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THE MASS SPECTRA OF ALKYL 2-DIETHYLPHOSPHONOALKANOATES

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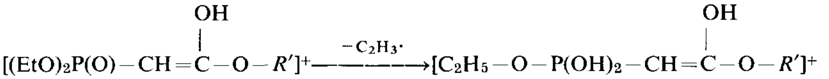
The mass spectra of five alkyl 2-diethylphosphonoalkanoates $[(EtO)_2P(O)-CH(CH_2-R)-CO_2R'$, where $R' = CH_3$ or C_2H_5, and $R = H$, n-C_7H_{15}, n-$C_{11}H_{23}$, and $-(CH_2)_5-CO_2CH_3]$ were investigated. A unique, prominent fragment $[M-R]^+$ is proposed to result from fission of the bond γ-to both the carboxylic ester and the phosphonate ester. Loss of a $C_2H_3^{\cdot}$ radical from the McLafferty rearrangement fragment ion

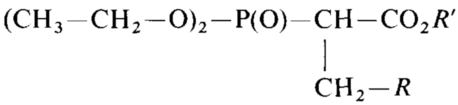


$$[(EtO)_2P(O)-CH=\overset{\overset{\displaystyle OH}{|}}{C}-O-R']^+ \xrightarrow{-C_2H_3^{\cdot}} [C_2H_5-O-P(OH)_2-CH=\overset{\overset{\displaystyle OH}{|}}{C}-O-R']^+$$

was an important secondary fragmentation process, although loss of this radical from the molecular ion itself was not a very significant process. The NMR spectra of these compounds are discussed.

Introduction

Although series of a variety of organic phosphorus compounds including alkyl and aryl phosphines[1,2]), phosphites[3]), phosphates[4,5,6]) and several phosphonic acid derivatives[7–11]) have recently been investigated, a study of the mass spectra of a partial homologous series of methyl and/or ethyl 2-diethylphosphonoalkanoates



$$(CH_3-CH_2-O)_2-P(O)-\underset{\underset{\displaystyle CH_2-R}{|}}{CH}-CO_2R'$$

has not been described. It was of interest to examine (a) the relative preference for cleavage of a bond to a phosphonate ester versus a carboxylic ester, (b) McLafferty rearrangement processes concerning transfer of γ-hydrogen atoms (when available, depending on R) to either or both the $C=O$ and/or $P=O$ oxygen atoms, and (c) preference for cleavage α, β, or γ-to these two functionalities.

Trialkyl phosphates[4–6]) such as triethyl phosphate show a rearrangement-fragmentation sequence analogous to that observed with alkyl phosphites and alkyl phosphonates. The first step is elimination of one alkyl substituent

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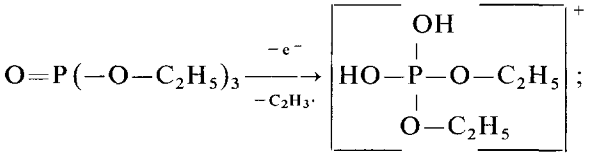
with back-transfer of two hydrogen atoms:



$$O{=}P(-O-C_2H_5)_3 \xrightarrow[-C_2H_3\cdot]{-e^-} \left[\begin{array}{c} OH \\ | \\ HO-P-O-C_2H_5 \\ | \\ O-C_2H_5 \end{array}\right]^+ ;$$

this process yields the base peak in this compound. Consecutive eliminations of two ethylene molecules then follow from this primary fragmentation ion to give significant secondary and tertiary fragmentation ions. The importance of these fragmentation modes in alkyl 2-phosphonoalkanoates was studied.

Experimental

Mass spectra were determined with a Perkin Elmer Hitachi RMU 6E single focusing mass spectrometer coupled with a gas chromatographic inlet system. The helium separator was maintained at 300 °C as was the ion source and the heated transfer line from the GLC. The ionizing current was 55 μa. Spectra were recorded in 4–10 seconds to m/e 450 or 600, according to the compound analyzed, at the apex of the GLC peak (1–50 μg of material) as determined by the continuous record produced by the total ion monitor. The Varian Aerograph Series 1200 gas chromatograph employed a 4 ft $\times \frac{1}{8}$ in. stainless steel column packed with 3% SE–30 coated on 60–80 mesh acid-washed Chromosorb W, with a flow rate of helium of 25 ml/min. Approximately 80–85% of the GLC effluent was diverted to the mass spectrometer. Elution of individual compounds was achieved by programming the column temperature from 150° to 250 °C or from 200 °C to 340 °C at 10°/min depending upon the compound analyzed. Injector temperature was at 300 °C, and detector at 350 °C. NMR spectra were obtained on a Varian Associates Model A–60 instrument. Samples of 50–100 mg were run in $DCCl_3$ with TMS added as an internal reference. Melting and boiling points were uncorrected. Microanalyses were performed by the Clark Microanalytical Laboratories, Urbana, Illinois. Barber Colman Model 10 and Beckman GC–5 gas chromatographs were employed for analytical work. Both instruments were equipped with programmable column baths and flame ionization detectors.

