

## The Chemistry of Organoborates. Part 7.<sup>1</sup> Protonation Studies of Alkynyltrialkylborates

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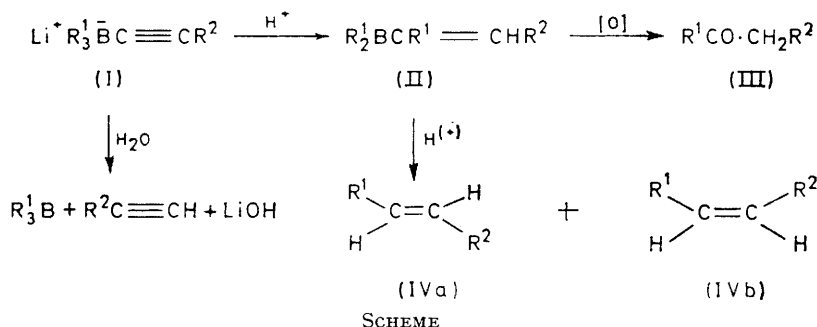
Protonation of trialkylalkynylborate salts followed by oxidation is a very general route to ketones that proceeds under mild conditions. Hydrolytic work-up gives olefins in good yields. When a phenyl group migrates then the *Z*-olefin results but in all other cases mixtures of isomers are obtained. However the protonation of dialkyl(phenylethynyl)-(1,1,2-trimethylpropyl)borates gives *Z*-olefins, but from alkynyldialkyl-(1,1,2-trimethylpropyl)borates the *E*-olefin predominates. Different acids give different stereochemical results with simple alkynyltrialkylborate salts. The intermediate boranes, not available by other methods, may be used to produce olefins by reaction with iodine and base.

We have previously shown<sup>1,2</sup> that electrophilic attack upon lithium alkynyltrialkylborates (I) by alkylating agents can be induced to proceed almost exclusively at the  $\beta$ -carbon atom of the alkyne, inducing migration from boron to carbon to yield synthetically valuable dialkylvinylboranes, unavailable by any other route.

The study has been extended to the use of the proton as electrophile<sup>3</sup> (Scheme). Under the same conditions<sup>4</sup>

traces of water, something we felt desirable in the first instance owing to our disappointing experience of water alone as a proton source.

When 1 equiv. of methanesulphonic acid was added at  $-78^\circ\text{C}$  to a salt (I) in an ether solvent and the mixture was allowed to warm to room temperature then oxidised in the usual fashion,<sup>5</sup> the ketones (III) were formed in acceptable yields (Table 1). The mild conditions



as were used for the successful alkylations of the salts (I), reaction with water proceeded entirely by  $\alpha$ -attack and

TABLE 1

Production of ketones  $\text{R}^1\text{CO}\cdot\text{CH}_2\text{R}^2$  from  $\text{R}_3^1\text{B}^-\text{C}\equiv\text{CR}^2\text{Li}^+$

R <sup>1</sup>	R <sup>2</sup>	Yield (%) <sup>a,b</sup>
n-Hexyl	n-Hexyl	82
n-Hexyl	Bu <sup>a</sup>	78
n-Hexyl	Ph	79
n-Octyl	n-Hexyl	78
Cyclopentyl	n-Hexyl	85
Cyclopentyl	Bu <sup>a</sup>	78
Cyclohexyl	Bu <sup>a</sup>	86
Ph	Bu <sup>a</sup>	83

<sup>a</sup> All yields given are of isolated purified products. <sup>b</sup> All ketones were compared with authentic samples or fully characterised.

simply regenerated the alkyne and the organoborane. We then turned to methanesulphonic acid as a proton source. This acid was chosen for two reasons: (i) as it was a mineral acid it would not rapidly hydrolyse the vinylborane intermediate (II) to the *E*- and *Z*-olefins (IVa and b), and therefore (II) would survive and could be utilised; (ii) the acid could readily be purified from

<sup>1</sup> Part 6, A. Pelter, C. R. Harrison, and K. J. Gould, preceding paper.

<sup>2</sup> A. Pelter, T. W. Bentley, C. R. Harrison, C. Subrahmanyam, and R. J. Laub, *J.C.S. Perkin I*, 1976, 2419.

