REACTION OF B-(1-ALKENYL)-DIALKYLBORANES WITH ISOCYANATES†

Bakthan Singaram, Gary A. Molander and Herbert C. Brown*
Richard B. Wetherill Laboratory, Purdue University, West Lafayette, Indiana 47907, U.S.A.

9-(1-Alkenyl)-9-borabicyclo[3.3.1]nonanes [9-(1-alkenyl)-9-BBN], easily prepared by hydroboration of the corresponding alkynes with 9-borabicyclo[3.3.1]nonane (9-BBN), undergo remarkably facile reaction with two equivalents of isocyanates to give the intermediates (6), which on hydrolysis, provide in excellent yield \( N,N' \)-disubstituted \( N-(2\text{-alkenyl}) \)-ureas. B-(1-Octenyl)-dicyclohexylborane reacts with aliphatic and aromatic isocyanates to furnish the novel heterocycle (U), which on hydrolysis yields \( N,N' \)-disubstituted \( N-(3\text{-cyclohexyl}) \)-nonanyl-ureas. B-(1-Alkenyl)disiamylboranes are inert towards isocyanates.

Recently we described the reaction of 9-(1-alkynyl)-9-borabicyclo[3.3.1]nonanes with isocyanates to provide, after protonolysis, the corresponding \( N,N' \)-disubstituted \( N-(2\text{-alkynyl}) \)-ureas (1).\(^1\)

\[
\begin{align*}
\text{BC} &= \text{CR} + 2 \text{R}_1 \text{NCO} \quad \text{Et}_2 \text{O} \quad \text{RT} \quad \text{H}_2 \text{NCH}_2 \text{CH}_2 \text{OH} \quad \text{R}_1 \text{NCOC} \text{C} &= \text{CR} \quad \text{B}_2 \text{N} \quad \text{H}_2 \text{N} \\
\end{align*}
\]

(1)

We noted in that article that the course of the reaction of organoboranes with isocyanates is critically dependent on the type of organoborane utilized.\(^2\) For example, trialkylboranes do not react with isocyanates under normal conditions, while triarylboranes react with two equivalents of isocyanates to provide diaminoboranes (2).

\[
\begin{align*}
\text{ArCN} &= \text{B} \quad \text{N} \quad \text{Ar} \\
\end{align*}
\]

(2)

†Cordially dedicated to Prof. Dr. Tetsuji Kametani on the occasion of his retirement.
Although Mikhailov had observed that the alkenyldialkylborane (3) reacted to provide the substituted urea derivative (4), no experimental details were published. Moreover, to our knowledge, the method was only utilized to prepare a single compound. Consequently, we set out to explore the reaction in greater detail to elucidate the structure of the intermediate formed and to establish that the method was indeed general for a variety of alkenyldialkylboranes and isocyanates.

Initially our study concentrated on the 9-(1-alkenyl)-9-borabicyclo[3.3.1]nonanes \(9-(1\text{-alkenyl})-9-\text{BBN} \) (5). We discovered that the reaction proceeded with remarkable ease in diethyl ether, (EE), to provide excellent yields of the intermediate (6), which precipitates in most cases from the reaction mixture as a yellow solid (Table I).

<table>
<thead>
<tr>
<th>(R^1)</th>
<th>(R^2)</th>
<th>Isolated yield</th>
<th>mp</th>
<th>(\text{H}^1\text{B nmr}) ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Chloro-n-propyl</td>
<td>Phenyl</td>
<td>80</td>
<td>124-126</td>
<td>+ 8.3</td>
</tr>
<tr>
<td>n-Butyl</td>
<td>Phenyl</td>
<td>80</td>
<td>128-130</td>
<td>+ 7.4</td>
</tr>
<tr>
<td>tert-Butyl</td>
<td>Phenyl</td>
<td>93</td>
<td>178-180</td>
<td>+ 9.6</td>
</tr>
<tr>
<td>n-Butyl</td>
<td>n-Butyl</td>
<td>---</td>
<td>---</td>
<td>+10.2</td>
</tr>
<tr>
<td>n-Butyl</td>
<td>Cyclohexyl</td>
<td>80</td>
<td>138-140</td>
<td>+ 7.5</td>
</tr>
<tr>
<td>n-Butyl</td>
<td>1-Naphthy</td>
<td>90</td>
<td>129-131</td>
<td>+ 8.6</td>
</tr>
</tbody>
</table>

The intermediate was hydrolyzed with excess methanol; the solid product (7) then crystallizes out as a colorless solid in essentially quantitative yield. When the product is highly soluble in methanol, it is isolated by pumping off the volatiles under reduced pressure (0.1 mm Hg) (Table II).
TABLE II.  \(N,N'-\text{disubstituted} N-(2\text{-alkenoyl})\text{-ur}eas (7)\)