Triethyl 2-phosphonotetradecanoate (II) was prepared by the Michaelis-Arbuzov reaction between triethyl phosphite and ethyl 2-bromotetradecanoate according to the procedure of Wolinsky and Erickson[18]). Fractional distillation afforded 55% yield of product *bp* 205–210 °C/2.0 mm; $n_D^{20°}$ 1.4495. IR showed 1740 cm^{-1} (ester $C{=}O$), 1265 cm^{-1} ($P{=}O$), and 1163 cm^{-1} ($P-O-C_2H_5$). PNMR showed τ5.84 [complicated resonance for 6 H from a quartet for 2 H of $-CO_2C\underline{H}_2-CH_3$ overlapping a doublet of quartets ($J_{PH_2} \simeq 8$

cps and $J_{H_2H_1}=7.0$ cps, respectively) for 4 H of $(\overset{1}{C\underline{H}_3}-\overset{2}{C\underline{H}_2}-O-)_2-P(O)-]$, 7.11 (triplet of doublets $J_{H_3H_4}=7.0$ cps and $J_{PH_3}=21.6$ cps, respectively, for 1 methinyl H α-to both the carboxylic ester and the phosphonate ester $\rangle P(O)-\underset{|}{\overset{3}{C\underline{H}}}-CH_2-$), 8.14 (*m*, 2, $\rangle P(O)-\underset{\underset{|}{C\underline{H}_2}}{\underset{|}{CH}}-CO_2Et$), 8.77 [t, 6, $(C\underline{H}_3-CH_2-O-)_2P(O)-$; and *t*, 3, $CO_2CH_2C\underline{H}_3$], 8.73 [*s*, 20, $-(C\underline{H}_2)_{10}-$], and 9.13 (*t*, 3, $-CH_3$). Mass, highest, $392=M^+$; $347=[M-45]^+$.

Anal. Calcd. for $C_{20}H_{41}O_5P$: C, 61.20%; H, 10.53%; P, 7.90%. Found: C, 61.27%; H, 10.42%; P, 7.82%.

Triethyl 2-phosphonopropionate (I). 85% yield based on ethyl 2-bromopropionate; *bp* 142–144 °C/8.5 mm; $n_D^{20°}$ 1.4312. IR showed 1737 cm^{-1} (ester C=O), 1260 cm^{-1} (P=O), and 1165 cm^{-1} ($P-O-C_2H_5$). Mass, highest, $238=M^+$.

Anal. Calcd. for $C_9H_{19}O_5P$: C, 45.38%; H, 8.04%; P, 13.00%. Found C, 45.43%; H, 7.98%; P, 13.19%.

Methyl 2-diethylphosphonodecanoate (IV) was prepared by the Michaelis-Arbuzov reaction between triethyl phosphite and methyl 2-bromodecanoate [prepared by α-bromination of decanoyl chloride with bromine in thionyl chloride according to the procedure of Schwenk and Papa[19])]. 70.5% yield of product *bp* 195–196 °C/7.5 mm; $n_D^{20°}$ 1.4421. Mass, highest $322=M^+$.

Anal. Calcd. for $C_{15}H_{31}O_5P$: C, 55.89%; H, 9.70%; P, 9.69%. Found: C, 55.81%; H, 9.52%; P, 9.68%.

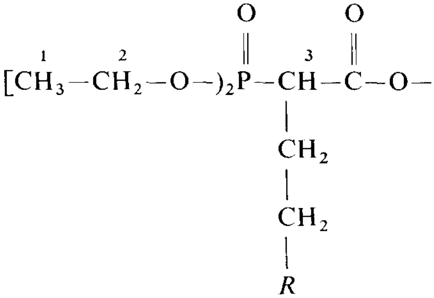
Dimethyl 2-diethylphosphonononane-1,9-dioate (V) was prepared by reaction between triethyl phosphite and dimethyl 2-bromononane-1,9-dioate [prepared by α-bromination of 8-carbethoxyotanoyl chloride with bromine in thionyl chloride[19])]. 72% yield of product *bp* 200–203 °C/1.5 mm; $n_D^{20°}$ 1.4491. PNMR showed τ 5.86 [complicated resonance for 4 H from $(\overset{1}{CH_3}\overset{2}{C\underline{H}_2}-O-)_2-P(O)-$consisting of a quintet with the three innermost components further split $J_{H_2H_1}=7.0$ cps and $J_{PH_2}\simeq 8$ cps[13])], τ 6.26 [*s*, 3, $(EtO)_2P(O)-\underset{|}{CH}-CO_2C\underline{H}_3$], 6.35 (*s*, 3, $-(CH_2)_6-CO_2C\underline{H}_3$), 7.07 (triplet of doublet $J_{H_3H_4}=7.0$ cps and $J_{PH_3}=22.6$ cps, respectively, for 1 methinyl H α-to both the carboxylic and the phosphonate ester $\rangle P(O)-\underset{|}{\overset{3}{C\underline{H}}}-\overset{4}{CH_2}-$).

Mass, highest, $352=M^+$.

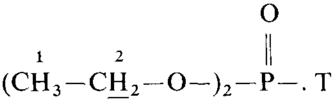
Anal. Calcd. for $C_{15}H_{29}O_7P$: C, 51.13%; H, 8.29%; P, 8.79%. Found: C, 51.32%; H, 8.27%; P, 8.69%.

