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STEREO- AND REGIOSPECIFIC SYNTHESES TO PROVIDE CONJUGATED (E,Z)- AND (Z,Z)-ALKADIENES, AND ARYLATED (Z)-ALKENES IN EXCELLENT YIELDS VIA THE PALLADIUM-CATALYZED CROSS-COUPLING REACTIONS OF (Z)-1-ALKENYLBORONATES WITH 1-BROMOALKENES AND ARYL IODIDES

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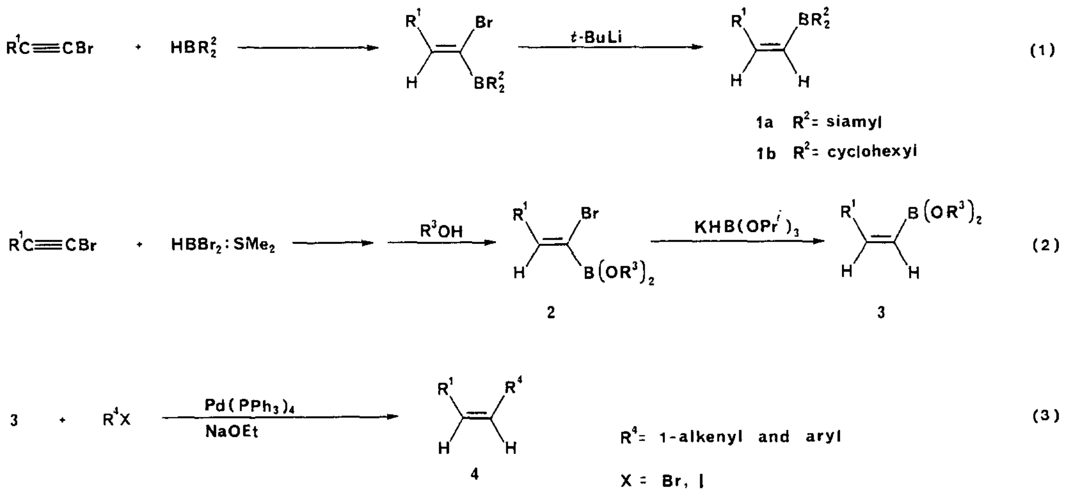
Abstract: Titled alkadienes are obtained in excellent yields stereo- and regiospecifically by cross-coupling between (Z)-1-alkenylboronates and (E)- or (Z)-1-bromoalkenes in the presence of a catalytic amount of $Pd(PPh_3)_4$ and sodium ethoxide.

Recently, we have reported a simple and versatile synthesis leading to conjugated (E,E)-, (E,Z)-, and (Z,Z)-alkadienes,[1] which involves a cross-coupling reaction of (E)- or (Z)-1-alkenyldisiamylboranes, or 2-[(E)-1-alkenyl]-1,3,2-benzodioxaborole (B-1-alkenylcatecholboranes) with either (E)- or (Z)-1-alkenyl halides in the presence of a catalytic amount of palladium catalyst and base in benzene. The coupling with (E)-1-alkenylboronic acids or their esters prepared via the hydroboration of alkynes with catecholborane always gives the expected dienes in 80-90% yields, while the coupling reactions with (Z)-1-alkenyldialkylboranes such as (Z)-1-alkenyldisiamyl- (**1a**) or (Z)-1-alkenyldicyclohexylboranes (**1b**) give relatively poor yields of the coupling products (**4**), less than 50%. One of the major reasons for this difficulty in the coupling with (Z)-1-alkenyldialkylboranes (**1**) appears to be side reactions arising from the two alkyl groups on boron atom. The desirable (Z)-1-alkenylboronates (**3**), not easily obtainable at that time, became available recently by the work of Brown and Imai[2] which utilized the reaction of potassium triisopropoxyborohydride (KIPBH) with 1-bromo-1-alkenylboronates (**2**) (eq. 2). Therefore we have investigated the reaction of **3** with alkenyl and aryl halides. The result is reported herein.

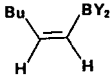
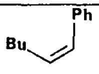
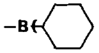
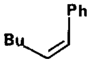
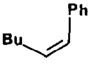
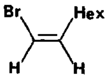
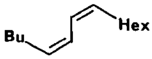
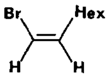
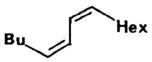
The reactions between 1-alkenyl halides or aryl halides and such (Z)-1-alkenylboronates (**3**) proceed smoothly to give corresponding (E,Z)- and (Z,Z)-alkadienes, and arylated alkenes in excellent yields stereo- and regioselectively (eq. 3). The reaction of diisopropyl (Z)-1-hexenylboronates[2] with phenyl iodide gives (Z)-1-phenyl-1-hexene in 98% yield with high isomeric purity (>97%), as summarized in Table I. This can be compared with the reaction of (Z)-1-hexenyldisiamylborane[3] and (Z)-1-hexenyldicyclohexylborane[3] with phenyl iodide to afford the same cross-coupling product in 58% yield (isomeric purity, >94%) and 49% (>83%). The similar result to the reaction of phenyl iodide was obtained in the reaction between (Z)-1-bromo-1-octene[4] and (Z)-1-hexenyldisiamylborane or diisopropyl (Z)-1-hexenylboronate.

