75299-26-2; **10**, 75299-27-3; **11**, 75299-28-4; **12**, 75299-29-5; **14**, 33283-69-1; **15a**, 75299-30-8; **15b**, 75299-31-9; **16a**, 75299-32-0; **17**, 565-62-8; 3-hexyne, 928-49-4; ethyl diazoacetate, 623-73-4; 3-(carboethoxy)-1,2-diethylcyclopropene, 35920-11-7; 1-pentyne, 627-19-0; 3-(carboethoxy)-1-propylcyclopropene, 26347-06-8; 2-butyne, 503-17-3; 3-(carboethoxy)-1,2-dimethylcyclopropene, 5783-75-5; allyl chloride, 107-05-1; vinyl bromide, 593-60-2; crotyl chloride, 591-97-9; cinnamyl chloride, 2687-12-9.

Addition of *n*-Butyllithium to Hydroxybicyclo[2.2.1]hept-2-enes[1]

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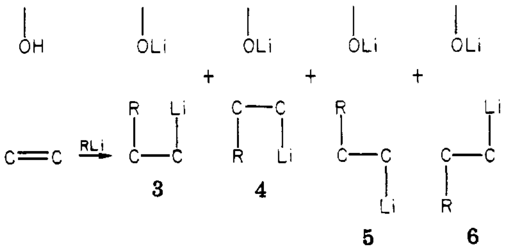
n-Butyllithium adds to the double bonds of bicyclo[2.2.1]hept-2-ene (**7**), *endo*-bicyclo[2.2.1]hept-5-en-2-ol (**9**), *exo*-bicyclo[2.2.1]hept-5-en-2-ol (**12**), *syn*-bicyclo[2.2.1]hept-2-en-7-ol (**14**), and *anti*-bicyclo[2.2.1]hept-2-en-7-ol (**18**). The *n*-butyl group was shown to be attached at an exo position and in the additions to **9** and **12** to be at C-5 rather than C-6. Competition experiments suggest that addition to **9** is somewhat faster than to **7** but that additions to **14** and **18** are slower. The role of a metalated hydroxyl group in assisting these reactions is considered. No addition products were obtained from reactions at ambient temperature of *n*-butyllithium with 3-(hydroxymethyl)-1,2-diethylcyclopropene (**20**), 3-(hydroxymethyl)-1,2-dimethylcyclopropene (**23**), or 3-(hydroxymethyl)-1-propylcyclopropene (**24**), but some 1-(hydroxymethyl)-2-ethylidene-3-deuterio-3-ethylcyclopropane (**21**) was obtained from a reaction with **20** at dry ice temperature followed by quenching with D_2O.

Crandall[4] and Felkin[5] and their co-workers were the first to report that organolithium compounds (in excess) add to allyl alcohol (**1** → **2**) and some other allylic alcohols. In

$$\underset{\mathbf{1}}{CH_2{=}CHCH_2OH} \xrightarrow[2.\ H_2O]{1.\ RLi} \underset{\mathbf{2}}{CH_3C(R)HCH_2OH} \qquad (1)$$

these reactions the hydroxyl group certainly reacts immediately with 1 equiv of the organolithium compound. Since organolithium compounds do not add as readily to comparable hydrocarbons lacking a hydroxyl group,[6] the metalated hydroxyl group that results must facilitate addition. Additions to other allylic alcohols[7,8] and propargylic alcohols[9,10] have since been noted. Moreover, tertiary amino,[11,12] alkoxyl,[12-16] and alkylthio[12] groups have also been found to facilitate addition to allylic or homallylic alkene functions and to propargylic alkyne functions.

We hoped that an understanding of the role played by a hydroxyl group in assisting additions to alkenes would be advanced by defining the stereochemical relationship at the time of addition between four critical groups: the alkene function, R and Li from the organolithium compound, and the metalated hydroxyl group. Do R and Li add in a syn or anti fashion? What is their relationship to the metalated hydroxyl group? Possible configurations of the resulting addition products are shown schematically in **3**–**6** (eq 2). The problem is similar to that of the addition of organomagnesium compounds to alkenols that we have discussed recently.[17,18]



(2)

In this paper, we describe reactions of organolithium compounds with 2- and 7-hydroxybicyclo[2.2.1]hept-2-enes and with 3-(hydroxymethyl)cyclopropenes. The possible advantages of these substrates, the same chosen for our studies with organomagnesium compounds, have already been considered.[17,18]

Results

It was important in this study to be able to add the same organolithium compound to both **9** and **14**, a pair of hydroxyl-substituted bicyclo[2.2.1]hept-2-enes in which the

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[1] Much of this work is taken from ref 2 and 3.

[2] Wilkins, C. W., Jr. Ph.D. Dissertation, The Pennsylvania State University, University Park, PA, 1976.

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[6] For a summary, see: Wakefield, B. J. "The Chemistry of Organolithium Compounds"; Pergamon Press: Oxford, 1974; Chapter 7.

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[16] Kool, M.; Klumpp, G. W. *Tetrahedron Lett.* **1978**, 1873.

[17] Richey, H. G., Jr.; Wilkins, C. W., Jr. *J. Org. Chem.*, companion paper in this issue.

[18] Richey, H. G., Jr.; Bension, R. M. *J. Org. Chem.*, previous paper in this issue.

