Organosilicon Compounds XVII. Introduction of the Dialkyl Phosphonate and Dialkyl Thiophosphonate Moieties on an Organosilicon Substituted Heterocyclic System (1)

Shelby F. Thames, Laroy H. Edwards, Thornton N. Jacobs, Paul L. Grube, and Frank H. Pinkerton

University of Southern Mississippi, Box 5165, Hattiesburg, Mississippi 39401

Received May 5, 1972

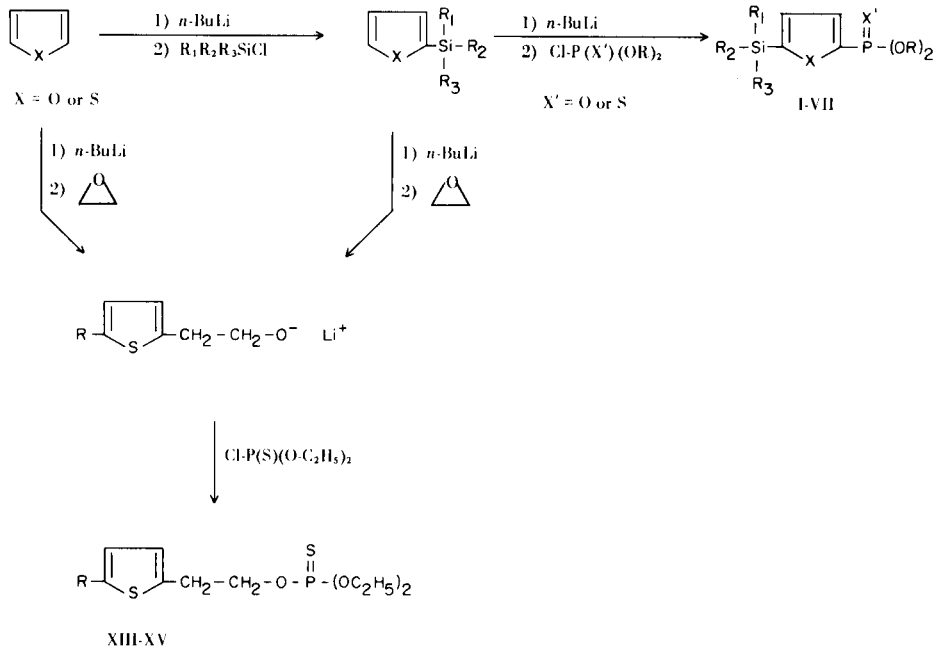
A number of new dialkyl 2-(5-trisubstitutedsilyl)thienylphosphonates and thiophosphonates as well as dialkyl 2-(5-trisubstitutedsilyl)furylphosphonates and thiophosphonates were prepared *via* reaction of the 5-(trisubstitutedsilyl)-2-lithiothiophenes and furans with dialkyl chlorophosphate and dialkyl chlorothiophosphate. Moreover, some diethyl 2-[5-(trisubstitutedsilyl)-2-thienyl]ethyl thiophosphates are reported.

Our interest in synthesizing physiologically active organosilicon containing agents has led us to prepare a number of derivatives, which possess the dialkyl phosphorus group in varying form, for pesticidal evaluation.

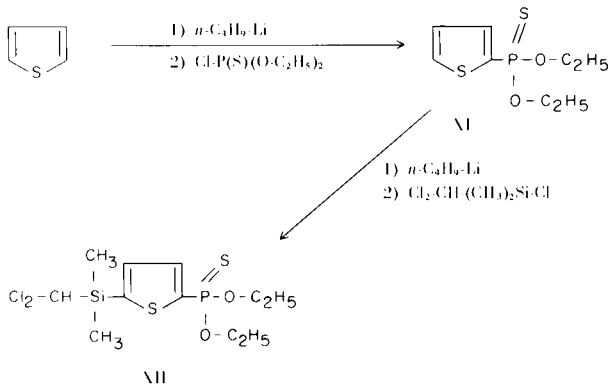
The synthesis of various organosilicon containing phosphonates (2), phosphates (3), and thiothionophosphates (4) are well documented as are phosphorus containing heterocycles (5). However, reports of heterocyclic systems which contain both a silicon and phosphorus group are nonexistent. Thus, we have prepared, for the first time, a number of organosilicon containing thiophosphonates (Scheme 1, 2, and 3) and thiophosphates (Scheme 1) as well as some phosphonates (Scheme 1 and 3), all of which possess the silicon- and phosphorus-groups substituted on a heterocyclic ring.

