Communications

Cyclization of 5-Hexenyllithium to (Cyclopentylmethyl)lithium[1]

Summary: The kinetics of cyclization of 5-hexenyllithium (1) to (cyclopentylmethyl)lithium (2), determined by direct observation of the isomerization using ^1H NMR, are characterized by $\Delta H^\ddagger = 11.8 \pm 0.5$ kcal/mol and $\Delta S^\ddagger = -30 \pm 2$ eu.

Sir: The 5-hexenyl radical is known to cyclize rapidly ($k \sim 10^5$ s^{-1} at 0 °C)[2] in essentially quantitative yield to the cyclopentylmethyl radical[2–4] and this behavior has led to the widespread use of 5-hexenyl substrates as probes for radical intermediates in reactions suspected of proceeding via single-electron transfer (SET).[4–7] The observation of products containing the cyclopentylmethyl moiety from reactions employing 5-hexenyl substrates has often been taken as prima facie evidence for the intermediacy of a 5-hexenyl radical.[4] Clearly, such a conclusion is valid only to the extent that other intermediates can be shown not to undergo rapid rearrangement to cyclopentylmethyl-containing products.[8] Although it is well-known that various organometallic derivatives of the 5-hexenyl system cyclize to cyclopentylmethyl organometallics,[9–12] the conventional wisdom has been, with few exceptions,[4,11,13] that such cyclizations are slow relative to the rapid radical-mediated process[3,4] and other reactions that consume anions. Quantitative kinetic data for relevant organometallic cyclizations are sparse but the sluggish isomerization of 5-hexenyl Grignard reagents[10] [i.e., $t_{1/2} = 20$ h for $H_2C{=}CHCH_2CH_2CH_2CH_2MgCl \rightarrow c\text{-}C_5H_9CH_2MgCl$ in THF at 100 °C][10] would seem to confirm this view.

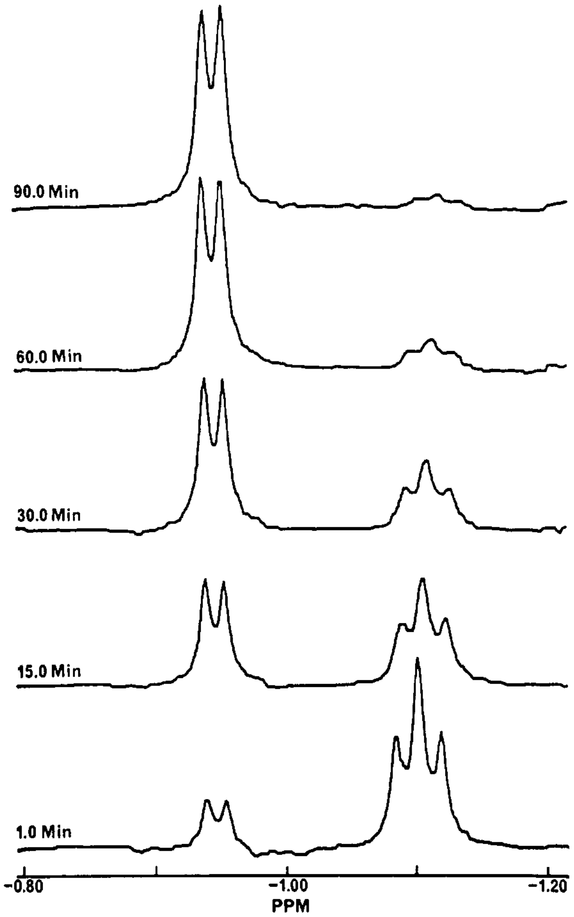


Figure 1. ^1H NMR spectrum (500-MHz) of the CH_2Li region during the isomerization of 1 to 2 at 0 °C in n-C_5H_{12}–Et_2O solution.