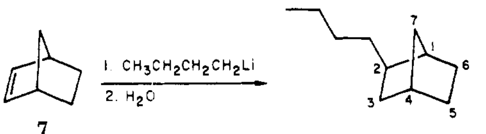
0022-3263/80/1945-5042$01.00/0

hydroxyl group is close to but on opposite sides of the double bond. If the additions involve assistance by the metalated hydroxyl group and if that assistance is associated with a particular stereochemical relationship between R (of RLi) and the hydroxyl group, then R would become attached at an exo position of one alcohol and at an endo position of the other. We first tried allyllithium and methyllithium. Products from addition of allyllithium could be compared with those obtained in other work from addition of the allyl Grignard reagent,[17] and many of the possible products from methyllithium addition have already been described.

Significant amounts of **9** were recovered from reactions with methyllithium (with or without TMEDA) or allyllithium. Although the methyllithium reactions were run in refluxing diethyl ether for 1 week and the allyllithium reaction was run in refluxing tetrahydrofuran–diethyl ether for 4 days, no addition products were detected. A large amount of **9** was recovered, and neither a carboxylic acid nor lactone was detected when an allyllithium reaction using TMEDA was heated for 10 days at 100 °C and then quenched with carbon dioxide. Therefore, the failure of allyllithium to add to **9** was apparently not due to metalation at carbon.[19]

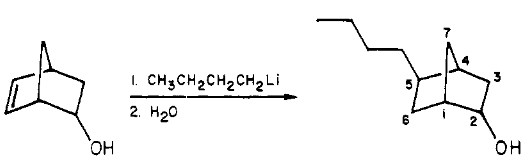
n-Butyllithium added both to **9** and **14** and was used in this study. The yield of **10** obtained from **9** was considerably greater when TMEDA was added. Therefore, TMEDA was used in all reactions with bicycloheptenols. This effect of TMEDA was noted both by Crandall[4] and Felkin.[5]

Addition of *n*-butyllithium to bicyclo[2.2.1]hept-2-ene (**7**) was studied to compare to additions to the hydroxyl-substituted bicyclo[2.2.1]hept-2-enes (eq 3). Compound **8** was isolated in 30% yield following hydrolysis of a reaction mixture of an excess of *n*-butyllithium and tetramethylethylenediamine (TMEDA, 1 mol/mol of RLi) with **7** in hexane for 24 h at ambient temperature. The assignment of configuration to **8** is considered in the Discussion.

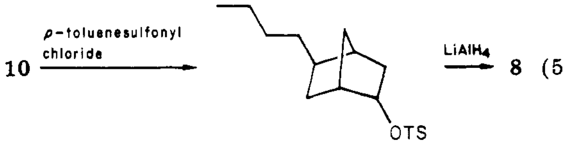


7 **8** (3)

Compound **10** was isolated in 51% yield from a similar reaction of *endo*-bicyclo[2.2.1]hept-5-en-2-ol (**9**; eq 4). GC analysis of the crude product from a similar reaction lacking TMEDA indicated the presence of only a 6% yield of **10** and the recovery of a large amount of **9**. The reactivities of **9** and **7** were compared in an experiment in which equimolar amounts of the two compounds were permitted to compete for an insufficient amount of *n*-butyllithium. The amounts of **7**–**10** found by GC analysis were consistent with addition to **9** being approximately 5–10 times faster than to **7**. Assignment of a structure and configuration to **10**, considered in the Discussion, rests partly on reduction of its *p*-toluenesulfonate (**11**) with lithium aluminum hydride (eq 5). This reaction produced the same compound (**8**) obtained from the reaction of *n*-butyllithium and **7**.

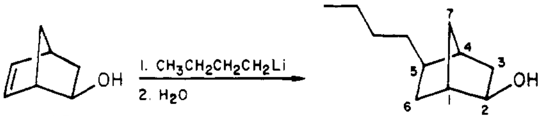


9 **10** (4)



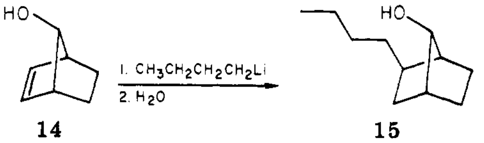
11 (5)

Compound **13** was isolated in 47% yield following hydrolysis of a reaction of *exo*-bicyclo[2.2.1]hept-5-en-2-ol (**12**), *n*-butyllithium, and TMEDA in hexane for 24 h at ambient temperature (eq 6). The assignments of structure and configuration to **13** are described in the Discussion.

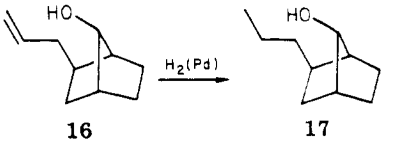


12 **13** (6)

Compound **15** was isolated in 26% yield from a reaction of *syn*-bicyclo[2.2.1]hept-2-en-7-ol (**14**), *n*-butyllithium, and TMEDA in hexane for 24 h at ambient temperature (eq 7). When a similar reaction was quenched with D_2O instead of H_2O, mass spectral analysis indicated that approximately 45% of the molecules of recovered **14** contained one excess deuterium bonded to a carbon. Therefore, metalation of **14** competed with addition. Metalation destroys the organolithium compound, and the resulting metalated species may be less prone to undergo addition. Therefore, metalation probably contributed to the low yield of **15** and perhaps to the only poor to fair yields obtained in other additions. The reactivities of **14** and **7** were compared in a competition experiment. Significant amounts of **8** and of unreacted **7** and **14** were found, and no **15** was detected, when **7** and (metalated) **14** were allowed to compete for a limited amount of *n*-butyllithium. The results of this experiment suggest that addition to **7** is at least 10 times faster than addition to **14**. The assignment of configuration to **15**, considered in the Discussion, rests partly on a spectral comparison with the *n*-propyl homologue **17**. Compound **17** was prepared by reduction of **16** (eq 8), whose configuration has already been established.[17]

