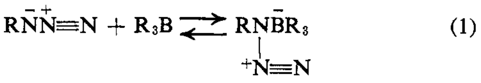
Facile Reaction of Dialkylchloroboranes with Organic Azides. A Remarkable Enhancement of Reactivity Relative to Trialkylboranes

Sir:

Organic azides undergo a facile reaction with a wide variety of dialkylchloroboranes, now readily available *via* hydroboration of olefins with chloroborane diethyl etherate.[1] The reaction is considerably faster than the related reaction with the corresponding trialkylboranes. In contrast to trialkylboranes, even dialkylchloroboranes containing a secondary alkyl group readily react with azides to give good yields of secondary amines upon hydrolysis.

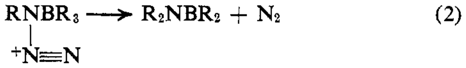
Triethylborane reacts with a wide variety of organic azides.[2] Refluxing xylene is required to achieve a convenient rate of reaction. Unfortunately, the reaction becomes quite slow with sterically hindered azides and fails when both sterically hindered azides and sterically hindered organoboranes are utilized.[2]

These results were interpreted in terms of a mechanism involving reversible coordination of the azide with the trialkylborane (eq 1). This step could be followed



$$R\overset{-}{N}\overset{+}{N}{\equiv}N + R_3B \rightleftharpoons R\underset{\substack{| \\ ^{+}N\equiv N}}{N}\bar{B}R_3 \qquad (1)$$

by loss of nitrogen from the intermediate with subsequent (or concurrent) migration of the alkyl group from boron to nitrogen (eq 2). Apparently with more hindered alkyl groups on boron the azide cannot coordinate with the borane.



$$R\underset{\substack{| \\ ^{+}N\equiv N}}{N}\bar{B}R_3 \longrightarrow R_2NBR_2 + N_2 \qquad (2)$$

The reagent 9-borabicyclo[3.3.1]nonane[3] (9-BBN) has been extensively utilized in other systems to overcome such steric difficulties.[4] However, in the present case, we discovered that the *B*-cyclooctyl bond migrates to the exclusion of the *B*-alkyl group. Similar results have been noted for the reaction of diazoacetone and ethyl diazoacetate with *B*-alkyl 9-BBN.[5]

The now ready availability of dialkylchloroboranes[1] led us to explore their reaction with organic azides. Di-*n*-butylchloroborane was prepared in diethyl ether and *n*-butyl azide added at room temperature. There occurred a surprisingly rapid evolution of a gas, presumably nitrogen. After 1 hr 1 mol of gas/mol of reagents had evolved. Upon hydrolysis with water and neutralization with aqueous 40% potassium hydroxide solution, glpc examination revealed a 71% yield of di-*n*-butylamine with no other amine products present.

The reaction of di-*n*-butylchloroborane with *n*-butyl azide may be compared to that of triethylborane with *n*-butyl azide. The former is relatively rapid even at room temperature while the latter requires 6 hr in refluxing xylene. As was pointed out earlier, more hindered azides, such as cyclohexyl azide, require up to 24 hr for completion of their reactions with triethylborane. With the more hindered trialkylboranes the reaction fails completely.

A number of dialkylchloroboranes with representative alkyl groups were prepared and treated with organic azides. The boranes proved to be quite reactive relative to the trialkylborane, even when the alkyl groups in the boron derivative and in the organic azide were both secondary. For example, dicyclopentylchloroborane requires only 4 hr for completion of its reaction with cyclohexyl azide in refluxing toluene and 24 hr in refluxing benzene. The results of these reactions are reported in Table I.

Table I. Reaction of Dialkylchloroboranes with Organic Azides for the Synthesis of Secondary Amines

Dialkylchloroborane, R_2BCl[a]	Organic azide, $R'N_3$,[b] R′ =	Time, hr	Yield,[c] % RR′NH
Di-*n*-butylchloroborane	*n*-Butyl	1[d]	71
	Cyclohexyl	1.1	72
	Phenyl	1	72
Diisobutylchloroborane	Cyclohexyl	4	73
Di-*sec*-butylchloroborane	Cyclohexyl	5	51
Dicyclopentylchloroborane	*n*-Butyl	1	80
	Cyclohexyl	4	80
	Phenyl	4	74
Dicyclohexylchloroborane	Cyclohexyl	4	76

[a] 5 mmol in 5.5 ml of diethyl ether. [b] 5 mmol added with 2.5 ml of toluene. [c] Based on azide by glpc analysis. All compounds were isolated by glpc and exhibited analytical and spectral data in accordance with the assigned structure. [d] The reaction was at room temperature.

The yields based on dialkylchloroborane may be improved by use of an excess of alkyl azide as indicated by the following results for dicyclopentylchloroborane with cyclohexyl azide in benzene (equivalents of azide (per cent yield)): 1.0 (80%), 1.3 (82%), 1.5 (92%).

