SOME REACTIONS OF
CYCLIC PHOSPHONIUM SALTS

By

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A thesis submitted for the degree of Doctor
of Philosophy at the University of Leicester

1968

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STATEMENT

The work described in this thesis was carried out by the author in the Department of Chemistry of the University of Leicester under the supervision of Dr. S. Trippett. No part of it is concurrently being submitted for any other degree.

October 1965 - May 1968

Signed W. Hawes

(W. Hawes)

ACKNOWLEDGEMENTS

The author would like to record his sincere thanks to Dr. S. Trippett for his supervision and constant encouragement, to Roche Products Ltd., for the award of a Research Scholarship and to Mrs. A. Dunning for the typing involved.

CONTENTS

Summary

A review of the Wittig olefin synthesis and some of its synthetic applications is given. The synthesis of substituted 1,6-diphenylhexa-1,3,5-trienes from phospholenium salts is described. Some interesting allylic rearrangements found while investigating the optimum conditions for olefin formation from allylic phosphine oxides are described.

Factors influencing the formation of phosphetanes are discussed and the syntheses of highly substituted phosphetane derivatives are described. Following a discussion of the mechanism of the alkaline hydrolysis of phosphonium salts, the alkaline hydrolysis of phospholenium and phosphetanium salts is described. Ring expansion of the methyl and iodomethyl salts of 2,2,3,4,4-pentamethyl-1-phenylphosphetane occurs during hydrolysis; the benzyl salt gives 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide with retention of configuration about phosphorus. This is the first example of the hydrolysis of a phosphonium salt proceeding with retention rather than inversion of configuration. Two other Walden cycles in which substitution at phosphorus proceeds with retention of configuration are described and a mechanism is proposed involving "pseudo-rotation" of a trigonal bipyramidal intermediate.

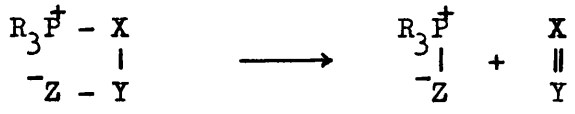
"Pseudo-rotation" is discussed in the elucidation of the mechanism of the alkaline hydrolysis of phosphate esters. A

neo-pentyl effect observed in the hydrolysis of esters with two t-butyl groups attached to phosphorus is described.

The stability of pentacovalent phosphorus compounds is found to be increased by a) increased electronegativity of the substituents, and b) the presence of rings constrained to have a preferred angle of 90° at phosphorus.

The Wittig Olefin Synthesis

Wittig and Schöllkopf[1] reported that the reaction of an alkylidenephosphorane with a carbonyl compound produced an intermediate betaine which formed an olefin by elimination of phosphine oxide. It has since been shown that this was an example of a much more general four centre reaction



where X and Y may be carbon and/or nitrogen and may already be joined by a double bond. Z is usually oxygen, but may be sulphur, chlorine[2], or the group -NHR'[2] (R' = H, Ph, $ArSO_2$, etc). A large variety of radicals, R, may be attached to phosphorus including dialkylamino, alkyl, aryl, chlorine, alkoxyl, and oxyanion (O^-).

Staudinger and Meyer[3] reported the first reaction of this type in 1919. The reaction of diphenyldiazomethane with triphenylphosphine gave an adduct which eliminated nitrogen on heating forming diphenylmethylenetriphenylphosphorane which gave triphenylketenimine by reaction with phenyl isocyanate and elimination of triphenylphosphine oxide.

The Wittig olefin synthesis has aroused much interest because it proceeds under mild conditions to a product in which the position of the double bond is not in doubt.[4]

Mechanism of The Wittig Olefin Synthesis.

The formation of an olefin and a phosphine oxide from a phosphorane and a carbonyl compound is a two stage reaction which proceeds via an intermediate betaine (1).

$$R^1_3P = CR^2R^3 \quad \rightleftharpoons \quad R^1_3\overset{+}{P} - \overset{-}{C}R^2R^3 \quad + \quad R^4R^5C{:}O \rightleftharpoons R^1_3\overset{+}{P} - CR^2R^3 \;(\text{with } {}^{-}O - CR^4R^5) \longrightarrow R^1_3P{:}O + R^2R^3C{:}CR^4R^5$$

(1)

Either of the two stages may be rate determining.

Generation of The Phosphorane.

Phosphoranes are formed by the action of a suitable base on a phosphonium salt. The strength of the base required depends on the acidity of the ∝-hydrogen. The less acidic the ∝-hydrogen is, the stronger the base required. Some of the bases and solvents commonly used are butyl- or phenyl-lithium in benzene, ether, or tetrahydrofuran, sodium or lithium alkoxides in the corresponding alcohol or dimethylformamide, and dimethylsulphoxide metallated with sodium hydride in dimethylsulphoxide.[5]

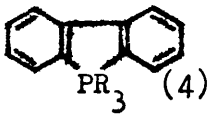
There are other, less general methods for the formation of alkylidenephosphoranes. A recent interesting one is the action of trimethylsilanol on a trimethylsilylmethylenephosphorane (2) giving a methylenephosphorane (3) and hexamethyldisiloxane. It is interesting to note that the phosphoranes (3) were found to be

stable to distillation.

$$R_3P{=}\underset{(2)}{CH.SiMe_3} + Me_3SiOH \longrightarrow R_3P{=}\underset{(3)}{CH_2} + Me_3SiOSiMe_3$$

Stability of the Phosphorane.

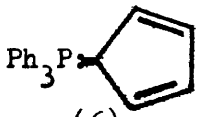
The reactivity of a phosphorane is increased by groups attached to phosphorus which decrease the positive charge, thus stabilising the dipolar form. Thus fluorenylidenetriphenylphosphorane (4, R= Ph) is less reactive than fluorenylidenetrialkylphosphoranes[7] (4, R = Me or Bu). The reactivity of phosphoranes is decreased by groups capable of delocalising the negative charge on the α-carbon. Thus phosphoranes (5) having an α-carbonyl substituent[8] are stable and may be isolated. Cyclopentadienylidenetriphenylphosphorane (6) is not decomposed even by boiling concentrated potassium hydroxide solution.[9]



(4)

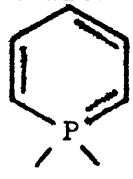
$Ph_3P{:}CHCOR$

(5)

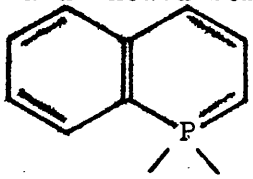


(6)

Märkl[10] found that incorporation of phosphorus into potentially aromatic systems gave phosphoranes (7, 8) that did not react with carbonyl groups and showed some aromatic character.



(7)

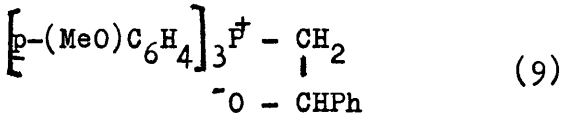


(8)

The Formation and Decomposition of the Betaine.

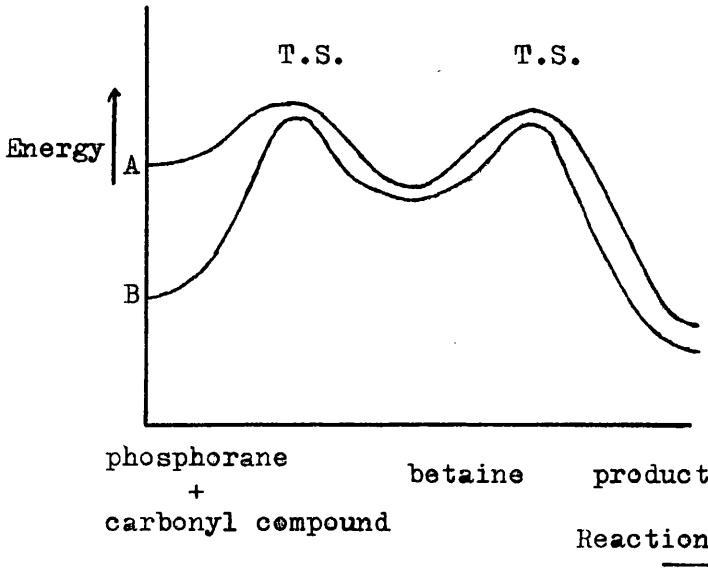
The more stable the phosphorane, the more difficult it is to form a betaine by reaction with a carbonyl compound. This indicates that betaines are formed by nucleophilic attack of the phosphorane on the carbonyl compound. Increased electrophilic character of the carbonyl compound would therefore be expected to enhance betaine formation; this has been found to be the case.

Reactive phosphoranes readily give betaines which are stable. Factors which facilitate betaine formation hinder betaine decomposition and vice-versa. Tris(p-methoxyphenyl)-methylenephosphorane reacts with benzaldehyde giving a betaine (9), in which the positive nature of the phosphorus is so reduced that decomposition to phosphine oxide and olefin does not occur.[11]



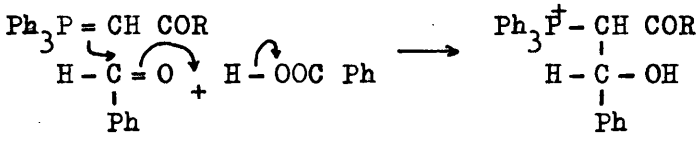
(9)

Attempts to isolate the intermediate betaine[7] from the reaction of fluorenylidenetributylphosphorane with carbonyl compounds have been unsuccessful. These results fit the energy profile shown overleaf:

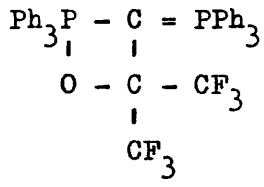


T.S. = Transition State
A is the path for reactive ylids
B is the path for stable ylids

If betaine formation is the rate determining step, the reaction can be acid catalysed[12] :

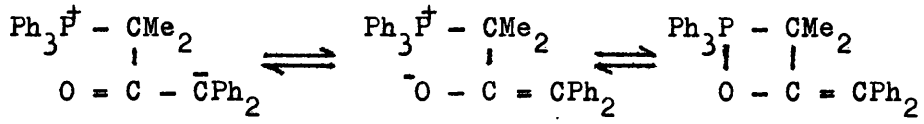


In one case only, a pentacovalent structure (10) for a betaine[13] has been found rather than the ionic structure normally postulated.



(10)

A stable betaine (11) was isolated from the reaction of isopropylidenetriphenylphosphorane with diphenylketene.[14]



(11a) (11b) (11c)

The dipole moment of this betaine was low, 4.34D, for a Zwitterionic betaine in which there was no interaction between the positive phosphorus and the oxyanion. The ^{31}P N.M.R. chemical shift was +36.6 p.p.m. (relative to 85% H_3PO_4), which was rather low for a pentacovalent compound. It was tentatively concluded that there was considerable interaction between the positive phosphorus and the oxyanion.

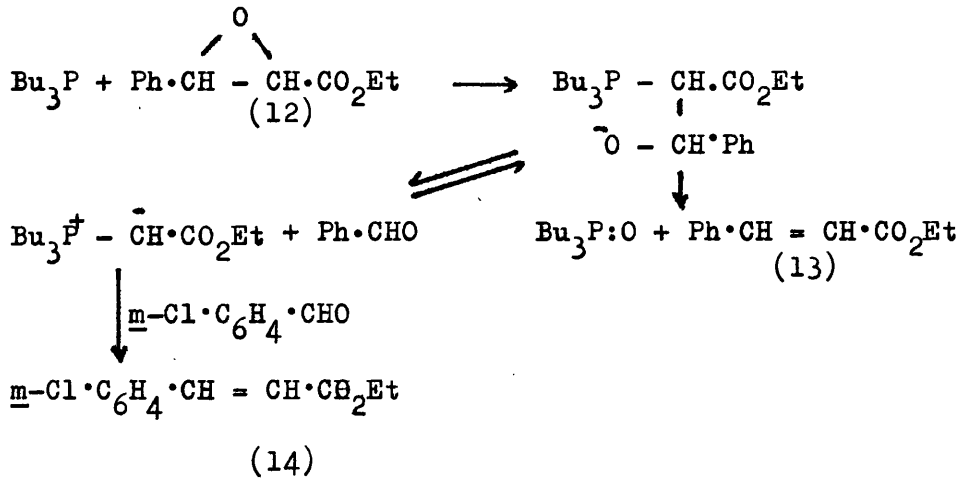
Reversibility of Betaine Formation.

Wittig et al. found only traces of 1,1-diphenylethylene from the reaction of methylenetriphenylphosphorane with benzophenone.[11] Hudson et al.[15] studied the same betaine by solution I.R., and concluded that the rate of formation of benzaldehyde was less than the rate of betaine formation but greater than the rate of betaine decomposition to phosphine oxide and styrene.

Schlosser and Christmann[16] have demonstrated the reversibility of betaine formation from benzaldehyde and ethylidenetriphenyl-

phosphorane by heating the betaine with m-chlorobenzaldehyde. m-Chloro-β-methylstyrene as well as β-methylstyrene was isolated from the reaction mixture.

The reversibility of betaine formation from stable phosphoranes has been demonstrated by Speziale and Bissing.[11] The reaction of tributylphosphine with ethyl-trans-phenylglycidate (12) in the presence of m-chlorobenzaldehyde gave ethyl cinnamate (13), as well as ethyl-m-chlorocinnamate (14).



(12) (13) (14)

Stereochemistry.

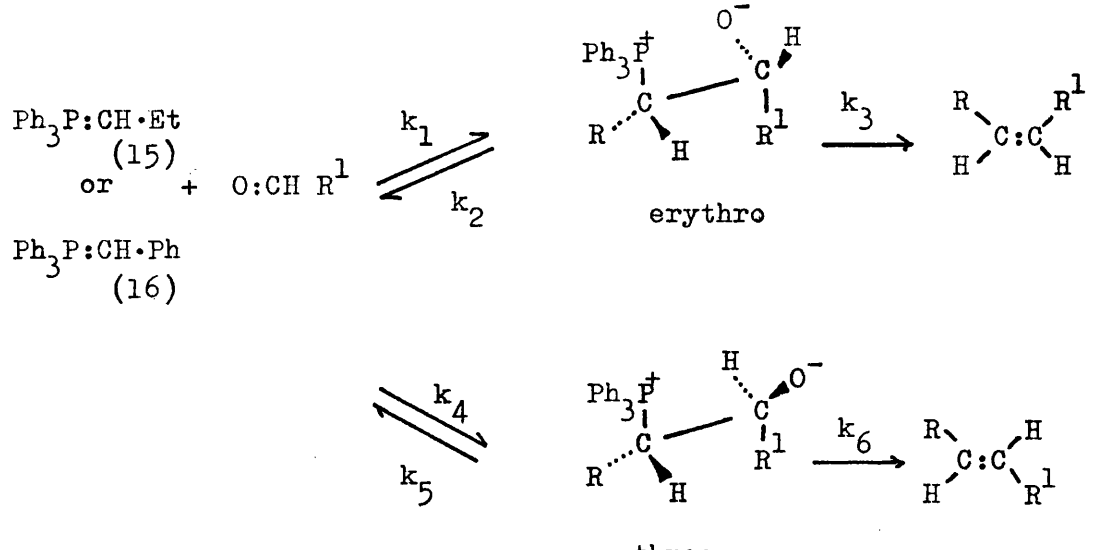
1. Optically Active Phosphonium Salts.

When an optically active phosphonium salt was used the phosphine oxide produced was optically active.[17] Alkaline hydrolysis of the same salt gave the enantiomorphic phosphine

oxide. Following the preparation of optically active phosphines it was possible to form a phosphonium salt and a phosphine oxide by respectively quaternisation and oxidation, having the same configuration about phosphorus. The phosphine oxide from the Wittig reaction of the phosphonium salt was the same as that from the oxidation of the phosphine; thus the Wittig reaction proceeds with retention and the alkaline hydrolysis with inversion of configuration about phosphorus.

2. Cis : trans Ratio of the Resultant Olefin.

Bergelson, Barsukov and Shemyakin[18] have studied the cis : trans ratio of olefins from the reactions of non-stabilised(15) and semi-stabilised(16) ylids (ylids = phosphoranes) .

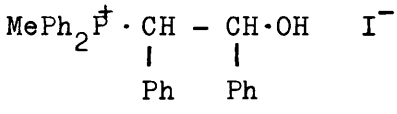


The reaction was studied both in the absence, and in the presence of inorganic lithium salts, in polar and non-polar solvents. In polar solvents the stereochemistry was independent of added salts, but in non-polar solvents it was dependent on added salts. With no salts present ylid (15) gave predominately cis-olefin and ylid (16) was non-stereospecific in polar solvents. In non-polar solvents ylid (15) gave predominately cis-olefin, and ylid (16) predominately trans-olefin. The cis : trans ratio in non-polar solvents is decreased for ylid (15), but increased for ylid (16), in the presence of added salts.

In the absence of salts, the first step of the reaction was rate determining, with olefin ratios governed by kinetic factors. Added salts co-ordinated with the betaine, promoting the formation of erythro betaine from ylid (16), which increased the proportion of cis-olefin formed; for ylid (15) the second step was so retarded that thermodynamic factors became isomer determining, leading to the formation of more trans-isomer.

The strength of the Lewis base (the inorganic anion) was definitely isomer determining, rather than the Lewis acid strength as postulated by House et al.[19] These results were in agreement with those of Schlosser et al.,[20] who have also found that treatment of a betaine formed at low temperatures with phenyl-lithium leads to the formation of more trans-olefin by the interconversion of betaine-ylids.

Jones and Trippett[21] have also studied the effects of added salts in a polar medium, finding little variation of isomer ratio. They concluded that for the salt (17) with various bases and solvents at different temperatures:



(17)

i) Betaine formation was reversible.

ii) Betaine dissociation and elimination were of comparable rates.

iii) Little double-bond character was developed in the transition state leading to olefin.

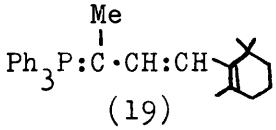
iv) Considerable desolvation occurred in the transition state leading to betaine.

Synthetic Applications:

Applications of the Wittig olefin synthesis are so numerous that only a few will be mentioned here.

Syntheses in The Vitamin A and Carotenoid Series.

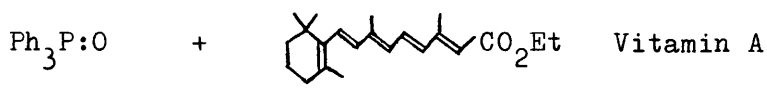
Pommer et al[22] have prepared members of the vitamin A series by several routes, of which the most successful involved the use of a formyl compound (18) and a phosphorane (19).



(19)

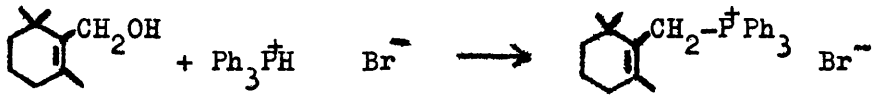
+ $OCH{\cdot}CH{:}CH{\cdot}CMe{:}CH{\cdot}CO_2Et$

(18)



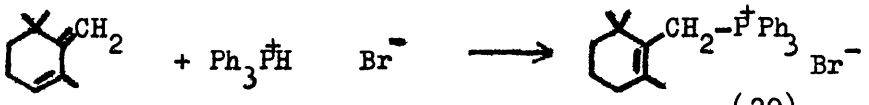
Vitamin A acid ethyl ester

In the course of these investigations, two very useful methods of preparation of phosphonium salts were discovered. The reaction of triphenylphosphonium bromide with 1-hydroxymethyl-2,6,6-trimethylcyclohex-1-ene gave the phosphonium salt (20) by elimination of the elements of water.



(20)

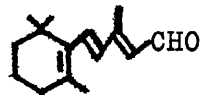
The reaction of triphenylphosphonium bromide with 1-methylene-2,6,6-trimethylcyclohex-2-ene also gave, by 1,4-addition, the phosphonium salt (20)



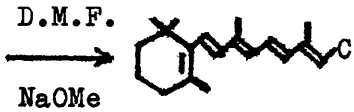
(20)

Both these reactions were found to be of general application. Vitamin A alcohol could be obtained from vitamin A acid by reduction with lithium aluminium hydride. On a larger scale, however, this reagent was too dangerous and a number of new reducing agents were consequently developed.

The synthesis of members of the vitamin A series was also effected using phosphonate esters. An example of the synthesis of olefins from "activated $\geqslant P{:}O$" compounds is outlined overleaf:



+ $(EtO)_2P(:O)CH_2 \cdot CMe:CH \cdot CO_2Et$

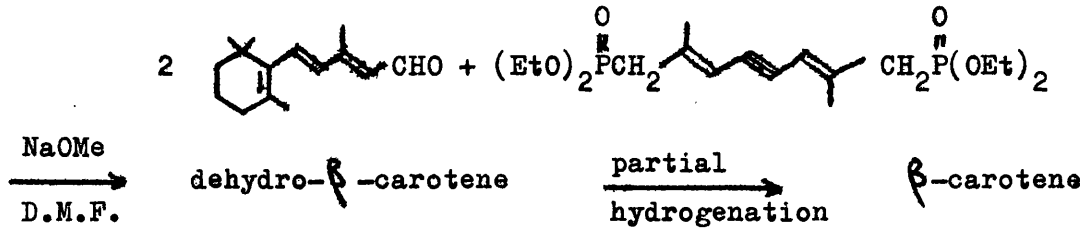


(D.M.F. = dimethylformamide)

The use of "activated $\geq P:O$" compounds for olefin synthesis was first investigated by Horner et al[23], and Dombrovskii and Dombrovskii[24] have reviewed this type of olefin synthesis. Wadsworth and Emmons[25] proposed that the mechanism of olefin formation from these compounds was the same as that of the conventional Wittig olefin synthesis using alkylidene phosphoranes.

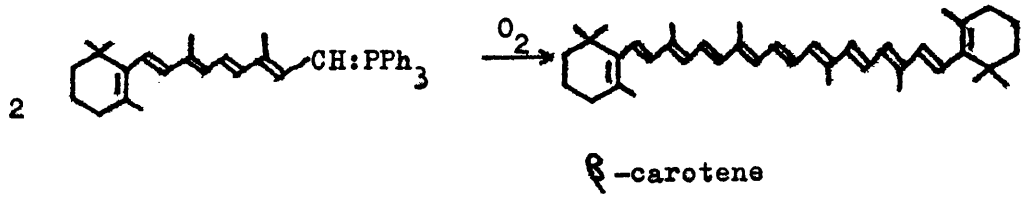
There are a number of advantages in the use of phosphine oxides, phosphinates and phosphonates, rather than phosphonium salts for olefin synthesis[24,26]. The starting materials are readily prepared by the Arbusov reaction. The carbanions formed are much more reactive than the corresponding phosphoranes and the water-soluble phosphate anions are easily separated from the olefinic products.

Pommer[27] also prepared β-carotene by the reaction of β-ionylideneacetaldehyde with 2,6-dimethyl-1,8-bis(diethoxyphosphinyl)octa-2,6-diene-4-yne.



This was an example of the use of a bifunctional reagent for olefin synthesis.

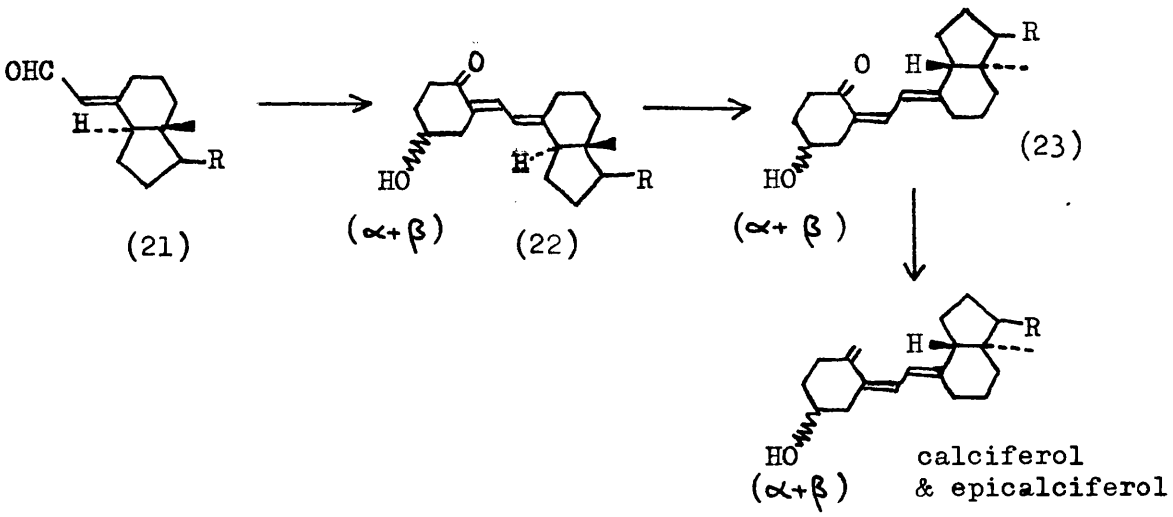
Bestmann and Kratzer[28] found that olefins were obtained by the partial oxidation of phosphoranes and applied this method to the synthesis of β-carotene.



The Synthesis of Vitamin D.

Lythgoe et al[29] developed a partial synthesis of vitamin D, involving the use of the Wittig reaction. The bicyclic analogue (21) of cyclohexylideneacetaldehyde was readily obtained by the method of Windaus and Riemann[30]. By condensing this aldehyde (21) with 4-acetoxycyclohexanone in the presence of sodium ethoxide, a mixture of the C_3 epimers of the conjugated dienone (22) was obtained. Irradiation of the dienone epimers (22) in methanol gave almost quantitatively the 5:6-*cis* 7:8-*trans*

epimers (23). Reaction of the mixture of epimers (23) with methylenetriphenylphosphorane gave a mixture of calciferol and epicalciferol



A Novel Ring Synthesis.

Schweizer et al[31] found that the reaction of a carbanion with vinyltriphenylphosphonium bromide gave a phosphorane, and by having a suitably placed carbonyl function present in the original carbanion, cyclic olefins were formed by an internal Wittig reaction: e.g.,

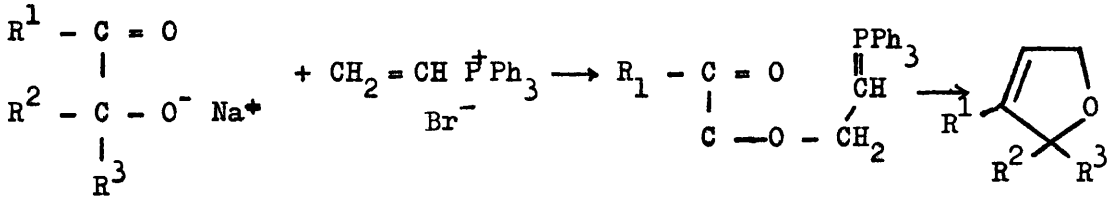
$$Ph_3\overset{+}{P}\text{-}CH=CH_2\ Br^- + CH_3CO\cdot(CH_2)_n\cdot CH(CO_2Et)_2 \xrightarrow{NaH} Ph_3P{:}CH\cdot CH_2\cdot C(CO_2Et)_2\cdot OHC\cdot(CH_2)_n$$

$$\longrightarrow Ph_3P{:}O + \text{cyclic olefin}$$

n = 1, 2 or 3

They extended this synthesis to the use of nitrogen anion and

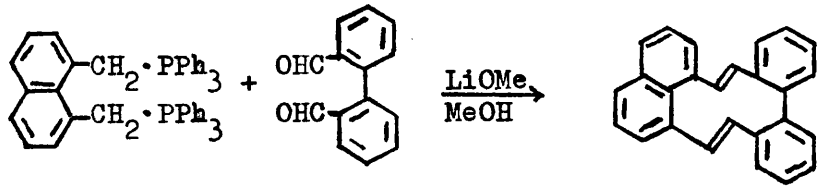
oxyanion. By the use of the latter they were able to prepare dihydrofurans (24) [32].



(24)

The Synthesis of Ring Polyenes.

Sondheimer and Mitchell[33] recently applied the Wittig reaction to the preparation of 9, 10 and 11 membered ring polyenes.

e.g. 

The transannular reactions of these systems were studied.

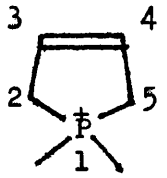
Conclusion.

The Wittig reaction has been successfully applied to the synthesis of many olefinic compounds with the double-bond in a known position. Many olefins difficult to prepare by other routes may be prepared. In some cases the double bond may be

produced stereospecifically in either the cis- or the trans- configuration, although there is nearly always a small amount of the other isomer present. Reviews of the reaction and its applications have been written by Wittig[34]; Levisalles[35], Schöllkopf[36], Trippett[37], Yanovskaya[38], Hudson[39], Johnson[40], and Kirby and Warren.[41]

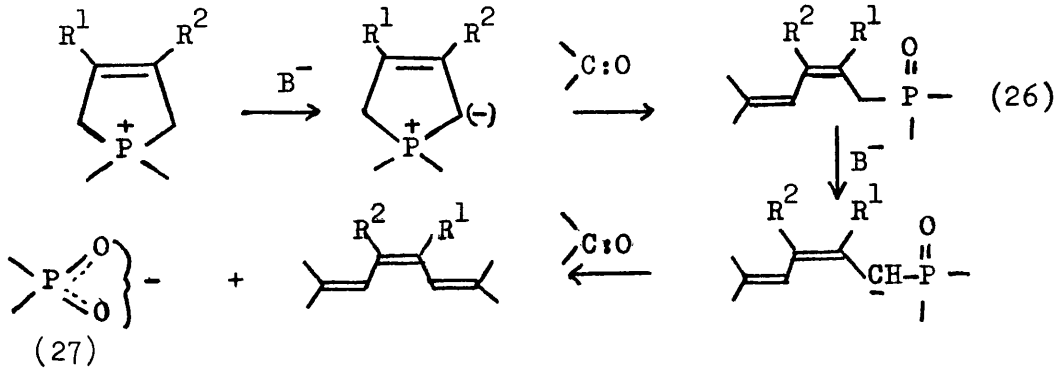
The Synthesis of Olefins from Phospholenium Salts.

