Journal of Organometallic Chemistry
Elsevier Sequoia S.A., Lausanne
Printed in The Netherlands

SYNTHESIS AND REACTIONS OF SOME SUBSTITUTED 1-PHENYLETHANEBORONIC ESTERS

D. S. MATTESON*, R. A. BOWIE, AND G. SRIVASTAVA
Department of Chemistry, Washington State University, Pullman, Washington 99163 (U.S.A.)

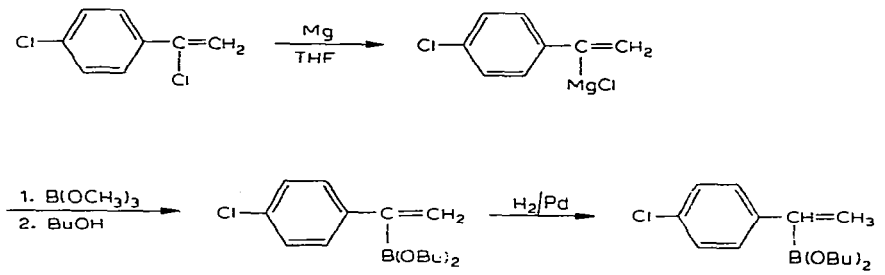
(Received June 10th, 1968; in revised form September 9th, 1968)

SUMMARY

1-Phenylethaneboronic esters bearing *p*-methyl and *p*-chloro substituents have been synthesized by hydrogenation of the α-styreneboronic esters. An alternative synthesis involving rearrangement of aryl(α-haloethyl)borinic esters was also explored with partially successful results. Other substituted 1-phenylethaneboronic esters prepared from dibutyl α-styreneboronate included the α-bromo, α-butoxy, and α-dibutoxyboryl derivatives. Displacement of boron by mercuric chloride has been surveyed. The *p*-chlorophenylethaneboronic ester reacts with mercuric chloride about 0.1 or 0.2 times as fast as the unsubstituted compound to yield the corresponding 1-phenylethylmercuric chloride. The α-substitued boronic esters yield unstable mercury derivatives which decompose to mercurous chloride and acetophenone.

INTRODUCTION

We have previously studied the stereochemistry of mercuri-deboronation of 1-phenylethaneboronic acid and found that retention of configuration is favored[1]. In the present work, we have synthesized a variety of substituted 1-phenylethaneboronic esters and explored their reactions with mercuric chloride for synthetic and mechanistic information.



(I) (II)

The general method of synthesis used has been described previously[1]. For

* (a) Alfred P. Sloan Foundation Fellow, 1966–68. (b) Supported by National Science Foundation grants GP 2953 and GP 6069.

example, dibutyl *p*-chloro-α-styreneboronate (I) was prepared from the corresponding Grignard reagent and was hydrogenated to form the *p*-chloro-1-phenylethaneboronic ester (II). This scheme also worked well for the analogous *p*-methyl compound, but only low yields of *p*-methoxystyreneboronic ester were obtained and further work with the *p*-methoxy series was not attempted.

We also explored a new route to 1-phenylethaneboronic acids involving the rearrangement of an (α-iodoethyl)phenylborinic ester (IV). The required borinic ester was synthesized by addition of hydrogen iodide to butylphenylvinylborinate (III)[2]. Treatment of the α-iodo compound with base, triethylamine in butanol, causes migration of the phenyl group from boron to carbon[3] to form dibutyl 1-phenylethaneboronate (V).

$$\underset{\substack{|\\OBu}}{C_6H_5-B-CH=CH_2}\ (III) \xrightarrow{HI} \underset{\substack{|\\OBu}}{C_6H_5-B-\overset{\overset{I}{|}}{CH}-CH_3}\ (IV)$$

$$\xrightarrow[BuOH]{Et_3N} (BuO)_2B-\underset{\substack{|\\C_6H_5}}{CH}-CH_3\ (V) + \text{some } (BuO)_2BC_6H_5$$

The difficulty with this synthesis turned out to be the ease of protolysis of the borinic ester. Approximately half the product, according to NMR measurements, consisted of benzeneboronic ester. This was separated from the desired product only with extremely careful fractionation. In several attempts to prepare 1-[*m*-(trifluoromethyl)phenyl]ethaneboronic ester, we obtained NMR evidence that the desired product was present but we were never able to separate it from the corresponding (trifluoromethyl)benzeneboronic ester.

