Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry

Reactive intermediates in the H-phosphonate synthesis of oligonucleotides

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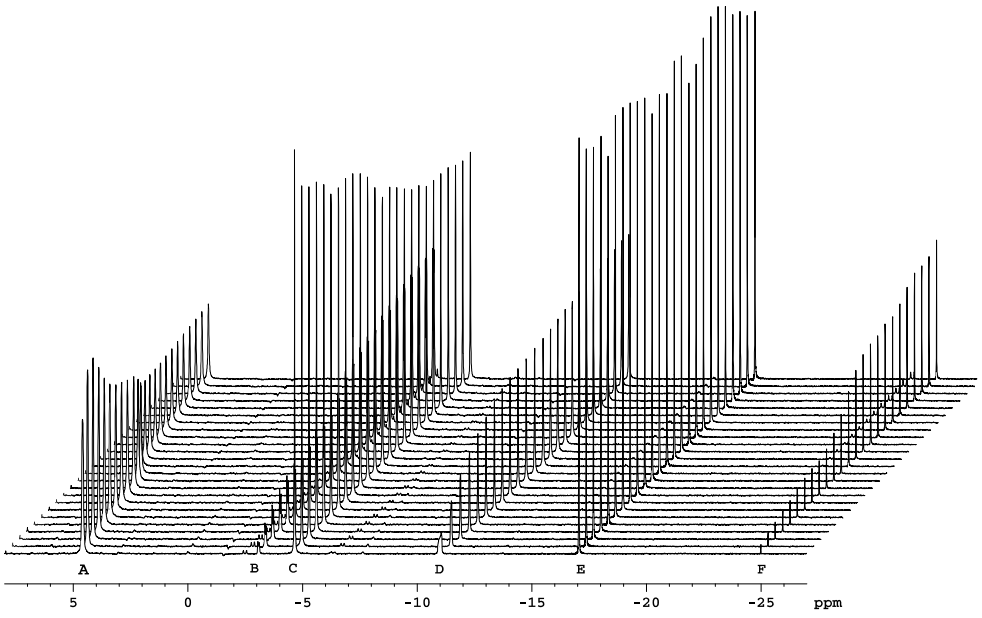
SUPPLEMENTARY INFORMATION

Fig. 1 ^{1}H decoupled ^{31}P NMR timescan for the addition of DPCP (0.19mmol, 0.25M) to triethylammonium ethyl H-phosphonate (0.24M) and triphenylphosphate (0.13M) as internal standard in $CDCl_3$ at 298K.



A graph of concentration versus time was produced using the integral ratios and the molarity of triphenylphosphate used. All the identified peaks were present and their rate of formation/reaction could be shown as a function of time (**Fig. 2**).

Fig. 2 The reaction of DPCP (0.19mmol, 0.25M) added to triethylammonium ethyl H-phosphonate (0.24M, 15% ethyl H-phosphonic acid) and triphenylphosphate (0.13M) as internal standard in $CDCl_3$ as measured by ^{1}H decoupled ^{31}P NMR at 298K.

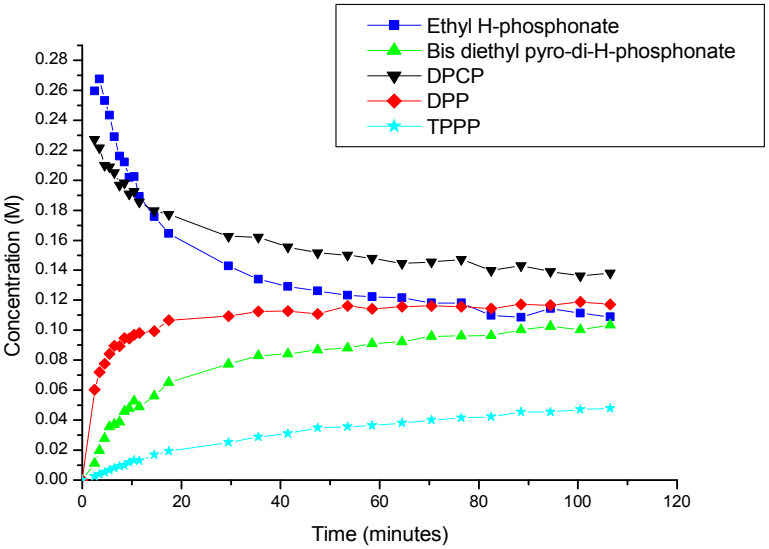


Fig. 3 ^{1}H decoupled ^{31}P NMR chemical shift for ethyl H-phosphonate anion and DPP during the reaction of DPCP (0.19mmol, 0.25M) added to triethylammonium ethyl H-phosphonate (0.24M, 15% ethyl H-phosphonic acid) and triphenylphosphate (0.13M) as internal standard in $CDCl_3$ at 298K shown in **Fig. 3**

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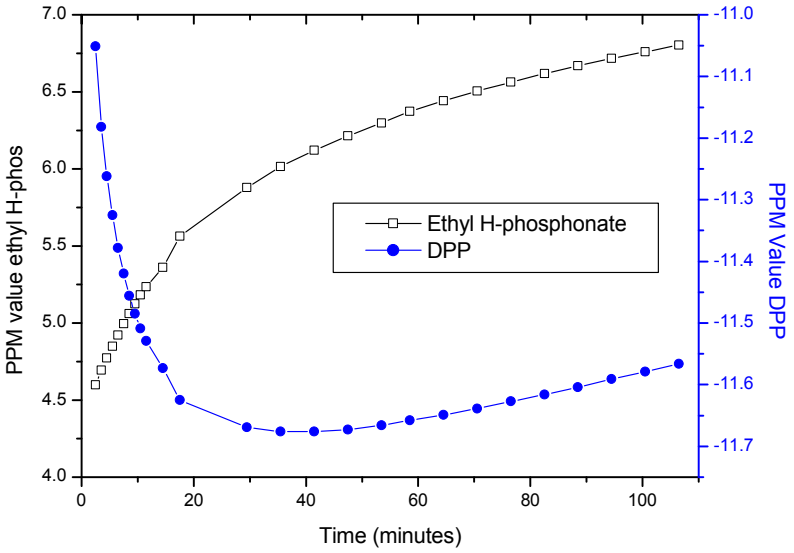
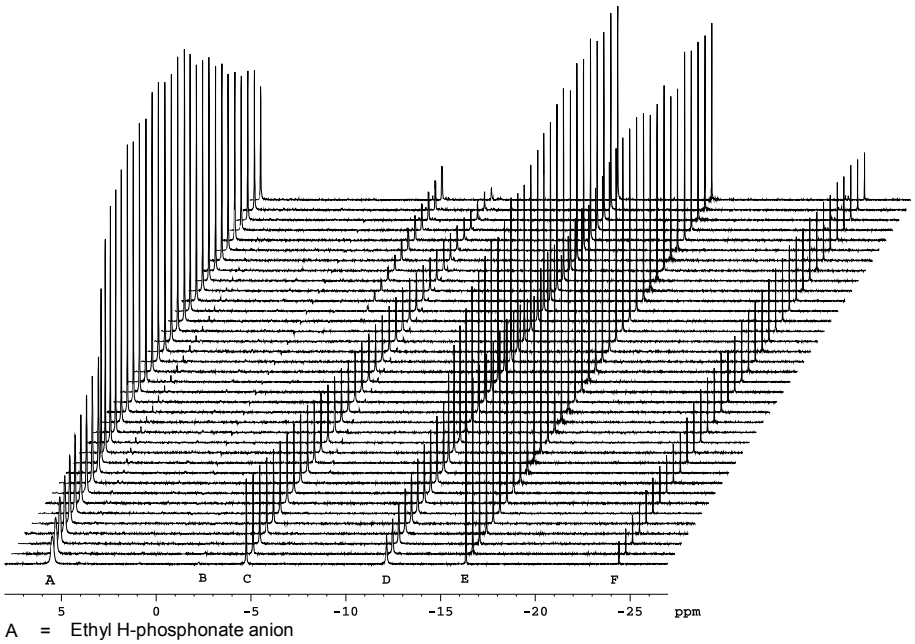


