# STUDIES IN PHOSPHINEMETHYLENE CHEMISTRY

## IX. THE REACTION OF ORGANOLITHIUM REAGENTS WITH tert-BUTYLTRIPHENYLPHOSPHONIUM BROMIDE[a]

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As part of a broad study of the action of reactive organometallic reagents on phosphonium salts, we have investigated the reactions occurring between tert-butyltriphenylphosphonium bromide and organolithium reagents. This study was of interest since two different modes of reaction seemed possible in this system: (1) attack by the lithium reagent at a C–H linkage of the tert-butyl group, resulting in β-elimination:

$$[(C_6H_5)_3PC(CH_3)_3]Br + RCH_2Li \longrightarrow (C_6H_5)_3P + (CH_3)_2C=CH_2 + RCH_3 + LiBr,$$
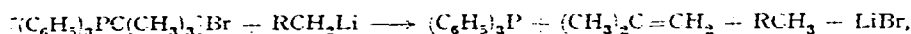
or (2) attack by the lithium reagent at the phosphorus atom, leading to the formation of a tert-butyldiphenylphosphinealkylidene:

$$[(C_6H_5)_3PC(CH_3)_3]Br + RCH_2Li \longrightarrow (C_6H_5)_2\overset{+}{P}-\overset{-}{C}HR + C_6H_6 + LiBr.$$
$$\underset{C(CH_3)_3}{}$$
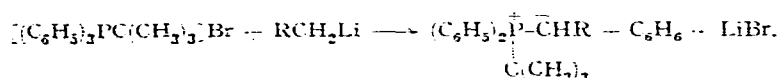
It may be noted that our previous studies[2] had demonstrated that such attack at phosphorus is possible, as shown by the reaction:

$$[(C_6H_5)_4P]Br + RCH_2Li \longrightarrow (C_6H_5)_3\overset{+}{P}-\overset{-}{C}HR + C_6H_6 + LiBr.$$
$$(60-70\%)$$
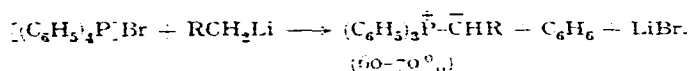
When ethereal methyllithium was added to a slurry of tert-butyltriphenylphosphonium bromide in tetrahydrofuran (THF), a red solution was formed rapidly, and after 1 h the Gilman[3] Color Test I was negative. Addition of cyclohexanone and refluxing of the resulting mixture discharged the color. Subsequent workup and gas chromatographic analysis of the organic layer showed that methylenecyclohexane and benzene had been formed in yields of 46 % and 68 % respectively. tert-Butyldiphenylphosphine oxide could be isolated from the distillation residue and was

identified by comparison with an authentic sample obtained from the decomposition of *tert*-butyltriphenylphosphonium bromide in aqueous base. In another experiment the reaction was carried out under a brisk nitrogen stream which was passed through a solution of bromine in chloroform in order to trap any isobutylene evolved. Only trace amounts of 1,2-dibromo-2-methylpropane were obtained. Thus the major reaction occurring when methyllithium attacks *tert*-butyltriphenylphosphonium bromide is the one which leads to formation of the *tert*-butyldiphenylphosphine-methylene reagent, presumably via transient *tert*-butylmethyltriphenylphosphorane. The remainder of the methyllithium consumed does not appear to attack at a β-C–H bond of the *tert*-butyl group. Just how this remaining 30 % of methyllithium reacts is not known. Other organophosphorus products appear to have been formed in the reaction, but none could be isolated as pure substances. It seems probable to us that these also resulted from attack at phosphorus by methyllithium.

A similar reaction was observed when ethyllithium in ether was added to a suspension of *tert*-butyltriphenylphosphonium bromide in ether or in THF. In this case, however, only *ca.* 30 % of the ethyllithium consumed could be accounted for in terms of pure products isolated. These products represented that portion of the attack at phosphorus which led to a phosphineethylidene reagent,

$$(C_6H_5)_2\overset{+}{P}-\overset{-}{C}HCH_3 ,$$
$$C(CH_3)_3$$
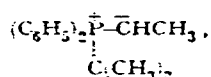
i.e., benzene (30 %) and ethylidenecyclohexane (25 %), when the reaction mixture was quenched with cyclohexanone. Phosphines appeared to be formed in this reaction as well, since a portion of the distillation residue reacted with methyl bromide to give an oily product which formed a solid on treatment with sodium tetraphenylborate.

