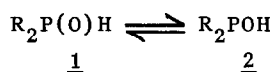DIALKOXYMETHYLATION OF PHOSPHORUS WITH TRIALKYL ORTHOFORMATES : REACTIONS

OF PHOSPHONIC AND PHOSPHINIC ACIDS VIA THEIR TRIVALENT TAUTOMERS

by

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The existence of the equilibrium ($\underline{1} \rightleftharpoons \underline{2}$) is generally accepted

$$R_2P(O)H \rightleftharpoons R_2POH$$
$$\underline{1} \qquad\qquad \underline{2}$$

but rests largely on indirect chemical evidence. With one

exception[1] there is no spectroscopic support for any P(III) character

in structures of type $\underline{1}$ though the corresponding ambient anions

($[R_2PO]^-$; R = alkyl or alkoxyl) are essentially P(III) as judged

by ^{31}P n.m.r.[2,3,4] We now report evidence suggesting that the

$P(III) \rightleftharpoons P(IV)$ equilibrium is rapidly attained under mild conditions

with phosphinic acid derivatives.

The preparation of methyl phosphinate, $\underline{3}$,   by the action of

an excess of trimethyl orthoformate on phosphinic acid[5] is accompanied

by the formation of a number of hitherto unrecognised by-products

whose structures may be assigned with confidence from the FT ^{31}P

n.m.r. (24.28 MHz) spectra.[6] Two compounds are thus identified in
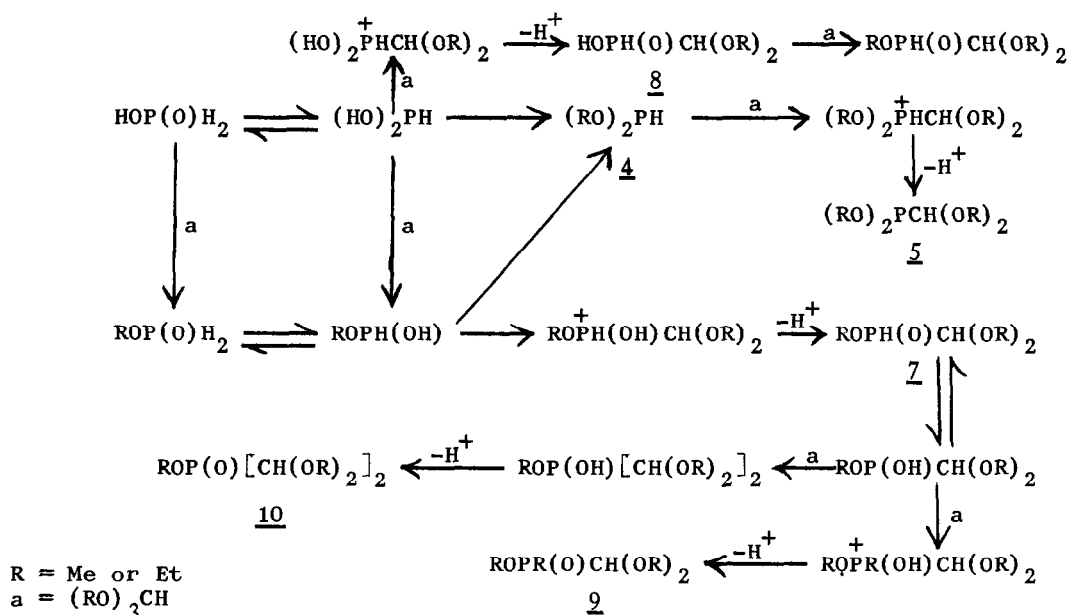
the lowfield region:

(a) dsp (δ 171.5, $^1J_{PH}$ 199 Hz, $^3J_{POCH}$ 9.6 Hz) due to

(MeO)$_2$PH, $\underline{4}$ (lit. vals:[7] δ 171, $^1J_{PH}$ 203 Hz, $^3J_{POCH}$ 9.4 Hz)

in a yield[8] of 3%

(b) sp (δ 157.9, $^3J_{POCH}$ 10.5 Hz); yield[8] 1-2%. The structure

$\underline{5}$ is chemically reasonable and accounts for the chemical

shift. The absence of further coupling is not too

surprising since $^2J_{P(III)CH}$ is often small ($<$1 Hz) in

acyclic compounds.

The P(IV) region of the spectrum shows, in addition to the principal product, methyl phosphinate ($\underline{3}$, δ 18.5, $\underline{tq}$, $^1J_{PH}$ 5 69 Hz, $^3J_{POCH}$ 12.8 Hz), and variable amounts (0-3%) of dimethyl phosphonate ($\underline{6}$, δ 10.8, $\underline{dsp}$, $^1J_{PH}$ 708 Hz, $^3J_{POCH}$ 12.1 Hz), a new compound ($\underline{ca}$. 10%) which is assigned the structure $\underline{7}$ (δ 29.3 $\underline{ddq}$, $^1J_{PH}$ 564 Hz, $^3J_{POCH}$ 11 Hz, $^2J_{PCH}$ 9 Hz). The PH proton ($\underline{dd}$, δ 6.9, $^1J_{PH}$ 566 Hz, $^3J_{POCH}$ 1.5 Hz), and the acetal proton ($\underline{dd}$, δ 4.67, $^2J_{PCH}$ 8 Hz, $^3J_{HPCH}$ 1.5 Hz) of $\underline{7}$ may also be seen in the proton spectrum (60 MHz).

