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THE ALUMINIUM CHLORIDE-CATALYSED ADDITION OF P(III) HALIDES TO CARBONYL COMPOUNDS

by

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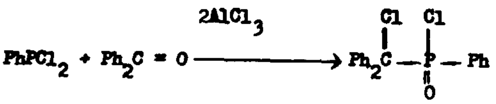
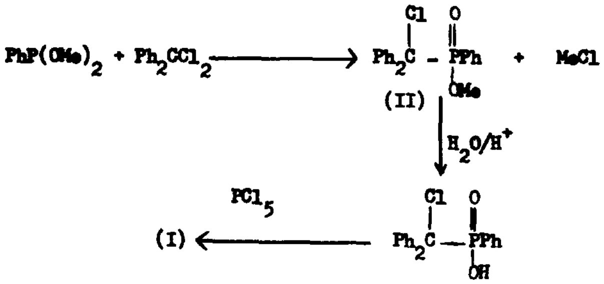
Michaelis reported[1] that benzophenone and phosphorus trichloride do not react in the presence of aluminium chloride and Conant and his co-workers in their extended study[2] of the uncatalysed reaction of phosphorus(III) halides with carbonyl compounds required forcing conditions[3] to bring about reaction. In the course of unrelated work we had occasion to investigate the reaction of phenylphosphonous dichloride and aluminium chloride with benzophenone. The reaction was carried out in excess halide as solvent and using two moles of partially hydrated aluminium chloride. The reaction mixture was heated at 100°C until hydrogen chloride evolution ceased (3 hrs.), the product poured into aqueous sodium hydroxide and extracted with benzene to give a 65% yield of diphenylchloromethylphenylphosphinic chloride (I), m.p. 103-104°C.



$$PhPCl_2 + Ph_2C=O \xrightarrow{2AlCl_3} Ph_2\overset{Cl}{\overset{|}{C}}-\underset{\underset{O}{\|}}{\overset{Cl}{\overset{|}{P}}}-Ph$$

(I)

If "anhydrous" aluminium chloride is used the yield is much lower. The structure (I) was confirmed by its independent synthesis as follows :



$$PhP(OMe)_2 + Ph_2CCl_2 \longrightarrow Ph_2\overset{Cl}{\overset{|}{C}}-\overset{O}{\overset{\|}{P}}Ph(OMe) + MeCl$$

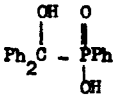
(II)

$$\downarrow H_2O/H^+$$

$$(I) \xleftarrow{PCl_5} Ph_2\overset{Cl}{\overset{|}{C}}-\overset{O}{\overset{\|}{P}}Ph(OH)$$

(III)

The acid chloride (I) is remarkably inert as indicated by its mode of isolation and the fact that it was unaffected by boiling in methanol. However, sodium methoxide in boiling methanol converted it to the ester (II; m.p. 100-101°; 73%), prolonged (14 hr.) aqueous alkaline hydrolysis afforded the hydroxy acid (IV; m.p. 191-192°), and boiling ethanolic hydrochloric acid afforded the chloro-acid (III).

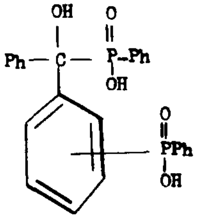


$$Ph_2\overset{OH}{\overset{|}{C}}-\overset{O}{\overset{\|}{P}}Ph(OH)$$

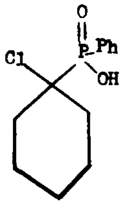
(IV)

This sluggish reactivity is interpreted as being due to steric hindrance to S_N2 attack. Horner has observed[8] similar but more pronounced effects for α-chlorobenzyldiphenylphosphine oxide and attributed it to the "positive" character of the halogen atom.

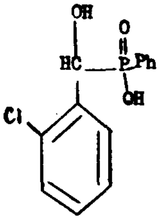
Varying the proportions of the reagents resulted in lowered yields. Extension of the reaction time to 6 hrs. also lowered the yield and led to the isolation of substantial amounts (40%) of a dibasic acid (m.p. 275–278°;) isolated by acidification of the alkaline hydrolysate. This apparently has one of the structures (V) and is currently under investigation



(V)



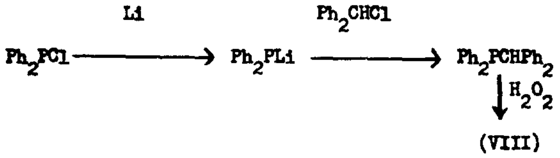
(VI)



(VII)

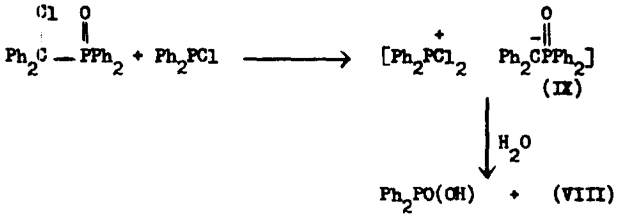
Substitution of aralkyl or dialkyl ketones for benzophenone led to complex mixtures of products. Aluminium chloride readily induces aldol type condensations[4] and the unsaturated carbonyl compounds resulting would be expected to add P(III) halides readily.[2] An example of this is the reaction of acetone with phosphorus trichloride and aluminium chloride.[5] Nevertheless, cyclohexanone afforded the acid (VI; m.p. 149–150°; 42%), and o-chlorobenzaldehyde the hydroxy acid (VII; m.p. 283–285°; 66%).

