Nucleophilic addition of phosphine to 4-chlorostyrenes in the KOH—DMSO system*

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In the superbasic system KOH—DMSO (H_2O) at 60—75 °C (2—2.5 h, atmospheric pressure), 4-chlorostyrene and 4-chloro-α-methylstyrene add phosphine at the double bond to form 1 : 1 and 2 : 1 anti-Markovnikov adducts in 10—18% and 58—67% yields, respectively.

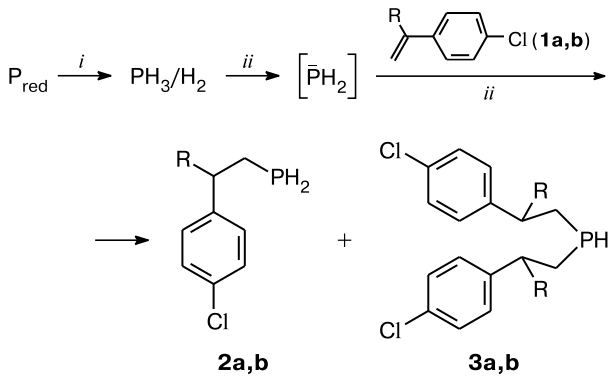
Key words: 4-chlorostyrenes, phosphine, superbasic medium, nucleophilic addition, alkylphosphines, hydrophosphination.

At the present time, elemental phosphorus[1—3] (or phosphine generated from it[3—5]) is frequently used in the reactions of direct phosphorylation of organic compounds for the formation of a P—C bond and preparation of earlier unknown or unavailable organophosphorus compounds. Successful accomplishment of such processes became possible upon the use of special superbasic reagents-activators,[1,2,6—8] as well as electrochemical methods.[3] This chlorine-free methodology of the formation of a P—C bond favorably differs from conventional methods for the synthesis of organophosphorus compounds from phosphorus chlorides, which are accompanied by the formation of considerable amounts of difficult to dispose chlorine-containing waste.

Earlier, we have reported that red phosphorus, as well as phosphine generated from it, react with styrene,[9—11] 4-*tert*-butylstyrene,[12,13] and 4-methoxystyrene[14,15] in the system KOH—DMSO with the formation of organic phosphines or phosphine oxides. Organic halides can be also involved in the reaction with red phosphorus and phosphine in the presence of strong bases. For example, in the systems alkali metal—liquid ammonia, halobenzenes react with red phosphorus, giving rise to triphenylphosphine.[7] Recently, a direct formation of the P—C_{sp^2} bond from red phosphorus (or phosphine) was demonstrated by phosphorylation of 1-bromonaphthalene[16] and 2-bromopyridine[17,18] in the presence of KOH—DMSO.

The purpose of the present work is to study the reaction of 4-chlorostyrene (**1a**) and 4-chloro-α-methylstyrene (**1b**) with phosphine in the superbasic system KOH—DMSO, determine its chemo- and regioselectivity, and synthesize new organophosphorus compounds (Scheme 1). Our experiments showed that phosphine reacts with styrenes **1a**,**b** according to the scheme of nucleophilic addition to the double bond, forming corresponding anti-Markovnikov adducts: primary (**2a**,**b**) and secondary (**3a**,**b**) phosphines. Upon slow addition of chlorostyrenes **1a**,**b** to a suspension of KOH—DMSO (H_2O) heated to 60—75 °C and simultaneous energetic bubbling of phosphine (generated together with hydrogen from red phosphorus and KOH in the water—toluene medium[13]), the yields of secondary **3a**,**b** and primary phosphines **2a**,**b** were 58—67% and 10—18%, respectively. No formation of possible products of nucleophilic substitution for chlorine with phosphide-anions was observed.

Scheme 1



R = H (**a**), Me (**b**)

Reagents and conditions: *i*. KOH, H_2O/toluene, 80 °C; *ii*. KOH—DMSO (H_2O), 60—75 °C, 2—2.5 h.