The following procedure for the preparation of cyclohexylcyclopentylamine is representative. A dry 200-ml flask equipped with a septum inlet, distilling head, and magnetic stirrer was flushed with nitrogen and maintained under positive nitrogen pressure. The flask was cooled to 0° and charged with 55 ml of a 0.91 *M* chloroborane (50 mmol) solution in ether.[1] Then 7.5 g of cyclopentene (110 mmol) was added dropwise. The solution was stirred at 0° for 1 hr. Finally, 6.25 g of cyclohexyl azide[6] (50 mmol) was added, followed by 25 ml of dry toluene. The resulting solution was heated to remove the diethyl ether and maintained at gentle reflux once the ether was removed. After 4 hr, nitrogen evolution had ceased. The reaction mixture was cooled and cautiously hydrolyzed with 20 ml of water. The amine was extracted with 20 ml of 6 *N* hydrochloric acid and 70 ml of water. The organic phase was washed with 20 ml of 6 *N* hydrochloric acid. The combined aqueous phases were washed with 50 ml of ether to remove residual boronic acid. The solution was made strongly basic with 40% aqueous potassium hydroxide and the amine extracted with ether. The ether layer was dried (K_2CO_3) and distilled. There was ob-

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(1) H. C. Brown and N. Ravindran, *J. Amer. Chem. Soc.*, **94**, 2112 (1972).

(2) A. Suzuki, S. Sono, M. Itoh, H. C. Brown, and M. M. Midland, *ibid.*, **93**, 4329 (1971).

(3) E. F. Knights and H. C. Brown, *ibid.*, **90**, 5280, 5281, 5283 (1968).

(4) H. C. Brown, M. M. Rogić, H. Nambu, and M. W. Rathke, *ibid.*, **91**, 2147 (1969).

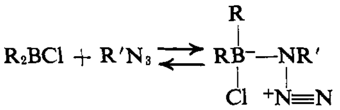
(5) H. C. Brown and M. M. Rogić, *ibid.*, **91**, 2146 (1969); J. Hooz and D. M. Gunn, *Tetrahedron Lett.*, 3455 (1969).

(6) Cyclohexyl azide was prepared from cyclohexyl bromide and excess sodium azide in DMF in analogy with A. J. Parker, *J. Chem. Soc.*, 1328 (1961).

tained 6.2 g (74%) of cyclohexylcyclopentylamine: bp 83.0–83.5° (2.4 mm); $n^{20}D$ 1.4796 (lit.[7] bp 118–120° (17 mm)).

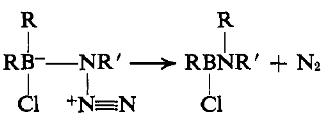
Primary dialkylchloroboranes and primary azides react smoothly at room temperature. Others require higher temperature. Addition of the azide at room temperature followed by distillation of the ether and slowly raising the temperature to refluxing toluene allows one to gradually increase the rate of reaction to bring it to completion.

The increased reactivity of the dialkylchloroboranes may be attributed to the increased Lewis acidity. The reaction presumably involves reversible coordination of the azide with the borane (eq 3), followed by a trans-

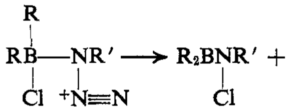


$$R_2BCl + R'N_3 \rightleftarrows R\overset{R}{\underset{Cl}{B^-}}—\underset{^+N{\equiv}N}{N}R' \quad (3)$$

fer from boron to nitrogen. Whether there is alkyl group (eq 4) or chloride (eq 5) migration has not as yet

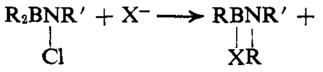


$$R\overset{R}{\underset{Cl}{B^-}}—\underset{^+N{\equiv}N}{N}R' \longrightarrow R\overset{R}{\underset{Cl}{B}}NR' + N_2 \quad (4)$$



$$R\overset{R}{\underset{Cl}{B}}—\underset{^+N{\equiv}N}{N}R' \longrightarrow R_2B\underset{Cl}{N}R' + N_2 \quad (5)$$

been established. Chloride migration would produce an intermediate, which upon attack by a nucleophile, X^-, could undergo alkyl group migration (eq 6), as may



$$R_2B\underset{Cl}{N}R' + X^- \longrightarrow \underset{X}{RB}\underset{R}{N}R' + Cl^- \quad (6)$$

occur in the reaction of trialkylboranes with chloramine.[8]

Irrespective of the precise nature of the reaction mechanism, the dialkylchloroboranes provide a remarkably facile method of achieving reactions which are very sluggish with trialkylboranes. This increased reactivity suggests that it may be possible to achieve with dialkylchloroboranes many other types of reactions which have either been sluggish or have failed with trialkylboranes. We are continuing to explore these developments.

