traction with 4 × 40 mL of $CHCl_3$, followed by concentration of the combined, dried (K_2CO_3) extracts to a small volume and filtration through a short column of neutral alumina, gave, after final evaporation, a brown oil which was purified by preparative TLC ($CHCl_3/CH_3OH$, 9:1) to give 78.5 mg (41%) of pure (±)-kreysigine: R_f 0.36; mp 185–186 °C (lit.[47] mp 185–186 °C); UV λ_{max} (CH_3OH) (log ϵ) 220 (4.63), 260 (4.16), 291 nm (3.87); IR ($CHCl_3$) 3500 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.72, 6.69 (2 s, 2 H, 2 ArH), 3.90 (s, 9 H, 3 OCH_3), 3.65 (s, 3 H, OCH_3), 3.2–2.0 (m, 10 H, 4 CH_2 + 1 CH + 1 OH), 2.39 (s, 3 H, NCH_3).

1-(3′,4′,5′-Trimethoxyphenethyl)-2-methyl-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline (19e). This compound was prepared in 95% yield from 1-(3′,4′,5′-trimethoxyphenethyl)-2-methyl-3,4-dihydroisoquinolinium iodide[67] as described for the preparation of **6b**: mp 76.5 °C (from hexane/ether); ^1H NMR ($CDCl_3$) δ 6.60, 6.40 (2 s, 4 H, 4 ArH), 3.87 (s, 15 H, 5 OCH_3), 3.50–1.90 (m, 9 H, 4 CH_2 + 1 CH), 2.50 (s, 3 H, NCH_3). Anal. ($C_{23}H_{31}NO_5$) C, H, N.

TTFA Coupling of 1-(3′,4′,5′-Trimethoxyphenethyl)-2-methyl-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline (19e) to (±)-*O*-Methylkreysigine (18b). The oxidative coupling of **19e** to **18b** was carried out as described above for the preparation of **18a**. Preparative TLC ($C_6H_6/CH_3OH/CHCl_3$, 1:4:10) then gave 58 mg (28%) of recovered **19e**, R_f 0.91, and 65 mg (46%) of pure (±)-*O*-methylkreysigine as an oil [R_f 0.86; UV λ_{max} (CH_3OH) (log ϵ) 220 (4.54), 260 (4.01), 296 nm (3.54); IR ($CHCl_3$) 1600 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.72, 6.59 (2 s, 2 H, 2 ArH), 3.90, 3.67, 3.58 (3 s, 15 H, 5 OCH_3), 3.40–2.00 (m, 9 H, 4 CH_2 + 1 CH), 2.41 (s, 3 H, NCH_3); methiodide mp 152.3 °C (from acetone–ether) (lit.[68] mp 150–153 °C)].

1-(4′-Benzyloxy-3′,5′-dimethoxyphenethyl)-2-methyl-6-methoxy-7-benzyloxy-1,2,3,4-tetrahydroisoquinoline (25). This compound was prepared in quantitative yield as an oil from the corresponding dihydroisoquinolinium iodide[67] as described above for the preparation of **6b**: IR (neat) 1585 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.20 (m, 10 H, 10 ArH), 6.60, 6.30 (2 s, 4 H, 4 ArH), 5.08, 4.95 (2 s, 4 H, 2 OCH_2Ar), 3.82, 3.75 (2 s, 9 H, 3 OCH_3), 3.40–1.90 (m, 9 H, 4 CH_2 + 1 CH), 2.43 (s, 3 H, NCH_3). Anal. ($C_{35}H_{39}NO_5$) C, H, N.

1-Methyl-3′,5′,5-trimethoxy-6-benzyloxy-1,2,3,8,9,9a-hexahydro-7*H*-benzo[*d*,*e*]quinoline-7-spiro[cyclohexa-2′,5′-dien]-4′-one (26) and (±)-Multifloramine (24). A solution of 100 mg (0.2 mmol) of **25** in 5 mL of CH_2Cl_2 was added to a stirred mixture of 118 mg (0.21 mmol) of TTFA in 100 mL of TFA at 0 °C, followed by rapid addition of 1 mL of $BF_3{\cdot}Et_2O$. After the intense green color had faded (ca. 3 min; by this time a starch–iodide test for Tl(III) was negative), the mixture was extracted with 4 × 100 mL of $CHCl_3$. The extracts were washed with 5% aqueous ammonium hydroxide solution, dried (K_2CO_3), and evaporated and the residue was purified by preparative TLC ($CHCl_3/CH_3OH$, 10:1) to give 58 mg (70%) of **26** as an amorphous powder: *m/e* M^+ 461; R_f 0.52; IR ($CHCl_3$) 1665, 1621 cm^{-1}; UV λ_{max} (CH_3OH) (log ϵ) 222 (4.6), 278 nm (4.12); ^1H NMR ($CDCl_3$) δ 7.25 (m, 5 H, 5 ArH), 6.65 (s, 1 H, ArH), 6.12, 6.00 (d, 2 H, J = 2 Hz, olefinic), 4.75 (q, 2 H, OCH_2Ar), 3.82, 3.55 (2 s, 9 H, 3 OCH_3), 3.20–1.90 (m, 9 H, 2 CH_2 + 1 CH), 2.42 (s, 3 H, NCH_3). Without further purification, 40 mg of **26** was added portionwise under nitrogen to 10 mL of ice-cold, degassed, concentrated H_2SO_4 over a period of 30 min. The reaction mixture was then stirred at 4 °C for 7 h and for a further 16 h at room temperature. It was then poured into 100 mL of ice water and the pH of the solution adjusted to 3 with aqueous sodium hydroxide solution, and then to 8 with a mixture of $NaHCO_3/Na_2CO_3$. The resulting solution was extracted with 4 × 100 mL of $CHCl_3$. Evaporation of the dried (K_2CO_3) $CHCl_3$ extracts gave 26 mg (81%) of pure (±)-multifloramine, mp 206–208 °C (from methanol) (lit.[48] mp 209–212 °C). This synthetic product, and an authentic sample of the natural material, had the same R_f values in three different solvent systems and superimposable IR, ^1H NMR, and UV spectra.

(67) Brossi, A.; Van Burik, J.; Teitel, S. *Helv. Chim. Acta* **1968**, *51*, 1965–1979.

(68) Yusupov, M. K.; Ngo, D. T. B.; Aslanov, Kh. A. *Khim. Prir. Soedin.* **1975**, 526–527.

Reaction of 1-Chloro-2-alkylcycloalkenes with Organolithium Reagents. A Novel Cyclopropanation Reaction Involving the Generation of Carbenes from Vinyl Halides[1]

Paul G. Gassman,* Joseph J. Valcho, Gary S. Proehl,[2] and Charles F. Cooper

Contribution from the Department of Chemistry, University of Minnesota, Minneapolis, Minnesota 55455. *Received May 8, 1980*

Abstract: The reactions of 1-chloro-2-alkylcycloalkenes with organolithium reagents have been investigated in detail. It has been demonstrated that six-, seven-, and eight-membered cyclic olefins yield bicyclo[4.1.0]heptanes, bicyclo[5.1.0]octanes, and bicyclo[6.1.0]nonanes, respectively. The mechanism of this transformation has been examined in detail and has been shown to involve a multistep process which includes (a) extraction of the allylic proton by the organolithium, (b) α elimination of lithium chloride to yield an allylic carbene, (c) intramolecular addition of the carbene to the double bond to produce a cyclopropene, (d) addition of the organolithium to the cyclopropene, and (e) neutralization. As part of the mechanistic investigation, 2-chloro-3-methylbicyclo[2.2.1]heptene was shown to yield 3-methylenetricyclo[2.2.1.$0^{2,6}$]heptane.

The reaction of vinyl halides with organolithium reagents has been investigated in detail because of the possibility of generating unusual alkynes by this path.[3-5] As part of our general interest in highly strained molecules of all types, we have explored the use of such reactions, especially for the synthesis of highly distorted alkynes such as bicyclo[2.2.1]hept-2-yne.[4] It was in connection with these interests that we first explored the reaction of 1-chloro-2-alkylcycloalkenes with organolithium reagents.[1] We now wish to report the details of this study, which demonstrated that a variety of 1-chloro-2-alkylcycloalkenes react with organolithium reagents to yield fused-ring cyclopropanes.

Our initial exploration of this area was prompted by the 1967 report of Montgomery and Applegate[3] that a mixture of 1-

(1) For a preliminary report of part of this work see P. G. Gassman, J. J. Valcho, and G. S. Proehl, *J. Am. Chem. Soc.*, **101**, 231 (1979).

(2) National Science Foundation Fellow, 1976–1979.

(3) L. K. Montgomery and L. E. Applegate, *J. Am. Chem. Soc.*, **89**, 2952 (1967); L. K. Montgomery, A. O. Clouse, A. M. Crelier, and L. E. Applegate, *ibid.*, **89**, 3453 (1967); L. K. Montgomery, F. Scardiglia, and J. D. Roberts, *ibid.*, **87**, 1917 (1965); L. K. Montgomery and J. D. Roberts, *ibid.*, **82**, 4750 (1960); F. Scardiglia and J. D. Roberts, *Tetrahedron*, **1**, 343 (1957); G. Wittig and G. Harborth, *Chem. Ber.* **77**, 306 (1944); see also G. Wittig, J. Weinlich, and E. R. Wilson, *ibid.*, **98**, 458 (1965); G. Wittig and P. Fritz, *Angew. Chem., Int. Ed. Engl.*, **5**, 846 (1966); A. T. Bottini, F. P. Corson, R. Fitzgerald, and K. A. Frost, II, *Tetrahedron*, **28**, 4883 (1972); G. Wittig and J. Heyn, *Justus Liebigs Ann. Chem.*, **756**, 1 (1972); G. Kobrich, *Angew. Chem., Int. Ed. Engl.*, **11**, 473 (1972).

