lectivity in these addition reactions as well as applications to stereoselective ring closure reactions are currently underway in our laboratories.

**Acknowledgment.** We thank M. Koreeda for helpful discussions and for allowing us to compare our spectral data with unpublished data relative to ref 10. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

**Supplementary Material Available:** Spectral data ($^1$H, $^{13}$C NMR, mass spectra and IR) of all new compounds (7 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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# Highly Selective Homocoupling Reaction of Allylic Halides Using Barium Metal

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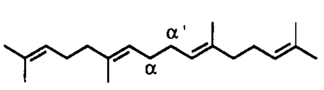
*Summary:* The highly $\alpha,\alpha'$ selective and stereocontrolled homocoupling reaction of allylic halides was achieved using barium reagent. The double-bond geometry of the starting allylic chloride was completely retained. $\alpha,\alpha'$ Cross-coupling products were also prepared stereospecifically and regioselectively by this method.

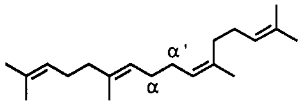
Homo- and cross-coupling of allylic halides are among the most basic carbon–carbon bond forming reaction in organic synthesis.[1] Subsequent to early studies on the use of nickel carbonyl in this coupling process by Corey et al.,[2] many groups have made important contributions to the steady improvement in this methodology.[3-5] Nonetheless, each of the published approaches suffers from some drawbacks and limitations. Described herein is a new method which is believed to be superior to earlier procedures, especially for stereospecificities and regioselectivities. The highly $\alpha,\alpha'$ selective and stereocontrolled homocoupling reaction of allylic halides was first achieved using barium reagent.[6]

We have examined various kinds of metals for homocoupling of geranyl bromide (1, Table I) at low temperature. Alkali metal naphthalenide (1.5 equiv) or reactive alkaline-earth metal (0.7 equiv) in THF was exposed to 1 (1 equiv) at −95 or −78 °C.[7] Among these metals, barium metal was found to be unique for $\alpha,\alpha'$ selective homocoupling reaction ($\alpha,\alpha'/\alpha,\gamma'$ = 97/3, 47% yield, entry 7). Furthermore, the geometric purity of the $\alpha,\alpha'$ product (2/3 = 96/1) indicates that geometric isomerization (trans to cis) of the allylic barium can be kept minimal during the coupling conditions.

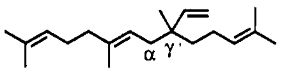
**Table I. Effect of Metals on the Regio- and Stereoselectivities of Dimerization Reaction of Geranyl Bromide (1)**



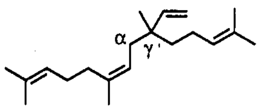
2, α-α'(*EE'*)



3, α-α'(*EZ'*)



4, α-γ'(*E*)



5, α-γ'(*Z*)

| entry | M* | T, °C | yield,[a] % | ratio ($\alpha,\alpha'/\alpha,\gamma'$) | ratio of isomers 2–5[b] 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| 1 | Li–Np[c] | −95 | 62 | 69:31 | 67 | 2 | 31 | 0 |
| 2 | Na–Np[c] | −95 | 86 | 61:39 | 60 | 1 | 39 | 0 |
| 3 | K–Np[c] | −95 | 99 | 78:22 | 76 | 2 | 22 | 0 |
| 4 | Cs–Np[c] | −95 | 27 | 65:35 | 65 | 0 | 35 | 0 |
| 5 | Mg | −95 | 61 | 63:37 | 60 | 3 | 34 | 3 |
| 6 | Ca | −78 | 58 | 62:38 | 58 | 4 | 38 | 0 |
| 7 | Ba | −78 | 47 | 97:3 | 96 | 1 | 3 | 0 |
| 8 | Cr | −40 | 85 | 74:26 | 68 | 6 | 26 | 0 |
| 9 | Mn | −40 | 60 | 74:26 | 62 | 12 | 26 | 0 |

[a] Isolated yield. [b] Determined by GC analysis. [c] Np = naphthalene.

