Communication

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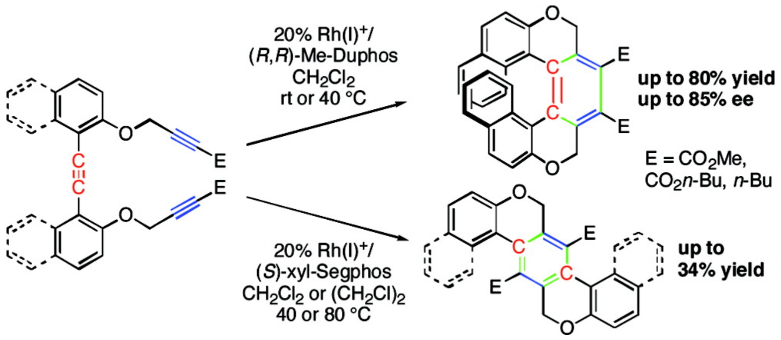

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Rh-Catalyzed Synthesis of Helically Chiral and Ladder-Type Molecules via [2 + 2 + 2] and Formal [2 + 1 + 2 + 1] Cycloadditions Involving C−C Triple Bond Cleavage

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Helicenes and helicene-like molecules possessing nonplanar ortho-fused scaffolds exhibit helical chirality.[1] Enantiopure forms of them are potentially applicable to optical or electronic functional materials and chiral reagents.[2] Consequently, the development of their practical enantioselective synthesis, which can introduce various substituents on their frameworks, is highly attractive. The classical nonasymmetric synthesis of helicenes is based on the oxidative photocyclization of stilbene-type precursors.[3] Although several nonphotochemical synthetic methods have been developed, which have been applied to the synthesis of enantioenriched helicenes,[4,5] the catalytic enantioselective method is scarce. Stará and co-workers reported that enantioenriched [6]helicene-like molecules can be obtained through a Ni-catalyzed [2 + 2 + 2] cycloaddition of triynes, although enantioselectivity was moderate (42−48% ee),[6b,e] and enantioselective synthesis of sterically more demanding [7]helicene-like molecules has not been reported.[6] Our research group reported cationic Rh(I)/modified-BINAP-catalyzed chemo-, regio-, and enantioselective [2 + 2 + 2] cycloadditions to construct axial, planar, and central chirality.[7] In this Communication, we describe highly enantioselective synthesis of functionalized helically chiral molecules via a Rh-catalyzed [2 + 2 + 2] cycloaddition and formation of ladder-type molecules via an unprecedented Rh-catalyzed formal [2 + 1 + 2 + 1] cycloaddition involving C−C triple bond cleavage.

For application of cationic Rh(I) catalysts to the enantioselective construction of helical chirality, we have chosen triyne **6a** possessing methoxycarbonyl at alkyne termini, which would show high reactivity to a cationic rhodium and furnish a donor−acceptor-type helically chiral molecule in conjugation of the electron-deficient phthalate unit with the electron-donating alkoxynaphthalene units. Triyne **6a** was readily prepared by repeating Sonogashira coupling starting from the protected 1-iodo-2-naphthol **1** followed by deprotection of **4** and introduction of alkyne moiety to **5**. Triynes **6b** and **6c** possessing butoxycarbonyl and butyl at alkyne termini were also prepared in a similar sequence (Scheme 1).

Scheme 1. Synthesis of Triynes **6a**−**c**

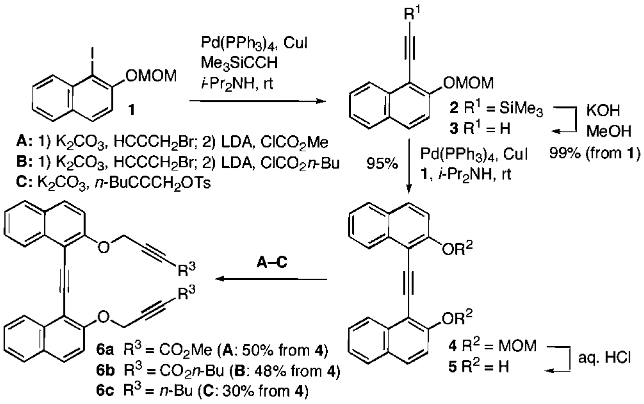
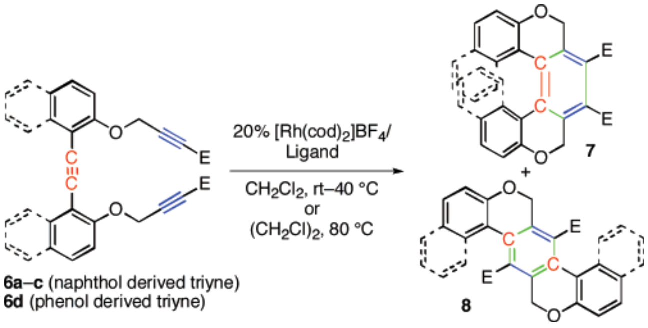


