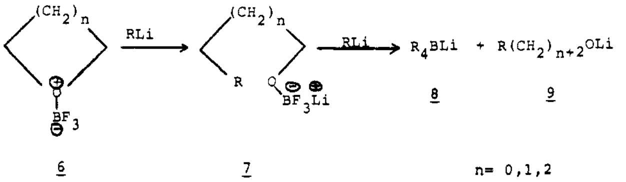
(upfield of $BF_3 \cdot OR_2$ standard). A second peak gradually appeared at −17.8 ppm. Independent synthesis confirmed that the two signals corresponded, respectively, to lithium *n*-octyloxyboron trifluoride[16] and lithium tetrabutylborate. The much faster butylation of oxetane produced a signal at −0.5 ppm but only a very minor resonance at −17.8 ppm. None of the characteristic resonances of mono- and dibutylfluoroboranes could be detected.

These observations support a mechanism involving Lewis acid coordination then nucleophilic addition by *n*-butyllithium leading first to alkoxyboron trifluoride salt **7**. Complex **7** undergoes attack by residual alkyllithium much more rapidly than does $BF_3 \cdot Et_2O$ to produce tetraalkylborate **8** and lithium alkoxide **9**. Low yields of 1-octanol from THF apparently result from deleterious consumption of the organolithium in this fashion. These reactions should find widespread use in organic synthesis.[17]



Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, and the Ayerst Corporation for generous financial assistance. J. Payack provided valuable experimental help. Support of the Cornell Nuclear Magnetic Resonance Facility by the National Science Foundation (CHE 7904825, PCM 8018643) is gratefully acknowledged.

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(16) Kolditz, L.; Lung, C.-S. *Z. Anorg. Allg. Chem.* **1968**, *360*, 25.

(17) The following is a representative experimental procedure: *n*-Butyllithium (2.13 M in hexane; 1.4 mL, 3.0 mmol) was added dropwise to a stirred solution of $BF_3 \cdot Et_2O$ (0.426 g, 3.0 mmol) in THF at −78 °C. Then neat cyclohexene oxide (0.098 g, 1.0 mmol) was added quickly. After 5 min of stirring, the reaction was quenched at −78 °C by addition of saturated aqueous $NaHCO_3$ (3 mL) and allowed to warm to room temperature. The bulk of solvent was removed in vacuo, more water added (3 mL), and the aqueous residue extracted using three 10-mL portions of 1:1 hexane:ether. Drying, evaporation, and then flash chromatography afforded *trans*-2-butylcyclohexanol (0.151 g, 97%).

Observation of the Novel Lithiated Pentacoordinate Carbocations $CH_nLi_{5-n}^+$ (n = 0–3) by Flash Vaporization Mass Spectroscopy

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On some occasions, theoretical predictions precede experiment as ideally they should. In 1978 in the course of ongoing dialogue of our laboratory with P.v.R. Schleyer, we were pleased to learn of the Schleyer–Pople prediction that the pentacoorindate carbocation CLi_5^+ would be stable and that its production by either of the two obvious ion–molecule reactions was favorable (exothermic) by some 60 kcal/mol:[1]

$$CLi_4 + Li^+ \rightarrow CLi_5^+$$

$$CLi_4^+ + Li \rightarrow CLi_5^+$$

When, in the course of our development of the flash vaporization mass spectra of polylithium organic compounds several years later, we observed the CLi_5^+ species among the ions produced by flash vaporization of tetralithiomethane, $(CLi_4)_n$, we congratulated Schleyer and Pople on the accuracy of their forecast and the result was a joint manuscript.[2]

Table I. Pentacoordinate Carbocations $Cli_{5-n}H_n^+$

ion	calculated mass	measured mass	source of ion
Cli_5^+	47.08000	47.08019	$(Cli_4)_n$
$CHLi_4^+$	41.07183	41.07196	$(CHLi_3)_n$
$CH_2Li_3^+$	35.06365	35.06380	$(CH_2Li_2)n$, $(CH_3Li)_4$
$CH_3Li_2^+$	29.05548	29.05559	$(CH_2Li_2)_n$, $(CH_3Li)_4$
CH_4Li^+	23.04730	[sought in CH_4 + Li reaction]	

We now report the observation of four of these unusual pentacoordinate carbocations by high-resolution mass spectroscopy. These novel ions are produced by the flash vaporization and electron impact of polylithium organic compounds. Some such species, $CH_2Li_3^+$ and $CLi_3H_2^+$, appear in the spectra of more than one lithium compound (Table I), while other species such as CLi_4H^+ appear to date only in the vapor species of a single new compound such as trilithiomethane, $(CHLi_3)_n$, which has been produced only very recently in our laboratory.[3] These new carbocations were forecast by Schleyer, Pople, and associates as well.[4]