RESULTS

The availability of α-styreneboronic ester (VI) led us to try several addition reactions to the double bond. Hydrogen bromide added in the usual manner[4]. Treatment of the resulting 1-bromo-1-phenylethaneboronic ester (VII) with sodium butoxide yielded dibutyl 1-butoxy-1-phenylethane-1-boronate (VIII).

$$\underset{\substack{|\\B(OBu)_2}}{C_6H_5-C=CH_2}\ (VI) + HBr \rightarrow \underset{\substack{|\\B(OBu)_2}}{C_6H_5-\overset{\overset{Br}{|}}{C}-CH_3}\ (VII) \xrightarrow{BuONa} \underset{\substack{|\\B(OBu)_2}}{C_6H_5-\overset{\overset{OBu}{|}}{C}-CH_3}\ (VIII)$$

The same butoxy compound was obtained when attempts were made to displace the bromide ion by mercaptide ions. Other similar examples of failure of mercaptide ions to displace bromide were discovered subsequent to this work and have been reported previously[3].

Mercuric chloride reacts readily with either the α-bromo or α-butoxy boronic ester (VII or VIII) in the presence of sodium acetate and glycerol in aqueous ethanol to yield mercurous chloride and acetophenone (confirmed as the 2,4-dinitrophenylhydrazone).

Hydroboration of dibutyl α-styreneboronate yielded mainly tetrabutyl phenylethane-1,2-diboronate (IX), with a little of the 1,1-isomer as by-product. Treatment of the 1,2-isomer with alkaline hydrogen peroxide under conditions we have described previously[6] gave a moderate yield of phenylethane-1,2-diol. Acetophenone was obtained by similar treatment of the 1,1-isomer. We did not look for any evidence of complex fragmentation products, which have been reported by Pasto and coworkers[7] subsequent to our completion of this brief investigation.

Treatment of phenylethane-1,2-diboronic ester (IX) with mercuric chloride and sodium acetate yielded polystyrene, confirmed by its infrared spectrum.

$$C_6H_5\underset{\underset{B(OBu)_2}{|}}{CH}-CH_2-B(OBu)_2 + HgCl_2 \rightarrow [C_6H_5CH=CH_2] \rightarrow \text{polymer} + Hg_2Cl_2$$

(IX)

$$\xrightarrow{H_2O_2} C_6H_5\underset{\underset{OH}{|}}{CH}-CH_2OH$$

One of our objectives in synthesizing a series of substituted 1-phenylethaneboronic esters was to compare their relative reactivities toward mercuric chloride. Dibutyl 1-(*p*-chlorophenyl)ethaneboronate (II) yielded the expected 1-(*p*-chlorophenyl)ethylmercuric chloride (X).

$$p\text{-}ClC_6H_4\underset{\underset{CH_3}{|}}{CH}-B(OBu)_2 + HgCl_2 + NaOAc \rightarrow p\text{-}ClC_6H_4\underset{\underset{CH_3}{|}}{CH}-HgCl$$

(II) (X)

1-*p*-Tolylethaneboronic ester reacted readily with mercuric chloride, but the organomercury product decomposed during attempted recrystallization.

The kinetics were followed by a method which has been described previously[8], involving oxidation of unreacted boronic ester with hydrogen peroxide and gas chromatography of the resulting alcohol. Previous precision was ±5–10%, but random errors with the present series of compounds were about ±10–20%. After this work was completed, Krämer developed a much better analytical method based on titration of the unreacted mercuric chloride[9]. The new method revealed some inherent curvature and randomness in the kinetics, as if the product were decomposing after an induction period. We therefore changed to the benzylboronic ester series for quantitative kinetic studies[9], and will summarize the semiquantitative results with the 1-phenylethyl series briefly here.

