to intramolecular hydrogen bonding in solution between the phosphonate oxygen atoms and the nitrogen-bonded hydrogens,[22] although no such interaction is present in the crystalline form. Strong intermolecular hydrogen bonding is observed in the solid state for both amino[26] and guanidino phosphonic derivatives.[25]

TABLE I

^1H and ^{13}C nmr data for *N*-(ω-aminoalkyl)- and *N*-(ω-guanidinoalkyl)-aminoalkanephosphonic acids $(HO)_2P(O)(CH_2)_mNHCH_2(CH_2)_{n-2}CH_2X$ [X = NH_2 (**3**, **7**) or X = NHC(:NH)NH_2 (**5**,**8**)][a]

			$\delta_H(J_{HCCH}/Hz)$			$\delta_C(J_{PC}$ or $J_{PCNC}/Hz)$					
X[b]	*m*	*n*	$\delta_H(J_{PCH_2}/Hz)$ P-CH_2	—$\overset{+}{N}H_2CH_2\cdots CH_2\overset{+}{X}H$[c]		δ_H $(CH_2)_{n-2}$[d]		P-CH_2	—$\overset{+}{N}H_2CH_2\cdots CH_2\overset{+}{X}H$		δ_C $(CH_2)_{n-2}$	δ_C NHC(:NH)NH_2
NH_2	1	2	3.47 (d, 14.1)	3.40	– 3.66(m)	—	—	46.2 (d, 135.3)	50.2 (d, 4.4)	39.2		—
NH_2	1	4	3.45 (d, 14.1)	3.28 (t, 6.8)	3.12 (t, 6.3)	—	1.82(m)	45.4 (d, 147.8)	51.9 (d, 8.2)	41.9	24.8, 26.2	—
NH_2	1	6	3.50 (d, 14.1)	3.25 (t, 7.7)	3.06 (t, 7.9)	1.48(m)	1.75(m)	45.7 (d, 148.5)	53.0 (d, 7.7)	43.1	27.6, 29.2	—
NH_2	1	8	3.43 (d, 13.6)	3.22 (t, 7.7)	3.04 (t, 7.7)	1.37(m)	1.72(m)	45.7 (d, 146.5)	52.6 (d, 7.5)	42.6	27.9, 28.1, 29.4, 30.4	—
NH_2	2[e]	8	2.33(dt)[f]	3.09 (2 overlapping t)		1.36(m)	1.70(m)	22.5[g]	51.4(s)	43.5	28.1, 29.4, 30.5	—
NH_2	1	10	3.46 (d, 14.4)	3.22 (t, 7.8)	3.05 (t, 7.4)	1.31(m)	1.71(m)	45.2 (d, 148.5)	52.9 (d, 6.8)	42.9	27.6, 27.8, 29.1, 30.4 30.6	—
NH_2	1	12	3.52 (d, 13.2)	3.22 (t, 7.7)	3.05 (t, 7.7)	1.29(m)	1.71(m)	45.4 (d, 150.1)	53.4 (d, 7.3)	43.3	28.2, 29.4, 30.9, 31.2	—
G	1	4	3.43 (d, 13.8)	3.27 (2 overlapping t)		—	1.80(m)	45.4 (d, 147.2)	51.9 (d, 7.5)	43.1	25.1, 27.4	159.3
G	1	6	3.46 (d, 14.0)	3.21 (2 overlapping t)		1.42(m)	1.74(m)	45.3 (d, 149.9)	52.9 (d, 7.5)	43.8	27.6, 27.7, 30.0	159.1
G	1	8	3.39 (d, 13.5)	3.11 (2 overlapping t)		1.32(m)	1.51(m)	45.2 (d, 149.9)	53.1 (d, 8.1)	43.8	27.6, 27.9, 30.2	159.0
G	2[h]	8	2.36(m)[j]	3.20 (2 overlapping t)		1.36(m)	1.68(m)	26.1 (d, 139.0)	51.5(s)	44.2	28.1, 28.3, 30.5, 30.6	159.3
G	1	10	3.50 (d, 13.5)	3.20 (t, 7.0)		1.31(m)	1.72(m)	45.6 (d, 146.5)	52.5 (d, 7.5)	44.1	27.9, 28.3, 28.5, 30.6 30.9, 31.0, 31.1	159.5
G	1	12	3.47 (d, 13.5)	3.21 (2 overlapping t)		1.29(m)	1.72(m)	45.6 (d, 148.5)	53.7 (d, 7.5)	44.4	28.0, 28.3, 28.6, 30.6 30.9, 31.0, 31.4	159.4

[a] All data for solutions in D_2O/D_2SO_4 (excess). [b] G = NHC(:NH)NH_2. [c] Resolved into separate triplets at 200 MHz for X = NH_2 (*n* = 4 – 12) only. [d] Appearing in two regions: $CH_2(CH_2)_{n-4}CH_2$ (lower field) and $CH_2(CH_2)_{n-4}CH_2$ (higher field). [e] δ_H 3.37 (PCH_2CH_2, overlapping dt); δ_C 44.9 (PCH_2CH_2). [f] J_{PCH} 22 Hz, J_{HCCH} 8 Hz. [g] One line of doublet only resolved. [h] δ_H 3.40 (m, unresolved). [i] Unresolved. [j] Appearing as one triplet.

TABLE II

Effect of acidification on the ^1H nmr parameters for ω-amino (**3**) and ω-guanidino- (**5**) derivatives.

X[a]	*n*	Medium[b]	PCH_2	δH $-\overset{+}{N}H_2CH_2\cdots$	$CH_2\overset{+}{X}H$	J_{PCH_2}/Hz
NH_2	6	D_2O	2.97	3.18	3.02	12.3
		D_2SO_4	3.50	3.25	3.06	14.1
G	4	D_2O	3.02	3.26		12.0
		D_2SO_4	3.43	3.27		13.8
G	6	D_2O	3.01	3.20		12.0
		D_2SO_4	3.46	3.21		14.0
G	8	D_2O	3.03	3.20		12.0
		D_2SO_4	3.39	3.11		13.5

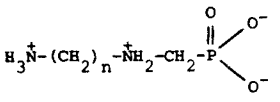
[a] G = NHC(:NH)NH_2. [b] All in D_2O with excess of D_2SO_4 where specified.

TABLE III

Effect of acidification on the ^{13}C nmr parameters for ω-amino (**3**) and ω-guanidino- (**5**) derivatives.

