J|A|C|S
COMMUNICATIONS

Metal-Mediated Efficient Synthesis, Structural Characterization, and Skeletal Rearrangement of Octasubstituted Semibullvalenes

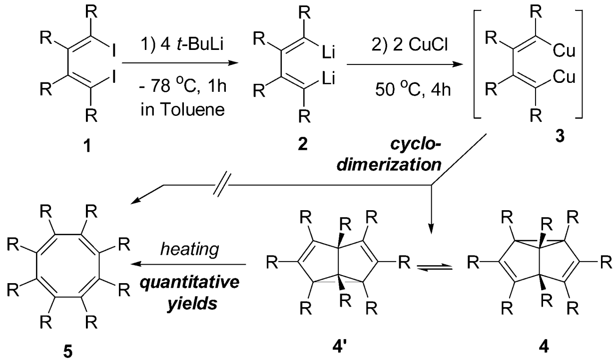
Chao Wang, Jian Yuan, Guotao Li, Zitao Wang, Shiwei Zhang, and Zhenfeng Xi*

Beijing National Laboratory for Molecular Sciences, Key Laboratory of Bioorganic Chemistry and Molecular Engineering of Ministry of Education, College of Chemistry, Peking University, Beijing 100871, China

Received November 22, 2005; E-mail: zfxi@pku.edu.cn

The structural diversity of the valence isomers of strained ring systems and the intramolecular skeletal rearrangements between these valence isomers have long been of great interest from the point of view of synthetic applications and mechanistic studies.[1] Among strained ring systems, semibullvalene, a valence isomer of cyclooctatetraene (COT for short), has attracted much attention.[1−3] Since Zimmerman and co-workers reported the synthesis of semibullvalene in 1966,[2] great interest has been continuously paid to the synthetic methods and skeletal rearrangement studies of this type of strained ring systems, not only because semibullvalenes demonstrate the extremely rapid *degenerate* Cope rearrangement, which deserves both theoretical and experimental investigations, but also because efficient and practical synthetic methods are still demanding.[1−3] In this communication, we would like to report an efficient synthetic method, structural characterization, and skeletal rearrangement of multi-substituted semibullvalenes (Scheme 1).[4] To the best of our knowledge, this is the first synthesis of semibullvalenes using the metal-mediated C−C bond forming approach.

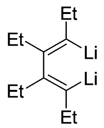
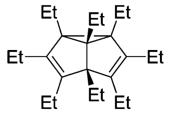
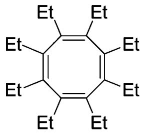
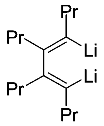
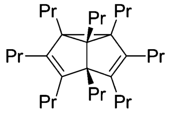
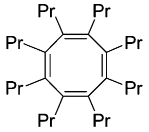
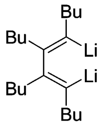
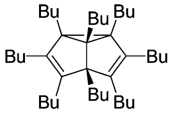
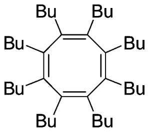
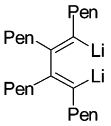
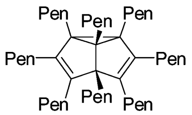
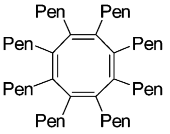
Scheme 1



1,2,3,4-Tetraethyl-1,4-dilithio-1,3-diene **2a** (1 mmol) in a 10 mL solution of toluene was generated in situ from its corresponding 1,4-diiodo compound **1a** (1 mmol) and *t*-BuLi (4 mmol) at 0 °C (Scheme 1).[5] After addition of 2 equiv of CuCl at 0 °C, the reaction mixture was heated to 50 °C and stirred at this temperature for 4 h. Quench of the reaction mixture with aqueous $NaHCO_3$ followed by normal workup procedure afforded the semibullvalene **4a** in 80% isolated yield as the only product (Table 1). These semibullvalenes could be thermally transformed to their corresponding COT derivatives **5** at 140 or 160 °C in quantitative yields (Table 1).[6,7]

The NMR data of semibullvalenes **4a**−**4d** show very interesting and characteristic patterns. For example, the ^{13}C NMR data of **4b** (75.4 MHz, $CDCl_3$, Me_4Si, room temperature, $\delta = 14.96$ [CH_3], 15.04 [CH_3], 15.20 [CH_3], 20.30 [CH_2], 21.71 [CH_2], 23.31 [CH_2], 29.90 [CH_2], 30.11 [CH_2], 30.37 [CH_2], 65.69 [quat. C], 100.68 [quat. C], 131.32 [quat. C]) show this molecule to have C_{2v} symmetry which may be explained by averaging of signals due to rapid degenerate Cope rearrangement. The structure of **4b** has been determined by single-crystal X-ray analysis (Figure 1). The apparent extremely long C2−C8 distance (1.913 Å) is quite different from that of unsubstituted semibullvalene in the gas phase (1.600 Å),[8] which is certainly due to a dynamic or static disorder of two nondegenerate semibullvalene molecules in the solid state.[3] The sum of distances of C2−C8 (1.913 Å) and C4−C6 (2.084 Å), which is regarded as a molecular property, is 4.01 Å, close to those of semibullvalenes rearranging rapidly (3.97−3.99 Å).[3a]

