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ORGANOPHOSPHORUS CHEMISTRY–II

P^1P^2-DISUBSTITUTED PYROPHOSPHORIC ACIDS FORMATION FROM ORGANOTHIOPHOSPHORYL DICHLORIDES OR ORGANOPHOSPHORUS(III) DICHLORIDES AND DIMETHYL SULPHOXIDE*

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Abstract—Organothiophosphoryl dichlorides and organophosphorus(III) dichlorides undergo a strongly exothermic reaction with DMSO to give P^1P^2-disubstituted pyrophosphoric acids. Reaction involving P=O bond formation by oxidation of P(S) or P(III) compounds has been found to occur.

$MeSCH_2Cl$, $(MeS)_2CH_2$, Me_2S and Me_2S_2 were the sulphur compounds detected as by-product of the reaction. Elemental sulphur also separated in the cases that thiophosphoryl compounds were used in the reaction.

INTRODUCTION

Recently it has been demonstrated that organophosphorus(V) dichlorides react with dimethyl sulphoxide (DMSO) to give P^1P^2-disubstituted pyrophosphoric acids.[1]

We have found that organothiophosphoryl dichlorides and organophosphorus(III) dichlorides react with DMSO to give also P^1P^2-disubstituted pyrophosphoric acids. P=O formation is suggested. This assumption is supported by the fact that DMSO is an oxidising agent able to react with tervalent phosphorus compounds to give phosphoryl compounds[2] and because thiophosphoric and dithiophosphoric acids[3,4] are converted into the sulphur-free analogues and elemental sulphur, DMSO being reduced to dimethyl sulphide.

This paper is concerned with the general reactions described in Scheme 1.

RESULTS AND DISCUSSION

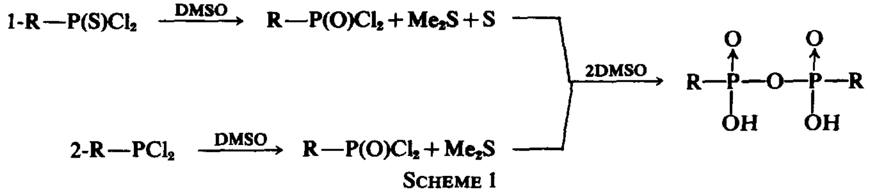
Reactions of the organophosphorus dichlorides with DMSO are rapid and quite exothermic. To moderate, dilution with anhydrous solvents and cooling in ice bath is necessary.

Pyrophosphates or pyrophosphonates were obtained from a 1:3 molar ratio of $R\text{-}P(S)Cl_2$ or $R\text{-}PCl_2$: DMSO in acetonitrile (Table 1). By comparison of their physical and spectral data with authentic samples,[1] they were found to be *vis-a-vis* identical.

Attempts to isolate or detect any $R\text{-}P(O)Cl_2$ as oxidative desulphurization product from organothiophosphoryl dichlorides with DMSO (1:1 molar ratio) in 1,2-dimethoxyethane were unsuccessful. P^1P^2-disubstituted pyrophosphoric acids (yield between 20–30%), Me_2S (yield by GLC between 40–60%), S (yield between 30–44%) and a complex mixture of sulphurated side-products (detected by GLC) were obtained. Sulphur separated as a solid, which was partially soluble in CS_2 (crystalline S), while the residue was insoluble, but soluble in piperidine with red coloration (amorphous S).

Assuming the mechanism previously proposed,[1] the course of the phosphorylation from $R\text{-}P(S)Cl_2$ might occur following the reactions sequences represented by Scheme 2.

Initial unstable sulphonium salt (1) formation is assumed.[1] Rearrangement to the cyclic form[4] (2) and subsequent intramolecular collapse, because of the strong (p → d)π interaction which stabilizes the resulting phosphoryl group, to give $R\text{-}P(O)Cl_2$



$$1\text{-}R{-}P(S)Cl_2 \xrightarrow{DMSO} R{-}P(O)Cl_2 + Me_2S + S$$

$$2\text{-}R{-}PCl_2 \xrightarrow{DMSO} R{-}P(O)Cl_2 + Me_2S$$

$$\xrightarrow{2DMSO} R{-}\underset{OH}{\overset{O\uparrow}{P}}{-}O{-}\underset{OH}{\overset{O\uparrow}{P}}{-}R$$

SCHEME 1

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*For Part I see ref. 1.