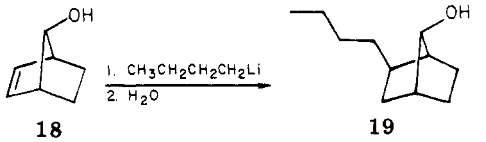


14 **15** (7)



16 **17** (8)

GC analysis indicated that **19** was formed in 2% yield in a reaction of *anti*-bicyclo[2.2.1]hept-2-en-7-ol (**18**), *n*-butyllithium, and TMEDA in hexane for 25 h at ambient temperature (eq 9). The reactivities of **18** and **7** were compared in a competition experiment. Significant



18 **19** (9)

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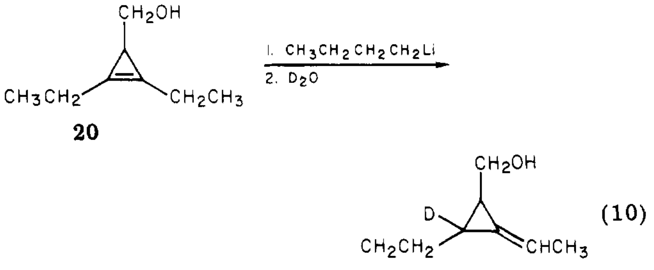
[19] Disappearance of the organolithium compound by attack on the solvent may have been significant.

amounts of **8** and of unreacted **7** and **18** were found, but no **19** was detected, in an experiment in which **18** and **7** competed for a limited amount of *n*-butyllithium. The results of this experiment suggest that addition to **7** is at least 10 times faster than addition to **18**. The assignment of configuration to **19** is considered in the Discussion.

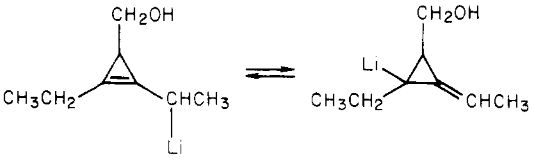
A considerable amount of reactant was recovered and no new compound obtained from an overnight reaction of 3-(hydroxymethyl)-1,2-diethylcyclopropene (**20**) and methyllithium in diethyl ether at ambient temperature. GC analysis indicated the presence of **20** and of one new component when a reaction of **20** and *n*-butyllithium in hexane at dry ice temperature was quenched after 8 h by addition of D_2O (eq 10). The ^1H NMR spectrum of the new component (18% yield) was consistent with structure **21**. Its configuration was not established. Formation of **21** must have resulted from metalation of **20** to produce **22**. Neither addition products nor reactants were detected in reactions of 3-(hydroxymethyl)-1,2-dimethylcyclopropene (**23**) and of 3-(hydroxymethyl)-1-propylcyclopropene (**24**) with *n*-butyllithium in hexane at ambient temperature.



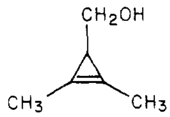
20

(10)

21



22



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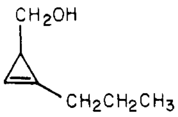

24

Discussion

Structure and Configuration of the Addition Products. An exo attachment of the *n*-butyl group of **8** seems likely on the basis of close precedents. The butyl groups have been shown to be exo in addition products obtained from reactions of **8**[20a] with *tert*-butyllithium and of benzobicyclo[2.2.1]heptadiene[20b] with *n*-butyl, *sec*-butyl-, and *tert*-butyllithium. Moreover, only exo attachment is consistent with the ^{13}C NMR spectrum of **8**. Except for absorptions at 14.3 and 23.1 ppm (downfield from Me_4Si) that are due to the butyl group, the highest field absorption of **8** is at 29.1 ppm. The endo isomer should have an absorption for C-6 similar to that at 22.1 ppm of C-6 of *endo*-2-methylbicyclo[2.2.1]heptane.[21]

Reduction of addition product **10** to **8** indicates that the butyl group of **10** also is exo. The chemical shift and splitting pattern of the absorption of the C-2 hydrogen of **10** is characteristic of *endo*-bicyclo[2.2.1]heptan-2-ols,[22] indicating that the hydroxyl group remains endo.

Attachment of the butyl group in **10** to C-5 rather than C-6 is shown by the ^{13}C NMR spectrum, which also rules out endo attachment at either carbon. The ^{13}C NMR spectra of the four possible addition products with a 2-*endo*-hydroxyl and with *n*-butyl attached exo or endo at C-5 or C-6 can be predicted from the known spectra[23] of the four corresponding methyl-substituted *endo*-bicyclo[2.2.1]heptan-2-ols. We did this by adding amounts for the effects of the new α, β, and γ interactions introduced when methyl is replaced by *n*-butyl.[24] The same conclusions are reached for any reasonable set of values, though below we specifically assume 9.1, 9.4, and −2.5 ppm for the effects of the α, β, and γ carbons.[25]

The observed spectrum matches remarkably well that predicted in this simple fashion for isomer **10** with its *exo*-5-butyl group. If the predicted and observed absorptions are arranged in order of chemical shifts, no observed absorption is more than 1.3 ppm from the corresponding predicted absorption, and the average deviation is less than 0.7 ppm. By contrast, the observed spectrum and that calculated for the *exo*-6-butyl isomer differ significantly. Four absorptions appear in the 41–43-ppm region, but none are predicted between 38.5 and 46.7 ppm for the *exo*-6-butyl isomer. Moreover, C-1 of that isomer is predicted to absorb at 46.7 ppm, but except for the absorption of C-2 (72.7 ppm), the observed absorption at highest field falls at 42.6 ppm. Similar arguments rule out endo attachment of butyl at C-5 or C-6.