Table 1. Rh-Catalyzed [2 + 2 + 2] and Formal [2 + 1 + 2 + 1] Cycloadditions of Triynes **6**



entry	**6** (E)	ligand	condition	**7**/% yield[a] (% ee)	**8** % yield[a]
1	**6a** (CO_2Me)	(*R*,*R*)-Me-Duphos	room temp, 15 h	80 (71)	<1
2	**6b** (CO_2*n*-Bu)	(*R*,*R*)-Me-Duphos	room temp, 15 h	71 (77)	<1
3	**6c** (*n*-Bu)	(*R*,*R*)-Me-Duphos	40 °C, 140 h	71 (85)	10
4	**6a** (CO_2Me)	(*S*)-xyl-Segphos	80 °C, 15 h	39 (31)	34
5	**6b** (CO_2*n*-Bu)	(*S*)-xyl-Segphos	80 °C, 15 h	42 (37)[b]	30[b]
6	**6d** (CO_2Me)	(*S*)-xyl-Segphos	40 °C, 14 h	87 (-)	5

[a] Isolated yield. [b] Isolated as a mixture of **7b** and **8b**. A small amount of **8b** could be isolated in a pure form for characterization.

The intramolecular [2 + 2 + 2] cycloadditions of triynes **6a** and **6b** were examined in the presence of various cationic rhodium(I) complexes, which revealed that the use of 20 mol % [Rh(cod)$_2$]BF$_4$/(*R*,*R*)-Me-Duphos at room temperature furnished the expected helically chiral molecules **7a** and **7b** in good yields with good enantioselectivity (Table 1, entries 1 and 2). Although the reactivity of electron-rich triyne **6c** is lower than that of electron-deficient triynes **6a** and **6b**, improved enantioselectivity was observed (entry 3). The enantiopure crystal of (*M*)-(−)-**7a** was readily prepared by a single recrystallization. As shown in Figure 1, the helically chiral molecules are stacked along the *b*-axis in the unit cell. In addition, the molecules locate near the crystallographic 2_1-axes and their pseudo-helical axes are almost parallel to the *b*-axis. Therefore, continuous chiral helical columns are formed in the crystals of **7a**.

Interestingly, unexpected ladder-type molecule **8c** presumably through a formal [2 + 1 + 2 + 1] cycloaddition of **6c** was obtained in 10% yield in the reaction of entry 3. When BINAP-type ligands were used in the reactions of **6a** and **6b**, ladder-type molecules **8a** and **8b** could also be obtained, and the use of xyl-Segphos furnished **8a** and **8b** in the highest yields (entries 4 and 5).[8] On the other hand, the reaction of a sterically less demanding triyne **6d** furnished the corresponding ladder-type molecule **8d** in low yield (entry 6).

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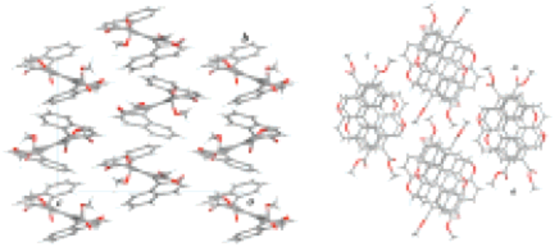


Figure 1. Packing structures of (*M*)-(−)-**7a** [*a*-projection (left) and *b*-projection (right) view].