<table>
<thead>
<tr>
<th>(R^1)</th>
<th>(R^2)</th>
<th>Yield(^a)</th>
<th>mp or bp(^b)</th>
<th>Molecular Formula</th>
<th>Calculated</th>
<th>Found</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>°C</td>
<td></td>
<td>C H N Cl</td>
<td>C H N Cl</td>
</tr>
<tr>
<td>3-Chloro-(n)-propyl</td>
<td>Phenyl</td>
<td>70</td>
<td>85-86</td>
<td>(C_{19}H_{19}N_2O_2Cl)</td>
<td>66.6 5.6 8.2 10.3</td>
<td>66.4 5.5 8.1 10.4</td>
</tr>
<tr>
<td>(n)-Butyl</td>
<td>Phenyl</td>
<td>75</td>
<td>74-75</td>
<td>(C_{20}N_2O_2)</td>
<td>74.5 6.9 8.7 —</td>
<td>74.4 6.7 8.6 —</td>
</tr>
<tr>
<td>tert-Butyl</td>
<td>Phenyl</td>
<td>94</td>
<td>125-126</td>
<td>(C_{20}H_{22}N_2O_2)</td>
<td>74.5 6.9 8.7 —</td>
<td>74.7 6.8 8.5 —</td>
</tr>
<tr>
<td>(n)-Butyl</td>
<td>tert-Butyl</td>
<td>70</td>
<td>130/0.1 mm Hg</td>
<td>(C_{16}H_{30}N_2O_2)</td>
<td>68.0 10.7 9.9 —</td>
<td>68.2 10.6 9.7 —</td>
</tr>
<tr>
<td>(n)-Butyl</td>
<td>Cyclohexyl</td>
<td>65(^d)</td>
<td>95-96</td>
<td>(C_{20}H_{34}N_2O_2)</td>
<td>71.8 10.2 8.4 —</td>
<td>72.0 10.3 8.2 —</td>
</tr>
<tr>
<td>(n)-Butyl</td>
<td>1-Naphthyl</td>
<td>85</td>
<td>119-120</td>
<td>(C_{28}H_{26}N_2O_2)</td>
<td>79.6 6.2 6.6 —</td>
<td>79.5 6.3 6.6 —</td>
</tr>
</tbody>
</table>

\(^a\) Refers to pure, recrystallized (or distilled) product. Satisfactory spectral data (IR, \(^1\)H nmr) were obtained for all compounds.

\(^b\) Solid products were recrystallized from methanol. \(^d\) Isolated by pumping off 9-methoxy-9-borabicyclo[3.3.1]nonane (8) at 0.1 mm Hg.

Recrystallized from petroleum ether (bp 40-60°C).
The stereochemistry of the alkenyl group transferred is predefined by the hydroboration reaction, and strict retention of stereochemistry is observed by all spectral data. Reaction with both equivalents of isocyanate is virtually instantaneous. Thus the reaction of 9-(1-hexenyl)-9-BBN (5, \(R^1 = n-C_4H_9\)) with one equivalent of phenylisocyanate, followed by methanolysis, affords 1-hexene (48\% by glc analysis), the urea derivative (7) (\(R^1 = n-C_4H_9\), \(R^2 = C_6H_5\)), and methoxy-9-borabicyclo[3.3.1]nonane (8) as the only isolated products.

The mechanism of the reaction can be envisioned as an initial 1,2-addition of 9-(1-alkenyl)-9-BBN to the isocyanate, followed by rapid addition of a second equivalent of isocyanate through a six-membered transition state. In most cases, the intermediate (6) immediately precipitates out of the solution as a yellow solid.

Internal 9-alkenyl-9-BBN and \(\beta\)-alkenyldisiamylboranes do not react with isocyanates under the experimental conditions. \(\beta\)-Alkenylidicyclohexylboranes react differently with isocyanates. For example, \(\beta\)-(1-Octenyl)-dicyclohexylborane (9) reacts with two equivalents of isocyanate to give the intermediate (10), which is converted into the novel heterocyclic compound (11). Both the intermediate (10), as well as the heterocyclic compound (11), give, on hydrolysis with methanol, the
N,N'-disubstituted N-(3-cyclohexylnonanoyl)-urea (12).

**EXPERIMENTAL SECTION**

The ir spectra were recorded on a Perkin-Elmer 700 spectrophotometer. The \(^1\)H nmr spectra were recorded on a Varian T-60 (60 MHz) spectrometer and all of the chemical shifts are relative to TMS (0 ppm). The \(^13\)C nmr spectra were recorded on a Varian FT-80A (80 MHz) spectrometer and all chemical shifts are relative to BF\(_3\).EE (0 ppm). The microanalyses were performed by the Purdue Micronalytical Laboratory.

\(N,N'-\text{Diphenyl-N-}(4,4\text{-dimethyl-2-heptenoyl})-\text{urea (7, } R^1 = t-C_4H_9; R^2 = C_6H_5)\); Typical Procedure.