Fig. 4 ^{1}H decoupled ^{31}P NMR timescan for the addition of neat DPCP (0.17mmol, 0.23M) to triethylammonium ethyl H-phosphonate (0.23M) and triphenylphosphate (0.14M) as internal standard in d_3-acetonitrile in 298K.



A = Ethyl H-phosphonate anion

B = Bis diethyl pyro-di-H-phosphonate

C = DPCP

D = DPP

E = Triphenylphosphate internal standard

F = TPPP

Fig. 5 ^{1}H decoupled ^{31}P NMR timescan for the addition of neat DPCP (0.17mmol, 0.23M) to triethylammonium ethyl H-phosphonate (0.23M, 15% ethyl H-phosphonic acid) and triphenylphosphate (0.14M) as internal standard in d_3-acetonitrile at 298K.

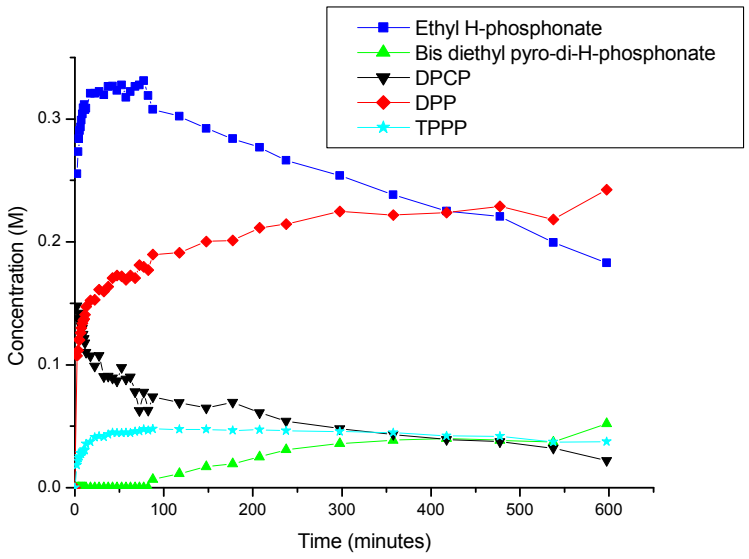


Fig. 6 ^{1}H decoupled ^{31}P NMR chemical shifts for ethyl H-phosphonate and DPP for the addition of neat DPCP (0.17mmol, 0.23M) to triethylammonium ethyl H-phosphonate (0.23M) and triphenylphosphate (0.14M) as internal standard in d_3-acetonitrile at 298K.

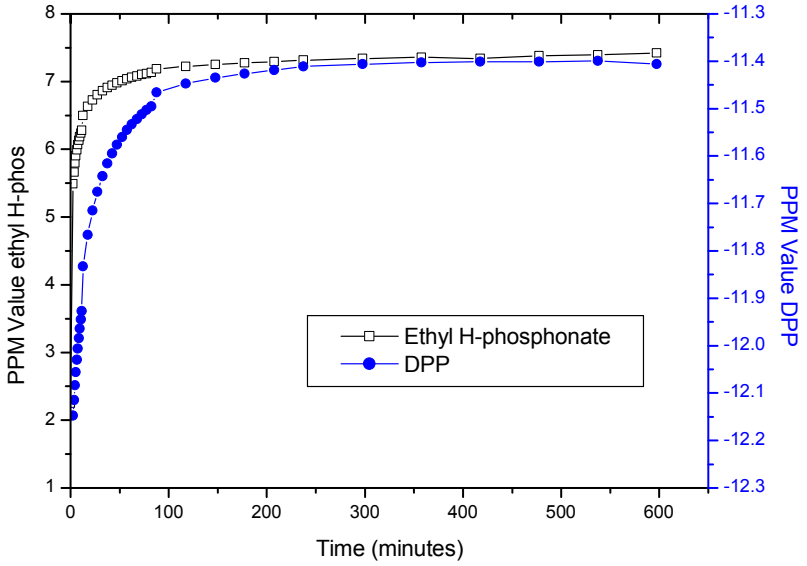


Fig. 7 ^{31}P coupled - ^{31}P coupled NMR COSY spectra for an equilibrium mixture of bis diethyl pyro-di-H-phosphonate and diphenyl ethyl pyro-H-phosphonate in $CDCl_3$ at 298K.

