New type formation of 1,3-enynes (or internal alkynes) *via* coupling of organoboranes with alkynylcopper compounds mediated by copper(II)

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The copper(II)—mediated coupling reaction of alkenyldialkyl- or trialkyl-boranes with alkynylcopper compounds (generated *in situ*), in the presence of appropriate solvents and a small amount of water, gives (*E*)-1,3-enynes (or disubstituted alkynes) with various functional groups in reasonable yields.

Conjugated enynes are attractive organic compounds,[1,2] and in recent years[3] have been mainly constructed *via* coupling reactions[4] of organometallic compounds (alkynyl[5] or alkenyl[6,7]) with organic halides (alkenyl[5] or alkynyl[6,7]) respectively. They can also be synthesized *via* the internal coupling of lithium (dialkyl) (alkenyl)(alkynyl)borates by I_2[8a] or of (alkyl)-(alkenyl) (alkynyl)boranes by I_2 and MeOK.[8b] Internal alkynes can also be formed in a similar manner.[4,8c]

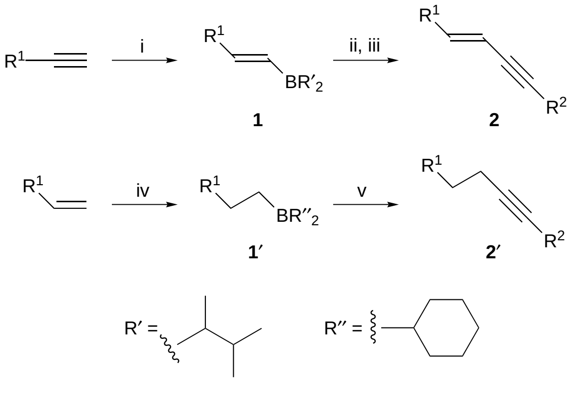
Previously we found a synthesis of alkenyl[9a] or alkyl[9b] cyanides *via* copper(II) acetate—mediated reactions of alkenyl- or alkyl-boranes[10] with copper(I) cyanide. This observation led us to investigate a synthetic approach to 1,3-enynes (or substituted alkynes) *via* a similar reaction employing copper(I) acetylides, regarding them simply as copper(I) cyanide analogues.

Thus, although the reaction of (*E*)-hex-1-enylbis(1,2-dimethylpropyl)borane[11] **1a** with neat hexynylcopper (prepared and isolated *via* the generally known method), in the presence of copper(II) acetate, HMPT and a small amount of water, generated (*E*)-dodec-5-en-7-yne **2a** in unsatisfactory yield (35%), accompanied with dodeca-5,7-diyne (10%), the introduction of copper(II) nitrate trihydrate to the reaction mixture provided the enyne **2a** in 77% yield (GC) and the diyne in 3% yield. In a similar reaction employing hexyldicyclohexylborane[11] **1a′**, the introduction of Cu(acac)$_2$[9b] along with Cu(OAc)·H_2O afforded dodec-5-yne **2a′** in 70% yield [in the absence of Cu(acac)$_2$, the yield was 25%].

In order to obtain more practical synthesis, further improvements of the reaction procedures were attempted. Consequently, the sequence shown in Scheme 1, which probably proceeds *via in situ* generation[12] of the alkynylcopper species [from alk-1-ynes with copper(I) iodide], was used instead of that previously described which utilised neat reactants prepared separately. DMA–pyridine was the solvent system of choice for enynes **2** (or DMA alone for internal alkynes **2′**).

For the synthesis of internal alkynes **2′**, the participation of CuI was not always essential (suggesting that copper acetate might take the place of the copper iodide).[13] However, for the syntheses of enynes **2**, its absence always led to poor results. In this manner, conjugated (*E*)-alkenynes **2** or disubstituted alkynes **2′** were produced easily‡ and isolated§ with high selectivities [*E*-isomers > 99%; the diynes (by-product) were present in trace amounts] and in reasonable yields as shown in Table 1 (entries 1–3 and 13–14).