Table 1. CuCl-Mediated Dimerization of 1,4-Dilithiodienes **2** Leading to the Synthesis of Substituted Semibullvalenes **4** and COT **5**

dilithio reagent **2**[a]		semibullvalene **4**		yield of **4**/%[b]	COT **5**[c]	
	**2a**		**4a**	80		**5a**
	**2b**		**4b**	85		**5b**
	**2c**		**4c**	88		**5c**
	**2d**		**4d**	74		**5d**

[a] Generated in situ from their corresponding diiodo compounds and *t*-BuLi as shown in Scheme 1. [b] Reaction conditions shown in Scheme 1. Isolated yield. [c] Quantitative yields of **5a**−**d** from **4a**−**d** at 140 to 160 °C.

When 1,2-diphenyl-3,4-dimethyl-1,4-dilithio-1,3-diene **2e** (Scheme 2) was treated with CuCl in Et_2O, semibullvalene **4e** was obtained in 44% isolated yield upon hydrolysis with aqueous $NaHCO_3$. If the reaction mixture was quenched with 3 N aqueous HCl instead of aqueous $NaHCO_3$, the pentalene derivative **6** was obtained in 45% isolated yield. No such acid-mediated transformation was observed for **4a**−**d**. In addition, unlike **4a**−**d**, heating of **4e** did not afford its corresponding COT derivatives, but a mixture of products, including the pentalene derivative **6** (Scheme 2). Treatment of isolated **4e** with 12 N aqueous HCl at room temperature

10.1021/ja0579208 CCC: $33.50 © 2006 American Chemical Society

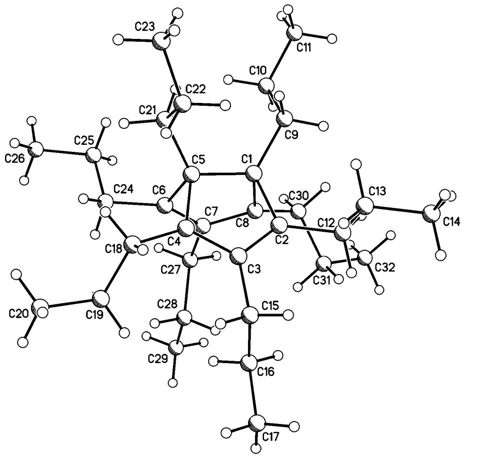
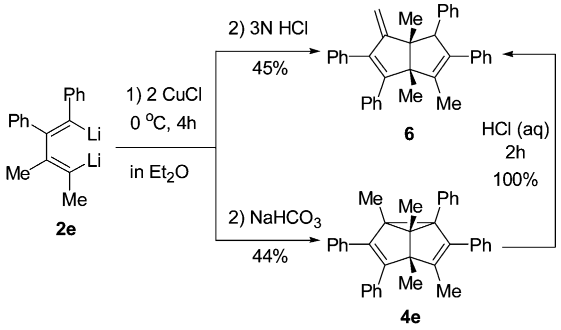


Figure 1. X-ray structure of **4b**.

Scheme 2



generated the pentalene derivative **6** in a quantitative yield within 2 h. Averaged signal of two methyl carbons in the ^{13}C NMR spectrum of **4e** (12.80, 13.68) suggests that the molecule also undergoes rapid degenerate Cope rearrangement.

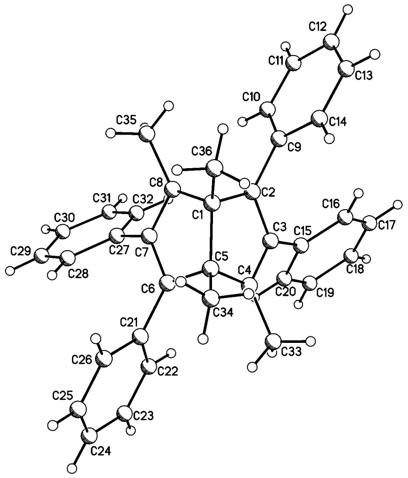


Figure 2. X-ray structure of **4e**.

The structure of **4e** has been determined by single-crystal X-ray structural analysis (Figure 2). The sum of the distance of C2−C8 (1.971 Å) and the one of C4−C6 (2.018 Å) is 3.99 Å. The values for both distances result from the superposition of two molecules in the solid state which may exchange by a nondegenerate or an almost degenerate Cope rearrangement. Definitive conclusions require further studies as described in the reference.[3b]

In conclusion, we report in this paper a simple and efficient synthetic method of multi-substituted semibullvalenes by metal-mediated C−C bond forming reactions. Structural characterization, skeletal rearrangement, and reaction chemistry are also preliminarily studied here. Further investigation into the reaction scope and studies on the chemical and physical properties of these otherwise unavailable semibullvalenes are in progress.