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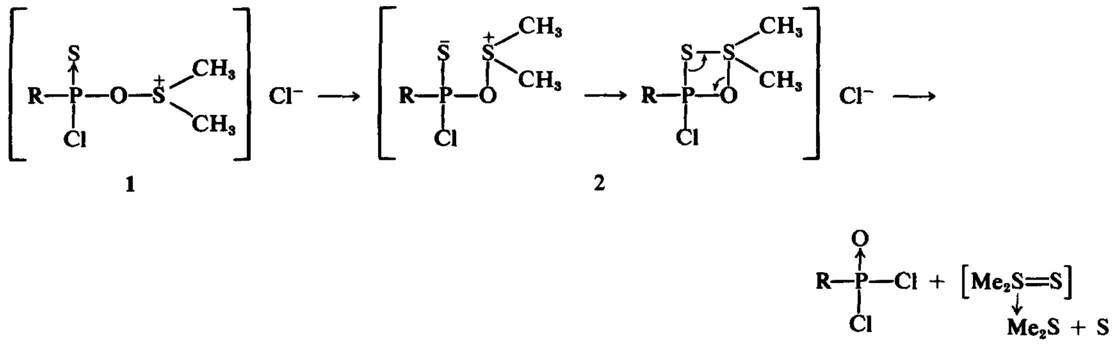

SCHEME 2

Table 1. Reaction of organothiophosphoryl and organophosphorus(III) dichlorides with DMSO

R—P(S)Cl$_2$: DMSO 1 : 3	R—P(O)—O—P(O)—R^a (OH, OH) Yield	S Yield
R=Me	60% as free anhydride	99%
=Et	66% as cyclohexyl amine salt (recryst. from water-acetone)	45%
=PhO	78% as cyclohexyl amine salt (recryst. from water)	75%
R—PCl$_2$: DMSO 1 : 3		
R=Me	29% as free anhydride	
=Et	52% as cyclohexyl amine salt (recryst. from water-acetone)	
=Ph	99% as anilinum salt (recryst. from EtOH—C$_6$H$_6$)^b	
=PhO	85% as cyclohexyl amine salt (recryst. from water)	

[a] In good agreement by comparison of their physical and spectral data with authentic samples;[1] [b] m.p. 184–185°, Found: C, 59·70; H, 5·75; N, 5·90. Calc. for $C_{12}H_{12}O_5P_2$-$(C_6H_5NH_2)_2$: C, 59·50; H, 5·41; N, 5·79.

and the transient thiosulphoxide[5] intermediate might be the following step. This last one loses S spontaneously to yield Me$_2$S.

After the R-P(O)Cl$_2$ formation, the course of reaction follows the previously postulated mechanistic scheme affording P^{1}P^2-disubstituted pyrophosphoric acids.[1]

The proposed mechanism might be assumed to proceed by attack on other P—S bond of the model sequences for the phosphorylation reaction previously described,[1] however it can be explained in terms of the initial decomposition of **1** to give the phosphoryl dichloride compounds. The following experimental results were observed: (a) all attempts to isolate or detect by GLC or PMR the oxygen dichloridate analogues were unsuccessful; (b) organopyrophosphoric acids were isolated from the mixture, while no thiopyrophosphoric acids were isolated; (c) in experiments carried out with methylphosphonic and methylphosphonothioic dichlorides, equimolar quantities in CCl$_4$ solution (in NMR sample tubes), showed the doublet signal corresponding to CH$_3$-P(O)(τ 7·5; $J_{P\text{-}CH_3}$ 16 c/s) to decrease until no signal was detected, when DMSO was added dropwise. Doublet signal corresponding to CH$_3$-P(S)(τ 7·2; $J_{P\text{-}CH_3}$ 16 c/s) was not affected until excess of 1 : 1 molar ratio of DMSO was added and, (d) in a separate experiment CH$_3$-P(S)Cl$_2$ was made react with DMSO added very slowly and the signal corresponding to the CH$_3$-P(O)Cl$_2$ was not observed.