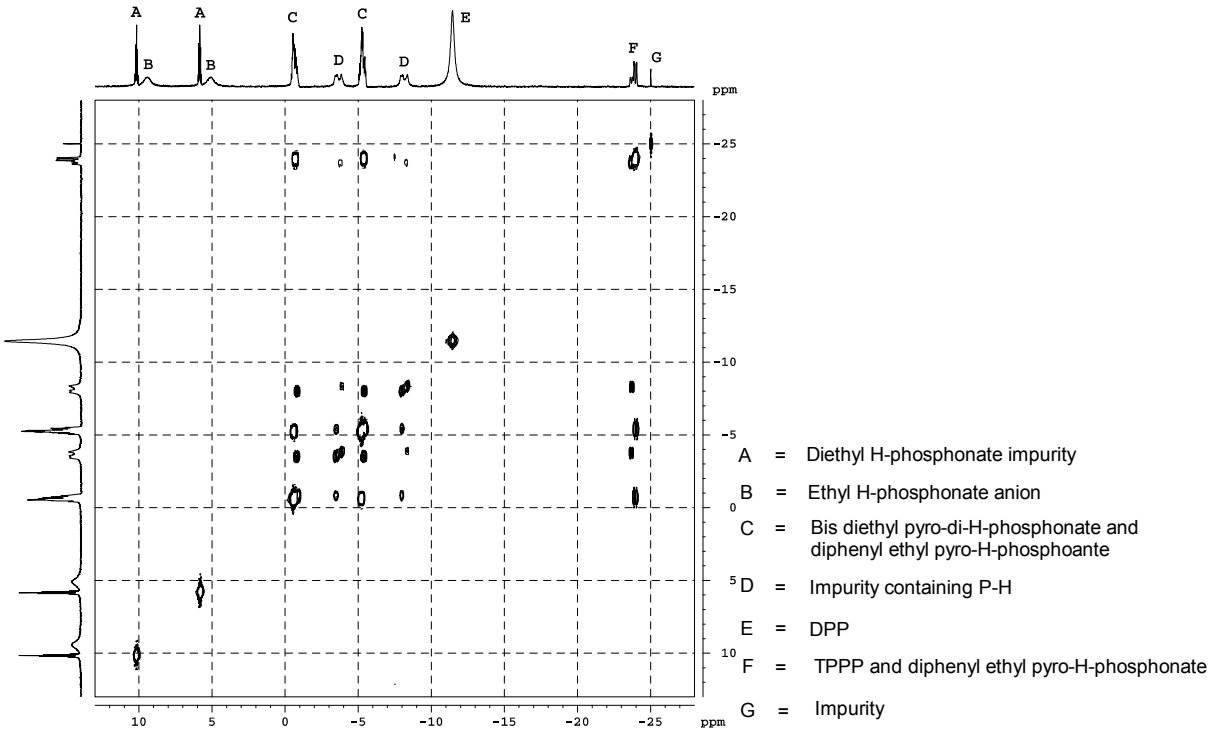


Fig. 8 Averaging of 16 scans per spectrum versus collection of 1 scan per spectrum. The larger markers show the data after averaging all 16 scans.

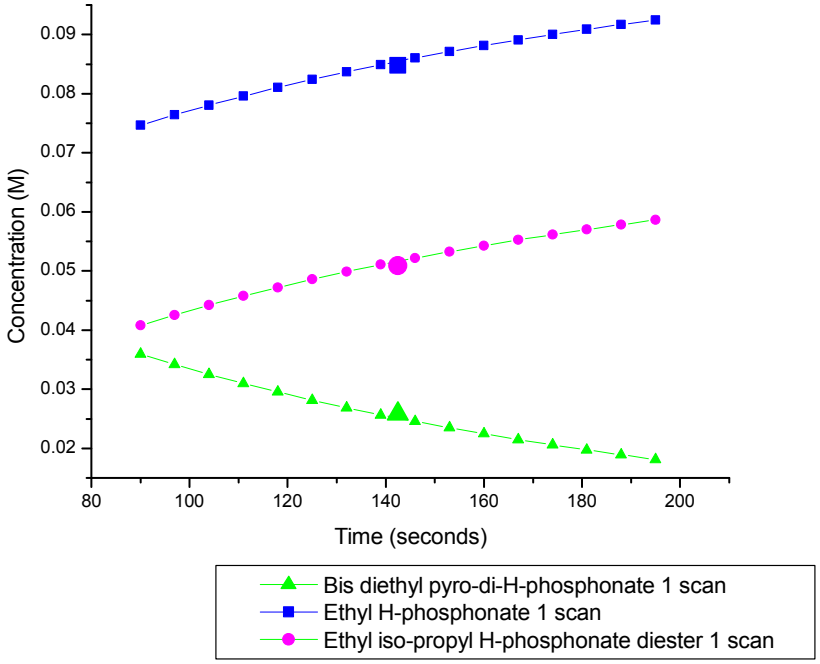


Fig. 9 ^{1}H decoupled ^{31}P NMR timescan for the addition of neat DPCP (0.18mmol, 0.24M) to ethyl H-phosphonate triethylammonium salt (0.23M), triethylamine (0.23M), and triphenylphosphate (0.14M) as internal standard in $CDCl_3$ at 298K.

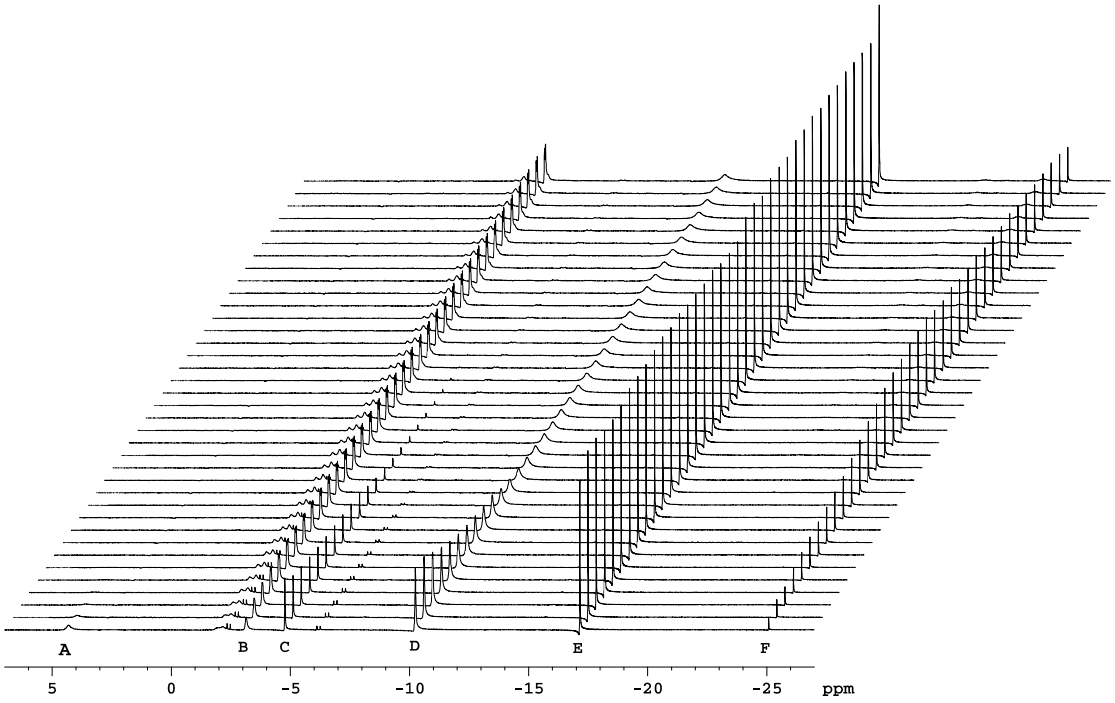


Fig. 10 Concentration – time plots for the addition of neat DPCP (0.18mmol, 0.24M) to ethyl H-phosphonate triethylammonium salt (0.23M) , triethylamine (0.23M) and triphenylphosphate (0.14M) as internal standard in $CDCl_3$ as measured by ^{1}H decoupled ^{31}P NMR at 298K.