The exo attachment of the hydroxyl group of **13** is demonstrated by a chemical shift and splitting pattern for the C-2 hydrogen that is characteristic of *exo*-bicyclo[2.2.1]heptan-2-ols.[22] Butyl can reasonably be expected to be exo since exo attachment was observed in addition to the parent hydrocarbon, **7**, and the hydroxyl group of **13** cannot play a direct role in the reaction.

The ^{13}C NMR spectrum also suggests an exo attachment of butyl and is consistent with its attachment at C-5 rather than C-6. In the manner outlined above, the ^{13}C NMR spectra of the four possible addition products with a 2-*exo*-hydroxyl and with butyl exo or endo and at C-5 or C-6 can be predicted from the known spectra[23] of the four corresponding methyl-substituted *exo*-bicyclo[2.2.1]heptan-2-ols. The spectrum predicted for the *exo*-5-butyl isomer satisfactorily matches the observed spectrum. Spectra predicted for the other three isomers do not. The observed spectrum has its five lowest field absorptions at 40.7 41.4, 43.4, 45.2, and 75.0 ppm. In this region, the *exo*-6-butyl isomer is predicted to have absorptions only at 41.3 (C-3), 48.6 (C-1), and 74.6 (C-2) ppm, the *endo*-5-butyl isomer only at 45.5 (C-1) and 74.6 (C-2) ppm, and the *endo*-6-butyl isomer only at 42.9 (C-3), 46.9 (C-1), and 69.0 (C-2) ppm.

Assignment of a *syn*-hydroxyl-*exo*-butyl configuration to **15** is based on the virtual identity of comparable portions of its ^{13}C NMR spectrum and that of its *n*-propyl homologue **17**. The *n*-propyl compound was obtained from **16** whose configuration has been established rigorously by

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(20) (a) Mulvaney, J. E.; Gardlund, Z. G. *J. Org. Chem.* **1965**, *30*, 917. (b) Caple, R.; Chen, G. M.-S.; Nelson, J. D. *Ibid.* **1971**, *36*, 2874.

(21) Stothers, J. B.; Tan, C. T.; Teo, K. C. *Can. J. Chem.* **1973**, *51*, 2893.

(22) For example, see: Musher, J. J. *Mol. Phys.* **1963**, *6*, 93.

(23) Stothers, J. B.; Tan, C. T.; Teo, K. C. *Can. J. Chem.* **1976**, *54*, 1211.

(24) We assume that C-2, C-3, and C-4 of the *n*-butyl chain would absorb at about 29.9, 23.7, and 14.5 ppm, values found for *n*-butylcyclohexane (Stothers, J. B. "Carbon-13 NMR Spectroscopy"; Academic Press: New York, 1972; p 67). The ^{13}C NMR spectra of *n*-butyl addition compounds **8**, **10**, **13**, and **15** are in reasonable accord with that expectation.

(25) Grant, D. M.; Paul, E. G. *J. Am. Chem. Soc.* **1964**, *86*, 2984.

chemical transformation.[17] A change in the stereochemistry of either the butyl or hydroxyl group should cause significant changes. For example, C-6 of an *endo*-2-butylbicyclo[2.2.1]heptan-7-ol should absorb at about 18.4 ppm.[26] However, except for two absorptions (14.5 and 23.1 ppm) that must be due to carbons of the butyl side chain, the observed absorption at highest field is at 26.1 ppm.

Since the hydroxyl group of **18** can play no direct role in additions to the double bond, we assume that (as in the products of additions to **7** and **12**) the butyl group in **19** is exo.

Conclusions. Since a competition experiment indicates that addition to **9** is somewhat faster than addition to **7**, we conclude that the hydroxyl group assists addition to **9**. In the absence of assistance, a metalated hydroxyl group probably would retard addition. This retardation is deduced from the behavior of **18**, a compound in which the hydroxyl group cannot approach the double bond and hence cannot be directly involved in an addition. The low yield of addition product **19** and the results of a competition experiment indicate that addition of *n*-butyllithium is slower to alcohol **18** than to hydrocarbon **7**. A similar observation that a nonassisting hydroxyl retards addition was made in a study of additions of the allyl Grignard reagent to bicycloheptenols.[17] The retarding effect of a metalated hydroxyl group, noted with **18**, might also be a factor in hydroxyl-assisted reactions. If it is, then the rate increase caused by hydroxyl assistance in the addition to **9** is larger than the ratio of 5–10 observed for the rate of addition to **9** relative to that to **7**. If hydroxyl-assisted additions follow a unique stereochemical pathway, then the result with **9** indicates that this pathway leads to attachment of R (from RLi) to the face of the double bond furthest from the hydroxyl group.

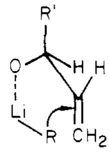
Attachment of R to the remote face of the double bond in hydroxyl-assisted additions would be confirmed if addition to **14** led to endo attachment of the butyl group. However, exo attachment is observed. The exo attachment observed in additions both to **9** and **14** may indicate that assisted additions have no strong preference for a unique stereochemistry of attachment of the organic group. If that is the case, then formation of exo products could be due simply to the usual preference for exo attachment, which is seen in additions to **7**, **12**, and **18** that must be unassisted. Alternatively, the addition to **14** may not be hydroxyl assisted. Although a competition experiment showed addition to **14** to be slower than to **7**, a rate slower than that of the corresponding hydrocarbon does not necessarily indicate the absence of hydroxyl assistance. If the effect of a metalated hydroxyl group that slows unassisted reactions also operates in assisted reactions, then whether an assisted addition is faster or slower than that to the corresponding hydrocarbon depends on the relative magnitudes of the deceleration due to a metalated hydroxyl group and the acceleration due to hydroxyl assistance.