(4) P. G. Gassman, J. P. Andrews, Jr., and D. S. Patton, *Chem. Commun.*, 437 (1969); P. G. Gassman and T. J. Atkins, *Tetrahedron Lett.*, 3035 (1975); P. G. Gassman and J. J. Valcho, *J. Am. Chem. Soc.*, **97**, 4768 (1975).

(5) For a general review see R. W. Hoffmann, "Dehydrobenzene and Cycloalkynes", Academic Press, New York, 1967, Chapter 8.

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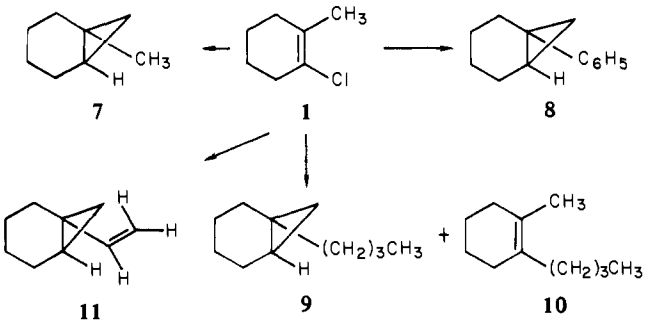
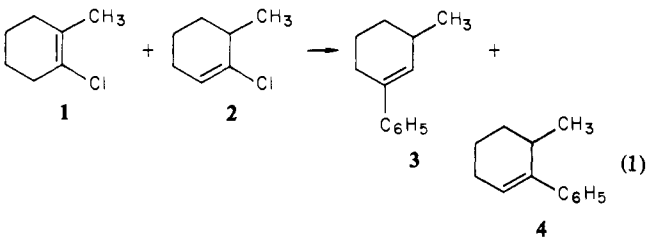
Scheme I



chloro-2-methylcyclohexene (**1**) and 1-chloro-6-methylcyclohexane (**2**) reacted with phenyllithium to yield 1-phenyl-3-methylcyclohexene (**3**), 1-phenyl-6-methylcyclohexene (**4**), and unreacted **1** (eq 1). In view of our earlier studies,[4] the lack of reactivity of

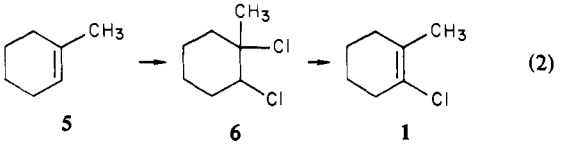


(1)

1 with phenyllithium seemed surprising. Thus, we set out to develop syntheses of pure **1** and of other 1-chloro-2-alkylcycloalkenes and to investigate their reactivity (or lack of reactivity) with organolithium reagents.

Syntheses of 1-Chloro-2-methylcycloalkenes and Their Reactions with Organolithium Reagents

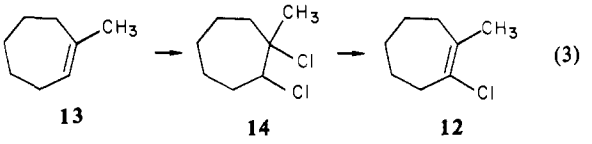
1-Chloro-2-methylcyclohexene (1). Treatment of 1-methylcyclohexene (**5**)[6] with iodobenzene dichloride gave a 70% yield of **6** which on treatment with sodium amide in liquid ammonia yielded 58% of **1** (eq 2). The addition of organolithium reagents



(2)

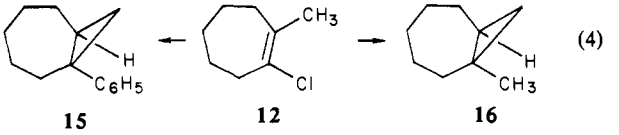
to **1** resulted in a relatively useful and hitherto unprecedented reaction sequence. When methyllithium was added to **1**, followed by aqueous workup, we obtained a 47% yield of 1-methylbicyclo[4.1.0]heptane (**7**). Phenyllithium addition to **1** gave a 90% yield of 1-phenylbicyclo[4.1.0]heptane (**8**) and addition of *n*-butyllithium gave 52% of **9** and 26% of **10**. The structures of **7**, **8**, and **9** were substantiated via comparison with authentic samples which were prepared through the addition of methylene via reaction of the appropriate olefin with methylene iodide and diethylzinc.[7,8] An authentic sample of **10** was prepared through the addition of *n*-butyllithium to 2-methylcyclohexanone followed by dehydration. Addition of vinyllithium to **1** gave a 30% yield of **11** (Scheme I). The structure of **11** was established on the basis of its spectral properties. In contrast to the other bicyclo[4.1.0]heptyl derivatives which could be prepared in an alternative manner through direct methylene addition, **11** could not be synthesized in this way since methylene addition occurred selectively to the monosubstituted vinyl group of 1-vinylcyclohexene. Thus, the synthetic approach developed in our laboratory offers certain unique advantages for the preparation of specific cyclopropanes.

1-Chloro-2-methylcycloheptene (12). 1-Methylcycloheptene[9] (**13**) was allowed to react with iodobenzene dichloride to yield 83% of crude **14** which, on dehydrohalogenation with sodium amide in liquid ammonia, gave a 38% yield of **12** (eq 3). When



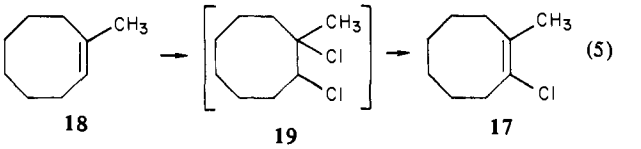
(3)

12 was allowed to react with excess phenyllithium in tetrahydrofuran containing *N,N,N',N'*-tetramethylethylenediamine (TMEDA), a 66% yield of **15** was obtained. Similarly, addition of methyllithium to **12** gave **16** in 41% yield (eq 4). The samples of **15** and **16** obtained from our reactions were identical in all respects to samples prepared by the Simmons–Smith addition[10] of methylene to the appropriate olefin.



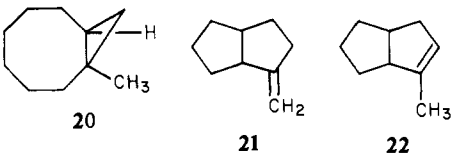
(4)

1-Chloro-2-methylcyclooctene (17). Both the synthesis and the reactions of 17 were more complicated than those observed for **1** and **12**. Treatment of 1-methylcyclooctene (**18**)[11] with iodobenzene dichloride gave a crude sample of **19** which was not readily purified due to its facile decomposition under a variety of conditions. When the crude reaction product from **18** was dehydrohalogenated with sodium amide in liquid ammonia, a 52% overall yield of **17** was obtained from **18** (eq 5). Treatment of



(5)

17 with methyllithium under the usual conditions gave a complex mixture of volatile products in contrast to our earlier observations with **1** and **12**. In this reaction, we obtained 19% of **20**, 19% of



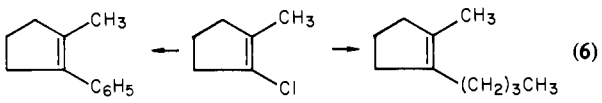
21, and 3% of **22** plus some very minor products which were not identified. The structure of **20** was established through comparison with an authentic sample which was prepared by the copper-promoted methylene iodide cyclopropanation of 1-methylcyclooctene.[12] Wittig reaction of bicyclo[3.3.0]octan-2-one[13] (**23**) with triphenylphosphonium methylide gave a 32% yield of 2-methylenebicyclo[3.3.0]octane (**21**) which was identical in all respects to the product we obtained from the reaction of **17** with methyllithium. Lastly, addition of methyllithium to **23**, followed by dehydration, gave ca. a 10:1 mixture of **22**–**21**. In view of the preponderance of **22**, we questioned whether **21** might be isom-

(6) F. K. Signaigo and P. L. Cramer, *J. Am. Chem. Soc.*, **55**, 3326 (1933).
(7) (a) Y. S. Shabarov, T. P. Surikova, V. S. Svirina, and R. Y. Levina, *Zh. Org. Khim.*, **1**, 1895 (1965); (b) S. I. Khromov, G. P. Kochnova, O. I. Guseva, and E. S. Balenkova, *Neftekhimiya*, **6**, 809 (1966).
(8) (a) J. Furukawa, N. Kawabata, and J. Nishimura, *Tetrahedron*, **24**, 53 (1968); (b) J. Nishimura, N. Kawabata, and J. Furukawa, *ibid.*, **25**, 2647 (1969).
(9) A. C. Cope, C. L. Bumgardner, and E. E. Schweizer, *J. Am. Chem. Soc.*, **79**, 4729 (1957).
(10) H. E. Simmons and R. D. Smith, *J. Am. Chem. Soc.*, **80**, 5323 (1958); *ibid.*, **81**, 4526 (1959).
(11) H. C. Brown and M. Borkowski, *J. Am. Chem. Soc.*, **74**, 1894 (1952).
(12) N. Kawabata, I. Kamemura, and M. Naka, *J. Am. Chem. Soc.*, **101**, 2139 (1979).
(13) R. K. Boeckman, Jr., *Tetrahedron Lett.*, 4281 (1977); A. C. Cope and W. R. Schmitz, *J. Am. Chem. Soc.*, **72**, 3056 (1950); A. C. Cope, M. Brown, and H. E. Petree, *ibid.*, **80**, 2852 (1958).

erized to **22**, hence making **22** a secondary product in our original study. This suspicion was confirmed when it was shown that **21** was completely converted to **22** on prolonged exposure to methyllithium in the presence of TMEDA.