			δ_C			J/Hz	
X[a]	*n*	Medium[b]	PCH_2	$-\overset{+}{N}H_2CH_2\cdots$	$CH_2\overset{+}{X}H$	PC	PCNC
NH_2	8	D_2O	46.8	52.4	42.3	128.2	11.4
		D_2SO_4	45.7	52.6	42.6	146.5	7.5
NH_2	10	D_2O	48.1	52.5	42.4	127.0	6.1
		D_2SO_4	45.2	52.9	42.9	148.5	6.8
G	8	D_2O	48.0	52.5	44.1	132.2	6.8
		D_2SO_4	45.2	53.1	43.8	149.9	8.1

[a] G = NHC(:NH)NH_2. [b] All in D_2O with excess of D_2SO_4 where specified.



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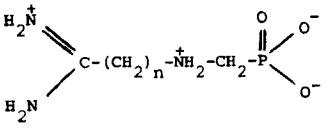

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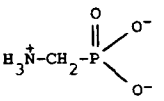

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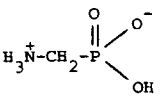

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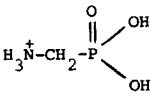

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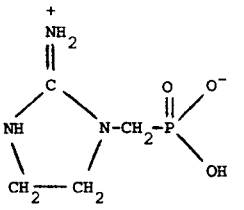


(16)

D_2SO_4 was generally the preferred medium for n.m.r. measurements in the present work since solubility was frequently improved and ^{13}C spectra in particular were better resolved. Under these conditions the region between 41 and 53 ppm revealed a characteristic pattern which was useful for purposes of fingerprinting, consisting of two doublets (J_{PC} 147–150 Hz, J_{PCNC} 7–8 Hz) and a singlet for the terminal carbon of the polymethylene chain. The chemical shift for the terminal carbon atom in the ω-guanidino compounds is 1–2 ppm upfield from that of the amino analogues and provides a useful means for identification in mixtures and for the monitoring of reactions.

The ^1H n.m.r. spectra of both the amino and guanidino compounds exhibit a PCH_2 doublet at *ca.* 3.0 ppm in D_2O (J 12 Hz) and at *ca.* 3.5 ppm in acid solution (J 14 Hz) but are not otherwise distinctive (Tables I and II). At 220 MHz, the terminal methylene groups of the polymethylene chain appear as separate triplets in the case of the ω-amino compounds but are not resolved for the guanidines. Broad overlapping triplets are obtained for all compounds at 60 or 80 MHz and under these circumstances the spectra are not markedly different in appearance from those of the diamine-chloromethanephosphonic acid salts, except that the PCH_2 signal in the latter is at slightly lower field and has a smaller coupling constant (δ_H 3.3, J 9 Hz in D_2O).

A zwitterionic structure (**16**) is also assigned to 1-phosphonomethyl-2-iminoimidazolidine. This accords with our previous structural studies of related guanidinophosphonic acids that show the imino nitrogen to be protonated.[25] The structure is also consistent with the ^{15}N n.m.r. spectrum of the iminoimidazolidine which exhibited two signals in the approximate ratio 2:1, as expected for the presence of two nitrogen atoms carrying two protons and one proton respectively. The tertiary nitrogen gave no detectable signal because of the absence of a nuclear Overhauser effect.[27] As for the guanidino derivatives discussed above, acidification had no significant effect on the carbon-13 chemical shifts of the nitrogen-bonded (ring) methylene groups, although the exocyclic methylene group adjacent to phosphorus became more shielded (with a concommitant increase in J_{PC} of *ca.* 10 Hz) as the phosphonate group was protonated and the ^{31}P signal moved downfield from 13.4 to 19.8 ppm.

Fast atom bombardment mass spectrometry gave rise to characteristic $[M + H]^+$ ions, frequently as the base peak, and provided a valuable aid in the characterisation of the zwitterionic ω-amino- and ω-guanidino-alkylaminoalkanephosphonic acids (Tables IV, V). Fragmentation occurred by a number of routes,

TABLE IV

Principal ions in the FAB mass spectra of *N*-(ω-aminoalkyl) aminoalkanephosphonic acids (**3**,**7**)[a]

Compound	*n*	$[MH]^+$ (**17**)	$[MH-82]^+$ (**18**)[b]	$[MH-94]^+$ (**19**)[c]	$[MH-99]^+$ (**20**)[d]	$[MH-111]^+$ (**21**)[e]
3	2	155/100	—	—	—	—
3	4	183/100	101/2.5	—	—	—
3	6	211/100	129/34.1	117/15.0	112/35.6	100/18.1
3	8	239/100	157/85.9	145/13.5	140/9.7	128/6.5
7	8	253/100	171/3.0	—[f]	0	—[g]
3	10	267/55.6	0	173/100	168/8.2[h]	156/27.1[i]
3	12	295/66.8	213/100	201/38.2	196/7.9[j]	184/14.2[k]

[a] Glycerol matrix. *m*/*z* (95 and above only recorded)/%. [b] P–C cleavage with loss of H_3PO_3. [c] N–C cleavage with loss of CH_3PO_3. [d] Loss of H_3PO_3 and NH_3. [e] C–N cleavage with loss of $NH_2CH_2PO_3H_2$ (or equivalent). [f] $[M-108]^+$, 145/2.9. [g] $[M-125]^+$, 128/6.2. [h] Losses of additional CH_2 groups give 154/10.4, 140/16.7, 126/19.7, 112/23.9, 98/38.4. [i] Losses of additional CH_2 groups give 142/15.8, 128/15.9, 114/15.3, 100/20.8. [j] Losses of additional CH_2 groups give 182/10.1, 168/6.2, 140/9.4, 126/9.7, 112/13.1, 98/16.5. [k] Losses of additional CH_2 groups give 170/7.6, 142/7.1, 128/7.3, 114/7.1, 100/6.8.

shown for the aminomethanephosphonic derivatives (**3**, **5**) in Scheme 6 and including the initial loss of phosphorous acid (pathway a). We have previously shown that phosphorous acid is eliminated from the MH^+ ion of simple α- and ω-amino- or α- and ω-guanidino-alkanephosphonic acids by a process of P–C_α cleavage and proton transfer.[28] In the case of the present series of doubly charged zwitterionic compounds two proton transfers are required for H_3PO_3 to be formed. These processes (not necessarily simultaneous) might be facilitated by intramolecular hydrogen–bonding of the type that has been postulated for α-aminomethanephosphonic acid (Scheme 7), although proton transfer from other sites in the molecule could also occur. For the aminoethanephosphonic types (**7**, **8**), proton transfer from the β-carbon atom is presumably involved (cf. ref. 28). Additional fragmentations occurred by simple N–C fission with the loss (for **3** or **5**) of CH_3PO_3 (Scheme 6, pathway b) and by cleavage of the alkylene chain from nitrogen, with proton transfer and the loss of $NH_2PO_3H_2$ (or of phosphorous acid followed by methyleneimine) (Scheme 6, pathway c). Analogous processes were observed for **7** and **8**, except that an additional CH_2 group was lost during cleavages at nitrogen.