Table II shows the representative results available by the reaction of various (Z)-1-alkenylboronates with 1-alkenyl and aryl halides. From these results, it is apparent that (Z)-1-alkenylboronates derived from *prim*-, *sec*-, and *tert*-alkyl acetylenes give excellent yields of the expected conjugated (E,Z)- and (Z,Z)-alkadienes with high stereospecificity (>98%). The cross-coupling with aryl halides provides corresponding arylated (Z)-alkenes in very good



yields (entries 8-10). However, the bulky alkenylboronates (entries 11 and 12) gave some (E)-isomers (10-15%), which should be attributable to the unavoidable *cis-trans* isomerization of (Z)-alkenylpalladium species.[5,6]

Table I. The Cross-Coupling Reaction of (Z)-1-Hexenylboranes (1 or 3) with Iodobenzene or (Z)-1-Bromo-1-octene (eq. 3)[a]

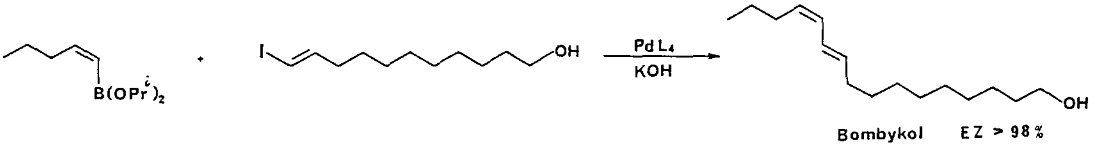
Entry	 , BY_2=	R^4X	Product	Yield (%)[b]	Isomeric Purity[c]
1	$-B(Sia)_2$	PhI		58	> 94
2		PhI		49	> 83
3	$-B(OPr^i)_2$	PhI		98	> 97
4	$-B(Sia)_2$			49	> 98
5	$-B(OPr^i)_2$			87	> 99

[a] All reactions were conducted at the reflux temperature of benzene by using 3 mole% of $Pd(PPh_3)_4$ and 2 equiv of NaOEt in EtOH for 3 h. [b] Glpc yields based on the R^4X employed. [c] Determined by glpc.

The usefulness of the present method is demonstrated by the stereospecific synthesis of four geometrical isomers of 5,7-tetradecadienes. We reported in our previous paper[1] that (5E,7E)- and (5E,7Z)-tetradecadienes were synthesized from (E)-1-hexenyl-1,3,2-benzodioxaborole and (E)- or (Z)-1-bromo-1-octene in yields of 86 and 88%. The present reaction of diisopropyl (*Z*)-1-hexenylboronate with (*E*)- or (*Z*)-1-bromo-1-octene gave (5*Z*,7*E*)- and (5*Z*,7*Z*)-isomers in 78 and 87% yields, respectively, both with high isomeric purities (>98%)(entries 1 and 2 in Table II).

The following general procedure was used. To a solution of diisopropyl (*Z*)-(3,3-dimethyl-1-bromo-1-butenyl)boronate[2] (2, R=*t*-Bu, 1.1 mmol) in ether (2 ml) is introduced slowly a solution of KIPBH[7] in THF (1 M, 1.2 mmol) at 0 °C. After stirring the mixture for 15 min at 0 °C, it is allowed to come to room temperature (30 min). The solvent was evaporated under reduced pressure, and then diisopropyl (*Z*)-3,3-dimethyl-1-butenylboronate[8] thus obtained was dissolved in benzene (4 ml). (*Z*)-1-Bromo-1-octene (1.0 mmol), $Pd(PPh_3)_4$[9](0.03 mmol), and 2M-NaOEt in EtOH (1.5 mmol) were added, and the mixture was refluxed for 3 h. The reaction mixture was diluted with hexane, washed with aqueous NaOH and brine, and dried over $MgSO_4$. Analysis by glpc (silica capillary column, OV-101, 25 m) using tridecane as a internal standard indicated that 0.87 mmol (87%) of (3*Z*,5*Z*)-2,2-dimethyldodecadiene (3*Z*,5*Z*/3*E*,5*Z*=97.4/2.6) had been formed.

Recently, the versatility of this specific synthesis of stereodefined conjugated alkadienes has been demonstrated by the synthesis of pheromone bombykol.[10] In eq.4, it is shown that bombykol can be also readily prepared by the present procedure using diisopropyl (*Z*)-1-pentenylboronate in 82% yield and 98% isomeric purity.