<sup>3</sup> A. Pelter, C. R. Harrison, and D. Kirkpatrick, *J.C.S. Chem. Comm.*, 1973, 544.

should allow the presence of even highly sensitive groups in this essentially neutral process. Phenyl and secondary alkyl groups migrate readily in the reaction. Indeed in a reaction involving lithium n-hexylhexynyl-bis-2-methylcyclohexylborate a mixture of products was obtained that seemed to indicate that the secondary group could migrate competitively with the primary alkyl group. The order of migration of various groups in this process will be investigated.

TABLE 2

Protonation of  $\text{R}_3^1\text{B}^-\text{C}\equiv\text{CR}^2\text{Li}^+$  to give olefins  $\text{R}^1\text{CH}=\text{CHR}^2$

R <sup>1</sup>	R <sup>2</sup>	% Yield <sup>a</sup>
n-Hexyl	n-Hexyl	84
n-Hexyl	Ph	74
n-Octyl	n-Hexyl	83
n-Octyl	Bu <sup>a</sup>	84
Et	Bu <sup>a</sup>	77
Cyclohexyl	n-Hexyl	73
Cyclopentyl	n-Hexyl	74
Ph	Bu <sup>a</sup>	81

<sup>a</sup> All yields are of isolated purified products.

We next tried the hydrolysis of the vinylborane (II) with a carboxylic acid, the yields of olefin being shown in Table 2. As would be expected the overall yields are

<sup>4</sup> P. Binger, G. Benedikt, G. W. Rotermond, and R. Köster, *Annalen*, 1968, **717**, 21.

<sup>5</sup> H. C. Brown, 'Organic Syntheses via Organoboranes,' Wiley, New York, 1975.

satisfactory but the products were mixtures of *Z*- and *E*-isomers. Thus the migration of the cyclohexyl group (Table 2) gave a 58:42 mixture of isomers whilst the migration of a primary hexyl group in a lithium tri-n-hexylphenylalkynylborate gave a 68:32 mixture of *E*- and *Z*-isomers. With one exception this is an important limitation of the reaction. The useful exception involved the migration of a phenyl group when the *Z*-isomer was produced overwhelmingly [*Z*:*E* 96:4 in diglyme, 6:1 in tetrahydrofuran (THF)]. That the product was the *Z*-isomer was made clear by the <sup>1</sup>H n.m.r. spectrum, which exhibited peaks due to two vinyl

used were derived from phenylacetylene, and it was possible that although a primary alkyl group was migrating the aryl group attached to the triple bond was having an effect. On the basis of these results, Suzuki<sup>7</sup> put forward a mechanistic hypothesis of some generality but one which did not in fact apply to our alkylation results.<sup>1,2</sup>

We therefore decided to make a more general study of the steric consequences of the protonation of lithium alkynyltrialkylborates. To make our conditions comparable with those of Suzuki we used THF as solvent,<sup>†</sup> caused an n-butyl group to migrate in each case, and

TABLE 3  
Protonation of R<sup>1</sup>Bu<sup>n</sup><sub>2</sub>BC≡CR<sup>2</sup>Li<sup>+</sup> to give Bu<sup>n</sup>CH=CHR<sup>2</sup>

	R <sup>1</sup>	R <sup>2</sup>	Proton source	Temp. (°C)	<i>Z</i> ( <i>cis</i> ): <i>E</i> ( <i>trans</i> )
(1)	Bu <sup>n</sup>	Bu <sup>n</sup>	EtCO <sub>2</sub> H	0	62:38
(2)	Bu <sup>n</sup>	Bu <sup>n</sup>	EtCO <sub>2</sub> H	-78	69:31
(3)	Bu <sup>n</sup>	Bu <sup>n</sup>	MeSO <sub>3</sub> H	0	42:58
(4)	Bu <sup>n</sup>	Bu <sup>n</sup>	MeSO <sub>3</sub> H	-78	39:61
(5)	Bu <sup>n</sup>	Ph	MeSO <sub>3</sub> H	0	56:44
(6)	Bu <sup>n</sup>	Ph	EtCO <sub>2</sub> H	0	77:23
(7)	Me <sub>2</sub> CH·CMe <sub>2</sub>	Bu <sup>n</sup>	EtCO <sub>2</sub> H	-78	29:71
(8)	Me <sub>2</sub> CH·CMe <sub>2</sub>	Bu <sup>n</sup>	MeSO <sub>3</sub> H	-78	21:79
(9)	Me <sub>2</sub> CH·CMe <sub>2</sub>	Ph	MeSO <sub>3</sub> H	-78	96:4
(10)	Me <sub>2</sub> CH·CMe <sub>2</sub>	Ph	EtCO <sub>2</sub> H	-78	97:3

protons, both as doublets of triplets, one at  $\tau$  3.64 (*J* 12 and 0.5 Hz) and the other at  $\tau$  4.44 (*J* 12 and 8 Hz). Irradiation of the higher field proton signal caused collapse of the other to a very narrow triplet (*J* 0.5 Hz). In addition the compound was identical with a sample of (*Z*)-1-phenylhex-1-ene produced from 1-phenylhex-1-yne by hydroboration with dicyclohexylborane followed by hydrolysis.