The results of this study are of some interest to the general problem of the types of reactions which can occur when an organolithium reagent attacks a quaternary phosphonium halide. In spite of the accessibility of the C–H linkages of the *tert*-butyl group and in spite of the steric hindrance associated with attack on phosphorus in *tert*-butyltriphenylphosphonium bromide, attack at phosphorus is the major reaction with methyllithium and is still appreciable with ethyllithium. When the alkyltriphenylphosphonium halide contains α-C–H bonds, attack at phosphorus is only a minor reaction[2]. Usually better than 75 % of the attack occurs at an α-C–H linkage. In the present case, however, there are only β-C–H bonds and these are less acidic since the phosphonium function is one carbon further removed. It appears that in the present case electronic factors, not steric considerations, are of greater importance.

(I)
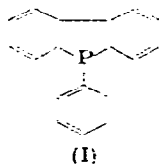
The reaction of lithium piperidide with *tert*-butyltriphenylphosphonium bromide cannot lead to a phosphinemethylene, and the most reasonable products to expect
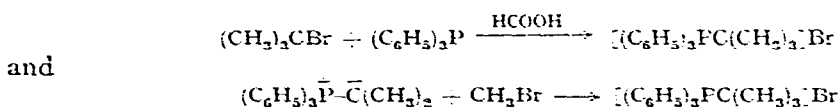
are those from β-elimination. Isobutylene (16%, as its dibromide) and triphenylphosphine (8.4%) indeed were isolated, but the major (42.4% yield) product isolated was 9-phenyl-9-phosphafluorene (I). This compound had been reported for the first time as a decomposition product of pentaphenylphosphorane[4].

It is our belief that the formation of (I) in the present reaction can best be rationalized as follows:


(II)

(I)
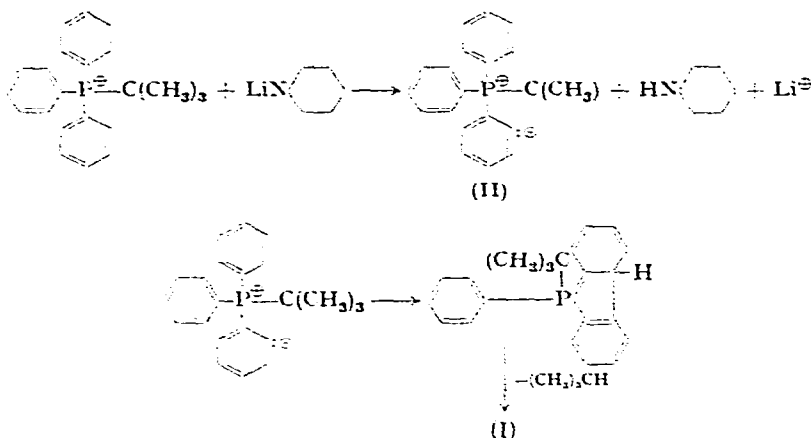
Ortho-metalation of triphenylphosphine by phenylsodium with resulting formation of (I) in low yield has been reported[4]. Similar *ortho*-metalation of phenyl-substituted phosphonium salts has not been reported to date, since in most cases more favorable sites of attack exist within the molecule*. The fact that *ortho*-metalation appears to be favored over β-elimination when lithium piperidide attacks *tert*-butyltriphenylphosphonium bromide suggests that here also electronic factors outweigh steric factors.

