SOLID SUPPORT SYNTHESIS: A NEW AND EFFICIENT METHOD FOR FACILE SYNTHESIS OF CYCLIC ALKYLPHOSPHONATES UNDER MILD CONDITIONS

Rajesh Kumar, A.K.Gupta, Deepak Pardasani, D.K.Dubey and M. P. Kaushik*
PTD Division, Defence Research & Development Establishment, Gwalior, India
E-mail: mpkaushik@rediffmail.com

Introduction

The chemistry of organophosphorus compounds is a rapidly developing area of research because of their importance in industrial, agricultural, biochemical and medicinal application. It is interesting to note that the variation in their physical, chemical and biological properties is governed by selection of the group attached to phosphorus atom.[1] One such class of compounds is known as phosphonates having wide applications in modern life[1]; they are used as flame retardants[2], pesticides[3], herbicides[4], lubricants[4-5] antifoaming agent, stabilizer, textile conditioner, antistatic agent, and in organic synthesis.[5-7] In addition to their biological activity, the phosphonates have also been recognized as attractive intermediates in organic chemistry. Owing to their anion stabilizing ability, they have been frequently applied for functionalization and manipulation of carbon skeletons.[8] Apart from their useful applications to the mankind, these compounds is important in the verification of alleged use of chemical warfare agents.[9]

The verification regime of Chemical Weapons Convention (CWC) is pivotally in its implementation. The treaty is administered by an organization know as Organization for Prohibition of Chemical Weapons (OPCW). The OPCW maintains a network of designated laboratories to verify the presence of CWAs and their markers in the samples collected by the inspectors from suspected and declared sites.[10] Due to the internationally sensitive nature of verification process, the analytical performance of designated laboratories and the laboratories seeking designation, is periodically evaluated by OPCW by conducting the official proficiency tests (PTs).[11,12] In PTs different environmental matrices such as soil, water, swab and organic liquid are spiked with schedules of compounds at the concentration ranging 1- 10 μg/g and sent to participating laboratories. The participating laboratories are expected to identify all spiked chemicals and submit the report with in the stipulated period of fifteen days.[11,12]

Since, schedules of compounds are based on commercial use and past use of chemicals as CWAs, the total number of scheduled compounds is several hundred thousands. Their synthesis (in pure form) by the reported methods and recording of spectral data shall be a daunting task. In order to resolve such problem, there is a need to develop efficient synthetic procedures which can provide the pure compounds as quickly as possible. Rapid synthesis of cyclic phosphonates in pure form is essential to confirm the structures of analytes identified from their spectral (e.g. GC-MS, ^{31}P NMR & GC-FTIR) analysis.[13] The spectral match with synthesized compounds is one of the unique ways to report the results of analysis. Furthermore, the spectra and chromatographic data gathered by synthesis of pure compounds are also helpful in off-site analysis of real samples.

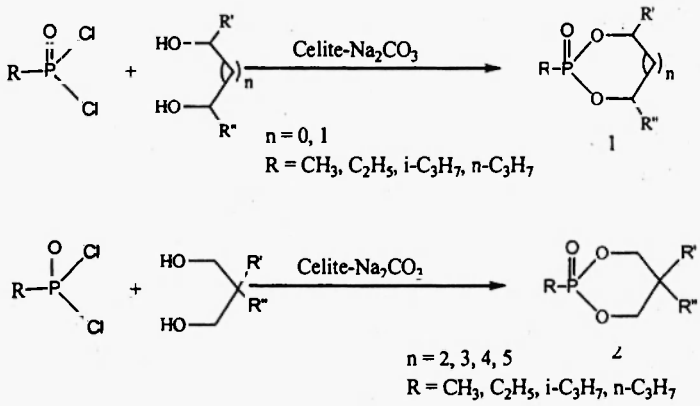
The cyclic alkylphosphonates (CAPs) are listed in schedule 2B4 of CWC text.[9] Thus CAPs become important markers for verification of CWC. The spectral data of CAPs are neither available with OPCW nor with any commercially available library. It is worth mentioning that in 19th PT conducted in April 2006, one of the spiking chemical was O,O-1,3-trimethylene isopropylphosphonate (a hexacyclic isopropylphosphonate) in an organic liquid and could not be identified by eleven out of thirteen participating laboratories.[14] Such a high percentage of failure (false negative identification) was due to non-availability of the spectral data of this class of compounds and the mass spectrum of this compound did not show even remote similarity with mass spectra of any of the CWC related organophosphorus compounds (particularly the acyclic O,O-dialkyl alkylphosphonates).