This result was in contrast to our earlier results in the alkylation experiments,<sup>2</sup> but these were based entirely on the migration of alkyl groups and it was readily conceivable that different rules would govern the migration of aryl groups. In fact we had methylated lithium n-hexynyltriphenylborate to give the trisubstituted olefin (73%) as a mixture of isomers in the ratio 5:1. However owing to a not unexpected inability to distinguish the two isomers of the disubstituted olefins by <sup>1</sup>H n.m.r.<sup>6</sup> or indeed by i.r., and lacking authentic models, we had been unable to assign the structures.

At this time a report appeared of the protonation of the salts (I) with a carboxylic acid (propionic acid) to give the olefins (IV) directly. In contrast to our results the alkyl groups migrated to give a predominance of the *Z*-isomer, and this became the overwhelming product when a thexyl\* group was introduced.<sup>7</sup> The study had two clear limitations, however. The first was that propionic acid only had been used as proton source, but the attack by protic acids even on simple alkynes is very complex, and may well depend on the proton source.<sup>8</sup> The second was that all the alkynyltrialkyl(thexyl)borates

\* Thexyl = 1,1,2-trimethylpropyl.

† There may be some solvent effect. Methanesulphonic acid reacted with lithium tri-n-butyl(phenylethynyl)borate in diglyme to give *E*- and *Z*-olefin in the ratio 44:56. In THF the same acid with the very similar lithium tri-n-hexyl(phenylethynyl)borate gave an *E*:*Z* ratio of 68:32.

used propionic acid for the hydrolysis of the vinylboranes (II). We also used the same reaction temperatures as Suzuki, but checked for temperature effects, which proved to be negligible. All reactions were run at the same concentrations.

The results of the study are shown in Table 3, products being isolated as usual but with no attempt made to optimise yields. For comparison the isomeric dec-5-enes were made by standard procedures (see Experimental section), and *Z*-1-phenylhex-1-ene was available as mentioned above. The results given are the mean values from several runs, analyses being carried out by g.l.c. on silver nitrate-impregnated columns. The proportions of isomers were measured by cutting out and weighing the appropriate areas of chart paper. Preliminary experiments established that the olefin ratio was not affected by the reaction and work up conditions.

Several important points emerge which show that Suzuki's results cannot be generalised. The presence of a phenyl group, whether it migrates (Table 2) or not, clearly affects the stereochemical consequences of the reaction [experiments (5) and (6)] and this effect can be strongly enhanced by the presence of a thexyl group [experiments (9) and (10)]. These latter experiments present a practical method for the production of the *Z*-isomers under mild conditions.

The dependance of the ratio of the stereoisomers upon the acid used in experiments (1)–(6) is both unexpected and remarkable. Clearly the protonating species is different for the two acids. In every case use of me-

<sup>6</sup> H. Rottendorf, S. Sternhell, and J. R. Wilmschurst, *Austral. J. Chem.*, 1965, **18**, 1759.

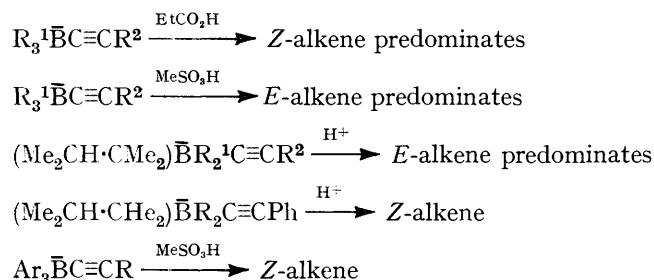
<sup>7</sup> N. Miyaura, T. Yoshinari, M. Itoh, and A. Suzuki, *Tetrahedron Letters*, 1974, 2961.

<sup>8</sup> T. W. Bentley, *Ann. Reports (B)*, 1974, 127.

thanesulphonic acid gives a higher proportion of the *E*-isomer.