We have prepared these phosphonates by reaction of the corresponding 5-(trisubstitutedsilyl)-2-lithiothiophenes or furans with dialkyl chlorophosphate and dialkyl chlorothiophosphate (Scheme 1). The 5-(trisubstitutedsilyl)-thiophenes or furans were metalated with *n*-butyllithium followed by addition of these lithioheterocycles to the chlorophosphate (Scheme 1). Yields obtained by this

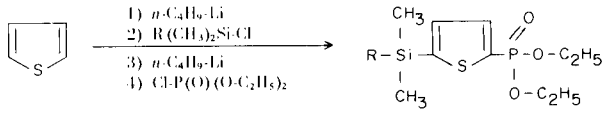
SCHEME 1



SCHEME 2



SCHEME 3



VIII R methyl
IX R allyl
X R vinyl

method ranged from 36 to 66%.

However, diethyl 2-(5-dichloromethyldimethylsilyl)-thienylthiophosphonate (XII) (Scheme 2) could not be prepared by this method since 2-(dichloromethyldimethylsilyl)thiophene could not be successfully metalated due to the reaction of *n*-butyllithium with the dichloromethyl group. Thus, diethyl 2-thienylthiophosphonate (XI) was prepared by metalation of thiophene with *n*-butyllithium and subsequent addition of the resulting 2-lithiothiophene to diethyl chlorothiophosphate (Scheme 2). Compound XII was then afforded by reaction of XI with *n*-butyllithium at -65° followed by the addition of this lithium salt to dichloromethyldimethylchlorosilane.

This data suggests that one can prepare dialkyl 2-(5-trisubstitutedsilyl)thienyl- or the 2-(5-trisubstitutedsilyl)-furylphosphonates or corresponding thiophosphonates by either metalation of the silyl-heterocycles or heterocyclic phosphonates with subsequent addition of these lithium salts to the chlorophosphates or chlorosilanes, respectively, in approximately the same yields.

The intermediate 2-(trisubstitutedsilyl)thiophenes or furans were synthesized *via* metalation of thiophene or furan with *n*-butyllithium followed by the addition of the appropriate chlorosilane. Compounds prepared by this procedure include, 2-(trimethylsilyl)furan and 2-(triethylsilyl)furan (6), 2-(trimethylsilyl)thiophene (7), and 2-(allyldimethylsilyl)thiophene (8).

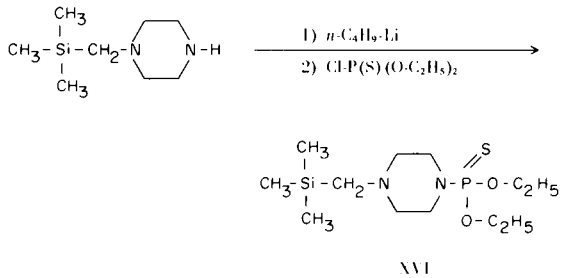
In addition, diethyl *N*-(trimethylsilylmethyl)-*N'*-(thiophosphonato)piperazine (XVI) which contains a phosphorus-nitrogen bond was prepared, in the above manner, by metalation of *N*-(trimethylsilylmethyl)piperazine with *n*-butyllithium followed by salt addition to diethyl chlorophosphate (Scheme 4). The compound *N*-(trimethylsilylmethyl)piperazine (Scheme 4) was prepared in the manner described by Thames and Edwards (9), *i.e.*, reaction of chloromethyltrimethylsilane with anhydrous piperazine in refluxing toluene in the presence of potassium carbonate.