1-Chloro-2-methylcyclopentene (24). In order to establish the complete scope of our cyclopropanation reaction, we decided to attempt to extend it to the cyclopentenyl system. 1-Chloro-2-methylcyclopentene was prepared through the same series of reactions utilized above, namely, conversion of 1-methylcyclopentene (**25**) to 1,2-dichloro-1-methylcyclopentane (**26**) in 80% yield through reaction with iodobenzene dichloride, followed by dehydrohalogenation of **26** to **24** in 44% yield with sodium amide in liquid ammonia.

The reactions of the five-membered ring system with organolithium differed greatly from those of six-, seven-, and eight-membered 1-chloro-2-methylcycloalkenes. Treatment of **24** with phenyllithium failed to yield any cyclopropane-containing products. Instead **27** was obtained as the only identifiable product (eq 6).

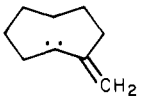


27 **24** **29** (6)

The structure of **27** was established through spectral comparison with an authentic sample (see Experimental Section). In order to establish that **27** was not being formed by phenyllithium promoted isomerization of the desired cyclopropane, we independently synthesized 1-phenylbicyclo[3.1.0]hexane (**28**) and exposed it to the reaction and workup conditions, both of which it survived. Having an authentic sample of **28** in hand also allowed us to establish that **28** was not formed even as a trace component in the reaction of **24** with phenyllithium.

The cyclopentenyl derivative **24** reacted with *n*-butyllithium in the same manner as with phenyllithium to give 1-*n*-butyl-2-methylcyclopentene (**29**) as the major product in addition to two unidentified minor products. Comparison with an authentic sample of 1-*n*-butylbicyclo[3.1.0]hexane (**30**) established that none of the minor products was the desired cyclopropane derivative.

As illustrated above, the reaction of 1-chloro-2-methylcycloalkenes with organolithium reagents offers an excellent synthetic path into certain bicyclo[4.1.0]heptanes and bicyclo[5.1.0]octanes. Surprisingly, neither the bicyclo[6.1.0]nonyl system nor the bicyclo[3.1.0]hexyl system could be readily prepared by our methodology. The products derived from 1-chloro-2-methylcyclopentene appeared to be formed via a mechanism quite different from that involved in the generation of the bicyclo[*n*.1.0]alkanes. Thus, the question of the source of this change of mechanism became of interest. One indication as to the mechanistic detail was provided by the studies of **17** which gave **21**. One rational possibility would involve the formation of **21** via the intramolecular insertion of the carbene **31**. This possibility prompted us to carry out a detailed mechanistic study of our reaction.

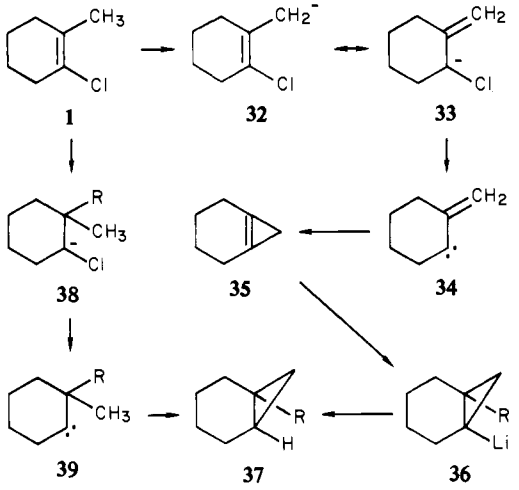


31

Mechanistic Studies

Since the reaction of **1** with various organolithium reagents was the cleanest and potentially the most useful of the ones studied, we initially directed our mechanistic studies to this system. In Scheme II we have illustrated two possible mechanisms, each of which involves the intermediacy of a carbenoid species. The preferred mechanism involves the initial use of the organolithium as a base to remove a proton from the methyl group of **1** to yield the allylic anion **32**. When considered as its resonance form, **33**, this intermediate is ideally set up for an α elimination of chloride anion to produce the allylic carbene **34**. Intramolecular insertion of **34** would give the cyclopropene **35**, which would be expected

Scheme II



to add a second equivalent of organolithium to produce **36**. Hydrolytic workup would then yield **37**. While this combination of steps is unique, ample precedent exists for each of the individual transformations. Allyl chlorides are known to react with strong base to yield allylic anions similar to **33**.[14] These anions are known to undergo α elimination to form allylic carbenes which subsequently intramolecularly insert to yield cyclopropenes.[14] The addition of organolithiums to cyclopropenes is well established.[15] The intermediacy of **34** in this mechanistic path would be consistent with the formation of **31** from **17** as an intermediate on the way to **21**.

An alternate mechanistic rationale would involve the initial addition of the organolithium reagent to **1** to yield the anion **38**. α elimination of lithium chloride would give the carbenoid species **39** which could then intramolecularly insert into the C–H bond of the methyl group to produce **37**. Such intramolecular insertion reactions have ample precedent.[16] If this second mechanistic scheme was involved, two competing mechanisms would be required because an addition elimination mechanism could not be invoked in the formation of **21**. Thus, differentiating between these two mechanistic schemes was of interest.

Examination of the two alternative mechanisms indicated that they might be differentiated by certain deuterium-labeling studies. The unlabeled starting material **1** should react with trideuteriomethyllithium to yield **37** (R = CD_3) if cyclopropene **35** were involved as an intermediate. Similarly, 1-chloro-2-trideuteriomethylcyclohexene (**40**) should react with unlabeled methyllithium to produce **41** via the cyclopropene mechanism. In contrast, the addition–elimination mechanism would require that both of the above described labeling experiments yield the same intermediate, **39** (R = CD_3). Thus, the same products should be obtained from both sets of starting materials if the addition–elimination process were involved in the cyclopropanation reaction.

The synthesis of **40** could not be achieved by a route similar to that used for **1**, **12**, **17**, and **24** because the dehydrohalogenation reaction using sodium amide in liquid ammonia led to considerable exchange of deuterium with the ammonia.[17] Fortunately, **40** could be prepared by a sequence of reactions which involved (a) the oxidation[18] of **42**[19] to **43** (46% yield), (b) the reduction of **43** to

(14) F. Fisher and D. E. Applequist, *J. Org. Chem.*, **30**, 2089 (1965); G. L. Closs and K. D. Krantz, *ibid.*, **31**, 638 (1966); G. L. Closs and L. E. Closs, *J. Am. Chem. Soc.*, **85**, 99 (1963).

(15) G. Wittig and J. Otten, *Tetrahedron Lett.*, 601 (1963); R. M. Magid and J. G. Welch, *J. Am. Chem. Soc.*, **90**, 5211 (1968).

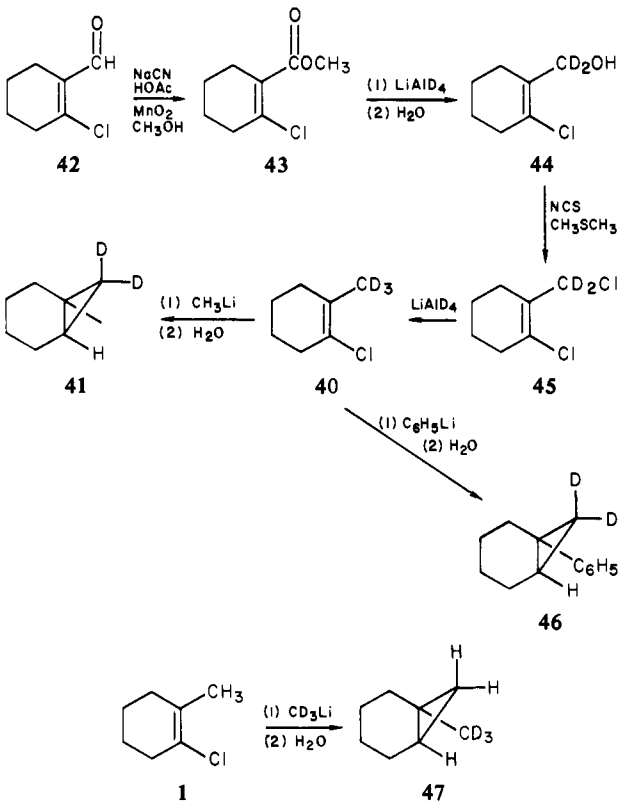
(16) L. Friedman and H. Shechter, *J. Am. Chem. Soc.*, **81**, 5512 (1959); L. Friedman and J. G. Berger, *ibid.*, **83**, 492, 500 (1961); W. Kirmse and B. G. v Wedel, *Justus Liebigs Ann. Chem.*, **666**, 1 (1963).

(17) This observation illustrated the acidity of the protons (deuterons) attached to this allylic position.

(18) E. J. Corey, N. W. Gilman, and B. E. Ganem, *J. Am. Chem. Soc.*, **90**, 5616 (1968).

(19) L. A. Paquette, B. A. Johnson, and F. M. Hinga, "Organic Syntheses", Collect. Vol. V, Wiley, New York, 1973, p 215.