Results and discussion

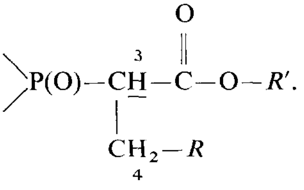
The integrated PNMR spectra of the four trialkyl 2-phosphonoalkanoates (compounds I, II, IV, and V in Table 1)



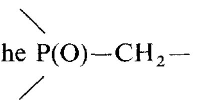
$[\overset{1}{CH_3}-\overset{2}{CH_2}-O-)_2\overset{\overset{O}{\|}}{P}-\overset{3}{\underset{\begin{array}{c}|\\CH_2\\|\\CH_2\\|\\R\end{array}}{CH}}-\overset{\overset{O}{\|}}{C}-O-R']$, which were prepared as intermediates for subsequent carbonyl olefination reactions showed two distinctive and characteristic resonances owing to long-range $^{31}P-{}^1H$ spin-spin couplings. A complicated resonance, centered at $\tau_{(\text{range for I-IV})}$ 5.84–5.86, consisted of a quintet with the three innermost components further split and was assigned to the 4 methylene protons of the diethyl phosphonate ester



$(\overset{1}{CH_3}-\overset{2}{C\underline{H}_2}-O-)_2-\overset{\overset{O}{\|}}{P}-$. This resonance, actually a doublet of quartets[12]) with $J_{H_2H_1}=7.0$ cps and $J_{PH_2}\simeq 8$ cps, respectively, was found to be present identically in each of I–IV. The J_{PH_2} value is to be compared with that of 8.3 cps accurately measured for the $P-O-CH_2$ couplings in bis-(diethoxyphosphonyl)-methane[13]). A second resonance, centered at $\tau_{(\text{range for I-IV})}$6.97–7.11, consisted of a doublet of a multiplet and was assigned to the methinyl proton α-to both the carboxylic ester and the phosphonate ester



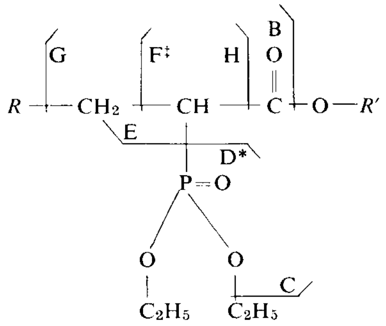
$>P(O)-\overset{3}{\underset{\begin{array}{c}|\\CH_2-R\\4\end{array}}{C\underline{H}}}-\overset{\overset{O}{\|}}{C}-O-R'$. The coupling constants of the doublets J_{PH_3} (range for I–IV) 21.5–22.6 cps, are to be compared with that of 23.0 cps reported for the



$>P(O)-CH_2-$ couplings in diethoxyphosphonylacetylmethane[13]). The multiplets were triplets with $J_{H_3H_4}=7.0$ cps in compounds II–IV $[R=-(CH_2)_x-]$ and a quartet with $J_{H_3H_4}=7.5$ cps in compound I

TABLE 1

Normalized intensities of key fragments in the mass spectra of trialkyl 2-phosphonoalkanoates



Cmpd. No.	$(C_2H_5{-}O{-})_2\overset{\overset{O}{\|}}{P}{-}\underset{\underset{CH_2R}{\vert}}{CH}{-}CO_2R'$		Fragment: m/e / Relative intensity %								Metastables $m^*_{obs.}$ $(F\xrightarrow{+}[F-C_2H_3^{\cdot}]^+)$
	R	*R′*	A**	B	C***	D	E	F	G	H	
I	H	$-C_2H_5$	238/16	193/97	211/2	137/90 138/57	102/58	223/0	238/16 G = A	165/100	
II	$-(CH_2)_{10}-CH_3$	$-C_2H_5$	392/1	347/15	365/0	138/11	255/3	224/100	237/57	319/13	173.4 (224→197)
III	$-(CH_2)_6-CH_3$	$-C_2H_5$	336/2	291/18	309/2	138/45	199/11	224/100	237/77	263/56	173.4 (224→197)
IV	$-(CH_2)_6-CH_3$	$-CH_3$	322/0.5	291/10	295/1	138/25	185/4	210/100	223/72	263/17	159.5 (210→183)
V	$-(CH_2)_5-CO_2CH_3$	$-CH_3$	352/7	321/44	325/0.5	138/47	215/11	210/100	223/98	293/21	159.5 (210→183)

‡ With addition of proton; **A = $[M]^+$; ***C = $[M-C_2H_3^{\cdot}]^+$.

(R=H). In all cases, the observed chemical shifts, peak multiplicities, coupling constants, and integrated intensities were consistent with the postulated structures.