In the 3-phospholenium system (25) there are two sites from which a proton may be removed, the 2 and the 5 positions. The reactions of this system with bases were investigated with



(25)

the object of finding a method of either forming two new double-bonds at once, or of forming one new double-bond, giving the phosphine oxide (26), followed by further treatment with a base and a carbonyl compound to form a second new double-bond by elimination of the phosphinic acid anion (27)



(26)

(27)

In the latter route, the position of initial attack by the base is of interest in cases where R^1 and R^2 are different, as two different carbonyl compounds could be used, leading to the formation of an asymmetric polyene; this is of particular interest in the case where R^1 and R^2 are respectively H and Me, as by this

route an isoprenoid unit could be incorporated into an asymmetric polyene.

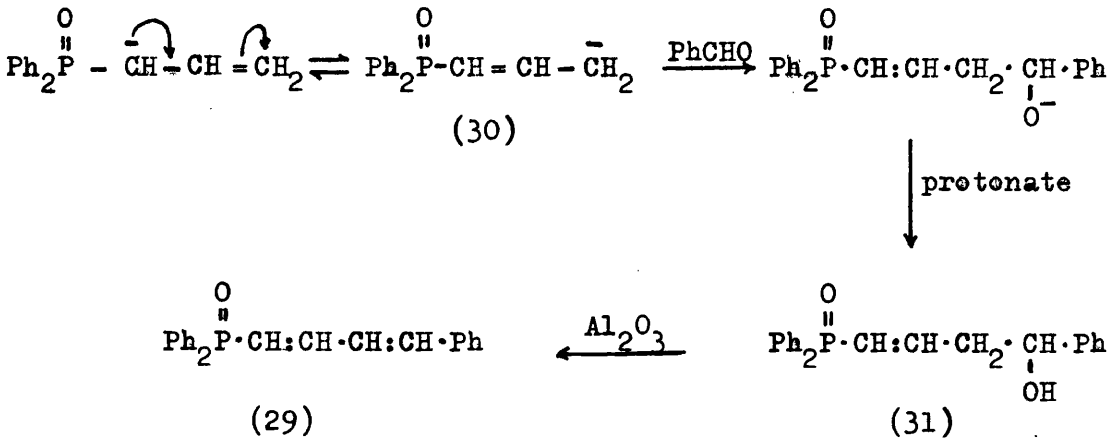
The Use of Allylic Phosphine Oxides for Olefin Synthesis.

In the two-step synthesis described above, the second step involves an "activated $\geq P{:}O$" compound olefin synthesis. The synthesis of olefins from allylic phosphine oxides was therefore investigated. By a series of experiments it was found that allyldiphenylphosphine oxide gave the best yield of olefin with benzaldehyde when treated with sodium ethoxide in dimethylformamide. In the course of these experiments, an interesting rearrangement was found. Treatment of allyldiphenylphosphine oxide with sodium methoxide in methanol gave the product (28) formed by addition of methanol across the double-bond of propenyldiphenylphosphine oxide, which was formed by an initial prototropic rearrangement.

$$\begin{array}{l} \overset{O}{\overset{\|}{Ph_2P}}\cdot CH_2 - CH = CH_2 \\ \quad MeOH \quad \downarrow\uparrow \quad NaOMe \\ \overset{O}{\overset{\|}{Ph_2P}} - CH = CH - CH_3 \xrightarrow{MeOH} \overset{O}{\overset{\|}{Ph_2P}} - CH_2 - \overset{OMe}{\overset{|}{CH}} - CH_3 \end{array} \quad (28)$$

In the presence of benzaldehyde the product (29) was formed by rearrangement of the carbanion of allyldiphenylphosphine oxide to that of propenyldiphenylphosphine oxide (30), followed by

reaction with benzaldehyde and dehydration on an alumina column.

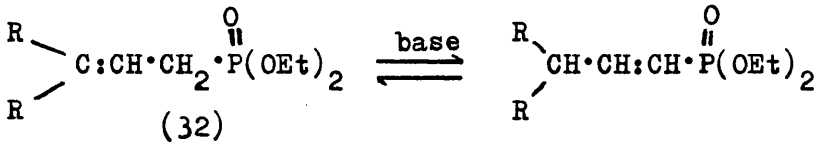


The crude reaction product (31) before chromatography did not show λmax 305 mμ (in ethanol) as found for the (4phenylbuta-1, 3-dienyl)diphenylphosphine oxide (29). Thus dehydration must have occurred on the alumina column. This phosphine oxide (29) could also be obtained by treatment of the crude reaction product (31) with p-toluene-sulphonic acid in refluxing benzene solution. The structure of the phosphine oxide (29) was supported by the mass spectrum and analysis (as well as λmax 305 mμ).

On attaching a phenyl or styryl group to the 3 position of the allyl group of the phosphine oxide, no rearrangement occurred with methanol and sodium methoxide alone; in the presence of benzaldehyde an increased yield of olefin was obtained using sodium ethoxide in ethanol. This showed that there was less tendency for the double bond of the 3-carbon system to conjugate

with the -P:O than with the phenyl or styryl group.

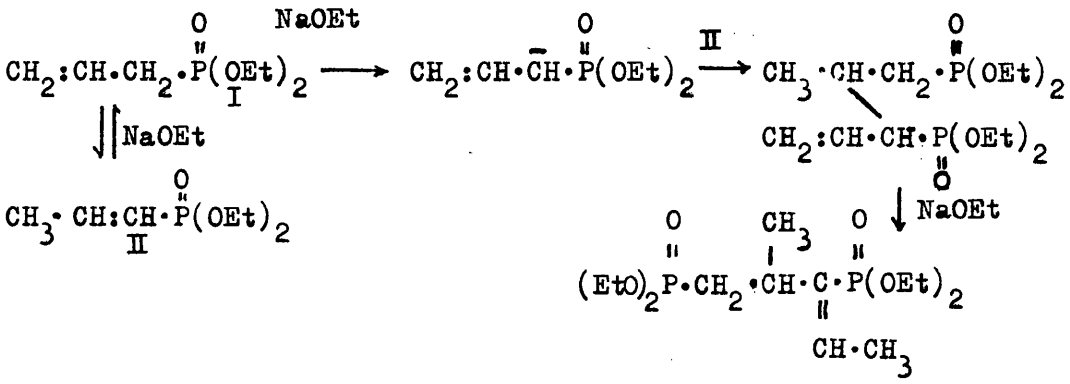
Mobility of the double-bond of 3-carbon system has been found in many cases where activating groups are attached to one end of the system. Other cases where phosphorus is present in the activating group have been reported, e.g., Ionin and Petrov[42] have reported the isomerisation of alkenylphosphonates (32) in the presence of sodium ethoxide.



(32)

The allyl phosphonate (32, R = R^1 = H) isomerised completely, the crotylphosphonate (32, R = H and R^1 = Me) only 25%, and the cinnamylphosphonate (32, R = H and R^1 = Ph) not at all, as I have found for the corresponding allyl and cinnamylphosphine oxides.

Pudovik and Konavalova[43] found a novel reaction of allylphosphonates in the presence of sodium ethoxide which gave bisphosphonates (33) by attack of the allyl anion on the propenylphosphonate formed by isomerisation.

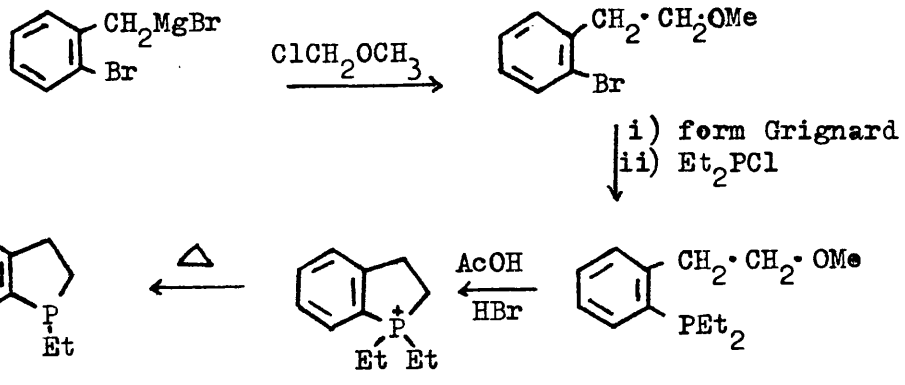


(33)

Davies and Kirby[44] found that diallylphosphine, diallylphosphine oxide, allyl phosphonic and phosphinic acids, all rearranged to the propenyl derivative in the presence of a base. They attributed this to the ability of phosphorus, with a +E effect, to stabilise the intermediate carbanion by overlap of the carbon p- and the phosphorus d- orbitals.

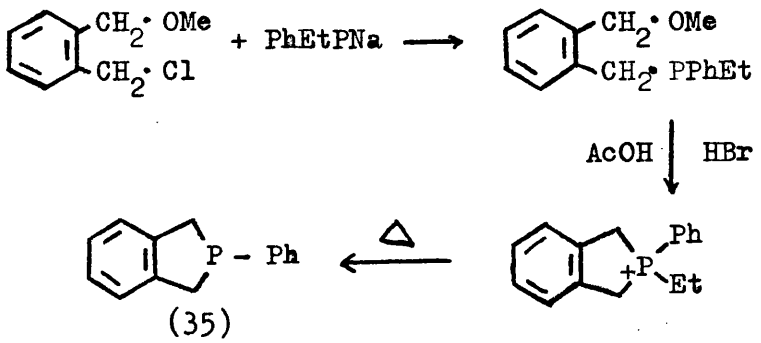
The Preparation of Phospholenes.

The only reported 5 membered ring containing phosphorus and 4 carbons was 1-phenylphospholane[45] until the preparation of a 1-substituted phosphindoline (34) by Mann and Millar[46] in 1951 by the route outlined below:



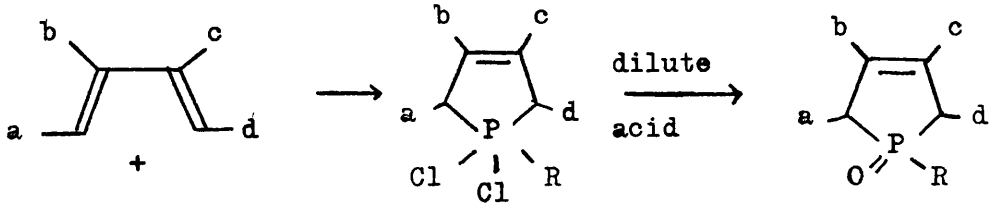
(34)

These workers also prepared 2-phenylisophosphindoline (35) by the route outlined below:



(35)

The Diels-Alder cyclisation reaction was first used for the synthesis of the phospholene system by McCormack[48], who obtained phospholene oxides (37) by the route outlined below:



Other workers have extended the Diels-Alder method of preparation of phospholenes using phosphorus trichloride and tribromide, as well as alkyl, alkoxy, aryl, and aryloxy dichloro or dibromophosphines with a variety of substituted dienes. In some cases Gustavson catalysts[49] were employed.

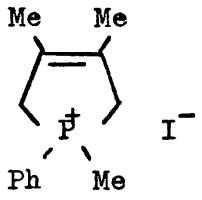
The synthesis of phospholenes <u>via</u> a Diels-Alder cyclisation and reduction of the adduct with magnesium[50] was adopted for the present work. Phospholenes have also been prepared by reduction of phospholene oxides with silanes[51].

The phospholenes obtained were quaternised with methyl iodide. At the time that this work was carried out it was thought that the double-bond of the phospholene was in the 3-position. More recent work by Quin et al[52] has shown that the double-bond is in the 2-position. It was shown that the position of the double bond was dependent on the nature of both reactants.

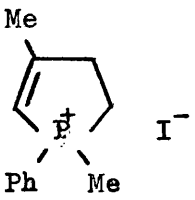
Dichloromethylphosphine and dibromophenylphosphine gave adducts with the double-bond in the 3-position. Dichlorophenylphosphine gave adducts with the double-bond in the 2-position, except when the diene was 2,3-dimethylbutadiene; the presence of the 3,4 methyl groups in the adduct stabilised the 3-double bond. Quin et al. concluded that a most attractive possibility was that the cyclo-addition proceeded normally to an adduct with the 3-double-bond, which then rearranged because of activation of the ∝-position by the positive phosphorus. Work by Hasserodt, Hunger and Korte[53] has shown that phosphorus trichloride gives adducts which with ethanol give a 2-phospholene oxide, and phosphorus tribromide gives adducts which with ethanol give a 3-phospholene oxide.

These workers have also shown that the 3-phospholene oxides may be thermally, or in the presence of alkali, rearranged to 2-phospholene oxides. The reverse rearrangement was reported by Müller and Korte[54] in the presence of cobalt, nickel, or iron acetylacetonates.

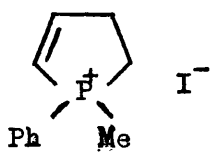
The structures of the salts studied for olefin synthesis were:



(38)



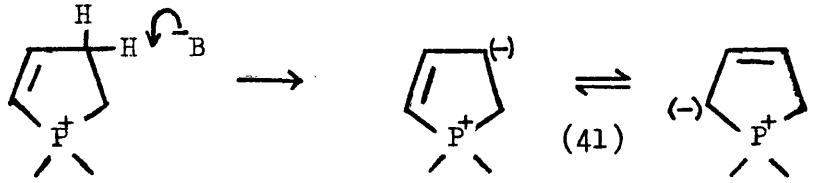
(39)



(40)

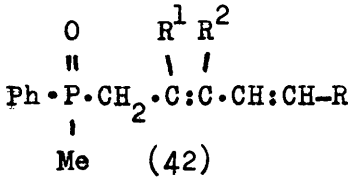
The Use of Phospholenium Salts for Olefin Synthesis.

The reactions of these salts with substituted benzaldehydes gave substituted 1,6-diphenyl-1,3,5-hexatrienes. The formation of olefins from the 2-phospholenium salts was explained by delocalisation of the carbanion formed by the removal of a proton from the 4-position, i.e.,



(41)

The carbanion formed by removal of a proton from the 2- or the 5-position of the 3-phospholenium salt can be similarly delocalised. This delocalised carbanion can then give an intermediate phosphine oxide (42) by reaction at the 2-position with a carbonyl compound.



(42)

Using sodium ethoxide in dimethylformamide only diphenyl-hexatrienes were isolated. Using sodium methoxide in methanol, however, the intermediate phosphine oxides (42) were obtained. In one case, the reaction of the 3-methyl-2-phospholenium salt (39) with benzaldehyde, a crystalline phosphine oxide was obtained (43).

$$\text{Me} - \underset{\underset{\text{Ph}}{|}}{\overset{\overset{\text{O}}{\|}}{\text{P}}}\cdot\text{CH}_2\cdot\underset{\sim}{\text{C:C}}\cdot\text{CH:CH}\cdot\text{Ph} \qquad (43)$$

H and Me at these positions.

The mass spectrum of this phosphine oxide (43) was satisfactory, but attempts to ascertain the position of the methyl group in the olefinic side chain were not successful as a suitable solvent could not be found in which to run the ^{1}H N.M.R. spectrum.

The intermediate phosphine oxides (42), on treating with sodium ethoxide in dimethylformamide and benzaldehyde, gave diphenylhexatrienes. As already mentioned, cinnamyldiphenylphosphine oxide similarly gave diphenylhexatriene.

Attempts to extend the reaction to the preparation of other, longer, polyenes using crotonaldehyde, or cinnamaldehyde were not successful. Likewise, attempts to find a better basic medium were also unsuccessful. p-Methoxybenzaldehyde and benzaldehyde were the only carbonyl compounds successfully employed. p-Nitrobenzaldehyde gave tars from which no recognisable products could be isolated.

Attempted Olefin Synthesis from Phospholenes.

Hoffmann[55] found that phosphines formed a betaine (44) in the presence of an activated olefin. Oda, Kawabata, and Tanimoto[56] found that these betaines (44) could rearrange to

the phosphorane (45) which gave olefins by reaction with a carbonyl compound.

$$R\cdot CH{:}CH_2 + Ph_3P \rightleftharpoons Ph_3\overset{+}{P}\cdot CH_2\cdot\overset{(-)}{C}H\cdot R \rightleftharpoons Ph_3\overset{+}{P} - \overset{(-)}{C}H\cdot CH_2R$$

(44) (45)

R = CN, CO_2Et, or $CONH_2$.

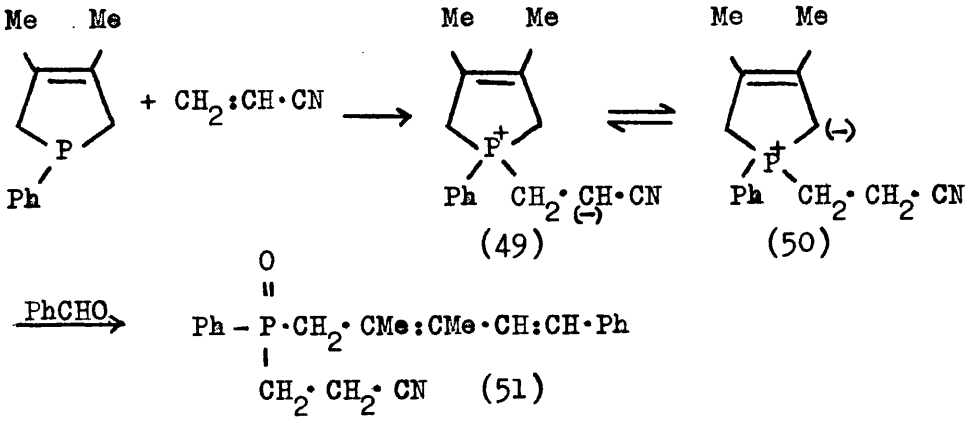
Trippett[57] showed that if phosphines (45a; R^2 is a stabilising group for an adjacent carbanion) were treated with an activated olefin, the betaine (46) transferred a proton, giving the phosphorane (47) which could be used for <u>in situ</u> Wittig olefin syntheses.

$$R^1 - CH = CH_2 + R_2P\cdot CH_2R^2 \rightleftharpoons \underset{\text{(45a)}}{R_2P - CH_2 - R^2} \rightleftharpoons \underset{\text{(46)}}{\begin{matrix} R_2\overset{+}{P} - \overset{(-)}{C}H - R^2 \\ | \\ CH_2 - \overset{(-)}{C}H - R^1 \end{matrix}} \qquad (47)$$

$$\begin{matrix} R_2\overset{+}{P} - \overset{(-)}{C}H - R^2 \\ | \\ CH_2 - CH_2 - R^1 \\ \downarrow R^3R^4C{:}O \\ R_2\overset{O}{\overset{\|}{P}}\cdot CH_2CH_2R^1 + R^3R^4C{:}CHR^2 \end{matrix}$$

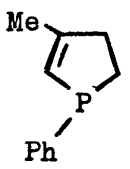
The reaction of the phospholene (48) with acrylonitrile in the presence of benzaldehyde, either with or without ethanol solvent, should give the betaine (49), which by proton transfer would give the phosphorane (50). Subsequent reaction with benzaldehyde

would give the phosphine oxide (51)



A phosphine oxide product was obtained from the reaction, but did not give any diphenylhexatriene by reaction with bendaldehyde and sodium ethoxide in dimethylformamide. Thus the activated olefin synthesis was not a successful method for making polyenes by this route.

A minor product from the reaction was 2-cyano-1,4-diphenyl-buta-1,3-diene (56). By further investigations, it was shown that cyanodiphenylbutadiene (56) was also formed by using the phospholene (52) or triphenylphosphine.



(52)

The mechanism for the formation of cyanodiphenylbutadiene (56) was formation of the betaine (53), followed by proton transfer giving the phosphorane (54), which reacted with benzaldehyde to give 3-cyano-1-phenylprop-1-ene (55). Condensation of cyano-

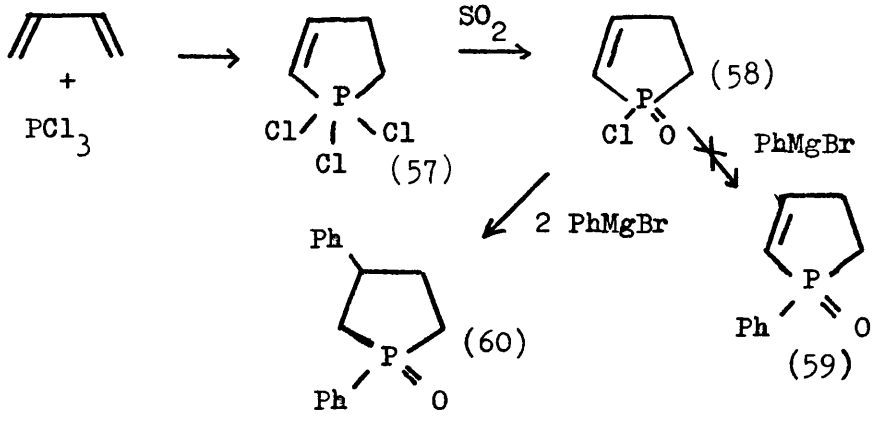
phenylpropene (55) with benzaldehyde gave cyanodiphenylbutadiene (56).

$$R_3P: + CH_2{:}CH\cdot CN \rightleftharpoons R_3\overset{+}{P}-CH_2-\overset{(-)}{C}H-CN \rightleftharpoons R_3P-\overset{(-)}{C}H-CH_2CN$$
(53) (54)

$$\xrightarrow{PhCHO} R_3PO + PhCH{:}CH\cdot CH_2CN \xrightarrow[B^-]{PhCHO} PhCH=CH-\overset{CN}{\overset{|}{C}}:CHPh$$
(55) (56)

Attempted Preparation of 1-Phenyl-2-phospholene Oxide.

By the reaction of buta-1,3-diene with phosphorus trichloride the adduct (57) was obtained. Reaction of this adduct (57) with sulphur dioxide gave 1-chloro-2-phospholene oxide (58). By anology with reactions carried out by Hasserodt, Hunger, and Korte[53], reaction of this acid chloride (58) with phenylmagnesium bromide would be expected to give 1-phenyl-2-phospholene oxide (59). The product obtained was 1,3-diphenylphospholane oxide (60). The structure (6o) was supported by the ^1H N.M.R, mass spectrum and analysis.



Formation of this phospholane oxide (60) was explained by addition of phenyl-magnesium bromide across the double-bond, followed by hydrolysis on work up. An attempt to add phenylmagnesium bromide across the double-bond of diphenylvinylphosphine oxide was not successful. Only polymeric material and unchanged diphenylvinylphosphine oxide were recovered.

The Alkaline Hydrolysis of Phospholenium Salts.

The alkaline hydrolysis of phospholenium salts will be discussed in the section on 'The Alkaline Hydrolysis of Phosphonium Salts'.

Conclusion.

Phospholenium salts can be used for the synthesis of olefins. Several interesting reactions were found while studying the conditions for optimum olefin formation from the phospholenium system.

The Synthesis of Phosphetanes.

The ring system containing phosphorus, oxygen, and 2 carbon atoms is well known as a postulated intermediate or transition state in the Wittig olefin synthesis. Birrum and Matthews[13] have prepared a betaine ylid which has a penta-covalent structure rather than the zwitterionic structure proposed for other betaines that have been studied.

Interest in the Wittig olefin synthesis therefore stimulated an interest in the properties of the ring system containing phosphorus and 3 carbon atoms. The question of whether this system would have abnormal properties like the betaine intermediates of the Wittig reaction was raised. This could be expressed in terms of the driving force of the Wittig reaction; is the sole driving force the affinity of phosphorus for oxygen, or is there a steric factor involved as well?

A General Ring Synthesis.

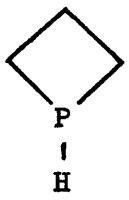
Attempts to synthesise ring compounds containing phosphorus and carbons only have been made by variations of the scheme outlined, where R^1 and R^2 may be alkyl, aryl, or hydrogen[58]. M

$$R^1R^2PM + X-(CH_2)_n-X \longrightarrow R^1R^2P(CH_2)_n-X + MX$$

$$\longrightarrow R^1R^2P\overset{+}{\frown}(CH_2)_n\ X^-$$

may be lithium, sodium, potassium, or hydrogen and X may be chlorine, bromine, or iodine. In cases where R^1 or R^2 is hydrogen, ring closure occurs by elimination of hydrogen halide.

Wagner[59] reported the synthesis of several small ring phosphorus compounds by this route using conventional vacuum techniques at low temperatures. Phosphetane (61) was obtained together with an acyclic biphosphine (62). Phosphetane (61) decomposed on warming to 0°. On substitution of methyl or phenyl for one of the hydrogens of sodium phosphide only an



(61)

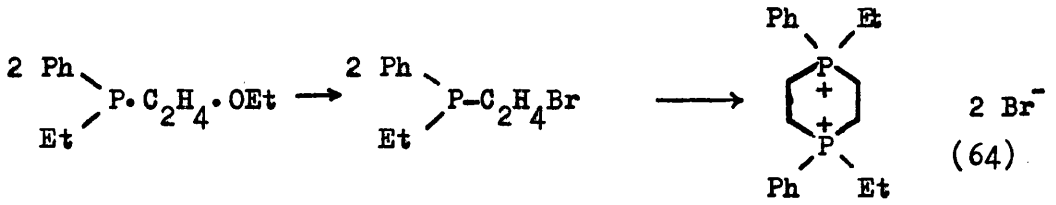
$$H_2P\cdot(CH_2)_3\cdot PH_2 \qquad (62)$$

acyclic biphosphine was obtained.

All other attempts to prepare phosphetanes by using compound $X-(CH_2)_3-X$ and substituted phosphines or phosphides gave only acyclic or cyclic biphosphines, e.g., Grim and Schaâff found that diphenylphosphine and 1,3-di-iodopropane gave the cyclic bisphosphonium salt (63).[60]

$$Ph_2PH + I-(CH_2)_3-I \longrightarrow Ph_2P\overset{(CH_2)_3}{\underset{(CH_2)_3}{<\!\!>}}PPh_2\ 2I \qquad (63)$$

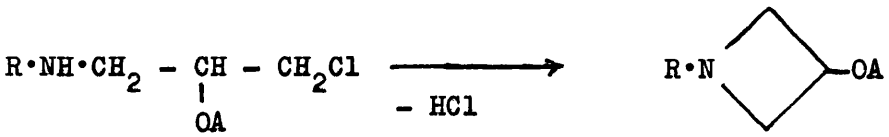
Hitchcock and Mann[61] obtained a similar bisphosphonium salt (64) by the route outlined



(64)

The Synthesis of Azetidines.

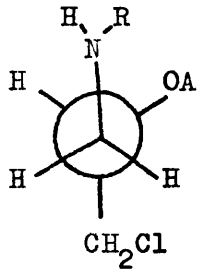
Gaertner[62] found that the analogous azetidines were obtained by the intramolecular cyclisation of an amine (65, A = H), which had a bulky substituent, R, on the nitrogen. This was in accord with earlier work which indicated that cyclisation was favoured by high steric bulk.[63]



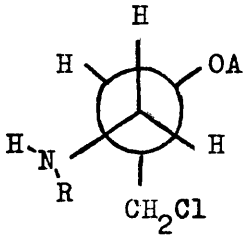
(65) (65a)

Gaj and Moore[64] found that the reaction of 1,3-dichloro-2methoxymethoxypropane with primary amines gave 3-methoxymethoxyazetidines (65a, A = $OCH_2 \cdot OCH_3$) even for groups, R, on nitrogen of low steric bulk such as methyl. It was assumed that the reaction proceeded via the amine (65). If R = Me and A = H for the formed amine (65), they found that intermolecular reaction was preferred. They proposed that for the intermediate amine (65)

intermolecular reaction was favoured by the preferred configuration (66) for groups R and A of small steric bulk. For groups of higher steric bulk the preferred configuration (67) favoured intramolecular reaction.

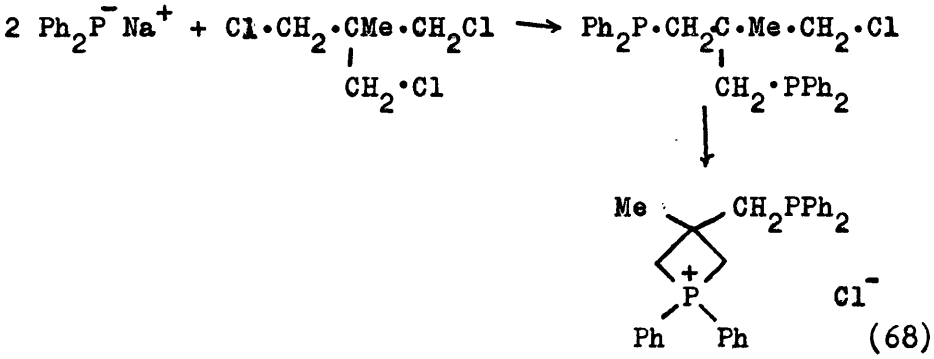


(66)



(67)

Bergland and Meek[65] have found that the reaction of sodium diphenylphosphide with 2-chloromethyl-1,3-dichloro-2-methylpropane gives the phosphetanium salt (68).

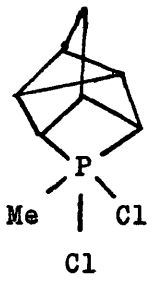


(68)

This indicates that as with nitrogen the presence of bulky substituents promotes intramolecular cyclisation.

The Synthesis of Highly Substituted Phosphetanes.