Results and Discussion:

Our continual efforts on the development of new synthetic procedures of scheduled chemicals for verification of CWC[15], have prompted us to advance the synthesis of CAPs. A plethora of effective chemical approaches have been devised for the preparation of Synthesis of six- and seven-membered cyclic alkylphosphonates.[16] The reported methods are time consuming, use of hazardous solvent, high temperature, formation of polymerized products, require chromatographic technique for purification and poor yield of desired products.

Surface mediated reactions under solvent free conditions have recently attracted the attention of workers due to ecological concerns and legislative enforcement.[17-19] The main advantages of procedure are that they are simpler in operation. The kinetic energy supplied during grinding can have several effects on a crystalline solid including heating, reduction of particle size, increase in surface area, generation of fresh surfaces, formation of defects, dislocations in crystal lattice, phase changes, mass transfer and save energy. The absence of solvent in organic synthesis also makes the reactions cleaner, prevents solvent wastes, and reduces hazards and toxicity. Furthermore, from the synthetic view point, these reactions significantly reduce the reaction time, and workup also becomes easier.

In the present communication we report an alternative and convenient synthesis of CAPs by cyclization of alkylphosphonic dichlorides with alkanediols in the presence of sodium carbonate and celite (Scheme 1). To study the effect of solid support on the reaction rate, various solid supports such as KF-celite, KF, Na_2CO_3, $NaHCO_3$, Na_2CO_3-celite, Na_2SO_4, Silca, Celite, Symctone Clay, Montmorillonite KSF clay, kieselgel, active charcoal and active carbon were screened; Na_2CO_3-celite was found to be superior in terms of conversion and reaction time. All the reactions with Na_2CO_3-celite reached to completion within 30-45 minutes under neat condition, while without Na_2CO_3-celite, even extended reaction time (up to 2.5 h) had no significant enhancement in the yields (38%). It was also observed that by increasing the reaction time on KF-celite, there was no significant change in the yield of products. By following the optimized procedure, a series of compounds were prepared and confirmed by spectroscopic techniques.



Scheme 1: Reaction scheme for the synthesis of cyclic alkylphosphonates

Table 1: Synthesis of Compounds 1a-n and 2a-d

Entry	R	n	X	R'	R"	Yield (%)	^{31}P-NMR (δ pmm)	bp (^{0}C)
1a	CH_3	1	O	CH_3	CH_3	75	27.52	80/0.5
1b	CH_3	1	O	CH_3	H	73	27.35	77/0.5
1c	$^iC_3H_7$	1	O	H	H	78	34.12	89/0.5
1d	$^iC_3H_7$	1	O	CH_3	H	76	33.98	93/0.5
1e	$^iC_3H_7$	1	O	CH_3	CH_3	83	33.87	100/0.5
1f	CH_3	1	S	H	H	76	80.25	100/0.2
1g	CH_3	1	S	CH_3	H	71	79.49	105/0.2
1h	CH_3	1	S	CH_3	CH_3	79	80.05	105/0.2
1i	C_2H_5	1	S	H	H	70	93.59	110/0.2
1j	C_2H_5	1	S	CH_3	H	74	92.78	113/0.2
1k	C_2H_5	1	S	CH_3	CH_3	84	92.35	115/0.2
1l	C_3H_7	1	S	H	H	75	89.23	115/0.2
1m	C_3H_7	1	S	CH_3	H	76	89.07	118/0.2
1n	C_3H_7	1	S	CH_3	CH_3	73	88.74	125/0.2
2a	CH_3	1	O	CH_3	CH_3	75	27.15	85/0.5
2b	C_2H_5	1	O	CH_3	CH_3	70	30.65	85/0.5
2c	C_3H_7	1	O	CH_3	CH_3	82	29.64	95/0.5
2d	$^iC_3H_7$	1	O	CH_3	CH_3	82	34.15	90/0.5

