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Acyl-Lithiation of Olefins: Formation of Cyclopentenones from 1-Lithio-butadienes and CO

Qiuling Song, Zhiping Li, Jinglong Chen, Congyang Wang, and Zhenfeng Xi*

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

zfxi@pku.edu.cn

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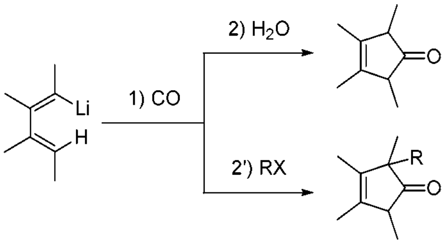
ABSTRACT



Intramolecular acyl-lithiation of C═C double bonds proceeds following carbonylation of 1-lithio-1,3-dienes with CO to afford 2- or 3-cyclopentenone derivatives in good to excellent yields after hydrolysis. Addition of electrophiles to the carbonylation reaction mixtures affords various multiply substituted cyclopentenones.

Carbonyllithium species, the initial intermediates in the addition reactions of CO with organolithium compounds, have attracted intensive attention as potential reagents for organic synthesis.[1] In principle, two types of successful applications have been developed using carbonyllithium species as reactive intermediates. Murai and others developed the intramolecular reaction pattern, in which the highly reactive carbonyllithium species were converted to stable enolates and ynolates.[2] Cyclic compounds, including cyclopentenones, were formed in the cases of 1-(silyl)vinyllithium, azadienyllithium, or aroyllithium with the participation of 1,2-silicon shift or aromatic π-electron systems,[2a,3,4] or in the cases of dilithium compounds.[5,6] Seyferth and others developed the intermolecular reaction pattern, trapping carbonyllithium species with electrophiles at very low temperatures.[7−9] Carbo-lithiation of unsaturated C−C bonds is a very important approach for construction of new C−C

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[1] (a) Murai, S.; Iwamoto, K. In *Modern Carbonyl Chemistry*; Otera, J., Ed.; Wiley-VCH: Weinheim, Germany, 2000; p 131. (b) Colquhoun, H. M.; Thompson, D. J.; Twigg, M. V. *Carbonylation-Direct Synthesis of Carbonyl Compounds*; Plenum: New York, 1991. (c) Wakefield, B. J. *Organolithium Methods*; Academic Press: San Diego, 1988; p 95. (d) Narayana, C.; Periasamy, M. *Synthesis* **1985**, 253. (e) Seyferth, D.; Weinstein, R. M.; Wang, W.; Hui, R. C.; Archer, C. M. *Isr. J. Chem.* **1984**, *24*, 167.

[2] (a) Murai, S.; Ryu, I.; Iriguchi, J.; Sonoda, N. *J. Am. Chem. Soc.* **1984**, *106*, 2440. (b) Ryu, I.; Hayama, Y.; Hirai, A.; Sonoda, N.; Orita, A.; Ohe, K.; Murai, S. *J. Am. Chem. Soc.* **1990**, *112*, 7061. (c) Kai, H.; Iwamoto, K.; Chatani, N.; Murai, S. *J. Am. Chem. Soc.* **1996**, *118*, 7634. (d) Ryu, I.; Yamamoto, H.; Sonoda, N.; Murai, S. *Organometallics* **1996**, *15*, 5459.

[3] (a) Orita, A.; Fukudome, M.; Ohe, K.; Murai, S. *J. Org. Chem.* **1994**, *59*, 477. (b) Kai, H.; Yamaguchi, M.; Murai, S. *Tetrahedron Lett.* **1997**, *38*, 9027. (c) Iwamoto, K.; Chatani, N.; Murai, S. *J. Org. Chem.* **2000**, *65*, 7944. (d) Iwamoto, K.; Kojima, M.; Chatani, N.; Murai, S. *J. Org. Chem.* **2001**, *66*, 169.

[4] (a) Smith, K.; Pritchard, G. J. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 282. (b) Smith, K.; El-Hiti, G. A.; Hawes, A. C. *Synlett* **1999**, 945. (c) Smith, K.; El-Hiti, G. A.; Pritchard, G. J.; Hamilton, A. *J. Chem. Soc., Perk. Trans. 1* **1999**, 2299.