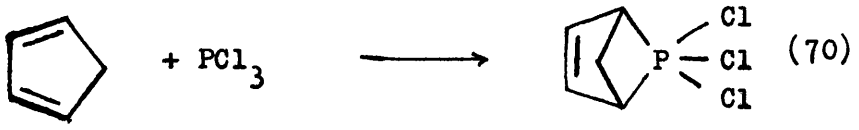
Green[66] reported that the reaction of 2,2,1-bicycloheptadiene with dichloromethylphosphine gave the compound (69) containing a phosphetane system.



(69)

Attempts were made to prepare adducts similar to that prepared by Green by the reaction of 2,2,1-bicycloheptadiene with phosphines, $RPCl_2$, where R was Cl, Ph, or PhO. No adduct was obtained from any of these reactions.

An attempt was also made to prepare an adduct (70) by the reaction of cyclopentadiene with phosphorus trichloride, but this was not successful. This was probably because of rapid dimerisation of the cyclopentadiene.

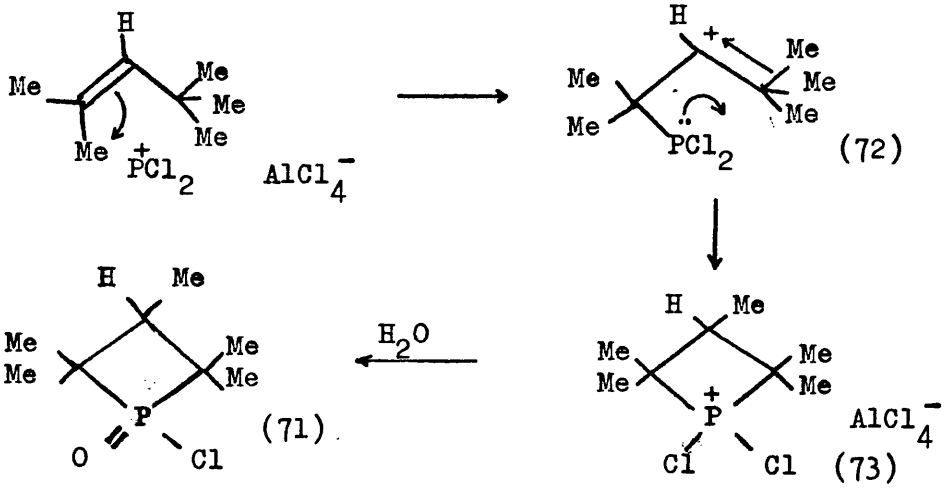


(70)

Jungermann and McBride[67] prepared 1-chloro-2,2,3,4,4-pentamethylphosphetane oxide (71) by the reaction of 2,4,4-trimethylpent-2-ene with phosphorus trichloride in the presence of

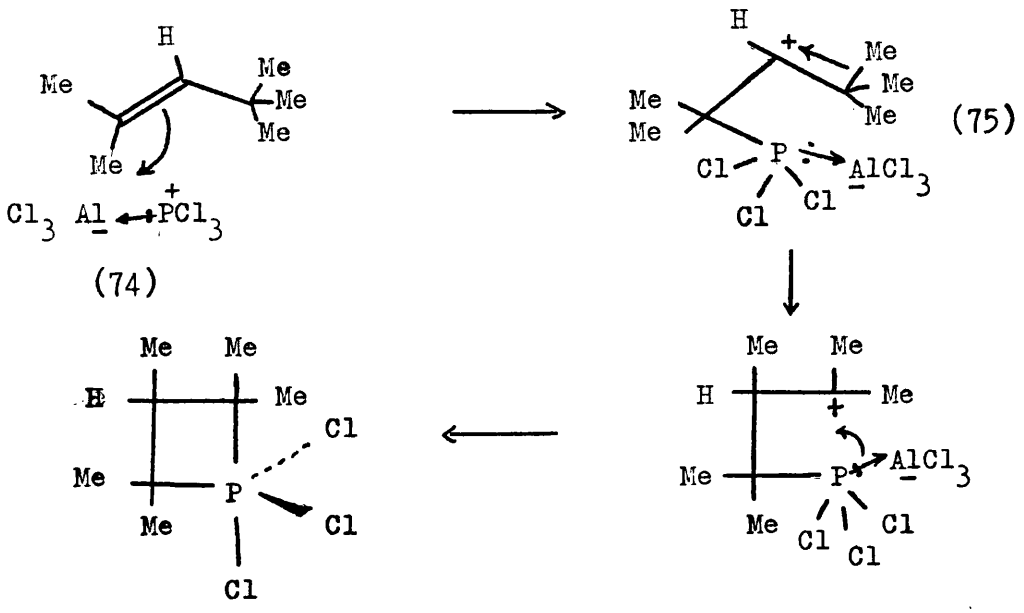
aluminium chloride. They discovered this novel cyclisation while studying the reactions of a series of substituted olefins with phosphorus trichloride and concluded that cyclic systems were obtained only from highly substituted olefins.

The postulated mechanism for the formation of this phosphetane oxide (71) is outlined below



In the presence of aluminium chloride, phosphorus trichloride gives the $P^{+}Cl_2$ species, which adds to the pentene double-bond to give an intermediate carbonium ion (72) which rearranges to the terminal tertiary carbonium ion by methyl migration. Ring closure is effected by the phosphorus lone pair of electrons to give the phosphetanium salt (73). Hydrolysis of this salt (73) gives the phosphetane oxide (71).

A mechanism which seems to fit the evidence more closely than the one proposed by Jungermann and McBride is outlined below

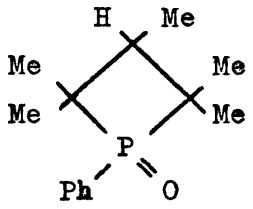


The attacking species (74) is most likely to be formed by donation of the phosphorus lone pair of electrons to aluminium, giving a complex containing a positively charged phosphorus atom. The reaction of this complex (74) with the pentene gives an intermediate carbonium ion (75) which rearranges by migration of a methyl group. The phosphorus in the pentacovalent state is ideally set up for the formation of a 4-membered ring because the preferred bond angle of 90° is easily accommodated by spanning an apical and an equatorial position.

In the mechanism proposed by Jungermann and McBride, the configuration about phosphorus was tetrahedral and so formation of the 4-membered ring would not be favourable.

The Preparation of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane.

A modification of the cyclisation discovered by Jungermann and McBride[67] was used for the work presented here. 2,2,3,4,4-Pentamethyl-1-phenylphosphetane oxide (76) was obtained by the reaction of 2,4,4-trimethylpent-2-ene with dichlorophenylphosphine. The oily phosphine oxide product of the reaction was separated into the 2 geometrical isomers of the phosphetane oxide (76) by column chromatography; the major isomer obtained had m.p.126° and the minor isomer had m.p.118°. These two oxides were distinguished by their N.M.R. and I.R. spectra. Their mass spectra were the same and satisfactory analyses were obtained for both isomers.



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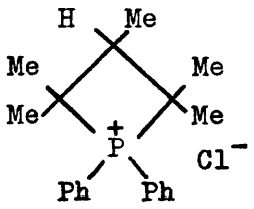

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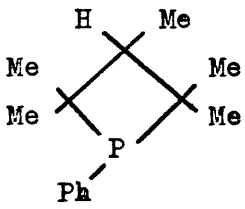


(78)

Attempted further modification of the reaction to the use of chlorodiphenylphosphine and 2,4,4-trimethylpent-2-ene did not yield any of the expected phosphetanium salt (77). By similar modifications Chorvatt and Cremer[69] have prepared two other phosphetane systems as well as the phosphetane oxide (76).

Reduction of the phosphetane oxide (76) with lithium aluminium hydride or trichlorosilane gave the phosphetane (78) which was a highly crystalline white solid, melting at a temperature slightly above ambient. The methyl, iodomethyl, benzyl, and p-nitrobenzyl salts of the phosphetane (78) were obtained by quaternisation with respectively methyl iodide, methylene iodide, benzyl bromide, and p-nitrobenzyl bromide.

Conclusion.

Only phosphetane and its highly substituted derivatives have been prepared. From the work of Gaj and Moore with the corresponding azetidines and the results of Bergland and Meek, it is apparent that steric factors are very important and by suitable modifications it may be possible to prepare 1,3-disubstituted phosphetanes.

The reaction of 1,1-dimethylbut-3-ene with phosphorus trichloride and with dichlorophenylphosphine also gave cyclic adducts. Preliminary studies of the salts derived from 2,2,3-trimethylphosphetane have led to further studies being carried out at present in this laboratory by other workers.

The reactions of the phosphetane derivatives prepared will be discussed in the following sections on "The Alkaline Hydrolysis of Phosphonium Salts" and "The Alkaline Hydrolysis of Phosphinate and Phosphonate Esters".

The Alkaline Hydrolysis of Phosphonium Salts.

Fenton and Ingold[70] found that the alkaline hydrolysis of phosphonium salts gave products different from those from the alkaline hydrolysis of ammonium salts. They found that, whereas ammonium salts gave an amine and an olefin, phosphonium salts gave a phosphine oxide and a paraffin. The proposed mechanisms are outlined below

$$R_3\overset{+}{P}-CH_2\cdot CH_2\cdot R^1 + OH^- \rightleftharpoons \underset{\underset{OH}{|}}{R_3P}-CH_2\cdot CH_2R^1 \rightleftharpoons \underset{\underset{O^-}{|}}{R_3P}\cdot CH_2\cdot CH_2R^1 + H^+ \quad (79) \quad (80)$$

$$R^1\cdot CH_2\cdot CH_3 \xleftarrow{\text{protonate}} R^1\cdot CH_2\cdot \overset{(-)}{C}H_2 + R_3P{:}O$$

$$R_3\overset{+}{N}-CH_2\cdot CH_2\cdot R^1 + OH^- \rightleftharpoons R_3\overset{+}{N}-CH_2-\overset{(-)}{C}H\cdot R^1 \longrightarrow R_3N + R^1\cdot CH{:}CH_2$$

It was suggested that because of the lower electron affinity of phosphorus even more severe conditions would be required for the phosphonium salt reaction to proceed to phosphine than those for the ammonium salt to proceed to amine. The conditions for the formation of phosphine oxide and paraffin were much milder than those for the production of amine and olefin. They concluded that by suitable substitution of the β-carbon it should be possible to obtain phosphine and olefin. Thus a β-phenylethylphosphonium salt was found to give mainly paraffin and some styrene. A ββ-diphenylethylphosphonium salt gave

1,1-diphenylethylene with some paraffin.

Ammonium salts could not decompose by the alternative mechanism because of the inability of nitrogen to form a pentacovalent intermediate.

Bestmann et al.[71] found that, when organolithium compounds or sodamide were used for the Hoffmann degradation of phosphonium salts, the α-proton was removed to form the ylid (81). This ylid (81) then decomposed by intermolecular proton shift to the olefin and phosphine.

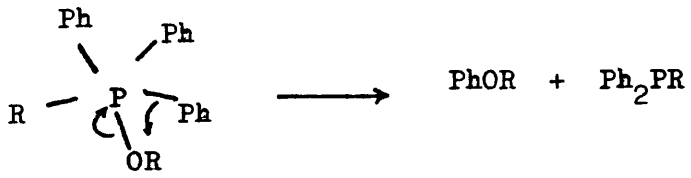
$$R^1 \cdot CH_2 \cdot CHR^2 - \overset{+}{P}Ph_3 \xrightarrow{B^-} R^1 \cdot CH_2 \cdot \overset{(-)}{C}R^2 - \overset{+}{P}Ph_3$$
(81)

$$R^1 \cdot CH - CR^2 - \overset{+}{P}Ph_3 \longrightarrow 2\ R^1 \cdot CH{:}CHR^2 + 2\ Ph_3P$$
(H, H; $Ph_3\overset{+}{P} - CR^2 - CH - R^1$)

The temperature required for the decomposition was taken as a measure of the mobility of the β-protons.

Trippett and Eyles[72] studied the thermal decomposition of phosphonium alkoxides. They found that no hydrocarbons could be detected when trying to repeat the reactions studied by Hey and Ingold[73]. When tetra-alkylphosphonium alkoxides were decomposed olefin and phosphine were obtained as the major products. n-Alkyltriphenylphosphonium alkoxides gave an alkyl

phenyl ether and n-alkyldiphenylphosphine oxide. Olefin formation became the major reaction when secondary- and tertiary-alkyltriphenylphosphonium alkoxides were decomposed. In the decomposition of secondary- or tertiary-alkoxides, sharply decreased amounts of alkyl phenyl ether were formed, suggesting that the reaction proceeded <u>via</u> a pentacovalent intermediate (82).



(82)

Formation of this intermediate was much hindered for bulky anion attack at phosphorus.

Majid Hamid and Trippett[74] found that the carbon atom of the phenyl attached to phosphorus in the intermediate (82) was the one attached to oxygen in the ether. This eliminated the possibility of the free phenyl radical being involved in the reaction.

The Mechanism of the Alkaline Hydrolysis.

The various stages of the mechanism proposed by Fenton and Ingold to explain their results were not very different from the present generally accepted mechanism. Hey and Ingold[73] studied the thermal decomposition of phosphonium alkoxides, finding that substitution of the stronger ethoxide base for hydroxide led to the formation of more olefin in favourable structural situations. From the reactions studied, Fenton, Hughes, and Ingold concluded that a) both olefin formation and paraffin formation must be dependent on the strength of the base; b) the rate determining step is the formation of the initial pentacovalent intermediate; c) the rate of reaction is probably proportional to $[OH^-].[salt]$ i.e., a second order reaction; d) a pentacovalent intermediate must be postulated, but loss of a proton from this intermediate before it decomposes to products is not essential; e) the relative ease of elimination of groups is parallel with their stability as the anion; f) the relative ease of elimination of a group is not dependent on the other groups attached to phosphorus.

Studies of the kinetics of the reaction have shown that the rate $\propto [OH^-]^2.[salt]$[75], p-Nitrobenzyltriphenylphosphonium bromide exhibits second order kinetics[76]. This result has been

explained by the much greater aptitude of p-nitrobenzyl to be a leaving group. Rather than having an equilibrium between the pentacovalent intermediate (79) and its conjugate base (80), the proton of the hydroxyl group of the pentacovalent intermediate (79) must be removed by a second hydroxide ion. In the case of the p-nitrobenzyl salt the conjugate base (80) is so rapidly decomposed to p-nitrobenzyl anion and phosphine oxide that the decomposition of the pentacovalent intermediate (79) becomes the rate determining step.

McEwen et al. proposed that the scheme outlined by Fenton and Ingold should be modified as outlined in the diagram

$$R_4P^+ + OH^- \underset{}{\overset{\text{fast}}{\rightleftharpoons}} R_4P\text{-}OH \underset{\text{fast}}{\overset{OH^-}{\rightleftharpoons}} R_4P\text{-}O^- + H_2O$$

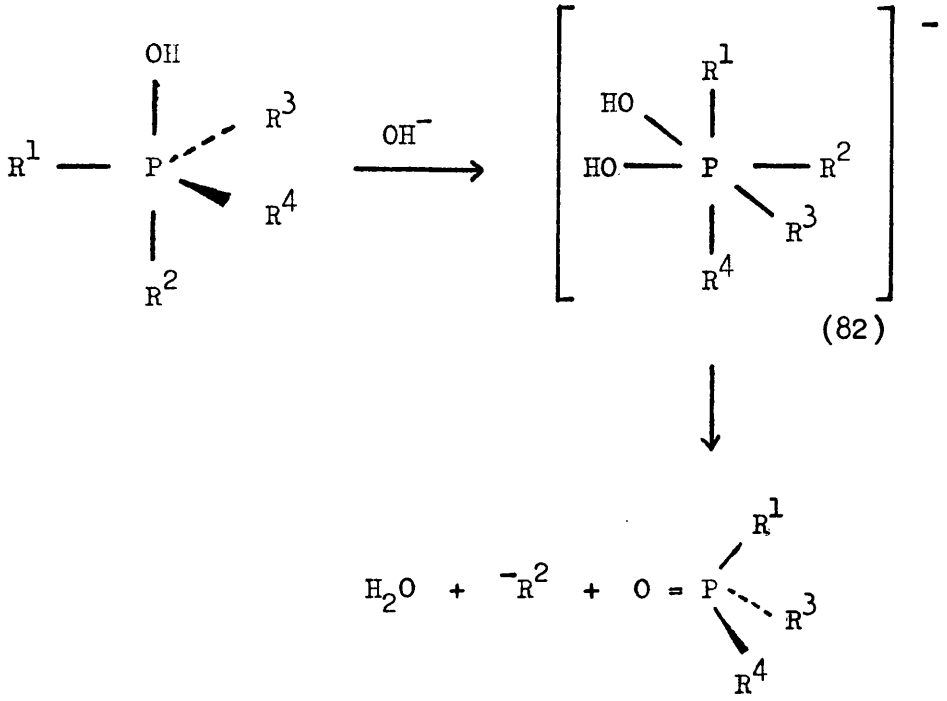
$$R_4P\text{-}O^- \xrightarrow{\text{slow}} R_3P{:}O + R^- \xrightarrow[\text{protonation}]{\text{fast}} R{\cdot}H$$

All later work has supported the conclusion that the ease of elimination of a group parallels its stability as the anion[75]. It has, however, been found that the ease of elimination of a group is dependent on the other groups attached to the phosphorus[75] contrary to the conclusion of Ingold et al.

Hays and Laughlin[68] found that the reactions of tetraalkylphosphonium salts with anhydrous sodium hydroxide proceeded under considerably milder conditions than the reactions in aqueous solution, and that the reactivity of the dodecyltrimethylphosphonium halides decreased in the order $Cl^- > Br^- > I^-$. This difference of reactivity was explained in terms of the energy of association of ion pairs. $R_4P^+ OH^-$ and $Na^+ OH^-$ were common to the three reactions and so the rate of reaction was dependent on the relative stabilities of $R_4P^+ X^-$ and $Na^+ X^-$. In the series, $Cl^- > Br^- > I^-$, the association energy of Na^+ with X^- increased more rapidly than that of R_4P^+ with X^-, and it followed that $R_4P^+ OH^-$ should be formed more readily in the order $Cl^- > Br^- > I^-$ These workers also found that mixtures of products were obtained from the reactions investigated. Substituted-benzyltribenzylphosphonium salts have also been found to give a mixture of products[75]. Other reactions studied have been found to give only one product as the energy difference for elimination of an alternative group is sufficiently large to ensure the formation of only one product.

An alternative mechanism has been suggested, which also fits the available evidence[77]. It is postulated that the second hydroxide ion attacks the phosphorus, forming a hexacovalent anion (82), which then decomposes by simultaneous loss of water

and the paraffin anion.



(82)

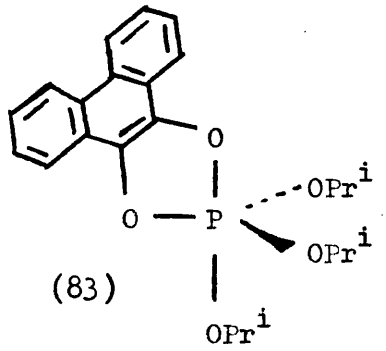
The Stereochemistry of Alkaline Hydrolysis.

It has been found that during the alkaline hydrolysis of optically active phosphonium salts the configuration about the phosphorus atom is inverted. McEwen et al.[78] compared the phosphine oxides formed from the Wittig reaction and from the alkaline hydrolysis of an optically active phosphonium salt. Horner and Winkler[79], following the preparation of optically active phosphines, prepared the phosphine oxide and phosphonium salt by respectively oxidation and quaternisation. They showed that the oxides from the oxidation and from the alkaline hydrolysis were of opposite configuration. The phosphine oxide from the Wittig reaction was the same as that from the oxidation.

This stereochemical requirement can be explained by either of the two postulated mechanisms, but only the more generally accepted mechanism will be discussed.

Reactions involving pentacovalent phosphorus intermediates are usually assumed to proceed via a trigonal bipyramid. They may be equally well described, however, by square pyramidal intermediates.

The structure of all the stable pentacovalent phosphorus compounds so far studied have been found to be trigonal bipyramidal from N.M.R. and X-ray evidence. Ramirez et al.[80] found a trigonal bipyramidal structure for the pentaoxyphosphorane (83). Berry, and later Schmutzler[81], in studies of the phosphoranes $(alkyl)_nF_{5-n}P$, found that the N.M.R. spectra were best explained



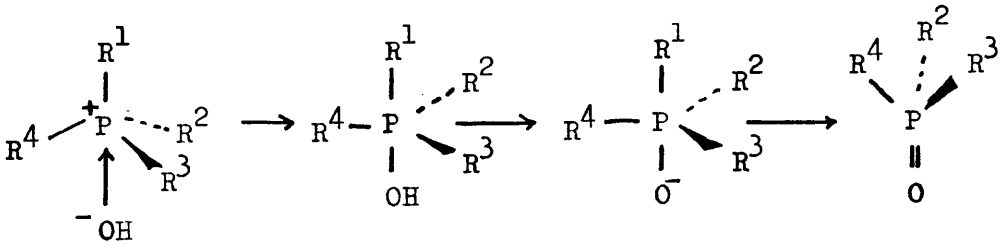
(83)

by interconversion of trigonal bipyramids. "Pseudo-rotation" of trigonal bipyramids has been postulated to explain the products of hydrolysis of phosphate esters. By "pseudo-rotation", one

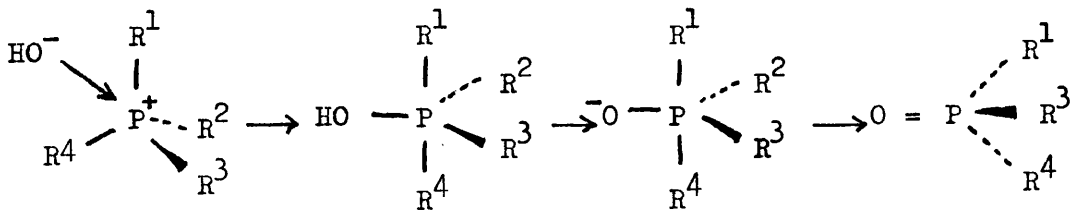
trigonal bipyramid is converted to another via an intermediate square pyramid[82]. Inversion of configuration of the central atom may be achieved by several successive "pseudo-rotations". This process of pseudo-rotation will be more fully discussed in the section on "The Alkaline Hydrolysis of Phosphinate and Phosphonate Esters".

The alkaline hydrolysis of a phosphonium salt may proceed with inversion of configuration by either of the routes shown.

a) entering group apical, leaving group apical

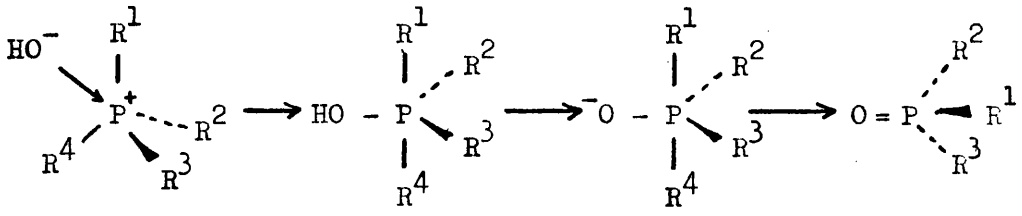


b) entering group equatorial, leaving group equatorial

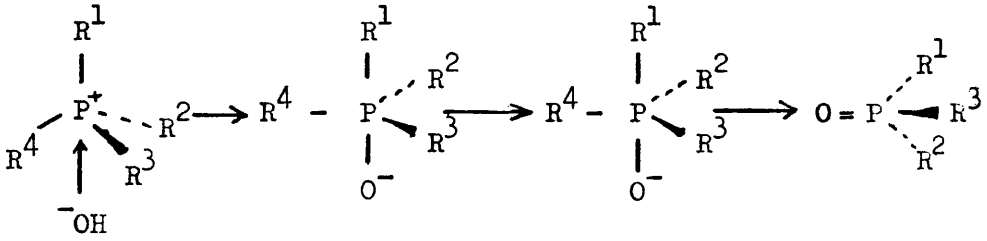


If, however, the leaving group is apical and the entering group equatorial or vice-versa, then retention of configuration is observed.

c) Entering group equatorial, leaving group apical



d) Entering group apical, leaving group equatorial



As inversion of configuration is observed in the alkaline hydrolysis of optically active phosphonium salts, if no process of "pseudo-rotation" is involved and if the reaction proceeds via a pentacovalent trigonal bipyramidal intermediate, then either path a) or path b) above must be followed

Steric Effects in Alkaline Hydrolysis

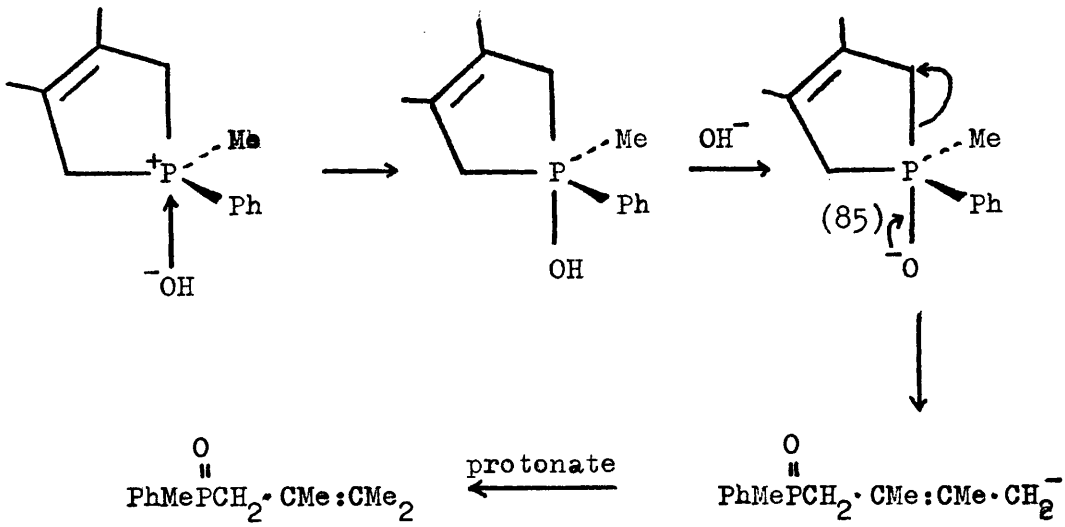
Pagilan and McEwen[83] studied the kinetics of the alkaline hydrolysis of a series of o- and p-tolylphosphonium chlorides

They found only 2.5 fold differences in rates of reaction from salts not sterically hindered. This small difference was explained by a cancellation of opposite effects. The addition of the hydroxide ion to give a pentacovalent intermediate relieved the angle strain of the salt in going from a 109° to a 120° bond angle, and so the rate of this step was increased. The rate of formation of the conjugate base was not affected, as no change of geometry was involved. Collapse of the trigonal bipyramidal conjugate base to the more sterically hindered tetrahedral phosphine oxide was slowed down. Thus the overall rate of reaction was not greatly affected by steric hindrance.

The Alkaline Hydrolysis of Phospholenium Salts.

The preferred bond angle for a 5-membered ring at phosphorus is about 90°. The preferred configuration for a trigonal bipyramidal intermediate would, therefore, have the ring spanning an apical and an equatorial position.

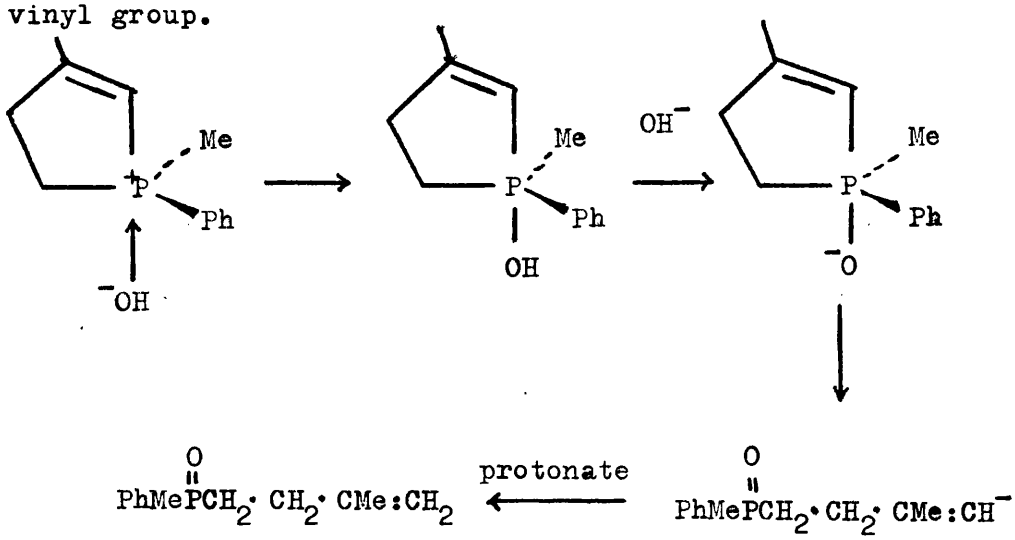
The product from the alkaline hydrolysis of 1-phenyl-1,3,4,-trimethyl-3-phospholenium iodide was methylphenyl(2,3,3-trimethylallyl) phosphine oxide (84). This was the expected product as the allylic group was the preferred leaving group and was ideally placed in the intermediate.



(84)

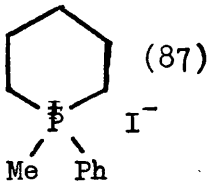
The proposed structure for this phosphine oxide (84) was supported by the ^{1}H N.M.R. spectrum, the mass spectrum, and the analysis.

