10736 *J. Am. Chem. Soc.* **2000,** *122,* 10736−10737

Migrating Alkynes in Vinylidene Carbenoids: An Unprecedented Route to Polyynes

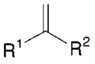
Sara Eisler and Rik R. Tykwinski*

Department of Chemistry, University of Alberta
Edmonton, Alberta, T6G 2G2 Canada

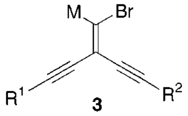
Received August 28, 2000

The Fritsch−Buttenberg−Wiechell (FBW) Rearrangement[1] of alkylidene carbenoids (**1**, M = metal) or carbenes (**2**) is a well-established method for the synthesis of acetylenes.[2] This transformation has been applied to numerous systems in which the migrating group in **1** or **2**, R^1 or R^2, is an aryl or heteroaryl moiety, a hydrogen atom, or an alkyl group (for which 1,5-C−H insertion is impossible).[3] In many cases, this rearrangement has been particularly effective in the formation of cyclic acetylenic systems that are otherwise difficult to synthesize.[4] To our knowledge, however, alkynes have never been made to migrate in a FBW rearrangement.

1



2

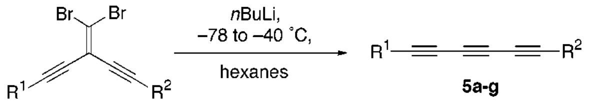


3

With this report we show that alkyne moieties readily undergo 1,2-shifts via an intermediate alkylidene carbene/carbenoid species. In these reactions, lithium−halogen exchange between *n*-BuLi and 1,1-dibromo-2,2-diethynylethenes initiates alkyne migration and affords synthetically useful yields of a wide range of polyynes. The dibromoolefinic precursors are readily available and can be strategically functionalized in order to afford polyyne systems that are difficult or impossible to attain by other methods.[5]

We expected that lithium−halogen exchange between *n*-BuLi and the appropriate 1,1-dibromoolefin could effectively generate the requisite carbenoid intermediate **3**.[6] In fact, intermediate **3** (M = Li) has been previously generated at low temperature by others from **4a**,**b** (Table 1).[7,8] Evidence of carbene formation, however, was not reported in these cases. Our initial experiments toward **3** utilized the more stable triisopropylsilyl (TIPS) protected **4a**. To a solution of **4a** in THF at −78 °C was added a slight excess of *n*-BuLi, and the reaction mixture was slowly warmed to room temperature. Quenching after various reaction times, however, failed to provide evidence of the formation of **5a**. Consistently isolated from these reactions was the product expected from protonation of **3** during the workup process.

Table 1. Synthesis of Triynes **5a**−**g** from Dibromoolefins **4a**−**g**



4a-g **5a-g**

	R^1	R^2	triyne yield (%)^a
4a	i-Pr$_3$Si	i-Pr$_3$Si	**5a** (70)^b
4b	Me$_3$Si	Me$_3$Si	**5b** (0)
4c	i-Pr$_3$Si	Me$_3$Si	**5c** (61)^b
4d^c	Me$_3$Si	1-naphthyl	**5d** (70)
4e	i-Pr$_3$Si	1-naphthyl	**5e** (62)
4f	n-Bu	n-Bu	**5f** (80)
4g	n-octyl	n-octyl	**5g** (66)

^{a} Isolated yields after column chromatography. ^{b} For an alternative synthesis, see ref 5. ^{c} Reaction conducted at 0 °C.

It was anticipated that perhaps the poor solvating ability of a less polar solvent might favor decomposition of intermediate **3** and initiate the FBW rearrangement. As a result, the reaction with **4a** was conducted in hexanes, with quite satisfying results. Addition of *n*-BuLi to a hexanes solution of **4a** at −78 °C and warming to −40 °C effected lithium−halogen exchange followed by rearrangement to the desired triyne **5a** (Table 1).[9] The reaction is very clean, and no product resulting from protonation of intermediate **3** was observed. Conversely, reaction of trimethylsilyl (TMS)-protected dibromoolefin **4b**[10] under analogous reaction conditions gave disappointing results—all attempts to generate triyne formation from **4b** have been unsuccessful.[11,12] The rearrangement reaction with differentially protected **4c**,[10] on the other hand, gave a good yield of the triyne **5c**. This suggested that perhaps the presence of a TIPS-protected alkyne moiety was necessary for the desired rearrangement. The successful rearrangement of 1-naphthyl derivative **4d** to afford the TMS-protected triyne **5d**, however, shows that the presence of the TIPS−C≡C moiety is not a requirement.[13] Comparable to the formation of **5d**, the reaction of TIPS-protected **4e** provided a 62% yield of **5e**.