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[5] Cross-coupling methods using allylic organometallics: (a) Katzenellenbogen, J. A.; Lenox, R. S. *J. Org. Chem.* **1973**, *38*, 326. (b) Derguini-Boumechal, F.; Lorne, R.; Linstrumelle, G. *Tetrahedron Lett.* **1977**, 1181. (c) Yamamoto, Y.; Maruyama, K. *J. Am. Chem. Soc.* **1978**, *100*, 6282. (d) Yamamoto, Y.; Yatagai, H.; Maruyama, K. *J. Am. Chem. Soc.* **1981**, *103*, 1969. (e) Trost, B. M.; Keinan, E. *Tetrahedron Lett.* **1980**, *21*, 2595. (f) Godschalx, J.; Stille, J. K. *Tetrahedron Lett.* **1980**, *21*, 2599. (g) Yamamoto, Y.; Maruyama, K.; Matsumoto, K. *J. Chem. Soc., Chem. Commun.* **1984**, 548. (h) Goliaszewski, A.; Schwartz, J. *Organometallics* **1985**, *4*, 417. (i) Calò, V.; Lopez, L.; Pesce, G. *J. Chem. Soc., Chem. Commun.* **1985**, 1357. (j) Calò, V.; Lopez, L.; Pesce, G. *J. Chem. Soc., Perkin Trans. 1* **1988**, 1301. (k) Araki, S.; Shimizu, T.; Jin, S.; Butsugan, Y. *J. Chem. Soc., Chem. Commun.* **1991**, 824. (l) Yanagisawa, A.; Nomura, N.; Noritake, Y.; Yamamoto, H. *Synthesis* **1991**, 1130.

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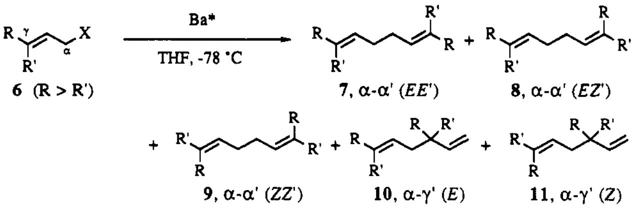
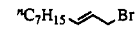
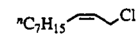
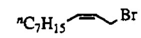
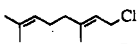
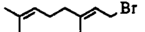
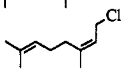
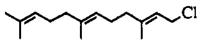
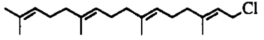
[7] Yanagisawa, A.; Habaue, S.; Yamamoto, H. *J. Am. Chem. Soc.* **1991**, *113*, 5893.

**Table II. Regio- and Stereoselective Dimerization Reaction of Various Allylic Halides Using Barium Metal**

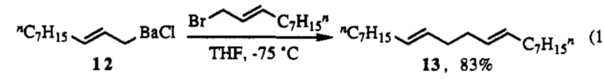


| entry | allylic halide 6 | yield,[a] % | ratio ($\alpha,\alpha'/\alpha,\gamma'$) | ratio of isomers 7–11[b] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 7 | 8 | 9 | 10 | 11 |
| 1 |  | 86 | 95:5 | 95 | 0 | 0 | 5 | 0 |
| 2 |  | 68 | 92:8 | 92 | 0 | 0 | 8 | 0 |
| 3 |  | 88 | 51:49 | 0 | 0 | 51 | 0 | 49 |
| 4 |  | 50 | 77:23 | 0 | 0 | 77 | 0 | 23 |
| 5 |  | 70 | 91:9 | 89 | 2 | 0 | 9 | 0 |
| 6 |  | 47 | 97:3 | 96 | 1 | 0 | 3 | 0 |
| 7 |  | 44 | 92:8 | 0 | 2 | 90 | 0 | 8 |
| 8 |  | 68 | 94:6 | 94 | 0 | 0 | 6 | 0 |
| 9 |  | 64 | 93:7 | 92 | 1 | 0 | 7 | 0 |

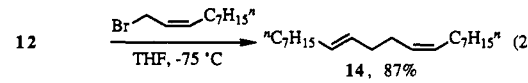
[a] Isolated yield. [b] Determined by GC analysis.

Table II summarizes the results obtained for the reaction of a variety of allylic halides 6 with reactive barium metal in THF at −78 °C.[8] Several characteristic features of the reaction have been noted: (1) Reaction of (*E*)-γ-mono- or disubstituted allyl halide resulted in >90% $\alpha,\alpha'$ selectivities except (*Z*)-2-decenyl chloride and bromide (entries 3 and 4).[10] (2) Both allylic chloride and bromide can be used for the reaction with equal efficiency. (3) The double-bond geometry of the starting allylic halide was completely retained in each case. (4) (*E*,*E*)-Farnesyl chloride was stereospecifically converted to squalene in 64% yield (entry 8).