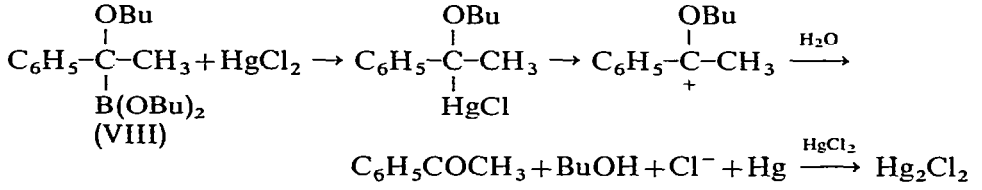
We began our studies with aqueous acetone as the solvent[8], but soon found that rate constants determined with day-old solutions of mercuric chloride, sodium acetate, and glycerol were considerably less than those obtained with fresh solutions, an effect not observed in the norborneneboronic ester work[8]. Aqueous ethanol showed no such mysterious aging effect and was therefore used for kinetic studies. However,

alcohol did have the disadvantage of shifting the equilibrium for dissociation of $HgCl_3^-$ into a mathematically inconvenient range[9].

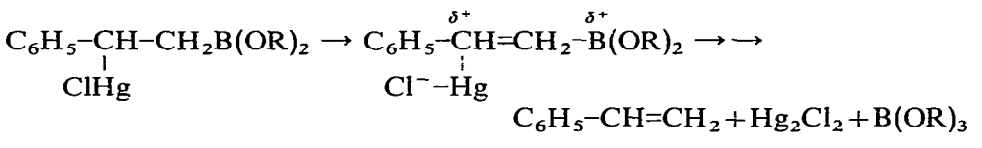
Relative rates of reaction with mercuric chloride are dibutyl benzylboronate[9], 1.0; 1-phenylethaneboronate, 0.50 (±0.07); 1-(*p*-chlorophenyl)ethaneboronate, 0.04 (±0.01); 1-[*m*-(trifluoromethyl)phenyl]ethaneboronate (impure), ~0.015, at 40° in 88% ethanol, 8% water, and 4% glycerol buffered with sodium acetate and acetic acid. All reactants were kept at a constant set of concentrations for purposes of comparison. With dibutyl 1-phenylethaneboronate, we also varied the initial concentrations of sodium chloride, mercuric chloride, and sodium acetate and observed the same rate dependences (± 15%) found subsequently with dibutyl benzylboronate[9].

DISCUSSION

Solvolyses of alkylmercuric ions, $R-Hg^+$, to carbonium ions, R^+, and metallic mercury are known and the rates are strongly dependent on the stability of the carbonium ion formed[10]. This or a related process seems the most likely cause of our failure to obtain an α-alkoxyalkylmercuric chloride from dibutyl 1-butoxy-1-phenylethaneboronate (VIII).



Similarly, the hypothetical mercury compound which would result from phenylethane-1,2-diboronic ester and mercuric chloride can form a "carbonium ion" which is probably stabilized by the concerted loss of the remaining boron atom.



The limited stability of the 1-phenylethylmercuric chlorides, especially the *p*-methyl-substituted compound, may be due to similar decomposition. Mercurous chloride was formed as a by-product during mercuri-deboronations, and our problems with the kinetics can be rationalized on this basis. Any 1-phenylethanol formed by solvolysis of the phenylethylmercuric chloride would appear as if it were unreacted boronic ester in the analytical results, and chloride ion released by the solvolysis would tend to inhibit the reaction. Some observations in the present and earlier[1] work suggest that a chain reaction, perhaps catalyzed by mercurous chloride, may be involved rather than simple solvolysis.