The alkaline hydrolysis of 1,3-dimethyl-1-phenyl-2-phospholenium iodide gave (3-methylbut-4-enyl)methylphenylphosphine oxide (86), i.e., loss of the ring vinylic group occurred. This was the preferred leaving group and its loss could be accounted for by apical attack of hydroxide ion followed by apical expulsion of the vinyl group.



(86)

The proposed structure of the phosphine oxide (86) was supported by the ^{1}H N.M.R. and the mass spectrum. This oxide (86) was hygroscopic and so an analysis was not obtained.



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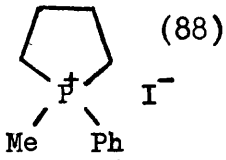


(88)

Aksnes and Bergesen[84] found that during the alkaline hydrolysis of cyclopentamethylene (87) and cyclotetramethylene (88) methylphenylphosphonium iodides the rings were preserved. The 5-membered ring compound was found to hydrolyse at 1300 times the rate of the 6-membered ring or acyclic compounds. Atomic models showed that the rotation of the methyl and phenyl groups of the phospholane was severely restricted by the eclipsing with the ring α-hydrogens, whereas for the phosphorinane this eclipsing was much milder. The rate difference was thus explained by relief of eclipsing strain. Kinetic data showed that the rate difference, within the limits of experimental error, was almost entirely due to a greater frequency factor. This increased frequency factor may have been due to a statistical effect. The phosphorus atom of the planar phospholane was much more exposed to attack by the hydroxyl ion because of the very restricted rotation of the methyl and phenyl groups attached to phosphorus, and so more effective collisions of the two ions were expected.

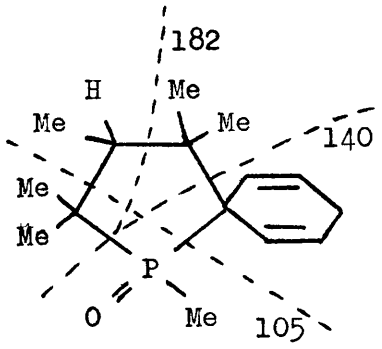
Retention of the phospholane ring during hydrolysis shows that ring opening of phospholenes is observed because the apical ring substituent is the preferred leaving group of the system. If ring opening was a consequence of steric effects constraining the ring to occupy an apical and an equatorial position, then the phospholane should also be cleaved.

The Alkaline Hydrolysis of 2,2,3,4,4-Pentamethyl-1-phenyl-phosphetanium Salts.

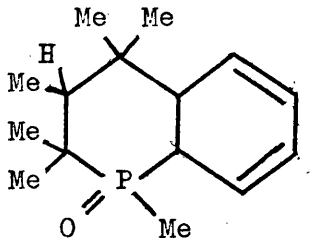
The alkaline hydrolysis of phosphetanium salts was studied to see if there were any anomolous properties connected with the presence of the 4-membered ring. In the trigonal bipyramidal intermediate formed during alkaline hydrolysis, the 4-membered ring would be expected to occupy one equatorial and one apical position. If no "pseudo-rotation" occurred and hydrolysis proceeded by apical attack followed by apical expulsion, ring opening should occur, giving an acyclic product.

a. The hydrolysis of the methyl and iodomethyl salts[85].

A phosphine oxide was obtained from the alkaline hydrolysis of 1,2,2,3,4,4-hexamethyl-1-phenylphosphetanium iodide (89). This phosphine oxide did not show a peak at 1430 cm characteristic of the P-phenyl group, or peaks characteristic of a mono-substituted phenyl group. The ^{1}H N.M.R. spectrum showed peaks for 2 allylic and 4 vinylic protons. The structure (90) was proposed for this phosphine oxide on the basis of the evidence available.



(90)



(91)

No benzene could be detected in the reaction mixture by g.l.c. The mass spectrum showed the breakdown pattern (90) as outlined as well as the mass peak $^{m}/_{e}$ 252. On catalytic hydrogenation 2 moles of hydrogen were taken up, indicating the presence of 2 double-bonds.

Chorvatt and Cremer[86] proposed an alternative structure (91) for this phosphine oxide. Examination of the U.V. spectrum, even of very concentrated solutions of this phosphine oxide, did not reveal a peak characteristic of a conjugated cyclohexadiene. The allylic protons in the alternative structure (91) were attached to different carbon atoms, whereas in the structure (90) they were attached to the same carbon atom. The doublet (2H) of the ^{1}H N.M.R. spectrum ascribed to the allylic protons indicated that the allylic protons were probably attached to the same carbon atom.

In order to establish which of the proposed structures was the correct one, the phosphetanium salt with a p-deuteriophenyl, instead of a phenyl group, was synthesised. The synthesis of

the required intermediate (p-deuteriophenyl)dichlorophosphine (92) was attempted by two routes.

Route a)

$$\underline{p}\text{-D-Ph}\cdot\text{Li} + SiCl_4 \longrightarrow \underline{p}\text{-D-Ph}\cdot SiCl_3 \xrightarrow[PCl_3]{AlCl_3} \underline{p}\text{-D-Ph}\cdot PCl_2\cdot AlCl_3 + SiCl_4$$

$$\underline{p}\text{-D-Ph}\cdot PCl_2\cdot AlCl_3 \xrightarrow{POCl_3} \underline{p}\text{-D-Ph}\cdot PCl_2 + POCl_3AlCl_3$$

(92)

Route b)

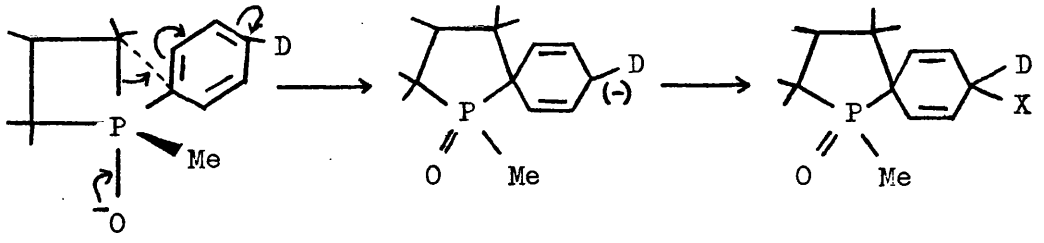
$$\underline{p}\text{-D-Ph}\cdot\text{Li} + Cl\cdot P(NEt_2)_2 \longrightarrow \underline{p}\text{-D-Ph}\cdot P(NEt_2)_2 \xrightarrow{4HCl} \underline{p}\text{-D-Ph}\cdot PCl_2$$

(92)

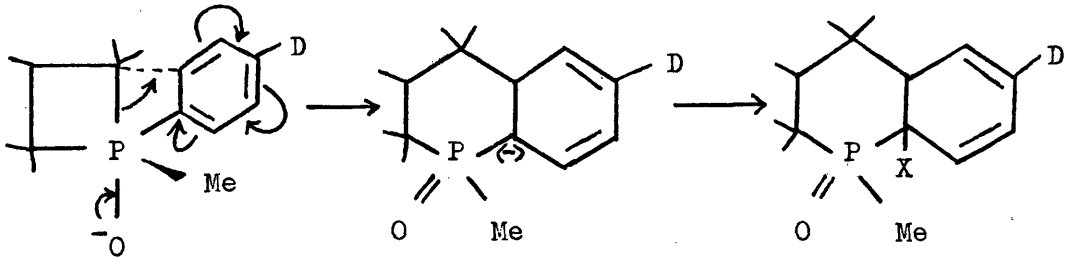
Route a. was not successful as the aluminium chloride complex could not be decomposed by addition of phosphorus oxychloride. The phosphine (92) was obtained in good yield by route b). Substitution of this phosphine (92) for dichlorophenylphosphine, in the modified phosphetane synthesis, gave 1-(p-deuteriophenyl)-1,2,2,3,4,4-hexamethylphosphetanium iodide (93).

Alkaline hydrolysis of this phosphetanium iodide (93) gave a phosphine oxide with properties the same as that from the hydrolysis of the non-deuteriated-phenyl phosphetanium iodide, except that the doublet at τ7.26 was broadened and integrated for only one proton. It was found that hydrolysis of this salt (93) in deuterium oxide instead of water gave a phosphine oxide which no longer had a doublet at τ7.26, but was otherwise identical with the phosphine oxide from the non-deuteriated-phenyl phosphetanium iodide.

The postulated mechanisms for the formation of the phosphine oxides (90) and (91) are outlined below:



(90)



(91)

X is the proton or deuterium from solvent.

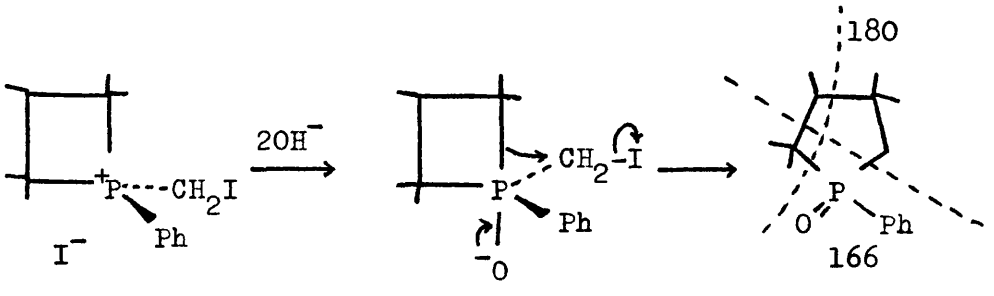
D is the proton or deuterium of the original p-D-phenyl.

It can be clearly seen that the 5-membered ring structure (90) fits the evidence obtained by deuterium labelling, whereas the 6-membered ring structure (91) does not.

Chorvatt and Cremer[86] found that the hydrolysis of the non-deuteriated phosphetanium iodide (89) in deuterium oxide gave a phosphine oxide with the same physical characteristics as those of the phosphine oxide from the hydrolysis of the deuteriated phosphonium salt in water. This piece of evidence fits for both of the proposed structures.

From the evidence available, it was concluded that the phosphine oxide had the spiro-structure (90).

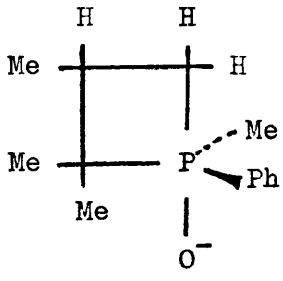
Finding this migration of the ring α-carbon atom during the alkaline hydrolysis of the methyl salt prompted the investigation of the alkaline hydrolysis of the iodomethyl salt (94) of 2,2,3,4,4-pentamethyl-1-phenylphosphetane. A phosphine oxide was obtained. The proposed structure (95) of this phosphine oxide was supported by the ^{1}H N.M.R. spectrum and the mass spectrum with a breakdown pattern as shown.

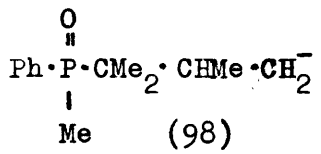


(94) (96) (95)

The mechanism for the formation of this phosphine oxide was very similar to that for the formation of the spiro-phosphine oxide (90) from the methyl salt. During the alkaline hydrolysis of acyclic α-heterofunctionally substituted phosphonium salts phenyl migration from phosphorus to the α-carbon was observed[87]. The 4-membered ring present in the salt studied prevented migration of the phenyl group because the phenyl group could not occupy an apical position in the intermediate (96).

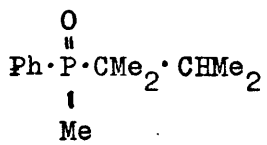
Fishwick and Flint[88] have found that the alkaline hydrolysis of 1,2,2,3-tetramethyl-1-phenylphosphetanium iodide gives the acyclic phosphine oxide (97) by protonation of the carbanion formed by cleavage of the ring.





(98)

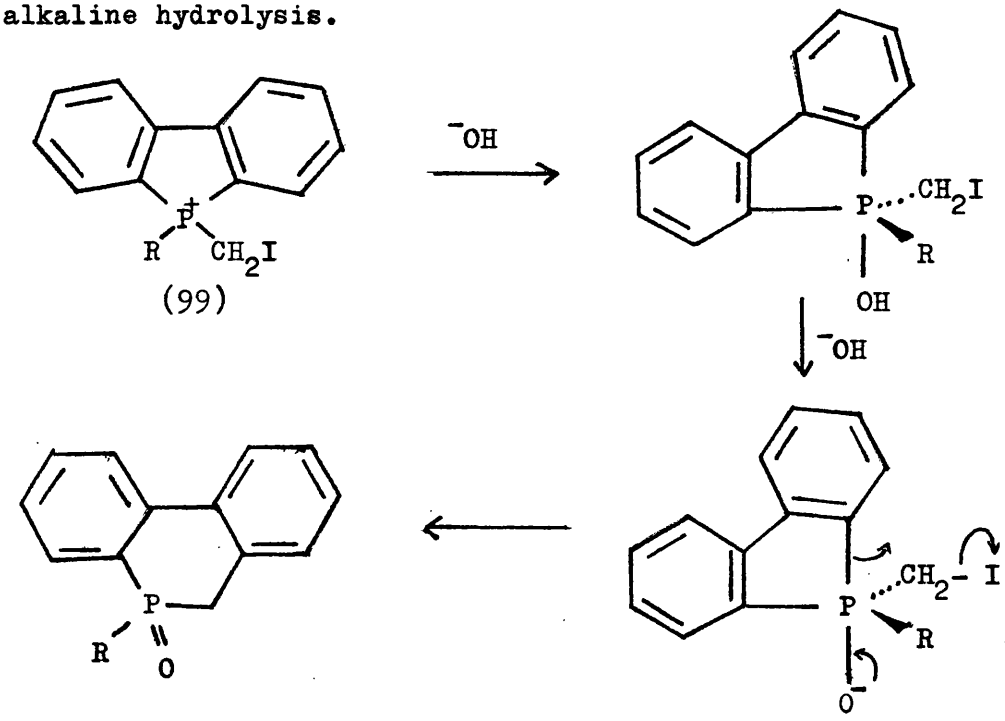
protonate



(97)

The primary carbanion (98) is much more stable than the tertiary carbanion that would be formed by ring cleavage of hexamethylphenylphosphetanium iodide (89). Thus the acyclic product is formed rather than the spiro-compound.

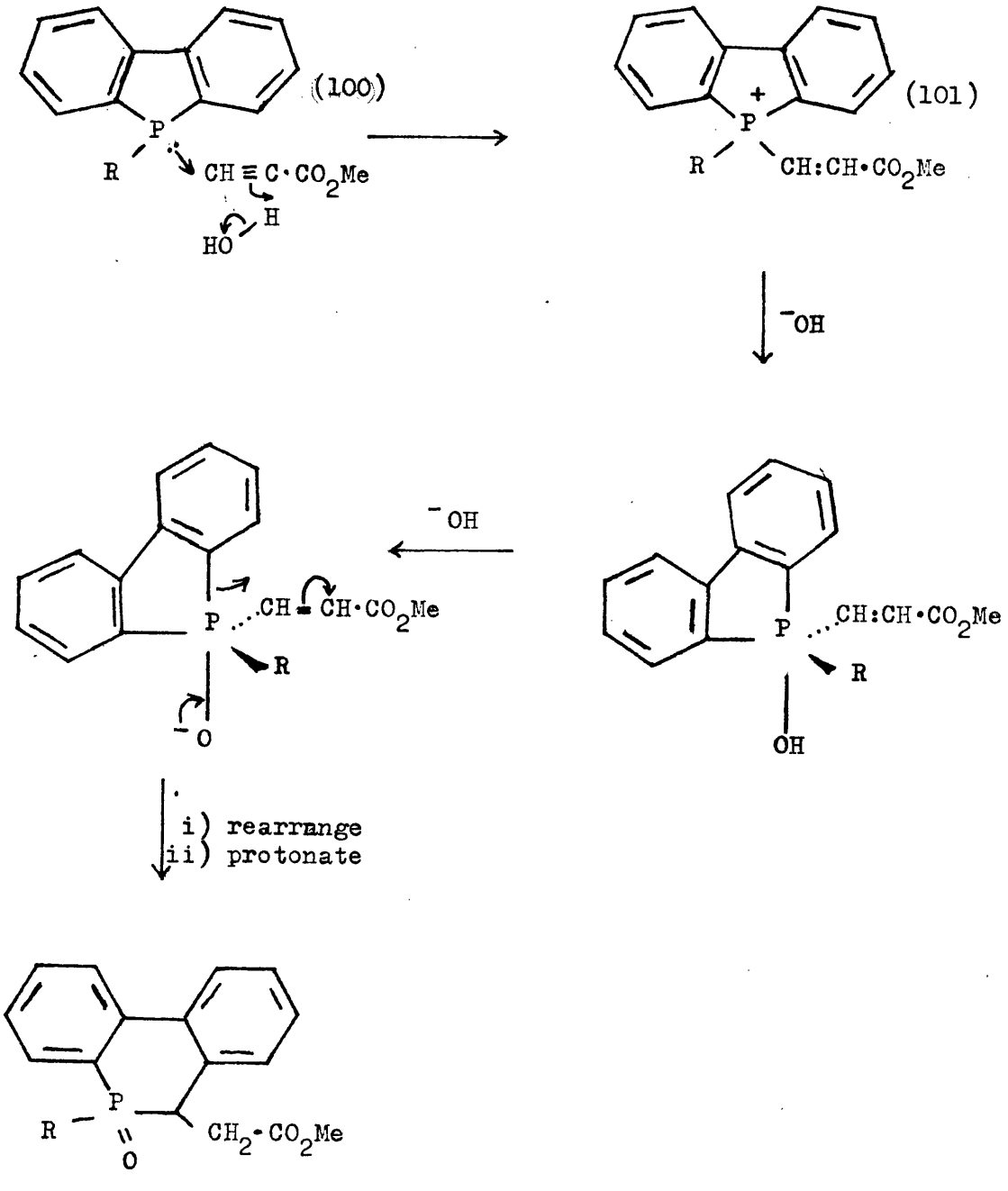
Allen and Millar[89] observed an analogous ring expansion reaction of a five membered ring phosphonium salt (99) on alkaline hydrolysis.



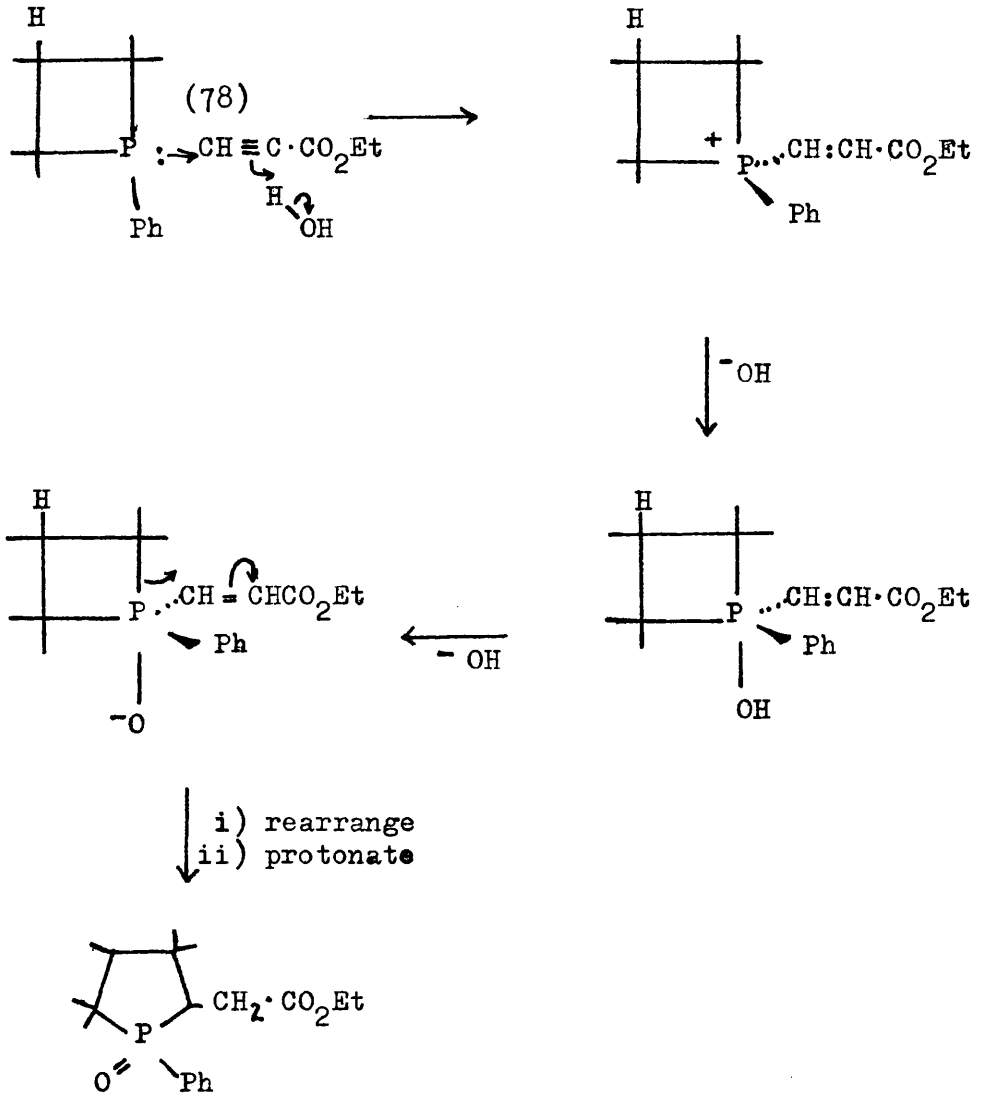
This rearrangement was found to occur for a variety of groups, R, including the benzyl group. Here again, the ring is constrained to occupy an apical and an equatorial position and the mechanism is the same as for the iodomethylpentamethylphenylphosphetanium salt (94).

Richards and Tebby[90] found that the reaction of 9-phosphafluorenes (100) with methyl propiolate in wet ether gave a

similar ring expansion. The mechanism for this rearrangement presumably involved alkaline hydrolysis of an intermediate phosphonium cation (101).



The reaction of pentamethylphenylphosphetane (78) with ethylpropiolate in wet ether gave a 5-membered ring phosphine oxide (102).

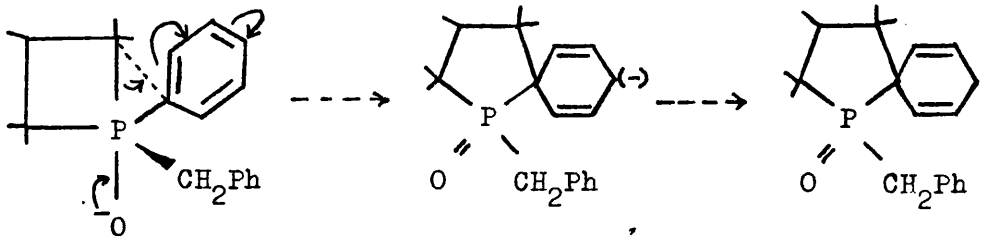


(102)

The mechanism of this reaction again involved migration of the apical $-CMe_2$ group.

b) Alkaline Hydrolysis of The Benzyl and p-Nitrobenzyl Salts[91].

By analogy with the hydrolysis of the methyl salt, a spiro product (103) might be expected from the hydrolysis of the benzyl and p-nitrobenzyl salts.

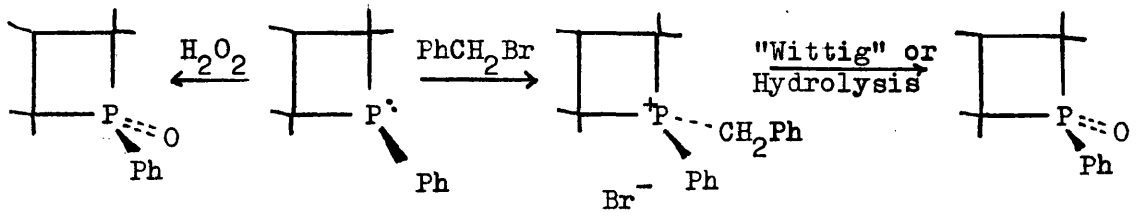


(103)

The product of these reactions was, however, identified as 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide (76), m.p.126°, i.e., the hydrolyses proceeded *via* loss of the benzyl or p-nitrobenzyl anion. Toluene and p-nitrotoluene were detected by g.l.c. p,p'-Dinitrodibenzyl was isolated from the hydrolysis of the p-nitrobenzyl salt, as has been found for acyclic analogues[92].

The Wittig reaction with the benzyl salt and benzaldehyde in the presence of sodium ethoxide also gave the pentamethylphenylphosphetane oxide (76), m.p.126°. The presence of the 4 membered ring would not be expected to affect the course of the Wittig reaction in which the configuration about phosphorus is maintained. The hydrolysis was therefore presumed to have proceeded with

retention of configuration. This was confirmed by oxidation of the phosphetane from which the benzyl salt was prepared. The phosphetane oxide (76), m.p. 126°, was again obtained.

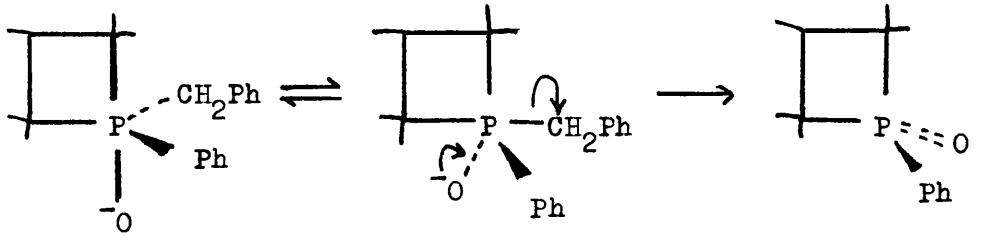


m.p. 126°
(76)

m.p. 126°
(76)

The hydrolysis must have proceeded <u>via</u> apical attack and equatorial expulsion or vice-versa unless pseudo-rotation could occur.

By "pseudo-rotation" of the trigonal bipyramidal intermediate it is possible to expel the benzyl anion from an apical position as shown below.

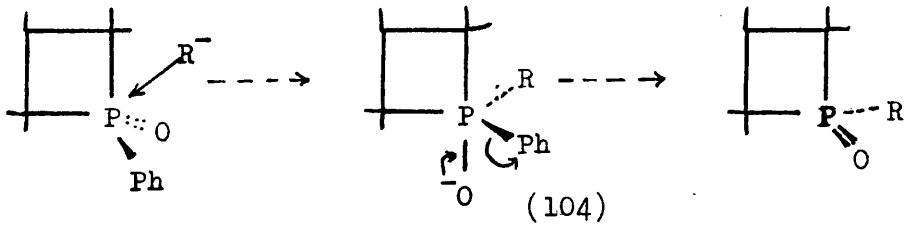


(76)

Further evidence in support of the "pseudo-rotation" mechanism postulated here is to be found from the study of the reactions of organo-lithium reagents with 2,2,3,4,4,-pentamethyl-1-phenylphosphetane Oxide and 1-chloro-2,2,3,4,4,-pentamethyl-phosphetane oxide.

The Reaction of 2,2,3,4,4,-Pentamethyl-1-phenylphosphetane Oxide with Organolithium Reagents.

Having found that the presence of suitable substituents could cause the alkaline hydrolysis of phosphonium salts to proceed with retention of configuration about phosphorus, the reactions of pentamethylphenylphosphetane oxide (76), m.p. 126°, with methyl- and phenyl-lithium were investigated. If the methyl- or phenyl anion attacks at an equatorial position, then by the principle of microscopic reversibility the phenyl group must leave from the equatorial position. Thus the reaction would proceed with inversion of configuration.

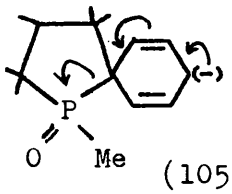


(104)

The intermediate (104,R = Me) is the same as that in the alkaline hydrolysis of the methyl salt (89). The rearrangement product (90) obtained from the alkaline hydrolysis was not, however, formed.

This does not eliminate the possibility of formation of

the carbanion (105) of the rearranged product. In the ether solvent employed for the reaction of methyl-lithium with the pentamethylphenylphosphetane oxide (76), immediate protonation of this carbanion (105) is not possible and rearrangement to the phosphorus anion (106) may occur.



(105)

- - - -

$Me-\overset{\overset{O}{\|}}{\bar{P}}-CMe_2\ CHMe\ CMe_2\ Ph$

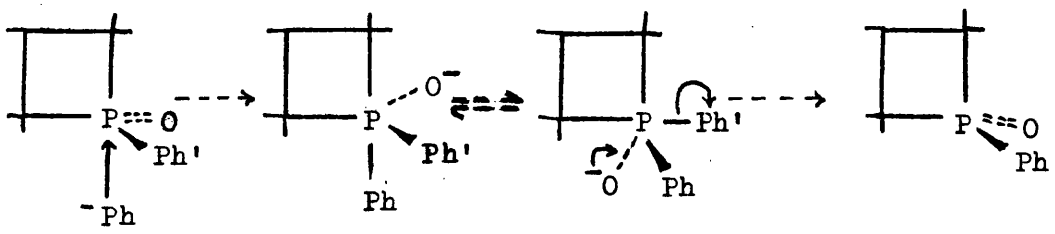
(106)

Work up of the reaction mixture by hydrolysis gave an oily product with νmax. 2130 cm^{-1} showing the presence of a P-H bond. This indicates that a phosphorus anion such as the one (106) postulated above must have been involved.

