

**(Z)-1,2,3,4-Tetraboryl-2-butene:
A Reagent for Stereoselective One-pot Triple Aldehyde Addition**

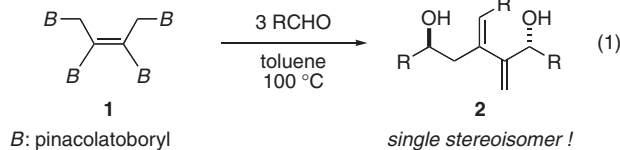
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(Z)-1,2,3,4-Tetraboryl-2-butene reacted with three molecules of 2,3-dialkylidene-1,5-alkanediol as a single stereoisomer. Preparation and triple addition of the butene can be effected in a single operation.

Dimetalated compounds have emerged as versatile reagents for an efficient construction of complex molecules,^{1,2} because the compounds, in principle, allow us to perform multiple carbon–carbon and carbon–heteroatom bond formations in one-pot and can also act as precursors of polyfunctional organometallic reagents.³ In view that allylmatal compounds are extremely useful reagents for carbon–carbon bond formation with excellent regio- and stereocontrol,⁴ γ -metalated allylmatal compounds constitute an especially attractive class of dimetalated reagents for stereoselective domino and sequential reactions.^{5,6} Indeed, Flamme and Roush demonstrated γ -borylated allylic boranes to react two molecules of aldehydes in one-pot, providing both *syn*- and *anti*-1,5-alkanediols with high enantioselectivities, respectively.^{5c} Further appropriate installation of metals into γ -metalated allylmatal compounds are quite intriguing not only to maximize the potential of the allylmatal compounds as reagents for domino reactions but also to shed a light on a new synthetic methodology utilizing polymetalated compounds, if such reagents can be easily prepared and handled as well as perform multiple carbon–carbon bond formation with high regio- and stereocontrol in all steps. We recently reported facile and stereoselective synthesis of (Z)-1,2,3,4-tetrakis(pinacolato)boryl-2-butene (**1**), involving Pt-catalyzed 1,4-diborylation of 2,3-diboryl-1,3-butadiene (**3**) with bis(pinacolato)diboron (**4**).⁷ We envisioned that the tetraborylated reagent **1** could perform multiple aldehyde addition because **1** can be regarded as double hybrid of the γ -borylated allylic boranes. We report herein that **1** undergoes triple aldehyde addition in one-pot, affording 2,3-dialkylidene-1,5-alkanediols **2** in good yields as a single stereoisomer (eq 1). In addition, one-pot preparation–triple addition of **1** is also demonstrated.



A toluene solution of **1** and 4 equiv. of benzaldehyde was heated at 100 °C for 14 h, giving rise to **2a** (R = Ph) in 86% yield as a single stereoisomer which turned out to be a 1:3 adduct (See Supporting Information). When the same reaction was carried out in toluene at 80 °C or in 1,2-dichloromethane or 1,4-dioxane at 100 °C resulted in decrease of the isolated yields (30–71%) of **2a**, respectively.