Appending an alkyl substituent to the enyne framework, as in **4f** and **4g**, allows for a competing intramolecular C−H bond insertion reaction,[14] depending on the rate of alkyne migration.[15,16]

---

(1) Fritsch, P. *Liebigs Ann. Chem.* **1894**, *272*, 319−323. Buttenberg, W. P. *Liebigs Ann. Chem.* **1894**, *272*, 324−337. Wiechell, H. *Liebigs Ann. Chem.* **1894**, *272*, 337−344.

(2) Kirmse, W. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 1164−1170. Stang, P. J. *Chem. Rev.* **1978**, *78*, 383−405. Hartzler, H. D. In *Carbenes*; Moss, R. A., Jones, M., Jr., Eds.; Wiley and Sons: New York, 1983; Vol. 2, pp 43−100. Ben-Efraim, D. A. In *The Chemistry of the Carbon−Carbon Triple Bond*, Part 2; Patai, S., Ed.; Wiley: New York, 1978, pp 755−808. Köbrich, G. *Angew. Chem., Int. Ed. Engl.* **1965**, *4*, 49−68.

(3) Rezaei, H.; Yamanoi, S.; Chemla, F.; Normant, J. F. *Org. Lett.* **2000**, *2*, 419−421. Creton, I.; Rezaeï, H.; Marek, I.; Normant, J. F. *Tetrahedron Lett.* **1999**, *40*, 1899−1902. Mouriès, V.; Waschbüsch, R.; Carran, J.; Savignac, P. *Synthesis* **1998**, 271−274. Sato, H.; Isono, N.; Miyoshi, I.; Mori, M. *Tetrahedron* **1996**, *52*, 8143−8158. Kunishima, M.; Hioki, K.; Ohara, T.; Tani, S. *Chem. Commun.* **1992**, 219−220. Back, T. G.; Muralidharan, K. R. *J. Org. Chem.* **1991**, *56*, 2781−2787. Fienemann, H.; Köbrich, G. *Chem. Ber.* **1974**, *107*, 2797−2803.

(4) Johnson, R. P.; Daoust, K. J. *J. Am. Chem. Soc.* **1995**, *117*, 362−367. Kawase, T.; Darabi, H. R.; Uchimiya, R.; Oda, M. *Chem. Lett.* **1995**, 499−500. Ando, T.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1971**, *44*, 172−177. Kataoka, M.; Ando, T.; Nakagawa, M. *Bull. Chem. Soc. Jpn.* **1971**, *44*, 177−184. Erickson, K. L.; Wolinsky, J. *J. Am. Chem. Soc.* **1965**, *87*, 1142−1143.

(5) Inter alia: Rubin, Y.; Lin, S. S.; Knobler, C. B.; Anthony, J.; Boldi, A. M.; Diederich, F. *J. Am. Chem. Soc.* **1991**, *113*, 6943−6949.

(6) Curtin, D. Y.; Flynn, E. W. *J. Am. Chem. Soc.* **1959**, *81*, 4714−4719.

(7) Feldman, K. S.; Weinreb, C. K.; Youngs, W. J.; Bradshaw, J. D. *J. Am. Chem. Soc.* **1994**, *116*, 9019−9026.

(8) Lange, T.; van Loon, J.-D.; Tykwinski, R. R.; Schreiber, M.; Diederich, F. *Synthesis* **1996**, 537−550. van Loon, J.-D.; Seiler, P.; Diederich, F. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 1187−1189.

(9) For the polymerization of triynes, see: Xiao, J.; Yang, M.; Lauher, J. W.; Fowler, F. W. *Angew. Chem. Int. Ed.* **2000**, *39*, 2132−2135.

(10) Anthony, J.; Boldi, A. M.; Rubin, Y.; Hobi, M.; Gramlich, V.; Knobler, C. B.; Seiler, P.; Diederich, F. *Helv. Chim. Acta* **1995**, *78*, 13−45.