Therefore, we are left with alternative conclusions: (1) addition to **14** is hydroxyl assisted, but attachment of R to either face of the double bond can result from assisted additions, or (2) addition to **14** is not hydroxyl assisted, and its stereochemistry is not necessarily that which would result from a hydroxyl-assisted pathway. As outlined below, we speculate that the reversed reactivities of **9** and **14** toward additions of the allyl Grignard reagent and *n*-butyllithium are (a) more in accord with the second possibility and (b) are consistent with an assisted addition of an organolithium compound to a homoallylic alcohol leading preferentially to attachment of R to the face of the double bond further from the hydroxyl group.

Addition of the allyl Grignard reagent to **14** is faster than to **9**.[17] Both reactions are faster than addition to **7** and hence are almost certainly hydroxyl assisted. Addition to **14** results in an exo attachment of the organic group and addition to **9** to an endo attachment, leading to the conclusion that in such systems, assisted addition of the allyl Grignard reagent results in preferential attachment of allyl at the face of the double bond nearer the hydroxyl. Of several factors that may contribute to the rate difference between **14** and **9**, one probably is the general preference for exo attachment to bicyclo[2.2.1]hept-2-enes to be faster than endo attachment.

By contrast, addition of *n*-butyllithium to **9** is faster than to **14**. This reversal of reactivity is consistent with an assisted addition resulting in attachment to the face of the double bond furthest from the hydroxyl. An assisted addition to **9** would lead to the favorable exo attachment that actually is observed. However, an assisted addition to **14** would lead to an unfavorable endo attachment and hence may be slower than an unassisted addition that leads to exo attachment.

The only prior observations related to the stereochemistry of addition of organolithium compounds to unsaturated alcohols concern allylic alcohols, rather than the cyclic homoallylic alcohols used in this study. Felkin,[5] and later Dimmel,[7] observed that threo isomers predominated in the products obtained upon additions to α-substituted, acyclic allylic alcohols. Of course, due to rotation around single bonds, the relative positions of OLi and R at the time of addition are not evident in the products. However, on the basis of steric arguments, Felkin proposed that this stereochemical preference was consistent with the intramolecular pathway in **25**. This interpretation, which predicts attachment of R to the face of the double bond nearer the hydroxyl group, is opposite to that tentatively suggested in this paper. However, Felkin's analysis seems reasonable, and it is possible that the pathways for assisted addition of organolithium compounds to allylic and homoallylic alcohols are different. Additions of the allyl Grignard reagent to allylic[27] and homoallylic[17,18,28] alcohols also seem to proceed with different stereochemistries.



25

Experimental Section

^{1}H NMR spectra were taken at 60 MHz with Me_4Si as an internal standard. Absorptions are reported with the following notations: s, singlet; d, doublet; t, triplet; q, quartet; m, a more complex multiplet; c, complex overlapping absorptions. Proton-decoupled ^{13}C NMR spectra were obtained by using $CDCl_3$ as an internal lock; absorptions are reported relative to Me_4Si. IR (in CCl_4) and low-resolution mass spectra, though not generally reported in this paper, were taken for many compounds and are described in ref 2. Chemical ionization mass spectra were obtained with a Finnigan Model 3200 gas chromatograph–mass spectrom-

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[26] The absorption of this carbon in bicyclo[2.2.1]heptan-7-ol is at about 25.9 ppm (estimated from the information in: Schneider, H.-J.; Bremser, W. *Tetrahedron Lett.* **1970**, 5197). An *endo*-2-methyl group causes a shift of about −7.5 ppm.[23]

[27] Chérest, M.; Felkin, H.; Frajerman, C.; Lion, C.; Roussi, G.; Swierczewski, G. *Tetrahedron Lett.* **1966**, 875.

[28] Eisch, J. J.; Merkley, J. H.; Galle, J. E. *J. Org. Chem.* **1979**, *44*, 587.

eter using methane as the reagent gas. Other mass spectra were obtained by using an AEI Model MS 902 spectrometer.

Analytical and preparative GC separations were performed with thermal conductivity instruments using helium as the carrier gas and the following columns constructed of aluminum tubing: A, 20% SE-30 on Gas Chrom Q (80–100 mesh), 0.25 in. × 12 ft; B, 20% FFAP on Chromosorb W (60–80 mesh), 0.25 in. × 12 ft; C, 20% SE-30 on Gas Chrom Q (60–80 mesh), 0.25 in. × 6 ft. For the reactions with bicycloheptenes, peak areas were determined by using a planimeter or by cutting out and weighing the peak tracings. For the reactions with cyclopropenes, peak areas were determined by tracing the peaks on the chart paper with an electronic plotter and converting the resulting signals to digital values with a computer program written by Hayden Clark of the Department of Chemistry at The Pennsylvania State University. When the amounts of the components of a reaction mixture were to be determined by GC analysis, a weighed amount of a standard was added. A standard was chosen whose GC peak was known from preliminary work not to overlap with those of components of the reaction mixture. The amount of a compound was determined from the area of its GC peak relative to the peak due to the standard by assuming that the response of the detector to different compounds was proportional to their molecular weights (the errors introduced by this assumption probably resulted in underestimating the yields of most products in this work). In GC analysis of a distilled material, it was assumed that all of the material appeared in the observed peaks (a reasonable assumption since substances having little volatility had been removed).