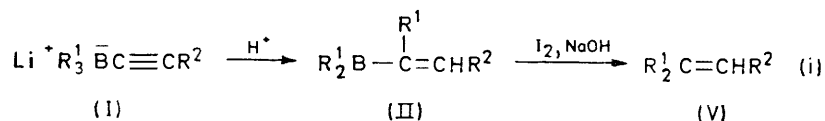
The hexyl group exerts a strong effect upon the protonation of trialkylalkynylborates—so strong indeed that the *E*-isomer predominates even when propionic acid is used [experiment (7)]. This reversal of the major isomer as compared with experiment (1) could not be predicted from Suzuki's study.

The results so far may be summed up as follows:



Before any meaningful mechanistic proposals can be put forward more experiments are required, but the present study indicates that the situation is far more complex than previously supposed. MINDO/3 calculations, as applied to the alkylations of alkynyltrialkylborates,<sup>2</sup> obviously cannot be used here.

As previously noted, the well characterised vinylboranes (II) are not available by hydroboration of an internal alkyne and hence this reaction represents the sole method for their preparation. Clearly they may be subjected to any of the known reactions of alkenylboranes, and illustrative of this is the sequence shown in equation (i).<sup>9</sup> After we had reported this sequence<sup>10</sup> it



was communicated independently,<sup>11</sup> and so only two examples need be given here. When  $R^1 = n\text{-octyl}$  and  $R^2 = n\text{-hexyl}$  the isolated yield of pure olefin (V) was 69%; when  $R^1 = n\text{-hexyl}$  and  $R^2 = n\text{-butyl}$  the yield of (V;  $R^1 = n\text{-hexyl}$ ,  $R^2 = Bu^m$ ) was 65%.

#### EXPERIMENTAL

The apparatus and reagents used and the general techniques were exactly as previously described.<sup>2</sup> For normal g.l.c. were used either a 6 ft 4% PEGA column programmed from 50 to 190 °C at 12° min<sup>-1</sup> or isothermal analysis on a 6 ft column of acid-washed, silylated Chromosorb G (60–80 mesh) coated with 15% (w/w) of a 20% (w/w) solution of silver nitrate in ethylene glycol. The latter column was used for the analysis of the aliphatic olefins, in particular. All ketones and olefins were compared with authentic samples where available, or where the compounds were known but not available the physical constants were compared. All substances gave the expected low resolution mass spectra, molecular weights by accurate mass measurements on molecular ions, and <sup>1</sup>H n.m.r. spectra. Details

<sup>9</sup> G. Zweifel, H. Arzoumanian, and C. C. Whitney, *J. Amer. Chem. Soc.*, 1967, **89**, 3652.

are given only for compounds data for which were unavailable.

*General Procedure.*—The following is a typical protonation experiment.

Trioctylborane (5 mmol) was prepared in the cooled dropping funnel,<sup>5</sup> the THF was evaporated off, and diglyme (5 ml) was added. In the reaction vessel were placed oct-1-yne (0.75 ml) and light petroleum (4 ml), and *n*-butyllithium (3.6 ml; 1.4M) was added by syringe at 0 °C. The mixture was then stirred for 1 h at 25 °C. The borane solution was added dropwise and the mixture stirred until all the solid had dissolved; the light petroleum was then removed under vacuum. The solution was cooled to -78 °C and anhydrous MeSO<sub>3</sub>H (0.36 ml, 5.5 mmol) was added, followed by diglyme (1 ml) as washing. The mixture was allowed to warm to 25 °C and stirred for 45 min.

*Hydrolytic work-up.* Acetic acid (1 ml) was added to the mixture, which was then stirred for 18 h at 25 °C. Water (15 ml) was added and the mixture extracted with light petroleum (3 × 15 ml). The extract was washed with saturated aqueous NaHCO<sub>3</sub> (2 × 10 ml) and water (3 × 20 ml), dried (MgSO<sub>4</sub>), and evaporated, and the residue (3.63 g) was placed on a dry column of silica. The light petroleum fraction (400 ml) on concentration gave the required olefin (83%), which ran as one peak on a PEGA column. *Note.* When lithium hexynyltriphenylborate was used, hydrolysis was followed by oxidation as usual with either 5M-NaOAc-50% H<sub>2</sub>O<sub>2</sub> or 3M-NaOH-50% H<sub>2</sub>O.