The experimental results show that: (1) as organothiopyrophosphoric acids were not isolated it is plausible to assume that the oxidative desulphurization is prior to phosphorylation and, (2) the rate of reaction with R-P(O)Cl$_2$ compounds is faster compared with R-P(S)Cl$_2$ which is consistent with the greater electrophilic effect of the phosphoryl O compared to thiophosphoryl S and explains that no R-P(O)Cl$_2$ has been detected.

In the reaction of organophosphorus(III) dichlorides with DMSO (1 : 1 molar ratio) in CH$_2$Cl$_2$, we confirm the initial formation of the phosphoryl compounds (Table II) according to Amonoo-Neizer *et al.*,[2] but no attempt was made to establish optimum conditions for each reaction.

In every reaction, MeSCH$_2$Cl, (MeS)$_2$CH$_2$, Me$_2$S and Me$_2$S$_2$ were detected qualitatively by means of GLC (for experimental conditions see ref. 1) by comparison of their retention times with those of authentic samples and identified by PMR. An hypothetical pathway about their formation has been described.[1]

EXPERIMENTAL

M.ps were determined with a Buchi apparatus and are uncorrected. Proton NMR spectra were obtained with a Varian T-60 spectrometer using TMS as an internal standard and CCl$_4$ as solvent. GLC was carried out with an Aerograph 1522 B. IR spectra were measured with a Perkin-Elmer 337 spectrometer. Analysis were performed by the Microanalysis Laboratory of Fac. Cs. Exactas, UNBA, Buenos Aires, and by Bernhardt Laboratory, W. Germany. All the solvents were reagent

Table 2. Reaction of organophosphorus(III) dichlorides with DMSO

$R—PCl_2$: DMSO	$R—P(O)Cl_2$[a]			Me_2S[b]
1:1	Yield	b.p.	PMR in CCl_4	yield
R=Me	65%	80–84°/35 mm m.p. 32–33°	CH_3(d) τ 7·5; J_{P-CH_3} 16 cps	96%
=Et	64%	54–58°/22 mm	$2CH_3$(3H,t) at τ 8·9 and τ 8·4 J_{P-C-CH} 30 cps; CH_2(2H,m) τ 7·2	89%
=Ph	55%	155–159°/27 mm	Ph(m) τ 2·7–1·7	55%
=PhO	50%	150–155°/40 mm	Ph(m) τ 2·7	80%

[a]All were checked by PMR with authentic samples, [b]Analysis by GLC was performed on the fraction which distillated until 40° (column: 6 ft × ⅛″ o.d., SS packed with 15% Carbowax 20M on 60/80 mesh Chromosorb W. Carrier gas: N_2, flow rate 25 ml/min, column temp 60°) in good agreement with quantitative PMR spectroscopy.

grade and further dried by usual procedures. Methylphosphorous dichloride (MPD), PMR consisted of a CH_3(d) at τ 7·8 (J_{P-CH_3}18 c/s); ethylphosphonous dichloride (EPD), PMR consisted of a CH_3(3H, m) at τ 8·7 and of a CH_2(2H, m) at τ 7·7; methylphosphonothioic dichloride (MPTD), PMR consisted of a CH_3(d) at τ 7·2 (J_{P-CH_3}16 c/s), and ethylphosphonothioic dichloride (EPTD), PMR consisted of two CH_3(3H, t) at τ 8·8 and τ 8·3 (J_{P-C-CH}30 c/s) and a CH_2(2H, m) at τ 7·2 were obtained from Ethyl InterAmerica Corp. and were used without further purification. Phenylphosphonous dichloride was prepared as previously described[6], b.p. 117–120°/36 mm. PMR showed a complex multiplet over the range of τ 1·9–2·7. Phenylphosphonic dichloride was purchased from Aldrich and redistillated, b.p. 155–157°/27 mm. PMR spectra showed a complex multiplet between τ 1·7–2·7. Phenyl phosphorodichloridothionate was prepared according to Tolkmith,[7] b.p. 92–95°/6 mm. PMR showed a signal at τ 2·7. Phenylphosphorodichloridite was synthetized according to Tolkmith,[8] b.p. 102–104°/21 mm. PMR showed a multiplet centred at τ 2·8. All others reactives used were reported in Part I[1] of this series. All the reactions were carried out in moisture-free N_2 atmosphere and general experimental conditions previously described[1] have been used.