Experimental

General

Melting points were determined on a hot stage microscope and are uncorrected. IR spectra were recorded on Bruker FT-IR spectrometer model Tensor 27 on KBr disk

and solid compounds were analyzed by making KBr pellets. ^{1}H and ^{31}P NMR spectra were recorded in $CDCl_3$ on Bruker DPX Avance FT- NMR at 400 and 162 MHz respectively using tetramethylsilane as an internal standard for ^{1}H and 85 % H_3PO_4 as an external standard for ^{31}P NMR. A Chemito GC model 1000 instrument was used with a flame ionization detector (FID). A capillary column (30m x 0.25mm I.D-BP5) packed with 5 % phenyl and 95% dimethyl polysiloxane (SGE) coated on fused silica was employed. The injection port and detector block were maintained at 280 ^{0}C and 260 ^{0}C respectively and the column oven was at programmed temperature profile started at 50 ^{0}C, ramped up to 280 ^{0}C at 25^{0}C/min. Nitrogen was used as carrier gas (at a flow rate of 30ml/min). Air for FID was supplied at 300ml/min and hydrogen at 30ml/min. In all analyses, 0.1µl sample was injected and peaks recorded on Iris32 data acquisition station. The GC-MS analyses were performed in EI (70 eV) in full scan mode with an Agilent 6890 GC equipped with a model 5973 mass selective detector (Agilent Technologies, USA). An SGE BPX5 capillary column with 30 m length x 0.32 mm internal diameter x 0.25 µm film thickness was used at temperature program of 80 ^{0}C (2 min)-20 ^{0}C / min-280 ^{0}C (3 min). Helium was used as the carrier gas at a constant flow rate of 1.2 ml/min.

Preparation of Na_2CO_3-Celite: Na_2CO_3 -Celite was prepared by combination of Na_2CO_3 (0.2mole, 20.6g) and Celite (Celite®521, 0.2mole, 12.0g)) in a mortar and pestle by grinding together until a fine, homogenous powder was obtained (10-15 min). It was mixed with 150 ml of distilled water and stirred for 1h at room temperature and then water was removed under vacuum using Heidolph rotary evaporator till dryness. It was shaken with 100 ml acetone, filtered and washed with 3x25 ml acetone. It was further dried under vacuum at 150^{0}C for 2h and stored in a stoppered flask under desiccators.

Experimental procedure for cyclic alkylphosphonates: Alkanediol (0.01mol) and Na_2CO_3 –Celite (3.12g, 0.02mol) was mixed and the reaction mixture was grinded with a pestle in the mortar for 10 min. Appropriate alkylphosphonic dichloride or alkylthiophosphonic dichloride (0.01 mol) was mixed and reaction mixture was further grinded for 20 -30 min at 60 ^{0}C.The progress of reaction was monitored by TLC and ^{31}P NMR after drawing few milligram of reaction mixture and extracting with ether. After disappearance of the alkyl phosphonicdichloride signal in ^{31}P NMR, the reaction mixture was washed with ether, filtered and the solvent was evaporated. The residue was distilled under vacuum to afford the pure compound. The boiling points and yield of the product is given in Table1.

Conclusion

In conclusion, we have developed a rapid and efficient surface mediated method for the synthesis of cyclic esters of alkylphosphonic acids with excellent yields. The main advantage of this method is that reactions were found clean and had operational simplicity. Since, column chromatography was not required to get the pure products, hence makes more attractive for organic chemists.

Spectral data

2, 4,6-Trimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 1a .

IR (υ cm^{-1}) : 2970 (C-H), 1290(P=O), 1060(P-O-C), 705 (P-C); ^{1}H NMR (δ ppm): 1.35 (d, 6H, CH_3), 1.50 (d, 3H, CH_3), 2.05 (m, 2H, CH_2), 4.35 (m, 2H, CH); GCMS (m/z %) : 164(5), 123(100), 97(95), 79(60), 71(23), 45(50), 43(42); Anal. Calcd. for $C_6H_{13}O_3P$: C, 43.90; H,7.98 %. Found: C, 43.93; H, 7.95 %.