The mass spectra of the five trialkyl 2-phosphonoalkanoates studied are given in Figures 1, 2, 3a and 3b and 4. Figure 5 illustrates schematically the key fragmentations of methyl 2-diethylphosphonodecanoate (IV) and triethyl 2-phosphonodecanoate (III, the ethyl ester of compound IV). The normalized intensities of the key fragments in the mass spectra of I, II, III, IV, and V are listed in Table 1. The molecular ion, fragment A, was of quite low (0.5–2%) intensity in the three compounds having long, normal alkyl branches ($R=(CH_2)_{6 \text{ or } 10}-CH_3$) but of somewhat greater intensity in the compounds having a very short branch (R=H, A = 16%) and having an ω-carbomethoxy substituted branch [$R=-(CH_2)_5-CO_2CH_3$], A = 7%. Similarly, fragment B, the $[M\text{-alkoxy}]^+$ ion, was of moderately low (10–18%) intensity in the three compounds having the long alkyl branches and of rather higher intensity in the R=H (97%) and $R=-(CH_2)_5-CO_2CH_3$ (44%) compounds. Fragment C, due to elimination of one ethyl substituent from the phosphonate ester with "back-transfer" of two hydrogen atoms and a net elimination

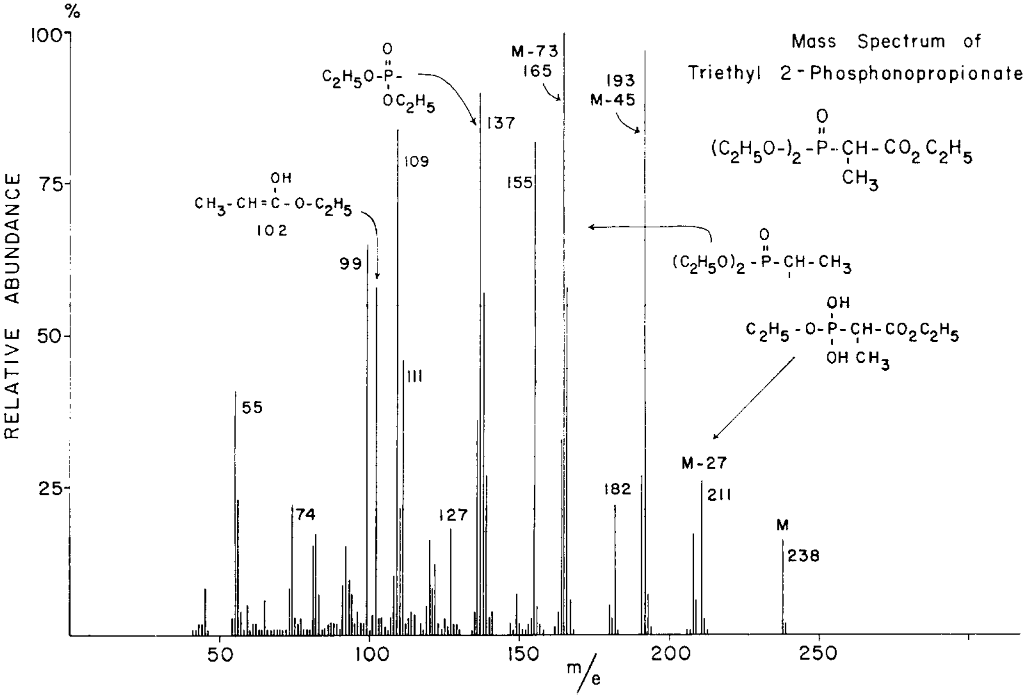


Fig. 1. Mass spectrum of triethyl 2-phosphonopropionate [I].