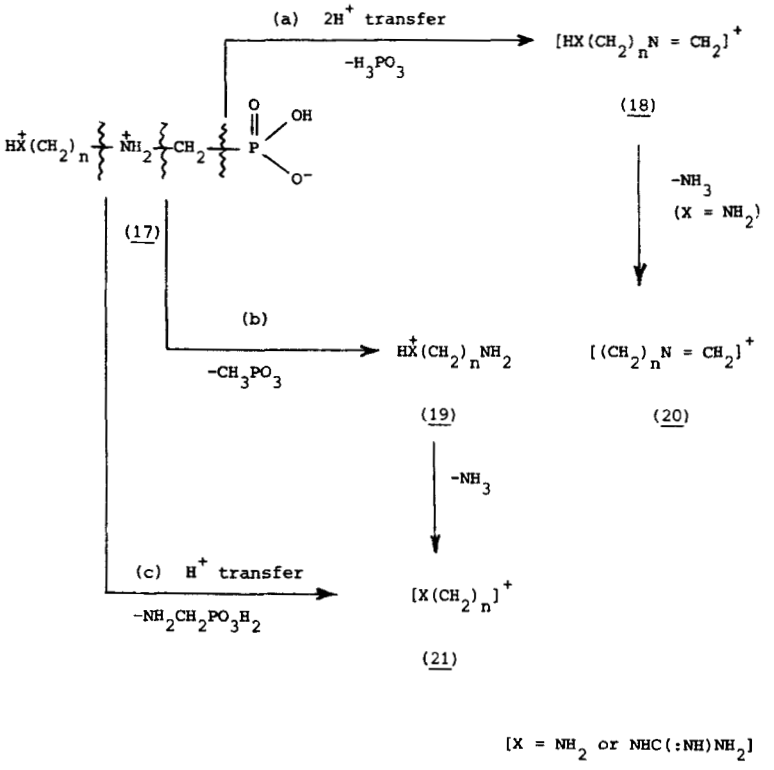
Fragmentation of the alkylene chain by carbon–carbon fission led to a series of ions separated by intervals of 14 mass units as observed for various straight-chain hydrocarbon derivatives.[29] These ions are especially clear for the guanidino derivatives [X = $NHC(:NH)NH_2$] and may be formally regarded as originating by the loss of CH_2 units from $[MH-111]^+$ (**21**), an ion that is formed (Scheme 6) by pathway c, or alternatively by pathway b followed by loss of ammonia. (The structure of $[MH-111]^+$ (**21**) is unknown and a number of isomeric forms including a cyclic structure are possible. A simple general formulation is used here for convenience). Ions resulting from carbon–carbon fission are less clear in the case of the amino compounds (X = NH_2) but are seen for the longer chain

TABLE V

Principal ions in the FAB mass spectra of *N*-(ω-guanidinoalkyl)aminoalkanephosphonic acids (**5**,**8**)[a]

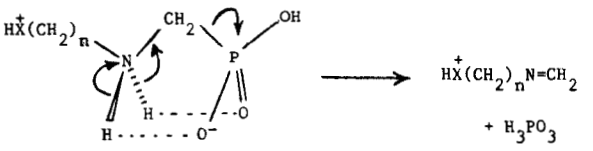
Compound	*n*	$[MH]^+$ (**17**)	$[MH-42]^+$ (**22**)[b]	$[MH-57]^+$ (**23**)[c]	$[MH-82]^+$ (**18**)[d]	$[MH-94]^+$ (**19**)[e]	$[MH-99]^+$ (**20**)[f]	$[MH-111]^+$ (**21**)[g]	$[MH-124]^+$ (**24**)[h]	$[MH-139]^+$ (**25**)[i]	$[MH-153]^+$ (**26**)[j]
5	4	225/100	0	168/4.7	143/9.5	0	126/2.4	114/12.8[k]	0	—	—
5	6	253/100	0	196/56.9	171/29.7	159/4.2	154/5.1	142/14.5[l]	129/3.2	114/74.7	100/3.1
5	8	281/100	239/4.8	224/12.6	199/48.6	187/8.1	182/7.7	170/24.8[m]	157/11.4	142/28.9	128/13.4
8	8	295/100	263/1.3	238/23.0	213/12.6	—[n]	196/3.5	—[o]	171/7.1	156/30.5	—[p]
5	10	309/100	267/56.6	252/7.6	227/37.4	215/5.4	210/5.2	198/14.5[q]	185/60.3	170/18.6	156/11.8
5	12	337/100	295/3.7	280/1.3	255/44.2	243/3.3	238/4.9	226/13.6[r]	213/4.8	198/8.7	184/6.2

[a] Glycerol matrix. *m*/*z* (95 and above only recorded)/%. [b] Loss of $CNNH_2$. [c] Loss of CH_3N_3. [d] P–C cleavage with loss of H_3PO_3. [e] N–C cleavage with loss of CH_3PO_3. [f] Loss of H_3PO_3 and NH_3. [g] C—N cleavage with loss of $NH_2CH_2PO_3H_2$ (or equivalent). [h] Loss of H_3PO_3 and $CNNH_2$. [i] Equivalent to the loss of H_3PO_3 and CH_3N_3 from MH^+ (**17**), or alternatively (for **5**) of C_2H_4 from **21**. [j] Equivalent to the loss of $CNNH_2$ or C_3H_6 from **21**. [k] Loss of CH_2 gives 100/4.6 [l] Losses of additional CH_2 groups give 128/6.4, 114/74.7, 100/3.1. [m] Losses of additional CH_2 groups give 156/13.1, 142/28.9, 128/13.4, 114/11.2, 100/14.5. [n] $[MH-108]^+$, 187/15.0. [o] $[MH-125]^+$, 170/50.6; losses of additional CH_2 groups give 156/30.5, 142/25.7, 128/26.9, 114/22.7, 100/26.3. [p] $[MH-167]^+$ 128/26.9; [q] Losses of additional CH_2 groups give 184/8.2, 170/18.6, 156/11.8, 142/8.7, 128/8.8, 114/8.6, 100/10.2. [r] Losses of additional CH_2 groups give 212/5.6, 198/8.7, 184/6.2, 170/5.9, 156/6.5, 142/7.0, 128/8.5, 114/7.9, 100/9.1.