2, 4 -Dimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 1b .
IR (υ cm^{-1}) : 2972 (C-H), 1293(P=O), 1063(P-O-C), 700 (P-C); ^1H NMR (δ ppm): 1.30 (d, 3H, CH_3), 1.50 (d, 3H, CH_3), 2.00 (m, 2H, CH_2), 4.10 (m, 1H, CH), 4.30 (m, 2H, CH_2); GCMS (m/z %) : 150(10), 123(30), 97(100), 79(65), 71(25), 54 (63), 43(71); Anal. Calcd. for $C_5H_{10}O_3P$: C, 40.41; H,7.39 %. Found: C, 40.40; H, 7.37 %.

2-Isopropyl-2-oxo-1, 3-dioxo-2-phosphacyclohexane 1c .
IR (υ cm^{-1}) : 2973 (C-H), 1290(P=O), 1060(P-O-C), 710 (P-C); ^1H NMR (δ ppm): 1.20 (dd, 6H, CH_3), 2.00 (m, 2H, CH_2), 2.05 (m, 2H, CH), 4.30 (m, 4H, CH_2); GCMS (m/z %) : 164(8), 149 (15),136(13), 122(100), 97(17), 92(19), 83(13) 65(25) ,58(50), 41(52); Anal. Calcd. for $C_6H_{13}O_3P$: C, 43.90; H,7.98 %. Found: C, 43.89; H, 8.00 %.

2–Isopropy-4-methyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 1d .
IR (υ cm^{-1}) : 2972 (C-H), 1295(P=O), 1063(P-O-C), 708 (P-C); ^1H NMR (δ ppm): 1.20 (dd, 6H, CH_3), 1.7(d, 3H, CH_3), 2.05 (m, 2H, CH_2), 2.05 (m, 2H, CH), 4.05 (m, 1H, CH), 4.35 (m, 2H, CH_2); GCMS (m/z %) : 178(15), 163 (11),136(95), 125(63), 109(65), 97(22), 92(35), 82(23) 65(43) ,55(78),43(100) 41(48); Anal. Calcd. for $C_7H_{15}O_3P$: C, 47.19; H,8.49 %. Found: C, 49.20; H, 8.50 %.

2–Isopropy-4,6-dimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 1e .
IR (υ cm^{-1}) : 2970 (C-H), 1293 (P=O), 1064(P-O-C), 709 (P-C); ^1H NMR (δ ppm): 1.20 (dd, 6H, CH_3), 1.7(d, 6H, CH_3), 2.10 (m, 2H, CH_2), 2.05 (m, 2H, CH), 4.15 (m, 2H, CH); GCMS (m/z %) : 192(7), 177 (4), 151(52),135(12), 125(75), 109(35), (96(29), 91(8), 82(5) 69(45), 55(21), 43(100) 41(84); Anal. Calcd. for $C_7H_{15}O_3P$: C, 49.99; H,8.92 %. Found: C, 50.00; H, 8.90 %.

2-Methyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1f .
IR (υ cm^{-1}) : 2965 (C-H), 1060(P-O-C), 745(P=S), 680 (P-C); ^1H NMR (δ ppm): 1.50 (d, 3H, CH_3), 2.09 (m, 2H, CH_2), 4.25 (m, 4H, CH_2); GCMS (m/z %) : 152(100), 119(23), 95(26), 80(19), 74(27), 47 (33), 41(43); Anal. Calcd. for $C_4H_9O_2PS$: C, 31.58; H,5.96 %. Found: C, 31.60; H, 6.00 %.

2,4-Dimethyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1g .
IR (υ cm^{-1}) : 2965 (C-H), 1065(P-O-C), 750(P=S), 690 (P-C); ^1H NMR (δ ppm): 1.30 (d, 3H, CH_3), 1.50 (d, 3H, CH_3), 2.08 (m, 2H, CH_2), 4.10 (m, 1H, CH), 4.25 (m, 4H, CH_2); GCMS (m/z %) : 166(100), 112(43), 95(39), 79(19), 71(27), 55(57), 47 (33), 43(40); Anal. Calcd. for $C_5H_{11}O_2PS$: C, 36.14; H,6.67 %. Found: C, 36.15; H, 6.70 %.