We have found that for the preparation of dialkyl 2-(5-trisubstitutedsilyl)thienylphosphonates (Scheme 3) comparable yields could be obtained if the 2-(trisubstitutedsilyl)thiophenes were not isolated subsequent to their preparation, but were reacted *in situ* with *n*-butyllithium followed by the addition of this salt to the chlorophosphate (Scheme 3). For example, thiophene is allowed to react with *n*-butyllithium followed by the addition of the corresponding chlorosilane, at which time, *n*-butyllithium is again added, ample time is allowed for metalation to occur, and the resulting mixture of lithio salt is added to diethyl chlorophosphate to afford the expected diethyl 2-(5-trisubstitutedsilyl)thienylphosphonates in good yield (Scheme 3).

We have also prepared derivatives in which the phosphorus-containing moiety is removed from the heterocyclic system by an alkyl chain (Scheme 1). Thus, the 2-(trisubstitutedsilyl)thiophenes were metalated with *n*-butyllithium and then treated with ethylene oxide to provide the lithium salts of the corresponding 2-[5-(trisubstitutedsilyl)-2-thienyl]ethanols. These salts were not isolated, but added in solution to diethyl chlorothiophosphate to give the expected diethyl 2-[5-(trisubstitutedsilyl)-2-thienyl]ethyl thiophosphates (Scheme 1) in good yield.

The compound diethyl 2-(2-thienyl)ethyl thiophosphate (XV), prepared by the above method, has been reported by Godfrey (10); however, no physical constants or analytical data were given.

SCHEME 4



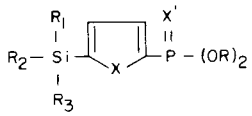
XVI

EXPERIMENTAL

The infrared spectra were determined with a Perkin-Elmer 257 grating spectrophotometer. Microanalyses were performed by

TABLE I

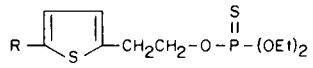
Dialkyl 2-(5-Silyl)heterocyclicphosphonates and Thiophosphonates



Compound	$R_1R_2R_3$	R	X,X′	% Yield	b.p. (°C)	n_D^{25}	Formula	Anal.	C	H	S	P	Si
I	Me,Me,Me	Et	O,S	56	102/0.6 mm	1.4876	$C_{11}H_{21}O_3PSSi$	Calcd.	45.21	7.19	10.96		
								Found	44.95	7.39	11.10		
II	Me,Me,Me	Et	S,S	46	110/0.25 mm	-----	$C_{11}H_{21}O_2PS_2Si$	Calcd.	42.86	6.82		10.06	
								Found	43.03	6.87		9.95	
III	Me,Me,allyl	Et	S,S	65	132/0.15 mm	1.5334	$C_{13}H_{23}O_2PS_2Si$	Calcd.	46.71	6.89	19.16		
								Found	46.82	6.88	19.29		
IV	Et,Et,Et	Et	O,O	36	139/0.3 mm	1.4736	$C_{14}H_{27}O_4PSi$	Calcd.	52.80	8.55			8.82
								Found	52.99	8.72			8.54
V	Et,Et,Et	Et	O,S	39	106/0.01 mm	1.4974	$C_{14}H_{27}O_3PSSi$	Calcd.	50.30	8.08	9.59		
								Found	50.22	8.11	9.31		
VI	Et,Et,Et	Me	O,S	38	100/0.03 mm	1.5036	$C_{12}H_{23}O_3PSSi$	Calcd.	47.06	7.51	10.47		
								Found	47.18	7.65	10.64		
VII	Me,Me,Me	Me	S,S	66	100/0.3 mm	1.5388	$C_9H_{17}O_2PS_2Si$	Calcd.	38.57	6.07	22.88		
								Found	38.76	6.19	22.65		
VIII	Me,Me,Me	Et	S,O	31	103/0.07 mm	1.4905	$C_{11}H_{21}O_3PSSi$	Calcd.	45.25	7.20			
								Found	45.47	7.04			
IX	Me,Me,allyl	Et	S,O	46	136/0.37 mm	1.5030	$C_{13}H_{23}O_3PSSi$	Calcd.	49.10	7.24			
								Found	49.16	7.28			
X	Me,Me,vinyl	Et	S,O	54.6	96/0.025 mm	1.5025	$C_{12}H_{21}O_3PSSi$	Calcd.	47.40	6.91			
								Found	47.39	6.73			
XII	Me,Me,-$CHCl_2$	Et	S,S	44	142/0.05 mm	1.5454	$C_{11}H_{19}Cl_2O_2PS_2Si$	Calcd.	35.11	5.05	17.02		
								Found	35.26	5.10	17.21		

