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# CONVERSION OF NON-CONJUGATED DIENES INTO CONJUGATED DIENE-ZIRCONOCENES VIA MULTIPOSITIONAL REGIOISOMERIZATION

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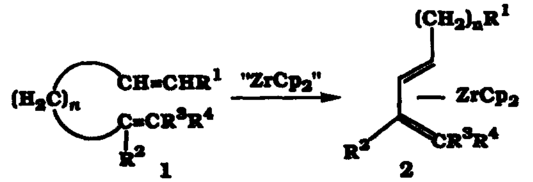
*Summary*: The reaction of $n$-$Bu_2ZrCp_2$ with non-conjugated dienes (1) containing a mono- or 1,2-disubstituted alkene at one end and a 1,1-di- or trisubstituted alkene at the other gives conjugated diene-zirconocenes 2 via multipositional regioisomerization.

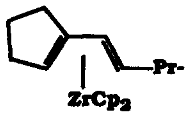
Bicyclization of non-conjugated dienes, such as 1,6-heptadiene and 1,7-octadiene,[1,2] with "$ZrCp_2$", such as that derived *in situ* from $n$-$Bu_2ZrCp_2$,[3] has been shown to give zirconabicycles, in which the *trans*-fused isomers tend to dominate under the thermodynamic conditions.[4] In further investigating the scope of this synthetically promising reaction, we have now found a facile reaction of certain non-conjugated dienes (1) with "$ZrCp_2$," such as $n$-$Bu_2ZrCp_2$, to produce conjugated diene-zirconocenes 2 (Eq. 1). Although isomerization of 1-alkenes to 2-alkenes[5] and of certain dienes [6] catalyzed by zirconocenes is known, the transformation shown in Eq. 1 appears to be unprecedented. This reaction is significant not only because it can compete and complement the previously reported bicyclization reaction[1,2] but also because it provides a novel route to 2. The previously known methods for the preparation of conjugated diene-zirconocenes include photolysis of $Ph_2ZrCp_2$ in the presence of conjugated dienes,[7] the reaction of $Cp_2ZrCl_2$ with enediylmagnesium derivatives,[8] and the reaction of ($t$-Bu)($i$-Bu)$ZrCp_2$ with conjugated dienes.[9]



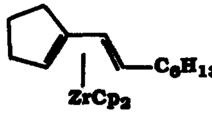
$R^1, R^3, R^4 =$ H or C group
$R^2 =$ C group (1)

The experimental results are summarized in Table 1. The diene-zirconocene products have been characterized by $^1H$ and $^{13}C$ NMR spectroscopy. In each case, 2 is *s-cis*,[7,8] and the diene moiety is ≥95% regio- and stereoisomerically pure, the stereochemistry of the 1,2-disubstituted alkene moiety being *E*. They have also been treated with $I_2$ to give the corresponding conjugated dienes, which, in turn, have been identified. We have previously reported[10] that the reaction of certain conjugated dienes, such as 1-vinylcyclohexene, with $n$-$Bu_2ZrCp_2$ gives the corresponding 1-butene-diene coupling products, such as 3 (from 1-vinylcyclohexene). Since one of the by-products in the reaction shown in Eq. 1 is 1-butene, the diene-zirconocene complexes 2 can, in principle, react further with 1-butene to give similar coupling products. While the formation of such products in minor quantities cannot be totally ruled out at this point, the major product in each case is 2. These seemingly contradictory results may be attributable to the fact that all of the conjugated dienes used in the previous study contained the parent vinyl group, i.e., $CH_2{=}CH$-, while the conjugated diene moiety in 2 do not. The higher degree of substitution in the dienes in 2 must hinder the further reaction of 2 with 1-butene. Indeed, treatment of ($E$, $E$)-3-

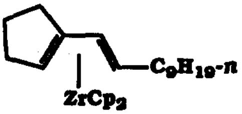
methyl-2,4-octadiene, prepared from **1e** as described above, with $n$-$Bu_2ZrCp_2$ gave **2e** in 88% yield. This reaction then provides yet another route to certain conjugated diene-zironocenes.