Attempts to detect organothiopyrophosphoric acids from $R-P(S)Cl_2$ *and DMSO reaction* (1:1 *molar ratio*)

DMSO (10 mmoles) dissolved in CH_2Cl_2 (1·5 ml) were made to react with a soln of the organothiophosphoryl dichloride (10 mmoles) in CH_2Cl_2 (1·5 ml) following the method previously described.[1] The product was centrifugated. The solid separated was washed twice with CH_2Cl_2. The last traces of solvent were evaporated *in vacuo* and the solid again washed with NH_4OH, MeOH and $(Et)_2O$ in this order, dried and characterized as elemental S. The ammoniacal soln was studied as indicated below. Solvent, unreacted $R-P(S)Cl_2$ and other volatile sulphurated side-products were removed by distillation at reduced pressure. The residue was taken up with NH_4OH and filtered. The alkaline extracts were combined and successively washed twice with recently distillated CS_2 and twice with CH_2Cl_2. The aqueous alkaline soln was acidified with HCl in order to decompose any R–SH salt, treated with activated carbon, warmed and filtered. The resulting colorless soln was evaporated under reduced pressure. S was investigated by conventional qualitative analysis. As traces were found, the residue of the evaporation was TLC analysed[9] (Silica gel "Kiesegel G Merck" (0·25 mm) was used as adsorbent. Solvent system: acetone 50: *t*-BuOH 40: water 10: conc. NH_4OH 10. The chromatogram was developed with Hanes and Isherwood[10] reagent). Thiono-thiol phosphorus compounds were not detected.

Attempts to isolate $R-P(O)Cl_2$ *from* $R-P(S)Cl_2$ *and DMSO reaction*

$R-P(S)Cl_2$ with DMSO (1:1 molar ratio) in 1,2-dimethoxy-ethane was made to react as previously reported.[1] The solid formed was separated by centrifuging. The supernatant was fractionated by distillation at reduced pressure. Every fraction was analysed by GLC (pyrex column, 10 ft × ⅛″ o.d., packed with 5% QFl-DC200 on 100/120 mesh Varaport 30. Carrier gas: N_2; flow rate: 25 ml/min; column temp 90°) by comparison of the retention times with pure specimens, by PMR and IR spectroscopy. Whilst the P=O band is absent, all the IR spectra exhibit the characteristic vibration of P=S bond (676 cm^{-1}).[11]

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REFERENCES

[1] M. A. Rúveda, E. N. Zerba and E. M. de Moutier Aldao, *Tetrahedron.*

[2] E. H. Amonoo-Neizer, S. K. Ray, R. A. Show and B. C. Smith, *J. Chem. Soc.* 4296 (1965).

[3] M. Mikolajczyk, *Angew. Chem.* Int. Ed. 5, 419 (1966).

[4] M. Mikolajczyk, *Chem. & Ind.* 2059 (1966).

[5] G. Hofle and J. E. Baldwing, *J. Am. Chem. Soc.* **93** (23), 6307 (1971).

[6] L. F. Fieser and M. Fieser, *Reagents for Organic Synthesis* p. 875. Wiley, New York (1967).

[7] H. Tolkmith, *J. Org. Chem.* **23**, 1685 (1958).

[8] H. Tolkmith, *Ibid.* **23**, 1682 (1958).

[9] A. Lamotte and J-C. Merlin, *J. Chromatog.* **38**, 296 (1968).

[10] G. S. Hanes and F. A. Isherwood, *Nature, Lond.* **164**, 1107 (1949).

[11] E. C. Corbridge, *The Infrared Spectra of Phosphorus Compounds, Topics in Phosphorus Chemistry* Vol. 6, p. 235. Wiley, New York (1969).