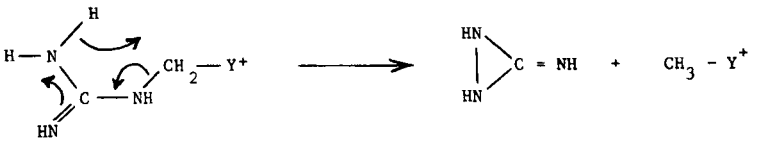


SCHEME 6

examples ($n = 10$, 12) for which two series of ions, differing by 2 mass units, are observed. One series is assumed to be formed from the $[MH\text{-}111]^+$ ion (**21**) by processes analogous to those described above. The other may arise (Scheme 6) *via* pathway a, followed by ammonia loss to give $[MH\text{-}99]^+$ (**20**) and subsequent losses of CH_2 to give $[MH\text{-}113]^+$ etc. The guanidino derivatives also showed losses corresponding to cyanamide (42 mass units) from the parent ion and from the ion at $[MH\text{-}82]^+$ which results from the initial loss of phosphorous acid (to give **22** and **24** respectively; see Table V). In addition, a peak at $[MH\text{-}57]^+$ is considered to be formed by cleavage of the guanidine group, with proton transfer, to eliminate a neutral fragment CH_3N_3 (possibly cyclic, e.g. 3-imino-1,2-diaza-cyclopropane, **27**). The $[MH\text{-}57]^+$ ion (**23**) is especially prominent for the



SCHEME 7



(27) (23)

$[Y^+ = (CH_2)_{n-1}\overset{+}{N}H_2CH_2PO_3H_2, \quad (CH_2)_{n-1}\overset{+}{N}H{=}CH_2, \text{ or}$

$(CH_2)_8NHC(:\overset{+}{N}H_2)NH_2]$

SCHEME 8

guanidino derivative (**5**) in which $n = 6$ and has also been observed as the base peak in the FAB mass spectrum of octamethylenediguanidinium sulphate.[30] Scheme 8 shows a possible fragmentation involving N–C cleavage and proton transfer from the neutral guanidine group in these cases. The formation of ions **25** and **26** (Table V) could be accounted for in several ways (see Table footnotes).

Numerous guanidine derivatives have been shown to possess microbiocidal activity[31] and several are of significance as agricultural fungicides.[32] The compounds reported here are the first examples of fungicidally active guanidinophosphonic acids. They are active against a number of pathogens of agricultural significance, including *Rhizoctonia solani, Septoria nodorum, Drechslera sativa, Fusarium avenaceum,* and *Piricularia oryzae.*[7] Optimum activity occurred for $n = 10$. Fungicidal activity was also recorded for the amino analogues[7] and for certain examples of the 1:1 salts formed between the diamines and chloromethanephosphonic acid.[33] A number of the guanidino compounds showed activity against *Candida albicans* and *Erwinia amylovora,* but not against *Trichophyton mentagrophytes.*[34]

EXPERIMENTAL

Starting Materials. Chloromethanephosphonic acid was obtained by the hydrolysis[35] of chloromethanephosphonyl dichloride (prepared as described)[36] and was dried over P_2O_5 to give fine white crystals, m.p. 89°C (lit.[37] 89–90°C), ^{1}H NMR (DMSO-d_6) δ 3.6 (2H, d, PCH_2, $J_{PCH} = 10$ Hz), 11.4 (2H, s, OH); ^{1}H NMR (D_2O) δ 3.64 (d, PCH_2, $J_{PCH} = 10$ Hz); ^{13}C NMR (D_2O) δ 37.2 (d, PCH_2, $J_{PC} = 159.6$ Hz); ^{31}P NMR (D_2O) δ 17.2 (t, $J_{HCP} = 9.9$ Hz). *O,O*-Diethyl 2-bromoethanephosphonate was prepared as described,[13] b.p. 78°C at 0.15 mmHg (lit.[13] 75°C at 1 mmHg), ^{1}H NMR ($CDCl_3$) δ 1.34 (6H, t, CH_3, $J_{HCCH} = 7.1$ Hz), 2.2–2.6 (2H, m, PCH_2), 3.4–3.7 (2H, m, CH_2Br), 4.13 (4H, m, $POCH_2$); ^{13}C NMR ($CDCl_3$) δ 1.65 (d, CH_3, $J_{POCC} = 5.9$ Hz), 23.9 (s, CH_2Br), 31.0 (d, PCH_2, $J_{PC} = 135.3$ Hz), 62.0 (d, $POCH_2$, $J_{POC} = 6.6$ Hz); ^{31}P NMR ($CDCl_3$) δ 23.5. α,ω-Diaminoalkanes and other reagents were obtained commercially.

Spectroscopy. N.m.r. spectra were recorded on Perkin-Elmer R12B (^{1}H, 60 MHz), Perkin-Elmer R34 (^{1}H, 200 MHz), Bruker WP80 (^{1}H, 80 MHz; ^{13}C, 20.12 MHz; ^{31}P, 32.4 MHz), and Bruker WH 180 WB (^{15}N, 18.24 MHz) instruments. Chemical shifts (downfield positive) are relative to TSP (in

D_2O) or TMS (in $CDCl_3$) for ^1H and ^{13}C spectra, 85% H_3PO_4 for ^{31}P spectra, and nitromethane for ^{15}N spectra. FAB mass spectra were obtained on a VG Analytical ZAB-1F double-focussing mass spectrometer fitted with an ion gun (Ion-Tech Ltd.) operating at 8 kV and providing a primary beam of xenon atoms.

General Preparative Procedure for 1:1-*Salts of Diamines and Chloromethanephosphonic Acid* (**6**). The acid (**2**) (2.5 g) and diamine (**1**) (5 mol. equiv.) were separately dissolved in dry pyridine (25–50 cm^3) and the solutions were mixed when the 1:1-salt precipitated. No further reaction occurred on heating. The salt was filtered off, washed with ethanol, and recrystallised from water and ethanol to give the product in each case as follows.

Tetramethylenediammonium chloromethanephosphonate (**6**, $n = 4$): m.p. 215°C, ^1H NMR (D_2O) δ 3.28 (d, 2H, PCH_2, $J_{PCH} = 9$ Hz), 3.0 (m, 4H, CH_2NH_3), 1.76 [m, 4H, $(CH_2)_2$]; Found: C, 27.1; H, 7.6; N, 12.8; P, 13.9. $C_5H_{16}ClN_2O_3P$ requires: C, 27.5; H, 7.3; N, 12. 8; P, 14.2%.