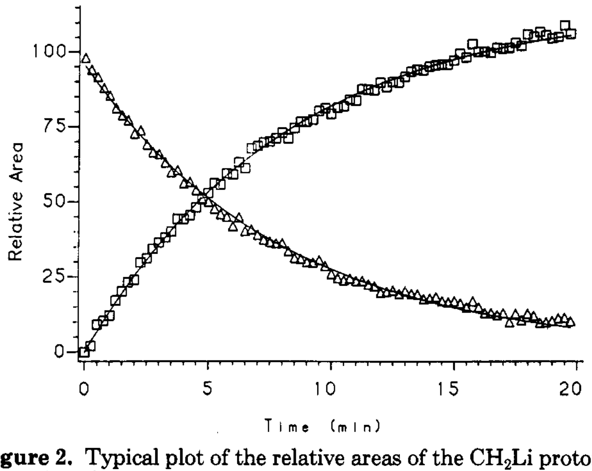


Figure 2. Typical plot of the relative areas of the CH_2Li protons of 1 (△) and 2 (□) as a function of time. Data from experiment at 20 °C in n-C_5H_{12}–Et_2O. The solid line represents the least-squares fit of the data.

Prompted by the results of our recent studies of the metal–halogen interchange reaction,[14] we have investigated

---

(1) Presented in part at the International Symposium on Carbanions, University of Durham, Durham, UK, July 19, 1984.

(2) (a) Griller, D.; Ingold, K. U. *Acc. Chem. Res.* **1980**, *13*, 317. (b) Chatgilialoglu, C.; Ingold, K. U.; Scaiano, J. C. *J. Am. Chem. Soc.* **1981**, *103*, 7739.

(3) Beckwith, A. L. J. *Tetrahedron* **1981**, *37*, 3073.

(4) (a) Beckwith, A. L. J.; Ingold, K. U. In "Rearrangements in Ground and Excited States"; deMayo, P., Ed.; Academic Press: New York, 1980; Vol. 1, Chapter 4. (b) Surzur, J.-M. In "Reactive Intermediates"; Abramovitch, R. A., Ed.; Plenum Press: New York, 1982; Vol. 2, Chapter 3.

(5) Mechanistic studies utilizing the 5-hexenyl radical cyclization as a diagnostic probe were pioneered by Garst and co-workers: (a) Garst, J. F.; Ayers, P. W.; Lamb, R. C. *J. Am. Chem. Soc.* **1966**, *88*, 4260. (b) Garst, J. F. *Acc. Chem. Res.* **1971**, *4*, 400. (c) Garst, J. F. In "Free Radicals"; Kochi, J. K., Ed.; Wiley-Interscience: New York, 1973; Vol. 1, Chapter 9.

(6) (a) Ashby, E. C.; DePriest, R. N.; Goel, A. B.; Wenderoth, B.; Pham, T. N. *J. Org. Chem.* **1984**, *49*, 3545 and references therein. (b) Ashby, E. C.; Argyropoulos, J. N. *Tetrahedron Lett.* **1984**, *25*, 7 and references therein.

(7) (a) Newcomb, M.; Courtney, A. R. *J. Org. Chem.* **1980**, *45*, 1707. (b) Kitching, W.; Olszowy, H. A.; Harvey, K. *J. Org. Chem.* **1981**, *46*, 2423 and references therein.

(8) A preponderance of the products derived from cyclization of the 5-hexenyl cation contain a cyclohexyl group: Bartlett, P. D.; Closson, W. D.; Gogdell, T. J. *J. Am. Chem. Soc.* **1965**, *87*, 1308.

(9) (a) Drozd, V. N.; Ustynyuk, Uy. A.; Tsel'eva, M. A.; Dmitriev, L. B. *J. Gen. Chem. USSR* **1968**, *38*, 2047; *Zh. Obsch. Khim.* **1968**, *38*, 2144. (b) Drozd, V. N.; Ustynyuk, Yu. A.; Tsel'eva, M. A.; Dmitriev, L. B. *J. Gen. Chem. USSR* **1969**, *39*, 1951; *Zh. Obsch. Khim.* **1969**, *39*, 1991.

(10) (a) Richey, H. G., Jr.; Rees, T. C. *Tetrahedron Lett.* **1966**, 4297. (b) Kossa, W. C., Jr.; Rees, T. C.; Richey, H. G., Jr. *Tetrahedron Lett.* **1971**, 3455. (c) Hill, E. A. *J. Organomet. Chem.* **1975**, *91*, 123.