[7] K. Jewers and J. McKenna, *J. Chem. Soc.*, 2209 (1958).

[8] H. C. Brown, W. R. Heydkamp, E. Breuer, and W. S. Murphy, *J. Amer. Chem. Soc.*, **86**, 3568 (1964).

[9] National Science Foundation Predoctoral Fellow.

[10] Postdoctorate research associate on Grant No. GM 10937 from the National Institutes of Health.

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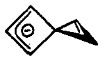
Kinetic Acidity as a Probe for Spiroaromaticity in a Spiro[2.3]hexadiene

Sir:

The electronic spectra of certain spirocycles[1] have been interpreted in terms of π-orbital interaction between the spiro-connected rings, an effect called spiroconjugation.[1] The ground states of particular spirocycles, called spirenes,[1b] with continuous ribbons of p orbitals in each ring,[2] are expected to be specially stabilized, a manifestation of spiroaromaticity. The effect should be noted in the stability of certain anions (*e.g.*, **1**), cations (*e.g.*, **2**), and diradicals (*e.g.*, **3**). Compared to the overlap of adjacent p orbitals in a benzene ring, the overlap between spirocyclic π systems is estimated at 20%.[1a,b] No previous study of spiroaromaticity in species **1–3** or related compounds has been reported.



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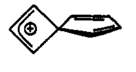

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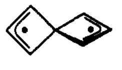

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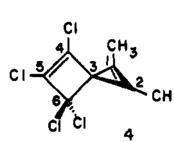
Part of the reason for the paucity of information is the absence of appropriate molecules from which to generate **1**, **2**, or **3**. We recently uncovered a simple route to the first examples of the spiro[2.3]hex-4-ene and spiro[2.3]hexadiene ring systems (*e.g.*, **4–6**)[3] and have therefore undertaken to test for spiroaromaticity in **7**, a derivative of anion **1**. Anion **7** is kinetically unstable, apparently undergoing α elimination of chloride anion and irreversible reaction of the resulting carbene,[4] which complicates the direct determination of the thermodynamic stability. Therefore, we studied the relative rates of formation of anion **7** and the corresponding anions of **5** and **6** where spiroaromaticity is not possible.



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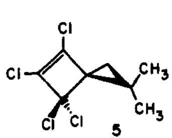

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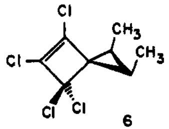

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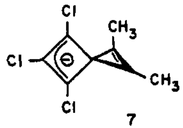

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Polarographic half-wave potentials for reduction of carbon–halogen bonds have been related to the stability of the resulting carbanions,[5] although in the case of benzylic halides, the half-wave potential seems to reflect the stability of the carbon radical rather than the carbanion.[5b] In acetonitrile, with 0.1 *M* tetraethylammonium perchlorate, the spirocycles **4**, **5**, and **6** show similar two-electron reduction half-wave potentials (1.68 ± 0.03 for **4**, 1.58 ± 0.02 for **5**, and 1.62 ± 0.02 V for **6**, relative to the saturated calomel electrode).[6] Thus the spiroaromaticity of **7** is *not* a significant factor in the rate of electrolytic formation of **7**; in fact, the polarographic results suggest that anion **7** is less easily formed than the anions from **5** and **6**.

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[1] (a) H. E. Simmons and T. Fukunaga, *J. Amer. Chem. Soc.*, **89**, 5208 (1967); (b) R. Hoffmann, A. Imamura, and G. D. Zeiss, *ibid.*, **89**, 5219 (1967); (c) R. Boschi, A. Dreiding, and E. Heilbronner, *ibid.*, **92**, 123 (1970).

[2] M. J. Goldstein and R. Hoffmann, *ibid.*, **93**, 6193 (1971).

[3] M. F. Semmelhack and R. J. DeFranco, *Tetrahedron Lett.*, 1061 (1971).

[4] Attempts to metalate **4** with *n*-butyllithium at −30 to 0° followed by quenching with water gave no trace of **4** or **8**.

[5] (a) P. Zuman, *Collect. Czech. Chem. Commun.*, **25**, 3225 (1960); (b) A. Streitwieser and C. Perrin, *J. Amer. Chem. Soc.*, **86**, 4938 (1964); (c) F. L. Lambert, *J. Org. Chem.*, **31**, 4184 (1966).

[6] Preparative-scale electrolyses in acetonitrile containing 0.1 *M* tetraethylammonium perchlorate under conditions parallel with the polarographic experiments afforded the series of spirocycles **8–11** as the only products; thus, the half-wave potentials correspond to reduction of one of the allylic chlorine atoms.[7]

[7] M. F. Semmelhack, R. DeFranco, and J. Stock, submitted for publication elsewhere.