Hexamethylenediammonium chloromethanephosphonate (**6**, $n = 6$): m.p. 212–214°C, ^1H NMR (D_2O) δ 3.28 (d, 2H, PCH_2, $J_{PCH} = 9$ Hz), 2.92 (m, 4H, CH_2NH_3), 1.45 [m, 8H, $(CH_2)_4$]; Found: C, 33.7; H, 9.0; N, 11.8; P, 12.1. $C_7H_{20}ClN_2O_3P$ requires: C, 34.1; H, 8.1; N, 11.4; P, 12.6%.

Octamethylenediammonium chloromethanephosphonate (**6**, $n = 8$): m.p. 210–211°C, ^1H NMR (D_2O) δ 3.26 (d, 2H, PCH_2, $J_{PCH} = 9$ Hz), 2.88 (m, 4H, CH_2NH_3), 1.55 [m, 12H, $(CH_2)_6$]; ^{13}C NMR (D_2O/D_2SO_4) δ 28.2, 29.5, 30.7 [singlets, $(CH_2)_6$], 41.0 (d, PCH_2, $J_{PC} = 137.3$ Hz), 42.5 (s, CH_2NH_3); ^{31}P NMR (D_2O/D_2SO_4) δ 12.1; Found: C, 39.5; H, 8.7; N, 10.2; P, 11.2. $C_9H_{24}ClN_2O_3P$ requires: 39.3; H, 8.7; N, 10.2; P, 11.3%.

Dodecamethylenediammonium chloromethanephosphonate (**6**, $n = 12$): m.p. 188–190°C, ^1H NMR (D_2O) δ 3.28 (d, 2H, PCH_2, $J_{PCH} = 9$ Hz), 2.98 (m, 4H, CH_2NH_3), 1.30 [m, 20H, $(CH_2)_{10}$]; Found: C, 46.3; H, 9.7; N, 8.4; P, 8.5. $C_{13}H_{32}ClN_2O_3P$ requires: C, 47.2; H, 9.7; N, 8.5; P, 9.4%.

General Preparative Procedure for N-(ω-Aminoalkyl)aminomethanephosphonic acids (**3**). The diamine (**1**) (5 mol excess) and chloromethanephosphonic acid (**2**) were dissolved in water (100–200 cm^3) and heated under reflux (20 h). Water (and for $n = 2$ only, excess of diamine) were removed by rotary evaporation under reduced pressure (100°C). The crude product was then precipitated ($n = 2$) by dissolving the viscous residue in water (20 cm^3) and adding ethanol (1200 cm^3), or ($n = 4$) by adding acetone (110 cm^3). Solid products were obtained directly in other cases ($n = 6$–12). Excess of diamine and its hydrochloride were then dissolved by heating under reflux with ethanol (200–300 cm^3). The remaining solid was filtered off, washed with ethanol, recrystallised from water and ethanol, washed (methanol or ethanol), and dried *in vacuo* at 60–70°C (3h) to give the crystalline monohydrate in each case as follows.

N-(2-Aminoethyl)aminomethanephosphonic acid (**3**, $n = 2$) was obtained from **1** ($n = 2$) (41.4 g) and **2** (15.4 g) in 63.8% yield as the monohydrate: m.p. 248–250°C (lit.[12] 251–253°C), ^{31}P NMR (D_2O) δ 7.9 (t, $J_{HCP} = 11.8$ Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 12.7 (t, $J_{HCP} = 14.0$ Hz), ^{15}N NMR (H_2O/D_2O) δ −348.0, −354.4, FAB MS: m/z 225 (MH^+, 100%); Found: C, 20.3; H, 7.2; N, 15.7. Calcd. for $C_3H_{13}N_2O_4P$: C, 20.9; H, 7.6; N, 16.3%.

N-(4-Aminobutyl)aminomethanephosphonic acid (**3**, $n = 4$) was obtained from **1** ($n = 4$) (30.0 g) and **2** (7.0 g) in 57.8% yield as the monohydrate: m.p. 258°C, ^{31}P NMR (D_2O) δ 7.2 (t, $J_{HCP} = 11.8$ Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 13.6 (t, $J_{HCP} = 14.0$ Hz), FAB MS: m/z 183 (MH^+, 100%); Found: C, 29.8; H, 8.3; N, 13.0. $C_5H_{17}N_2O_4P$ requires: C, 30.0; H, 8.5; N, 14.0%.

N-(6-Aminohexyl)aminomethanephosphonic acid (**3**, $n = 6$) was obtained from **1** ($n = 6$) (34.8 g) and **2** (6.5 g) in 54.6% yield as the monohydrate: m.p. 235°C, ^{31}P NMR (D_2O) δ 7.6 (t, $J_{HCP} = 11.4$ Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 14.1 (t, $J_{HCP} = 14.3$ Hz), FAB MS: m/z 211 (MH^+, 100%); Found: C, 36.1; H, 9.3; N, 12.2. $C_7H_{21}N_2O_4P$ requires: C, 36.8; H, 9.2; N, 12.3%.

N-(8-Amino-octyl)aminomethanephosphonic acid (**3**, $n = 8$) was obtained from **1** ($n = 8$) (50.0 g) and **2** (7.5 g) in 64.1% yield as the monohydrate: m.p. 242°C, ^{31}P NMR (D_2O) δ 8.7 (t, $J_{HCP} = 11.4$ Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 13.5 (t, $J_{HCP} = 13.8$ Hz), FAB MS: m/z 239 (MH^+, 100%); Found: C, 42.0; H, 9.3; N, 11.1 $C_9H_{25}N_2O_4P$ requires: C, 42.2; H, 9.8; N, 11.0%.

N-(10-Aminodecyl)aminomethanephosphonic acid (**3**, $n = 10$) was obtained from **1** ($n = 10$) (44.0 g) and **2** (5.5 g) in 61.8% yield as the monohydrate: m.p. 238°C, ^{31}P NMR (D_2O) δ 7.4 (t,

J_{HCP} = 11.8 Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 14.2 (t, J_{HCP} = 14.0 Hz), FAB MS: m/z 267 (MH^+, 87%); Found: C, 46.4; H, 9.6; N, 9.3. $C_{11}H_{29}N_2O_4P$ requires: C, 46.5; H, 10.2; N, 9.9%.