The *tert*-butyltriphenylphosphonium bromide required in these studies was prepared by two different routes:

and

$$(CH_3)_3CBr + (C_6H_5)_3P \xrightarrow{HCOOH} [(C_6H_5)_3PC(CH_3)_3]Br$$

$$(C_6H_5)_3P-\bar{C}(CH_3)_2 + CH_3Br \longrightarrow [(C_6H_5)_3PC(CH_3)_3]Br$$

Of these, the former, developed by Horner and Mentrup[6] for the preparation of the corresponding chloride is the more practical. *tert*-Butylmethyldiphenylphosphonium bromide also was required for purposes of comparison. It could be prepared in a straightforward manner by the reaction of methyl bromide with *tert*-butyldiphenylphosphine. However, the action of *tert*-butyl bromide on methyldiphenylphosphine resulted in dehydrobromination of the former:

$$(CH_3)_3CBr + CH_3P(C_6H_5)_2 \longrightarrow (CH_3)_2C=CH_2 + [(C_6H_5)_2(CH_3)PH]Br$$

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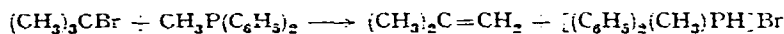
* In this connection it is of interest to note that 9-phenyl-9-phosphafluorene also is a byproduct in the reaction of methyllithium with tetraphenylphosphonium bromide in THF/ether medium. Studies in progress indicate that an *ortho*-metalation sequence similar to that postulated in this paper is operative[5].

The phosphine hydrobromide formed decomposed in aqueous solution, and the methyldiphenylphosphine which resulted was characterized by quaternization with methyl iodide.

<div align="center">EXPERIMENTAL</div>

General comments

All reactions were carried out under an atmosphere of prepurified nitrogen. Melting points are uncorrected. Benzene yields were calculated using quantitative gas chromatography with toluene as an internal standard. The columns used were Dow Corning 710 Silicone Fluid or SE-30 Grease on Chromosorb W, with helium as carrier gas. Normal operating conditions were: 80–100° jacket temperature, 10 p.s.i. helium, and 70° preheater temperature. NMR spectra were measured using a Varian Associates A60 NMR spectrometer. Chemical shifts are given in ppm downfield from tetramethylsilane. Analyses were performed by Dr. S. M. NAGY, M.I.T. Microchemical Laboratory, and by the Schwarzkopf Microanalytical Laboratory.

(1) Reaction of methyllithium with tert-butyltriphenylphosphonium bromide

To a suspension of 10 g (25 mmoles) of *tert*-butyltriphenylphosphonium bromide in 100 ml of THF in a three-necked flask (equipped with magnetic stirrer, reflux condenser topped with a nitrogen inlet tube, and a dropping funnel) was added 22.7 ml (25 mmoles) of 1.11 N methyllithium (from methyl bromide) in ether dropwise with vigorous stirring. The reaction mixture immediately became red, and became deeper in color as more and more of the lithium reagent was added. The phosphonium salt disappeared completely. After the mixture had been stirred for 1 h, Gilman[3] Color Test I was negative. Cyclohexanone (5.0 g, 50 mmoles) was added, causing the color to become lighter. The resulting mixture was stirred at room temperature for 1 h, then was heated at reflux overnight. Part of the solvent was removed using a Widmer column; the distillate was shown by gas chromatography to be free of benzene or methylenecycohexane. The remaining portion of the reaction mixture was distilled in high vacuum (pot temperature to 100°). The colorless distillate contained ether, THF, benzene and methylenecyclohexane. Quantitative gas chromatography (toluene as internal standard) established the benzene and methylenecyclohexane to have been formed in yields of 67.6% and 46% respectively. These products were identified by comparison of their infrared spectra and retention times with those of authentic samples.

The distillation residue was extracted with ether, and the extracts were treated with methyl iodide to quaternize any phosphines present. An oily mass deposited; attempts to obtain a crystalline solid failed. Further extraction of the residue with benzene gave 1.43 g of a yellow oil, while subsequent extraction with chloroform gave 3.15 g of yellow, resinous material. No attempts to obtain crystalline solid were successful.