Materials. (a) Substrates for Reactions with Organolithium Compounds. *exo*-Bicyclo[2.2.1]hept-5-en-2-ol (**12**) was prepared as previously reported;[29] mp 86–88 °C (lit.[29] mp 92–93 °C). ^1H NMR analysis using the absorptions[30] of the C-2 H's indicated that the sample contained a small amount of **9**. The other substrates were prepared as described in the preceding papers.[17,18] The *endo*-bicyclo[2.2.1]hept-5-en-2-ol (**9**) used for the competition experiment was purified by GC and contained only about 1% of the exo isomer.[17]

(b) Organolithium Compounds. The concentrations of organolithium compounds (typical values in parentheses) were usually determined before use by a double-titration procedure.[31] Methyllithium in diethyl ether (1.5 M) and *n*-butyllithium in hexane (2.7 M) were commercial samples (Ventron Corp.). Allyllithium in diethyl ether–tetrahydrofuran (THF) was prepared from allyl phenyl ether and lithium shot (Ventron Corp.) as already described.[32] The concentration (about 2.0 M) was determined by a double-titration procedure.[33] Diethyl ether and THF were distilled from lithium aluminum hydride or dried over sodium.

Procedure for Reactions with Organolithium Compounds. Reactions were carried out in standard-taper, three-necked, round-bottomed flasks containing a magnetic stirring bar and fitted with a condenser having a gas-inlet tube at the top, a pressure-equalizing addition funnel, and a rubber septum. Glassware was stored at 120 °C prior to assembly; after assembly, the apparatus was heated with a Bunsen burner while nitrogen flowed rapidly through it. During the course of a reaction, a slight positive pressure of nitrogen was maintained in the closed reaction system.

Except where specifically noted, the following reaction procedure was used. The solution of the organolithium compound was added to the flask which was cooled in an ice bath. Gas-tight syringes were used for all transfers of anhydrous solvents and solutions of organolithium compounds. When it was used, *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA, distilled from potassium hydroxide, ratio of RLi to TMEDA of 1:1) was then added and the mixture stirred for 15 min. A solution of the substrate, dissolved in 20–50% of the amount of solvent containing the organolithium compound, was added over 15 min from the dropping funnel to the stirred mixture, and then the solution was warmed to the desired reaction temperature. Diethyl ether and THF were distilled from lithium aluminum hydride or stored over sodium before use; hexane was stored over sodium. The molar ratio of the organolithium compound to the substrate is indicated in the following sections for each reaction.

Reaction mixtures were quenched by being cooled to 0 °C with addition of sufficient methanol to destroy any organolithium compound. Then sufficient water to dissolve the lithium salts was added. The organic layer was separated, the aqueous layer was extracted with several portions of ether, and the combined organic extracts were dried (Na_2SO_4 or $MgSO_4$). Most of the solvent was removed at reduced pressure. The residue was distilled at reduced pressure or subjected to GC analysis. Samples were often collected for spectral analysis by using glass U-shaped tubes cooled in liquid nitrogen and inserted into the exit port of the chromatograph.

Reaction of Bicyclo[2.2.1]hept-2-ene (7) with *n*-Butyllithium. Isolation of 8. A reaction (3:1) using TMEDA for 24 h at ambient temperature gave **8**: 30% yield; bp 28–31 °C (0.35 torr); ^1H NMR (CCl_4) τ 7.85 (m, 1, H at C-4), 8.06 (m, 1, H at C-1), 8.37–9.39 (c, 18, all other H's); ^{13}C NMR ($CDCl_3$) δ 14.3, 23.1, 29.1, 30.4 (2), 35.4, 36.9 (2), 38.5, 41.4, 42.5; mass spectrum, m/z 152.1556 (M^+, calcd for $C_{11}H_{20}$ 152.1565).

The only other compounds (except **7**) noted on GC analysis (column A, 130 °C) had much shorter retention times than did **7**.

Reactions of *endo*-Bicyclo[2.2.1]hept-5-en-2-ol (9) with Organolithium Compounds. (a) With *n*-Butyllithium. Isolation of 10. A reaction (3:1) using TMEDA for 26 h at ambient temperature gave a material [bp 68–75 °C (0.05 torr)] that on GC analysis (column A, 150 °C) exhibited one major peak, though about 5% of the total absorption was in several additional peaks. The compound responsible for the major peak was collected and assigned structure **10**: 51% yield; ^1H NMR (CCl_4) τ 5.80 (m, 1, CHOH), 7.56–9.42 (c, 19, all other H's); ^{13}C NMR ($CDCl_3$) δ 14.3, 23.0, 29.0, 30.3, 34.8, 37.0, 41.0, 42.1, 42.5, 42.6, 72.7; mass spectrum, m/z 168.1513 (M^+, calcd for $C_{11}H_{20}O$ 168.1514).

GC analysis (column A, 130 °C, retention time of 2.15 for **10** relative to dodecane, the internal standard) of a similar reaction in which no TMEDA was used showed **10** to be formed in only 6% yield. A considerable amount of **9** remained.

(b) With Methyllithium. A reaction mixture (4:1) was refluxed for 7 days. The ^1H NMR spectrum of the crude product showed it to contain only **9** (81% recovery). Another reaction mixture (3:1) containing TMEDA was refluxed for 6 days. ^1H NMR and GC analysis (column A, 150 °C) showed the presence of a large amount of **9** and gave no indication of an addition product.