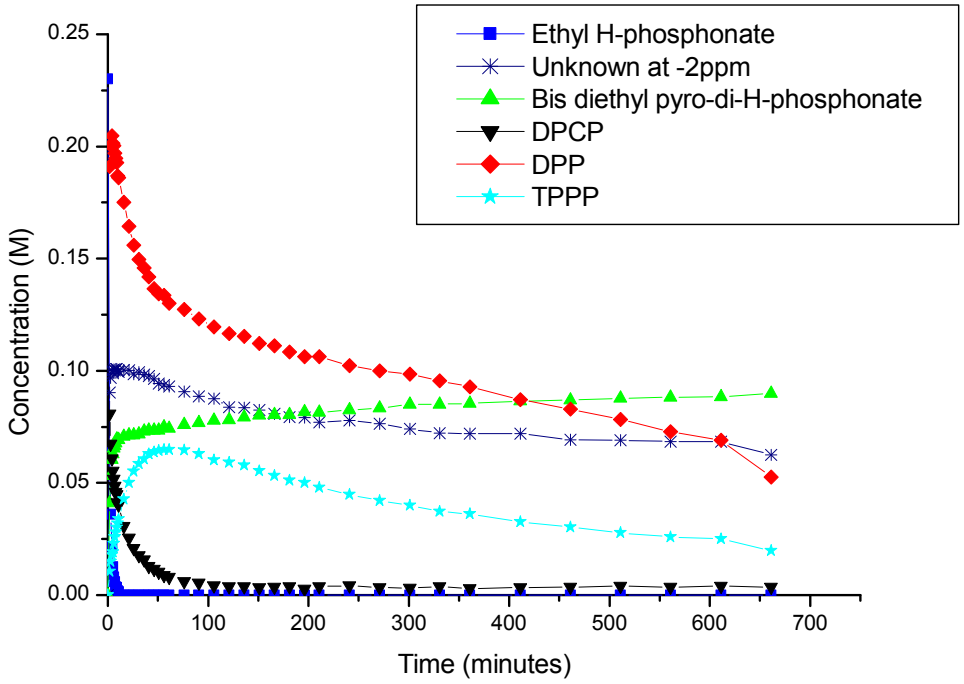


Fig. 11 The second order fit for the reaction of DPCP (0.21mmol, 0.42M) with DPP (0.42M) in the presence of pyridine (0.25mmol, 0.49M, 1.19moleq) and triphenylphosphate (0.29M) as internal standard in $CDCl_3$ (0.5ml) as measured by ^{1}H decoupled ^{31}P NMR at 298K.

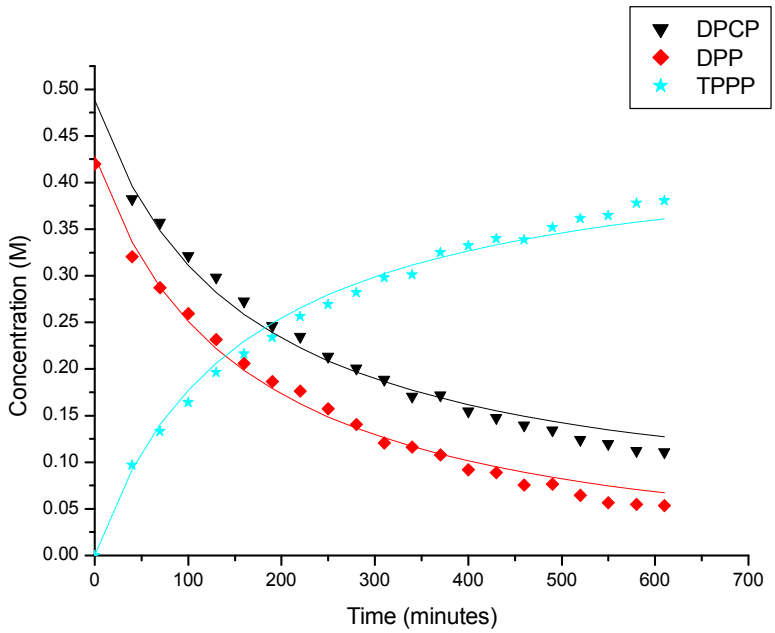


Fig.12 ^{1}H decoupled ^{31}P NMR of diphenylchlorophosphate in $CDCl_3$

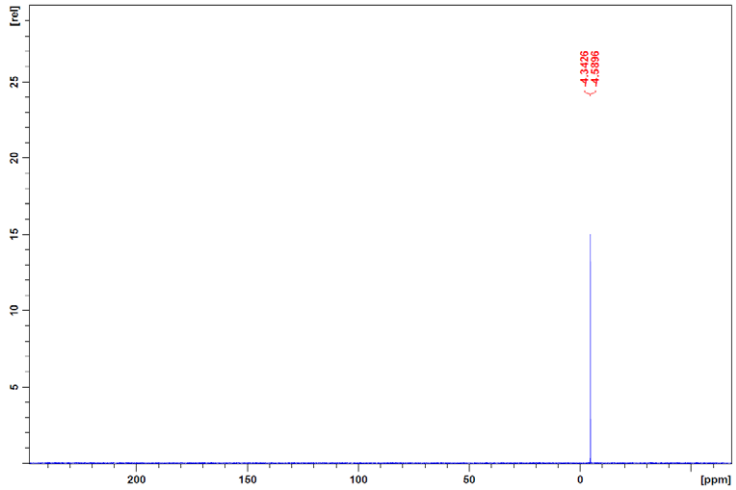


Fig.13 ^{1}H NMR of diphenylchlorophosphate in $CDCl_3$

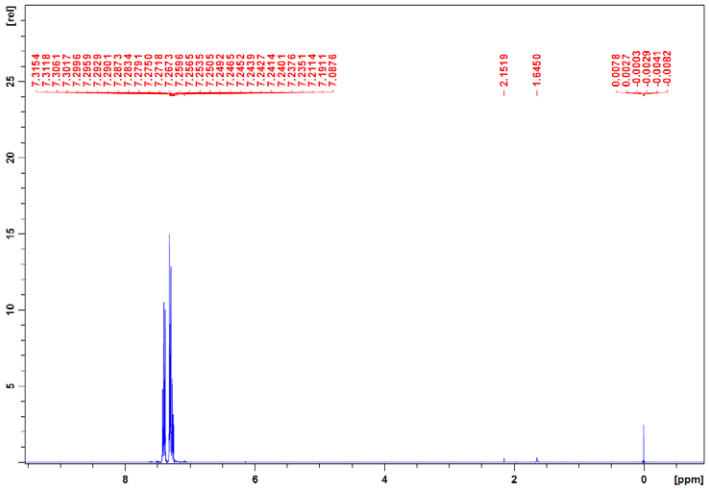


Fig.14 ^{31}P NMR of triethylammonium ethyl H-phosphonate in $CDCl_3$

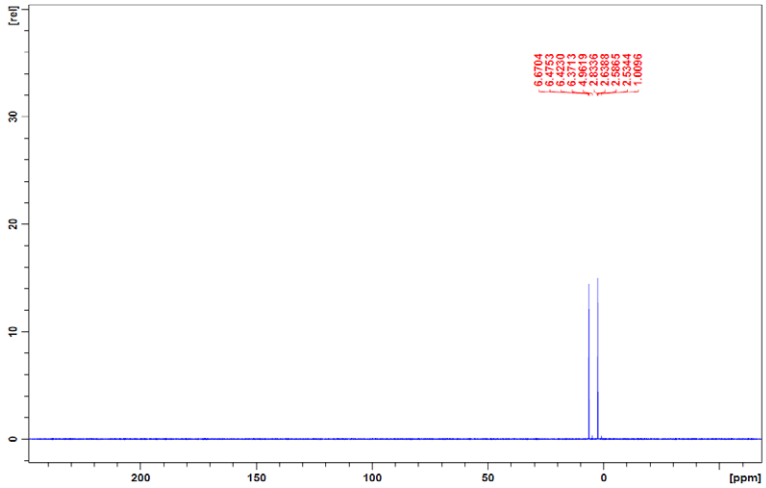


Fig.15 ^{1}H decoupled ^{31}P NMR of triethylammonium ethyl H-phosphonate in $CDCl_3$