In view of these results we reinvestigated the reaction of phosphorus trichloride with benzophenone but we could induce no reaction under a wide variety of conditions. On the other hand diphenylphosphinous chloride reacted readily with benzophenone under the same conditions as were used for phenylphosphonous dichloride, but the product was benzhydryldiphenylphosphine oxide (VIII; m.p. 304-305°, lit.[6] 303° ; 35%). This substance has previously been prepared in unstated yield by the action of benzhydrylchloride on diphenylphosphinous chloride.[6] Its structure was confirmed as follows :



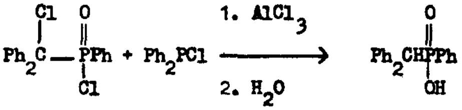
$$\begin{tikzcd} Ph_2PCl \arrow[r, "Li"] & Ph_2PLi \arrow[r, "Ph_2CHCl"] & Ph_2PCHPh_2 \arrow[d, "H_2O_2"] \\ & & (VIII) \end{tikzcd}$$

This unexpected result presumably arises by attack of diphenylphosphinous chloride on initially formed diphenylchloromethyldiphenylphosphine oxide to give the ion pair (IX) which on hydrolysis would give (VIII) and diphenyl phosphinic acid.



$$\begin{tikzcd} Ph_2\overset{Cl}{C} - \overset{O}{\overset{\|}{P}}Ph_2 + Ph_2PCl \arrow[r] & {[Ph_2\overset{+}{P}Cl_2 \quad Ph_2C\overset{O}{\overset{-\|}{P}}Ph_2]} \, (IX) \arrow[d, "H_2O"] \\ & Ph_2PO(OH) + (VIII) \end{tikzcd}$$

Attack of tervalent phosphorus compounds on "positive" halogen has received much attention[7] recently and the reduction of a related compound in similar fashion has been observed.[8] In part confirmation we find that the acid chloride (I) is reduced to benzhydrylphenylphosphinic acid (X; m.p. 243-245°) by diphenylphosphinous chloride in the presence of aluminium chloride



$$\mathrm{Ph_2\overset{Cl}{\overset{|}{C}}-\overset{O}{\overset{\|}{\underset{\underset{Cl}{|}}{P}}}Ph + Ph_2PCl \xrightarrow[2.\ H_2O]{1.\ AlCl_3} Ph_2CH\overset{O}{\overset{\|}{\underset{\underset{OH}{|}}{P}}}Ph}$$

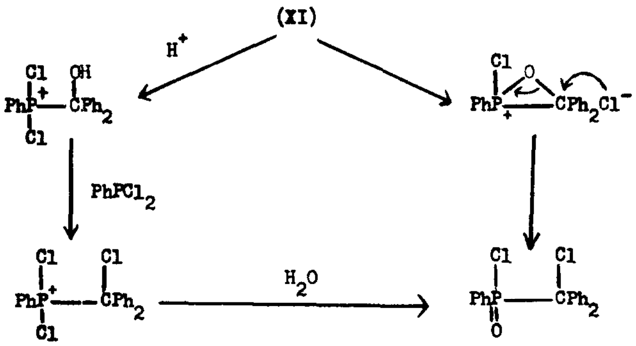
(I) (X)

In the absence of aluminium chloride no reaction occurs and the catalyst presumably functions by co-ordinating with the P = O group of (I) and thereby facilitating "positive" halogen removal. Phenylphosphonous dichloride is presumably insufficiently nucleophilic to effect this reduction since (X) could not be detected in the reaction mixtures from the preparation of (I).

The following alternative mechanisms are suggested to explain the ready reaction between benzophenone and phenylphosphonous dichloride

$$\mathrm{Ph\ PCl_2 + Ph_2C = O \longrightarrow Ph\ \overset{Cl}{\overset{|}{\underset{\underset{Cl}{|}}{\overset{+}{P}}}}-\overset{O^-}{\overset{|}{C}}Ph_2}$$

(XI)



The initial addition step is supported by Conant's detailed study[2] of the uncatalysed reaction. No evidence is available to clearly distinguish between the two subsequent paths but it is hoped to carry out the experiment with $Ph_2C = O^{18}$.*

References

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* All compounds gave satisfactory analytical, infra-red and p.m.r. figures. All reactions involving P(III) compounds were carried out under nitrogen.