In conclusion, we for the first time have accomplished phosphorylation of chlorostyrenes with phosphine in the

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superbasic system KOH—DMSO (H_2O), which chemo- and regioselectively led to the formation of anti-Markovnikov adducts. The primary and secondary phosphines synthesized can be further successfully used in organophosphorus synthesis and as ligands for design of catalytically active metal complexes.[19]

Experimental

^1H, ^{13}C and ^{31}P NMR spectra were recorded on a Bruker DPX-400 spectrometer (400.13, 101.61 and 161.98 MHz, respectively), using HMDS as an internal standard and 85% aqueous H_3PO_4 (^{31}P NMR) as an external standard. 4-Chlorostyrene and 4-chloro-α-methylstyrene are commercial products (Aldrich). All the experimental steps were carried out under argon. A phosphine-hydrogen mixture was obtained according to the method described earlier.[13]

Hydrophosphination of 4-chlorostyrene. A solution of 4-chlorostyrene (15.0 g, 108 mmol) in DMSO (10 mL) was added dropwise over 2.5 h to a suspension of $KOH \cdot 0.5H_2O$ (20.0 g, 308 mmol), DMSO (50 mL), and H_2O (12.0 mL) heated to 60 °C and saturated with a phosphine-hydrogen mixture with continuous bubbling of phosphine. Then, the mixture was cooled, diluted with water (100 mL), and extracted with diethyl ether (30×3 mL). The extract was washed with water (40×2 mL) and dried with K_2CO_3, the solvent was evaporated, the residue was fractionally distilled *in vacuo*.

2-(4-Chlorophenyl)ethylphosphine (2a). The yield was 1.85 g (10%), colorless liquid, b.p. 81—82 °C (1 Torr). ^1H NMR ($CDCl_3$), δ: 1.70—1.79 (m, 2 H, CH_2P); 2.65 (dt, 2 H, PH, $^1J_{P,H}$ = 195.0 Hz); 2.73—2.78 (m, 2 H, $CH_2C_6H_4$); 7.06 (d, 2 H, C_6H_4, $^3J_{H,H}$ = 8.3 Hz); 7.22 (d, 2 H, C_6H_4, $^3J_{H,H}$ = 8.3 Hz). ^{13}C NMR ($CDCl_3$), δ: 15.6 (d, $CH_2C_6H_4$, $^2J_{P,C}$ = 9.5 Hz); 38.2 (d, CH_2P, $^1J_{P,C}$ = 2.5 Hz); 128.4 and 129.5 (*o*,*m*-$C_{C_6H_4}$); 131.8 (*p*-$C_{C_6H_4}$); 140.2 (d, *ipso*-$C_{C_6H_4}$, $^3J_{P,C}$ = 4.4 Hz). ^{31}P NMR ($CDCl_3$), δ: −137.85 (t, $^1J_{P,H}$ = 195.0 Hz). Found (%): C, 55.51; H, 6.01; P, 17.83. $C_8H_{10}ClP$. Calculated (%): C, 55.67; H, 5.84; P, 17.95.

Bis[2-(4-chlorophenyl)ethyl]phosphine (3a). The yield was 11.3 g (67%), colorless liquid, b.p. 208—210 °C (1 Torr), rapidly crystallizes to colorless needles (m.p. 40—42 °C). ^1H NMR ($CDCl_3$), δ: 1.81—1.96 (m, 4 H, CH_2P); 2.73—2.81 (m, 4 H, $CH_2C_6H_4$); 3.16 (d, 1 H, PH, $^1J_{P,H}$ = 199.4 Hz); 7.13 (d, 4 H, C_6H_4, $^3J_{H,H}$ = 8.4 Hz); 7.28 (d, 4 H, C_6H_4, $^3J_{H,H}$ = 8.4 Hz). ^{13}C NMR ($CDCl_3$), δ: 22.2 (d, $CH_2C_6H_4$, $^2J_{P,C}$ = 11.4 Hz); 33.9 (d, CH_2P, $^1J_{P,C}$ = 10.9 Hz); 128.6 and 129.5 (*o*,*m*-$C_{C_6H_4}$); 131.9 (*p*-$C_{C_6H_4}$); 140.7 (d, *ipso*-$C_{C_6H_4}$, $^3J_{P,C}$ = 8.4 Hz). ^{31}P NMR ($CDCl_3$), δ: −70.45 (d, $^1J_{P,H}$ = 199.4 Hz). Found (%): C, 61.63; H, 5.46; P, 9.78. $C_{16}H_{17}Cl_2P$. Calculated (%): C, 61.75; H, 5.51; P, 9.95.