N-(12-Aminododecyl)aminomethanephosphonic acid (**3**, $n = 12$) was obtained from **1** ($n = 12$) (100.0 g) and **2** (15.1 g) in 51.8% yield as the monohydrate: m.p. 234°C, ^{31}P NMR (D_2O) δ 7.4 (t, J_{HCP} = 11.2 Hz) ^{31}P NMR (D_2O/D_2SO_4) δ 14.8 (t, J_{HCP} = 14.0 Hz), FAB MS: m/z 295 (MH^+, 67%); Found: C, 49.9; H, 10.0. N, 9.0. $C_{13}H_{33}N_2O_4P$ requires: C, 50.0; H, 10.6; N, 9.0%.

Preparation of N-(ω-aminooctyl)aminoethanephosphonic acid (**7**, $n = 8$). Diethyl 2-bromoethanephosphonate (15.3 g, 62.4 mmol) and 1,8-diaminooctane (54.0 g, 375 mmol) were heated under reflux (5 h) in water (250 cm^3). Volatiles were removed under reduced pressure and the excess of diamine (*ca.* 35 g) was removed by distillation (b.p. 62–3°C at 0.2 mmHg). The glassy residue was heated under reflux (8 h) with concentrated hydrochloric acid (280 cm^3) and the solution was then freed of water and other volatile materials by rotary evaporation. The oily residue was dissolved in methanol and an excess of propylene oxide added to give the product which was recrystallised as described above to give the monohydrate (35.0% yield): m.p. 210°C, ^{31}P NMR (D_2O) δ 18.4, ^{31}P NMR (D_2O/D_2SO_4) δ 27.9, FAB MS: m/z 253 (MH^+, 100%); Found: C, 43.9; H, 9.4; N, 9.8. $C_{10}H_{27}N_2O_4P$ requires: C, 44.4; H, 10.0; N, 10.4%.

General Preparative Procedure for N-(ω-Guanidinoalkyl)aminoalkanephosphonic acids (**5**, **8**). The amino compound (**3** or **7**) and *S*-methylisothiouronium chloride (**4**) (2 mol. equiv.) were dissolved in water (50–100 cm^3) in the presence of sodium or potassium hydroxide (4–5 mol. equiv.). The solution was heated at 60–90°C (4 h), cooled, and then acidified to pH 1 (HCl). Water was removed by rotary evaporation under reduced pressure (100°C) and methanol (50–100 cm^3) was added to the residual oil. Sodium (or potassium) chloride was removed by filtration and propylene oxide was added in excess to precipitate the free guanidinophosphonic acid. The acid was dissolved in the minimum of cold water and acetone was added until a faint cloudiness appeared. A little water was added to clear the solution which was then stored at 4°C for several days when crystallisation ensued. The product was filtered off, washed with acetone and dried *in vacuo* at 60°C (3 h) to give the crystalline dihydrate in each case as follows.

N-(4-Guanidinobutyl)aminomethanephosphonic acid (**5**, $n = 4$) was obtained from **3** monohydrate ($n = 4$) (3.8 g) and **4** (4.8 g) in 63.1% yield as the dihydrate: m.p. 160–161°C, ^{31}P NMR (D_2O) δ 7.8 (t, J_{HCP} = 11.8 Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 13.3 (t, J_{HCP} = 13.3 Hz), FAB MS: m/z 225 (MH^+, 100%); Found: C, 27.7; H, 7.9; N, 21.0; P, 11.2. $C_6H_{19}N_4O_4P$ requires: C, 27.7; H, 8.1; N, 21.5; P, 11.9%.

N-(6-Guanidinohexyl)aminomethanephosphonic acid (**5**, $n = 6$) was obtained from **3** monohydrate ($n = 6$) (6.1 g) and **4** (6.3 g) in 59.5% yield as the dihydrate: m.p. 182°C, ^{31}P NMR (D_2O/D_2SO_4) δ 14.6 (t, J_{HCP} = 14.0 Hz), FAB MS: m/z 253 (MH^+, 100%); Found: C, 33.5; H, 8.4; N, 19.8; P, 10.8. $C_8H_{23}N_4O_4P$ requires: C, 33.3; H, 8.7; N, 19.4; P, 10.8%.

N-(8-Guanidino-octyl)aminomethanephosphonic acid (**5**, $n = 8$) was obtained from **3** monohydrate ($n = 8$) (5.6 g) and **4** (5.5 g) in 60.0% yield as the dihydrate: m.p. 171°C, ^{31}P NMR (D_2O) δ 8.0, ^{31}P NMR (D_2O/D_2SO_4) δ 13.0 (t, J_{HCP} = 13.6 Hz), FAB MS: m/z 281 (MH^+, 100%); Found: C, 38.1; H, 9.0; N, 17.8; P, 9.7. $C_{10}H_{27}N_4O_4P$ requires: C, 38.0; H, 9.2; N, 17.7; P, 9.8%.

N-(8-Guanidino-ocytl)aminoethanephosphonic acid (**8**, $n = 8$) was obtained from **7** monohydrate ($n = 8$) (4.0 g) and **4** (3.8 g) in 58.4% yield as the dihydrate: m.p. 108°, ^{31}P NMR (D_2O) δ 18.0, ^{31}P NMR (D_2O/D_2SO_4) δ 26.6, FAB MS: m/z 295 (MH^+, 100%); Found: C, 40.3; H, 8.2; N, 17.0. $C_{11}H_{29}N_4O_4P$ requires: C, 40.0; H, 8.2; N, 17.0%.

N-(10-Guanidinodecyl)aminomethanephosphonic acid (**5**, $n = 10$) was obtained from **3** monohydrate ($n = 10$) (4.1 g) and **4** (3.7 g) in 80.7% yield as the dihydrate: m.p. 133–134°C, ^{31}P NMR (D_2O) δ 8.8 (t, J_{HCP} = 10.7 Hz), ^{31}P NMR (D_2O/D_2SO_4) δ 12.9 (t, J_{HCP} = 13.6 Hz), FAB MS: m/z 309 (MH^+, 100%); Found: C, 42.2; H, 9.2; N, 15.8; P, 8.3. $C_{12}H_{31}N_4O_4P$ requires: C, 41.9; H, 9.6; N, 16.2; P, 9.0%.