Though our kinetic data are reproducible at the ±20% level, there remains the possibility of larger systematic errors. The *p*-chloro compound in particular gave an abnormally low temperature coefficient (factor of ~1.5 increase between 30 and 40°) and seemed to stop reacting short of completion, as if some solvolysis of the

mercurial product were occurring. Even so, the apparent relative rate constant at 40° must be a substantial fraction (half or more) of the true value, and the qualitative relationship that it reacts slower than the unsubstituted compound is not in doubt.

The two electron-withdrawing groups tested, *p*-Cl and *m*-CF_3, clearly have a considerable rate-retarding effect on mercuri-deboronation. (The *p*-CH_3 rate was not measured.) This is the reverse of the overall effect observed in the benzylboronic ester series[9]. The mechanism is believed to involve attack of $HgCl_2$ on the anion (*i.e.*, hydroxide ion adduct) of the glyceryl boronic ester[9], the details of which will not be repeated here. In spite of the overall negative charge, the carbon atom on which the displacement takes place evidently acquires a partial positive charge in the transition state. Carbonium ion character is normally associated with nucleophilic displacement, but in an electrophilic displacement involving electropositive heteroatoms it would seem natural to expect some carbanion character in the transition state, as seen in some mercury(II) exchanges[11]. A qualitative quantum mechanical rationalization of our observations requires that there be some direct mercury–boron interaction in the transition state[9], an idea which will be discussed more fully in a forthcoming review[12].

We also synthesized dibutyl butane-2-boronate and attempted to react it with mercuric chloride, but we were unable to find any conditions under which any reaction other than slow formation of mercurous chloride would take place. It is clear that the very low reactivity of this sec-alkaneboronic ester is not a result of polar or steric effects, but that the phenyl group stabilizes the transition state for electrophilic displacement by a nonpolar conjugative effect.

EXPERIMENTAL

Dibutyl p-chloro-α-styreneboronate

p,α-Dichlorostyrene was prepared from *p*-chloroacetophenone and phosphorous pentachloride by a method previously described for the preparation of α-chlorostyrene[1], b.p. 104–107° (10 mm) [reported[13], 108–110° (18 mm)]. This was converted to *p*-chlorostyrylmagnesium chloride and from there to dibutyl *p*-chloro-α-styreneboronate in the manner previously described for dibutyl styreneboronate[1]. The yield was 40%, b.p. 95–98° (0.1 mm), $n_D^{25.5}$ 1.4971. (Found: C, 65.47; H, 8.36; B, 3.55; Cl, 11.79. $C_{16}H_{24}BClO_2$ calcd.: C, 65.22; H, 8.21; B, 3.67; Cl, 12.03%.)

Dibutyl 1-(p-chlorophenyl)ethaneboronate

This compound was prepared by catalytic hydrogenation[1] of dibutyl *p*-chloro-α-styreneboronate, b.p. 80° (0.1 mm). (Found: C, 64.99; H, 9.05; B, 3.84; Cl, 11.69. $C_{16}H_{26}BClO_2$ calcd.: C, 64.77; H, 8.84; B, 3.65: Cl, 11.95%.)

Dibutyl p-methyl-α-styreneboronate

This compound was prepared by the usual method, b.p. 98–101° (0.05 mm), $n_D^{25.5}$ 1.4091. (Found: C, 74.18; H, 9.98; B, 3.73. $C_{17}H_{27}BO_2$ calcd.: C, 74.46; H, 9.93; B, 3.95%.)

Dibutyl 1-(p-methylphenyl)ethaneboronate

This compound was prepared by the usual hydrogenation procedure, b.p.

78–80° (0.05 mm), n_D^{26} 1.4722. (Found: C, 74.01; H, 10.56; B, 4.11. $C_{17}H_{25}BO_2$ calcd.: C, 73.92; H, 10.58; B, 3.92%.)