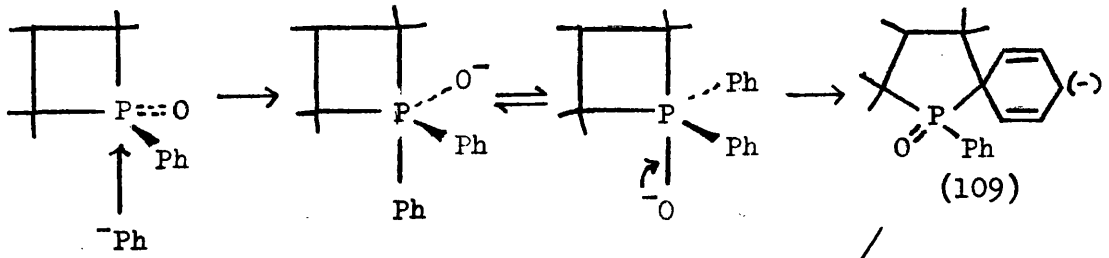
Crystalline 1,2,2,3,4,4-hexamethylphosphetane oxide (107) was obtained by sublimation from the crude reaction mixture. The remaining oil could not be crystallised but still showed νmax. 2130 cm^{-1} indicative of the P-H bond.

As the methyl anion was found to displace the phenyl anion from the pentamethylphenylphosphetane oxide (76), m.p. 126°, the reaction of phenyl-lithium with pentamethylphenylphosphetane oxide, m.p. 126°, was investigated. If the substitution of one phenyl for another involves equatorial attack, a mixture of isomers should be obtained, whereas apical attack followed by "pseudo-rotation" would give unchanged pentamethylphenylphosphetane oxide,(76) m.p. 126°. The former route is outlined at the beginning of

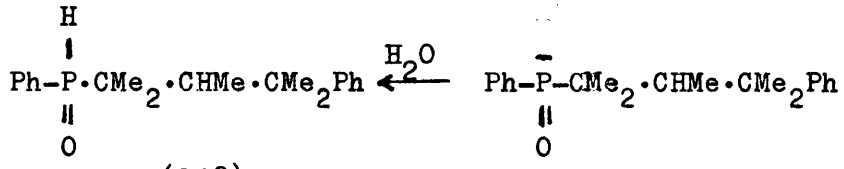
the section. Apical attack - "pseudo-rotation" - apical expulsion is outlined below.



None of the starting material was recovered from the reaction. The product obtained by hydrolysis was (1,1,2,3,3-pentamethyl-3-phenylpropyl)phenylphosphine oxide (108). The postulated mechanism for the formation of this phosphine oxide (108) involves an intermediate carbanion (109) similar to that formed in the alkaline hydrolysis of the methylphosphetanium salt.



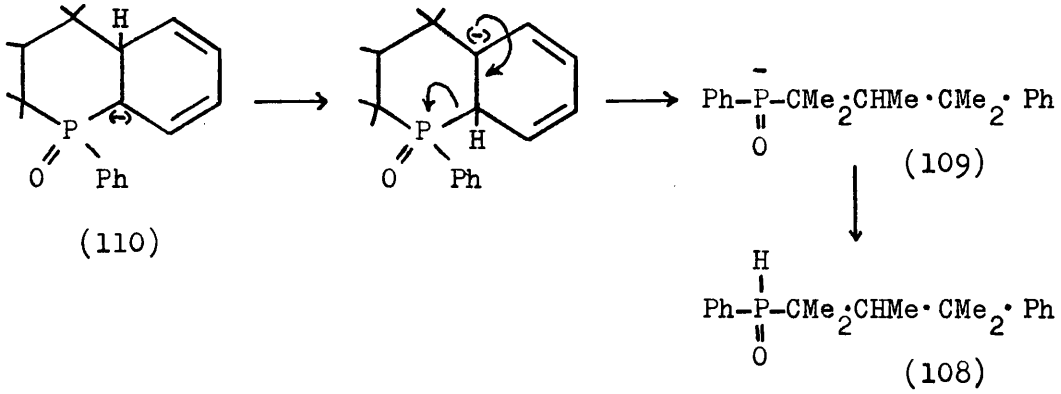
(109)



(108)

It was demonstrated that during the course of the reaction the two phenyl groups became equivalent by using p-deuteriophenyl-lithium. The two phenyl groups of the ^{1}H N.M.R. spectrum integrated for the same number of protons indicating that the deuterium was equally distrubuted between them in the product (108).

An alternative mechanism can be postulated for the formation of the phosphine oxide (108). The anion (110) could be formed by attack of the carbanion at the o-position. Rearrangement of this anion (110) to the anion (109) followed by protonation would give the phosphine oxide (108).

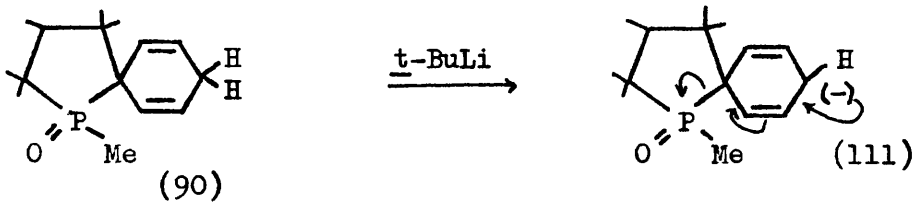


(110) (109) (108)

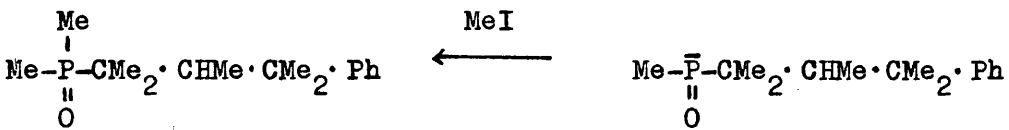
To distinguish between these two postulated mechanisms the (p-deuteriophenyl)phosphetane oxide and p-deuteriophenyl-lithium were used instead of the non-deuteriated compounds. The position of the deuterium atom in the phenyl group which migrates should distinguish between the two mechanisms; if it is in the p-position the former mechanism is correct, whereas if it is in the m-position the latter is the correct one. The N.M.R. spectrum was

not sufficiently well resolved to distinguish between these isomers of the phosphine oxide (110).

As rearrangement of the intermediate carbanion (109) occurred in aprotic solvents to give an acyclic product (108), the spiro-phosphine oxide (90) was treated with t-butyl-lithium. Removal of an allylic proton should give the intermediate anion (111) which could then rearrange to give an acyclic product (112). The reaction mixture was worked up by addition of methyl iodide and a phosphine oxide was obtained with a ^{1}H N.M.R. spectrum very similar to that of the phosphine oxide (110) from the phenyl-lithium reaction. The structure (112) was postulated for this phosphine oxide.



(90) (111)



(112)

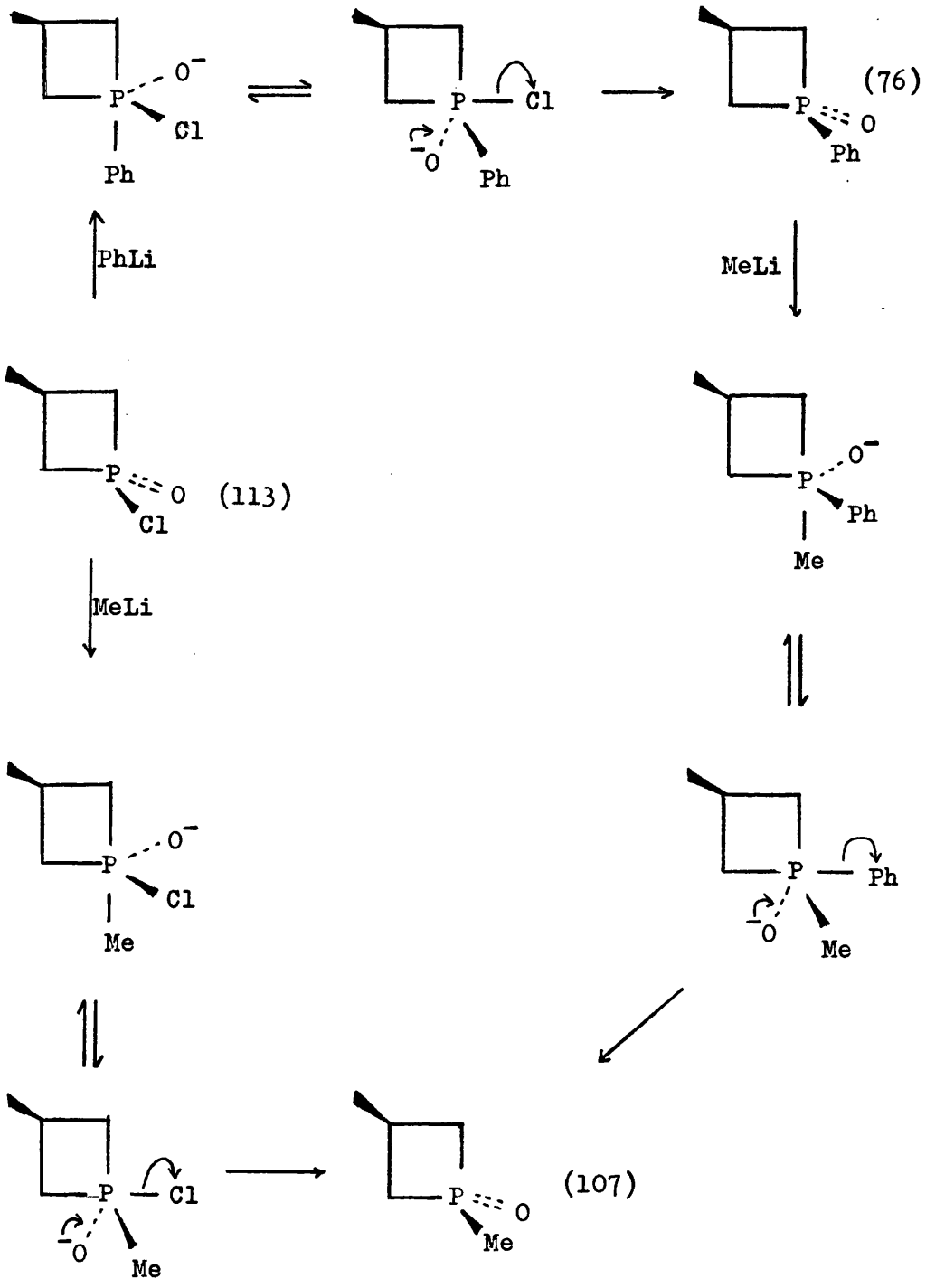
No analysis was obtained as the product contained some of the starting phosphine oxide (90) even after chromatography. The mass spectrum supported the proposed structure (112) for the product.

The Reaction of 1-Chloro-2,2,3,4,4-pentamethylphosphetane Oxide with Organolithium Reagents.

The reaction of pure crystalline chloropentamethylphosphetane oxide (113) with phenyl-lithium gave the acyclic phosphine oxide (108) which was also obtained from the reaction of phenyl-lithium with pentamethylphenylphosphetane oxide (76). This indicated that the initially formed pentamethylphenylphosphetane oxide (76) was more reactive with phenyl-lithium than the chloropentamethylphosphetane oxide (113). A minor product of the reaction was pentamethylphenylphosphetane oxide (76), m.p. 126°; none of the isomer m.p. 118° was found.

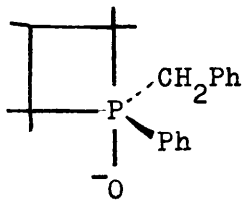
The reaction of pure crystalline chloropentamethylphosphetane oxide (113) with methyl-lithium gave 1,2,2,3,4,4-hexamethylphosphetane oxide (107). The ^{1}H N.M.R. spectrum, m.p., and mixed m.p. for this hexamethylphosphetane oxide (107) were the same as for the hexamethylphosphetane oxide (107) from the reaction of methyl-lithium with pentamethylphenylphosphetane oxide (76).

This is another demonstraction of a series of substitutions proceeding with retention of configuration in a Walden cycle, as shown on the next page.


(76)
PhLi
MeLi
(113)
MeLi
(107)

As the same phosphetane oxide (107) was obtained by both routes it is clear that retention of configuration must have occurred in each step. One route involved two stages and the other only one stage; two steps proceeding with inversion would give the original configuration and one step proceeding with inversion would give the inverted configuration.

This is evidence against the loss of the benzyl anion from an equatorial position of the trigonal bipyramidal intermediate (114) during alkaline hydrolysis of the benzyl salt.



(114)

If the benzyl anion left from an equatorial position, the microscopic reverse would be equatorial attack by similar alkyl anions. The above Walden cycle demonstrated that the configuration about phosphorus was maintained when the phenyl anion was displaced by the methyl anion. Equatorial attack by the methyl anion should lead to equatorial loss of the phenyl anion and the configuration about phosphorus would be inverted. Thus it appears that this series of substitutions must proceed <u>via</u> the postulated mechanism involving "pseudo-rotation".

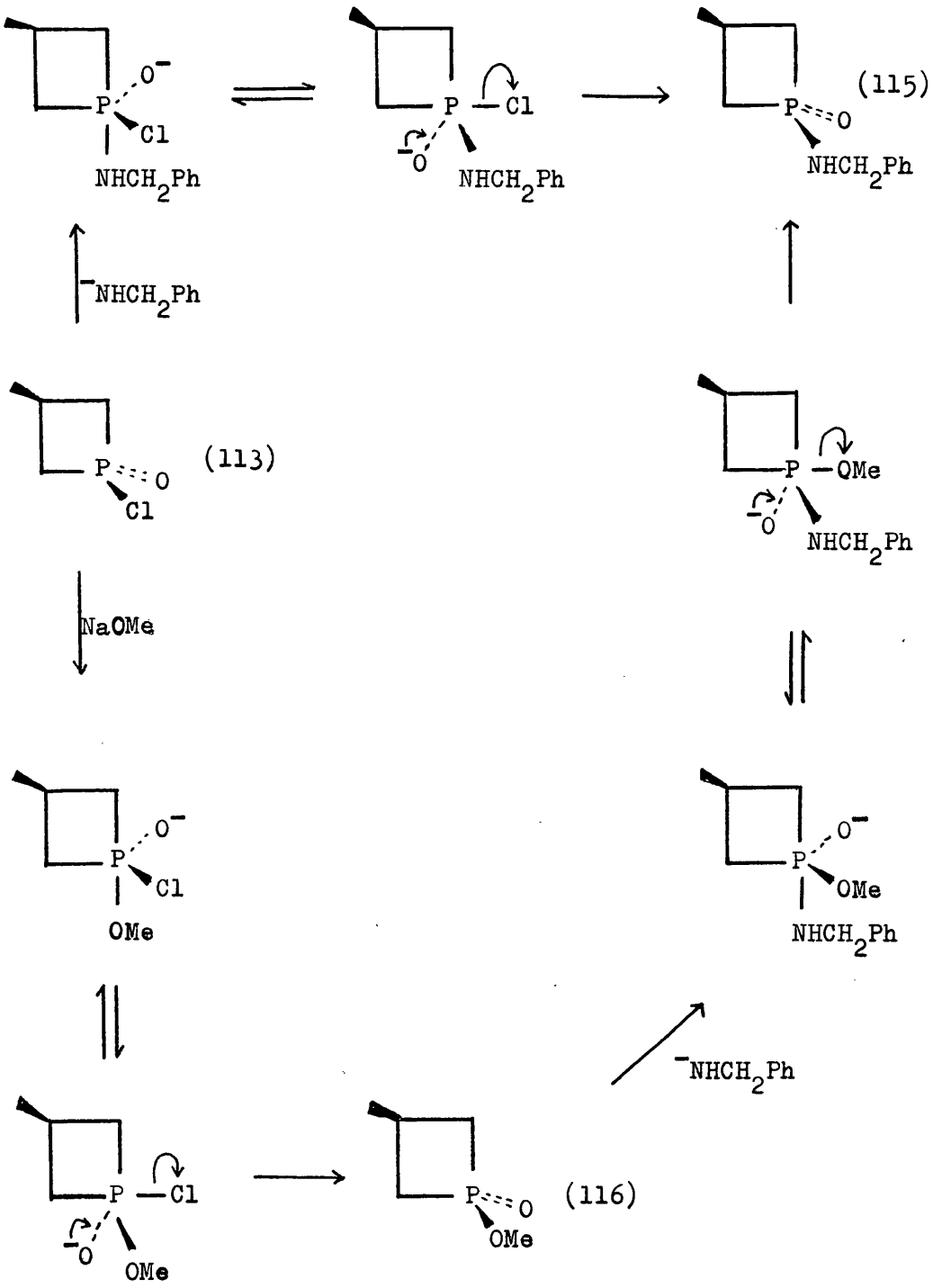
The Preparation of 1-(Benzylamino)-2,2,3,4,4-pentamethylphosphetane Oxide

The reaction of benzylamine with chloropentamethylphosphetane oxide (113) gave a moderate yield of benzylaminopentamethylphosphetane oxide (115), m.p. 160°. The reaction of the benzylamino-anion with chloropentamethylphosphetane oxide (113) gave, almost quantitatively, the benzylaminopentamethylphosphetane oxide (115), m.p. and mixed m.p. 160°.

The reaction of chloropentamethylphosphetane oxide (113) with sodium methoxide gave 1-methoxy-2,2,3,4,4-pentamethylphosphetane oxide (116). The reaction of methoxypentamethylphosphetane oxide (116) with the benzylamino-anion gave a high yield of benzylaminopentamethylphosphetane oxide (115), m.p. and mixed m.p. 160°.

This is another series of substitutions which proceeds with retention of configuration about phosphorus. The same amide is obtained by two routes; one route involves only one step whereas the other route involves two steps.

The "pseudo-rotation" mechanism for retention of configuration in this Walden series is shown on the next page.


(115)
(113)
(116)
NaOMe
NHCH2Ph
OMe
Cl

Conclusion.

Substitution at phosphorus may proceed with retention of configuration under the influence of certain steric constraints. For retention of configuration to occur, a group other than the preferred leaving group must be constrained to occupy an apical position of the intermediate, then by "pseudo-rotation" a second trigonal bipyramid is formed in which the preferred leaving group now occupies the other apical position. Further "pseudo-rotation" could lead to a product of inverted configuration, but it is assumed that the energy barrier to "pseudo-rotation" is higher than the energy barrier to loss of the preferred leaving group from the apical position.

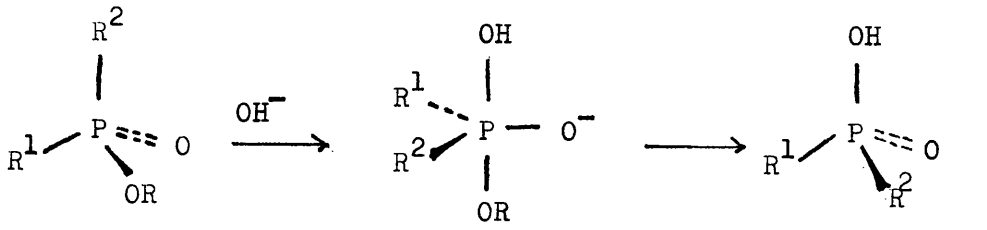
In some cases, ring cleavage occurs rather than loss of the preferred leaving group of an acyclic analogue. This occurs if the energy barrier to "pseudo-rotation" is greater than the energy barrier to ring opening. In some cases the energy balance between the two paths is so fine that both ring-opened and ring-retained products are obtained.

The Alkaline Hydrolysis of Phosphinate and Phosphonate Esters.

The hydrolysis of phosphate esters has been the subject of many studies because of the importance of these esters and other phosphoryl compounds in biosynthesis. 5-membered ring phosphates and phosphonates have been found to hydrolyse at vastly increased rates compared with their acyclic and 6- and 7-membered ring analogues[93]. The hydrolysis may be catalysed by acid or base; alkaline hydrolysis is much more rapid than acid hydrolysis.

The Mechanism of Alkaline Hydrolysis of Phosphate Esters.

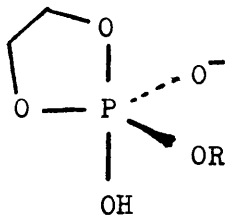
Kinetic studies have shown that the reaction is second order; rate $\propto [OH^-].[ester]$ [93]. The generally accepted mechanism of the reaction involves a trigonal bipyramidal intermediate (117).



(117)

The vast rate enhancements found for 5-membered ring phosphates and phostonates have been explained by the relief of angle strain on formation of the intermediate (118). Theoretical calculations have shown that the preferred bond angle for the ring of methyl

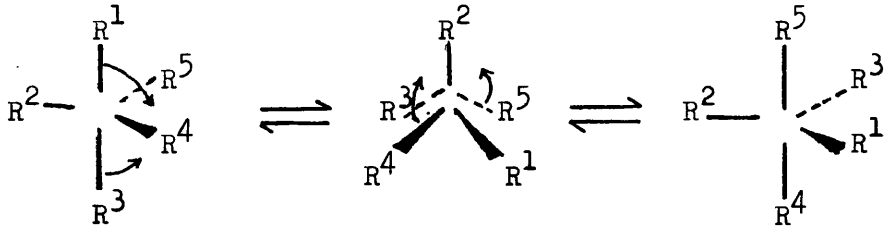
ethylene phosphate is 99° at phosphorus[94] and this is the angle found by X-ray crystallography.[95] The normal tetrahedral angle is 109° and so there must be considerable angle strain. The preferred angle at phosphorus for a 5-membered ring is about 90°. This is the angle between an apical and an equatorial position of a trigonal bipyramid, and thus there is considerable relief of angle strain on the formation of the trigonal bipyramidal intermediate (118) during alkaline hydrolysis.



(118)

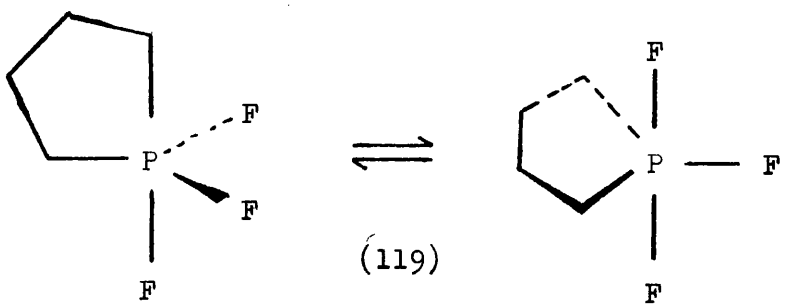
"Pseudo-rotation".

"Pseudo-rotation" of trigonal bipyramids has been suggested to explain the ^{1}H N.M.R. spectra of pentacovalent phosphorus compounds. By the process of "pseudo-rotation", trigonal bipyramids are interconverted *via* intermediate square pyramids[96].



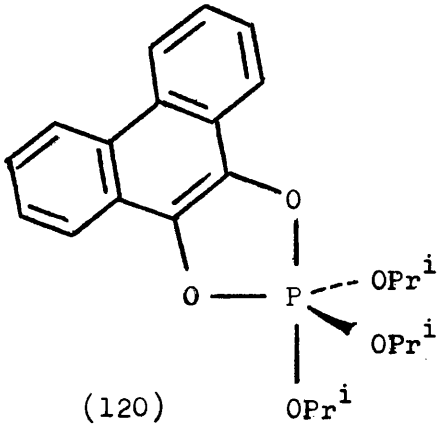
For the interpretation of the preferred configurations of pentacovalent phosphorus compounds it is also postulated that the more electronegative substituents always occupy the apical positions of the trigonal bipyramid.

Studies of a series of fluorides, $R_nF_{5-n}P$, have shown that wherever possible apical positions are occupied by fluorine[97]. The 5-membered ring fluoride (119) was an exceptional case. The ring alternated between apical-equatorial and diequatorial with an energy barrier to the apical-equatorial configuration of about 7 k.cal. The preferred configuration to minimise ring strain would have the ring equatorial-apical, but in this configuration a carbon would have to occupy an apical position. Thus a balance of angle strain against the higher energy for carbon apical was set up.

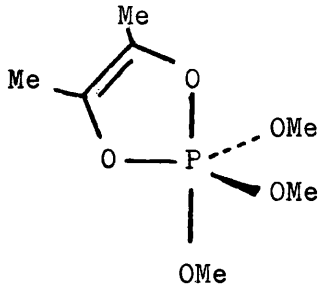


(119)

A trigonal bipyramidal structure was found by x-ray crystallography for the pentaoxyphosphorane (120)[98].

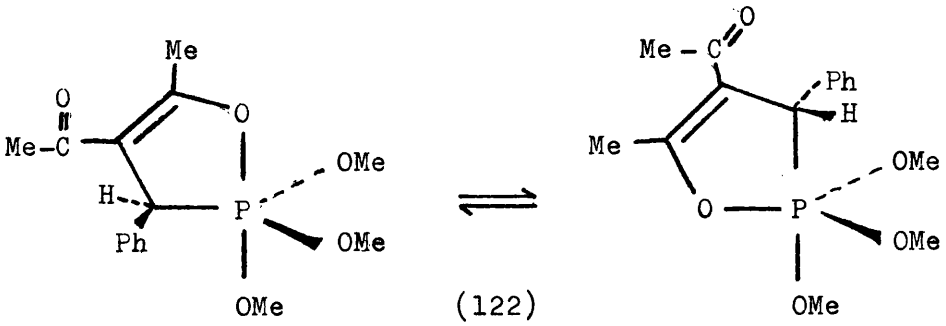


(120)



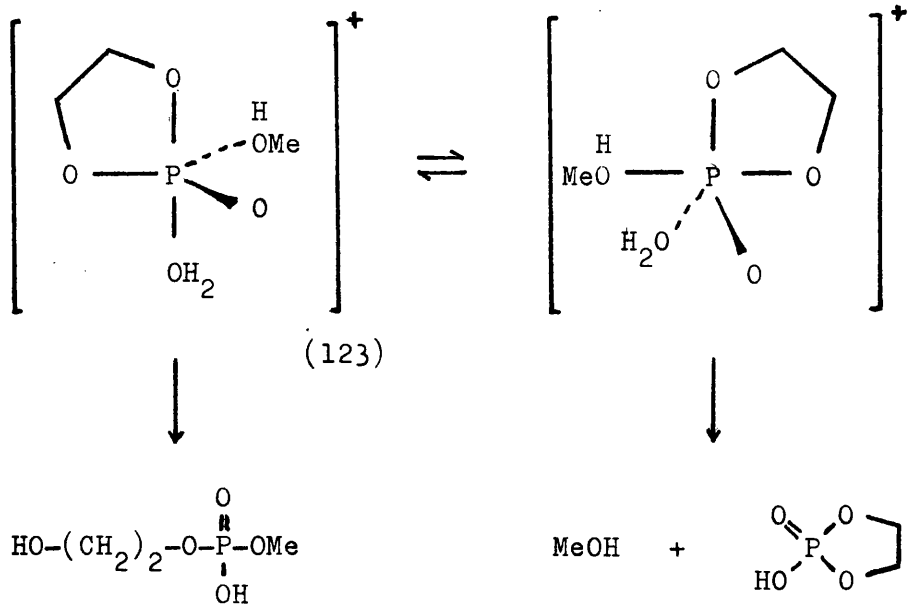
(121)

To explain the equivalence of the methoxyl groups in the ^{1}H N.M.R. spectrum of the pentaoxyphosphorane (121) rapid "pseudo-rotation" of trigonal bipyramids was postulated[99]. The spectrum of this phosphorane (121) did not show a dependence on temperature. The spectrum of the phosphorane (122) was temperature dependent. At room temperature the methoxyls were equivalent but on cooling two types of methoxyl group were seen. In this case "pseudo-rotation" involved putting the carbon apical instead of oxygen. At low temperatures there was not sufficient energy available for this "pseudo-rotation" and the phosphorane was locked into the more stable configuration with the ring oxygen apical.



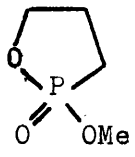
(122)

This theory of "pseudo-rotation" was also used to explain the products of alkaline hydrolysis of phosphate esters. The rapid acid hydrolysis of 5-membered ring phosphates was found to proceed equally with ring opening or with ring retention[100]. By rapid "pseudo-rotation" of the trigonal bipyramidal intermediate (123) both products could be formed.

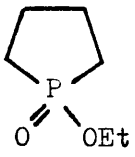


(123)

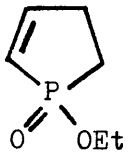
The extremely fast alkaline hydrolysis of the methyl ester of propylphostonic acid (124) gave almost exclusively ring opened product[100]. Here the barrier to putting the carbon apical stopped "pseudo-rotation" from occurring.



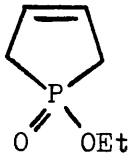
(124)



(125)



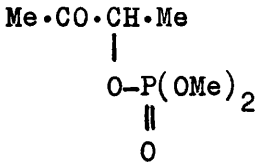
(126)



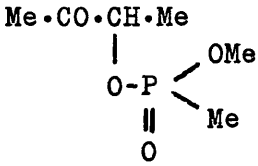
(127)

Cyclic phosphinates (125-127) did not hydrolyse at enhanced rates because the barrier to putting the carbon apical balanced the relief of angle strain on formation of the trigonal bipyramidal intermediate[101].

Frank and Usher[102] found that the phosphate ester (128) gave methanol and the phosphonate ester (129) gave acetoin on alkaline hydrolysis.



(128)

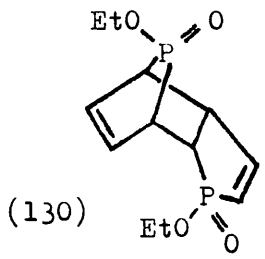


(129)

Again these results could be explained by "pseudo-rotation" and the barrier to putting a carbon function apical.

The Alkaline Hydrolysis of Esters of 1-Hydroxy-2,2,3,4,4-Pentamethylphosphetane Oxide[103].

From prior results using the theory of "pseudo-rotation", Westheimer et al.[104] predicted that highly strained phosphinate esters should hydrolyse extremely rapidly. They found that the first ester group of the esters (130 and 131) hydrolysed very rapidly in comparison with the second ester group or the monocyclic analogue, confirming their hypothesis.