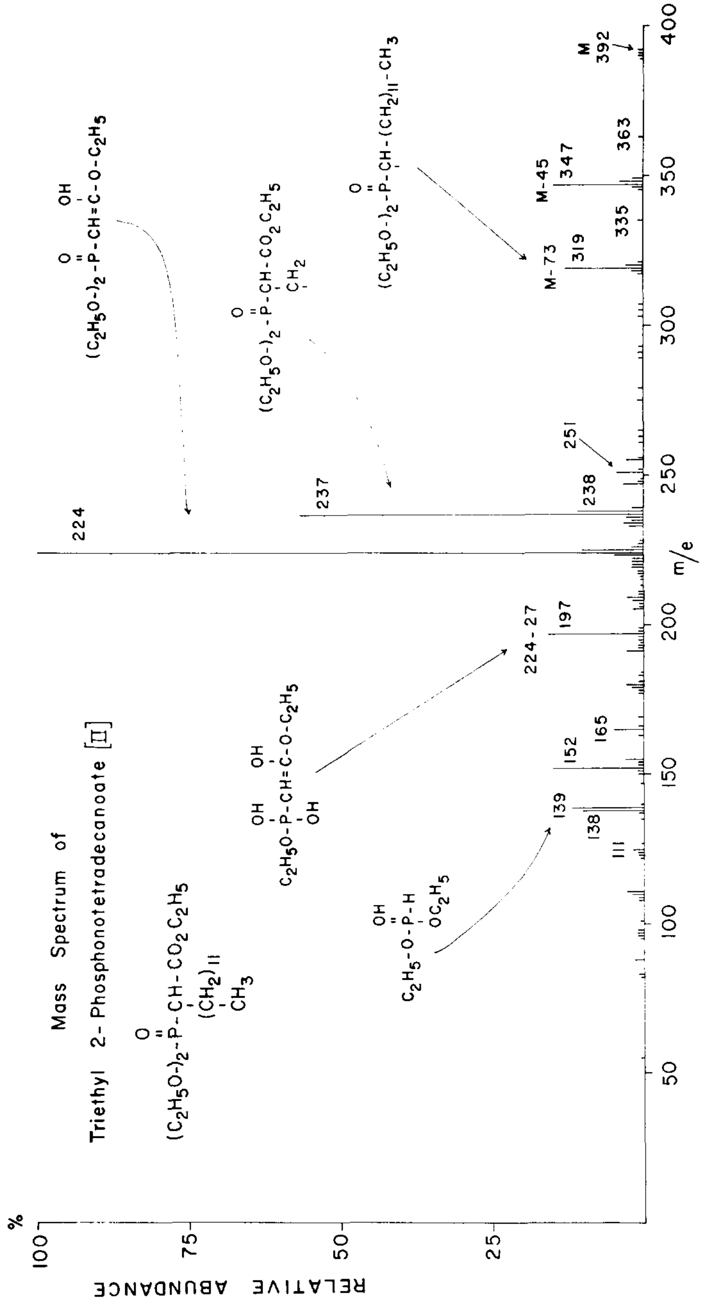


Fig. 2. Mass spectrum of triethyl 2-phosphonotetradecanoate [II].

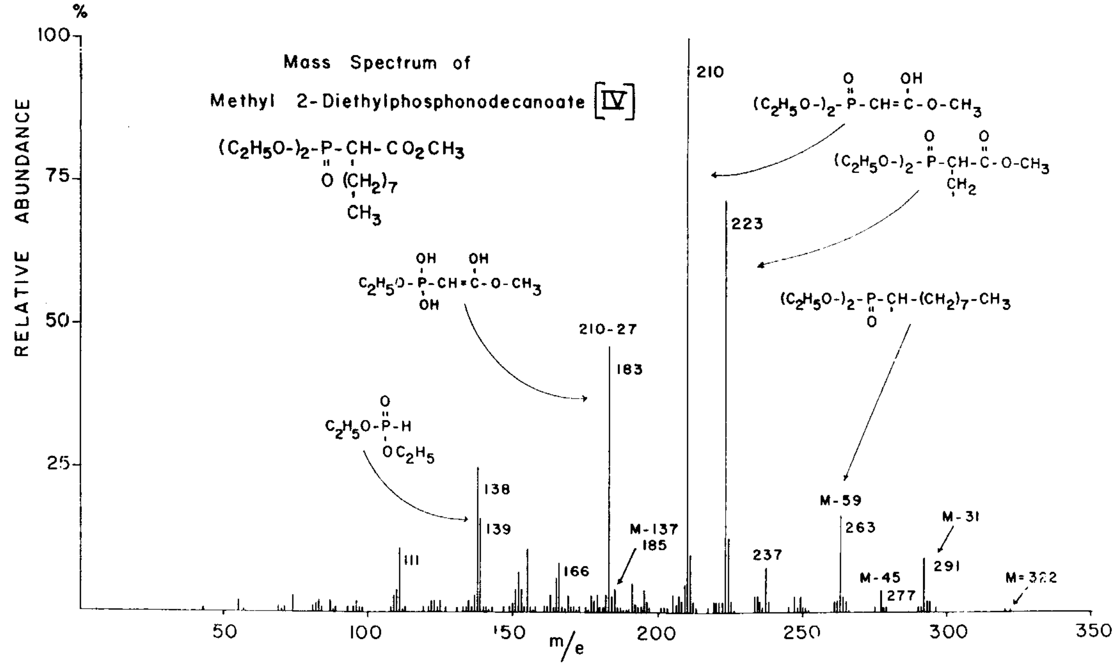


Fig. 3a. Mass spectrum of methyl 2-diethylphosphonodecanoate [IV].

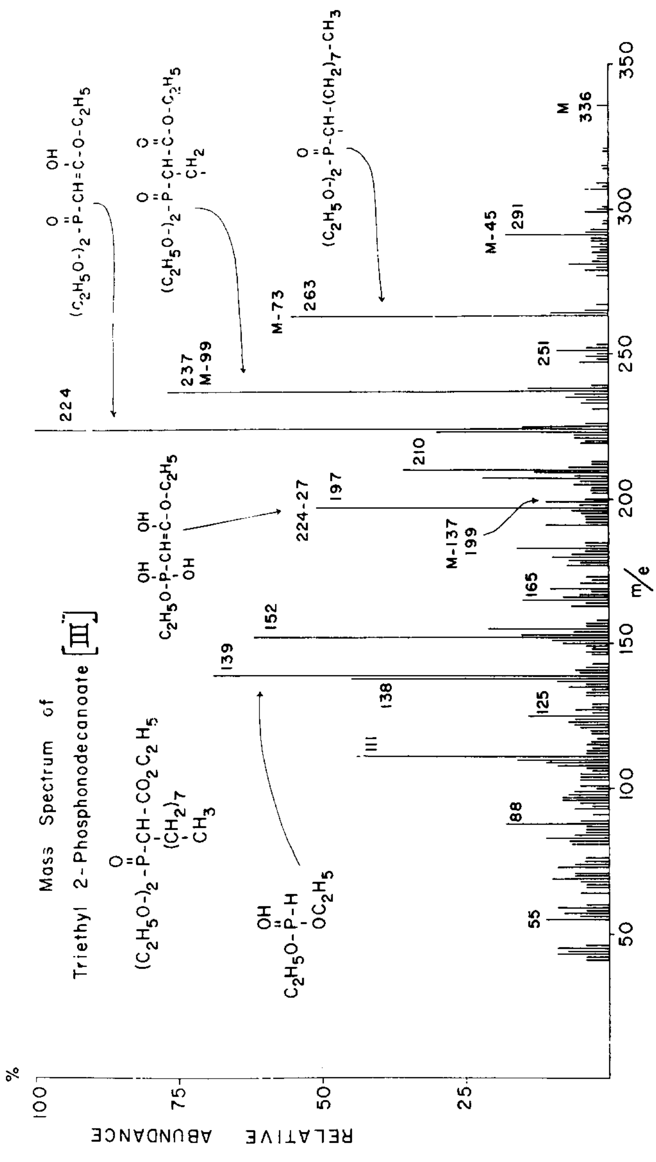


Fig. 3b. Mass spectrum of triethyl 2-phosphonodecanoate [III].