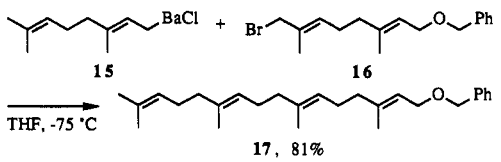
We have extended the scope of the reductive coupling method to include the synthesis of unsymmetrical dienes. Thus, $\alpha,\alpha'$ cross-coupling products can be prepared stereospecifically and regioselectively by this method. For example, treatment of (*E*)-2-decenylbarium reagent (12) with (*E*)-2-decenyl bromide and (*Z*)-2-decenyl bromide afforded (*E*,*E*)-diene 13 and (*E*,*Z*)-diene 14 in high yield (eqs 1 and 2). Benzyl ether of geranylgeraniol 17 was obtained almost exclusively in 81% yield by treatment of the primary allylic bromide 16[11] with geranylbarium reagent 15 in THF at −75 °C (eq 3). Functionalized allylic barium reagent 19 was also readily prepared and allowed to react with neryl bromide (18) to provide a (10*Z*)-isomer of benzyl geranylgeranyl ether 20 (eq 4).



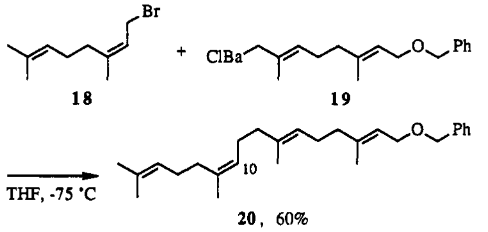
(1)



(2)



(3)



(4)

**Acknowledgment.** Financial support from the Ministry of Education, Science and Culture of the Japanese Government is gratefully acknowledged.

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(8) A representative experimental procedure is given by the homocoupling of (*E*,*E*)-farnesyl chloride: To a suspension of anhydrous $BaI_2$[9] (458 mg, 1.2 mmol) in dry THF (3 mL) was added at room temperature a solution of preformed lithium biphenylide, prepared from freshly cut lithium (16 mg, 2.3 mmol) and biphenyl (365 mg, 2.4 mmol) in THF (5 mL) under argon atmosphere; the reaction mixture was stirred for 30 min at room temperature. To the resulting dark brown suspension of barium powder in THF was slowly added a solution of (*E*,*E*)-farnesyl chloride (378 mg, 1.6 mmol) in THF (1.5 mL) at −78 °C. The reaction mixture was stirred for 1 h at this temperature. 2 N HCl (10 mL) was added to the mixture at −78 °C, and the aqueous layer was extracted with ether. The combined organic extracts were washed with dilute sodium thiosulfate solution, dried over anhydrous $MgSO_4$, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel (hexane) to afford a mixture of squalene and its regioisomer (220 mg, 68% combined yield): the $\alpha,\alpha':\alpha,\gamma'$ ratio was determined to be 94:6 by GC analysis. The large-scale reaction can be performed with equal efficiency. A procedure of the large-scale reaction using allylbarium will be submitted to *Org. Synth.*

(9) Anhydrous $BaI_2$ was prepared by drying commercially available $BaI_2 \cdot 2H_2O$ at 150 °C for 2 h under reduced pressure (<10 Torr).

(10) (*Z*)-γ-Monosubstituted allylbarium showed relatively low α-selectivities in the reaction with carbonyl compounds, see ref 6.

(11) Allylic bromide 16 was synthesized from geranyl benzyl ether by allylic oxidation with cat. $SeO_2$/TBHP/salicylic acid[12] and subsequent bromination with $PBr_3$.

(12) (a) Umbreit, M. A.; Sharpless, K. B. *J. Am. Chem. Soc.* 1977, *99*, 5526. (b) Takahashi, T.; Nemoto, H.; Kanda, Y.; Tsuji, J.; Fukazawa, Y.; Okajima, T.; Fujise, Y. *Tetrahedron* 1987, *43*, 5499. (c) Chappe, B.; Musikas, H.; Marie, D.; Ourisson, G. *Bull. Chem. Soc. Jpn.* 1988, *61*, 141.

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# Asymmetric Synthesis of Sulfinimines: Applications to the Synthesis of Nonracemic β-Amino Acids and α-Hydroxyl-β-amino Acids

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*Received August 31, 1992*

*Summary:* Asymmetric oxidation of sulfenimines 1 affords sulfinimines 2 (88–90% ee) which are chiral ammonia imine synthons useful in the enantioselective synthesis of β-amino acids and α-hydroxy-β-amino acids such as the C-13 side chain of taxol (2*R*,3*S*)-7.

The oxidation of sulfenimines (*N*-alkylideneareneulfenamides) 1 to racemic sulfinimines 2 with *m*-chloro-

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