[5] Takahashi, T.; Huo, S.; Hara, R.; Noguchi, Y.; Nakajima, K.; Sun, W. *J. Am. Chem. Soc.* **1999**, *121*, 1094.

[6] Song, Q.; Chen, J.; Jin, X.; Xi, Z. *J. Am. Chem. Soc.* **2001**, *123*, 10419.

[7] (a) Seyferth, D.; Weinstein, R. M. *J. Am. Chem. Soc.* **1982**, *104*, 5534. (b) Seyferth, D.; Weinstein, R. M.; Wang, W. *J. Org. Chem.* **1983**, *48*, 1144. (c) Weinstein, R. M.; Wang, W.; Seyferth, D. *J. Org. Chem.* **1983**, *48*, 3367. (d) Seyferth, D.; Weinstein, R. M.; Wang, W.; Hui, R. C. *Tetrahedron Lett.* **1983**, *24*, 4907. (e) Seyferth, D.; Hui, R. C. *Tetrahedron*

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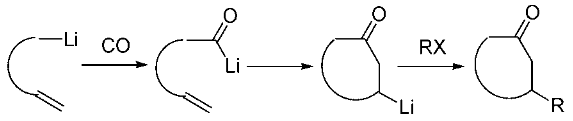
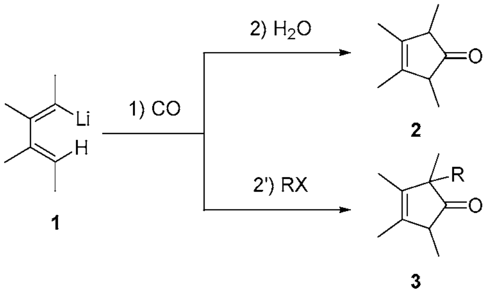
bonds.[10] Conceptually, acyl-lithiation of unsaturated C−C bonds demonstrated in Scheme 1 is more interesting and more useful, since not only new C−C bonds but also carbonyl groups can be introduced into the products. However, to the best of our knowledge, such a reaction has not been reported.

Scheme 1



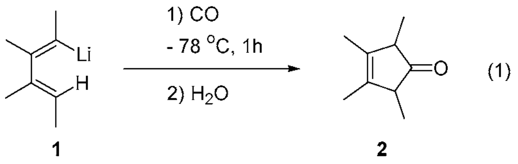
In this paper, we report the first example of acyl-lithiation reactions of C−C double bonds, in which a tandem carbonylation/cyclo-acylation reaction takes place to afford useful cyclopentenone derivatives (Scheme 2).

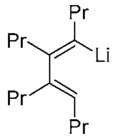
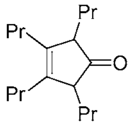
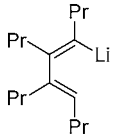
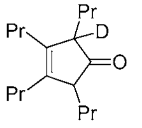
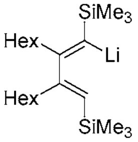
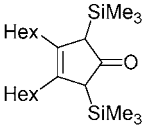
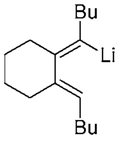
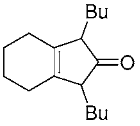
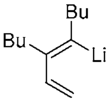
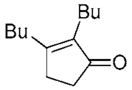
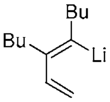
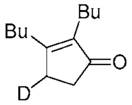
Scheme 2



1-Lithio-1,3-diene derivatives **1** were generated in situ by lithiation of their corresponding 1-iodo-1,3-diene derivatives using t-BuLi.[11] Inlet of CO gas directly from a CO gas cylinder into the Schlenk tube of **1** under a slightly positive pressure of CO resulted in an immediate reaction. Hydrolysis of the reaction mixture with water affords 3-cyclopentenones **2** in high isolated yields (eq 1). Representative examples are given in Table 1. 3-Cyclopentenones instead of 2-cyclopentenones are obtained after hydrolysis.[5,6] Monolithio compounds **1a**−**c** all afforded their corresponding 3-cyclopentenones **2a**−**c** as mixtures of trans and cis isomers, with cis isomers being the major ones. One exceptional case is the reaction of **1d**, which gave 2-cyclopentenone **2d** as the only product in 79% isolated yield.[12] No 3-cyclopentenone was formed in this case.