TABLE II

Diethyl 2-(5-Silyl-2-thienyl)ethyl Thiophosphates



Compound	R	% Yield	b.p. (°C)	n_D^{25}	Formula	Anal.	C	H	S	P
XIII	Me_3Si	51	134/0.025 mm	1.5005	$C_{13}H_{25}O_3PS_2Si$	Calcd.	44.32	7.10	18.18	8.81
						Found	44.52	7.21	18.52	8.93
XIV	CH_2=CH-$CH_2(Me)_2Si$-	62.5	151/0.07 mm	1.5136	$C_{15}H_{27}O_3PS_2Si$	Calcd.	47.62	7.14	16.93	
						Found	47.69	7.13	17.22	
XV	H	60	130/0.6 mm	1.5146	$C_{10}H_{17}O_3PS_2$	Calcd.	42.86	6.07	22.86	
						Found	42.69	6.03	22.75	

Galbraith Laboratories, Knoxville, Tennessee. Distillations were carried out with a Vigreux column (12 in.), and all reactions were run under a nitrogen atmosphere.

Method A.

Diethyl 2-(5-Trimethylsilyl)furylthiophosphonate (I).

A solution of 2-(trimethylsilyl)furan (6) (10.0 g., 0.07 mole) and anhydrous ether (200 ml.) was placed in a 500 ml. flask to which was added, in a dropwise manner over a one hour period, *n*-butyllithium (44.5 ml., 0.07 mole). After stirring for 12 hours, the mixture was added, in a dropwise manner over a period of 2 hours, to a stirred solution of diethyl chlorothiophosphate (13.5 g., 0.07 mole) in 100 ml. of anhydrous ether precooled to -10°. This latter mixture was stirred for 24 hours, at which time, after filtering, the ether was removed *in vacuo*. Fractionation of the residue afforded 11.6 g. (56%) of I boiling at 102°/0.6 mm, n_D^{24} 1.4876.

Anal. Calcd. for $C_{11}H_{21}O_3PSSi$: C, 45.21; H, 7.19; S, 10.96. Found: C, 44.95; H, 7.39; S, 11.10.

A procedure identical to that described above was utilized in the synthesis of diethyl 2-(5-trimethylsilyl)thienylthiophosphonate (II), diethyl 2-(5-allyldimethylsilyl)thienylthiophosphonate (III), diethyl 2-(5-triethylsilyl)furylphosphonate (IV), diethyl 2-(5-triethylsilyl)furylthiophosphonate (V), dimethyl 2-(5-triethylsilyl)furylthiophosphonate (VI), and dimethyl 2-(5-trimethylsilyl)-thienylthiophosphonate (VII). Experimental data for these compounds is given in Table I.

Diethyl *N*-(Trimethylsilylmethyl)-*N'*-(thiophosphonato)piperazine (XVI).

The reaction of *N*-(trimethylsilylmethyl)piperazine (9) (6.0 g., 0.035 mole) and *n*-butyllithium (22 ml., 0.035 mole) at -10° over a 20 minute period followed by reaction with diethyl chlorothiophosphate (6.5 g., 0.035 mole) in the manner described for the preparation of I afforded 6.0 g. (53%) of XVI boiling at 94-96°/0.1 mm, n_D^{24} = 1.4845.