N-(12-Guanidinododecyl)aminomethanephosphonic acid (**5**, $n = 12$) was obtained from **3** monohydrate ($n = 12$) (2.5 g) and **4** (2.0 g) in 66.7% yield as the dihydrate: m.p. 129–130°C, ^{31}P NMR (D_2O) δ 8.6, ^{31}P NMR (D_2O/D_2SO_4) δ 15.1 (t, J_{HCP} = 13.2 Hz), FAB MS: m/z 337 (MH^+, 100%); Found: C, 45.1; H, 9.4; N, 15.3; P, 8.1.$C_{14}H_{35}N_4O_4P$ requires: C, 45.2; H, 9.9; N, 15.0; P, 8.3%.

Formation of 1-*phosphonomethyl-2-iminoimidazolidine* (**9**). *N*-(2-Aminoethyl)aminomethanephosphonic acid (**3**, $n = 2$) as the monohydrate (3.3 g, 19.2 mmol), *S*-methylisothiouronium chloride (5.5 g, 43.5 mmol) and potassium hydroxide (4.8 g) were heated at 60°C (4 h) in water (15 cm^3). Isolation as described above for **5** or **8** gave a product after propylene oxide treatment that was washed with methanol, recrystallised from water and methanol, and dried *in vacuo* at 70°C (3 h) to give fine white crystals of **9** (1.7 g, 49.5% yield): m.p. 345–349°C, ^{1}H NMR (D_2O) δ 3.48 (d, PCH_2, $J_{HCP} = 10.8$ Hz), 3.75 [m, $(CH_2)_2$], ^{1}H NMR (D_2SO_4) δ 3.55 (d, PCH_2, J_{PCH} 10.7 Hz), 3.66–3.84 [m, $(CH_2)_2$], ^{13}C NMR (D_2O) δ 43.7 (s, CH_2NH), 46.0 (d, PCH_2, $J_{PC} = 147.4$ Hz), 52.5 (s, NCH_2), 162.0 [d, NHC(:NH)NH_2, $J_{PCNC} = 2.2$ Hz]; ^{13}C NMR (D_2SO_4) δ 43.9 (s, CH_2NH), 44.4 (d, PCH_2, $J_{PC} =$ 157.3 Hz), 52.5 (s, NCH_2), 160.8 [d, NHC(:NH)NH_2, $J_{PCNC} = 2.0$ Hz); ^{31}P NMR (D_2O) δ 13.4 (t, $J_{HCP} = 10.5$ Hz); ^{31}P NMR (D_2SO_4) δ 19.8; ^{15}N NMR (H_2O/D_2O) δ −306.2, −318.6 (approx. 2:1 ratio), FAB MS: m/z 180 (MH^+, 100%); Found: N, 23.4. $C_4H_{10}O_3P$ requires: N, 23.5%.

Formation of N-(12-*ureidododecyl)aminomethanephosphonic acid* (**10**). The ω-amino compound (**3**, $n = 12$) as the monohydrate (6.9 g, 22.1 mmol), cyanamide (7.5 g, 178.6 mmol) and potassium hydroxide (3.7 g) in water (200 cm^3) were heated under reflux (20 h). The solution was cooled, acidified to pH 1 (HCl), and concentrated by rotary evaporation to give an oily residue which was dissolved in methanol (100 cm^3) and treated with propylene oxide in excess. The insoluble product was washed successively with water, ethanol, boiling water, and ethanol, and dried *in vacuo* at 60°C to give **10** monohydrate (2.7 g, 34.4%) as a fine white crystalline solid: m.p. 129–130°C, ^{13}C NMR (D_2O/D_2SO_4) δ 28.0, 28.3, 30.4, 30.9, 31.4 [singlets, $NHCH_2(CH_2)_{10}$], 44.3 (s, $CH_2NHCONH_2$), 45.2 (d, PCH_2, $J_{PC} = 152.6$ Hz), 53.7 (d, $NHCH_2$, $J_{PCNC} = 10.2$ Hz), 162.1 (s, $NHCONH_2$). FAB MS m/z 338 (MH^+, 100%); Found: C, 47.0; H, 9.6; N, 11.9. $C_{14}H_{34}N_3O_5P$ requires: C, 47.3; H, 9.6; N, 11.8%.

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REFERENCES

1. D. Redmore, *Topics in Phosphorus Chemistry*, Vol. 8, eds. E. J. Griffith and M. Grayson, Interscience, New York, pp. 515–85 (1976).
2. K. Baylis, C. D. Campbell and J. G. Dingwall, *J. Chem. Soc., Perkin Trans. 2*, 2845 (1984).
3. J. G. Allen, F. R. Atherton, M. J. Hall, C. H. Hassall, S. W. Holmes, R. W. Lambert, L. J. Nisbet and P. S. Ringrose, *Nature*, **272,** 56 (1978); F. R. Atherton, M. J. Hall, C. H. Hassall, R. W. Lambert and P. S. Ringrose (to Hoffmann–La Roche Inc.) *Ger. Offen.* 2,602,193, 29 July, (1976), *Chem. Abstr.*, **85,** 143525r (1976); *idem, Ger. Offen.* **2**, 721,760, 1 Dec. (1977), *Chem. Abstr.*, **88,** 13699z (1978); J. G. Dingwall, E. K. Baylis and C. D. Campbell, *Ger. Offen.* 2,722,162 1 Dec (1977), *Chem. Abstr.*, **88,** 10559j (1978).
4. J. Oleksyszyn, R. Tyka and P. Mastalerz, *Synthesis*, 571 (1977); *idem, Pol. J. Chem.*, **53,** 2129 (1979).
5. G. L. Rowley, A. L. Greenleaf and G. L. Kenyon, *J. Am. Chem. Soc.*, **93,** 5542 (1971).
6. E. Moreaud, A. M. Lacoste and E. C. R. Neuzil, *Hebd. Seances Acad. Sci., Ser. D.*, **280,** 1309 (1975); E. De Tinguy-Moreaud, B. Bioulac, J. D. Vincent and E. Neuzil, *Gen. Pharmacol.*, **11,** 513 (1980); E. De Tinguy-Moreaud, B. Bioulac and E. Neuzil, *Biochem. Soc. Trans.*, **9,** 246 (1981).
7. D. G. Cameron, H. R. Hudson, I. Lagerlund, M. Pianka and A. Stroömberg (to KenoGard AB), U.S. Patent 4,600,429, 15 July (1986), *cf. PCI Int. Appl. WO* 85 00,038, 3 Jan (1985), *Chem. Abstr.*, **103,** 22780b (1985); D. G. Cameron, H. R. Hudson, I. A. O. Ojo and M. Pianka, Poster **C-19,** *X Internat. Conf. Phosphorus Chem.*, Bonn, 31 August–6 September (1986), *Phosphorus Sulfur* Vol. **38,** (1988).
8. G. Schwarzenbach, H. Ackermann and P. Ruckstuhl, *Helv. Chim. Acta*, **32,** 1175 (1949).
9. F. C. Bersworth, U.S. Patent, 2,599,807, 10 June (1952), *Chem. Abstr.*, **47,** 4360i (1953); *idem,* U.S. Patent 2,609,390, *Chem. Abstr.*, **47,** 6437a (1953).