Dibutyl p-methoxy-α-styreneboronate

Great difficulty was encountered in forming the Grignard reagent from *p*-methoxy-α-chlorostyrene in tetrahydrofuran, but a small amount resulted sometimes when the reaction mixture was refluxed 15 h. The best yield of product was about 10%, b.p. 119° (0.5 mm), n_D^{27} 1.4989. (Found: C, 70.53; H, 9.46; B, 3.57. $C_{17}H_{27}BO_3$ calcd.: C, 70.35; H, 9.38; B, 3.73%.)

1-(*p-Chlorophenyl*)*ethylmercuric chloride*

A solution of 3.6 g of sodium chloride, 3.0 g of mercuric chloride, and 0.9 g of sodium acetate in 15 ml of glycerol and 24 ml of water was mixed with a solution of 1.93 g of dibutyl-1-(*p*-chlorophenyl)ethaneboronate in 9 ml of acetone, 15 ml of glycerol, and 24 ml of water. The crystalline product was collected after 24 h, yield 1.3 g, recrystallized under nitrogen from aqueous acetone and finally from acetone alone, m.p. 129–131°. (Found: C, 25.71; H, 2.40; Cl, 18.67; Hg, 53.66. $C_8H_8Cl_2Hg$ calcd.: C, 25.58; H, 2.15; Cl, 18.88; Hg, 53.40%.)

1-(*p-Methylphenyl*)*ethylmercuric chloride*

This compound was prepared by the same method, m.p. 110–112°. However, this compound seemed to be unstable and we were unable to obtain a satisfactory analytical sample.

Dibutyl 1-bromo-1-phenylethaneboronate

This compound was prepared by the addition of 15.6 g of dibutyl α-styreneboronate to 20 ml of liquid hydrogen bromide at −75°. The mixture was stirred at −75° for 2 h, then allowed to warm to room temperature and purified by molecular distillation. (Found: C, 56.32; H, 7.39; B, 3.16; Br, 23.70. $C_{16}H_{26}BBrO_2$ calcd.: C, 56.34; H, 7.68; B, 3.17; Br, 23.43%.)

Dibutyl 1-butoxy-1-phenylethaneboronate

This compound was prepared by the method used by Matteson and Mah for similar compounds[3], b.p. 105° (0.2 mm). (Found: C, 71.88; H, 10.47; B, 3.15. $C_{20}H_{35}BO_3$ calcd.: C, 71.85; H, 10.55; B, 3.24%.)

Tetrabutyl 1-phenylethane-1,2-diboronate

A diborane solution was prepared by the addition of 42.5 g of boron trifluoride etherate in 125 ml of tetrahydrofuran to a solution of 7.9 g of sodium borohydride in 50 ml of diglyme and 125 ml of tetrahydrofuran at 0°. Dibutyl α-styreneboronate was added dropwise in 0.5 h. After stirring overnight, the mixture was cooled to 0° and treated with 75 ml of butanol added in 1 h (hydrogen evolution). Distillation yielded 22 g of tetrabutyl 1-phenylethane-1,2-diboronate, b.p. 118–122° (0.1 mm), $n_D^{25.5}$ 1.4722. (Found: C, 68.72; H, 10.32; B, 5.40. $C_{24}H_{44}B_2O_4$ calcd.: C, 68.92; H, 10.60; B, 5.17%.) A higher boiling fraction (5 g) contained mainly tetrabutyl 1-phenylethane-1,1-diboronate mixed with some 1,2-isomer, b.p. 134–140° (0.1 mm), as shown by alkaline hydrogen peroxide oxidation[6].

Dibutyl 2-butaneboronate

This compound was prepared by the usual boronic ester synthesis from 2-butylmagnesium bromide and methyl borate followed by treatment with butanol, b.p. 50–52° (0.2 mm), n_D^{28} 1.4108. (Found: C, 66.85; H, 12.40; B, 4.88. $C_{12}H_{17}BO_2$ calcd.: C, 67.03; H, 12.71; B, 5.06%.) With mercuric chloride under the usual conditions for mercuri-deboronation the only mercury-containing product was mercurous chloride.

