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THE REACTION OF PHOSPHITES WITH SULPHOXIDES[1]

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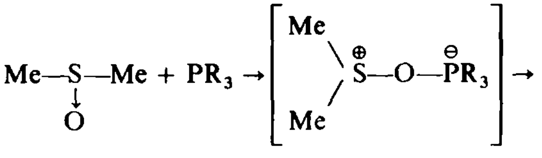
Abstract—In reactions between phosphites and sulphoxides, the basicity of the phosphorus atom in phosphites appears to play an important role in determining the reaction process. Triphenyl phosphite and diphenyl methyl phosphite were oxidized quantitatively to the corresponding phosphates by treating with phenyl methyl sulphoxide, while trimethyl phosphite was found to rearrange to dimethyl methylphosphonate by the catalytic action of sulphoxides. Similarly, triethyl phosphite was found to rearrange to diethyl ethylphosphonate. Dimethyl phenyl phosphite gave a mixture of dimethyl phenyl phosphate and a phenyl methyl methylphosphonate in the reaction with phenyl methyl sulphoxide.

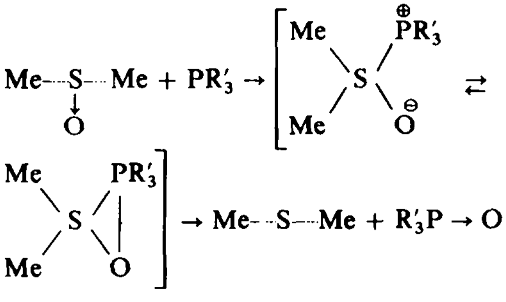
INTRODUCTION

TRIVALENT phosphorus compounds are known to be oxidized to the corresponding phosphine oxides or phosphates not only by strong oxidizing agents as peroxides,[2] peracids,[3] or peresters[4] but also weak oxidizing agents such as epoxides[5] and episulphides.[6] Both tertiary amine N-oxides[7] and sulphoxides[8] are also known to react similarly with trivalent phosphorus compounds to afford the corresponding oxides of the phosphorus compounds and the corresponding reduction products, i.e., amines and sulphides, respectively.

Amonoo-Neizer *et al.*[8a] reported that dimethyl sulphoxide was deoxygenated as shown in the following scheme.

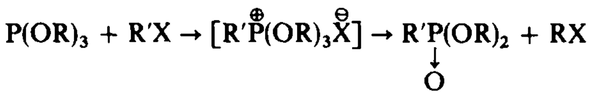


R = electron-withdrawing groups



R′ = electron-donating groups

When phenyl methyl sulphoxide was used, triphenyl phosphite was oxidized to triphenyl phosphate. However, we found unexpectedly that trialkyl phosphite rearranged to the corresponding dialkyl alkylphosphonate on reaction with sulphoxides though there were a few oxidation-reduction products. The reaction to form the phosphonate from the phosphite, known as the Michaelis-Arbuzov reaction[9] (eq. 1),

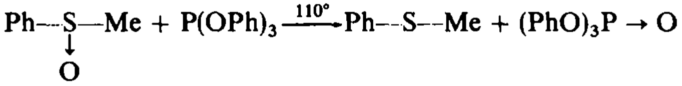


$$P(OR)_3 + R'X \rightarrow [R'\overset{\oplus}{P}(OR)_3\overset{\ominus}{X}] \rightarrow R'\underset{\substack{\downarrow\\ O}}{P}(OR)_2 + RX \qquad (1)$$

generally takes place in the presence of an alkylating agent. We have found a rearrangement of phosphites which is apparently catalyzed by sulphoxides, and hence carried out a somewhat detailed investigation in order to learn the nature of the reaction.

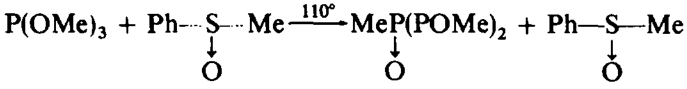
RESULTS AND DISCUSSIONS

In the reaction of triphenyl phosphite with phenyl methyl sulphoxide at 110° for 2-3 days, phenyl methyl sulphide was isolated in nearly quantitative yield by distillation, the reaction being shown by eq. 2.