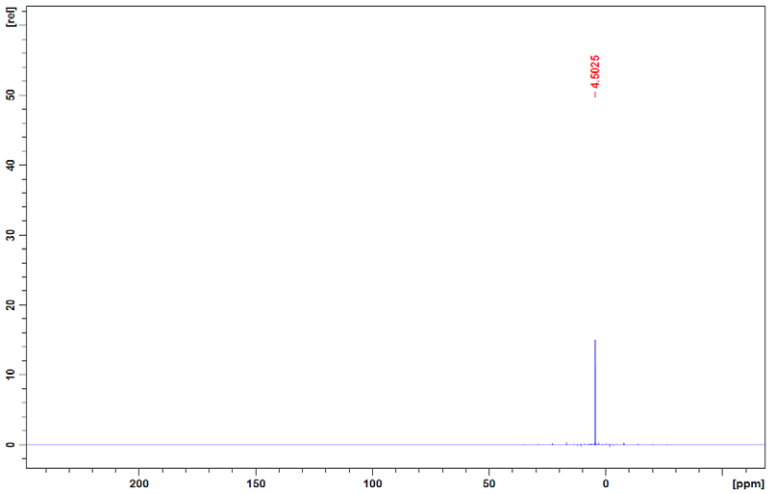


Fig.16 ^{1}H NMR of triethylammonium ethyl H-phosphonate in $CDCl_3$

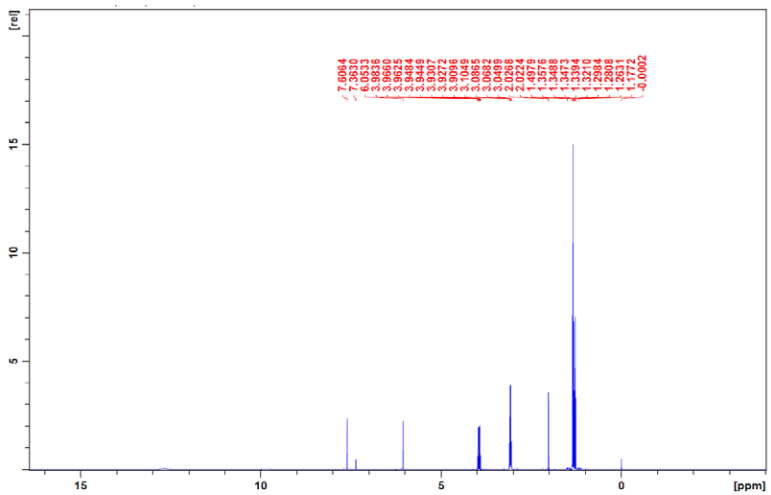


Fig.17 ^{1}H decoupled ^{31}P NMR of ethyl H-phosphonate free acid in $CDCl_3$

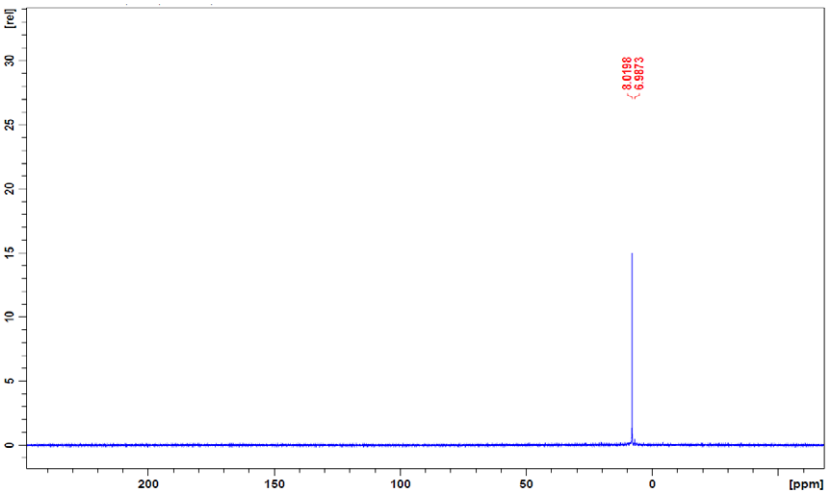


Fig.18 ^{31}P NMR of ethyl H-phosphonate free acid in $CDCl_3$

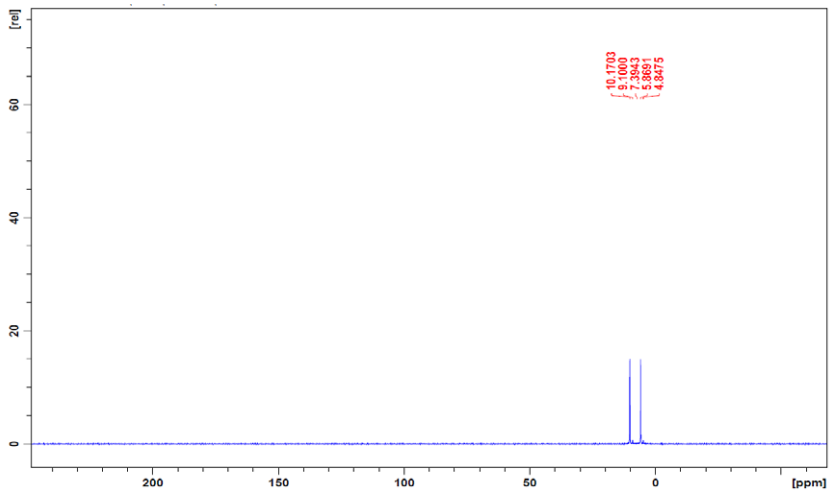


Fig.19 ^{1}H NMR of ethyl H-phosphonate free acid in $CDCl_3$

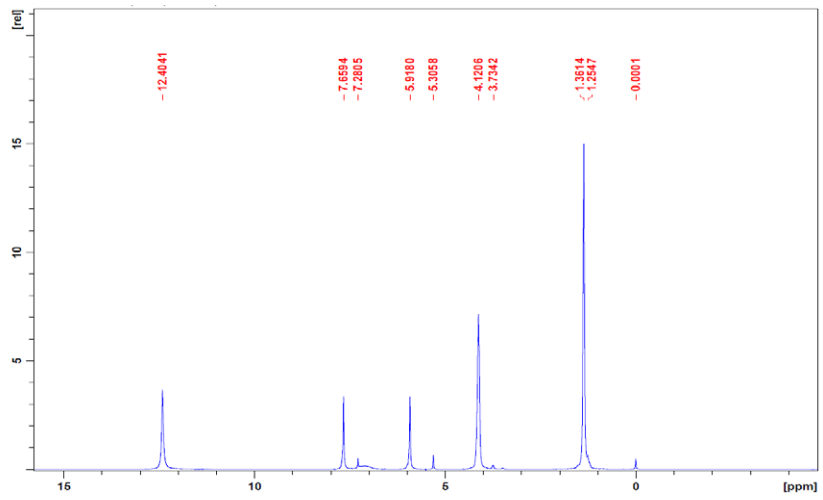


Fig.20 ^{1}H decoupled ^{31}P NMR of diphenylphosphate

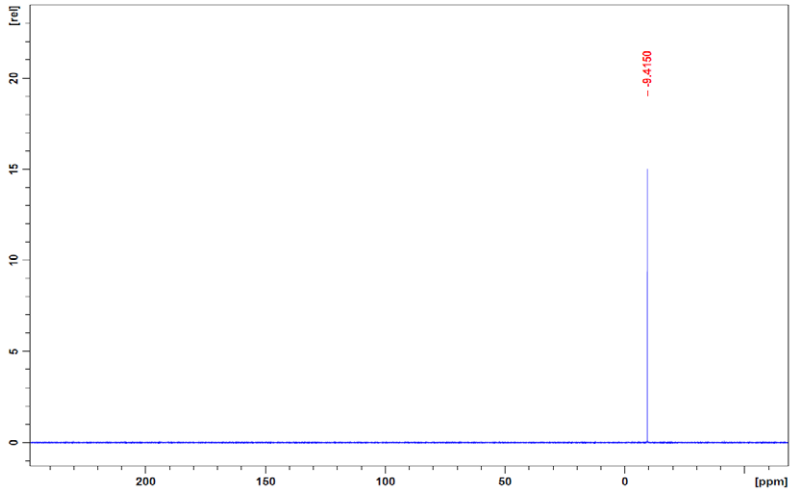
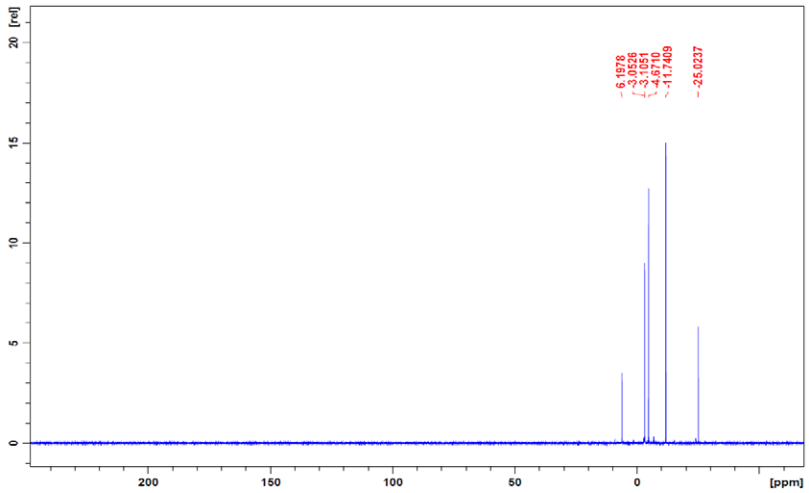


Fig.21 ^{1}H decoupled ^{31}P NMR of diphenylchlorophosphate and triethylammonium ethyl H-phosphonate in $CDCl_3$



6.2ppm ethyl H-phosphonate anion, -4.6ppm diphenylchlorophosphate, -11.7ppm diphenylphosphate anion, -25.0ppm tetraphenylpyrophosphate; the doublet at -3.0ppm is bis diethyl pyro-di-H-phosphate.