Another reaction carried out in the same way on a 50 mmole scale resulted in benzene (66.4%) and methylenecyclohexane (42%) when all volatiles (at bath temperature of 100° *in vacuo*) were removed. The residue was extracted with ether. Evaporation of the extracts left an oil which was distilled (100–140°/0.1 mm) to give 5.2 g of colorless oil. The distillation residue was extracted with chloroform, leaving 1.06 g of water-soluble solid. The residue obtained by evaporating the chloroform

extracts was extracted with petroleum ether. Evaporation of the petroleum ether extracts le t a small amount of sticky solid. Treatment of the latter with methyl iodide in ether gave an oily precipitate which could not be crystallized. The residue from the petroleum ether extraction was dissolved in chloroform and chromatographed on neutral alumina. Elution with chloroform gave first crystalline solid, then a viscous oil. Recrystallization of the former from cyclohexane produced 1.20 g of *tert*-butyldiphenylphosphine oxide, m.p. 131°. Sublimation raised the m.p. to 132–133°. This material was identical (IR, mixed m.p.) with an authentic sample (see below).

The original pot residue, after being extracted with ether, was extracted with hot benzene. An oil was obtained when the benzene was removed. Chromatography on neutral alumina as above gave another 1.04 g of *tert*-butyldiphenylphosphine oxide (total isolated yield, 2.24 g, 17.4 %), and 7.74 g of yellow resinous solid was finally isolated from a chloroform extraction of the pot residue.

In another experiment (50 mmole scale) the nitrogen stream was passed through two traps containing solutions of bromine in chloroform. After the reaction was completed, excess bromine was destroyed by an aqueous $NaHSO_3$ wash. The chloroform solutions from the traps then were combined, concentrated and analyzed by gas chromatography (Dow Corning 710 Silicone Fluid on Chromosorb P, jacket temperature at 90°). It was determined that 1,2-dibromo-2-methylpropane was formed in 1.6 % yield. Its identity was confirmed by comparison of its retention time and infrared spectrum with those of an authentic sample.

(2) Reaction of ethyllithium with tert-butyltriphenylphosphonium bromide

(a) In ether. To 10 g (25 mmoles) of *tert*-butyltriphenylphosphonium bromide in 75 ml of ether was added 19.2 ml (25 mmoles) of 1.31 *N* ethereal ethyllithium. A deep red-brown solution resulted. Gilman Color Test I was negative after 10 min. The mixture was stirred at room temperature for 1 h and then 5 g of cyclohexanone was added. The reaction mixture was heated at reflux overnight. Analytical gas chromatography of the reaction mixture (toluene as internal standard) showed that benzene (23.6 %) and ethylidenecyclohexane (23.2 %) had been formed. (In another experiment, the yields were 27 % and 28 % respectively). Volatiles (to 100° *in vacuo*) then were removed in a bulb-to-bulb distillation. From the distillate were isolated by preparative gas chromatography samples of benzene and ethylidenecyclohexane, whose infrared spectra were identical with those of authentic samples. The distillation residue was extracted with ether. The ether extracts were saturated with methyl bromide. The tacky precipitate which resulted was extracted with benzene and dissolved in chloroform. Addition of ethyl acetate to the chloroform caused separation of an oil. This was dissolved in methanol and treated with methanolic sodium tetraphenylborate. The resulting white precipitate could not be identified.

Another similar experiment designed to detect any isobutylene formed (using bromine as above) showed that no β-elimination had occurred.

(b) In THF. The same procedure was used as in *(a)*, except that the phosphonium salt was suspended in 75 ml of THF. Benzene (32 %) and ethylidenecyclohexane (25 %) were formed. The distillation residue was worked up as in *(a)*, but no pure products could be identified.

(3) Reaction of lithium piperidide with tert-butyltriphenylphosphonium bromide

Lithium piperidide was prepared by the reaction of piperidine (2.34 g, 27.5 mmoles), which had been dried over solid KOH, distilled and stored over sodium, with 27.5 mmoles of 1.4 N ethereal methyllithium. After the mixture had been stirred for 3 h, the Gilman Color Test I was negative.

The lithium piperidide solution was added dropwise to a suspension of 10 g (25 mmoles) of *tert*-butyltriphenylphosphonium bromide in 75 ml of THF. A red color developed immediately, which, however, disappeared while the reaction mixture was heated for 36 h at reflux.