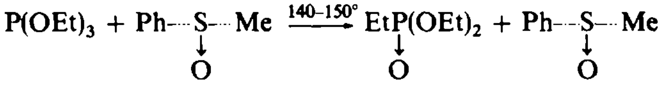
$$Ph-\underset{\substack{\downarrow\\ O}}{S}-Me + P(OPh)_3 \xrightarrow{110^\circ} Ph-S-Me + (PhO)_3P \rightarrow O \qquad (2)$$

However, when trimethyl phosphite was mixed with phenyl methyl sulphoxide at 110°, deoxygenation of sulphoxide did not take place but the rearrangement of trimethyl phosphite to dimethyl methylphosphonate was observed (eq. 3). Triethyl



$$P(OMe)_3 + Ph-\underset{\substack{\downarrow\\ O}}{S}-Me \xrightarrow{110^\circ} Me\underset{\substack{\downarrow\\ O}}{P}(POMe)_2 + Ph-\underset{\substack{\downarrow\\ O}}{S}-Me \qquad (3)$$

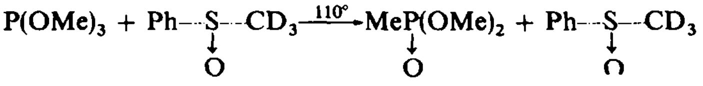
phosphite was also found to undergo a similar rearrangement at 140-150° (eq. 4). Other sulphoxides such as benzyl phenyl, phenyl ethyl and dimethyl sulphoxides



$$P(OEt)_3 + Ph-\underset{\substack{\downarrow\\ O}}{S}-Me \xrightarrow{140-150^\circ} Et\underset{\substack{\downarrow\\ O}}{P}(OEt)_2 + Ph-\underset{\substack{\downarrow\\ O}}{S}-Me \qquad (4)$$

were also effective for the rearrangement. Even by the use of a less than equivalent amount of sulphoxide this reaction was found to proceed. The results are summarized in Table 1. Thermal rearrangement of the phosphites did not occur under the same reaction conditions in the absence of sulphoxide.

In order to examine the possible exchange of the alkyl group with the sulphoxide during the reaction a tracer experiment was performed using phenyl methyl-d_3 sulphoxide in the reaction with the trimethyl phosphite. Dimethyl methyl-phosphonate thus produced by rearrangement, however, was found not to contain any deutero-methyl group from analysis of NMR spectrum (eq. 5).



$$P(OMe)_3 + Ph-\underset{\substack{\downarrow\\ O}}{S}-CD_3 \xrightarrow{110^\circ} Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2 + Ph-\underset{\substack{\downarrow\\ O}}{S}-CD_3 \qquad (5)$$

TABLE 1. THE REACTIONS OF PHOSPHITES WITH SULPHOXIDES AT 110°

Phosphite	Sulphoxide	Amount Used	Reac. Time (day)	Product	Yield (%)
$P(OMe)_3$	$Ph\underset{\substack{\downarrow\\ O}}{S}Me$	1:1	5	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$	quant.[a]
$P(OMe)_3$	$Ph\underset{\substack{\downarrow\\ O}}{S}Me$	2:1	7	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$	quant.[a]
$P(OMe)_3$	$Ph\underset{\substack{\downarrow\\ O}}{S}Et$	2:1	13	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$	70[a]
$P(OMe)_3$	$Ph\underset{\substack{\downarrow\\ O}}{S}CH_2Ph$	2:1	14	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$	90[a]
$P(OMe)_3$	$Me\underset{\substack{\downarrow\\ O}}{S}Me$	2:1	10	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$	40[c]
$P(OMe)_3$	$Ph\underset{\substack{\downarrow\\ O}}{S}Ph$	2:1	15	--	0[d]
$P(OEt)_3$[b]	$Ph\underset{\substack{\downarrow\\ O}}{S}Me$	2:1	16	$Et\underset{\substack{\downarrow\\ O}}{P}(OEt)_2$	80[a]

[a] Sulphoxide did not change through the reaction.