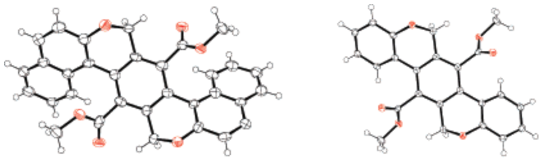
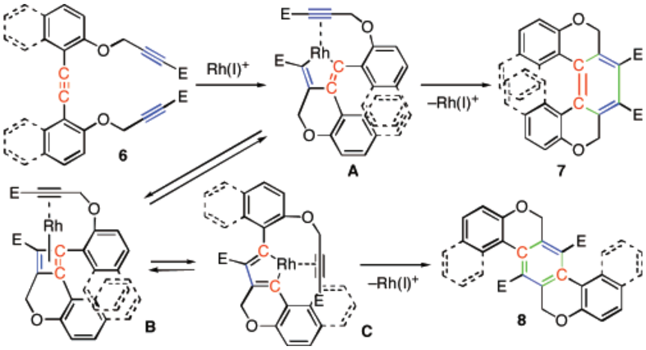


Figure 2. ORTEP drawings of **8a** (left) and **8d** (right).

Table 2. Optical Properties of **7a**−**c**, **8a**, and **10** (measured in $CHCl_3$)

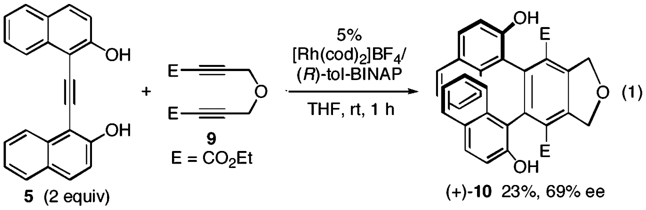
entry	compd	$[\alpha]^{25}_D$	UV–vis λ_{abs} (nm)	fluorescence λ_{em} (nm)
1	(−)-**7a**	−909° (71% ee)	380	471
2	(−)-**7b**	−846° (77% ee)	378	468
3	(−)-**7c**	−604° (85% ee)	358	443
4	**8a**		400	508
5	(+)-**10**	+122° (69% ee)	324	

Scheme 2. Possible Mechanism for the Formation of **7** and **8**



The structures of **8a** and **8d** were unambiguously determined by the X-ray crystallographic analyses (Figure 2).

In the course of this study, we found that ethyne-bridged binaphthol **5** reacted with electron deficient diyne **9** to give enantioenriched 1,2-teraryl compound **10** possessing an axially chiral donor−acceptor-type structure (eq 1).[9,10]



The optical characteristics of **7a**−**c**, **8a**, and **10** were compared as shown in Table 2. Helically chiral molecules **7a**−**c** showed large optical rotations despite not being fully aromatic structures. When the compounds possess donor−acceptor-type helical structures (**7a** and **7b**), a siginificant bathochromic shift in absorption and fluorescence was observed in comparing **7c** and **10**. More significant bathochromic shift and strong emission were observed in the ladder-type molecule **8a**.

A possible mechanism is outlined in Scheme 2. Helically chiral molecules **7** could generate through rhodacyclopenta-diene **A**. To release the steric hindrance, the rhodacyclopentadiene **A** may be converted to rhodacyclopentadiene **C**, presumably through Rh(I)/cyclobutadiene complex **B**, which furnishes the ladder-type molecules **8**.[11,12] Expansion of the scope and detailed mechanistic studies are underway in our laboratory.