Fig.22 ^{1}H decoupled ^{31}P NMR of diphenylchlorophosphate, triethylammonium ethyl H-phosphonate, triphenylphosphate and ethanol in $CDCl_3$

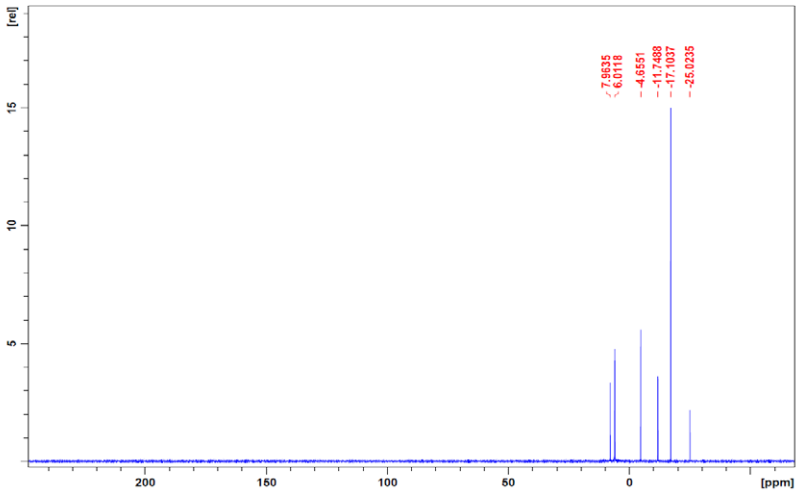


Fig.23 ^{1}H decoupled ^{31}P NMR of Bis Diethyl pyro-di-H-phosphonate (IS:triphenylphosphate) in $CDCl_3$

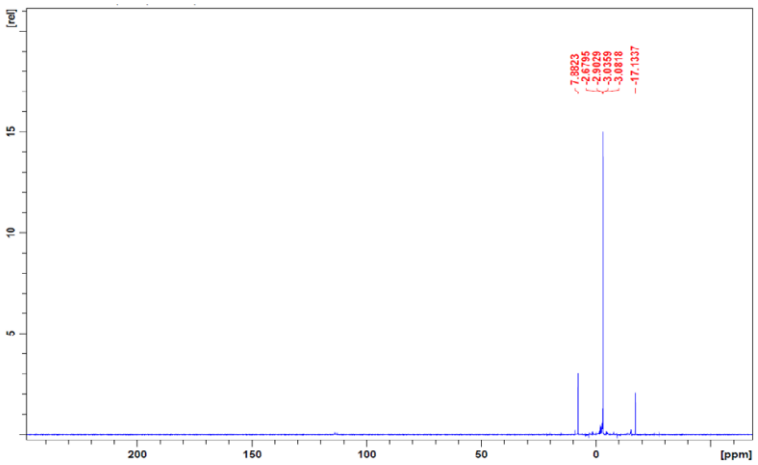


Fig.24 ^{1}H decoupled ^{31}P NMR of bis diethyl pyro-di-H-phosphonate with diphenylphosphate added (IS:triphenylphosphate) in $CDCl_3$. Diphenyl ethyl pyro-H-phosphonate is generated as shown by the doublets at -24.0ppm and at -3.1ppm

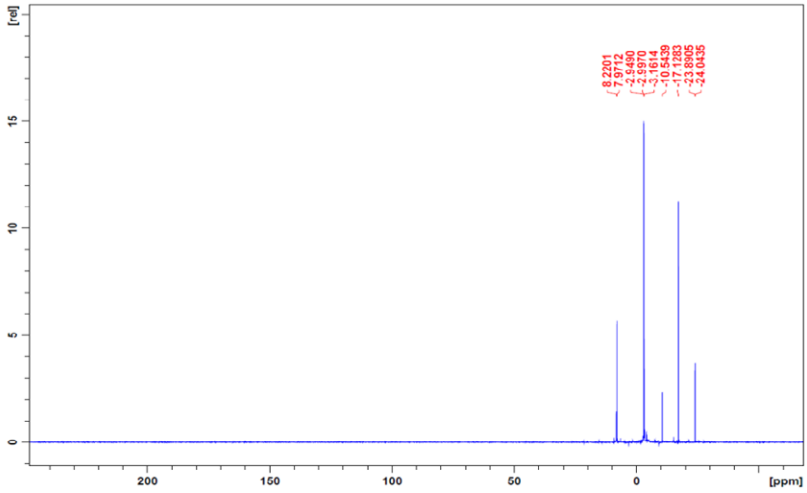


Fig. 25 ^{31}P NMR of bis diethyl pyro-di-H-phosphonate and pyridine in $CDCl_3$ (IS triphenylphosphate). The metaphosphite formed as shown by triplet at 112.8ppm, a doublet at 113.5ppm and a singlet at 114.0ppm.