Representative examples of this stereoselective triple aldehyde

Table 1. Stereoselective triple aldehyde addition of **1** leading to **2**

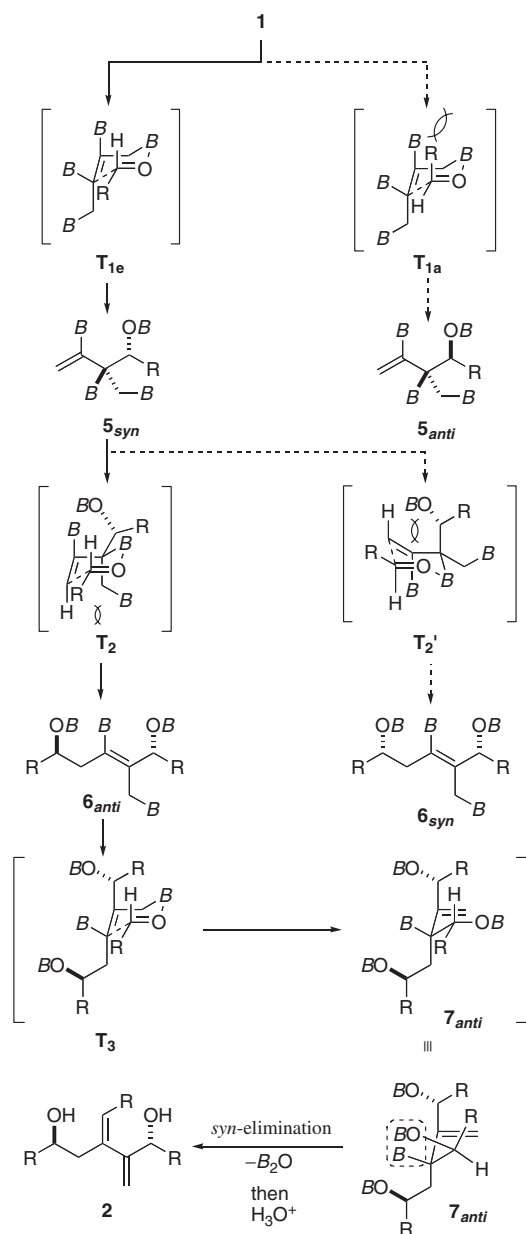
Entry	R	Product	Yield/% ^a
1	2-Naphthyl	2b	63
2	4-C ₆ H ₅ -C ₆ H ₄	2c	86
3	4-CF ₃ -C ₆ H ₄	2d	63
4	4-MeO-C ₆ H ₄	2e	80
5	3-MeO-C ₆ H ₄	2f	69
6	2-MeO-C ₆ H ₄	2g	82
7	3,5-(MeO) ₂ -C ₆ H ₃	2h	57
8	C ₆ H ₅ (CH ₂) ₂	2i	83
9	C ₂ H ₅	2j	71
10 ^b	PhCH ₂ OCH ₂	2k	73

^aIsolated yield. ^bThe reaction proceeded at 80 °C.

addition are summarized in Table 1. Various kinds of aromatic aldehydes were applicable to the reaction in good yields (Entries 1–7), while the addition to such aliphatic aldehydes as 3-phenylpropanal and propanal also proceeded in good yields (Entries 8 and 9). Benzoyloxyacetaldehyde was found to react smoothly at 80 °C (Entry 10). Noteworthy is that all products **2b–2k** were isolated as a single stereoisomer, indicating that each step of the whole transformation proceeded in a highly stereoselective manner (for mechanism, see *vide infra*). As a consequence, we succeeded one-pot conversion of four C–B bonds into two C–C bonds and a C=C bond with perfect 1,5-remote and olefinic stereocontrol.⁸

The stereochemical outcome is reasonably explained by assuming 6-membered cyclic transition states which is well accepted for allylation of allylic borane reagents (Scheme 1).⁴ Reagent **1** would react with RCHO via **T_{1e}** in which substituent R adapted an equatorial position in favor of **T_{1a}** with axial-positioned R, giving rise to **5_{syn}**. The second allylation with **5_{syn}** would proceed via **T₂** over **T_{2'}** to produce **6_{anti}**, because 1,3-diaxial repulsion between H and CH(OB)R was much severe than those between H and CH₂B. Third RCHO would be allylated with **6_{anti}** via **T₃** to generate **7_{anti}** which should cause β -elimination of the remaining boryl and boroxo groups in a *syn*-fashion to give **2** in preference to the fourth addition due probably to the steric hindrance around the boryl group. Even when one equiv. of RCHO was employed, neither 1:1 nor 1:2 adduct was detected during the reaction, indicating that the first addition was considered to be a rate-determining step of the sequence.

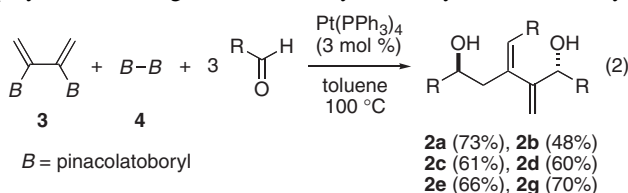
Furthermore, the triple addition can be performed in conjunction with the preparation of **1** (eq 2). Thus, a solution of **3** (1.0 equiv.), **4** (1.4 equiv.), RCHO (3.5 equiv.), and Pt(PPh₃)₄ (3 mol %) in toluene was heated at 100 °C for 11–17 h, affording **2a–2e**, and **2g** as a single stereoisomer, respectively, in acceptable yields at once.^{7b} In other words, sequential stereoselective formation of two carbon–boron bonds and three carbon–carbon



Scheme 1. Plausible mechanism for the stereoselective triple aldehyde addition [B = pinacolatoboryl].

bonds is possible in a single operation.

In summary, we have demonstrated that the first triple aldehyde addition of the tetraborylated 2-butene takes place under excellent stereocontrol. The present results illustrate high potential of a novel synthetic methodology that utilizes tetrametalated compounds. Further studies on preparation and reactions of polymetalated reagents are currently underway in our laboratory.



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