A dry, 50-ml centrifuge tube capped with a rubber septum and equipped with a magnetic stirring bar was flushed with dry nitrogen. The tube was charged with 9-(3,3-dimethyl-1-hexeny1)-9-BBN (5, \(R^1 = t-C_4H_9; 2.1 \text{ g, } 10 \text{ mM} \) dissolved in dry ethyl ether (8 ml). Phenylisocyanate (2.4 g, 20 mM) was added dropwise and the stirring continued for 6 h. The yellow solid was separated by centrifugation, washed with n-pentane (2 \(\times\) 10 ml) and dried to give the adduct (6, \(R^1 = t-C_4H_9; R^2 = C_6H_5\); 4.1 g (93%), mp 178-180°C. The adduct (2.2 g, 5 mM) was taken in a 50-ml centrifuge tube and methanol (5 ml) was added with stirring. The yellow adduct went into solution, and after 1 h, the crude urea derivative precipitated out. The reaction mixture was cooled to 0°C to insure complete precipitation and the product was separated from the mother liquor, which contained 9-methoxy-9-BBN (8), by centrifugation. The product was crystallized from a minimum amount of methanol, 1.5 g (94%), mp 125-126°C. (Found: C, 74.7; H, 6.8; N, 8.5. \(C_{20}H_{22}N_2O_2\) requires C, 74.5; H, 6.9; N, 8.7); ir (KBr) 3200, 2940, 1710, 1640, 1600, 1580 and 1500 cm\(^{-1}\); \(^1\)H nmr CDCl\(_3\) \(\delta\) 0.92 (s, 9H, \(t-\))
C₄H₉); 5.5 (d, J = 16 Hz, 1H, olefinic); 7.0-7.8 (m, 11H, aromatic and olefinic); and 11.6 (s, 1H, NH).

Reaction of α-(1-Octenyl)-dicyclohexylborane (9) with Phenyl Isocyanate. With the usual experimental setup, α-(1-octenyl)-dicyclohexylborane (2.88 g, 10 mM) in EE (8 ml) was mixed with phenyl isocyanate (2.4 g, 20 mM) at 25°C. After 3 h, a yellow solid precipitated out of solution. The solid was separated by centrifugation, washed with n-pentane (2 x 5 ml) and dried to give the intermediate (10), 3.7 g (70%), mp 129-131°C. ¹H nmr (CDCl₃) δ 0.8-2.3 (m, 35H); 5.6 (d, J = 16 Hz, 1H, olefinic), and 7.2 (m, 11H, aromatic and olefinic). When the above reaction mixture was stirred for 10 h without isolating the intermediate (10), a clear, colorless solution resulted. The intermediate (11) was isolated by pumping off the solvent, 4.5 g (85%), mp 105-107°C, ¹H nmr (CDCl₃) δ 0.86-2.0 (m, 35H); 3.13 (d, J = 12 Hz, 1H, olefinic) and 7.3 (m, 10H, aromatic). The intermediate (11) (2.6 g, 5 mM) was stirred with methanol (5 ml) for 1 h. Excess methanol and dimethoxydicyclohexylborane were pumped off at reduced pressure (0.1 mm Hg, 50°C). The crude N,N'-diphenyl-N-(3-cyclohexylnonanoyl)-urea (12, R = C₆H₅) was recrystallized from petroleum ether (bp 40-60°C), 1.65 g (75%), mp 103-104°C. (Found: C, 77.7; H, 8.6; N, 6.4. C₂₈H₃₈N₂O₂ requires C, 77.4; H, 8.8; N, 6.4). ¹H nmr (CDCl₃) δ 0.9-2.3 (m, 27H), 7.0-7.7 (m, 10H, aromatic), and 11.7 (s, 1H, NH).

Reaction of α-(1-Octenyl)-dicyclohexylborane (9) with n-Butylisocyanate. With the regular experimental setup, α-(1-octenyl)-dicyclohexylborane (2.88 g, 10 mM) in EE (8 ml) was mixed with n-butylisocyanate (1.98 g, 20 mM) at 25°C. The reaction mixture developed a yellow color, and after stirring for 24 h, the solution became almost colorless. Methanol (5 ml) was added to the reaction mixture and the stirring continued for one hour more. Excess methanol and dimethoxydicyclohexylborane were pumped off at reduced pressure (0.1 mm Hg, 50°C) to give pure N,N' -di-n-butyl-N-(3-cyclohexylnonanoyl)-urea (12, R = n-C₄H₉), 3.6 g (90%), bp 180-182°C (0.1 mm Hg). (Found: C, 73.11; H, 11.8; N, 7.0. C₂₄H₄₆N₂O₂ requires C, 73.0; H, 11.7; N, 7.1); ¹H nmr (CDCl₃) δ 0.87-2.2 (m, 41H), 3.0-3.3 (m, 4H).

Acknowledgement. The research was assisted financially by a grant from the National Institutes of Health.

REFERENCES

Received, 16th June, 1980