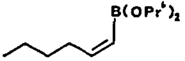
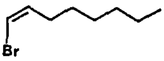
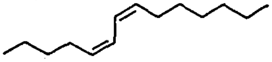
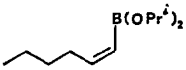
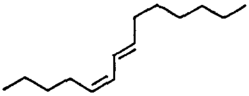
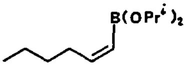
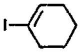
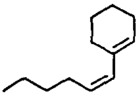
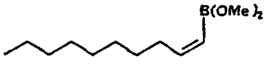
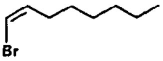
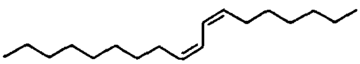
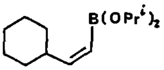
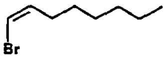
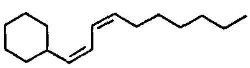
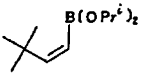
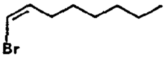
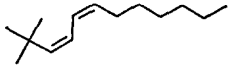
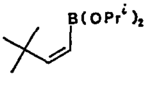
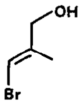
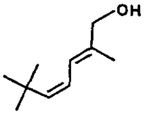
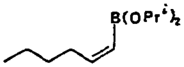
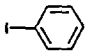
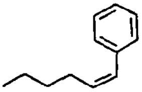
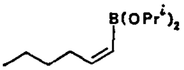
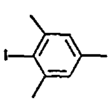
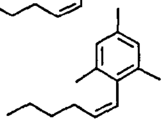
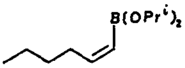
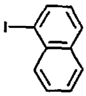
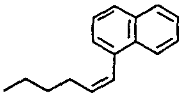
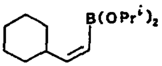
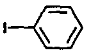
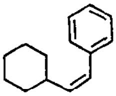
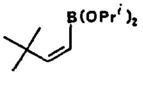
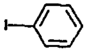
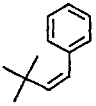
(4)

The ready availability of (*E*)- and (*Z*)-1-alkenylboronates by the Brown's method[2] provides a great advantage, compared with related alkenylmetallics as reagents for cross-coupling reactions. Although an elegant route to (*E*,*Z*)- and (*Z*,*Z*)-dienes via the cross-coupling reaction of (*Z*)-1-alkenylcuprates obtained by the carbocuplation of alkynes was reported by Normant and his coworkers,[11] the present procedure affords a general and simple alternative of obtaining conjugated alkadienes and arylated alkenes containing (*Z*)-double bonds.

References and Notes

1. N. Miyaura, K. Yamada, H. Suginome, and A. Suzuki, *J. Am. Chem. Soc.*, 107, 972 (1985).
2. (a) H. C. Brown and T. Imai, *J. Organometallics*, 3, 1392 (1984) (b) H. C. Brown and V. Somayaji, *Synthesis*, 919 (1984).
3. J. B. Campbell, Jr. and G. A. Molander, *J. Organomet. Chem.*, 156, 71 (1978).
4. (a) H. C. Brown, "Organic Synthesis via Boranes," John Wiley & Sons, New York, 1975. (b) C. F. Lane, *Tetrahedron*, 32, 981 (1976). (c) H. C. Brown, N. G. Bhat, and V. Somayaji, *Organometallics*, 2, 1311 (1983).
5. A. Schoenberg, I. Bartoletti, and R. F. Heck, *J. Org. Chem.*, 39, 3318 (1974).
6. M.Zenbayashi, K. Tamao, and M. Kumada, *Tetrahedron Lett.*,1917 (1975).
7. H. C. Brown, J. S. Cha, and B. Nazer, *Inorg. Chem.*, 23, 2929 (1984).
8. Diisopropyl (*Z*)-1-alkenylboronates can be purified by distillation under reduced pressure.[2] However, we used those boronates without purification. The reaction of 2 with KIPBH proceeded almost quantitatively, and $(i\text{-PrO})_3B$ and KBr contaminated in boronates did not cause any difficulty in the next cross-coupling reaction.
9. D. R. Coulson, *Inorg. Synth.*,13, 121 (1972).
10. (a) N. Miyaura, H. Suginome, and A. Suzuki, *Tetrahedron Lett.*, 24, 1527 (1983). (b) N. Miyaura, H. Suginome, and A. Suzuki, *Tetrahedron*, 39, 3271 (1983).
11. N. Jabri, A. Alexakis, and J. Normant, *Tetrahedron Lett.*, 22, 959 (1981)

Table II. The Synthesis of (E,Z)- and (Z,Z)-Alkadienes and Arylated (Z)-Alkenes[a]

Entry	(Z)-1-Alkenylboronate	R^4X	Product	Yield[b] (%)	I.P.[c]
1				87	>99
2				70	>99
3				67	>98
4				86	>98
5				87	—[d]
6				81	>97
7				79	—[d]
8				98	>97
9				80	>98
10				89	>97
11				93	>90
12				96	>84

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[a] All reactions were carried out in benzene at 80°C for 2 h, using 3 mole% of $Pd(PPh_3)_4$ and 2 equiv of 2 M NaOEt. [b] Glpc yields based on R^4X. [c] Determined by glpc. [d] We have no stereoisomers of these dienes,however, ^1H NMR, C^{13}-NMR, and glpc analyses indicate that these dienes are almost pure single isomers.

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