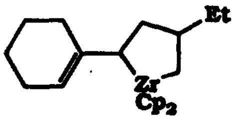
**2a**



**2b**

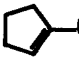
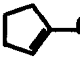
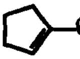
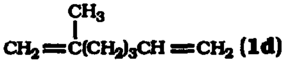


**2c**

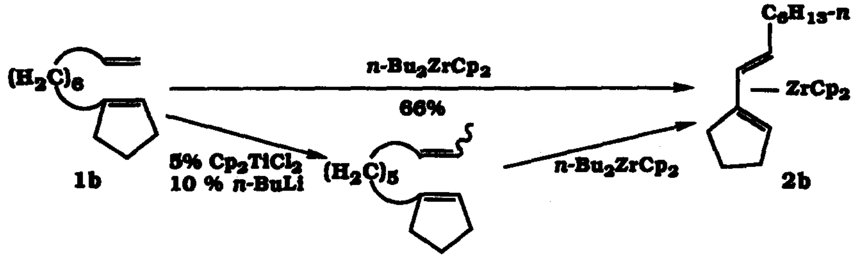


**3**

**Table 1.** Reaction of Non-conjugated Dienes with $n$-$Bu_2ZrCp_2$ in THF to Give Conjugated Diene-Zirconocenes

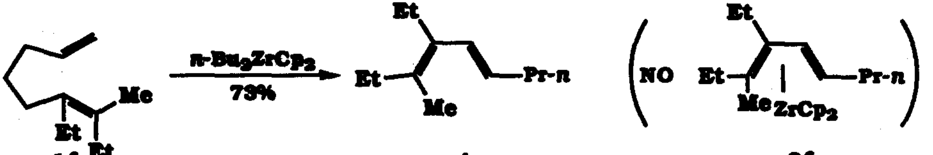
| Non-conjugated diene | Product | Yield (%)[a] | NMR Cp signals (ppm) $^1H$[b] | $^{13}C$[c] |
|---|---|---|---|---|
| —$(CH_2)_3CH{=}CH_2$(**1a**) | **2a** | 73 | 5.02 and 5.51 | 101.00 and 103.81 |
| —$(CH_2)_6CH{=}CH_2$(**1b**) | **2b** | 66 | 5.06 and 5.55 | 100.93 and 103.73 |
| —$(CH_2)_9CH{=}CH_2$(**1c**) | **2c** | 51 | 5.04 and 5.54 | 100.71 and 103.51 |
|  $CH_2{=}C(CH_3)(CH_2)_3CH{=}CH_2$ (**1d**) | **2d** | 59 | 5.11 and 5.58 | 100.60 and 103.85 |
|  $CH_3CH{=}C(CH_3)(CH_2)_3CH{=}CH_2$ (**1e**) | **2e** | 78 | 5.01 and 5.55 | 100.50 and 103.64 |

[a]By $^1H$ NMR. [b]In THF-hexane-$p$-xylene-$Me_4Si$. [c]In $C_6D_6$-$p$-xylene-$Me_4Si$.



(2)