Hydrophosphination of 4-chloro-α-methylstyrene. A solution of 4-chloro-α-methylstyrene (7.0 g, 46 mmol) in DMSO (10 mL) was added dropwise over 2 h to a suspension of $KOH \cdot 0.5H_2O$ (20.0 g, 308 mmol), DMSO (50 mL), and H_2O (3.0 mL) heated to 70—75 °C and saturated with a phosphine-hydrogen mixture with continuous bubbling of phosphine. The reaction mixture was cooled, diluted with water (100 mL), and extracted with diethyl ether (30×3 mL). The extract was washed with water (40×2 mL) and dried with K_2CO_3, the solvent was evaporated, the residue was fractionally distilled *in vacuo*.

2-(4-Chlorophenyl)propylphosphine (2b). The yield was 1.5 g (18%), colorless liquid, b.p. 109—111 °C (3 Torr). ^1H NMR ($CDCl_3$), δ: 1.36 (d, 3 H, Me, $^3J_{H,H}$ = 7.0 Hz); 1.85 (br.s, 2 H, CH_2P); 2.34 (br.s, 1 H, PH); 2.77—2.87 (m, 2 H, CHC_6H_4, PH); 7.14—7.33 (m, 4 H, C_6H_4). ^{13}C NMR ($CDCl_3$), δ: 22.6 (d, CHC_6H_4, $^2J_{P,C}$ = 10.1 Hz); 22.9 (d, Me, $^3J_{P,C}$ = 4.9 Hz); 41.7 (d, CH_2P, $^1J_{P,C}$ = 3.6 Hz); 128.2 and 128.5 (*o*,*m*-$C_{C_6H_4}$); 131.9 (*p*-$C_{C_6H_4}$); 145.0 (d, *ipso*-$C_{C_6H_4}$, $^3J_{P,C}$ = 3.1 Hz). ^{31}P NMR ($CDCl_3$), δ: −146.48 (t, $^1J_{P,H}$ = 195.4 Hz). Found (%): C, 57.87; H, 6.40; P, 16.86. $C_9H_{12}ClP$. Calculated (%): C, 57.92; H, 6.48; P, 16.70.

Bis[2-(4-chlorophenyl)propyl]phosphine (3b). The yield was 4.5 g (58%), colorless liquid, b.p. 235—238 °C (3 Torr). ^1H NMR ($CDCl_3$), δ: 1.31 (dd, 6 H, Me, $^3J_{H,H}$ = 6.9 Hz, $^3J_{P,H}$ = 2.5 Hz); 1.79 (br.s, 4 H, CH_2P); 2.79—2.90 (m, 2 H, CHC_6H_4); 7.11—7.31 (m, 8 H, C_6H_4). ^{13}C NMR ($CDCl_3$), δ: 23.2 (dd, Me, $^3J_{P,C}$ = 6.9 Hz); 30.0 (d, CHC_6H_4, $^2J_{P,C}$ = 11.6 Hz); 38.5 (d, CH_2P, $^1J_{P,C}$ = 10.8 Hz); 128.1 and 128.5 (*o*,*m*-$C_{C_6H_4}$); 131.8 (*p*-$C_{C_6H_4}$); 145.5 (d, *ipso*-$C_{C_6H_4}$, $^3J_{P,C}$ = 4.6 Hz). ^{31}P NMR ($CDCl_3$), δ: −82.44, −82.29, −81.59 (all td, $^1J_{P,H}$ = 198.1, 198.9, 199.7 Hz), the ratio intensities 1.4 : 1.9 : 1, respectively. Found (%): C, 63.65; H, 6.21; P, 9.40. $C_{18}H_{21}Cl_2P$. Calculated (%): C, 63.73; H, 6.24; P, 9.13.

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