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Regioselective Allylmetalation of Allenes with Tetraallylmanganate or Allylmagnesium Chloride under $MnCl_2$ Catalysis

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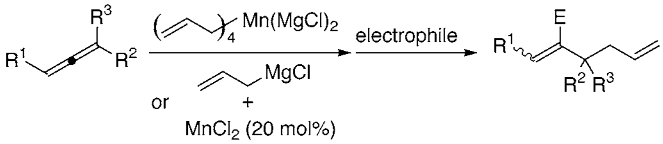
ABSTRACT



Treatment of allenes with tetraallylmanganate provides allylated products with high regioselectivity. A catalytic amount of $MnCl_2$ combined with allylmagnesium chloride also achieves efficient allylmetalation of allenes. The resulting alkenylmagnesium species react with various electrophiles. In the presence of molecular oxygen, the alkenylmagnesium undergoes diallylation reaction. A cyclization reaction of 1,2,6-heptatriene with tetraallylmanganate is also described.

Carbometalation of carbon−carbon multiple bonds is an important process in organometallic chemistry from both theoretical and practical standpoints.[1] A variety of unsaturated substrates such as alkenes and alkynes have hitherto been employed. However, allenes and their derivatives have received relatively little attention.[2] Alexakis and Normant reported that organocopper and organocuprate reagents add to 1-methoxypropa-1,2-diene stereo- and regioselectively.[3,4] We have recently demonstrated that tetraallylmanganate reacts, stereo- and regioselectively, with homopropargylic alcohol methyl ethers to provide allylmanganation products.[5] Here we wish to describe highly regioselective allylmetalation of allenes mediated by tetraallylmanganate.[6] We also report that allylmagnesium chloride efficiently adds to allenes with high regioselectivity under $MnCl_2$ catalysis.

Treatment of cyclic allene **1a** with tetraallylmanganate, derived from allylmagnesium chloride and manganese(II) chloride in a 4:1 ratio, furnished allylated product **2a** in 69% yield after aqueous workup (Scheme 1).[7] However, the reaction of **1a** with triallylmanganate provides **2a** in only 12−15% yield along with regioisomeric product **3** in 18% yield.

Treatment of terminal allene **1b** with tetraallylmanganate in THF at 0 °C for 20 h afforded **2b** in 33% yield

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[1] For reviews on carbometalation, see: (a) Normant, J. F.; Alexakis, A. *Synthesis* **1981**, 841. (b) Oppolozer, W. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 38. (c) Negishi, E. *Pure Appl. Chem.* **1981**, *53*, 2333. (d) Knochel, P. In *Comprehensive Organometallic Chemistry II*; Able, E. W., Stone, F. G. A., Wilkinson, G., Eds.; Pergamon: Oxford, 1995; Vol. 11, p 159. (e) Knochel, P. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 4, p 865. (f) Yamamoto, Y.; Asao, N. *Chem. Rev.* **1993**, *93*, 2207. (g) Negishi, E.; Kondakov, D. Y. *Chem. Rev.* **1996**, *96*, 417. (h) Marek, I.; Normant, J. F. In *Metal Catalyzed Cross-Coupling Reactions*; Diederich, F., Stang, P., Eds.; Wiley VCH: New York, 1998; p 271.

[2] Examples of carbometalation of allenes: (a) Mikhailov, B. M. *Pure Appl. Chem.* **1974**, *39*, 505 (allylboration). (b) Richey, H. G., Jr.; Szucs, S. S. *Tetrahedron Lett.* **1971**, *12*, 3785 (allylmagnesation). (c) Normant, J. F.; Quirion, J. Ch. *Tetrahedron Lett.* **1989**, *30*, 3959. (d) Normant, J. F.; Quirion, J. Ch.; Alexakis, A.; Masuda, Y. *Tetrahedron Lett.* **1989**, *30*, 3955 (allylzincation). (e) Normant, J. F.; Quirion, J. Ch.; Masuda, Y.; Alexakis, A. *Tetrahedron Lett.* **1990**, *31*, 2879 (allylcupration). (f) Araki, S.; Usui, H.; Kato, M.; Butsugan, Y. *J. Am. Chem. Soc.* **1996**, *118*, 4699 (allylindation). (g) Shirakawa, E. Nakao, Y. Hiyama, T. *Chem. Commun.* **2001**, 263 (acylstannylation). (h) Shirakawa, E. Nakao, Y. Tsutimoto, T. Hiyama, T. *Chem. Commun.* **2002**, 1962 (alkynylstannylation).

[3] Klein, H.; Eijsirga, H.; Westmijze, E.; Meijer, J.; Vermeer, P. *Tetrahedron Lett.* **1976**, *12*, 947.