[b] The reaction was carried out at 140–150°.

[c] Dimethyl sulphide and trimethyl phosphate was also detected.

[d] The starting materials were recovered quantitatively.

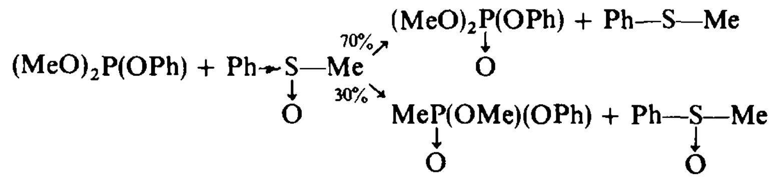
The result of the reactions of diphenyl methyl phosphite and dimethyl phenyl phosphite with phenyl methyl sulphoxide is shown in Table 2. Inspection of the data in Table 2 suggests that the mode of the reaction of phosphites with sulphoxides depends on the basicity of phosphorus atom in the phosphites. Thus the reaction is considered to proceed through either one or both of the following mechanistic routes (eq. 6).

TABLE 2. THE REACTION OF $(MeO)_xP(OPh)_{3-x}$ WITH PHENYL METHYL SULPHOXIDE AT 110°

Phosphite	Products
$P(OPh)_3$	Ph–S–Me, $(PhO)_3P \rightarrow O$
$(MeO)P(OPh)_2$[a]	Ph–S–Me,[b] $(MeO)(PhO)_2P \rightarrow O$
$(MeO)_2P(OPh)$[a]	70% Ph–S–Me and $(MeO)_2(PhO)P \rightarrow O$, 30% $Me\underset{\substack{\downarrow\\ O}}{P}(OMe)(OPh)$
$(MeO)_3P$	$Me\underset{\substack{\downarrow\\ O}}{P}(OMe)_2$

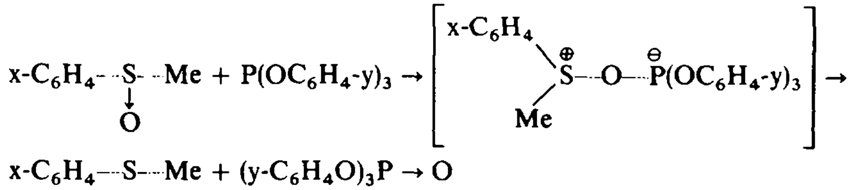
[a] Reaction mixture was heated for 4–5 days and the products were obtained quantitatively.

[b] The yield of phenyl methyl sulphide in this reaction was quantitative.



$$(MeO)_2P(OPh) + Ph\overset{}{\underset{\downarrow \atop O}{S}}\!-\!Me \;\begin{cases} \xrightarrow{70\%} (MeO)_2\underset{\downarrow \atop O}{P}(OPh) + Ph-S-Me \\ \xrightarrow{30\%} Me\underset{\downarrow \atop O}{P}(OMe)(OPh) + Ph-\underset{\downarrow \atop O}{S}-Me \end{cases} \quad (6)$$

In the deoxygenation of aryl methyl sulphoxide by triphenyl phosphite a preliminary kinetic study showed that the rates of reduction were in the following order: *p*-methylphenyl methyl sulphoxide > phenyl methyl sulphoxide > *p*-chlorophenyl methyl sulphoxide: while deoxygenation did not take place in the presence of phenol. The rate of deoxygenation of phenyl methyl sulphoxide with tris(*p*-chlorophenyl) phosphite was faster than that with triphenyl phosphite. These results suggest clearly that the phosphorus atom of the phosphite acts as an electrophile and attacks the oxygen atom of the sulphoxide as postulated by Amonoo-Neizer *et al.*[8a] (eq. 7).