Anal. Calcd. for $C_{12}H_{29}N_2O_2PSSi$: C, 44.44; H, 8.95; S, 9.88. Found: C, 44.61; H, 9.18; S, 10.08.

Method B.

Diethyl 2-(5-Trimethylsilyl)thienylphosphonate (VIII).

To a solution of thiophene (8.4 g., 0.1 mole) in anhydrous ether (200 ml.), heated at reflux, was added *n*-butyllithium (62 ml., 0.1 mole). The mixture was stirred at reflux for 2 hours, at which time, trimethylchlorosilane (10.8 g., 0.1 mole) was added rapidly and stirred for 2 hours. At this point *n*-butyllithium (62 ml., 0.1 mole) was added and stirred for 3 hours at reflux. The ethereal solution of lithio salt was then added to a stirred solution of diethyl chlorophosphate (17.2 g., 0.1 mole). Stirring was continued for 14 hours at which time the solution was washed with sodium bicarbonate solution, the resulting layers separated, and the ethereal layer dried over magnesium sulfate. The ethereal layer was concentrated *in vacuo* and fractionated to give 9.0 g. (31%) of VIII boiling at 103°/0.07 mm., n_D^{25} 1.4905.

Anal. Calcd. for $C_{11}H_{21}O_3PSSi$: C, 45.25; H, 7.20. Found: C, 45.47; H, 7.04.

Method B was utilized in the synthesis of diethyl 2-(5-allyldimethylsilyl)thienylphosphonate (IX) and diethyl 2-(5-vinyldimethylsilyl)thienylphosphonate (X). Experimental data for these compounds is listed in Table I.

Method C.

Diethyl 2-Thienylthiophosphonate (XI).

Thiophene (10.0 g., 0.12 mole), *n*-butyllithium (75 ml., 0.12 mole) and diethyl chlorothiophosphate (22.4 g., 0.12 mole) were reacted as described in the synthesis of I (Method A) to give 16.0 g. (58%) of XI boiling at 85-87°/0.25 mm, n_D^{19} 1.5423.

Anal. Calcd. for $C_8H_{13}O_2PS_2$: C, 40.68; H, 5.51; S, 27.12. Found: C, 40.79; H, 5.61; S, 27.34.

Diethyl 2-(5-Dichloromethyldimethylsilyl)thienylthiophosphonate (XII).

A solution of XI (5.0 g., 0.02 mole) in anhydrous ether (200 ml.) was cooled to -65°, at which time *n*-butyllithium (13 ml., 0.02 mole) was added. After stirring for 15 minutes, the mixture was added rapidly to a stirred solution of dichloromethyldimethylchlorosilane (3.7 g., 0.02 mole) in anhydrous ether (100 ml.) at -10°. This latter mixture was stirred for 48 hours, filtered, and concentrated *in vacuo*. Fractionation afforded 3.5 g. (44%) of XII boiling at 140-142°/0.05 mm, n_D^{25} 1.5454.

Anal. Calcd. for $C_{11}H_{19}Cl_2O_2PS_2Si$: C, 35.11; H, 5.05; S, 17.02. Found: C, 35.26; H, 5.10; S, 17.21.

Method D.

Diethyl 2-[5-(Trimethylsilyl)-2-thienyl]ethyl Thiophosphate (XIII).

To a solution of 2-(trimethylsilyl)thiophene (7) (7.8 g., 0.05 mole) in anhydrous ether (200 ml.) was added *n*-butyllithium (31 ml., 0.05 mole). After stirring for 24 hours, the solution was cooled to -10° and ethylene oxide (2.2 g., 0.05 mole) was added. The mixture, after being brought to ambient conditions, was stirred for 4 hours, at which time it was added in a dropwise

manner to a stirred solution of diethyl chlorothiophosphate (9.4 g., 0.05 mole) in anhydrous ether at -10°. After the addition was complete, stirring was continued for 24 hours, after which the solution was filtered and concentrated *in vacuo*. Fractionation of the residue produced 9.0 g. (51%) of XIII boiling at 132-134°/0.025 mm, n_D^{25} 1.5005.