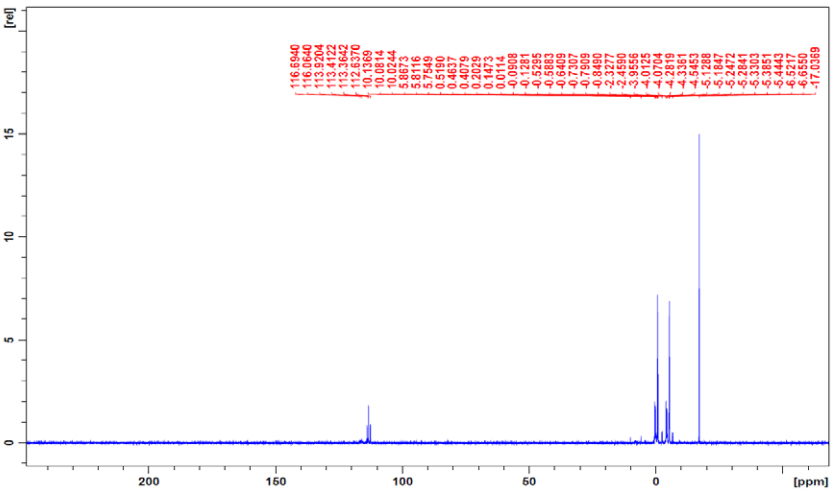


Fig.26 ^{1}H NMR of triethylammonium ethyl H-phosphonate in $CDCl_3$

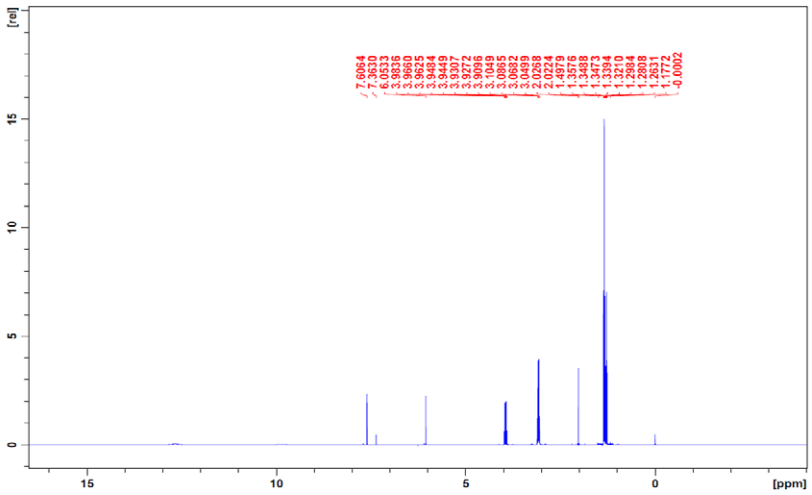


Fig.27 ^{1}H NMR of triethylammonium ethyl H-phosphonate and diphenylphosphate in $CDCl_3$

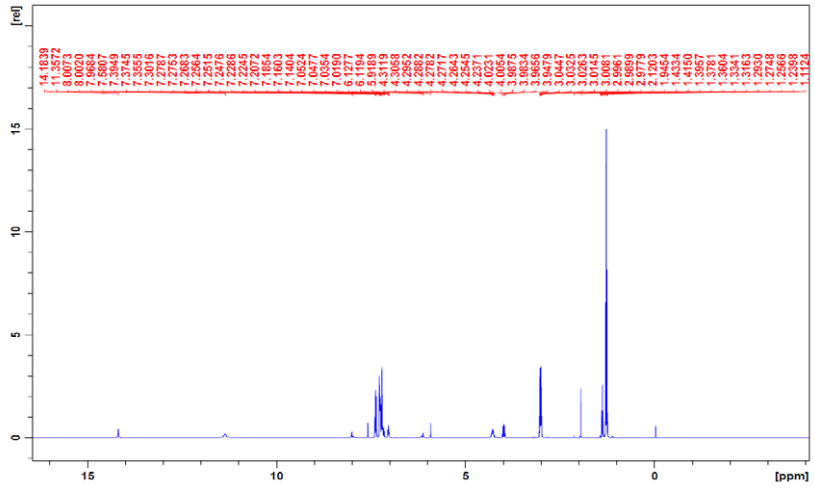


Fig.28 ^{31}P NMR of triethylammonium ethyl H-phosphonate and diphenylchlorophosphate in $CDCl_3$