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Supporting Information Available: Experimental procedures, compound characterization data, and X-ray crystallographic information files. This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) For a review, see: Schmuck, C. *Angew. Chem., Int. Ed.* **2003**, *42*, 2448.
(2) For a review, see: Nuckolls, C.; Shao, R. F.; Jang, W. G.; Clark, N. A.; Walba, D. M.; Katz, T. J. *Chem. Mater.* **2002**, *14*, 773.
(3) Liu, L.; Yang, B.; Katz, T. J.; Poindexter, M. K. *J. Org. Chem.* **1991**, *56*, 3769.
(4) For a review, see: Urbano, A. *Angew. Chem., Int. Ed.* **2003**, *42*, 3986.
(5) For selected recent examples of asymmetirc helicene synthesis, see: (a) Nakano, K.; Hidehira, Y.; Takahashi, K.; Hiyama, T.; Nozaki, K. *Angew. Chem., Int. Ed.* **2005**, *44*, 7136. (b) Carreño, M. C.; González-López, M.; Urbano, A. *Chem. Commun.* **2005**, 611. (c) Miyasaka, M.; Rajca, A.; Pink, M.; Rajca, S. *J. Am. Chem. Soc.* **2005**, *127*, 13806. (d) Rajca, A.; Miyasaka, M.; Pink, M.; Wang, H.; Rajca, S. *J. Am. Chem. Soc.* **2004**, *126*, 15211. (e) Ogawa, Y.; Toyama, M.; Karikomi, M.; Seki, K.; Haga, K.; Uyehara, T. *Tetrahedron Lett.* **2003**, *44*, 2167. (f) Carreño, M. C.; García-Cerrada, S.; Urbano, A. *Chem.-Eur. J.* **2003**, *9*, 4118 and references cited therein.
(6) For syntheses of helicenes and helicen-like molecules by [2 + 2 + 2] cycloadditions, see: (a) Stará, I. G.; Alexandrová, Z.; Teplý, F.; Sehnal, P.; Starý, I.; Šaman, D.; Buěšínský, M.; Cvačka, J. *Org. Lett.* **2005**, *7*, 2547. (b) Teplý, F.; Stará, I. G.; Starý, I.; Kollárovič, A.; Šaman, D.; Vyskočil, Š.; Fiedler, P. *J. Org. Chem.* **2003**, *68*, 5193. (c) Stará, I. G.; Starý, I.; Kollárovič, A.; Teplý, F.; Šaman, D.; Fiedler, P. *Collect. Czech. Chem. Commun.* **2003**, *68*, 917. (d) Teplý, F.; Stará, I. G.; Starý, I.; Kollárovič, A.; Šaman, D.; Rulíšek, L.; Fiedler, P. *J. Am. Chem. Soc.* **2002**, *124*, 9175. (e) Stará, I. G.; Starý, I.; Kollárovič, A.; Teplý, F.; Vyskočil, Š.; Šaman, D.; *Tetrahedron Lett.* **1999**, *40*, 1993. (f) Stará, I. G.; Starý, I.; Kollárovič, A.; Teplý, F.; Šaman, D.; Tichý, M. *J. Org. Chem.* **1998**, *63*, 4046. (g) Han, S.; Bond, A. D.; Disch, R. L.; Holmes, D.; Schulman, J. M.; Teat, S. J.; Vollhardt, K. P. C.; Whitener, G. D. *Angew. Chem., Int. Ed.* **2002**, *41*, 3223. (h) Han, S.; Anderson, D. R.; Bond, A. D.; Chu, H. V.; Disch, R. L.; Holmes, D.; Schulman, J. M.; Teat, S. J.; Vollhardt, K. P. C.; Whitener, G. D. *Angew. Chem., Int. Ed.* **2002**, *41*, 3227. (i) Caeiro, J.; Peña, D.; Cobas, A.; Pérez, D.; Guitián, E. *Adv. Synth. Catal.* **2006**, *348*, 2466. (j) Peña, D.; Cobas, A.; Pérez, D.; Guitián, E.; Castedo, L. *Org. Lett.* **2003**, *5*, 1863.
(7) For an account, see: Tanaka, K. *Synlett* **2007**, 1977.
(8) The use of BINAP-type ligands in the reaction of **6c** did not furnish **8c**, and **7c** was obtained with low ee.
(9) A meso isomer that could not be isolated in a pure form and dimer of **9** were generated as by-products, but mono- or bis-lactones were not generated.
(10) Ir-catalyzed enantioselective synthesis of 1,2-teraryls, see: Shibata, T.; Tsuchikama, K.; Otsuka, M. *Tetrahedron: Asymmetry* **2006**, *17*, 614.
(11) For reviews of metal-cyclobutadienes, see: (a) Efraty, A. *Chem. Rev.* **1977**, *77*, 691. (b) Bergstrasser, U. *Adv. Strain Org. Chem.* **1996**, *5*, 161.
(12) C−C bond rupture of hexalabeled cobalt/cyclobutadiene complexes was reported, see: Ville, G. A.; Vollhardt, K. P. C.; Winter, M. J. *Organometallics* **1984**, *3*, 1177.

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