(11) (a) St. Denis, J.; Dolzine, T.; Oliver, J. P. *J. Am. Chem. Soc.* **1972**, *94*, 8260. (b) Smart, J. B.; Hogan, R.; Scherr, P. A.; Emerson, M. T.; Oliver, J. P. *J. Organomet. Chem.* **1974**, *64*, 1. (c) St. Denis, J.; Oliver, J. P.; Dolzine, T. W.; Smart, J. B. *J. Organomet. Chem.* **1974**, *71*, 315. (d) Dolzine, T. W.; Oliver, J. P. *J. Organomet. Chem.* **1974**, *78*, 165.

(12) Garst, J. F.; Hines, J. B., Jr. *J. Am. Chem. Soc.* **1984**, *106*, 6433 and references therein.

(13) Garst, J. F.; Pacifici, J. A.; Felix, C. C.; Nigam, A. *J. Am. Chem. Soc.* **1978**, *100*, 5974.

0022-3263/85/1950-1999$01.50/0

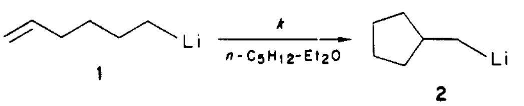
Table I. First-Order Rate Constants and Activation Parameters for the Cyclization of 5-Hexenyllithium (1) to (Cyclopentylmethyl)lithium (2)[a]

temp, °C	10^4k, s^{-1}	ΔH^*, kcal/mol	ΔS^*, eu
−11.1	1.75 ± 0.02	11.8 ± 0.5	−30 ± 2
−9.4	1.77 ± 0.02		
−0.5	4.18 ± 0.03		
0.8	5.71 ± 0.09		
9.4[b]	10.3 ± 0.1		
20.0[c]	20.6 ± 0.2		

[a] Errors are reported as standard deviations. [b] Average of two experiments. [c] Average of three experiments.

the kinetics of the cyclization of 5-hexenyllithium ($CH_2{=}CHCH_2CH_2CH_2CH_2Li$, 1)[15] to (cyclopentylmethyl)lithium ($c\text{-}C_5H_9CH_2Li$, 2)[15] by direct observation of the organolithiums using ^1H NMR spectroscopy. The results of these experiments are summarized in Table I.

Treatment of a 0.5 M solution of 6-iodo-1-hexene in *n*-pentane–diethyl ether (3:2 by volume)[14] with 2-equiv of freshly prepared *tert*-butyllithium[16] (*t*-BuLi) at −78 °C under argon affords an essentially quantitative yield of 1. The isomerization of 1 to 2 was monitored at four temperatures between −10 °C and +20 °C by NMR observation[17] of the CH_2Li region of the spectrum (Figure 1). The CH_2Li protons of 1 appear as a triplet at δ −1.11 (J = 8.67 Hz) while those of 2 appear as a doublet at δ −0.95 (J = 7.18 Hz). This latter assignment was confirmed by synthesis of 2 in quantitative yield upon treatment of a solution of cyclopentylmethyl iodide in $n\text{-}C_5H_{12}\text{–}Et_2O$ (3:2 by volume) with 2 equiv of *t*-BuLi at −78 °C.[14]



The conversion of 1 to 2 is a clean first-order process when care is taken to exclude moisture and oxygen from the reaction mixture. In contrast to the behavior of other 5-hexenylalkalis in ethereal solvents,[13] there was no evidence for prototropic rearrangement of 1 to a 1-propylallyl species. The cyclization was followed through 3–4 half-lives by integration of the CH_2Li patterns of 1 and 2. These data were fit by nonlinear least-squares analysis to the standard exponential form of the first-order rate expression (Figure 2) to give the rate constants reported in Table I. Activation parameters were determined by application of the Eyring equation: a linear plot of ln (k/T) vs. $1/T$ gave (Figure 3) ΔH^* = 11.8 kcal/mol and ΔS^* = −30 eu. The corresponding Arrhenius parameters were also determined: E_a = 12.6 ± 0.6 kcal/mol and ln A = 15.5 ± 1.2.