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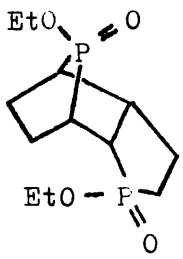
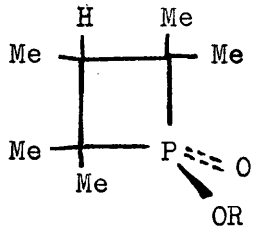


(131)

This led to the investigation of the rates of alkaline hydrolysis of the methyl and ethyl esters of hydroxypentamethylphosphetane oxide (132).

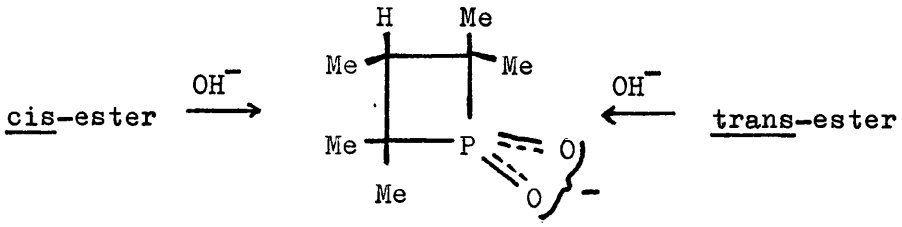


R = Me or Et

(132)

There is considerable angle strain in these esters (132) which would be relieved on going to the pentaco-ordinate intermediate and rapid hydrolysis would be expected.

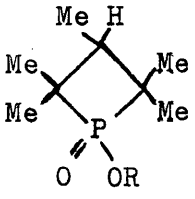
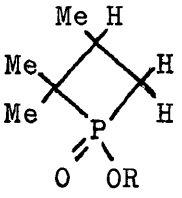
Bergesen[105] obtained rate constants for the alkaline hydrolysis of the cis- and trans- isomers of the ester (132, R = Et). The cis-acid (132, R = OH) was obtained by partial alkaline hydrolysis of a mixture of the isomers of the ester (132, R= Et), as the cis-ester hydrolysed more rapidly than the trans-ester. The anion of the acid (133) would, however, be formed during alkaline hydrolysis and this anion is common to both isomers. The status of this work, therefore, is uncertain.



(133)

The rate constant obtained for the ester (132, R = Et), which appeared homogeneous from its ^{1}H N.M.R. spectrum, was the same as the rate constant obtained by Bergesen for the trans-ester (132, R = Et). This rate constant was approximately equal to the rate constant for triethyl phosphate. (See Table 1.)

Table 1. Alkaline Hydrolysis of Phosphonate and Phosphinate Esters Second Order Rate Constants ($l.mole^{-1}sec^{-1} \times 10^6$)

	R	k
$RP(=O)(OEt)_2$	Et	300/70° 1200/90°
	Pr^i	440/120°
	Bu^t	60/120°
$R_2P(=O)OEt$	Et	260/70°
	N- Pr^i	10/100° 41/120°
	2N- Bu^t	0.08/120°
	Me	840/70°
	Et	300/70°
	Me	390,000/45° *

Hydrolyses were carried out under pseudo-first order conditions in 0.1N NaOH except where stated.

* Determined by automatic titration at pH 10.0.

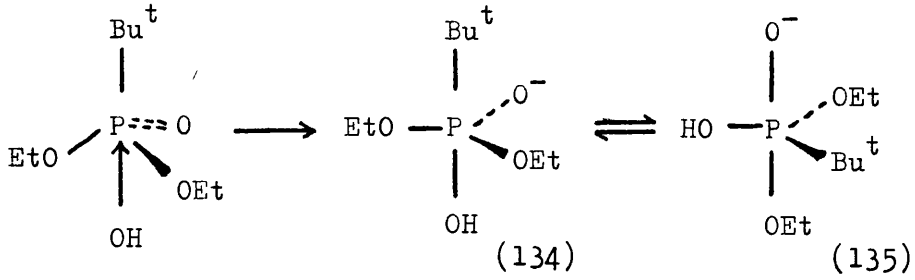
This led to speculation as to whether the relief of angle strain in formation of the intermediate was balanced by the steric hindrance to attack by the hydroxyl ion at phosphorus, i.e., was there a "neo-pentyl" effect in organophosphorus chemistry analogous to that observed in substitution at sulphur[106].

Steric Hindrance in The Alkaline Hydrolysis of Phosphonates and Phosphinates.

Results obtained for the alkaline hydrolysis of the esters, $R\,P(:O)(OEt)_2$, were in agreement with those obtained by Hudson and Keay[107]. One t-butyl group attached to phosphorus produced little steric hindrance to attack by OH^- at phosphorus.

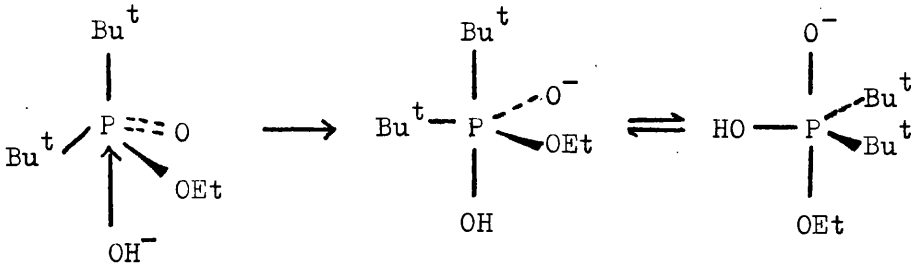
A sharp decrease in the rate of hydrolysis was observed between the esters $R_2P(:O)\cdot OEt$ where $R = Pr^i$ and $R = Bu^t$. This steric hindrance was also observed in another substitution reaction. Dialkylphosphinyl chlorides normally react with sodium ethoxide in ethanol exothermically at room temperature, but di-t-butylphosphinyl chloride is recovered almost quantitatively after 24 hours in refluxing ethanolic sodium ethoxide.

It was postulated that when only one t-butyl group was attached to phosphorus attack by the hydroxyl anion could occur at the opposite side of the phosphorus to give a trigonal bipyramidal intermediate (134). There would be little steric hindrance to attack in this case.

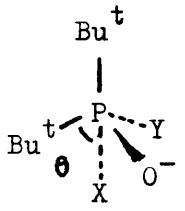


(134) (135)

By "pseudo-rotation" the ethoxyl anion could be lost from an apical position of a second trigonal bipyramidal intermediate (135). When a second t-butyl group was attached to phosphorus, attack had to occur adjacent to one of the t-butyl groups and steric hindrance was therefore observed.

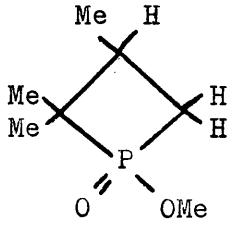


In the transition state (136) leading to the intermediate, the angle θ was less than 90° and so despite the P-C bond length of 1.87Å substantial hindrance from the "equatorial" t-butyl group was apparent at this point.



(136)

Confirmation for this theory of sterio hindrance was obtained from the alkaline hydrolysis of 1-methoxy-2,2,3-trimethylphosphetane oxide (137). For this ester there was no "neo-pentyl" effect to balance the relief of steric strain and extremely rapid hydrolysis was observed.



(137)

Examples of Steric Hindrance to Substitution at Phosphorus.

Kosolapoff et al.[108] concluded from studies of the reactions of t-butylmagnesium chloride with dichlorophosphine oxides that attachment of two t-alkyl residues to phosphorus was sterically hindered, but not prohibited. Several products were obtained from these reactions.

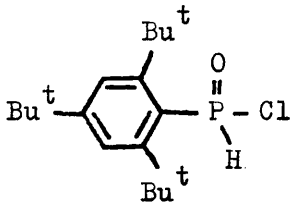
$$R\,P(:O)\,Cl_2 + Bu^tMgCl(\text{excess}) \longrightarrow \underset{(137)}{RBu^tP(:O)H} + \underset{(138)}{Bu^t{}_2P(:O)R}$$

$$+\underset{(139)}{(Bu^tR\,P(:O))_2} + \underset{(140)}{R\,Bu^tP\,(:O)OH}$$

Compounds of type (140) could have been formed by oxidation of compounds of type (137) or by hydrolysis of $R\,Bu^tP(:O)Cl$, a normal product of such reactions. The yield of compounds of type

(137) increased with increased chain length of the radical, R, on phosphorus. The yield of product (138) was always low. Product (139) was only obtained when R = Ph. The formation of this product (139) was explained, possibly, by dimerisation of the radical $R Bu^t P(:O)$ formed by abstraction of chlorine from $R Bu^t P(:O)Cl$.

Cook[109] found that di-(substituted phenyl)chlorophosphine oxides were increasingly resistant to hydrolysis with increasing substitution of the phenyl groups. Chloro(2,4,6-tri-t-butyl-phenyl)phosphine oxide (141) was particularly resistant to both oxidation and hydrolysis. These effects were explained by



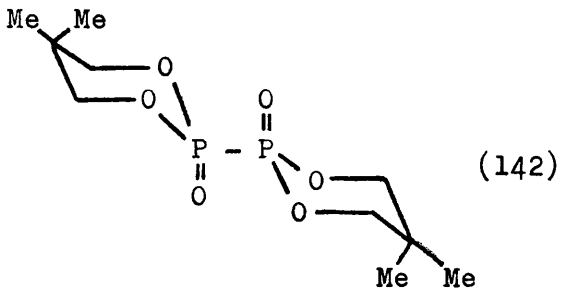
(141)

steric hindrance to attack at phosphorus.

Kosolapoff et al.[110] found little steric hindrance to the reaction of 2,6-dialkyl-phenols with phosphorus oxychloride, except when the alkyl substituents were bulky. When bulky substituents were present the normal course of the reaction was not followed. The reaction proceeded only in the presence of a Friedel-Crafts type catalyst after either dealkylation or rearrangement of the o-alkyl groups. O-phosphorylation was observed in all cases. This work was directed to suppress O-phosphorylation

in an attempt to cause p-carbon phosphorylation in the presence of a suitable catalyst. This objective was not accomplished.

Stec and Zwierzak[111] found that the hydrolysis of the ester (142) was extremely slow. Very little product could be detected even after 20 hours at reflux in aqueons tetrahydrofuran by contrast with the acyclic analogues which hydrolysed extremely rapidly.



(142)

This result was explained by steric hindrance to attack by the hydroxyl anion.

Conclusion.

Angle strain in 4-membered ring phosphinate esters led to extremely rapid hydrolysis when one of the ring α-carbons was unsubstituted. When both ring α-carbons were substituted the relief of angle strain on forming the intermediate trigonal bipyramid was balanced by steric hindrance to attack by the hydroxyl ion. Studies of acyclic phosphonates and phosphinates showed that there was a "neo-pentyl" affect in substitution at phosphorus, but only in the presence of two t-butyl groups.

Pentacovalent Phosphorus Compounds.

Previous sections have been concerned with reactions involving pentacovalent intermediates. Several stable pentacovalent compounds have already been mentioned, and trigonal bipyramidal structures have been found for all the phosphorus pentacovalent compounds studied. The spectra of these compounds can be explained by "pseudo-rotation" of trigonal bipyramids, and wherever possible apical positions are occupied by the more electronegative substituents.

Stability of Pentacovalent Phosphorus Compounds.

Pentacovalent compounds may be stabilised by electronegative substituents on phosphorus and when the phosphorus is contained in a ring with a preferred angle of 90° at phosphorus.

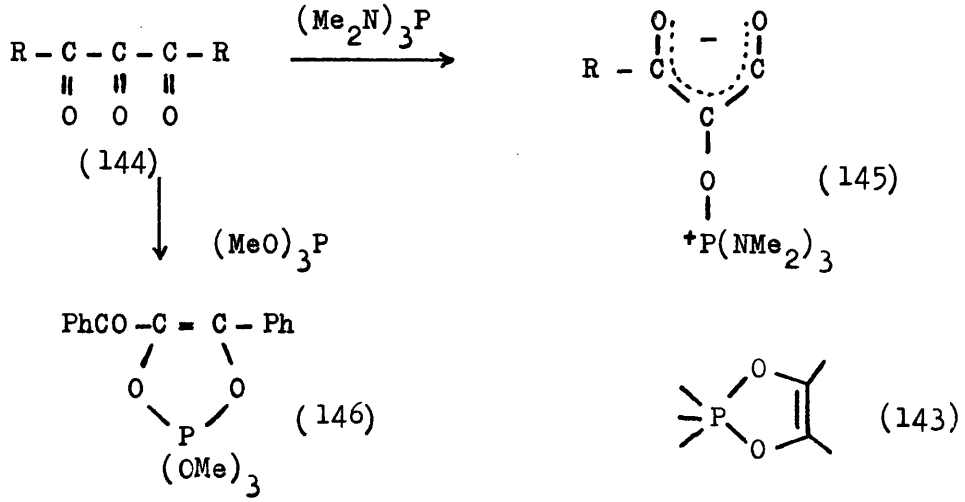
a) Stabilisation by electronegative substituents.

The series of pentacovalent phosphorus fluoride, $RnF_{5-n}P$, are stabilised by the electronegative fluorines. The spectra of these compounds are explained on the assumption that "pseudo-rotation" can occur and that the apical positions are occupied by the more electronegative substituents.

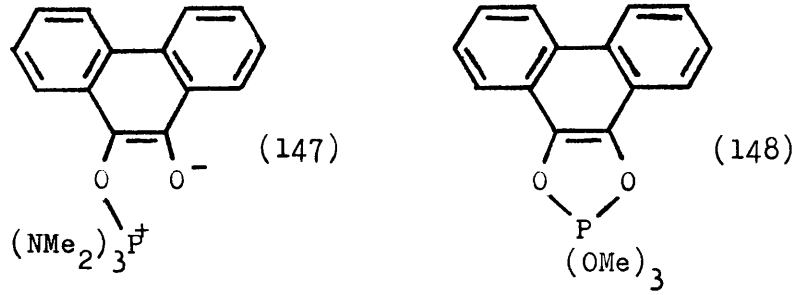
Ramirez et al. have observed a combination of stabilising effects in a series of reactions of α-diketones and o-quinones with trivalent phosphorus compounds. Phosphite esters react exothermically at room temperature, giving stable pentacovalent compounds (143) containing a 5-membered ring.[112] Triphenylphosphine will give an adduct only with phenanthraquinone and then only on

heating to 120°. When one or two ethoxl groups are substituted for the phenyls of triphenylphosphine, adducts can be formed with ∝ -diketones. Increased electronegativity of the substituents facilitates the formation of the pentacovalent compounds (143).

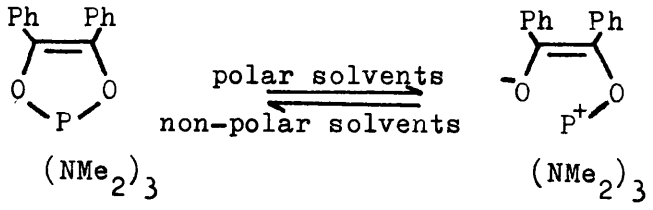
The reaction of tris(dimethylamino)phosphine with a tri-carbonyl compound (144) gives a dipolar adduct (145).[114] The reaction of the carbonyl compound (144 ,R = Ph) with trimethylphosphite gives, however, a pentacovalent adduct (146).[112]



The adduct of trisdimethylaminophosphine with phenanthraquinone is also dipolar (147)[114] whereas the adduct (148) of trimethylphosphite with phenanthaquinone is pentacovalent.[112]



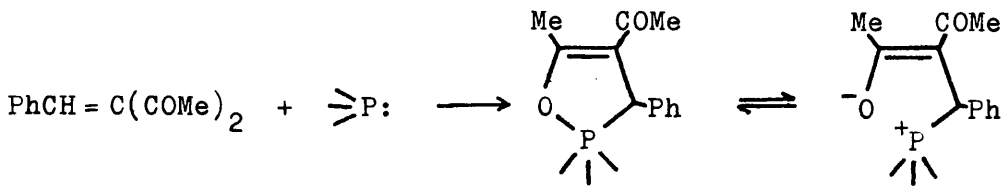
The polarity of the solvent affects the structure of the adduct of tris(dimethylamino)phosphine with benzil. In non-polar solvents a pentacovalent adduct (149) predominates, whereas in polar solvents the dipolar adduct (150) predominates.[115]



(149) (150)

The examples show that the more electronegative oxygen substituents favour the pentacovalent structure, whereas the less electronegative nitrogen substituents sometimes give dipolar adducts.

Benzylidene acetylacetone gives pentacovalent adducts (152) with phosphites, phosphonites and phosphinites.[116] At elevated temperatues the phosphonite and phosphinite adducts are converted to the dipolar structure (153). Aryl and arylalkylphosphines give only dipolar adducts.[117]



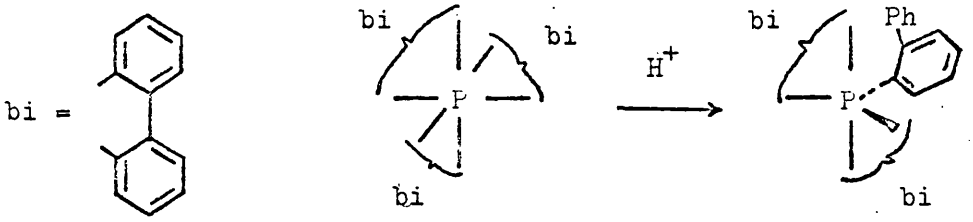
(152) (153)

Again, the more electronegative substituents favour the formation of the pentacovalent adduct.

b. Stabilisation by rings containing the phosphorus.

Pentacovalent compounds of phosphorus are stabilised by rings sterically constrained to prefer an angle of 90° at phosphorus. When there is only one ring in the compound the stability is enhanced when a ring oxygen occupies the apical position.

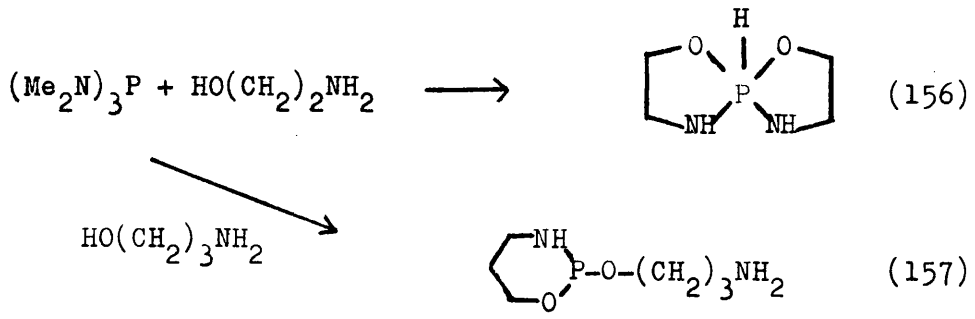
Hellwinkel[118] has studied compounds containing biphenylyl groups. A hexacovalent anion (154) with three bridging biphenylyl groups can be obtained which gives a pentacovalent compound (155) on treating with acid.



(154) (155)

In this case, with two rings present, the pentacovalent compound was stable with carbon apical.

Reetz and Powers[119] have found that tris(dimethylamino)phosphine gives a bicyclic pentacovalent compound (156) with 2-hydroxyethyl amine, whereas with 3-hydroxypropylamine a trivalent compound is obtained.

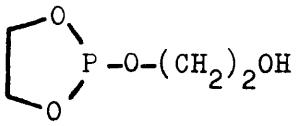


(156)

(157)

Again two 5-membered rings attached to phosphorus stablise the pentacovalent compound. The stability conferred by the rings is shown by the presence of the hydrogen substituent on phosphorus in the compound (156).

Wolf et al.[120] have found that the phosphite ester of ethylene glycol (158) does not have the expected structure but has instead a pentacovalent structure (159). Again, a hydrogen is attached to phosphorus



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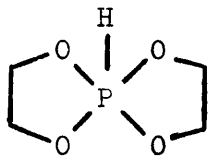
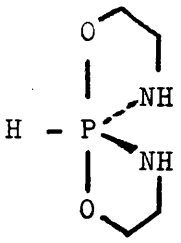


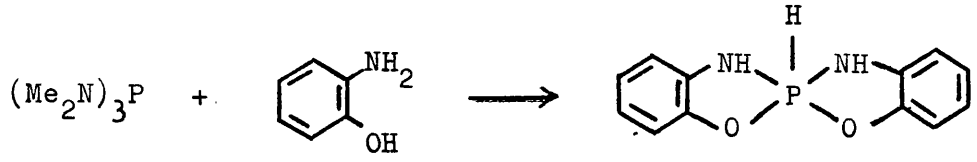
(159)

Further work by Wolf et al.[121] has confirmed the work of Reetz and Powers and X-ray analysis has shown that the compound has a trigonal bipyramidal structure (160).



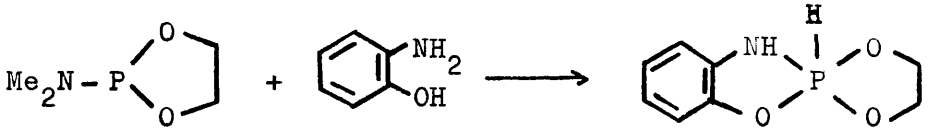
(160)

Wolf et al.[122] have also found that tris(dimethylamino) phosphine and o-aminophenol give a bicyclic pentacovalent compound (161) containing a P-H bond.



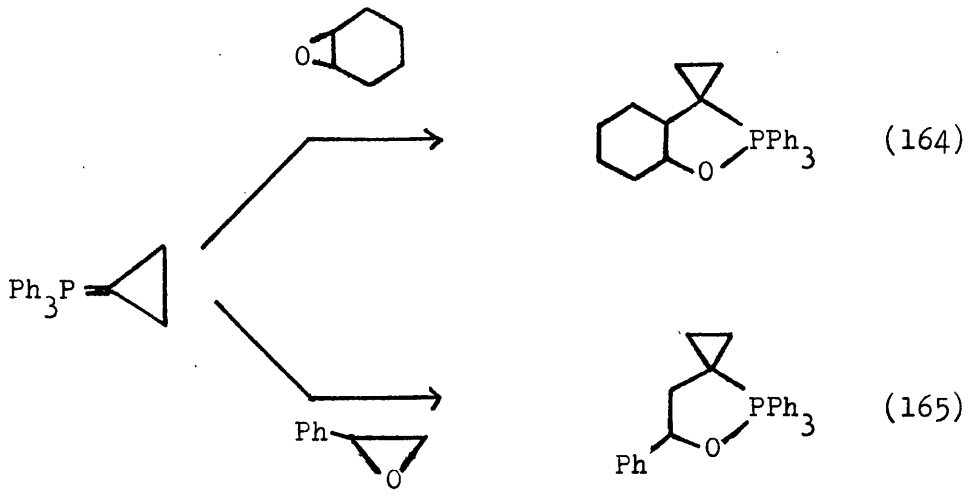
(161)

The reaction of o-aminophenol with 1-dimethylamino-2,5-dioxaphospholane (162) gives a similar pentacovalent compound (163).

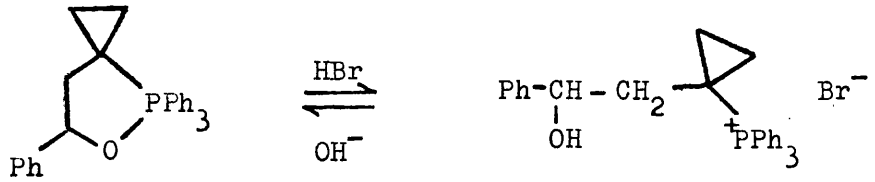


(162) (163)

Bestmann et al.[123] found that the reactions of cyclohexene oxide or styrene oxide with cyclopropylidenetriphenylphosphorane gave pentacovalent compounds (164-165) which were stable to distillation. These compounds were stabilised by the 5-membered ring containing the phosphorus and the spiro cyclopropyl ring further increased the stability.



Treatment of either of these compounds with hydrogen bromide gave the ring opened phosphonium salt and treatment of the phosphonium salt with sodium hydroxide regenerated the pentacovalent compound, i.e.,



This demonstrates the stability of these pentacovalent compounds (164-165) to aqueous base, whereas pentacovalent phosphorus compounds are often susceptible to water.

These examples all indicate that considerable stability is conferred on pentacovalent phosphorus compounds by the presence of one or more 5-membered rings.

Adducts of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane

The phosphetane system is constrained to prefer a ring angle of 90° at phosphorus. Previous examples have demonstrated the stability of pentacovalent phosphorus compounds with other ring systems constrained to have a preferred angle of 90° at phosphorus. The formation of adducts from α-diketones and phenanthraquinone and pentamethylphenylphosphetane was therefore an interesting possibility.

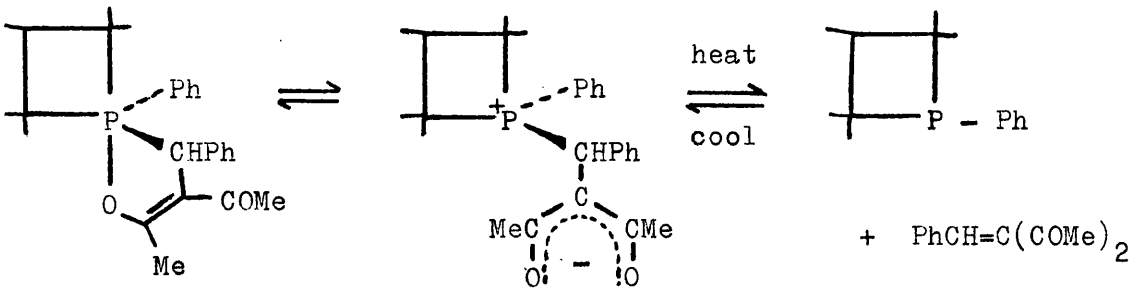
Pentamethylphenylphosphetane and phenanthraquinone gave a stable adduct in an exothermic reaction; there were also signs of the reaction of this phosphetane with benzil at 100° [124]. The phosphetane, therefore, formed adducts much more readily than triphenylphosphine.

Ramirez investigated the formation of dipolar adducts from phosphines and benzylidene acetyl acetone[117]. Pentacovalent adducts were obtained when more electronegative groups were attached to phosphorus. The stabilisation of the pentacovalent adduct by the presence of a 4-membered ring containing phosphorus instead of electronegative substituents was investigated.

The 1:1-adduct of benzylidene acetylacetone with pentamethylphenylphosphetane was a white crystalline solid (166). The nujol mull I.R. spectrum of this compound (166) was similar to the I.R. spectra of the pentacovalent adducts obtained by Ramirez. The strong absorption at ν_{max} 1620 cm^{-1} showed the presence of the

conjugated carbonyl; for the dipolar adducts prepared by Ramirez the carbonyl absorption was at ν_{max} 1470cm^{-1}. The ^{1}H N.M.R. spectrum in o-dichlorobenzene was, however, similar to the spectra of the dipolar adducts prepared by Ramirez. The six protons of the two methyl groups adjacent to C - O showed as a singlet, whereas the pentacovalent adduct would contain two different methyl groups as found by Ramirez for the pentacovalent adducts. In the o-dichlorobenzene in which the N.M.R. spectrum was run the adduct dissociated to phosphetane and benzylidene acetylacetone at elevated temperatures.

It was concluded that in the solid state the adduct had the pentacovalent structure (166), but in polar solvents it was converted to the dipolar structure (167) which dissociated on heating.



(166) (167)

Thus the 4-membered ring constrained to have an angle of 90° at phosphorus stabilised the pentacovalent compounds studied.

Conclusion.

The results obtained supported the hypothesis that rings constrained to have an angle of 90° at phosphorus stabilise pentacovalent phosphorus compounds.

Experimental.

All reactions involving reactants or products susceptible to water or air were carried out in an atmosphere of dry oxygen-free nitrogen.

Liquid reactants were freshly distilled.

Solvents were dried as listed below:

benzene and ether were sodium dried;

tetrahydrofuran was distilled from sodium onto sodium and was redistilled before use;

dimethylformamide was refluxed over calcium hydride and distilled;

dimethylsulphoxide was refluxed over calcium hydride at reduced pressure and distilled;

methylene chloride was refluxed over calcium hydride and distilled;

ethanol and methanol were dried by the magnesium alkoxide and were distilled before use.

A Perkin Elmer F.11 gas chromatography unit was used for g.l.c. analysis of dilute solutions ($\sim$ 2% weight for volume). A 2 metre Apiezon D.E. 102 column was used except where otherwise stated.

Mass spectra were determined on an A.E.I. M.S. 9 instrument; in each case the mass peak is given first, followed by those which are of structural significance.

^{1}H N.M.R. spectra were recorded for solutions in deuteriochloroform or for neat liquids on a Varian A. 60 spectrometer, except where otherwise stated.

The Preparation of Butyl-lithium[125].

30 drops of a solution of butyl bromide (68.5 g.) in ether (100 ml.) was added to finely divided lithium (8.6g) in ether (200ml.). When bright spots began to appear on the lithium indicating that the reaction had started, the mixture was cooled to -10°. The temperature was held between -10° and -20° while the rest of the butyl bromide was added dropwise to the stirred mixture (30 minutes). The reaction mixture was allowed to warm to room temperature over a period of two hours and was then filtered through glass wool.

The strength of the butyl-lithium solution produced was ascertained by titration. A 5ml. portion was hydrolysed with water (10ml.) and titrated against 0.1 N hydrochloric acid, using phenol phthalein as the indicator. A further 5ml. portion was treated with benzyl chloride (1 ml.) in ether (10ml.) to destroy the butyl-lithium. The ether mixture was then added to water (10ml.) and titrated against 0.1 N hydrochloric acid, using phenol phthalein indicator. The difference of the titrations gave the amount of acid required for the butyl lithium. The solution produced was 1.25 N butyl-lithium in ether.