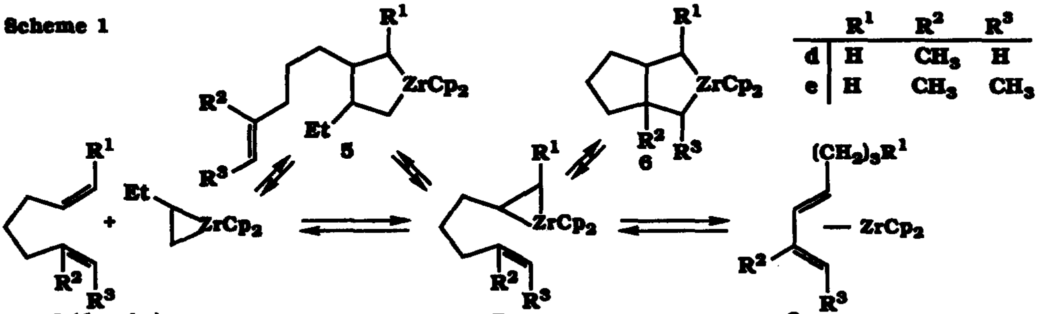
Some other noteworthy aspects of the reaction shown in Eq. 1 are as follows. The migrating alkene can be either mono- or 1,2-disubstituted, as indicated by the results shown in Eq. 2. The results also suggest that the double bond migration must take place along the chain. The double bond migration can take place over a long carbon chain, although the yield of **2** does appear to diminish with the chain length. Thus, the yields of **2a**, **2b**, and **2c** from the terminal vinyl-containing dienes (**1a**-**1c**) were 73, 66, and 51%, respectively. The alkene group at the migration terminus must be either 1,1-di- or trisubstituted for the formation of a single predominant diene-zirconocene **2**. The reaction of $n$-$Bu_2ZrCp_2$ with $\alpha$, $\omega$-dienes containing two monosubstituted alkenes is known to give relatively stable zirconabicycles in cases where the carbocyclic moiety is five- or six-membered.[1,2] The corresponding reaction of 1,8-nonadiene, on the other hand, has produced a mixture of products, none of which predominates.[11] Trisubstituted alkenes may be either proximally or distally disubstituted. All of those that have been tested in this study, such as those in **2a**-**2c**, are proximally disubstituted, and no information about the latter is available at this time. When the migration terminus is a tetrasubstituted alkene as in **1f**,[12] double bond migration can still take place, but the product is a free conjugated diene unaccompanied by the expected diene-$ZrCp_2$ product **2f**, as shown in Eq. 3.



**1f** **4** **2f** (3)

A more subtle effect of degree of substitution at the migration terminus has been observed in the comparison of the reaction of **1d**[13] and **1e**[13] with $n$-$Bu_2ZrCp_2$. Both gave the expected diene-zirconocenes **2d** and **2e** in 59 and 78% yields, respectively. However, the rate of formation of **2e** was considerably higher (complete in 15 h at 25 °C) than that of **2d**, which required 70 h under the same conditions. Furthermore, examination of the reaction of **2d** within the first few hours revealed the formation of **5d** in ca. 60% yield, as judged by quantitative analysis of $^1H$ NMR Cp signals at δ 6.11 and 6.17 ppm as well as by GLC analysis of the protonolysis product of **5d**, i.e., 2,6,7-trimethyl-1-nonene. It is likely that the overall course of the reaction may be represented by Scheme 1 and that the exact outcome and rate of the reaction significantly depend on the nature and degree of substitution. Thus, 1,6-heptadiene itself gives **6** ($R^1 = R^2 = R^3 = H$) via **7** ($R^1 = R^2 = R^3 = H$) as a relatively stable species.[1,2] In the reaction of **1d**, **5d** which is initially formed may not readily bicyclize to give **6d** due presumably to the presence of Me as $R^2$. With time **5d** may be converted to **2d** via **7d**. The greater rate of formation of **2e** relative to that of **2d** may be attributable to the greater ability of the 1,1-disubstituted alkene in **1d** to stabilize **7d** through chelating π-complexation than that of the trisubstituted alkene in **1e**.

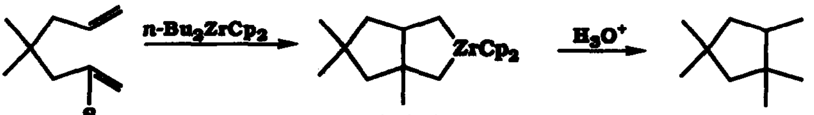
**Scheme 1**



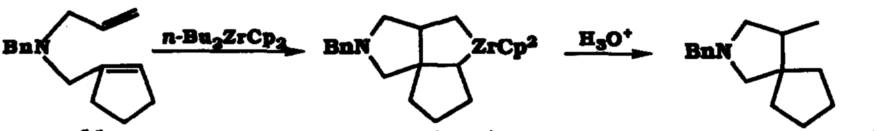
| | $R^1$ | $R^2$ | $R^3$ |
|---|---|---|---|
| **d** | H | $CH_3$ | H |
| **e** | H | $CH_3$ | $CH_3$ |

