BRIEF COMMUNICATIONS

SYNTHESIS OF ASYMMETRIC SECONDARY PHOSPHINES BY THE CROSS COUPLING OF ARYL HALIDES WITH SILYLPHOSPHINES

I. P. Beletskaya, Yu. A. Veits, V. A. Leksunkin, and V. L. Foss

UDC 547.241

The cross coupling of aryl halides with alkyl(trimethylsilyl)phosphines catalyzed by zero-valent palladium complexes yields secondary alkylarylphosphoranes containing both electron-donor and electron-withdrawing substituents in the aromatic ring. The reversible disproportionation of alkylsilylphosphines to give $AlkPH_2$ and $AlkP(SiMe_3)_2$ was observed for the first time during this reaction. This disproportionation does not affect the yield of AlkArPH, which are formed in virtually quantitative yield, due to the high rate of cross coupling with $AlkP(SiMe_3)H_2$ and the reversibility of the disproportionation process.

Keywords: *alkyl(trimethyl)phosphines, cross coupling, catalysis, palladium, alkyarylphosphines.*

The synthetic use of secondary phosphines is extremely varied [1]. However, there are only a limited number of such compounds containing functional groups, while compounds containing a function in the aromatic moiety are virtually unknown. This latter circumstance arises since most functional groups are sensitive to the action of complex hydrides as well as organomagnesium and organolithium compounds, which are reagents usually employed in the synthesis of secondary phosphines [1, 2]. Tunney and Stille [3] have shown that aromatic tertiary phosphines containing functional groups can be obtained by a method permitting the retention of these groups, namely, the cross coupling of substituted aryl bromides or iodides with diphenyl(trimethylsilyl)phosphine catalyzed by palladium complexes.

In order to obtain secondary phosphines $R(AC_6H_4)PH$ (**1**), we carried out the reaction of aryl halides containing both electron-donor and electron-withdrawing substituents with isopropyl(trimethylsilyl)phosphine (**2a**) and *tert*-butyl(trimethylsilyl)phosphines (**2a, b**) upon catalysis by $PdCl_2(MeCN)_2$ or $PdCl_2(Ph_3P)_2$:

$$\underset{(2a,b)}{RP(SiMe_3)H} + \underset{(3)}{AC_6H_4X} \xrightarrow{1-2\ \%\ \ll Pd(0)\gg,\ 20-100^\circ,\ 2-48\text{ч}} \mathbf{1} \qquad (1)$$

R=*i*-Pr(a), *t*-Bu(b); A=H, Me, Cl, Br, OMe, COOMe, CN.

Silylphosphines **2** are more reactive than diphenyl(trimethylsilyl)phosphine, which permitted us to decrease the amount of catalyst used to 1-2 mole %, i.e., as a rule, to half the amounts used by Tunney and Stille [3]. The aryl halide and silylphosphine in reaction (1) were taken in 1:1.04 ratio. The reduction of the palladium salt to zero-valent palladium by silylphosphines **2** is complete immediately after mixing the reagents. The cross coupling may be monitored conveniently by the change in the ^{31}P NMR spectra. The yields of phosphines **1** according to the NMR spectral data are close to quantitative in most cases. If aryl iodides are used in reaction (1), complications may arise in the isolation of phosphines **1** related to the similar boiling points of the starting reagents and products **1**. Thus, aromatic bromine derivatives should be used in reaction (1) rather than iodine derivatives. The unavoidable drop in rate in this case is readily compensated by heating since reaction (1) is very sensitive to a rise in temperature. Thus, the formation of isopropylphenylphosphine from iodobenzene at 75°C is complete after 50 h, but the same phosphine is quantitatively formed after 5 h at 95-100°C even from bromobenzene. In both cases, the cross coupling is not complete at 20°C even after 100 h.

The lower rate of the reaction with **2c** than in the reaction with **2a** is less pronounced at ~100°C. The arrangement of the halogen atom and functional group in arenes **3** significantly affects the rate of reaction (1). Thus, the conversion of isomeric bromobenzonitriles with silylphosphine **2c** in reaction (1) using 2 mole % catalyst after 3 h at 70°C is 70% for the *para* isomer, 50% for the *meta* isomer, but only 30% for the *ortho* isomer. The reactions with *para* and *meta* isomers at this temperature

M. V. Lomonosov Moscow State University, 119899 Moscow. Translated from Izvestiya Akademii Nauk, Seriya Khimicheskaya, No. 7, pp. 1645-1648, July, 1992. Original article submitted May 29, 1991.

1063-5211/92/4107-1272$12.50

is virtually complete after heating the reaction mixtures for 7 h, while the conversion is only about 50% for *o*-bromobenzonitrile after 7 h and this reaction is complete only after 30 h at 100°C.