Anal. Calcd. for $C_{13}H_{25}O_3PS_2Si$: C, 44.32; H, 7.10; P, 8.81; S, 18.18. Found: C, 44.52; H, 7.21; P, 8.93; S, 18.52.

Method D was utilized in the synthesis of diethyl 2-[5-(allyldimethylsilyl)-2-thienyl]ethyl thiophosphate (XIV) and diethyl 2-(2-thienyl)ethyl thiophosphate (XV). Experimental data for these compounds is listed in Table II.

REFERENCES

(1) This investigation was supported in part by Diamond-Shamrock Corporation, who provided T. N. J. and P. L. G. with financial assistance, and by the National Aeronautics and Space Administration, who provided L. H. E. with a predoctoral research fellowship. Previous communication in this series, Organosilicon Compounds XVI, *J. Heterocyclic Chem.*, **9**, 725 (1972).

(2) R. W. Bott, B. F. Dowden, and C. Eaborn, *J. Organometal. Chem.*, **4**, 291 (1965); *ibid.*, *J. Chem. Soc.*, 4994 (1965); W. H. Keeber, *Diss. Abstr. B*, **28**, 1854 (1967); *Chem. Abstr.*, **68**, 78340 (1968); N. F. Orlov and B. L. Kaufman, *Zh. Obshch. Khim.*, 37, 2320 (1967); *Chem. Abstr.*, **68**, 87343q (1968); A. E. Canavan and C. Eaborn, *J. Chem. Soc.*, 592 (1962); *ibid.*, 3751 (1959); G. H. Barns, Jr. and M. P. David, *J. Org. Chem.*, **25**, 1191 (1960); W. H. Keeber and H. W. Post, *ibid.*, **21**, 509 (1956); F. Feher, G. Kuhlborsch, A. Blumcke, H. Keller, and K. Lippert, *Chem. Ber.*, **90**, 134 (1957).

(3) K. A. Andrianov and I. K. Kuznetsova, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk.*, 1454 (1961); *Chem. Abstr.*, **56**, 501 (1962), R. Schwarz and K. Schoeller, *Chem. Ber.*, **91**, 210° (1958).

(4) F. Feher and A. Blumcke, *ibid.*, **90**, 1934 (1957).

(5) R. H. Rigterink, U.S. Patent 3,399,205 (Aug. 27, 1968); *Chem. Abstr.*, **69**, 96483h (1968); U.S. Patent 3,385,859 (May 28, 1968); *Chem. Abstr.*, **69**, 19105r (1968), Mobil Oil Corp. British Patent 1,097,634 (Jan. 3, 1968); *Chem. Abstr.*, **69**, 10353f (1968); T. M. Melton, U.S. Patent 3,336,314 (Aug. 15, (1967); *Chem. Abstr.*, **68**, 68898h (1968), J. B. Levy, *Diss. Abstr. B*, 27, 4315 (1967); *Chem. Abstr.*, **68**, 2952q (1968); M. Bentov, L. David, and E. D. Bergmann, *J. Chem. Soc.*, 4750 (1964).

(6) E. Lukevics and M. G. Voronkov, *Khim. Geterotskl. Soedin.*, 31, (1965); *Chem. Abstr.*, **63**, 2994 (1965).

(7) R. A. Benkeser and R. B. Currie, *J. Am. Chem. Soc.*, **70**, 1780 (1948).

(8) S. F. Thames, J. E. McClesky and P. L. Kelly, *J. Heterocyclic Chem.*, **5**, 749 (1968).

(9) S. F. Thames and L. H. Edwards, *J. Chem. Soc.* (C), 2339 (1968).

(10) K. L. Godfrey, U.S. Patent 3,205,238 (Sept. 7, 1965); *Chem. Abstr.*, **63**, 18032h (1965).