[4] (a) Alexakis, A.; Normant, J. F. *Isr. J. Chem.* **1984**, *24*, 113. (b) Alexakis, A.; Mangeney, P.; Ghribi, A.; Marek, I.; Sedrani, R.; Guir, C.; Normant, J. F. *Pure Appl. Chem.* **1988**, *60*, 49.

[5] (a) Okada, K.; Oshima, K.; Utimoto, K. *J. Am. Chem. Soc.* **1996**, *118*, 6076. (b) Tang, J.; Okada, K.; Shinokubo, H.; Oshima, K. *Tetrahedron* **1997**, *53*, 5061.

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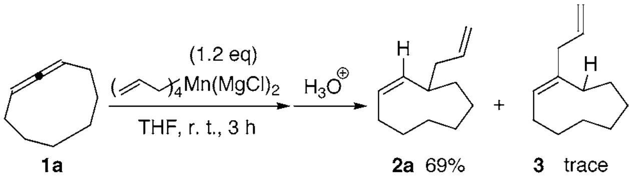
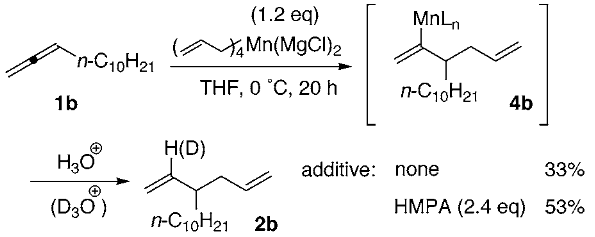
Scheme 1



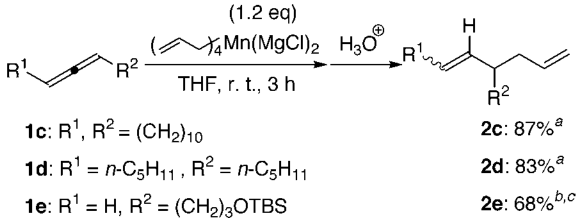
accompanied by unidentified complex side products. The addition of HMPA increased the yield of **2b** up to 53%.[8] Quenching the reaction intermediate **4b** with D_2O provided the corresponding deuterated product (Scheme 2).

Scheme 2



Scheme 3 shows other examples of the reaction of various allenes with tetraallylmanganate. Internal allenes such as **1c** and **1d** afforded the desired products **2c** and **2d** in good yields. Terminal allene **1e** was smoothly allylated regioselectively in the presence of HMPA.

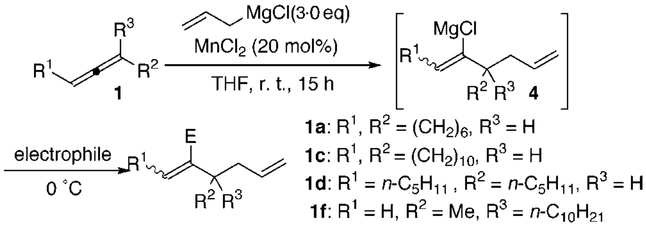
Scheme 3[a]



[a] Z/E ratio of product was not determined. [b] In the presence of HMPA (2.0 equiv), 0 °C, 20 h. [c] NMR yield.

Next, we investigated the catalytic use of $MnCl_2$. An addition of **1c** to a solution of allylmagnesium chloride (3.0 equiv) in the presence of $MnCl_2$ (20 mol %) in THF at 25 °C afforded **2c** in 76% yield (Table 1, entry 1). The intermediary alkenylmagnesium species **4**, furnished by $MnCl_2$-catalyzed allylmagnesation, reacted with various electrophiles (Table 1). The use of water, iodine, allyl bromide, and aldehyde[9] as electrophiles provided the corresponding products **2**, **5**, **7**, and **8** in moderate to good yields. In the case of acetyl chloride, the addition of CuCN•2LiCl (20 mol %) improved the yields of α,β-unsaturated ketones **6**. It is particularly noteworthy that 1,1-disubstituted allene **1f** yielded the corresponding products **2f**, and **5f**−**7f** bearing a quaternary center.