2,4,6-Trimethyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1h .
IR (υ cm^{-1}) : 2980 (C-H), 1050(P-O-C), 730(P=S), 700 (P-C); ^1H NMR (δ ppm): 1.30 (d, 6H, CH_3), 1.50 (d, 3H, CH_3), 2.05 (m, 2H, CH_2), 4.15 (m, 2H, CH); GCMS (m/z %) : 180(100), 113(93), 95(53), 79(21), 71(27),69(71), 55(57), 47 (33), 43(69); Anal. Calcd. for $C_5H_{11}O_2PS$: C, 39.99; H,7.27 %. Found: C, 40.00; H, 7.30 %.

2-Ethyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1i .
IR (υ cm^{-1}) : 2970 (C-H), 1040(P-O-C), 728(P=S), 700 (P-C); ^1H NMR (δ ppm): 1.20(m, 3H,CH_3), 1.83 (m, 2H, CH_2), 2.09 (m, 2H, CH_2), 4.25 (m, 4H, CH_2); GCMS (m/z %) : 166(75), 138(45), 105(100), 80(19), 74(27),65(30), 47 (22), 41(35); Anal. Calcd. for $C_5H_{11}O_2PS$: C, 36.14; H,6.67 %. Found: C, 36.15; H, 6.70 %.

2-Ethy-4-methyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1j .
IR (υ cm^{-1}) : 2975 (C-H), 1045(P-O-C), 730(P=S), 710 (P-C); ^1H NMR (δ ppm): 1.10(m, 3H,CH_3), 1.28 (d, 3H, CH_3), 1.85 (m, 2H, CH_2), 2.05 (m, 2H, CH_2), 4.12 (m, 1H, CH), 4.30 (m, 2H, CH_2); GCMS (m/z %) : 180(83), 152(9), 126(27),119(57), 109(17), 80(19), 71(23),63(11), 55(100), 47 (22), 43(24); Anal. Calcd. for $C_6H_{13}O_2PS$: C, 39.99; H,7.27 %. Found: C, 40.00; H, 7.30 %.

2-Ethy-4,6-dimethyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1k .

IR (υ cm^{-1}) : 2982 (C-H), 1050(P-O-C), 750(P=S), 690 (P-C); ^1H NMR (δ ppm): 1.20(m, 3H,CH_3), 1.30 (d, 6H, CH_3), 1.80 (m, 2H, CH_2), 2.00(m, 2H, CH_2), 4.10 (m, 2H, CH), 4.15 (m, 2H, CH_2); GCMS (m/z %) : 194(80), 139(25), 127(83),119(5), 110(37), 80(11), 71(23),69(100), 63(11), 55(7), 47 (22), 43(53); Anal. Calcd. for $C_7H_{15}O_2PS$: C, 43.29; H,7.78 %. Found: C, 43.30; H, 7.75 %.

2-Propyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1l .

IR (υ cm^{-1}) : 2980 (C-H), 1065(P-O-C), 730(P=S), 680 (P-C); ^1H NMR (δ ppm): 1.10(m, 3H,CH_3), 1.85 (m, 4H, CH_2), 2.00 (m, 2H, CH_2), 4.18 (m, 4H, CH_2); GCMS (m/z %) : 180(55), 138(35), 105(100), 65(21), 47 (9), 41(35); Anal. Calcd. for $C_6H_{13}O_2PS$: C, 39.99; H,7.27 %. Found: C, 39.95; H, 7.29 %.

2-Propyl-4-methyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1m .

IR (υ cm^{-1}) : 2965 (C-H), 1055(P-O-C), 740(P=S), 685 (P-C); ^1H NMR (δ ppm): 1.05(m, 3H,CH_3), 1.35 (d, 3H, CH_3), 1.83 (m, 4H, CH_2), 2.09 (m, 2H, CH_2), 4.10 (m, 1H, CH), 4.25 (m, 2H, CH_2); GCMS (m/z %) : 194(53), 152(33), 140(5), 119(100), 55(82), 47 (4),43(15), 41(13); Anal. Calcd. for $C_7H_{15}O_2PS$: C, 43.29; H,7.78 %. Found: C, 43.30; H, 7.80 %.