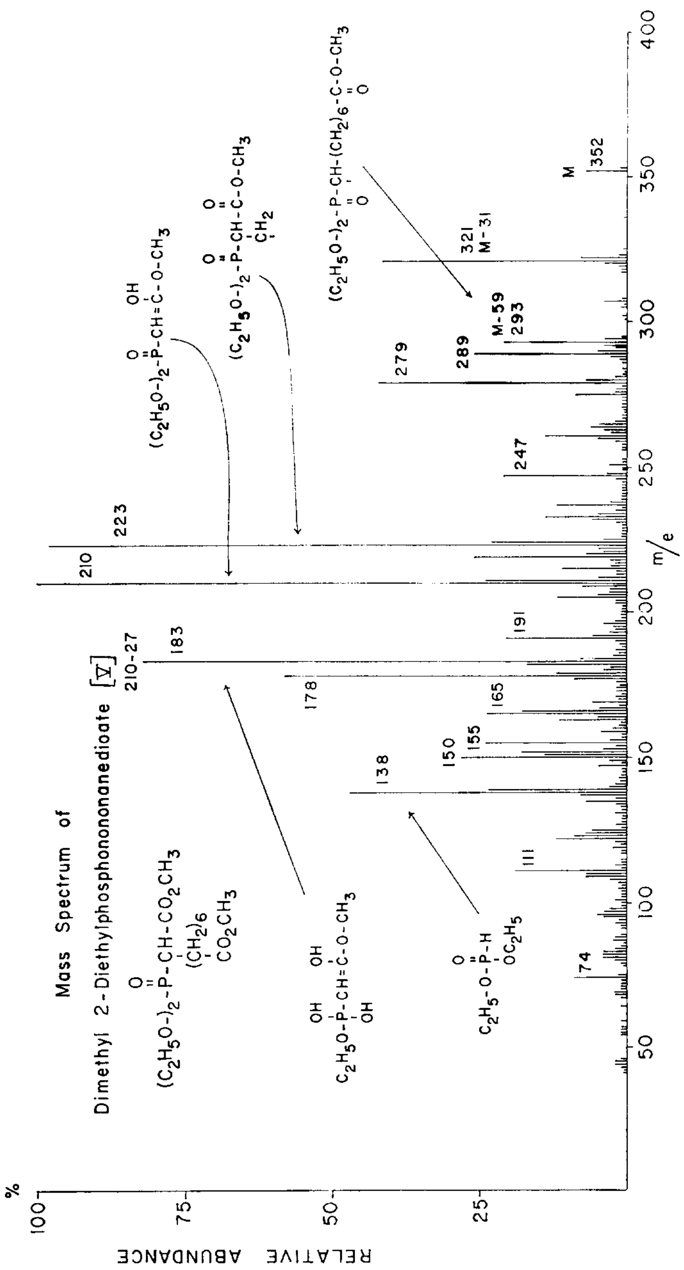
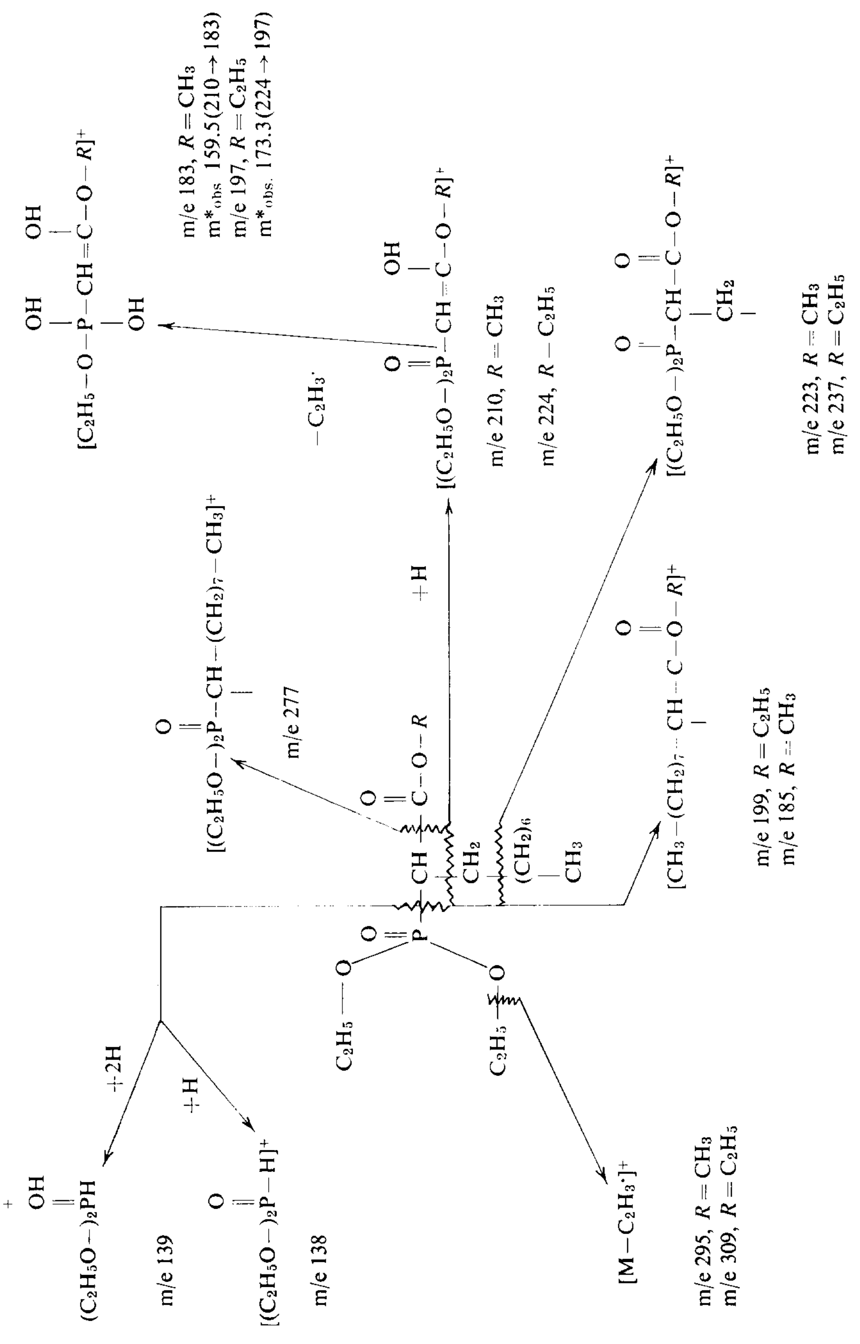
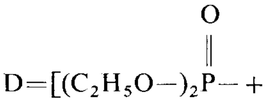
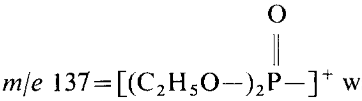
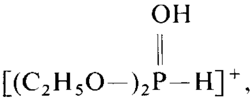
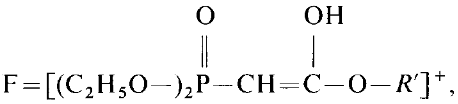