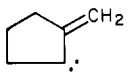
Scheme III



44 (97% yield), (c) replacement of the hydroxyl group of **44** by chloride[20] (72% yield), and (d) lithium aluminum deuteride reduction of **45** to **40** (75% yield). Mass spectral analysis of **40** showed 97% d_3; the ^{1}H NMR spectrum showed the complete absence of any signal due to an unlabeled methyl group.

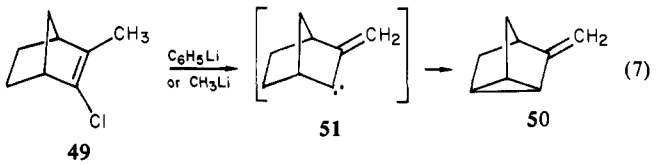
Treatment of **40** with methyllithium gave **41** which had chromatographic behavior identical with that of **7**. However, **41** was devoid of any ^{1}H NMR signals in the δ 0.5–0.0 region where **7** has strong signals for the cyclopropane methylene protons. Surprisingly, **41** showed mass spectral analysis of 30% d_3, 66% d_2, and 4% d_1. Similarly, treatment of **40** with phenyllithium gave **46**, which lacked the cyclopropyl protons, but analyzed for 44% d_3, 53% d_2, and 3% d_1 by mass spectroscopy. The presence of substantial amounts of d_3 material in both **41** and **46** could be interpreted to mean that a combination of the cyclopropene and addition–elimination mechanisms were involved. However, this rationale would require that the portion of the conversion which occurred via the addition–elimination path must have involved exclusive insertion of the intermediate carbene (**39**) into the deuterated methyl group (because of the complete deuteration of the cyclopropyl methylene group). Obviously, this unlikely possibility could be tested by the addition of trideuteriomethyllithium to **1**. When this was done, **47** was obtained (Scheme III) which showed no ^{1}H NMR absorption due to the methyl group at the bridgehead but did show a strong signal due to the cyclopropyl methylene group. Mass spectral analysis of **47** indicated 97% d_3. This experiment ruled out any anomalous selectivity for insertion into a C–D bond, and this eliminated the addition–elimination mechanism from further consideration.[21]

Additional evidence for the cyclopropene mechanism was obtained as an outgrowth of our observations with **24**. The formation of **27** and **29** could be interpreted as "simple coupling" reactions. However, it was not apparent why **24** should not be deprotonated by the organolithium to eventually yield an allylic carbene, **48**.



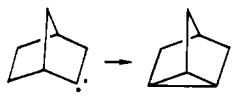
48

Ring strain could be invoked to rationalize the failure of the hypothetical intermediate, **48**, to form a cyclopropene but would not seem to be a justification for its "apparent" lack of formation. In order to test these considerations of strain effects on our reaction, we subjected 2-chloro-3-methylbicyclo[2.2.1]heptene (**49**)[22] to treatment with both methyllithium and phenyllithium. In both cases, the major product formed was 3-methylenetricyclo-[2.2.1.0^{2,6}]heptane (**50**) (eq 7). The tricyclo[2.2.1.0^{2,6}]heptyl



49 51 50 (7)

system (**52**) is well-known for its facile formation via transannular insertion of carbene **53** (eq 8).[23] Thus, **51** would appear to be



53 52 (8)

a logical intermediate in the formation of **50** from **49**. We believe that this example provides added evidence for the conversion of 1-chloro-2-methylcycloalkenes into allylic carbenes through reaction with organolithium reagents.[24]

Mechanistically, the results presented above are consistent with the intermediacy of allylic carbenes and cyclopropenes. Although 1,2-bridged cyclopropenes have been previously reported[25] and postulated[26] as highly reactive intermediates, those examples previously described had been derived from quite different precursors. In our examples, the starting materials have been readily available, and the yields of the bicyclo[4.1.0]heptyl and bicyclo[5.1.0]octyl systems should make this reaction synthetically useful.

Experimental Section[27]

***trans*-1,2-Dichloro-1-methylcyclohexane (6).** Nitrogen was bubbled through a suspension of 100.3 g (0.36 mol) of iodobenzene dichloride in 750 mL of carbon tetrachloride for 15 min and 35.0 g (0.36 mol) of 1-methylcyclohexene (**5**) was added. The solution was then brought slowly to reflux, while being irradiated (through the Pyrex flask) with a Hanovia 30620 quartz ultraviolet lamp. The solution was heated at reflux for 0.5 h and cooled in an ice–salt bath, and chlorine was bubbled through the solution for 2 h to regenerate the iodobenzene dichloride.

(20) E. J. Corey, C. U. Kim, and M. Takeda, *Tetrahedron Lett.*, 4339 (1972).

(21) The presence of some d_3 material in the product from the reactions of organolithium with **40** can be rationalized in terms of the cyclopropene mechanism. Addition of an organolithium to the intermediate dideuterated cyclopropene would generate **36**-d_2. This might be expected to be of comparable or stronger base strength than either methyllithium or phenyllithium. If this were the case, **36**-d_2 could remove a deuteron from **40** to generate **32**-d_2 and **41**-d_3.

(22) Compound **49** was prepared according to the method of I. Gennick, Ph.D. Thesis, University of Minnesota, 1979.

(23) H. Meerwein and K. van Emster, *Chem. Ber.*, **53**, 1815 (1920); K. Alder, H. K. Schäfer, H. Easer, H. Kreiger, and R. Reubke, *Justus Liebigs Ann. Chem.*, **593**, 23 (1955); P. K. Freeman, D. E. George, and V. N. M. Rao, *J. Org. Chem.*, **29**, 1682 (1964).

(24) The results obtained in the conversion of **49** into **50** make the mechanism of the conversion of **24** into **27** and **29** even more of a curiosity. Although we lack proof, we would like to speculate at this time that **24** is converted into **48** and that **27** and **29** are formed by the addition of phenyllithium and *n*-butyllithium to **48** followed by neutralization.

(25) G. L. Closs and W. A. Böll, *J. Am. Chem. Soc.*, **85**, 3904 (1963); G. L. Closs, W. A. Böll, H. Heyn, and V. Dev, *ibid.*, **90** 173 (1968).

(26) E. P. Blanchard, H. E. Simmons, and J. S. Taylor, *J. Org. Chem.*, **30**, 4321 (1965). The results described in this study could have been attributed to the intermediacy of the methylenecyclopropane derivative, bicyclo[3.1.0]-hexene-$\Delta^{1,2}$. Evidence for the intermediacy of bicyclo[3.1.0]hexene-$\Delta^{1,5}$ was not definitive.

(27) Melting and boiling points were not corrected. Elemental analyses were carried out by Scandanavian Microanalytical Laboratories, Herlev, Denmark.

The solution was allowed to warm slowly, dry nitrogen was again bubbled through the system, and the mixture was filtered to remove iodobenzene dichloride. The filtrate was washed sequentially with saturated sodium chloride solution and dried over anhydrous magnesium sulfate. The solution was filtered, the solvent was removed by distillation, and the residue was fractionally distilled to yield 42.2 g (70%) of **6**, bp 103–105 °C (55mmHg).[28]

1-Chloro-2-methylcyclohexene (1). A solution of sodium amide in liquid ammonia was prepared by the addition of 15.5 g (0.67 mol) of sodium to 400 mL of ammonia containing 0.2 g of ferric nitrate nonahydrate (0.2 g of sodium was first added, and air was bubbled through the solution until the blue color dissipated and the black catalyst formed). The solution was stirred for 0.5 h, and 39.3 g (0.23 mol) of *trans*-1,2-dichloro-1-methylcyclohexane (**6**) was added dropwise over 0.5 h. Stirring was continued for 9 h, and 30 mL of ether was then added, followed by 27.2 g (0.5 mol) of solid ammonium chloride (added cautiously in small portions through a piece of Gooch tubing). The ammonia was allowed to boil off overnight, and water was added to the mixture. The layers were separated, and the aqueous layer was further extracted with two 125-mL portions of ether and 150 mL of pentane. The combined organic extracts were washed with saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, the ether was removed by distillation, and the residue was distilled through a Vigreux column to yield 17.9 g (58%) of **1**, bp 79–81 °C (44mmHg) [lit.[29] bp 41–42 °C (8mmHg)] of greater than 99% purity as indicated by VPC; $n^{24.6}_D$ = 1.4831. No olefinic protons could be detected by NMR analysis.

Reaction of 1-Chloro-2-methylcyclohexene (1) with Methyllithium. The solvent was removed from 19.2 mL (38.5 mmol) of 2.0 M methyllithium in ether on a rotary evaporator. The solid was cooled to 0 °C, and 17.0 mL of dry tetrahydrofuran, 2.2 g (19.2 mmol) of *N,N,N',N'*-tetramethylethylenediamine (TMEDA) and 1.0 g (7.7 mmol) of **1** were sequentially added. The solution was warmed to reflux, stirred under argon for 25 h, and poured onto ice. Ether was added, the layers were separated, and the aqueous layer was extracted with two 75-mL portions of ether and 75 mL of 1:1 pentane–ether. The combined organic extracts were washed with saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, the solvents were removed by distillation through a glass-helices-packed column, and the residue was chromatographed on 150 g of Fisher basic alumina to yield 0.40 g (47%) of **7** whose properties were identical with those of an authentic sample.

