SHORT PAPER

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Nickel and palladium catalysed reaction of triethyl phosphite with aryl halides under microwave irradiation[†]

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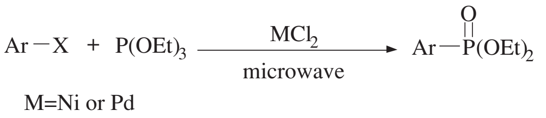
Diethyl aryl phosphonates are efficiently and rapidly obtained from halides and triethyl phosphite without solvent. The reaction was catalysed by $NiCl_2$ or $PdCl_2$ (10%) under focussed microwave radiation .

Keywords: phosphonates, microwave, palladium, nickel

The reaction of triethyl phosphite with aryl halides catalysed by nickel (0) complexes has been described previously by Tavs.[1] This reaction is one of the more convenient synthesis of aryl phosphonates[2] although it involves rather extreme conditions (200°C, 6h). Microwave dielectric heating effects are increasingly used in organic synthesis.[3] Microwave irradiation and the use of a resonance cavity was recently employed to activate catalysis by transition metal complexes in organic synthesis,[4] and in phosphorous chemistry.[5] The improvement[5a] of Hirao's reaction,[6] prompted us to re-investigate Tav's reaction under microwave irradiation. The results of this study are presented below.



$$Ar-X + P(OEt)_3 \xrightarrow[\text{microwave}]{MCl_2} Ar-\overset{O}{\overset{\|}{P}}(OEt)_2$$

M=Ni or Pd

Scheme 1

The reaction of triethyl phosphite with aryl halides catalysed by a nickel (0) complex $[Ni\{P(OEt)_3\}_{24}]$, which is very air-sensitive. However, it is possible to form such a nickel complex starting from nickel (II) chloride which is inexpensive and not air-sensitive. Our reactions were carried out under argon in commercially available Ace pressure tubes (supplied with a safety valve) with a maximum pressure of 2 bars. Irradiation was done with a Prolabo Synthewave 402 cavity at 2.45 GHz. Similar results were obtained with the Discover® cavity of CEM. The reaction conditions (100–150 W, 5–8 min) and yields of the various products obtained are reported in Table 1. Hydrated nickel chloride ($NiCl_2$, 6 H_2O) can be used instead of dry nickel chloride with similar results. Different metallic salts were tested (Ni, Pd, Co, Fe, Cu) but only nickel and palladium salts were efficient as catalyst precursors. Nickel chloride requires higher power microwave irradiation than palladium chloride.

With iodoaryls, nickel chloride gave similar results to those obtained with palladium chloride (Table 1, entries 1, 2, 8, 9). In the case of slow reactions [with bromoaryls (Table 1, entries 3, 4, 10–13) or with a hindered group in the ortho position (Table 1, entries 8 and 9)], palladium led to higher yields than nickel chloride. In all cases palladium (0) or nickel (0) catalysts were formed[7] and resulted from the reduction of palladium (II) or nickel (II) by triethyl phosphite while heating according to Scheme 2. The colour of the reaction mixture changes to yellow [solution of $[M\{P(Oet)_3\}_4]$, M= Ni, Pd]. Reduction of the palladium salt proceeds at lower temperature (80°C) than that of the nickel salt (120°C).

$$MCl_2 + 5\,P(OEt)_3 \xrightarrow{\text{microwave}} (P(OEt)_3)_4\,M + ClPO(OEt)_2 + EtCl$$

M= Pd or Ni

Scheme 2

Table 1 Reaction of triethyl phosphite with aryl halides (in presence of $NiCl_2$ or $PdCl_2$) under microwave irradiation

Entry	Substrate	Product	Metal	Conditions	Yield/%
1	C_6H_5I	$C_6H_5PO(OEt)_2$	Ni	5 min, 100 W	98
2	C_6H_5I	$C_6H_5PO(OEt)_2$	Pd	5 min, 100 W	97
3	C_6H_5Br	$C_6H_5PO(OEt)_2$	Ni	5 min, 100 W	82
4	C_6H_5Br	$C_6H_5PO(OEt)_2$	Pd	5 min, 100 W	90
5	*p*-$CH_3C_6H_4I$	*p*-$CH_3C_6H_4PO(OEt)_2$	Ni	5 min, 130 W	85
6	*p*-$CH_3OC_6H_4I$	*p*-$CH_3OC_6H_4PO(OEt)_2$	Ni	8 min, 100 W	75
7	*m*-$CH_3OOCC_6H_4I$	*m*-$CH_3OOCC_6H_4PO(OEt)_2$	Pd	5 min, 100 W	86
8	*o*-$CH_3OOCC_6H_4I$	*o*-$CH_3OOCC_6H_4PO(OEt)_2$	Ni	5 min, 100 W	67
9	*o*-$CH_3OOCC_6H_4I$	*o*-$CH_3OOCC_6H_4PO(OEt)_2$	Pd	5 min, 100 W	86
10	α-Br $C_{10}H_7$	α-$C_{10}H_7PO(OEt)_2$	Ni	5 min, 100 W	60
11	α-Br $C_{10}H_7$	α-$C_{10}H_7PO(OEt)_2$	Pd	5 min, 100 W	80
12	*p*-BrC_6H_4CHO	*p*-$HOCC_6H_4PO(OEt)_2$	Ni	5 min, 100 W	62
13	*p*-BrC_6H_4CHO	*p*-$HOCC_6H_4PO(OEt)_2$	Pd	5 min, 100 W	86

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[†] This is a Short Paper, there is therefore no corresponding material in *J Chem. Research (M)*.