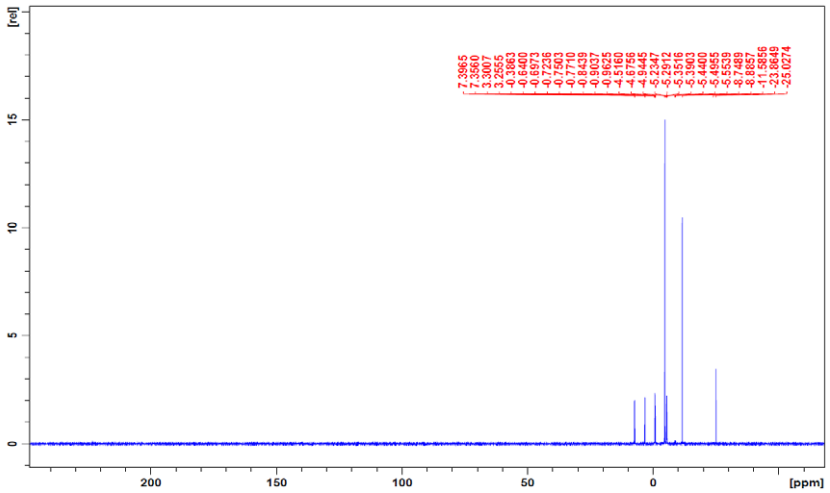


Fig.29 ^{1}H NMR of ethyl H-phosphonic acid in $CDCl_3$

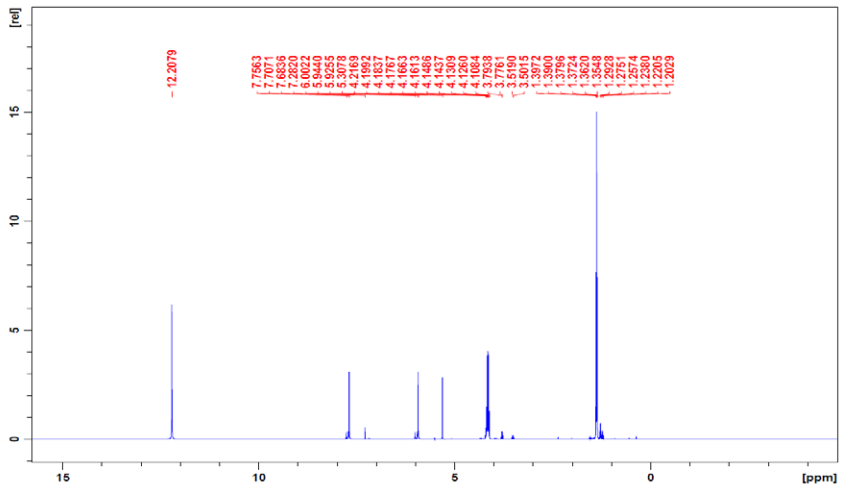


Fig.30 ^{1}H decoupled ^{31}P NMR of ethyl H-phosphonic acid in $CDCl_3$

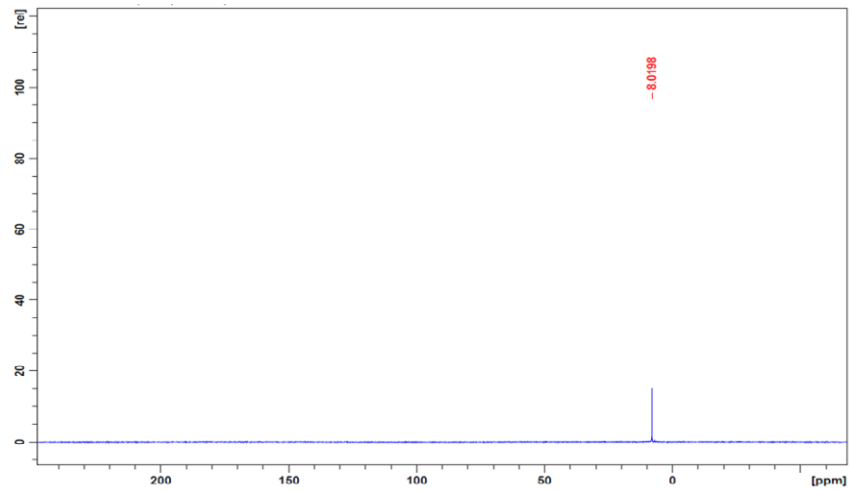


Fig.31 ^{1}H decoupled ^{31}P NMR of bis diethyl pyro-di-H-phosphonate in $CDCl_3$ (IS triphenylphosphate)

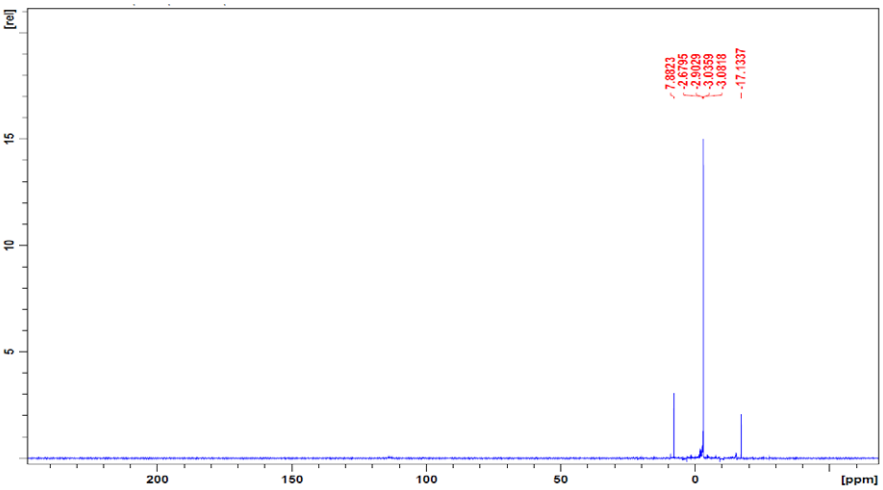


Fig.32 ^{31}P NMR of bis diethyl pyro-di-H-phosphonate and diphenylphosphate in $CDCl_3$

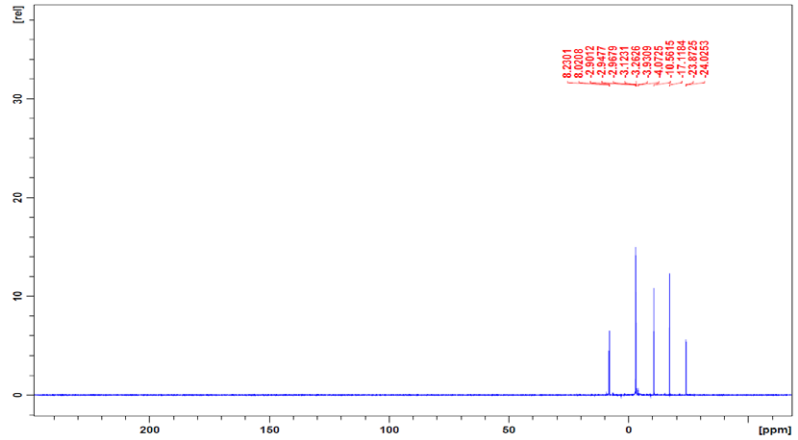


Fig.33 ^{1}H decoupled ^{31}P NMR of bis diethyl pyro-di-H-phosphonate and diphenylphosphate in $CDCl_3$

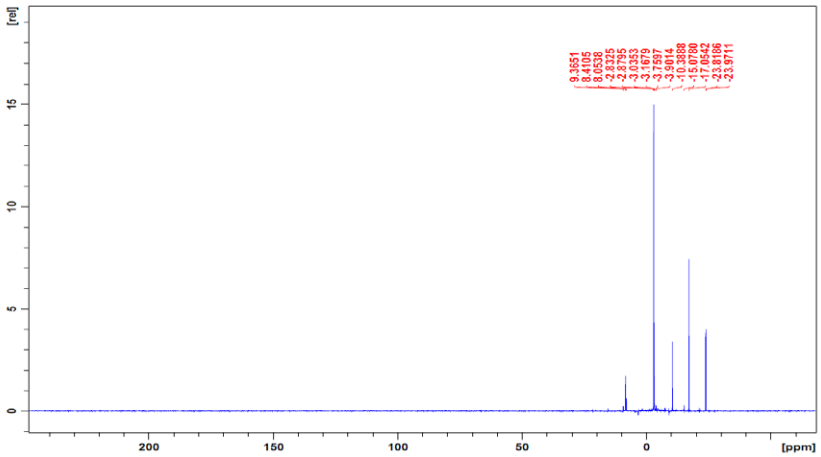


Fig.34 ^{31}P NMR of triethylammonium ethyl H-phosphonate, diphenylchlorophosphate and tetrahydrofurfuryl alcohol in $CDCl_3$