Dibutyl 1-phenylethaneboronate from butyl B-phenyl-B-vinylborinate

Butyl *B*-phenyl-*B*-vinylborinate[2] (14.0 g) was added dropwise in 35 min under nitrogen to 6 ml of liquid hydrogen iodide at −50° and kept at −50° 2 h. The mixture was then allowed to warm to room temperature and the residue was treated with 30 ml of ether and cooled to −75°. 20 ml of butanol was added, followed by 20 ml of triethylamine. The precipitated triethylammonium iodide was filtered at 0° and the solution was concentrated under vacuum. Fractionation of the residue yielded 8.7 g of dibutyl 1-phenylethaneboronate, b.p. 88° (0.2 mm), infrared spectrum the same as that of an authentic sample.

Butyl B-(p-chlorophenyl)-B-vinylborinate

This compound was prepared by the method used by Matteson and Mah for similar compounds[2] in 52% yield, b.p. 95–97° (0.2 mm). (Found: C, 64.92; H, 7.25; B, 4.78; Cl, 15.75. $C_{12}H_{16}BClO$ calcd.: C, 64.78; H, 7.20; B, 4.86; Cl, 15.97%.) An attempt to rearrange this compound to dibutyl 1-(*p*-chlorophenyl)ethaneboronate by the method used for the unsubstituted compound gave only dibutyl *p*-chlorobenzeneboronate.

Butyl B-[m-(trifluoromethyl)phenyl]-B-vinylborinate

This compound was similarly prepared and purified by fractional distillation, b.p. 50–52° (0.2 mm). It appeared to disproportionate slowly during distillation to yield some dibutyl *m*-(trifluoromethyl)benzeneboronate. (Found: C, 61.24; H, 6.40; B, 4.21; F, 21.38. $C_{13}H_{16}BF_3O$ calcd.: C, 60.98; H, 6.25; B, 4.22; F, 22.28%.)

Dibutyl 1-[m-(trifluoromethyl)phenyl]ethaneboronate

Butyl *B*-[*m*-(trifluoromethyl)phenyl]-*B*-vinylborinate was added to hydrogen bromide at −78° and treated in the same manner as the unsubstituted borinic ester to yield impure dibutyl 1-[*m*-(trifluoromethyl)phenyl]ethaneboronate, b.p. 95–98° (0.2 mm). The NMR spectrum showed some contamination with *m*-(trifluoromethyl)-benzeneboronic ester, as did the analytical results. (Found: C, 62.0; H, 7.3; B, 4.3; F, 16.9. $C_{17}H_{26}BF_3O_2$ calcd.: C, 61.9; H, 7.9; B, 3.3; F, 17.3%.)

Dibutyl 1-butoxy-1-phenylethaneboronate and mercuric chloride

A solution of 1.2 g of sodium chloride, 1.0 g of mercuric chloride, and 0.3 g of sodium acetate in 8 ml of water, 5 ml of glycerol, and 3 ml of acetone was mixed with a solution of 0.65 g of dibutyl 1-butoxy-1-phenylethaneboronate in the same quantities of solvents. After 3 days at 20–25°, filtration yielded 0.48 g of mercurous chloride (confirmed by formation of mercury metal in pyridine) and extraction of the filtrate with ether yielded butanol and acetophenone (confirmed by infrared). The acetophenone was further identified by conversion to its 2,4-dinitrophenyl-

hydrazone, which was identical with an authentic sample by mixture m.p. (249–250°). Similar reaction conditions with dibutyl 1-bromo-1-phenylethaneboronate yielded the same products.

Tetrabutyl phenylethane-1,2-diboronate and mercuric chloride

A solution of 6.0 g of sodium chloride, 5.0 g of mercuric chloride, and 1.5 g of sodium acetate in 25 ml of glycerol, and 40 ml of water was mixed with 2.1 g of tetrabutyl phenylethane-1,2-diboronate in 15 ml of acetone, 25 ml of glycerol, and 40 ml of water. Precipitation of mercurous chloride began almost at once. After 16 h, filtration yielded 2.3 g of mercurous chloride. Extraction of the filtrate with ether followed by distillation yielded butanol, butyl acetate, and a nonvolatile residue indentified as polystyrene by its characteristic infrared spectrum.