*Oxidative work-up.* The mixture was cooled to 0 °C and 5M-NaOH (1.0 ml) was added slowly, followed by 50% H<sub>2</sub>O<sub>2</sub> (1 ml). The oxidation mixture was left at room temperature for 4 h (sometimes overnight), the required ketone (78%) being isolated from the dichloromethane eluate from a silica column. *Cyclohexyl pentyl ketone* had b.p. 88–92° at 2 mmHg,  $n_D^{19}$  1.459 9 (Found: C, 78.9;

H, 12.3%;  $M^+$ , 182.167 1 ± 5. C<sub>12</sub>H<sub>22</sub>O requires C, 79.05; H, 12.15%;  $M$ , 182.167 06). *Cyclopentyl pentyl ketone* had b.p. 85–87° at 23 mmHg,  $n_D^{19}$  1.456 5 (Found: C, 78.7; H, 12.0%;  $M^+$ , 168.151 4 ± 5. C<sub>11</sub>H<sub>20</sub>O requires C, 78.5; H, 12.0%;  $M$ , 168.151 41).

*Comparative hydrolysis experiments.* All the migrations were carried out at the same concentrations, the protic acid being added at the temperature indicated in Table 3.

*Procedure.* Hexylborane (5 mmol) was prepared as usual<sup>5</sup> in a cooled dropping funnel and to it was added but-1-ene (0.84 g) in THF (7.4 ml). In the reaction flask were placed light petroleum (b.p. 40–60°) (8 ml) and hex-1-yne (0.6 ml). To this solution held at 0 °C was added, by syringe, a solution of *n*-butyllithium in hexane (2.70 ml; 1.86M), and the solution was stirred for 1 h. The solution of the borane was then slowly dropped in, with stirring, all volatile materials were removed at a rotary pump, and THF (4 ml) was added, followed by a further portion (2 ml) as washing. The THF solution of lithium di-*n*-butylhexynyl(thexyl)borate was cooled to -78 °C and propionic acid (3.40 ml) was added. The temperature was kept at -78 °C

<sup>10</sup> A. Pelter and C. R. Harrison, *J.C.S. Chem. Comm.*, 1974, 828.

<sup>11</sup> G. Zweifel and R. P. Fisher, *Synthesis*, 1975, 376.

for 1 h, allowed to rise to room temperature, and left overnight. Oxidation was effected with 3M-NaOH (5 ml) and 30% H<sub>2</sub>O<sub>2</sub> (5 ml) and the reaction worked up as usual. The light petroleum eluate from a silica column gave dec-5-ene (72%) as a 29:71 mixture of the *Z*- and *E*-isomers.

*Reaction of Protonated Lithium Alkynyltrialkylborates with Sodium Hydroxide-Iodine.*—*Preparation of 8-n-octylhexadec-7-ene* (V; R<sup>1</sup> = n-octyl, R<sup>2</sup> = n-hexyl). Lithium octynyltri-n-octylborate (5 mmol) was prepared in diglyme in the normal way. The solution was cooled to 78 °C, treated with MeSO<sub>3</sub>H (5 mmol) and allowed to warm to room temperature. After 45 min the mixture was cooled to 0 °C, and aqueous NaOH (5 mmol) was added, followed by a solution of iodine (5 mmol) in diglyme (5 ml) added dropwise over 30 min. There was immediate decolourisation of the iodine solution added up to ca. 80% addition, after which

colour persisted. Saturated aqueous Na<sub>2</sub>S<sub>2</sub>O<sub>7</sub> (5 ml) was added and then the organic product was taken into light petroleum. Work-up as usual gave 8-*n*-octylhexadec-7-ene (69%) from the light petroleum eluate from a silica column; b.p. 130–134° at 3 mmHg, *n*<sub>D</sub><sup>19</sup> 1.4470 (Found: C, 85.8; H, 14.50%; *M*<sup>+</sup>, 336.375 6. C<sub>24</sub>H<sub>28</sub> requires C, 85.65; H, 14.35%; *M*, 336.375 38).

By a similar procedure was prepared 6-*n*-hexyldodec-5-ene (V; R<sup>1</sup> = n-hexyl, R<sup>2</sup> = n-butyl) in 65% yield; b.p. 88–89° at 1 mmHg, *n*<sub>D</sub><sup>19</sup> 1.445 0 (Found: C, 85.8; H, 14.1%; *M*<sup>+</sup>, 252.281 7. C<sub>18</sub>H<sub>36</sub> requires C, 85.65; H, 14.35%; *M*, 252.281 69).

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