10. W. M. Ramsey and C. Kezerian (to Victor Chemical Works), U.S. Patent 2,917,528, 15 Dec, (1959), *Chem. Abstr.*, **54,** 24399i (1960).
11. E. Uhlg and W. Achilles, *J. prakt. Chem.*, **311,** 529 (1969).
12. K. Moedritzer and R. R. Irani, *J. Org. Chem.*, **31,** 1603 (1966).
13. G. M. Kosolapoff, *J. Am. Chem. Soc.*, **70,** 1971 (1948).
14. D. R. Peck and D. Hudson (to Albright and Wilson Mfg. Ltd.), Br. Patent 1,230,121, 26 Apr (1968), *Chem. Abstr.*, **75,** 36342a (1971); H. Zondler (to Ciba-Geigy A.-G.), *Ger. Offen.* 2,435,438, 6 Feb (1975), *Chem. Abstr.*, **83,** 10386h (1975); H. J.. Koetzsch, C. D. Seiler and H. J. Vahlensieck (to Dynamit Nobel A.-G.), *Ger. Offen.* 2,344,197, 27 Mar. (1975), *Chem. Abstr.*, **83,** 44864c (1975); V. Oakes, R. E. Hutton and D. F. W. Cross (to Interstab Ltd.), *Ger. Offen.* 2,212,390, 21 Sep. (1972), *Chem. Abstr.*, **78,** 3086v (1973); W. J. Rabourn and E. E. Jones (to Dow Chemical Co.), U.S. Patent 3,322,863, 30 May (1967), *Chem. Abstr.*, **67,** 54261n (1967).
15. J. A. Gallaghan and R. Evans (to U.S. Dept. of Navy), U.S. Patent 2,994,695 (1961) (Appl. 25 Aug. 1955), *Chem. Abstr.*, **56,** 2461f (1962).
16. C. D. Adams and R. Schlatter (to E. I. Du Pont de Nemours and Co.), S. A. Patent 67,06,589, 8 Mar (1968), *Chem. Abstr.*, **70,** 57837c (1969).
17. G. G. Badcock and W. J. C. Dyke (to Evans Medical Ltd.), Br. Patent 1,114,115, 15 May (1968).
18. J. H. Paden and A. F. McLean (to American Cyanamid Co.), U.S. Patent 2,425,341, 12 Aug. (1947), *Chem. Abstr.*, **41,** 7414f (1947); J. A. C. Björklund and A. R. Reuterhäll (to KemaNord AB), *Ger. Offen.* 26 47 915, 5 May (1977); *Chem. Abstr.*, **87,** 17304w (1977).
19. C. Nyman, C. Murbach and G. Millard, *J. Am. Chem. Soc.*, **77,** 4194 (1955); J. R. Van Wazer, *Phosphorus and its Compounds,* Vol. 1, Interscience, New York, p. 360 (1958); R. Kluger, P. Wasserstein and K. Nakaoto, *J. Am. Chem. Soc.*, **97,** 4298 (1975); M. Wozniak and G. Nowogrocki, *Talanta,* **25,** 633 (1978); *idem. Bull. Soc. chim. France,* 153 (1978).
20. D. D. Perrin, *Dissociation Constants of Organic Bases in Aqueous Solution*; IUPAC Analytical Chemistry Division, Commission on Electroanalytical Chemistry, Butterworths, London, pp. 13–51 (1965).
21. Ref. 20, pp. 444–446.
22. T. G. Appleton, J. R. Hall, A. D. Harris, H. A. Kimlin and I. J. McMahon, *Aust. J. Chem.*, **37,** 1833 (1984).
23. G. C. Levy, R. L. Lichter and G. L. Nelson, *Carbon-13 Nuclear Magnetic Resonance Spectroscopy,* 2nd edition, Wiley, New York, p. 67 (1980).
24. J. E. Sarneski, H. L. Surprenant, F. K. Molen and C. N. Reilly, *Anal. Chem.*, **47,** 2116 (1975).
25. G. J. Adetunji, D. G. Cameron, K. Henrick, H. R. Hudson, M. McPartlin and M. Pianka, *Proc. IX Internat. Conf. Phosphorus Chem.* Nice, 5–9 Sep. (1983), eds. J. G. Riess, F. Mathey, D. Robert and R. Wolf, *Phosphorus Sulfur,* **18,** 481 (1983).
26. Y. Okaya, *Acta. Cryst.*, **20,** 712 (1966); J. J. Daly and P. J. Wheatley, *J. Chem. Soc. (A),* 212 (1967).
27. G. J. Martin, M. L. Martin and J.-P. Gousenard, *^{15}N NMR Spectroscopy,* Springer, Heidelberg, (1981).
28. D. G. Cameron, C. S. Creaser, H. R. Hudson, M. Pianka and H. Wright, *Chem. and Ind.*, 774 (1984).
29. F. McLafferty, *Interpretation of Mass Spectra,* 2nd edition, Benjamin, Mass, p. 98 (1973).
30. D. G. Cameron, PhD thesis (CNAA), Oct, 1983.
31. H. R. Hudson, I. A. O. Ojo and M. Pianka, *Internat. Pest Control,* **28,** 148 (1986).
32. C. R. Worthing and S. B. Walker, eds., The Pesticide Manual, A World Compendium, 7th edition, The British Crop Protection Council, Croydon, pp. 55, 229, 305 (1983).
33. D. G. Cameron, H. R. Hudson, I. A. O. Ojo and M. Pianka, unpublished.
34. B. N. Kliger, personal communication.
35. R. A. B. Bannard, J. R. Gilpin, G. R. Vavasour and A. F. McKay, *Can. J. Chem.*, **31,** 976 (1953).
36. M. I. Kabachnik and E. S. Shepleva, *Izvest. Akad. Nauk S.S.S.R., Otdel Khim. Nauk,* 185 (1951); P. C. Crofts and G. M. Kosolapoff, *J. Am. Chem. Soc.*, **75,** 5738 (1953).
37. A. M. Kinnear and F. A. Perrin, *J. Chem. Soc.*, 3437 (1952).