1-Methylbicyclo[4.1.0]heptane (7). According to a general literature procedure,[8a] 21.4 g (80 mmol) of methylene iodide was added slowly to a solution of 5.0 g (52 mmol) of 1-methylcyclohexene (**5**) and 5.2 mL (52 mmol) of diethylzinc (Stauffer) in 25 mL of pentane, under nitrogen. The reaction was exothermic, and occasional cooling was necessary to maintain a gentle reflux. The solution was stirred at 25 °C for 5 h and then poured into a mixture of ice in dilute hydrochloric acid. Pentane was added, the layers were separated, and the organic layer was washed with saturated sodium bicarbonate solution and dried over anhydrous magnesium sulfate. The solution was filtered, the pentane was removed by distillation, and the residue was fractionally distilled to yield 2.4 g (42%) of **7**, bp 120–124 °C (750mmHg), n^{23}_D = 1.4503 [lit.[7a] bp 124.5 °C (762mmHg), n^{20}_D = 1.4480]. The spectral properties of **7** were identical with those of the product derived from the reaction of 1-chloro-2-methylcyclohexene (**1**) with methyllithium.

Reaction of 1-Chloro-2-methylcyclohexene (1) with Phenyllithium. The solvents were removed from 3.2 mL (5.5 mmol) of 1.72 M phenyllithium in 70:30 benzene–ether on a rotary evaporator and were replaced by 2.5 mL of dry tetrahydrofuran. The solution was cooled to 0 °C, and 0.64 g (5.5 mmol) of *N,N,N',N'*-tetramethylethylenediamine (TMEDA) followed by 0.15 g (1.1 mmol) of **1** was added. The solution was warmed to reflux and stirred under argon for 5 h, poured onto ice, and diluted with ether. The layers were separated, and the aqueous layer was further extracted with two 10-mL portions of ether and two 10-mL portions of ether–pentane (1:1). The combined organic extracts were washed with 50 mL each of water and saturated sodium chloride solution and dried over anhydrous magnesium sulfate. The solution was filtered, and the solvents were removed by distillation. The residue was chromatographed on 20 g of Fisher basic alumina to yield 0.17 g (90%) of 1-phenylbicyclo[4.1.0]heptane (**8**), bp 92–97 °C (0.65mmHg) [lit.[7a] bp 104–105 °C (3.0mmHg)].

Reaction of 1-Chloro-2-methylcyclohexene (1) with *n*-Butyllithium. To a solution of 38.3 mL (76.5 mmol) of 2.0 M *n*-butyllithium in hexane at 0 °C under argon was added 4.45 g (38.2 mmol) of *N,N,N',N'*-tetramethylethylenediamine, followed by 2.0 g (15.3 mmol) of **1**. The solution was stirred at room temperature for 29 h and poured carefully onto ice. The layers were separated, and the aqueous layer was further extracted with two 50-mL portions each of ether and 1:1 ether–pentane. The combined organic extracts were washed with 100 mL of water and saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, the solvents were removed by distillation, and the residue was chromatographed on 200 g of Fisher basic alumina (pentane) to yield 1.82 g (78%) of a 2:1 mixture of 1-*n*-butylbicyclo[4.1.0]heptane (**9**) and 1-*n*-butyl-2-methylcyclohexene (**10**), bp 88–91 °C (44mmHg) [lit.[7b] bp 102.5 °C (41mmHg)]. These compounds were separated by preparative VPC on a $^1/_4$ in. × 15 ft, 15% FFAP on 60/80 Chromosorb P column at 70 °C with **10** eluting first and were identified by spectral comparison with authentic samples.

The spectral properties of **9** were as follows: NMR (CCl_4/Me_4Si) δ 2.24–0.44 (18 H, br m, sharp peaks at δ 1.24 and 0.89), 0.44–0.05 (2 H, m); IR (CCl_4 solution) 2976, 1460 (d), 1247, 1017, 864 cm^{-1}; $n^{25.2}_D$ = 1.4543. The spectral properties of **10** were as follows: NMR (CCl_4/Me_4Si) δ 2.15–0.76 (br m, sharp peaks at δ 1.62, 1.27, and 0.91); IR (CCl_4 solution) 2941, 1451, 1381, 1247, 863 cm^{-1}; $n^{21.8}_D$ = 1.4628.

Anal. Calcd for $C_{11}H_{20}$: C, 86.76; H, 13.24. Found: C, 86.52; H, 13.42.

1-*n*-Butylbicyclo[4.1.0]heptane (9). Utilizing a literature procedure,[8a] we added 20.0 g (75 mmol) of methylene iodide (Aldrich) under argon to a solution of 5 mL (50 mmol) of diethylzinc (Stauffer) and 5.0 g (36 mmol) of 1-*n*-butylcyclohexene in 20 mL of pentane, and the solution was then stirred for 4 h. Water was carefully added, the layers were separated, and the aqueous layer was further extracted with two 50-mL portions of ether. The aqueous layer was then acidified with saturated ammonium chloride solution and extracted with two additional 50-mL portions of ether. The combined organic extracts were washed with saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, the solvents were removed by distillation, and the residue was fractionally distilled to yield 2.75 g (50%) of a 5:1 mixture (VPC) of **9** and an unidentified olefin, bp 108–110 °C (42mmHg). Separation of **9** was achieved by preparative VPC on a $^1/_4$ in. × 10 ft 10% FFAP on 60/80 Chromosorb W column at 85 °C. The spectral properties of **9** were identical with those of a sample obtained from the reaction of 1-chloro-2-methylcyclohexene (**1**) with *n*-butyllithium.

1-*n*-Butyl-2-methylcyclohexanol. A solution of 10 mL (24 mmol) of 2.4 M *n*-butyllithium in hexane was cooled to −78 °C in a dry ice–2-propanol bath. To this was added slowly 0.98 g (10 mmol) of 2-methylcyclohexanone (Aldrich Chemical Co.), and the solution was warmed to 25 °C and stirred for 1 h. The solution was poured onto ice, the layers were separated, and the aqueous layer was extracted with three 40-mL portions of ether. The combined organic extracts were washed with saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, and the solvents were removed on a rotary evaporator to yield 1.6 g (100%) of crude 1-*n*-butyl-2-methylcyclohexanol,[30] contaminated with a small amount of starting ketone.

1-*n*-Butyl-2-methylcyclohexene (10). A mixture of 1.6 g (10 mmol) of crude 1-*n*-butyl-2-methylcyclohexanol and 0.5 g of 85% phosphoric acid was heated under vacuum to give a mixture of water and olefins which steam distilled from 75–80 °C (35mmHg). The mixture was diluted with ether, the layers were separated, and the ether layer was washed with saturated salt solution and dried over anhydrous magnesium sulfate. The solution was filtered, the ether was removed by distillation, and the residue was chromatographed on 100 g of Fisher basic alumina to give 0.84 g (61%) of **10** contaminated with two other olefins (presumably 2-*n*-butyl-3-methylcyclohexene and 1-butylidene-2-methylcyclohexene). A pure sample of **10**, $n^{21.8}_D$ = 1.4628, was obtained by preparative VPC on a $^1/_4$ in. × 15 ft, 15% FFAP on 60/80 Chromosorb P column at 70 °C. The spectral properties of **10** were identical with those of a sample of **10** obtained from the reaction of 1-chloro-2-methylcyclohexene (**1**) with *n*-butyllithium.

Tetravinyltin. To 31.15 g (1.28 mol) of clean magnesium turnings in a carefully dried 2-L flask equipped with a dry-ice condenser, dropping funnel, and mechanical stirrer was added enough dry tetrahydrofuran (THF) to cover the turnings. Approximately 6 mL of a 1:1 mixture of vinyl bromide–THF was added followed by 1 mL of methyl iodide. After the reaction started, a solution of 150 g (1.40 mol) of vinyl bromide in 350 mL of THF was added dropwise at a rate sufficient to maintain mild reflux. After the addition was complete, the reaction mixture was refluxed for 1 h. The dry-ice condenser was replaced by a water condenser, and 12 mL (27 g, 0.10 mol) of anhydrous tetrachlorotin was added dropwise with vigorous stirring. After the addition was complete, the reaction mixture was stirred and refluxed for 20 h, cooled to room temperature, and hydrolyzed by the addition of ca. 500 mL of saturated ammonium chloride solution. The layers were separated, and the aqueous

(28) For IR data of **6** see C. Altona, H. J. Hageman, and E. Havinga, *Spectrochim. Acta, Part A*, **24A**, 633 (1968).

(29) M. Mousseron and R. Jacquier, *Bull. Soc. Chim. Fr.*, 648 (1950).

(30) A. N. Volkow, A. V. Bogdanova, and G. P. Kugatova-Shemyakina, *Zh. Org. Khim.*, **3**, 316 (1967).

layer was extracted with seven 100-mL portions of ether. The combined organic solution was washed with saturated salt solution and dried over anhydrous sodium sulfate. After filtration, the solvents were removed by distillation to give a heavy oil which on fractional distillation gave 10.68 g (47%) of tetravinyltin, bp 64–66 °C (20mmHg) [lit.[31] bp 67–70 °C (28mmHg)].

Vinyllithium.[32] To a solution of 14.94 g (0.066 mol) of tetravinyltin in 100 mL of dry pentane was added dropwise 60 mL of 2.23 M (0.134 mol) *n*-butyllithium. The precipitate, which formed rapidly, was removed by filtration under a nitrogen atmosphere in a glovebag. The white solid was rinsed with two 50-mL portions of dry pentane. This solid vinyllithium was then dissolved in a minimum amount of very dry tetrahydrofuran, transferred under nitrogen pressure to a septum-sealed amber bottle. Standardization showed that the 45 mL of solution obtained was 1.64 M (28% yield).

