Stereoselective Synthesis of Arylated (*E*)-Alkenes by the Reaction of Alk-1-enylboranes with Aryl Halides in the Presence of Palladium Catalyst

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Summary The reaction of aryl halides with alk-1-enylboranes, readily obtainable *via* monohydroboration of acetylenes, provides a convenient new method for stereoselective synthesis of arylated (*E*)-alkenes in high yields; these reactions are effectively catalysed by tetrakis(triphenylphosphine)palladium and bases such as sodium ethoxide.

CROSS-COUPLING reactions between alkyl halides and alkenyl metal compounds in the presence of a transition metal catalyst provide convenient syntheses of regio- and stereo-defined alkenes. Recently, such coupling reactions have been studied using organo-magnesium,[1] -zinc,[2] -copper,[3] -aluminium,[4] -mercury,[5] -zirconium,[6] and -silicon reagents.[7] However, alkenylboranes or their ate-complexes have been reported to be inert in such coupling reactions.[4,8]

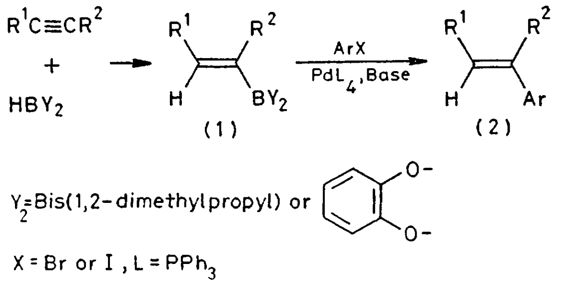
We report that the coupling reaction of alkenylboranes with aryl halides is catalysed by $Pd(PPh_3)_4$ and base. The reactions provide a new stereoselective synthetic procedure for arylated alkenes from aryl halides and acetylenes.

Table. Synthesis of arylated (E)-alkenes by the reaction of alk-1-enylboranes with aryl halides in the presence of palladium catalyst.[a]

ArX	Alkenylborane (1)[d] R^1	R^2	Catalyst[c] (mol %)	Reaction time/h	Yield[b] of (2)/%
PhI	Bu^n	H	1	2	100
PhBr	Bu^n	H	1	2	63
PhBr	Bu^n	H	1	4	98
PhCl	Bu^n	H	1	2	3
PhBr	n-Hexyl	H	3	4	98
PhBr	Ph	H	5	4	50
PhBr	Ph	H	3	3	41[e]
PhBr	Et	Et	3	4	87
o-MeC_6H_4Br	Bu^n	H	3	4	93
o-$MeOC_6H_4Br$	Bu^n	H	3	4	81
p-ClC_6H_4Br	Bu^n	H	1	3	100
o-$EtO_2C_6H_4Br$	Bu^n	H	1	3	87
2-Bromothiophen	Bu^n	H	1	2	86
2-Bromopyridine	Bu^n	H	1	2	83

[a] Unless otherwise mentioned, the reactions were carried out in boiling benzene for 2 h using a 10% excess of alkenylboranes and 2 N EtONa–EtOH as a base. The ratio of base : alkenylborane was 2 : 1 in all the cases. [b] Based on aryl halides and determined by g.l.c. The isolated products were adequately characterized by i.r., n.m.r., and mass spectroscopy and by elemental analysis. [c] $Pd(PPh_3)_4$ was used in all the cases. [d] 1,3,2-Benzodioxaborole was used as the hydroborating agent, unless otherwise mentioned. [e] Bis(1,2-dimethylpropyl)styrylborane in tetrahydrofuran was used and the reaction was carried out at 65 °C using aqueous 2 N NaOH as base.

We have used bis(1,2-dimethylpropyl)borane and 1,3,2-benzodioxaborole as hydroborating agents in reactions with various aryl halides in the presence of $Pd(PPh_3)_4$ and base. In the absence of base we failed to obtain the expected arylated alkenes in any noticeable amounts. In general, aqueous sodium hydroxide and sodium ethoxide in ethanol are satisfactory bases for these cross-coupling reactions. The formation of arylated alkenes proceeds cleanly without the formation of any by-products in significant amounts. Lewis bases, such as triethylamine, did not accelerate the cross-coupling.



The following procedure for the preparation of (E)-1-(2′-methoxyphenyl)hex-1-ene is representative. To a solution of $Pd(PPh_3)_4$[9] (0·5 mmol) in benzene (10 ml) was added 1-bromo-2-methoxybenzene (5 mmol) at room temperature. After stirring for 15 min, (E)-hex-1-enyl-1,3,2-benzodioxaborole (5·5 mmol)[10] and sodium ethoxide in ethanol (5 ml of a 2 M solution) were added. The mixture was heated to reflux for 2 h, and then the residual organoborane was oxidised by 3 N NaOH (0·3 ml) and 30% H_2O_2 (0·3 ml) for 1 h at room temperature. The product was extracted with hexane, and the extract was analysed by g.l.c. which confirmed the formation of (E)-1-(2′-methoxyphenyl)hex-1-ene (4·05 mmol), 81%. G.l.c. analysis indicates that the alkenes prepared by this method consist of a single isomer (isomeric purity $\geqslant 99\%$), believed to be the E-isomer on the basis of the ^1H n.m.r. (J_{trans} 16 Hz) and i.r. (ν 955 cm^{-1}) spectra.

The results are summarized in the Table which shows that this new cross-coupling reaction is applicable to 1-alkenylboranes and aryl bromides and iodides. The reaction proceeds with retention of configuration with respect to alkenylboranes. No difficulty was encountered with derivatives of benzene having functional groups, because organoboranes can tolerate groups such as OMe, CO_2Et, and halogens. Although we have not carried out a detailed comparative study of substituent effects, the relative reactivity appears to be PhI $>$ p-ClC_6H_4Br $>$ PhBr $>$ o-MeC_6H_4Br $>$ o-$MeOC_6H_4Br$. This is in good agreement with substituent effects in the oxidative addition of aryl halides to palladium(O).[11] It is therefore likely that the oxidative addition of aryl halides to Pd^0 is the rate determining step. The transfer of alkenyl groups from alkenylboranes to ArPdX is a relatively fast step. On the other hand, aryl chlorides, such as chlorobenzene are quite inert under similar conditions.

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