Fig. 4. Mass spectrum of dimethyl 2-diethylphosphonononedioate [V].

Figure 5. Fragmentation Scheme for Methyl 2-Diethylphosphonodecanoate and Triethyl 2-Phosphonodecanoate



of a $C_2H_3{}^{\cdot}$ radical from the molecular ion [4,5,7]),was a very weak intensity (0–2%) fragment ion in all the spectra. Fragment  $D=[(C_2H_5O-)_2\overset{\overset{O}{\|}}{P}-+H]^+$ $=138$, due to fission of the bond to the phosphonate ester and transfer of a hydrogen atom [14]), was a weak-to-moderate intensity (11–57%) ion in the spectra. The fragment  $m/e\ 137=[(C_2H_5O-)_2\overset{\overset{O}{\|}}{P}-]^+$ was of 90% relative intensity in triethyl 2-phosphonopropionate, the compound with R=H. In this latter compound the lack of γ-hydrogen atoms available for transfer to the phosphonate moiety [15]) was expected to limit the resulting fragment ion to the 137 ion radical exclusively; nevertheless, the 138 ion was present at 57% relative intensity. Furthermore, in all but this "short branched" (R=H) compound, a fragment ion of *m/e* 139, which was attributed to fission of the bond to the phosphonate ester and transfer of two hydrogen atoms giving  $[(C_2H_5O-)_2\overset{\overset{OH}{\|}}{P}-H]^+$, was also present in moderate intensity (12–69%). Fragment E, also resulting from fission of the bond to the phosphonate ester, was a weak intensity ion (3–11%) except in the case of the "short branched" (R=H) member which was a relatively abundant 58%.

Fragment  $F=[(C_2H_5O-)_2\overset{\overset{O}{\|}}{P}-CH=\overset{\overset{OH}{|}}{C}-O-R']^+$, resulting from fission of the bond β-to both the carboxylic ester and the phosphonate ester with concomitant transfer of a γ-hydrogen atom from the alkyl chain, i.e. McLafferty rearrangement [15]), was the base peak in all members of the series except the "short (methyl) branch" (R=H) member where F was 0%. This exception was not considered to be an anomaly, however, since cleavage of a bond to a methyl substituted tertiary carbon atom and loss of methyl radical is known not be to a favored process [16]) and lack of γ-hydrogen atoms precluded the occurrence of a McLafferty rearrangement.