Since the lithiated methanes are involatile below about 650 °C but thermally unstable above 225 °C[5] it was necessary to flash vaporize the lithiocarbons to obtain transient vapor species in a mass spectrometer. A conically wound, tungsten wire sample probe (which could be heated resistively from room temperature to incandescene [>1500 °C] in less than 2 s) was used for this propose and is illustrated and described elsewhere.[6]

High-resolution peak-matching studies were performed using a CEC model 21-110C double-focusing mass spectrometer (resolution 12000+). The EI ionizing energy was maintained at 70 eV, with the accelerating voltage held at 8 kV. In the actual experiments, the reference ion was positioned in the center of one oscilloscope channel, and the correct $\Delta m/m$ value was selected to position the desired sample ion in the center of the second oscilloscope channel. While sweeping rapidly (<0.5 s/cycle) across the sample ion channel, the appearance of a rising and falling peak with concomitant heating of the sample was confirmatory evidence for the existence of the lithiated carbocation. Each peak-matching experiment was performed a number of times to obtain a value for the relative error in the measured mass.

Halide-free methyllithium was prepared by transmetalation of dimethylmercury with lithium using the Wittig procedure.[7] Dilithiomethane, $(CH_2Li_2)_n$, was formed by the pyrolysis of methyllithium and is detailed elsewhere.[3,8] Trilithiomethane, $(CHLi_3)_n$, and tetralithiomethane, $(CLi_4)_n$, were prepared by metal vapor reactions using the appropriate chlorocarbon precursor.[3,9]

Table I contains calculated and measured masses of the pentacoordinate cations found. As can be seen, all of the lithium-stabilized methanonium ions except CH_4Li^+ are found in the EI mass spectra of the lithiated methanes. Numerous attempts to find this ion in the mass spectra of methyllithium and dilithiomethane were unsuccessful. Calculations predict that this ion may dissociate into CH_4 and Li^+ and probably be stable only at low temperatures.[4] However, the ion appears to be reasonably stable

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(1) Schleyer, P. v. R., private communication, 1978.

(2) Chinn, J. W., Jr.; Landro, F. J.; Schleyer, P. v. R.; Pople, J. A.; Lagow, R. J. *J. Am. Chem. Soc.* **1982**, *104*, 4275.

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(7) Wittig, G.; Meyer, F. J.; Lange, G. *Justus Liebigs Ann. Chem.* **1951**, *571*, 167.

(8) Ziegler, K.; Nagel, K.; Patheigher, M. *Z. Anorg. Allg. Chem.* **1955**, *282*, 345.

(9) Chung, C.; Lagow, R. J. *J. Chem. Soc., Chem. Commun.* **1972**, 1079.

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and has been reported in ion-molecule reactions (Li^+–CH_4) at moderate pressures.[10]

With the exception of $CH_3Li_2^+$, which has been reported[2,11] to be the base peak in some unpublished work of G. D. Stucky and co-workers on the decomposition mass spectrum of $LiB(CH_3)_4$, all of the carbocations in the table were first observed in this laboratory. $CH_3Li_2^+$ is also found to be the base peak in the high-resolution spectrum of methyllithium.[12]

A further collaborative study[13] is planned to ascertain whether these five-coordinate carbocations are produced by ion-molecule reaction or by ionization of neutral species. Further, the ionization potentials and other thermodynamic data of these interesting species will be measured.

Schleyer, Pople, and co-workers have recently produced an optimistic forecast for the prospects of stability of hypervalent neutrals such as $C(Li)_n$ ($n = 5,6$) and similar mixed hydrogen-lithium species.[14] Experimental conformation of these predictions would be both surprising and important.

Acknowledgment. Support of this research by the Nation Science Foundation (CHE-8210708) and partial support by the Robert A. Welch Foundation (F-700) is gratefully acknowledged. We also thank Dr. James E. Hudson for helpful technical assistance with the mass spectrometer.

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[13] Lagow, R. J.; Beynon, J. E., unpublished results.

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Bifunctional Chiral Synthons via Biochemical Methods. 3. Optical Purity Enhancement in Enzymic Asymmetric Catalysis[1]

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Microorganisms and enzymes are becoming increasingly recognized as valuable chiral catalysts for asymmetric syntheses, and many examples of their synthetic utilities have been documented.[2] The hydrolytic enzymes have been particularly widely investigated because many of them are capable of transforming diesters into chiral monoesters via enantiotopic group differentiation.[3] While these enzymes generally have relaxed substrate specificities toward unnatural compounds, suitable enzyme systems with high stereochemical specificity are often not readily accessible. Herein we describe a concept that allows one to prepare monoesters of high optical purity using esterases of low to moderate stereoselectivity for the enantioselective hydrolysis of diesters.

