

Simple Stereospecific Syntheses of (*E*)-1-Chloro(or Bromo)alk-1-enes from Alk-1-yne*s* *via* Hydroboration

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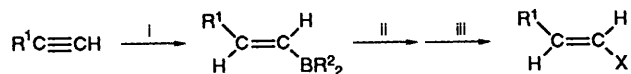
Stereochemically pure (*E*)-1-chloro(or bromo)alk-1-enes were obtained in sufficiently good yields from alk-1-yne*s* *via* hydroboration with dialkylborane followed by reactions with facile reagents; corresponding copper(II) halides, in the presence of a small amount of water, in polar aprotic solvents.

Among many useful reactions involving organoboranes,¹ syntheses of (*E*)-1-chloro- and (*E*)-1-bromo-alk-1-enes are amongst the most interesting. However, many of these syntheses are not always highly efficient and convenient and require some improvements.^{2a,†} For example, the reaction procedures were not simple and the yields were not always high. However, it was found that copper(II) salts were effective reagents for the conversion of an alkyl group of trialkylborane into a halogenoalkane^{3,‡} and of an alkenyl group of an alkenyldialkylborane into a cyanoalk-1-ene.⁵

During our studies on the reactions of organoboranes with metal salts, we found that 1-chloro- and 1-bromo-alk-1-ene were provided highly efficiently by reactions of alk-1-enyldialkylborane (derived from alk-1-yne by hydroboration with dialkylborane) with copper(II) chloride, and bromide respectively, in a polar aprotic solvent.

Thus, a subsequent reaction of (*E*)-hex-1-enylbis(1,2-dimethylpropyl)borane⁶ [prepared by hydroboration of hex-1-yne with bis(1,2-dimethylpropyl)borane in tetrahydrofuran (THF)], with copper(II) chloride in the presence of hexamethylphosphoric triamide (HMPT) and a small amount of water gave (*E*)-1-chlorohex-1-ene in 86% yield (GC), with no by-products, such as 1,2-dimethylpropyl chloride which might be formed by chlorination of the 1,2-dimethylpropyl group on the boron atom. In the absence of HMPT or water, little product was formed (*ca.* 5%).⁵ However the use of *N,N*-dimethylacetamide (DMA) in place of HMPT gave a similar result to that using HMPT, although the product yield was a little lower (70%). A reasonably detailed stoichiometric study revealed that 2 equiv. of copper(II) chloride and 1 equiv. of water were necessary for formation of 1 equiv. of 1-chloroalk-1-ene. The present reaction proceeded with retention of configuration, providing almost entirely *E*-isomers, in contrast with the previously reported reaction of alkenylborane derivatives using chlorine where the reaction proceeded with inversion.^{2,7} In the reaction employing hex-3-yne, an internal alkyne, the corresponding product was afforded similarly. The chloroalkenes thus obtained were isolated from the worked-up⁸ reaction mixtures by simple column chromatography. For example, (*E*)-1-chlorooct-1-ene was afforded in 80% isolated yield from oct-1-yne. Some representative results obtained by reactions depicted in Scheme 1 are shown in Table 1.

The reaction employing iron(III) chloride in place of copper(II) chloride afforded only trace amount of the product in



Scheme 1 Reagents and conditions: i, R^2BH , THF, $-15^\circ C$ then $0-5^\circ C$; ii, $(Me_2N)_3P(O)$, $CuCl_2$ [or $CuBr_2-Cu(OAc)_2$], H_2O and THF, $0^\circ C$; iii, $20^\circ C$ then $70^\circ C$. X = Cl (or Br). R^1 = alkyl or phenyl, R^2 = 1,2-dimethylpropyl

contrast with our previous work.⁴ Furthermore, the presence of galvinoxyl (25%), a radical scavenger, did not depress the present reaction at all. These features seem to suggest the formation of an alkenylcopper-like intermediate and a subsequent ionic chlorination with a further 1 equiv. of copper(II) chloride, although the reaction mechanism cannot be clarified at present, in the absence of more direct evidence.

Although a direct application of the above reaction to the synthesis of bromoalkenes using copper(II) bromide failed to give satisfactory results (about 50% yields, accompanied by two conspicuous by-products), the additional introduction of copper(II) acetate⁵ to the reaction mixtures gave very remarkable results. Thus, a subsequent reaction of (*E*)-hex-1-enylbis(1,2-dimethylpropyl)borane in THF with an excess of copper(II) acetate and copper(II) bromide in the presence of HMPT and a small amount of water provided (*E*)-1-bromohex-1-ene in 88% yield (GC), little contaminated by 1,2-dimethylpropyl bromide (3%). This bromination also proceeded with retention of configuration and (*E*)-isomers were produced exclusively. They were isolated in a similar manner to that described above (in the case of 1-chloroalk-1-ene). For example, (*E*)-1-bromooct-1-ene was obtained in 82% isolated yield from oct-1-yne. Some representative results obtained by reactions depicted in Scheme 1 are shown in Table 1.

The reaction process seems to be essentially similar to that of the above chlorination, since the bromoalkene was afforded in 50% yield by using only 2 equiv. of copper(II) bromide without the additional introduction of copper(II) acetate. However, the mechanistic role of copper(II) acetate in this reaction is not obvious.

In the present reactions highly pure (*E*)-1-chloro- and (*E*)-1-bromo-alk-1-enes, valuable synthetic intermediates,⁹ were provided in higher yields than have been obtained in previous work using alkenylborane derivatives.² All reaction procedures included were carried out in one flask starting from the preparation of dialkylborane and by employing commonly available and easily handled reagents.