Acknowledgment. This work was supported by National Science Fund for Distinguished Young Scholars (29825105), the Major State Basic Research Development Program (G2000077502-D), and the National Natural Science Foundation of China. Cheung Kong Scholars Program and Qiu Shi Science & Technologies Foundation are gratefully acknowledged.

Supporting Information Available: Experimental details, characterization data, copies of ^{1}H and ^{13}C NMR spectra for all isolated compounds and crystallographic data, positional and thermal parameters, and lists of bond lengths and angles for **4b** and **4e**. This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) (a) Scott, L. T.; Jones, M., Jr. *Chem. Rev.* **1972**, *72*, 181−202. (b) Liebman, J. F.; Greenberg, A. *Chem. Rev.* **1976**, *76*, 311−365. (c) Hassenrueck, K.; Martin, H. D.; Walsh, R. *Chem. Rev.* **1989**, *89*, 1125−1146. (d) Williams, R. V.; Kurtz, H. A. *Adv. Phys. Org. Chem.* **1994**, *29*, 299−307. (e) Quast, H.; Dietz, T.; Peters, E.-M.; Peters, K.; von Schnering, H. G. *Liebigs Ann.* **1995**, 1159−1168. (f) Williams, R. V. *Adv. Theor. Interesting Mol.* **1998**, *4*, 157−201. (g) Hopf, H. *Classics in Hydrocarbon Chemistry*; Wiley-VCH: Weinheim, Germany, 2000: Chapter 10, pp 209−215. (h) Williams, R. V. *Chem. Rev.* **2001**, *101*, 1185−1204. (i) Williams, R. V. *Eur. J. Org. Chem.* **2001**, 227−235.

(2) (a) Zimmerman, H. E.; Grunewald, G. L. *J. Am. Chem. Soc.* **1966**, *88*, 183−184. (b) Zimmerman, H. E.; Binkley, R. W.; Givens, R. S.; Sherwin, M. A. *J. Am. Chem. Soc.* **1967**, *89*, 3932−3923. (c) Zimmerman, H. E.; Binkley, R. W.; Givens, R. S.; Grunewald, G. L.; Sherwin, M. A. *J. Am. Chem. Soc.* **1969**, *91*, 3316−3323.

(3) Leading references for X-ray structures of semibullvalenes: (a) Quast, H.; Carlsen, J.; Janiak, R.; Peters, E.-M.; Peters, K.; von Schnering, H. G. *Chem. Ber.* **1992**, *125*, 955−968. (b) Benesi, A.; Bertermann, R.; Förster, H.; Heubes, M.; Jackman, L. M.; Koritsanszky, T.; Luger, P.; Mayer, A.; Quast, H.; Seefelder, M.; Zobel, D. *J. Am. Chem. Soc.* **2000**, *122*, 4455−4463.

(4) Octamethylsemibullvalene has been reported. (a) Criegee, R.; Askani, R. *Angew. Chem., Int. Ed. Engl.* **1968**, *7*, 537. (b) Askani, R.; Wieduwilt, M. *Chem. Ber.* **1976**, *109*, 1887−1897.

(5) (a) Xi, Z.; Song, Q.; Chen, J.; Guan, H.; Li, P. *Angew. Chem., Int. Ed.* **2001**, *40*, 1913−1916. (b) Song, Q.; Chen, J.; Jin, X.; Xi, Z. *J. Am. Chem. Soc.* **2001**, *123*, 10419−10420. (c) Li, G.; Fang, H.; Xi, Z. *Tetrahedron Lett.* **2003**, *44*, 8705−8708. (d) Li, G.; Fang, H.; Zhang, S.; Xi, Z. *Tetrahedron Lett.* **2004**, *45*, 8399−8402.

(6) Quast, H.; Heubes, M.; Dietz, T.; Witzel, A.; Boenke, M.; Roth, W. R. *Eur. J. Org. Chem.* **1999**, 813−822.

(7) Formation of COT via dimerization of 1-cuprio-4-halo-1,3-dienes: (a) Takahashi, T.; Sun, W.; Nakajima, K. *Chem. Commun.* **1999**, 1595−1596. Formation of COT via cross-coupling of 1,4-dicuprio-1,3-dienes with 1,4-diiodo-1,3-dienes: (b) Yamamoto, Y.; Ohno, T.; Itoh, K. *Chem. Commun.* **1999**, 1543−1544. (c) Yamamoto, Y.; Ohno, T.; Itoh, K. *Chem.*−*Eur. J.* **2002**, *8*, 4734−4741. Formation of COT via dimerization of 1,4-dicuprio-1,3-dienes: (d) Chen, C.; Xi, C.; Lai, C.; Wang, R.; Hong, X. *Eur. J. Org. Chem.* **2004**, 647−650.

(8) Wang, Y. C.; Bauer, S. H. *J. Am. Chem. Soc.* **1972**, *94*, 5651−5657.

JA0579208