2-Propyl-4-methyl-2-thio-1,3-dioxo-2-phosphacyclohexane 1n .

IR (υ cm^{-1}) : 2972 (C-H), 1063(P-O-C), 735(P=S), 700 (P-C); ^1H NMR (δ ppm): 1.10(m, 3H,CH_3), 1.30 (d, 6H, CH_3), 1.85 (m, 4H, CH_2), 2.09 (m, 2H, CH_2), 4.20 (m, 2H, CH); GCMS (m/z %) : 208(47),166(11), 151(3), 141(15),133(100), 123(18),69(91), 55(4), 47 (7), 43(45), 41(51); Anal. Calcd. for $C_7H_{15}O_2PS$: C, 46.14; H,8.23 %. Found: C, 46.15; H, 8.25 %.

2, 5, 5-Trimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 2a .

IR (υ cm^{-1}) : 2958 (C-H), 1265(P=O), 1055(P-O-C), 715 (P-C); ^1H NMR (δ ppm): 1.50 (d, 3H, CH_3), 1.85 (m, 6H, CH_3), 4.27 (m, 2H, CH); GCMS (m/z %) : 164(3), 97(55), 79(30), 71(6), 68(19), 56(100), 47(5), 41(22); Anal. Calcd. for $C_6H_{13}O_3P$: C, 43.90; H,7.98 %. Found: C, 43.95; H, 7.96 %.

2-Ethyl-5,5-dimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 2b .

IR (υ cm^{-1}) : 2985 (C-H), 1275(P=O), 1065(P-O-C), 695 (P-C); ^1H NMR (δ ppm): 1.20(m, 3H,CH_3),1.80 (m, 2H, CH_2), 1.85 (m, 6H, CH_3), 4.30 (m, 2H, CH); GCMS (m/z %) : 178(3),111(54), 93(25), 79(3), 71(5), 68(15), 56(100), 47(5), 41(22); Anal. Calcd. for $C_7H_{15}O_3P$: C, 47.19; H,8.49 %. Found: C, 49.20; H, 8.51 %.

2-Propyl-5,5-dimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 2c .

IR (υ cm^{-1}) : 2975 (C-H), 1280(P=O), 1060(P-O-C), 715 (P-C); ^1H NMR (δ ppm): 1.25(m, 3H,CH_3),1.80 (m, 2H, CH_2), 1.85 (m, 6H, CH_3),2.05(m,2H,CH_2), 4.35 (m, 2H, CH); GCMS (m/z %) : 192(7), 177 (14), 164(11), 150(15),135(12), 125(35), 109(35), 97(63), 68(55), 56(100), 43(10) 41(44); Anal. Calcd. for $C_7H_{15}O_3P$: C, 49.99; H,8.92 %. Found: C, 50.00; H, 8.90 %.

2–Isopropy-5,5-dimethyl-2-oxo-1,3-dioxo-2-phosphacyclohexane 2d .

IR (υ cm^{-1}) : 2980 (C-H), 1283 (P=O), 1045(P-O-C), 725 (P-C); ^1H NMR (δ ppm): 1.23 (dd, 6H, CH_3), 1.70(m, 6H, CH_3), 2.05 (m, 2H, CH), 4.15 (m, 4H, CH_2); GCMS (m/z %) : 192(7), 177 (4), 150(12), 125(65), 107(15), 96(2), 83(5) 68(35), 56(100), 43(23) 41(44); Anal. Calcd. for $C_7H_{15}O_3P$: C, 49.99; H,8.92 %. Found: C, 50.02; H, 8.91 %.