These results demonstrate that the present reactions provide more convenient and practical methods to those reported earlier.²

Typical Experimental Procedures: Preparation of (*E*)-1-Chlorooct-1-ene.—In an argon-flushed flask, (*E*)-oct-1-enylbis(1,2-dimethylpropyl)borane (20 mmol) in THF was prepared

† The synthesis *via* mercuriation of alkenylboronic acids has been reported, however the only chlorination gives a mixture of stereoisomers.^{2b}

‡ Both copper(II) and iron(III) chlorides reacted with trialkylborane in water and THF (without polar aprotic solvent) to provide the halogenoalkane in a radical-like manner.⁴

Table 1 Syntheses of chloro(or bromo)alkenes from alkynes *via* hydroboration by dialkylborane

| Alkyne | Product | X | % Yield ^a | | |
|-----------------|---|----|----------------------|-----------------------|---------------------|
| | | | GC | Isolated ^b | <i>E</i> : <i>Z</i> |
| Hex-1-yne | <i>(E)</i> -BuCH=CHX | Cl | 86 | 72 ^c | >99: <1 |
| | | Br | 88 | 78 ^d | >99: <1 |
| Oct-1-yne | <i>(E)</i> -C ₆ H ₁₃ CH=CHX | Cl | 85 | 80 ^c | 100 |
| | | Br | 86 | 82 ^d | >99: <1 |
| Phenylacetylene | <i>(E)</i> PhCH=CHX | Cl | 80 | 75 ^e | 100 |
| | | Br | 94 | 89 ^e | >99: <1 |
| Hex-3-yne | <i>(E)</i> -EtCH=C(Et)X | Cl | 87 | 70 ^c | 99:1 |
| | | Br | 86 | 75 ^d | >99: <1 |

^a All yields are for the overall process, and are based on starting alkynes. ^b On flash column (silica gel; pentane). ^c GC purity is 98–99%. ^d GC purity is 96–97%. ^e Eluted with pentane–dichloromethane. GC purity is 95–96%.

by the successive reactions of borane (20 mmol) in THF (15 cm³) with 2-methylbut-2-ene (2.81 g, 40 mmol) in THF (10 cm³) at –15 °C for 30 min then 0–5 °C for 2 h and oct-1-yne (2.21 g, 20 mmol) in THF (5 cm³) at –15 °C for 30 min then 0–5 °C for 3 h.⁶ To the solution, HMPT (20 cm³), copper(II) chloride (6.46 g, 48 mmol), water (0.432 g, 24 mmol) and THF (20 cm³) were added successively at 0 °C under argon, followed by stirring at 0 °C for 1 h then 20 °C for 8 h and additionally at 70 °C for 4 h. The contents of the flask were washed with aqueous NH₄Cl and then with brine and extracted with diethyl ether. The extract was evaporated and the residue oxidized with sodium perborate tetrahydrate (10 g, 65 mmol) in water (20 cm³) and THF (20 cm³) with stirring at 0–20 °C for 4 h.⁸ The mixture was washed with aqueous NH₄Cl and then with brine, extracted with diethyl ether, and the extract dried (Na₂SO₄), filtered and evaporated. Chromatography of the organic residue (consisting of the chloroalkene and an almost quantitative amount of 3-methylbutan-2-ol derived from the residual dialkylboronyl group by above oxidative treatment) on a flash column (silica gel; pentane) gave pure *(E)*-1-chlorooct-1-ene (2.35 g, 80%); *n*_D²⁰: 1.4402 [lit.,² *n*_D²⁰: 1.4385]; *v*_{max}(neat)/cm⁻¹ 3050 (C=CH), 1620 (C=C) and 930 (*trans*-CH=CH); *δ*_H(200 MHz; CDCl₃) 0.88 (3 H, deformed t, Me), 1.1–1.6 [8 H, m, (CH₂)₄], 1.8–2.3 (2 H, m, CH₂C=C) and 5.8–6.1 (2 H, m, CH=CH); *m/z* 146 (M⁺) and 148 (M⁺ + 2). GC analysis showed 100% stereochemical purity, contrasting with the retention time of (*Z*)-1-chlorooct-1-ene prepared *via* hydroboration of 1-chlorooct-1-yne followed by protonolysis.⁷

Preparation of (*E*)-1-Bromooct-1-ene.—To the solution of (*E*)-1-oct-1-enylbis(1,2-dimethylpropyl)borane (20 mmol) in THF prepared as described above, HMPT (20 cm³), copper(II) acetate (14.6 g, 80 mmol), copper(II) bromide (8.94 g, 40 mmol), water (0.720 g, 40 mmol) and THF (20 cm³) were added successively at 0 °C under argon, followed by stirring at 0 °C for 1 h, then 20 °C for 8 h and additionally at 70 °C for 4 h. After filtration of the contents of the flask, the solution was worked up in a similar manner to that described above. Chromatography of the organic residue (consisting of the bromoalkene and an almost quantitative amount of 3-methylbutan-2-ol) gave pure

(E)-1-bromooct-1-ene (3.13 g, 82%) in a similar manner to that described above; *n*_D²⁰ 1.4634 [lit.,² *n*_D²⁵ 1.4620]; *v*_{max}(neat)/cm⁻¹ 3050 (C=CH), 1615 (C=C) and 930 (*trans*-CH=CH); *δ*_H(200 MHz; CDCl₃) 0.89 (3 H, deformed t, Me), 1.1–1.6 [8 H, m, (CH₂)₄], 1.8–2.2 (2 H, m, CH₂C=C), 6.00 (1 H, d, *J* 13.8) and 6.18 (1 H, dt, *J* 13.8 and 6.8); *m/z* 190 (M⁺) and 192 (M⁺ + 2). GC analysis showed >99% stereochemical purity, contrasting with the retention time of (*Z*)-1-bromooct-1-ene prepared *via* hydroboration of 1-bromooct-1-yne followed by protonolysis.⁷

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