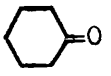
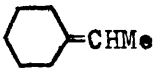
The Wittig Reaction Using Butyl-lithium as Base

In a typical experiment ethyltriphenylphosphonium iodide (16.7g.) was added to butyl-lithium (35ml.; 1.25N) in ether (150ml.). The mixture was stirred for 2 hours and then cyclohexanone (3.9g.) was added to the ice cooled solution. The mixture was stirred at reflux for 2 hours, filtered, and the solvent removed by distillation. The residual oil was fractionated on a spinning band column. The results of this and several similar experiments are summarised in Table 2. The olefins thus prepared were checked for purity by g.l.c. and were used in solution as standards for following experiments.

The Wittig Reaction Using Alkoxide Base in Alcoholic Solution.

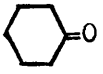
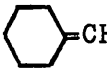
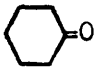
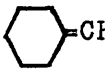
In a typical experiment sodium (0.5g.) in ethanol (25ml.) was added to ethyltriphenylphosphonium iodide (8.4g.) and benzaldehyde (2.1g.) in ethanol (25ml.) and the solution set aside at room temperature for 3 days. The solution was then analysed for olefin by g.l.c. The results of this and several similar experiments are outlined in Table 3.

Table 2.

Phosphonium salt	Aldehyde or ketone	Olefin formed	Yield %	B.p.
$EtPh_3P^+ I^-$	PhCHO	PhCH:CHMe	70	170°
$EtPh_3P^+ I^-$			36	120°
$EtPh_3P^+ I^-$ *	Ph·CO·Me	PhMeC:CHMe	60	180-6°
$(Allyl)Ph_3P^+ Br^-$	PhCHO	$PhCH:CH\cdot CH:CH_2$	42	94-100°/20mm.

* Excess Wittig reagent was used in this case as originally much difficulty was experienced in separating the olefin from excess ketone.

Table 3.

Phosphonium salt and solvent	Aldehyde or ketone	Olefin formed	Yield %	Isomer ratio cis:trans
$EtPh_3P^+ I^-$ in EtOH	PhCHO	PhCH:CHMe	70	1:2.3
$EtPh_3P^+ I^-$ in EtOH			6	-
$EtPh_3P^+ I^-$ in MeOH			17	-
$EtPh_3P^+ I^-$ in MeOH	PhCHO	PhCH:CHMe	70	1:1.6
$EtPh_3P^+ I^-$ in MeOH	MeCH:CHCHO	$Me(CH:CH)_2Me$	see note a)	
$EtPh_3P^+ I^-$ in MeOH	Ph·CO·Me	PhMeC:CHMe	62	1:1.5
$(Allyl)Ph_3P^+ Br^-$ in MeOH	PhCHO	$PhCH:CH\cdot CH:CH_2$	30	single peak on g.l.c.

a) No separate peak was found for this olefin by g.l.c. There was, however, an edge on the benzene peak which may have been due to the olefin

Preparation of Allyldiphenylphosphine Oxide[126].

Chlorodiphenylphosphine (22 g.) in ether (25 ml.) was added dropwise with stirring and ice cooling to allyl alcohol (5.8 g.) and pyridine (8 ml.) in ether (100 ml.). The resultant mixture was stirred for half an hour, filtered, and the ether removed by distillation. The residual oil was heated to 120°, when an exothermic reaction occurred. After the subsidence of the reaction the temperature was maintained at 130° for a further half hour. The product, which crystallised on cooling, was recrystallised from benzene-petroleum ether (b.p. 60-80°). Yield 60%, m.p. 94-5° (literature[126] m.p. 93-4°) ν max 1175 and 924 cm^{-1}.

Cinnamyldiphenylphosphine oxide was similarly prepared, using cinnamyl alcohol.

Investigation of The Optimum Conditions for Olefin Formation from Allyldiphenylphosphine Oxide.

1) Sodium Methoxide in Methanol.

Allyldiphenylphosphine oxide (2.5 g.) was added to sodium (0.25 g) in methanol (15 ml.). Benzaldehyde (1.2 g.) was added and the mixture set aside at room temperature for three days. Analysis of the resultant mixture by g.l.c. showed the presence of phenylbutadiene (22%). By chromatographing the reaction mixture on basic alumina a highly crystalline phosphine oxide product, m.p. 175-6°, was obtained by elution with 1% methanol in ether, λ max 305 mμ (in ethanol) ν max 1180 cm^{-1}, m/e 330, 242, 227, 215, 202. The ^1H N.M.R.

spectrum showed only aromatic and vinylic protons in the ratio 15:4. (Found C, 79.8; H, 5.8; P, 9.2. $C_{22}H_{19}OP$ requires C,79.6; H, 5.8, P, 9.4%). The crude reaction product before chromatography did not show a maximum in the U.V. spectrum at 305 mμ . On refluxing this crude product with p-toluenesulphonic acid in benzene, a peak appeared at 305 mμ.

2. Butyl-lithium in Tetrahydrofuran.

Butyl-lithium (8 ml.;1.3 N solution in ether) was added to allyldiphenylphosphine oxide (2.5 g.) in tetrahydrofuran (30 ml.). After half an hour, benzaldehyde (1.2 g.) was added. The solution was set aside at room temperature for three days. Analysis of the resultant mixture by g.l.c. showed that the amount of phenylbutadiene produced was very small.

3. Sodium Methoxide in Dimethylformamide.

Sodium (0.25 g.) was added to methanol (15 ml.). The sodium methoxide formed was dried under high vacuum at 200° for two hours. Allyldiphenylphosphine oxide (2.5 g.) and benzaldehyde (1.2 g.) in dimethylformamide (30 ml.) were added, the mixture magnetically stirred for two days, and then poured into water (100 ml.). The aqueous solution was extracted with three portions of chloroform (30 ml.) and the combined extracts washed with water (50 ml.). Analysis of the chloroform solution by g.l.c. showed the presence of phenylbutadiene (30%).

4. Sodium Ethoxide in Dimethylformamide.

The method employed was the same as for sodium methoxide in

dimethylformamide, using ethanol in place of methanol. Analysis of the chloroform solution by g.l.c. showed the presence of phenylbutadiene (35%).

5. Metallated Dimethylsulphoxide in Dimethylsulphoxide.

Sodium hydride (4g.; 50% dispersion in mineral oil) was washed twice by decantation with dry petroleum spirit (b.p. 40-60°) and dried under high vacuum at room temperature. Dimethylsulphoxide (100 ml.) was added and the mixture heated with stirring to 50°, when an exothermic reaction occurred, causing a rapid increase of the temperature to 70°. The temperature of the stirred mixture was carefully maintained at 70-75° while metallation proceeded with evolution of hydrogen (approximately half an hour). The normality of the metallated dimethylsulphoxide solution produced was ascertained by titration against wet dimethylsulphoxide in an anaerobic burette. The indicator used was triphenylmethane.

Metallated dimethylsulphoxide (16.5 ml.; 0.6 N in dimethylsulphoxide) was added to allyldiphenylphosphine oxide (2.0 g.) in dimethylsulphoxide (8.5 ml.). After stirring for half an hour at room temperature, benzaldehyde (1 g.) was added. The mixture was stirred for three days at room temperature and then poured into water (50 ml.). The aqueous solution was extracted with chloroform (3 x 20 ml.) and the combined extracts were washed with water (50 ml.). Analysis by g.l.c. showed the presence of phenylbutadiene (10%).

The Reaction of Allyldiphenylphosphine Oxide with Sodium Methoxide.

Allydiphenylphosphine oxide (2.5 g.) was added to sodium (0.25 g.) in methanol (25 ml.) and the solution was set aside at room temperature for three days. The methanol was removed by distillation and the residue taken up in chloroform (20 ml.). The solution was extracted with water (2 x 20 ml.), dried over anhydrous sodium sulphate and the chloroform removed by evaporation. The ^{1}H N.M.R. spectrum of the residue did not show the presence of vinylic protons. Singlet (3H) at τ 6.9, quadruplet (2H) at τ 7.59, doublet (3H) at τ 8.75. The compound could not be obtained in a pure crystalline form.

The Reaction of Cinnamyldiphenylphosphine Oxide with Sodium Methoxide.

Cinnamyldiphenylphosphine oxide (0.75 g.) in methanol (10 ml.) was added to sodium (0.07 g.) in methanol (10 ml.) and the solution was set aside at room temperature for three days. The methanol was removed by evaporation and the residue taken up in chloroform (20 ml.). The solution was extracted with water (2 x 20 ml.), dried over anhydrous sodium sulphate, and the chloroform was evaporated. The ^{1}H N.M.R. spectrum of the crude product was the same as that of the original phosphine oxide.

The Reaction of Cinnamyldiphenylphosphine Oxide with Benzaldehyde.

Cinnamyldiphenylphosphine oxide (0.8 g.) in dimethylformamide (15 ml.) was added to dried sodium ethoxide prepared from sodium (0.07 g.). Benzaldehyde (0.4 g.) was added and the mixture stirred at room temperature for three days. The mixture was then poured into water (40 ml.) and the aqueous solution was extracted with

chloroform (3 x 20 ml.). The combined extracts were washed with water (50 ml.), dried over anhydrous sodium sulphate and the chloroform was evaporated. The residue was crystallised from methanol, yielding 1,4-diphenylbuta-1,3-diene (57%) m.p. 151-2° (literature m.p. 152.5°).

In a similar reaction, diphenyl(5-phenylpenta-2,4-dienyl)phosphine oxide gave 1,6-diphenylhexa-1,3,5-triene (40%) m.p. 202° (literature[128] m.p. 203°), λmax 354 mμ (in ethanol) log ε = 4.89.

The Reaction of 2,3-Dimethylbuta-1,3-diene with Dichlorophenylphosphine.

Dichlorophenylphosphine (35 g.), dimethylbutadiene (16 g.) and copper stearate (0.8 g.) were set aside for three weeks in a stoppered flask at room temperature. A yellow oil formed, which gradually crystallised. The adduct was broken up and washed with petroleum ether (b.p. 40-60°). Magnesium turnings (5 g.) were added in portions to the stirred suspension of the adduct in tetrahydrofuran (300ml.). The mixture was stirred at reflux for a further 1½ hours and then half of the solvent was removed by distillation. Cold water (200 ml.) was slowly added and the mixture made strongly basic using 10 N sodium hydroxide. The resultant slurry was extracted several times with ether and the combined extracts dried over anhydrous sodium sulphate. The ether was removed by distillation and the 1-phenyl-3-phospholene distilled in vacuo (24 g.) b.p. 112-5°/2mm.

The phospholene (12 g.) was converted to the methiodide (15 g.) m.p. 206-7° (from methanol-ethyl acetate) (literature[129] m.p. 210°),

ν max. 1120, 940 and 915 cm^{-1}, singlet (6H) at τ 8.13, doublet (3H) at τ 7.26 (J_{P-H} = 19 c.p.s.) (Found : C, 47.0; H, 5.5; P, 9.5. Calculated for $C_{13}H_{18}PI$ C, 47.05; H, 5.6; P, 9.3%). The methanol-chloroform mother liquor was set aside at 0° for several weeks. A further crop of crystals was obtained m.p. 120-32°. From the ^1H N.M.R. spectrum it appeared that this was 1,3,4-trimethyl-1-phenyl-2-phospholenium iodide, ν max 1115 and 920 cm^{-1}, doublet (3H) at τ 8.75, doublet (3H) at τ 7.3, doublet (1H) at τ 3.7. The methiodide could not be further purified by recrystallisation.

1,3-Dimethyl-1-phenyl-2-phospholenium iodide was similarly prepared using isoprene instead of dimethylbutadiene m.p. 125-6° (from methanol-ethyl acetate), ν max. 1115 and 930 cm^{-1}, singlet (3H) at τ 7.78, doublet (3H) at τ 7.30, doublet (1H) at τ 3.74. (Found: C, 45.7; H, 5.1 ; P, 10.0. $C_{12}H_{16}PI$ requires C, 45.3, H, 5.1 ; P, 9.7%).

By using buta-1,3-diene instead of dimethylbutadiene, a methiodide was obtained m.p. 100-115°, ν max. 1115 and 930 cm^{-1}, doublet (3H) at τ 7.33, multiplet (4H) at τ 6.65, doublet (2H) at τ 3.22. This methiodide could not be purified by recrystallisation.

By using dichlorophenoxyphosphine instead of dichlorophenylphosphine an oily adduct was obtained. Reduction with magnesium gave a product which appeared from the ^1H N.M.R. spectrum to be very impure. No crystalline methiodide could be obtained.

The Reaction of 1,3,4-Trimethyl-1-phenyl-3-phospholenium Iodide with Benzaldehyde in Dimethylformamide.

The methiodide (3 g.) and benzaldehyde (1.9 g.) were added to dry sodium ethoxide (6.8 g.) in dimethylformamide (70 ml.) and the mixture was stirred at room temperature for three days. The mixture was then poured into water (400 ml.) and extracted with chloroform (3 x 50 ml.). The combined extracts were washed with water (100 ml.), dried over anhydrous sodium sulphate, and the chloroform removed by distillation. Crystallisation of the residue from ethanol gave 3,4-dimethyl-1,6-diphenylhexa-1,3,5-triene, m.p. 177-8°, λmax. 366 mμ in ethanol log ϵ = 4.76, (Found: C,92.2; H,7.6. $C_{20}H_{20}$ requires C,92.3, H,7.7%).

A further yield of triene (0.5 g.) was crystallised from the mother liquor, m.p. 70-90°, λ max. 363, 273, and 265 mμ in ethanol. The intensities of the peaks at 273 and 265 mμ decreased relative to that at 366 mμ on further crystallisation, giving triene m.p. 150-6°.

The results of several similar experiments are outlined in the following table:

Table 4.

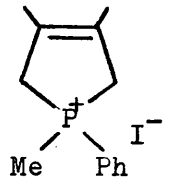
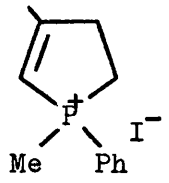
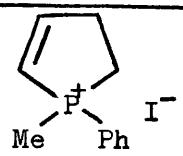
Phosphonium salt	Aldehyde	Molar ratio base/aldehyde	Yield %	Olefin m.p.	$\lambda_{max.}$ mμ
	PhCHO	10	50	177-8°	366
	PhCHO	1.1	7	"	"
	PhCH:CH·CHO	10	no olefin detected		
	p(NO_2)PhCHO	10	" " "		
	PhCHO	10	30	130-2°	360 a)
	PhCHO	1.1	3	"	" b)
	PhCH:CH CHO	10	no olefin detected		
	p(NO_2)PhCHO	10	" " "		
	p(MeO)PhCHO	10	35	166-7°	366 c)
	MeCH:CH·CHO	10	no olefin found		
	PhCHO	10	9	204°	354

Table 4. contd.

a) 3-Methyl-1,6-diphenylhexatriene, m.p. 131-2° (literature[130] m.p. 130-1°)

(Found: C, 92.6; H, 7.4. Calculated for $C_{19}H_{18}$: C, 92.6; H, 7.4%).

b) 3-Methyl-1,6-di(p-methoxyphenyl)hexatriene, m.p. 166-7°

(Found: C, 82.2; H, 7.1. $C_{21}H_{22}O_2$ requires C, 82.3; H, 7.2%).

c) A crystalline phosphine oxide, m.p. 135-6°, was also isolated,

λmax. 292mμ, ν max. 1180cm^{-1}, m/e 296, 166, 154, 139, 122, 105.

The Reaction of 1,3,4-Trimethyl-1-phenyl-3-phospholenium Iodide with Benzaldehyde in Methanol.

The methiodide (1.5 g.) was added to sodium (1.2 g.) in methanol (40 ml.). Benzaldehyde (0.9 g.) was added and the solution set aside at room temperature for three days. The solution was evaporated and water (40 ml.) was added. The solution was extracted with chloroform (3 x 30 ml.). The combined extracts were dried over anhydrous sodium sulphate and evaporated. The residual oil could not be crystallised, λ max. 295 mμ, ν max. 1180 and 1115 cm^{-1}. Treatment of this oil with sodium ethoxide and benzaldehyde in dimethylformamide gave a solution with λ max. 366 mμ, indicating the formation of 3,4-dimethyl-1,6-diphenyl-hexatriene.

A similar oil, λ max. 292 mμ, ν max. 1180 and 1115 cm^{-1}, was obtained using 1,3-dimethyl-1-phenyl-2-phospholenium iodide. Some methyl diphenylhexatriene was also formed.

The Reaction of 1,3,4-Trimethyl-1-phenyl-3-phospholenium Iodide with Benzaldehyde in Hexamethylphosphoric Triamide.

The methiodide (0.8 g.) and benzaldehyde (0.5 g.) were added to dry sodium ethoxide (1.4 g.) in hexamethylphosphoric triamide (15 ml.). The mixture was stirred at room temperature for three days and then poured into water (50 ml.) and extracted with chloroform (3 x 30 ml.). The combined extracts were washed with water (50 ml.), dried over anhydrous sodium sulphate, and the chloroform evaporated. The residue was chromatographed on basic alumina. Dimethyldiphenyl-

hexatriene (8%) was obtained by elution with petroleum ether b.p. (40-60°).

The Reaction of 3-Methyl-1-phenyl-2-phospholene with Acrylonitrile and Benzaldehyde.

Acrylonitrile (0.9 g.) was added to the phospholene (3 g.) in ethanol (50 ml.). After fifteen minutes benzaldehyde (2 g.) was added and the mixture was refluxed for two hours. The ethanol was removed by distillation and the residue taken up in water (50 ml.), and extracted with chloroform (3 x 30 ml.). The combined extracts were washed with water (50 ml.), dried over sodium sulphate, and evaporated. The residual oil was subjected to chromatography on basic alumina. By elution with petroleum spirit (b.p. 40-60°) 2-cyano-1,4-diphenylbuta-1,3-diene was obtained (0.2 g.) m.p. 118° (literature[131] m.p. 115-6°), λmax 340 mμ , in ethanol log ε = 4.59, ν max 2210 and 965 cm^{-1}, m/e 231, 203, 153, 127, (Found C,87.3; H, 5.5. Calculated for $C_{17}H_{13}N$: C, 88.3; H, 5.6%).

By elution with 2% methanol in ether an oil was obtained λ max 297 mμ , ν max. 2230, 1620, 1220 and 1180 cm^{-1}. This oil did not react with benzaldehyde and sodium ethoxide in dimethylformamide to give methyldiphenylhexatriene.

3,4-Dimethyl-1-phenyl-3-phospholene also gave cyanodiphenylbutadiene and a similar oil λ max 300 mμ , ν max. 2230, 1600, 1220, and 1180 cm^{-1}.

In both cases by carrying out the reaction in the absence of solvent the same products were obtained together with some polymeric material.

Cyanodiphenylbutadiene was also obtained by using triphenylphosphine instead of phospholenes. Triphenylphosphine with several other aromatic aldehydes also gave substituted cyanobutadiene products, of which the maleic anhydride adducts were made as tabulated below:

Table 5.

Aldehyde	Olefin	m.p.	Found C;H;N	Required C;H;N%	λmax. mμ	Adduct m.p.
		189°	67.9;3.8;4.8	68.0;3.7;4.7	335	200–2°
		158–9°	78.4;5.7;4.8	78.3;5.9;4.8	360	170–2°
		132–3°	68.0;3.5;4.5	68.0;3.7;4.7	325	178–80°

The Alkaline Hydrolysis of 1,3,4-Trimethyl-1-phenyl-3-phospholenium Iodide.

The methiodide (0.5 g.) was added to 1 N sodium hydroxide (10 ml.) and ethanol (10 ml.) and the mixture was refluxed for three hours. Analysis of the reaction mixture by g.l.c. did not show any benzene. The solution was evaporated and taken up in water (20 ml.). The aqueous solution was extracted with chloroform (3 x 20 ml.) and the combined extracts dried over anhydrous sodium sulphate and the chloroform evaporated. The residue was crystallised from petroleum spirit (b.p. 40-60°)-ether to give methylphenyl(2,3,3-trimethylpropyl)phosphine oxide (0.2 g.), m.p. 93-4°, ν max. 1160 cm^{-1}, $^{m}/e$ 222, 207, 140, 125, multiplet (9H) at τ 8.36, doublet (3H) at τ 7.18, (Found C, 70.2; H, 8.5; P, 14.1. $C_{13}H_{19}OP$ requires C, 70.25; H, 8.6; P, 13.9%).

The Reaction of Buta-1,3-diene with Phosphorus Trichloride[132].

Phosphorus trichloride (56g.), butadiene (22g.) and copper stearate (1 g.) were placed in an autoclave at 25° for two weeks. The oily mixture was suspended in methylene chloride (1500 ml.) and the stirred suspension was cooled to -10° while sulphur dioxide (33g.) was bubbled in over a period of two hours. The solvent was removed under reduced pressure and the residue distilled in vacuo, giving 1-chloro-2-phospholene oxide.

The phospholene oxide (3g.) was added to the Grignard reagent prepared from bromobenzene (7g.) and magnesium (1g.) in ether (50 ml.). The mixture was stirred for 1½ hours at reflux and then after cooling

water (50 ml.) was added. The ether layer was dried over anhydrous sodium sulphate and evaporated. The residue was chromatographed on basic alumina. Elution with 1% methanol in ether gave 1,3-diphenylphospholane oxide m.p. 106-7°, ν max. 1175 and 1120 cm^{-1}, $^{m}/e$ 256, 241, 227, 201, 152, doublet (4H) at τ 7.66, quadruplet (2H) at τ 5.00. (Found: C,74.8; H,6.5; P,12.25. $C_{16}H_{17}OP$ requires C,75.0; H,6.7; P,12.1%).

Attempted Reaction of Diphenylvinylphosphine Oxide with Phenylmagnesium Bromide.

The phosphine oxide (2 g.) was added to the Grignard reagent prepared from bromobenzene (1.4 g.) and magnesium (0.24 g.) in ether (30 ml.). The mixture was stirred for 1½ hours at reflux and then after cooling water (30 ml.) was added. The ether layer was dried over anhydrous sodium sulphate and evaporated. The residue was chromatographed on basic alumina. Diphenylvinylphosphine oxide (1g.) was recovered, but no products could be isolated. The white precipitate formed during the reaction was probably poly-diphenylvinylphosphine oxide.

The Alkaline Hydrolysis of 1,3-Dimethyl-1-phenylphospholenium Iodide

The same procedure was used as for 1,3,4-trimethylphospholenium iodide. The product was recrystallised from ether-petroleum spirit (b.p. 40-60°) giving (3-methylbut-4-enyl)methylphenylphosphine oxide, m.p. 56-8°, ν max 1440, 1180, and 900 cm^{-1}, singlet (2H) at τ5.29, doublet (3H) at τ8.24 (J_{P-H}=13c.p.s.), singlet (3H) at τ8.31. No analysis could be obtained as the oxide was hygroscopic.

Preparation of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane Oxide.

2,4,4-Trimethylpent-2-ene (29g.) was added dropwise to the stirred mixture of aluminium chloride (33.3 g.) and dichlorophenylphosphine (44.8 g.) in methylene chloride (150 ml.) over a period of twenty minutes, keeping the temperature of the mixture at 0 - 10°. After stirring for one hour water (150 ml.) was added dropwise, keeping the temperature of the stirred mixture below 25°. The organic layer was separated, washed with sodium hydroxide, and then water, and dried over anhydrous sodium sulphate. The oily phosphine oxide obtained by evaporation of the solvent was chromatographed on basic alumina.

By elution with 50% ether in petroleum spirit (b.p. 40-60°) a highly crystalline phosphine oxide (35 g.) was obtained, m.p. 126-7°, ν max. 1190, 1165, 750, 715 and 703 cm^{-1}, $^{m}/e$ 236, 235, 220, 168, 166, 125, 119 and 108, doublet (6H) at τ 8.60 (J_{P-H} = 17 c.p.s.), doublet (6H) at τ 8.90 (J_{P-H} = 18 c.p.s.), doublet (3H) at τ 8.93 (J = 15 c.p.s.) (Found: C, 71.05; H, 8.8; P, 13.2. $C_{14}H_{21}OP$ requires C, 71.2; H, 9.0; P, 13.1%).

After the elution of several intermediate fractions containing a mixture of phosphine oxides, a second highly crystalline phosphine oxide (300 mg.) was obtained by elution with 2% methanol in ether, m.p. 117-8°, ν max 1180, 1155, 757, 743, 715, 693 cm^{-1}, $^{m}/e$ as for the oxide m.p. 126-7°, doublet (6H) at τ 8.58 (J_{P-H} = 15 c.p.s.), doublet (6H) at τ 8.66 (J_{P-H} = 19 c.p.s.), doublet (3H) at τ 9.04 (J = 1.5 c.p.s.). (Found: C, 71.05; H, 8.8; P, 13.3. $C_{14}H_{21}OP$

requires C, 71.2; H, 9.0; P, 13.1%).

Neither of the isomers was affected by boiling with either concentrated sodium hydroxide or with concentrated hydrochloric acid.

Preparation of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane.

a) Using Lithium Aluminium Hydride.[133]

2,2,3,4,4-Pentamethyl-1-phenylphosphetane oxide (10 g.) in benzene (44 ml.) was added dropwise during one hour to a stirred suspension of lithium aluminium hydride (3.6 g.) in di-butyl ether (44 ml.) with heating on a steam bath to maintain gentle reflux. The mixture was stirred at reflux for a further four hours. Water (20 ml.) was very cautiously added dropwise to the stirred ice/water cooled mixture, followed by 2N sulphuric acid (150 ml.). The organic layer was separated, washed with water (100 ml.) and dried over anhydrous sodium sulphate. The phosphine was used in the solution thus obtained.

b) Using Trichlorosilane.[134]

The phosphetane oxide (10g.) in benzene (50 ml.) was added dropwise during one hour to the stirred mixture of trichlorosilane (5 mls.) and triethylamine (5 g.) in benzene (100 ml.). The reaction mixture was stirred at reflux for fifteen hours and then ice/water cooled while 2N sodium hydroxide solution was cautiously added dropwise. The organic layer was separated, washed with saturated sodium chloride solution, and dried over anhydrous sodium sulphate. The solvant was evaporated and the phosphetane distilled in vacuo

b.p. 111°/1.5 mm. ^{1}H N.M.R. in o-dichlorobenzene quadruplet (1H) at τ 7.18 (J = 7 c.p.s.), doublet (6H)at τ 8.71 (J_{P-H} = 24 c.p.s.), doublet (6H) at τ 8.94 (J_{P-H} = 13 c.p.s.), doublet (3H) at τ 9.2 (J = 7 c.p.s.).

Phosphetanium Salts prepared from 2,2,3,4,4-Pentamethyl-1-phenyl-phosphetane.

1. By Quaternisation with Methyl Iodide.

The salt was recrystallised from chloroform-ethyl acetate m.p. 279-80° (decomposes), ν max. 1110 and 910 cm^{-1}, doublet (6H) at τ 8.28 (J_{P-H} = 20 c.p.s.), doublet (6H) at τ 8.47 (J = 19 c.p.s.), doublet (3H) at τ 7.27 (J_{P-H} = 14 c.p.s.), doublet (3H) at τ 8.91 (J = 7 c.p.s.). (Found C, 49.6; H, 6.4; P, 8.2. $C_{15}H_{24}IP$ requires C,49.7; H, 6.7; P, 8.7%).

2. By Quaternisation with Methylene Iodide.

The salt was recrystallised from chloroform-ethyl acetate m.p.234-5° (decomposes), ν max. 1110 and 910 cm^{-1}, ^{1}H N.M.R. run in hexadeuteriodimethylsulphoxide, doublet (6H) at τ 8.46 (J_{P-H} = 20 c.p.s.), doublet (6H) at τ 8.57 (J_{P-H} = 19 c.p.s.), doublet (3H) at τ 8.98 (J = 8 c.p.s.), (Found: C, 37.0; H, 4.95: P, 6.5. $C_{15}H_{23}I_2P$ requires C, 36.9; H, 4.75; P, 6.35%).

3. By Quaternisation with Benzyl Bromide.

The salt was recrystallised from chloroform-ethyl acetate m.p.220-1° (decomposes), ν max. 1115 and 865 cm^{-1}, doublet (6H) at τ 8.07 (J_{P-H} = 20 c.p.s.), doublet (6H) at τ 8.39 (J_{P-H} = 19 c.p.s.),

doublet (3H) at τ8.88 (J = 8 c.p.s.), doublet (2H) at τ 5.01 (J_{P-H} = 14 c.p.s.). (Found: C, 65.0; H, 6.9; P, 8.0. $C_{21}H_{28}BrP$ requires C, 64.5; H, 7.2; P, 7.9%).

4. By Quaternisation with p-Nitrobenzyl Bromide.

The salt was recrystallised from chloroform-ethyl acetate m.p.202-3° (decomposes), ν max. 1530, 1450, 1115 cm^{-1}, doublet (6H) at τ 8.25 (J_{P-H} = 21 c.p.s.), doublet (6H) at τ 8.57 (J_{P-H} = 18 c.p.s.), doublet (3H) at τ 8.94 (J = 7 c.p.s.), quadruplet (2H) at τ 5.01.

(Found: C, 58.0; H, 6.5; P, 7.1. $C_{21}H_{27}BrNO_2P$ requires C, 57.8; H, 6.25; P, 7.1%).

The Alkaline Hydrolysis of Phosphetanium Salts.