The present reaction tolerates various functional groups on the alkyne moiety (R^2) to afford **2d** (entry 4), **2e** (entry 5), **2f** (entry 6), **2g**¶ (entry 7), **2h**‖ (entry 8), **2l** (entry 12), **2d′** (entry 15) and **2m′** (entry 16), in a similar manner to that for the reaction using alkynylcopper.[5a] In contrast, the reaction using lithium alkynylborate[8a] would have some problems in this aspect. Also, the toleration of functional groups on the boron reagent (R^1)[15] was confirmed by the reactions which gave **2i** (entry 9), **2j** (entry 10), **2k** (entry 11), **2l** (entry 12) and **2n′** (entry 17).



Scheme 1 *Reagents and conditions*: i, R′$_2$BH (1 equiv.), THF, −15 °C, then 0 °C, 3 h; ii, $R^2C{\equiv}CH$ (1 equiv.), CuI (1.1 equiv.), pyridine (2 equiv.), DMA, 0 °C, then 20 °C, 3 h; iii, Cu(OAc)$_2$ (2 equiv.), Cu(NO$_3$)$_2$·3H_2O (2 equiv.), THF, 0 °C, then 20 °C, 18 h; iv, R″$_2$BH (1 equiv.), THF, 0 °C, 2 h; v, $R^2C{\equiv}CH$ (1 equiv.), Cu(OAc)$_2$·H_2O (2 equiv.), Cu(acac)$_2$ (0.25 equiv.), DMA–THF, 0 °C, then 20 °C, 18 h

We feel that the organocopper species (*i.e.* alkenyl- or alkylcopper) is probably generated *via* a transmetalation of the organoborane. However, the detailed mechanism of the present reaction is unclear due to the absence of direct or obvious evidence, like many organocopper reactions to date.

In summary, the present reaction is not only interesting as a new method for formation of (*E*)-1,3-enynes (or disubstituted alkynes), but is also remarkably useful for the synthesis of such

Table 1 Products and their yields

Product (enyne) **2** or (alkyne) **2′**			Yield
Entry	R^1	R^2	(%)[a]
1 **2a**	Bu	Bu	85 (90)[b]
2 **2b**	Bu	Ph	70
3 **2c**	Bu^t	Bu^t	76
4 **2d**	Bu	$(CH_2)_2COMe$	84
5 **2e**	Bu	$(CH_2)_2CN$	87
6 **2f**	Bu	$(CH_2)_2CO_2Et$	79
7 **2g**	Bu	$(CH_2)_4OH$	86
8 **2h**	Ph	$C(Me)_2OH$	72
9 **2i**	$(CH_2)_2CN$	Bu	80
10 **2j**	$(CH_2)_2CO_2Et$	Bu	75
11 **2k**	$(CH_2)_2OH$	Bu	86[c]
12 **2l**	$(CH_2)_2COMe$	CH_2OH	72
13 **2a′**	Bu	Bu	76 (83)[b]
14 **2b′**	Bu	Ph	72
15 **2d′**	Bu	$(CH_2)_2COMe$	77
16 **2m′**	Bu	CH_2OH	75
17 **2n′**	$(CH_2)_2COMe$	Bu	73

[a] Isolated, based on **1** or **1′** employed: *E*-isomers > 99%. [b] By GC. [c] Using 2 equiv. of R′$_2$BH.

compounds having a variety of functional group. Further investigations are underway.

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Notes and References

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‡ It was observed that galvinoxyl (a radical scavenger) depressed the formation of the disubstituted alkyne **2′** but not that of the enyne **2**.

§ After filtration the reaction mixture was washed and extracted, followed by oxidation with $NaBO_3 \cdot 4H_2O$ in H_2O and THF (ref. 14). The mixture was then worked up as usual. The pure product, isolated from the mixture (consisting of **2** or **2′** and an almost quantitative amount of R′OH or R″OH derived from the residual dialkylboryl groups) by column chromatography or Kugelrohr distillation, gave satisfactory spectral data (IR, ^{1}H NMR, ^{13}C NMR, mass).

¶ This would be applicable to the synthesis of the pheromone of the tent caterpillar *Malacosoma disstria* [(5*Z*,7*E*)-dodeca-5,7-dien-1-ol] [ref. 8(*b*)].

‖ Such enynes are known to be converted into terminal enynes ($RCH{=}CHC{\equiv}CH$) *via* the elimination of acetone using alkali (ref. 16).

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