(11) A preliminary report of the formation of **5b** via a carbenoid process has been brought to our attention, see: Tobe, Y.; Iwasa, N.; Sonoda, M. *Abstracts of Papers*, Eighth International Kyoto Conference on New Aspects of Organic Chemistry, Kyoto, Japan; 2000, PP-288.

(12) The major product isolated from this reaction results from butylation of intermediate **3**, and its formation is independent of temperature and the number equivalents of *n*-BuLi that are used.

(13) The purity and structure of all new compounds were confirmed by ^{1}H- and ^{13}C NMR, IR, MS, and either EA or HRMS. Synthetic and characterization details are provided as Supporting Information.

(14) Feldman, K. S.; Mareska, D. A. *J. Org. Chem.* **1999**, *64*, 5650−5660.

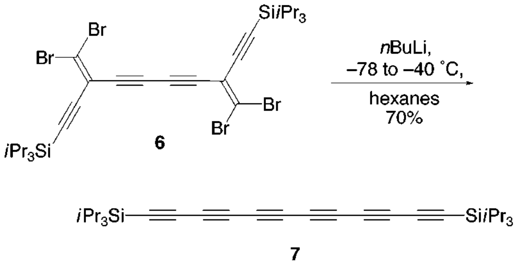
(15) Whereas H or aryl groups migrate rapidly in FBW reactions to yield alkynes, alkyl substituents migrate more slowly, often yielding mixtures of products, including those from C−H insertion (refs 16).

(16) von der Schulenburg, W. G.; Hopf, H.; Walsh, R. *Angew. Chem., Int. Ed.* **1999**, *38*, 1128−1130. Xiang, J. S.; Fuchs, P. L. *Tetrahedron Lett.* **1996**, *37*, 5269−5272. Taber, D. F.; Meagley, R. P.; Doren, D. J. *J. Org. Chem.* **1996**, *61*, 5723−5728. Gilbert, J. C.; Giamalva, D. H.; Weerasooriya, U. *J. Org. Chem.* **1983**, *48*, 5251−5256. Wolinsky, J.; Clark, G. W.; Thorstenson, P. C. *J. Org. Chem.* **1976**, *41*, 745−750.

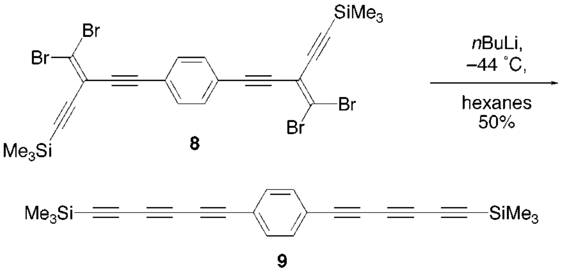
10.1021/ja005557t CCC: $19.00

Intramolecular cyclization was not anticipated for **4f** due to the significant ring strain that would be generated in the product. As such, the reaction of **4f** under standard conditions provided an 80% yield of **5f**. Precursor **4g**, however, contains pendant *n*-octyl substituents of sufficient length to allow C−H bond insertion. α-Elimination of **4g** effected only formation of the desired triyne **5g**, and no evidence of intramolecular cyclization was observed. The formation of **5g** and lack of insertion products from these reactions suggests that the FBW rearrangement process is quite fast and successfully competes with intra- and intermolecular insertion or addition reactions for these cases.

The formation of **5a**−**f** demonstrates a straightforward and useful route into a variety of symmetrical and unsymmetrical substituted triynes. We sought next to explore the scope of this new method toward extended polyynes that would be more difficult or impossible to synthesize using established methodology. In particular, systems that involve the concurrent or sequential rearrangement of more than one carbene/carbenoid species were targeted (eq 1). Tetrabromide **6** is accessed easily from **4c** via protodesilylation and oxidative acetylenic homocoupling.[17] Reaction of **6** with 2.2 equiv of *n*-BuLi provided an excellent yield of dodecahexayne **7** as highly crystalline red solid. Using a similar strategy, tetrabromide **8** gave the unprecedented hexayne **9** (eq 2). One might envision the synthesis of **9**, or the analogous TIPS-protected derivative, via the palladium-catalyzed coupling of *p*-diiodobenzene with 1-trimethyl- or 1-triisopropylsilylhexatriyne, respectively. In both cases, however, such methodology would be challenging, if not impossible, due to the inherent instability and difficult preparation of the 1-trialkylsilylhexatriynes.[5,18,19]