The nitrogen stream under which the reaction mixture was maintained was passed through two traps containing bromine in chloroform. Removal of excess bromine and gas chromatographic analysis of the chloroform solutions as in (1) showed that 1,2-dibromo-2-methylpropane (16 %) was present. A sample (n_D^{25} 1.5074; lit.[7] n_D^{25} 1.5070) was isolated by gas chromatography; its IR spectrum was identical with that of an authentic sample.

Distillation of all volatile components of the reaction mixture was followed by extraction of the residue with ether. This left 0.33 g (3.3 %) of starting phosphonium salt. Evaporation of the ether extracts left a residue which crystallized on being triturated with methanol to give 3.87 g of solid. The latter was extracted with six 200 ml portions of warm 6N HCl. The acid extracts were poured into water. The solid which formed was extracted with ether. The residue obtained on evaporation of the ether extracts was recrystallized to give 0.54 g (8.4 %) of triphenylphosphine, m.p. and mixed m.p. 79–80°.

The residue from the acid extraction was washed with water and dried to give white crystals (2.66 g), m.p. 91–92°. Recrystallization from methanol raised the m.p. to 92–93°. This product was identified as 9-phenyl-9-phosphafluorene (lit.[4] m.p. 93–94°). Its infrared spectrum was identical with that published previously[4], and it could be converted to the known 9-phenyl-9-oxo-9-phosphafluorene using the procedure of ref. 4. The product obtained had m.p. 166–166.5° (from cyclohexane); lit.[4] m.p. 163.5–166.5°. (Found: C, 78.33; H, 4.71. $C_{18}H_{13}OP$ calcd.: C, 78.19; H, 4.74 %.)

Another 0.11 g of 9-phenyl-9-phosphafluorene was obtained by workup of mother liquors. Total yield 2.77 g (42.4 %).

(4) Preparation of phosphonium salts

(a) *tert-Butyltriphenylphosphonium bromide*. (i) *Via quaternization of triphenylphosphine*. A solution of 26.2 g (0.1 mole) of triphenylphosphine and 20.5 g (0.15 mole) of *tert*-butyl bromide (isomerically pure by gas chromatography) in 15 ml of 98–100 % formic acid was heated in a sealed, heavy-walled Pyrex tube at ca. 100° for 15 h. All volatile material then was removed *in vacuo*. Gas chromatographic analysis of the recovered *tert*-butyl bromide showed that no isomerization had occurred. The residue was taken up in water, and the water extracts were shaken with benzene. The aqueous phase was saturated with KBr and extracted with chloroform. To the dried, boiling chloroform solution was added ethyl acetate slowly until solid began to form. The precipitate obtained on cooling was recrystallized from chloroform–ethyl acetate to give 28.05 g (70.3 %) of product, m.p. 237–238°(dec.). Two

further recrystallizations raised the m.p. to 239–240°(dec.). (Found: C, 66.39; H, 6.17; Br, 19.94. $C_{22}H_{24}BrP$ calcd.: C, 66.17; H, 6.06; Br, 20.01 %.)

NMR spectrum (saturated solution in $CDCl_3$): doublet ($J = 17.2$ cps) at 1.68 ppm [$C(CH_3)_3$ protons split by ^{31}P]; phenyl absorption at 7.5–7.92 ppm.

Derivative: $[(C_6H_5)_3PC(CH_3)_3][B(C_6H_5)_4]$, m.p. 219° (from nitromethane–methanol). (Found: C, 86.49; H, 6.97. $C_{46}H_{44}BP$ calcd.: C, 86.51; H, 6.94%.)

(ii) *Via the ylid route.* The ylid from 9.41 g (24.5 mmoles) of isopropyltriphenylphosphonium bromide and 24.5 mmoles of ethereal methyllithium was quenched with an excess of methyl bromide in 75 ml of ether. The solution was decolorized immediately. The resulting precipitate was recrystallized from methanol-ethyl acetate to give 8.75 g (90%), m.p. 233–234°(dec.). A small sample was recrystallized from water–KBr and dried *in vacuo* over P_2O_5 to give material of m.p. 241°(dec.).