Table 1. $MnCl_2$-Catalyzed Allylmagnesation of Various Allenes



entry	allene	electrophile[a]	product	yield (%)[b]	*E*/*Z* ratio
1	**1a**	H_2O	**2a**	58	1:>99
2	**1a**	I_2	**5a**	40	>99:1
3	**1a**	CH_3COCl[f]	**6a**	34	>99:1
4	**1c**	H_2O	**2c**	76	nd[c]
5	**1c**	I_2	**5c**	62	23:77
6	**1c**	CH_3COCl[f]	**6c**	50	14:86[e]
7	**1d**	H_2O	**2d**	70	nd[c]
8	**1d**	I_2	**5d**	63	54:46[d]
9	**1d**	CH_3COCl[f]	**6d**	45	62:38[e]
10	**1d**	$CH_2{=}CHCH_2Br$	**7d**	71	59:41 or 41:59
11	**1d**	PhCHO[g]	**8d**	47	nd[c]
12	**1f**[h]	H_2O	**2f**	78	
13	**1f**[h]	I_2	**5f**	68	
14	**1f**[h]	CH_3COCl[f]	**6f**	57	
15	**1f**[h]	$CH_2{=}CHCH_2Br$	**7f**	69	

[a] Electrophiles (4.0 equiv) were employed. [b] Isolated yield. [c] Not determined. [d] *Z*/*E* ratio of product was determined by ^1H NMR. [e] The configuration of the product was confirmed by NOESY experiments. [f] CuCN•2LiCl (20 mol %) was added before the addition of acetyl chloride. [g] The reaction of **4d** with benzaldehyde proceeded at −78 °C for 1.5 h. [h] In the presence of HMPA (2.0 equiv).

At the present stage, the reaction mechanism, especially the regiochemical control, is not clear. We illustrate here our speculation in Scheme 4. The reaction is triggered by the coordination of tetraallylmanganate to allene. The ab initio calculation at the B3LYP/6-31G* level indicates that the HOMO of 1,2-butadiene is developed at the more

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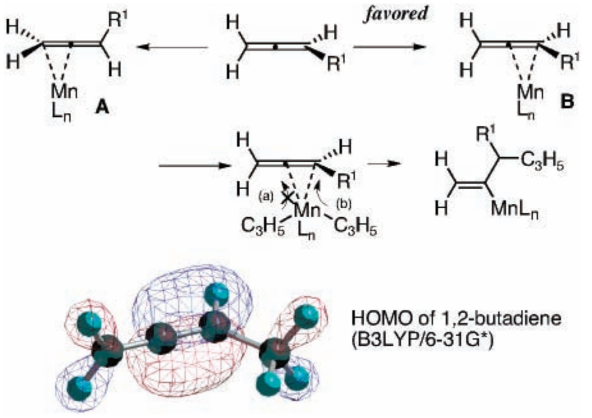
[6] For the use of organomanganate reagents in organic synthesis, see: (a) Oshima, K. *J. Organomet. Chem.* **1999**, *575*, 1. (b) Shinokubo, H.; Oshima, K. *J. Synth. Org. Chem. Jpn.* **1999**, *57*, 27. (c) Shinokubo, H.; Oshima, K. *Catal. Surv. Asia* **2003**, *7*, 39. (d) Hojo, M.; Harada, H.; Ito, H.; Hosomi, A. *J. Am. Chem. Soc.* **1997**, *119*, 5459. (e) Hojo, M.; Harada, H.; Ito, H.; Hosomi, A. *Chem. Commun.* **1997**, 2077. (f) Hojo, M.; Sakuragi, R.; Murakami, Y.; Baba, Y.; Hosomi, A. *Organometallics* **2000**, *19*, 4941. (g) Cahiez, G. *An. Quimm.* **1995**, *91*, 561. (h) Normant, J. F.; Cahiez, G. In *Modern Synthetic Methods*; Scheffold, R., Ed.; Otto Salle Verlag: Frankfurt am Main, 1983; Vol. 3, p 173.

[7] The reaction of **1a** with allylmagnesium chloride in the absence of $MnCl_2$ did not proceed, and the starting material **1a** was recovered quantitatively.

[8] Other allylic manganates derived from the corresponding Grignard reagents were studied on the reaction with **1b**. The tetramethallylmanganate reagent provided 4-decyl-2-methylhexa-1,5-diene in only 30% yield. Treatment of **1b** with tetracrotylmanganate afforded a complex mixture.

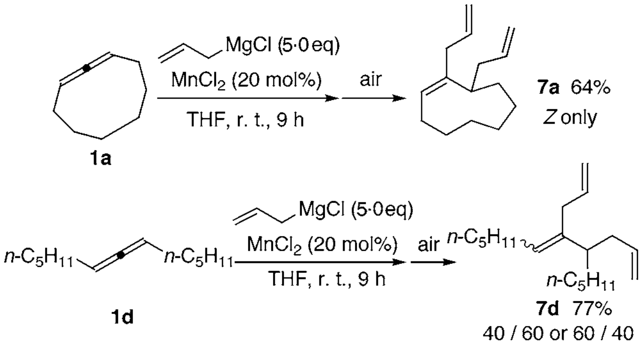
[9] The reaction of **4** with aldehyde at 0 °C afforded a mixture of the coupling product and α,β-unsaturated ketone derived from the product.