A unique, prominent fragment ion, fragment G, is proposed to result from fission of the bond γ-to both the carboxylic ester and the phosphonate ester. The relative intensity of this fragment ranged from 57–98% in all but the "short (methyl) branch" (R=H) member of the series. Formation of fragment G from this latter compound (R=H) would involve loss of a lone, primary hydrogen atom from the methyl group, an unfavored fragmentation. The structure postulated for fragment G was advanced after comparison of the fragmentation patterns of methyl 2-diethylphosphonodecanoate (III) and triethyl 2-phosphonodecanoate (III "ethyl"). Figure 5 illustrates the formation of fragment G, *m/e* 223 and 237, respectively, from these compounds. That the transesterification reaction employed for the preparation of the ethyl ester merely converted III to III "ethyl" without other structural alterations is attested to by a comparison of the key fragment ions (as well as the total mass spectra of the two esters) in the spectra (cf. figs. 3a and 3b) of these compounds. Fragments B, D, and H, which do not contain the carboxylic ester alkoxy group, have identical *m/e*'s. Fragments A, C, E, F, and G, however, which contain the carboxylic ester alkoxy group, differ by the expected 14 mass units increase in going from a methyl to an ethyl carboxylic ester. The increase from 210 to 224 in fragment F and from 223 to 237 in fragment G confirmed the presence of the carboxylic ester functionality in these fragment ions. The presence of these latter two fragment (G) ions in the spectra of dimethyl 2-diethylphosphonononane-1, 9-dioate (cf. fig. 4) and triethyl 2-phoshonotetradecanote (cf. fig. 2), respectively, also added support to the formation and structure of fragment G by fission of the bond γ-to both the phosphonate and the carboxylic ester with loss of an "aliphatic" radical $[R\cdot]$: $G=[M-R\cdot]^+$ where $R=-(CH_2)_5-CO_2CH_3$ and $-(CH_2)_{10}-CH_3$, respectively.

Fragment H, resulting from fission of the bond to the carboxylic ester and loss of the carbalkoxy radical $[M-\overset{\overset{\displaystyle O}{\|}}{C}-O-R']^{+}$ [17]), was a moderately intense (13–56%) fragment in all members of the series except the "short (methyl)branch" ($R=H$) compound, where it was the base peak.

An additional prominent and distinguishing peak in the spectra of all but the "short ($R=H$) branch" compound resulted from a secondary fragmentation process. This fragment ion, *m/e* 183 and $197=[C_2H_5O-P(OH)_2-CH=\overset{\overset{\displaystyle OH}{|}}{C}-O-R']^+$ (cf. fig. 5), resulted from elimination of one ethyl substituent from the phosphonate ester moiety of fragment F with "back-transfer" of two hydrogen atoms and a net elimination of a $C_2H_3\cdot$ radical[4,5,7]) from the fragment F: $[F-C_2H_3\cdot]^+$. The relative intensity of this fragment ion ranged from 16–82% (mean average 48.7%). Metastable peaks observed for this secondary fragmentation process ($F^+\rightarrow[F-C_2H_3\cdot]^+$ are tabulated in table 1. Both these metastables and the fragments $[F-C_2H_3\cdot]^+$ were necessary for the structure assignment of fragment F.

Acknowledgements

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References

1) Y. Wada and R. W. Kiser, J. Phys. Chem. **68** (1964) 2290
2) J. M. Miller, Ph. D. Thesis, Cambridge University (1966)
3) J. L. Occolowitz and G. L. White, Anal. Chem. **35** (1963) 1179
4) A. Quayle, in: Advances in Mass Spectrometry, J. D. Waldron, ed. Pergamon Press, London, (1959) 365–384
5) F. W. McLafferty, Anal. Chem. **28** (1965) 313
6) D. A. Bofus, E. J. Gallegos and R. W. Kiser, J. Phys. Chem. **70** (1966) 2614
7) H. R. Harless, Anal. Chem. **33** (1961) 1387
8) J. L. Occolowitz and J. M. Swan, Austral, J. Chem. **19** (1966) 1187
9) T. Nishikawa, Tetrahedron **22** (1966) 1383
10) H. Budzikiewicz and Z. Pelah, Monatsh. **96** (1966) 1739
11) P. Haake, M. J. Frearson, and C. E. Diebert, J. Org. Chem. **34** (1969) 788
12) C. E. Griffin and S. K. Kundu, J. Org. Chem. **34** (1969) 1532
13) J. D. Baldeschwieler, F. A. Cotton, B. D. Nageswara Rao, and R. A. Schunn, J. Amer. Chem. Soc. **85** (1963) 2394
14) H. Budzikiewicz, C. Djerassi, and D. H. Williams, Mass Spectrometry of Organic Compounds, Holden Day, Inc., San Francisco (1967) 648–651
15) H. Budzikiewicz, C. Djerassi, and D. H. Williams, Mass Spectrometry of Organic Compounds, Holden Day, Inc., San Francisco (1967) 155
16) H. Budzikiewicz, C. Djerassi, and D. H. Williams, Mass Spectrometry of Organic Compounds, Holden Day, Inc., San Francisco (1967) 648–651
17) H. Budzikiewicz, C. Djerassi, and D. H. Williams, Mass Spectrometry of Organic Compounds, Holden Day, Inc., San Francisco (1967) 175
18) J. Wolinsky and K. L. Erickson, J. Org. Chem. **30** (1965) 2208
19) E. Schwenk and D. Papa, J. Amer. Chem. Soc. **70** (1948) 3626