If the ester preparation is carried out using equimolar quantities then the product mixture contains, in addition to the foregoing, unreacted phosphinic acid and compound $\underline{8}$. The structure is assigned on the basis of the ^{31}P n.m.r. data, (δ 22.2, $\underline{dd}$, $^1J_{PH}$ 538 Hz, $^2J_{PCH}$ 7 Hz) and the fact that addition of further trimethyl orthoformate removes these peaks without otherwise a ltering the spectrum.

At an orthoester to phosphinic acid mole ratio of 2.2:1, no new products are formed but if another acid (H_2SO_4, p-toluenesulphonic, CF_3CO_2H, gaseous HCl, BF_3OEt_2) is present the phosphinate, $\underline{7}$, becomes the major product with only small amounts of $\underline{3}$ remaining. In addition, a further substance, $\underline{9}$, is formed in appreciable quantities. The latter compound is identified spectroscopically (^1H n.m.r. : δ 1.45, $\underline{d}$, $^2J_{PCH}$ 14.5 Hz, 3H(PCH_3); 3.56, $\underline{s}$ 6H($COCH_3$); 3.75, $\underline{d}$, $^3J_{POCH}$ 10.0 Hz, 3H($POCH_3$); 4.57, $\underline{d}$, $^2J_{PCH}$ 7.5 Hz, 1H[$PCH(OCH_3)_2$]; ^{31}P n.m.r. : δ 46.8 $\underline{cm}$), and by direct preparation from $\underline{7}$ by treatment with CH_3ONa followed by CH_3I.

Finally, all preparations of $\underline{8}$ contain another compound ($\underline{cm}$, δ 30.05, apparent $\underline{sx}$, J = 8 Hz) and this may be prepared essentially quantitatively by treating $\underline{7}$ with one mole of trimethyl orthoformate in the presence of acid; it is, therefore, assigned the structure $\underline{10}$.

$(HO)_2\overset{+}{P}HCH(OR)_2 \xrightarrow{-H^+} HOPH(O)CH(OR)_2 \xrightarrow{a} ROPH(O)CH(OR)_2$

$HOP(O)H_2 \rightleftharpoons (HO)_2PH \longrightarrow (RO)_2PH \xrightarrow{a} (RO)_2\overset{+}{P}HCH(OR)_2$

$\underset{8}{\quad} \quad \underset{4}{\quad}$

$(RO)_2\overset{+}{P}HCH(OR)_2 \downarrow -H^+$

$(RO)_2PCH(OR)_2$

$\underline{5}$

$ROP(O)H_2 \rightleftharpoons ROPH(OH) \longrightarrow RO\overset{+}{P}H(OH)CH(OR)_2 \xrightarrow{-H^+} ROPH(O)CH(OR)_2$

$\underline{7}$

$ROP(O)[CH(OR)_2]_2 \xleftarrow{-H^+} ROP(OH)[CH(OR)_2]_2 \xleftarrow{a} ROP(OH)CH(OR)_2$

$\underline{10}$

$\downarrow a$

$ROPR(O)CH(OR)_2 \xleftarrow{-H^+} R\overset{+}{O}PR(OH)CH(OR)_2$

$\underline{9}$

R = Me or Et
a = $(RO)_3CH$

<center>SCHEME</center>

Repetition of the foregoing experiments using $HC(OEt)_3$ as the esterifying agent affords a completely analogous range of compounds whose [31]P n.m.r. spectra show the expected simplification in splitting patterns. All reactions are carried out at room temperature and are complete within half an hour : under these mild conditions, the products can only be accounted for reasonably by the inter-mediacy of P(III) forms (Scheme). Since no reactions occur in the absence of acids the establishment of the P(IV) $\rightleftharpoons$ P(III) equilibrium may be acid catalysed. An alternative function for the acid would be generation of $(AlkO)_2\overset{+}{C}H$ from the orthoformate[9] and, we find that dialkyl phosphonates are easily alkylated on phosphorus when treated with a solution of a dialkoxymethyl carbonium ion (0.5 hr. room temperature), e.g.

$$(EtO)_2P(O)H + (EtO)_2\overset{+}{C}H \; BF_4^- \longrightarrow (EtO)_2P(O)CH(OEt)_2$$
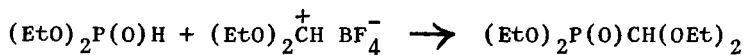
$$\underline{11}$$

The same product is formed from a dialkyl phosphonate and a trialkyl orthoformate in the presence of toluenesulphonic acid though the reaction is much slower (1 week at room temperature).

It is apparent that the P(IV) $\rightleftharpoons$ P(III) equilibrium in phosphinic acid and its esters is rapidly established though the percentage of the two forms is uncertain. In view of the ease, high yield and

mild conditions of these transformations, we believe that the equilibrium is more readily attained with phosphinic acid and its esters than with the corresponding phosphonates.

Recently, Gross and Costisella[10] have reported that the phosphonate (11) is the major product of the reaction of an excess of triethyl orthoformate with anhydrous phosphonic acid whereas if some water is present the expected product, diethyl phosphonate, is formed exclusively. This suggests to us that the dialkoxymethyl carbonium ion is the active P-alkylating species but reacts preferentially with water if present; O-alkylation could then occur by reaction of phosphonic acid (or its anion) with protonated orthoformate. Other instances of the dialkoxymethylation of organophosphorus compounds[12] have been carried out under much more vigorous conditions where the production of small amounts of acidic material and hence the dialkoxymethyl carbonium ion would reasonably account for their formation.

Though we have no direct evidence for the percentage of the P(III) form of phosphinic acid or its esters, some of the very low figures suggested in the literature[11] would seem to be unrealistic.

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