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References

1. R.Hildebrand, The Role of Phosphonates in Living Systems; CRC Press: Boca Raton, 1983.
2. (a) E. S. Papazoglou, Flame Retardants for Plastics. In Handbook of Building Materials for Fire Protection; C. A. Harper, Ed: McGraw-Hill: New York, p.4.1-4.88 (2004); (b) E. D. Weil, Phosphorus Flame Retardents. In Kirk-Othmer Encyclopedia of Chemical Technology; 4th ed.; John Wiley, New York, vol. 10, p. 976-998 (1993).
3. (a) C.Fest; K. J.Schmidt, The Chemistry of organophosphorus pesticides; Springer Verlag, Berlin 1982;(b) P.Hinkle; R. Y. McCarty, Sci. Amer. 104, 238 (1978).
4. (a) M. Eto, Organophosphorus Pesticides: Organic and Biological chemistry, CRC Press Inc. USA, p. 18 (1974); (b) R.Van Wazer John, Phosphorus and its Compounds Vol. II, Interscience Publishers, Inc. New York. 1961; (c) F.M.Ashton; A.S. Crafts, Mode of action of herbicides , Wiley Interscience, New York, 1973.
5. (a) G. M. Kosolapoff, Organic Phosphorus Compounds, Wiley-Interscience, New York, Vol. 6, 503 (1950); (b) P.Kafarski, B.Lejczak, Phosphorus Sulfur Silicon Relat. Elemn. 63, 193(1991);(c) E.Shi; C. Pei, Synthesis, 2995 (2004).
6. (a) J. P.Krise; V. J. Stella, Adv. Drug Delivery Rev. 19, 287, (1996);(b) R. Engel, Chem. Rev. 77, 349 (1977); (c) A. Whitehead; J.D. Moore; P.R. Hanson, Tetrahedron Lett. 44, 4275(2003).
7. B. Maryanoff ; A. Ritz, Chem. Rev. 89, 863(1989).
8. C. A. Verbicky; C. K. Zencher, J.Org. Chem., 65, 5615 (2000).
9. Convention on the Prohibition of the Development, Production, Stockpiling and use of Chemical Weapons and their Destruction, Technical Secretariat of the Organization for Prohibition of Chemical Weapons. The Hague, 1997. Available: http://www.opcw.nl.
10. Criteria for Designation of Laboratories (1997) OPCW-C-I/DEC.61, 22 May 1997.
11. J. Hendrikkse, A Comprehensive Review of the Official OPCW Proficiency Test in Chemical Weapons Chemical Analysis: Sample Collection, Preparation, and Analytical Methods, Ed. by Markku Mesilaakso, John Wiley & Sons Ltd., Chichester, UK, 89(2005).
12. E.W.J. Hooijshuur; A.G. Hulst; A.d. L. De Jong; L.P.De Reuver; S.H.Van Krimpen; B.L.M. Van Baar; E.R.J. Wils; C.E. Kientz; U.A.T. Brinkman, Trends Anal. Chem. 21, 116(2002).
13. M. Mesilaakso, Chemical Weapons Chemical Analysis: Sample Collection, Preparation, and Analytical Methods, Ed. by Markku Mesilaakso, John Wiley & Sons Ltd., Chichester, UK, 151(2005).
14. Evaluation of results, 19th Official Proficiency Test, OPCW Verification division, July 2006.
15. (a) A.K. Gupta; P.D.Shakya; D. Pardasani, M. Palit, D.K. Dubey, Rapid Commun. Mass Spectrom, 19, 975(2005).(b) A.K. Gupta; M. Palit; P.D. Shakya; D. Pardasani; R.K. Srivastava; D.K.Dubey, Eur. J. Mass Spectrom. 11, 309(2005).
16. C. Yuan; S. Cheng Liz, Synthesis, 3, 186(1988).
17. (a) Solvent-Free Organic Synthesis;Tanaka, K. Wiley-VCH: Weinheim,2003; (b) R. J . Gedye; K. Westaway; H. Ali; L.Baldisera; L. Laberge; J. Rousell, Tetrahedron Lett. 27, 279 (1986).

18. (a) R. J. Giguere; T. L. Bray; S. M. Duncan; G.Majetich, Tetrahedron Lett. 27, 4945 (1986) (b) A.Abramovitch, Org. Prep. Proc. Int. 23, 685 (1991) (c) , D. M. P.Migos; D. R. Baghurst, Chem. Soc. Rev. 20, 1 (1991). (d) S. Caddick, Tetrahedron, 51, 10403 (1995) .
19. A.Loupy; A.Petit; M.Ramdiani; C.Yvanaeff; M.Majdoub; B.Labiad; D.Villemin, Can. J. Chem. 71, 90 (1993). (b) A.Baezza; C.Najera; R.Gracia; J. M. Sansano, Synthesis, 16, 2787(2005).

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