$$x\text{-}C_6H_4-\underset{\downarrow \atop O}{S}-Me + P(OC_6H_4\text{-}y)_3 \rightarrow \left[\begin{matrix} x\text{-}C_6H_4 \\ Me \end{matrix} \!\!>\! \overset{\oplus}{S}-O-\overset{\ominus}{P}(OC_6H_4\text{-}y)_3 \right] \rightarrow$$

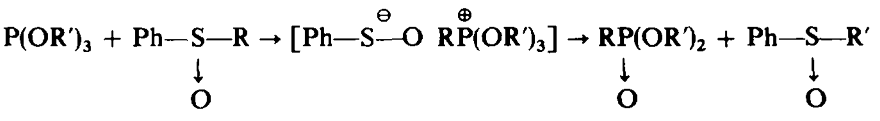
$$x\text{-}C_6H_4-S-Me + (y\text{-}C_6H_4O)_3P \rightarrow O \quad (7)$$

$x = p\text{-Me}, H, p\text{-Cl} : y = H, p\text{-Cl}$

Trimethyl phosphite and triethyl phosphite rearranged to the corresponding phosphonates in the reactions catalysed by sulphoxides, while in the reaction of triphenylphosphine with phenyl methyl sulphoxide (without solvent at 150–180° for 5 days) starting materials were quantitatively recovered. Meanwhile, it was reported that triphenylphosphine is oxidized to triphenylphosphine oxide by sulphoxides in refluxing CCl_4[8b] or in the presence of a Lewis-acid such as BF_3[8c].

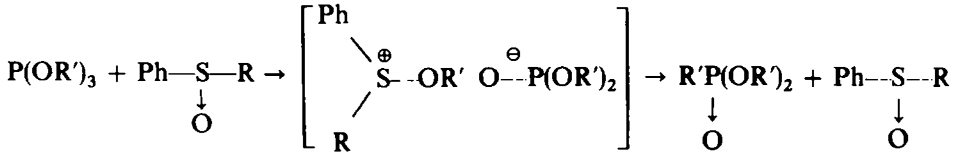
Two possible mechanisms may be postulated for this rearrangement reaction of phosphites. The first mechanism is a Michaelis-Arbuzov type, while the other involves prior alkylation of sulphoxide oxygen and subsequent realkylation to form the *p*-alkylation product. The first mechanism is apparently ruled out by the following two observations: there is no incorporation of a deuteromethyl group in the dimethyl methylphosphonate formed by the reaction of trimethyl phosphite and phenyl methyl-d_3 sulphoxide while in the reaction of trimethyl phosphite with phenyl ethyl sulphoxide no dimethyl ethylphosphonate but only dimethyl methylphosphonate was formed. On the other hand, in view of the fact that the rate of rearrangement of phosphite is larger than that in the absence of phosphonate,[10] the second mechanism seems to be more attractive.

Path 1



$$P(OR')_3 + Ph-\underset{\downarrow \atop O}{S}-R \rightarrow [Ph-S-\overset{\ominus}{O}\;\overset{\oplus}{R}P(OR')_3] \rightarrow R\underset{\downarrow \atop O}{P}(OR')_2 + Ph-\underset{\downarrow \atop O}{S}-R'$$

Path 2



EXPERIMENTAL

Sulphoxides. The sulphoxides listed below were prepared by oxidation of the corresponding sulphides by Br_2 in the presence of pyridine in AcOH and water, according to the usual procedure.[11]
phenyl methyl sulphoxide b.p. 110°/1-2 mm (lit.[11] b.p. 84°/0·25 mm)
p-chlorophenyl methyl sulphoxide m.p. 46 47° (lit [11] m p. 47-48)
p-methylphenyl methyl sulphoxide m.p. 42–43° (lit.[11] m.p. 42–43°)
phenyl ethyl sulphoxide b.p. 101·5–102°/2 mm (lit.[12] b.p. 101–102°/1 mm)
phenyl benzyl sulphoxide m.p. 127° (lit.[13] m.p. 127°).