(c) With Allyllithium. A reaction (6:1) refluxed for 92 h was hydrolyzed with a saturated aqueous ammonium chloride solution. The organic extracts were washed with 5% aqueous sodium hydroxide (to remove phenol, a byproduct of the preparation of allyllithium) and then with water. Distillation of the crude product furnished a material [bp 30–40 °C (0.05 torr)] shown by its ^1H NMR spectrum to be **9** (37% recovery) containing some phenol.

Another reaction mixture (3:1) containing TMEDA was transferred to several glass ampules which were sealed and then heated at 100 °C for 10 days. GC analysis (column C, 165 °C) of the crude product obtained from one ampule showed no evidence for an addition product. The contents of the other ampules were transferred to a flask cooled in an ice bath and stirred while carbon dioxide was passed through the flask for 2 h. After hydrolysis by addition of a saturated ammonium chloride solution, the mixture was acidified with dilute hydrochloric acid. The organic layer was separated, the aqueous layer was extracted with diethyl ether, and the combined extracts were dried ($MgSO_4$). The IR spectrum of the material remaining after removal of the solvent showed no absorptions in the 1600–1900-cm^{-1} region except those that could be attributed to phenol. The ^1H NMR spectrum showed the material to be a mixture of **9** (72% recovery) and phenol.

Reduction of Addition Product 10 to 2-*exo*-*n*-Butylbicyclo[2.2.1]heptane (8). A solution of freshly purified[34] *p*-

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(29) Brown, H. C.; Zweifel, G. *J. Am. Chem. Soc.* **1959**, *81*, 5832.

(30) Wong, E. W. C.; Lee, C. C. *Can. J. Chem.* **1964**, *42*, 1245.

(31) The procedure in one of the following references was used: Vlismas, T.; Parker, R. D. *J. Organomet. Chem.* **1967**, *10*, 193; Kofron, W. G.; Baclawski, L. M. *J. Org. Chem.* **1976**, *41*, 1879.

(32) Eisch, J. J.; Jacobs, A. M. *J. Org. Chem.* **1963**, *28*, 2145.

(33) Gilman, H.; Haubein, A. H. *J. Am. Chem. Soc.* **1944**, *66*, 1515.

toluenesulfonyl chloride (2.48 g, 13.0 mmol) in pyridine (10 mL, distilled from barium oxide) was added to a solution of **10** (1.97 g, 11.7 mmol) in pyridine (10 mL) that was cooled in an ice bath. The solution was left under a nitrogen atmosphere in the ice bath for 70 h. Then the reaction mixture was poured into ice–water (300 mL), stirred for 15 min, and extracted several times with diethyl ether. The ether extracts were washed with a hydrochloric acid solution (3 M), a saturated sodium bicarbonate solution, and a saturated sodium chloride solution and then dried ($MgSO_4$). The oil that remained after removal of the solvent at reduced pressure was dissolved in diethyl ether (15 mL) and added to a solution of lithium aluminum hydride (1.5 g, 36 mmol) in diethyl ether (20 mL). The solution was refluxed for 3 h under a nitrogen atmosphere. The mixture was cooled in an ice bath and hydrolyzed by addition first of wet ether and then of water. Aqueous sodium hydroxide (150 mL, 1 M) was added, the mixture was extracted several times with diethyl ether, and the extracts were dried (K_2CO_3). Removal of the solvent at reduced pressure left 1.20 g of material shown by GC (column A, 150 °C) and ^1H NMR analysis to be more than 95% **8** (64% yield). A sample purified by GC had ^1H and ^{13}C NMR spectra, an IR spectrum, and a GC retention time identical with those of **8** obtained from the reaction of *n*-butyllithium and **7**.

Reaction of *exo*-Bicyclo[2.2.1]hept-5-en-2-ol (12) with *n*-Butyllithium. Isolation of 13. A reaction (5:1) using TMEDA for 24 h at ambient temperature gave a material [bp 80 °C (0.35 torr)] shown by GC analysis (column A, 170 °C) to contain 81% of a new compound (retention time 5.2 relative to that of **12**), most of the remainder being **12**. The compound responsible for the major peak was collected and assigned structure **13**: 47% yield; ^1H NMR (CCl_4) τ 6.36 (m, 1, CHOH), 7.25 (s, 1, OH), 7.82–8.15 (c, 2, H's at C-1 and C-4), 8.17–9.33 (c, 16, all other H's); ^{13}C NMR ($CDCl_3$) δ 14.6, 23.4, 30.8, 31.7, 33.3, 36.8, 40.7, 41.4, 43.4, 45.2, 75.0; mass spectrum, m/z 168.1508 (M^+, calcd for $C_{11}H_{20}O$ 168.1514).

The retention time of **13** was 0.91 relative to that of **10**.

Reaction of *syn*-Bicyclo[2.2.1]hept-2-en-7-ol (14) with *n*-Butyllithium. Isolation of 15. A reaction (5:1) using TMEDA for 24 h at ambient temperature gave a crude product [bp 85 °C (0.7 torr)] shown by GC analysis (column A, 175 °C) to contain 81% of a new component (retention time 4.3 relative to that of **12**), as well as 5% of **12** and some lower boiling materials. The compound responsible for the major peak was collected and shown to be **15**: 26% yield; ^1H NMR (CCl_4) τ 6.17 (m, 1, CHOH), 7.83–9.42 (c, 19, all remaining H's); ^{13}C NMR ($CDCl_3$) δ 14.5, 23.1, 26.1, 28.2, 31.3, 35.8, 37.1, 41.4, 42.8, 45.2, 80.9; mass spectrum, m/z 168.1529 (M^+, calcd for $C_{11}H_{20}O$ 168.1514).