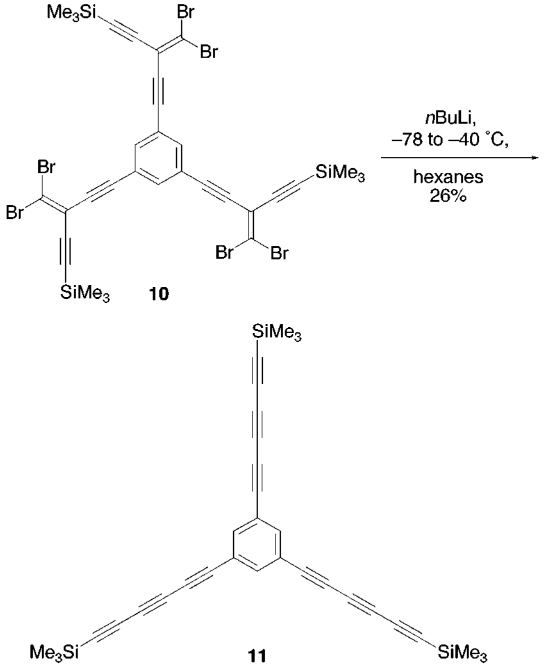


(1)



(2)

This new method is applicable to the convergent synthesis of two-dimensional systems such as **11** (eq 3). The addition of 3.6 equiv of *n*-BuLi to a dilute solution of hexabromide **10** at −78 °C and warming to −40 °C successfully effected the formation of tris(triyne) derivative **11** in 26% yield. Whereas the yield of **11** is modest, it is quite simple to purify (as are **7** and **9**). All major byproducts from these reactions are considerably more polar than the desired polyynes and are easily removed via column chromatography. The highly unsaturated **11** is isolated as a surprisingly stable solid, and it represents a valuable precursor toward expanded carbon networks.[20]



(3)

In conclusion, we have demonstrated the first known examples of alkyne migrations in a Fritsch−Buttenberg−Wiechell rearrangement via lithium−halogen exchange in 1,1-dibromo-2,2-diethynylethenes. This rearrangement can be effected on a variety of substrates, and it tolerates silyl, aryl, acetylenic, and alkyl substitution on the precursor dibromo-olefins. Most significant, however, is the ability to accomplish multiple FBW rearrangements within the same molecule. This promises to provide a synthetic route to a wide range of extended polyynes that are currently difficult or impossible to produce using known methods. The extension of this methodology to longer linear, as well as cyclic polyyne systems, is currently underway.

Acknowledgment. Financial support for this work has been provided by the University of Alberta, the Alberta Science, Research, and Technology Authority, and NSERC. We thank Ms. Navjot Chahal for her contributions to this project.

Supporting Information Available: Experimental procedures and characterization for all new compounds and ^{1}H and ^{13}C NMR spectra for **7**, **9**, and **11** (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

JA005557T

---

(17) Siemsen, P.; Livingston, R. C.; Diederich, F. *Angew. Chem. Int. Ed.* **2000**, *39*, 2633−2657.

(18) Eastmond, R.; Johnson, T. R.; Walton, D. R. M. *Tetrahedron* **1972**, *28*, 4601−4616.

(19) Yamaguchi, M.; Park, H. J.; Hirama, M.; Torisu, K.; Nakamura, S.; Minami, T.; Nishihara, H.; Hiraoka, T. *Bull. Chem. Soc. Jpn.* **1994**, *67*, 1717−1725.

(20) (a) Carbon Rich Compounds II. *Top. Curr. Chem.* **1999**, *201*. (b) Bunz, U. H. F.; Rubin, Y.; Tobe, Y. *Chem. Soc. Rev.* **1999**, 107−119. (c) Haley, M. M.; Wan, W. B. In *Advances in Strained and Interesting Organic Molecules*; Halton, B., Ed.; JAI Press: New York, 2000; Vol. 8, pp 1−41. (d) Stang, P. J.; Diederich, F. *Modern Acetylene Chemistry*; VCH: Weinheim, 1995. (e) Diederich, F.; Rubin, Y. *Angew. Chem., Int. Ed. Engl.* **1992**, *31*, 1101−1123.