Reaction of 1-Chloro-2-methylcyclohexene (1) with Vinyllithium. A solution of 58.5 mmol of vinyllithium in 45 mL of tetrahydrofuran was added via syringe to a dry, round-bottomed flask which was maintained with a nitrogen atmosphere. The reaction mixture was cooled to 0 °C, 4.15 g of TMEDA was added dropwise, and 1.50 g (11.5 mmol) of **1** was then added dropwise at 0 °C. The reaction mixture was allowed to warm to room temperature and then refluxed for 15 h. After being cooled, the reaction mixture was poured into ice–water, extracted with five 75-mL portions of ether, and washed with five 50-mL portions of 10% hydrochloric acid, three 50-mL portions of 10% sodium bicarbonate, and five 50-mL portions of saturated sodium chloride solution. After the solution was dried over anhydrous calcium chloride and filtered, the solvent was removed by distillation at atmospheric pressure. The brown residue was chromatographed on Brockman activity I neutral alumina, and the desired fraction was further purified by distillation at atmospheric pressure. Final purification by preparative VPC on a 10% SE-30 on Chromosorb P column at 130 °C gave 0.43 g (30%) of 1-vinylbicyclo[4.1.0]heptane (**11**): IR (neat) 3037, 2879, 1633, 1451, 891 cm^{-1}; NMR δ 0.3–2.5 (11 H, br m), 4.65–5.75 (3 H, br complex m).

Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.75; H, 11.54.

1-Chloro-2-methylcycloheptene (12). 1-Methylcycloheptene (**13**)[33] (20.4 g) was dissolved in 500 mL of carbon tetrachloride which contained 50.5 g of iodobenzene dichloride and which had been thoroughly purged with nitrogen. The solution was refluxed and irradiated as described in the preparation of **1** (vide supra). Workup as described for **1**, followed by distillation of the residue, gave 27.58 g of crude **14**.

The crude product obtained above (25.8 g) was added slowly over 0.5 h to the sodium amide in liquid ammonia solution obtained from 10.6 g of sodium, 500 mL of liquid ammonia, and 0.2 g of ferric nitrate. The reaction mixture was then stirred for an additional 0.5 h, 100 mL of anhydrous ether was added, 25.3 g of solid ammonium chloride was then added in small portions, and the ammonia was allowed to evaporate overnight. The reaction mixture was diluted with 100 mL of ether and water and stirred for 1 h. The layers were separated, the aqueous phase was washed thoroughly with ether, and the combined organic phases were dried over anhydrous sodium sulfate. After filtration and removal of the solvent, the residue was distilled to yield 7.85 g (38%) of **12**: bp 36–37 °C (1.5mmHg); IR (neat) 2899, 1661, 1451, 998, 974 cm^{-1}; NMR δ 1.54 (2 H, br m), 1.63 (6 H, br m), 1.82 (3 H, s), 2.20 (2 H, br m).

Anal. Calcd for $C_8H_{13}Cl$: C, 66.43; H, 9.06. Found: C, 66.18; H, 9.04.

Reaction of 1-Chloro-2-methylcycloheptene (12) with Phenyllithium. A solution of phenyllithium in 70:30 benzene–ether (48 mL, 1.44 M, 69 mmol) was placed in a 250-mL, three-necked, round-bottomed flask under nitrogen. The solvent was removed under reduced pressure, and the flask was cooled to 0 °C prior to the addition of 50 mL of tetrahydrofuran and 4.0 g (34.5 mmol) of TMEDA (both added dropwise). To the stirred solution was added dropwise 1.96 g (13.4 mmol) of **12**, and the reaction mixture was refluxed for 10 h. The reaction mixture was allowed to cool, poured into ice–water, and extracted with five 50-mL portions of ether. The combined extracts were washed with three 50-mL portions of 10% hydrochloric acid, three 50-mL portions of saturated aqueous sodium bicarbonate, and saturated sodium chloride solution and dried over anhydrous calcium chloride. After filtration, the solvent was removed by distillation to yield a residue which was passed through a short column of neutral alumina to yield a colorless residue consisting of tetrahydrofuran, **12**, and 1-phenylbicyclo[5.1.0]octane (**15**, 66% yield vs. internal standard). Purification by preparative VPC on a 3 ft × 3/8 in., 10% SE-30 on Chromosorb P column gave a 55% isolated yield of **15**: IR (neat) 2888, 2847, 1610, 1496, 1468, 1451, 1032, 767, 700 cm^{-1}; NMR δ 0.50–2.8 (13 H, complex m), 7.24 (5 H, s). This material was identical with an authentic sample[34] prepared by Simmons–Smith addition of methylene to 1-phenylcycloheptene.

Reaction of Methyllithium with 1-Chloro-2-methylcycloheptene (12). In a manner similar to that described above for the reaction of phenyllithium with **12**, 1.95 g (13.5 mmol) of **12** was added to 68 mmol of methyllithium in tetrahydrofuran in the presence of TMEDA. Workup as described above, followed by concentration of the solution, gave a mixture of tetrahydrofuran and 1-methylbicyclo[5.1.0]octane (**16**). Use of an internal standard gave a VPC yield of 51%. Distillation [bp 24 °C (0.8mmHg)] gave 0.69 g (41%) of **16** which was identical in all respects with an authentic sample.[35]

1-Chloro-2-methylcyclooctene (17). To 55.45 g (0.20 mol) of freshly prepared iodobenzene dichloride in 500 mL of carbon tetrachloride under nitrogen was added 25.56 g of 1-methylcyclooctene (**18**),[11] and the reaction mixture was refluxed and irradiated with a Hanovia high-pressure lamp for 0.5 h. The mixture was cooled to −10 °C in an ice–salt bath, and chlorine was bubbled through the solution for 2 h to regenerate the iodobenzene dichloride which precipitated from solution. The solid was collected by filtration and washed with cold carbon tetrachloride. The solvent was removed at reduced pressure, and the residue was vacuum distilled to yield 21.13 g of crude 1,2-dichloro-1-methylcyclooctane (**19**), bp 65–69 °C (2.5mmHg).

The crude product obtained above was added dropwise over a 0.5-h period to a solution of sodium amide prepared from 14.55 g of sodium in 400 mL of liquid ammonia. The reaction mixture was stirred for 7 h, and 100 mL of anhydrous ether was added, followed by 40.46 g of solid ammonium chloride (added in small portions). The reaction mixture was allowed to warm to room temperature overnight. After all of the ammonia had evaporated, 400 mL of water and 100 mL of ether were added, the reaction mixture was stirred for 1 h and filtered, and the layers were separated. The aqueous layer was extracted thoroughly with ether, and the combined ethereal solution was washed with water, dried over anhydrous sodium sulfate, and filtered, and the solvent was removed by distillation. The residue was distilled to give a 52% yield of **17**: bp 53–54 °C (3.0mmHg); IR (neat) 2880, 1658, 1466, 1445, 1375 cm^{-1}; NMR δ 1.46 (8 H, br peak), 1.78 (3 H, s), 2.20 (2 H, br s), 2.46 (2 H, m).

Anal. Calcd for $C_9H_{15}Cl$: C, 68.12; H, 9.53. Found: C, 67.85; H, 9.51.

Reaction of 1-Chloro-2-methylcyclooctene (17) with Methyllithium. To a solution of 63.6 mmol of methyllithium in 75 mL of tetrahydrofuran containing 3.73 g (32 mmol) of TMEDA was added, at −10 °C, 1.98 g (12.5 mmol) of **17**. The reaction mixture was warmed to room temperature followed by refluxing for 18 h. Workup, as described for the related reactions of **1** and **12** (vide supra), gave 1.26 g of a mixture of compounds which was shown to consist of two major components and three minor components by VPC analysis. Since this mixture could not be readily separated by preparative VPC, the two major components and one of the minor products were identified through VPC retention times and comparison of GC–MS spectra with those of authentic samples. In this manner, it was demonstrated that we obtained 19% of 1-methylbicyclo[6.1.0]nonane (**20**), 19% of 2-methylenebicyclo[3.3.0]octane (**21**), and 3% of 2-methylbicyclo[3.3.0]oct-2-ene (**22**). The generation of **22** was a secondary reaction which resulted from the isomerization of **21** (vide post).

1-Methylbicyclo[6.1.0]nonane (20). 1-Methylcyclooctene (**18**) was allowed to react with methylene iodide in the presence of copper powder[12] to give a 65% yield of **20**:[35] bp 65–67 °C (15mmHg); IR (neat) 2924, 1475, 1389, and 1023 cm^{-1}.

Bicyclo[3.3.0]octan-2-one (23). A literature procedure[13] was used to prepare bicyclo[3.3.0]octan-2-one, bp 73–74 °C (20mmHg), in 67% yield.