After irradiation, the temperature reached was generally about 200°C. It is important to note that this method requires a simple work up and that reaction times can be very short. In spite of the high reaction temperatures (about 200°C), the products were always obtained in a good yield and unsatisfactory purity. In very rare cases, deterioration of the products was observed; however we believe that attentively surveying the temperature evolution in the course of reaction should be sufficient to solve this problem. Contrary to Hirao's reaction this reaction proceeds under neutral conditions. With the Hirao reaction,[6] the phosphonation of halogenobenzaldehyde without protection of the aldehyde group was not possible; in our case the phosphonation of 4-bromobenzaldehyde was possible in the presence of nickel or palladium catalysts (Table 1, entries 12 and 13).

Tav's reaction catalysed by palladium was not previously reported. Under classical heating conditions yields obtained were quite similar but the reaction took longer (ex: N° 4, heating 140 °C, 3 h, yield 89%). There is no experimental evidence of a nonthermal microwave effect[8] in this reaction.

In conclusion, although yields under classical conditions and under microwave irradiation are often comparable, irradiation dramatically increases the reaction rates. The work-up is very simple and the procedure very convenient (use of $NiCl_2$ or $PdCl_2$). Phosphonation can be carried out under neutral conditions and palladium catalysis occurs under milder conditions than nickel catalysis.

Experimental

Focussed microwave irradiation was done with a Prolabo[9] Synthewave 402 or Discover® cavity of CEM[9] at 2450 MHz.

Typical procedure: To dry nickel chloride (0.3 mmol) or palladium chloride (0.3 mmol), placed in an Ace pressure tube under an argon atmosphere, the aryl halide (3 mmol) and triethyl phosphite (3.1 mmol) were added under an argon flow. The tube was closed and irradiated in a Prolabo Synthewave 402 at 2450 MHz. After cooling to room temperature, 20 ml of diethyl ether was added and the salts were removed by filtration. The solvent was removed and the residue was purified by distillation with Kugelrohr or by column chromatography on silica gel (dichloromethane / ethanol: 98/2). Satisfactory elemental analytical data and spectroscopic data (^1H, ^{31}P and ^{13}C NMR, MS) have been obtained for all compounds described in this paper.

Diethyl phenylphosphonate, diethyl 4-methylphenylphosphonate, diethyl (3-methoxycarbonyl) phenylphosphonate, diethyl 1-naphtylphosphonate were described in the literature.[5,6]

2(Diethoxy-phosphoryl)benzoic acid methyl ester: Oil, B.p.: 145°C/0.4 mm Hg; $C_{12}H_{17}O_5P$; 1H NMR: 1.28 (t; 6H; $^3J_{H-H}$= 7.6 Hz; CH_3); 3.92 (s; 3H; CH_3 (OCH_3)); 4.12 (dq; 4H; $^3J_{H-H}$= 7.6 Hz; $^3J_{H-P}$= 9.6 Hz; CH_2); 7.56 (m; 2H; CHar); 7.69 (m; 1H; CHar); 7.99 (m; 1H; CHar). ^{31}P NMR: 17.07 ^{13}C NMR: 16.03 (d; $^3J_{C-P}$= 6.3 Hz; CH_3); 51.28 (s; CH_3 (OCH_3)); 61.89 (d; $^2J_{C-P}$= 7,3 Hz; CH_2); 127.67 (d; $^3J_{C-P}$= 16.2 Hz; C_3); 128.12 (d; $^4J_{C-P}$= 1.9 Hz; C_4); 129.17 (d; $^1J_{C-P}$= 217.3 Hz; C_1); 130.72 (d; $^2J_{C-P}$= 10.3 Hz; C_6); 132.47 (d; $^3J_{C-P}$= 17.5 Hz; C_5); 134.88 (d; $^2J_{C-P}$= 9.6 Hz; C_2); 134.88 (d; $^2J_{C-P}$= 9.6 Hz; C2). Mass(EI) *m/z:* 272.

4-(Diethoxy-phosphoryl)benzaldehyde: Oil, B.p.: 133°C/0.3 mm Hg; $C_{11}H_{15}O_4P$; ^1H NMR: 1.19 (t; 6H; $^3J_{H-H}$= 7.1 Hz; CH_3); 4.10 (dq; 4H; $3J_{H-H}$= 7.1 Hz; $^3J_{H-P}$= 3.1 Hz; CH2); 7.93 (dd; 2H; $^3J_{H-H}$= 7.9 Hz; $^3J_{H-P}$= 9.7 Hz; CHar (3 et 5)); 7.97 (m; 2H; CHar (2 et 6)); 10.04 (s; 1H; CH_O). ^{31}P NMR:17.26 .^{13}C NMR:15.73 (d; $^3J_{C-P}$= 6.1 Hz; CH_3); 61.94 (d; $^2J_{C-P}$= 5.4 Hz; CH2); 128.78 (d; $3J_{C-P}$= 15.1 Hz; C_{2-6}); 131.76 (d; $^2J_{C-P}$= 9.9 Hz; C_{3-5}); 134.24 (d;$^1J_{C-P}$ = 186.7 Hz; C_4); 138.26 (d; $^4J_{C-P}$= 2.5 Hz; C_1); 191 (s; CHO).Mass (EI) *m/z*: 242.

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