Scheme 4



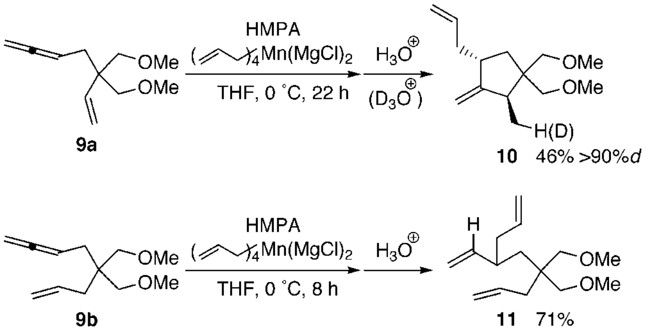
substituted carbon−carbon double bond. Consequently, the interaction of manganate reagent with allene provides a π-complex **B** rather than **A**. The allyl group on manganese then attacks the terminal carbon via path b, evading a steric repulsion between the coplanar hydrogen atom and the migrating allyl group.

Scheme 5



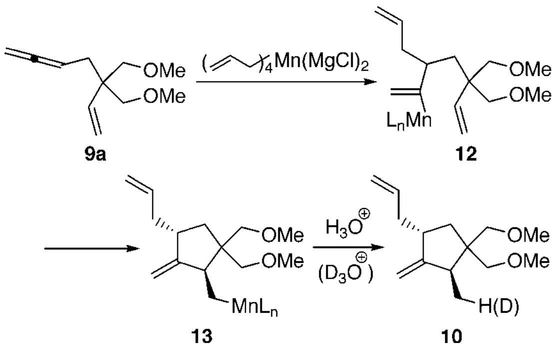
Diallylation products were formed in the presence of molecular oxygen.[10] A THF solution of **1a** was treated with allylmagnesium chloride (5.0 equiv) in the presence of MnCl$_2$ (20 mol %) under argon atmosphere for 9 h at 25 °C. The mixture was then exposed to air for 40 h to provide diallylated product **7a** in 64% yield (Scheme 5). In the reaction mixture, monoallylated product **2a** was not detected. Starting from **1d**, the corresponding diallylated product **7d** was obtained in 77% yield.

Scheme 6



We next picked up enallene **9** as a substrate in the reaction with tetraallylmanganate (Scheme 6). Treatment of 1,2,6-triene **9a** with tetraallylmanganate at 0 °C for 22 h afforded cyclized product **10** in 46% yield. The reaction proceeded diastereoselectively. The stereochemistry of **10** was assigned by NOESY experiments. An addition of D$_2$O to the reaction mixture yielded the labeled product with deuterium incorporation at the methyl group. In contrast to **9a**, 1,2,7-triene **9b** provided none of cyclized products. Instead, the reaction with **9b** afforded allylated product **11** in 71% yield.[11]

Scheme 7



We propose the following reaction mechanism for the enallene cyclization reaction (Scheme 7). An addition of allylmanganate to the allenyl moiety of **9a** provides the alkenylmanganese intermediate **12**. The terminal olefin intramolecularly inserts into the Mn−C bond of **12**, yielding alkylmanganese **13**. Finally, quenching of **13** with H$_2$O furnishes **10**. The formation of the alkylmanganese intermediate **13** was indicated by the deuterium labeling experiment (vide supra).

In conclusion, we have demonstrated that allylmanganation of allenes with tetraallylmanganate proceeded with high regioselectivity. A catalytic version of allylmetalation of allenes with allylmagnesium chloride under MnCl$_2$ catalysis has also been achieved. The resulting alkenylmagnesium species can be efficiently functionalized upon the treatment with various electrophiles. In the presence of molecular oxygen, the alkenylmagnesium undergoes diallylation reac-

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[10] We assume that molecular oxygen oxidizes manganese to a higher oxidation state, facilitating reductive elimination from alkenylallylmanganese intermediate **4**. We conducted a preliminary experiment of cross-coupling of two different Grignard reagents. Exposure of a mixture of *p*-methoxyphenylmagnesium bromide (1.0 equiv) and allylmagnesium chloride (2.0 equiv) in the presence of MnCl$_2$ (20 mol %) with air provided *p*-methoxyallylbenzene in 75% yield.

[11] Trost, B. M.; Tour, J. M. *J. Am. Chem. Soc.* **1988**, *110*, 5231.

tion. Finally, tetraallylmanganate induces cyclization of 1,2,6-heptatriene.

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Supporting Information Available: Experimental procedures and compound data. This material is available free of charge via the Internet at http://pubs.acs.org.

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