A similar reaction mixture was cooled in an ice bath and quenched by addition of D_2O. The resulting solution was extracted several times with diethyl ether. The extracts were washed with water and dried (Na_2SO_4). A crude product as well as an isotopically normal sample of **12** were injected into the gas chromatograph (SE-30 column)–mass spectrometer, and chemical ionization mass spectra were obtained. Calculations[35] indicated that about 45% of the molecules of **12** obtained from D_2O hydrolysis contained one excess D. Relatively few molecules contained more than one D.

Reaction of *anti*-Bicyclo[2.2.1]hept-2-en-7-ol (18) with *n*-Butyllithium. Isolation of 19. A reaction (5:1) using TMEDA for 25 h at ambient temperature gave about 50% of recovered **18**, bp 35 °C (0.08 torr). GC analysis (column A, 170 °C) of the distillation residue showed the presence of a new component (retention time 3.03 relative to undecane, the internal standard). A sample was collected and tentatively identified as **19**: 2% yield; ^1H NMR (CCl_4) τ 6.10 (m, 1, CHOH), 7.98–9.25 (c, 19, all other H's); mass spectrum, m/z 168.1517 (M^+, calcd for $C_{11}H_{20}O$ 168.1514).

Competition for a Limited Amount of *n*-Butyllithium. The relative amounts of *n*-butyllithium, TMEDA, **7**, and alkenol were 1.5:1.5:1.0:1.0, and the reactions were at ambient temperature.

(a) 7 and 9. GC analysis (column A, 175 °C, retention times relative to **7** of 2.06 for **9**, 4.51 for **8**, and 11.0 for **10**) of the products from a reaction for 3 h indicated the relative molar amounts of **7**, **9**, **8**, and **10** to be 0.61:0.08:0.22:1.0.

(b) 7 and 14. GC analysis (column A, 175 °C, retention times relative to **7** of 1.75 for **14**, 4.50 for **8**, and 6.98 for **15**) of the products from a reaction for 24 h indicated the relative amounts of **7**, **14**, **8**, and **15** to be 1.4:3.0:1.0:0.

(c) 7 and 18. GC analysis (column A, 160 °C, retention times relative to **7** of 2.10 for **18**, 4.31 for **8**, and 11.5 for **19**) of the products from a reaction for 24 h indicated the relative amounts of **7**, **18**, **8**, and **19** to be 0.35:1.6:1.0:0.

Reduction of 16 to 17. A sample of **16**[17] (0.65 g) and 5% palladium on carbon (0.05 g) in 95% ethanol (30 mL) was left under 2 atm of hydrogen in a Parr hydrogenator for 2 h. The solution was filtered and the solvent removed by distillation. The product, collected by GC (column A, 185 °C, retention time 1.75 relative to undecane, the internal standard), was assigned structure **17**: ^1H NMR (CCl_4) τ 6.20 (m, 1, CHOH), 7.70–9.50 (c, 17, all other H's); ^{13}C NMR ($CDCl_3$) δ 14.6, 22.1, 26.2, 28.4, 36.0, 39.8, 41.5, 42.7, 45.3, 81.0; mass spectrum, m/z 154.1348 (M^+, calcd for $C_{10}H_{18}O$ 154.1357).

Reactions of 3-(Hydroxymethyl)-1,2-diethylcyclopropene (20) with Organolithium Compounds. (a) With Methyllithium. The ^1H NMR spectrum of the residue isolated from a reaction (12:1) run overnight at ambient temperature showed it to be **20** (60% recovery).

(b) With *n*-Butyllithium. Isolation of 21. The solution of **20** was added to a solution of *n*-butyllithium (8:1) cooled in a dry ice bath. The reaction mixture was left in the dry ice bath and stirred for 8 h. The cooled reaction mixture was then hydrolyzed by the slow addition of D_2O. GC analysis (column B, 150 °C) showed the presence of a new component and of **20** (retention time of the new component was 1.27 relative to that of **20**). A sample of the compound responsible for the new peak was collected and shown to be **21**: 18% yield; ^1H NMR (CCl_4) τ 4.28 (q, 1, J = 6 Hz, =CH), 6.62 (m, 2, CH_2O), 7.62 (s, 1, OH), 8.22 (d, 3, J = 6 Hz, =$CHCH_3$), 8.4–8.8 (c, 3, CH_2CH_3, CH), 9.00 (t, 3, J = 6 Hz, CH_2CH_3).

GC analysis of the crude product from a reaction (8:1) run overnight at ambient temperature showed no evidence for the presence of **20**, **21**, or an addition product.

Reactions of 3-(Hydroxymethyl)-1,2-dimethylcyclopropene (23) and 3-(Hydroxymethyl)-1-propylcyclopropene (24) with *n*-Butyllithium. GC analysis (column A, 140 °C) of the crude material isolated from a reaction of **23** (6:1) run overnight at ambient temperature showed the absence of **23** but no evidence for the presence of an addition product. The ^1H NMR spectrum of the crude material isolated from a similar reaction of **24** failed to show absorptions expected for **24** or an addition product.

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Registry No. **7**, 498-66-8; **8**, 28436-13-7; **9**, 694-97-3; **10**, 75311-43-2; **11**, 75332-10-4; **12**, 2890-98-4; **13**, 75363-54-1; **14**, 13118-70-2; **15**, 75311-44-3; **16**, 60166-73-6; **17**, 75311-45-4; **18**, 694-70-2; **19**, 75363-55-2; **20**, 65016-07-1; **21**, 75311-46-5; **23**, 33283-69-1; **24**, 75299-28-4.

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