2-Methylenebicyclo[3.3.0]octane (21). To the ylide prepared from triphenylmethylphosphonium iodide (6.51 g, 16.2 mmol) and *n*-butyllithium (16.1 mmol) in 50 mL of tetrahydrofuran at 0 °C was added a solution of 2.00 g (16.0 mmol) of bicyclo[3.3.0]octan-2-one (**23**) in 10 mL of anhydrous ether, and the reaction mixture was stirred overnight. Anhydrous ether (150 mL) was added, the reaction mixture was filtered through a Celite pad, and the filtrate was washed thoroughly with saturated brine (until the washings were neutral). The ethereal solution was dried over anhydrous calcium chloride and filtered, and the solvent was removed at atmospheric pressure to yield a residue which gave 0.63 g (32%) of **21** on isolation by preparative VPC on a $^3/_8$ in. × 4 ft, 10% SE-30 column: IR (neat) 3028, 2913, 2839, 1658, 1451, 882 cm^{-1}; ^{13}C

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(32) D. Seyferth and M. A. Weiner, *J. Am. Chem. Soc.*, **83**, 3583 (1961).
(33) Compound **13** was prepared by methylmagnesium iodide addition to cycloheptanone followed by acid-catalyzed dehydration using 88% phosphoric acid to give a 67% overall yield of **13** which compared well with the literature (see ref 9).
(34) A. C. Cope and S. S. Hecht, *J. Am. Chem. Soc.*, **89**, 6920 (1967).
(35) W. G. Dauben and W. T. Wipke, *J. Org. Chem.*, **32**, 2976 (1967).

NMR δ 26.5, 31.8, 33.5, 34.2, 43.7, 47.9, 103.8 (t), 158.8 (s); ^{1}H NMR δ 1.0–3.1 (12 H, broad complex envelope of peaks), 4.75 (2 H, m).

Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.46; H, 11.53.

2-Methylbicyclo[3.3.0]oct-2-ene (22). To a solution of methyllithium (112 mmol) in 80 mL of ether at −75 °C was added 3.53 g of bicyclo[3.3.0]octan-2-one, and the reaction mixture was refluxed for 20 h. Hydrolysis followed by workup gave 3.98 g (99%) of the desired alcohol which was dehydrated without purification.

The crude alcohol was mixed with 3.45 g of anhydrous copper sulfate, and the resulting mixture was heated in an oil bath at 160 °C for 1 h. The reaction mixture was cooled, diluted with water, and extracted with ether. After the solution was dried over anhydrous sodium sulfate and filtered and the solvent was evaporated, the residue was vacuum distilled to yield 41% of 2-methylbicyclo[3.3.0]oct-2-ene (**22**), bp 57–59 °C (20mmHg). This product was identical with the product formed by the isomerization of **21** (vide post).

Isomerization of 2-Methylenebicyclo[3.3.0]octane (21) to 2-Methylbicyclo[3.3.0]oct-2-ene (22). A solution of 21 mmol of methyllithium in 15 mL of tetrahydrofuran, 0.53 g (4.3 mmol) of **21**, and TMEDA was refluxed for 48 h. The reaction mixture was poured into ice–water and extracted with five 15-mL portions of ether, and the ethereal extracts were washed with 10% hydrochloric acid, water, and saturated sodium chloride solution. The organic phase was dried over anhydrous sodium sulfate and filtered, and the solvent was evaporated at atmospheric pressure to yield a crude product which consisted of 80% of **22** and 2% of **21**. Isolation by preparative VPC gave 0.15 g (28%) of **22** (97% pure): IR (neat) 3000, 2904, 2830, 1658, 1449, 1360, 1020, 795 cm^{-1}; NMR δ 5.15 (1 H, br s), 3.10–1.00 (13 H, m, peaks at δ 1.65, 1.50, and 1.45). Exact mass calculated for C_9H_{14}: 122.1096. Found: 122.1091.

1-Chloro-2-methylcyclopentene (24). A solution of 32.86 g (0.40 mol) of 1-methylcyclopentene (**25**)[36] and 113 g (0.41 mol) of freshly prepared iodobenzene dichloride in 650 mL of carbon tetrachloride was refluxed and irradiated with a Hanovia high-intensity lamp for 0.5 h. The reaction mixture was cooled to 0 °C, and the iodobenzene dichloride was regenerated by passing chlorine gas through the solution with stirring. After 15 h, the iodobenzene dichloride was removed from the solution by filtration. The filtrate was concentrated at atmospheric pressure, and the residue was fractionally distilled to give 49.0 g (80%) of 1,2-dichloro-1-methylcyclopentane (**26**): bp 32–33 °C (4.5mmHg); NMR δ 1.74 (3 H, s), 1.70–3.00 (broad complex m), 4.28 (1 H, br d).

The crude product obtained above (47.9 g, 0.287 mol) was added dropwise over a 0.5-h period to a solution of sodium amide formed from 20.18 g of sodium in 500 mL of liquid ammonia. The reaction mixture was stirred for 6 h, and 50 mL of ether was added followed by portionwise addition of 47.6 g of ammonium chloride. The ammonia was allowed to evaporate, and 500 mL of water was added. The ether layer was separated, and the aqueous phase was extracted with six 80-mL portions of ether. The extracts were combined, washed with saturated sodium chloride solution, dried over anhydrous calcium sulfate, and filtered, and the ether was removed by careful distillation through a fractionating column. Distillation of the residue gave 14.83 g (44%) of **24**, bp 126–128 °C (lit.[3] bp 120–123 °C).

Reaction of 24 with Phenyllithium. A solution of 85.3 mmol of phenyllithium in 50 mL of tetrahydrofuran containing 5.01 g of TMEDA was allowed to react with 1.98 g of **24** at 0 °C. The mixture was refluxed for 12 h, cooled, poured into water, and extracted with ether. Standard workup and evaporation of the solvent gave 2.34 g of a residue which was shown to consist primarily of **27** and biphenyl. VPC analysis vs. an internal standard indicated that the yield of **27** was 21%. This same analysis indicated the complete absence of 1-phenylbicyclo[3.1.0]hexane.

1-Methyl-2-phenylcyclopentene (27). 2-Methyl-1-phenylcyclopentanol (7.55 g) was mixed with 8.0 g of 80% phosphoric acid and heated to reflux for 1 h. The acid-containing reaction mixture was cooled to room temperature, poured into ice–water, and extracted with five 50-mL portions of ether. The combined extracts were washed with saturated sodium chloride solution, dried over anhydrous calcium chloride and filtered, and the solvent was removed by distillation. Vacuum distillation of the residue gave 3.55 g of **27**, bp 58–62 °C (1.3mmHg) [lit.[37] bp 128 °C (30mmHg)]. Gas chromatographic analysis showed three impurities. A pure sample of **27** was obtained by preparative VPC. This sample of **27** was shown to be identical with that formed in the reaction of **24** with phenyllithium.

Reaction of 24 with *n*-Butyllithium. To 75.5 mmol of commerical *n*-butyllithium was added 4.36 g of TMEDA with stirring at 0 °C over a 0.5-h period. With the solution stirring, 1.95 g of **24** was added at such a rate as to maintain the temperature below 5 °C. The reaction mixture was stirred for 24 h, poured carefully onto ice, and extracted with five 25-mL portions of ether and two 25-mL portions of 1:1 ether–pentane. The combined extracts were washed with water, dried over anhydrous calcium chloride, and filtered, and the solvents were removed by distillation. Distillation of the residue gave 0.67 g of a clear liquid, bp 47–50 °C (25mmHg). VPC analysis indicated one major and two minor components. Comparison of retention times with an authentic sample of 1-*n*-butylbicyclo[3.1.0]hexane (**30**) indicated that none of this material was present. Mass spectral analysis showed that all of the components had a mass of 138. Comparison with an authentic sample[38] showed that one of the components was 1-*n*-butyl-2-methylcyclopentene (**29**): NMR δ 2.50–0.70 (m, peaks at δ 2.30, 2.20, 1.60, and 0.90). Exact mass calculated for $C_{10}H_{18}$: 138.1409. Found: 138.1407.

1-Chloro-2-carbomethoxycyclohexene (43). A mixture of 25.00 g (0.17 mol) of 1-chloro-2-formylcyclohexene (**42**),[19] 38.58 g (0.79 mol) of sodium cyanide, 14.15 g (0.24 mol) of acetic acid, and 270 g (3.11 mol) of manganese dioxide in 1.5 L of dry methanol (distilled from magnesium methoxide) was mechanically stirred for 1 day, following the procedure of Corey.[18] After removal of the solvent by rotary evaporation, the residue was partitioned between 1 L of ether and 1 L of water. After separation of the two phases, the ethereal layer was washed with 500 mL of saturated sodium chloride solution, dried over anhydrous magnesium sulfate, and filtered. Removal of the solvent by rotary evaporation gave 19.64 g of a yellow oil. This oil was fractionally distilled to yield 13.82 g (46%) of 1-chloro-2-carbomethoxycyclohexene (**43**): bp 94–96 °C (5mmHg); n^{24}_D = 1.4930; IR (neat) 2940, 1735, 1435, 1345, 1285, 1240, 1140, 1085, 1055, 995 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.75 (3 H, s), 2.60–2.10 (4 H, m) and 2.00–1.50 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 167.39 (s), 136.34 (s), 127.12 (s), 51.57 (q), 34.53 (t), 27.61 (t), 22.92 (t), 21.21 (t). Exact mass calculated for $C_8H_{11}{}^{35}ClO_2$: 174.0447. Found: 174.0447.

Anal. Calcd for $C_8H_{11}ClO_2$: C, 55.02; H, 6.35; Cl, 20.31. Found: C, 54.86; H, 6.43; Cl, 20.05.