In a typical hydrolysis the methiodide (1 g.) was added to 1 N sodium hydroxide (10 ml.) and ethanol (10 ml.) and the mixture was stirred at reflux overnight. Most of the solvent was evaporated and the residue taken up in water (30 ml.). The aqueous layer was extracted with ether (3 x 30 ml.) and the combined extracts were dried over anhydrous sodium sulphate. The residue after evaporation of the ether was recrystallised from ether-petroleum spirit (b.p.40-60°), giving a phosphine oxide, m.p.133-4°, no λmax. above 220 mμ, νmax. 1630 and 1150 cm^{-1}, m/e 252, 182, 140, 105, multiplet (4H) at τ 3.8-4.8, doublet (2H) at τ 7.26 (J = 18 c.p.s.), quartet (1H) at τ 8.17 (J = 7.2 c.p.s.) doublet (3H) at τ 8.61 (J_{P-H} = 12 c.p.s.), and the remaining methyl groups 8.81τ (6H), 9.06τ (3H) 8.88 τ and 9.18τ (6H). (Found: C, 71.3, H, 9.65; P, 12.5. $C_{15}H_{25}OP$ requires C, 71.4; H, 9.9; P, 12.3%). On catalytic hydrogenation, the

phosphine oxide took up 2 moles. of hydrogen to give a product phosphine oxide, recrystallised from ether-petroleum spirit (b.p. 40-60°), m.p. 133-5°, ν max. 1230 cm^{-1}, $^{m}/e$ 256, 235, 107, complex multiplet at τ 8.2-9.3 with no other peaks. The reaction of the phosphine oxide with t-butyl-lithium, followed by methyl iodide, gave a phosphine oxide product of which the ^{1}H N.M.R. was very similar to that of (1,1,2,3,3-pentamethyl-3-phenylpropyl)phenylphosphine oxide. This product phosphine oxide contained some of the starting phosphine oxide, m.p. 133-4° and could not be purified by chromatography. The phosphine oxide had $^{m}/e$ 266, 250, 235, 147, 119.

The alkaline hydrolysis of the methylene iodide salt gave a phosphine oxide product which was recrystallised from ether-petroleum spirit (b.p.40-60°) m.p. 140-1°, ν max 1590, 1430, 1165, 760 and 695 cm^{-1}, $^{m}/e$ 250, 180, 166, multiplet (5H) from τ 2-2.7, multiplet (2H) at τ 7.68-7.85. (Found: C, 71.8; H, 9.1; P, 12.5. $C_{15}H_{23}OP$ requires C, 72.0; H, 9.3; P, 12.4%).

The alkaline hydrolyses of the benzyl and p-nitrobenzyl bromide salts both gave the starting 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide m.p. and mixed m.p. 126°, and toluene and p,p^{1}-dinitrodibenzyl respectively.

The Oxidation of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane.

The crystalline phosphetane (1 g.) was dissolved in methylene chloride (15 ml.). Hydrogen peroxide solution (30%; 5ml.) was added dropwise to the stirred, ice/water cooled, solution. The

mixture was stirred overnight at room temperature. The organic layer was separated, dried over anhydrous sodium sulphate, and the methylene chloride evaporated. The residue was recrystallised from ether-petroleum spirit (b.p. 40-60°), giving an almost quantitive yield of the starting 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide m.p. and mixed m.p. 126-7°.

The Wittig Olefin Synthesis Using 1-Benzyl-2,2,3,4,4-pentamethyl-1-phenylphosphetanium Bromide.

The phosphetanium salt (1g.) and benzaldehyde (0.3 g.) were added to sodium (0.06 g.) in ethanol (14 ml.). The solution was set aside at room temperature for three days. Analysis by g.l.c. showed the presence of stilbene (49%), cis:trans = 1:5. The ethanol was removed by distillation and water (30 ml.) was added to the residue. The aqueous layer was extracted with ether (3 x 30 ml.) and the combined extracts were dried over anhydrous sodium sulphate. The residue after evaporation of the ether was chromatographed on basic alumina. Elution with petroleum spirit (b.p. 40-60°) gave crystalline trans-stilbene. Elution with ether gave 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide m.p. and mixed m.p. 126-7°.

The Reaction of 2,2,3,4,4,-Pentamethyl-1-phenylphosphetane Oxide with Methyl-lithium.

Methyl-lithium (9.35 ml.; 0.97 N in ether) was added to the stirred solution of the oxide (2 g.) in ether (25 ml.). After

the exothermic reaction had subsided the reaction mixture was stirred at reflux for ½ hour. 2N Hydrochloric acid (10ml.) was added. The organic layer was separated and dried over anhydrous sodium sulphate. An oily residue was obtained on evaporation of the solvent and 1,2,2,3,4,4-hexamethylphosphetane oxide was obtained by sublimation from this oil, m.p. 159-60° νmax. 1160 and 895cm^{-1}, m/e 174,169,104, doublet (3H) at τ8.46, (J_{P-H}= 14c.p.s.), doublet (6H) at τ8.72 (J_{P-H}= 16c.p.s.), doublet (6H) at τ8.83 (J_{P-H}= 19c.p.s.), doublet (3H) at τ9.08 (J= 8c.p.s.), (Found: C, 62.0; H, 10.7; P, 18.0. $C_9H_{19}OP$ requires C, 62.1; H, 10.9; P, 17.8%).

The Reaction of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane Oxide with Phenyl-lithium.

Phenyl-lithium (6ml.; 1.5N) was added to the stirred solution of the oxide (2g.) in ether (25ml.). After the exothermic reaction had subsided the mixture was stirred at reflux for ½ hour. Two routes were followed from this stage.

In one case, methyl iodide (2g.) was added, followed by water (25ml.). The organic layer was separated and dried over anhydrous sodium sulphate. The residue after evaporation of the ether was recrystallised from ether-petroleum spirit (b.p.40-60°), m.p. 106-11°. This phosphine oxide, methyl(1,1,2,3,3-pentamethyl-3-phenylpropyl)phenylphosphine oxide, was the same as that obtained by Chorvatt and Cremer[86] by this route.

In the other case, 2N hydrochloric acid (25ml.) was added.

The organic layer was separated, dried over anhydrous sodium sulphate, and the solvent removed by evaporation. The residue was recrystallised from ether-petroleum spirit (b.p. 40-60°) giving (1,1,2,3,3-pentamethyl-3-phenylpropyl)phenylphosphine oxide m.p. 83-4°, ν max 3500, 3400, 2310, 1430, 1140, 935 cm^{-1}, m/e 314, 244, 195, 119, multiplet (5H) at τ 2.2-2.6, singlet (5H) at 2.83, doublet (1H) at τ 6.97 and -0.97 (J_{P-H} = 476 c.p.s.), doublet (6H) at τ 8.68 (J_{P-H} = 12 c.p.s.), doublet (6H) at τ 8.76 (J_{P-H} = 11 c.p.s), multiplet (3H) at τ 8.98, doublet (3H) at τ 9.35 (J_{P-H} = 19 c.p.s.). The phosphine oxide was hygroscopic and so an analysis was not obtained.

Using p-deuteriophenyl-lithium instead of phenyl-lithium and working up by addition of methyl-iodide, the phosphine oxide m.p. 106-111° was obtained. From ^1H N.M.R. and mass spectral evidence it was shown that the p-deuteriated phenyl group was equally distributed between the phosphorus and the end of the carbon side chain.

The Reaction of Phenyl-lithium with 1-Chloro-2,2,3,4,4-pentamethyl-phosphetane Oxide.

The acid chloride was prepared by the method of Jungermann and McBride[68]. Phenyl-lithium (12.5 ml.; 1.9 N in ether) was added to the stirred solution of the acid chloride (4.8 g.) in ether (35ml.). Water (30 ml.) was added to the reaction mixture. The organic layer was separated and dried over anhydrous sodium sulphate. The oily residue after evaporation of the solvent was chromatographed on

silica. The first fraction obtained by elution with ether was an oil, which was shown to contain some of the 2,2,3,4,4-pentamethyl-1-phenylphosphetane oxide by t.l.c. Further chromatography of this oil on basic alumina gave the phosphetane oxide m.p. and mixed m.p. 126-7° and the secondary phosphine oxide, m.p. 83-4°, obtained from the reaction of phenyl-lithium with the phosphetane oxide, m.p. 126-7°. Further elution of the silica column yielded only the secondary phosphine oxide described above.

The Reaction of 1-Chloro-2,2,3,4,4-pentamethylphosphetane oxide with Methyl-lithium.

The procedure was the same as that for phenyl-lithium and the acid chloride. The residue from the evaporation of the ether solution was recrystallised from ether-petroleum spirit (b.p.40-60°) m.p. 160-2°. The mixed m.p. of this phosphine oxide with 1,2,2,3,4,4-hexamethylphosphetane oxide was 158-61°. It was therefore concluded that they were identical. Further confirmation was obtained from the I.R., ^{1}H N.M.R. and mass spectra.

The Preparation of 1,2,2,3,4,4-Hexamethyl-1-(p-deuteriophenyl)-phosphetanium Iodide.

a) The Preparation of Tris(diethylamino)phosphine.[135]

The solution of diethylamine (219 g.) in ether (500 ml.) was added dropwise to the stirred solution of phosphorus trichloride (55 g.) in ether (150 ml.) cooled to 5° in an ice/water bath. After the addition the mixture was stirred at reflux for four hours. The mixture was filtered and the solid washed well with ether. The ether

was distilled from the combined solution and washings and the residue was distilled in vacuo, giving the phosphine b.p. 78-80°/1mm.

b) The Preparation of Chlorobis(diethylamino)phosphine[136].

Tris(diethylamino)phosphine (70 g.) was added dropwise to stirred phosphorus trichloride (19.5 g.) keeping the temperature of the mixture below 20°. After the addition the mixture was heated to 100° for twenty minutes and then distilled in vacuo, giving the phosphine b.p. 70-2°/2m.m.

c) The Preparation of Bis(diethylamino)-p-deuteriophenylphosphine.

p-Deuteriophenyl-lithium (0.225 mole in ether 200 ml.) was added dropwise to the stirred solution of chlorobis(diethylamino)phosphine in ether (100 ml.) keeping the temperature of the mixture at -10°. After allowing the mixture to warm to room temperature during one hour, it was refluxed for a further 1½ hours. The residue after removal of the ether solvent was distilled in vacuo, giving the phosphine b.p. 132-4°/2m.m.

d. The Preparation of p-Deuteriophenyldichlorophosphine[137].

Anhydrous hydrogen chloride (40 g.) in ether (200 ml.) was added dropwise to the stirred solution of bis(diethylamino)-p-deuteriophenylphosphine (46 g.) in ether (50 ml.) keeping the temperature at -10°. The mixture was allowed to warm to room temperature and was set aside at room temperature overnight. The precipitated diethylamine hydrochloride was filtered off and washed well with ether. The ether solvent was removed from the combined filtrate and washings and

the residue distilled in vacuo, giving the phosphine (23.4 g).

e) The Preparation of 1-p-Deuteriophenyl-2,2,3,4,4-pentamethylphosphetane oxide.

The procedure was the same as for the preparation of the phenylphosphetane oxide, using p-deuteriophenyldichlorophosphine instead of dichlorophenylphosphine.

f) Preparation of 1-p-Deuteriophenyl-1,2,2,3,4,4-hexamethylphosphetanium Iodide.

The phosphetane oxide was reduced, using lithium aluminium hydride, and the phosphetane solution was quaternised with methyl iodide giving the phosphonium salt which was recrystallised from chloroform-ethyl acetate, m.p. 279-81°. The ^{1}H N.M.R. spectrum was the same as that of the non-deuterated salt, except that in the aromatic region the splitting was more complex and the integration was for 4 instead of 5 protons.

The Alkaline Hydrolysis of 1-p-Deuteriophenyl-1,2,2,3,4,4-Hexamethylphosphetanium Iodide.

The methiodide (1 g.) was added to 1 N sodium hydroxide (10ml.) and ethanol (10ml.) and the mixture was stirred at reflux overnight. The solvent was removed by evaporation and water (25 ml.) was added. The aqueous solution was extracted with ether (3x 25 ml.) and the combined extracts were dried over anhydrous sodium sulphate. The residue after removal of the ether was recrystallised from ether-petroleum spirit (b.p.40-60°), giving a phosphine oxide m.p.133-4°. The ^{1}H N.M.R. spectrum was the same as that of the product phosphine

oxide from the non-deuteriated methiodide, except that the doublet at τ 7.26 integrated for 1 instead of 2 protons.

The alkaline hydrolysis using sodium deuteroxide in deuterium oxide gave the phosphine oxide m.p. 133-4°. The ^{1}H N.M.R. spectrum no longer showed a doublet at τ7.26.

The Reaction of p-Deuteriophenyl-lithium with 1-p-Deuteriophenyl-2,2,3,4,4-pentamethylphosphetane Oxide.

The procedure was the same as for the reaction of the non-deuteriated oxide with phenyl-lithium. The mixture was worked up by the addition of methyl iodide. The phosphine oxide product was recrystallised from petroleum spirit (b.p. 40-60°), m.p. 106-112°. The ^{1}H N.M.R. was the same as for the non-deuteriated oxide, except that the integration was for 2 less aromatic protons. The aromatic region of the spectrum was not sufficiently well resolved to determine the position of the deuterium on the phenyl group which migrated to the carbon side chain.

The Preparation of 1-Benzylamino-2,2,3,4,4-pentamethylphosphetane Oxide.

Method a) The acid chloride (4 g.) was added to benzylamine (4.4 g.) in benzene (40 ml.) and the mixture was refluxed overnight. 2N Hydrochloric acid (25 ml.) was added and the organic layer was separated, washed with water (50 ml.) and dfied over anhydrous sodium sulphate. The residue after evaporation of the benzene was chromatographed on basic alumina. Elution with ether gave the amide which was recrystallised from ether-petroleum spirit (b.p.40-60°) m.p.159-60°, ν max3180

1160, 860, 730, and 695 cm^{-1}, $^{m}/e$ 265, singlet (5H) at τ 2.62, triplet (2H) at τ 5.75 (J = 7 c.p.s.), doublet (6H) at τ 8.74 (J_{P-H} = 17 c.p.s.), doublet (6H) at τ 8.83 (J_{P-H} = 19 c.p.s.), multiplet (3H) at τ 9.1. Addition of small amounts of acidic compounds caused the triplet at τ 5.75 to collapse to a doublet (J = 7 c.p.s.). (Found: C,67.6; H, 9.3; N, 5.3. $C_{15}H_{24}NOP$ requires C, 67.9; H, 9.1; N, 5.3%).

Method b) The acid chloride (1 g.) in ether (10 ml.) was added dropwise to the stirred suspension of the benzylamine anion prepared by the addition of butyl-lithium (7.4 ml.; 2.5 N in ether) to benzylamine (2 g.) in ether (15 ml.). The mixture was stirred for one hour and then acidified by addition of 2N hydrochloric acid (20 ml.), and dried over anhydrous sodium sulphate. The residue after evaporation of the ether was recrystallised from ether-petroleum spirit (b.p. 40-60°) giving the amide m.p. and mixed m.p. 159-60°. The spectral properties were the same as those of the amide prepared by method a).

Method c) The acid chloride (10 g.) in methanol (30 ml.) was added dropwise with stirring to sodium (1.3 g.) in methanol (50 ml.). The mixture was stirred overnight, filtered, and the methanol removed by distillation. Water (50 ml.) was added to the residue and the aqueous solution was extracted with methylene chloride (3 x 30 ml.). The combined extracts were dried over anhydrous sodium sulphate. The methylene chloride was evaporated and the residue distilled in vacuo, giving the methyl ester b.p. 75-7°/5m.m., ν max. 1250, 1200, and 1035 cm^{-1},

doublet (3H) at τ6.28 (J= 10 c.p.s.), doublet (12H) at τ 8.85 (J = 18 c.p.s.), doublet (3H) at τ 9.13 (J = 17 c.p.s.).

The methyl ester (1.4 g.) in ether (25 ml.) was added dropwise to the stirred suspension of the benzylamine anion prepared from benzylamine (3 g.) and butyl-lithium (11.5 ml.; 2.5 N in ether). After stirring the one hour, 2N hydrochloric acid (25 ml.) was added. The organic layer was separated, washed with water (30 ml), and dried over anhydrous sodium sulphate. The residue after evaporation of the ether was recrystallised from ether-petroleum spirit (b.p. 40 - 60°) giving the amide, m.p. and mixed m.p. 159-60°. The spectral properties were the same as those for the amide prepared by the other methods.

The Preparation of 1-Ethoxy-2,2,3,4,4-pentamethylphosphetane Oxide.

The procedure was the same as for the preparation of the methyl ester using ethanol instead of methanol, giving the ethyl ester b.p. 69-71°/1 m.m. ν max. 1250, 1210 and 1035 cm^{-1}, quintuplet (2H) at τ 5.85 (J = 7 c.p.s.), doublet (6H) at τ8.79 (J_{P-H} = 19 c.p.s.), doublet (6H) at τ 8.83 (J_{P-H} = 18 c.p.s.), doublet (3H) at τ 9.13 (J = 7 c.p.s.).

The Reaction of 2,2,3,4,4-Pentamethyl-1-phenylphosphetane with Ethyl Propiolate.

Ethyl propiolate (0.5 g.) was added to the phosphetane (1g.) in wet ether (15 ml.). A vigorous exothermic reaction took place and as the reaction mixture cooled to room temperature a white

precipitate was formed which was filtered off and recrystallised from ether-petroleum spirit (b.p. 40-60°), giving a phosphine oxide m.p. 131-2°, ν max. 1715, 1430, 1260 and 1160 cm^{-1}, m/e 336, 291, 224, 195, 125, quadruplat (2H) at τ4.12 (J = 7 c.p.s.), aliphatic protons in a complex multiplet at τ 8.3 - 9.3. (Found: C, 67.85; H, 8.55; P, 9.05. $C_{19}H_{29}O_3P$ requires C, 67.9; H, 8.6; P, 9.2%).

The Preparation of Chloridi-t-butylphosphine.[138]

The Grignard reagent prepared from magnesium (18.5 g.) and t-butyl chloride (87.5 g.) in ether (120 ml.) was added dropwise to the stirred solution of phosphorus trichloride (20.6 g.) in ether (100 ml.). The temperature was kept at -25° while half of the Grignard reagent was added and then the cooling bath was removed during the addition of the other half. Precipitated magnesium chloride was filtered off and washed well on the filter with ether (2 x 75 ml.). The ether was removed by distillation from the combined filtrates and the residue was distilled in vacuo, giving the phosphine (17 g.) b.p. 70-2°/5m.m., doublet at τ 8.82 (J = 12 c.p.s.)

The Oxidation of Chlorodi-t-butylphosphine.

Hydrogen peroxide (25 ml.; 28% w/v) was added dropwise to the stirred, ice/water cooled, solution of the phosphine (11 g.) in methylene chloride (25 ml.) and the mixture was stirred overnight at room temperature. The organic layer was separated, washed with water (30 ml.) and dried over anhydrous sodium sulphate. The solvent was removed by evaporation and the residue distilled in vacuo, giving di-t-butylphosphine oxide (5g.) b.p. 114°/ 6m.m.,

ν max. 2300, 1160, and 820 cm^{-1}, doublet (18H) at τ 8.75 (J_{P-H} 14 c.p.s.), doublet (1H) at τ 0.1 and τ 8.4 (J = 480 c.p.s.).

The Chlorination of Di-t-butylphosphine Oxide.

A solution of chlorine (2.3 g.) in carbon tetrachloride (100ml.) was added dropwise to the stirred solution of di-t-butylphosphine oxide (3.3 g.) in carbon tetrachloride (20 ml.). After stirring for one hour the excess chlorine and carbon tetrachloride were removed by evaporation and the residue was recrystallised from petroleum spirit (b.p. 40-60°) giving chlorodi-t-butylphosphine oxide (3.2 g.), m.p. 77-9° (literature[139] m.p. 80°), ν max. 1230, 1210, 1180 and 820 cm^{-1}, doublet at τ 8.66 (J_{P-H} = 17 c.p.s.), ^1H N.M.R. in carbon tetrachloride, (Found: Cl, 18.3. Calculated for $C_8H_{18}ClOP$: Cl, 18.1%).

Direct Oxidation of Chlorodi-t-butylphosphine to Chlorodi-t-butylphosphine Oxide.

It was found that by reverse addition the acid chloride was obtained. A solution of the phosphine (10 g.) in methylene chloride (90 ml.) was added dropwise with stirring to hydrogen peroxide (25ml.; 28% w/v). The organic layer was separated, washed with water (30 ml.) and dried over anhydrous sodium sulphate. The residue after the removal of the solvent by evaporation was recrystallised from petroleum spirit (b.p. 40-60°) giving the acid chloride (5.3 g.), m.p. 79-80°.

Attempted Reaction of Chlorodi-t-butylphosphine Oxide with Sodium Ethoxide.

The acid chloride (3.2 g.) in ethanol (15 ml.) was added dropwise to sodium (0.6 g.) in ethanol (35 ml.). The solution was stirred overnight at room temperature. No white precipitate of sodium chloride was formed and so the mixture was stirred at reflux for four hours. The ethanol was removed by distillation and the residue was taken up in water (40 ml.). The aqueous solution was extracted with ether (3 x 30 ml.) and the combined ether extracts were dried over anhydrous sodium sulphate. The residue after evaporation of the ether was recrystallised from petroleum spirit (b.p. 40-60°), giving the unchanged acid chloride (75%) m.p. 79-80°.

The Preparation of Di-t-butylphosphinic Acid.

A solution of the acid chloride (23 g.) in 2 N sodium hydroxide (50 ml.) was refluxed for five days. The solution was acidified with 2 N sulphuric acid and extracted with chloroform (3 x 30ml.). The combined extracts were dried over anhydrous sodium sulphate and the chloroform removed by evaporation. The residue was recrystallised from petroleum spirit (b.p. 40-60°) giving the phosphinic acid (1.7 g.) m.p. 207-9° (literature[140] m.p. 208-10°), ν max. 1150, 950, 830, and 820 cm^{-1}, singlet (1H) at τ -2.8, doublet (18H) at τ 8.79 (J_{P-H} = 14 c.p.s.), ^1H N.M.R. in carbon tetrachloride.

Preparation of Methyl Di-t-butylphosphinate.

Diazomethane in ether solution was added to a solution of the phosphinic acid (2.8 g.) in ether (20 ml.) until the solution retained a permanent yellow colour. The solvent was removed by evaporation, leaving a white crystalline solid which was extremely hygroscopic. The solid was recrystallised from petroleum spirit (b.p. below 40°) by cooling to - 40°. The white crystals were filtered in a dry box, ν max. 1190, 1055, 835 cm^{-1}, doublet (3H) at τ 6.32 (J_{P-H} = 14 c.p.s.), ^1H N.M.R. in carbon tetrachloride.

The Preparation of Ethyl Di-t-butylphosphinate.

A solution of chlorodi-t-butylphosphine (9.3 g.) in ethanol (10 ml.) was added dropwise with stirring to sodium (1.5 g.) in ethanol (35 ml.). After stirring for 1½ hours the white precipitate of sodium chloride was filtered off. Dry air was bubbled through the ethanolic filtrate for three hours and then the ethanol was removed by distillation. The residue was distilled in vacuo, giving the ethyl ester (7 g.), b.p. 85-7°/0.3 m.m., ν max. 1185, 1045, and 825 cm^{-1}, quintuplet (2H) at τ 5.94 (J = 7.3 c.p.s.), multiplet (3H) at τ 8.65, doublet (18H) at τ 8.83 (J_{P-H} = 14 c.p.s), ^1H N.M.R. in carbon tetrachloride, (Found: C, 58.1; H, 11.0; P, 15.2. $C_{10}H_{20}O_2P$ requires C, 58.3; H, 11.2; P, 15.0%).

The Preparation of Ethyl Di-iso-propylphosphinate.[138]

The Grignard reagent prepared from magnesium (12.5 g.) and iso-propyl chloride (50 g.) in ether (30 ml.) was added dropwise to

the stirred solution of phosphorus trichloride (26.5g.) in ether (150ml.), keeping the temperature of the mixture at -20°. The solution was filtered and the magnesium chloride was washed on the filter with ether (2x50ml.). The ether was removed by distillation from the combined filtrate and washings and the residue distilled in vacuo, giving chlorodi-iso-propylphospine (20g.), b.p. 26°/0.6mm.

The chlorophosphine (10g.) in ethanol (20ml.) was added to sodium (1.5g.) in ethanol (50ml.). The precipated sodium chloride was filtered off. Air was bubbled through the ethanolic filtrate for 3 hours. A mixture of esters was obtained by this method of oxidation.

An alternative route was therefore used for the oxidation. The ethanol was removed from the filtrate by evaporation and the residue was dissolved in methylene chloride (50ml.). Peracetic acid (11ml.; 33% solution in acetic acid) was added dropwise to the stirred solution. After 1½ hours the solution was washed with water, followed by saturated sodium bicarbonate solution and finally with water again. The methylene chloride solution was dried over anhydrous sodium sulphate, the methylene chloride removed by evaporation and the residue distilled in vacuo, giving ethyl di-iso-propylphosphinate (2.4g.), b.p. 64-5°/5m.m., νmax. 1180,1030, and 950 cm^{-1}, quintuplet (2H) at τ 5.94, complex multiplet (15H) at τ 8.54-9.15, multiplet (2H) at τ 8.25, ^1H N.M.R. in carbon tetrachloride, (Found: C, 53.8;

H, 10.7; P, 17.2. $C_8H_{19}O_2P$ requires C, 53.9; H, 10.7; P, 17.4%).

Preparation of Diethyl t-Butylphosphonate.

t-Butyl chloride (46.2 g.) was added dropwise with stirring to the mixture of aluminium chloride (33.3 g.) and phosphorus trichloride (34.35 g.), keeping the temperature of the mixture at 5°. A vigorous reaction ensued as the temperature was allowed to rise to 15° [141]. The temperature of the mixture was kept below 25° during the reaction and when the reaction subsided the mixture was set aside at 0° overnight. The excess t-butyl chloride was removed at reduced pressure and the vigorously stirred residue was cooled in an ice/water bath while concentrated hydrochloric acid (57 ml.) was added dropwise. The resultant mixture was extracted with methylene chloride (100 ml.) and the extract dried over anhydrous sodium sulphate. The methylene chloride was removed by evaporation and the residue recrystallised from petroleum spirit (b.p.40-60°) giving dichloro-t-butylphosphine oxide, m.p. 122-3°, ν max. 1160 and 820 cm^{-1}.

Dichloro-t-butylphosphine oxide (9.5 g.) in ethanol (35 ml.) was added dropwise with stirring to sodium (3 g.) in ethanol (50ml.). The mixture was stirred overnight and then filtered. The ethanol was removed from the filtrate by evaporation and the residue distilled at reduced pressure, giving diethyl t-butyl-phosphonate (5.4 g.) b.p. 67-8°/5m.m., ν max. 1255, 1220, and

1060 cm^{-1}, quintuplet (4H) at τ 5.94 (J = 6 c.p.s.), doublet (9H) at τ 8.89 (J_{P-H} = 16 c.p.s.), multiplet (6H) at τ 8.67 (Found: C, 49.5; H, 9.7; P, 16.2. $C_8H_{19}O_3P$ requires C, 49.4, H, 9.8; P, 16.0%).

Diethyl iso-propylphosphonate was similarly prepared b.p. 76°/1m.m., ν max 1230 and 1020 cm^{-1}, quintuplet (4H) at τ5.94 (J = 6 c.p.s.), multiplet (12H) at τ 8.5 - τ9.1,

(Found: C, 46.8; H, 9.6; P, 16.9. $C_{17}H_{17}O_3P$ requires C, 46.6; H, 9.5; P, 17.2%).

The Alkaline Hydrolysis of Diethyl Ethylphosphonate.

The hydrolysis was followed by g.l.c. analysis of the ethanol produced in samples taken at regular intervals and quenched on solid potassium hydrogen phthalate. The ester (7μl) was injected through a serum cap into 0.1 N carbonate free sodium hydroxide (10 ml.) and propanol (2.2 μl.) in a thermostat bath at 90°. The solution was shaken and a sample taken. Samples (0.3 ml.) were taken at regular intervals and the ethanol concentrations were determined relative to the propanol internal standard by g.l.c. using a carbowax 400 column. The ∞ ethanol concentration was taken after at least ten half lives.

A table of the results is given on the following page:

Table 6

Time minutes	Peak height inches EtOH	PrOH	Time minutes	Peak height inches EtOH	PrOH
12	2.80	4.50	71	5.65	4.13
20	3.10	4.00	87	6.05	4.18
28	4.00	4.34	99	6.32	4.00
43	4.03	3.93	114	6.82	4.00
55	5.00	4.00	∞	5.38	2.07

The data given in the table was fitted by computer to a best curve by the method of least squares and the pseudo-first order rate constant determined.

$$\text{Second order rate constant} = \frac{\text{Pseudo-first order rate constant}}{\text{base concentration}}$$

The derived second order rate constants for this and several other esters are given in table 1., in the section: "The Alkaline Hydrolysis of Phosphinate and Phosphonate Esters".

Preparation of The Adduct of Benzylidene Acetylacetone and 2,2,3,4,4-Pentamethyl-1-phenylphosphetane

Benzylidene acetylacetone (0.9g.) was added to the stirred

ice-water cooled solution of the phosphetane (1g.) in methylene chloride (15ml.). The solution was allowed to warm to room temperature and set aside for 3 hours. The residue after evaporation of the methylene chloride crystallised from petroleum spirit on standing, m.p. 93-4°, νmax. 1620, 1520, 1120, and 950 cm^{-1}, multiplet (10H) at τ 2.3-3.0, doublet (1H) at τ4.92 (J = 6c.p.s.), singlet (6H) at τ7.79, multiplet (16H) at τ8.2-9.3, (Found: C, 76.2; H, 8.3; P, 7.57. $C_{26}H_{33}O_2P$ requires C, 76.3; H, 8.1; P, 7.6%). In o-dichlorobenzene the adduct was almost entirely dissociated to phosphetane and benzylidene acetylacetone at 85°; the ^1H N.M.R. spectrum showed that the adduct was reformed on cooling to room temperature.

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