The data in Table I indicate that although the conversion of 1 to 2 is very much slower (by a factor of 10^8–10^{10}) than the cyclization of the 5-hexenyl radical,[2-4] it is, as suggested by the qualitative observations of Oliver and co-workers,[11] much faster than the analogous isomerization of the 5-hexenyl Grignard.[10] Indeed, nonnegligible quantities of product containing the cyclopentylmethyl group may arise from cyclization of 1 to 2 since the half-life for this process at temperatures above 0 °C ($t_{1/2} \sim$ 23 min at 0 °C, 5.5 min at 23 °C) is short relative to the time scale of many experiments that seek to probe for radical intermediates. Be that as it may, the 5-hexenyl-to-cyclopentylmethyl cyclization remains a useful probe for radical intermediates even in reactions that produce 1,[14] provided account is taken of the relative rates of isomerization of the radical and the organolithium.

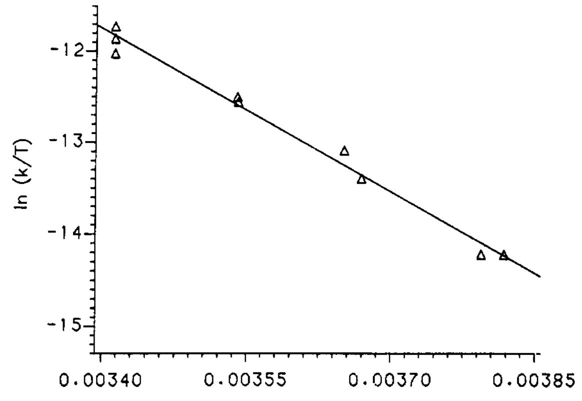


Figure 3. Plot of ln (k/T) vs. $1/T$ (K) for the conversion of 1 to 2. Data from Table I.

The results noted above, and those recently reported by Garst and Hines for (1-methyl-5-hexenyl)sodium,[12] serve to emphasize the caveat that observation of products containing the cyclopentylmethyl group from reactions employing 5-hexenyl substrates is not sufficient evidence to establish the intermediacy of radicals particularly when organometallic species may be involved.

Acknowledgment. We are grateful to Dr. Mark Granville of the University of Connecticut for helpful advice on the kinetic analyses. This investigation was supported in part by the donors of the Petroleum Research Fund, administered by the American Chemical Society, and in part by a generous grant from the Humphrey Chemical Company, North Haven, CT.

William F. Bailey,* Jeffrey J. Patricia
Vincent C. DelGobbo
Department of Chemistry
University of Connecticut
Storrs, Connecticut 06268

Ronald M. Jarret, Paul J. Okarma
Department of Chemistry
Yale University
New Haven, Connecticut 06511

Received February 13, 1985

---

[14] Bailey, W. F.; Gagnier, R. P.; Patricia, J. J. *J. Org. Chem.* **1984**, *49*, 2098.

[15] Although organolithiums are often (as here) represented as monomeric, they are in fact aggregates whose degree of association may be affected by such factors as solvent, concentration, and temperature [Wakefield, B. J. "The Chemistry of Organolithium Compounds"; Pergamon Press: New York, 1974]. The degree of aggregation of 1 and 2 under the reaction conditions is unknown.

[16] Kamienski, C. W.; Esmay, D. L. *J. Org. Chem.* **1960**, *25*, 1807.

[17] ^1H NMR spectra were recorded at the Northeast Regional NMR Facility at Yale University on a Bruker WM-500 spectrometer operating in the FT-mode. The isomerization of 1 to 2 was monitored for 3 to 4 half-lives (70–90 points per experiment). Temperatures were measured as described by Van Geet [*Anal. Chem.* **1970**, *42*, 679] and are considered accurate to ±0.5°.

Stereochemistry of Crotylboronate Additions to α,β-Dialkoxy Aldehydes

Summary: The stereochemistry of the reactions of crotylboronates 1–4 with chiral α,β-dialkoxy aldehydes 5 and 6 is described.

Sir: A transformation with broad significance for control