Table 1. Hydrolysis of Reaction Mixtures of 1-Lithio-1,3-dienes **1** with Carbon Monoxide[a]



run	lithio compound **1**		product **2**		yield of **2**/%[b]
1		**1a**		**2a**[c]	93
2		**1a**		**2aD**[c]	91
3		**1b**		**2b**[d]	70
4		**1c**		**2c**[c]	71
5		**1d**		**2d**[e]	79
6		**1d**		**2dD**[e]	74

[a] Reaction conditions: shown in eq 1. [b] Isolated yields. Combined isolated yields are given in cases of mixtures. [c] A mixture of cis and trans isomers in 4:1. [d] A mixture of cis and trans isomers in 5:1. [e] Only product.

Monodeuterated 3-cyclopentenone **2aD** was obtained in 91% isolated yield with D incorporation being more than

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Lett. **1984**, *25*, 2623. (f) Seyferth, D.; Wang, W.; Hui, R. C. *Tetrahedron Lett.* **1984**, *25*, 1651. (g) Seyferth, D.; Hui, R. C. *J. Org. Chem.* **1985**, *50*, 1985. (h) Seyferth, D.; Hui, R. C. *J. Am. Chem. Soc.* **1985**, *107*, 455. (i) Seyferth, D.; Hui, R. C.; Wang, W.; Archer, C. M. *J. Org. Chem.* **1993**, *58*, 5843.

(8) (a) Nudelman, N. S.; Vitale, A. A. *J. Org. Chem.* **1981**, *46*, 4625. (b) Nudelman, N. S.; Outumuro, P. *J. Org. Chem.* **1982**, *47*, 4347. (c) Perez, D.; Nudelman, N. S. *J. Org. Chem.* **1988**, *53*, 408. (d) Nudelman, N. S.; Doctorvich, F. *Tetrahedron* **1994**, *50*, 4651.

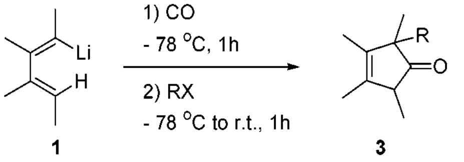
(9) (a) Li, N.; Yu, S.; Kabalka, G. W. *J. Org. Chem.* **1995**, *60*, 5973. (b) Kabalka, G. W.; Li, N.; Yu, S. *Organometallics* **1995**, *14*, 1565. (c) Li, N.; Yu, S.; Kabalka, G. W. *Organometallics* **1998**, *17*, 3815.

(10) Intramolecular insertion of an unactivated alkene into a carbon (sp^3)−lithium bond has been attractive for construction of C−C bonds. For examples, see: (a) Bailey, W. F.; Khanolkar, A. D.; Gavaskar, K.; Ovaska, T. V.; Rossi, K.; Thiel, Y.; Wiberg, K. B. *J. Am. Chem. Soc.* **1991**, *113*, 5720 and references therein. (b) Zhang, D. W.; Liebeskind, L. S. *J. Org. Chem.* **1996**, *61*, 2594. (c) Norsikian, S.; Marek, I.; Klein, S.; Poisson, J. F.; Normant, J. F. *Chem. Eur. J.* **1999**, *5*, 2055.