Kinetics

The analytical method[8] and mathematical analysis[9] have been described in detail previously. In the present work, we used benzyl alcohol or 3-phenylpropanol as the internal reference standard for the gas chromatographic analyses. Representative data shown in Fig. 1 were plotted assuming the initial sodium chloride concentration equalled the total free chloride, one of the arbitrary choices which generally gives linear plots[9].

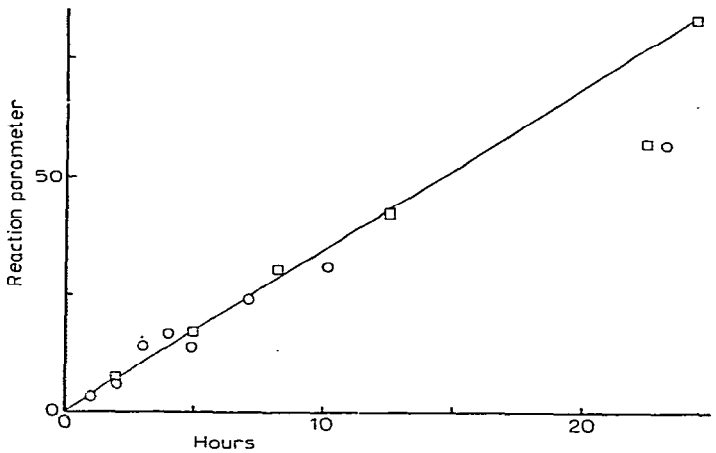


Fig. 1. Plot of $A \cdot \ln[a/(a-x)] + B \cdot \ln[b/(b-x)] + C \cdot \ln[c/(c-x)]$ ("reaction parameter") against time for the reaction of glyceryl 1-phenylethaneboronate with mercuric chloride in aqueous ethanol at 40°. ○: boronic ester, 0.032; $HgCl_2$, 0.066; NaCl, 0.051; NaOAc, 0.043 *M*; □: boronic ester, 0.021; NaCl, 0.079 *M*; others unchanged.

REFERENCES

1 D. S. MATTESON AND R. A. BOWIE, *J. Amer. Chem. Soc.*, 87 (1965) 2587.
2 D. S. MATTESON AND R. W. H. MAH, *J. Org. Chem.*, 28 (1963) 2171.
3 D. S. MATTESON AND R. W. H. MAH, *J. Amer. Chem. Soc.*, 85 (1963) 2599.
4 D. S. MATTESON AND G. D. SCHAUMBERG, *J. Org. Chem.*, 31 (1966) 726.
5 D. S. MATTESON AND J. D. LIEDTKE, *Chem. Ind. (London)*, (1963) 1241.

6 D. S. MATTESON AND J. O. WALDBILLIG, *J. Org. Chem.*, 28 (1963) 366.
7 D. J. PASTO, J. CHOW AND S. K. ARORA, *Tetrahedron Lett.*, (1967) 723.
8 D. S. MATTESON AND M. L. TALBOT, *J. Amer. Chem. Soc.*, 89 (1967) 1119.
9 D. S. MATTESON AND E. KRÄMER, *J. Amer. Chem. Soc.*, in press.
10 F. R. JENSEN AND R. J. OUELLETTE, *J. Amer. Chem. Soc.*, 83 (1961) 4477, 4478; 85 (1963) 363, 367.
11 J. A. REUTOV, *Dokl. Akad. Nauk SSSR*, 163 (1965) 909.
12 D. S. MATTESON, *Organometal. Chem. Rev.*, manuscript in preparation.
13 D. WOODCOCK, *J. Chem. Soc.*, (1949) 203.