(b) *tert-Butylmethyldiphenylphosphonium bromide.* Diphenylchlorophosphine (22 g, 0.1 mole) in 100 ml of pentane was treated with 43 ml (0.1 mole) of $2.27N$ tert-butyllithium in pentane (Lithium Corp. of America). Fifty ml of ether was added, and the mixture was stirred for 30 min. It then was filtered, and the filtrate was saturated with methyl bromide. The precipitate which had formed overnight was recrystallized from chloroform–ethyl acetate to give pure material, m.p. 207–208°. (Found: C, 60.26; H, 6.50. $C_{17}H_{22}BrP$ calcd.: C, 60.54; H, 6.58%.)

Derivative: $[(C_6H_5)_2(CH_3)PC(CH_3)_3][B(C_6H_5)_4]$, m.p. 169–170° (from methanol). (Found: C, 85.56; H, 7.34. $C_{41}H_{44}BP$ calcd.: C, 85.41; H, 7.34%.) The NMR spectrum in pyridine solution of this salt showed the expected two doublets with area ratio 1:3, with $J = 12.4$ and 17.2 cps respectively.

(c) *Attempted quaternization of methyldiphenylphosphine with tert-butyl bromide.* Ca. 30 mmoles of methyldiphenylphosphine[8] diluted with a small amount of ether was treated at reflux for 38 h under nitrogen with 14 g (0.1 mole) of tert-butyl bromide. The solid which resulted was recrystallized from chloroform–ethyl acetate: 3.31 g, m.p. 200–206°. The aqueous solution of this solid was highly acidic. Chromatography on alumina (chloroform) gave a colorless, malodorous liquid which was soluble in ethyl acetate.

One g of this solid was dissolved in 10 ml of water, and the aqueous solution was stirred overnight under nitrogen with 50 ml of ether. The dried ether layer was treated with an excess of methyl iodide. The precipitated solid was recrystallized from chloroform–ethyl acetate to give dimethyldiphenylphosphonium iodide, m.p. 250–251°. A mixture m.p. with authentic material[8] was not depressed.

Methyldiphenylphosphine dehydrobrominated tert-butyl bromide also in formic acid solution.

(5) *Preparation of tert-butyldiphenylphosphine oxide*

A solution of tert-butyltriphenylphosphonium bromide (5 g, 12.5 mmoles) and 1 g (25 mmoles) of NaOH in 70 ml of water was heated at reflux for 24 h under nitrogen. The aqueous phase was saturated with NaCl and extracted with ether. Gas chromatography established the presence of benzene (79% yield). Evaporation of the ether solution left white crystals, m.p. 127–128°. The aqueous layer then was extracted with chloroform. The chloroform extracts were evaporated and the residue was extracted with benzene. Evaporation of the benzene solution gave more solid of m.p. 127–128°. Total yield: 3.18 g (98%). Recrystallization from cyclohexane and subli-

mation raised the m.p. to 132–133°. (Found: C, 74.53; H, 7.59. $C_{16}H_{19}OP$ calcd.: C, 74.40; H, 7.41%.) NMR spectrum (CCl_4 solution): doublet ($J = 14.0$ c.p.s.) at 1.16 ppm; phenyl absorption at 7.18–7.33 and 7.61–7.95 ppm.

SUMMARY

Methyllithium attacks tert-butyltriphenylphosphonium bromide principally at the phosphorus atom, giving benzene (68%) and tert-butyldiphenylphosphinemethylene (46% as methylenecyclohexane after its reaction with cyclohexanone). Ethyllithium shows reaction in this sense to a lesser degree, giving benzene and tert-butyldiphenyl-phosphineethylidene in yields of 30% and 25% respectively. With lithium piperidide formation of 9-phenyl-9-phosphafluorene in 42.4% yield was found; some 16% β-elimination also was observed in this reaction. Thus in the RLi + $[(C_6H_5)_3PC(CH_3)_3]Br$ reactions electronic factors appear to be more important than steric factors.

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