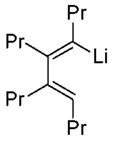
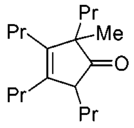
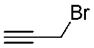
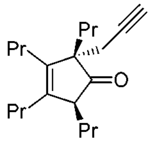
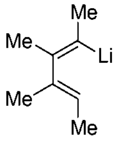
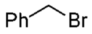
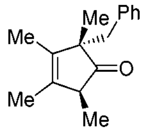
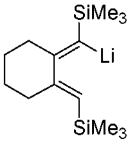
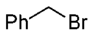
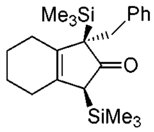
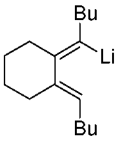
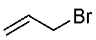
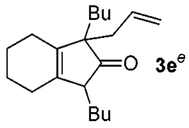
(11) Preparative methods for 1-iodo-1,3-diene derivatives, see: (a) Takahashi, T.; Kondakov, D. Y.; Xi, Z.; Suzuki, N. *J. Am. Chem. Soc.* **1995**, *117*, 5871. (b) Takahashi, T.; Sun, W.; Xi, C.; Ubayama, H.; Xi, Z. *Tetrahedron* **1998**, *54*, 715. (c) Ubayama, H.; Sun, W.; Xi, Z.; Takahashi, T. *Chem. Commun.* **1998**, 1931.

(12) Takahashi, T.; Xi, Z.; Nishihara, Y.; Huo, S.; Kasai, K.; Aoyagi, K.; Denisov, V.; Negishi, E. *Tetrahedron* **1997**, *53*, 9123.

Table 2. Alkylation of Reaction Mixtures of 1-Lithio-1,3-dienes **1** with Carbon Monoxide[a]



(2)

run	lithio compound **1**		reagent	product **3**		yield of **3**/%[b]
1		**1a**	MeI		**3a**[c]	90
2	**1a**				**3b**[d]	67
3		**1e**			**3c**[d]	78
4		**1f**			**3d**[d]	75
5		**1c**			**3e**[e]	79

[a] Reactions conditions: shown in eq 2. [b] Isolated yields. Combined isolated yields are given in cases of mixtures. [c] A mixture of cis and trans isomers in 3:2. [d] Only product. [e] A mixture of cis and trans isomers in 10:1.

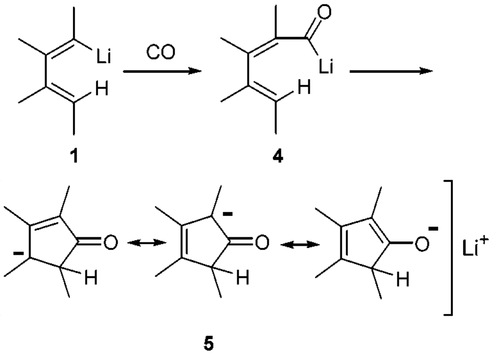
95% from deuteriolysis of the carbonylation reaction mixture of **1a** and CO. Deuteriolysis of the carbonylation reaction mixture of **1d** (run 6) afforded monodeuterated 2-cyclopentenone **2dD** in 74% isolated yield with D being at the β position. These results are informative for understanding the reaction mechanisms.

It is interesting to compare the stereochemistry of **2a** with that obtained from the reaction of 1,4-dilithio-1,3-dienes.[6] The dilithio reagents gave *trans*-3-cyclopentenones, while these monolithio reagents afforded *cis*-3-cyclopentenones as major products.

Instead of hydrolysis of the carbonylation reaction mixtures, addition of electrophiles afforded various multiply substituted 3-cyclopentenones (eq 2). Methyl iodide, benzyl halides, allylic halides, and propargyl halides could be used as alkylation reagents to produce monoalkylated 3-cyclopentenones **3**.[6] Results are given in Table 2. Compounds **3a** and **3e** were obtained as mixtures of cis and trans isomers, with the cis isomers being the major ones. However, cyclopentenones **3b**−**d** were obtained as the only isomers. In comparison, the ratio of cis to trans selectivity for **3** is different from that for **2**.

A proposed reaction mechanism is given in Scheme 3. The carbonyllithium species **4**, proposed to be the first reaction intermediate, immediately undergoes intramolecular acyl-lithiation of the C═C double bond to afford **5**.[13] Further investigation into the reaction mechanisms and further applications of this novel and synthetically useful reactions are in progress.

Scheme 3



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Supporting Information Available: Experimental details and full characterization of all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

OL026977L

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[13] A novel reaction of the 1-lithio-1,3-dienes with nitriles has been reported. Chen, J.; Song, Q.; Wang, C.; Xi, Z. *J. Am. Chem. Soc.* **2002**, *124*, 6238.