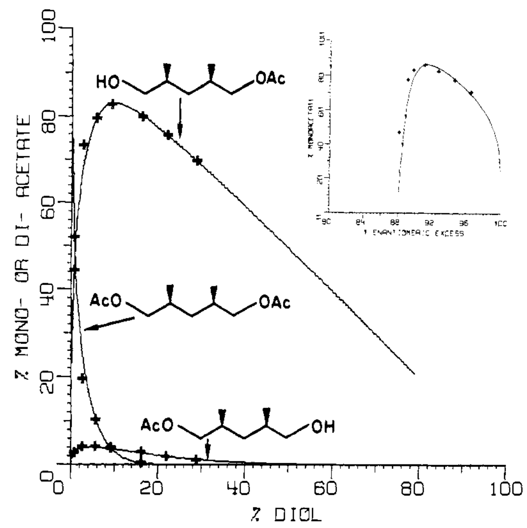

Figure 1. Plot of percent diacetate or monoacetate as a function of percent diol. The curves were computer generated (eq 1, 2, and 3) by using the following: $\alpha = 15.6$, $E_1 = 0.036$, and $E_2 = 0.18$. (#) Experimentally determined values. Insert: Percent monoacetate as a function of percent enantiomeric excess.

Suppose that S is an achiral diester with a plane of symmetry, which is converted by an esterase yielding the two enantiomeric monoesters P (fast forming) and Q (slow forming); in turn, they are further hydrolyzed by the same enzyme to afford R.

$$\begin{tikzcd} & P \arrow[dr, "k_3"] & \\ S \arrow[ur, "k_1"] \arrow[dr, "k_2"'] & & R \\ & Q \arrow[ur, "k_4"'] & \end{tikzcd}$$

When the substrate is a dicarboxylic ester, the reaction generally terminates at the monoester stage with most carboxyesterases.[4] Thus, the ratio of the rates of formation of P and Q is dictated by the constant $\alpha = k_1/k_2$, and the optical purity of the monoester fraction is simply defined by $\beta = (\alpha - 1)/(\alpha + 1)$. On the other hand, when the substrate is a diacetoxy ester, the resulting monoesters (P and Q) usually undergo further concomitant cleavage to yield the diol, R. If the same stereochemical preference is maintained, one would expect the relative rate constants of hydrolysis to follow the order $k_1 > k_2$ and $k_4 > k_3$.[5] Hence, in such cases, this combined procedure (enantioselective hydrolysis followed by kinetic resolution) provides a convenient method of enhancing the optical purity of the monoester fraction.

Since the hydrolytic reaction is virtually irreversible and product inhibition is generally noticeable only at very late stages of the reaction, one may derive quantitative expressions[6] to calculate the concentrations of S, P, Q, and R at any extent of conversion. Definition of the kinetic parameters α, E_1, and E_2 allows the

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[1] For parts 1 and 2 of this series, see: (a) Chen, C. S.; Fujimoto, Y.; Sih, C. J. *J. Am. Chem. Soc.* **1981**, *103*, 3580. (b) Takaishi, Y.; Yang, Y. L.; DiTullio, D.; Sih, C. J. *Tetrahedron Lett.* **1982**, *23*, 5489.

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[5] k_1, k_2, k_3, and k_4 (apparent first-order rate constants) can be related to the kinetic constants of the enzyme as $k_1 + k_2 = k_{\mathrm{cat(S)}}/K_S$, $k_3 = k_{\mathrm{cat(P)}}/K_P$, and $k_4 = k_{\mathrm{cat(Q)}}/K_Q$, where $k_{\mathrm{cat(S)}}$, $k_{\mathrm{cat(P)}}$, and $k_{\mathrm{cat(Q)}}$ are turnover numbers and K_S, K_P, and K_Q are their respective Michaelis constants.

[6] Quantitative expressions:

$$P = \frac{\alpha S_0}{(\alpha + 1)(1 - E_1)}\left[\left(\frac{S}{S_0}\right)^{E_1} - \left(\frac{S}{S_0}\right)\right] \qquad (1)$$

$$Q = \frac{S_0}{(\alpha + 1)(1 - E_2)}\left[\left(\frac{S}{S_0}\right)^{E_2} - \left(\frac{S}{S_0}\right)\right] \qquad (2)$$

$$R = S_0 - S - P - Q \qquad (3)$$

where $E_1 = k_3/(k_1 + k_2)$ and $E_2 = k_4/(k_1 + k_2)$. See supplementary material for (a) derivation of equations, (b) determination of α, E_1, and E_2, and (c) analytical methods.