**1** (**d** and **e**) **7** **2**

Finally, the presence of a quaternary carbon or an amine[1a, 2b, 4, 14] in the tether part of dienes not only blocks alkene isomerization but also promotes bicyclization, as shown in Eqs. 4 and 5.



**8** **9** (85%) **10** (100%) (4)



**11** **12** (70%) **13** (100%) (5)

The following procedure for the conversion of **1e** into **2e** is representative. To a mixture of $Cp_2ZrCl_2$ (0.40 g, 1.37 mmol) and (*E*)-6-methyl-1,6-octadiene (0.16 g, 1.28 mmol) in 2 mL of THF was added dropwise at -78 °C *n*-BuLi in hexane (2.63 M, 1.05 mL, 2.75 mmol). After 1 h at -78 °C, the mixture was stirred for 15 h at 23 °C. Analysis of the $^1$H NMR Cp signals at $\delta$ 5.01 and 5.55 ppm using *p*-xylene as an internal standard indicated the formation of **2e** in 78% yield. After removal of the solvents and salts, the product yielded the following data: $^1$H NMR ($C_6D_6$, *p*-xylene, $Me_4Si$) $\delta$ -0.95 (q, $J$ = 6 Hz, 1 H), -0.55 to -0.4 (m, 1 H), 1.07 (t, $J$ = 7 Hz, 3 H), 1.2-1.7 (m, 2 H), 1.80 (s, 3 H), 1.99 (d, $J$ = 6 Hz, 3 H), 2.0-2.4 (m, 2 H), 4.33 (d, $J$ = 11 Hz, 1 H), 4.88 (s, 5 H), 5.42 (s, 5 H); $^{13}$C NMR ($C_6D_6$, *p*-xylene, $Me_4Si$) $\delta$ 14.54, 17.93, 24.14, 28.19, 40.12, 69.46, 69.99, 100.50, 103.65, 112.14, 122.65. Treatment of **2e** with $I_2$ (1.2 equiv) in THF at 0 °C followed by washing with aqueous $Na_2S_2O_3$ and the usual workup provided a 79% GLC yield (based on **1e**) of (*E,E*)-3-methyl-2,4-octadiene: $^1$H NMR ($CDCl_3$, $Me_4Si$) $\delta$ 0.90 (t, $J$ = 7 Hz, 3 H), 1.2-1.5 (m, 2 H), 1.70 (d, $J$ = 7 Hz, 3 H), 1.72 (s, 3 H), 2.0-2.15 (m, 2 H), 5.35-5.7 (m, 2 H), 6.05 (d, $J$ = 16 Hz, 1 H); $^{13}$C NMR ($CDCl_3$, *p*-xylene, $Me_4Si$) $\delta$ 12.07, 13.67, 13.76, 22.90, 34.98, 124.29, 127.07, 134.46, 134.81; High Resolution MS Calcd for $C_9H_{16}$: 124.1253; Found: 124.1257.

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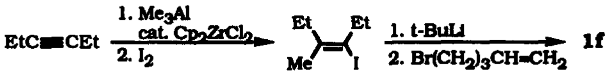
(10) Negishi, E.; Miller, S. R. *J. Org. Chem.* **1989**, *54*, 6014.

(11) Preliminary results obtained by D. Choueiry.

(12) The preparation of **1f** was carried out as follows:



(13) The reaction of 1-hepten-6-yne with $Me_3Al$ and $Cp_2ZrCl_2$ (5 mol %) followed by protonolysis gave **1d**, while iodinolysis of the carboalumination product, lithiation, and methylation with MeI provided **1e**.

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