Dimethyl sulphoxide was purified by repeated vacuum distillation in the presence of NaH, b.p. 81–82°/20 mm (lit.[14] b.p. 86°/25 mm).

Diphenyl sulphoxide was prepared by the reaction of $SOCl_2$, C_6H_6 and $AlCl_3$, m.p. 70–71° (lit.[15] m.p. 71°).

Phenyl methyl-d_3 *sulphoxide.* After 2 g of phenyl methyl sulphoxide which was dissolved in 10 cc. of 5% NaOD solution was heated at 120–130° for 3 days the product was extracted with $CHCl_3$ and dried (sodium sulphate). $CHCl_3$ was evaporated, and 1·5 g of phenyl methyl-d_3 sulphoxide obtained upon vacuum distillation, b.p. 110–111°/1–2 mm. The deuterium content of this sulphoxide, (> 95%), was determined from the analysis of NMR spectrum.

Phosphites. Triphenyl phosphite and tris-(*p*-chlorophenyl)-phosphite were prepared by the reaction of the corresponding phenols (3 moles) with PCl_3 (1 mole) at 100–110° for 20 hr and the products dissolved in anhyd. C_6H_6. To this solution, KOH was added and excess phenol removed. Evaporation of C_6H_6 and repeated vacuum distillation gave pure phosphites.

Triphenyl phosphite b.p. 185–186°/1–2 mm (lit.[16] b.p. 184–185°/1 mm) Tris (*p*-chlorophenyl)phosphite b.p. 221–222°/2 mm (lit.[17] b.p. 230–231°/3 mm).

Pure trimethyl and triethyl phosphites were obtained by repeated fractionation after commercial phosphites were treated with Na for a day.

Trimethyl phosphite b.p. 110–111°/760 mm (lit.[18] b.p. 110–111·5°/745 mm)

Triethyl phosphite b.p. 155–156°/760 mm (lit.[19] b.p. 52°/14 mm).

Diphenyl methyl phosphite was prepared by treating $(MeO)PCl_2$[20] (1 mole) with pure phenol (2 moles) and Et_3N (2 moles) at 0–5° in anhyd. ether, b.p. 155°/5 mm (lit.[21] b.p. 169·5°/11 mm).

Dimethyl phenyl phosphite was similarly prepared by treating $(PhO)PCl_2$[22] (1 mole) with anhyd. MeOH (2 moles) and Et_3N (2 moles) at 0–5° in anhyd. ether, b.p. 98–99°/10 mm (lit.[21] b.p. 86°/12 mm).

The reaction of trimethyl phosphite with phenyl methyl sulphoxide. Phenyl methyl sulphoxide (2 g) and 6 g of triphenyl phosphite were heated at 110° for 3 days in a sealed tube giving 1·5 g of phenyl methyl sulphide containing a small amount of phenol (formed by decomposition of triphenyl phosphite) upon distillation. After washing the remaining residue with hexane recrystallization gave 3·5 g of triphenyl phosphate, m.p. 43–44° (lit.[23] m.p. 45°).

The reaction of trimethyl phosphite with phenyl methyl sulphoxide. Trimethyl phosphite (2 g) and 2 g of phenyl methyl sulphoxide were mixed, and heated at 110° for 5–6 days in a sealed tube. Distillation gave 1·9 g of dimethyl methylphosphonate, identified by comparing its IR, NMR and the GLC retention time with those of an authentic sample prepared by reaction of trimethyl phosphite with MeI. The NMR spectrum of this phosphonate in CCl_4 has two doublets, at 1·2 ppm ($J_{P\text{-}CH} = 17$ cps) and at 3·5 ppm ($J_{P\text{-}OCH} = 11$ cps) from the external TMS standard.

In other reactions of phosphites with sulphoxides the yields of the products were determined only by NMR or GLC measurements without isolation.

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