In a more detailed study of reaction (1), we observed the previously unknown reversible disproportionation of silylphosphines **2**, which occurs much more rapidly than reaction (1):

$$\mathbf{2a, b} \underset{}{\overset{\ll Pd(0) \gg,\ ArX}{\rightleftharpoons}} \underset{\textbf{(4a, b)}}{RP(SiMe_3)_2} + \underset{\textbf{(5a, b)}}{RPH_2}. \qquad (2)$$

Special experiments showed that, in the absence of aryl halide, this reaction does not proceed by the action of the Pd(0) complexes even over 20 h at 100°C. The presence of at least 10-15% aryl halide is required to enable the onset of disproportionation (2). The rate of the disproportionation of **2a** is rather high and equilibrium is achieved after 5 min at about 100°C. The equilibrium ratio of components **4a**:**2a**:**5a** is close to 1:3:1. Virtually the same ratio is achieved after 15 min at 100°C from equimolar mixtures of **4a** and **5a**, i.e., upon approaching equilibrium (2) from the other side. The component ratio gradually shifts to 1:6:1 upon cooling to 20°C, while reheating again shifts equilibrium (2) toward the right. Similar data were obtained for the disproportionation of silylphosphine **2b** although it proceeds somewhat more slowly and leads to a lower fraction of disilylphosphine **4b**, apparently, due to steric hindrance. We should note that the catalyst activity decreases upon standing and, especially, upon warming. Thus, the equilibrium data are not reproducible upon repeated heating. The decrease in catalyst activity reduces the rate of cross coupling (1) to a lesser extent than the rate of disproportionation (2). The "aging" of the catalyst may be related partially to the circumstance that cross coupling (1), which proceeds in parallel, leads to the formation of new ligands, namely, phosphines **1**, which alter the properties of the catalyst.

Since reaction (2) is an equilibrium process, it may have virtually no effect on the yield and purity of **1** if we do not exceed the optimal temperatures, above which disilylphosphine **4a** enters the cross coupling, leading to the formation of side products, initially *i*-Pr(Ar)$PSiMe_3$ (**6**) and then *i*-$PrPAr_2$ (**7**). The cross coupling rates are much lower for more hindered **4b** than for monosilylated phosphine **2b** and reaction (1) may go to completion with the quantitative formation of **1** although all the components of equilibrium (2) are observed at low temperatures at medium conversions in the ^{31}P NMR spectrum.

The reaction rates differ strongly in the cross coupling of silylphosphines **2** with halopyridines depending on the nature and position of the halogen. The reaction for β-bromopyridine is complete after 20 h only at 100°C. On the other hand, α-bromopyridine may undergo complete conversion at 20°C over 14 days. The secondary phosphine obtained may be contaminated with the starting bromopyridine and an analytically pure sample is best obtained from α-chloropyridine, which may be readily separated by distillation, although it reacts significantly slowly; the completion of the reaction with silylphosphine **2b** requires 40 h at 100°C.

Phosphine products **1** are liquids, which are readily distilled in vacuum, rather stable upon storage and heating even in the presence of functional groups such as CO_2Me and C≡N. We should note that secondary phosphines **1** are incapable of undergoing cross coupling with aryl halides under the reaction conditions employed and the formation of tertiary phosphines **7** during reaction (1) occurred only through the formation of disilylphosphines **4**.

EXPERIMENTAL

The ^{31}P NMR spectra were taken on a Varian FT-80A spectrometer at 32.2 MHz using 85% H_3PO_4 as the external standard. All the operations were carried out in thoroughly dried solvents in a dry argon atmosphere.

***tert*-Butyl(3-methoxycarbonylphenyl)phosphine.** A sample of 5.0 g (30.9 mmoles) *tert*-butyl(trimethylsilyl)phosphine, 216 mg (1 mole %) $PdCl_2(Ph_3P)_2$, and 6.5 g (30.2 mmoles) methyl 3-bromobenzoate were placed into an argon-filled ampule. The ampule was sealed. After several minutes, the mixture became homogeneous and turned red-brown. The ampule was maintained at constant 75°C for 16 h and the volatile components were then removed at 15 mm Hg and 60°C. The residue was distilled to give 4.75 g (71%) *tert*-butyl(3-methoxycarbonylphenyl)phosphine as a light brown, viscous liquid with bp 86-87°C (0.01 mm Hg). ^{31}P NMR spectrum (δ, ppm): −4.73 ($^1J_{PH}$ = 207.7 Hz). Found: C, 64.20; H, 7.70; P, 13.80%. Calculated for $C_{12}H_{17}O_2P$: C, 64.27; H, 7.64; P, 13.81%.

Alkylphenylphosphines. Analogously, heating a mixture of 2.18 g (13.5 mmoles) *tert*-butyl(trimethylsilyl)phosphine, 2.1 g (13.2 mmoles) bromobenzene, and 94 mg (1 mole %) $PdCl_2(PH_3P)_2$ for 16 h at 90°C gave 1.93 g (88%) *tert*-butyl(phenyl)phosphine with bp 115-118°C (3 mm). ^{31}P NMR spectrum (δ, ppm): −5 ($^1J_{PH}$ = 215 Hz). Lit. data [4]: (bp 40-41°C (0,05 mm), δ_P = −5.7, ($^1J_{PH}$ = 200 Hz [4]). Isopropyl(phenyl)phosphine [5] was obtained analogously in 74% yield, bp 105-107°C (2 mm), δ_P = −26.5, ($^1J_{PH}$ = 218 Hz).

REFERENCES

1. Houben-Weyl, *Methoden der Organischen Chemie*, Vol. E1, Stuttgart--New York (1982), p. 106.
2. G. M. Kosolapoff, *Organic Phosphorus Compounds*, Vol. 1, Wiley—Interscience, New York (1972), p. 17.
3. S. E. Tunney and J. K. Stille, *J. Org. Chem.*, **52**, 748 (1987).
4. S. O. Grim, A. W. Yankawsky, S. A. Bruno, W. J. Bailey, E. F. Davidoff, and T. J. Marks, *J. Chem. Eng. Data*, **15**, 497 (1970).
5. W. Wolfsberger, *Chim. Z.*, **112**, No. 12, 379 (1988).