1-Chloro-2-hydroxymethyl-d_2-cyclohexene (44). To a suspension of 1.0 g (23.8 mmol) of lithium aluminum deuteride in 25 mL of dry ether was added dropwise 4.16 g (23.8 mmol) of 1-chloro-2-carbomethoxycyclohexene (**43**) dissolved in 5 mL of dry ether. The mixture was then stirred under a dry atmosphere for 2 h. At that time, the reaction was quenched by the sequential addition of 1 mL of water, 1 mL of 15% sodium hydroxide solution, and 3 mL of water. The solids were removed by filtration and rinsed with additional ether. The ethereal layer was dried over anhydrous magnesium sulfate and filtered, and the solvent was removed by rotary evaporation to yield 3.44 g (23.0 mmol, 97%) of the desired labeled alcohol (**44**), as was shown by a combination of mass spectral, ^{1}H NMR, and ^{13}C NMR analyses: mass spectrum *m/e* (relative intensity) 150 (6.3, M^+), 148 (18.3, M^+), 113 (100, M^+ − Cl); ^{1}H NMR ($CDCl_3$) δ 2.9 (1 H, br s), 2.6–2.0 (4 H, m), 2.0–1.5 (4 H, m); ^{13}C NMR ($CDCl_3$) δ 132.28, 128.49, 62.03 (pentuplet), 33.60, 27.71, 23.58, 21.92.

1-Chloro-2-(chloromethyl-d_2)-cyclohexene (45). Following the procedure of Corey,[20] to a stirred solution of 2.5 g (18.7 mmol) of *N*-chlorosuccinimide in 100 mL of methylene chloride (distilled from phosphorus pentoxide) under nitrogen at 0 °C was added 1.45 mL (20.5 mmol) of dimethyl sulfide dropwise via syringe. Cooling to −20 °C produced a white slurry to which 2.5 g (16.8 mmol) of **44** in 5 mL of methylene chloride was added dropwise, again via syringe. The mixture was warmed to room temperature and stirred overnight. At that time, the clear solution was poured into 100 mL of ice-cold, saturated sodium chloride solution. Extraction of the aqueous layer with two 40-mL portions of ether and combination of the organic extracts was followed by two washings with 40-mL portions of ice-cold, saturated sodium chloride solution. Drying over anhydrous magnesium sulfate, filtering, and removing of the solvents by rotary evaporation was followed by distillation to give 2.03 g (72%) of 1-chloro-2-(chloromethyl-d_2)-cyclohexene (**45**): bp 77 °C (6mmHg); ^{1}H NMR ($CDCl_3$) δ 2.60–2.00 (4 H, m) and 2.00–1.50 (4 H, m). Due to its slight instability, the product was carried on to the next step without further characterization.

1-Chloro-2-methyl-d_3-cyclohexene (40). Under a dry atmosphere, 2.03 g (12.2 mmol) of **45** and 0.26 g (6.1 mmol) of lithium aluminum deuteride in 20 mL of dry tetrahydrofuran were refluxed for 1 h. The reaction was cooled and then quenched by the sequential addition of 0.26 mL of water, 0.26 mL of 15% sodium hydroxide solution, and 0.78 mL of water. The solids were filtered off and rinsed with ether. The organic layer was washed with saturated sodium chloride solution, dried over anhydrous magnesium sulfate, and then filtered. The solvents were removed by distillation through a 5-cm, glass-helices-packed column. Vacuum distillation yielded 1.23 g (75%) of 1-chloro-2-methyl-d_3-

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(38) G. Dielmann, D. Schwengers, and G. Schomburg, *Chromatographia*, **7**, 215 (1974).

cyclohexene (**40**): bp 80–81 °C (50mmHg); ^{1}H NMR ($CDCl_3$) δ 2.50–1.90 (4 H, m), 1.9–1.5 (4 H, m) (**1** has a methyl signal at δ 1.72 which the spectrum of **40** lacked); ^{13}C NMR ($CDCl_3$) δ 128.92, 125.96, 33.54, 31.96, 24.07, 22.46. (The normally strong methyl-carbon signal at δ 32.74 was absent.) A small amount of sample was purified for mass spectral deuterium analysis by preparative VPC at 100 °C on a $^1/_4$ in. × 15 $^1/_4$ ft 10% UCON W 98 on 60/80 Chromosorb W column. The sample analyzed for 97% d_3, 2% d_2, 1% d_1, and 0% d_0.

Reaction of 1-Chloro-2-methyl-d_3-cyclohexene (40) with Methyllithium. The solvent was removed from 3.7 mL (7.5 mmol) of 2.0 M methyllithium in ether with the aid of a stream of argon. It was replaced with 4 mL of dry tetrahydrofuran. The system was sealed under argon, and the solids were dissolved by mechanical stirring. To the solution was added 0.87 g (7.5 mmol) of TMEDA. After a few minutes, 0.20 g (1.5 mmol) of **40** was added by syringe, 2 mL of dry tetrahydrofuran being used to aid the transfer. The mixture was kept at reflux for 18 h, cooled, and then poured onto ice. Ether was added, and the layers were separated. The aqueous layer was further extracted with two 20-mL portions of ether and two 20-mL portions of ether–pentane (1:1). The combined organic extracts were washed with 100 mL of saturated sodium chloride solution and dried over anhydrous sodium sulfate. Filtration and removal of solvents by distillation through a glass-helices-packed column was followed by chromatography of the residue on 25 g of Woelm basic alumina with pentane as eluant to yield 0.033 g (0.3 mmol) of crude **41**. The sample was further purified by preparative VPC on a $^1/_4$ in. × 16$^1/_2$ ft 20% FFAP on Chromosorb P 45/60 column at 80 °C. Mass spectral analysis of deuterium content indicated that **41** was 30% d_3, 66% d_2, 4% d_1, and 0% d_0. The ^{1}H NMR spectrum of **41** was devoid of any signals in the δ 0.5–0.0 region.

Reaction of 1 with Methyllithium-d_3. A solution of 34.5 mmol of methyllithium-d_3 in 25 mL of ether was made by slow, portionwise addition of iodomethane-d_3 (99% d_3) in ether to lithium wire in ether under argon at −78 °C. After filtration of the solution to remove excess lithium wire, it was used in an analogous manner to the above reaction of **40** with methyllithium; in this case, **1** was substituted for **40**. After removal of the solvents by distillation through a glass-helices-packed column, there remained 1.13 g of crude **47**, contaminated with solvent. The residue was purified by preparative VPC as for the above reaction to give a sample for mass spectral deuterium analysis. The sample analyzed for 97% d_3, 3% d_2, 0% d_1, and 0% d_0. The ^{1}H NMR spectrum of **47** lacked the normally prominent methyl signal at δ 1.0 of 1-methylbicyclo[4.1.0]-heptane (**7**).

Reaction of 1-Chloro-2-methyl-d_3-cyclohexene with Phenyllithium. The solvent was removed from 7.5 mL (7.5 mmol) of 1.0 M phenyllithium in ether with the aid of a stream of argon. It was replaced with 7.5 mL of dry tetrahydrofuran, and the solids were dissolved by mechanical stirring, an argon atmosphere being maintained throughout the process. To the solution was added 0.87 g (7.5 mmol) of TMEDA by syringe. This was followed by the addition of 0.2 g (1.5 mmol) of **40**, a few milliliters of dry tetrahydrofuran being used to aid complete transfer. The mixture was refluxed overnight and then poured onto 50 mL of ice. Ether (50 mL) was added, and the layers were separated. The aqueous layer was further extracted with two 40-mL portions of ether and two 40-mL portions of 1:1 pentane–ether. The combined organic extracts were washed with two 50-mL portions of water and 50 mL of saturated sodium chloride solution. The organic layer was dried over anhydrous sodium sulfate and filtered, and the solvents were removed by rotary evaporation to yield 0.40 g of a dark yellow oil. This oil was chromatographed on 25 g of Woelm basic alumina with pentane as eluant to yield 0.0755 g (0.4 mmol, 29%) of crude **46**. The sample was further purified by preparative VPC on a $^1/_4$ in. × 15$^1/_4$ ft 10% UCON W 98 on a 60/80 Chromosorb W column at 130 °C. Mass spectral deuterium analysis indicated **46** to be 44% d_3, 53% d_2, 3% d_1, and 0% d_0. ^{1}H NMR analysis showed the δ 1.0–0.0 region to be devoid of any signals.

Reaction of Methyllithium and Phenyllithium with 2-Chloro-3-methylbicyclo[2.2.1]hept-2-ene (49). To a solution of 70.0 mmol of methyllithium in 50 mL of tetrahydrofuran containing 4.01 g of TMEDA was added 1.95 g of 2-chloro-3-methylbicyclo[2.2.1]hept-2-ene[22] at 0 °C. The reaction mixture was warmed to room temperature and then refluxed for 5 h. The reaction mixture was cooled, poured into ice–water, and extracted with five 50-mL portions of ether. The organic extracts were combined, washed with water, dried over anhydrous sodium sulfate, and filtered, and the solvent was evaporated at atmospheric pressure. The residue was chromatographed on neutral alumina and then vacuum transferred to give 0.55 g (38%) of 3-methylenetricyclo[2.2.1.0^{2,6}]heptane:[39] IR (neat) 3030, 2907, 2825, 1678 cm^{-1}; NMR δ 1.32 and 1.46 (8 H, broad overlapping multiplets), 4.55, 4.66 (2 H, br s).

Anal. Calcd for C_8H_{10}: C, 90.51; H, 9.49. Found: C, 90.55; H, 9.51.

Under essentially identical conditions phenyllithium reacted with 1.70 g of **49** to yield 0.45 g (35%) of **50**.

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